Improvement of Shutdown Margin Calculation Methodology under ARI Condition

Sang-Rae Moon *, Dong-Hwan Park, Young-Ae Kim, Yu-Sun Choi
Nuclear Reactor Safety Lab., KHNP Central Research Institute 1312-70 Yuseong-daero Yuseong-gu Daejeon, 34101, Korea
**Corresponding author: srmoonsr@khnp.co.kr*

Keywords: Shutdown Margin (SDM), Stuck Rod, Boron Concentration, PDIL

1. Introduction

In a nuclear power plant, it is essential to ensure a shutdown margin (SDM) to prevent exceeding Specified Aceptable Fuel Design Limit (SAFDL) during normal reactor operation or expected operational transients. The shutdown margin is defined as the extent of subcriticality that can be immediately reached when all control rod assemblies are inserted, assuming that a single control rod assembly with the highest reactivity is fully withdrawn. During full power operation, compliance with the Power Dependent Insertion Limit (PDIL) in accordance with the technical specification is being used to verify satisfaction with the shutdown margin. Additionally, during operation modes 3, 4, and 5, shutdown margin must be verified by considering various nuclear power plant operational conditions such as initial assumptions of safety analysis, boron concentration, and control rod assembly positions.

2. Methods and Results

2.1 Technical Background of Shutdown Margin

In safety analysis, the minimum required shutdown margin is assumed as the initial condition, and it is assumed that even after the reactor has come to a shutdown, the control rod with the highest reactivity value is stuck. The most restrictive accidents related to shutdown margin are the main steam line rupture accident and the inadvertent boron dilution accident.

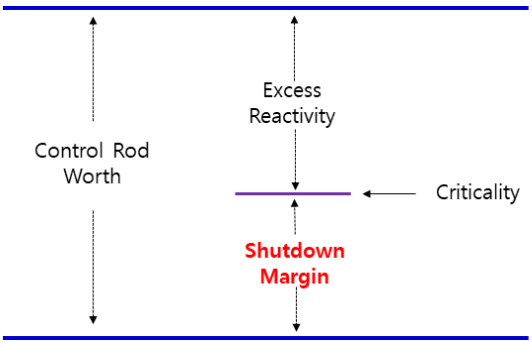

Fig. 1. The Concept of Shutdown Margin

2.2 Scheduled Power Decrease

Shutdown margin check should be applied differently depending on the insertion state of the control rod during operation modes 3, 4, and 5. When decreasing reactor power for scheduled maintenance, since not all control rods are inserted, it is necessary to conservatively calculate the shutdown margin by considering the possibility of stuck control rods. If the boron concentration for satisfying the shutdown margin is insufficient considering the periodic shutdown margin check interval, boron should be injected at the maximum rate.

2.3 Unscheduled Reactor Trip

During unscheduled reactor trip while in normal operation, all control rods are dropped and inserted into the core. Therefore, the consideration of stuck rod is not necessary. When it is confirmed that all control rods are fully inserted into the core through two independent methods, such as the bottom indicator light of the control rod being illuminated and control rods being reached the lower electric limit, the stuck control rod with the highest reactivity need not be considered in the shutdown margin calculation.

2.4 Review of Nuclear Design Report

2.4.1 Short-Term Improvement Method

The nuclear design report that nuclear reactor operators are using as reference material for shutdown margin calculations is overly conservative, as it presents control rod worth only under the assumption of stuck control rod. To accurately calculate the most reactive stuck control rod for shutdown margin, sensitivity evaluations were performed based on boron concentration and temperature variations. In conclusion, by improving the method of calculating boron concentration for shutdown margin satisfaction under all control rod insertion conditions, it was confirmed that shutdown margin is satisfied under various power plant operational conditions.

C_B *(ARI)=*C_B *(N-1)–SRW*(1-Uncertainty)/BW* ------(1)

Where, C_B *(ARI): boron concentration for shutdown margin satisfaction (ppm)*
C_B *(N-1): boron concentration under stuck rod out condition (ppm)*
SRW: stuck rod worth (pcm)
Uncertainty: uncertainty of stuck rod worth
BW: boron worth (pcm/ppm)

2.4.2 Long-Term Improvement Method

As a long-term solution, a proposal was presented to the fuel vender to incorporate all control rod insertion status conditions into the "Minimum Boron Concentration Curve for Reactivity Margin Satisfaction" in the nuclear design report for improvement. For accurate shutdown margin calculations, it is necessary to improve the design process during subsequent cycle core design.

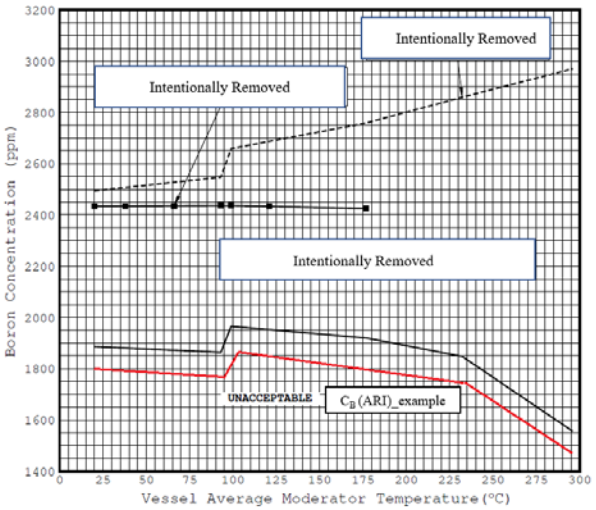

Fig. 2. Minimum RCS Boron Concentration for Shutdown Margin Requirement

2.5 Restart after Reactor Shutdown

When withdrawing control rods for reactor restart after an unplanned shutdown, the reactivity margin calculation should assume, as in the existing procedure, that the most reactive control rod is stuck to calculate the shutdown margin conservatively.

3. Conclusions

When all control rods are fully inserted into the core, there is no need to consider the most reactive stuck control rod when calculating shutdown margin. This has led to a more precise calculation of shutdown margin. By developing a method for calculating the minimum boron concentration required to satisfy shutdown margin with all control rods inserted, it has become possible to minimize the generation of liquid waste through unnecessary boron injection and dilution operation. Additionally, technical justifications have been established to enable nuclear reactor operators to accurately apply technical specification that match the operating conditions. Following the revision of shutdown margin-related procedures and nuclear design report, there is plan to implement them at the power plant. Furthermore, validation will be conducted using measurement data.

REFERENCES

[1] The Nuclear Design Report for OPR1000 and APR1400 Plant, KNF
[2] Procedure of Shutdown Margin Calculation, KHNP
[3] ANSI/ANS-19.6.1-2005, “Reload startup physics tests for PWRs,” American Nuclear Society, 2005