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UK RESPONSE TO THE DISCOVERY OF FLAWS IN THE RPV AT DOEL 3

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ABSTRACT

In June 2012, flaws were discovered in the Reactor Pressure Vessel (RPV) at Doel 3, a Pressurised Water Reactor (PWR) in northern Belgium. This paper discusses how the UK regulator has responded to this issue, how the learning was captured and promulgated to the industry and what regulatory action was taken. This includes interactions with the affected licensees, the stakeholder communities and the wider UK nuclear environment.

BACKGROUND

Doel 3 and Tihange 2 are pressurised water reactors (PWRs) operating in Belgium since 1982 and 1983 respectively. Non-destructive examinations of the Doel 3 reactor pressure vessel (RPV) conducted in June and July 2012 identified several thousand defect indications occurring in clusters in parent forging materials. Following the observations at Doel 3, similar inspections were undertaken at Tihange 2, whose RPV is of identical design and construction. These inspections also revealed a high number of defect indications, albeit fewer than found at Doel 3.

The Belgian Nuclear Regulator (FANC) has made details of its findings from its investigations at Doel 3 and Tihange 2 available publically via its website. Full documentation regarding is available via the link in the References section of this paper. Readers seeking more information on the ramifications for nuclear power in Belgium, should seek advice from the Belgian regulator. This paper deals with the implications for the UK only.

The licensee at Doel 3 and Tihange 2 performed an investigation into the root cause of the indications in the RPVs. They concluded that these were due to hydrogen bursts, also widely reported as hydrogen flaking. This is a mechanism of flaw production that is linked to high hydrogen levels during the production of the forgings. Following forging, and other high-temperature operations, hydrogen can collect at metallurgical inclusions. If these inclusions are lamellar in shape, the hydrogen concentrations possible can lead to high pressures at the inclusion and, hence, the laminations may burst open. These defects are generated in the production and manufacture of the component and not through-life.

I judged that the Doel 3 and Tihange 2 defects are likely to be hydrogen induced defects. I am in concurrence with the judgements made by FANC and the Belgian Licensee.

The potential for growth of the hydrogen induced defects during service has been examined by the Doel 3 Licensee and reviewed by the Belgian regulator. This work is presented on the Belgian Regulator's website. UK responses to this issue centre around the likelihood of cracking occurring; not on the likelihood of any cracking present growing.

UK RESPONSE

UK regulatory Position

The UK Civil nuclear fleet consists, primarily, of gas-cooled reactors that, having reinforced concrete pressure vessels, were unaffected by the findings at Doel 3 and Tihange 2. The plant potentially affected at the time of the discovery of the flaws were the single PWR reactor at Sizewell B (SZB) and the planned construction of 2 EPR™s at Hinkley Point C (HPC). The manufacture of long lead items for HPC, including the RPV, had begun when the flaws were discovered.

The material used at SZB for the RPV was to a recognised international standard: SA508 Grade 3 Class 1 (using the new ASME designation). The materials for use in the RPV at HPC will be 16MND5, a French grade of material very similar in chemistry and metallurgy to the American grade used at SZB. This material is known, without suitable controls, to be susceptible to hydrogen flaking.

The UK, currently, has plans to build both the Hitachi-GE ABWR and the Westinghouse AP1000. Although these plants were not considered at the time of the original findings, learning from these events will also be applied to these plants as appropriate.

ONR engaged with FANC through participation in technical working groups comprising representatives from regulatory authorities worldwide. UK Licensees for have engaged with Electrabel and industry forums to consider the safety implications. I am grateful to FANC for their open and honest discussions and for providing the opportunities to discuss the situation in Belgium.

UK nuclear regulation, in line with UK health & safety law more generally, is non-prescriptive. Meeting or adherence to an internationally accepted code does not guarantee compliance with the law. It is incumbent upon the licensee to demonstrate that the plant is safe to operate, but any reasonable means. In line with UK nuclear law, ONR required that the licensee demonstrate that the plant that were, potentially, affected produce documentation to show that their continued operation was adequately safe.

Sizewell B (SZB) Position

In accordance with UK regulatory law, it was incumbent upon UK licensees potentially affected by this OPEX to demonstrate that their plants were safe. The licensee at SZB produced a safety case giving their position on the potential for hydrogen bursts occurring at that plant. The manufacturing records from the forgings used at SZB form part of the through-life records for the plant. This includes measurements made of hydrogen and chemical composition more generally. Chemical composition gives an indication of the likelihood of formation of laminations. The licensee’s case centred upon there being insufficient hydrogen present to lead to hydrogen bursts, and that the number of laminations being sufficiently small so as to be negligible.

The hydrogen flakes observed on test and rejected forgings have all been associated with non-metallic stringer inclusions, such as manganese sulphides, formed from impurity elements in the steel. Therefore, control of the steelmaking process is vital in ensuring absence from hydrogen flakes. This puts great onus on any evidence that the levels of such inclusions were controlled during steelmaking. Manufacturing records were available showing that levels of tramp elements were suitably low within the steelmaking process. I, therefore, considered that all reasonably practicable measures were taken to ensure that the microstructure was as resistant to lamination formation as possible. This gave me confidence that the risk of gross hydrogen flake occurrence was suitably low.

The hydrogen content of a given steel is difficult to measure with great accuracy. It is there are a number of different techniques in common use and these do not always produce consistent results. It was clear, however, from the evidence presented by the licensee that the levels of hydrogen, and the effectiveness of recording hydrogen levels, was superior for the SZB forgings compared with the Doel 3 forgings. The levels of hydrogen reported in forging product analyses for SZB were, generally, below the 0.8 ppm level often quoted in the literature as being a level above which hydrogen flaking might occur. I judged, therefore, that the levels of hydrogen in the forgings for SZB had been controlled in a suitable manner.

SZB was the subject of substantial inspection prior to the installation of the reactor plant. This inspection was aimed primarily at the detection of defects of structural significance, i.e. through-thickness defects. Flaws of the type seen at Doel 3 and Tihange 2 should, however, have also been observable. The inspection used during construction of the plant was diverse and redundant, that is it used different methods applied independently. There were also more than one independent body contracted to do the inspection. Hence, I have a high degree of confidence that, should hydrogen flaking have been present, it would have been detected, and recorded.

The defects recently reported in RPVs at Doel 3 and Tihange 2 are believed to have been detectable by the original manufacturing inspections, although, the requirement to report these is not clear as they are in an orientation that is considered benign. Whilst the reporting criteria at Doel 3 and Tihange 2 were judged to be adequate, the defect acceptance criteria specified in the inspection procedure were not stringent when compared with practice used at SZB during manufacture.

From this information, I judged that the likelihood of hydrogen flaking occurring in the RPV forgings had been controlled and minimised and no further regulatory action was necessary.

Hinkley Point C (HPC)

As part of the site licencing process, ONR has been sampling arrangements for control of the procurement and manufacture of long lead item forgings for HPC. These interventions have included a review of the controls applied to prevent hydrogen cracking and to detect it at an early stage should it occur. These assessments were extended to take account of the Doel 3 and Tihange 2 experience.

As part of these interventions, inspection visits have been made by ONR to manufacturers of major forgings for HPC to review the quality systems and adherence to procedural controls. Particular attention was given to the procedural controls to limit the occurrence of hydrogen induced defects during the manufacture of these forgings. This follows the detection of hydrogen cracking in two forgings being produced at a French supplier during 2012 and intended for another utility. No hydrogen-induced defects have been found in HPC forgings.

The licensee provided copies of the ultrasonic inspection procedures applicable to certain forgings being procured from their two major forging suppliers; ONR compared the capabilities of these procedures with those applied at Doel 3 and Tihange 2, at Sizewell B and with relevant good practice. This comparison concentrated on the detection of hydrogen flake defects, but also considered a wider range of defects.

I judge that the licensee has undertaken a well-reasoned comparison between the manufacturing routes for Hinkley Point C forgings with those used at Doel 3 and Tihange 2. I judge that this comparison has identified a number of factors likely to influence the formation of hydrogen flakes and that controls are in place to minimise the likelihood of formation of these defects in the HPC forgings.

The justification for no defects of significance entering service also depends on the adequacy of manufacturing inspection. The licensee at HPC has expanded the range of the manufacturing inspections and provided detailed assessments of inspection capability. I judge that the licensee's inspection techniques and procedures are adequate to detect and report defects of the type reported at Doel 3 and Tihange 2.

CONCLUSION

In 2012, defects, characterised as hydrogen bursts, were discovered in the RPVs at Doel 3 and Tihange 2. The only affected civil plant in the UK were the PWR at Sizewell B and the EPR new build project at Hinkley Point C. UK law places the onus on the licensee to show that their plant is safe; compliance with a design code does not infer compliance with UK law.

ONR influenced the licensees at Sizewell B and Hinkley Point C to produce safety documentation collating the information available for each plant and assessing the impact of the findings at Doel 3 and Tihange 2. ONR's assessment is detailed above and given, in full, on the ONR website.

The extant safety cases at both sites were seen to be unaffected, and means for incorporating lessons learned were demonstrated. This was all achieved without exercising any formal regulatory powers.

REFERENCES

FANC – Dossier on the Pressure Vessels at Doel 3 and Tihange 2. (In French and Dutch with links to documentation in English). http://www.fanc.fgov.be/fr/page/dossier-pressure-vessel-doel-3-tihange-2/1488.aspx?LG=1

ONR Assessment Report ONR-CNRP-AR-13-09: Doel 3 and Tihange 2 Reactor Pressure Vessel Inspection Findings and their implications for Sizewell B and Hinkley Point C http://www.onr.org.uk/intervention-records/2013/non-site-specific-13-009.pdf