AUTORITÉ DE SÛRETÉ NUCLÉAIRE

DIRECTION DES ÉQUIPEMENTS
SOUS PRESSION NUCLÉAIRES

RÉPUBLIQUE FRANÇAISE

Montrouge, 14 December 2015

Ref N°: CODEP-DEP-2015-043888

Monsieur le Président d'AREVA
Tour AREVA
92084 PARIS LA DEFENSE cedex

Subject: Evaluation of the conformity of the Flamanville 3 EPR reactor pressure vessel
Procedure to confirm the adequate toughness of the reactor pressure vessel bottom head and closure head domes

References: See appendix 1.

Dear Sir,

Concerning the technical qualification of the Flamanville 3 EPR reactor pressure vessel (RPV) bottom head and closure head, further to the discovery of impact strength values below the criteria set in point 4 of appendix 1 of the order in reference [1] you submitted a procedure to ASN designed to demonstrate the adequate toughness of the material of these components.

I asked the Advisory Committee for nuclear pressure equipment to give me their opinion on:

- the acceptability in principle of an procedure 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.

The Advisory Committee for nuclear pressure equipment met on 30 September 2015 and informed ASN of its opinion and its recommendations in reference [2].

The appendix contains the resulting detailed requests from ASN.

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You proposed a procedure to demonstrate the adequate toughness of the material used for the Flamanville 3 EPR RPV domes. ASN considers that the demonstration procedure proposed, which consists in determining an adequate toughness and in verifying that it is below the actual toughness of the material, is appropriate provided that the phenomenon in question is identified and explained and that the understanding of the mechanical properties is sufficient.

ASN would however point out that the demonstration procedure proposed is based on an assumption of satisfactory mechanical properties at mid-thickness, more specifically with regard to toughness. If this hypothesis were not to be confirmed by the results of the tests performed on scale-one replica domes, your demonstration file would need to be revised.

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ASN considers that the test program proposed on two scale-one replica domes should be able to assess the scale and depth of the segregated zone as well as its influence on the mechanical properties.

Therefore, subject to the contents of the appendix being taken into account, I consider that the procedure you propose to demonstrate the adequate toughness of the Flamanville 3 EPR RPV bottom head and closure head domes is acceptable and I have no objection to the initiation of a test programme as stipulated in the notices in references [3] to [8].

Please note that ASN will be delegating a notified body to oversee all the operations involved in your demonstration procedure.

I would also ask you to keep ASN informed without delay of any anomaly encountered in the test programme operations and, more generally, to keep it informed of the results obtained as implementation of the procedure progresses.

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I note that you envisage continuing with manufacturing operations on the RPV head (hydrostatic pressure test, welding of instrumentation adapter closures, shipment to the site, lining, heat insulation, etc.), without waiting for the results of the tests to be performed on the scale-one replica domes.

I also note that the specific operating conditions planned for hydro-static pressure test of the closure head have been defined to take account of the presence of positive macrosegregations.

I agree that no additional inspection on top of those already performed, concerning the demonstration of the presence of positive macrosegregations, could be envisaged on the RPV closure head.

Therefore, without anticipating the results of the demonstration of its suitability for service, I have no objection to the continuation of manufacturing work on the Flamanville 3 EPR RPV head. I would however remind you that rejection of the RPV closure head and bottom head further to the investigation cannot be ruled out.

This is why I consider it necessary for you to study all alternative technical scenarios, such as replacement of the RPV bottom head and manufacture of a new closure head.

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The presence of segregations, which are the cause of non-compliance with the toughness values mentioned in the order in reference [1], arises from the process adopted by AREVA and its supplier Creusot Forge. This is based on the use of high-tonnage ingots and leads to insufficient elimination of the segregations in the final component to be able to guarantee the minimum expected mechanical properties for the design of the equipment.

I consider that the technical qualification file you presented for the Flamanville 3 RPV closure head and bottom head domes shows that the risk of heterogeneity due to positive residual macrosegregations, a known metallurgical phenomenon, was incorrectly assessed and its consequences inadequately quantified.

I therefore consider that the technical qualification requirements are not met and that you did not choose the best available technique for production of the EPR RPV domes. You are therefore required to submit an application pursuant to Article R. 557-1-3 of the Environment Code. This application shall be backed up by alternative solutions such as replacement of the RPV bottom head and the manufacture of a new closure head and shall include compensatory measures with respect to the impact of these deviations on the first level of defence in depth.

Yours sincerely,

The Chairman
of the Nuclear Safety Authority (ASN -
Autorité de Sûreté Nucléaire)

Pierre-Franck CHEVET

Appendix 1 to letter CODEP-DEP-2015-043888

References

[1] Order of 12 December 2005 relative to nuclear pressure equipment

[2] Letter CODEP-MEA-2015-040055 of 1 October 2015 – Opinion and recommendations from the Advisory Committee for Nuclear pressure Equipment of 30 September 2015

[3] Notice TTZSGN/NCR0003 revision A: "Simulated stress-relieving heat treatment procedure"

[4] Notice PFCSGN/NCR0003 revision B: "Scale-one replica part test programme: first phase"

[5] Notice MDHTDM DT 15.020 revision A: "Scale-one replica dome test programme: determination of the carbon positive macrosegregation zone in the thickness"

[6] Notice PFCSGN/NCR0002 revision D: "Scale-one replica dome test programme: mechanical tests"

[7] Notice PFCSGN/NCR0004 revision A: "Cross-section of the UK upper segregated zone for carbon mapping"

[8] Notice PFCSGN/NCR0005 revision A: "First step of the UA lower scale-one replica part test programme"

[9] ARR-DEP-2015-00354 of 11 September 2015 – AREVA undertakings concerning the draft report to the GP ESPN

Appendix 2 to letter CODEP-DEP-2015-043888

Additional requests

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

ASN considers that the presence of a positive macrosegregation zone in the Flamanville 3 EPR RPV bottom head and closure head domes is the result of the process used, which was unable to guarantee the minimum mechanical properties expected in the design of the equipment.

ASN notes that, even if care was taken to position the segregation zone in each of the two domes 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%.

ASN notes that other manufacturing processes, in particular that used for the domes of the Olkiluoto 3 EPR RPV, would have avoided the positive macrosegregation phenomenon observed.

ASN considers that the technical qualification file for the Flamanville 3 RPV closure head and bottom head domes shows that the risk of heterogeneity due to positive residual macrosegregations, a known metallurgical phenomenon, was incorrectly assessed and its consequences inadequately quantified.

ASN considers that the technical qualification requirements are not met and that AREVA did not choose the best available technique for the manufacture of the Flamanville 3 EPR RPV domes. These observations affect the first level of defence in depth, which aims to guarantee a high level of design and manufacturing quality for the RPV intended for the Flamanville 3 EPR.

B. Determination of adequate toughness

1. Condition of Flamanville 3 EPR domes

ASN notes that the inspections carried out detected no flaws in the domes of the Flamanville 3 EPR.

ASN has no particular remarks concerning either the non-destructive tests that you carried out to detect non-surface breaking flaws, or the performance of the tests.

However, ASN considers that the dye-penetrant inspections you performed were unable to ensure that there were no small, disoriented, surface-breaking flaws, possibly filled with oxide and potentially with a smooth surface.

Request n° 1 : ASN asks you to 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 flaws, using a non-destructive testing procedure with conventional qualification approach.

2. Analysis in the brittle and brittle-ductile transition zones

a. Flaw analysed

ASN considers that the "detailed analysis" in appendix ZG of the RCC-M is acceptable for determining adequate toughness, enabling the minimum temperature required to prevent the risk of fast fracture in a hydrostatic pressure test situation to be deduced.

In this respect, ASN notes that you intend to determine the temperature of the hydrostatic pressure tests on the basis of a "detailed analysis", in accordance with appendix ZG 4000 of the RCC-M code, insofar as a "conventional analysis" in accordance with appendix ZG 3000 would lead to a temperature that is industrially problematical or which would entail risks for the safety of the personnel involved.

ASN also notes your undertaking in reference Erreur ! Source du renvoi introuvable. **which aims to complete the fast fracture risk assessment file with operating situation evaluations taking account of a flaw corresponding to a "conventional analysis" for the sensitivity studies.**

b. Situations and loads

At a later date, ASN will issue a position statement on the list of situations to be examined in order to ensure compliance with the criteria associated with the demonstration of in-service conformity of the second containment barrier.

ASN would already point out that AREVA selected the limit situations and loadings on the assumption that the impact of the segregated zone extends from the outer surface of each dome, without exceeding mid-thickness.

Request n° 2 : By means of a test programme, ASN asks you to validate the hypothesis whereby the mechanical toughness properties of the domes from mid-thickness to the interior of the RPV are in excess of 60 joules at 0°C. Failing which, ASN asks you to complete the list of situations and the justification file, more specifically by analysing other transients.

c. Ageing

ASN notes that the fluence in the zones considered is not such as to lead to irradiation-induced damage.

ASN notes your undertaking in reference Erreur ! Source du renvoi introuvable.**, together with EDF, 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.**

3. Analysis in the ductile zone

Request n° 3 : By means of the test results, ASN asks you to demonstrate that in the ductile zone the behaviour of the material is sufficiently ductile and tough and is compatible with the design rules used.

C. Determination of the minimum toughness and mechanical properties of the material

1. Representative nature of the UK upper dome and the UA lower dome

ASN considers that the UK upper and UA lower RPV domes are representative of the Flamanville 3 RPV upper dome in the light of their ladle chemical composition and that measured on the part, their manufacturing specifications and the levels of carbon measured on the surface.

ASN notes that the carbon concentration measurements made do not allow an assessment of the depth of the segregated zone in the lower dome intended for the Flamanville 3 EPR RPV. ASN also considers that the programme to characterise the mechanical properties of the segregated zone cannot be limited to a simple determination of the mechanical properties of a material taken from a single component.

ASN thus notes your undertaking in reference Erreur ! Source du renvoi introuvable. **to perform a chemical characterisation and mechanical test programme on the UA lower RPV dome that is identical to those to be performed on the UK upper RPV dome.**

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

2. Heat treatment

Insofar as your goal is to determine the mechanical properties of the material of the Flamanville 3 EPR RPV in its operating context, ASN considers that heat treatment equivalent to that experienced by this RPV should be applied to the part from which the test specimens are to be taken.

In this respect, ASN notes your undertaking in reference Erreur ! Source du renvoi introuvable. **to carry out simulated stress-relieving heat treatment on the test specimens taken from the UA lower and UK upper RPV domes.**

3. Sufficiency of number of tests

ASN considers that the segregated zones must be the subject of in-depth characterisation. ASN considers that the adequacy of the test programme could only be fully assessed subsequently, after analysis and interpretation of the test results.

Request n° 4 : ASN asks you to identify and keep all the material (test specimens, discards, etc.) taken from the UK upper and UA lower RPV domes for any further investigations.

4. Interpretation of test results

ASN 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.

ASN considers that the macrographic and micrographic examinations 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.

<u>Request n° 5 :</u> before initiating the test programme and after characterising the extent of the segregated zone, ASN asks that you specify the location of the macrographic and micrographic examinations. ASN also asks you to analyse the fracture surfaces of the test specimens.

ASN notes that the test specimens will be positioned taking account of the results of the surface spectrometry chemical mapping of the eight slices intended for the mechanical tests (tensile, impact strength and toughness).

<u>Request n° 6 :</u> ASN asks you to present it with the sampling plan you intend to use following this chemical mapping, before it is actually implemented.

5. Choice of laboratory

ASN considers that the NF EN ISO 17025 accreditation of the Erlangen laboratory selected by yourselves 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. ASN also notes that this laboratory is involved in the appraisal programmes for nuclear reactors in other countries (more specifically Doel 3, Tihange 2 and Olkiluoto 3).

ASN 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.

<u>Request n° 7 :</u> ASN asks you to have chemical analyses performed by a laboratory accredited in accordance with standard NF EN ISO 17025.

ASN considers that having some of the mechanical tests performed by a laboratory independent of the AREVA group would enhance the robustness of the test programme results and boost confidence in their impartiality.

<u>Request n° 8 :</u> ASN asks you to have some of the mechanical tests, except for the drop-weight tests, performed by a laboratory accredited in accordance with standard NF EN ISO 17025 and independent of the AREVA group.

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D. <u>Comparison between the minimum toughness of the material and the adequate toughness</u>

ASN considers that the properties of the steel in the segregated zone of the Flamanville 3 EPR RPV domes should be compared with the properties observed in the acceptance zones. During the acceptance tests on the RPV domes, it was found that the RT_{NDT}[1] was identical to the T_{NDT}[2] as is commonly the case with a 16MND5 type steel[3]. ASN considers that the T_{NDT} measured locally in the positive macrosegregation zone should be compared with the RT_{NDT} value measured in the acceptance zone.

[1] Nil ductility transition reference temperature
[2] Nil ductility transition temperature
[3] Equivalent to a SA-508 grade 3 class 1 steel

It is also necessary to ensure that at the end of the service life the toughness of the steel in the Flamanville 3 EPR RPV domes in the segregated zone will be sufficient.

<u>Request n° 9 :</u> ASN asks you to assess:

- **the conservative nature of the ZG 6110 curve in the RCC-M code indexed on the end-of-service RT_{NDT} adopted in the design, minus the shift linked to thermal and strain ageing, as well as the maximum difference between the acceptance RT_{NDT} of the Flamanville 3 RPV domes and that of each of the two scale-one replica domes, with respect to the toughness values measured;**
- **consistency between the local T_{NDT} and the design value.**

In addition, the mechanical tests to be performed on the material in the segregated zone of the two scale-one replica domes will make it possible to determine different indexing temperatures, more specifically:

- an indexing temperature encompassing the toughness measurements in the segregated zone (lowest temperature enabling the curve in appendix ZG 6110 of the RCC-M code to encompass the measurements taken in the segregated zone);
- an indexing temperature resulting from the procedure given in section MC 1230 of the RCC-M code (that is the T_{NDT} nil ductility transition temperature determined using the drop-weight test) in the segregated zone;
- an indexing temperature resulting from the procedure given in section MC 1240 of the RCC-M code (that is the RT_{NDT}, determined using T_{NDT} and Charpy testing) in the segregated zone.

<u>Request n° 10 :</u> ASN asks you to determine:

- **the indexing temperature encompassing the toughness measurements in the segregated zone;**
- **the indexing temperature resulting from the drop-weight tests in the segregated zone;**
- **the indexing temperature resulting from the Charpy tests in the segregated zone, if the local RT_{NDT} is not equal to the local T_{NDT}.**

As necessary, ASN asks you to provide any data to help interpret the difference between the local T_{NDT} and the local RT_{NDT}.

<u>Request n° 11 :</u> ASN asks you to verify that the indexing temperature encompassing the toughness measurements in the segregated zone is lower than the two other indexing temperatures mentioned in request n° 10.

The fracture mechanics analyses will also be able to calculate a maximum allowable indexing temperature to prevent the risk of fast fracture during the hydrostatic pressure tests, with appropriate margins.

<u>Request n° 12 :</u> ASN asks you to verify that the indexing temperatures determined by the test programme are lower than the maximum allowable indexing temperature resulting from the fracture mechanics analyses.

ASN considers that failure to comply with the criteria mentioned in requests n° 11 and 12 would seriously undermine the demonstration procedure proposed by AREVA.

E. Consequences of the demonstration procedure on the implementation of the defence in depth principle

ASN notes that the demonstration procedure you propose 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 replica parts. This procedure could show that the manufacturing process gives the material mechanical properties that are sufficient to rule out the feared risks.

However, ASN considers that this procedure on its own 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.

Request n° 13 : ASN asks you to propose reinforced oversight for commissioning, operation and in-service monitoring, appropriate to the situation encountered and to incorporate them into the equipment operating instructions.

F. Other requests

Given the safety issues linked to the Flamanville 3 EPR RPV, and without in any way anticipating the results of the tests to be carried out and the interpretation of said results, ASN considers that all alternative technical scenarios should be examined.

Request n° 14 : Together with the licensee, ASN asks you to carry out a technical assessment of scenarios for extracting the RPV body from the reactor building cavity and replacing the RPV bottom head dome. This study shall analyse the advantages and drawbacks in terms of the quality of the work done and the safety of the facility.

It should also be pointed out that the RPV closure head is a component which can be replaced.

Request n° 15 : Without in any way anticipating the results of the forthcoming mechanical tests campaign, ASN asks you to initiate studies into the manufacture of a new RPV closure head, taking account of experience feedback from the design and manufacture of the current item.