UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

December 20, 2010

The Honorable Gregory B. Jaczko
Chairman
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: LONG-TERM CORE COOLING FOR THE WESTINGHOUSE AP1000 PRESSURIZED WATER REACTOR

Dear Chairman Jaczko:

During the 577th and 578th meetings of the Advisory Committee on Reactor Safeguards (ACRS), November 4-6, and December 2-4, 2010, we reviewed the NRC staff's safety evaluation of the adequacy of long-term core cooling as it applies to the AP1000 design certification amendment application. AP1000 long-term core cooling performance was also reviewed during subcommittee meetings held on November 19-20, 2009, October 5, November 17-19, and December 1, 2010. During these meetings, we had the benefit of discussions with representatives of the NRC staff and the Westinghouse Electric Company (WEC or applicant). We also had the benefit of the documents referenced.

CONCLUSION AND RECOMMENDATION

1. The regulatory requirements for long-term core cooling for design basis accidents have been adequately met, and the issue is closed for the AP1000 design.

2. This conclusion is based on the cleanliness requirements specified in the amendment. Any future proposed relaxation of these requirements will require substantial additional data and analysis.

BACKGROUND

On May 8, 2008, the Commission issued a Staff Requirements Memorandum (SRM) stating that, "the ACRS should advise the staff and Commission on the adequacy of the design basis long-term core cooling approach for each new reactor design based, as appropriate, on either its review of the design certification or the first license application referencing that reactor design." The main focus of the Commission's concern was the ability of the safety systems to provide adequate core cooling over extended time periods when the Emergency Core Cooling System (ECCS) recirculation mode is activated during a design basis accident (DBA).

The AP1000 is a pressurized light water reactor design that incorporates new passive safety features not found in current operating pressurized water reactors (PWRs). These include a Passive Containment Cooling System (PCS) to transport heat to the ultimate heat sink for accident scenarios.

Many aspects of long-term cooling (LTC), excluding the effects of debris, were considered as part of the AP1000 certification process that was completed in January 2006. This letter report addresses the effect of debris on LTC.

DISCUSSION

For AP1000 LTC, coolant is driven by gravity head through the core. The coolant exits, as a steam-water mixture, mainly through the Automatic Depressurization System (ADS-4) valves. The steam flowing out from the core removes decay heat and is condensed on the inside of the steel containment shell. The condensed water flows down the containment walls, is collected in the In-Containment Refueling Water Storage Tank (IRWST), and is recirculated. Screens placed between the IRWST and the core capture debris. Sump screens are placed in another possible flow path, which is through the loop compartment to the core.

During loss-of-coolant accidents (LOCAs) the level in the IRWST tank drops, redistributing water to the region around the reactor vessel and associated piping, causing much of the piping to be submerged. Breaks in this piping, such as in the cold legs or the direct vessel injection (DVI) lines, can be submerged and provide an unfiltered flow path to the reactor core.

The main sources of debris are: 1) latent containment debris, such as hair and clothing fibers; 2) debris generated by LOCA jets and exposure to post LOCA conditions; and 3) chemical precipitates that form in the recirculating water stream. WEC has taken advantage of what has been learned with regard to the GSI-191 issue for the fleet of operating PWRs. Efforts have been made in the design to minimize LOCA-generated debris by selecting low fiber, low particulate insulation and LOCA resistant qualified coatings. Stringent containment cleanliness requirements have been imposed in the amendment that limit fibrous latent debris and the amount of aluminum that can be submerged. Sump screens have been designed to assure negligible reduction in recirculation flows due to debris accumulation on them.

Because of these actions, any potential problems with LTC would primarily be due to flow blockage in the core which may trap materials that pass through the screens, and more importantly, materials that enter the core directly through submerged breaks. The possibility that unfiltered water, carrying in some cases a major portion of the suspended fibrous and particulate debris, will gain ingress directly to the core is unique to the AP1000 design. Furthermore, the gravity head available in the AP1000 for driving flow through a core in which debris has accumulated is limited. Both of these factors add to the difficulties in determining the adequacy of AP1000 LTC.

In the certified design, the applicant carried out a series of calculations using WCOBRA/TRAC, which had been accepted for analysis of LTC, without considering debris. Resolution of debris effects was deferred to the combined license (COL) stage but is now being addressed in the amendment. In the calculations for the design certification amendment, WCOBRA/TRAC was also used. The effect of debris, which mainly causes in-vessel head losses, was modeled by introducing a constant loss factor at the core inlet. The purpose of these calculations was to determine how the loss factor affected ADS-4 vent qualities (the mass fraction of steam), pressure loss across the debris bed, and mass flux through the core. Based on analysis of the results, the applicant proposed what is effectively an acceptance criterion that requires pressure drop through the debris bed to be less than a specified amount at a specified flow rate. When the criterion was met, the WCOBRA/TRAC results indicated that the ADS-4 vent quality would be less than 50 percent which resulted in acceptable boron concentration. At our request, additional results were obtained with higher loss factors to elucidate the margins inherent in the proposed acceptance criterion with regard to critical heat flux and boron concentrations. These indicated sufficient margin to account for uncertainties, and we agree that the acceptance criterion should be as proposed by the applicant.

To determine whether blockage under representative debris loadings and flow conditions would meet the acceptance criterion, the applicant conducted a series of tests in a pumped flow loop. The loop incorporated a part-length fuel bundle with representative inlet and spacer geometries. Flow rates were varied to simulate the transient mass flux through the core as the debris bed built up, though the lowest flow rates studied were somewhat higher than the value of the flow rate for the acceptance criterion. Fibrous and particulate debris loadings were conservative but were varied over a narrow range. An approved surrogate material was added over a period of time to simulate the effect of chemical precipitates, such as aluminum oxyhydroxide that might form. The reference experimental protocol was selected to follow the sequence of events expected for the long term recirculation phase of a DBA. However, the exact protocol that should be used is unclear, and tests have shown that variations in protocol can result in significant differences in pressure losses. For example, in a test where the protocol was inadvertently varied to follow a non-representative event sequence, a significantly larger debris-bed pressure loss was obtained than for the same case run with the reference protocol. However, the pressure loss still remained within acceptable limits.

For the tests used to determine whether the acceptance criterion could be met, the fibrous debris used was derived from NUKON insulation which may not be typical of the latent debris that might accumulate in the core in an AP1000 DBA. Two tests were conducted with non-reference protocols using debris containing hair and clothing fibers. While the pressure loss behavior was somewhat different from that observed in the NUKON-based test, the pressure losses were within the acceptable range.

Most of the tests were conducted at room temperature. In two exploratory tests, debris-bed pressure losses decreased significantly when the temperature was raised to values closer to those expected during LTC. The lower pressure losses are consistent with the effect of increasing temperatures on water viscosity. However, the net effect of increased temperature on head loss is still uncertain since organic materials may behave differently at LTC temperatures than the NUKON-based debris used in the tests. Absent additional experiments at LTC temperatures using organic fibers (hair, clothing) and prototypical water chemistry, it is not certain that the observed benefit of higher temperature will provide additional margin.

In the tests, the head losses that arose from debris accumulation in the fuel inlet region were rather low when the debris consisted of fibers and particulates alone. However, when the surrogate chemical precipitates were added gradually, head losses rose sharply initially, but generally leveled off as more was added. The effect of the chemical precipitates will depend on the rate of their formation. Although this is uncertain, the rate at which surrogates were added in the tests appears to be conservative.

Radiolysis in the containment atmosphere and doses to cable insulation might form small amounts of nitrogen oxides and hydrogen chloride which may acidify the water condensed on the containment wall. The acidified water may leach zinc from the containment coating. If some zinc does dissolve into the recirculating water stream, the chemical load that should be considered in evaluating debris head losses would be increased. While the experiments indicating that head losses level off with the addition of chemical surrogates suggest that the effect of the possible zinc load could be small, the effect has not been investigated and adds to the uncertainties.

In view of the relatively narrow range of conditions explored in the applicant's test program and the significant uncertainties in the results, a site visit was conducted to better understand the AP1000 related results in the context of in-core debris effects found in the PWR Owner's Group (PWROG) experiments. These cover a wide range of conditions and, while not directly applicable to the AP1000, offer valuable insights into the effects of various experimental parameters.

As a result of the issues arising in subcommittee meetings and the site visit, additional experimental results from the PWROG program at lower flow rates and higher fiber loadings were made available to us.

When the additional WCOBRA/TRAC analyses and the additional experimental results are taken into account, in-core debris bed pressure losses appear to meet the acceptance criterion with sufficient margin to account for the uncertainties, including those due to chemical effects, experimental protocol, and debris constituents. This conclusion is based on the limits on latent debris and submerged aluminum specified in the amendment. These cleanliness specifications should not be relaxed without additional analyses, a much wider range of experiments at prototypical conditions, and NRC review of these findings.

In summary, debris generation during DBAs has been minimized by the choice of LOCA-resistant insulation and coatings. This, together with the large flow area sump screens, results in negligible head losses except in the inlet regions of the core. With regard to in-vessel debris effects, the acceptance criterion established by the applicant is adequate to assure LTC. The criterion is met with sufficient margin to account for uncertainties provided the stringent cleanliness requirements specified in the amendment are maintained. The AP1000 design, therefore, meets the regulatory requirements for LTC during design basis accidents.

Sincerely,

/RA/

Said Abdel-Khalik
Chairman

References:

1. Letter to Edwin M. Hackett, "AP1000 Subcommittee Review of Selected Chapters of the Advanced Safety Evaluation Report – AP1000 Design Certification Amendment," 09/20/2010 (ML102580168, Chapter 6 SER ML102410012)

2. Letter to U.S. Nuclear Regulatory Commission, Submittal of APP-GW-GLE-002 Revision 7 – "Impacts to the AP1000™ to Address Generic Safety Issue (GSI) – 191," 07/13/2010 (ML101970030)

3. Westinghouse Technical Report, WCAP-17028-P Revision 6, "Evaluation of Debris-Loading Head-Loss Tests for AP1000™ Fuel Assemblies During Loss of Coolant Accidents," 06/29/2010 (ML102030227; ML102030219; ML102030221; ML102030222; ML102030223; ML102030215)

4. Westinghouse Technical Report, WCAP-16914-PR0, "Evaluation of Debris Loading Head Loss Tests for AP1000 Recirculation Screens and In-Containment Refueling Water Storage Tank Screens," 07/14/2010 (ML102000156)

5. Letter to U.S. Nuclear Regulatory Commission, "Transmittal of IRWST and CR Screen Related Documents," 02/26/2010 (ML100640574)

6. Letter to U.S. Nuclear Regulatory Commission, "Transmittal of IRWST and CR Screen Related Documents, Enclosure 21," 02/26/2010 (ML100640578)

7. Letter to U.S. Nuclear Regulatory Commission, "Transmittal of IRWST and CR Screen Related Documents, Enclosure 22, APP-GW-GLR-092 Proprietary Rev. 0," 02/26/2010 (ML100640585)

8. Letter to U.S. Nuclear Regulatory Commission, "Transmittal of IRWST and CR Screen Related Documents, Enclosure 25, APP-GW-GLR-110 Rev. 0 Proprietary," 02/26/2010 (ML100640586)

9. Letter to U.S. Nuclear Regulatory Commission, "Transmittal of Technical Report APP-GW-GLR-079 Revision 8 (TR-026), (Proprietary & Non-Proprietary) "AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA" Enclosure 3, 07/20/2010 (ML102170124)

10. Letter to U.S. Nuclear Regulatory Commission, "Submittal of APP-GW-GLE-002 Revision 7 - Impacts to the AP I000™ to Address Generic Safety Issue (GSI) - 191," 12/13/2010 (ML101970030)

11. Letter to U.S. Nuclear Regulatory Commission, "AP1000 Response to Request for Additional Information (SRP6.2.2)," Enclosure, 07/30/2010 (ML102160216)

In view of the relatively narrow range of conditions explored in the applicant's test program and the significant uncertainties in the results, a site visit was conducted to better understand the AP1000 related results in the context of in-core debris effects found in the PWR Owner's Group (PWROG) experiments. These cover a wide range of conditions and, while not directly applicable to the AP1000, offer valuable insights into the effects of various experimental parameters.

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Said Abdel-Khalik
Chairman

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Letter to the Honorable Gregory B Jaczko, Chairman, NRC, from Said Abdel-Khalik, Chairman, ACRS, dated December 20, 2010

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