

**ADVISORY COMMITTEE OF EXPERTS
FOR NUCLEAR PRESSURE EQUIPMENT**

Opinion concerning the procedure proposed by AREVA to demonstrate the adequate toughness of the domes of the Flamanville 3 EPR reactor pressure vessel (RPV) bottom head and closure head

I

In accordance with the request by the Autorité de sûreté nucléaire (ASN), in its letter CODEP-DEP-2015-038781 of 22 September 2015, the Advisory Committee for nuclear pressure equipment convened on 30 September 2015, with the participation of members of the Advisory Committee for reactors and in the presence of observers invited by ASN, to analyse the approach proposed by AREVA to demonstrate the adequate toughness of the Flamanville 3 EPR reactor pressure vessel (RPV) bottom and closure head domes. This demonstration follows the fact that during the demonstration of compliance with the technical qualification, bending rupture energy values lower than the criteria set in point 4 of Appendix 1 of the order of 12 December 2005 were found.

II

The Advisory Committee familiarised itself with the conclusions of the rapporteur's examination of the data provide by AREVA concerning the approach adopted to demonstrate the adequate toughness of the material of the Flamanville EPR RPV domes. The Advisory Committee in particular examined:

- the acceptability in principle of an approach to demonstrate the adequate toughness of the Flamanville 3 EPR RPV bottom head and closure head;
- the notion of the adequate toughness of the material proposed by AREVA and the method with which this is determined;
- the method for determining the minimum toughness of the material, based in particular on a programme of tests, especially the transposability to the Flamanville 3 EPR RPV domes of the results obtained on other domes;
- the comparison between the minimum toughness of the material and the adequate toughness, in particular the associated criteria.

III

A. Technical qualification and choice of manufacturing process for Flamanville 3 EPR RPV domes

The Advisory Committee noted that the presence of a positive macrosegregation zone in the Flamanville 3 EPR RPV bottom head and closure head domes was the result of the process adopted by AREVA and its supplier Creusot Forge, which used high-tonnage ingots without sufficient elimination of the segregations from the final component.

The Advisory Committee noted that, even if care was taken to position the segregation zone in each dome at a location which would minimise the drawbacks, the process used led to the presence in the finished part of a positive macrosegregation zone reaching a segregation ratio of 50%.

The Advisory Committee noted that other manufacturing processes, in particular that used for the domes of the Finnish EPR RPV, would have avoided the positive macrosegregation phenomenon observed.

The Advisory Committee considers that the technical qualification file presented by AREVA for the Flamanville 3 RPV closure head and bottom head domes shows that the risk of heterogeneity due to positive residual segregations, a known metallurgical phenomenon, was incorrectly assessed and its consequences inadequately quantified. The technical qualification did not lead to results in conformity with the standards resulting from the work carried out on this subject as of 2010.

B. Principle of the demonstration approach

The Advisory Committee considers that the demonstration principle proposed by AREVA, which consists in determining adequate toughness and verifying that it is below the toughness of the material, is appropriate, provided that the phenomenon in question is known and controlled and that there is sufficient knowledge of the mechanical properties.

C. Determination of adequate toughness

Condition of the domes

The Advisory Committee noted that the inspections carried out detected no flaws in the domes concerned, which will be an important factor in the assessment of the situation.

It has no particular remarks concerning either the non-destructive tests carried out by AREVA to detect non surface-breaking flaws, or the performance of the tests.

The Advisory Committee does however make recommendation n° 1 regarding surface inspections.

Analysis in the brittle and brittle-ductile transition zones

Situations and loads

The Advisory Committee notes that at this stage, the list of situations to be examined to ensure compliance with the criteria associated with the second barrier has not been validated.

The Advisory Committee also underlines that the restrictive situations and loadings presented by AREVA were selected assuming that the reduction in toughness in the segregated zone extends from the outer surface of each dome to mid-thickness.

The Advisory Committee considers that the hypothesis whereby the mechanical properties of the domes from mid-thickness to the interior of the RPV are greater than 60 joules, will need to be validated by the test programme. Failing which, other transients will need to be analysed and the demonstration approach completed.

Ageing

The Advisory Committee concurs with AREVA's position on the fact that the fluence in the zones considered is not such as to lead to irradiation-induced damage. It notes that, together with EDF, AREVA undertakes to provide a file based on the test results, making it possible to rule on the need to initiate a specific thermal ageing programme for the heavily segregated parts. The Advisory Committee will review this question if it appears that the material considered is inadequately covered by the available tests.

Analysis in the ductile zone

The Advisory Committee considers that it is necessary to ensure that in the ductile zone the behaviour of the material is sufficiently ductile and tough and is compatible with the design rules used.

D. Determination of the minimum toughness and mechanical properties of the material**Representativeness of the UK upper dome**

The Advisory Committee considers that the UK upper dome is representative of the Flamanville 3 upper dome in the light of their pouring chemical composition and that measured on the part, their manufacturing specifications and the levels of carbon measured on the surface.

The Advisory Committee notes that the carbon concentration measurements taken so far do not allow an assessment of the depth of the positive segregation zone in the lower dome intended for Flamanville 3. The Advisory Committee also considers that the programme to characterise the mechanical properties of the segregation zone cannot simply rely on a determination of the properties of a material taken from a single component.

In this respect, the Advisory committee considers that AREVA's undertaking to perform a chemical characterisation and mechanical test programme on the UA lower dome that is identical to those to be performed on the UK upper dome is satisfactory.

Heat treatment

Insofar as AREVA's goal is to determine the properties of the material of the Flamanville EPR RPV material in an operating context, the Advisory Committee considers that heat treatment equivalent to that experienced by this vessel should be applied to the part from which the test specimens are to be taken. In this respect, the Advisory Committee considers AREVA's undertaking to be satisfactory.

Sufficiency of number of tests

The Advisory Committee considers that the segregated zones must be the subject of in-depth characterisation. The Advisory Committee considers that the adequacy of the test programme could only be fully assessed subsequently, after analysis and interpretation of the test results. The Advisory Committee also considers that all the material (test specimens, discards, etc.) taken from the UK upper and UA lower domes should be identified and kept for any further investigations.

Interpretation of test results and choice of laboratories

The Advisory Committee considers that the chemical analyses planned as close as possible to the fracture zone on each broken test specimen, will ensure that the test programme does indeed characterise the segregated zone.

The Advisory Committee considers that the macrographic and micrographic examinations planned by AREVA should be able to characterise the structure of the segregated material and that an analysis of the fracture surfaces of the test specimens is required, to ensure that the structures and behaviours are indeed understood.

If the test results reveal that the mechanical properties are degraded by a phenomenon other than the presence of a positive macrosegregation, the Advisory Committee considers that AREVA will need to demonstrate that the UK and UA domes are representative of those of Flamanville 3 with respect to the new phenomenon brought to light.

The Advisory Committee considers that the accreditation of the Erlangen laboratory selected by AREVA for the mechanical tests, with the exception of the drop-weight tests, offers sufficient guarantees in terms of technical know-how and quantification of uncertainties. The Advisory Committee also notes that this

laboratory is involved in the appraisal and research programmes for nuclear reactors in other countries (Doel 3, Tihange 2 and Olkiluoto 3).

The Advisory Committee considers that the drop-weight tests should be performed in conditions enabling them to be compared with those performed previously on the French NPP fleet in operation.

It notes that all the analyses and tests shall be specifically monitored by an organisation.

It formulates recommendation n° 2.

E. Comparison between the minimum toughness of the material and the adequate toughness

After analysis of the AREVA proposals and the recommendations by the rapporteur, the Advisory Committee formulates recommendations n° 3 and 4.

IV

Subject to integration of recommendations n° 1 to 4, the Advisory committee considers that the approach proposed by AREVA to demonstrate the adequate toughness of the Flamanville 3 EPR RPV bottom head and closure head domes is acceptable.

Compliance with the toughness criterion in the transition zone, correct performance in the ductile zone, the absence of anomalies during the tests and inspections, compliance with the bending rupture energy criterion at mid-thickness and the adequacy of the choice of situations studied, are the points still to be verified in order to reach a conclusion as to the aptitude for service of the Flamanville 3 EPR RPV domes.

The Advisory Committee notes that the demonstration approach proposed by AREVA is an analysis of the fast fracture mechanical behaviour of the Flamanville 3 RPV closure head and bottom head domes, based on tests conducted on two representative scale one replicas. This approach could show that the manufacturing process gives the material mechanical properties that are sufficient to rule out the feared risks.

However, the Advisory Committee considers that this will not be able to give the same degree of guarantee concerning the first level of defence in depth as would have been provided by technical qualification in compliance with current standards.

In line with its opinion of 2011, the Advisory Committee therefore considers that the file must be accompanied by proposed operational or in-service inspection measures suitable for the situation encountered and that they should, as necessary, be incorporated into the equipment instruction notice. It wishes to examine them in the light of the results of the tests to be performed.

Recommendations

Recommendation n°1

The Advisory Committee recommends that AREVA perform non-destructive surface testing other than dye-penetrant on the RPV bottom head, in addition to those tests already performed during manufacturing, to confirm the absence of defects, as part of a conventional non-destructive testing qualification approach.

Recommendation n°2

The Advisory Committee recommends that AREVA:

- before initiating the test programme and after characterising the extent of the segregated zone, specify the location of the macrographic and micrographic examinations;
- analyse the fracture surfaces of the test specimens;
- have chemical analyses performed by an accredited laboratory.

Recommendation n°3

The Advisory Committee recommends that the demonstration approach be based first of all on a verification that the toughness values remain bounded by curve ZG6110 of the RCC-M indexed on 0°C and that the local TNDT remains consistent with the design values.

Recommendation n°4

The Advisory Committee recommends that if this first approach fails, AREVA should determine:

- an indexing temperature encompassing the toughness measurements in the segregated zone;
- an indexing temperature resulting from the drop-weight tests in the segregated zone;
- an indexing temperature resulting from the Charpy tests in the segregated zone;
- an indexing temperature resulting from a practical allowable re-hydrotest temperature with appropriate margins;

and should provide additional interpretation data should these four temperatures not be classified in this order.