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Supplementary Information

Renseignements supplémentaires

Presentation from Dr. Sunil Nijhawan

Présentation de Dr. Sunil Nijhawan

In the Matter of the

À l'égard d'

Ontario Power Generation Inc.

Ontario Power Generation Inc.

Application for a licence to construct one BWRX-300 reactor at the Darlington New Nuclear Project Site (DNNP)

Demande visant à construire 1 réacteur BWRX-300 sur le site du projet de nouvelle centrale nucléaire de Darlington (PNCND)

Commission Public Hearing
Part-2

Audience publique de la Commission
Partie-2

January 8-10 and 13-14, 2025

8-10 et 13-14 janvier 2025

SEE PAGE 5 FOR HIGHLIGHTEST TEXT CONFIRMING THAT THE BWR DESIGN PRECLUDES CONSIDERATION OF LEAK BEFORE BREAK CERTIFICATION AND NO BOILING WATER REACTOR HAS EVER BEEN GRANTED ONE

News

An Historical Survey of Leak-Before-Break in Nuclear Plant Piping

Leak-before-break (LBB) is a term that has been used for decades in reference to a methodology that means that a leak will be discovered prior to a fracture occurring in service. LBB is most often used in main steam lines of nuclear power plant piping and it has also been applied to missile casings, gas and oil pipelines and pressure vessels.

Clarion Energy Content Directors

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EDF's Flamanville 3 on the north coast of France. Flamanville 3 and Olkilutoto 3 in Finland, both currently under construction, considered the LBB concept in the design stage. Photo, EDF.

Leak-before-break (LBB) is a term that has been used for decades in reference to a methodology that means that a leak will be discovered prior to a fracture occurring in service. LBB is most often used in main steam lines of nuclear power plant piping and it ha[s] also been applied to missile casings, gas and oil pipelines and pressure vessels.

The basic idea of LBB is to exclude any potential for pipe break and then prove that the critical crack–which occurred in spite of the exclusion of all detrimental mechanisms–will be safely detectable within one hour. Early detection enables shut down of the reactor in the case of a nuclear power plant.

There are several technical definitions for LBB. For instance, LBB can occur for an axial flaw in a pipe where the penetration of the wall thickness will result in a stable axial through-wall crack. This is LBB under load-controlled conditions.

LBB could also occur for a circumferential crack in a pipe with high thermal expansion stresses. This can be considered as LBB under compliant displacement-controlled conditions.

Finally, LBB might occur when the flaw is stable under normal operating conditions and remains stable when there is a sudden dynamic event such as seismic loading. This can be termed as a time-dependent inertial LBB analysis.

These analyses are deterministic and could be extended to probabilistic evaluations as well.

LBB Background

Historically, the hypothetical double-ended guillotine break (DEGB) has been considered the most severe reactor loss of coolant accident (LOCA) in nuclear power plant design. The original purpose and intent of the postulated DEGB was to provide a clearly limiting basis for sizing the reactor containment system. However, the postulate was extended to the design of the high energy piping system, resulting in the construction of massive pipe whip restraints and jet impingement shields, simply because no alternate acceptable design basis was available. The DEGB postulate was further extended to the design for environmental qualification and even in the sizing of the emergency core cooling systems (ECCS).

For many years, the commercial nuclear industry has recognized that a DEGB is highly unlikely even under severe accident loads and that a design basis LOCA based on DEGB is an unnecessary and undesirable design restriction.

The LBB methodology could be accepted as a technically justifiable approach for eliminating postulated DEGB in high energy piping systems. This conclusion resulted from extensive research, development and rigorous evaluations by the U.S. Nuclear Regulatory Commission (NRC), the German Commission on Reactor Safety (RSK) and the commercial nuclear power industry and its organizations since the early 1970s. Efforts in other Europea countries (France and the U.K.) have not resulted in regulatory action, as is the case in the U.S.

Applications of the LBB concept gathered momentum in the latter part of the 1980s. The benefits of LBB are multifold, with maximum economic benefits derived if the concept is applied from the early design stages. However, owing to lack of new construction orders for nuclear power plants in recent years, the LBB concept has been generally applied in a backfit mode rather than at the preliminary design stage.

Yonggwang Units 3 and 4 in South Korea are the first nuclear power plants in the world that adopted the LBB concept in early stages of design. In Germany, for all advanced Convoi nuclear power plants, the break preclusion concept including LBB was introduced during the design phase of the plants and was successfully achieved during their construction. The reactor cooling system (RCS) piping in Areva's new US EPR design (currently being reviewed by the NRC) is designed using the LBB concept. This eliminates the need to design RCS components and piping and supports to accommodate the dynamic effects of large or double-ended ruptures in these piping systems.

Consequently, large pipe whip restraints and jet impingement shields are not required. To justify the LBB design, a monitoring system is required to detect leakage from this piping into the reactor building. Olkiluoto 3 (OL3), the first third-generation plant in the world, also designed by Areva and currently being built in Finland, and Flamaville 3 currently under construction in France, consider the LBB concept in the design stage. Both these plants use the EPR model as well.

The reactor pressure vessel (RPV) and primary coolant piping of pressurized water reactors (PWRs) are usually manufactured from tough fracture-resistant steel. For this material, the load corresponding to rupture of the component would be significantly influenced by cracks, which could occur in the component wall. This has been demonstrated in numerous studies, including an extensive experimental program carried out in Germany.1

The results suggest that there is more probability of an extensive leakage for a component rather than a net section break (in the case of primary piping, the so-called DEGB) and that there would be safe shutdown of the power plant if leakage is reliably monitored. However, for safety reasons and for lack of a reliable treatment of the above argument, the DEGB has been considered as a possible accident in the guidance documents of the regulatory commissions of countries with nuclear power programs. Pertinent safety arrangements to deal with a DEGB accident were therefore obligatory for the utilities.

LBB Methodology

LBB analyses are based on advanced fracture mechanics techniques and include critical flaw size evaluation; leakage calculation; crack propagation analysis; ultrasonic flaw detection/sizing; leak detection; and service experience.

The original application of LBB was for the elimination of protective structures such as pipe whip restraints, jet impingement shields and other applications, which provide protection against high energy line breaks. Recently LBB has been used as part of overall safety assessments for leaving real or postulated flaws in service for some operating period.

"Modification of General Design Criterion 4 (GDC-4): Requirements for Protection against Dynamic Effects of Postulated Pipe Ruptures,"2 released by the NRC, uniquely defines the leak-before-break case and assigns legislative consequences to the LBB status. For U.S. utilities that can prove the LBB case according to that release, extensive measures to handle the dynamic consequences of the DEGB accident are no longer obligatory. This had sweeping practical implications for the layout of the primary piping (for example, pipe whip restraints and jet shields are no longer needed) and economic savings were significant, while the safety margin is not affected.

Other countries have adopted different attitudes toward applying the LBB concept in their nuclear power plants. In some countries, such as the United Kingdom, the application of the LBB concept is still to be submitted to development and validation before strong legislative conclusions can be drawn up. Before that, LBB can be seen and used as an independent safety case argument.

In other cases, such as Germany,3 the basic safety concept is preferred, which also includes such phenomena as leak and loss of integrity, with, however, a different logic and different legislative consequences. In Germany, RSK issued Guidelines in 19794 dealing with requirements for protection against dynamic effects.

LBB in the U.S. and Europe

In the U.S., the DEGB concept was originated by the U.S. Atomic Energy Commission for the multiple purposes of sizing containments and establishing "accident" doses and, later, for the sizing of ECCS. This safety philosophy was supported by many regulatory guides and codes, including SRP 3.6.3-Revision 1 (March 2007): Leak Before Break Evaluation Procedure, approved by the NRC, which described the procedure for establishing an LBB case for the primary piping.

The most characteristic feature of European attitudes to LBB relies on direct treatment of the part-through cracks within the logic of the LBB concept. The concept of Nuclear Electric of United Kingdom includes characterizing the defect at a suggested critical site; the ultimate LBB case5 then relates to defects in the framework of this characterization and to the pre-selected critical sites.

In Germany,4,6,7,8 the RSK Guidelines on LBB for primary system for pressurized water reactors (PWR) have come into operation since 1979. Basic safety concept and independent redundancies are reflected in realization in the German Code, evaluation of LBB and the principle of LBB. The procedure is to consider defects and analyze fatigue crack growth, then demonstrate that this growth will not go beyond certain prescribed design parameters.

The Czechoslovak LBB program was started in October 1991. The first objective of the program was to prove the LBB status of the primary piping of the WWER-230 in Jaslovske Bohunicem, the first generation of the WWER nuclear power plants in Czechoslovakia. This was completed in 1993. The second objective was to prove the LBB case for primary piping of the WWER-type nuclear power plants. The Czechoslovak LBB concept is pursued as a part of the strategy to meet Western-style safety standards.

The NRC's Position on LBB

It is permissible in the U.S. to eliminate the dynamic effects of a postulated high energy pipe rupture from the design basis of nuclear power plants utilizing the NRCs LBB concept.9 This regulatory approach has been adopted by some other countries, including Spain (for Westinghouse plants) and the former Czechoslovakia,10 and is used as the basis for their assessments.

The NRC issued a Standard Review Plan to provide guidance for the implementation of the LBB concept. The development of the NRC's Standard Review Plan 3.6.3 brought together the concept that forms the LBB regulatory approach.

TABLE 1 DEFLAGRATION INDEX AND MAXIMUM UNVENTED DEFLAGRATION PRESSURE

Material	Mass Median Diameter (micron)	Minimum Flammable Concentration (g/m3)	Pmax (bar)	Kst (bar-m/sec)
Bituminous coal	24	60	9	129
PRB coal		37-60	7.86	200
Wood flour	29		10.5	205
Cellulose	33	60	9.7	229
Kst: Deflagration Index (bar-m/sec)				
Pmax: Maximum unvented deflagration pressure (bar)				

Currently, approximately two-thirds of the PWRs in the U.S. have approval for the application of the LBB concept in the primary coolant loop. There are also four PWRs that have approval for the application of the LBB concept for their auxiliary lines, specifically, pressurizer surge, accumulator and residual heat removal (RHR) lines. One of the four plants also has approval for its application for the safety injection lines and the reactor coolant loop bypass lines. The approved auxiliary lines are all inside containment, fabricated from austenitic stainless steel and at least 150 mm (6 inches) in diameter. The application of the LBB concept has not been approved as yet for any boiling water reactor (BWR).

The application of LBB is limited to piping that is not likely to be susceptible to failure from various degradation mechanisms in service.11 From the NRC experience, a significant portion of any LBB review involves the evaluation of the susceptibility of the candidate piping to various degradation mechanisms.

The LBB approach cannot be applied to piping that can fail in service from such effects as water hammer, creep, erosion or corrosion excessive fatigue. The rationale is that these degradation mechanisms challenge the assumption in the LBB acceptance criteria. For example, water hammer may introduce excessive dynamic loads that are not accounted for in the LBB analyses, and corrosion and fatigue crack growth may introduce flaws whose geometry may not be bounded by the postulated "through wall" flaw in the LBB analyses. In line with the "defense in depth" principle, piping susceptible to failure from these potential degradation mechanisms has to be excluded from LBB application.

To demonstrate that the candidate piping is not susceptible to failure from these degradation mechanisms, the operating history and measures to prevent their operation or mitigate their effects must be reviewed.

LBB acceptance criteria in U.S.

After the LBB candidate piping has been reviewed for degradation mechanisms, as discussed previously, and found to be acceptable, the piping is subjected to a rigorous fracture mechanics evaluation. The purpose of this evaluation is to show that there is flaw stability and the resulting leakage will be detected in the unlikely event that a flaw should develop.

Germany's Position on LBB

The preclusion of breaks of piping in the German assessment route is based on the basic safety concept.12,13 The concept consists of the basic safety (design, material, manufacture) and the independent redundancies (multiple testing, worst-case principle, in-service inspection and verification by fracture mechanics). The basic philosophy of the LBB concept as used in Germany is that a leak occurs long before the critical "through wall" crack length is reached. Break preclusion based on the basic safety concept can be achieved with LBB behavior. Break preclusion without LBB behavior, however, requires equivalent safety measures.

Japan's Position on LBB

The standardization work on the application of the LBB concept to stainless steel pipes in Japan was started in December 1984 at the Sub-Committee on Structural Components within the Technical Advisory Committee of Nuclear Power Plant Operation of the Ministry of International Trade and Industry (MITI). The Sub-Committee finished writing a draft of LBB standards in March 1986. A review of the draft from the standpoint of the MITI text was then started and it was expected that the draft would be opened as one of the MITI private regulations in 1992.14

OECD Countries

Leak before break is now widely applied in the nuclear industries of the member countries of the Organisation for Economic Co-operation and Development (OECD) as a means of assessing the susceptibility of pressurized components to failure by unstable crack propagation.

While the detailed nature of the applications differs widely depending on the country and the component, the basic concept does not. A crack is postulated to exist in a structure and assumed to grow stably by some mechanism to a size at which it penetrates the wall of the component resulting in leakage of the pressurized fluid. When the crack, through continued growth, reaches a size at which leakage is deemed to be detectable (with margin), an assessment is done to show the margin against failure. The margin can be expressed either as a factor of safety on the stress or crack length for instability or on the time available to effect a safe shutdown of the reactor before the crack grows to a critical size.

The NRC held several meetings on the topic of LBB with organizations like the Committee on the Safety of Nuclear Installations (CSNI), the International Piping Integrity Research Group (IPIRG), the OECD and finally, based on the October 1989 meeting in Canada, it was concluded that the LBB concept is a route to guaranteeing structural integrity of reactor components. The uses of the LBB have been discussed for various systems and to varying degrees as a part of a defense in depth procedure. These systems include zirconium alloy pressure tubes, piping systems and steam generator tubing.

The 30 member countries of OECD are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republi Spain, Sweden, Switzerland, Turkey, the U.K. and the U.S.

LBB General Questions

Issues that should be addressed for the LBB concept include the following.

1.) Further development and validation is required for predicting the growth and stability of "through wall" cracks in PWR primary circuit components (including branches and elbows) subjected to combined axial, bending and torsion loads.
2.) If the likelihood of failure of cracked primary coolant loop pipe due to seismic loads is considered a design basis event for PWRs, there will be a need to consider methods for predicting crack growth and stability under combined static and dynamic loadings.
3.) The adequacy of existing models for predicting the leak rates from cracks in PWR piping materials, the performance and sensitivity of the various leak detection systems available and the evidence for plugging of leaks to occur in the PWR environment all need to be reviewed.
4.) The role of inspection must be clarified and the nature, location and minimum sizes of the defects that will have to be reliably detected by non-destructive evaluation methods in order to make an acceptable LBB case must be determined.
5.) The ability of pre-service and in-service inspection methods to reliably detect the defects defined in (4) must be demonstrated.
6.) A probabilistic model for primary circuit pipe failures should be developed that could be used to ensure that the work carried out under items (1) to (5), when combined with existing data and methodologies, was sufficient to meet safety requirements for primary coolant loop integrity.
(7) The available data on the causes, nature and consequences of major failures in PWR primary coolant loop and similar piping should be reviewed. The frequency, causes and likely consequences of such failures form an essential input to the probabilistic model described in item (6) above.

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EDITOR'S NOTE: For the unabridged version of the paper from which this article was condensed, please contact Nancy Spring at nancys@pennwell.com.

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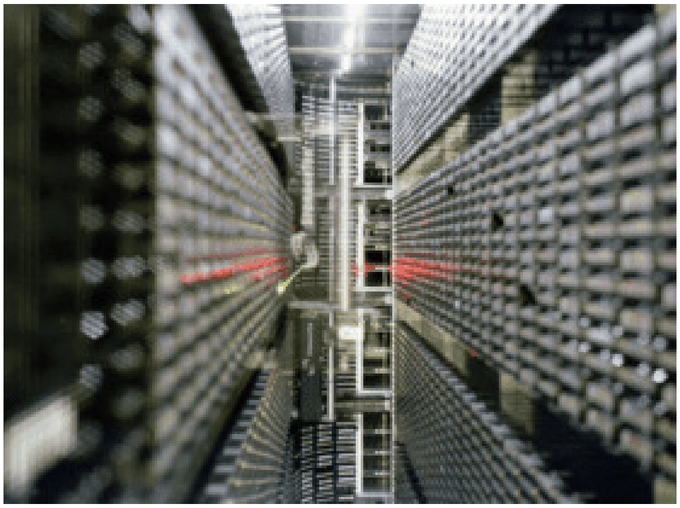

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