Transactions of the **13th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, August 13-18, 1995

Additional requirements for the application of the leak before break concept in Belgium

Lafaille, J.P.,
TRACTEBEL Energy Engineering, Brussels, Belgium
Roussel, G.
AVN, Brussels, Belgium

ABSTRACT: An LBB (Leak-Before-Break) analysis has been performed on the primary loops of the Doel 3 and Tihange 2 units in order to eliminate primary pumps snubbers. During the same outage, power output was uprated, the possibility of operating in stretch-out conditions was introduced and, in the Doel 3 unit, steam generators were replaced, allowing a further increase in output power.

The new conditions induced by these modifications lead to the necessity of a stress re-analysis of the primary equipment, especially for LOCA loads increased due to the low stretch-out temperature.

A successful LBB analysis of the primary loop should very much simplify these analyses, as the consequences of the main primary breaks are eliminated. In the course of trial use of the LBB benefits on the Doel 3 Unit, the Belgian Safety Authorities put however some restrictions to their use.

These restrictions very much decrease the interest of the LBB approach

1 INTRODUCTION

1.1 *Power-Output Increase and Steam Generator Replacement*

In the late 80's, studies were undertaken to assess the possibility for increasing the power output of the Tihange 2 and Doel 3 units, which both started commercial operation in 1983. In addition, the option for a stretch-out mode of operation was included in the analyses. As thermal-hydraulic operational conditions would be different from the original design ones, a new stress analysis of the primary components was required to show their adequacy under these modified operating conditions.

Later on, it was decided to replace the steam generators of the Doel Unit 3 because of SG tube bundle corrosion problems. The replacement steam generators allowed a higher power output, leading to further modified thermal-hydraulic parameters. A specific stress re-analysis was hence required for that case.

From the mechanical point of view, it soon became apparent that in stretch-out conditions, LOCA analyses of the components would be more severe than in the original design conditions because of the lower coolant temperature, which increases the amplitude of the transient hydraulic forces. The RPV and its internals are especially sensible to this effect. One of the most critical aspects of this analysis is the asymmetrical pressurization of the reactor cavity. The reason for this is that the reactor pressure vessel, its supports and its internals are analyzed as a whole for the loadings arising from breaks at the inlet and outlet nozzle of the reactor pressure vessel. Under the loads corresponding to the original design conditions, the calculated response values (stresses, displacements...) are close to the acceptable values. Using the same methods as the original ones, chances are high that the criteria would not be met under the loads corresponding to the stretch-out conditions.

The original NSSS vendor was in charge of the re-analysis. He was aware of the problem and had developed the concept of the so called «Realistic Breaks» as opposed to the «Conventional Breaks».

Conventional breaks were defined at the time of initial design. They include 11 breaks located along the primary loop and on top of the SG. Break area's conservatively envelope the area that can be developed, taking into account the presence of restraints. Opening time was 1 millisecond.

With the realistic breaks approach, the break area and, more important, the break opening time, are based on the actual calculated motion of the primary equipment connected to the broken pipe on either side of the break. These parameters are taken from analyses performed on previous similar cases. Recent experience of the NSSS vendor in similar cases had showed the benefits of this approach.

He consequently proposed to follow it to show the adequacy of the primary components in stretch-out conditions.

1.2 *Replacement of Primary Snubbers*

It is customary in Belgium to perform a general review and safety reassessment after every ten years of operation. In the case of Tihange Unit 2 and Doel Unit 3, one of the items to be looked at were the snubbers around the primary loop.

Four snubbers maintain each steam generator at the upper level (close to its center of gravity) in the direction of the hot leg. They are needed for earthquake loading, LOCA loadings and mostly for steam break loadings. Three snubbers laterally maintain each primary pump. Two of them are needed only for LOCA loadings, the third one being also required for seismic loadings. For the two units (three-loops plants), the total number of snubbers is 42 (4 000 and 6 000 kN types).

At the time of original design and construction, the requirements for In-Service Inspection of large snubbers were not well defined. They became more drastic in the course of construction, too late to be taken into account in the design. The Safety Authorities demanded, however that the problem of primary snubbers inspectability be addressed at the first decennial review.

Upon examination, it soon became apparent that the most practical way of dealing with the problem was to replace the original snubbers by snubbers designed to meet the inspectability requirements. As two out of three pump snubbers were needed only to cope with LOCA forces, the question was raised about showing their unusefulness through a successful LBB analysis and consequently not replacing them. An economic cost/benefit analysis showed the advantage of performing an LBB analysis instead of replacing the two snubbers (on six pumps!). It was consequently decided to perform such an analysis and to replace only one snubber per pump, needed for seismic loadings. The analysis is described in full details in Ref. [1].

1.3 *Use of LBB to Validate Primary Components*

Replacing only one of the primary pumps snubbers obviously invalidated the «Realistic Breaks» approach, as this approach assumes a complete lateral bracing system. As an example, with two pump snubbers out of three withdrawn, the break at the RPV inlet must be assumed as a full guillotine break.

However, according to the Modified General Design Criterion 4, with a successful LBB analysis available, the «*dynamic effects*» of the primary breaks do not have to be considered. It was thus decided to present the mechanical justification of the primary components to the Belgian Safety Authorities in the framework of the Leak Before Break.

2 ANALYSIS OF US REGULATORY DOCUMENTS

2.1 *General Design Criterion 4*

The right to use the LBB approach is formally recognized in the US regulatory documents by the General Design Criterion 4 -GDC4- Ref. [2] in its modified version of 1992, which states:

«*Criterion 4 - Environment and dynamic effects design bases.*

[...] *However* dynamic effects *associated with postulated pipe ruptures in nuclear power units may be excluded from the design when analyses reviewed and approved by the Commission demonstrate that the probality of fluid systems piping rupture is extremely low under conditions consistent with the design basis for the piping.*»

«Dynamic effects» is further defined in Ref. [3] and [4].

2.2 *Statement of Consideration*

Paragraph II (Scope of Rulemaking - Page 50-SC-17) of Ref. [3] states that:

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

This text allows, in case of a successful LBB analysis, to ignore loadings on RPV, SG and RCP internals arising from decompression waves travelling along the primary circuit. It also eliminates the need to consider the asymmetric pressurization of the reactor cavity.

2.3 *Standard Review Plan 3.6.3 (Ref. [4])*

Most of this text addresses the conditions for an LBB analysis to be acceptable. It also states that the loadings arising from breaks can be eliminated from the design of the internals and the supports of systems components for which a successfull LBB analysis has been conducted:

«*[...] Approval of these "Leak Before Break" analyses by the Staff permits the case-by-case removal of protective hardware, such as pipe whip restraints and jet impingement barriers,* the redesign of pipe connected components, their supports and their internals *and other related changes in operating plants.*»

2.4 *Conclusion*

Analysis of US regulatory documents leads to the conclusion that the application of a successfull LBB analysis allows to avoid considering the following effects:

- The loading of the primary components supports due to pipe-break reactions;
- The subcooled blowdown loading of the RPV internals;
- The subcooled blowdown loading of the steam generator internals (Divider plate and Tube bundle);
- The asymmetrical pressurization of the reactor cavity;
- The effects resulting from pipe whipping, jet impingement and missiles.

The USNRC rules clearly exclude the containment design, the ECCS performance and the qualification of the mechanical and electrical equipment from the benefits of the LBB analysis.

3 CONSEQUENCES OF THE MODIFIED GDC4

3.1 *Inconsistency in the Mitigation Measures*

Before the GDC4 was amended, the design bases for the reactor coolant circuit (piping, heavy components and their internals and supports), the containment systems and the ECCS and the requirements for qualification of the mechanical and electrical equipment were consistent. The modified GDC4 introduces an inconsistency in the mitigation measures to face a LOCA.

Firstly, it does not seem logical not to consider a double guillotine break for designing the reactor core and internals whereas this break is assumed in the design basis of the ECCS. Secondly, the question can be raised why the ECCS should be designed for a double-ended guillotine break if the mechanical effects impair the core assembly geometry to such an extent that control rods cannot be dropped and the core cannot be adequately cooled or cause such a large distorsion of the primary piping that the ECCS water cannot enter the reactor vessel.

The USNRC acknowledged this inconsistency and clarified its position by introducing the distinction between the local and the global effects (Ref. [5]). However this clarification does not address the consequences on core reactivity control and core cooling of the large distorsions of the reactor core and internals or primary piping.

3.2 *Non Increase of the Accident Severity*

The safety requirement for non increasing the severity of the accident does not seem to have been considered.

3.3 *Protection Against Non Identified Events*

For each Plant Condition a limited number of design basis events is defined. These were analyzed to ensure that they envelope other (non identified) related possible initiating events belonging to the same Plant Condition. By eliminating from the design basis the dynamic effects associated with the postulated LOCA, the protection against some effects of the related possible initiating events may have been lost.

The consequences of the elimination of the protection against the dynamic effects of the LOCA on the protection against possible initiating events do not seem therefore to have been taken into account.

4 BELGIAN SAFETY AUTHORITIES POSITION

4.1 *Applying Modified GDC4 vs. Retaining Safety Margins*

The concept of Defence-in-Depth relies first on preventing the event from happening and then mitigating its consequences.

The modified GDC4 does not change the design bases for the containment system and the requirements for the qualification of the mechanical and electrical equipment. However the elimination of the mechanical effects associated with the postulated primary pipe breaks could result in severe consequences in terms of core shutdown, core cooling and non increase of accident severity. Indeed, the modified GDC4 results in reducing the structural capacity of the:

- Primary components supports;
- Reactor cavity;
- Reactor core and internals;
- Steam Generator tube bundle.

It furthermore does not consider the pipe whip nor jet impingement forces.

4.2 *Acceptable Modifications to the Design Bases*

The design bases of the reactor coolant circuit of plants originally designed in accordance with the non-amended GDC4 can be adjusted according to the following rules:

- The LBB anlysis can be considered as an acceptable method for removing restraints. However some protection against pipe whip and jet impingement effects resulting from primary pipe breaks remains required.
- The LBB analysis can be considered as an acceptable method for not designing the heavy components supports to the postulated LOCA reaction loads. This may result in elimination of existing snubbers or decrease in their load rating. However, the ability of the components supports to avoid excessive distorsion of the reactor-coolant piping under the dynamic loadings of the LOCA shall be maintained.
- For plants initially designed for conventional LOCA breaks, the reactor cavity concrete structures and the steel supports of the heavy components are considered to have sufficient safety margin to accomodate any dynamic loadings during LOCA related possible initiating events.
- The design basis of the reactor core and internals and of the steam generator tube bundle shall include the rapid rupture (1 ms) of the steam generator manway covers (hot leg and cold leg) and a slow break (3 seconds) of one times the flow area anywhere in the primary coolant piping.
- The existing physical separation shall be maintained.

5 APPLICATION TO THE TIHANGE 2 AND DOEL 3 UNITS

In depth analyses were performed on Doel 3, as this case enveloped the Tihange 2 case.

The structural adequacy of the primary components was assessed on a sample basis. A certain number of representative zones were chosen for each component on the basis of their high stress level or usage factor in the original design calculations. Coarseness of original calculations and estimated variations of stress levels were also considered. These zones were fully reanalized under the new conditions.

Standard LOCA analysis was performed on the primary components for the breaks postulated in the auxiliary lines. In addition, the RPV internals and the SG internals (divider plate and tube bundle) were analyzed for the instantaneous loss of one SG manway cover. RPV internals were also analyzed for a «slow» break (opening time of 3 seconds).

These additional breaks lead to non trivial loads. Taking them into account very much reduced the expected benefits of the LBB analysis. As an unexpected effect they could even increase the loads compared to the standard analyses. This occurs for instance with cross-over leg breaks. When this leg is well restrained, the corresponding break area is smaller than the break area corresponding to the loss of the manway cover.

The Replacement Steam Generator of Doel 3 has been analyzed for a full double-ended break at either side. This was caused by the fact that these analyses had started long before the questions on how to apply LBB had been settled. As a consequence this new component possesses the same ruggedness against LOCA loads as the older components.

Primary pump overspeed was also analyzed with the LBB breaks. In this case the LBB approach brought much relief: the overspeed was limited to a few percents of the nominal speed.

6 CONCLUSION

Belgian Safety Authorities accept to apply the LBB approach to the mechanical analyses with some restrictions.

They accept the reduction in bracing of the primary loop (withdrawal of restraints or snubbers) when a successful LBB analysis shows that the corresponding breaks can be suppressed.

They demand that additional breaks be considered, namely the loss of one SG manway cover and the slow (3 seconds opening time) longitudinal break in either hot or cold leg. The corresponding loads are to be applied to the RPV and its internals and SG and its internals (divider plate and tube bundle).

It must be recognized that neither conventional nor realistic breaks can be justified when the primary loop bracing is modified to take advantage of the benefits of the LBB approach. However, LBB allows to eliminate these breaks, replacing them by the above mentioned breaks. They thus constitute the new justification basis for the primary components.

These new breaks lead to loads of the same order of magnitude as the original design ones. They consequently very much reduce the advantages of the LBB approach in the analyses.

With the LBB approach, the problem of primary coolant pump overspeed in case of the slow cold leg break or cold side manway cover loss is not an issue.

REFERENCES

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2 10CFR50 (Code of [USA] Federal Regulations - Title 10 - Part 50). Appendix A:*GDC4 (General Design Criterion 4)*. August 31, 1992.

3 10CFR50. *Statement of Consideration* - 50-SC-16/22. November 30, 1988.

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5 *Leak-Before-Break Technology: Sollicitation of Public Comment on Additional Applications*. In Federal Register, Vol. 53, N°66, published by the Office of the Federal Register, Washington DC, 6 April 1988, pp 11311-2.