Report of the National Scientific Expert Group on the RPVD3T2

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The National Scientific Expert Group (further termed NSEG) has been installed by the scientific council of the Belgian Nuclear Safety authorities (FANC) with the aim of providing an independent technical and scientific assistance for the critical assessment of the technical reports prepared by the license holder regarding the structural integrity of the Doel 3 and Tihange 2 reactor pressure vessels (RPV) containing very large numbers of laminar and nearly-laminar embedded flaws, occurring in different planes. These flaws were discovered in July 2012.

The report consists of two parts. **Part A** outlines the applied flaw evaluation procedure and the factors which require special attention. **Part B** is concerned with the results of the assessment.

DOCUMENTATION

FANC provided the technical information (documents) produced by the licensee and its experts. After a first analysis of the documents and following specific meetings with the licensee and their fracture mechanics experts, the licensee (a) provided through FANC additional information and (b) clarified the issues addressed by the NSEG. The responses to the requests of the NSEG are incorporated in the licensee's final reports.

MISSION / TASK

At the request of FANC, NSEG reviewed the technical documentation related to the Doel 3 and Tihange 2 RPV issue. In particular, the members of NSEG verified the methodology, the assumptions and the estimates made for the different input parameters used in the Engineering Critical Assessment (ECA)[1] (also termed 'fitness-for-purpose analysis') of the RPVs. The NSEG did not do any additional calculations, nor did it have the means to verify the numerical values of calculations, nor the validity of the experimental tests.

[1] Using fracture mechanics principles, an Engineering Critical Assessment determines whether or not a given flaw is safe under specified loading conditions.

PART A - PRELIMINARY CONSIDERATIONS

Structural Analysis and Fracture Mechanics

The licensee has performed an assessment of the effect of the detected laminar and nearly-laminar indications/flaws on the integrity of the Doel 3 and Tihange 2 RPVs. When possible, the licensee performed the analysis in accordance with the ASME Section XI procedure[2]. However, due to the high density of discovered indications, the ASME XI procedure cannot be applied integrally, motivating the development of a new procedure by the licensee. Although ASME XI is commonly used, the R6 approach developed by the Central Electric Generation Board (CEGB) - UK provides a similar procedure. The R6 procedure, however, was not used since the Doel and Tihange vessels were designed in accordance with the ASME rules.

1. Background

For a toughness dominated Engineering Critical Assessment (ECA)[3], the stress intensity factor, K_I[4] (also abbreviated as SIF), is compared with the material's toughness or critical stress intensity factor, K_{Ic}. Factor K_I or the driving force on a flaw is a function of the size of the flaw, structure geometry and of the applied loads.

Failure initiation will not occur for known flaw dimensions and known applied stresses if K_I is smaller than K_{Ic}, assuming that conservative assumptions are made at every step in the analysis. Consequently, the analysis procedure requires that the most critical loading conditions, the most critical flaw dimensions and the orientation of the flaw, and effect of the position of the flaw on the fracture toughness are known. The other key element concerns the fracture toughness K_{Ic} which, in general, depends on the material microstructure, fluence, material orientation, and temperature.

An ECA also allows the determination of the dimensions of the allowable flaw when the material's fracture toughness and applied loads are known. Thus, once the maximum allowable flaw size is determined, it can then be compared with the size(s) of the defected flaws. To exclude the possible effect of crack extension, fatigue crack growth has to be taken into account.

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2 ASME XI is an internally accepted industry-based consensus standard that is widely applied by the nuclear industry.

3 A toughness based assessment assumes that the structure fails due to crack propagation. In contrast, a plastic collapse (or flaw size dominated) assessment prevents failure by local or overall yielding of the flawed cross section. In that case, flaw size and applied stress are compared with a notional flow stress, derived from the tensile properties of the flawed region.

4 The index refers to flaw opening mode under the applied load. Mode I represents the flaw opening under a normal tensile stress perpendicular to the flaw.

2. ***Issues***

As discussed, the primary input parameters for an ECA analysis are: the level of applied stress (or the driving force which causes a flaw to extend), the flaw type, orientation and size, and the toughness of the material containing the flaw(s). Consequently, an ECA analysis requires a multidisciplinary approach to obtain reliable and safe allowable flaw size predictions. In addition, the quantitative nature of an ECA analysis implies a need for quantitative input data. Safe predictions are obtained when the driving force, fracture toughness and flaw size(s) can be adequately determined. In deterministic terms, this means that:

- the most onerous applied loads acting on the flaw(s) are conservatively estimated,
- the lower bound toughness of the flawed region must be determined,
- the tensile properties of the flawed region are known;
- the actual flaw dimensions as well as its position can be accurately measured with conservative assumptions on the detection error for the size and orientation.

The above considerations are simply meant to say that uncertainties surrounding the values of the input parameters will be transmitted through to the final result. However, this does not mean that the actual numerical values of these parameters must be known. When they are not known or cannot be determined with the required precision, a conservative yet realistic estimate can be used. Since the Doel 3 and Tihange 2 RPVs constitute a critical component in a nuclear power station for which failure cannot at all be admitted, it is essential to make worst case (lower bound on material properties and upper bound on loads and on flaw sizes and orientations) estimates with the highest possible level of certainty. Therefore, arguments which would state that a very conservative assumption could compensate for a lack of conservativeness in another step of the analysis are not acceptable.

3. ***Challenges***

The following sections provide a brief description of the challenges associated with the determination of the numerical values of the input parameters for an ECA of an RPV containing an unusually large number of embedded laminar and nearly-laminar flaws. A more detailed discussion on the implementation of the methodology and the treatment of the input parameters proposed by the licensee is provided in Part B of this report.

1. **Loading conditions -** The combined effect of the regular operating conditions (internal pressure) and the accidental (thermal-shock) loads have to be taken into account. In particular, thermal shock is a key variable because it might cause high tensile stresses and a reduction in toughness near the inner surface of the RPVs. The procedures to assess this effect are well defined in ASME XI. The licensee addressed both loading conditions, which are well defined and not under question here. The NSEG, however, has insufficient active expertise to determine whether other, but rather unlikely, loading regimes should be considered for the evaluation of laminar flaws.

2. **Flaw dimensions –**The result of an ECA is critically dependent on the ability to reliably find and accurately determine the size, orientation and location of any potential critical flaw. In addition, when multiple flaws in close proximity are detected, their interaction must be considered. When the flaws are deemed to interact, they must be replaced by a single flaw with dimensions that are more severe than the actual flaws they represent. On the other hand, laminar and nearly-laminar flaws are less detrimental than flaws perpendicular to the circumferential (hoop) stress. However, their high number of occurrence complicates their assessment. In particular, the following aspects need special consideration.

    - **Inspection and flaw sizing** - The inspection procedure and the type of in-service inspection tool used have a direct effect on the effectiveness in detecting (PoD - probability of detection) and sizing (flaw sizing accuracy) any possible detrimental flaw. The cladding (stainless steel layer at the inside of the RPVs), the acoustic velocity properties of the material and the variation of the metallurgical structure across the flaws and across the full through thickness direction as well as the flaw characteristics (type, size, inclination, topology) also influence the performance level of the NDE[5] inspection. Unfortunately, it must be noted that current NDE inspection codes give little guidance on how to inspect laminar and near laminar (slightly inclined) flaws occurring in planar and non-planar (often overlapping) planes (inspection technique/inspection procedure issue).

    - **Flaw interaction** - ASME XI stipulates that closely spaced flaws must be combined into a single bigger "idealised" flaw whose dimensions are related to those of the original flaws. For example, ASME XI requires that laminar flaws within 25 mm from the vessel surface must be grouped as a single larger flaw. The rules contained in ECA standards assume brittle material behaviour while the rules were developed for flaws of equal size. In addition, the ASME XI flaw interaction rules were not developed to assess a high density of laminar and nearly laminar flaws. Because of this limitation, the licensee developed case specific flaw interaction criteria.

    - **Flaw dimensions and flaw geometry –** The flaw dimensions of an "idealised" embedded (interacting) flaw(s) to be used in the analysis are determined by the size of the containment rectangle that fully contains the (interacting) flaw(s). For the analytical evaluation, the flaw geometry is then represented by the dimensions of the bounding ellipse

3. **Crack driving force (K_I) -** The crack driving force $\mathbf{K_I}$ (linear elastic material behaviour) or $\mathbf{J_I}$ (elastic-plastic material behaviour) of each individual flaw or a combination of them can be obtained from analytical solutions or finite element modelling. However, the high density of interacting/non-interacting laminar and slightly inclined laminar flaws complicates the calculations. Therefore, the

[5] NDE: Non Destructive Examination

licensee developed a theoretical/modelling solution to solve this issue. The proposed solution was not experimentally validated.

4. **Fracture toughness -** The fracture toughness or the resistance of the material containing the flaw is an essential variable in the determination of critical/allowable flaw dimensions. However, because of sampling and irradiation issues, the fracture toughness properties (denoted as K_{Ic} - linear elastic analysis or J_{Ic} - elastic-plastic analysis) of the Doel 3 and Tihange 2 vessels cannot be directly measured on samples involving exactly the same flaw distribution, the same irradiation embrittlement and the same (local) microstructure. Therefore, the fracture toughness is directly derived from the (lower bound) reference curves of Appendix A of ASME XI. When the reference curve is used, it is worth noting that the fracture toughness of a material containing multiple (micro) flaws might depend on (a) the crack growth direction with respect to the material microstructure (fracture toughness anisotropy) which is an issue here, and on (b) any possible additional embrittlement of the material ligament(s) between neighbouring flaws. Thus, additional tests are needed to quantify the possible effects of the crack orientation, microstructure and segregations on the fracture toughness. The results of these tests are also valuable to justify the use of the lower bound reference curve.

4. Deterministic vs. probabilistic assessment

A deterministic analysis is capable of providing assurance that failure is not to be expected when the lower bound values or the lower bound estimates of the input parameters are used. However, since a deterministic analysis uses crisp values, it does not quantify the effect of the variability or uncertainty of the input parameters (loads, material properties and geometry) and the level of conservatism involved.

The quantification of the conservatism/risk can be assessed by a probabilistic assessment if validated probability distributions of the input variables are available to account for the potential uncertainties of the input values. As flaw sizing is a possible issue, the NSEG does not take into account the results of a probabilistic analysis and limits, therefore, their evaluation to the conservatisms used in the deterministic approach.

PART B - OBSERVATIONS

The analysis of licensee's technical documents related to the issues labelled as "Material", "Inspection", "Structural Mechanics and Fracture Mechanics", allowed the NSEG to make the following comments and observations:

1. __Inspection__

The licensee performed the on-site inspection with an inspection technique that was not fully calibrated for the detection and sizing of large amounts of laminar flaws occurring in different planes in the forged shells of the Doel 2 and Tihange 3 RPVs. However, the capabilities of the on-site ultrasonic testing (UT) technique to detect and size laminar and nearly laminar flaws as well as the integrity of the ligament between the flaws were validated by the licensee on a similar material – without the stainless steel clad layer – and containing similar, though larger flaws (block VB395/1 of dimensions 500 mm * 500 mm * full thickness). This appreciable effort, however, does not exclude the possibility that potentially critical flaws were not captured during on-site inspection (overlapping issue). The NSEG does not have the expertise nor the means to provide a definitive judgment on the accuracy and the degree of conservatism with respect to reported indications/flaws.

In addition to the influential factors discussed in Part A, it should be noted (a) that the flaws occur in different planes in very large numbers, (b) that the inclination of the individual flaws varies and (c) that it cannot be excluded that potentially critical flaws, damaged or embrittled ligaments, were not captured by the on-site NDT procedure used.

2. __Documentation (Archive)__

The NSEG has no comments on this informative topic.

3. __Metallurgy__

Following the analysis of the technical documents related to the metallurgy part of the investigations, the NSEG has asked for clarification on the following items

3.1 Origin of the indications

The recently detected flaw indications in Doel 3 and Tihange 2 RPVs were not reported in the manufacturing reports. Thus, the indications were not detected by the inspection equipment/procedure used and/or were not reported, possibly due to human factors. Note that the manufacturer RDM has rejected components for hydrogen flaking reasons. The NSEG requested the licensee to demonstrate that flaw growth, for example due to the presence of H or H_2 in the flaws, did not occur prior to the 2012 inspections. This concern was also addressed by AREVA.

The licensee argues that other origins can be ruled out. The argument is that the possible causes for the formation of the flaws (during manufacturing and in service) have been analysed in detail. Since the orientation of the flaws is not perpendicular to the major principal stress during loading, it is concluded that hydrogen flaking at the manufacturing stage is the most likely cause. Concerning the possible in-service flaw growth, only low cycle flaw propagation during transient loading could be a possibility. However, this effect is shown to be negligible, while the effect of H can be considered as negligible on propagation. Further, ligament cracking can be excluded because of the low H/H_2 levels measured in AREVA flakes.

3.2 Combined effects of micro-structure, embrittlement, orientation and metallurgical composition on toughness

The licensee demonstrated that the toughness and fatigue growth rate are dependent on the presence of (a) H under irradiation and (b) segregation pockets. In the documentation, it is mentioned that the presence of phosphorous in ghost lines can have a detrimental effect (but this will be tested). The NSEG requested the licensee to consider the combined effects of these factors in a conservative way.

The claim that the fracture toughness values used in the analyses are conservative, meaning that they constitute a lower bound of the actual fracture toughness is discussed in detail in the licensee's technical documents. Practically, a shift in reference temperature to nil ductility transition (RT_{NDT}) of 50°C is used in the analyses. This is a conservative approach because it is very likely that the H concentration decreased to very low levels during the first days of operation of the pressure vessel.

Analyses of other RPV materials have shown that segregation has a reduced effect on the temperature shift and no effect on the irradiation embrittlement. They have also shown that the orientation does not affect significantly the toughness:

- Analysis of the un-irradiated Doel 3 block – sampled from the upper core shell (containing no macro-segregation and no hydrogen flakes) confirms the absence of any effect of the orientation in the brittle condition and on the tensile strength, while a reduction of toughness exists in the T direction in the ductile range, implying an upper bound 150MPa $m^{1/2}$ limit to be used in the analysis;

- Analysis of the un-irradiated AREVA H2BQ3 block (containing no macro-segregation,) showed no difference due to segregation along S-L on toughness;

- Analysis of the un-irradiated Doel 3 H1 nozzle cut-out (containing macro-segregation and no hydrogen flakes,) confirms the absence of the effect of the orientation and of the segregations on the toughness in the brittle range and on the yield strength. In the ductile range there exists an effect of the segregation in the

SL direction implying that an upper bound 150MPa.m$^{1/2}$ limit can be used in the analysis;

- Tihange-2, Doel 3 surveillance programs (material contains no segregation) confirm that the FIS curves are conservative to predict the effect of irradiation embrittlement;

- Using the FIS formula, the effect of segregation predicts a 17°C shift in RT_{NDT}. Effect of irradiation on segregated zone can be obtained with the FIS formula;

- Fluence corresponding to 40-year service was obtained by numerical models, and a conservative comparison of the corresponding delta RT_{NDT} with the one measure from the non-segregated D3T2 surveillance program specimen was achieved.

3.3 Toughness of the material surrounding the flaws

The NSEG believes that the transferability of the fracture toughness, derived from tests on sound material, to the possibly altered/embrittled material between the indications requires due consideration in the analysis. As direct measurements are not possible to verify this, there is no absolute guarantee that the ligaments between the flaws or the regions surrounding the flaws (these regions might contain small micro-flaws whose dimensions are below the UT detection limit) have not been damaged.

The licensee's reply to this concern is based on (a) the published results of earlier test campaigns (these results are reported by the licensee) and (b) the analysis on the VB395 block with hydrogen flakes that has shown that the ligaments were "perfectly sound". These are important but not fully convincing arguments. For the NSEG, one additional argument that the possibility of ligament embrittlement is conservatively taken into account in the analysis lies in the flaw grouping procedure, which implicitly assumes that the ligaments for interacting/closely spaced flaws have a very low (local) toughness. Hence, ligament embrittlement cannot be completely discarded but it is unlikely. However, the shift in RT_{NDT} of 50°C considered in the analysis provides a significant safety margin.

Finally, it should be noted that the application of the FIS formula was based on the phosphor content in the macro-segregated zone. Since the phosphor content in ghost-lines (in or outside the macro-segregated zone) could be higher, a shift higher than 50°C could be needed. In this regard, one should note that:

- In the only reference studying this phenomenon [*Soulat, P. E., Houssin, B., Bocquet, P., and Bethmont, M., "Analysis of Radiation Embrittlement Results from a French Forging Examined in the ...],* a shift of about 80° is observed at a low irradiation level, but at high irradiation levels, this shift can be limited to about 40° only;

- The thickness of the ghost-lines is lower than 1mm and that the ghost-lines are not oriented in a critical direction. It is thus possible that a crack initiated in this weaker zone will arrest as soon as it gets out of it; although this point should be developed further.

- The shift does not reduce the toughness at low temperature (the shift occurs in the transition temperature), so proving with a 3D analysis that the SIF remains lower than the minimal toughness is a way to exclude this effect as a potentially critical phenomenon.

3.4 Summary

The answers provided by the licensee allow the NSEG to conclude that the fracture toughness estimates used in the calculations are conservative because:

- The flaws / hydrogen flakes were formed during manufacturing;

- A shift of 50°C in RT_{NDT} is higher than the FIS predicted shift in irradiated macro-segregated zone. However, to remove any discussion, the licensee should document the phosphor content effects on RT_{NDT}.

- The use of the fluence map up to 40 years;

- Neither segregation nor anisotropy effects have been found in the new test campaigns;

- The ligaments between the hydrogen flakes in the VB395 block were sound;

- Literature does not report any ligament embrittlement effect;

- The used grouping methodology also circumvents the problem of ligament embrittlement.

4. Calculation (Structural Analysis and Fracture Mechanics)

The licensee evaluated the flaw propagation risks on the assumption that the flaws detected in 2012 were also present, with the same sizes, at the start of the vessels' operational service. Upon the analysis of the technical documents, NSEG has received, on their request clarification on the following items.

4.1 Assumptions related to licensee's grouping criterion

The licensee's calculations of crack initiation for interacting flaws are based on their ad-hoc developed grouping criterion. To assess the conservatism of the proposed methodology, the NSEG requested the licensee to justify the use of linear fracture mechanics in the interaction of the resulting grouped flaws, which should be shown to be conservative. This need for clarification is of importance because:

- Flaws/indications within a few mm are not systematically grouped: in particular, indications at 3.125 mm or 25 mm are not systematically grouped, which corresponds for linear elastic fracture mechanics (LEFM) to be conservative to have K_I values lower than respectively 13 ($L<2.5K^2/379^3$) and 38 ($L<2.5K^2/379^3$) MPa $m^{1/2}$. Note that ASME XI requires indications within 1 inch to be grouped;

- The presence of a(n extended) plastic zone between two indications invalidates a K dominated assessment (may be not even a J-dominated zone) and does not allow a displacement based method to be used to determine K;

- Less than 20% of the indications are grouped

The above observations have been addressed by the licensee in their updated technical documents. In particular, critical groups of flaws near the cladding are studied using elasto-plastic analyses and by assuming that each flaw interacted with its neighbours. Far away from the cladding, critical groups of flaws are studied using elastic assumptions and by considering that each flaw interacts with its neighbours. The use of LEFM is justified as CENAERO reported XFEM (eXtended Finite Element Method) simulations with K <10 $MPa.m^{1/2}$ for each individual flaw. Moreover in both cases, the J-integral is computed from domain integrations and not from a displacement extrapolation Thus, although the method is not standardised yet, the NSEG concludes, with all the knowledge that is currently available to its members, that the applied approach meets the conditions to be considered as conservative.

4.2 Application of the new grouping criterion

The licensee's methodology for crack initiation makes use of their case specific grouping criterion for the interacting flaws. In order to justify the applicability of the proposed criterion and to demonstrate the accuracy of the results, the NSEG has invited licensee to provide;

- A graphical representation of the resulting grouped flaws after having applied the grouping criterion developed;

- Given the sensitivity of the risk to the correct application of the grouping criterion, an independent team to perform the same grouping analysis with the same criterion and the same input, for comparison purpose, involving the repetition by this team of the most realistic 3D FE simulation of the worst case situation.

These points have been positively addressed in the updated technical document.

4.3 Verification of the ASME III requirements

During the verification of the ASME III design requirements, the licensee does not consider flaw grouping, and instead the individual flaws are used as input. The NSEG has asked to justify this approach given the high density of (interacting) flaws.

This has been addressed by experiments on blocks with similar defects, which have shown that the net surface can be used in the assessment.

4.4 Fatigue analysis

In the flaw growth calculations, the grouped flaws are not considered. Instead the individual flaws are used as input. The NSEG has asked to justify the approach given the high density of flaws.

The updated documents have addressed this issue by considering grouped flaws when required.

4.5 Use of LEFM far away from the cladding

In the assessment of flaw size limits, it is assumed that no plastic correction is required for flaws 20 mm away from the inner wall as the stress remains below the material's yield strength. This is not the correct justification. The correct justification arises from the value of K and of the corresponding plastic zone. The licensee agreed with this point of view. In addition, the licensee also argued that the plastic zone sizes were very small, ensuring the validity of the use of the linear elastic theory.

4.6 Summary and conclusion

The review of the technical documents and the supplementary clarifications allow the NSEG to conclude that the estimate of the K value is conservative:

- The grouping criteria have shown to be conservative because 3D numerical calculations account for (a) the interactions (through J-integral computed on annular domains), (b) plasticity when needed and (c) mechanical and thermal stresses;

- The inclinations of the grouped indications are higher than for the individual flaw(s). In addition, the use of the projected area in the circumferential and axial directions of the grouped indications is also a conservative approach;

- The pressure closing effect of the laminar and nearly-laminar flaws is neglected;

- The analysis is focussed on crack initiation and not the crack arrest, this approach is conservative;

- The multiple service and accidental transients used to calculate the flaw size limits is conservative;

- Warm-pre-stress effect has not been considered, which is conservative

5. Safety

The NSEG did not study this topic and has thus no specific comments.

6. Project

The NSEG did not study this topic and has thus no specific comments.

7. Summary

The licensee has summarised the different elements of conservatism that are taken into account:

- Flaw size and orientation of detected flaws:

    - The UT inspection technique used overestimates the size of the detected flaws;
    - The orientation of the flaws are overestimated;
    - The grouping criterion for interacting (multiple) flaws used overestimates the size of the individual flaws that are present.

  As a result, the geometrical characteristics of all flaws that are detected are used in subsequent analysis in a conservative way.
  On the other hand, it is not entirely certain that the inspection procedure has left one or more flaws undiscovered.

- Material properties:

    - The material properties used in the calculations are lower bound estimates of the actual fracture toughness and yield strength values;
    - The neutron fluence is overestimated, leading to a conservative increase of the resulting RT_{NDT}.

- Loads:

    - The pressure and thermal (effect of high cooling rate) load conditions are overestimated;
    - The crack closure effects, that have a beneficial effect on the stress state, are not taken into account.

Although the combination of all these uncorrelated conservative estimations adds up to additional conservatism of the analysis result, it should noted that, as discussed in Part A, a very conservative assumption on one variable cannot be used to compensate for a lack of conservativeness in another step in the analysis. However, the accumulated conservativeness of the entire assessment process should still be acknowledged.

8 General conclusions

The analysis of the technical documents and the complementary clarifications provided by licensee, allow the NSEG to conclude:

1) that the recently detected flaws in Doel 3 and Tihange 2 RPVs are very likely manufacturing related and that the flaws/indications were, for unknown reasons, not mentioned in the manufacturing reports after the manual inspection procedure that is conducted before commissioning the RPV. In addition, the fatigue calculations covering the past 30 years of operation illustrate that the undiscovered indications/flaws should not have grown significantly during the operations;

2) that the methodology and fracture mechanics calculations, performed and/or subcontracted by the licensee, are sound and reflect the current state-of-the art;

3) that all assumptions and the numerical values of input parameters used in the calculation - other than those related to the size, orientation and position of the flaws as they are detected by the inspection tool - are conservative. However, a study of the detrimental effect of the potentially high phosphor contents in ghost-lines on fracture toughness merits consideration.

4) that, as a result of observations 2 (methodology) and 3 (geometrical and load input data), the predictions on the structural resistance of the RPVs of Doel 3 and Tihange 2 may be considered to represent a worst case scenario once the effect of the phosphor content on fracture toughness has been investigated (4, material property input data);

5) that, as a result of observation 4 (results of the analysis), the restart of operations on the nuclear reactors Doel 3 and Tihange 2 would have to be taken into consideration;

6) that, however, the available information on the validation of the inspection procedure does not give conclusive evidence that the inspection tool and inspection procedure used ensure that all potentially critical flaws have been detected with certainty;

7) that, because of observations 5 (conservatism) and 6 (uncertainties with respect to NDE inspection), the restart of the nuclear reactors Doel 3 and Tihange 2 can only

be justified when an expert opinion on the available and additional (observation 6) NDE inspection results confirms that the real number, size, position and orientation of the flaws are no worse than the reported and detected flaws.