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MEMORANDUM TO: John A. Grobe, Associate Director for
Engineering and Safety Systems
Office of Nuclear Reactor Regulation

FROM: Michele G. Evans, Director
Division of Component Integrity
Office of Nuclear Reactor Regulation

SUBJECT: DIVISION OF COMPONENT INTEGRITY RESPONSE

recommended the development of an LBB knowledge management document to clearly describe the Nuclear Regulatory Commission's policy and practice on the application of LBB. Accordingly, the Division of Component Integrity (DCI) staff has completed the enclosed document, entitled "Leak-Before-Break (LBB) Knowledge Management Document." This completes our effort on TAC No. MD3570. The staff intends to update and revise this document in the future as warranted.

Enclosure:
Leak-Before-Break Knowledge Management Document

CONTACT: Simon Sheng, DCI/CVIB
(301) 415-2708

Leak-Before-Break (LBB) Knowledge Management Document

A. Introduction

General Design Criterion 4 (GDC-4) of Appendix A to Part 50 of Title 10 of the Code of Federal Regulations (10 CFR Part 50) allows the use of analyses reviewed and approved by the Commission to eliminate from the design basis the dynamic effects of postulated pipe ruptures. Guidance on postulation of pipe ruptures is contained in Standard Review Plan (SRP) Section 3.6.2, "Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping." A staff-approved leak-before-break analysis permits licensees to remove protective hardware such as pipe whip restraints and jet impingement barriers, to redesign pipe-connected components, their supports and their internals, and other related changes in operating plants.

The scope of the application of LBB evolved from 1985 to 1989 and the NRC positions regarding the issue were discussed in Nuclear Regulatory Commission (NRC) policy documents issued during that time frame [1 - 6]. Each of these documents contains some NRC positions regarding the application of LBB, but so far there is not one NRC document which provides a summary of the current NRC positions regarding the application of LBB. Consequently, knowing the contents of one or two documents could lead an individual to misinterpret NRC's positions on the application of LBB. This LBB Knowledge Management Document is meant to address this deficiency by providing such a summary on the application of LBB.

B. Discussion

Among the documents referenced above, Draft SRP Section 3.6.3 [3], "Leak-Before-Break Evaluation Procedures," contains acceptance criteria and review procedures for staff to evaluate an LBB analysis supporting the elimination of the dynamic effects of pipe ruptures of a piping system from a facility's design basis. SRP Section 3.6.3 [7], Revision 1, based on Draft SRP Section 3.6.3 [3], was issued in March 2007. The LBB analysis defined in the SRP is a deterministic fracture mechanics analysis, coupled with a leakage analysis. A detailed discussion of limitations and acceptance criteria for LBB is provided in NUREG-1061, Vol. 3 [8]. Currently, a document which considers various LBB-related technical issues, especially those that occurred after 1989, is proposed as a NUREG [9]. When the proposed NUREG and the proposed SRP Section 3.6.3 are issued, the former will supplement the latter and provide a detailed technical basis for LBB evaluation procedures for future LBB applications. The purpose of this Knowledge Management Document is not to discuss the technical issues related to LBB, but to clearly define the scope of application of LBB based on the relevant NRC policy-related statements contained in References 1 to 6 and to discuss briefly some specific applications of LBB to operating plant and design certification reviews.

To achieve the purpose stated above, the staff classifies the regulatory positions on application of LBB into five categories: (C1) qualification of high energy piping systems for LBB analysis, (C2) allowable licensing/design basis changes via LBB applications, (C3) limitations on applying LBB to containment design, emergency core cooling system (ECCS), and environmental

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qualification (EQ) of safety related electrical and mechanical equipment, (C4) recent applications requiring interpretation of regulatory positions on LBB, and (C5) future position changes regarding LBB applications. High energy piping is defined [4] as those systems having pressures exceeding 275 psig or temperatures exceeding 200 °F.

The LBB approach originated from the resolution of Unresolved Safety Issue (USI) A-2, "Asymmetric Blowdown Loads on Reactor Primary Coolant Systems." This issue, which was initially identified in 1975, concerns asymmetric blowdown loads that result from postulation of rapid-opening double-ended rupture of pressurized water reactor (PWR) primary piping at the most adverse location in the piping system. USI A-2 was resolved in 1984 by the industry and the NRC by the adoption of the LBB approach utilizing fracture mechanics techniques, as indicated in Generic Letter (GL) 84-04 [10]. GL 84-04 contains the safety evaluation of the Westinghouse topical reports dealing with elimination of postulated pipe breaks in PWR primary main loops. Resolution of USI A-2 in 1984 set the stage for the modifications of GDC-4 which have occurred since 1985 to allow the use of LBB for excluding from the design basis dynamic effects of postulated pipe ruptures. Thus, the application of LBB was originally limited to primary main loop piping in PWRs [2]. The application was extended in 1987 [4] to all qualified high energy piping in all LWR nuclear power units. In addition to acceptance criteria and review procedures, Draft SRP 3.6.3 [3] also identified specific technical limitations associated with high energy piping systems which would disqualify them for LBB applications.

C. Regulatory Positions on Application of LBB

C1. Qualification of high energy piping systems for LBB analysis

Before starting a quantitative LBB analysis in support of an LBB application to a high energy piping system in a nuclear power plant, a high-level qualification process must be conducted. The LBB technology can be applied to a high energy piping system if it does not fall into any of the following categories [3]. These positions may be revised as a result of the on-going research program addressing primary water stress corrosion cracking (PWSCC) in LBB systems [11].

- <u>ASME Code Class 3 piping.</u> Although LBB can be applied to ASME Code Class 1 and Class 2 piping systems or their equivalent, the majority of the NRC approved applications were for the ASME Code Class 1 piping systems.

- <u>Piping individual welded joints or other discrete locations.</u> LBB applies only to an entire piping system or an analyzable portion of a system such as piping segments between anchor points.

- <u>Piping repaired by weld overlays.</u>

This paragraph was redacted because of an error in the paragraph. Piping repaired by weld overlays is the subject of a position paper that is being developed by the NRC staff and that will be made publicly available.

- <u>Piping supported by masonry walls.</u> This piping will not be considered for LBB applications unless compliance with Multi-Plant Action B-59 is achieved.

- Piping susceptible to water hammer, creep, erosion, corrosion, and fatigue. Piping affected by water hammer is excluded from the LBB application because the established LBB evaluation procedure does not consider the dynamic loads associated with water hammer. For the listed degradation mechanisms, they are excluded from LBB applications because they all tend to challenge the postulated through-wall flaw configuration used in the LBB evaluation.

For piping susceptible to corrosion such as intergranular stress corrosion cracking (IGSCC), Draft SRP 3.6.3 indicates that LBB may be considered if two mitigation measures are in place. This aspect of Draft SRP 3.6.3 was written to address IGSCC in boiling water reactors (BWRs) prior to the discovery of PWSCC in PWRs. To date the NRC has not approved use of LBB to piping susceptible to IGSCC, e.g., LBB has not been approved for use in any BWRs. The staff, however, did approve use of LBB in piping which we learned years later is susceptible to PWSCC. Recently, the industry has used weld overlays and mechanical stress improvement or inspection schedules more stringent than that in the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Section XI, to mitigate or monitor PWSCC in susceptible welds in PWR piping systems. The NRC staff is conducting a research program [11] to evaluate management approaches including the number of mitigation measures needed for maintaining the use of LBB in systems susceptible to PWSCC. At the conclusion of this program the NRC will develop a revised position, as appropriate.

Once it has been demonstrated that a high energy piping system is free of the above considerations, the system can be considered a candidate system for LBB approval.

C2. Allowable licensing/design basis changes via LBB applications

When LBB is approved for a particular piping system, applicants are to exclude from the design basis only local dynamic effects associated with postulated pipe ruptures in that system in the nuclear power unit. The local dynamic effects are:

- missiles,
- pipe whipping,
- pipe break reaction forces, and
- discharging fluids.

References 1 and 2 mentioned all these local dynamic effects while GDC 4, due perhaps to the concise nature of its statement, only presented a partial list: missiles (the first), pipe whipping (the second), and discharging fluids (the fourth). Although Draft SRP 3.6.3 [3] did not restate all four local dynamic effects, later NRC publications [4, 5] discussed all of them. It should be noted that before the issuance of Reference 5 in 1988, these local dynamic effects were referred to as only "dynamic effects."

For each local dynamic effect listed above, the applicant, upon NRC approval, is permitted to perform a well-defined plant activity as a result of excluding this dynamic effect from the design basis. The permitted plant activities are, in the order of local dynamic effects:

- remove jet impingement barriers or shields,
- remove pipe whip restraints,
- redesign pipe connected components, their supports and their internals, and other related changes, and
- disregard jet impingement forces on adjacent components, decompression waves within the intact portion of the piping system, and dynamic or nonstatic pressurization in cavities, subcompartments, and compartments.

The first three permitted plant activities, which correspond to the first three local dynamic effects that are excluded from the design basis, can be found in Draft SRP 3.6.3 [3]. The last permitted plant activity, which corresponds to discharging fluids that are excluded from the design basis, was first discussed in Reference 1 in 1985 and subsequently in Reference 4 in 1987 and Reference 5 in 1988. Reference 5 further characterizes the "dynamic or nonstatic pressurization" as "local pressurization."

Specific plant activities that the LBB applicant shall not apply for are identified below:

- Redefine loss-of-coolant accidents (LOCAs) that place requirements on safety systems and structures.
- Change design margins in the primary loop heavy component supports.

Both examples are from Reference 1 and can be considered as being related to global dynamic effects. It should be noted, however, that the wording in the reference regarding existing heavy component supports designed for the dynamic effects of pipe rupture and seismic events might lead people to conclude that redesign of existing heavy component supports is not permitted. Reference 2 modified this wording and stated that the NRC will accept redesign of heavy component supports if "reliability and adequate margins under each required design and service load condition is achieved."

C3. Limitations on applying LBB to containment design, ECCS, and EQ

The LBB technology cannot be applied to containment design, ECCS design, and EQ associated with the following [5]:

- For Containments. Global loads and environments associated with postulated pipe ruptures, including pressurization, internal flooding, and elevated temperature.

- For ECCS. Heat removal and mass replacement capability needed because of postulated pipe ruptures.

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

ECCS performance and containment design were identified in 1985 [1] as areas that LBB shall not be applied to. In 1986 [2], "environmental qualification of electrical and mechanical equipment," was identified as an additional area to which LBB cannot be applied. All three have been mentioned as a group since then, though more frequently as only "containment, ECCS, and EQ." In 1988 [5] NRC solicited public comments on use of LBB technology to modify functional and performance requirements for ECCS and EQ of safety-related electrical and mechanical equipment. This document contains the most detailed information regarding NRC's explanation of the applications of LBB technology and is still valid today. As a result of this solicitation, the NRC issued a policy statement in 1989 on additional applications of LBB technology [6]. The key information in the 1989 policy statement was that NRC had decided not to undertake rulemaking which would extend the scope of application of LBB technology to ECCS or EQ of safety-related electrical and mechanical equipment. There was nothing in the 1989 policy statement which would change the NRC's interpretation of the existing scope of applications of LBB technology to ECCS or EQ as defined above. However, the policy statement did indicate that the exemption process could be used for applying LBB to EQ but did not extend this option to ECCS. Since application of LBB to containment design was outside the scope of the 1988 solicitation, the 1989 policy statement on LBB did not mention containment design.

The policy statement presented above in the first bullet for containments appears to be inconsistent with an earlier policy statement made in the public comment solicitation section preceding the 1987 draft SRP [3]:

> [T]he staff's current position is that the cited requirements [containment design requirements that are not affected by LBB] include pressurizations, pipe whip effects and jet impingement effects from pipe ruptures on containment pressure boundaries and primary structures, and in the case of containments with pressure suppression design features, the effects of pipe ruptures on those features.

It is apparent that there is no inconsistency if one considers that although pipe whip effects and jet impingement effects are local, their effects on containment pressure boundaries and primary structures are global. This is a good example showing that the distinction between local effects from pipe ruptures and global effects from pipe ruptures are not always clear.

Pipe rupture dynamic effects that can be excluded from an LBB applicant's plant design bases for containment, ECCS, and EQ are further explained in Reference 5:

> ...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 (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.

Similar to Section C2 regarding allowable licensing/design basis changes in LBB applications, local dynamic effects uniquely associated with pipe rupture may be deleted from the design basis of containments, ECCS, and EQ. For example, the local dynamic effects of jet impingement deleted from the design basis are not considered in the functional design of ECCS components, such as sump screens. So far, such a list of local dynamic effects or plant activities does not exist. However, considering the limited number of LBB applications related to containments, ECCS, and EQ to date, the staff has found it unnecessary to come up with the list of postulated applications. Instead, the staff will rely on fundamental principles to decide on a case-by-case basis when a proposed area of LBB application appears to be new.

C4. Recent applications requiring interpretation of regulatory positions on LBB

Two of the LBB applications submitted after 2003 appear to be outside the past experience and are discussed below.

<u>Example 1: Low pressure injection (LPI) system cross-connect modification</u>

This issue concerns an LPI system cross-connect modification at all three units of a nuclear power plant in 2003 [12]. Specifically, the application requested that the dynamic effects of postulated pipe breaks associated with a selected portion of the core flood (CF) and LPI piping be excluded from the plant design basis. The application also requested approval to change the technical specifications to eliminate requirements associated with the capability to cross connect, by manual action, the trains outside containment during a postulated CF line break.

This application was new because the requested action included a technical specification change, which is not one of the listed plant activities as described in Section C2. However, this application neither modified the containment design criteria, nor changed the functional design basis of the ECCS. Further, the applicant's re-analysis of LOCA events confirmed that the LPI modification will not adversely impact the large break LOCA results and benefits the CF line break event [12]. Based on the above, the NRC agreed to review the application and eventually approved it.

Example 2: Containment sump performance

This issue concerns a proposed containment sump strainer performance requirement. Specifically, the industry requested that local debris generation due to the dynamic effects associated with the postulated double-ended guillotine breaks (DEGBs) of LBB-approved piping be excluded from facility design and licensing bases. The LBB application was rejected in 2004 [13] because: (1) although an acceptable LBB evaluation provides assurance with regard to the low probability of piping failure, it is consistent with the Commission's defense-in-depth principle, given the consequences of sump failure, to expect containment sump operability under such circumstances, (2) the NRC staff concluded that any decision to extend LBB for the purpose of addressing LOCA-generated debris and sump performance to the detriment of defense-indepth principles is, at a minimum, a policy decision which would require Commission approval, and (3) PWSCC was a concern. It should be noted that an on-going research program [11] is addressing the concern of PWSCC in approved LBB piping.

Although one may not consider the sumps serving the ECCS and the containment spray system part of the ECCS, the ECCS functional performance is directly affected by the containment sump performance. Therefore, requiring the dynamic effects such as debris generation associated with the postulated DEGBs of LBB-approved piping be included in the sump performance evaluation is a logical extrapolation of the Section C3 limitations on LBB.

C5. Future position changes regarding LBB applications

It was mentioned in Section C1 that the NRC is currently addressing the PWSCC issue and a definitive NRC position regarding the effect of PWSCC on LBB applications will be provided in appropriate regulatory guidance documents.

D. A Review of Past LBB applications

Over the years, the NRC has approved LBB applications to the following high energy piping systems:

- Main coolant lines,
- Pressurizer surge lines,
- Residual heat removal lines,
- Accumulator lines,
- Reactor coolant bypass lines,
- Safety injection system lines into cold and hot legs,
- CE System 80+ direct vessel injection lines,
- CE System 80+ shutdown coolant line, and
- AP1000, AP600, and CE System 80+ main steam line inside containment.

Although the NRC allows the application of LBB technology to BWRs [4] if the piping is treated by two IGSCC mitigating measures, so far LBB has not been applied to BWR piping. Also, due to the potential for water hammer, LBB has not been approved for feedwater lines.
Although NRC has been prudent in its review of LBB submittals for new areas of application, there has been one potential misapplication of LBB
This is discussed below as a lesson-learned experience.

The issue is the instrumentation and control common-mode failure (CMF) analysis for CE System 80+, which did not address CMF due to large break loss of coolant accidents (LBLOCA) and main steam line breaks based on the justification that "the leak detection systems would detect flawed piping before large failures occurred" [14]. This justification is essentially LBB. Before the CE System 80+ approval, the staff position regarding instrumentation and control was that a design certification applicant shall analyze each postulated CMF for each event that is evaluated in the accident analysis sections of the safety analysis report, which would include LBLOCAs and main steam line breaks. Based on likelihood arguments, it may be reasonable to exclude main steam line breaks and LBLOCAs corresponding to piping above a certain diameter (e.g., 12 inches) from CMF analysis, but the reason cited in the CE System 80+ safety evaluation represented inappropriate reliance on LBB.

However, the statement that "I&C system vulnerability to CMF affecting LBLOCAs and main steam line breaks has been accepted in the past based upon leakage detection" has since been removed from the applicable SRP Branch Technical Position [15].

E. References

1. U.S. NRC, "Modification of General Design Criterion 4 Requirements for Protection Against Dynamic Effects of Postulated Pipe Ruptures," Federal Register, Vol. 50, No. 126, Office of the Federal Register, Washington D.C., July 1, 1985, pp. 27006-27009.

2. U.S. NRC, "Modification of General Design Criterion 4 Requirements for Protection Against Dynamic Effects of Postulated Pipe Ruptures," Federal Register, Vol. 51, No. 70, Office of the Federal Register, Washington D.C., April 11, 1986, pp. 12502-12505.

3. U.S. NRC Draft Standard Review Plan 3.6.3, "Leak-Before-Break Evaluation Procedures," Federal Register, Vol. 52, No. 167, Office of the Federal Register, Washington D.C., August 28, 1987, pp. 32626-32633.

4. U.S. NRC, "Modification of General Design Criterion 4 Requirements for Protection Against Dynamic Effects of Postulated Pipe Ruptures," Federal Register, Vol. 52, No. 207, Office of the Federal Register, Washington D.C., October 27, 1987, pp. 41288-41295.

5. U.S. NRC, "Leak-Before-Break Technology; Solicitation of Public Comment on Additional Applications," Federal Register, Vol. 53, No. 66, Office of the Federal Register, Washington D.C., April 6, 1988, pp. 11311-11312.

6. U.S. NRC, "Policy Statement on Additional Applications of Leak-Before-Break Technology," Federal Register, Vol. 54, No. 83, Office of the Federal Register, Washington D.C., May 2, 1989, pp. 18649-18851.

7. U.S. NRC NUREG-0800, "Standard Review Plan," Section 3.6.3, Rev. 1, "Leak-Before-Break Evaluation Procedures," ADAMS (ML063600396), March 22, 2007.

8. U.S. NRC NUREG-1061, "Report of the U.S. Nuclear Regulatory Commission Piping Review Committee - Evaluation of Potential for Pipe Breaks," Vol. 3, November 1984.

9. U.S. NRC Draft NUREG-6765, "Development of Technical Basis for Leak-Before-Break Evaluation Procedures," to be published.

10. U.S. NRC Generic Letter 84-04, "Safety Evaluation of Westinghouse Topical Reports Dealing with Elimination of Postulated Pipe Breaks in PWR Primary Main Loops (Generic Letter 84-04)," February 1, 1984.

11. U.S. NRC Memorandum from Brian W. Sheron, RES Office Director, to James E. Dyer, NRR Office Director, "User Need Request NRR-2005-011, Primary Water Stress Corrosion Cracking in Leak-Before-Break Systems," ADAMS (ML061380039), June 13, 2006.

12. U.S. NRC Safety Evaluation, "Oconee Nuclear Station, Units 1, 2, and 3 Re: Issuance of Amendments (TAC Nos. MB8083, MB8084, and MB8085)," ADAMS (ML032721590), September 29, 2003.

13. U.S. NRC Safety Evaluation, "Nuclear Energy Institute's Proposals for Determining Limiting Pipe Break Size Used in Assessing Debris Generation Following a Design Basis LOCA (TAC No. MC1154)," ADAMS (ML040410433), March 4, 2004.

14. U.S. NRC NUREG-1462, "Final Safety Evaluation Report Related to the Certification of the System 80+ Design," August 1994.

15. U.S. NRC NUREG-0800, "Standard Review Plan," Chapter 7, Branch Technical Position 7 -19, "Guidance for Evaluation of Diversity and Defense-in-Depth in Digital Computer-Based Instrumentation and Control Systems," Revision 5, March 2007.