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A Preliminary PIRT Development Related to SWR Accidents from an SG Tube Failure

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1. Introduction

The Phenomena Identification and Ranking Table (PIRT) process was created as a systematic and documented means of completing a U.S. NRC's Code Scaling, Applicability, and Uncertainty exercise with a limited amount of resources [1]. This paper describes a preliminary PIRT development for a Sodium-Water Reaction (SWR) accident with regard to a Steam Generator (SG) tube failure of the KALIMER-600 (Korea Advanced Liquid Metal Reactor) [2].

2. Initiating Event and SWR Scenario

2.1 Definition of Causes of Initiating Event

The SWR is a phenomenon that occurs after the penetration leakage of an SG tube. The leak rate, leak hole size, and leak location are important variables to be considered in determining the consequences of an SWR. These items depend greatly on the failure causes, while the failure causes themselves do not have a direct effect on the consequences of the SWR. The candidate phenomena of failure causes are known to be as follows: corrosion, stress corrosion cracking, thermal expansion, thermal transient, dry out/departure from nucleate boiling, flow-induced vibration, droplet flow, galling, and fretting. The locations for the leak hole can be a tube sheet, tube/tube sheet weld, tube-tube weld, tube base material, and tube support. The initiating events can therefore be developed from the possible combinations of the cause and location of the tube failure.

2.2 Scenario for general evolution of SWR in a SG

A scenario for the general evolution of an SWR is categorized by the leak rate, because the water/steam leak rate has a decisive influence on the event sequence and consequence. The relation between leak rate and associated main event is typically classified as follows [3]:

- Large leak rate (>1 to 2 kg/s): e.g., generation of a large amount of hydrogen gas
- Intermediate leak rate (50 g/s - 1 to 2 kg/s): e.g., overheating, target wastage, multi-tube wastage
- Small leak rate (0.1 g/s - 50 g/s): e.g., wastage
- Very small leak rate (<0.1 g/s): e.g., self-plugging

Figure 1 shows the scenario for the general evolution of SWR in an SG

2.3 Partitioning of Plant System

In the PIRT process, to make the selection of plausible phenomena easier, the overall plant system is divided into subsystems or components. The only subsystem related to this PIRT is the Intermediate Heat Transport System (IHTS), and the only component related to this PIRT is the "SG system" in the IHTS. Therefore, this PIRT partitions the "SG system" into 6 subcomponents, as shown in Figure 2.

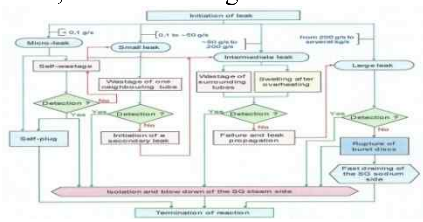

Fig. 1 Scenario for the general evolution of an SWR

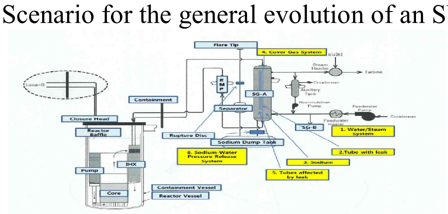

Fig. 2 IHTS of the KALIMER-600

3. PIRT Development

3.1 Figure of Merit (FoM)

In the PIRT process, the degree of importance of a phenomenon is evaluated by its relative importance against a criterion called the Figure of Merit (FoM), which are often derived from the regulatory requirements of 10CFR 50 [4]. In the KALIMER-600 design, the primary sodium is maintained in the double containment, blanketed with inert argon gas, and a secondary sodium loop isolates the primary system from the SGs and Balance of Plant (BOP). This PIRT considers FoM based on the point of view of "Integrity of Primary Coolant Boundary." The scenario of this PIRT bounds within the SG system. Since the pressure generated in the SG might cause damage to the IHX boundary, it is important to consider the pressure on this boundary. In addition, the integrity of the neighboring heat transfer tubes is important because a failure of the neighboring tubes would cause an increase in pressure[5]. In this PIRT, two FoMs are selected. One is the pressure on the IHX boundary between the PHTS and the IHTS. The other is the cumulative damage fraction (CDF) of the neighboring heat transfer tubes owing to overheating, wastage in the lifetime.

3.2 Phenomena Identification

Plausible phenomena for an SWR accident are listed in Table 1.

Table 1. Plausible Phenomena for SWR accident

Water/Steam(W/S) System(5)	- Initial operating point (P,T,Q) - Change in P - Change in T - Change in Q - Blow down rate of water
Tube with leak(1)	- LR of W/S at FP
Sodium(10)	- Initial operating point(P,T) - Change in P - Change in T - Reaction area - RP at FP - Reaction T - Energy produced/absorbed at FP - Initial pressure pulse at FP - Ratio of RP (NaOH, Na_2O) - Length of reaction jet
Cover gas system(4)	- Change in cover gas P - Change in cover gas T - Concentration of hydrogen gas - FI of cover gas P control
Tubes affected by leak(8)	- Change in stress of NT - Chemical effect - Impingement - Tube inside T - Tube outside T - Heat conduction of material - HT on tube outside - HT on tube inside
Sodium-Water Reaction Pressure Release System(SWRPS)(6)	- FI of RD - FI of RD(for SDT) - FI of SDT - FI of separator - Transport of SWR products - FI of igniter

T: Temperature P: Pressure Q: Quality of Steam
FP: Failure Position FI: Functional Integrity
SDT: Sodium Dump System NT: Neighboring Tube
HT: Heat Transfer W/S: Water/Steam
LR: Leak Rate (up on size of each leak hole and steam pressure) RD: rupture Disc RP: Reaction Products

3.4 Sensitivity Analysis

Sensitivity analyses would be performed for plausible phenomena for which the parameters can be varied, such as the heat transfer coefficient. From the sensitivity analysis, the uncertainty width of the parameter is determined based on the reference values regarding the Design Basis Accidents (DBAs). Generally, a standard deviation of 1σ can be set, and the scales of standard deviation for the parameters are set as follows based on the design accuracy or engineering judgment.

- Parameters related to flow: 10%
- Parameters related to heat: 20%
- Parameters related to physical properties: 1-10%

From the sensitivity analyses, the cases of significant sensitivity can be obtained. The sensitivity for the time to a tube failure from an overheating rupture can be obtained through a separate analysis.

3.5 PIRT Ranking Process

Based on Table 1, the rankings for the relative importance of the phenomena and the current state of knowledge (SoK), which are different before and after a blow down in the scenario, can be established by the PIRT team, consisting of engineers and experts. Tables 2 and 3 show the rank of relative importance and state of knowledge on the phenomena, respectively. The final priority ranking table can then be obtained for each phase for a further investigation to reduce the uncertainties for a safety analysis model.

Table 2. Ranking Scale of Relative Importance of Phenomena

High (H):	3	A large effect on FoM.
Medium(M):	2	A medium effect on FoM.
Low (L):	1	A small effect on FoM.
Not Applicable:	0	Little or nothing to do with FoM.

Table 3. Ranking Scale of State of Knowledge of Phenomena

Known (K):	0	Well-known Little uncertainty in model
Partially known (P):	1	Partially known Moderate uncertainty in model.
Unknown (U):	2	Little knowledge. Large uncertainty in model

4. Conclusion

The plausible phenomena related to SWR accidents were developed. Based on the results of the PIRT, the uncertainties of the phenomena ranked as high priority can be reduced by an investigation or/and theoretical evaluation. The PIRT for IHTS due to SG tube rupture of Prototype GEN-IV Sodium cooled Fast Reactor (PGSFR) is on developing stage by the KAERI-ANL experts. These plausible phenomena can be applicable to the PIRT development of PGSFR having the similar concept of KALIMER-600.

Acknowledgements

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