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A Study on the Risk Reduction Effect by MLCS (Mid-loop Level Control System) of EU-APR using the Low-Power and Shutdown PSA Result

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1. Introduction

The EU-APR design has been developed in order to expand and diversify the global nuclear power market of APR1400. The EU-APR design complied with the latest Revision D of the European Utility Requirements (EUR) aiming at development of a standard design that can be built and licensed in Europe with minor changes.

For the improvement of shutdown risk for the EU-APR, the mid-loop level control system (MLCS) is considered during mid-loop operation for the EU-APR, which is not incorporated into SKN 3&4 (APR1400 Type) in Korea.

Commonly, the risk associated with the NPP can be identified through the PSA. Thus, this paper discusses the low power and shutdown (LPSD) risk reduction effect by MLCS using the Low-Power and Shutdown PSA Result.

2. Methods and Results

2.1 Characteristics of EU-APR Design

In general, mid-loop operation (POS 5, POS11) is the most important state during LPSD in the perspective of risk. Particularly, the loss of shutdown cooling function during mid-loop operation is one of the most vulnerable events so that the cautious RCS level controls as well as the continuous monitoring of shutdown cooling function are essential in this operation.

To prevent uncontrolled RCS level drop event during the mid-loop operation, automatic level control system is adopted in EU-APR. The MLCS of EU-APR provides an automatic control of RCS water inventory by continuously monitoring the RCS level and controlling the charging and letdown flow rates. When the RCS water level is lowered to the low level set-point of the narrow range refueling water indicators, the safety injection (SI) pumps will be actuated automatically and provide the borated water into the RCS to raise the level up to the required set-point.

2.2 Development of LPSD PSA Model

The first step in the LPSD PSA analysis is the identification of unique plant operational states (POSs). The POSs defined for the EU-APR PSA are based on the 15 POSs defined in NUREG/CR-6144 [1] with adjustments made to account for the refueling practices expected for the EU-APR. The POS defined for the EU-APR PSA represents all conditions that can occur over the course of a fuel cycle. The first 7 POSs from POS 1 to POS 7 show the progression of shutdown operation modes and before refueling process. The remained 7 POSs from POS 9 to POS 15 show the progression of the startup operation modes after refueling process. POS 8 shows defueled process. POS 1, POS 2, POS 14, and POS 15 are similar to those considered in the at-power internal events PSA and POS 5, 11 are correspond to mid-loop operation.

The second step in the LPSD PSA analysis is the identification of initiating event for each operation mode. The identification of potential initiating events considers generic information sources, information from similar plants, and a systematic review of the EU-APR design to identify unique initiating events. The potential initiating events are grouped into similar functional categories to reduce the complexity of the PSA. The initiating event frequency for each of these groups is then quantified.

The accident sequence analysis and the success criteria analysis have been performed. The accident sequence analysis is appropriately modeled the combinations of system responses and operator actions that could occur during the event. Success criteria for the LPSD PSA are generally based on the thermal-hydraulic analysis of LPSD PSA for the reference plant (APR1400). EU-APR and the reference plant (APR1400) have the similar design characteristics in perspective of thermal-hydraulics. For each initiating event, progression of potential scenarios leading to either a safe state or to core damage is modeled using an event tree.

The human reliability analysis (HRA) for the LPSD PSA is performed using the same methods as the at-power PSA. The system analysis for LPSD PSA has been performed using system fault trees which are deductive approach to identify the relationship between an undesired system event and the subsystem failure events that may contribute to its occurrence.

The data analysis is performed for calculating the initiating event frequency, the failure rate, and the component unavailability of basic components of the PSA model.

2.3 Quantification Results and Insights

2.3.1. The result for model without MLCS

For the model without MLCS, the CDF resulting from internal event for the LPSD operation of EU-APR was evaluated. The CDF contributions by POS are presented in Fig. 1. The result of LPSD PSA shows that the most risk values are POS 5 and POS 11, mid-loop operation. The important risk contributor occurred in POS 5 and the sequence takes 49% of the total LPSD CDF. The CDF in POS 11 accounts for 22% of the total shutdown CDF. The detailed sequence can be demonstrated by the following scenario description: During the start of mid-loop operation, operator actions failed initial makeup to restore inventory. And then, operators tried to feed & bleed (F&B) operation, but failed.

As shown in Fig. 2, in terms of the LPSD initiating events, the over-drainage during reduced inventory operation (SO) is the most significant initiating event, contributing 51% of the total CDF. The loss of offsite power (LOOP) and failing to maintain water level during reduced inventory operation (SL) are dominant, and take 14% and 9% portions of total LPSD CDF.

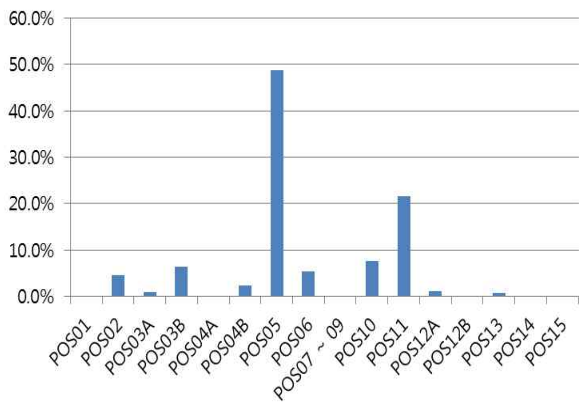

Fig. 1. Fraction of Core Damage Frequency by POS

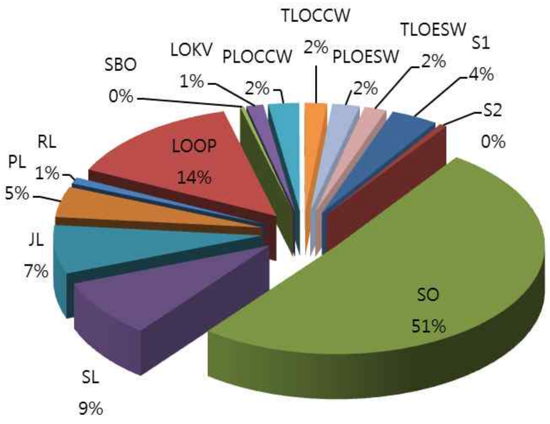

Fig. 2. Fraction of Core Damage Frequency by Initiating Event

2.3.2. The result for model with MLCS

The CDF resulting from internal event for the LPSD operation of EU-APR was evaluated. Fig 3 and Fig 4 show the CDF distribution for POS groups and initiating events, respectively. The most risk significant POS is POS 10 and the sequence takes 23% of the total LPSD CDF. Because MLCS is actuated automatically RCS injection, the risk of contribution of POS 5, POS 11 (mid-loop operation) is significantly lower than that of model without MLCS.

A LOOP is the most significant initiating event, contributing 37% of the total shutdown CDF. The POSRV's fail to reclose event (PL) contribute a 13%, followed by unrecoverable LOCA (JL) which contributes 10%. The MLCS using accurate, redundant and diverse instrumentation provides the continuous system status to the operators with precise information for monitoring the RCS reduced inventory operations. Therefore, the over-drainage during reduced inventory operation (SO) is significantly reduced.

As MLCS is adopted during the mid-loop operation for decay heat removal and inventory control, the total LPSD CDF was reduced to 66%.

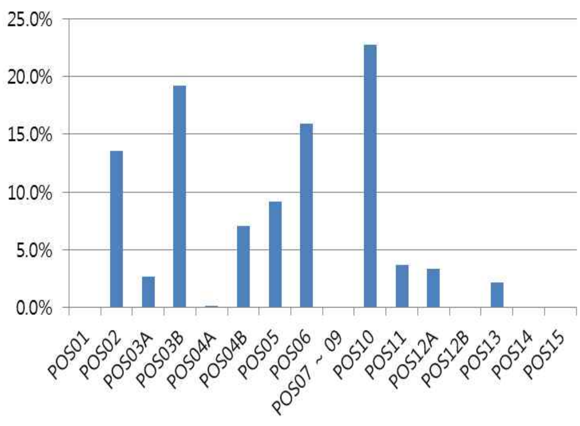

Fig. 3. Fraction of Core Damage Frequency by POS

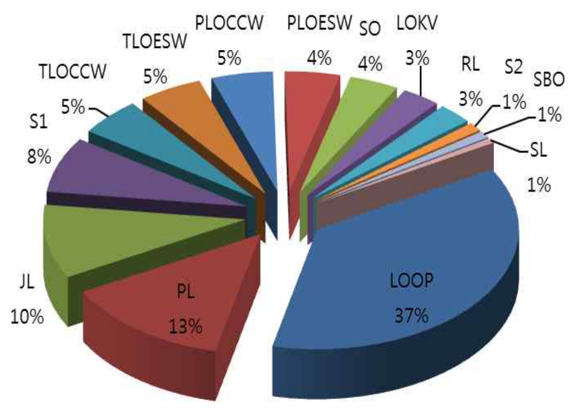

Fig. 4. Fraction of Core Damage Frequency by Initiating Event

3. Conclusions

LPSD level 1 PSA models for EU-APR have been developed. The risk reduction effect by MLCS is discussed. Because the loss of shutdown cooling function during mid-loop is one of the most vulnerable events, the MLCS have a significant influence on CDF in LPSD PSA. The shutdown risk of domestic power plants would likely be reduced if the MLCS is adopted in all operating NPPs in Korea during the mid-loop operation. It is expected that this work will contribute to reduce shutdown risk of domestic power plants.

ACKNOWLEDGMENT

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