SAFETY APPROACHES

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

The break preclusion approach

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ABSTRACT

French Pressurized Water Reactors are designed according to the defense-in-depth principle. The safety approach considers equipment failure, notwithstanding the design and manufacturing requirements that are applied to prevent such breaks.

Due to the difficulty of limiting the consequences of the breaks of some components for these reactors, such events are not considered in safety studies. The lack of realistic and demonstrable provisions to limit consequences according to current knowledge and available techniques, is justified by the implementation of particularly stringent requirements for design, manufacturing and both initial and in-service reinforced inspection aiming to guarantee that these components will not break: the “break preclusion” approach.

Regarding pressurized water reactors, these cases of “break preclusion” relate to large components of the main primary system and main secondary systems.

Concerning pipework, “break preclusion” approach can only be considered for main primary pipings and main secondary steam line pipings: “break preclusion” is then a choice. According to ASN guide n° 22, produced jointly with IRSN, this choice may only be regarded as acceptable on the basis of justified major safety benefits. Furthermore, the possibility to apply the “break preclusion approach” shall be assessed at an early stage of the design as it is a decisive choice for the design.

IRSN has established a non-exhaustive list of necessary conditions which shall be satisfied in order to consider the application of the “break preclusion” approach for components or pipings, given that such an approach shall remain an exception and shall be justified either by the absence of a physical means of mitigation or by major safety benefits.

RESUME

Les réacteurs à eau sous pression français sont conçus selon le principe de défense en profondeur. La démarche de sûreté consiste à considérer la défaillance d’équipements indépendamment des exigences de conception et de fabrication des circuits qui visent à prévenir leur rupture.

Les difficultés de limitation des conséquences de la rupture de certains équipements mécaniques de ces réacteurs ont conduit à ne pas postuler de tels évènements dans les études de sûreté. L’absence de disposition de limitation des conséquences, raisonnable et dont l’efficacité peut être démontrée au vu de l’état des connaissances et des techniques disponibles, est alors justifiée par l’application d’exigences particulièrement fortes en matière de conception, de fabrication et par une surveillance initiale et en service renforcée visant à garantir la prévention de la rupture de ces équipements : c’est la démarche d’exclusion de rupture.

Ces cas d'exclusion de rupture concernent, pour les réacteurs à eau sous pression, les gros composants du circuit primaire principal et des circuits secondaires principaux.

Pour les cas des tuyauteries, la démarche d’exclusion de rupture ne peut être envisagée que pour les tuyauteries primaires principales et pour les tuyauteries secondaires principales véhiculant de la vapeur : l’exclusion de rupture résulte alors, sauf exception, d’un choix. Ce choix ne pourrait être accepté conformément au guide de l’ASN n°22 élaboré conjointement avec l’IRSN que par la mise en évidence de gains significatifs pour la sûreté. Par ailleurs, l’opportunité du recours à la démarche d’exclusion de rupture doit faire l’objet d’un examen à un stade précoce de la conception, celui-ci étant un choix structurant pour la conception.

L'IRSN a établi une liste non exhaustive de conditions nécessaires pour que l'exclusion de rupture puisse être envisagée pour un équipement mécanique étant entendu que le recours à une démarche d'exclusion de rupture pour des équipements mécaniques doit rester exceptionnel et être impérativement justifié soit par l'absence de moyen physique permettant de faire face à la rupture soit par des gains significatifs en matière de sûreté.

KEY WORDS

Preclusion, break, requirements, defense in depth, pipework, large component, main primary system, main secondary systems

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1 INTRODUCTION

The break preclusion approach[1] is based on the principle of not considering a break in a vessel or piping as a single initiating event to be studied in a deterministic manner in the safety demonstration.

This document describes the position of IRSN (Institut de radioprotection et de sûreté nucléaire) on this approach.

After giving a reminder of the break preclusion approach in current practices, the document identifies the vessels and pipings of pressurized water reactors (PWR) for which an operator may apply this approach in the safety demonstration and defines the associated conditions.

This document is an English translation of the original report in French which is to be referred to for a guaranteed content.

[1] According to the definition in the French Official Journal of 23 September 2015, break preclusion is a "*decision to not consider a complete break of an equipment containing fluid as an initiating event in the safety analysis of this equipment*".

2 THE DEFENSE-IN-DEPTH PRINCIPLE AND ITS ADAPTATION TO MECHANICAL EQUIPMENT

Pressurized water reactors are designed according to the defense-in-depth principle: a series of provisions are defined, on the one hand to avoid any incidents or accidents occurring, and, on the other hand, to limit the consequences of any which occur despite the preventive provisions applied. On this basis, various levels of defense-in-depth are differentiated, with each level aiming to limit the consequences of the failure of the previous level(s) and prevent the next level being affected, in compliance with general safety objectives.

ASN guide n° 22, produced jointly with IRSN, specifies some elements which help to implement the defense-in-depth principle, particularly the consideration of events with a potential effect on the nuclear safety of the facilities. "*in the nuclear safety demonstration [such events are] "precluded" or "postulated"* ". An event "*can" be "excluded" if it is demonstrated that this event is physically impossible or extremely unlikely with a high degree of confidence, with regard to the safety objectives*". However, for the special case of break preclusion for vessels and pipings, some specific considerations are also recommended in ASN guide n° 22.

This document is related to the integration of the risk of breaks for vessels and pipework - hereafter called mechanical equipment - based on these considerations, given that, in terms of the defense-in-depth principle, the objectives for the different levels may be satisfied by:

- at level one, by preventing the different types of damage by an appropriate design, manufacturing and inspection;
- at level two, by checking that the structural integrity[2] of the equipment is kept by defining appropriate equipment monitoring conditions during operation and in-service inspections in order to ensure no damage;
- beyond, by defining the failures considered, despite the precautions based on the applicable requirements for the first two levels, and limit the consequences of such failures.

[2] The structural integrity of an equipment is kept if it is not affected by any degradation mechanism which would question the prevention of degradation mechanisms made at the design stage**Erreur ! Source du renvoi introuvable.**.

3 THE BREAK PRECLUSION APPROACH: CURRENT PRACTICES

The order of 30 December 2015 on pressurized nuclear equipment (ESPN) does not cover the safety demonstration of reactors, and only considers the safety of each pressurized nuclear equipment separately. According to this order, all the components and pipings of the main coolant system (MCS or main primary system) and the main secondary systems shall be classed as level N1, as defined in article 3, and designed on this basis. Thus, the operator adopted the level 1 RCC-M rules[3] when designing these components and pipings. The order does not refer to a possible break preclusion for some of these components.

3.1 MAIN COMPONENTS (VESSELS)

Provisions can be applied in order to limit the consequences of most breaks, according to current knowledge and available techniques. Nonetheless, realistic and demonstrable provisions to limit consequences cannot be applied to breaks in some main components: it cannot be ensured that the consequences are compatible with the safety objectives adopted for the corresponding facilities. Efforts are therefore made to improve the prevention of the corresponding events in order to eventually “preclude” them.

This applies for the castratrophic failure in main components such as the reactor pressure vessel, the pressure boundary of steam generators (SG), the reactor coolant pump casing or the pressurizer. The mechanical effects of a break in one of these components, should it occur, would have unavoidable consequences on the fuel assemblies, internal vessel structures, steam generator tubes or the containment, which would prevent PWR safety objectives from being achieved.

For such main components, it appears that a break shall be regarded as extremely unlikely with a high degree of confidence thanks to compliance with the reinforced design, manufacturing and monitoring requirements.

From the design phase for the initial PWR, the decision was reached to not consider accidents initiated by such breaks in deterministic safety studies, and therefore to not define additional equipment and procedures to limit the consequences of these breaks as required by the 3rd level of the defense-in-depth. Consequently, particularly stringent requirements were adopted for equipment design and manufacturing, and both initial and in-service inspections to prevent breaks for these components. Therefore:

- the design choices aiming to prevent the occurrence of any degradation mechanism, combined with the application of manufacturing procedures and inspection so as to ensure a high level of quality;
- In-service inspection is used to check the absence of degradation mechanism or to detect any occurrence sufficiently early.

On this basis, the break preclusion approach is mentioned in ASN guide n° 22, produced jointly with IRSN, which covers the design of pressurized water reactors. In particular, this guide indicates "[that] “*break preclusion” shall be implemented for the large components of the main primary system and main secondary systems. This is because no reasonable measure to limit the consequences of their rupture - as an initiating event - could be defined. These components are said to be "non-ruptible*"”. The guide then mentions the following as part of the selected means for the design and manufacturing of these components: "*the conservative determination of the*

[3] Design and construction rules for mechanical equipment for PWR nuclear islands

loads applied, the analysis of the behaviour of the structures under these loads, the existence of margins with respect to the mechanical criteria in particular, the qualification of the manufacturing and procurement processes, the choice, extent and precision of the inspection techniques with respect to the manufacturing processes, the determining of acceptance criteria for manufacturing defects, the in-service accessibility of the areas to monitor and the extent of the associated checks, the integration of experience in the behaviour of similar materials or installations, are means necessary for the implementation of this procedure. "

Finally, it is important to remember that the selected manufacturing procedures and inspections shall take into account "*technical improvements and changing practices*".

3.2 PIPINGS

Accident studies of breaks on piping are part of the safety demonstration of a facility. They lead to postulate location and dimensions of breaks. In practice, the operator selects specific locations for these breaks. For example, according to design rules, for level 1 auxiliary pipings, as defined in the RCC-M, one break shall be considered at the end of each section and at least at two intermediate points where the level of stresses is high. Locations with special characteristics (particularly welds) are also considered. Other points can also be taken into consideration, particularly in hazard studies. Finally, the positions of the breaks considered is partially based on their estimated frequency of occurrence, however positions are also determined by convention.

Positioning the breaks at specific points on a piping, to study the consequences, implies that breaks in other locations will not be studied. This approach is not part of a break preclusion approach. In this case, the operator shall justify that the events studied are representative and lead to an evaluation covering the consequences of all break situations considered as plausible. This is the case for the main coolant lines (MCL) used in French reactors – excluding the EPR reactor at Flamanville, where breaks are not assumed to be precluded, and for which the consequences of seven breaks, positioned at welds by convention, are studied.

By applying reinforced requirements to specific piping sections, it may be considered that the breaks to be studied are necessarily positioned outside of these sections. Attention shall be paid to the requirement reference document applied to the sections in question for this type of approach, which can be rightfully considered as a break preclusion. Elements mentioned hereafter in the document also apply to this case.

On this basis, the break preclusion approach was adapted to the main steam lines (MSL) sections located between the containment penetration in the reactor building and the main steam isolation valve[4]. This approach leads to the notion of "*SUPERPIPE*", designed and produced to meet specific requirements, which correspond to a reinforced design requirement compared to those applicable to safety level 2 pipings[5].

Finally, the break preclusion approach was agreed, for the EPR reactor at Flamanville, for the MCL and the MSL, in accordance with technical guidelines for the design and construction of the next generation of nuclear power plants with pressurized water reactors and with conclusions of the Expert meeting (SPN) on 21 June 2005.

[4] If MSL breaks between the penetration in the reactor building and the anchor point downstream from the isolation valve, this could drain two steam generators if we assume the failure of the isolation valve on the broken pipe (due to the forces induced by the break) and if we apply the single failure criterion to another isolation valve (taken from RCC-P).

[5] MSL are classed as safety level 2 for French reactors, excluding the EPR reactor at Flamanville.

However, technical guidelines still provide for the continuation of some studies considering "*a double-ended guillotine break in the MCL*" with realistic assumptions, particularly without considering an aggravating failure.

On this basis, the break preclusion approach for pipings is also mentioned in ASN guide n° 22, produced jointly with IRSN**Erreur ! Source du renvoi introuvable.**, which does however specify that it can only be considered for the MCL and MSL. The aforementioned guide specifies the provisions required to implement this approach, particularly including, over and beyond similar provisions used to preclude breaks in main components, the need to "*demonstrating that this choice is reasonable considering the advantages and drawbacks it brings to the overall level of safety of the installation and to radiation protection "*. In fact, concerning pipings, unlike the main components of the primary system, provisions can be defined in order to limit the consequences of a double ended guillotine break *in principle*[6].

[6] However, it appears that the consideration of all effects induced by a double ended guillotine break cannot be demonstrated, particularly the dynamic effects on the reactor pressure vessel (RPV) internals.

4 CONDITIONS TO BE SATISFIED

According to IRSN, the circumstances leading an operator to preclude breaks in some components or pipings as an initiating event in the safety demonstration, can be considered as one of the following two cases:

- **Case 1:** breaks cannot be considered as, based on current knowledge and available techniques, the definition and implementation of realistic provisions to limit the inherent consequences are not feasible or not demonstrable;
- **Case 2:** breaks can be considered and provisions to limit the inherent consequences can be both defined and implemented, however the operator decides to ignore such breaks and considers that break preclusion is possible to be applied based on specific design, manufacturing and inspection requirements.

Case 1

The consideration of a break in mechanical equipment is not feasible as the consequences of such a break cannot be limited using dedicated provisions or their efficiency cannot be demonstrated using the usual study practices.

Break preclusion is mandatory in this case as no alternative option is available. Reinforced design, manufacturing and inspection requirements are necessary in this case, to ensure that the break can be considered as extremely unlikely with a high degree of confidence.

A complete break for main MCS components in French NPPs is typically covered by case 1.

In this case, the break preclusion approach and the practical elimination approach can be associated.

Case 2

The consideration of a complete break for mechanical equipment, as an initiating event, is not postulated by the operator, which deems that it can justify that its design, manufacturing and inspection requirements are such that this break can be considered as extremely unlikely with a high degree of confidence.

In general, in this situation, the break preclusion is the outcome of a deliberate decision by the operator, based on the high quality and appropriate application of design, manufacturing and inspection requirements, in view of the "deliberate" absence of provisions to limit consequences.

Thanks to this decision, the operator can optimize its resources to a certain degree as some studies, as well as the deployment of provisions to limit consequences, are unnecessary.

To begin with, IRSN highlights that no regulations or prescriptive technical reference document defines the requirements to be satisfied by an operator to justify the break preclusion[7].

In addition, even defining these requirements is delicate as the equipment in question already benefits from manufacturing provisions intended to ensure high quality levels. This is true for MCL piping and main components of the MCS, which are designed and manufactured according to RCC-M class 1 rules. On this basis, the difference between equipment covered by a break preclusion approach and similar equipment not covered by this approach could appear minimal. This could lead to the conclusion that applying RCC-M class 1 is equivalent to a break preclusion approach. IRSN rejects this conclusion.

The definition of mechanical criteria which could reinforce RCC-M level 1 criteria associated with the prevention of conventional damages has been mentioned previously, however no such works have been completed. In all events, according to IRSN, such a proposal would not appear satisfactory as "safety coefficients" applied at the

[7] It is, however, noteworthy that the concept of "SUPERPIPE" for MSL has a clearly-identified definition.

design stage are considered to be sufficient to prevent the equipment from failing. Increasing these coefficients would not lead to any significant safety benefits. Thus, this proposal is not used to prevent conventional damage and a different type of input shall be identified.

This different type of input could, in particular, include selecting provisions to simplify access to the equipment in question and the use of several inspection procedures, tried and tested manufacturing methods, enhanced inspection during manufacturing and in-service, and in-service requalifications. Two conditions also appear as indispensable prerequisites:

- There shall not have been failure caused by damage mechanisms detected on the type of mechanical equipment in question;
- previsions shall be applied to guarantee that no loads are likely to lead to damage, other than the thermal and mechanical loadings considered during the design phase.

On this basis, IRSN has established a non-exhaustive list of conditions to be satisfied based on technical improvements and enhancing practices, in order to allow a break preclusion approach to be acceptable for mechanical equipment. This list includes:

a. **positive operating experience from the manufacturing and use of similar components, including the materials used and the manufacturing procedures implemented. No loss of structural integrity should have been reported. In addition, a detailed analysis of any difficulties faced by the selection of materials and manufacturing process is required;**
b. **reinforced design requirements:**
    - **easier access for the purposes of mandatory inspection, with 100% accessibility and inspectability;**
    - **the number of welds, the length of the piping and the distance between two fixed points shall be reduced to the strict necessary;**
    - **no stresses exist other than the transient stresses described in the safety report. The pessimistic values of the stresses assumed shall be justified. On this basis, significant hydrodynamic effects, for example, shall be avoided. Stresses induced by the effects of internal aggressions shall be avoided as far as reasonably possible;**
    - **close attention shall be paid to the risk of corrosion when selecting materials and defining chemical specifications for fluids flowing through systems;**
    - **mechanical design shall be at least equivalent to RCC-M level 1 rules[8];**
c. **reinforced requirements applicable to manufacturing and associated inspection, taken from RCC-M level 1 or better, completed by the requirements defined in the equipment specification, including:**
    - **procurement qualification;**
    - **volumetric inspection of products from procurement;**
    - **manufacturing processes to guarantee the homogeneity and compactness of products;**
    - **inspection of edges to be welded;**

[8] Equivalence shall be considered in terms of the types of damage covered and of the safety coefficients applied. RCC-M level 1 particularly requires detailed studies of fatigue and the risk of fast failure.

- **welding using a qualified procedure specifically developed for the purposes of the break preclusion approach;**
- **representative test specimens shall be tested for all load-bearing welds;**
- **double volumetric inspections for all load-bearing welds using different procedures. It is important to aim to ensure the redundancy and diversification of these procedures, in line with the type of defects to be detected;**

d. reinforced in-service inspection requirements:

- **a in-service inspection program shall be defined – the intervals of these inspections is a key parameter – and an initial zero point shall be determined. In particular, this program shall include volumetric testing for all load-bearing welds;**
- **in-service inspection procedures shall be qualified.**

e. appropriate suppliers and sub-contractors shall be selected for all manufacturing and inspection activities. The selected parties shall be justified based on their experience and qualifications, in particular.

In addition, feedback from the production of some items of mechanical equipment of the EPR reactor at Flamanville recently revealed organisational shortfallings, both in terms of specifications and manufacturing, and the associated inspections, despite the applicable requirements. This raises the question of the efficiency of the quality management system.

On this basis, IRSN considers that a reinforced management quality is required for the design and manufacturing phases for mechanical equipment selected for break preclusion. This reinforced quality management shall ensure that any non-compliance is detected at the earliest possible stage, in particular.

Furthermore, the justification of the extremely unlikeliness with a high degree of confidence cannot be simply based on compliance with a probabilistic cutoff threshold, just like the safety approach in general. Some past studies were completed to estimate the probability of a break in a piping of the nuclear section, but results varied widely due to significant uncertainty. IRSN considers that these probabilistic tools are not suitable for integrating a type of damage mechanism whose properties are unknown during the study phase. Feedback for a few piping breaks which have occurred at French nuclear facilities in recent years illustrates this point:

- the incident on the cooling system during an outage (RHR) at the Civaux 1 power plant was caused by a longitudinal break attributed to thermal fatigue during normal operation, which was not identified during the design;
- between 2005 and 2008, several incidents led to significant leaks in the steam generator tube bundles at French electronuclear facilities; clogging, which was not identified during the design phase, was detected in the secondary side of the steam generators. Such clogging increases the risk of fluid-elastic instability of some tubes.

Probabilistic studies would not have forecast these incidents. Although the sections mentioned in these examples are clearly not designed based on break preclusion, IRSN considers that phenomena which were not identified during the design phase can also occur for sections designed based on break preclusion.

Finally, the possible contribution of probabilistic studies remains extremely limited in these conditions. **IRSN considers that probabilistic input cannot be used to justify the use of a break preclusion approach.**

According to feedback on manufacturing non-conformities for large forged components in the primary system in France and abroad, the level of quality required or specified for these components was not systematically reached and this non-compliance was not detected during the manufacturing process. In the same way, welds in the main steam pipework sections of the EPR reactor at Flamanville failed to comply with the break preclusion reference document defined by the operator. **On this basis, IRSN considers that the break preclusion approach should only be used in certain circumstances.**

For case no. 1, which covers "non-ruptible" large components, IRSN considers that the approach has been adequately tested, particularly according to operating experience, and no reconsideration is necessary when constructing new PWR providing that the aforementioned conditions are correctly implemented and controlled.

For case no. 2, which covers MCL and MSL pipings, IRSN considers that the preferred approach is to consider plausible breaks, study accident scenarios and implement provisions to limit consequences, if applicable, for example, by implementing whip restraints, leaktighting of neighboring areas or selecting a double-walled piping, combined with a safety-classed leak detection system in the inner space.

Applying the "selected" break preclusion approach may be acceptable if provisions to limit the consequences of a guillotine break lead to safety drawbacks. For example, the EDF operator highlighted that the presence of restraints on the MCL hampered in-service inspection and could induce stresses in the line if incorrect values of the gaps were used. IRSN considers, as per guide**Erreur ! Source du renvoi introuvable.**, that use of the break preclusion approach could be acceptable if:

- applying this approach is demonstrated to bring significant safety benefits;
- above conditions a) to e) are satisfied.

In terms of potential significant benefits, we could list:

- installing piping with forged connections, improving both robustness and inspectability;
- optimising the layout of the pipings connected to the piping designed based on break preclusion, thanks to the absence of restraints ;
- reducing the doses absorbed during inspection thanks to an easier access to the equipment and systems to be inspected[9].

Safety benefits shall be analyzed on a case-by-case basis. **IRSN therefore considers that, if an operator wishes to use the break preclusion approach, it shall precisely justify the expected safety benefits from the initial project phases**.

It is important to realize that using a break preclusion approach is a structural design decision as this approach has consequences on the main design assumptions applied for some systems. Applying a break preclusion approach to the MCL piping can have consequences on the design of the safety injection, RPV internals, the containment and internal structures as well as on the qualification profiles of components. Whether or not this approach may be used shall therefore be assessed during an early design stage.

[9] Despite this, it appears difficult to compare such an argument with the drawbacks of a safety demonstration excluding a guillotine piping break, as additional provisions to limit exposure can be defined.

5 CONCLUSIONS

French Pressurized Water Reactors are designed according to the defense-in-depth principle. The safety approach considers equipment failure notwithstanding the design and manufacturing requirements that are applied to prevent such breaks. In-service inspections can be used to check that design assumptions are verified during operations and that the structural integrity of the systems remains throughout the life of the facility.
Breaks are considered as initiating events and studied in a deterministic manner as part of the safety demonstration in order to mitigate their consequences.

Due to the difficulty of limiting the consequences of breaks for some types of mechanical equipment of pressurized water reactors, such events are not considered in safety studies. On this basis, the lack of realistic and demonstrable provisions to limit consequences according to current knowledge and available techniques, is justified by the implementation of particularly stringent requirements for design, manufacturing and both initial and in-service reinforced inspection aiming to guarantee that these items of equipment will not break: the “break preclusion” approach.
For these break preclusion cases, which we could qualify as "necessary", and which involve main coolant system and the main secondary systems components for pressurized water reactors, IRSN considers that the approach implemented for all operating reactors is satisfactory and no reconsideration is necessary when constructing new reactors, providing that the aforementioned conditions are correctly implemented and controlled, particularly during manufacturing.

Concerning piping, “break preclusion” approach can only be considered for main coolant line and main steam lines. The break preclusion approach is therefore an active decision and IRSN considers that provisions aiming to limit the consequences of a break shall be granted priority where possible. According to ASN guide n° 22, produced jointly with IRSN, a break preclusion approach can only be accepted for piping if this break preclusion approach is proven to have significant safety benefits. The possibility to apply this approach shall be considered at an early design stage as this choice establishes the design structure.

To conclude, IRSN considers that a break preclusion approach can only be used for mechanical equipment on an exceptional basis, and such an approach shall be justified either by the absence of a physical means of limiting the consequences of breaks or by major safety benefits. In both cases, the existence of positive feedback in relation to similar items of equipment and the application of reinforced design, manufacturing and monitoring requirements are necessary.
IRSN has established a non-exhaustive list of conditions which shall be satisfied in order to allow a break preclusion approach for mechanical PWR main coolant system and the main secondary systems equipment. These conditions could provide input for any operator wishing to apply a break preclusion approach to other items of equipment, including another type of facility (non-PWR). A case-by-case approach shall be adopted in all events.

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