A comparative evaluation of NDR & PSAR using the CASMO-3/MASTER code system

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1. Introduction

In order to validate nuclear design data such as the nuclear design report (NDR) and data in preliminary (or final) safety analysis report (PSAR/FSAR) and to use data for the conceptual design of new plants, the CASMO-3/MASTER code system is selected as utility code. The nuclear design of OPR1000 and APR1400 is performed with the DIT/ROCS code system. In contrast with this design code system, the accuracy of CASMO-3/MASTER code system has not been verified. Relatively little design data has been calculated by the CASMO-3/MASTER code system for OPR1000 and APR1400 and a bias system has not been developed yet. As such, validation of the performance of the CASMO-3/MASTER code system is necessary.

In order to validate the performance of the CASMO-3/MASTER code system and to develop a calculation methodology, a comparative evaluation with NDR of Ulchin unit 4, cycle 1(U4C1) [2] and the PSAR of Shinkori units 3&4 [1] is carried out. The results of this evaluation are presented in this paper.

2. Evaluation Method and Results

Among the contents in NDR [2], 26 items are selected for the comparative evaluation excluding Isotopic Inventory, Xenon and Samarium related data, and Minimum Boron concentration for the shutdown margin requirement. Table1 shows the representative items.

Table 1. Representative evaluation items in NDR

- Critical boron concentration (CBC) vs. Core average burn-up
- Core average axial power profile
- The assembly-wise relative power distribution
- MTC vs. Burn-up
- MTC vs. Moderator temperature and ppm
- Fuel temperature coefficient vs. Power level
- ITC vs. Moderator temperature and ppm
- Boron worth vs. Burn-up
- Boron worth vs. Temperature and ppm
- Integral and Differential CEA group worth vs. cm Withdrawal with overlap

In the case of the PSAR [1], CBC vs. core average burn-up, assembly-wise relative power distribution, core average axial power profile, and CEA group worth are selected.

The calculation procedure and methodology of the NDR are followed for the evaluation. The uncertainty values of the CASMO-3/MASTER nuclear analysis system [4] are used as criteria of satisfaction. If the difference between the calculation result and NDR (or PSAR) value is inside the range of uncertainty, the result is considered satisfactory. These uncertainty values are presented in Table 2.

Table 2. Uncertainty of CASMO-3/MASTER

Nuclear Design Parameter	Uncertainty
Reactivity	410pcm
Power peaking factors (Fxy, Fr, Fq)	0.05-0.07
Isothermal / Moderator temp. Coefficient	2.5pcm/℃
Power Coefficient	1.6pcm/power
Individual / Accumulated rod worth	15 / 10%
Inverse boron worth	12%
Fuel Temperature Coefficient	15%

2.1 CBC vs. Core Average burn-up

The design criterion of the critical boron concentration is typically ±50ppm, the difference between actual data of nuclear power plant and design values. This value is adopted as the satisfaction criterion for the evaluation. The maximum difference of the U4C1 NDR case is -40.8ppm at 2,008MWD/ MTU and that of PSAR case for Shinkori units 3&4 is -44.5ppm at 4,000MWD/MTU. Fig. 1 shows the results of the PSAR case.

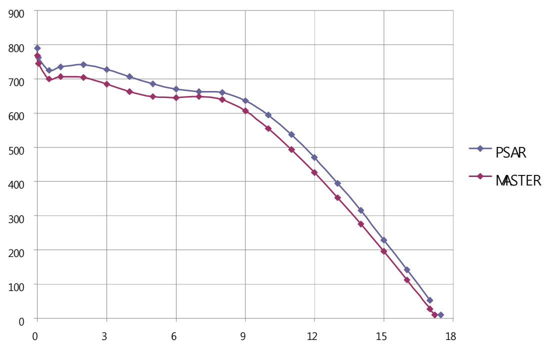

Fig. 1. Critical Boron Concentration (CBC) vs. Core average burn-up for Shinkori units 3&4 PSAR

CBC calculated by MASTER is lower than that of PSAR by an average of 32ppm. This corresponds to 6.7 full power days. Judging from this comparative evaluation of U4C1 NDR and Shinkori units 3&4 PSAR, the CASMO-3/MASTER code system appears to produce a lower CBC than the DIT&ROCS code system.

2.2 Power distribution

In the case of assembly-wise relative power, the maximum difference of the NDR case is 4.05% at 7,999 MWD/MTU and that of the PSAR case is 7.8% at 0MWD/MTU. Generally, however, the validation of the radial power distribution error is fulfilled with the assembly node bigger than relative power 1.0. Under this condition, the maximum differences are 2.65% at 3,011MWD/MTU and 5.13% at 0MWD /MTU. Fig. 2 shows the axial power profile. Judging from this comparison, the power distribution calculated by the CASMO-3/MASTER code system is reasonable.

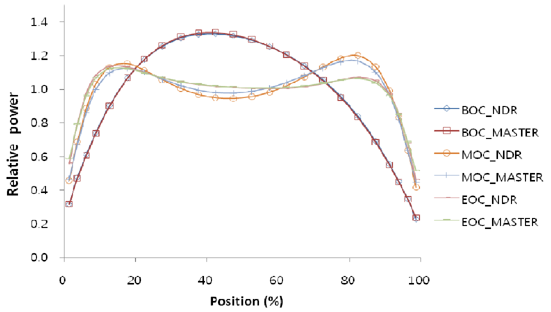

Fig. 2. Axial power profile for U4C1 NDR case

2.3 Reactivity Parameter

In order to produce “Fuel temperature coefficient vs. Power level” data for the U4C1 NDR case, the equation presented below is used. Table 3 presents the differences between the calculated values and NDR values.

$$FTC = \frac{\text{Reactivity2 - Reactivity1}}{\text{Fuel Temperature2 - Fuel Temperature1}} \times 10^5$$

Table 3. FTC difference vs. Power Level

Power(%)	0	20	40	60	80	100
Burn-up	difference (%)					
BOC	1.9	1.2	3.7	5.2	6.8	7.4
MOC	0.3	0.6	1.6	1.7	1.7	2.5
EOC	1.4	0.6	0.3	0.0	0.3	0.3

ITC corresponding to each power level is calculated by the addition of MTC corresponding to the power level and FTC at zero power. The maximum difference of ITC is 2.38pcm/℃ at EOC for a 60% power level.

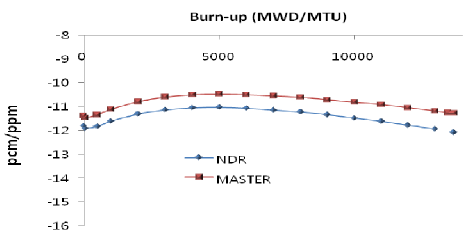

Fig. 3. Boron worth of U4C1 NDR

Fig. 3 presents the Boron worth. Its maximum difference is 6.4%.

The Power defect is calculated by the summation of the Moderator defect and Doppler power defect. Its maximum difference is 63.8pcm at BOC, 600ppm.

The Doppler power defect is the most dominant value with respect to the power defect. At the same burn-up, the moderator defect increases as the boron concentration decreases. The moderator temperature defect is most affected by the boron concentration.

Differential CEA worth is calculated with this equation and Bias is not applied. (bias = 1.0)

$$\text{CEA Worth Diff.(pcm/cm)} = \frac{(\rho 2 - \rho 1) \times \text{bias} \times 100000}{\text{CEA position2 - CEA position1}}$$

The maximum difference of the CEA group worth is 2.77%. In addition, Integral worth and Differential worth values are acceptable. Fig.4 shows the control group worth with overlap at EOC.

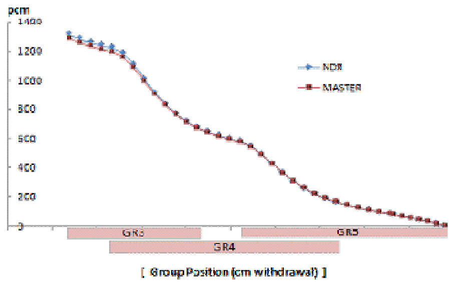

Fig. 4. Control group worth with overlap at EOC

3. Conclusions

All evaluation results are acceptable with respect to the applied criteria. This comparative evaluation shows the availability of the CASMO-3/MASTER code system for the validation of design data and the conceptual design of new plants. If a bias system is developed, it can be used as a design code.

MASTER code is the reference code of ASTRA (Advanced Static and Transient Reactor Analyzer) code, which is being developed as a nuclear design code. The findings of this study could facilitate the future use of ASTRA.

REFERENCES

[1] “Shinkori unit 3&4 Preliminary Safety Analysis Report”, 2003.

[2] “Nuclear Design Report for ULCHIN Nuclear Power Plant Unit 4 Cycle 1”, June 1999.

[3] “MASTER 3.0 USER’S MANUAL”, KAERI, March, 2004.

[4] “Verification and Uncertainty Evaluation of CASMO-3/ MASTER Nuclear Analysis System”, KAERI, June, 2000.

[5] “CASMO-3 A Fuel Assembly Burn-up Program User’s Manual”, January, 1991.