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# Comparative Analysis of the DNBR in the Major Non-LOCA Transients Considering Realistic Operating Condition

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## 1. Introduction

As concern on the nuclear safety is getting more increased by public and there is a rising safety issue on the high burn-up fuel in worldwide, it has possibility highly to submit operating licensing or amendment to use the realistic evaluation method for non-LOCA transients. So, in order to prepare the future regulatory demands or needs, KINS keeps developing the overall framework for the non-LOCA evaluation method for regulation in Korea [1].

This study presents applicability to Non-LOCA regulatory evaluation methodology and comparative analysis of DNBR safety margin between conservative assumption and realistic operating condition using MARS-KS system code to verify licensee's conservatism.

## 2. Application to MSLB and LR

A concern on the asymmetric phenomena in core region has been increased as safety issues that are highly possible to reduce the thermal margin significantly. It dues to the considerable asymmetric balance of core mass flow, temperature, pressure and reactivity. Three asymmetric events were selected by PIRT [1], which developed in the previous study among the 27 events; they were MSLB (main steam line break), MFLB (main feed line break) and LR (locked rotor). MSLB and LR among the asymmetric events were applied to non-LOCA regulatory methodology to assess the DNBR using both conservative assumptions described in FSAR and optimized input as representative of all normal operating condition with MARS-KS system code.

Table 1 briefly shows the contents of how we applied to sequences of non-LOCA methodology in this study. Table 2 shows the difference between conservative assumption and optimized input to analyze the MSLB and LR. Conservative input means to fully implement conservative conditions of FSAR [3] for each transient. Optimized input means incorporation of the realistic operating conditions. Therefore, the result of each steady state was needed to analyze each transient due to different initial and boundary condition. In contrast to conservative input, optimized input was needed to get a unique result of steady state because it is a representative of all non-LOCA transient reflecting realistic plant condition.

Table 1. Overall Framework for non-LOCA

| Step | Contents |
|---|---|
| 1 | determination of event scenario; selection of event sequence that is willing to analyze<br>- comparative analysis between optimized operation and conservative assumption on the MSLB and LR<br>- DNBR assessment between MARS, MARS-CFD, MARS-CFD-CTF<br>Where : CFD (Computational Fluid Dynamics), CTF (COBRA-TF) |
| 2 | selection of plants; selection of plant that is willing to analyze<br>- APR 1400 |
| 3 | making a PIRT; verification and classification of important phenomena to each event<br>- already developed in the previous study |
| 4 | specifying codes; specifying codes<br>- MSLB; MARS, MARS-CFD<br>- LR; MARS, MARS-CTF, MARS-CFD-CTF [2] |
| 5 | codes assessment; requirements vs. code capabilities<br>- No special action but CTF needs V&V with long term |
| 6 | defining NPP modeling and nodalization; BOP modeling and its node defining<br>- described in Table 2 |
| 7 | base calculation of the NPP; construction of base decks for non-LOCA (steady and transient) |
| 8 | sensitivity analysis; reasonable conservative assumptions and initial conditions<br>- MSLB; core TH, kinetics, PZR TH, critical flow, core mixing<br>- LR ; PZR TH, pump behavior, SG TH, natural circulation, core mixing |
| 9 | the final assessment of the events; final assessment by comparing FSAR or another code results.<br>- assessment of safety margin on the MSLB and LR |

Table 2. The differences between the two inputs

| Variables | Optimized | Conservative |
|---|---|---|
| Power (%) | 100 | 102 |
| Decay heat model | ANS-79 (yield: 1.0) | ANS-73 (yield: 1.2) |
| Feedback | FSAR | FSAR |
| Geometry | Latest | Classical |
| Lower plenum | single | Two volume |
| Core | A:1, HA:1, HP:1 | A:1, HA:2, HP:2 |
| Trip Control | Real value | Conservative value |
| Event initiation | MSLB : 30%, 100% break<br>LR: modeled by branch | MSLB : 30%, 100% break<br>LR: modeled by branch |
| Non-safety grade component | Considered | Not Considered |
| Containment Pr. | Considered | Atmosphere |

### 3. Transient Results of MSLB and LR

Calculations of the steady state on the MSLB and LR were properly completed and it resulted in maximum 2.07% deviation in steam pressure.

Transient results of the MSLB which is one of the over-cooling events showed mass flow rate from the intact SG side and the faulted SG side forward to core inlet were not largely different until steam generator tubes were uncovered significantly. However, asymmetry of mass flow rate to the core inlet was increased from the beginning time when a large area of steam generator tubes uncovered. Other asymmetric phenomena were also shown in each loop at the same time. Additionally, both two different inputs had similar overall trends except starting time of phenomena. In case of reactor power, conservative input was intentionally using the trip signal of overpowering at 121%, and optimized input was tripped by a low level of the affected steam generator. So, conservative input indicated power increase due to negative reactivity. Fig. 1 shows mass flow rate at cold-leg during MSLB transient.

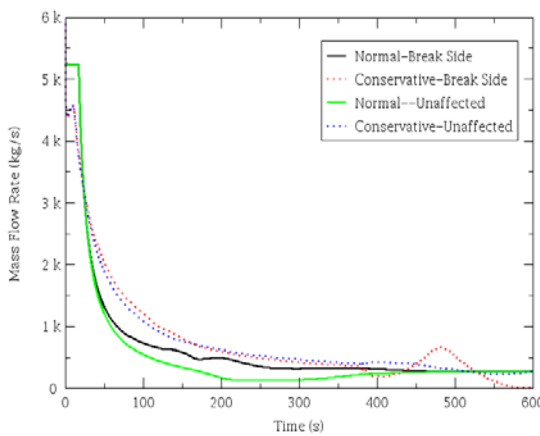


Fig. 1. Mass flow rate during MSLB transient.

The transient results of LR which is one of loss of RCS flow showed that core asymmetry was significantly shown on the mass flow rate between the affected loop and unaffected loop. Moreover, a large amount of reverse flow was observed for several seconds in the loop where RCP was locked, but the mass flow rate was temporally increased in the unaffected loop due to high driving force compared to affected loop.

Both conservative input and optimized input were tripped by signal actuation of low RCS flow and they experienced frequently openings of MSSVs equipped in a secondary system. In case of optimized input, operating parameter had smoothly increased or decreased due to more detailed modeling of the control system including the non-safety graded system in contrast to conservative input. Fig. 2 shows mass flow rate at cold-leg during Locked Rotor transient.

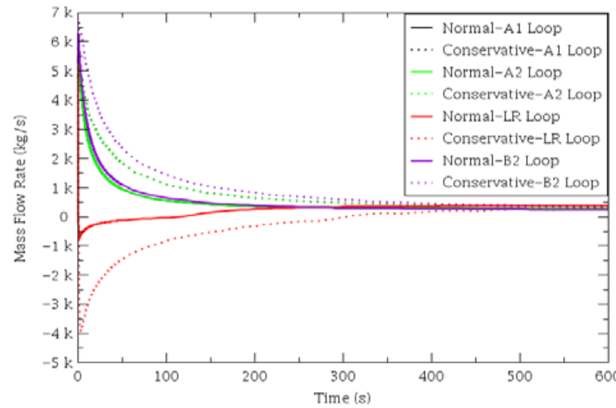


Fig. 2. Mass flow rate during Locked Rotor transient.

DNBR assessment, which is the most important one of acceptance criteria according to the safety review guide [4] was conducted in this study using system code. At the 16th node of the total 20 nodes in hot rod, maximum heat flux was found in both MSLB and LR. The values of DNBR in conservative input were less than optimized input as it expected. Figs. 3 and 4 showed the results of DNBR in MSLB and LR.

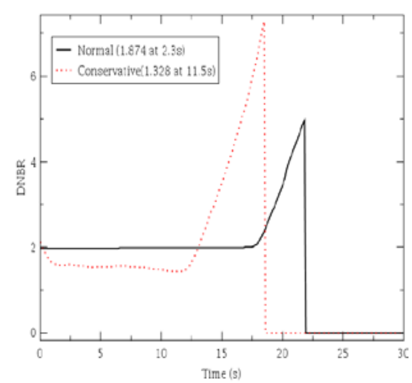


Fig. 3 DNBR result of MSLB

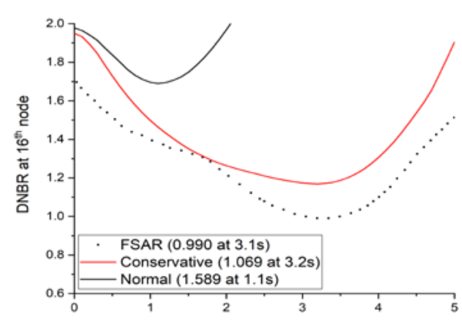


Fig. 4 DNBR result of LR

## 4. Discussion

DNBR assessment in this study confirmed again that safety analysis described in FSAR was proper. Core asymmetry on the MSLB wasn't significantly strong at each loop in the period when DNBR was important. However, core asymmetry such as mass flow rate into core inlet and the cold-leg temperature was significantly affected to DNBR. Especially, DNBR was very sensitive to reverse flow rate in the affected loop where RCP was locked because the total amount of mass flows into the core to remove decay heat decreased. Fig. 5 shows the decay trend of total mass flow rate into core inlet. A variation on the total mass flow rate described in FSAR was more conservative than this study, which was the severe condition corresponding to 23% of total mass flow rate reversely flowed to affected loop. Even though it confirmed licensee's proper conservatism, more detailed core asymmetry is needed to confirm whether unknown adverse effects may exist or not. So, commercial computational fluid dynamics will be used in the detailed analysis of lower plenum according to regulatory code system developed in the previous study [2].

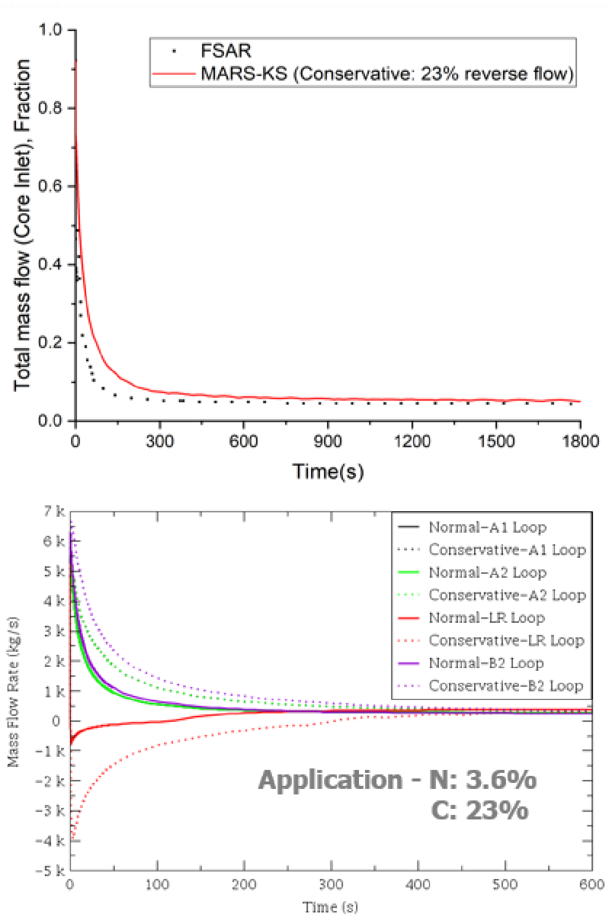


Fig. 5 Mass flow rate into the core

## 5. Conclusions

This study presents results of regulatory audit assessment pertinent to non-LOCA regulatory evaluation methodology developed in previous study. It identifies how much conservatism has safety margin on the DNBR compared to normal operating status. There was enough safety margin when MSLB and LR were analyzed without excessive conservatism. Conservative input and optimized input have shown no asymmetry in the lower plenum until U-tubes were uncovered significantly in MSLB assessment. Core asymmetry affecting DNBR was sensitive to the amount of reverse flow in the loop where LR occurred. Therefore, LR was needed to analyze more detailed phenomena using CFD. Additionally, KINS plans to precisely analyze sub-channel phenomena using CTF in consistence with non-LOCA methodology as a further study.

## Acknowledgements

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