Experimental Evaluation of Leak Before Break for CANDU Pressure Tube Operated in Wolsong-1 Nuclear Reactor

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1. Introduction

The CANDU reactor utilizes horizontal fuel channels which are installed in a low pressure calandria tank filled with cool heavy water. The operating regulation requires periodic inspection of pressure tube operating nuclear reactors. The inspections are intended to ensure that unacceptable degradation in component quality is not occurring and that the probability of failure remains acceptably low for the life of the reactor. Part of the fitness procedures is centered around the demonstration that tubes will operate in a condition that if they do fail, they will leak at a rate sufficiently large that the leak will be detected and the reactor shutdown before unstable crack propagation occurs. This condition is known as Leak-Before-Break (LBB) and the proposed role of the LBB concept in the flaw evaluation methodology is adopted and evaluated for pressure tube operated in the Wolsung CANDU reactor, based on the tensile, fracture, DHCV test results.

2. Evaluation Procedure and Criteria

In this section the guide line for Wolsong-1 reactor to evaluate LBB safety and the LBB evaluation procedure for the cracked tube are described.

2.1 Guide Line for LBB Safety

The LBB philosophy is applicable to CANDU pressure tube because the annular gas system(AGS) has been developed into a leak detection system which is very sensitive to the presence of moisture resulting from a break of the primary heat transport pressure boundary that passes through the reactor core. The space between the pressure tube and the calandria tube is filled with annulus gas. These gas annuli are part of a closed loop, having header and intermediate tubing connections, which ensure a uniform flow through each annulus.

To apply the LBB on a pressure tube, many parameters should be set up to judge the operation safety. A crack length at the onset of leakage(Lp) can be decided through the operation experience and the leaking test. According to the leaking tube experience with Pickering and Bruce reactor [1], it were conservatively 16mm(4x tube thickness) in the except of the rolling joint area and 28mm in the rolling joint. A leak rate with crack show that cracks maintained at operating pressure has developed a leak rate much larger than 1 kg/h at some length well below the CCL, but that the leak rate will diminish if the pressure is reduced and that short cracks may clog when maintained at reduced pressure. A leak detection time with AGS capability can be apply with the result of moisture shooting test in Wolsong-2 reactor [2], it is 1 hour in the leak detect time and 2.6 hours in the detection time considering the operator action. The operating procedures in the cooling and de-pressuring in coolant are devided with the two case, which are the coolant operating procedure(COP) in normal operating and the sequence of event(SOE) in accident.

2.2 Evaluation Procedure

The evaluation procedure in the guidelines consists of a flaw growth analysis to determine the maximum size of flaw at the end of the evaluation period. It must be then be demonstrated that the flaw is stable with adequate margins of safety. Under the postulation to advance for crack to leakage, Fig.1 summarizes the procedure to evaluate LBB safety. A crack driving force(J_{cdf}) is calculated by Eq. 1 proposed by Kiefner, Dugdale, using flow strength and yield strength from tensile test.

$$J_{cdf} = \frac{8a\sigma f^{2}}{\pi} \ln \sec\left(\pi M F \sigma h \big/ 2\sigma f \right) \qquad (1)$$

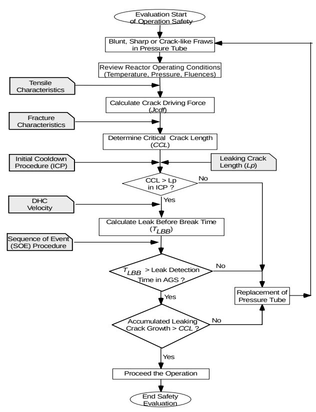

Fig 1 Flow chart to evaluate operation safety based on LBB

Using a crack driving force, A critical crack length (CCL) can be determined using the tearing modulus method [3] which are proposed by USNRC. If a CCL were shorter than a Lp, the corresponding tube should be replaced to a new one, otherwise the LBB evaluation proceeds. The T_{LBB} is determined to divide the CCL into a delayed hydride cracking velocity (DHCV), which comes from the test results.

Finally T_{LBB} compares with the leak detection time depend on the annular gas system capability in reactor. If the leak detect time and the action time in total were shorter than T_{LBB}, it means that the operator can provide in the coolant leaking accident during reactor operation. In this case a pressure tube can satisfy with the LBB evaluation.

3. Safety Evaluation to Leak Before Break

In this section various parameters to evaluate the LBB safety are calculated and reviewed according to the operating conditions.

2.1 Material Characteristics for the LBB Evaluation.

For the LBB evaluation mechanical characteristics of the irradiated pressure tube is essentially required, like as tensile for elastic constant and flow strength, fracture for the crack resistance curve and delayed hydride cracking velocity for the crack growth velocity. In paper material characteristics are gained from the M-11 tube operated in Wolsong-1 reactor during 13 yrs. [4,5,6]

2.2 CCL Variation in the Operated Tube.

To decide the CCL, the crack driving force diagram is showed in Fig.2 in the case of the operating pressure 10 MPa according to crack length. Fig.2 is decided by equation (1) from the test results for the irradiated pressure tube [6]. In Fig.2 the crack driving force is increased exponentially with the crack length, and the higher operating temperature has the higher driving force value. A CCL can be decided using the J_{cdf} diagram in Fig. 1 and the crack growth resistance(J-R) test results, which is the minimum crack length crossing Jcdf and J-R curve. Fig. 3 shows the CCL variations according to the operation temperature under 10 MPa, 8 MPa, 7 MPa in coolant pressure. The CCL has the trend to decrease after increasing on the temperature 180 ~ 200 ^{o}C.

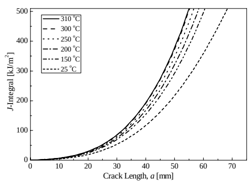

Fig.2 Variation of CCL under 10 MPa in pressure

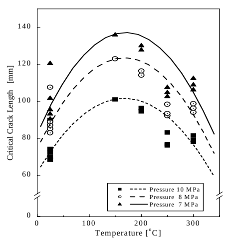

Fig. 3 Variation of CCL with the temp.

2.3 LBB Safety Evaluation

LBB time means the time for DHC growth from the initial leak to the CCL in the viewpoint of crack growth and the time to take action to protect tube breakage in the operator. From the review of article 2.1 it is known to be different from the crack initiation points. Fig. 4 shows the variation of the LBB time according to coolant temperature under 10 MPa in coolant pressure. LBB time is rapidly increased with the temperature decrease. This means that it is important to drop the coolant temperature in the leaking accident.

Fig 5 shows the LBB time variation in the initial cooldown procedure with COP, From the figure it is known that the LBB time in 8.8 hrs for the rolled joint area is about two times longer than in 4.3 hrs for the other area. Considering 2.6 hrs to detect the initial leaking the minimum action time recommended for the operator is 1.7 hrs. Fig. 6 shows a comparison of the accumulated crack growth and the CCL with the elapsed time under the SOE procedure. From the figure the amount of crack growth doesn't violate, it means that the reactor can be stopped without the tube breakage in the leaking accident as following the present SOE procedure.

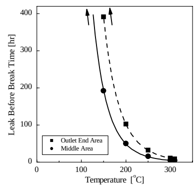

Fig. 4 Variation of LBB time with temp.

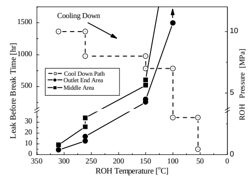

Fig. 5 LBB time with the IOP

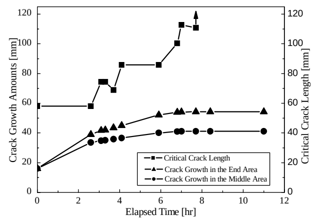

Fig. 6 Comparison of the accumulated crack growth and CCL

4. Conclusion

The safety evaluation in the coolant leak accident is performed based on the LBB notation for Wolsong-1 CANDU pressure tube using the test results from the operated tube. The time for the operator to take action against to coolant leaking accident is 1.7 hrs and the operation safety is confirmed at the present conditions for the COP and SOE procedures.

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