ASN – Autorité de Sûreté Nucléaire

Montrouge, 20 June 2019

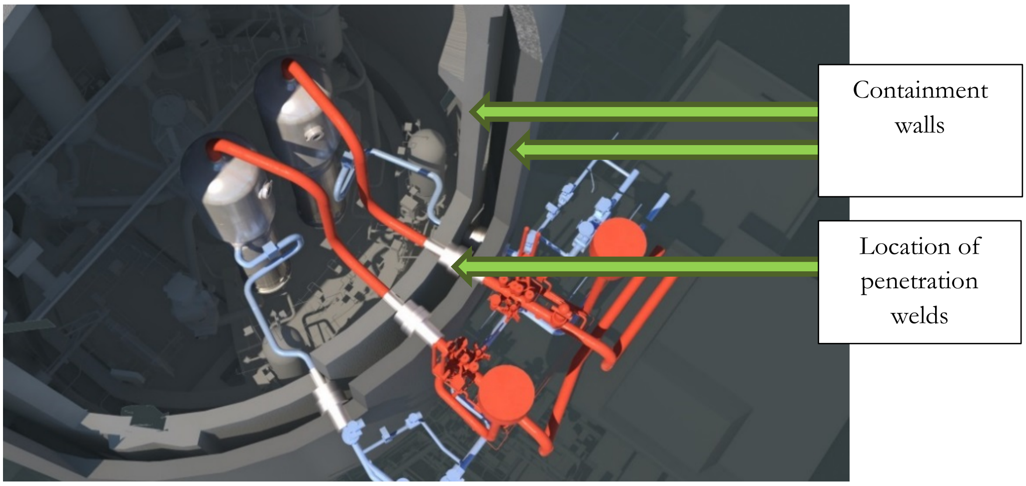
Technical Notice

Flamanville EPR reactor
Deviations affecting the welds on the main steam lines at the Flamanville EPR reactor containment penetrations

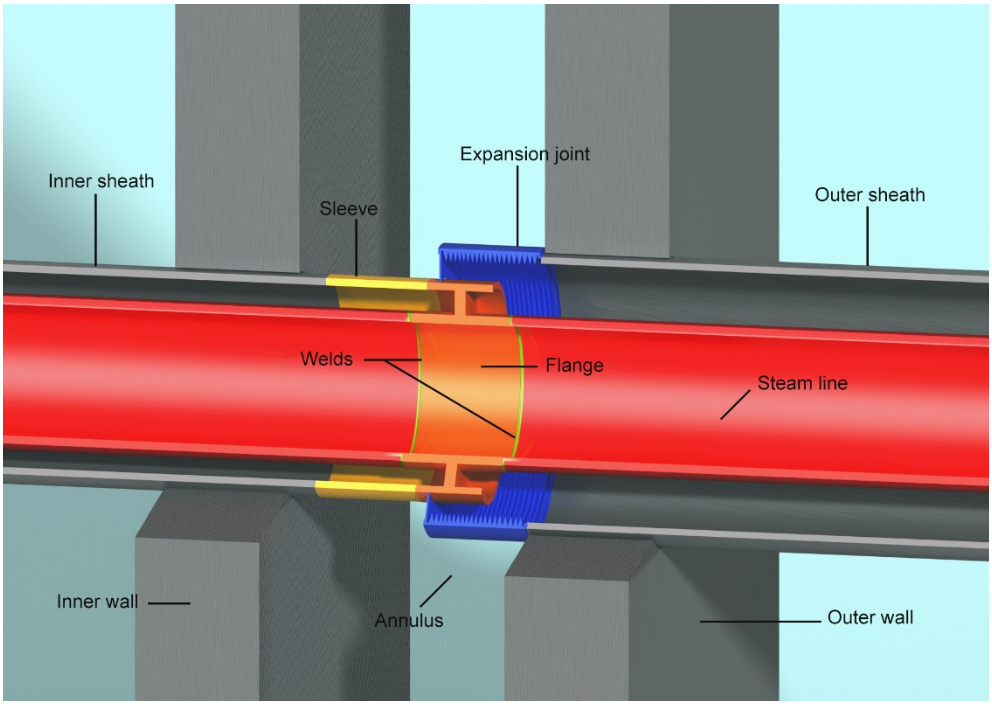
1. Description of the equipment concerned

The main steam lines (VVP) are pipes carrying the pressurised steam produced in the steam generators to the turbine. There are four such lines on an EPR reactor.

These pipes pass through the two walls of the reactor containment. On each of the four lines, there are two "penetration" welds between these two walls.



Overview of the VVP lines (shown in red)



Simplified cross-section of a penetration

2. Principle of defence in depth and break preclusion approach

The design of nuclear installations is based on the principle of defence in depth, which leads to the implementation of successive levels of defence designed to prevent incidents and accidents and mitigate their consequences[1].

For nuclear pressure equipment, defence in depth is based on the quality of design and manufacturing (first level), inspection of equipment both on completion of manufacturing and in-service (second level) and provisions in the installation designed to mitigate the consequences of any break (third level).

In the case of the VVP pipes, EDF wished to implement a "break preclusion" approach, which consists in taking steps to ensure the highly improbable nature of any break in the equipment, thereby avoiding having to define third level defence in depth measures.

It should be noted that such an approach also applies to other equipment such as the reactor vessel and the steam generators, for which it is not technically possible to define third level defence in depth provisions. This is then no longer a licensee choice, but a requirement linked to the technology of pressurised water reactors.

3. Requirements related to the break preclusion approach and deviations observed

The demonstration of the highly improbable nature of the breakage of equipment covered by a break preclusion approach notably involves a significant reinforcement in the quality of their design and manufacture by comparison with the provisions adopted for equipment of the same importance for reactor safety.

To achieve this, EDF and its manufacturer, Framatome, proposed break preclusion requirements supplementing the provisions derived from the RCC-M[2] code normally applied to this type of equipment. These requirements more particularly comprise reinforced criteria for the mechanical properties of the welds on the VVP pipes. These requirements are not the result of regulatory provisions, but were defined

[1] This approach appears in Article 3.1 of the Order of 7th February 2012 setting out the general rules concerning basic nuclear installations.

[2] The RCC-M code (Design and Construction Rules for Mechanical Equipment) is a professional guide which defines manufacturing rules for mechanical components intended for nuclear reactors.

by EDF consistently with the mechanical properties obtained for the penetration welds of the last reactors built in France and are similar to what has been adopted and achieved on the EPR reactors built abroad.

The deviations occurred during the implementation of these requirements, the production of the welds and their inspection and in no way call into question the design of the EPR reactor.

More specifically, these break preclusion requirements were not transmitted by Framatome to its supplier in charge of the VVP pipe manufacturing operations. The supplier thus applied the provisions of the RCC-M code, which are not sufficient for the adoption of a break preclusion approach.

The mechanical characteristics of a material can only be directly determined by means of destructive tests. However, adequate design choices and good manufacturing quality can provide guarantees as to the reproducibility of the welding process and thus the result obtained. For this, the RCC-M code comprises a system involving several steps, each of which must receive particular attention, notably with:

- the choice of an appropriate filler material;
- prior qualification of the welding procedures used;
- verification of the quality of the filler materials procured by means of acceptance testing;
- the production of control assemblies[3] in conditions representative of the production welds, on which destructive tests are performed;
- the performance of non-destructive checks to guarantee the absence of flaws in the welds produced.

Examination showed that **numerous deviations occurred during these various manufacturing steps**: inappropriate filler material, incomplete qualification of the welding procedure, subsequent detection of deviations in the performance of the acceptance tests which led to the mechanical properties being over-estimated, control assemblies produced belatedly and in conditions that were not representative of the production welds, etc. ASN thus observes a general lack of control of the operations and processes.

The deviations identified were also frequently dealt with belatedly, once the manufacture of the penetrations was completed. Some deviations were brought to light by ASN and IRSN in 2018, during the course of their review of the EDF file.

4. Consequences of the deviations

For the eight penetration welds, these deviations led to toughness[4] values, obtained on control assemblies and scale-one replica parts, that were lower than the break preclusion requirements and, in certain cases, than those of the RCC-M code. These values also varied widely. The tests also showed uncontrolled strain ageing[5] for which there is not as yet any satisfactory explanation.

Moreover, the number and nature of the deviations found call into question the conditions in which these welds were produced and the ability to identify the actual properties of the welds produced with a high level of confidence.

ASN and its Advisory Committee for nuclear pressure equipment (GP ESPN) therefore consider that the manufacturing conditions needed for application of a break preclusion approach were not met and that the breakage of the welds can no longer be considered as highly improbable, thus calling into question the possibility of adopting a break preclusion approach.

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[3] When making production welds, welds called "control assemblies" are produced in conditions guaranteeing that these control assemblies are representative of the actual production welds. Destructive mechanical tests are then performed on these control assemblies.

[4] Toughness is the ability of a material to absorb energy when it deforms under the effect of an impact.

[5] Strain ageing is a phenomenon leading to embrittlement of the metal structure over time and according to the temperature. Tests carried out in early 2019 revealed that the scale of the phenomenon affecting the VVP line welds is greater than was considered in the design.

ASN also notes the presence of numerous deviations from the RCC-M code, such as to compromise the regulatory compliance of these welds, which therefore remains to be demonstrated.

5. ASN's position regarding EDF's proposal for deferred repair

In a letter dated 7 June 2019, EDF asked ASN for its opinion on the possibility of repairing these welds in 2024, a few years after commissioning of the reactor.

To demonstrate the safety of the reactor between its commissioning and the repair of the welds, EDF relies on the highly improbable nature of their rupture. Further to the review carried out and the opinion of the GP ESPN, this type of approach can however no longer be adopted.

ASN therefore considers that an approach aiming to justify the acceptability of deferred repair would entail consideration of all the consequences of a break, in order to demonstrate the adequacy of the modifications to be made to the reactor prior to its commissioning. In this respect, the robustness studies that EDF feels able to carry out by the time of reactor commissioning are partial and are unable to assess all the consequences of a break.

The break of a VVP pipe can notably lead to the following phenomena:

- the release of large quantities of steam and energy which could damage, on the one hand, some of the equipment located in neighbouring areas and, on the other, the buildings housing the VVP lines;
- significant mechanical loadings on the affected pipe, which could damage the equipment located nearby or connected to the pipe;
- the pressure wave resulting from the break, propagating through the secondary system and subjecting the internal structures of the steam generators to significant loads;
- cooling of the primary system as a result of the break, leading to an input of reactivity into the core which could result in fuel damage.

Given that it is impossible to carry out the studies using the conventional rules of the EPR safety case, EDF could use appropriate rules and hypotheses, although proof would be needed that they lead to an acceptable level of safety. ASN considers that the possibility of carrying out sufficiently convincing studies is highly uncertain and has already identified a number of obstacles:

- EDF envisages not taking account of the worst-case aggravating factor, as is usual. ASN however considers that in this case, the aggravating factor represented by non-closure of the steam shut-off valve of the neighbouring steam generator cannot be ruled out, as this valve would probably be damaged in the event of a weld break;
- the welds are located between the walls of the containment and therefore in a confined space, through which numerous pipes and electrical cables pass. The penetration weld break scenarios have never been studied, notably with respect to the consequences within the containment annulus. Carrying out such studies would require the development of specific methods (modelling of the phenomena, simulation tools, etc.).

ASN therefore considers that the EDF proposal entails major difficulties and that repair of the penetration welds before commissioning of the reactor remains the baseline solution.