Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2023

Development of a mobile application for fire influence analysis to support fire protection inspection

Seokhyeon Han *, Yongjae Kim, Seungjun Oh
PNE Co., Ltd., C-1001&1002, 7, Beobwon-ro 11-gil, Songpa-gu, Seoul, 05836, Republic of Korea
**Corresponding author: shhan@pnecorp.co.kr*

Keywords : fire influence analysis, mobile application, fire dynamics, zone of influence

1. Introduction

Various computational programs have been developed to analyze the influence of a fire. However, in the country, there has been no application for a regulatory body, that was portable, user-friendly, and efficient in calculation to support fire protection inspection. As a part of the R&D project for performance-based fire protection technology, we have developed a domestic proprietary fire analysis program that is expected to improve the quality of fire protection inspection for domestic nuclear power plants (NPPs) significantly.

2. Overall Program Design

2.1 Program scope

The fundamental purpose of the program is to provide real-time and on-site support for fire protection inspections, and to meet this purpose, a mobile application for devices such as smartphones and tablet PC was developed. Since the inception of the development in January 2021, Android and iOS have maintained a market share of over 99% in the domestic mobile and tablet device operating systems [1, 2]. Considering both operating systems of current and future maintenance, it was decided to create the mobile application in the form of a "Hybrid app" using web technologies (e.g., HTML/CSS/JS for Front-end development and Apache Cordova™ (Open-source Framework for Cross platform development). To primarily serve as a support for fire protection inspections of domestic nuclear power plants, normal operation under offline circumstances must be secured without an online server being provided.

The application is composed of two main functional modules and an additional add-on for supporting tasks. The first module is the "Fire Dynamic Module" (See section 2.2) responsible for calculating functionality related to various independent fire dynamics-related influences. This module adopts several relevant reference literatures to calculate and estimate fire influences such as mean flame height and the like. The second module is the "Fire Zone of Influence (ZOI) module" responsible for calculating a zone where specific critical conditions could be reached as a result of fire. This module deals with five fire influence zones (Flame, Fire Plume, Ceiling Jet, Hot gas layer, Radiation area), and each zone is composed of combined fire dynamics-related functionalities. The additional add-on is included in the application for supporting V&V (Verification and Validation) task (See sections 2.4).

Table I represents the calculation functionalities included in this application (the table shows only the main functionalities. There may be incidental calculation results.). Algebraic models of simple and prompt calculation, mostly based on experimental results (such as Heskestad's mean flame height correlation [3]) were utilized as fire modeling tools, considering the mobile device execution environment. The algebraic correlation from various literatures [3~5] could be used appropriately for supporting fire protection inspection in nuclear power plants.

2.2 Function 1: Fire Dynamics module

Fire Dynamics module, which calculation functionalities represented in Table I, utilizes the correlations derived in various literatures related to fire dynamics, including NUREG-1805: FDT^s [3~5]. This module enables real-time verification of specific elements at nuclear power plant fire protection inspection sites. One example of the functionality

Table I: Functionality included in the application

Calculation functionality
Hot gas layer temperature
Mean flame height
Radiant heat flux from fire to a target
Ignition time of a target fuel
Full-scale heat release rate of cable tray fire
Burning duration of solid combustibles
Fire plume centerline temperature
Ceiling-jet temperature and radius
Auto suppression/detection device response time
Compartment flashover calculation
Pressure rise associated with fire
The rate of hydrogen gas generation in the battery room
Fire resistance of structural steel members
Visibility through smoke
THIEF (Thermal induced electrical failure of cables) model calculation

❖ For more details on the above functionalities, please refer to the original text [3~5] (algebraic model correlation) is the Method of MQH (Equation (1)), which calculates the temperature of a hot gas layer as a function of time (See reference [3] for more information).

$$\Delta T_g = 6.85\left[\frac{\dot{Q}^2}{\left(A_V\sqrt{h_V}\right)(A_T h_k)}\right]^{\frac{1}{3}} \qquad \cdots (1)$$

User interface of Fire Dynamics module (UI) was designed for users to naturally comprehend the emphasized contents from the original texts of the correlations while maintaining readability and conciseness on a small mobile device display.

User experience of Fire Dynamics module (UX) was configured in two phases as below:

- Phase 1: necessary variables input stage
- Phase 2: calculated results of the output stage.

The UX was designed by focusing on the efficiency enhancement of the user's experience.

Until now real-time usage of algebraic models like FDT[s] [3] in desktop PC for fire protection inspections was not feasible. However, by making supporting real-time fire protection inspection possible through Function 1, Fire Dynamics Module, it is expected to provide valuable insights into fire dynamics.

2.3 Function 2: Fire Zone of Influence (ZOI) module

Fire Zone of Influence (ZOI) module predicts a zone where specific criteria (mainly temperature or incident heat flux) will be reached due to a postulated fire scenario within the compartment under analysis in real-time. The real-time prediction allows an identification of zone where targets may be damaged by a fire from a specific ignition source at NPP fire protection inspection site. The calculation functionality of Fire ZOI module utilizes the correlations derived in various literature related to fire dynamics similar to the functionality of Fire Dynamics module. Table II represents the correlations used for the functionality of Fire ZOI module and indicates the source for each correlation. The criteria are adopted from the guidelines provided in Appendix F.2 of NUREG/CR-6850 [7].

User interface of Fire ZOI module was designed for users to naturally comprehend the emphasized contents from the original texts of the correlations. User experience of Fire ZOI module (UX) was configured in three phases as below:

- Phase 1: correlation for analysis selection stage
- Phase 2: necessary variables input stage
- Phase 3: calculated results output stage

By utilizing information on heat release rates and other data from various references, including NUREG/CR-6850 Vol.2 for each ignition source individually, additional insights from fire protection inspection can be obtained.

Table II: The functionality of Fire Zone of Influence (ZOI) module

Virtual zone of influence	Detailed model options *(Year of experimental correlation)*	Ref. No.
Estimation of the zone of hot gas layer	MQH Method *(1981)*	[3]
	FPA Method *(1985)*	
	Method of Deal & Beyler *(1990)*	
	Method of Beyler *(1991)*	
Estimation of the zone of ceiling-jet	Alpert's Method *(1972)*	[3]
	Alpert's Method *(1972)* + Fire location factor *(2005&2020)*	[3, 7, 8]
	New Alpert's Method *(2016)*	[4]
	New Alpert's Method *(2016)* + Fire location factor *(2005&2020)*	[4, 7, 8]
Estimation of the zone of fire plume	Heskestad's Method *(1995)*	[3]
	Heskestad's Method *(1995)* + Fire location factor *(2005&2020)*	[3, 7, 8]
Estimation of the zone of flame	Heskestad's Method *(1995)*	[3]
	Heskestad's Method *(1995)* + Fire location factor *(2005&2020)*	[3, 7, 8]
	Thomas' Method *(1962)*	[3]
	Delichatsios' Method *(1997)*	[3]
	Hashemi & Tokunaga's Method *(1983 and 1984)*	[3]
Estimation of the zone of radiation	Point source model *(1998)*	[3]
	Solid flame model *(2002)*	[3]
	Adjusted solid flame model *(2019)*	[8]

2.4 Additional function: V&V task add-on

V&V task add-on serves as an additional function and can be utilized alongside the two previous modules to evaluate the applicability of the modules to fire scenarios under analysis. This additional function is to calculate normalized parameters with input variables of the previous two modules and the applicability of the modules is determined by whether each calculated parameter is within a validation range or not. Table III represents the normalized parameters and their validation range according to NUREG-1824 Supp. 1, which are used in the present Additional function. So far, the V&V task was performed separately from and independent of fire modeling. The present way of UI/UX approach reviews the normalized parameters and input variables simultaneously so simplifies the modeling process and enhances a convenience of the inspection process.

Table III: Normalized parameters and experimental validation range [NUREG-1824 Supp.1]

Quantity	Normalized parameters	Exp. range
Fire Froude Number	$\dot{Q}^* = \frac{\dot{Q}}{\rho_\infty c_p T_\infty D\sqrt{gD}}$	0.2~9.1
Flame Length Ratio	$\frac{H_f + L_f}{H}$	0.0~1.6
Ceiling-jet Distance Ratio	$\frac{r_{cj}}{H}$	0.0~8.3
Equivalence Ratio	$\varphi = \frac{\dot{Q}}{\Delta H_{O_2}\dot{m}_{O_2}}$	0.0~0.6
Compartment Aspect Ratio	$\frac{L \text{ or } W}{H}$	0.6~8.3
Radial Distance Ratio	$\frac{r}{D}$	0.3~8.0

❖ For more details, please refer to the original text [6]

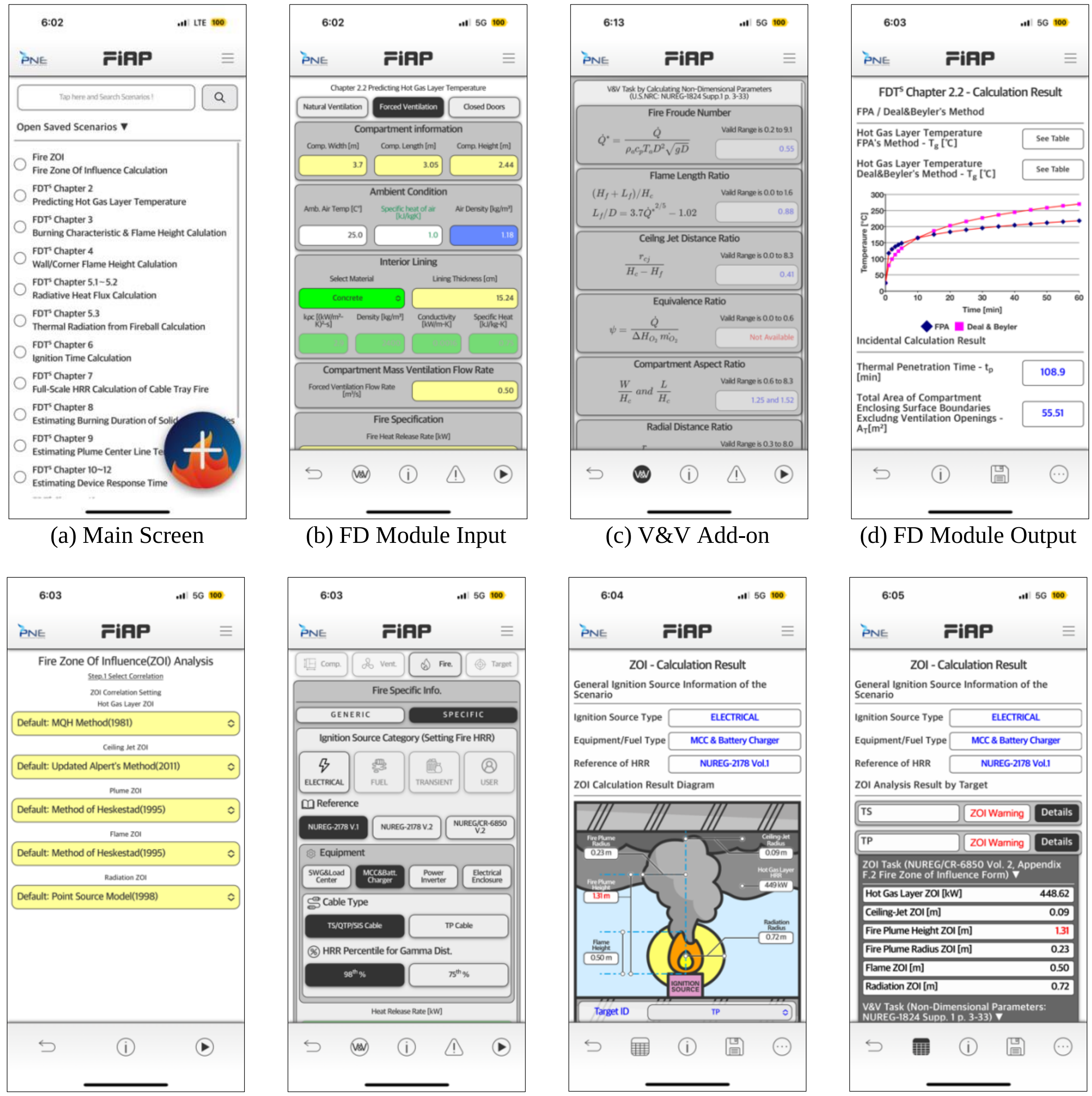
3. Program implementation

All processes including numerical calculation and response to user input were performed within 2 seconds effectively in various displays like smartphones and tablet PCs when the developed application was used.

Fig. 1 shows exemplary screens displayed in mobile devices that implement functionalities mentioned in Chapter 2. A user enters the main screen (Fig. 1 (a)) to select the functionality for a new or previously saved fire scenario. Saved fire scenarios are based in web-view local storage which doesn't allow user to access directly in mobile environment. This will prevent unauthorized access to enhance security.

UI to implement the design purpose is configured of a simple three-tier structure comprised of Header-Main-Footer. Through Header, user can access the functionality on the main screen or that related to the saved scenario. Through Main, user inputs all information necessary for calculation, and outputs calculated results. Through Footer, a user may refer to the literature, assumption/limitation, and may access the V&V add-on task related to the current fire scenario of Main. All the input, output information, and V&V add-on task results are saved through Footer.

Fig. 1 (b) and (d) are screens showing the functionality of Fire Dynamics module that calculates hot gas layer temperature. Users can check the detailed process of calculation by clicking the rightmost icon on the Footer in Fig. 1 (d) (round icon with three dots).



(a) Main Screen (b) FD Module Input (c) V&V Add-on (d) FD Module Output

(e) ZOI Correlation Select (f) Fire ZOI Input (g) Fire ZOI Result - 1 (h) Fire ZOI Result - 2

Fig 1. Implementation result of Fire Influence Analysis Program (FIAP)

Fig. 1 (e), (f), (g), and (h) are screens showing the functionality of Fire ZOI module that calculates a zone that may be influenced by fire. Fig. 1 (e) is a screen for the user to select the correlation dependent on a fire influence factor (hot gas layer, ceiling jet, plume, and flame). Fig. 1 (f) is a screen for the user to input information necessary for Fire ZOI module calculation. In this screen, a user may use heat release rate data from various references [3~8] for ignition source. Fig. 1 (g) and (h) are screens showing the result output from Fire ZOI module. Fig. 1 (g) is a screen showing Fire ZOI module result whether the target is located within a zone of Fire ZOI or not schematically. Fig. 1 (h) is a screen showing the calculated numerical results of Fire ZOI module.

Fig. 1 (c) is a screen showing the functionality of V&V task add-on when the user clicks the rightmost icon on the Footer during a stage of inputting information for Fire Dynamic or ZOI module.

4. Summary and Future works

As a part of the R&D project for performance-based fire protection technology, a mobile application for fire influence analysis was designed and implemented to support fire protection inspections at domestic nuclear power plants.

The application has functionalities as follows:

- Calculating correlations in Fire Dynamic module
- Calculating fire influence zone in Fire ZOI module
- Checking validation of using correlation for user fire scenario in V&V task add-on through calculating normalized parameters.

As a future research task, we plan to conduct source code optimization, debugging, and create a user manual for the application.

Acknowledgment

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety (KoFONS) using the financial resource granted by the Nuclear Safety and Security Commission (NSSC) of Republic of Korea. (No. 2105031)

REFERENCES

[1] Statcounter. *Mobile Operating System Market Share Republic of Korea*. 2021-2023. gs.statcounter.com/os-market-share/mobile/south-korea/#monthly-202101-202306
[2] Statcounter. The *Tablet Operating System Market Share Republic of Korea. 2021-2023*. gs.statcounter.com/os-market-share/tablet/south-korea/#monthly-202101-202306
[3] Iqbal, N., M. H. Salley, and S. Weerakkody. *"NUREG-1805: Fire Dynamics Tools (FDT^s): Quantitative fire hazard analysis methods for the US nuclear regulatory commission fire protection inspection program"*. US Nuclear Regulatory Commission, Washington, DC., 2004.
[4] Morgan J.H., *"SFPE Handbook of Fire Protection Engineering 5th Edition"*. Springer, New York., 2016.
[5] D. Stroup, G. Taylor, G. Hausman, M. H. Salley. *"NUREG-1805 Supplement 1, Vol.2: Fire Dynamics Tools (FDT^s) Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program"*. US Nuclear Regulatory Commission, Washington, DC., 2013.
[6] Hamins, Anthony P., and Kevin B. McGrattan. *"NUREG-1824: Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications. Volume 2. Experimental Uncertainty"*. US Nuclear Regulatory Commission, Washington, DC., 2007.
[7] R. P. Kassawara, J. S. Hyslop. *"NUREG/CR-6850 Vol.2, EPRI 1011989: EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities, Final Report"*. US Nuclear Regulatory Commission, Washington, DC., 2005.
[8] M. H. Salley., A. Lindeman, *"NUREG-2178, Vol.2: Refining and Characterizing Heat Release Rates from Electrical Enclosures During Fire"*. US Nuclear Regulatory Commission, Washington, DC., 2020.