

Thermal Margin Model for Transition Core of KSNP

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Abstract

The PLUS7 fuel was developed with mixing vane grids for KSNP. For the transition core partly loaded with the PLUS7 fuels, the procedure to set up the optimum thermal margin model of the transition core was suggested by introducing AOPM concept into the screening method which determines the limiting assembly. According to the procedure, the optimum thermal margin model of the first transition core was set up by using a part of nuclear data for the first transition and the homogeneous core with PLUS7 fuels. The generic thermal margin model of PLUS7 fuel was generated with the AOPM of 138%. The overpower penalties on the first transition core were calculated to be 1.0 and 0.98 on the limiting assembly and the generic thermal margin model, respectively. It is not usual case to impose the overpower penalty on reload cores. It is considered that the lack of channel flow due to the difference of pressure drop between PLUS7 and STD fuels results in the decrease of DNBR. The AOPM of the first transition core is evaluated to be about 135% by using the optimum generic thermal margin model which involves the generic thermal margin model and the total overpower penalty. The STD fuel is not included among limiting assembly candidates in the second transition core, because they have much lower pin power than PLUS7 fuels. The reduced number of STD fuels near the limiting assembly results in decreasing the loss of flow from the limiting assembly to increase the thermal margin for the second transition core. It is expected that cycle specific overpower penalties increases the thermal margin for the transition core. Using the procedure to set up the optimum thermal margin model makes sure that the enhanced thermal margin of PLUS7 fuel can be sufficiently applied to not only the homogeneous core but also the transition core.

1. Introduction

The PLUS7 fuel was developed for Korean Standard Nuclear Power Plants (KSNP). The most outstanding feature of the PLUS7 fuel is the mixing vane grid, which the current KSNP

standard (STD) fuel doesn't have. The mixing vane improves heat transfer between coolant and fuel rod to increase thermal margin, while it also increases pressure drop of fuel assembly. The thermal performance of PLUS7 fuel was evaluated by comparing the corresponding Critical Heat Flux (CHF) data of the PLUS7 and STD fuels. The increase in thermal margin of the PLUS7 fuel against KSNP STD fuel is about 12.8% in term of power. The KCE-1 CHF correlation was developed based on the data of PLUS7 fuel, whose functional form is the same as that of the CE-1 CHF correlation^[1] used for thermal design of KSNP. The pressure drop of PLUS7 fuel was evaluated to increase 9.8% compared with that of the STD fuel. A series of safety analyses were performed for the KSNP transition core, partly loaded with the PLUS7 fuel. When nuclear fuels of new type are loaded in core, there are normally twice transition cores because the fuels burn during three cycles. The first step of the analyses is to set up thermal margin model for the transition core. The thermal margin model calculates the minimum Departure from Nucleate Boiling Ratio (DNBR) and the overpower margin at the operating condition obtained by the on-line monitoring and protection systems and evaluates the accident analyses related to DNB. However, the procedure to set up the thermal margin model for a transition core has not been established, because there is no experience in a transition core for the digital plant with Core Operating Limit Supervisory System and Core Protection Calculator System (COLSS/CPCS), like KSNP. To fully employ the enhanced thermal margin of the PLUS7 fuel, it is required to optimize thermal margin model for transition cores as well as homogeneous cores. The objectives of this paper are to present the generation methods of thermal margin model and to set up the optimum thermal margin model for transition cores.

2. Procedure to Set up Optimum Thermal Margin Model

Generally the thermal margin model (CETOP model) is benchmarked to calculate the DNBR conservatively against the TORC DNBR results; the CETOP code^[2] is a fast running tool with the simplified model which calculates the minimum DNBR in the limiting subchannel, while the TORC code^[3] performs detailed subchannel analysis for both the core and the limiting assembly and calculates DNBR in the subchannels.

2.1. Screening Method

For the generation of thermal margin model, a limiting assembly is first determined through DNBR analysis. TORC code calculates DNBRs of the assemblies with pin power above 90 % of the core maximum pin power and limiting assembly candidates are selected. It is difficult to determine the limiting assembly by the DNBR analysis, especially for the transition core loaded with new and STD fuels. The reasons are as follows:

- It is possible for an once burned STD fuel to be the limiting assembly in the first transition core which consists of the PLUS7 fuel and the once/twice burned STD fuels, due to the enhanced thermal margin of the PLUS7 fuel. However, the STD fuel is not included among assemblies with pin power above 90 % of the core maximum pin power, because STD fuel has lower pin power than PLUS7 fuel.

- DNBR values of new and STD fuels do not have the same meaning from the viewpoint of thermal margin, because CHF correlations and DNBR limits of new and STD fuels are different from each other.

The screening method should be modified to select the limiting assemblies for the transition core. The following methods were suggested in this paper to solve the problems above:

- New and STD fuels of the transition core are separately considered even in the same core. PLUS7 fuel assemblies with pin power above 90 % of the maximum pin power of PLUS7 fuels are chosen among PLUS7 fuels and STD fuel assemblies with pin power above 90 % of the maximum pin power of STD fuels are chosen among STD fuels, respectively.
- Instead of DNBR calculation, heat flux searching is introduced into the screening method to determine the limiting assembly. TORC code searches the heat flux corresponding with DNBR limit of each fuel type at a given operating condition. It is a distance from the nominal heat flux to the heat flux corresponding with DNBR limit at the current operating condition, and the ratio of the searched heat flux to the nominal heat flux means an available overpower margin (AOPM). By comparing the AOPMs for new and STD fuels, the limiting assemblies can be determined for the transition core.

2.2. Optimum Thermal Margin Model

A generic thermal margin model is generated for a reference cycle and its conservatism is verified using cycle specific data in every reload designs. If its conservatism is violated, the loss should be compensated by the following equation:

$$OP_{TM} = \frac{(Heat\ Flux)_{TORC}}{(Heat\ Flux)_{CETOP}} \quad (1)$$

where OP_{TM} is an overpower penalty on the thermal margin model and $(Heat\ Flux)$ is the heat flux searched by the corresponding code. This approach can be applied for the fuels of the same type because DNBR values of new and STD fuels have different meanings from the viewpoint of thermal margin. The thermal margin model of PLUS7 fuel is used on the transition core so that the enhanced thermal margin of PLUS7 fuel can be applied sufficiently to the transition core, but first an applicable evaluation method of the thermal margin model should be established in case of occurring limiting assembly in STD fuels. The procedure to set up the optimum thermal margin model of transition core is suggested as follows:

- a. TORC code calculates heat flux for fuel assemblies with pin power above 90 % of the maximum pin power in the homogeneous core of PLUS7 fuel. Using the inlet flow distribution of quarter core with the lowest inlet flow factor of the fuel assembly performs the calculation at the nominal operating condition. Limiting assembly is selected from the viewpoint of AOPM. A generic thermal margin model is generated to benchmark against the DNBR results of TORC simulating the core and the limiting assembly in detail.
- b. The limiting assemblies are determined for PLUS7 and STD fuels in the transition

core, respectively. If the AOPM of PLUS7 fuel is lower than that of STD fuel, go to next step. Otherwise, an overpower penalty is calculated by following equation.

$$OP_{LA} = \frac{(AOPM)_{STD}}{(AOPM)_{PLUS7}} \quad (2)$$

where OP_{LA} is an overpower penalty on the limiting assembly and $(AOPM)$ is available overpower margin calculated by TORC code for corresponding fuel.

- c. The conservatism of the generic thermal margin model, generated in step 1, is verified against the limiting assembly of PLUS7 fuel selected in step 2. If its conservatism is violated, the overpower penalty is calculated by the equation (1). Basically, no overpower penalty means to be OP of 1.0. The optimal thermal margin model of the transition core involves the generic thermal margin model and total overpower penalty as follows;

$$OP = OP_{LA} \times OP_{TM} \quad (3)$$

The procedure is plotted in Figure 1.

3. Application

The generic thermal margin model and its overpower penalty will be produced for the homogeneous core of PLUS7 fuels and the first transition core of Yonggwang Unit 5, respectively. The loading pattern of the transition core is presented in Figure 2. A part of the nuclear data in the first transition and the homogeneous cores were used to verify the procedure to set up the optimum thermal margin model of transition core, described in Chapter 2.

3.1. Limiting Assemblies

At first, limiting assembly candidates were selected to generate the generic thermal margin model for the homogeneous core of PLUS7 fuels. TORC code was used to search heat fluxes corresponding with the DNBR limit of PLUS7 and to calculate AOPMs for assemblies with pin power above 90 % of the core maximum pin power. DNBR analysis was performed to compare the new screening method with the old one for the same assemblies. Then, 10 axial power shapes whose peaks distribute evenly between top and bottom peaks, were used at the nominal operating condition as follows:

System Pressure	:	2250	<i>psia</i>
Core Inlet Temperature	:	564.5	<i>°F</i>
System Flow Rate	:	330,000	<i>gpm</i>

The limiting assembly candidates determined through the calculation of AOPM and DNBR

were a little different from each other, but limiting assembly was finally same after the generation of thermal margin model. It can be concluded that both of the new and old method have basically the same concept and are valid. Secondly, limiting assemblies were determined by using the new screening method to evaluate overpower penalty of the STD fuel in the first transition core. AOPMs were calculated by using TORC code for PLUS7 assemblies with pin power above 90 % of the maximum pin power of PLUS7 fuel in the transition core. By using the same method, the minimum AOPM was calculated for STD fuels as follows:

	PLUS7 Fuel	STD Fuel
Minimum AOPM [%]	129	133
Assembly # ^(*)	19	23

^(*): Identification number of fuel assembly in Figure 2

Fortunately, there is no overpower penalty on the limiting assembly because the minimum AOPM of PLUS7 fuel is lower than that of STD fuel. It means that PLUS7 fuel is more limiting than STD fuel in the first transition core, despite of the enhanced thermal margin. If the screening method is applied to the entire data of the first transition core, the results can be changed, because the current results came from the analysis for only a part of the entire data. If the results is changed, the overpower penalty on the limiting assembly has to be calculated by the equation (2). Anyway, there is no overpower penalty on the limiting assembly, that is, $OP_{LA} = 1.0$.

3.2. Optimum Thermal Margin Model

The generic thermal margin model was generated to benchmark against the DNBR results of TORC simulating the core and the limiting assembly selected in the homogeneous core of PLUS7 fuel on section 3.1. A CETOP model was prepared based on the subchannel of TORC model where the minimum AOPM was calculated and was tuned to calculate DNBR conservatively against the TORC result. This procedure was repeated at all 138 operating condition sets, selected within COLSS/CPCS applicable range. The final CETOP model with the resultant tuning factor is the generic thermal margin model for PLUS7 fuel. Its AOPM was calculated at the nominal operating condition and compared with the AOPM of the generic thermal margin model of STD fuel.

	PLUS7 Fuel	STD Fuel
AOPM [%]	138	120

The thermal margin gain is about 18 % due to the PLUS7 fuel. It should be sufficiently applied to both the homogeneous core and the transition core. The overpower penalty on the generic thermal margin model was calculated to set up the optimum thermal margin model of transition core. The generic thermal margin model calculated heat flux at the DNBR limit of PLUS7 fuel and the TORC model of the limiting assembly, determined for the first transition core, calculated DNBR at the heat flux. The minimum DNBR of the TORC model was lower than the DNBR limit. It means that the generic thermal margin

model is not conservative for the first transition core. The loss of the conservatism was converted into overpower penalty, by using the equation (1), as follows:

$$OP_{TM} = \frac{(Heat\ Flux)_{TORC}}{(Heat\ Flux)_{CETOP}} \approx 0.98$$

The total overpower penalty of the first transition core was

$$OP = OP_{LA} \times OP_{TM} = 0.98$$

The optimum thermal margin model of the first transition core is the generic thermal margin model with the overpower penalty of 0.98. The AOPM of the first transition core can be calculated to multiply the AOPM of the generic thermal margin model by the total overpower penalty as follows:

$$\text{AOPM of first transition core} \quad : \quad 135 \%$$

As mention above, the results were for only a part of the entire data for the homogeneous core and the first transition core. If the approach is applied to the entire data of the homogeneous and the first transition core, the results can be changed. The STD fuel is not included among limiting assembly candidates in the second transition core, because it has much lower pin power than PLUS7 fuel. The number of STD fuels decreases near the limiting assembly. It causes to decrease the loss of flow from the limiting assembly and to increases the thermal margin of the second transition core. It is expected that cycle specific overpower penalties increases the thermal margin for the transition core.

4. Conclusion

The procedure to set up the optimum thermal margin model of the transition core was suggested by introducing AOPM concept into the screening method which determines the limiting assembly.

- a. TORC code calculates heat fluxes for fuel assemblies with pin power above 90 % of the maximum pin power in the homogeneous core of PLUS7 fuel. Using the inlet flow distribution of quarter core with the lowest inlet flow factor of the fuel assembly performs the calculation at the nominal operating condition. Limiting assembly is selected from the viewpoint of AOPM. A generic thermal margin model is generated to benchmark against the DNBR results of TORC simulating the core and the limiting assembly in detail.
- b. The limiting assemblies are determined for PLUS7 and STD fuels in the transition core, respectively. If the AOPM of PLUS7 fuel is lower than that of STD fuel, go to next step. Otherwise, an overpower penalty is calculated by the equation (2).
- c. The conservatism of the generic thermal margin model, generated in step 1, is verified against the limiting assembly of PLUS7 fuel selected in step 2. If its conservatism is violated, the overpower penalty is calculated by the equation (1).

Basically, no overpower penalty means to be *OP* of 1.0. The optimal thermal margin model of the transition core involves the generic thermal margin model and total overpower penalty. Basically, no overpower penalty means to be *OP* of 1.0. The optimal thermal margin model of the transition core involves the generic thermal margin model and total overpower penalty

According to the procedure, the optimum thermal margin model of the first transition core was set up by using a part of nuclear data for the first transition and the homogeneous core with PLUS7 fuels. The generic thermal margin model of PLUS7 fuel was generated with the AOPM of 138%. The overpower penalties of the first transition core were calculated to be 1.0 and 0.98 on the limiting assembly and the generic thermal margin model, respectively. It is not usual case to impose the overpower penalty on reload cores. It is considered that the lack of channel flow due to the difference of pressure drop between PLUS7 and STD fuels results in the decrease of DNBR. The AOPM of the first transition core is evaluated to be about 135% by using the optimum generic thermal margin model which involves the generic thermal margin model and the total overpower penalty. The STD fuel is not included among limiting assembly candidates in the second transition core, because they have much lower pin power than PLUS7 fuels. The reduced number of STD fuels near the limiting assembly results in decreasing the loss of flow from the limiting assembly to increase the thermal margin. It is expected that cycle specific overpower penalties increases the thermal margin for the transition core. Using the procedure to set up the optimum thermal margin model makes sure that the enhanced thermal margin of PLUS7 fuel can be applied sufficiently to not only the homogeneous core but also the transition core.

5. References

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2. CEN-191(B)-P, "CETOP-D Code Structure and Modeling Methods", December 1981.
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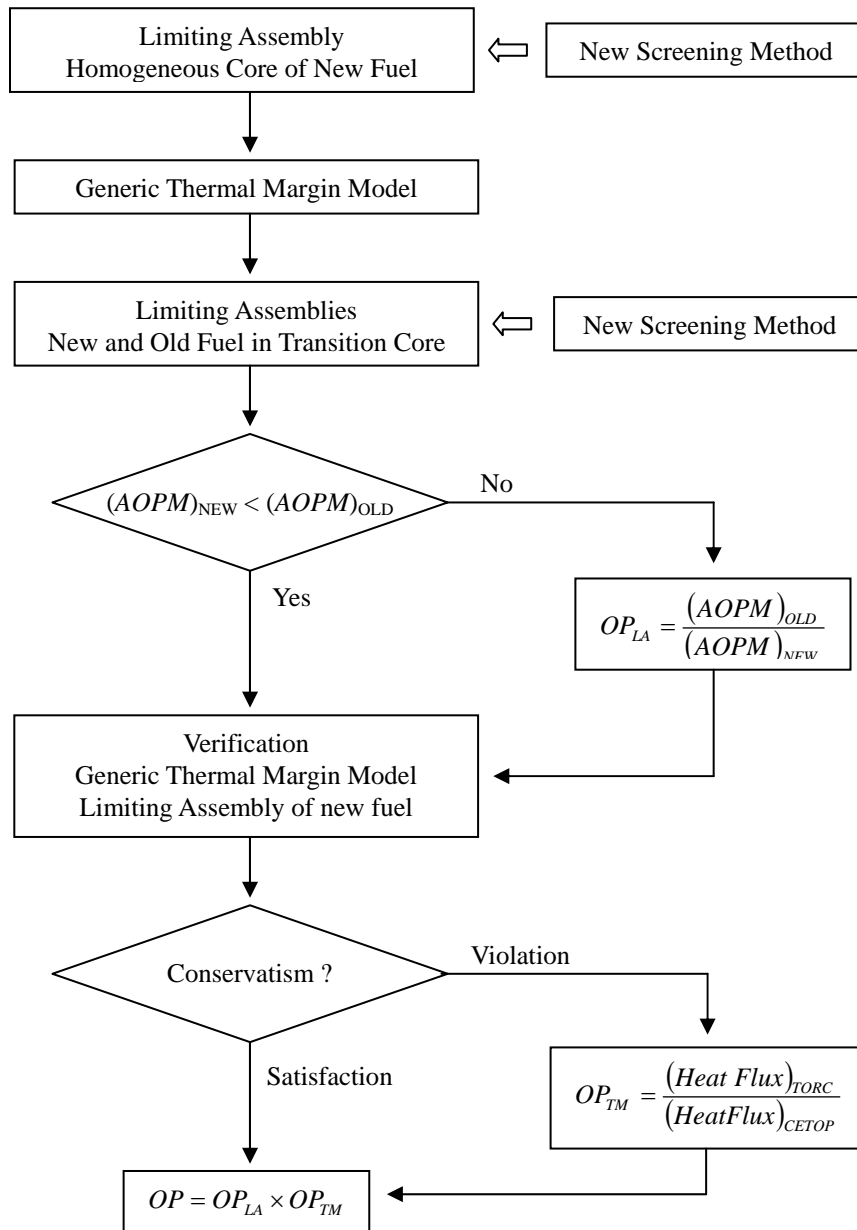


Figure 1. Procedure to Set up Optimum Thermal Margin Model in Transition Core

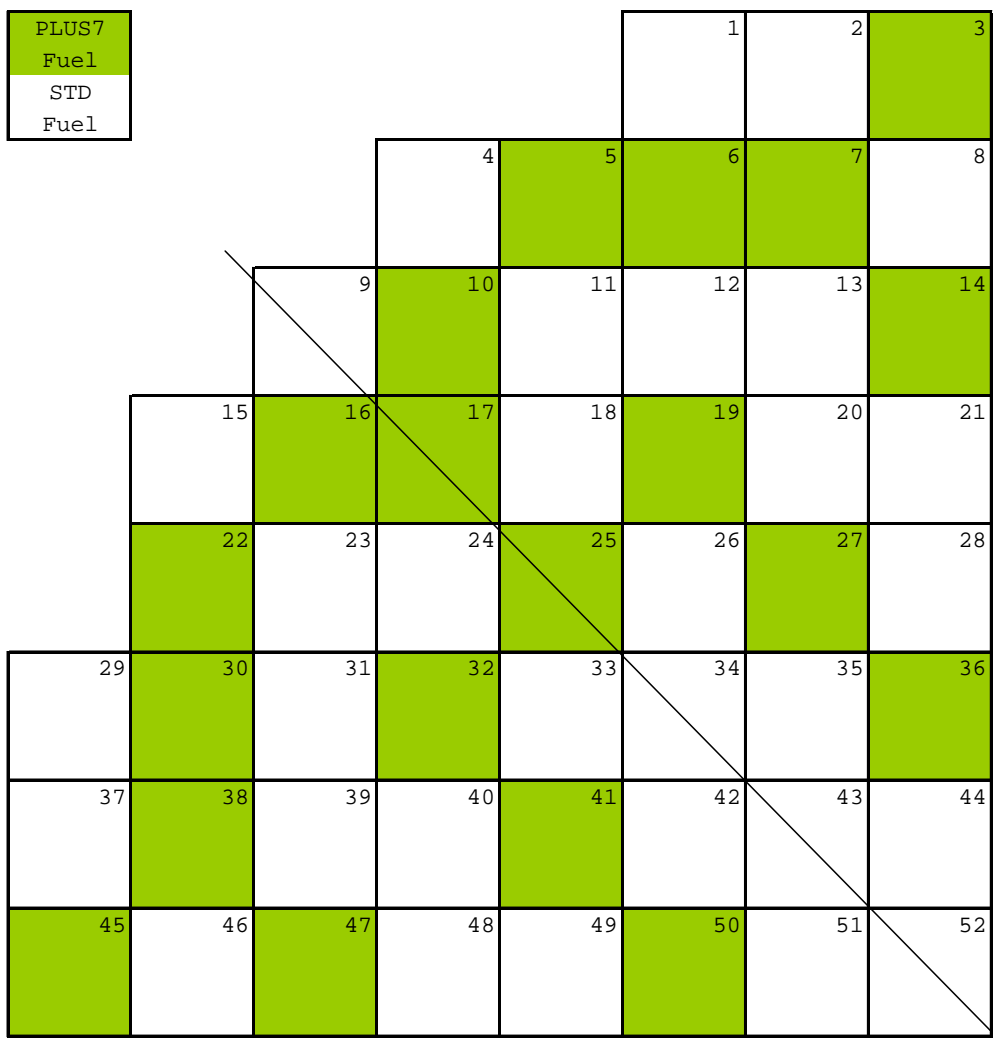


Figure 2. Loading Pattern in First Transition Core Loaded with PLUS7 fuels