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A New Proposal on Leak Before Break for Future Plants

Claude Faidy

EDF-SEPTEN Villeurbanne, France, e-mail: claude.faidy@edf.fr

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1 ABSTRACT

After a lot of analysis in USA, USNRC has accepted a leak before break procedure developed in NUREG 1061. An updated version is under preparation , including field experience, for future plants.

In France, EDF and AREVA has developed a new "break exclusion" methodology in 2 steps :

- the safety consideration and defense in depth principle,
- a modernized procedure to justify applications of break exclusion on a given system.

Finally, large piping double-ended guillotine break are not considered in EPR-FA3 as a design transient. The Large Break Loss of Coolant Accident (LB-LOCA) is not considered as a design transient, only safety analysis with realistic data and methods are performed. The larger LOCA is the double end guillotine break of the surge line (16" instead of 28 or 32").

The paper will present the details of these 2 step procedure and will discuss extension to other unbreakable piping systems

2 INTRODUCTION

The break exclusion is included in the regulatory and the safety framework, in particular the defence in depth principle.

For the French European Pressure Reactor (EPR) under construction in FLAMMANVILLE (FA3), the utility and AREVA have proposed to review the major piping rupture hypothesis. The objective was to take benefit of the field experience and the improvement of design, fabrication and examination of large, in order to justify the "incredibility of failure" of some large diameter pipe.

In these pipes are unbreakable, their rupture will not be considered in the design-basis transients to design the nuclear power plant (NPP).

This objective leads to consider:

- safety and defence in depth,
- beyond design transients,
- design, fabrication, examination of the concerned piping, including potential degradation mechanisms,
- surveillance in operation,
- Pressure Equipment Regulation (PER).

3 BREAK EXCLUSION AND SAFETY

along the design phase, the construction phase, the operation and shutdown phase in order to protect workers, population and natural environment against radioactive product dispersion.

Consequently 2 different aspects :

- during normal operation radioactive waste release very stringently limited,

- prevent any accidental situation and limit their consequences. This aspect include "defense-in-depth" concept, that is confirmed for EPR.

3.1 Defense in depth

4 levels can be considered :

- the 1st level is a combination of design margins, quality assurance and control in order to limit the possibility to operate outside of normal conditions,

- the 2nd level is concerned by detection and protection in order to correct deviation from normal operation and some system failures; fuel and primary system integrity has to be assured,

- the 3rd one is assured by safety systems in order to reduce the consequences of accidental events, and assure no severe accident consequences; in the other hand all the radioactive products has to be confined,

- the 4th level includes all the measures to assure containment integrity and management of severe accidents.

For EPR, the safety demonstration is done through deterministic approaches, with complementary probabilistic approaches; initiator events are "treated" or "excluded".

Some initiator events can be excluded, if sufficient measures are taken during design and construction, and during operation, in order to justify that is "practically possible to eliminate" such accidental situation. This "practically possible to eliminate" is associated with the 2 first levels of defense in depth.

It's the case for large primary components like reactor pressure vessel, primary pump casing, stem generators… Consequently these ruptures are not consider at the 3rd defense-in-depth level.

For high energy piping, breaks are considered as simple initiator events, and the defense-in-depth principles can be adapted :

- level 1 : design and fabrication requirements; high level with high confidence level (proof of quality)

- level 2 : surveillance in operation and early detection of possible degradation that can affect piping integrity,

- level 3 : consideration of local effects of rupture with deterministic rules,

- level 4 : consideration of pipe ruptures with equipment or system failures in order to be able to manage severe accidents.

3.2 Break exclusion

It's a particular case of defense-in-depth, in order to consider that is "practically possible to eliminate" accidental events connected to some pipe rupture.

It's considered from the design phase for EPR-FA3 for main coolant loops and steam lines (inside the containment and outside up the anchor points).

Justification are based on :

- level 1 : the piping systems has to be design and manufacture with the maximum quality level of the corresponding industry, a detailed and robust justification of absence of possible degradation in operation, a set of stringent criteria for end of fabrication examination,

- level 2 :
    - o surveillance of relevant parameters in operation, like water chemistry or transient bookkeeping…
    - o accessibility and controllability of all the pipe fitting and welds, in order to assure capability of very efficient in-service inspections,

The 2 other actions support these 2 levels of defense-in-depth, and are more associated to level 3 :

- rupture prevention through justification of tolerance to large through wall crack compare to leak detection capabilities,

- analysis of the consequences of rupture with more realistic hypothesis.

The 1st of these 2 actions are clearly the classical "leak before break" concept based on the justification that the critical conventional through wall crack is sufficiently large to assure detection during normal operation before accidental catastrophic failure. The leak detection systems have to be redundant and have to detect a 1gpm leak before 24 hours. For piping outside the containment (like part of the steam lines), , a complementary "risk" of rupture analysis will be performed including all aspects and in particular the layout, simple, short but not too much stiffen, in order to balance the absence of real dedicated leak detection system. The stress criteria reduction has to be handle with precaution in order to assure the minimum flexibility for thermal expansion and seismic design.

The second of these 2 action is the consequences of the break exclusion : the corresponding accidental events are suppressed of the design transient list. Nevertheless, the corresponding ruptures are studied at the level 3 of defense-in-depth of the plant safety analysis, with realistic hypothesis :

- the 2A (A: section of the pipe) loss of coolant accident (LOCA) is used to design the safety injection system, the maximum pressure inside the containment and the stability analysis (supports) of the major primary components (RPV, SG, pressurizer, pump).

- the 2A Steam Line Break (SLB) for the maximum pressure inside the containment and the safety component qualification

- the A rupture of the SL connected lines in order to design containment penetrations.

All the non break exclusion line are considered in the 3rd level of defence in depth in the safety analysis of the plant.

Finally, it's important , when some rupture are not strictly considered, to assure that all the other events that are initially covered by the event, remain acceptable with these new hypotheses.

4 DEFENSE-IN-DEPTH PRACTICAL CONSEQUENCES

4.1 New rupture hypothesis

For the main primary system and the steam lines, the double-end guillotine break is not consider for EPR-FA3.
The mechanical design and the integrity analysis of component have to consider the guillotine break of connected lines, in particular the larger one : the surge line for primary system and small line break for steam lines.
The design of other safety and protection systems are considering the same hypothesis: maximum connected line rupture, without consideration of flow limitation devices in the nozzle.
The rupture of SG bolted closure plate for SG maintenance will be designed with particular attention and margins. If not, corresponding rupture has to be considered.

4.2 Complementary analysis

Some analysis will use more realistic hypothesis with the 2A pipe rupture :

- justification of core cooling, including re-circulation phase,
- containment design,
- equipment qualification.

piping systems interaction
During a primary loop rupture:

- no damage from one loop to an other loop,
- the RPV will remain an anchor point (support has to filter the different loads)

During a steam line rupture :

- no damage from one line to an other line,
- two line rupture has to be considered in term of safety analysis

5 MECHANICAL JUSTIFICATION

5.1 Design and construction

The mechanical behavior of the corresponding lines with all the Safety Analysis Report hypothesis in term of transients and combination with seismic events or other external/internal hazard. All the dynamic effects of connected line break or short time closure of valves have to be considered, no water hammer has to be envisaged without justification of negligible consequences.
All the indirect cause of failure have to be analyzed.
Only large diameter pipes are considered for EPR-FA3. They are not sensitive to small pipe break whip. No local masses on smaller piping systems can affect the break preclusion piping systems.
The design is done with the RCC-M class 1 design and construction rules.

5.2 Material selection

Similar material than existing similar operating plan will be used : stainless steel for primary loop and carbon steel for steam lines. The field experience is large and good. Some other materials can be used with justification.
The RCCM material properties will be used. If some are not available the manufacturer has to propose some validated values, generally through direct measurement during fabrication, with complementary simulation of end of life material properties.

5.3 Degradation mechanism

No degradation mechanism has to affect the life of these piping systems. The list of all the degradation mechanisms to be considered has to be justified.
As a minimum, the manufacturer has to consider :

- fatigue, including high cycle fatigue in mixing areas and vibrations; a usage factor less than 1 has to be justified in any location of the piping system,
- brittle fracture has to be excluded, including thermal ageing and low temperature hazard outside the buildings,
- erosion-corrosion has to be excluded through material selection in particular,
- all possible type of corrosion has to be excluded in accordance with existing field experience,
- erosion has to be excluded by integration of the field experience.

5.4 Surface crack consideration

A set of conventional surface cracks, between ¼ t and ½ t, has to be considered in accordance with RCCM appendix ZG.
The corresponding needs of toughness material properties has to be justified through measurement on real material.
Through wall crack analysis
A complete through wall crack analysis will be developed, based on validated modern methods and data. Concerning the toughness the necessary measurements on real material will be done.
The load will be the maximum load reaches during normal operation plus maximum design seismic event.
All the fracture mechanic parameters, crack area determination and flow rare estimation will be issued from RSE-M Appendix 5 Code and RCC-MR Appendix 16 Code, or similar validated practices.
The safety factors of 10 on the flow rate and 2 on the critical crack size will be used, with a 1 gpm flow detection capability.

5.5 Large component support

Support will be designed with a 2A x pressure quasi-static load and corresponding code criteria.

6 SURVEILLANCE IN OPERATION

6.1 Leak detection systems

A redundant set of devices are installed inside the containment in order to assure a leak detection capability of 1 gpm in 24 hours.

6.2 In-service inspection

A specific and detailed in-service inspection program is developed with particular attention with on the dissimilar metal weld, the fatigue sensitive nozzles or the maximum load areas. As a complement, random inspection of main butt welds of the 2 systems will be inspected with volumetric techniques.

7 CONCLUSION

A complete set of rules are proposed to justify "break exclusion" of some large diameter piping systems. For EPR-FA3 only the main coolant loops and the steam lines are concerned.
A step by step review of defense-in-depth levels has been done to take benefit of the fact that is possible that certain pipe breaks are "practically possible to eliminate".
All the consequences in term of safety consistency of the proposal and corresponding precautions in design-construction and operation phases are presented in the paper.
The leak before break concept is a part of the level 3 defense in depth and nor the center part of the break exclusion concept.

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