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Database and User Interface Design of Computer Program based on Data Change History Management for Fire Load Calculation of Nuclear Power Plant

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1. Introduction

All nuclear power plants (NPPs) in operation in Republic of Korea, were designed to reflect domestic and foreign fire protection codes and standards valid at the time of construction for proving safe-shutdown capability of reactor in event of fire and minimizing possibility of radioactive materials leakage to external environment. In the notification of the Nuclear Safety and Security Commission (NSSC), it is stipulated that NPPs operators should revise and manage reports by reflecting changes in design or operation methods during operation after the initial fire risk analysis performed at the time of construction for all NPPs [1, 2]. Therefore, according to the relevant notifications, fire hazard analysis (FHA) for all NPPs in operation should be conducted periodically to confirm the effects on safety due to design changes after construction in the event of fire, and to re-evaluate them by reflecting the latest requirements.

The FHA is carried out according to a series of work processes such as fire protection technical standard and analysis methodology review, NPP data collection, fire compartment classification, design changes review & effects evaluation, fire hazard analysis & safe-shutdown analysis, suitability review of fire protection plan, and deriving problems & suggesting improvement measures. The 'Fire Load Calculation Sheet' is a document prepared for each fire area and zone as shown in Fig. 1 during the FHA work-processes listed above, and be utilized as basic data for regulatory review. The fire load calculation is applied to the type of combustibles and their unit heat load specified in the relevant power industry code [3]. However, in the actual field, design changes occur during operation, there are different combustibles from documents, and changes occur in the base data such as setting or adjusting fire compartments according to the time of analysis, so a computerization tool is required to manage them systematically.

In order to reflect these requirements, database design and user interface design of a software for NPP fire load calculation based on data change history management provided as a sub-function in the "Computer Program to Support Fire Hazard Analysis Regulatory Activities" were performed.

방화지역번호 **Fire Area ID**

방화지역명 **Fire Area Name Eng.**

Fire Area Name Kor.

가. 상존가연물

번호	가연물 종류	가연물 수량	단위 열하중 (Btu/unit)	열 하중 (Btu)
1	케이블 절연체(전력 및 제어)	ft	1,612	
2	케이블 절연체(계측)	ft	907	Class C
3	케이블 절연체(패널)	lb	10,990	
4	윤활유	gal	155,000	
5	그리스	lb	20,000	
6	변압기 오일	gal	143,000	Class B
7	디젤 연료유	gal	146,000	
8	제2 연료유	gal	155,000	
9	축전지	lb	18,000	
10	고효율 입자여과기(HEPA)	module	16,000	
11	프리필터	module	16,000	
12	활성탄 흡착기	lb	14,000	Class A
13	나무/종이	lb	8,000	
14	플라스틱	lb	18,000	
15	의류	lb	7,200	
16	고무	lb	8,000	
17	공업용 세정액	gal	155,000	Class B
18	페인트	L	46,357	
19	덕트 내부라이닝(가스킷)	lb	8,000	
20	차음 블랑킷류	lb	10,000	Class A
21	플렉시블접속체(HVAC)	lb	10,000	
22	P-10	L	35	Class B
23	신너	L	155,000	
합계				0

나. 임시가연물

1	케이블 절연체			
2	윤활유 및 그리스			
3	부수 가연물			
합계				0

다. 총 발열량 (Btu) **0**

라. 바닥 면적 (ft2)

마. 화재하중 (Btu/ft2)

바. 화재심각도 (min.)

Fig. 1. Template Example of Fire Load Calculation Sheet

2. Design of Computer Program for Fire Load Calculation of NPP

The main purpose of this program is to calculate fire load & severity for each fire areas and zones based on fire compartment information and combustibles data of NPPs, and to generate 'Fire Load Calculation Sheet' of form shown in Fig. 1 below. A computer program with similar function was already implemented by VBA embedded in Microsoft Excel [4]. However, there was a limit to output the results of fire load calculation at a specific time when base data were provided, as a concept of change history management for fire compartments and combustibles data of NPP was not applied.

2.1 Data Change History Management

Since the fire load calculation for fire area and zone of target NPP are based on fire compartment and stored combustibles in each room, collection, review, and analysis of the latest data before estimation time should be carried out first. In addition, the combustibles data, which is the basis for calculating the fire load, are required tracking management as changes in stored location, types and quantity during operation.

The compartment information includes description, location, and floor area of each room. Depending on estimation time, each room is assigned to a fire area and zone to establish fire compartments and adjust or reset them as needed. The fire area is a building or a part of building separated by a fireproof structure to prevent the spread of fire, and the fire zone is subdivision of the fire area to prevent fire spreading due to restrictions on combustibles, spatial isolation or fire suppression equipment.

Since the fire area and fire zone of each room are designated according to the compartment definition, combustibles located in each room are also assigned to the same fire area and zone as the compartment and reflected in the fire load for area and zone. As shown in Fig. 2 below, the concept of data change history management was reflected in the program design so that the fire load calculation results at each estimation time point ($t_1 \sim t_3$) can be derived even if there are changes or adjustments on combustibles or compartments.

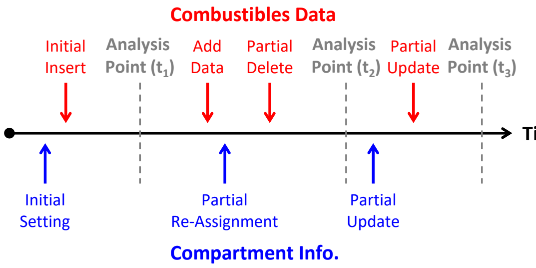

Fig. 2. Example of Data Change History

2.2 Database Design of Computer Program based on Data Change History Management

In the software development process, database design is the process of creating and generating a detailed data model according to the purpose and use of the database, and its main purpose is to represent required data and relations between data.

When developing software or constructing information systems, a database is used to store 'structured' data. The 'structure' of data and accompanying constraints can be designed by various techniques. One of the techniques is Entity-Relation Modeling (ERM), and the output of the ERM process is called Entity-Relation Diagram (ERD). The ERD consists of entities, primary keys (PK) and attributes of each entity, and relations between entities.

Fig. 3 below is the ERD (partial) of DB for "Computer Program to Support Fire Hazard Analysis Regulatory Activities" prepared based on user requirements, input/output, and related data analysis.

All functions provided by this program, such as FHA and information management, are executed at the plant level. The fire compartment definition of a 'plant' is subdivided by buildings and rooms, and fire areas and zones. In above the compartments, 'building' and 'room' were established at the time of construction and 'room' information is dependent on the 'building', and 'fire zone' and 'fire area' are set as one or more 'room' in each 'building' and one or more 'fire zone' in each 'fire area' for FHA. The combustibles data for each room is managed in 'Combustibles Info.', and the quantities of each type of combustibles in the room belonging to the fire area and zone are summed up to calculate the fire load for fire areas and zones.

Objects to data change management for fire load calculation are fire area/zone of compartment and combustibles data, and these objects are given 'reference date' and 'data status' attributes to identify change history and current data status. In this way, by the concept of data change management, the fire load for area/zone is calculated based on the latest compartment information and combustibles data at the time of estimation specified by the user. The total amount of heat generated by each type of combustibles in each fire area and zone are calculated by summing the amount of heat generated by each room by the fire compartment.

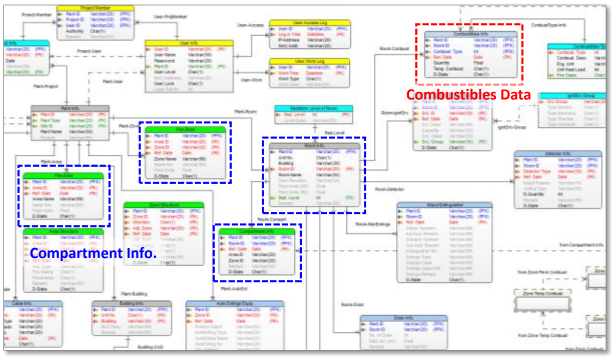

Fig. 3. DB E-R Diagram (partial) of Computer Program to Support Fire Hazard Analysis Regulatory Activities

2.3 User Interface Design of Computer Program based on Data Change History Management

The logical workflow of this computer program with the concept of data change history management is shown in Fig. 4 below. With the change history management for combustibles data of each room and compartment information separately from the fire load calculation work, when the user selects the estimation reference date, the latest combustibles data and compartment information are retrieved based on the estimation date, and the combustibles data for fire zone and area are collected and used to calculate the fire load.

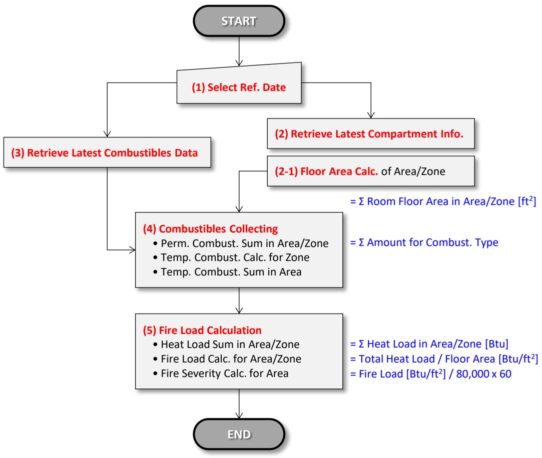

Fig. 4. Logical Work-flow Chart of the Computer Program

Fig. 5 and 6 below show the UI design (draft) of the room data management screen and the fire compartment assignment screen, respectively. It manages the information of rooms (C/R/U/D) and fire areas (Fig. 5), zones in the building separately, and sets up fire compartments by assigning each room to the fire zone on another screen (Fig. 6). When the user adds, updates, or deletes data, the working time is automatically recorded to accumulate the change history, and when updating or deleting, new data is added and existing data changes only the data state attribute, so the existing data is not actually deleted.

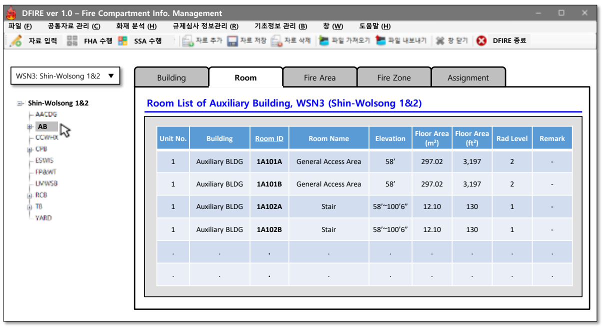

Fig. 5. UI Design (draft) of Room Data Management

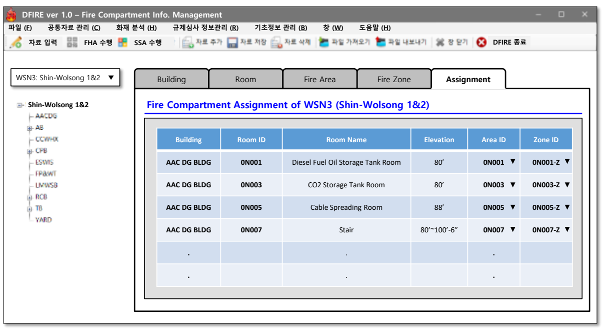

Fig. 6. UI Design (draft) of Compartment Assignment

As shown in Fig. 7 combustibles data management UI design (draft) below, combustible data is managed for each room. Only the quantity for types of combustibles located in each room is managed, and the change history is also tracked by working time.

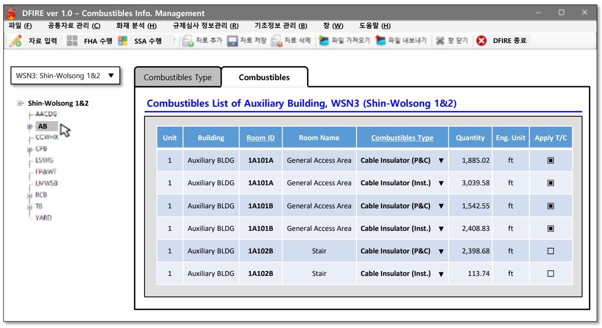

Fig. 7. UI Design (draft) of Combustibles Data Management

Fig. 8 below shows the UI design (draft) of the screen that inquires about the latest combustible data for the fire zone by combining compartment information (in Fig. 6) and combustible data (in Fig. 7) based on the estimation date selected by the user. On this screen, if the user selects the estimation reference date, the latest combustible data for each fire zone is displayed based on the date. After checking this, when the user clicks the [Fire Load Calculation] button, then the fire load for each the fire zone and area is calculated.

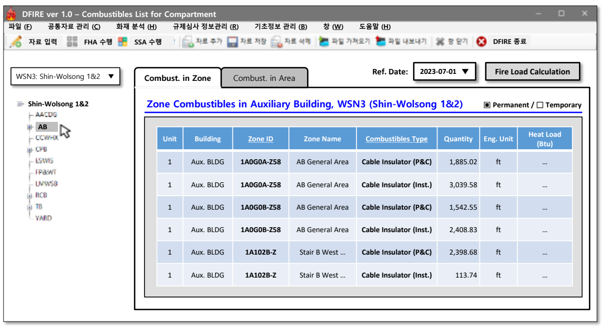

Fig. 8. UI Design (draft) of Retrieving Combustibles List for Fire Zone

Fig. 9 below shows the UI design (draft) of the screen displaying the results of the fire load calculation for each fire zone at the estimation reference date. The fire load calculation results of the fire zones in the selected building in the ‘compartment tree’ on the left side of the screen are displayed in tabular form., with the main items being the description of the fire zone, the heat load due to permanent combustibles, the heat load due to temporary combustibles, the total heat load, the floor area of the zone, the fire load, and the fire severity.

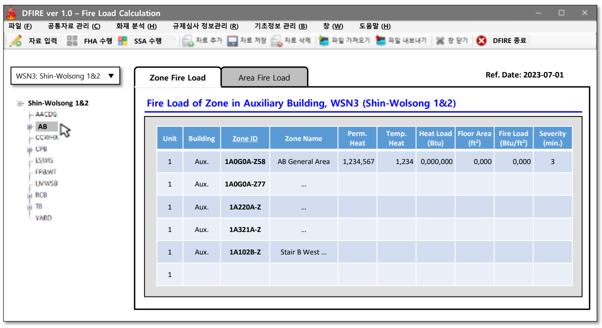

Fig. 9. UI Design (draft) of Fire Load Calculation Result for Fire Zone

2.4 Verification Computer Program Design by Retrieving Base Data on Reference Date

In order to verify the DB and UI design of the computer program described above, after implementing the DB schema, constructing temporary DB by generating (creating) data of fire compartments and combustibles, and modifying (updating or deleting) some of the data, and then checking whether the data could be properly retrieved by each screen according to the UI design purpose.

Tables 1 and 2 below are examples of inquiring change history of fire compartment information and combustible data, and changes (Inert: I, Update: U, Delete: D) of data with the same unique identifier (PK) can be checked in the order of reference date.

Table I: Retrieving Result Example of Change History of Fire Compartment Info.

plant_id	room_id	ref_date	area_id	zone_id	remark	state	rno
WSN3	0B001	2023-06-01	Y-0B1G1	Y-0B1G1-Z		U	1
WSN3	0B001	2023-05-25	Y-0B1G1	Y-0B1G1-Z		I	2
WSN3	0B001	2023-05-20	Y-0B1G1	Y-0B1G1-Z		D	3
WSN3	0B002	2023-06-01	Y-0B1G1	Y-0B1G1-Z		U	1
WSN3	0B002	2023-05-25	Y-0B1G1	Y-0B1G1-Z		I	2
WSN3	0B002	2023-05-20	Y-0B1G1	Y-0B1G1-Z		D	3
WSN3	0B003	2023-06-01	Y-0B1G1	Y-0B1G1-Z		U	1
WSN3	0B003	2023-05-25	Y-0B1G1	Y-0B1G1-Z		I	2
WSN3	0B003	2023-05-20	Y-0B1G1	Y-0B1G1-Z		D	3

Table II: Retrieving Result Example of Change History of Combustibles Data

plant_id	room_id	combust_type	ref_date	quantity	state	rno
WSN3	0B001	3	2023-06-01	214.2	U	1
WSN3	0B001	3	2023-05-25	214.0	I	2
WSN3	0B001	3	2023-05-20	214.0	D	3
WSN3	0B001	5	2023-06-01	3.3	U	1
WSN3	0B001	5	2023-05-25	3.0	I	2
WSN3	0B001	5	2023-05-20	3.0	D	3

Table 3 below is an example of inquiring results for the combustible data for the fire zone by combining the compartment and combustible data described above based on the specific date to be estimated.

In this way, the DB and UI design of the computer program with the concept of data tracking was verified by the results of retrieving combustibles by combining base data at the time of random estimation points.

Table III: Retrieving Result Example of Combustibles Data for Fire Compartments on Reference Date

room_id	area_id	zone_id	combust_desc	quantity	eng_unit	unit_heat
1A101A	1A0G0A	1A0G0A-Z58	케이블 절연체(전력 및 제어)	1,885.0	ft	1,612
1A101A	1A0G0A	1A0G0A-Z58	케이블 절연체(계측)	3,039.6	ft	907
1A101B	1A0G0B	1A0G0B-Z58	케이블 절연체(전력 및 제어)	1,542.6	ft	1,612
1A101B	1A0G0B	1A0G0B-Z58	케이블 절연체(계측)	2,408.8	ft	907
1A102A	1A102A	1A102A-Z	케이블 절연체(전력 및 제어)	2,109.8	ft	1,612
1A102B	1A102B	1A102B-Z	케이블 절연체(전력 및 제어)	2,398.7	ft	1,612
1A102B	1A102B	1A102B-Z	케이블 절연체(계측)	113.7	ft	907
1A107A	1A0G0A	1A0G0A-Z58	케이블 절연체(전력 및 제어)	733.4	ft	1,612
1A107A	1A0G0A	1A0G0A-Z58	케이블 절연체(계측)	1,345.0	ft	907
1A107B	1A0G0B	1A0G0B-Z58	케이블 절연체(전력 및 제어)	708.8	ft	1,612
1A107B	1A0G0B	1A0G0B-Z58	케이블 절연체(계측)	1,482.0	ft	907

3. Conclusions

Currently, the fire load calculation of NPP is applied to the type of combustibles and its unit heat load specified in the relevant power industry code [3, 4], but the concept of data change history management for compartment and combustible data is not applied, so it has limitations in outputting results only at a specific estimation point when base data is provided. To supplement this, the DB design and UI design for the "Computer Program to Support Fire Hazard Analysis Regulatory Activities" with concept of data change history management were carried out. These will be used as an important development document for the implementation of the computer program

REFERENCES

[1] Nuclear Safety and Security Commission Notification No. 2018-9, Technical Standard for Fire Risk Analysis.
[2] Nuclear Safety and Security Commission Notification No. 2020-2, Regulation on the Establishment and Implementation of Fire Protection Plan.
[3] KEPIC FPN 2000 Nuclear Power Plant Fire Prevention, Appendix A.
[4] Young-Suk Jung, et al. "Development of Computer Program for Automatic Generating Fire Load Calculation Sheet", KNS Spring Meeting, May 17~19, 2023.

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