Leak Before Break (LBB) Status Report

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NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 30 OECD member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Russia, the Republic of Korea, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

Within the OECD framework, the NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made of senior scientists and engineers, with broad responsibilities for safety technology and research programmes, as well as representatives from regulatory authorities. It was set up in 1973 to develop and co-ordinate the activities of the NEA concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations.

The committee's purpose is to foster international co-operation in nuclear safety amongst the NEA member countries. The CSNI's main tasks are to exchange technical information and to promote collaboration between research, development, engineering and regulatory organisations; to review operating experience and the state of knowledge on selected topics of nuclear safety technology and safety assessment; to initiate and conduct programmes to overcome discrepancies, develop improvements and research consensus on technical issues; and to promote the co-ordination of work that serves to maintain competence in nuclear safety matters, including the establishment of joint undertakings.

The clear priority of the committee is on the safety of nuclear installations and the design and construction of new reactors and installations. For advanced reactor designs the committee provides a forum for improving safety related knowledge and a vehicle for joint research.

In implementing its programme, the CSNI establishes co-operative mechanisms with the NEA's Committee on Nuclear Regulatory Activities (CNRA) which is responsible for the programme of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with the other NEA's Standing Committees as well as with key international organizations (e.g., the IAEA) on matters of common interest.

Executive Summary

One of the principal objectives of the OECD/NEA/CSNI Working Group on Integrity and Ageing of Components and Structures (WGIAGE) is to advance the current understanding of those aspects relevant to ensuring the integrity of structures, systems and components under design and beyond design loads, to provide guidance in choosing the optimal ways of dealing with challenges to the integrity of operating as well as new nuclear power plants, and to use an integrated approach to assess design, safety and plant life management.

This status report has been written within the Working Group on Integrity and Ageing of Components and Structures (WGIAGE) of NEA, through active participation of members of the metal sub-group. This activity was initiated by a CSNI Activity Proposal Sheet (CAPS) on Leak-Before-Break Research which was approved in December, 2009. This first phase of this Leak-Before-Break (LBB) activity included a survey on LBB practises in the member countries.

The survey was conducted by means of a questionnaire and a total of 15 questions were asked. The questions fell into one of three topic areas associated with LBB: the regulatory framework, research activities and knowledge gaps, and collaborative research opportunities. Questions related to collaborative research opportunities asked respondents for their interest in sharing information and conducting collaborative research in both deterministic and probabilistic approaches to evaluating LBB.

The survey results identified possible topic areas for a follow-on CAPS. These areas were discussed by the WGIAGE members to more clearly articulate possible follow-on activities. The idea that garnered the most support is to conduct a series of benchmark analyses of test cases using the LBB approach utilized in each participant’s country. The results of the benchmark analyses will be used to evaluate the differences in the approaches and the effects of analysis choices or prominent assumptions on the margins predicted for each test case. The particular test cases to be evaluated will be defined in detail by the participants prior to initiating the work. This second phase of Leak-Before-Break (LBB) Research work is planned to be initiated sometime in 2016 and will have the following specific objectives:

1. evaluate leak-before-break (LBB) in benchmark piping systems using the regulations and approved guidance applicable within each participating country, and
2. determine the effect of differences among the LBB procedures on the margins predicted for each benchmark case.

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List of Acronyms

ASME	American Society of Mechanical Engineers
BP	break preclusion
BWR	boiling water reactor
CAPS	CSNI Activity Proposal Sheet
CSNI	Committee on the Safety of Nuclear Installations
CNSC	Canadian Nuclear Safety Commission
DMW	dissimilar metal welds
ECCS	emergency core cooling system
ENSI	Swiss Federal Nuclear Safety Inspectorate
EPR	European Pressurized Reactor
EPRI	Electricity Power Research Institute (USA)
DB	design basis
DEC	design extension condition
DEGB	double-ended guillotine break
DID	defense-in-depth
EQ	environmental qualification
IAEA	International Atomic Energy Agency
IRSN	Institut Radioprotection Sûreté Nucléaire (France)
LBB	leak before break
LBLOCA	large break LOCA
LOCA	loss of coolant accidents
LWR	light water reactor
MCL	main coolant lines
ND	nominal diameter
NDT	Non-destructive Test
NEA	Nuclear Energy Agency
NRAJ	Nuclear Regulation Authority Japan
NRC	Nuclear Regulatory Commission
NSC	Nuclear Safety Committee
OECD	Organisation for Economic Cooperation and Development
OL3	Olkiluoto 3 (EPR type reactor under construction in Finland)
POD	probability of detection
PWSCC	Primary Water Stress Corrosion Cracking
RCM	Risk Control Measures
RPV	reactor pressure vessel
SRP	standard review plan
SSC	Systems, Structures and Components
SSE	Safe shutdown earthquake
SSM	(Strålsäkerhetsmyndigheten) Swedish Radiation Safety Authority
TSO	Technical Support Organization
TWC	through-wall crack
WGIAGE	Working Group on Integrity and Ageing of Components and Structures

Foreword

This status report has been written within the Working Group on Integrity and Ageing of Components and Structures (WGIAGE) of NEA, through active participation of members of the metal sub-group. This activity was initiated by a CSNI Activity Proposal Sheet (CAPS) on Leak-Before-Break Research, which was approved in December, 2009.

The CAPS was proposed and led by the Nuclear Regulatory Commission (NRC), which is the representative from the United States (US) to CSNI. The stated purpose of the CAPS is to identify technical areas of mutual interest related to 1) the structural integrity evaluation of piping systems using deterministic and/or probabilistic methods and 2) the demonstration that flaws in piping systems will exhibit leaks prior to failure.

As stated in the original CAPS, the work has the following two phases:

Phase I

> Phase I will initially conduct a survey to identify the current regulatory and technical requirements that are used to demonstrate the structural integrity of primary pressure boundary piping and the leak-before-break (LBB) concept in these systems. The survey will also identify any technical or regulatory concerns related to the aging degradation in these systems, with a particular emphasis on systems that are susceptible to stress corrosion cracking (SCC).
>
> The responses to the questionnaire will be evaluated to identify common issues among the interested countries. A cooperative research plan will then be developed based on these common issues so that countries can share information and potentially conduct joint testing and/or analysis.
>
> The survey responses will be evaluated by the lead organization (i.e., US) to identify similarities and differences in the regulatory and technical requirements and concerns associated with the primary pressure boundary piping. Then, a cooperative research plan will be developed based on concerns or issues of greatest interest to the most countries. The research plan will focus on sharing information, conducting joint testing and/or analysis, and coordinating research activities within each country to maximize the benefit that each country receives.

Phase II

> Interested countries will explore continuing the project into phase II. The scope and details of phase II activities will be defined by the research plan completed during phase I. The research plan, and specific follow-on activities identified by this plan, will be proposed in a new CAPS.

This report of the survey results is provided to satisfy Phase I of the CAPS as described above. The report is published as a working level document because previous state-of-the-art reports have been published related to LBB requirements and research in member countries [1, 2]. The metals subgroup members agree that much of this prior information remains valid such that an additional state-of-the-art report as a result of this survey is not required.

A new activity - CAPS: "A benchmark analysis of test cases using the Leak-Before-Break (LBB) rules appropriate for each country", has been presented to CSNI in June 2015 based on the results of this survey. It is intended that this follow-on CAPS will satisfy Phase II of the original CAPS as described above.

Analysis of results

This work conducted a survey to identify the current regulatory and technical requirements that are used to demonstrate the structural integrity of primary pressure boundary piping and the LBB concept in these systems. The survey was performed by means of a questionnaire and a total of 15 questions were asked. The questions are intended to identify technical and regulatory concerns related to the aging degradation in these systems and potential areas of research for follow-on efforts.

The LBB questions fell into one of the following three topic areas:

- I Regulatory Questions
- II Research Activities and Knowledge Gaps
- III Collaborative Research Opportunities

The questions and their answers are presented in appendix 1.
It was originally intended that a state-of-the-art report may be developed summarizing the regulatory approaches, discussing current technical issues, and identifying any existing technical and regulatory gaps. However, the working group decided not to develop a state-of-the-art report on LBB because three summary reports have been published within the last 15 years that still adequately represent the international situation [1 - 3]. Therefore, the questionnaire responses and their analysis is published as a WGIAGE working level document.

Most countries currently directly credit LBB either within their regulations or as a method to meet existing regulations for piping systems if it can be demonstrated that those system exhibit acceptable margin in an LBB analysis. An LBB analysis is conducted to demonstrate that a piping system will leak with sufficient time to identify the leak and subsequently repair or replace the component before complete failure occurs. Many countries use LBB to address local pipe rupture effects such as pipe whip or jet impingement and some countries credit LBB for addressing asymmetric blow down loads. The LBB concept is used almost in all countries for main coolant lines (MCL) and high energy piping of primary circuit of PWR's as well as for the main steam and feed water lines of BWR's, but requirements and applications for other piping varies country by country.

The LBB analyses that countries employ are deterministic and are typically based on either the US Standard Review Plan (SRP) 3.6.3, "Leak-Before-Break Evaluation Procedures" or the German break preclusion (BP) concept. Additionally almost all LBB analyses contain the following attributes: evaluation of the piping line between anchor points, evaluation of subcritical crack growth by fatigue, evaluation of leak rate margins for a calculated or postulated through-wall crack (TWC), and evaluation of the crack stability margin for this TWC. However, many countries have slightly different acceptance criteria or impose additional considerations than are required in the SRP or in BP methods. Additional considerations include establishing operating procedure to ensure timely response, requiring qualified inspections before and after LBB is credited, demonstrating stability of the TWC for an additional reactor operating life, and identifying additional loading sources to consider in the crack stability analysis. Many countries also have questions related to various assumptions and simplifications required in LBB analyses Questions relate to topics such as properly accounting for residual stresses, determining the proper crack morphology for evaluations, identifying appropriate load combinations for the stability analysis, and the effect of weld strength mismatch on crack stability.

Recommendations for future work

In the questionnaire, respondents expressed interest in both sharing information and conducting collaborative research related to LBB analyses. As a result of possible collaborative research topics identified by the questionnaire, and more substantive discussion held by the WGIAGE members, it was determined that there was not sufficient interest expressed in exploring probabilistic LBB analyses. Rather, the most interest was expressed for conducting benchmark analyses of test cases with the deterministic LBB analyses required by different countries. The topic was approved within the WGIAGE metal sub-group to be the subject for the work during phase 2.

The objective of the benchmark analyses is to evaluate the effect of differences in the various LBB analyses, including, in particular, studying the effects of analysis choices or prominent assumptions on the results. It was also indicated that one (or more) of the test cases should consider application of LBB in dissimilar metal welds.

Once phase 2 has been initiated, the specific parameters associated with the test cases will be more fully developed by the participants to evaluate the technical issues identified during the questionnaire. Each test case will define the pipe system and geometry, applied loads, piping supports, weld residual stress, postulated initial crack size and shape, crack morphology, and all necessary material parameters. Benchmark problems will be nominated by participants and the final problems will be selected by consensus among the participants. The intent is that this phase 2 effort will be initiated in 2016.

Appendix 1 Questions and their Answers

I Regulatory Questions

1. Discuss whether your regulatory approach necessitates that the design of nuclear power plants address postulated piping ruptures

Netherlands: Yes, it does: Loss of coolant accidents (LOCA) were included in the original design basis of the Borssele NPP. Dynamic effects of piping rupture were not taken into consideration at the time.

Japan: Yes. Design against postulated piping rupture is required in following ordinances.

- Article 12 (5) of the NRA Ordinance on Standards for the Location, Structure and equipment of Commercial Power Reactors (Prevention of damage due to external hazards), Ordinance No. 5 of the Nuclear Regulation Authority.

  "Safety systems shall be such that their safety functions will not be compromised by postulated man-induced events (excluding intentional acts) within the station or the vicinity thereof that might impair the safety of power reactor facility."

- Article 15 (4) of the NRA Ordinance on Technical Standards for Commercial Power Reactors Facilities (Functions of SSCs for DB)

  "With regard to equipments belonging to systems, structures, and components (SSCs) for design basis (DB) whose damage due to flying objects resulting from damage of any of the steam turbines, pumps, or other components or pipes may possibly impair the safety of the power reactor facilities, protection facilities shall be installed or other measures to prevent their damage shall be taken. "

Germany: Yes, pipe breaks of various sizes are assumed for different analyses (i.e., LOCA analysis, containment design, equipment qualification, internal forces).

Switzerland: Yes, The Swiss regulatory requirements on design criteria of light water NPP deal with various pipe rupture scenarios in the primary loop piping.

Slovakia: Yes, and LBB concept has been applied in accordance with the decision of the regulatory authority (UJD SR).

JRC: N/A

Canada: Postulated pipe rupture is required be considered in design of CANDU nuclear power plants.

- Regulatory document R-7 "Requirements for Containment Systems for CANDU Nuclear Power Plants" stipulates that the positive design pressure of each part of the containment envelope shall be not less than the highest pressure which could be generated in that part as a result of any postulated events, including the event of "failure of any pipe or header in any fuel cooling system".
- Regulatory document REGDOC-2.5.2 (http://www.nuclearsafety.gc.ca/eng/acts-and-regulations/regulatory-documents/history/regdoc2-5-2.cfm) titled "Design of Reactor Facilities: Nuclear Power Plants" [4] specifies that "SSC design includes protection against postulated pipe ruptures, unless otherwise justified".

Sweden: Yes, reactors shall be able to withstand global and local loads and other effects, which can occur in connection with a pipe break.

- For the early reactors, only the global effects from pipe breaks were accounted for in the original design.
- Later reactors were also designed to withstand local dynamic effects.

Belgium: Belgian reactors have been designed following the criteria of the original GDC-4.

- In particular, primary piping, heavy components of the primary system and their supports, and internals have been sized to withstand dynamic effects of postulated large primary piping breaks.
- Since power uprates and allowance of stretch out, these components were not sufficiently protected any more against dynamic effects, and an LBB analysis has been applied for the primary coolant loops of all Belgian reactors.

Czech Republic: Yes, postulated piping ruptures are adopted into design (LOCA analysis, containment design, safety system design, equipment qualification). For high energy piping approaches of SRP 3.6.1, 3.6.2 and 3.6.3. has been fully adopted as part of Final Safety Analysis Report.

Finland:

- According to Government Decree (733/2008), pipe breaks that may jeopardize important safety functions must be considered in NPP design.
- The probabilities and safety implications must be rendered insignificant via design, layout and protection of the SSC's.
- The detailed requirements are given in the regulatory body STUK's YVL guides.

France: The postulate of pipe break is part of the defence-in-depth principle which is retained by the French regulation. In practice, the GDC-4 was applied for the first series of 900-MWe reactor under Westinghouse licensee. The code RCC-P, with equivalent rules than those in GDC-4, was applied for the 1300 and 1450-MWE reactors designed by Framatome.

Technical guidelines for the design and construction of the next generation of nuclear power plants with PWR, approved by ASN, mention explicitly that piping ruptures, as double-ended guillotine break, have to be postulated in the safety demonstration.

The ministerial order of 12/12/2005 also requires that “very unlikely accidental situations” are postulated but without more details.

US: Yes, the U.S. Code of Regulations requires that postulated pipe ruptures be considered in the design of nuclear power plants (NPPs). In particular, §50.46, “Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors”, §50.49, “Environmental Qualification of Electric Equipment Important to Safety for Nuclear Power Plants”, Criterion 4 to Part 50, Appendix A, “Environmental and Dynamic Effects Design Basis”, and Criterion 50 to Part 50, Appendix A, “Containment Design Basis” require consideration of the effects of loss-of-coolant-accidents arising from postulated pipe ruptures up to and including a break equivalent in size to the double-ended rupture of the largest pipe of the reactor coolant system.

2. **Describe how LBB is credited within your country's regulations. That is, if your country allows credit for LBB, is LBB credited to ease existing regulations or is any credit incorporated directly into the regulations? Discuss the scope of LBB credit that your country allows, i.e., dynamic effects only or also containment design, emergency core cooling system design or design for environmental qualification.**

Netherlands: We follow the standards as described in 'ANSI/ANS-58.2-1988: Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture'. This issue was discussed as part of the first Periodic Safety Review in the period 1995-1996. The implementation in the Dutch nuclear power plant took place in 1997.

Japan:

- A document, "Design considerations for internally originated flying objects" [5], issued by Nuclear Safety Committee (NSC), summarizes the results of reviews on acceptability of introducing the LBB concept to austenitic stainless steel piping belonging to the reactor coolant pressure boundary to ensure that the requirements for protecting against internal missiles was met.
- Applications of the LBB concept to design conditions of containment vessel, performance evaluation of ECCS, design considerations for environmental conditions such as electrical and instrumentation systems with safety functions and radiation exposure evaluation are not specified in the document.

Germany:

- There is no regulatory credit for LBB per say.
- The RSK Guidelines postulate the specific leaks and breaks to be analyzed. Further material, design and manufacturing requirements are included in Appendix 2 (Basis Safety) of the RSK Guidelines. The requirements are detailed in the nuclear safety standards KTA 3201 for "Components of the Reactor Coolant Pressure Boundary of Light Water Reactors" (KTA 3201.1 "Materials and Product Forms", KAT 3201.2 "Design and Analysis", KTA 3201.3 "Manufacture" and KTA 3201.4 "In-service Inspections and Operational Monitoring").
- A new KTA safety standard (KTA 3206 "Verification of Break Preclusion for Pressure Retaining Components in Nuclear Power Plants") dealing with the criteria and the implementation of the break preclusion concept has also been developed.

Switzerland:

- Swiss regulation (Reg.-Guide ENSI-A01 – appendix 2) grants credit for a LBB reviewed and approved by ENSI.

Slovakia:

- The LBB concept is applied at NPPs in Slovakia because of decision of the regulatory authority (UJD SR).

JRC: N/A

Canada:

- REGDOC-2.5.2 specifies that "Pressure-retaining components whose failure will affect nuclear safety are designed to permit inspection of their pressure boundaries throughout the design life. If full inspection is not achievable, then it is augmented by indirect methods such as a program of surveillance of reference components. Leak detection is an acceptable method when the SSC is leak-before-break qualified". **This means that LBB is credited within our regulation for new nuclear power plants**.
- For new plants or for existing plants applying for license extension, LBB is credited to address only the local dynamic affects such as pipe whip restraints and jet impingement shields and for

the purpose of supporting continued operation of degraded components. LBB has not been used to address issues associated with environmental qualification of components, containment sizing and ECCS performance.

- LBB assessments have been used in risk-informed structural integrity assessments of potentially flawed components to demonstrate low frequency of rupture in support of continued service for specified operating periods.

Sweden:

- Credit for LBB is included directly in the regulations. The scope is limited to the local dynamic effects which do not need to be accounted for if LBB can be demonstrated. Also, the consequences of asymmetric blow down loads in PWRs are not in general allowed to be excluded by using LBB.

Belgium:

- Historically, the application of the LBB has been proposed by the plant owners mainly to allow power uprates and stretch out.
- LBB did not exist in the Belgian regulations, and therefore plant owners referred to the modified GDC-4 and SRP 3.6.3.
- The regulatory body accepted the application of the LBB principle on the primary piping for the dynamic effects, but dictated the following limitations:
    - The internals of the heavy components, and in particular the internals of the reactor vessel, must be able to withstand dynamic loads associated to a postulated rapid (1 ms) break, having a size of 0.3A, and located in the hot or cold leg, in the vicinity of the steam generator.
    - SRP 3.6.3 requires determining the critical break size under normal loads taking also into account loads associated to the SSE. However, the Belgian regulatory body requires that the additional loads to consider in the LLB analysis include also the ones produced by the break of a steam line or of an auxiliary piping to the primary circuit, whichever is larger.
    - The reactor vessel supports and the steam generators supports are important components in the protection against the worsening of an accident. These components were originally designed to withstand dynamic loads associated with large breaks and this requirement is maintained under LBB.

Czech Republic:

- SRP 3.6.3 has been fully adopted with small changes. Local dynamic effects are excluded. No change in the ECCS, containment design, RPV blowdown loads, and environmental qualifications.

Finland: The YVL guides formulate the credit for LBB explicitly.

- The YVL guides address the DB safety implications of high-energy pipe breaks (LOCA, pipe whip, jet impingement, asymmetric blowdown loads, flywheel overspeed, pressure/temperature/ humidity rise, debris etc.).
- LBB enables exclusion of local dynamic effects (pipe whip, jet impingement) from the DB of primary circuit piping in case that the physical protection against these would be inadequate and whip restraints are not provided.
- LBB does not affect the Design Basis and the Design Requirements for containment, ECCS, EQ and blowdown effects to RPV internals.
- The new YVL guides B.5 (primary circuit) and E.4 (strength analyses) will expand the LBB credit to blowdown effects on RPV internals so that these shall be considered as a design extension condition (DEC), analyzable with best estimate methodology, as defined in YVL guides B.5 and E.4 [6].

France: No credit is allowed to LBB by itself, except as a possible complement to the break preclusion demonstration. Break preclusion assumption adopted by France which means the prevention and the exclusion of break enable not to consider in the plant design basis postulated initiating events resulting from the complete rupture of main coolant line and main steam lines. It is an assumption relying on Defence-in-Depth approach (DID). Break preclusion has to be demonstrated by a reinforcement of the two first lines of the DID to verify the absence of damage that could put into question the piping integrity:

- First line: Gaining assurance by reinforcing controls of the high quality of design and manufacturing according to Code and Standard (RCC-M level 1)
- Second line: Enhancing and reinforcing in-service inspection.

These two inescapable lines must remain independent from each other.

Hence, break preclusion is an assumption adopted at the design stage contrarily to LBB which was at the origin a justification of an event which could no longer be considered after the design and manufacturing stage.

A LBB type analysis can be performed within the frame of the third line of the defence-in-depth to demonstrate the piping robustness to through-wall crack and the capacity to detect a leak before a critical break. Realistic assumptions retained in the LBB analysis shall be justified.

As a result, for the lines for which DEGB can be deemed as exclude, anti-whips are no more needed. Nevertheless, the DEGB has still to be assumed under realistic assumptions for the design of safety injection system and the containment, as well as for the supports of the components and the qualification of equipment.

The break preclusion assumption was largely used for the EPR design which followed the European Technical Guidelines for the design and construction of the next generation of nuclear power plants with PWR.

US:

- LBB is not explicitly credited within the US regulations.
- However, Criterion 4 to Part 50, Appendix A allows that "… dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses … demonstrate that the probability of fluid system piping rupture is extremely low…"
    - An approved LBB analysis is accepted as having demonstrated that the rupture probability of that approved lines is extremely low.
    - Therefore, LBB can be credited to ease this requirement.
- The scope of the LBB credit only encompasses the design requirements associated with dynamic effects associated with pipe rupture. It does not extend to design requirements associated with containment design, emergency core cooling system design, or design of SCCs important to safety to accommodate the effects of environmental conditions.

3. Does your country allow piping systems that are susceptible to SCC or other active degradation mechanisms to be credited for LBB?

a. If so, how are mitigation and/or management of the active degradation mechanism(s) credited?

Netherlands: This is not an issue for the Dutch PWR because the LBB credited lines are equipped with piping materials not susceptible to SCC.

Japan: No. Application of the LBB concept to austenitic stainless steel piping, including cast austenitic stainless steel, in the reactor coolant pressure boundary is limited to only those locations where countermeasures against SCC and fluctuation phenomenon due to the thermal stratification are applied as preventive measures.

Germany: No

Switzerland: It is not allowed to apply the LBB approach for piping susceptible to SCC.

Slovakia: The LBB has been applied only on piping which is not susceptible to SCC. However, fatigue crack growth was assumed in the analysis.

JRC: N/A

Canada: For new construction, LBB applications are not allowed for piping systems that are susceptible to SCC or other active degradation mechanisms.

To support life extension and fitness for service assessments in an operating plant, LBB assessments may be used to risk-inform structural integrity assessments for piping systems susceptible to active degradation for uninspected components within a population that is subject to sampling inspections, with the following conditions:

- The evaluation should demonstrate that there is an acceptably low probability of rupture due to the degradation mechanisms.
- Degradation mechanisms are understood and controlled (e.g.,initiation and growth models have been developed for the degradation mechanism, chemistry control programs are implemented and other mitigating actions exist, such as operation with restrictions and operating procedures for timely response to events)
- Effects of consequential leakage are evaluated
- Enhanced inspection program exist (e.g., increased extent and frequency of inspection, examinations with improved detection capabilities)
- The evaluation should demonstrate that an assumed flaw satisfies the acceptance criteria permitted by CSA N285.4/ASME Code Section XI or demonstration that the affected component is fit for service in accordance with approved fitness-for-service criteria and guidelines, or other criteria acceptable to the regulatory authority.

Sweden: Any active damage mechanism shall be excluded before LBB can be applied. SSM has not issued detailed rules for how to assess mitigation as sufficiently effective in order to prevent SCC.

- An application to use LBB for the surge line nozzle with an Alloy 182 weld was not allowed. The question of mitigation for this nozzle has not been an issue as frequent ISI is required.
- The plant owner in this case did perform further analyses to demonstrate that the local dynamic effects could indeed be accommodated with the design of the nozzle.

Belgium: No

Czech Republic: No.

Finland:

- Active degradation mechanisms must not be present for piping systems designed based on LBB.
- Even susceptibility to degradation (SCC, thermal ageing) is regarded as a concern for dissimilar welds in large-diameter primary circuit piping, and in those cases mitigation and management programs are required to enable LBB application.
- A contrary situation arises in defect assessment of an operating plant to address an active degradation mechanism;
    - LBB demonstration could be then required as a supplementary technical justification if normal acceptance standards are exceeded.

- We have an example from Loviisa NPP (VVER 440) where such LBB demonstration helped to decide that a thermal stratification-induced leakage detected in a small-bore primary circuit piping in one unit did not necessitate shut-down of the sister unit for inspections.

France: The break preclusion assumption can't be applied to piping with a risk of fatigue, fast fracture or erosion-corrosion. The choice of materials shall ensure protection against fast-fracture and erosion-corrosion.

US: The Standard Review Plan (SRP) 3.6.3, "Leak-Before-Break Evaluation Procedures" (Rev.1) does not specifically preclude crediting LBB in systems that are experiencing active degradation.

- SRP 3.6.3 requires that the LBB evaluation demonstrate that active degradation mechanisms such as corrosion, creep, fatigue, and erosion are not potential sources of pipe rupture in the candidate LBB line or system. That is, the evaluation should demonstrate that there is an extremely low probability of rupture due to the mechanisms.
- Additionally, two mitigation methods are needed to address materials susceptible to an active stress corrosion cracking degradation mechanism, which would be reviewed a case-by-case basis. For example, in boiling water reactors (BWR) hydrogen water chemistry and remedial stress improvement treatments are two appropriate mitigation methods. Piping that has been treated by two mitigating methods may qualify for LBB if the piping contains no flaws larger than those permitted by Section XI of the ASME Code.

4. Please describe the piping systems 1) that your country allows to be credited for LBB, and 2) that your country is considering allowing credit for LBB (e.g., primary loop piping, surge line, main steam line, feedwater line).

Netherlands:

1) Main coolant lines; Pressurizer surge line; Main steam lines (inside containment only, replaced in 1997); Feedwater lines (inside containment only, replaced in 1997)
2) Not applicable

Japan:

1) The concept of LBB is applicable to piping line of primary loop re-circulation system for BWR and main coolant piping of reactor coolant pressure boundary for PWR.
2) Application of the concept of LBB to piping other than described above in 1) is not being considered.

Germany: Break preclusion is applied to PWR as well as BWR piping systems as follows.

- PWR:
  - Main coolant lines (MCL) of all PWRs
  - Piping with nominal diameter (ND) of ND700 to ND800 depending on plant concerns made of low-alloy fine-grained steel (22NiMoCr3-7 similar to A 508 Cl.2 or 20MnMoNi5-5 similar to A 533 Cl.2) with austenitic internal cladding.
  - In a plant specific way for pipes with nominal diameter ND150 to ND350 made of ferritic and austenitic steels connected to the MCL within the pressure-retaining boundary.
  - Main steam and feed water lines with nominal diameter ND150 to ND700 made of low-alloy ferritic steel grades in a plant specific way especially areas within the reactor containment.

- BWR:
    - Main steam and feed water lines within the pressure-retaining boundary up to the first isolation outside.
    - Selected systems within the pressure-retaining boundary in a plant specific way.

Switzerland: The application of LBB concept is limited to the following piping as contained in ENSI-A01, App. 2:

- BWR: double-ended pipe rupture of main steam and feed water pipe outside of primary containment; double-ended pipe rupture of main coolant line
- PWR: double-ended pipe rupture of main steam and feed water pipe inside and outside of primary containment; double-ended pipe rupture of main coolant line

Slovakia:

- LBB can be applied on any high energy piping.
- At Bohunice Unit 3&4, Mochovce Unit 1&2, the LBB concept has been applied on the main reactor coolant piping and the pressurizer surge line.

JRC: N/A

Canada:

- LBB application has been accepted for protection against postulated primary heat transport system failures.
- LBB assessments have been accepted to risk-inform structural integrity assessments of components, such as pressure tubes, feeder pipes, and steam generator tubes, with potential flaws for specified operating periods to demonstrate that rupture is an unlikely event. These assessments are generally applied to component groups, for which only a representative sample is inspected, to demonstrate that the risk of rupture of a component from the portion of the population that has not been inspected is acceptably low.

Sweden: SSM has not made a list of piping system for which LBB is allowed to be used. But SSM has approved for using LBB (with conditions) for the following pipe systems in a PWR:

a) Main cooling pipe system.
b) Surge line, except the surge line nozzle.
c) Residual heat removal system.
d) Accumulator (safety injection) system

Belgium:

- The primary loop piping is allowed to be credited for LBB.
- Not considering allowing credit for other piping systems at this time.

Czech Republic:

- The LBB is applicable on high energy piping safety class 1 and 2. For other safety classes the evaluation is reviewed by taking into account in service inspection requirement
- Usually, the application is to the main circulating piping, surge line and other piping if feasible (especially ECCS). Reasonable results are for outer diameter equal to or greater than 250 mm.

Finland:

- The LBB candidate piping include PWR main coolant lines and BWR main steam and feed water lines provided that they are not susceptible to direct and indirect failure mechanisms.
- The PWR surge line does not meet this condition, hence its break is becoming the modified DB for the RPV internals.
- No other piping systems are under consideration for LBB credit

France: Break preclusion assumption, possibly completed by LBB concept, can be applied to PWR piping mentioned below:

- main coolant lines,
- main steam lines from the exit of steam generator to the fixed point downstream the main isolation valve,
- feedwater piping outside the building reactor.

US:

- As stated in SRP 3.6.3, LBB is applied to high energy, ASME Code Class 1 or 2 piping or the equivalent.
- Applications to other high energy piping are considered based on an evaluation of the proposed design and in-service inspection requirements as compared to ASME Code Class 1 and 2 requirements.
- Examples of lines/systems that LBB has been approved for includes the hot leg, cold leg, crossover leg, pressurizer surge line, residual heat removal line, accumulator system, and safety injection system.
- No different or additional systems are currently under consideration for LBB credit.

5. Explain whether the regulatory authority approves LBB before it can be used to satisfy the intended regulatory requirement (see Question 2), or if the analysis can be conducted without explicit regulatory review and approval.

Netherlands: Option 1: The licensee has provided for review by the regulatory body an extensive justification of LBB for the piping sections mentioned under question 4. After approval the licensee was free to refrain from the installation of pipe whip restraints.

Japan: Review and approval of utilities' application for LBB is required before LBB can be credited.

Germany: The analysis for break preclusion is approved by the regulatory authority before accepted and applied to a piping system.

Switzerland: ENSI has to review and approve the LBB application before it can be credited.

Slovakia: The LBB is applicable on high energy piping safety class 1 and 2. For other safety classes the evaluation is reviewed by taking into account in service inspection requirement.

Usual extension of the application is main circulating piping, surge line and other piping if feasible (especially ECCS). Reasonable results are for outer diameter equal to or greater than 250 mm.

JRC: N/A

Canada: Regulatory authority approval of LBB application is required before it can be credited.

Sweden: All LBB analyses have to be sent to SSM for regulatory approval before the plant owner can take credit for LBB.

Belgium: LBB has to be approved by the regulatory body before any plant changes are allowed

Czech Republic: The regulatory authority approves LBB before it can be used.

Finland: LBB applications affecting the design basis of a new plant or a major plant modification shall be submitted to STUK as part of the related safety assessment documentation.

- This documentation focused on technical prerequisites like weld design, material properties and accurate leak detection as well as validation of inspection and monitoring techniques during manufacturing and operation

- LBB analysis is the second step and will be submitted to STUK as part of the design report for the candidate pipe line.

France: The applicability of break preclusion assumption is reviewed by the French nuclear safety authority before being applied to a piping system.

US: Explicit review and approval of a licensee's application for LBB on a system is required before LBB can be credited. SRP 3.6.3 describes one acceptable method for reviewing and approving LBB submittals.

6. Describe any approved evaluations that licensees use to demonstrate LBB in systems. Please include in this description the scope of the analysis (i.e., are entire systems, subsystems, single components, and/or single welds considered), the nature of the analysis (i.e., deterministic or probabilistic), the approach (i.e., step-by-step analysis procedure), and the acceptance criteria.

Netherlands:

- The justification is mainly deterministic and oriented on piping sections.
- LBB has been justified on the basis of the German Break Preclusion concept (Bruch Ausschluss) and relies on:
  - quality through production of the piping (as "Basis Safety"),
  - plant monitoring and inspection to confirm the quality during operation,
  - Leak-before-break (LBB) behaviour of the piping.
- These principle requirements are safeguarded by further principles (often referred to as "independent redundancies"):
  - Multiple party testing (for quality assurance)
  - Worst case principle (to cope with deviations from the optimized quality)
  - Validation of methods and codes used (for monitoring and inspection techniques as well as the analyses of component behaviour).
- The procedure consists of 6 steps:
  1) Postulation of an initial defect size
  2) Fatigue crack growth analysis of this initial defect during 1 Reactor Life (RL)
  3) Calculation of the time (in multiples of RLs) required for the crack to penetrate the wall (growth by fatigue)
  4) Demonstration of stability of this through-wall crack (result of step 3) during earth-quake loadings by comparison with critical crack size
  5) Demonstration of stability (subcriticality) of this through-wall crack even after further crack growth during 1 RL; this shall assure the detection and safe shut down of the plant before the crack might become critical.
  6) Detectability of a leak through the stable (subcritical) through-wall crack size (also used in step 4) by leak detection systems.

Japan: An acceptable evaluation method in Japan is shown in "Design considerations for internally originated flying objects". Following is a synopsis of the evaluation.

- The approach is deterministic. Application of LBB is limited to austenitic stainless steel piping belonging to the reactor coolant pressure boundary.
- The document prescribes a feasibility evaluation of the LBB concept with clarification of factors including evaluation locations, initial defect for evaluation, load for evaluation, crack growth analysis, determination of assumed crack based on the result of crack growth analysis, stability analysis of assumed crack, crack opening area for design.

Germany: Break preclusion can only be applied to a system between the anchor points and to not a single component or single weld. The analysis is of deterministic nature, probabilistic analysis is not allowed. Approved evaluations that shall be demonstrated are related to material, design and manufacturing as well as continuous respectively recurrent monitoring and testing

Switzerland:

- LBB for primary loop piping and primary loop pumps was performed for NPP Beznau and NPP Gösgen according to the requirements of the SRP 3.63. LBB approach was approved by ENSI.
- Other documents accepted by ENSI for use in the LBB evaluation are the following: EUR-18549, NUREG-1061 Vol. 3, NUREG -0800, 10 CFR 50 App. A 4, USNRC Reg. Guide 1.45.

Slovakia: A deterministic approach has been applied following the UJD SR Decree (former ČSKAE, 1/1991 document) that was created on the basis of NUREG-1061 and SRP 3.6.3 documents. During the development of the LBB concept, the following areas were subject of a dedicated thorough research task force conducted in the 90s by the contractor (VUJE, NRI Řez):

- Increase of sensitivity of monitoring (diagnostic) systems:
- Increase of NDE sensitivity
- Evaluation of critical components
- Evaluation of fatigue crack growth
- Development of database on mechanical and corrosion properties (such properties has been verified by the experimental tests)
- Evaluation of the heavy component stability
- Experiments on the real (1:1 scale) models for the selected welded joints,

JRC: N/A

Canada: The deterministic fitness for service evaluations that licensees use to demonstrate LBB include the feeder pipes and pressure tubes which are the main components in the primary heat transport system. One of the approved evaluations is a deterministic leak-before-break assessment for pressure tubes which requires the following elements:

- Maintain expanded ISI
- Establish leak detection system requirements
- Evaluate effects of consequential leakage
- Demonstrate sufficient margin on crack stability
- Evaluate operational leakage limit
- Establish operating procedure to ensure timely response to a rupture event
- Consider actual characteristics of the degradation mechanisms in the analysis.

Sweden: A deterministic LBB procedure is recommended, based upon NUREG/CR-6765, Level 2 but with certain additions.

- LBB should be applied on an entire pipe segment within class 1 or 2, typically between two anchor points. Pipe sections with high and low stresses should be analysed. However, in a case by case, only portions of a pipe system need to be evaluated. An example is the surge line where LBB can be accepted except for the DMW at the surge line nozzle.
- It should be demonstrated that no active degradation mechanisms exist or presence of water/steam hammer loads.
- A leak detection system should exist, at least fulfilling RG 1.45. The detection and measurement of the leakages should be connected to limits of unidentified and identified leak flow rates and clear requirements for plant shut-down.
- The pipe segment should earlier have been subjected to qualified inspections and sufficient qualified inspection should also be applied in the future. This is a requirement in order to support the belief that absence of active damage mechanisms is still fulfilled.

- A circumferential leakage size crack is postulated with a crack front parallel to the pipe radius. The size of the crack is determined by the leak flow rate, which during normal operating loads including weld residual stresses, is a factor of 10 larger than the leak flow rate which can be detected with that plant specific leak detection system.
- The leakage size crack is postulated in pipe sections with both high and low stresses. Effects from the flexibility of the pipe system and the specific crack morphology on the leak flow rate should be accounted for.
- The critical crack length is determined from the material properties and the combination of normal operating loads and one of the worst loads according to the plant specific design load specifications.
- It shall be demonstrated that a margin of at least 2 exists between the critical crack length and the leakage crack size. It shall be demonstrated that the leakage size crack is stable when subjected to a load which is 1.4 times the load used to determine the critical crack.

Belgium: The LBB study performed by the plant owners is largely based on the different steps described in SRP 3.6.3 and NUREG 1061: Specific steps include

- Verification of the applicability of the LBB concept for the primary piping: no water hammer, no erosion/corrosion, no SCC, no creep and no significant fatigue, as demonstrated by a fatigue propagation study.
- Determination that the crack size leading to a leak is ten times larger than the detectable leak.
- Determine the critical crack size leading to a stable ductile crack growth in accidental conditions with combined loads.
- Verify that the ratio between the critical crack and leakage crack size is greater than 2 at all crack locations.

Czech Republic:

- Analysis is deterministic and related to primary piping including pressurizer surge line and ECCS (for OD larger than 250 mm).
- Acceptance criteria are the same as in SRP3.6.3.
- Probabilistic approach is under development.

Finland:

- For the OL3 unit (EPR, under construction), LBB analyses have been done in the context of Break Preclusion (BP) concept implementation for the main coolant lines, main steam lines and main feed water lines (inside containment). These primary and secondary lines are made from austenitic and ferritic steels, respectively.
- Only complete sections between terminal ends (nozzles, penetrations) were considered.
- Full conformance to Code Class 1 construction requirements was a prerequisite, also for the main secondary lines.
- For the analysis, surface cracks, matching the NDT qualification target size, were first postulated to demonstrate insignificant live-long propagation by fatigue under the design transients, and to demonstrate the stability of the remaining ligament.
- For postulated through-wall cracks, SRP 3.6.3 margins on critical crack size and leak detection were evaluated with deterministic analyses as follows:
    - Through-wall cracks postulated in most stressed welds, including nozzle-to-safe-end transition welds
    - Loading enveloped all DB accidents, including isolation valve closures and postulated breaks in the non-LBB sections
    - Tearing resistance (J-R) data and extrapolation validation with testing of CT-specimens from representative mock-ups as per ASTM E 1820 – 05a standard

  - Critical crack size and leak area evaluation with EPRI handbook methodology; reasonable stable growth permitted and conservative assumptions for weld strength mismatch
  - Qualification tests to demonstrate specified leak detection sensitivity, particularly if below 1 gpm
  - SQUIRT-type leak rate analysis.

France: In the frame of EPR design, LBB type analyses have been done. They rely on a deterministic evaluation of the size of the smallest through-wall crack which leads to a detectable leak in normal condition in purpose to compare it to the critical crack size under the most penalizing accidental condition. Significant margin must be shown between the detectable crack and the critical crack. For the main coolant lines for instance, this demonstration must be given for each circumferential weld.

US: The approved evaluations in the US essentially adhere to SRP 3.6.3. A synapsis of this evaluation is as follows:

- As discussed previously, LBB is applied to high energy, ASME Code Class 1 or 2 piping or the equivalent. Applications to other high energy piping are considered on a case-by-case basis.
- The scope of LBB is an entire piping system or analyzable portion of a system.
  - LBB cannot be applied to individual welded joints or other discrete locations.
  - Analyzable portions are typically segments located between piping anchor points.
- The LBB evaluation is a deterministic analysis with the following general characteristics and acceptance criteria, as appropriate:
  - Pipe rupture over the entire life of the plant due to water hammer, corrosion, creep damage, fatigue, erosion, and environmental conditions is evaluated to demonstrate that these mechanisms have an extremely low likelihood of resulting in a system failure
  - The factors which contribute to the initial quality of the piping and the provisions adopted to maintain this quality are evaluated to ensure that these factors are acceptable.
  - Leak detection methods for the reactor coolant are examined to ensure that adequate detection margins exist for the postulated through wall flaw used in the deterministic fracture mechanics evaluation.
  - Indirect failure mechanisms which could lead to pipe rupture are also evaluated to provide assurances that these mechanisms of pipe rupture are also unlikely and that the treatise of such mechanisms are in compliance with Commission regulations as applicable
  - A fracture mechanics and leak rate evaluation is then conducted using the following steps:
    - Specify the type and magnitude of the loads applied to the piping system, their sources, and method of combination.
    - For each pipe size in the piping system, identify the location(s) that have the least favorable combination of stress and material properties for base metal, weldments, nozzles, and safe ends.
    - Postulate a through-wall flaw at the above location(s). The size of the flaw should be large enough so that leakage from the flaw during normal operation would be 10 times greater than the minimum leakage the detection system is capable of sensing.
    - Perform a stability or limit load analysis to determine the critical crack size for the postulated through-wall crack using loads from the normal plus safe shutdown earthquake (SSE).
    - Determine the crack size margin by comparing the selected leakage crack size to the critical crack size. Demonstrate that there is a margin of 2 between the leakage crack size and critical crack size.

- Calculate the margin on the flaw size in terms of applied loads by acrack stability analysis. Demonstrate that the size of leaking cracks will not become unstable if 1.4 times the normal plus Safe Shutdown Earthquake (SSE) loads are applied.
- Demonstrate that the crack growth is stable and the final crack size is limited such that a double-ended pipe break will not occur.

7. Is the approved evaluation discussed in item 6 above based on the US NRC's Standard Review Plan (SRP) 3.6.3? If so, please describe any differences between the approved evaluation and SRP 3.6.3 or any additional considerations or requirements beyond those in SRP 3.6.3. that are addressed in the evaluation.

Netherlands:

- No, it is based on:/RSK 79/ (identical to /RSK 96/, supplements 1 and 2 (in German language)) Supplements to chapter 4.2 of the 2nd edition of the RSK Guidelines for Pressurized Water Reactors, January 24, 1979: 1) List of Systems and Components which shall be subject to suppl. 2 2) General Specification: "Basis Safety of Pressurized Components", Bundesanzeiger Nr. 167, September 6, 1979
- /RSK 01/ (translation of /RSK 96/ without supplements) RSK Guidelines for Pressurized Water Reactors 3rd edition, October 1981, amended 1982, 1984 and 1996 Editor: Bundesamt für Strahlenschutz, Salzgitter (Safety codes and guides translations, edition 1/01).

Japan: No, the assessment method for LBB shown in "Design considerations for internally originated flying objects" is different from the NRC Standard Review Plan 3.6.3. The major difference is as follows;

- The scope of allowable LBB application is limited to design for austenitic stainless steel pipe, including cast austenitic stainless steel

Germany: No

Switzerland: The ENSI approved evaluations based on SRP 3.6.3. Additionally, analyses were performed to meet requirements for the concept of pipe rupture exclusion. Rules for break exclusion concepts are governed by German KTA 3201.

Slovakia: Yes, evaluation is in accordance with SRP 3.6.3, (NUREG-1061). The requirements were adopted in the national legal basis.

JRC: N/A

Canada: The evaluations discussed in item 6 above are aligned with on the US NRC's Standard Review Plan 3.6.3. There is no specific difference between the evaluations and SRP 3.6.3, except that to demonstrate fitness for service of degraded components, operating procedures for the LBB application are expected to be established to ensure appropriate actions to be taken before the leaking crack reaches to the critical size with sufficient margin.

Sweden: Yes, the analysis is based on SRP 3.6.3 but some additions and deviations are identified in the answer to Question 6.

Belgium: The LBB study is largely based on SRP 3.6.3. However, the following additional considerations have to be addressed (as in question 2):

- The internals of the heavy components, and in particular the internals of the reactor vessel, must be able to withstand dynamic loads associated to a postulated rapid (1 ms) break, having a size of 0.3A, and located in the hot or cold leg, in the vicinity of the steam generator.
- For critical crack size calculation, the additional loads to consider include steam line break or rupture of auxiliary piping to the primary circuit, whichever is larger.

- The reactor vessel supports and the steam generators supports are important components in the protection against the worsening of an accident. These components were originally designed to withstand dynamic loads associated with large breaks and this requirement is maintained under LBB.

Czech Republic: SRP 3.6.3 has been fully adopted with small changes. The acceptance criteria are the same as in SRP 3.6.3

Finland:

- Regarding the objectives, SRP 3.6.3 aims more at removal of protective hardware from operating plants. The evaluation of failure modes is accordingly done based on the as-built configuration and records available since commissioning.
- The Finnish procedure, given in the YVL E.4 guide, formulates LBB as a combination of the SPR 3.6.3 approach and the German BP concept for design of new plants.
- Regarding the analysis described under item 6, the fatigue and remaining ligament analysis seem to be beyond SRP 3.6.3 requirements, though its intent obviously is that defect sizes conforming to acceptance standards must not question LBB.
- For through-wall crack analysis, SRP would permit a simpler net-section collapse approach in case of austenitic steel. Assuming SRP 3.6.3 applicability to the OL3 main secondary lines, our loading assumptions are more stringent.

France: No

US: The approved evaluation discussed in item 6 is SRP 3.6.3.

8. Does your country allow licensees to conduct alternative LBB analysis procedures (i.e., probabilistic), or must a prescriptive approach specified within the regulations (or specifically approved by the regulator) be followed?

a. If so, please describe alternative analyses that have been allowed. Please include the same items in the description as in item 3 above.

b. Would or has your country allowed probabilistic analysis to demonstrate LBB? If so, please describe.

Netherlands: A prescriptive approach must be followed.

Japan: An alternative acceptable method is not given in “Design considerations for internally originated flying objects".

Germany: No

Switzerland: So far ENSI has not accepted probabilistic analysis to demonstrate LBB.

Slovakia: Alternative analyses are not allowed. No probabilistic approach has been allowed as well.

JRC: N/A

Canada: Probabilistic evaluations to demonstrate the extremely low probability of rupture of degraded CANDU components may be reviewed by the regulator on a case-by-case basis. One example is the evaluation of the dissimilar metal welds in outlet feeders. The licensee initially performed deterministic leak-before-break assessment which produced marginal results for the feeder piping. Then, a probabilistic assessment was developed to demonstrate the low probability of rupture of the dissimilar metal welds. The probabilistic assessment method was used because for small-diameter feeder piping it is difficult to comply with the traditional deterministic leak-before-break methodology presented in SRP 3.6.3. In should also be noted that cracking of these dissimilar metal welds has never been observed in service. This assessment was conducted to assess the need to carry out targetted periodic inspections in light of access difficulties and the high personnel dose that results from such inspections.

Another application is probabilistic demonstration of leak-before-break for CANDU reactor core based on evaluation of a limiting pressure tube (Method 1 PLBB) or entire reactor core (Method 2 PLBB).

Sweden:

- SSM does not in general approve LBB for a complete break of the main coolant loops in a PWR because of the risk to jeopardize an entire safety function due to the consequences of asymmetric blowdown loads. However, one reactor owner did submit an application to use LBB for the main coolant loops. The applicant was required to present further analysis and actions to strengthen the LBB case. These actions involved:
    - Conducting an analysis to demonstrate why installation of pipe whip restraints was not possible or reasonable.
    - Conducting an analysis of leak and rupture probabilities for postulated breaks at selected welds.
    - Providing a report on what kind of NDE-efforts which is possible to perform.
- The SSM view is that a probabilistic analysis may strengthen the assessment that there is a sufficiently low probability for a pipe rupture and that there is a sufficient margin between initial detectable leak and break. A probabilistic analysis should be able to demonstrate that the frequency of a pipe break is so low that it can be considered as a residual risk. In the particular case for the main coolant loops in the PWR, this was able to be demonstrated by the plant owner. In these evaluations, no active degradation mechanisms are assumed, only a flaw distribution from welding defects. In this case, SSM approved using LBB in order not to take full account of the consequences of asymmetric blowdown loads. However, it was required to perform periodic inspection for a sample of welds of the pipe system.

Belgium: No specific LBB approach is prescribed within the regulations, but some conditions in the applications of the LBB approach have to be fulfilled (see answers to questions 2 & 7). Up to now, no alternative LBB analysis procedure has been proposed by the plant owners.

Czech Republic:

- Alternative analyses are not allowed.
- Only deterministic analyses are allowed.

Finland:

- The scope of LBB analyses ranges between simple estimation schemes and detailed EPFM analysis.
- Probabilistic alternatives are not currently provided as an option, but approval of alternative approaches leading to equivalent safety level is always possible.
- This approach might work for medium-bore piping for which failure data are available and SRP 3.6.3 margins may not be easily demonstrated.

France: No

US:

- The US does not preclude licensees from conducting alternative LBB analysis procedures, including probabilistic analyses.
- However, as mentioned previously, all such analyses must be reviewed and approved prior to crediting LBB
- The analyses also have to fulfill the basic design requirement by demonstrating that the likelihood of system rupture is extremely low.

The NRC has not approved any LBB submittals that have used an analysis other than one based on the deterministic method and acceptance criteria described in SRP 3.6.3.

II Research Activities and Knowledge Gaps

9. Describe gaps in your country's understanding of LBB

Netherlands: No gaps

Japan: More data for introducing probabilistic analysis.

Germany: More data for dissimilar welds and piping components.

Switzerland:

- Little experience exists with probabilistic procedures. Such procedures are currently under development (e.g. by US NRC) in order to consider active degradation.
- ENSI is lacking evaluation criteria to review such new LBB concepts.

Slovakia: No gaps identified.

JRC:

- Understanding LBB for long-term operation, when degradation mechanisms or reduction of safety margins because of e.g. residual stresses are involved.
- Another issue is LBB for complex geometries.

Canada: No answer.

Sweden:

- Better guidance of the requirements of adequate leak detection systems. There are unclear positions regarding unidentified versus identified leakage, requirements of availability of the leak detection systems, which alarm levels to be used and what actions should be taken when certain leakage levels have been passed.
- Uncertainties as to what crack morphology should be used for leak rate evaluations.
- Uncertainties regarding what kind of consequences an LBB demonstration is guarding against. Definition of local versus global effects of pipe breaks.
- Unclear positions on what load combinations should be used for analyzing the most limiting LBB-case. The importance of weld residual stresses in leak rate evaluations and the critical crack size for pipe welds which are not completely governed by plastic collapse is one concern.
- It is not clear what pipe break probabilities the deterministic LBB-concept is corresponding to. Are the margins 10 on leak rate and 2 on leakage size crack justified?

Belgium: No particular gap in the understanding of LBB.

Czech Republic:

- Understanding LBB challenges for long term operation, and identifying examples of possible issues associated with long term operation,
- Procedures and acceptance criteria for probabilistic LBB

Finland: Currently there are no gaps in our understanding of LBB.

France: No answer.

US: The technical gaps in the US result from the need to understand of LBB is piping systems that are undergoing active degradation (i.e., predominantly SCC). Earlier work has demonstrated that a conservative deterministic LBB method (i.e., SRP 3.6.3) is generally not sufficient to demonstrate LBB in such systems. This issue has motivated work to develop less-conservative, probabilistic methods in order to demonstrate extremely low probability of rupture in such systems. The following technical issues are of interest and under consideration in the development of alternative methods. This list is not meant to be comprehensive but to identify several of the more prominent considerations.

- Use of probabilistic fracture mechanics as the framework for an LBB analysis
- Development of appropriate probabilistic acceptance criteria consistent with US regulations.
- Crediting of crack initiation times and susceptibility within an LBB analysis
- Use of realistic loading patterns (i.e., weld residual stress) to predict crack growth of postulated flaws.
- Characterizing and treating uncertainty within a probabilistic analysis
- Quantitatively crediting the effect of mitigation measures.
- Development of appropriate best estimate models for crack initiation, crack growth, crack coalescence, crack transition from a surface to through-wall crack, leak rate estimation, crack stability, and the effect of mitigation methods.
- Conducting appropriate quality assurance and validation and verification efforts to ensure computer code integrity and accuracy.
- Gaining regulatory approval for the use of a probabilistic code

10. Describe any current research activities in your country related to LBB.

Netherlands: No research going on at present.

Japan: Japan Atomic Energy Agency (JAEA) is carring out a research program on probabilistic fracture mechanics for structural integrity assessment of pipings. The scopes of the study are IGSCC of austenitic stainless steel and PWSCC of nickel based alloy.

Germany:

- Fatigue test to develop more fatigue data under air environment as well as under high temperature water conditions.
- Research concerning the interaction between piping system / support / concrete structure under dynamic loading (e.g. earthquake).

Switzerland:

- ENSI follows the international development of new LBB concepts.
- Research work at the Paul Scherrer Institute (PSI) is ongoing on Stress Corrosion Cracking and Corrosion Fatigue.

Slovakia: None at the moment.

JRC: None at the moment.

Canada: One of the activities related to LBB is the Large LOCA Reclassification. Large break LOCA (LBLOCA) reclassification incorporating pipe failure probability concepts is being discussed as one of several proposals for resolving the LBLOCA safety margin issue. A CNSC/Industry Working Group was established to better define the issues pertaining to LBLOCA and to identify risk control measures (RCM) that could address the LBLOCA-related issues. RCMs for high energy line break effects include:

- A systematic review of the effects of high energy piping breaks inside the containment and the consequences on plant safety,
- Assessment of the consequential damage associated with the postulated failure and identification of potential design improvements, and
- The use of CANDU specific probabilistic fractures mechanics codes.

Additional acticities include probabilistic demonstration of leak-before-break for pressure tubes in CANDU reactor core and development of probabilistic acceptance criteria.

Sweden: Probabilistic analyses may strengthen the assessment that there is a sufficiently low probability for a pipe rupture and that there is a sufficient margin between initial detectable leak and break.

- The ProLBB. project compared the deterministic criteria used in the current LBB guidelines with a probabilistic analysis. In these evaluations, no active degradation mechanisms are assumed, only a flaw distribution from welding defects. The resulting SKI Report 2007:43 can be ordered from SSM.

Belgium: No research activities related to LBB.

Czech Republic: Probabilistic LBB using a Monte Carlo approach is under development.

Finland:

- In the national nuclear safety research program SAFIR2014, conducted by VTT Technical Research Centre of Finland, a related project (LBB) has been underway since 2011. Based on a state-of-the-art review of the fracture mechanics methodology, its applicability to topical issues (ageing, dissimilar metal and narrow-gap welds, complex crack shapes etc.) is evaluated to identify the development needs.
- Another project (RAIPSYS) is devoted to probabilistic aspects.

France: No current research activity on LBB

US: The main research program in the US (xLPR) is developing a probabilistic fracture mechanics code for use in LBB evaluations, primarily in piping systems undergoing SCC and potentially other active degradation mechanisms. There are several related projects to develop the code framework and models used within the code. However, there are also research efforts underway where the main objective is not to support xLPR, but are nonetheless providing information to models being developed or used within the xLPR program. This includes research in the following areas:

- Development of crack growth rates in A600 and A690 materials and their corresponding welds.
- Characterization of techniques to predict weld residual stress and development of more accurate predictive tools.

11. Describe any technical or regulatory concerns that your country has related to LBB.

Netherlands: LBB is an issue in the activities from long term operation of the Dutch NPP.

Japan: At this time there are no regulatory concerns, since the scope is limited to only those locations where countermeasures against SCC and fluctuation phenomenon due to the thermal stratification are applied as preventive measures.

Germany: At this time there are no regulatory concerns.

Switzerland: So far active degradation mechanisms are excluded for the LBB analyses. If active degradation needs to be considered, ENSI has to establish a respective regulatory approach.

Slovakia: At this time there are no regulatory concerns.

JRC: LBB for long-term operation (see Question 9 for more information)

Canada:

- Environmental qualification is an issue if the consequences of a pipe break can result in damage to sensitive electrical equipment.
- Validation of probabilistic fracture mechanism codes.
- LBB application to components with active degradation mechanism.
- Improvement of probabilistic assessment methodologies (i.e., treatment of uncertainties of input, codes validation, determination of acceptance criteria);

- Implementation of appropriate inspection program in terms of inspection interval, scope of inspection, and inspection method; and
- Implementation of several types of monitoring systems to capture the number of thermal cycles, vibration, and leakage

Sweden: Technical and regulatory concerns are contained in the answer to question 9.

Belgium: No concerns with the current application of LBB in Belgium, which is quite severe.

Czech Republic: No explicit concerns identified in the survey response.

Finland:

- Even though SRP 3.6.3 is quite established, the national practices of deterministic LBB analysis seem to vary in details such as the basis for critical crack size definition (how much stable growth is allowed or is just crack initiation permitted).
- Rejecting stable growth for austenitic stainless steel, and thereby ignoring its hardening capacity, might lead to overly conservative evaluations.
- The tearing resistance test procedures, such as ASTM E 1820 – 05, are limited to homogeneous materials.
- In LBB analysis, cracks are typically postulated to the weld area, and the weld strength mismatch may significantly affect the results.
    - A proven approach would be needed for specimens representing the nonhomogeneity in the vicinity of welds.

France: Trust concerns about assumptions retained in LBB analysis.

US: Many of the US technical concerns/issues have previously been identified in the response to question 9. Several regulatory concerns have also been identified in this response. It's appropriate, however, to emphasize the principal regulatory concerns.

- Currently, LBB has been approved in several piping systems/lines (at multiple plants) that contain dissimilar metal welds (DMWs).
    - When the approval was granted, it was based partly on the presumption that no active degradation due to SCC was occurring.
    - However, operating experience has uncovered cracking at DMWs in several piping systems.
    - Therefore, there is a question if these systems still demonstrate LBB.
- A related concern is reviewing and approving a probabilistic analytical code (xLPR) for regulatory applications that predicts the piping systems propensity to rupture and quantitatively demonstrates the effectiveness of various mitigation measures that have been approved by the NRC to alleviate DMW cracking.

III Collaborative Research Opportunities

12. Are you interested in sharing information among countries related to LBB? Indicate if your interest is (H)igh, (M)edium, of (L)ow and what information would be most useful to share.

Netherlands:
- Yes, medium.
- It would be usefull to have (more) insight into approaches used elsewhere.

Japan:
- Yes, Medium.
- Sharing information among countries, in particular, research and practices related to application of LBB to operating plants as part of repair or replacement activities for primary loop piping system of PWR and for primary loop recirculation piping system of BWR.

Germany:
- Yes, High
- Experimental data for piping components (elbows, T-branches, weldments, …)
    - More data for dissimilar welds and piping components.
    - Fatigue test to develop more fatigue data under air environment as well as under high temperature water conditions.
    - Research concerning the interaction between piping system / support / concrete structure under dynamic loading (e.g. earthquake).

Switzerland: Yes, according to the following priorities

- Sharing information related to LBB (Medium).
- Review procedures for new LBB concepts (High).

Slovakia: Yes, we are highly interested in sharing information;

JRC: Yes, medium; but JRC has no information to offer.

Canada:
- Yes, we are highly interested in sharing information.
- The regulatory perspective is the most useful information that would be shared.

Sweden: Yes, highly interest in sharing information.

Belgium: Sharing information related to LBB could be interesting, but current interest is low.

Czech Republic:
- Yes, we are highly interested in sharing information;
- Highly, interested in information related to probabilistic LBB methods
- Medium interest in application of LBB in dissimilar metals welds and addressing active degradation mechanisms with LBB

Finland: Yes, we are interested in sharing information related to failures in bolted connections.

- Failure in bolted connections, like that for the SG manhole cover, presents in primary circuit a risk comparable to the postulated pipe breaks.
- The boron corrosion issue underlines this concern, and sound criteria would be needed for its inclusion in or exclusion from the design basis.

- Technically, the manhole cover is beyond LBB and break preclusion (BP) scope, though also in this case, leakage would be a precursor for which a margin could be defined.

In the Finnish OL3 construction project, a preliminary technical evaluation has been done on this issue and a need has been identified to share possible similar work and experiences with other countries.

France: Medium interest in sharing information about LBB

US:

- Yes, we are highly interested in sharing information
- The principal topic areas are related to assessments of LBB using methods based on probabilistic fracture mechanics. Some topics include
    - Sampling methods and framework development
    - Development of physics-based models and verification
    - Uncertainty treatment
    - Basically, any of the topics associated with the technical issues identified in the response to item #9 would be of interest.

13. Are you interested in conducting collaborative research related to LBB? Indicate if your interest is: (H)igh, (M)edium, of (L)ow.

a. If interested, identify possible collaborative study areas and rank your proposals from highest to lowest.

Netherlands: No

Japan: Yes.

- Material property including J-R curve for thermally aged cast austenitic stainless steel piping **High**
- Evaluation of structural integrity for dissimilar metal weld, including probabilistic fracture mechanics. **High**

Germany: Yes, medium interest in following research topics:

- Experimental data for piping components (elbows, T-branches, weldments, …)
    - More data for dissimilar welds and piping components.
    - Fatigue test to develop more fatigue data under air environment as well as under high temperature water conditions.
    - Research concerning the interaction between piping system / support / concrete structure under dynamic loading (e.g. earthquake).

Switzerland: ENSI has no organizational resources to conduct independent research related to LBB but does currently support related projects at research institutes. ENSI is interested in collaborating on these ongoing projects.

Slovakia: No.

JRC: Yes, high, for PWSCC in dissimilar metal welds, but there may not be sufficient resources to conduct work.

Canada:

- Yes, we are highly interested
- Regulatory perspective would be ranked as the highest topic of interest.

Sweden: Medium interest of conducting collaborative research_related to LBB for old reactors considering that Plant Owners in Sweden have declared that they do not expect to submit any more LBB-applications to SSM. However, recently Vattenfall AB has applied to SSM to build 2 new reactors of a design not yet determined. Some of these reactors will have LBB as a prerequisite and SSM is interested to conduct collaborative research related to LBB for new reactor designs. The following are research topics of interest:

- Investigate the role of probabilistic methods to verify LBB.
- Consequences of asymmetric blowdown loads and how these depend on pipe break opening times and opening areas.
- Investigate the influence from weld residual stresses on crack opening areas and leak flow rates.
- Investigate the possibility to apply LBB using risk-informed methods to compare the conditional core damage probability by PRA for a given pipe break both with and without pipe whip restraints with the change in pipe probability due to more effective ISI or leak rate detection. It may be possible to demonstrate that the risk associated with ISI or leak detection may be equivalent or less the effect of pipe whip restraints.

Belgium: Interest is low in general except for research related to PWSCC in dissimilar metal welds, as in question 15.

Czech Republic:

- Yes, we are highly interested;
- Probabilistic LBB – High.
- Regulatory perspective - High

Finland: Yes, we are interested in possibly collaborating on research related to failures in bolted connections such as those in the SG manhole cover.

France: No

US:

- Yes, we are highly interested in research collaboration.
- LBB assessments using probabilistic methods: High
- Regulatory treatment of probabilistic LBB assessments: High
- Technical issues associated with developing a probabilistic LBB code: High
- PWSCC in dissimilar metal welds: High
- Development of less-conservative deterministic LBB approaches: Medium

14. Are you interested in compiling a state-of-the-art report summarizing LBB regulations, knowledge, and current activities? Indicate if your interest is (H)igh, (M)edium, of (L)ow.

Netherlands: No

Japan: Yes. Medium.

Germany: Yes, high interest

Switzerland: Yes, medium interest

Slovakia: Yes, high interest

JRC: Yes, high, but little to offer for report.

Canada: Yes, we are interested in compiling a state-of-the-art report summarizing LBB regulations, knowledge, and current activities (High).

Sweden: Medium interest of compiling a state-of-the-art report summarizing LBB regulations, knowledge and current activities. However, high interest to compile LBB regulations, knowledge, and current activities for new reactor designs.

Belgium: Global report related to LBB could be interesting, but current interest is low.

Czech Republic: Yes, we are highly interested;

Finland: This is a matter to be discussed. State-of-the-art reports have been recently compiled on LBB, e.g. by order of the Canadian authorities. There are no resources currently available to participate in such an activity.

France: Global report related to LBB could be interesting, but current interest is low.

US:

- The interest in developing a summary report LBB regulations, knowledge, and current activities is low.
- Within the last 10 years, the following two summary reports related to LBB already do an excellent job of summarizing international technical approaches and regulatory positions.
    - NUREG/CR-6765, "Development of Technical Basis for Leak-Before-Break Evaluation Procedures," May 2002.
    - CNSC Report RSP-0250, "Future Directions for Using the Leak-Before-Break Concept in Regulatory Assessments," September 1, 2009.

15. The US has initiated a joint program between the regulator and industry to use probabilistic modeling to assess the risk of piping failure in dissimilar metal welds that are susceptible to PWSCC. Is your country interested in collaborating in this research?

a. If so, provide a point of contact.

Netherlands: No, the Dutch power plant which is based on a Siemens design, is constructed without dissimilar welds in the LBB piping sections.

Japan: Yes, NRA is interested in a study on probabilistic structural integrity evaluation for components and piping.
Contact: Mr. Kensaku Arai

Germany: Yes, we are interested.

Contact: Xaver.Schuler@mpa.uni-stuttgart.de or Karl-Heinz.Herter@mpa.uni-stuttgart.de

Switzerland: We are interested if the joint program can be fitted into our current projects. More detailed information would be appreciated. In the PSI (Switzerland) current R&D projects are ongoing on structural integrity topics. ENSI gives technical and financial support for research projects conducted at PSI. There are current projects related to

- Structural integrity topics
- Probabilistic fracture mechanics modeling.
- PWSCC issues.

Contact: Hans-Peter Seifert, hans-peter.seifert@psi.ch

Slovakia: Yes, we are interested; although current potential ageing degradation represent issues associated with thermal ageing and embrittlement of dissimilar primary welds, thus the major emphasis and efforts are focused on these mechanisms and effects.

Contact: Mr. Miloslav Hrazsky

JRC: Yes, we are interested, but participation depends on availability of resources in 2016.

Contact: Oliver Martin, oliver.martin@ec.europa.eu

Canada: Yes, we are interested in collaborating in this research.

Contact: Jovica Riznic, jovica.riznic@canada.ca

Sweden: Yes, Sweden is interested to be a part of a joint program to use probabilistic modeling to assess DMW susceptible to PWSCC.

Already involved through the SSM funding of PARTRIDGE.

Contact: Björn Brickstad, bjorn.brickstad@ssm.se

Belgium: PWSCC has been found in some dissimilar metal welds in some of the Belgian plants. We are thus interested in following these research activities.

Contact: Robert Gérard, Robert.gerard@gdfsuez.com

Czech Republic: Yes, we are highly interested;

Contact: J.Žďárek, jiri.zdarek@ujv.cz (NRI Rez) and Jolana Rýdlová, jolana.rydlova@sujb.cz (for regulator)

Finland: In principle we are interested, though thermal ageing now seems to be our main concern for dissimilar welds. Again, this depends on the available resources.

Contact: Rauli Keskinen, rauli.keskinen@stuk.fi

France: No answer.

Contact: Isabelle Delvallée, isabelle.delvallee@irsn.fr

US: Yes, we are highly interested

Contact: Rob Tregoning, robert.tregoning@nrc.gov

References

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[2] Wilkowski, G.M., "Future Directions for Using the Leak-Before-Break Concept in Regulatory Assessments, RSP-0250, Canadian Nuclear Safety Commission, September 1, 2009.

[3] Comparison of National Leak-Before-Break Procedures and Practices - Summary of Results and Potential for Greater Harmonisation. Revision 2, EU Study Contract B7-5200/97/000782/ MAR/C2 of DG XI, Final report, April 2000

[4] CNSC, Design of Reactor Facilities: Nuclear Power Plants, Regulatory Document REGDOC 2.5.2, May 2014, Canadian Nuclear Safety Commission.

[5] "Design considerations for internally originated flying objects caused by pipe rupture accidents" (in Japanese), Nuclear Safety Committee (NSC), March 26,1992 (Partially revised on September 19, 2006)

[6] Finnish Regulatory Guide (YVL) E.4 - Strength analyses of nuclear power plant pressure equipment, 15 Nov 2013 http://www.stuk.fi/web/en/regulations/stuk-s-regulatory-guides/regulatory-guides-on-nuclear-safety-yvl-