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A Reactivity Evaluation of Hypothetical Misloadings for WEC 3-Loop Type Plant

Seong-ho Park*, Seung-beom Son, Ki-bong Seong, Chae-joon Lim
KEPCO Nuclear Fuel, 242, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon 34057, Republic of Korea
**Corresponding author: seonghopark@knfc.co.kr*

1. Introduction

A fuel misloading is collectively referred to as a case where one or more fuel assemblies are unintentionally loaded in improper positions, or the fuel assemblies manufactured such that the enrichment or the number of burnable absorbers are different from the design specifications are loaded.

Since, generally in WEC (Westinghouse Electric Company) type plants, the fuel misloading is prevented by administrative procedures implemented during core loading, it is considered as one of Condition III incidents that may occur very infrequently during the life of the plant. Based on this, the relevant safety analysis is composed of a detectability assessment for loading errors and is contained in SAR (Safety Analysis Report). However, there would be the potential for losing the required safety shutdown margin or for an inadvertent criticality due to any severe misloaded fuel assembly configuration that is very difficult to arise practically in the course of a refueling. Furthermore, current circumstances of plant operation using fuel assemblies which have a highly enriched U-235 to extend the length of fuel cycles amplifies that concern.

This study is designed to confirm the adverse effects caused by fuel misloading for a domestic WEC 3-loop type plant reflecting the recent operation condition. An evaluation of the core criticality for some severe cases of fuel misloading is involved in this study. With results of the evaluation, it can be estimated roughly how safety limits for refueling which are specified in plant Technical Specifications are effective even in any hypothetical severe misloading cases.

2. Backgrounds

The purpose of this chapter is to provide the knowledge needed for the study of fuel misloading to be focused on. First, the descriptions of the fuel misloading in WEC type plant design methodology are introduced, and then the previous study performed for loss of shutdown margin and inadvertent criticality due to fuel misloading for CE (Combustion Engineering) type plants is summarized and reviewed.

2.1 Fuel Misloading in WEC Plant Design Methodology

WEC plant design methodology suggests a method for dealing with the accident caused by the inadvertent loading and operation of a fuel assembly in an improper position.

It's assuming the accident hardly occurs because core loading is governed by administrative procedures intended to conform the Technical Specification requirements in which the loss of shutdown margin for safety during refueling is not permitted. Fuel assembly misloading which makes power distribution peaked significantly in excess of the design value could be easily discovered by in-core flux movable detector systems. In addition to the in-core detector, thermocouples which are located at the outlet of about one third of the core is capable of detecting any abnormally high coolant enthalpy rise that would be caused by fuel assembly misloading. Through these systems, abnormal core conditions due to fuel misloading is sufficiently detected during the startup subsequent to every refueling operation and thus the accident can be prevented from occurring.

In this unlikely event, analyses are intended to confirm that resulting power distributions will either be easily detected by the in-core movable detector system or their effects will be small enough to be acceptable within the uncertainties allowed.

The analyses reported in the SAR consist of evaluating the reaction rate error at the detected location for five representative cases that indicate various fuel configurations misloaded by interchanging or enrichment error.

Meanwhile, these descriptions in this methodology don't include the consideration for the consequences caused by any severe intermediate fuel assembly misloading configuration which would arise during refueling operation.

2.2 Loss of Shutdown Margin for Refueling in CE Type Plant [1]

This contains a study of the frequency and consequences of misloading fresh fuel assemblies during the refueling of CE type plants. The study had been carried out by Brookhaven National Laboratory at the request of NRC to understand the potential for losing shutdown margin and for inadvertent criticality due to misloading of fuel.

The quantitative analysis for the consequences of fuel misloading was achieved by evaluating the shutdown margin of misloaded core. The evaluation was done with modeling a few cases of misloading core and calculating the k-effective value of each case by using particular codes which have been widely used as a reactor analysis tool. For modeling a core, the basic neutronics data needed for each fuel assembly were generated from the unit assembly calculations based on two-dimensional, multi-group transport theory. Using these data, core calculations which result in core design parameters were done by a three-dimensional few collapsed group-based nodal code.

A specific plant and cycle (Cycle 9 of Calvert Cliff 2) in which reload fuel assemblies with a high U-235 enrichment (4.3 w/o) were used was chosen to be modeled. Misloaded configurations were determined to have the fresh fuel assemblies clustered together at the center of the core with some different patterns. Calculations were performed at a temperature (311K) and boron concentration (2300 ppm) corresponding to the lower limit imposed by Technical Specifications during refueling operation. In order to make the calculation conservative it is assumed that the misloaded fresh fuel is the type with no burnable poison rods.

Results of calculations were shown as a graph of k-effective vs the number of fresh fuel assemblies (1, 3, 5 and 9) clustered together at the center of the core. From the curve it could be seen that the required shutdown margin of 5% is lost when 5 or more assemblies are clustered and critical state is possible when 9 assemblies are grouped together.

A frequency of fuel misloading was analyzed for the same plant by probabilistic assessments. The assessment was carried out with calculating the probability of obtaining either of two patterns of misloading fresh fuel assemblies. Those patterns was composed of a group of four fuel assemblies placed in a 2×2 array with no CEA (Control Element Assembly) and five assemblies in a cross configuration again with no CEAs, which could be considered to cause the loss of shutdown margin as mentioned above. The probabilities of filling these two different types of positions with fresh fuel without a CEA were calculated by multiplying together individual probabilities which had estimated by developing fault trees that included various human errors which could contribute to the problem.

According to the results of the frequency analysis, assuming the industry average of 0.75 refuelings per RY (reactor year), the frequency of losing the required shutdown margin which could be caused by 4 fresh fuel assemblies clustered together was expected as 8.0E-7/RY. In addition, the frequency of inadvertent criticality occurrence by 9 fresh fuel assemblies clustered together was found to be less than 1.0E-8/RY.

3. Calculation Methods

This study for reactivity worth effect due to fuel misloading was performed in a WEC 3-loop type plant with the method used in the previous study of loss of shutdown margin described in section 2.2.

A core model designed for the recent cycle of a domestic WEC 3-loop type plant was used for this study. In the core model, fresh fuel assemblies which had UO_2 rods consisting of high enriched U-235 of 4.65 w/o (with 2.2 w/o axial blanket) and 8 w/o gadolinia rods as burnable absorbers equipped with specific patterns were used.

In the similar way as the previous study, the configurations of misloaded core were constructed to make fresh fuel assemblies gathered into the center of the core by interchanging. The fuel assemblies to be misloaded should be intended to derive large increase of core reactivity. Therefore, the fuel assembly type with the number of burnable absorber as small as possible is chosen as the fresh fuel to be misplaced. In addition, it deserves to be considered for more conservative evaluations that misplaced fuel does not contain a control rod as that would lead to the reactivity worth reduction. The configurations with 1, 3, 5 and 9 fresh fuel assemblies misplaced in this manner were illustrated in Fig. 1.

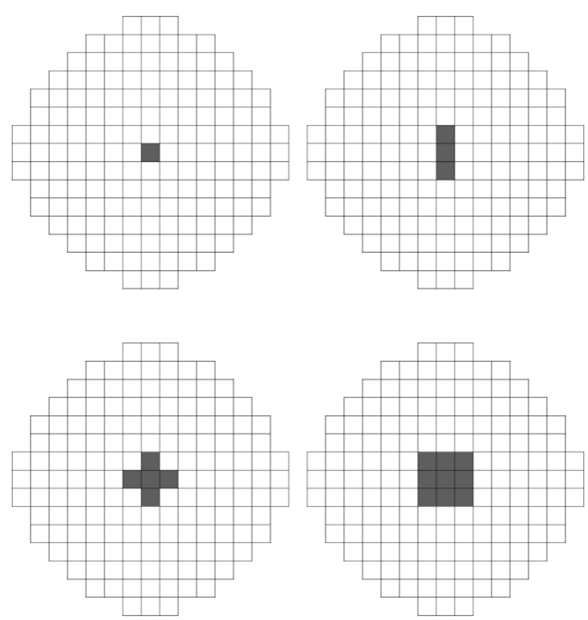

Fig. 1. Configurations for Multiple Misloading Feed Assemblies

Using a code system which is being utilized in practice for nuclear design, the unit assembly calculations for each assembly and whole core calculations were conducted. The calculations have assumed the refueling operation condition in which a temperature was 68˚F and no xenon exist with all control rods inserted. In the exceptive case, the calculation for 9 misloads was done with four control rod elements which were located diagonally from the center fully withdrawn to make the calculation conservative. Results of those calculations were shown as values of boron concentration expected to make the core get to the loss of shutdown margin or inadvertent criticality.

4. Results and Discussion

Fig. 2 is a graph of boron concentrations which were calculated at eigenvalues of 0.95 and 1 versus the number of fresh fuel assemblies clustered together at the center of the core. Detailed resulting value are summarized in Tab. 1.

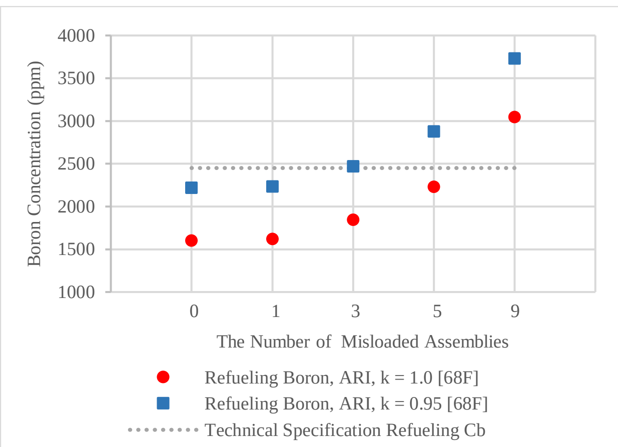

Fig. 2. Boron Concentrations for Misloaded Configurations

Cases	Misloaded Assemblies				
	0	1	3	5	9
Refueling Boron (ppm), ARI, k = 1.0 [68F]	1601	1618	1844	2228	3042
Refueling Boron (ppm), ARI, k = 0.95 [68F]	2215	2231	2466	2876	3730

Tab. 1. Boron Concentrations for Misloaded Cases

According to the plant Technical Specifications, it is required that k-effective be less than or equal to 0.95 to assure the core is maintained to be subcritical sufficiently during refueling operation. Based on this requirement, the check of operation limiting condition for refueling is done by calculating the boron concentration required to retain the shutdown margin of 5% and comparing with the limit value.

Two curves in the graph show the results of each calculation with k-effective set to 0.95 and 1 respectively. These resulting values were estimated considering uncertainty allowance (100 ppm) which has been applied for evaluation of boron concentration at refueling condition in the actual nuclear design procedure. With no misplaced fuel the boron concentrations calculated for 5% shutdown margin is 2215 ppm, which is less than the limit value of 2450 ppm determined in plant Technical Specification.

From the above table, it can be found out that misloading 3 or more fresh fuel assemblies in the center of the core especially make the core lose the required shutdown margin of 5% and 9 assemblies lead to the critical state.

5. Conclusions

This paper contains the quantitative study for loss of shutdown margin and inadvertent criticality caused by such a hypothetical multiple fuel misloading which would arise during refueling operation. The study was attained by core calculations for some misloaded configurations realized to make fresh fuel assemblies placed together in the center of the core.

Although the results show that 3 or more clustered fresh fuel assemblies need more boron concentration than the limit for refueling specified in Technical Specifications to retain the shutdown margin of 5%, the occurrence of this event seems to be extremely rare. [1]

In the conclusion, this study can help understanding the consequences of hypothetical multiple misloading fuel and can be utilized as a reference case study.

6. Future Plan

This study was performed for only a WEC 3-loop type plant. For more general evaluation, further studies for various core condition seem to be necessary.

REFERENCES

[1] David. J. Diamond, “LOSS OF SHUTDOWN MARGIN DURING PWR REFUELING”, Brookhaven National Laboratory, 1991.