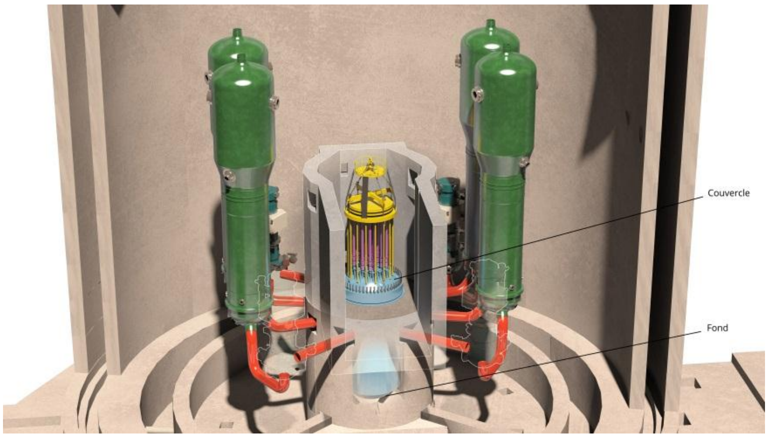
Montrouge, 28th June 2017

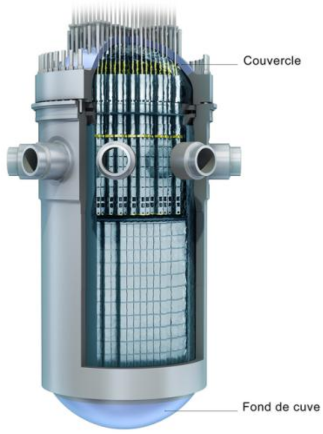
Technical notice

Flamanville 3 EPR reactor pressure vessel anomaly

1. Nature and cause of the anomaly

The reactor pressure vessel (RPV) is a pressurized steel structure that is essential for nuclear safety. It contains the nuclear fuel.



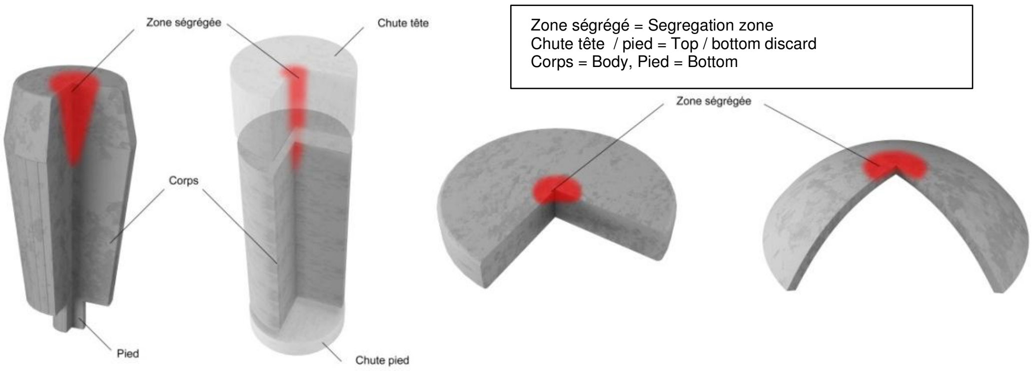


Main primary cooling system of the EPR reactor

EPR reactor pressure vessel

The anomaly concerns the lower and the closure head domes of the reactor pressure vessel. The steel from which these components are made does not have the required chemical composition. During the manufacturing of these forged parts, Areva NP's Creusot Forge plant did not remove enough of a zone that naturally contains an excess of carbon (shown in red on the diagrams below). This zone is therefore still present in the centre of the finished parts.

INGOT	BLOOM	BLANK	DOME



Successive stages in the forging of the RPV lower head and closure head
Zone with excess carbon shown in red

2. Risks resulting from the anomaly

An excess of carbon reduces the resistance of the steel to the propagation of cracks, a property known as "toughness". The risk resulting from this anomaly is therefore that a crack in the RPV lower head or closure head propagates and results in the fast fracture of the reactor pressure vessel. If the reactor pressure vessel fractures, the nuclear fuel will no longer be cooled. The safety case must therefore demonstrate that it is impossible for the vessel to fracture.

3. Demonstration provided by Areva NP and EDF

Areva NP and EDF have analysed the risk of fast fracture of the RPV lower head and closure head. This analysis aims at proving that the material is sufficiently strong to rule out the risk of initiation of a potential crack due to the thermomechanical loadings to which the parts can be subjected during reactor operation in normal and accident situations.

This analysis is based on the assessment of three parameters:

- the dimensions of a crack potentially present in the Flamanville EPR RPV lower head or closure head;
- the mechanical properties of the steel with an excessively high carbon content;
- the thermomechanical loadings to which the RPV lower head and closure head can be subjected during reactor operation.

3.1 Crack potentially present in the RPV lower head or closure head

Areva NP has provided proof that the manufacturing process employed cannot create a crack that is prejudicial to the quality of the parts.

Areva NP also carried out surface and volumetric inspections using non-destructive testing techniques to detect cracks that might be present in the RPV lower had and closure head. These inspections revealed no flaws of dimensions reaching or exceeding the detection limits. Consequently, in the remainder of its substantiation process, Areva NP postulated the presence of the smallest detectable flaw in both parts.

ASN mandated a third party organisation to monitor performance of these inspections.

3.2 Characterisation of the mechanical properties of the steel of the RPV lower and closure heads

Areva NP conducted an extensive programme of chemical analyses and mechanical tests on parts manufactured under the same conditions as those of the Flamanville EPR RPV and provided proof that these parts are representative of the Flamanville parts. ASN mandated third party organisations to monitor this programme and ensured that it was essentially carried out by laboratories that are independent of the Areva group.

The results of this programme show that the material toughness is not as good as planned for in the design.

3.3 Evaluation of the thermomechanical loadings

All the situations that can stress the RPV lower head and closure head were listed and characterised. These stresses are mainly thermal shocks caused by rapid variations in the temperature of the fluid contained in the reactor pressure vessel. These thermal shocks can occur in normal operating situations (during the reactor startup or shutdown phases, for example) or in accident situations (such as a break in the primary cooling system).

3.4 Conclusions of the Areva NP analysis

Areva NP compared the toughness of the steel at the stresses induced on a crack by the thermomechanical loadings, integrating a safety factor, and it calculated a reserve factor:

$$F_m = \frac{\text{Toughness}}{\text{Safety factor x Stress}}$$

The reserve factors are greater than 1, which guarantees the mechanical strength of the RPV lower head and closure head. The excess carbon significantly reduces the reserve factors.

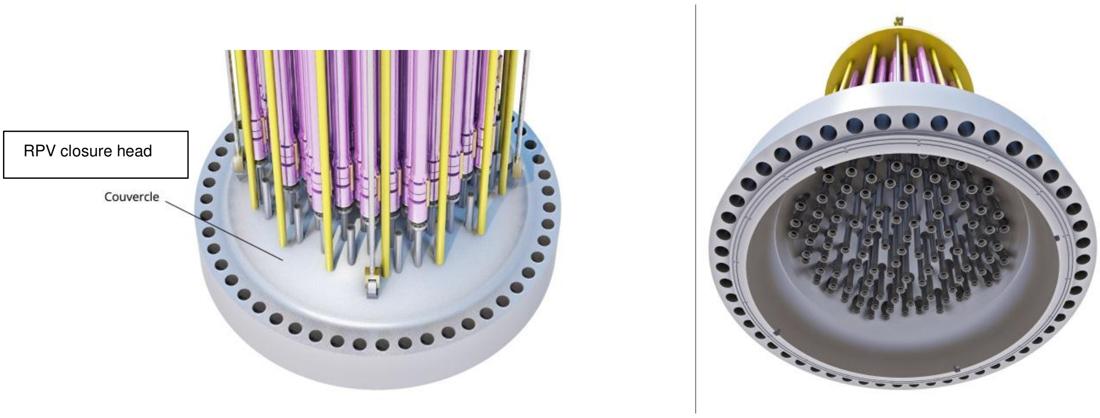
4. ASN position

The nuclear safety case rules out RPV fracture on the basis of the particularly stringent measures adopted in design, manufacture and in-service monitoring with the aim of preventing RPV fracture.

ASN considers that the mechanical characteristics of the RPV lower head and closure head are sufficient to withstand the stresses to which the parts are subjected, accident situations included.

Nevertheless, the anomaly in the chemical composition of the steel does lead to a reduction in the margins with respect to the fast fracture risk. ASN therefore considers that EDF must conduct additional periodic inspections to ensure that flaws do not subsequently appear. ASN notes that such inspections can be performed on the RPV and therefore considers that they must be carried out.

The technical feasibility of similar inspections on the RPV closure head, however, is not certain. ASN therefore considers that the service life of this RPV closure head must be limited in time. It notes that the manufacture of a new RPV closure head would take about seven years. A new closure head could thus be available by the end of 2024. Under these conditions, ASN considers that the current closure head will not be able to remain in service beyond that date.



Accessibility of the external surface (on the left) and internal surface (on the right) of the RPV closure head to be inspected

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