Development of Computer Program for Automatic Generating Fire Load Calculation Sheet

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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 notification of 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 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 during the FHA in above work-processes, and is attached as an appendix to the report and applied as basic data for regulatory review. Currently, the fire load calculation is applied the type of combustibles and its unit heat load specified in the relevant power industry code [3], but since there are more diverse combustibles in the NPPs actually, standardization and computerization tools were needed to systematically manage related basic data. Also, the traditional method of preparing the sheet takes excessive working time by copying the calculation results for each fire area/zone one by one into a certain document format, and human errors may occur due to manual works. In addition, it was difficult to manage history by changing basis data and tracking cause of abnormal results. In order to improve these issues, the Computer Program for Automatic Generating Fire Load Calculation Sheet was developed.

2. Development of Computer Program for Automatic Generating Fire Load Calculation Sheet

This program is a kind of business task automation program, it's main purpose is to calculate fire load & severity for each fire areas based on fire compartment and combustibles data of NPPs, and to generate 'Fire Load Calculation Sheet' of form shown in Fig. 1 below. To develop this program, it is performed a series of work-processes such as review & analysis of fire compartments information and combustibles data of NPPs, logic regulations for calculating fire load, implementing program, and verifying the calculation results.

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	
3	케이블 절연체(패널)	lb	10,990	
4	윤활유	gal	155,000	
5	그리스	lb	20,000	
6	변압기 오일	gal	143,000	
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	
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	
18	페인트	L	46,357	
19	덕트 내부라이닝(가스킷)	lb	8,000	
20	차음 블랭킷류	lb	10,000	
21	플렉시블접속체(HVAC)	lb	10,000	
22	P-10	L	35	
23	신너	L	155,000	
합계				0

나. 임시가연물

1	케이블 절연체		10,990	
2	윤활유 및 그리스		155,000	
3	부수 가연물		8,000	
합계				0

다. 총 발열량 (Btu) 0
라. 바닥 면적 (ft2)
마. 화재하중 (Btu/ft2)
바. 화재심각도 (min.)

Fig. 1. Template of Fire Load Calculation Sheet

2.1 Basis Data Management

Since the fire load calculation for fire area and zone of target NPP is based on fire compartment and stored combustibles data in each room, collection, review, and analysis of the latest data before estimation time should be carried out first.

Compartment information includes list of fire area, zone, and room, hierarchical classification, and floor area of each room. The fire area is building or 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. The fire area is consisting of one or more zones, and the fire zone is consisting of one or more rooms, and a fire area and a fire zone may coincide depending on setting and classification of compartment.

Combustibles types and quantities listed in permanent combustibles (#1 ~ #23) of Fig. 1 above for each room should be investigated, and managed as a data sheet.

2.2 Calculation of Fire Load and Fire Severity

The fire load and severity of each fire area and zone are computed based on the compartment information and combustibles data mentioned above. Floor area of the fire area and zone are calculated by summing floor area of room in each fire area and zone.

The heat generation is calculated by multiplying unit heat and amount of each permanent combustibles, and room heat load due to combustibles during event of fire is computed by summing the heat generation of each combustible in room.

After summing the permanent combustibles for fire zone, quantity of temporary combustibles and their heat load are computed as follows by applying the relevant power industry code [3]. The heat load due to cable insulator (temporary combustible 1) is added 400,000 Btu when cable insulator (power & control, instrument) is present among the permanent combustibles, amount of lubricant and grease (temporary combustibles 2) is counted one multiple of amount when lubricant is included among the permanent combustibles, and the heat load of the subordinate combustibles (temporary combustibles 3) is added 400,000 Btu when item in no. 9 to 23 is present among the permanent combustibles. The heat load due to temporary combustibles is calculated in units of fire zones, and for fire area composed of multiple fire zones, the sum of the heat loads of temporary combustibles for each zone is applied. The fire load of fire area and fire zone are calculated by dividing the total heat load of area and zone by the floor area of fire area and zone.

Fig. 2 in below is logical flow-chart applied in this computer program for fire load calculation and the sheet automatic generation.

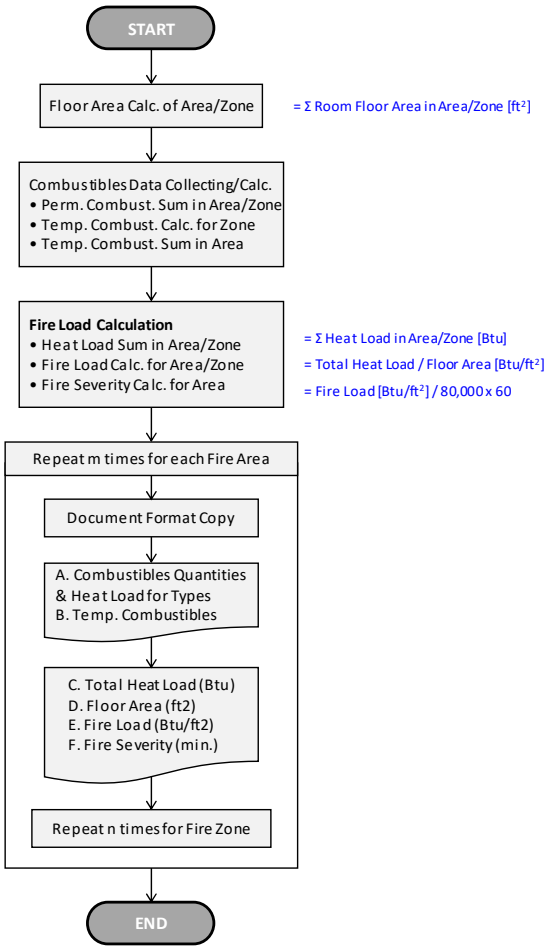

Fig. 2. Logical Flow Chart of the Computer Program for Automatic Generating Fire Load Calculation Sheet

2.3 Implementation of the Computer Program for Auto Generating Fire Load Calculation Sheet

This program was implemented using VBA (Visual Basic for Application) embedded in Excel [4], and it consists of form sheet, compartment information sheet, combustibles raw data sheet, permanent & temporary combustibles sheet for checking intermediate results during calculation, and result sheet for verifying fire load calculation for each areas and zones. After loading data organized in each sheet, this program was coded to calculate floor area of area and zone, and to compute heat load and fire load by zone and area. And the intermediate results were stored in another memory arrays. Then it was generated repeatedly as many times as number of total area and zone refer to the sheet format.

A user can execute this program by clicking [Auto Report] button in the ‘Compart’ sheet after entering compartment and permanent combustibles data by copy & paste to each data sheet. Fig. 3 below is a screenshot of the program that is calculating fire load for each fire areas, and Fig. 4 below is example output of fire load calculation sheet.

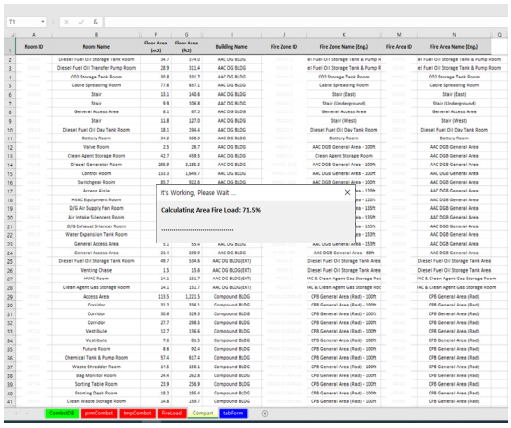

Fig. 3. Screenshot of the Program Calculating Fire Load

방화지역번호 1A0G0B
방화지역명 AB General Area B
(보조건물 일반지역 B)

가. 상존가연물

번호	가연물 종류	가연물 수량	단위 열하중 (Btu/unit)	열 하중 (Btu)
1	케이블 절연체(전력 및 제어)	198,529 ft	1,612	320,029,292
2	케이블 절연체(계측)	121,074 ft	907	109,814,315
3	케이블 절연체(패널)	3,010 lb	10,990	33,082,497
4	윤활유	1 gal	155,000	180,165
5	그리스	0 lb	20,000	0
6	변압기 오일	0 gal	143,000	0
7	디젤 연료유	0 gal	146,000	0
8	제2 연료유	0 gal	155,000	0
9	축전지	0 lb	18,000	0
10	고효율 입자여과기(HEPA)	23 module	16,000	368,000
11	프리필터	0 module	16,000	0
12	활성탄 흡착기	6,261 lb	14,000	87,655,771
13	나무/종이	44 lb	8,000	352,740
14	플라스틱	0 lb	18,000	0
15	의류	44 lb	7,200	317,466
16	고무	0 lb	8,000	0
17	공업용 세정액	0 gal	155,000	0
18	페인트	0 L	46,357	0
19	덕트 내부라이닝(가스킷)	0 lb	8,000	0
20	차음 블랑킷류	0 lb	10,000	0
21	플렉시블접속체(HVAC)	0 lb	10,000	0
22	P-10	0 L	35	0
23	신너	0 L	155,000	0
	합계			551,800,245

나. 임시가연물

1	케이블 절연체		10,990	3,200,000
2	윤활유 및 그리스		155,000	180,165
3	부수 가연물		8,000	1,200,000
	합계			4,580,165

다. 총 발열량 (Btu)	556,380,411
라. 바닥 면적 (ft2)	46,994
마. 화재하중 (Btu/ft2)	11,742
바. 화재심각도 (min.)	9

Fig. 4. Example Output of Fire Load Calculation Sheet

2.4 Verifying Fire Load Result Calculated by the Program

In order to confirm the reliability of the developed program, the heat load and fire load values calculated by this program and the results calculated by Excel were compared as shown in table 1 below, based on random 29 fire area composed of multiple fire zones. In table 1, the left blue results are computed by this program, and the right black results are calculated by Excel. The differences (red colored) are 10^{-15} ~ 10^{-16}, these could be ignored in engineering, so this program was properly implemented.

Table 1: Example of program result
checked by comparison with manual calculation

Area ID	Total Heat (Btu)	Floor Area (ft2)	Fire Load (Btu/ft2)	Area ID	Total Heat (Btu)	Error	Floor Area (ft^2)	Fire Load (Btu/ft^2)	Error
	575,557,702	48,654	11,579		575,557,702	0.0E+00	48,654	11,579	2.5E-15
	556,380,411	46,994	11,742		556,380,411	6.4E-16	46,994	11,742	-2.8E-15
	6,670,109	1,168	5,025		6,670,109	2.8E-16	1,168	5,025	-5.4E-16
	242,741,609	10,594	22,762		242,741,609	1.2E-16	10,594	22,762	9.6E-16
	0	692	0		0		692	0	
	0	693	0		0		693	0	
	3,800,918	130	26,114		3,800,918	-9.8E-16	130	26,114	-2.8E-16
	4,369,822	130	30,482		4,369,822	0.0E+00	130	30,482	-3.6E-16
	472,546	1,253	58		472,546	-1.2E-16	1,253	58	-1.1E-15
	0	171	0		0		171	0	
	0	284	0		0		284	0	
	0	515	0		0		515	0	
	0	202	0		0		202	0	
	11,961,352	1,590	6,822		11,961,352	0.0E+00	1,590	6,822	-1.3E-16
	11,623,963	1,590	6,609		11,623,963	8.0E-16	1,590	6,609	-1.4E-16
	3,111,127	371	4,191		3,111,127	-1.5E-16	371	4,191	-6.5E-16
	2,778,509	450	2,962		2,778,509	0.0E+00	450	2,962	-7.7E-16
	2,785,822	450	2,982		2,785,822	-1.7E-16	450	2,982	9.2E-16
	2,861,300	401	3,377		2,861,300	0.0E+00	401	3,377	-4.0E-16
	3,116,501	405	3,978		3,116,501	0.0E+00	405	3,978	-8.0E-16
	5,845,859	383	8,072		5,845,859	0.0E+00	383	8,072	-1.1E-16
	6,206,648	383	9,014		6,206,648	0.0E+00	383	9,014	2.0E-16
	3,774,894	391	7,820		3,774,894	9.9E-16	391	7,820	1.3E-15
	3,645,595	391	7,490		3,645,595	-2.6E-16	391	7,490	2.4E-16
	2,209,831	757	2,023		2,209,831	2.1E-16	757	2,023	-2.1E-15
	2,632,003	657	2,973		2,632,003	1.8E-16	657	2,973	-4.6E-16
	41,500,487	514	40,884		41,500,487	-1.8E-16	514	40,884	7.1E-16
	41,500,487	614	34,229		41,500,487	-1.8E-16	614	34,229	-6.4E-16
	0	2,362	0		0		2,362	0	

3. Conclusions

Currently, the fire load calculation is applied the type of combustibles and its unit heat load specified in the relevant power industry code [3], but since there are more diverse combustibles in the NPPs actually, standardization and computerization tools were needed to support regulatory verification by systematically managing related basic data. Also, the preparation of the fire load calculation sheet for fire area and fire zone attached to FHA report took excessive working time by manually copying the calculation results into a certain document format, and human errors may occur due to manual works. In addition, it was difficult to manage history by changing basis data and tracking cause of abnormal results. Applying the developed program that automatized the preparation process of the statement will resolve these problems. The program will reduce the time and effort needed for the statement preparation so that engineers can focus on the evaluation of FHA.

The data structure of fire compartment and combustibles information, and the calculation method of heat load for room and fire load for fire area/zone applied in this program will be used in future to development database and program to support the fire protection safety issues and regulatory activities.

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] Microsoft Corp., Excel, Microsoft Office Standard 2016.

Acknowledgement

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