Research Status on the Safety Issues for Aged Pressure Tubes in PHWR

Jong Yeob Jung
Intelligent Accident Mitigation Research Division, KAERI, Daejeon, Korea

Corresponding author: agahee@kaeri.re.kr

1. Introduction

Pressure tubes in PHWR have been degraded their performances according to the increase of operation time under the severe operating conditions of high temperature and pressure and neutron irradiation. Examples of the pressure tube degradation are material property change such as a fracture toughness decrease owing to the increase of equivalent hydrogen concentration and crack initiation and growth owing to the delayed hydrogen cracking and deformation such as a diametrical expansion, axial elongation, sagging and wall thinning. These degradations result in some safety issues which affect operating safety margin and fitness-for-service of aged pressure tubes.

Because pressure tubes serve as the pressure boundary in the primary heat transport system of operating CANDU reactors, they should be checked their integrity periodically whether they maintain their function appropriately in spite of the degradations.

KAERI (Korea Atomic Energy Research Institute) has been doing researches regarding pressure tube safety issues to demonstrate the integrity and fitness-for-service of the aged pressure tubes. JY2020 model [1], which is a prediction model for pressure tube diameter change according to the operation time, was developed and a flaw assessment system [2], which is an evaluation program for flaw initiation and growth and following pressure tube failure by the plastic collapse or fatigue mechanism, was established. Also the occurrence of the short range ordering of the pressure tube material was verified by experimental study and it was concluded that the atomic ordering may be the fundamental mechanism of the pressure tube aging. However, in order to clarify the integrity of the aged pressure tubes over the 210,000 operation hour, more comprehensive researches need to be done including a leak-before-break (LBB) evaluation, contact assessment of pressure tube and calandria tube and appropriate life management of aged pressure tubes.

In this paper, we summarized generic safety issues regarding the aged pressure tubes including degradation phenomena and their effects on the operating margin and also described researches that have been carried out and to be done to enhance the operating safety through resolving the pressure tube safety issues.

2. Degradation and Safety Issues for Pressure Tube

Fig.1 shows the degradation phenomena occurred to pressure tube material and their effects on the operation of PHWR.

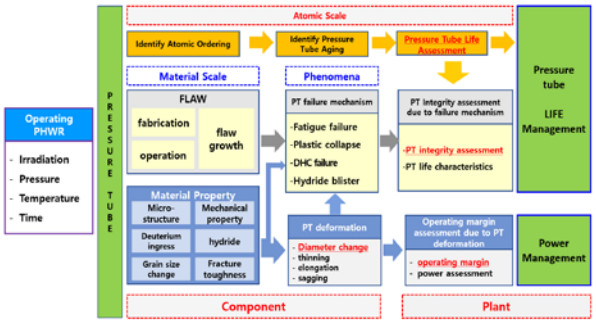

Fig. 1 Degradation and safety issues for pressure tube.

2.1 Degradations

As the operation time increases the following degradations occur in the pressure tube.

• Material property change:

Material property change is the one of the important degradation phenomena occurred in the pressure tube during the operation such as a fracture toughness, tensile strength, micro-structure etc. As the equivalent hydrogen concentration increases, the fracture toughness decreases and it results in the increase of the pressure tube failure possibility.

• Deformation:

Another important degradation is the deformation of the pressure tube such as diameter expansion, axial elongation, thinning and sagging. Dimensional changes affect not only the reactor physics and thermal-hydraulic characteristics but also operational safety margin and derating.

• Flaw/Crack initiation and growth:

Number of flaws at the inside surface of the pressure tube increases and some of them might turn into the crack and would have a chance to develop as through-wall cracks.

2.2 Operational safety issues for pressure tube

The following safety issues may occur during operation of CANDU reactor due to degradation of the pressure tube caused by the increase in operating time as shown in Fig. 1.

• Decrease in operational safety margin:

This is caused mainly by the expansion of the pressure tube diameter. An increase in the pressure tube diameter increases the bypass flow between the fuel

bundle and the pressure tube, which leads to a decrease in the critical channel power, and eventually the reactor power should be de-rated in order to maintain a constant operating margin. Therefore, the exact prediction of the pressure tube diameter according to the operation time is very important to evaluate the accurate operational safety margin.

• Increase in the possibility of PT failure:

Pressure tube was designed to maintain its integrity until 210 kEFPH (Effective Full Power Hour) and it is equal to the 30 years of licensed operation time under the condition of 80% capacity factor. However, since Korean CANDUs have been operated more than 80% capacity factor, 210,000 operation hour may be met earlier than 30 years so we have to check whether the pressure tubes maintain their integrity over the 210,000 hour or not in terms of the failure point of view.

• Coolant leak and necessity of LBB evaluation:

If the crack grows and penetrates through the thickness of pressure tube, the coolant inside the pressure tube leaks, and the operator should safely shut down the reactor for measures such as replacing the leaking pressure tube. During the cool-down process since pressure tube may have a chance to be broken owing to a rapid crack growth to critical crack length, a leak-before-break evaluation needs to be done for safe reactor shut-down.

• Contact of pressure tube and calandria tube:

When the pressure tube and calandria tube contact owing to the local swelling of the pressure tube, the pressure tube may be broken from the formation of the hydride blister which is very brittle. In order to avoid this failure, pressure tube and calandria contact should be inspected and the assessment should be carried out based on the technical standard.

3. Researches for Aged Pressure Tube

As described earlier, operational safety issues owing to the degradation of the pressure tube should be resolved for the safe operation of domestic CANDU reactors until the licensed period of operation. Fig.2 shows the overall research subjects needed to verify the fitness-for-service regarding the aged pressure tubes.

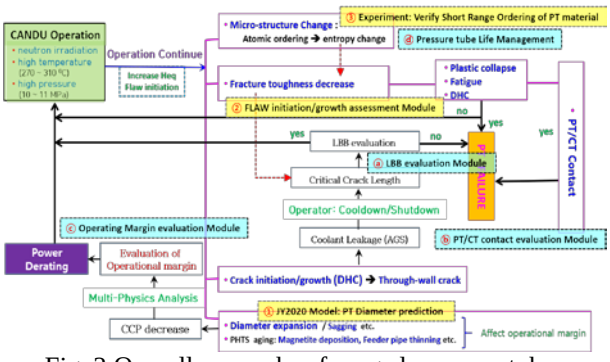

Fig. 2 Overall researches for aged pressure tubes

3.1 What have been done

Among the research subjects shown in Fig. 2, the following subjects were carried out by KAERI through the government funded project.

① Pressure tube diameter prediction model

JY2020 model which is a diameter prediction model for aged pressure tube was developed based on the temperature and neutron flux distributions and diameter measurement data [1]. As shown in Fig. 3, JY2020 model predicts pressure tube diameter very closed to the measured data compared to the Canadian methodology.

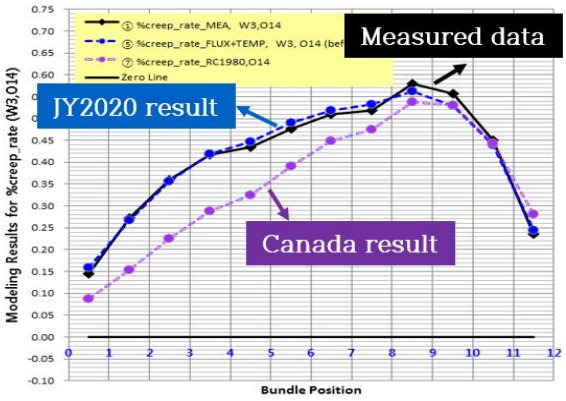

Fig. 3. PT diameter prediction result from JY2020

② Flaw initiation/growth evaluation module

FACAPT (Failure Assessment Program for CANDU Pressure Tube) was developed, as shown in Fig. 4, based on the CSA N285.8 standard [3]. FACAPT was applied to the flaw assessment and crack initiation of the pressure tube by the fatigue and delayed hydride cracking and also to the crack growth and integrity assessment.

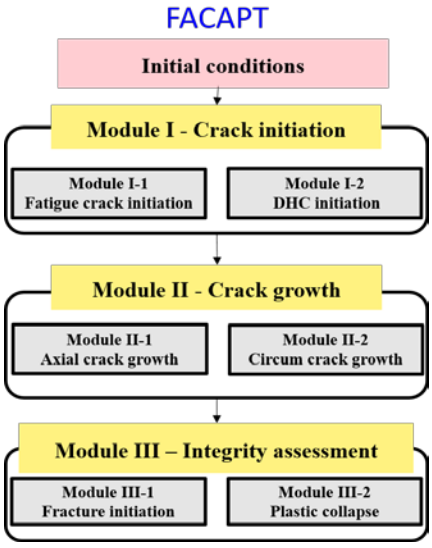

Fig. 4 FACAPT structure

③ Experiment for verifying SRO in PT material

Experiment was conducted to investigate the effect of aging treatment on the mechanical properties of the pressure tube material. The short range ordering (SRO) phenomenon during aging process was confirmed by DSC (differential scanning calorimetry) inspection and slow strain rate tensile test. Fig. 5 shows the schematic principle of SRO owing to the entropy change inside the material.

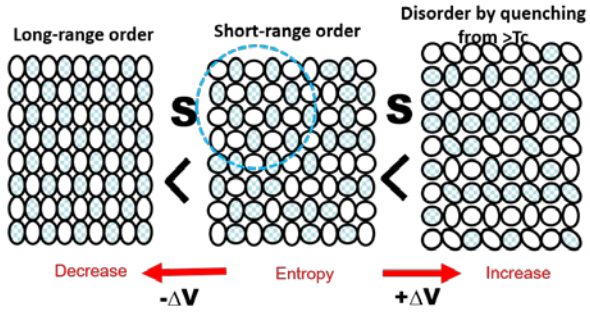

Fig. 5 Schematic principle of SRO and entropy change

3.2 What needs to be done

In order to ensure the safe operation until the end of the licensed operation period for domestic CANDU reactors, the following additional researches on the aged pressure tubes should be performed as shown in Fig. 2.

ⓐ Leak-before-break (LBB) evaluation

The premise of LBB evaluation is that the materials used are sufficiently tough (ductile) that small through-wall cracks resulting in coolant leak rates well in excess of those detectable by installed leak detection system would remain stable and not result in a guillotine break or equivalent rupture [4]. Fig. 6 shows the procedure of LBB assessment described in CSA N285.8 code. In order to accomplish LBB assessment we should calculate the delayed hydride cracking growth rate, fracture toughness of the material and critical crack length at which the unstable failure occurs.

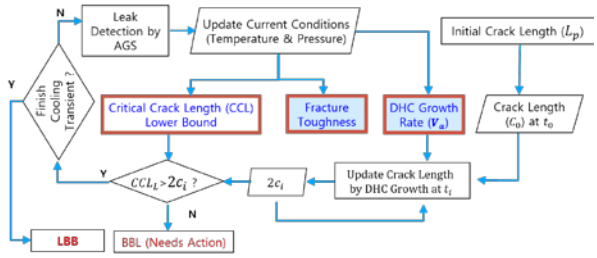

Fig. 6 LBB assessment procedure of pressure tube

ⓑ PT/CT contact evaluation

The utility should demonstrate whether the pressure tube can be acceptable for continued operation or not when the pressure tube contacts with the calandria tube. The procedure is as follows:

- Evaluation period is determined.
- The time and zone of contact are calculated.
- PHTS temperature and moderator saturation temperature at the location of contact are determined.
- Bulk hydrogen equivalent concentration, Heq, from the start of the operation to the end of evaluation period is determined.
- For each hot operating condition, an evaluation to determine whether the Heq is predicted to exceed the blister formation threshold (BFT) over the zone of contact is performed.
- When the Heq is predicted to exceed the BFT, and the prediction is either for o Limited Operating Condition or the maximum equivalent depth of a blister at the end of the evaluation period is calculated.

ⓒ Operating margin evaluation

An operating safety margin regarding ROPT (regional over-power protection trip) decreases as the operational time increases due to aging of PHTS and core components. Currently, an operational margin and deration are evaluated by probabilistic assessment with consideration of pressure tube diametrical creep and PHTS aging. Newly proposed methodology is the more detailed evaluation system consisting of multi-physics calculation of physics and thermal hydraulic analyses considering additional aging phenomena such as pressure tube sagging. Multi-physics evaluation system enables to assess the conservatism of the current operational margin and to suggest the quantitative margin change according to the operation condition change.

ⓓ Aged pressure tube life management

In order to assess the fitness for service of the aged pressure tube, it is important to know the current status of the pressure tube material and to determine how to manage through the remaining operation period. Pressure tube life diagnosis solution is to be developed by using the entropy change data from the experiment and appropriate management knowhow will be suggested for safe operation.

4. Conclusions

In this paper, the generic safety issues regarding the aged pressure tubes were summarized including degradation phenomena and their effects on the operating margin and also described researches that have been carried out and to be done to enhance the operating safety through resolving the pressure tube safety issues.

In order to ensure the safe operation until the end of the licensed operation period for domestic CANDU reactors, the following researches should be carried out.

- Leak-before-break evaluation
- Pressure tube/Calandria tube contact evaluation
- Operating margin evaluation
- Aged pressure tube life management

ACKNOWLEDGEMENTS

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