

Flawed Reactor Pressure Vessels in the Belgian NPPS Doel 3 and Tihange 2

Comments on the FANC Final Evaluation Report 2015

Ilse Tweer
Materials Scientist, Consultant

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B-1047 Brussels



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- It has to be kept in mind that the inherent safety margin of the FIS formula has been eliminated by the new predictive formula. The extra shift supposed to consider possible higher embrittlement does not envelop the experimental results.

3. Conclusions

The defense in depth approach (in Germany the basic safety philosophy) requires for the safe operation of nuclear power plants superior quality of design, materials and operation.

- Basic safety or highest quality in accordance with defense in depth during manufacture of the reactor pressure vessels of Doel 3 and Tihange 2 cannot be demonstrated due to the incomplete documentation.
- The detection of thousands of flaws proves that highest quality is not given, the pressure vessels were not licensable neither today nor at the time of manufacture. It is therefore highly questionable in the frame of basic safety or the defense-in-depth approach that 30 years thereafter the nuclear authority is authorizing the restart of both plants.

The evaluation of the documents showed with respect to the detected flaws:

- The real nature of the defects that cause the indications found by ultrasonic testing can only be disclosed by destructive testing. The argumentation by Electrabel and accepted by FANC is only based on plausibility considerations.
- The hydrogen flaking assumption cannot explain why only the four shells in the NPPs Doel 3 and Tihange 2 are affected and not all of the RPVs produced by the same manufacturer.
- The hydrogen flaking assumption cannot explain why the flaws have not been detected during acceptance testing after manufacture.
- The possibility of irregular processes before or during cladding of the RPV that could have introduced impurities into the vessel wall with following growth during operation has not been discussed by Electrabel and FANC.
- The hypothesis of electrolytic/radiolytic hydrogen that could contribute to the growth of defects during operation (W.Bogaerts, D.D.Macdonald) was rejected by FANC.
- In the further argumentation by FANC and the different expert groups the defects behind the UT indications are assumed as hydrogen flakes without any restriction although still no proof for this assumption exists.

With respect to number and size of the defects and the indication of growth during operation:

- The fact that no defects have been found during the acceptance testing after manufacture is obviously no issue for FANC and the consulting expert groups.
- The restricted comparability between the measurements in 2012 and 2014 is also only a minor concern for FANC and the expert groups.

- It is implausible that a more sensitive UT technique reveals larger defects that were not detected by a less sensitive technique. The reverse observation has to be expected: large flaws detected with a less sensitive technique appear to be an assembly of small flaws using a more sensitive technique.
- The imprecise exclusion of radial connections between the flaws that implies that there exist radial connections indicates a further reduction of the strength of the reactor pressure vessel wall.
- The fact that no indications were observed after manufacture but thousands of flaws 30 years thereafter with an increase in size in the latest UT test results can only be explained by defect development/growth during operation.
- The exclusion of any defect growth except low cycle fatigue during operation is inconsistent with the state of science and technology. Even in case the observed flaws are hydrogen flakes growth mechanisms as described by Bogaerts and Macdonald cannot be ruled out.

For the structural integrity of the reactor pressure vessels during operation the state of the mechanical characteristics throughout service life are of crucial importance.

- The fracture toughness of the defect-containing base metal (without the irradiation effect) is not known. Due to the lack of representative sample material there is no possibility for experimental determination.
- Experimental results from non-representative samples cannot be used for a credible prediction of the actual mechanical properties.
- FANC does not mention the slightest restriction concerning the transfer of results from the non-representative (VB395 and KS02) samples to the characteristics of the RPV material.
- The possible reduction of fracture toughness due to the defects assumed in 2012/2013 has been reduced to zero – this is a considerable reduction of conservatism.

In order to study radiation effects on defect containing material FANC had decided that Electrabel should use samples from the rejected steam generator block VB395 and the German FKS material KS02 since no representative RPV material was available.

- The sample materials VB395 and KS02 are not representative for the RPV material in the sense of identical manufacture, heat treatment and operational history, even the steel is only similar but not identical.
- The sample materials VB395 and KS02 are also not representative for the defect-containing RPB wall because the nature of defects in the D3T2 shells is still not proven.
- The results from irradiation experiments performed using VB395 and KS02 samples characterize these materials with respect to their mechanical characteristics and the radiation sensitivity, but will not allow to deduce credible information on the actual state of

the RPV vessel wall. The results could be used to enhance the embrittlement database for similar steels.

- The predictive FIS formula from the French standards has been replaced by “Electrabel made” predictive trend curves that are supposed to include an extra safety margin based on the VB395 embrittlement. There is no quantitative explanation or justification for the different terms of the new equation.
- The new predictive formula does not fulfill the definition to be an enveloping upper boundary for similar steels.
- The trend curves to be used for the structural integrity assessment show that RT_{NDT} for 40 years of operation is slightly below the limit of 132°C. This indicates that the so called “variable margin” is designed to consider this limit.
- The observed remarkable embrittlement in the VB395 samples surmounting the predictive trend curves shows that this material is not applicable for RPV manufacture due to its severe radiation sensitivity but cannot be utilized to rule out enhanced embrittlement of the D3T2 shells.
- It is not possible to deduce that enhanced embrittlement cannot be expected for the D3T2 shells based on the assumption that the flaws in D3T2 are hydrogen flakes and the additional assumption that the strong embrittlement is not linked to hydrogen flakes.
- The observed embrittlement exceeding the predictive trend curves could as well be an indication that the predictive trend curves are not conservative.
- A possible flux effect (higher embrittlement at lower irradiation flux compared with the embrittlement at higher flux for the same total radiation dose) cannot be excluded.
- The FANC requirements concerning irradiation experiments using samples of the rejected steam generator block AREV VB395 were based on the agreement between Electrabel and FANC that VB395 is representative for the RPV steel. As a consequence of the unexpected high embrittlement results the VB395 was defined as an abnormal outliner.
- The procedure to declare VB395 as abnormal outliner because of the unexpected embrittlement and to exclude based on this definition a higher embrittlement for the D3T2 shells is highly questionable.
- The still valid predefinition of hydrogen flakes in the D3T2 shells ignores the fact that this cannot be proven. With respect to the irradiation experiments the unexpected embrittlement of VB395 is defined by Electrabel as not yet clarified but not due to hydrogen flakes. In fact there are no credible experimental results on the radiation effect in the flaw-containing RPV shells.
- The experimental data on radiation effects using the samples VB395 and KS02 show that the new trend curves are not conservative. The data scatter of up to 20°C above the trend curve

should trigger the requirement of an extra safety margin or an adjustment of the trend curve to an enveloping upper bound.

- The safety margin “in the magnitude of the VB935 embrittlement” to be used for the structural integrity assessment is not quantified. The figures show that this extra margin might only be an adjustment to the requirement that RT_{NDT} has to remain below 132°C until end-of-life.
- Since it cannot be excluded that the enhanced embrittlement does not occur in the D3T2 shells the so called extra shift defined by Electrabel is not a safety margin. It might not even be a conservative estimate of the possible embrittlement.

The structural integrity assessment in the Safety Case 2015 has been adjusted to the new data but not with respect to the methodology.

- Compared to the structural integrity assessment in 2012 Electrabel has updated the neutron fluence distribution and the flaw sizes, has replaced the FIS formula by a new predictive trend curve and has introduced the warming of the safety injection water to 40°C. FANC does not quantify this temperature in the Final report 2015; Jan Bens (director of FANC) stated in the Belgian chamber representatives that the temperature of the safety injection water will be 45-50°C.
- The heating requirement of the safety injection water is raising a further problem: the large amount of safety injection water (presumably about 1800 m³) has to be continuously warmed up to about 45°C. The temperature may not be lower than 40°C because this would violate the requirements for the structural integrity and may not reach 50°C because this would endanger the coolability of the core under accidental conditions. It is clear that the tolerance window is rather small and there is no safety margin at all.
- No experimental validation has been presented for the grouping method introduced by Electrabel in 2012.
- The doubts of the French regulatory Authority that the set of studied accident transients included the most penalizing scenarios have not been discussed.
- According to the ORNL calculations several flaws did not comply with the ASME acceptance criterion.
- It was necessary to include the WPS effect (which is not foreseen by the French standards) to reach compliance with the ASME criterion for most flaws.
- For one flaw this procedure was not enough, a “more realistic” modeling had to be adopted to reach the required compliance. This is certainly a further reduction of conservatism.
- It has to be kept in mind that the inherent safety margin of the FIS formula has been eliminated by the definition of the new predictive formula. The extra shift supposed to consider possible higher embrittlement does not envelop the experimental results.

The evaluation of the published documents has revealed the reduction of conservatism throughout the performed Safety Case analysis. The non-representative samples that were supposed to confirm the safety margin in the uncertainty assessment in the Safety Case 2012 have converted to abnormal outliers. Keeping in mind that growth of the flaws in the RPV shells during operation cannot be excluded the authorized restart of the two nuclear power plants not understandable.

Acronyms

DBTT	ductile-brittle transition temperature
EBL	Electrabel ENGIE Group
FANC	Federal Agency for Nuclear Control
FIS	Formule d'irradiation Supérieure
FKS	Forschungsvorhaben Komponentensicherheit
NDT	nil-ductility temperature
NSEG	National Scientific Expert Group
ORNL	Oak Ridge National Laboratory
RPV	reactor pressure vessel
RSE-M	Règles de Surveillance en Exploitation des Matériaux Mécaniques
SCP	Service de Contrôle Physique
SI	Safety injection
SIA	structural integrity assessment
UT	ultrasonic testing
WPS	warm prestress