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Study on Methodology for Establishment of the Minimum Allowable Fuel Channel Flow Rate in Steady State

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1. Introduction

To assure safety of NPPs, cooling capacity must be greater than heat generation from core. Especially regional overpower should be prevented to grantee cladding intactness and protect public and environment from radiation hazard eventually. At this point, minimum allowable channel flow rate must be set and complied.

In CANDU reactors, maximum channel flow rate are set to 30kg/s for single phase flow and 24kg/s for two phase flow by experiment to prevent excessive vibration and maintain mechanical stability.[1] However, minimum channel flow rate are not set obviously in CANDU reactors. Thus as a groundwork of establishment of minimum allowable fuel channel flow, method for setting preliminary minimum allowable channel flow in steady state is studied.

Furthermore considering characteristics of CANDU reactor, regional overpower could be deepened by creep in pressure tube, change in reactor inlet and outlet header temperature and transition of difference pressure between RIH and ROH caused by degradation. Thus effect of degradation on minimum allowable channel flow is evaluated in this study.

2. Method and prerequisite for establishing preliminary minimum allowable channel flow rate

2.1 Computational code methodology

Methodology and Computational code system used in sensitivity analysis for determining minimum channel flow is depicted in Fig 1 and Fig 2 respectively.

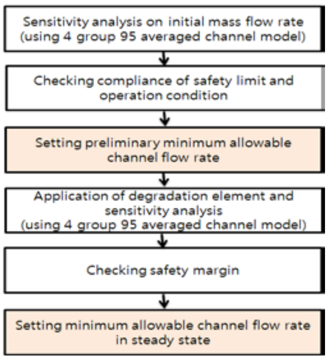

Fig 1. Evaluation logic used to establish preliminary minimum allowable channel flow rate

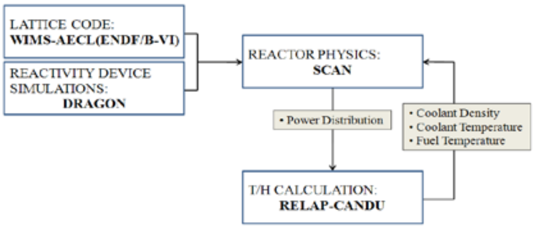

Fig 2. Computational code system used in sensitivity analysis

2.2 Limiting condition and allowable criteria

Safety limits, operating limits and allowable criteria below are used to evaluate validity of flow rate. [1][2]

\# Safety Limits
- Maximum channel power < 9.03MW (Mode 1, 2)
- OHD pressure < 11.77MP(g) (Mode 1, 2, 3)

\# Operating Limits
- Channel power from reactor to coolant: < 7.07MW
- Bundle power from reactor to coolant: < 898kW
- Pressurizer level: 0.8m < level < 13.91m
- OHD quality: < 4% etc.

\# Allowable Criteia
- Stored energy of hottest fuel rod: 840kJ/kg-UO_2
- Cladding temperature: < 800℃ - intact cladding
- Pressure tube temperature: < 600 ℃
- Maximum channel power: <7300kW
- Maximum bundle power: <935kW etc.

2.3 Degradation elements

Aging elements clarified in the previous studies are used to evaluate degradation effect.[3] The aging elements are listed on Table 1.

Table 1: Aging elements related to operating parameter.

Component	Ageing Element
Fuel Channel	Roughness, Loss Coefficient, Hydraulic Diameter, Flow Area
Pump	Pump Head, Pump Rated Flow
Steam Generator	Roughness, Hydraulic Diameter, S/G Divider Plates Leakage Area
Inlet Feeder + End Fitting	Roughness

3. Preliminary minimum flow rate in steady state evaluated from sensitivity analysis

3.1 Sensitivity Analysis on mass flow rate

To determine preliminary minimum channel flow, sensitivity analysis is fulfilled by varying flow rate from 90% to 115% of nominal value. As results of sensitivity analysis, it is obvious that many limits and criteria are satisfied. One example is depicted in Fig 3.

However OHD quality does not meet operating limits at the design values.(Fig 4) To determine optimal value for meeting the criteria, cubic fit of Fig4 path 2 which is most limiting path are obtained in Table 2. The optimal value evaluated using cubic fit is **1938.6kg/s** per 95 channels.

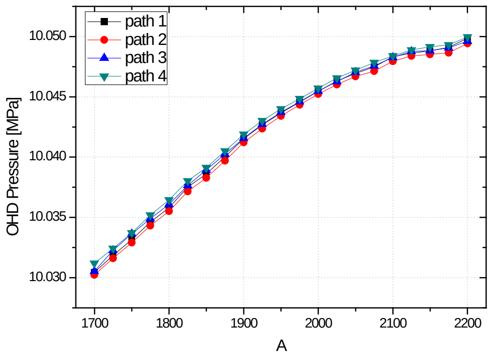

Fig 3. Sensitivity analysis example – relationship btw mass flow rate and OHD pressure

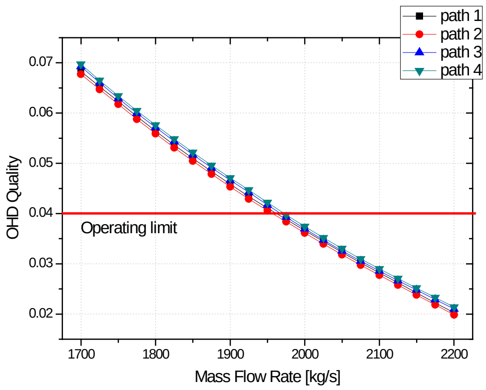

Fig 4. Sensitivity analysis example – relationship btw mass flow rate and OHD quality

Table 2:Cubic fit of Fig 4 path2

$y = A + Bx + Cx^2 + Dx^3$		
Reduced chi square	3.21×10^{-9}	
Adj. R square	0.999	
Parameter	Value	Standard Error
A	8.04×10^{-1}	3.38×10^{-2}
B	-8.87×10^{-4}	5.23×10^{-5}
C	3.55×10^{-7}	2.69×10^{-8}
D	-5.19×10^{-11}	4.60×10^{-12}

3.2 Sensitivity Analysis on Aging Elements

Effect of aging elements listed in Table 1 is evaluated through sensitivity analysis. According to previous study, fuel channel flow area is most affecting element on regional overpower.[4] The Fig 5 represents OHD quality change along with degradation in fuel channel flow area.

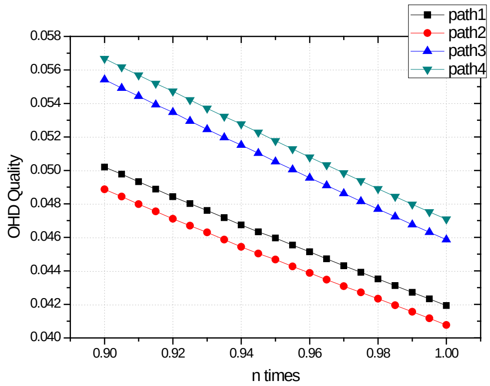

Fig 5. Sensitivity analysis example – relationship btw fuel channel flow area and OHD quality

OHD quality can be changed up to 120.8% of nominal value is identified through Fig 5. Thus minimum flow rate determined previous section should be revised. The modified value considering aging effect and applying conservatism is **2013.4kg/s** per 95 channels.

4. Conclusions

CANDU reactors are generally operated with 110% of nominal flow rate (2100kg/s) for securing safety margin, although design value of flow rate is set to 1900kg/s. But minimum allowable flow must be determined and complied to enhance reactor safety by assuring cooling capacity.

In this study, preliminary minimum allowable flow rate in steady state is determined considering aging effect and conservatism. Accident analysis is to be performed additionally for establishment of trustable minimum allowable flow rate.

REFERENCES

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