Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1995

An Analysis of a Post-Trip Return-to-Power Steam Line break Events

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Abstract

An analysis for Steam Line Break (SLB) events which result in a return-to-power conditions after reactor trip was performed for a postulated Yonggwang Nuclear Power Plant Unit 3 cycle 8. Analysis methodology for post-trip return-to-power SLB is quite different from that of a no return-to-power SLB and is more complicated. Therefore, it is necessary to develop an methodology to analyze the response of the NSSS parameter and the fuel performance for the post-trip return-to-power SLB events. In this analysis, the cases with and without offsite power were simulated by crediting 3-D reactivity feedback effect due to local heatup around stuck CEA and compared with the cases without 3-D reactivity feedback with respect to fuel performance, departure from nucleate boiling ratio (DNBR) and linear heat generation rate (LHGR).

1. Introduction

Steam line break events analyzed with respect to post-trip return-to-power is very sensitive to the core physics data such as moderator and fuel temperature feedback, inverse boron worth (IBW) and scram worth etc.. The progression of the event is closely related on the balance of the above reactivity components. The cooldown of the RCS will insert positive reactivity from moderator and fuel temperature feedbacks. Negative reactivity contribution comes from the CEA insertion and the addition of boron from safety injection. If the positive reactivity insertion is sufficient to erode the core subcriticality, a power increase (spike) may occur which could result in a fuel failure.

Due to the potential of very high local power peaking in the area of the stuck CEA, it is possible for significantly high localized heat flux to occur for SLB events even though the core as a whole is at a low average power level and has a sufficient shutdown margin. The high values of local heat flux can cause relatively high local heatup of the coolant which can in turn lead to changes in density in the hot channel which are much different from the core average conditions. The local feedbacks tend to reduce the radial flux peaking, forcing neutrons into the surrounding fuels and control rods. This flux redistribution represents a significant reactivity effect. This negative reactivity due to local heatup effect is called "3-D reactivity feedback".

Generally, the physics data has a tendency to become worse as the cycle progresses and the cycle period is extended longer. An extended cycle period might be adapted for YGN 3&4 reload cycles and followed plants. Therefore, it is necessary to setup and develop an analysis methodology to deal with return-to-power for SLB events even though there is no return-to-power condition for the YGN 3&4 cycle 1 SLB analysis [1]. This paper presents the evaluation and comparison of the analysis results for the cases with and without 3-D reactivity feedback.

2. Analysis Methodology

In this analysis, the SLB with offsite power available (high flow) and with loss of offsite power (low flow) cases were selected for the evaluation of the 3-D reactivity feedback effect on the consequences of the post-trip return-to-power SLBs. Thermal-hydraulic responses to a post-trip return-to-power SLBs were simulated using CESEC-III [2], which is a licensing computer code for Non-LOCA analysis, to generate the major transient system parameters which are used for fuel performance calculation. Fuel performance is evaluated with respect to DNBR and LHGR. For DNBR calculations, HRISE computer code [3], in which Macbeth Critical Heat Flux (CHF) correlation [4] approved by USNRC for Calvert Cliff Plant (CE type PWR) is modeled.

For both the high and low flow cases, a postulated YGN 3 cycle 8 physics data except scram worth were used. The scram worth for cycle 8 is -9.3626 %$\Delta\rho$. Using this scram worth, no return-to-power was occurred for both the high and low flow cases. In order to evaluate post-trip return-to-power SLB events, the scram worth was artificially lowered to -9.0 %$\Delta\rho$, which is sufficient to make both cases a return-to-power conditions. The RCS pressure at peak power during return-to-power condition for these events are 1432.9 psia and 1491.4 psia respectively, which are out of upper limit of the pressure range of the Macbeth CHF correlation (500-1000 psia). DNBR has a tendency to become adverse as the pressure decreases. A DNBR sensitivity study was performed on the RCS pressure to verify that the minimum DNBR decreases as the

RCS pressure at peak power is reduced. The results of this sensitivity study are presented in Figure 2. Also, among the axial shapes which are possible to occur, the worst one with respect to DNBR was selected by an extensive sensitivity study on various axial shapes. Hand calculation was performed for LHGR instead of detailed fuel temperature calculation using STRIKIN-II computer code [5]. The basic approach of hand calculation of LHGR is that first, the core average LHGR of fission and decay power is obtained by taking the ratio of the fission power to rated power and multiplying it by the LHGR at rated power conditions and then increased by 3-D peaking factor to calculate hot channel LHGR at peak power. Fuel performance was evaluated against the YGN 3&4 specific DNBR and LHGR specified acceptable fuel design limit (SAFDL), which are 1.30 and 21 Kw/ft respectively. Amount of the 3-D reactivity feedback was controlled by a 3-D reactivity feedback multiplier. A multiplier of 0.5 (m=0.5) means that 50% of 3-D reactivity feedback is credited in the analysis. A schematic diagram of the analysis procedure is presented in Figure 1.

3. Results and Discussions

3.1 DNBR

The major factors that determine DNBR are core heat flux, coolant temperature, coolant pressure and core flowrate. Core heat flux for both the high and low flow cases without 3-D reactivity credit are presented in Figure 3. From Figure 3, the peak core heat flux for high flow case is larger than that for low flow case while the core flowrate is larger. Therefore, both the high and low flow cases must be analyzed to determine the limiting case with respect to DNBR. Transient DNBRs for the cases with offsite power available and with loss of offsite power are presented in Figures 4 and 5 respectively. For the cases with offsite power available, the minimum DNBR reaches the DNBR SAFDL for the case without 3-D reactivity credit. By crediting the 3-D reactivity feedback effect, the minimum DNBR increases in proportion to the amount of the negative 3-D reactivity feedback. Similar trends are observed for the cases with loss of offsite power. The effect of 3-D reactivity feedback is more evident in the high flow cases.

3.2 LHGR

The examination of the behavior of the fuel with respect to the SAFDL on peak LHGR is one of the factors to evaluate the fuel performance of the post-trip return-to-power SLB. LHGR depends strongly on the core heat flux. If the LHGR calculated by the procedure described in section 2 (Analysis Methodology) is not in excess of the LHGR SAFDL, then no fuel failure is expected to occur due to LHGR. Transient LHGRs for the cases with offsite power available and with loss of offsite power are presented in Figures 6 and 7 respectively. For cases with offsite power available, transient LHGRs exceed the LHGR SAFDL of 21 Kw/ft if 3-D reactivity feedback is not credited. When 3-D reactivity feedback is credited, LHGR decreases much below the LHGR SAFDL in proportion to the amount of the 3-D reactivity feedback. For the cases with loss of offsite power, LHGRs are much lower than the SAFDL value regardless of the adaptation of the 3-D reactivity feedback. This is based on the fact that LHGR depends strongly on the core heat flux.

4. Conclusions

An evaluation of the local heatup effect in the vicinity of stuck CEA, 3-D reactivity feedback, on the consequences of a post-trip return-to-power SLBs was performed for a postulated YGN 3 cycle 8. The results of analysis indicates that fuel performance with respect to DNBR and LHGR are much improved if 3-D reactivity feedback are credited for SLBs resulting in a return-to-power conditions. Also, even though the scram worth was lowered to -9.0 %$\Delta\rho$ artificially, no fuel failure was occurred due to DNBR and LHGR degradation for both the high and low flow cases when the 3-D reactivity feedback is credited. Detailed calculation of the fuel performance using STIKIN-II computer code and extensive bounding value study are further required to setup a complete and thorough methodology which is available for a post-trip return-to-power SLB events.

References

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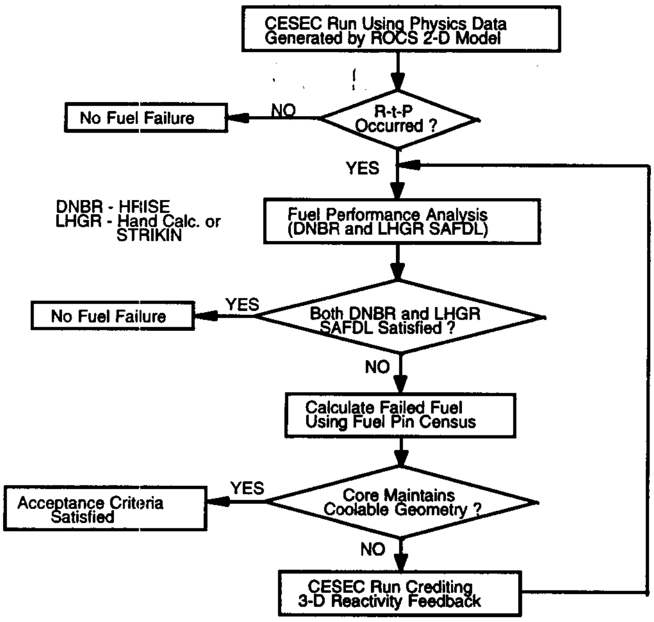

Figure 1 Schematic Analysis Procedure

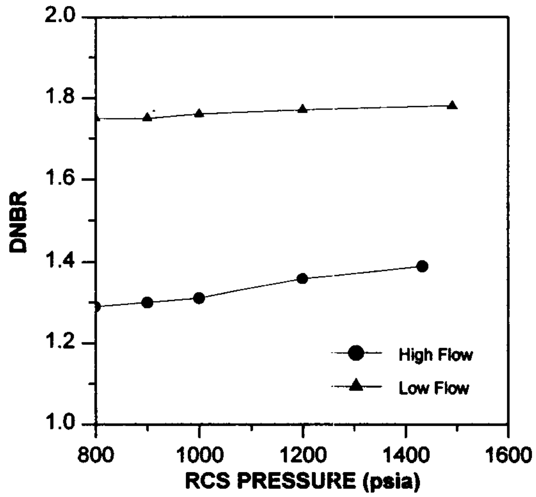

Figure 2 Minimum DNBRs vs. RCS Pressure at Peak Power

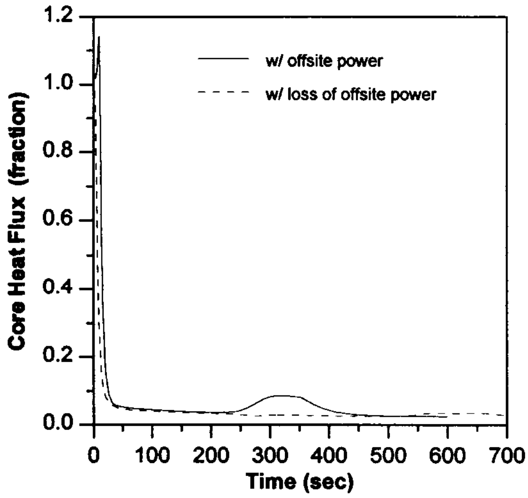

Figure 3. Core heat flux vs. Time for high and low flow cases (without 3-D reactivity feedback)

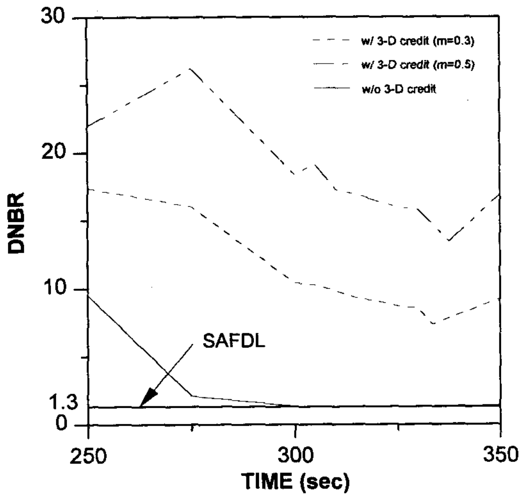

Figure 4. Transient DNBRs for the Cases
with Offsite Power Available

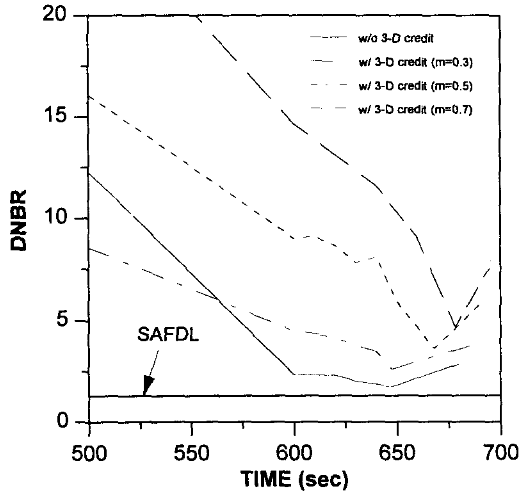

Figure 5. Transient DNBRs for the Cases
with Loss of Offsite Power

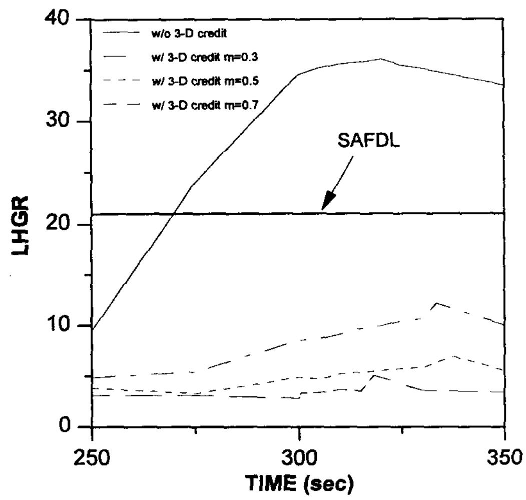

Figure 6. Transient LHGRs for the Cases
with Offsite Power Available

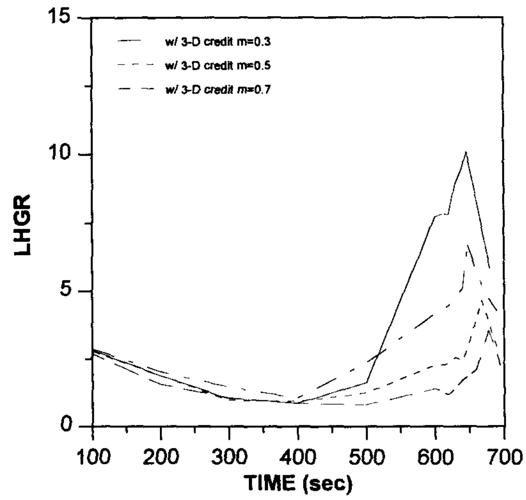

Figure 7. Transient LHGRs for the Cases
with Loss of Offsite Power