September 23, 2005

MEMORANDUM TO: Luis A. Reyes
Executive Director for Operations

FROM: Carl J. Paperiello, Director ***/RA/***
Office of Nuclear Regulatory Research

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

The Office of Nuclear Regulatory Research (RES) has completed the technical assessment of Generic Safety Issue (GSI) 185, "Control of Recriticality Following Small-Break Loss-of-Coolant Accidents (LOCAs) in PWRs," and the issue will be closed. The Office of Nuclear Reactor Regulation (NRR) identified GSI-185 on February 1, 1999, in a NRR request for reconsideration of the safety priority ranking (DROP) of Generic Issue 22, "Inadvertent Boron Dilution Events." The issue addressed the concern for reactivity insertion accidents resulting from boron dilution. This concern was deemed to be of potential safety significance to all pressurized water reactors (PWRs) and was based on (1) new information on reactivity insertion accident experiments on high burnup fuel; and (2) new analyses performed by Framatome Technologies and submitted to the U.S. Nuclear Regulatory Commission (NRC) by the Babcock and Wilcox Owners' Group (B&WOG). In accordance with Management Directive 6.4, "Generic Issues Program," the staff screened and classified the issue as a GSI, after which, technical assessment was approved on July 7, 2000.

GSI-185 addressed those small-break LOCA scenarios in PWRs that involve steam generation in the core and condensation in the steam generators, causing deborated water to accumulate in the loop seals. Restart of either natural circulation or a reactor coolant pump (RCP) was postulated to cause a recriticality event when the deborated water was transported to the core. The governing regulatory requirements for power reactors are described in the General Design Criteria (GDC) of Appendix A to Title 10, Part 50, of the Code of Federal Regulations (10 CFR Part 50). In particular, GDCs 20 – 29 concern various aspects of reactivity control. Specifically, GDC 28 states the following requirement:

> The reactivity control systems shall be designed with appropriate limits on the potential amount and rate of reactivity increase to assure that the effects of postulated reactivity accidents can neither (1) result in damage to the reactor coolant system pressure boundary greater than limited local yielding nor (2) sufficiently disturb the core, its support structures or other reactor pressure vessel internals to impair significantly the capability to cool the core.

Fuel behavior experiments conducted during the 1970s (mainly on low-burnup fuel) supported the establishment of an enthalpy limit of 280 cal/g for reactivity insertion accidents to preclude the expulsion of molten fuel into the coolant. (See Regulatory Guide 1.77, "Assumptions Used for Evaluating a Control Rod Ejection Accident for Pressurized Water Reactors," dated May 1974.) More recently, RES extended the database to include high-burnup fuel, and the experiments suggest that fuel damage may occur at enthalpy levels lower than 280 cal/g.

During small-break LOCAs, the progression of the transient may include tripping of the RCPs and a period of natural circulation. That natural circulation would be driven by the core decay heat as the energy source, and heat removal by the steam generator (and the break) as an energy sink. At some point, natural circulation (in which the liquid phase is continuous) may be interrupted. Such transients may include boiling in the core, with condensation of steam in the steam generator. This distillation process would increase the concentration of boron in the reactor vessel region, while diluting the volume of water in the cold leg loop seals. If natural circulation should be reestablished later in the event, or if an RCP should be restarted, the diluted water from the loop seal may be transported to the core. The question can then be posed as to whether flow through the core could be sufficiently dilute as to cause recriticality and, if so, whether sufficient fission energy could be produced to cause fuel damage.

Analyses performed by Framatome Technologies for the B&WOG indicated the possibility of prompt critical excursions under certain conditions and assumptions. Additionally, experiments on fuel behavior during reactivity insertion accidents suggested that, as burnup increases, different fuel damage mechanisms may come into play, or become more important, than indicated by earlier experimental work conducted during the1970s on new or low-burnup fuel. Any evaluation of the consequences of reactivity insertion accidents should consider the possibility of fuel damage at enthalpy levels lower than those previously considered.

<u>Boron Dilution With Restart of Natural Circulation</u>

Westinghouse, Combustion Engineering, and Framatome B&W Reactors: Westinghouse or Combustion Engineering reactors will remain subcritical in any boron dilution scenario with restart of natural circulation. Under the most bounding assumption for the size of a diluted slug, and with realistically conservative treatment of mixing, calculations for a Framatome B&W reactor indicated a return to criticality with no fuel damage. Therefore, boron dilution with restart of natural circulation is not a significant event at all Westinghouse, Combustion Engineering, and Framatome B&W reactors.

<u>Boron Dilution With Restart of an RCP</u>

Westinghouse and Combustion Engineering Reactors: Calculations for Westinghouse and Combustion Engineering reactors showed that they will remain subcritical for boron dilution with restart of an RCP. These reactor designs have relatively small loop seal volumes that might accumulate unborated water, and the piping geometry in the loops is similar among plants designed by both vendors. Larger plants, such as the Combustion Engineering System 80^+, have larger volumes throughout the systems, as well as larger cores. Hence, the loop seal volumes we considered should be typical. The calculations also show significant margin before recriticality is predicted to occur. Therefore, boron dilution with restart of an RCP is not a significant event at Westinghouse and Combustion Engineering reactors.

Framatome B&W: Accumulation of a large volume of diluted water in the loop seal is not possible under realistic (best estimate) or design-basis (single-failure criterion) accident scenarios. Therefore, the scenario of boron dilution with restart of an RCP falls outside the design-basis envelope in B&W reactors.

For beyond-design-basis accidents, the staff estimated the probability of recriticality for a small-break LOCA in a B&W lowered loop plant[1], early in the fuel cycle, with such a particular and unusual combination of equipment malfunctions and/or operator errors as to dilute the loop seals, followed by and in combination with, a specific operator error, with the complicity of the Technical Support Group, to restart an RCP. This probability is estimated as 3×10^{-8}. The consequence of such a beyond-design-basis event is considered to be the possibility of some high-burnup fuel rods experiencing cladding cracks, with limited fuel centerline melting in high-power rods. This consequence is based on (1) a bounding value for the volume and boron concentration of the dilute slug, and (2) realistically conservative treatment of mixing during slug transport. These two factors tend to dominate the outcomes of the analyses. Therefore, the staff also closed GSI-185 for Framatome B&W plants based on the low probability and low consequence of the scenario.

Research programs sponsored by RES were instrumental in providing the technical basis to support the technical assessment of GSI-185. Experimental programs sponsored by RES provided data on fluid-fluid mixing, which were used as the basis for, and to validate, the RES mixing model. These research programs were conducted at the University of Maryland and in the German Primärkreislauf (PKL) facility (the latter under the PKL Project conducted by the Organization for Economic Cooperation and Development). Development of the Purdue Advanced Reactor Core Simulator (PARCS) computer modeling code, and its coupling to the RELAP5 thermal-hydraulic systems code allowed the integrated three-dimensional neutronics-thermal-hydraulics analysis that was necessary to calculate a reactivity insertion event. Additionally, RES cooperation with the Russian Research Centre, Kurchatov Institute, provided key validation results for the PARCS code. Moreover, RES participation in fuel behavior research programs with in-reactor testing in France, Japan, and Russia permitted a better understanding of fuel behavior at high-burnup levels subjected to reactivity insertion accidents. The results of the research performed during the technical assessment of GSI-185 will be published in a NUREG-series report.

The staff presented its technical findings to the NRC's Advisory Committee on Reactor Safeguards (ACRS), Subcommittee on Thermal-Hydraulic Phenomena, on June 26 and September 9, 2002, and September 23, 2004. The staff then presented its draft technical assessment to the ACRS on October 7, 2004, and received ACRS agreement on the proposed completion of GSI-185 on October 22, 2004. As such, the staff has completed all work on GSI-185, and the issue will be closed with no changes to existing regulations or guidance. For additional information on this issue, please contact David E. Bessette at (301) 415-6763 or deb@nrc.gov.

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1 B&W lowered loop plants have the steam generator at about the same elevation as the reactor vessel. This design has a large volume of water below the elevation of the cold leg. Five of the six B&W plants in operation are lowered loop.

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