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NUCLEAR ENERGY INSTITUTE

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Mr. Gary M. Holahan
Director, Division Systems Safety and Analysis
Office of Nuclear Reactor Regulation (NRR)
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Project Number: 689

SUBJECT: Proposed Meeting Between NRC and Industry to Discuss PWR Sump Performance Issues

Dear Mr. Holahan:

On July 17, 1997, at the request of the NRC, representatives of NEI, EPRI and PWR owners groups met with NRC staff to discuss concerns about potential blockage of PWR sump screens by LOCA-generated debris. During the meeting the NRC identified areas of concern and initial plans for further investigation. Since this meeting, a number of industry activities have been initiated to address PWR sump performance issues. We believe that coordination of industry and NRC activities will promote a better understanding of potential problem areas and concerns.

In discussions with NRC staff, we have proposed a meeting to exchange thoughts and proposals for activity in this area. NRC staff prefer to meet with us only after an NRC action plan for PWR sump performance issues has been fully developed. NRC staff have agreed to meet with us to discuss the topic of application of Leak-Before-Break (LBB) provisions of Generic Design Criteria (GDC) 4. This is an important topic because it relates to PWR sump performance. It is discussed further below.

We believe it is important that LBB application be considered as part of a broader discussion and that the proposed NRC/industry meeting encompass the full range of sump performance issues. We request that this meeting be scheduled for the earliest possible date.

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In a letter to the NRC dated November 25, 1997, the Westinghouse Owners Group (WOG) requested the use of LBB provisions to allow the exclusion of the dynamic

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effects of pipe rupture loads in the consideration of debris generation and coatings removal following a design basis LOCA. Favorable consideration of this request would eliminate the need to address debris generation as a direct result of a postulated pipe rupture for LBB qualified piping and allow efforts to focus on more risk significant debris generation sources (*e.g.*, submergence, washdown, containment environmental changes).

A discussion paper that examines the application of LBB technology to pipe-break debris generation is enclosed. We look forward to discussing this paper as part of the topics discussed at the requested meeting. Other topics for discussion at this meeting include recent generic communications, industry/NRC activities to address PWR sump performance, and containment protective-coatings.

If you have any questions in this regard, please contact me at (202) 739-8084, or John Butler at (202) 739-8108.

Sincerely,

David J. Modeen

JCB/edb

Enclosure

c: Mr. Carl H. Berlinger, U.S. Nuclear Regulatory Commission
Mr. Jack R. Strosnider, U.S. Nuclear Regulatory Commission
Mr. Richard M. Lobel, U.S. Nuclear Regulatory Commission
Mr. Stewart Magruder, U.S. Nuclear Regulatory Commission

Discussion Paper
Application of LBB Technology
to Pipe Break Debris Generation

1. Background

1.1 GDC-4 Revision

In October 1987, General Design Criterion (GDC) 4 in Appendix A to 10 C.F.R. Part 50 was revised to allow the use of leak-before-break technology. Specifically:

> "***Criterion 4 - Environmental and dynamic effects design bases****.* *Structures, systems, and components important to safety shall be designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents. These structures, systems and components shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit. However, dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping."* [emphasis added]

The supplementary information section of the Federal Register (FR) notice (52 FR 41288) states that the dynamic effects covered by the rule are missile generation, pipe whipping, pipe-break reaction forces, jet impingement forces, decompression waves within the ruptured pipe and dynamic or nonstatic pressurization in cavities, subcompartments and compartments. But, cavities, subcompartments and compartments necessary to the containment function are not affected by the rule change.

To retain high safety margins, the FR notice states that the application of leak-before-break technology to various piping systems should not decrease the capability of containments to perform their function of isolating the outside environment from potential leaks, breaks, or malfunctions within containment. Containments will continue to be designed to accommodate LOCAs resulting from breaks in the reactor coolant system pressure boundary up to and including a break equivalent in size to the double-ended rupture of the largest pipe in the reactor coolant system. Also, the functional design for emergency core cooling systems still retains nonmechanistic pipe rupture.

The FR notice further states:

> *"This rulemaking will introduce an inconsistency into the design basis by excluding the dynamic effects of postulated pipe ruptures while still retaining the nonmechanistic pipe rupture for emergency core cooling systems, containments, and environmental qualification..."*

1.2 Proposed Rulemaking to Extend LBB Applications

In April of 1988, to address the inconsistency introduced by the modification to GDC-4, the NRC requested public comments (53 FR 11311) on potential additional applications of leak-before-break technology to modifying functional and performance requirements for emergency core cooling systems and for environmental qualification of safety related electrical and mechanical equipment. Modification of functional and performance requirements for containments was explicitly excluded from consideration as part of the FR notice.

In the supplementary information section of the FR notice, the NRC provided a clarification on the specific functional and performance requirements retained when leak-before-break was accepted under the 1987 modification to GDC-4:

1. *For Containments. Global loads and environments associated with postulated pipe ruptures, including pressurization, internal flooding, and elevated temperatures.*
2. *For ECCS. Heat removal and mass replacement capacity needed because of postulated pipe ruptures.*
3. *For EQ. Pressure, temperature, flooding level, humidity, chemical environment, and radiation resulting from postulated pipe ruptures.*

In SECY-88-325 (November 22, 1988) the NRC staff addressed public comments on extending LBB applicability to address ECCS and EQ functional and performance requirements. In this SECY, the staff recommended that no rulemaking be undertaken to apply LBB to either environmental qualification or ECCS. A reason cited was that safety benefits for ECCS could be more readily obtained under the recently revised ECCS rule, which enabled the use of best estimate LOCA methodologies. Also, the GDC-4 final rule already permitted the use of exemptions for EQ, which the NRC felt had not been utilized by the industry. The Commission, in an April 13, 1989 SRM, approved the NRC staff position.

2. LBB Consideration for Debris Generation

During a July 17, 1997 meeting between NRC, NEI and Owners Group Representatives, the NRC expressed concerns about the potential for PWR containment sump blockage from LOCA-generated debris. The NRC is taking action to investigate the merits of these concerns. The NRC has also identified separate but related concerns on containment protective-coatings programs and on plant NPSH calculations for ECCS recirculation. These concerns have been the subject of recent generic communications.

Until recently, NRC investigations have centered on BWR plants. These investigations are discussed in NRC Bulletin 96-03 and have resulted in actions or plans by BWR plants to install larger suction strainers. Calculations of debris impacts on containment recirculation capability must consider debris generation, debris transport, sump-blockage potential and pump performance. From the BWR experience the industry has learned that each phase of consideration involves a high degree of complexity, unknowns and uncertainty that lead to the use of highly conservative assumptions. This is due in part to a shortage of test data covering the full range of potential debris materials and debris-generation conditions. In addition, the high degree of variability in PWR containment designs limits the generic applicability of available test data.

The application of LBB as a consideration in debris generation would have a significant impact on ongoing PWR sump performance evaluations and investigations. Its application would allow resources to be focused on more risk-significant aspects of PWR sump performance by minimizing the need to address debris generation characteristics for LBB qualified piping. In doing so, it is anticipated that resolutions for and closure of PWR sump performance issues can be expedited for all PWRs.

3. Discussion Questions

The following questions are raised in this paper to facilitate discussions between industry and NRC staff at an upcoming meeting. These questions are intended to address the key focus areas.

1. What is the scope of the application of LBB toward consideration of debris generation?

2. Is debris generation within the zone of influence of a break a "local dynamic effect" covered by GDC-4?

3. Does debris generation fall within the scope of functional and performance requirements retained in the GDC-4 revision?

4. What is the impact of LBB on sump-blockage probabilities?

5. What are the possible means for incorporation of LBB as a consideration in debris-generation potential in PWR containments?

The following sections provide a discussion of these questions and current industry views.

3.1 What is the scope of the application of LBB toward consideration of debris generation?

Debris sources during and following a design-basis LOCA can be divided into two categories:

1. Materials within the zone of influence around a postulated break location that are subject to the local dynamic forces of the break.

   These include insulation, painted surfaces, and fibrous, cloth, plastic, or particulate materials. This category can be further subdivided based on the qualification of piping at each location:

   A) Material within the zone of influence around a break location for LBB qualified piping
   B) Material within the zone of influence around a break location for piping not qualified for LBB

2. Materials outside the zone of influence around a postulated break location that are subject to the global loads and environments associated with a break (e.g., pressurization, internal flooding, elevated temperatures, washdown). These include unqualified coatings and corrosion products.

The application of LBB in considering debris generation is limited to debris sources within the zone of influence around a postulated break location (i.e., Category 1) and will not affect sources of debris outside of the zone of influence. In addition, consideration of LBB is limited to those pipe-break locations within piping systems that meet LBB qualification requirements (Category 1A).

This means that consideration of LBB has no effect on debris-source considerations outside the zone of influence around a break (i.e., Category 2) and has no effect on debris-source considerations for break locations that do not meet LBB requirements (Category 1B). Consideration of debris generation for these sources (Categories 1B and 2) will have to address the effects from a postulated rupture. For non-LBB pipe break locations, debris generation resulting from the initial blast wave and the ensuing break jet expansion and impingement forces for a postulated rupture must be considered. Consideration of debris sources outside of the zone of influence of a break will continue to address the global loads resulting from a range of postulated LOCAs of different sizes (up to and including a double-ended guillotine break) and locations; including piping that is LBB qualified.

Conclusion: Use of LBB in considering debris generation following a design basis LOCA is limited to local dynamic effects for LBB-qualified piping systems and does not impact considerations of debris generation at non-LBB piping locations or debris generation resulting from global containment loads.

3.2 Is debris generation within the zone of influence around a break a "local dynamic effect" covered by GDC-4?

The dynamic effects addressed by GDC-4 are delineated in the Federal Register notice that modified GDC-4 (52 FR 41288):

> *"Dynamic effects of pipe rupture covered by this rule are missile generation, pipe whipping, pipe break reaction forces, jet impingement forces, decompression waves within the ruptures pipe and dynamic or nonstatic pressurization in cavities, subcompartments and compartments."*

This is further restated in 53 FR 11311:

> *"'Local dynamic effects uniquely associated with pipe rupture' means dynamic effects due to pipe whipping, jet impingement, missiles, local pressurizations, pipe break reaction forces, and decompression waves in the intact portions of piping postulated to rupture."*

These forces are a dominant source of debris in containment following a postulated LOCA. As stated in Section 2.4 of NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris,":

> *"The initial blast wave exiting a DEGB and the ensuing break jet expansion and impingement forces are the dominant contributors to insulation debris generation following a LOCA. Other contributors, such as pipe whip and pipe impact, have been studied and shown to be of secondary importance."*

Conclusion: Debris generation as a result of break jet expansion, impingement forces, pipe whip and pipe impact is a "dynamic effect uniquely associated with pipe rupture" and is encompassed within the scope of GDC-4.

3.3 Does debris generation fall within the scope of functional and performance requirements retained in the GDC-4 revision?

In its modification of GDC-4, the NRC limited the application of LBB to local dynamic effects uniquely associated with ruptures in piping that is qualified for leak-before-break. Non-mechanistic pipe rupture was retained as a part of the functional and performance requirements for containment, ECCS and EQ.

In doing so, the NRC acknowledged that application of LBB to local dynamic effects has the potential to affect the design basis of ECCS hardware. As stated in 53 FR 11311, "*...local dynamic effects uniquely associated with pipe rupture may be deleted from the design basis of containment systems, structures and boundaries, from the design basis of ECCS hardware [emphasis added] (such as pumps, valves,* *accumulators, and instrumentation), and from the design bases of safety related electrical and mechanical equipment when leak-before-break is accepted".*

The statements of consideration in 53 FR 11311 state:

> *"Thus, while functional and performance requirements for containment, ECCS, and EQ remain unchanged under the now effective modification of GDC-4, the design bases for these aspects of facility design have been modified in that local dynamic effects uniquely associated with ruptures in piping which qualified for leak-before-break may be excluded from consideration."*

The specific functional and performance requirements retained when GDC-4 was amended are as follows (53 FR 11311):

1. *For Containments. Global loads and environments associated with postulated pipe ruptures, including pressurization, internal flooding, and elevated temperatures.*

2. *For ECCS. Heat removal and mass replacement capacity needed because of postulated pipe ruptures.*

3. *For EQ. Pressure, temperature, flooding level, humidity, chemical environment, and radiation resulting from postulated pipe ruptures.*

Containment

The supplemental information in 53 FR 11311 provides further clarification on the "containment" exclusion:

> *"Global pressurizations, temperature transients, and flooding transients on containment systems and structures are not local dynamic effects and may not be uniquely related to pipe rupture, and therefore are retained for containment design".*

Thus, evaluations of debris generation and transport potential resulting from the global pressure and temperature changes in containment following a postulated pipe rupture, along with washdown and flooding effects, cannot consider LBB technology and will continue to include the effects resulting from a full range of break sizes and locations (up to a full DEGB).

ECCS

The "ECCS" exclusion addresses the design-basis criteria, assumptions and models used in determining that the Emergency Core Cooling System (ECCS) meets applicable regulations, e.g., 10 C.F.R. 50.46. The primary impact of this exclusion is a continued need to address a full range of break sizes and locations as part of ECCS calculations (i.e., double-ended guillotine breaks must be considered). In

1988, the NRC requested public comments on the extension of LBB applications to include ECCS functional and performance requirements (53 FR 11311). In reviewing public comments (SECY-88-325), the NRC noted that extension of LBB technology to include ECCS functional and performance requirements would allow smaller pipe ruptures to be postulated but that the main benefits of this change would also be obtained under a then recent change to the ECCS rule to allow use of best estimate LOCA technology. As a result, the exclusion of LBB technology application to ECCS functional and performance requirements was maintained.

Thus, long term recirculation operation of ECCS must continue to consider a full range of postulated break locations and sizes except for the allowance currently provided in GDC-4 that enables local dynamic effects uniquely associated with ruptures in LBB qualified piping to be excluded from consideration.

Environmental Qualification (EQ)
The "EQ" exclusion provides assurance that systems, structures and components will continue to be qualified for operation in the global environment (pressure, temperature, flooding level, humidity, chemical environment, and radiation) resulting from postulated pipe ruptures up to and including full DEG breaks.

Conclusion: With the exception of debris generation resulting from local dynamic effects uniquely associated with ruptures in piping qualified for LBB, debris generation potential and effects are not affected by LBB considerations.

3.4 What is the impact of LBB on sump blockage probabilities?

The probability of sump blockage depends on a number items, many of which are plant specific. These include the probability of a pipe break and the debris generated as a result of the break. Estimates of core damage probabilities were developed in 1985 by the NRC as part of the regulatory analysis addressing USI A-43 (NUREG-0869 Revision 1). The estimated core melt frequencies from a blocked sump ranged from 1.5×10^{-6} to 2.5×10^{-5}/Rx-yr. These estimates conservatively assume that all fibrous debris was transported to the sump and led to blockage and that 50% of cases resulting in sump blockage lead to core melt.

A key factor in the calculation of core damage probabilities due to sump blockage is the frequency of pipe breaks. The NRC study used pipe-break probabilities, from a 1977 data base, ranging from 3×10^{-6} /Rx-yr for large pipes (>28 inches) to 3×10^{-4} /Rx-yr for small pipes (2 to 6 inches). In their study of USI A-43, the NRC acknowledged information from then recent studies supporting LBB technology that indicated the effect of LBB on pipe-break probabilities. As stated in NUREG-0869:

> *"The more recent experimental and analytical work, which is based on mechanistic fracture mechanics, results in probabilities of the rupture of large-size ductile piping (unaffected by IGSCC) significantly lower (better by several decades in magnitude) than those employed in the A-*

> *43 analyses. Therefore, if pipe failure probabilities are extremely low – because of such considerations as leak-before-break, etc. – these calculations would result in very low estimated releases, and backfits would not be supportable on the basis of value/impact criteria."*

Plant LBB applications have primarily focused on large-diameter piping. Thus, the exclusion of debris-generation potential would generally be limited to large diameter piping. However, large diameter piping has the greatest debris-generation potential. In NUREG-0869, the NRC notes that *"small pipes (< 10 inch diameter) generate small amounts of debris; therefore debris blockage effects produced by small pipes are not significant."*

Because large diameter piping is the primary contributor to debris generation and LBB primarily addresses large diameter piping, the overall favorable impact of LBB considerations on sump blockage probabilities is amplified. The general decrease in sump blockage probabilities is anticipated to be in the range of two orders of magnitude.

Conclusion: Application of LBB technology in consideration of debris-generation potential, will result in a significant decrease (approximately two orders of magnitude) in sump blockage probabilities and a similar decrease in conditional core-damage frequencies.

3.5 What are the possible means for incorporation of LBB as a consideration in debris generation potential in PWR containments?

Most PWRs have some piping inside containment that meets LBB acceptance criteria and have LBB as part of their licensing basis. This allows for consideration of LBB as part of generic evaluations of PWR sump performance in addition to consideration on a plant specific basis.

In 1985, the NRC regulatory analysis for USI A-43, "Containment Emergency Sump Performance," acknowledged the impact of LBB technology, which at that time had not been fully accepted as a regulatory alternative. NUREG-0869, Revision 1, "USI A-43 Regulatory Analysis," states:

> *"The more recent experimental and analytical work, which is based on mechanistic fracture mechanics, results in probabilities of the rupture of large-size ductile piping (unaffected by IGSCC) significantly lower (better by several decades in magnitude) than those employed in the A-43 analyses. Therefore, if pipe failure probabilities are extremely low — because of such considerations as leak-before-break, etc. — these calculations would result in very low estimated releases, and backfits would not be supportable on the basis of value/impact criteria."*

The consideration of LBB technology in NUREG-0869 was limited in that it involved only the impact on the probability of pipe rupture and the resultant effect on sump-blockage probabilities. Future generic investigations can be expanded to specifically address the effects of LBB on debris-generation characteristics and volumes.

An important aspect in the considerations of sump performance characteristics is the relative risk importance of each distinct portion of the overall evaluation. This allows attention (and resources) to be focused on areas of higher risk importance. The size and location of a postulated break has a significant effect on the amount of debris generation, debris transport characteristics and event timings. Elimination of debris generation from LBB-qualified piping enables a more focused review of the unique transport and event-timing characteristics for the remaining break locations. This is an important consideration since evaluation of debris generation and transport phenomena can require a very detailed understanding and modeling of plant geometry and LOCA event timings and characteristics.

4. Conclusions/Recommended Position

In summary, the discussion provided in this paper supports the following position with respect to application of LBB technology to debris generation:

- In accordance with the LBB final rule, the local dynamic effects due to pipe rupture can be excluded from consideration in the structural design basis of safety related equipment and structures. Accordingly, debris generation that is a direct consequence of those dynamic effects can also be excluded.

- The evaluation of global, non-mechanistic debris generation is retained.

All effects of pipe breaks not covered by LBB, whether dynamic or otherwise, must still be considered in the evaluation of safety related equipment and structures.