Lessons Learned from the New Fire PRA Methodology (NUREG/CR-6850) Application in Korea under Fire Ignition Frequency Perspectives

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Abstract: The objectives of the Fire Probabilistic Risk Assessment (PRA) are to estimate the contribution of in-plant fires to overall plant Core Damage Frequency (CDF) and Large Early Release Frequency (LERF), to identify its vulnerabilities, and to provide recommendations for reducing fire-induced plant risk. Risk due to internal fire has been one of the major concerns in design and for operation of nuclear power plants. So far, Korea has applied Fire PRA Implementation Guide (EPRI TR-105928: FPRAIG) to conduct Fire PRA. In the meantime, NUREG/CR-6850 was issued as a current state-of-the-art method, which was studied by joint activity between Electrical Power Research Institute (EPRI) and U.S Nuclear Regulatory Commission (NRC) office of Nuclear Regulatory Research (RES), in August 2005. This paper covers comparison results for fire ignition frequency analysis separately conducted by FPRAIG and NUREG/CR-6850 and lessons learned from outcomes performed by newly developed Fire PRA methodology, NUREG/CR-6850, from fire ignition frequency perspectives. As a result, when applying new Fire PRA methodology, NUREG/CR-6850, compared to the previous Fire PRA methodology, FPRAIG, fire frequency for fixed ignition source has been decreased, while fire frequency for transient ignition source has been increased.

Keywords: PRA, Fire PRA, NUREG/CR-6850, Fire, CDF, LERF, FPRAIG, CCDP, CLRP

1. INTRODUCTION

The objectives of the Fire Probabilistic Risk Assessment (PRA) are to estimate the contribution of in-plant fires to overall plant Core Damage Frequency (CDF) and Large Early Release Frequency (LERF) to identify vulnerabilities and to provide recommendations for reducing fire-induced plant risk. Risk due to internal fire has been one of the major concerns for design and operation of nuclear power plants.

That's why Korea has performed Fire PRA for all plants, considering its 23 operating plants and 5 plants under construction. And Korea also has applied Fire PRA Implementation Guide (EPRI TR-105928: FPRAIG) to implementation of Fire PRA so far. In the meantime, NUREG/CR-6850 was issued as a current state-of-the-art Fire PRA method, which was studied by joint activity between Electrical Power Research Institute (EPRI) and U.S Nuclear Regulatory Commission (NRC) office of Nuclear Regulatory Research (RES), in August 2005.

Especially, NUREG/CR-6850 consists of 16 tasks and 2 support tasks, and it shows substantially details and deep approach task by task and suggests more realistic values for ones which are assumed a little conservatively compared to FPRAIG especially in part of Circuit Analysis, Human Reliability Analysis (HRA), etc.

Also, the new Fire PRA methodology, NUREG/CR-6850 needs relatively much more time and efforts than FPRAIG in many areas in order to perform in-deep and detailed analysis. But, in approach perspectives, both FPRAIG and NUREG/CR-6850 have similar approaches, except that NUREG/CR-6850 uses more realistic and recent fire ignition frequency, detailed fire scenarios, detailed cable failure probability, detailed human error probability, etc. than FPRAIG.

This paper tries to find out the difference from the results between new Fire PRA methodology, NUREG/CR-6850 and old Fire PRA methodology, FPRAIG, in same fire compartments for plants with almost similar design from Fire PRA perspectives.

Especially, comparison of fire frequency results conducted by FPRAIG and NUREG/CR-6850 separately and lessons learned from outcomes performed by newly developed Fire PRA methodology, NUREG/CR-6850, will be covered.

2. THE APPLICATION OF NUREG/CR-6850 IN KOREA

Korea has applied new Fire PRA methodology, NUREG/CR-6850, to an advanced nuclear power plant under design whose reference plant has already conducted Fire PRA in accordance with FPRAIG, EPRI TR-105928 before. One of the prime design characteristics of both plants analyzed is to adapt quadrant arrangement concept as shown in Figure 1, where most cables and equipment are located in each quadrant (A/B/C/D).

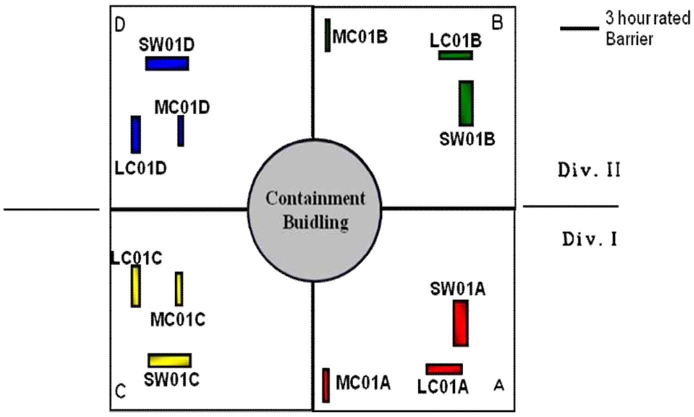

Figure 1. Quadrant arrangement concept in Auxiliary Building

And Main Control Room (MCR) has employed fully digitalized control system including Large Display Panel which is one of the differences from the conventional plants.

2.1. New Fire PRA Methodology

New Fire PRA methodology, NUREG/CR-6850, is composed of 16 tasks as below and shows task flow like Figure 2.

Task 1: Plant Boundary Definition and Partitioning is to define the Global Plant Analysis Boundary, and to divide the Global Plant Analysis Boundary into discrete physical analysis units (fire compartments).

Task 2: Fire PRA Component Selection is to select the plant equipment that will be included and/or credited in the Fire PRA.

Task 3: Fire PRA Cable Selection is to identify the cables associated with all Fire PRA components, and their physical routing throughout the plant.

Task 4: Qualitative Screening is to identify physical analysis units whose potential fire risk contribution can be judged negligible without quantitative analysis.

Task 5: Plant Fire-Induced Risk Model is to create the Fire PRA model that will be used in estimating the fire risk.

Task 6: Fire Ignition Frequency is to determine the fire ignition frequencies for fixed and transient ignition sources on a fire compartment basis.

Task 7A/7B: Quantitative Screening is to screen physical analysis units located within the Global Plant Analysis Boundary from further consideration based on preliminary conservative estimates of fire risk contribution using established quantitative screening criteria.

Task 8: Scoping Fire Modeling is to eliminate or reduce the frequency of those fixed ignition sources in a fire compartment that do not pose a threat to any Fire PRA target.

Task 9: Detailed Circuit Failure Analysis is to conduct a more detailed analysis of circuit operation and functionality to determine equipment responses to specific fire-induced cable failure modes. This information is then used to screen out cables that cannot prevent a component from completing its credited function.

Task 10: Circuit Failure Mode Likelihood Analysis is to quantify the probabilities for fire-induced hot short circuit failures that lead to component failure modes of interest. The failure mode probabilities are estimated for the cables of risk-significant components.

Task 11: Detailed Fire Modeling - In prior tasks, the analyses assumed that a fire would have widespread impact within the fire compartment. In this task, for those fire compartments found to be potentially risk-significant (i.e., unscreened compartments), a detailed analysis approach is provided. As part of the detailed analysis, fire growth and propagation may be modeled. Furthermore, the possibility of fire suppression before damage to a specific target set is analyzed. This task is composed of the following three sub-tasks:

a. Detailed fire modeling of single fire compartments
b. MCR fire analysis
c. Multi-compartment fire analysis.

Task 12A/12B: Post-Fire HRA - In this task, human failure events (HFEs) associated with the fire scenarios are identified, and associated human error probabilities (HEPs) are estimated. Operator actions after fire ignition are assumed to be affected by the fire unless it can be clearly shown otherwise.

Task 13: Seismic Fire Interactions is to identify and correct any weaknesses in the fire protection systems and vulnerabilities in the ignition sources due to seismic events. This is the qualitative evaluation of the potential for: 1) seismically induced fires, 2) degradation of fire suppression systems and features, 3) spurious actuation of fire suppression and/or detection systems, and 4) degradation of manual fire fighting effectiveness. No risks are computed.

Task 14: Fire Risk Quantification - In this task of the analysis process, the Fire PRA model is quantified for each final fire scenario, the associated risk values (i.e., CDF and LERF) are computed and risk contributors are identified.

Task 15: Uncertainty and Sensitivity Analyses are to determine, characterize and assess the impact of uncertainty on the CDF and LRF estimates. In addition, sensitivity analyses are used to identify and understand the impact of risk significant modeling assumptions.

Task 16: Fire PRA Documentation is to ensure that the previous analyses are documented in a manner which facilitates review and update.

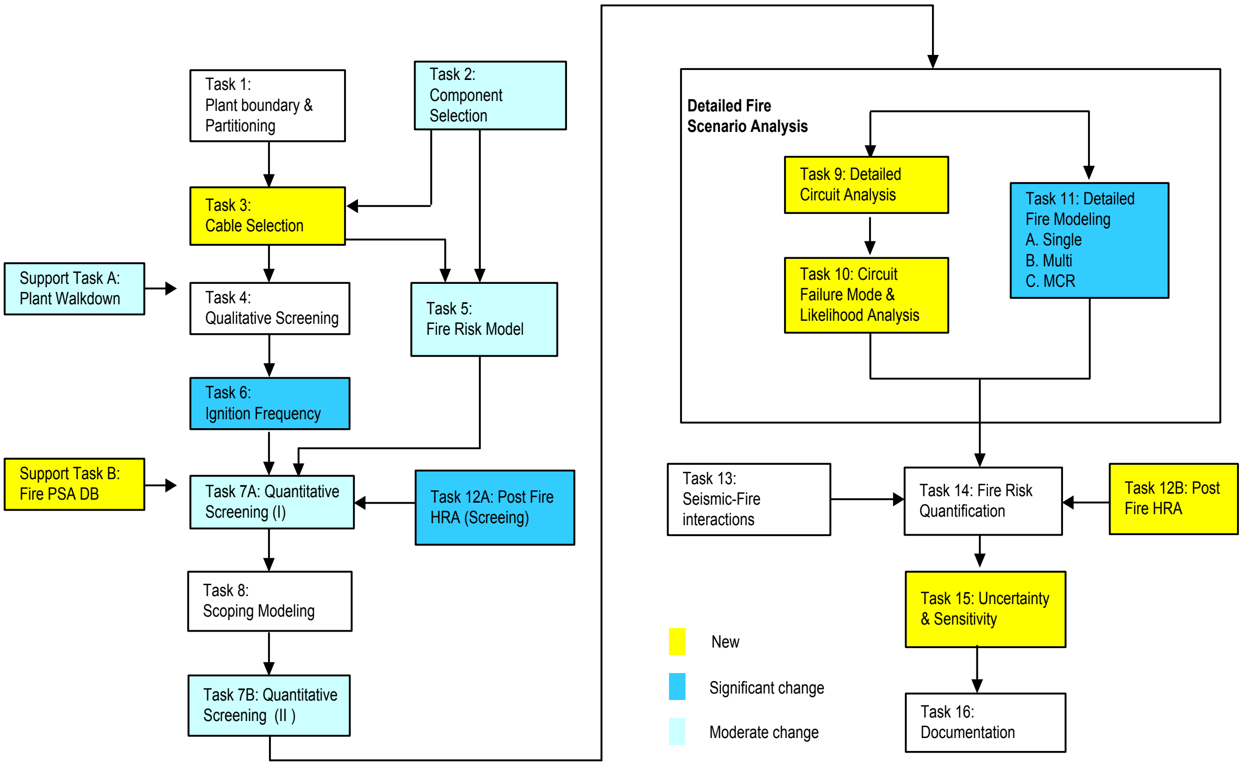

Figure 2. Overview of the Fire PRA Process in NUREG/CR-6850

2.2. Comparison of Frequency Results from NUREG/CR-6850 and FPRAIG Methodology

According to the result for fire frequency comparison between plant that NUREG/CR-6850-based fire frequency has been applied to and plant that FPRAIG based fire frequency has been applied to and those two plants have same design concept and are almost similar except several design changes such as from 2 diesel generators to 4 diesel generators, battery room's location, Essential Service Water system configuration, etc.

2.2.1 Electrical Equipment Room

For major electrical equipment rooms, comparison results for fire frequency are given in Table 1, which shows that fire frequency for fire compartment with NUREG/CR-6850 methodology has a tendency to be lower than that with FPRAIG methodology.

Table 1. Electrical Equipment related Fire Compartment Fire Frequency

Fire Compartment	Description	NUREG/CR-6850	FPRAIG
F078-A25A	Class 1E SWGR01A Room	3.21E-04	8.05E-04
F078-AEEB	Class 1E SWGR01B Room	3.66E-04	1.04E-03
F157-A01D	I &C Equipment Room	1.75E-04	2.06E-04
F157-A19C	I &C Equipment Room	1.94E-04	2.38E-04
F157-A19D	I &C Equipment Room	1.96E-04	2.61E-04
F157-A20C	I &C Equipment Room	1.65E-04	1.91E-04
F157-A20D	I &C Equipment Room	1.67E-04	1.76E-04

Figure 3 shows more explicitly difference for fire frequency results between NUREG/CR-6850 methodology and FPRAIG methodology for same fire compartments.

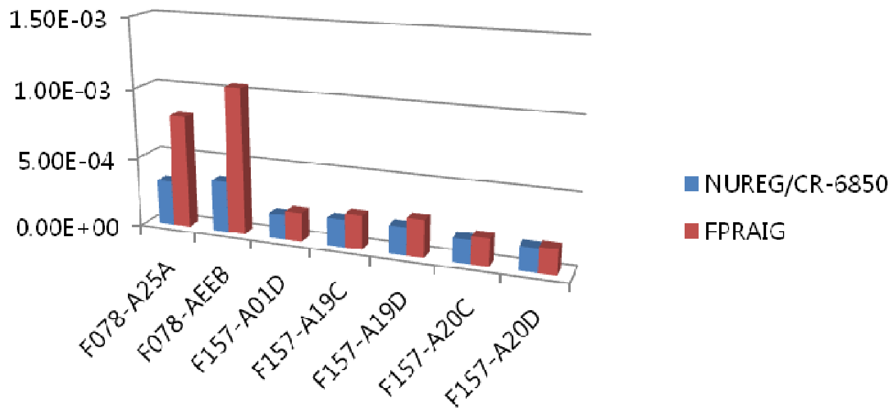

Figure 3. Electrical Equipment Room

2.2.2 Pump Room

For major pump rooms, comparison results for fire frequency are given in Table 2, which shows that fire frequency for fire compartment with NUREG/CR-6850 methodology has a tendency to be lower than that with FPRAIG methodology.

Table 2. Pump Room Fire Frequency

Fire Compartment	Description	NUREG/CR-6850	FPRAIG
F050-A03A	SI Pump A Room	8.29E-05	1.83E-04
F050-A03B	SI Pump B Room	8.28E-05	1.83E-04
F050-A02C	SI Pump C Room	8.33E-05	1.83E-04
F050-A02D	SI Pump D Room	8.33E-05	1.83E-04
F055-A02A	CCW Pump A Room	8.71E-05	1.83E-04
F055-A02B	CCW Pump B Room	8.51E-05	1.83E-04
F055-A02C	CCW Pump C Room	9.41E-05	1.83E-04
F055-A02D	CCW Pump D Room	9.10E-05	1.83E-04

Figure 4 illustrates more explicitly difference for fire frequency results between NUREG/CR-6850 methodology and FPRAIG methodology for same fire compartments.

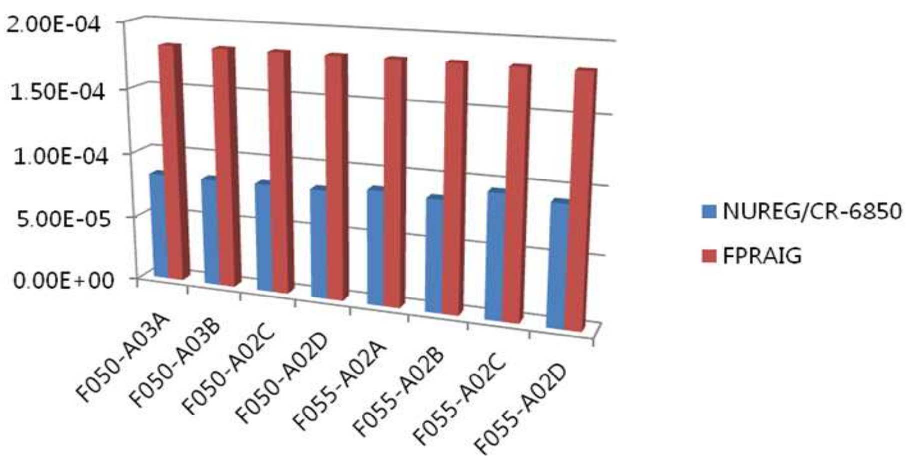

Figure 4. Pump Room

2.2.3 Transients

For transient fire, comparison results for fire frequency are given in Table 3, which shows that fire frequency for fire compartment with NUREG/CR-6850 methodology has a tendency to be higher than that with FPRAIG methodology for almost same fire compartments unlike fixed ignition sources. This is because in FPRAIG methodology, transient fire includes cigarette smoking, extension cord, heater, candle, overheating and hot pipe, which can be considered the impact to be ignored when procedurally prohibited or not existing. On the other hand, in NUREG/CR-6850, when calculating transient-relevant fire frequency, it is assumed that transient fires may occur at all areas of a plant unless precluded by design or operation, and also administrative controls don't preclude their occurrence in light of industry evidence. This is one of the differences between FPRAIG based frequency and NUREG/CR-6850 based frequency application.

Table 3. Transient Fire Frequency

Fire Compartment	Description	NUREG/CR-6850	FPRAIG
F073-T08	Stair	8.68E-05	0.00E+00
F073-T10	Stair	8.68E-05	0.00E+00
F079-P01	Access Area	7.89E-05	0.00E+00

Figure 5 represents more explicitly difference for fire frequency results between NUREG/CR-6850 methodology and FPRAIG methodology for same fire compartments.

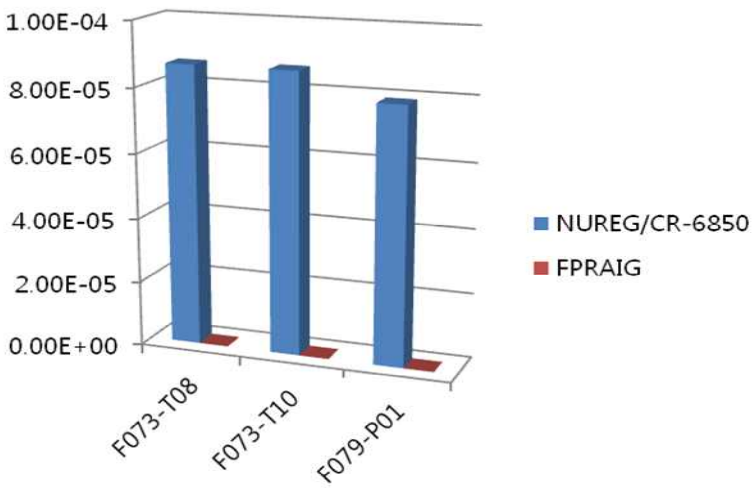

Figure 5. Transient Fire

2.2.4 Main Control Room

For main control room fire, fire frequency comparison was performed like Table 4, which shows that fire frequency for fire compartment with NUREG/CR-6850 methodology has a tendency to be much lower than that with FPRAIG methodology for same fire compartment.

Table 4. Main Control Room Fire Frequency

Fire Compartment	Description	NUREG/CR -6850	FPRAIG
F157-AMCR	Main Control Room	1.22E-04	7.94E-03

Figure 6 depicts more explicitly difference for fire frequency results between NUREG/CR-6850 methodology and FPRAIG methodology for same main control room.

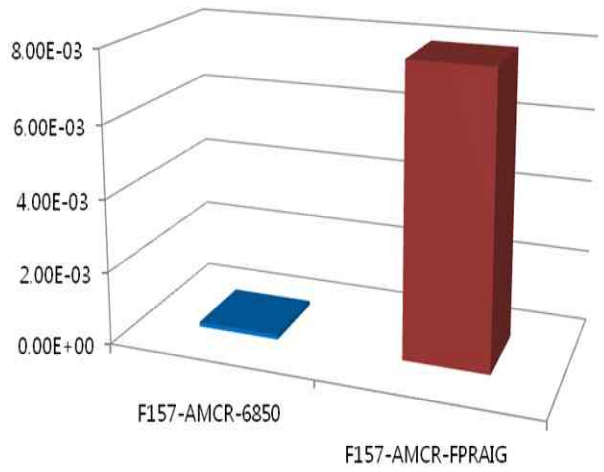

Figure 6. Main Control Room

2.2.5 Total Plant Fire Frequency

For plant total fire, fire frequency comparison was performed like Table 5, which shows that plant total fire frequency with NUREG/CR-6850 methodology has a tendency to be much lower than that with FPRAIG methodology. Especially, in terms of fixed ignition source, fire frequency with NUREG/CR-6850 methodology is lower than that with FPRAIG methodology. On the other hand, in case of transient fire frequency, fire frequency with NUREG/CR-6850 methodology is higher than that with FPRAIG methodology for reason mentioned in 2.2.3.

Table 5. Total Plant Fire Frequency

Ignition Source	NUREG/CR-6850	FPRAIG
Fixed Ignition Source	1.02E-01	2.92E-01
Transients	3.39E-02	1.19E-03
Total Frequency	1.36E-01	2.93E-01

Figure 7 shows more explicitly difference for fire frequency results between NUREG/CR-6850 methodology and FPRAIG methodology for same fire compartment.

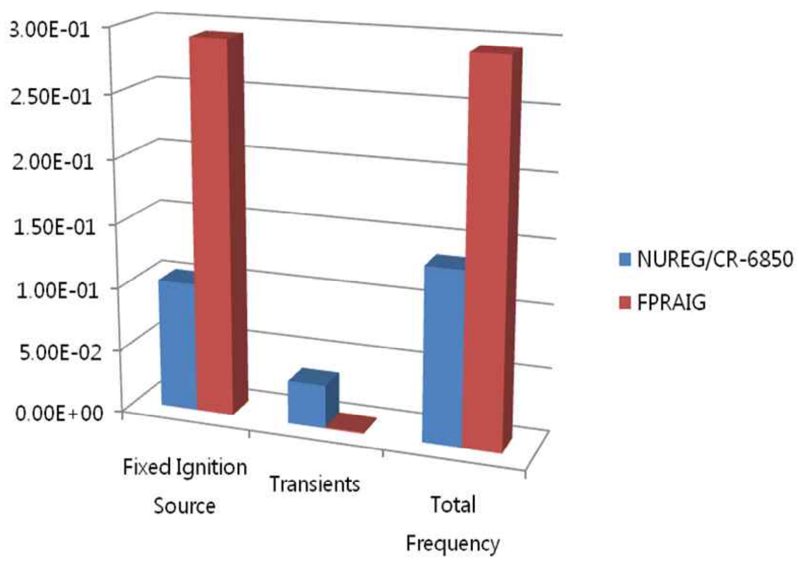

Figure 7. Total Plant Fire Frequency

3. CONCLUSIONS

When applying new Fire PRA methodology, NUREG/CR-6850, compared to the previous Fire PRA methodology, FPRAIG, fire frequency for fixed ignition source has been decreased, while fire frequency for transient ignition source has been increased. However, increased transient fire frequency is judged to be fully able to get lowered through transient-relevant procedure improvement and ignition source management. Consequently, NUREG/CR-6850 methodology leads that individual compartment fire frequency has been decreased compared to FPRAIG methodology.

Additionally, one of things that we should take care of is that NUREG/CR-6850 has the high chance to increase Conditional Core Damage Probability (CCDP)/Conditional Large Release Probability (CLRP) because Fire PRA equipment in NUREG/CR-6850 methodology should be incorporated into analysis more than that in the previous methodology. Therefore, CDF calculated from fire frequency multiplied by CCDP is not always reduced in proportion to the decrease in fire frequency based on NUREG/CR-6850 methodology.

References

[1] NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities Volume 1: Summary & Overview," USNRC, Washington, DC, August 2005.

[2] NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities Volume 2: Detailed Methodology," USNRC, Washington, DC, August 2005.

[3] EPRI 1019259, "Fire Probabilistic Risk Assessment Methods Enhancements: Supplement 1 to NUREG/CR-6850 and EPRI 1011989," EPRI, September 2010.

[4] EPRI TR-105928, "Fire PRA Implementation Guide," EPRI, December 1995.