Effect of Axial Nodal Sections in a Faster-Running DNBR Program

Wang-Kee In [a*], Tae-Hyun Chun [a], Seung-Yeob Baeg [b]
[a] *Korea Atomic Energy Research Institute*
[b] *Doosan Heavy Industries Constructions Company Ltd.*
[*] *Corresponding author: wkin@kaeri.re.kr*

1. Introduction

A faster-running thermal-hydraulic code, CETOP [1], has been developed to calculate the minimum Departure from Nucleate Boiling Ratio (DNBR) in a pressurized water reactor core. It calculates the minimum DNBR based on a four-channel core model. A three-dimensional transport coefficient model is used to radially group a flow subchannel into a 4-channel core representation. The CETOP program solves the transport coefficient conservation equations by the finite-difference method. The conservation equations in the finite-difference form are solved by a non-iterative numerical scheme, i.e., prediction-correction scheme. The prediction-correction method is a non-iterative numerical scheme which provides a fast solution for thermal-hydraulic parameters at each axial elevation from the core inlet to outlet.

The accuracy of the finite-difference solution would largely depend on the size of the axial nodal sections particularly for the non-iterative scheme for solving the transport coefficient conservation equations. The number of axial nodes in CETOP varies depending on its applications to a Core Operating Limit Supervisory System (COLSS) [2], a Core Protection Calculator (CPC) [3] and the CETOP-D code [4]. The CETOP program is also employed in an advanced reactor core protection system (RCOPS) [5]. It is therefore valuable to examine the effects of the axial nodal sections in the faster-running DNBR program. This paper presents the variations of the minimum DNBR depending on the number of axial nodes.

2. Methods and Results

2.1 CETOP Models

The simpler versions of the CETOP program are used in COLSS and CPC to determine an on-line minimum DNBR. COLSS and CPC solve the finite-difference governing equations using the pre-determined values of the transport coefficients for an enthalpy, axial velocity and pressure. The number of axial nodal sections is 20 and 10 for COLSS and CPC, respectively.

The CETOP-D code has been developed to predict the minimum DNBR (MDNBR) using the 4-channel core model(Fig.1) and the prediction-correction scheme. Channel 2 is a quadrant of the hottest assembly in the core and Channel 1 is an assembly representing the average coolant conditions for the remaining portion of the core. Lumped channel 2 includes channels 3 and 4. Channel 3 lumps the subchannels adjacent to the MDNBR hot channel 4. Lumped channels $2'$ and $2''$ are used to estimate the value of the transport coefficient for an enthalpy (N_H). CETOP-D solves the finite-difference governing equations with a self-generation of the N_H value. Since the value of N_H is known to be strongly dependent upon core operating conditions, the CETOP-D code determines N_H for each axial node using the enthalpies of channels $2'$ and $2''$. The CETOP-D model is recommended to use 40-axial nodal sections.

The CETOP-D code is as accurate as and faster-running than the simplified subchannel code, S-TORC [6]. Thus, it is used in practical thermal-hydraulic designs and a DNB-limiting transients analysis. It also provides the reference calculations of MDNBR for COLSS and CPC. Furthermore, a slightly modified version of CETOP-D is implemented in RCOPS in order to more accurately calculate the MDNBR than the CPC. Hence, the CETOP-D code is used in this study to compare the MDNBR values for the axial nodal sections of 10, 20, 30 and 40.

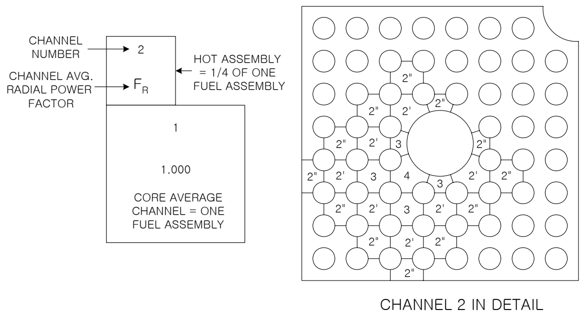

Fig. 1. Layout of the CETOP-D four-channel model.

2.2 Results

96 test cases were used to calculate the MDNBR values for the four different axial nodal sections. These cases include a wide range of reactor core operating conditions. The MDNBR values for the 40-node case are used as a reference to estimate a relative error of the MDNBR for the cases with a lesser number of axial nodes.

Figure 2 shows the comparison of the relative MDNBR errors for different numbers of axial nodes. It clearly shows that the relative error increases as the number of axial node decreases. Particularly, the 10-node case significantly increases the MDNBR error. The maximum error is estimated as 1.37%, 6.65% and 14.1% for the 30, 20 and 10-node cases, respectively.

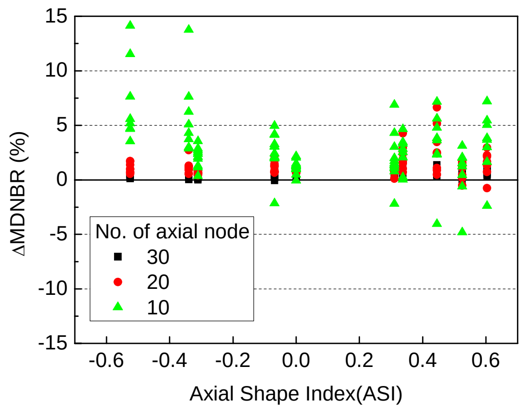

Fig. 2. Relative MDNBR error depending on the number of axial node.

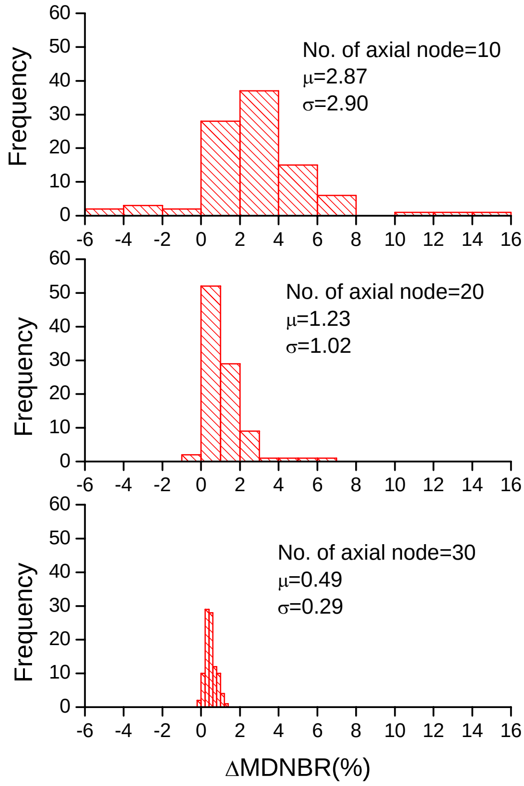

Fig. 3. Statistical distributions of relative MDNBR errors.

The relative error appears to increase as the axial shape index of the core power increases.

Figure 3 compares the statistical histograms of the relative MDNBR error. The 30-node case shows a normal distribution of the relative error that is bounded by a 1.5% difference from the 40-node case. Although the 20-node case gives a somewhat larger error at some specific conditions, its relative error appears to be bounded by 5%. It can be noted that the relative error for the 10-node case is larger than 5% at a significant number of operating conditions. It can be seen in Fig. 3 that both the mean value(μ) and standard deviation(σ) significantly increase as the number of axial nodes decreases. The positive mean error indicates that the MDNBR value is over-predicted as the number of axial nodes decreases.

3. Conclusions

Using the reference faster-running DNBR program, CETOP-D, the variation of the minimum DNBR is examined for the axial nodal sections of 10, 20, 30 and 40. It was found that the relative MDNBR error increases and the MDNBR value is over-predicted as the number of axial nodes decreases. The relative MDNBR error tends to increase significantly if the number of axial nodes is less than 20. The bounding relative MDNBR error is estimated as 5% and 1.5% for the 20 and 30-node cases, respectively. It is recommended for a faster-running DNBR program to use more than 20 axial nodes for an accuracy as well as a faster running.

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