ADVISORY COMMITTEE OF EXPERTS
FOR NUCLEAR PRESSURE EQUIPMENT
(GP ESPN)

Opinion on the consequences of the carbon concentration anomaly on the fitness for service of the Flamanville EPR reactor pressure vessel domes

Meeting held in Montrouge on 26th and 27th June 2017

27th June 2017
Chair of the GP ESPN

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I

In accordance with the request of the French Nuclear Safety Authority (ASN) made in letter CODEP-DEP-2017-015644 of 12th June 2017, the Advisory Committee of Experts for Nuclear Pressure Equipment (GP ESPN) met on 26th and 27th June - with the participation of members of the Advisory Committee of Exerts for Reactors and in the presence of observers invited by ASN - to analyse the consequences of the carbon concentration anomaly on the fitness for service of the affected lower and upper domes of the Flamanville EPR reactor pressure vessel (RPV).

This session follows on from those of 30th September 2015 and 24th June 2016 during which the GP ESPN analysed Areva NP's justification approach.

II

The Advisory Committee reviewed the conclusions of the rapporteur's examination of the files submitted by Areva NP and EDF. The Advisory Committee more specifically examined the approach and the conclusions of Areva NP and EDF concerning:

- the inspections carried out on the Flamanville EPR RPV lower head and closure head;
- the material mechanical properties adopted further to the test programme;
- the identification and characterisation of the thermomechanical loadings applied to the two components;
- Areva NP's analysis of the fast fracture risk, and in particular the consistency of its assumptions with the results of the inspections, the mechanical properties of the material and the thermomechanical loadings;
- the in-service monitoring measures envisaged by Areva NP and EDF.

III

Substantiation approach

In order to substantiate the sufficiency of the mechanical properties of the material of the Flamanville EPR RPV lower and closure heads, Areva NP carried out an analysis on fast fracture risk of these components. This approach - conventional in its principles - aims at demonstrating that the material in the segregation zone is sufficiently tough to prevent the risk of initiation of the defects postulated in each of the domes under the thermomechanical loadings to which they could be subjected during operation in normal, incident or accident situations.

The Advisory Committee notes that the approach followed by Areva NP is consistent with the one it analysed during its sessions of 30th September 2015 and 24th June 2016 and takes into account the recommendations and observations it made on these occasions.

Compactness inspections carried out on the Flamanville EPR RPV lower head and closure head;

The Advisory Committee notes that at the dome procurement stage, Areva NP conducted volumetric and surface inspections on the two parts using non-destructive testing (NDT) techniques. The results of these inspections did not reveal any compactness flaws of dimensions exceeding the technical specification criteria. The complementary inspections carried out in 2016 and 2017, particularly in the segregation zone, also confirmed the absence of surface flaws and under-cladding flaws.

Material mechanical properties adopted further to the test programme

Areva NP conducted a destructive test programme on sacrificial scale-1 replica domes in order to characterise the segregated material, and the Advisory Committee analysed the representativeness of this programme. The Advisory Committee underlines the large scale of this programme. As differences in the fabrication of the domes lead to variations in the mechanical properties of the steel which, although limited, are difficult to evaluate with precision, the Advisory Committee considers that a conservative approach must be adopted when assessing the properties of the material.

The Advisory Committee notes that the presence of residual carbon segregation is indeed the cause of a change in the mechanical properties of the steel. The observed behaviour is nevertheless as would be expected for this grade of steel. The change in toughness results primarily in an increase in the transition temperature between the brittle and the ductile behaviour of the material, ranging from some ten to several tens of degrees, depending on the assessment method used.

The Advisory Committee considers that the fact that for the remainder of its demonstration Areva NP used an increase in transition temperature between the brittle fracture mode and the ductile mode calculated from a conservative shift in the reference temperature at zero ductility (RT_{NDT}) between the segregation zone and the acceptance test zone of the tested domes adds to the conservatism of the approach.

Lastly, the Advisory Committee considers that the assumption for the thermal ageing of the material is reasonable, but must be consolidated by tests. The test programme proposed by EDF, which comprises several temperature levels, is appropriate. The corresponding elements must supplement the regulatory files (instruction manual, material file, in-service ageing monitoring file).

Identification and characterisation of the thermomechanical loadings

The Advisory Committee reviewed the rapporteur's conclusions on the analysis of the thermomechanical loadings to which the two domes could be subjected.

The Advisory Committee considers that the approach adopted by Areva NP to identify the situations causing the most severe stresses for the RPV domes is satisfactory and that the loadings deduced from them are effectively conservative. The Advisory Group notes that the rod ejection situation was analysed as a thermohydraulic transient and considers that Areva NP must also confirm that the levels of the mechanical loadings induced on the RPV closure head does not challenge this analysis.

Analysis of the fast fracture risk

Areva NP's assessment of the fast fracture risk is consistent with the approach prescribed in the RCC-M code, as much in the choice of postulated and analysed flaws as in the definition of the minimum toughness value and the evaluation of the stress intensity factors. The Advisory Committee considers that the postulated size of the flaws introduces a determining degree of conservatism. In the light of this analysis, the Advisory Committee considers that the mechanical properties of the material in the segregation zone are sufficient to preclude the fast fracture risk.

Impact of the irregularities detected within the Areva NP Creusot Forge plant

The Advisory Committee reviewed the rapporteur's analysis of the impact of the irregularities detected in the Creusot Forge plant in 2016 concerning the treatment of the anomaly affecting the Flamanville EPR reactor pressure vessel domes. The Advisory Group notes in particular that, at the request of ASN, Areva NP repeated the tensile tests and the Pellini drop-weight tests initially performed by Creusot Forge in the acceptance test zone on the various domes, and the NDT volumetric inspections on the RPV lower head. These new tests and inspections, the results of which are satisfactory and consistent with those of the original tests, provide further guarantees as to the quality of the parts concerned and the absence of differences that could call into question the mutual representativeness of the domes. Furthermore, the mechanical property values determined during these tests do not call into question the conclusions of the fast fracture risk analysis.

Conclusion concerning the substantiation approach

In the light of the elements provided to support the substantiation approach presented by Areva NP, the Advisory Committee observes that the consequences of the carbon concentration anomaly in the domes of the Flamanville EPR reactor vessel have been characterized. The Advisory Committee notes that the file presented by Areva NP, which is based on the determining physical property of toughness, concludes that the risk of fast fracture is precluded, even though the bending rupture energy value specified in the regulations is not attained in the segregation zone. The Advisory Committee considers that the approach followed introduces significant conservatism with regard to the material mechanical properties deduced from the tests on the

sacrificial scale-1 replica domes, integrating an assumption of ageing, the loadings considered and the characteristics of the postulated flaws; this approach therefore leads to the conclusion that the material displays sufficiently good mechanical properties to preclude the feared risks and ensure the fitness for service of the domes.

The Advisory Committee nevertheless considers that the observed failings regarding the technical qualification, the use of a manufacturing process that does not enable the risks associated with the residual carbon segregations and the reduction in the margins for the fast fracture risk affect the robustness of the first level of defence in depth.

Planned in-service monitoring measures

The Advisory Committee points out that in its opinion issued at the session of 30th September 2015, it had considered that the Areva NP file should come with proposed operating or in-service monitoring measures appropriate for the situation encountered in order to strengthen the second level of defence in depth.

RPV lower head

The Advisory Committee notes that EDF has planned RPV lower head inspections capable of detecting flaws with circumferential or radial orientation. Given that no particular damage mode is specifically expected, it considers that the in-service inspections must not be defined in consideration of a preferential flaw orientation. It notes that during this session EDF undertook to adapt its inspections in order to be able to detect all flaws perpendicular to the skins, whatever their orientation. The Advisory Committee considers that these inspections, performed in advance of the first ten-yearly outage and to which these adaptations would be made, will significantly bolster the second level of defence in depth.

RPV closure head

In the same way as for the RPV lower head, the Advisory Committee considers that inspections of the RPV closure head are necessary due to the reduction in the margins on the fast fracture risk which affects the robustness of the first level of defence in depth and that these inspections must not be defined according to a flaw orientation preferred *a priori*. These inspections are all the more necessary given that the closure head has geometrical particularities associated with the vessel head adapters and different operating conditions to those of the lower head (temperatures, closure head manipulations, etc.).

The Advisory Committee notes that the technical file submitted by Areva NP and EDF for the in-service monitoring inspections is prospective, succinct and does not provide any technical information on the feasibility of the inspections, their performance, or the applicable radiation protection measures. The Advisory Committee observes that EDF is currently not able to carry out RPV closure head inspections using NDT techniques that have the same range and represent the same time frames as for the lower head.

The Advisory Committee considers that EDF must provide elements demonstrating the feasibility of these inspections within two years.

The Advisory Committee also notes that the RPV closure head is replaceable.

IV

Having failed to reach a consensus on the conclusion concerning the justification approach and the in-service monitoring provisions, the Advisory Committee registered the minority opinion of two of its members. It is appended to this opinion.

Appendix

Minority opinion of Messrs. Marignac and Autret

Although the elements produced by Areva NP to substantiate the fitness for service of the RPV are in conformity with the expected approach and despite the efforts made in the extent of characterisation of the material, the exhaustiveness of the envisaged situations and the conservatism of the assumptions show that the margins of the material mechanical properties in the segregation zone with respect to prevention of the RPV fast fracture risk are significantly reduced in comparison with the expected properties when there is no macrosegregation.

Noncompliance with the technical qualification requirement of the RPV constitutes an unprecedented threat, due to its nature and context, for the first level of defence in depth. The excess confidence, the lateness of detection of the segregations and the industrial decision to take installation of the RPV through to completion before characterising the segregations constitute aggravating factors in this threat to the fundamental principle of defence in depth.

From the regulatory aspect there is no simple response to the resulting situation, as the necessary references for assessing the acceptability of the parts concerned in this context do not exist, therefore it leads to a derogation procedure of which the result will, over and beyond resolving this file, set a lasting precedence.

The elements provided concerning in-service monitoring do not constitute effective compensatory measures insofar as they aim at monitoring the feared phenomena in this situation of reduced properties, and not to restore, through in-service measures, all or part of the margins lost in design and fabrication. Consequently, the mechanical strength of the RPV is not sufficient to achieve a satisfactory level of safety with regard to defence in depth.

This conclusion should be considered in relation to whether or not it is possible to replace the segregated elements before the contingent commissioning of the RPV. Although the Advisory Committee was not asked to examine this question, it is important in this respect to emphasise that the information in the file submitted by Areva seems to indicate that replacement of the RPV closure head and lower head at this stage is still technically possible.