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

October 22, 2004

The Honorable Nils J. Diaz
Chairman
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: PROPOSED RESOLUTION OF GENERIC SAFETY ISSUE 185, "CONTROL OF RECRITICALITY FOLLOWING SMALL-BREAK LOCAs IN PWRs"

Dear Chairman Diaz:

During the 516th meeting of the Advisory Committee on Reactor Safeguards, October 7-9, 2004, we met with representatives of the NRC staff to review the draft NUREG-XXXX, "Avoiding Recriticality From Transport of Diluted Water From Loop Seals to Core During Small Break Loss-of-Coolant Accidents in Pressurized Water Reactors," dated February 2004 (Ref. 1), prepared by the Office of Nuclear Regulatory Research (RES) to provide the technical basis for resolution of Generic Safety Issue (GSI) -185. Our Subcommittee on Thermal-Hydraulic Phenomena reviewed this matter during a meeting on September 23, 2004. We also had the benefit of the documents referenced.

CONCLUSION

We agree with the RES recommendation that GSI-185 be closed without imposition of any new regulatory requirements for all existing Framatome-Babcock & Wilcox (B&W), Westinghouse, and Combustion Engineering Plants.

DISCUSSION

Boron dilution accidents have been historically considered in pressurized water reactor (PWR) safety analyses. A new concern about boron dilution accidents arose in 1995 when Framatome Technologies submitted an analysis suggesting that if a B&W-designed nuclear steam supply system (NSSS) spends some time in a boiler-condenser mode following a small-break loss-of-coolant accident (LOCA), a substantial amount of deborated water may accumulate in the steam generator, loop seal, reactor coolant pump (RCP), cold leg, downcomer, and lower plenum. The resumption of natural circulation or the restart of a RCP were identified as mechanisms for causing deborated water to flow into the core and potentially cause a prompt criticality. Subsequently, in late 1996, Framatome Technologies developed guidance to restrict RCP restart in order to prevent potential fuel damage.

On February 1, 1999, the Office of Nuclear Reactor Regulation (NRR) requested the establishment of a GSI relating to reactivity insertion accidents resulting from boron dilution (Ref. 2). This request was based on 1) new information about reactivity insertion accident experiments on high burn-up fuel indicating that fuel damage would occur at lower energy deposition, and 2) new analyses performed by Framatome Technologies and submitted by the B&W Owners Group (B&WOG) (Ref. 3). The event was deemed to be of potential importance for all PWRs.

In accordance with the procedures described in NUREG-0933, RES performed a prioritization study for this issue (Ref. 4). The prioritization study supported establishing GSI-185. RES subsequently prepared a plan that focused on the major assumptions and limitations of the prioritization study in order to develop a more accurate and realistic, yet conservative, analysis (Ref. 5). The results of this research are documented in draft NUREG-XXXX. The boron dilution accidents of interest are associated with small-break LOCAs, involving break sizes of 0.5 to 2 in. diameter. The coolant loss from these small-break LOCAs is large enough to decrease the system coolant inventory but not large enough to depressurize the system. During such LOCAs, natural circulation ceases at approximately 60% coolant inventory and the system enters a boiler-condenser mode of operation in which steam is generated in the core and flows though the voided hot leg to the steam generator tubes, where condensation will occur. In once-through steam generator systems, all the condensate drains to the lower portion of the steam generator tubes and displaces and mixes with the borated water. Eventually, the steam generator outlet plenum and loop seal could become filled with deborated water and the tubes partially filled. For U-tube steam generator systems the scenario is similar except that only condensate from the downside of the U-tubes displaces and mixes with the borated system coolant in the outlet plenum, RCP, and loop seal.

If natural circulation resumes or if a RCP is restarted, then the deborated mass of coolant would be swept through the cold leg into the reactor vessel downcomer and lower plenum. As the deborated water flows into the core, an increase in reactivity will occur, with the potential for recriticality and for fuel damage if sufficient energy deposition occurs. A key technical issue associated with the evaluation of this accident sequence is the extent of mixing between the deborated coolant and the borated coolant in the reactor vessel as the deborated slug is transported to the core. Both the Framatome Technologies analyses for the B&WOG and the RES prioritization study were based on the conservative assumption of plug flow with no mixing.

RES used two new analytical elements to address the limitations of the previous analyses: (1) a more realistic model for the mixing of deborated water with the borated system coolant and (2) improved methods for calculating the core neutronic behavior as the deborated water enters the core.

The RES mixing model incorporates realistic, yet conservative, quantification of the mixing of the deborated water slug with the borated system coolant as the slug flows through the cold leg, downcomer, and lower plenum and into the core. The mixing model combines the elements of two mixing extremes, namely plug flow (no mixing) and back-mixed flow (ideally mixed). The cold leg loop seal, cold leg, and downcomer are treated as pipe components with plug flow while the steam generator outlet plenum, the RCP, and the reactor vessel lower plenum are modeled as a back-mixed volumes. The mixing model was validated for the components external to the reactor using experimental data from the University of Maryland B&W integral test facility. The model was then validated with regard to the in-vessel mixing using the FLUENT code. FLUENT was used to produce a multi-dimensional computational fluid dynamics model of the downcomer and the lower plenum consisting of 353,690 cells. The FLUENT results were compared to University of Maryland downcomer mixing data and good agreement was obtained. The FLUENT model was then used to predict the core inlet transient concentration for a step change in the cold leg concentration and this result was compared to the RES mixing model prediction. This result demonstrated that the mixing model provided a realistic but conservative prediction of core inlet boron concentration.

The new core neutronic behavior model uses a 30 channel RELAP5 model for thermal hydraulics in the fuel assemblies coupled to the multidimensional PARCS code for neutron kinetic analysis. The core has one-eighth symmetry and the multi-dimensional model used has 29 fuel bundles. The RELAP5 code is used to model flow in the 29 bundles with one channel for the core bypass flow. The PARCS-RELAP5 code was validated by comparing its power predictions to predictions obtained with French and Russian codes for boron dilution reactivity transients. This model is judged to be appropriate and accurate for boron dilution transient simulation.

The RES analyses for resolution of GSI-185 have shown that recriticality for the postulated boron dilution event is not possible in Westinghouse and Combustion Engineering reactor designs for either resumption of natural circulation or restart of a RCP. The volumes of the steam generator outlet plena, loop seals, and RCPs are too small to accumulate sufficient deborated water to cause recriticality of the core. For B&W reactor designs with lowered loop seals, however, the resumption of natural circulation may cause a brief criticality event but the fuel temperatures remain within the normal full-power operating conditions. The inadvertent restart of a RCP in a lowered-loop B&W plant may cause fuel temperatures to rise above design limits, but would result only in limited fuel damage and would not lead to a loss of coolable core geometry.

The probability of this event is believed to be very small for the following reasons: (1) the range of break sizes that will result in boiler-condenser operation is small; (2) the high-pressure injection system must fail; (3) the plant is vulnerable to this event only during the first 20% of a fuel cycle; (4) additional failures or operator actions, such as break isolation, must occur to allow the system to remain in the boiler-condenser mode long enough (approximately one hour) to generate sufficient deborated water and (5) a RCP must be inadvertently restarted. The low probability of this event, coupled with its limited consequences, supports the conclusion that GSI-185 can be considered resolved for B&W lowered-loop plants, as well as for all other operating PWRs.

Sincerely,

/RA/

Mario V. Bonaca
Chairman

References:

1. Draft NUREG-XXXX, “Avoiding Recriticality From Transport of Diluted Water From Loop Seals to Core During Small Break Loss-of-Coolant Accidents in Pressurized Water Reactors,” Generic Safety Issue 185, February 2004.
2. Memorandum to A. Thadani from S. Collins, “Potential Need to Reprioritize/Reopen Aspects of Generic Safety Issue 22 Pertaining to Boron Dilution Following Loss-of-Coolant Accidents,” February 1, 1999.
3. “Evaluation of Potential Boron Dilution Following Small Break Loss of Coolant Accident,” The B&W Owners’ Group Analysis Committee, Framatome Technologies, Inc., 77-5002260-00, September 1998.
4. Memorandum to Ashok C. Thadani From Farouk Eltawila, Generic Issue No. 185, “Control of Recriticality Following Small-Break LOCAs in PWRs,” July 7, 2000.
5. Eltawila, F., “Generic Issue No. 185, Control of Recriticality Following Small-Break LOCAs in PWRs,” U.S. Nuclear Regulatory Commission, ML003730563, July 7, 2000.