Development of the Level 1 PSA Model for PGSFR Regulatory

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1. Introduction

SFR (sodium-cooled fast reactor) is Gen-IV nuclear energy system, which is designed for stability, sustainability and proliferation resistance. KALIMER-600 and PGSFR (Prototype Gen-IV SFR) are under development in Korea with enhanced passive safety concepts, e.g. passive reactor shutdown, passive residual heat removal, and etc.

Risk analysis from a regulatory perspective is necessary for regulatory body to support the safety and licensing review of SFR. Safety issues should be identified in the early design phase in order to prevent the unexpected cost increase and the delay of PGSFR licensing schedule. In this respect, the preliminary PSA Model [1] of KALIMER-600 had been developed for regulatory.

In this study, the development of PSA Level 1 Model is presented. The important impact factors in the risk analysis for the PGSFR, such as Core Damage Frequency (CDF), have been identified and the related safety insights have been derived.

2. PSA Level 1 Model of PGSFR

2.1 Initiating Event

In case of SFR, the vessel leak and sodium water interaction in SG are considered as characteristic initiating events in SFR as well as the general transients and the loss of off-site power also have a potential to be happen just like in light water reactor. The initiating events of PGSFR are applied in the same manner as those of KALIMER-600. Following initiating events are applied in this study:

○ General Transients
○ Loss of Offsite Power
○ Station Blackout
○ Loss of Flow
○ Vessel Leak
○ Reactivity Insertion
○ Sodium Water Interaction in SG
○ Loss of All RHR
○ Local Core Coolant Blockage (> 6 sub-channels)
○ Main Steam Line Break

2.2 Event Tree

The event trees for the applied ten initiating events are developed. The each Decay Heat Removal System (DHRS) was designed to remove the residual heat of 1MWt. If the power source is not available, the Active Decay Heat Removal System (ADHRS) has only 70% of its regularly designed performance. The safety function for the safe shutdown should be ensured even in a single failure. Since the total residual heat of 2.4MWt can be removed even in the case without power source and 1 train of Passive Decay Heat Removal System (PDHRS), the total residual heat of PGSFR after reactor shutdown are assumed as 2.4MWt.

The success criteria of the DHRS for KALIMER-600 and PGSFR are compared in table 1. According to the event sequence in the safety analysis of KALIMER-600, heat removal headings are classified with ADHRS and PDHRS respectively, but the single heat removal heading are applied as DHRS in PGSFR (Refer to figure 1 and 2).

Table 1. Success criteria of decay heat removal system for KALIMER-600 and PGSFR

Case		Heat Removal Capacity	Success Criteria
KALIMER-600	With Power	2 PDHRS X 50% 2 ADHRS X 50%	2 DHRS (PDHRS or ADHRS)
	W/O Power	2 PDHRS X 50% 2 ADHRS X 25%	2 PDHRS, or 1 PDHRS + 2 ADHRS
PGSFR (2.4MWt)	With Power	2 PDHRS X 41% (2MWt) 2 ADHRS X 41% (2MWt)	3 DHRS (PDHRS or ADHRS)
	W/O Power	2 DHRS X 41% (2MWt) 2 ADHRS X 29% (1.4MWt)	

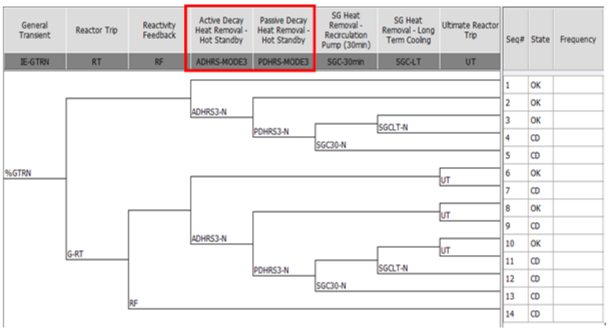

Figure 1. General Transient Event Tree (KALIMER-600)

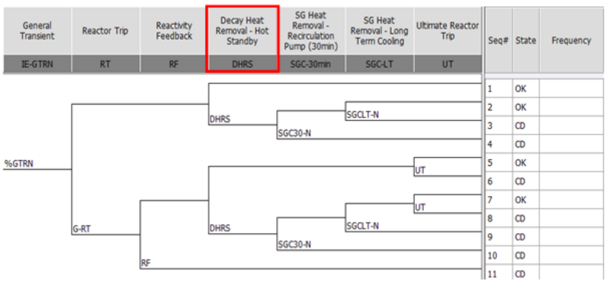

Figure 2. General Transient Event Tree (PGSFR)

2.3 Fault Tree and Reliability

The features neither designed nor considered so far in PGSFR are developed and applied with consideration for the similar features in PRISM, OPR-1000, and etc. The major modifications in fault trees are as follows;

(1) The modelling of supporting system (e.g. electric system) based on OPR 1000: 2 trains of 125V DC control center bus
(2) The latest equipment reliability data (e.g. NUREG-6928) are used: the frequency of pneumatic damper fail to open, 1.00E-05 → 3.66E-04 (increase in 36 times)
(3) For common cause failure (CCF), the latest data (e.g. NUREG-5497) are used.

3. Risk Analysis Result

3.1 Base Case Result

The base case model is quantified and the result of CDF is 2.25E-5/yr. LOISF (Loss of Intermediate Secondary Flow) is identified as an initiating event with the largest contribution to CDF (85%) as shown in figure 3. Minimal cut sets with the reliable contribution to CDF are listed in table 2. Basic events with highest contribution to CDF are the uncertainty factor of the event frequency of LOISF, uncertainty parameter for loss of 125V DC control center bus and damper CCF.

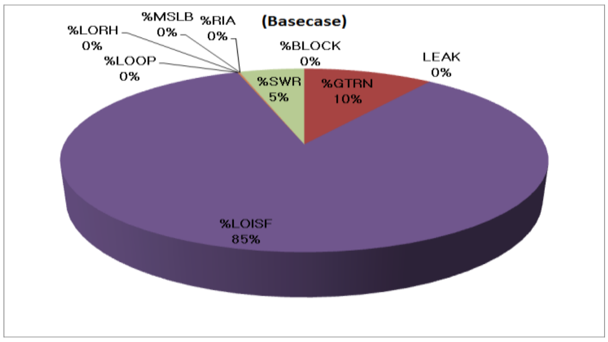

Figure 3. Initiating Event Frequency

Table 2. Minimal Cut Sets (MCS) of base case model

CDF Value	Initiating Event	Initiating Event Frequency	Basic Event 1	Basic Event 1 Probability	Accident Sequence
5.00E-06	%LOISF (Loss of Intermediate, Secondary Flow)	0.5	PDPVW-PDRC-AB (PDHRS T/H uncertainty factor)	1.00E-5	#IE-LOISF-2
2.82E-06	%LOISF (Loss of Intermediate, Secondary Flow	0.5	EDBSYDC01A (Loss of 125V DC CONTROL CENTER BUS)	5.64E-6	#IE-LOISF-2
2.82E-06	%LOISF (Loss of Intermediate, Secondary Flow	0.5	EDBSYDC01B (Loss of 125V DC CONTROL CENTER BUS)	5.64E-6	#IE-LOISF-2
9.39E-07	%LOISF (Loss of Intermediate, Secondary Flow	0.5	PDDMW-AC (PDRHS/ADRHS Damper 2/4 CCF - AC)	1.88E-6	#IE-LOISF-2
9.39E-07	%LOISF (Loss of Intermediate, Secondary Flow	0.5	PDDMW-BD (PDRHS/ADRHS Damper 2/4 CCF - BD)	1.88E-6	#IE-LOISF-2

3.2 Sensitivity Case Result

The sensitivity analyses for important factors identified in the base case are conducted and the assumptions of each sensitivity analysis are followed.

○ [Case 1] LOISF frequency: 0.5/yr → 1.15E-01/yr (Sum of LOFW and LOCV frequency for domestic PWRs (2012))
○ [Case 2] Without uncertainty parameter for Passive System CCF
○ [Case 3] The number of trains for 125V DC control center bus Train: 2 → 4
○ [Case 4] Using KALIMER-600 success criteria

The results of the sensitivity analysis are summarized in table 3. For all cases, CDFs are decreased.

Table 3. Sensitivity Analysis Result

Case	CDF (/yr)	# of MCS	DHRS Assumption	Reduction ratio (based on base case)
Base	2.25E-5	335	PGSFR(2.4MWt)	
Case 1	7.83e-6	288	Lowered the LOISF frequency (0.5/yr → 0.115/yr) LOFW : 3.11E-02 LOCV : 8.36E-02	2.87 time
Case 2	1.65e-5	284	Neglect PDHRS thermal hydraulic uncertainty factor (1.0E-5)	1.36 time
Case 3	1.59e-5	377	Increase the number of trains (2→4)	8.49 time
Case 4	2.65e-6	107	Apply KALIMER-600 success criteria	1.4 time

4. Conclusion

The PSA level 1 model for PGSFR regulatory is developed and the risk analysis is conducted. Regarding CDF, LOISF frequency, uncertainty parameter for passive system CCF, loss of 125V DC control center bus and damper CCF are identified as the important factors. Sensitivity analyses show that the CDF would be differentiated (lowered) according to their values. Since the primary system of PGSFR is very dependent on PDHRS, the design which ensures that 2 trains of ADHRS have ability to cool the primary system even in the loss of 2 trains of PDHRS should be considered. According to the change of initiating event frequency and application data, however, the other important factors to the CDF of PGSFR can be derived.

ACKNOWLEDGMENT

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