Proceedings of the Korean Nuclear Society Autumn Meeting
Taegu, Korea, October 1997

Development of a Preliminary PIRT (Phenomena Identification and Ranking Table) of Thermal-Hydraulic Phenomena for SMART

Bub Dong Chung , Won Jae Lee, Hee Cheol Kim, Jin Ho Song, Suk Ku Sim

Korea Atomic Energy Research Institute

Abstract

The work reported in this paper identifies the thermal-hydraulic phenomena that are expected to occur during a number of key transients in SMART (System-integrated Modular Advanced ReacTor) which is under development at KAERI. The result of this effort is based on the current design concept of SMART integral reactor. Although the design is still evolving, the preliminary Phenomena Identification and Ranking Table (PIRT) has been developed based on the experts' knowledge and experience. The preliminary PIRT has been developed by consensus of KAERI expert panelists and AHP(Analytical Hierarchy Process). Preliminary PIRT developed in this paper is intended to be used to identify and integrate development areas of further experimental tests needed, thermal hydraulic models and correlations and code improvements for the safety analysis of the SMART.

1. Introduction

The US Nuclear Regulatory Commission (NRC) has amended its LWR safety regulations in 1988 to allow the use of best-estimate safety analysis codes to demonstrate that the emergency core cooling system would protect the reactor core during a postulated loss-of-coolant accident (LOCA)[1]. A key feature of this revised rule is that the licensee will be required to quantify the uncertainty of the best-estimate calculations and include that uncertainty when comparing the calculated results with the 10CFR50 Appendix K limits. The NRC has further proposed a Code Scaling, Applicability, and Uncertainty (CSAU) evaluation methodology[2]. One of the cornerstones of that methodology is the identification and ranking of all the processes that occur during a specific transient scenario. The ranking is done according to relative importance during the scenario and is used to focus the scope of the uncertainty analysis in a sufficient but cost effective manner. The work, which identifies the thermal-hydraulic phenomena and generates ranking table, is called a PIRT(Phenomena Identification and Ranking Table) process.

There have been several PIRT studies. One of these studies is a PIRT during a LBLOCA for a Westinghouse four-loop pressurized water reactor.[3] The major phenomena were ranked with relative importance with respect to the principal safety criteria (PSC), e.g., peak cladding temperature. Similar efforts for a SBLOCA scenario for a B&W NPP design and AP600 also have been performed[4,5,6]. The objective of this paper is to document the application of PIRT process on the SMART [7].

2. Scenario Specification

An important step toward identifying the phenomena that dominate the transient is establishing a detailed description of specific scenario. Because phenomena identification is a transient phase specific process, this procedure has :

a) Advantage because it results in the smallest uncertainty, with strong technical justification, for any transients

b) Disadvantage because it requires significant resources to cover all the transients.
One of compromised approaches for the reduction of the required resources is the introduction of "nucleus set of transients" with extensions to the complete analysis envelop by phenomenological similarity. "Nucleus set of transients" consist of the representative transients that bound the subsets of transients grouped in view of the similarity of phenomena and consequences. Thus, this approach [8] can reduce significantly the resources required to address all the phenomena for whole transients envelop. Although it remains to be demonstrated that sufficient technical arguments can be developed to show the phenomena of the nucleus set of transients fully bound that of the transient envelop, the above approach was adopted as a preliminary PIRT process. To ensure the PIRT process, a panel of experts is used to define the nucleus set of transients and scenario.

Finding of Nucleus Set of Transients

To find out "nucleus set of transients", all the design base events identified by KAERI were considered. The design base events were classified into the performance related design basis event(PRDBE) and safety related design basis event(SRDBE). Panelists grouped the events having phenomenological similarity, then defined the bounding transients of each group as the "nucleus set of transients". The final nucleus set of transients is tabulated in Table 1. The phenomena which occur during seven transient events would cover all phenomena of design basis transients and bound that of analysis envelop.

Table 1. Nucleus Set of Transients

Type of Transients
1. Steam Line Break (SLB)
2. Total Loss of Feedwater (TLOFW)
3. Complete Loss of Flow (LOFA)
4. CEDM Withdrawal at Power (CEAW)
5. CEDM Ejection (CEAE)
6. Primary to Secondary Break Accident (PSBA)
7. Loss of Coolant Accident(SBLOCA Only)

Specification of Transient Phases

The scenario corresponds to a best estimate design situation, which in the experts opinion represents the worst realistic scenario. It was also noted that the particular consequences of transients are quite sensitive to control system performance; it may alter the nature and outcoming of the transient. It was decided that the control systems are assumed to behave and perform as designed. However, since the control systems design for SMART are not available yet, its performance was determined by expert panelist opinion. The scenario was identified for the nucleus set of transients in Table 2.

3. PIRT Process

Expert panel decided that AHP(Analytic Hierarchy Process) is the principal methodology employed in the whole PIRT process. AHP is a tool used to accurately determine the relative importance of a group of selections with respect to some prescribed criteria. In order to systematically identify the phenomena for each nucleus transient, it is convenient to identify the major plant components and subsequent phenomena in sub-components.

Table 2. Identified Transient Phases

Event	Phases	Remark
SLB	1 Pre-Trip Phase	Phase 1 & 2 were consolidated in later step
	2 Post-Trip Phase	
TLOFW	1 Heat up by loss of heat sink before reactor trip phase	
	2 Single phase natural circulation after reactor trip phase	
LOFA	1. Power to flow mismatch phase	
	2. Decay Heat Removal by Natural Circulation phase	
CEA Withdrawal	1 Pre-Trip Phase	
	2 Post-Trip Phase	
CEA Ejection	1. Power Excursion Phase	
PSBA	1. Depressurization phase	Phase 2 & 3 were consolidated in later step
	2. Natural Circulation phase	
	3. Cooldown phase	
SBLOCA	1 Gas Discharge phase	Phase 3 & 4 were consolidated in later step
	2 Subcooled/Two Phase Discharge phase	
	3. Loss of Natural Circulation phase	
	4. Recovery phase	

Identification of Associated Components

The whole primary system of SMART integral reactor was divided into 5 main component; Fuel, Vessel, Pump, Pressurizer, and Steam Generator. Safety systems were classified into 3 features; Scheduled Emergency Cooldown System (SECS), Emergency Core Cooling System (ECCS), Makeup System. Sub-components for each main component were also identified.

Identification of Phenomena

The expert panelists divide each event into several phases, and for each phase the phenomena that are likely to occur were identified. All phenomena identified by the panelists were assigned to sub-compartment.

Selection of Primary Safety Criteria

The ranking process is an evaluation of the relative importance of identified phenomena with respect to certain safety concern. Thus it is necessary to determine the primary safety concern for nucleus set of transients. Safety concern may be different for each phase of transient. Panelists decided the major safety concern, i.e. Primary Safety Criteria (PSC) as table 3..

Table 3. Primary Safety Criteria for Nucleus Events

Event	Primary Safety Criteria
SLB	MDNBR
TLOFW	Peak PZR Pressure / Decay Heat Removal (DHR) (For Phase 2)
LOFA	MDNBR / DHR(For Phase 2)
CEA Withdrawal	MDNBR
CEA Ejection	Maximum Fuel Failure Fraction
PSBA	Radiation Release/ DHR (For Phase2)
SBLOCA	Core Mass Inventory

Ranking Process by AHP Methodology

To realize the Analytical Hierarchy Process (AHP) approach, the panel of experts was asked to rank the phenomena in pair-wise fashion (relative importance of component i with respect to component j only) with respect to primary safety criteria, using their knowledge and experiences. The scale chosen to quantify this importance was ranged from 1 to 4. If the phenomena i was much more important than j, then it was given a relative rank of 4; if i was only slightly more important than j it was given a relative rank of 2; and for equal importance the rank was 1. A rank matrix was established and the panelists were asked to rank by rows, comparing column element i vs row element j.
The next step is to generate a new row by averaging the elements in each corresponding column and finally normalize with respect to the highest value. The final ranking is obtained from the normalized rankings by scaling them according to the scale of choice. In this paper, it was decided to have the final ranking up to 10, so the highest rank is assigned to be 10 and every element is ranked proportionally. As an AHP application for SMART, the following 3 steps were processed to obtain the final ranking of phenomena.

Step 1. Relative Component Ranking with respect to PSC

The panel of experts was asked to rank the importance of component and component rank matrix were generated for each phases of events. The final component ranking tables are obtained by following the above AHP process.

Step 2. Relative Phenomena Ranking with respect to PSC

If the hierarchy has one more level, as it is in our case, then the normalized component rankings are kept as weighting factors to be used later. The next level items, the identified phenomena in each sub-component, are ranked in the same way as the components have been ranked.

Step 3. Composition of Component Ranking & Phenomena Ranking

The final ranking of each phenomena in each phase of the nucleus transients is a composite of component ranking (1st step) and phenomena ranking of each component (2nd step). The ranking results obtained by the expert panelists' voting for each phase of nucleus transients were processed though this procedures.

5. PIRT Results

The resulting final PIRT contains the subset of all phenomena of interest for each phase during nucleus transients of the SMART and summarized in table 4. In the ranking procedure, the panelists found some phases such that the separation of phases is not required with respect to the importance of identified phenomena on the primary safety criteria. In such cases, the phases were consolidated into one phase. The phase I and II for SLB, the phase II and Phase III for PSBA , and Phase III and IV for SBLOCA are consolidated into a unified phase.

6. Conclusion

Based on the expert assessment, the expected thermal hydraulic behavior of the SMART has been identified based on the current design features and expert opinion. All the transients relevant to the licensing issues were grouped phenomenologically into a nucleus set of transients representing subset of transients. Each nucleus transient was divided into several phases depending on the different physical processes. Expected phenomena for each phase of a transient are identified for sub-components of the reactor system, and ranked by the AHP approach. The AHP approach was proved to be a useful tool, not only to determine the final rankings by expert panelists' consensus, but also for evaluating the minor disagreements on the final outcome.

The preliminary PIRT for SMART reactor should be refined later since currently the design of SMART is not finalized and still evolving. The final PIRT will be developed as the design and experimental test data as well as the results of the transient analysis are available. In the mean time, however, the reported results will be used to guide the experimental test program, scaling of the test facility and the developments of thermal hydraulic models and system code. The preliminary PIRT should be also utilized to focus and integrate the SMART integral reactor development in a sufficient and cost effective manner.

References

1. Compendium of ECCS Research for Realistic LOCA Analysis, NUREG-1230, Final Report, December (1988)
2. Technical Program Group, Six Papers describing the CSAU Methodology and its Demonstration to LBLOCA", Nuclear Engineering and Design, Vol. 119, No.1 (1990)
3. Shaw, R.A., Rouhani, S.Z., Larson, T.K., Dimenna, R.A., "Development of a Phenomena Identification and Ranking Table (PIRT) for thermal-hydraulic phenomena during a PWR (pressurized water reactor) large-break LOCA (loss-of-coolant accident)", NUREG/CR-5074; EGG-2527, November (1988)
4. M.G. Ortiz, L.S. Ghan, and G.E. Wilson , "Development of a Phenomena Identification and Ranking Table (PIRT) of thermal hydraulic Phenomena during a PWR Small Break LOCA", Informal Report, EGG-EAST-9080, May (1990)
5. M.G. Ortiz and L.S. Ghan, " Uncertainty Analysis of Minimum Vessel Inventory During SBLOCA in a B&W Plant : An Application of the CSAU Methodology using the RELAP5/MOD3 Computer Code", NUREG/CR-5818, EG&G Idaho, Inc. , December (1992)
6. G.E. Wilson et. al, " Phenomena Identification and Ranking Tables for Westinghouse AP600 Small Break Loss-of-Coolant Accident, Main Steam Line Break, and Steam Generator Tube Rupture Scenarios", NUREG/CR-6541, INEL-94/0061, Rev.2, June (1997)
7. M.H.Chang, " Preliminary Design Concepts of an Advanced Integral Reactor", the 17th KAIF-JAIF Seminar on Nuclear Industry, Seoul, Korea, Oct. 17 (1995)
8. G.E.Wilson " Overview of the CSAU Methodology for Quantifying Code Uncertainty", Report of CSNI Workshop on Uncertainty Analysis Methods, NEA/CSNI/R(94)20/Part.2, Volume 2, London, March 1-4 (1994)

Table 4. Ranking Results for the Nucleus Set of Transients for SMART

Ranking Number 10 : Highest Rank
Ranking Number 1 : Lowest Rank

Component	Phenomena	Events A	B		C		D		E	F		G		
			I	II	I	II	I	II		I	II	I	II	III
Fuel	Neutron Power	7	2		10		10	5	9			4	1	
	Power Distribution								8					
	Fuel Stored Energy		1						2	2		4		
	Decay Heat			7		10					7		4	5
	Gap Heat Transfer Coefficients	3							4					
	Clad Heat Transfer	8	3	7	10		10	10	10		7	4	2	
Vessel	Downcomer Mixing	3									2			
	Lower Plenum Mixing	3												
	Core Asymmetric Reactivity Feedback	8												
	Upper Plenum Mixing	1												
	Core Coolant Heatup		5				5	3						
	Core Voiding								3				5	
	Core Inlet Flow Distribution				6									
	Cross Flow in Core				3									
	Natural Circulation					7								
	Displacer Latent Heat										3			
	N2 Gas Release											2		
	Upper Plenum Voiding												3	
	Upper Plenum Phase Separation													9
	Upper Plenum Condensation													2
Pump	Flow Coastdown			3	10								1	
	Pump Discharge 3D Flow				3									
	Stopped Impeller Restriction										2			
	Pump Discharge Voiding												1	
	Pump Discharge Condensation													2
	Pump Impeller Water Plugging													9
Pressurizer	End Cavity N2 Gas De-/Pressurization	1	6			3	3	3	2	3		3		
	Safety Valve Flow		10											
	In-surge Flow		6											
	End Cavity Mixing		4	2						2	2		1	3
	End Cavity Wall Condensation													2
	Intermediate Cavity Wall Condensation													2
	Level Tracking									2	2		1	
	Surge Line Critical Flow												4	
S/G	Secondary Heat Transfer	8	10	7	2	7							1	2
	Primary Heat Transfer		5	3	2						4		2	2
	Secondary Flashing									10	3			
	Secondary Steam/Water Interaction									3	3			
	Steam/Feedwater Pipe Fill-up										2			
	Condensation in Stm/FW Pipe										2			
SECS	ECT Heat Exchanger Heat Transfer			10		7					10		4	2
	Thermal Mixing in ECT			7							7		5	2
	Compensating Tank Gas Expansion			3							3		3	
	Faulted SECS Loop Fill-up										5			
Break	Break Critical Flow	10										6	10	9
	Primary to Secondary Break Discharge									10	2			
	Break Critical Flow of N2 Gas											10		
ECCS	Adiabatic Expansion of N2 Gas												7	
	Intermittent Flow Injection													7

A: Steam Line Break (SLB)
B: Total Loss of Feedwater Flow (TLOFW)
C: Loss of Flow Accident (LOFA)
D: CEA Withdrawal Event
E: CEA Ejection Accident
F: Primary to Secondary Break Accident (PSBA)
G: Small Break Loss of Coolant Accident (SBLOCA)