PCT Margin Quantification in Nuclear Power Plants

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1. Introduction

The objective of this research is to quantify the peak clad temperature (PCT) margin for significant plant operational modifications using the framework to integrate risk and safety margins (IRSM)[1].

IRSM approach starts with generating (1) the risk space (i.e., all event sequences affected by the modification) and (2) the phenomena/variables identification table used to compute the conditional probability of loss of function for each event sequence. This application of IRSM for Kori-3 power uprate could limit the risk space to LBLOCA and SBLOCA when it can be shown that they dominate the risk. Several practical simplifications can be made that are consistent with current practice in PRAs.

2. Event identification

The accident sequences of LBLOCA and SBLOCA are presented in event trees shown in Figure 1 and Figure 2 respectively
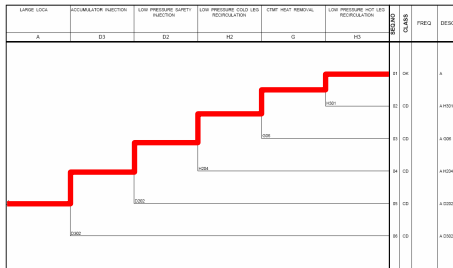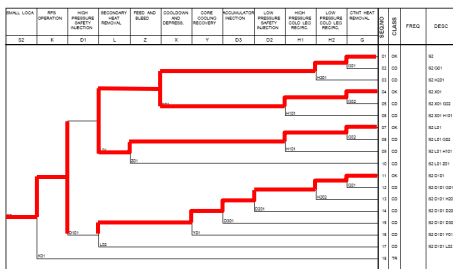

Figure 1. LBLOCA Event Tree for Kori unit 3

Figure 2. SBLOCA Event Tree for Kori unit 3

3. Calculating margin in each sequence

Determination of the amount of PCT margin available in each event sequence can be identified through sensitivity analysis for significant variables which could affect safety margin. Selected sensitivity variables are decay heat, discharge coefficient, HPSI injection setpoint, HPSI flowrate multiplier, and HPSI borated

water temperature based on the insights from UMS group report[2] and KINS report[3].

Class "OK" event sequences shown in Figure 1 and 2 are selected to generate the distribution of PCT. Initial conditions are shown in Table 1 and RELAP5/Mod3.3 nodalization of Kori-3 is shown in Figure 3. PCT for base case (100% power) and uprate case (104.5% power) of Kori unit 3 are calculated for LBLOCA and SBLOCA.

The probability density functions of PCT are generated from 59 computation results for each event sequence. Figure 4 shows the histogram for PCTs in SBLOCA SB07 sequence at 104.5% rated power. Normal distribution is assumed for calculated PCTs based on the histogram also.

Table 1. Initial Conditions

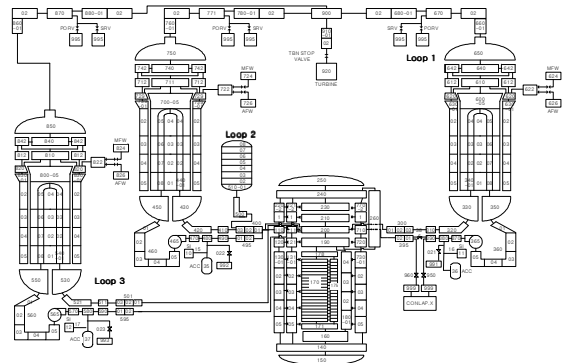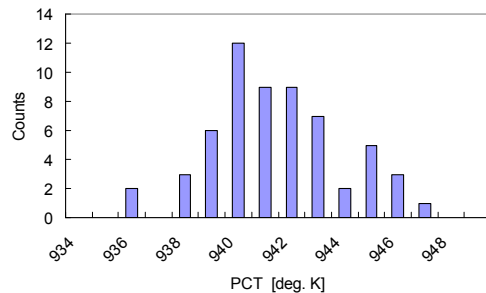|	100% Power	104.5% Power
Reactor Power [MWt]	**2775**	**2900**
Operating Pressure [MPa]	**15.5**	
Operating Temperature [^{O}K]		
- Cold Leg	**564**	**562**
- Hot Leg	**600**	
Break Size at Cold Leg [cm]		
- Small Break LOCA	**5**	
- Large Break LOCA	**Guillotine**	

Figure 3. RELAP5/Mod3.3 Nodalization

Figure 4. Histogram for SBLOCA PCT at 104.5% power

Figure 5 shows the distribution of PCT in LBLOCA. Figure 6 and 7 show the distribution of PCT for the SBLOCA cases. All PCTs are well below the safety limit value (1477 K). PCTs at 104.5% power are increased compared to that of 100% rated power cases. PCT distribution shapes are well matched to normal distribution shape.
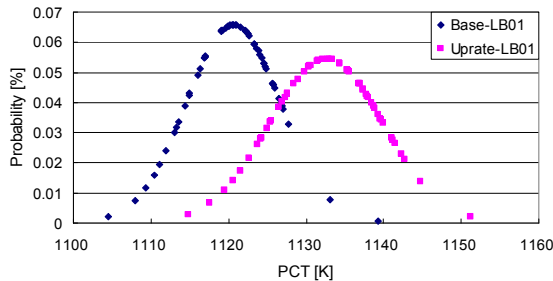

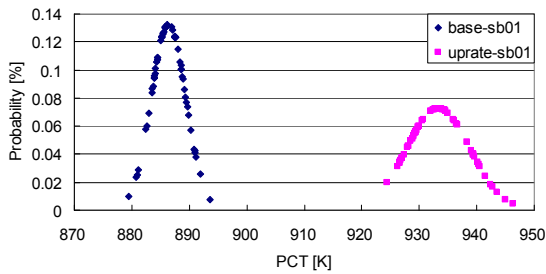Figure 5. Distributed Probability of PCT at LBLOCA

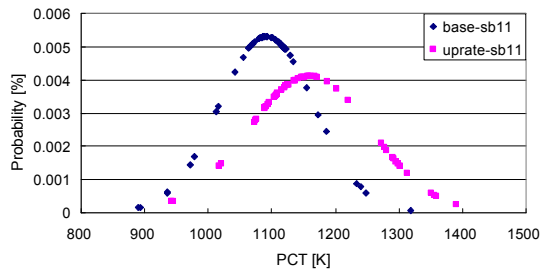Figure 6. Distributed Probability of PCT at SBLOCA SB01 Sequence

Figure 7. Distributed Probability of PCT at SBLOCA SB11 Sequence

Calculated PCT distributions for base and uprate case in Figure 7 are much overlapped compared with PCT distributions for other SBLOCA event sequences due to the failure of HPSI in early phase of event sequence 11.

3. PCT margin quantification

As shown in Figures 5 to 7, all PCTs are well below the safety limit value. This means that the adequate safety margin is ensured after power uprate.

Figure 8 illustrates the quantification concept of margin to safety limit for that adequate safety margin can be ensured.

The margin to the safety limit for each event sequence or SM_{Es_i} can be obtained by dividing ΔPCT by standard deviation of PCT distribution calculated as shown in Eq. (1)

$$SM_{Es\_i} = \frac{\text{safety limit} - \text{best estimate value}}{\sqrt{\sigma_{\text{best estimate}}{}^2 + 0^2}} \quad (1)$$
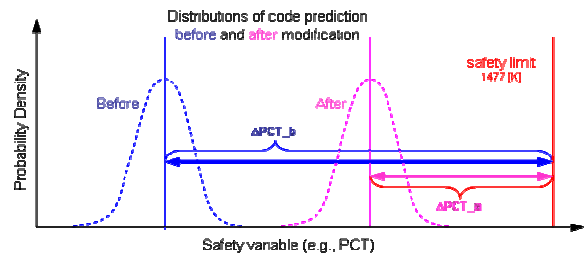

Figure 8. Safety Margins by Setting Safety Limit and Code Prediction Values

PCT margins in LBLOCA before and after power uprate are 58.82 and 47.08 respectively.

For SBLOCA, 4 event sequences are considered to generate PCT margin. In this case, total PCT margin of SBLOCA is computed from the following equation with consideration of event frequency:

$$SM_{SBLOCA} = \sum_{i=1}^{n} \frac{freq_{Es\_i}}{freq_{SBLOCA}} SM_{Es\_i} \quad (2)$$

Where $freq_{Es\_i}$ is frequency of event sequence i, $freq_{SBLOCA}$ is initiating event frequency of SBLOCA estimated from Kori unit 3 PSA report [4]., SM_{Es_i} is the margin to the safety limit in event sequence i as calculated in Eq. (1). PCT margin of SBLOCA before power uprate is 195.73 and PCT margin after power uprate is 98.43.

5. Conclusion

Through the application of IRSM methodology to Kori-3 power uprate case, following insights were derived.

- PCT margins after power uprate is reduced
- PCT margin of SBLOCA is much more reduced than that of the LBLOCA.
- IRSM could have substantial approach to quantify changes in safety margins.

REFERENCES

[1] M. Garvrilas, "A Framework for Integrating Risk and Safety Margins," Draft NUREG Report, Aug. 2006
[2] Tony Wickett, et al., "Report of the Uncertainty Methods Study", NEA/CSNI/R(97)35, OECD/NEA CSNI, June 1998
[3] In-goo Kim, et al., "Improvement of the ECCS Best Estimate Methodology and Assessment of LOFT L2-5 Experiment", KINS/RR-279, Korea Institute of Nuclear Safety, January 2005.
[4] Jae-hun Yang, "Kori unit 3,4 PSA final report – internal event quantification analysis", K34-PSA-INT-07, Korea Power Engineering Company, Inc., June 2003