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3-Dimensional Methodology for the Control Rod Ejection Accident Analysis Using UNICORN™

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1. Introduction

The control rod ejection accident has been analyzed with STRIKIN-II code using the point kinetics model coupled with conservative factors to address the three dimensional aspects. This may result in a severe transient with very high fuel enthalpy deposition.

KNFC, under the support of KEPRI and KAERI, is developing 3-dimensional methodology for the rod ejection accident analysis using UNICORN™ (Unified Code of RETRAN, TORC & MASTER).

For this purpose, 3-dimensional MASTER-TORC [1],[2] codes, which have been combined with the dynamic-link library by KAERI, are used in the transient analysis of the core and RETRAN[3] code is used to estimate the enthalpy deposition in the hot rod.

2. Accident Descriptions

The control rod ejection accident is defined as the mechanical failure of a control rod drive mechanism pressure housing such that the reactor coolant system pressure would cause the ejection of a partially or fully inserted control rod and drive shaft to its fully withdrawn position. If the reactor is at or near critical, the consequences of this mechanical failure are a rapid reactivity insertion and core power increase together with an adverse core power distribution, possibly leading to localized fuel rod damage. The negative reactivity due to the Doppler feedback resulting from the fuel heat-up can mitigate the power increase, and the transient is terminated by a reactor trip that is initiated shortly after the beginning of the transient.

3. Description of Methodology

The new methodology for the rod ejection accident being developed adopts not a realistic method but multi-dimensional approach with conservative assumptions. This means that conservatism of key safety parameters is still preserved in this method while trying to introduce the best-estimate concept if possible. Several different categories of conservatisms such as operational history, initial core conditions, key transient analysis parameters and hot rod analysis model are considered.

The operational history spells the depletion scheme that can vary from cycle to cycle or time in life. The limiting history among the various depletion models would be chosen conservatively.

The initial core conditions at the beginning of the transient such as the rod position, axial power shape and the xenon distribution are directly related to the ejected rod worth and the peaking factors. Thus, the influence of the initial core conditions on the key safety parameters is investigated in advance and the limiting core conditions are determined conservatively. For example, the extremely top-skewed axial power shape of -0.6 axial shape index may be used for the hot zero power analysis.

The key transient parameters are the ejected rod worth and the reactivity coefficients. To identify their impact, various sensitivity calculations are performed. Also, the ejected rod worth can be increased conservatively by increasing the absorption cross section of the ejected rod.

Conservatism to be imposed on the fuel parameters for the hot rod evaluation is typically opposite to one that applied to the average core calculation. Whereas the rise of the fuel temperature is minimized to mitigate the Doppler feedback in the average core calculation, the increase of fuel temperature is maximized to get the highest fuel enthalpy in the hot rod analysis. Thus the different fuel rod models are required for the average core and for the hot rod calculations respectively.

The analysis procedure is summarized as follow. The bounding initial conditions and limiting accident scenario are fixed through the static analysis by using MASTER code. Thereafter, the 3-dimensional transient analysis using the initial conditions determined in advance is performed with the coupled MASTER-TORC code. The behavior of the limiting hot rod is analyzed by RETRAN code based upon 3-dimensional transient results.

4. Analysis

4.1. Static nuclear analysis

The MASTER models for the static analysis are extracted from ROCS models by using the utility program ACARDIS. ROCS models are prepared previously for various depletion models to cover all the feasible operational histories.

In the static analysis, bounding initial conditions and ejected rod scenarios with respect to the ejected rod worth and peaking factors are investigated by MASTER code. Various control rod bank locations and depletion scenarios are investigated to determine the most limiting conditions.

4.2. Transient analysis

The 3-dimensional transient analysis has been performed with a coupled MASTER-TORC code applying the limiting initial conditions determined above. As shown in Figure 1, the 3-dimensional nuclear power and thermal hydraulics data are mutually transmitted between MASTER and TORC codes. The average core power and 3-diemensional peaking factors as a result of transient analysis are used as the input of the hot rod analysis.

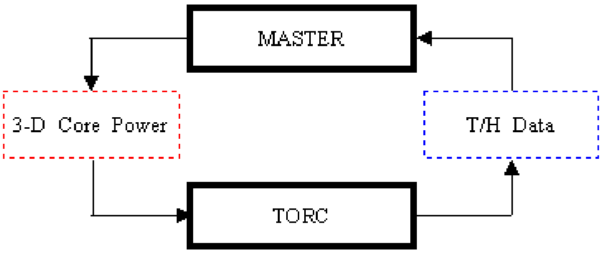

Figure 1. Data flow between codes in transient analysis

4.3. Hot rod analysis for the peak fuel enthalpy

In the hot rod analysis, the single channel-single rod RETRAN model is applied as shown in Figure 2 and the pellet-to-clad heat transfer is simulated with the dynamic gap conductance model. Conservatisms such as the peaking factor are imposed on the modeling and initial conditions in order to maximize the increase in the fuel temperature which can be translated into enthalpy easily.

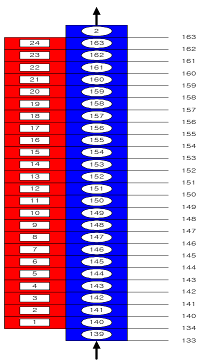

Figure 2. RETRAN hot rod model

5. Results of Sample Application Analysis

First, the RETAN hot rod model is examined with the same average core power and peaking factors as those used in the STRIKIN-II code. Per the results, the average fuel temperature of the hot rod reveals a good agreement between the RETRAN hot rod model and STRKIN-II model as shown in Figure 3. Therefore, the applicability of the RETRAN model for the hot rod analysis can be verified.

The fuel enthalpy is evaluated by the 3-D methodology using MASTER-TORC and RETRAN codes. The average core power and the peaking factor calculated by MASTER-TORC are used in RETRAN hot rod calculation. For the comparison, the STRIKIN-II run is performed separately using the same conditions of 3-D calculation. The result shows that the significant gain is found as shown in Figure 4. The margin gain is partly due to the reduction in the nuclear power and also due to the use of the actual power peaking factor.

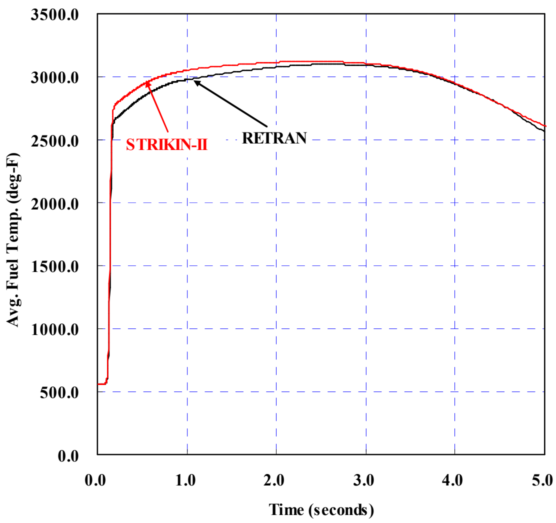

Figure 3. Comparison of the results of hot rod analysis

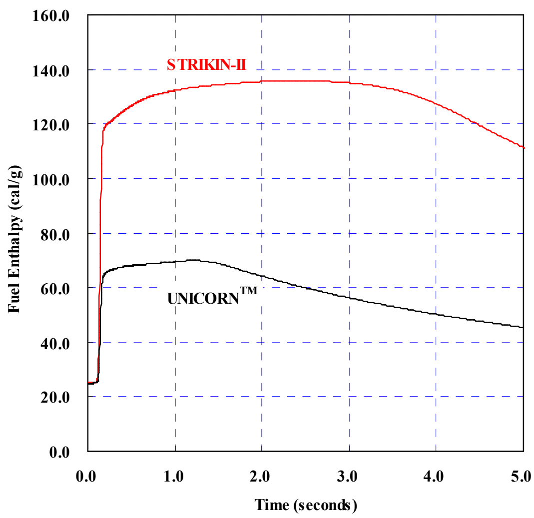

Figure 4. Comparison of the fuel enthalpy deposited

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