Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Evaluation Result of PIRT Methodology for Fire Modeling

Moon-Hak Jee *, Hyeong-Taek Kim
KNHP Central Research Institute (CRI) 70-1312-gil,
Yuseong-daero Yuseong-gu Daejeon 305-343, Korea
**Corresponding author: jmhak@khnp.co.kr*

1. Introduction

In nuclear power plants (NPPs), a fire risk is analyzed by use of engineering equations or quantitative fire modeling tools. For fire modeling, the widely used programs are the Consolidated Fire Growth and Smoke Transport Model (CFAST) which is zone model and the Fire Dynamics Simulator (FDS) which is CFD model. One of sensitive items for the fire risk analysis with fire models is the major effect of input data to modeling result. If input factors are influential to the output of the program, their reliability must be appraised at the initial stage of design. In addition to the importance of input data, modeling itself should be reviewed by the verification and validation process. As shown in NUREG-1824, EPRI and NRC already verified the mathematical solution of the governing equations for CFAST and FDS. However, the validation of fire modeling must be done to quantify uncertainties originated from the physical approximation and immature capabilities of the program designer.

A way to reduce uncertainties of fire modeling is to compare the predicted values by fire models and the experimental results. However, it is not practical to implement such fire experiments in order to confirm all on-site situations. Consequently, fire modeling tools are introduced to quantify fire phenomenon. One of the ways to upgrade the fire modeling credibility is to find out what sort of phenomenon is important at fire scenarios and how much the fire model is adequate to the real fire situations. In this purpose, we studied PIRT to apply to fire modeling tools and PIRT means Phenomena Identification Ranking Table which has been used to assess the code scaling, applicability, and uncertainty (CSAU) by NRC.

2. Methods and Results

To apply PIRT method to fire modeling, the first thing was to organize the expert panel. Next step was to rank the importance of fire scenarios by expert panel. At this study, the process of PIRT application to fire models in NPPs was referred to the NUREG/CR-6978 which was developed by NRC.

2.1 Selection of Expert Panel

Initially, seven experts were selected as panelists to analyze and evaluate the PIRT method to apply to fire modeling processes. Unfortunately, one Canadian expert could not complete the evaluation process and he did not finalize the ranking table. At table 1, technical careers of experts and moderator are given.

Table 1: Expert Panel and Moderator

	Name	Expert	Experience
1	H DD	Professor	- Fire modeling analysis - 25 years of experience
2	A Kim	PhD	- fire suppression analysis - 25 years of experience
3	G DI	PhD	- fire & PSA analysis - 15 years of experience
4	K YJ	Engineer	- fire risk and modeling - 15 years of experience
5	K CH	Professor	- fire risk and modeling - 10 years of experience
6	K SC	Professor	- fire risk and modeling - 10 years of experience
7	H JH	Professor	- fire modeling analysis - 20 years of experience
8	H MH (moderator)	P. E.	- fire risk and modeling - 25 years of experience

2.2 Representative Fire Scenarios

In NPPs, there are many fire areas and potential fire situations. However, the purpose of fire modeling is to speculate the figure of merits. Figure of merit means which kind of target should be protected from the fire and the important effect due to fire. At this study, six fire scenarios were selected with consideration of fire characteristics and the reference guidelines in NUREG-1934. Major figure of merits are the operator habitability in main control room, safe shutdown function and fire propagation to other areas.

Table 2: Representative Fire Scenarios

No	Scenario	Figure of Merit
FS-1	Main Control Room Fire	- operator evacuation - safety function
FS-2	Electric Fire (General)	- safety function - fire propagation
FS-3	Electric Fire (HEAF)	- safety function - fire propagation
FS-4	Cable and A-type Fire	- safety function - fire propagation
FS-5	Oil Fire (Pool Fire)	- safety function - fire propagation
FS-6	Oil Fire (Spray Fire)	- safety function - fire propagation

2.3 Fire Phenomena and Ranking of Sub-phenomena

At six representative fire scenarios, all the potential fire phenomena at each scenario were classified by the moderator. Potential fire phenomena were assorted into sub-phenomena again which are subordinate to the fire phenomenon. The panelists identified both the potential phenomena and the sub-phenomena to determine the importance ranking of the sub-phenomena. Fire scenario (FS) #1 is the main control room fire. For FS #1, there are two kinds of figure of merits. One is the evacuation threshold for operator due to temperature, heat flux, and smoke concentration and the other is the functional failure of safe shutdown capabilities of cable, electric panel, instrument, and facilities in MCR.

At FS #1, seven fire phenomena were classified and each phenomenon was divided into several sub-phenomena to evaluate the importance ranking. The following table shows the kinds of fire phenomena. In Table 2, FS means fire scenario and PH designates phenomenon of FS #1.

Table 2: Representative Fire Scenarios (FS #1)

FS-1: the main control room fire	
PH-1	Fire detection at residential area of MCR
PH-2	Fire detection at under-floor of MCR
PH-3	Fire effect of internal circumstances of MCR
PH-4	Effect due to characteristics of wall, floor, ceiling
PH-5	Fire propagation to neighboring electric panels
PH-6	Effect due to characteristics of fire source
PH-7	Effect of heat, smoke, combustion products

Table 3 represents the other six fire scenarios and the number of phenomenon to each scenario.

Table 3: Description of Fire Scenarios (FS #2~#6)

Fire Scenario	# of Phenomenon
FS #2: General electric fire	6
FS #3: HEAF electric fire	7
FS #4: Cable and A-type fire	4
FS #5: Oil fire (pool fire)	4
FS #6: Oil fire (spray fire)	4

2.4 Importance Ranking of Major Phenomenon

The panelists assessed the potential phenomenon and determined the importance ranking to each phenomenon. The ranking of importance for each phenomenon, referring to NUREG/CR-6978, is noted in Table 4.

Table 4: Definition of Phenomenon Importance Ranking

Degree	Definition
H	First order of importance to figure of merit
M	Secondary importance to figure of merit
L	Negligible importance to figure of merit
U	Importance should be examined further study

It was categorized the degree of panelists' importance ranking into H, M, L, U and extracted the highest degree of sub-phenomenon, which was determined to be the maximum number of H degree, as shown in Table 5.

Table 5: The most important ranking of Sub-Phenomenon

FS- #	PH- #	Highest Degree of Sub-Phenomenon
FS-1	PH-1	Fire detection by MCR internal configuration
	PH-2	Type of fire detection (heat, smoke, vesda)
	PH-3	Heat flux to the target in MCR
	PH-4	Heat transfer to neighboring electric panel
	PH-5	Fire propagation to neighboring panel
	PH-6	Radiation heat emitted from fire source
	PH-7	Accumulated smoke and toxic gas
FS-2	PH-1	Fire propagation to neighboring cables
	PH-2	Location of fire detector inside fire zone
	PH-3	Room temperature and heat flux
	PH-4	Activation of automatic fire suppression system
	PH-5	Physical and thermal characteristics of cable
	PH-6	Infiltration of heat, smoke, and products
FS-3	PH-1	Cascading fire to neighboring combustibles
	PH-2	Fire propagation to neighboring cables
	PH-3	Location of fire detector inside fire zone
	PH-4	Room temperature and heat flux
	PH-5	Operation of fire detection and suppression system
	PH-6	Physical and thermal characteristics of cable
	PH-7	Infiltration of heat, smoke, and products
FS-4	PH-1	Fire propagation to neighboring cables
	PH-2	Room temperature and heat flux
	PH-3	Operation of fire detection and suppression system
	PH-4	Surface temperature and heat flux to target
FS-5	PH-1	Heat releases rate from pool fire source
	PH-2	Activation of automatic fire suppression system
	PH-3	Location of fire detector inside fire zone
	PH-4	Heat and smoke movement, and fire rating
FS-6	PH-1	Movement of heat, smoke, and products
	PH-2	Operation of fire detection and suppression system
	PH-3	Location and type of fire detection system
	PH-4	Air intrusion to fire zone through opening

2.5 Adequacy of Existing Fire Models

For the practical realization of sub-phenomenon, it was asked to the expert panel that the existing fire models could implement the real circumstances of fire situation as described in sub-phenomenon. Additionally, the panelists evaluated that the present fire models could simulate the fire situation fitting to the sub-phenomenon.

For the fire model adequacy with reference to NUREG/CR-6978, the definition of ranking for the fire modeling adequacy was given as noted in Table 6.

Table 6: Definition of Fire Model Availability Ranking

Degree	Definition
H	At least, one mature model is available that can adequately represent the phenomenon
M	At least, one candidate model is available
L	Model form is still unknown or speculative
U	The panel is unaware of existing fire model

Following to the definition of fire modeling ranking, the expert panel evaluated the adequacy of existing fire model. In summary, the degree of fire modeling adequacy did not agree each other. Expert's degree was randomly distributed from H, M, L, U, N/A. However, it showed some tendency that the degree was quite dependent on the expert's knowledge and his experience. Table 7 notes for the adequacy degree for the sub-phenomenon which were evaluated for the highest phenomenon ranking by the panelists.

Table 7: Ranking of Adequacy for Existing Fire Models

FS- #	PH- #	Sub-Phenomenon	Fire Model Ranking
FS-1	PH-1	Fire detection by MCR	M
	PH-2	Type of fire detection	M
	PH-3	Heat flux to target	From M to H
	PH-4	Heat transfer to panel	From M to H
	PH-5	Fire propagation to panel	M
	PH-6	Radiation from fire source	H
	PH-7	Smoke and toxic gas	M
FS-2	PH-1	Fire propagation to cables	M
	PH-2	Location of fire detector	H
	PH-3	Temperature and heat flux	From M to H
	PH-4	Automatic fire suppression	From M to H
	PH-5	Characteristics of cable	M
	PH-6	Infiltration of heat, smoke	From M to H
FS-3	PH-1	Cascading fire	From L to M
	PH-2	Fire propagation to cables	From L to M
	PH-3	Location of fire detector	From M to H
	PH-4	Temperature and heat flux	From M to H
	PH-5	Detection and suppression	M
	PH-6	Characteristics of cable	M
	PH-7	Infiltration of heat, smoke	From M to H
FS-4	PH-1	Fire propagation to cables	From M to H
	PH-2	Temperature and heat flux	From M to H
	PH-3	Detection and suppression	From M to H
	PH-4	Temperature and Heat flux	From M to H
FS-5	PH-1	HRR from pool fire source	From M to H
	PH-2	Automatic fire suppression	From M to H
	PH-3	Location of fire detector	From M to H
	PH-4	Heat and smoke movement	From M to H
FS-6	PH-1	Movement of heat, smoke	From M to H
	PH-2	Detection and suppression	From M to H
	PH-3	Fire detection system	From M to H
	PH-4	Air intrusion to fire zone	From M to H

2.6 Availability of Input Parameters

As part of parameter uncertainty, the availability of reliable input data is important factor to the uncertainty of fire modeling result. In this sense, it was asked to the expert panel whether input data or parameters for the existing fire models are available to implement the potential sub-phenomenon based on the definition of adequacy for existing model input data (Table 8).

The degree for the availability of input parameters showed similar ranking with that of the adequacy for the existing fire models. It is evident that if input data is readily available it is easier to implement the fire modeling to the specific fire phenomena. In addition, it was also asked to the expert panel whether or not the input data is not available or the reliability is not ideal to execute the fire modeling for the phenomenon. Panelists' evaluation of the ranking for the feasibility of acquiring new input data was a little biased when it is compared to the ranking of the availability for existing input parameters. If the existing input data are available, the feasibility of new input data should be less needed.

We expected that if the ranking of the availability for existing data was high, the ranking of the feasibility for new data should be low. If the ranking for the availability of existing data was moderate or low, the ranking for the feasibility of new data should be moderate or high. However, evaluation result by the panelists was not consistent to above technical logic. It can incur strong argument among panelists when it is relying on the definition for the degree of input data at Table 8 and at Table 9 which were referred to NUREG report. At Table 9, it shows the definition for the adequacy of new data development.

In this reason for disagreement in panel, the detail analysis for the experts' evaluation for the availability of existing and new parameter was not progressed.

Table 8: Adequacy for Existing model input data

Degree	Definition
H	A high resolution database exists or a highly reliable assessment can be made based on the existing knowledge. Data needed are readily available
M	Existing database is of moderate resolution, or not recently updated. Data are available but are not ideal. Moderately reliable assessment of models can be made based on existing knowledge
L	No existing database or low-resolution database in existence. Assessments cannot be made with even moderate reliability based on existing knowledge

Table 9: Adequacy for new data development

Degree	Definition
H	Data needed are readily obtainable based on existing experimental capabilities
M	Data would be obtainable but would require moderate, readily attainable extensions to existing capabilities
L	Data are not readily obtainable and/or would require significant development of new capabilities

2.6 Other Factors

Through the expert panel, other factors for the application of PIRT methodology were also reviewed. Major other factors which are relevant to the state of knowledge ranking are the availability of data for model validation and feasibility of new data acquisition for validation if the existing data is not available or less reliable. At the final step of study, ranking for the importance of key parameters for each sub-phenomenon was asked to panelists. Most experts' evaluation results agreed to the importance ranking for key parameters. In fact, some key parameters are used as same input data to sub-phenomena and experts' evaluation result also showed that key parameters with high ranking in sub-phenomena were also high degree in other situation.

Key parameters can be grouped into two parts. One part is related with input data for fire modeling and the other deals with the output behavior of fire modeling. Fire modeling designers or the users can take significant insight at the critical input data and the expected modeling results from the expert panels' evaluation report. The key parameters to which more than 3 experts gave H ranking degree are listed in Table 10.

Table 10: Key Parameters with more than 3H Degree

Key Parameter	Ranking
Distance between fire source and detector	3-H, 3-M
Type of fire detector (or system)	4-H, 2-M
Sensitivity of fire detector (or system)	4-H, 2-M
Ventilation type	5-H, 1-M
Heat flux to target	4-H, 2-M
Surface temperature to target	3-H, 3-M
Smoke height	4-H, 2-M
Combustion product (toxicity, visibility)	6-H
Type of finish material	3-H, 1-M, 2-L
Ceiling height	3-H, 3-M
Type of combustibles (source, neighbor)	4-H, 2-M
Flame spread of combustibles	3-H, 1-M, 2-L
Radiation fraction	5-H, 1-M
Flame height and temperature	4-H, 2-M
Location of fire source	5-H, 1-M
Heat release rate of fire source	6H
Fire growth rate	5-H, 1-M
Effect of oxygen (starvation)	5-H, 1-L
Air movement through cabinet or panel	3-H, 2-L, 1-U
Smoke and combustion products	6-H
Size and structure of cabinet or panel	4-H, 1-M, 1-L
Type, location, layout of combustibles	5-H, 1-M
Heat transfer (convection, radiation, etc)	5-H, 1-M
Ignition temperature, mass loss rate, etc	5-H, 1-M
Fire resistance rating of cables	3-H, 3-M
Pressure relief device (HEAF)	3-H, 3-M
Flame projectile, cascading (HEAF)	6-H
Physical changing process of combustion	3-H, 2-M, 1-L
Activation of automatic fire suppression	5-H, 1-L
Manual fire suppression or fire fighting	3-H, 3-M
Early alarming of fire detection system	6-H
Cable type (thermoset/plastc, IEEE-383)	4-H, 2-M
Heat transfer properties of cabinet, panel	3-H, 3-M
Temperature (room, atmosphere)	3-H, 3-M
Location of target (height, radius, distance)	5-H, 1-M
Damage criteria (temperature, flux, etc)	5-H, 1-M
Movement characteristics of heat and smoke	5-H, 1-M
Initial operation time of fire suppression	3-H, 2-M, 1-L
Activation (operation) of smoke ventilation	3-H, 3-M
Area of fire source (dike area, fuel area)	4-H, 1-M, 1-L

3. Conclusions

When fire models are used to simulate the real fire situation, it is important to identify the critical input data and effective factors to modeling output. To enhance the reliability of the fire modeling, the PIRT methodology was studied to apply to fire modeling. By the expert panel, the ranking for the importance of fire phenomenon and the adequacy of existing fire model was determined whose methodology was based on NUREG/CR-6978.

At this study, it was confirmed that the fire modeling in NPPs can be implemented by the representative six types of fire scenarios and major fire phenomena which was originated from the baseline fire scenarios. The expert panel also determined the most important sub-phenomenon of fire in major fire situation. One of most valuable output at this study is the list of ranking table for the key parameters. By use of this result, the fire modeling practices in NPPs can be more upgraded with enhanced credibility.

REFERENCES

[1] Richard D. Peacock, Paul A. Reneke, Glenn P. Forney, NIST, "CFAST – Consolidated Model of Fire Growth and Smoke Transport User Guide", 2013

[2] Kevin McGrattan, Simo Hostikka, Jason Floyd, "Fire Dynamics Simulator (version 5) User's Guide", 2009

[3] US NRC, NUREG-1824, "Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications", 2006

[4] US NRC, NUREG-1834, "Nuclear Power Plant Fire Modeling Analysis Guidelines", 2012

[5] US NRC, NUREG/CR-6978, "A Phenomena Identification and Ranking Table (PIRT) Exercise for Nuclear Power Plant Fire Modeling Applications", 2008

[6] NFPA, "The SFPE Handbook of Fire Protection Engineering", 3rd edition

[7] NFPA, "Fire Protection Handbook", 18th edition