*Transactions of the Korean Nuclear Society Autumn Meeting*
*Gyeongju, Korea, October 29-30, 2009*

# Safety Margin Assessment due to Ageing-Induced Thermal-hydraulic Effects for CANDU Reactors

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## 1. INTRODUCTION

To develop the safety assessment system of safety margin effect due to degradation of CANDU reactors, it is required to explore the ageing elements aimed to analyzing the thermal-hydraulic effects using RELAP-CANDU code [3]. However, it is difficult to establish an explicit relationship between the thermal-hydraulic parameters and ageing mechanism because of insufficient data and lack of applicable models to identify the ageing elements. Therefore, in this study, the expected ageing components and phenomena are analyzed using several researches findings on ageing mechanisms in CANDU reactors. Thereafter, ageing elements are determined in the basis of the phenomenological considerations in order to analyze the thermal-hydraulic effects. In addition, the comparison study on the relationship between the individual ageing effect and the coupled effect for all elements is analyzed.

## 2. IDENTIFICATION OF AGEING COMPONENT AND FACTOR

To develop the analytical method for ageing-induced thermal-hydraulic effect using RELAP-CANDU code for CANDU reactors, the expected ageing mechanisms and components (Table I) are reviewed referred to the several researches on ageing mechanism in CANDU reactors [1, 2].

TABLE 1 [1]
Effect of potential ageing mechanisms on component life

| | Material | Irradiation embrittlement | SCC | Crevice corrosion | General corrosion | Erosion | Fatigue | Comments |
|---|---|---|---|---|---|---|---|---|
| Calandria Shell | SS 304L | L | L | L | L | L | L | |
| Tubesheets | SS 304L | L | L | L | L | L | L | |
| Welds | | | | | | | | |
| -annular plate to main shell | | L | L | L | L | L | L | |
| -subshell to annular plate | | L | L | L | L | L | L | |
| -subshell to tubesheet | SS 308L | L | L | L | L | L | L | |
| -tubesheet | | L | L | L | L | L | L | |
| -nozzles to shell | | L | L | L | L | L | L | |
| -RCU thimble to shell | | L | L | M* | L | L | L | *Pickering A only |
| Shell shields* | SS 304L | L | L | L | L | L | L | *Pickering A only |
| Moderator inlet nozzles | SS 304L | L | L | L | L | L | M | |
| Dump ports* | SS 304L | L | L | L | L | L | L | *Pickering A only |
| Dump bellows* | | L | L | L | L | L | L | *Pickering A only |
| Calandria tubes | Zr. 2 | L | L | L | L | L | L | Creep/sag-L Rolled/Joint Stress Relaxation-L |
| Spray clusters* | SS | L | L | L | L | M | L | *Pickering A only |
| Calandria support rods* | CS | L | L | N/A | L | N/A | L | *Pickering A only |
| End shield embedment ring | CS | L | N/A | M | L | L | L | |
| -CANDU 6 only | CS | L | N/A | N/A | L | L | L | |
| -Pickering A only | | | | | | | | |
| Sheield tank bearings*** | SS & Bronze | L | L | L | L | N/A | N/A | ***Shield Tank Reactors only Mechanical Wear - M |
| End shields | SS 304L | L | L | L | L | L | L | |
| Ring thermal shield* | Ni Steel | L | M | L | H** | M | L | *Pickering A only **External only |
| Shield tank | CS | L | L | L | L | L | L | ***Bruce and Darlington only |

L = little or no concern for end of life
M = credible ageing mechanism
H = potentially life limiting degradation
N/A = ageing mechanism is not applicable

Using Table 1, ageing thermal-hydraulic factors are identified in the basis of the phenomenological considerations as shown in Table 2. For example, the pipe roughness, in general, increase due to the corrosion on the surface. As creeping or sagging of the pipe increases the flow resistances, the hydraulic diameter and flow area are also changed. Hence, the variations of the aging factors at Table II are identified in this way.

TABLE 2
Identified ageing components and factors

| Ageing Component | Ageing factor | Ageing Mechanism | Variation |
|---|---|---|---|
| Fuel Channel | roughness | Corrosion | + |
| | loss coefficient | Pressure Tube (PT) Creep and Sagging | + |
| | hydraulic Diameter | PT Creep and Sagging Corrosion | - |
| | flow area | PT Creep and Sagging | - |
| Pump | pump head | Degradation | - |
| | pump flow | Degradation | - |
| Steam Generator | roughness | Corrosion | + |
| | hydraulic diameter | Corrosion | - |
| | Divided plates leakage | Degradation | + |
| Feeder Inlet + End Fitting | roughness | Corrosion | + |

## 3. EVAUATION OF AGEING FACTOR EFFECT: S/G divider plate leakage area

According to operation data of CANDU reactors [6], there was a leakage on the Divider Plate due to ageing which might be affected to the operating parameters. The averaged leakage area was measured as a values of 30~210cm$^2$. For example, according to the operational data of the inlet header temperature for Gentilly-2(CANDU reactor) as shown in Fig. 1, there is rapid temperature drop on 1995 after replace Divider Plate. This shows that leakage of S/G divider plate affects increase of reactor inlet header temperature (RIH T). If the divider plate of steam generator isolates hot coolant flow, the leakage in the divider plate could induce an increase of the inlet header temperature. To evaluate the thermal-hydraulic effect, the nodalization is modified as shown in Fig. 2 so that the divider plate leakage Area is included as ageing factor.

The Fig 3 shows the result that is applied divider plate leakage. It shows the increase of inlet header temperature as the increase of leakage area.

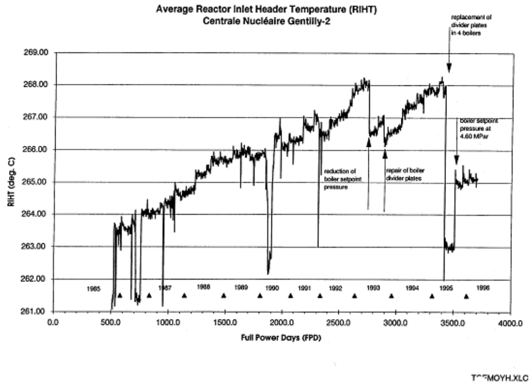



Fig. 1 Average reactor inlet header temperature [4]

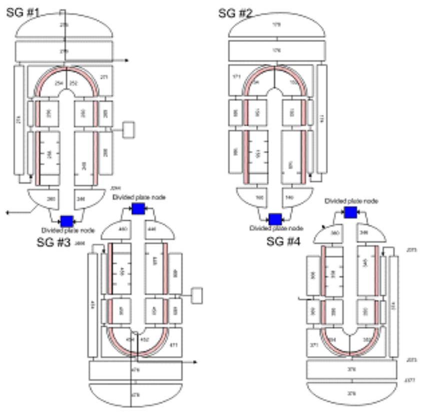



Fig. 2 The modification of nodalization for S/G divider plates leakage.

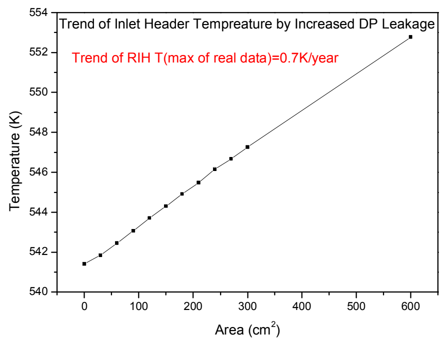


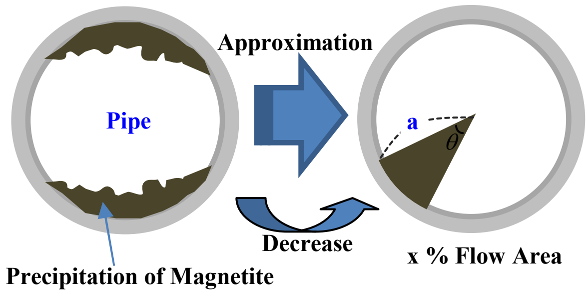

Fig. 3 Average reactor inlet header temperature with change of S/G divider plate leakage area (RIH T)

## 4. EFFECT ON AGEING ELEMENTS

The comparison study on the relationship between the individual ageing effect and the coupled effect for all elements is conducted. In this regard, an analysis of relation between change of flow area and hydraulic diameter according to degradation is carried out.

As creep or sagging of the pipe and precipitation of magnetite increase, the flow area and flow resistance are also changed and affected on the hydraulic diameter. Therefore, the degradation relationship between change of flow area and hydraulic diameter is established as below.(Fig.4 & Eq.1)

Fig. 4. Simplification of hydraulic diameter




**Flow Area** $$= \pi \times a^2 \times \frac{x}{100}$$

**Hydraulic Diameter** $$= \frac{4 \times Flow\ Area}{Wetted\ Parameter} = \frac{4 \times \pi \times a^2 \times \frac{x}{100}}{2a\pi \times \frac{x}{100} + 2a}$$

$$= 2a \frac{\frac{x\pi}{100}}{\frac{x\pi}{100}+1} = H.D_0 \times \frac{\frac{x\pi}{100}}{\frac{x\pi}{100}+1} = H.D_a$$

## 5. CONCLUSIONS

The expected ageing phenomena and regions are analyzed from several researches on ageing phenomena in CANDU reactors. And then ageing elements to analyze the thermal-hydraulic effects are selected based on the phenomenological considerations. Also, the relation of ageing elements to have dependency each other is analyzed from selected ageing elements. For example, according to degradation relation between change of flow area and hydraulic diameter is established. This research could be contributed to development of degradation model with realistic data.

## REFERENCES

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