FANC
federal agency for nuclear control

Flaw indications in the reactor pressure vessels of Doel 3 and Tihange 2

Technical information note – 2013.02.01

1. Context

Doel 3 and Tihange 2 are two of the seven Belgian nuclear reactors operated by Electrabel, a GDF-SUEZ Group company.

In June 2012, during a new type of in-service inspection conducted for the first time in Belgium, several thousands of flaw indications were detected in the base metal of the Doel 3 reactor pressure vessel, located mainly in the upper and lower core shells. As a precaution, similar inspections were conducted in September 2012 on the Tihange 2 unit, whose reactor pressure vessel is of identical design and construction. Flaw indications were detected as well, but to a lesser extent.

The pressure vessel is a key-component in a reactor unit, and its failure is not covered by safety studies. As a result, the licensee decided to keep both units in cold shutdown state, core unloaded, at least until in-depth analyses have been achieved and submitted to the Federal Agency for Nuclear Control (FANC) in view of a possible restart of the operation.

With the support of internal and external experts, the licensee started an investigation of the precise nature and origin of these indications in the summer of 2012, and built its own analysis to determine whether or not the reactor units in question could safely resume operation in spite of the detected flaws. The demonstration of the licensee was recorded in two safety case reports and backed by a number of technical documents, leading the licensee to conclude that both Doel 3 and Tihange 2 reactor units were eligible for immediate restart. In parallel, the licensee also proposed several additional measures designed to further increase the safe operation of the units, to monitor the pressure vessels state along time or to extend its initial material testing program.

Meanwhile, the FANC built up a dedicated organisation and commissioned several national and international expert groups to seek scientific and technical advice in order to elaborate an independent, founded and balanced judgement about the issue.

Along the assessment process, the expert groups raised a number of questions that were discussed with the licensee and its technical supports. From those discussions, a number of open issues were raised about the manufacturing of the reactor pressure vessels, the suitability of the in-service inspection technique, the possible evolution of the flaws during future operation, the characterization of the material properties, and the structural integrity of the reactor pressure vessels under penalizing loadings.

2. FANC Findings

Based on the data provided by the licensee and the conclusions released by Bel V, AIB-Vinçotte and the national and international experts groups about the flaws of the Doel 3 and Tihange 2 reactor pressure vessels, the Federal Agency for Nuclear Control draws the following **global conclusions** for each topic:

Regarding the manufacturing of the reactor pressure vessels:

Based on the sole manufacturing files, the presence of flaw indications since the manufacturing stage cannot be confirmed as the indications which were detectable at this stage were not reported in the final inspection reports of the manufacturing of the reactor pressure vessels.

Regarding the in-service inspections:

Some uncertainty still exists regarding the capability of the in-service inspection techniques to properly detect and characterize all present flaws in the reactor pressure vessels.

Regarding the metallurgical origin and evolution of the indications:

The most likely origin of the indications identified in the Doel 3 and Tihange 2 reactor pressure vessels is hydrogen flaking due to the manufacturing process. Significant evolution over time of hydrogen flakes due to the operation of the reactor units is unlikely.

Regarding the material properties:

More experimental data on tensile and toughness properties of the materials are needed to validate the approach followed in the structural integrity assessment.

Regarding the structural integrity of the reactor pressure vessels:

The approach adopted by the licensee to justify the structural integrity of the reactor pressure vessels still needs to be completed or validated for some topics. The probabilistic assessment approach provided by the licensee is used only for information.

Regarding the additional measures and actions proposed by the licensee:

The additional operational measures proposed by the licensee are relevant.

The in-service inspection program proposed by the licensee should focus particular attention on the most adverse flaws.

Some uncertainties still remain in the structural integrity assessment and call for additional experimental verification.

In the current state of knowledge and given the available data, the open issues identified along the assessment process do not represent conditions that require a definitive shutdown of the Doel 3 and Tihange 2 reactor units.

However, these open issues lead to some uncertainties that might reduce the conservatism of the licensee's safety demonstration and hence impair the level of confidence in the safe operability of the reactor units in question.

As a consequence, the Federal Agency for Nuclear Control considers that, in the current state, the Doel 3 and Tihange 2 reactor units may only restart after the requirements listed in the next paragraph §3 hereafter are fulfilled by the licensee.

The licensee shall elaborate an action plan to meet those requirements, including a methodology and associated acceptance criteria where applicable. This action plan shall be approved by the Belgian nuclear safety authority.

Once the licensee has implemented its action plan, the FANC, together with Bel V and AIB-Vinçotte, will evaluate whether all the safety concerns at the origin of the requirements are solved and whether the related reservations can be lifted. On this basis, the FANC will motivate its decision about the possible restart of the Doel 3 and Tihange 2 reactor units in a final evaluation report.

This position applies only to the Doel 3 and Tihange 2 reactor units and does not extend to other nuclear reactors potentially concerned elsewhere in the world. The evaluation of their safety remains within the jurisdiction of the competent national authorities.

3. FANC requirements

The suggestions, observations and conclusions of these different organisations and working groups were evaluated by the Federal Agency for Nuclear Control. Wherever appropriate and relevant, the FANC decided to use this input in the formulation of the specific requirements for the licensee.

The FANC issues the following requirements for each topic.

Regarding the manufacturing of the reactor pressure vessels:

Given that the whole documentation currently available was exploited and no additional finding can be derived from that material, the FANC issues no further requirement on this topic.

Regarding the in-service inspections[1]:

As a prerequisite to the restart of both reactor units, the short-term requirements on inspections mentioned in the AIB-Vinçotte assessment shall be fulfilled by the licensee:

- The licensee shall re-analyze the EAR acquisition data for Tihange 2 in the depth range from 0 to 15 mm in the zones with hydrogen flakes to confirm whether or not some of these technological cladding defects have to be considered as hydrogen flakes.
- The licensee shall demonstrate that no critical hydrogen flake type defects are expected in the non-inspectable areas.
- The licensee shall demonstrate that the applied ultrasonic testing procedure allows the detection of the higher tilt defects in the Doel 3/Tihange 2 data (2012 inspections) with a high level of confidence.
- The licensee shall present the detailed report of all macrographical examinations including the sample with the 45°T reflections and shall also analyze and report additional samples with 45°T reflectivity.
- The licensee shall include a set of defects partially hidden by other defects for macrographic examination, to confirm whether the sizing method continues to function well.
- The licensee shall re-analyze the tilts of the defects in the VB-395/1 block with the same method as applied on-site.

As soon as possible after the restart of both reactor units:

- The licensee shall achieve a full qualification program to demonstrate the suitability of the in-service inspection technique for the present case. The qualification shall give sufficient confidence in the accuracy of the results with respect to the number and features (location, size, orientation…) of the flaw indications. Where appropriate, the process shall be substantiated by appropriate

[1] The FANC would like to stress that the requirements related to the verification of the non-destructive examination procedure and the review and follow-up of their qualification program is the responsibility of AIB-Vinçotte, which is the authorized inspection agency in Belgium..

experimental data using representative specimens. The full qualification program shall be achieved before the next planned outage for refuelling.

Regarding the metallurgical origin and evolution of the indications:

After the restart of both reactor units:

- The licensee shall perform follow-up in-service inspections during the next planned outage for refuelling to ensure that no evolution of the flaw indications has occurred during operation.

Regarding the material properties:

As a prerequisite to the restart of both reactor units:

- The licensee shall complete the material testing program using samples with macro-segregations containing hydrogen flakes. This experimental program shall include:
    - small-scale specimen tests:
        - local toughness tests at hydrogen flake crack tip,
        - local tensile tests on ligament material near the flakes;
    - large-scale (tensile) specimen tests.
- The licensee shall perform additional measurements of the current residual hydrogen content in specimens with hydrogen flakes, in order to confirm the results of the limited number of tests achieved so far. For example, the licensee has estimated an upper bound on the amount of residual hydrogen that might still be present in the flaws. The licensee shall demonstrate that the chosen material properties are still valid, even if the upper bound quantity of hydrogen would still be present in critical flaws.

As soon as possible after the restart of both reactor units:

- A further experimental program to study the material properties of irradiated specimens containing hydrogen flakes shall be elaborated by the licensee.
- The licensee shall further investigate experimentally the local (micro-scale) material properties of specimens with macro-segregations, ghost lines and hydrogen flakes (for example local chemical composition). Depending on these results, the effect of the composition on the local mechanical properties (i.e. fracture toughness) shall be quantified.
- The licensee shall further evaluate the effect of thermal ageing of the zone with macro-segregation.

Regarding the structural integrity of the reactor pressure vessels:

As a prerequisite to the restart of both reactor units:

- Taking into account the results of the actions related to the previous requirement on the detection of the higher tilt defects during in-service-inspections, the licensee shall evaluate the impact of the possible non-reporting of flaws with higher tilts on the results of the structural integrity assessment.
- The licensee shall complete the on-going material testing program by testing larger specimens containing hydrogen flakes, with the following 2 objectives:
    - Objective 1 : Tensile tests on samples with (inclined) multiple hydrogen flake defects, which shall in particular demonstrate that the material has sufficient ductility and load bearing capacity, and that there is no premature brittle fracture.

- Objective 2 : An experimental confirmation of the suitability and conservatism of the 3D finite elements analysis.

Regarding the action plan proposed by the licensee:

As a prerequisite to the restart of both reactor units:

- In addition to the actions proposed by the licensee and the additional requirements specified by the FANC in the previous sections, the licensee shall perform a load test of both reactor pressure vessels. The objective of the test is not to validate the analytical demonstration on the reactor pressure vessel itself but to demonstrate that no unexpected condition is present in the reactor pressure vessels. The methodology and associated tests (acoustic emission and ultrasonic testing...) will be defined by the licensee and submitted to the nuclear safety authority for approval. The acceptance criterion will be that no crack initiation and no crack propagation are recorded under the pressure loading.