The Risk Impact from Hazard Factor of Fire Probabilistic Safety Assessment for the PWR Nuclear Power Plant in Taiwan

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INTRODUCTION

- A Westinghouse 3 loop PWR plant is located at Taiwan.
- Previous fire PSA model was developed in 1987, its CDF was 1.3E-5/ry.
- Living PSA model developed under the NUPRA code environment was completed in 1995.
- The CDF of internal, seismic, and typhoon events are 1.6E-5, 1.0E-5, 1.8E-6/ry, respectively.
- Fire PSA model is updated in this study, the CDF of fire event is 4.3E-6/ry.

INTRODUCTION (cont.)

- This study is consulted by EQE/PLG Company.
- Effects of hot short and seismic-induced fire are not analyzed in this study.
- Easy to update by tabulated EXCEL spreadsheets to evaluate the fire risk.
- The key conservative assumption is that damage of cable trays of a specific train will induce loss function of the whole associated train.

OVERVIEW OF THE METHODOLOGY

- Screening Analysis
  - Large Area Screening Analysis
  - Qualitative Screening Analysis
  - Quantitative Screening Analysis
- Detailed Analysis
  - General Area Detailed Analysis
  - MCR Detailed Analysis

Large Area Screening Analysis

- Large Area: Building as Screening unit
- Non-safety related buildings, e.g. radwaste building, fuel building, administration building were screened in the first step.
- Diesel generator building was also screened because the additional fifth diesel generator.
- Reactor building, auxiliary building, control building, turbine building, and safety-related pump houses were left for next step.

Qualitative Screening Analysis

- Small Area: Fire zone as screening unit
- Screen Criteria:
  - Not cause an initiating event
  - Not contain any safety-related equipment
  - Not contain enough fuel load to propagate to neighbor fire zones

Quantitative Screening Analysis

- Both localized and propagation fire scenarios were considered for a certain fire zone.
- For localized fire scenarios, the worst assumptions were made in this step.
  - Fire initiating frequency is equal to the summation of all fire initiating frequencies of fire sources within the fire zone.
  - Conditional Core Damage Probability (CCDP) is calculated from the worst fire damage category, i.e. the worst initiating event with damage items within the fire zone.

Quantitative Screening Analysis (cont.)

- For propagation fire scenarios, the worst assumptions were also made in this step.
  - Fire propagation probability is assumed as 1, if it meets the propagation criteria.
  - CCDP is calculated from the worst fire damage category that the scenario in these affected fire zones may cause.
- Propagation criteria used in this step:
  - No fire barrier within fire zones, or
  - Fuel load larger than 75% of the fire barrier rating within fire zones and without automatic fire suppression system.
- Screening criteria used: 0.1% of CDF from internal events.

General Area Detailed Analysis

- Fire sub-scenarios were defined within a certain fire zone according to each fire source.
- Both localized and propagation sub-scenarios were considered.
- As real as possible assumptions were made for all sub-scenarios.

General Area Detailed Analysis (cont.)

- Fire Hazard factors include:
  - F_G=geometric factor
  - F_S=severity factor
  - F_{NS}=fire non-suppression factor (manual)
  - F_{NR} =non-recovery factor
  - F_{NR1} =fire non-suppression factor (automatic)
- For localized sub-scenarios, almost all fire hazard factors, exclude F_G for transient fuel and switchgear, are given as 1.

General Area Detailed Analysis (cont.)

- For propagation sub-scenarios, the COMPBRN IIIe code and experimental curves are used to estimated the fire hazard factors, F_S and F_{NS}.

- Mathematical model for Detailed Analysis:

$$CDF = IE \times F_G \times F_S \times F_{NS} \times F_{NR} \times F_{NR1} \times CCDP$$

MCR Detailed Analysis

- Special Spreadsheets for MCR detailed analysis were used without any screening process.
- Each control panel was analyzed as a fire zone.
- Both localized and propagation sub-scenarios were considered.
- Evacuation of MCR to remote shutdown panel was considered in the propagation sub-scenarios.
- Only F_S factor with it special experimental curve was considered in the propagation sub-scenarios.
- Total 80 sub-scenarios were analyzed.

RESULTS AND RISK IMPACTS

- Fire-induced CDF for MCR and other fire zones are 1.1E-6 and 2.8E-6/ry, respectively.
- Quantitative Screening CDF are 3.9E-7/ry.
- Fire risk contributes a total of 4.3E-6/ry, 27% of the internal events.
- More than 70% of the total fire risk is contributed from the fire zones excluding MCR.

RESULTS AND RISK IMPACTS (cont.)

- Geometric Factor, Non-Recovery Factor, and Failure Probability of Automatic FSS

Sensitivity Case	CDF of detailed analyses for fire zones	CDF of raising (or lower) factor to 10 times	CDF of setting factor equal to 1.0
Sub-scenarios 115L1 & L2, F_G	2.78E-6	3.36E-6 (+21%)[a]	3.99E-6 (+44%)
Another 8 sub-scenarios, F_G	4.98E-7 (-82%)[b]	6.18E-7 (-78%)[c]	3.99E-6
Non-recovery factor, F_{NR}	2.78E-6	—	2.96E-6(+6 %)
Automatic FSS factor, F_{NR1}	2.78E-6	2.79E-6 (+0.4 %)	2.80E-6 (+1 %)

[a]F_G is set to 0.5, [b]F_G is set to 0.05, [c]F_G is set to 0.1

CONCLUSION

- In-depth review of fire-induced hot short for circuit breaker in the switchgear should be implemented.
- The PWR plant rely less on the remote shutdown panel to mitigate the fire-event consequences.
- The failure probability of automatic FSS is not sensitive to the fire CDF.

The Fire Projects of Taiwan's NPPs

- The large early release frequency (LERF) model for the updated fire PSA was completed.
- The living fire PRA models for all three domestic NPPs had been established in December 2000.
  - Based on the living PRA model
  - Fire and smoke hazards and associated risks
  - Lost all accident mitigation functions of the entire corresponding train
- A risk-informed application project of the BWR-4, BWR-6 plant had been completed in December 2002 and September 2004, respectively.
  - Cable-tray fire-barrier wrapping exemption
  - Evaluate the function lost by affected cable tray in detail
  - Evaluate the fire propagation probabilities and fire hazards
  - Improve some simplified system fault tree and human actions dependence
- Another project for the same application to the PWR plant is currently in progress.

Example of EXCEL Spreadsheet

Subscenario	Fire ignition source	Fire target	IE freq.	$F_{G,i}$	$F_{S,i}$	$F_{NS,i}$	$F_{NR,i}$	$F_{NR1,i}$	CCDP	CDF
56A-W-L1	56A-W-DIV II-1	56A-W-DIV I-1	1.14E-5	1	1	0.01	1	1	8.89E-4	1.01E-10
56A-W-L2	56A-W-DIV I-1	56A-W-DIV II-1	3.41E-5	1	1	0.01	1	1	8.89E-4	3.03E-10
56A-W-L3	All DIV I	None	-	-	-	-	-	-	-	7.14E-08
56A-W-L3-1	56A-W-DIV I-1	None	3.41E-5	1	1	1	1	1	5.20E-4	1.77E-08
56A-W-L3-2	56A-W-DIV I-2	None	2.99E-5	1	1	1	1	1	5.20E-4	1.55E-08
56A-W-L3-3	56A-W-DIV I-3	None	3.00E-5	1	1	1	1	1	5.20E-4	1.56E-08
56A-W-L3-4	56A-W-DIV I-4	None	3.29E-5	1	1	1	1	1	5.20E-4	1.71E-08
56A-W-L3-5	56A-W-DIV I-5	None	1.05E-5	1	1	1	1	1	5.20E-4	5.46E-09
56A-W-L4	All DIV II	None	-	-	-	-	-	-	-	1.76E-10
56A-W-L4-1	56A-W-DIV II-1	None	1.14E-5	1	1	1	1	1	1.59E-5	4.51E-11
56A-W-L4-2	56A-W-DIV II-2	None	9.41E-6	1	1	1	1	1	4.79E-6	4.51E-11
56A-W-L4-3	56A-W-DIV II-3	None	8.94E-6	1	1	1	1	1	4.79E-6	4.28E-11
56A-W-L4-4	56A-W-DIV II-4	None	8.94E-6	1	1	1	1	1	4.79E-6	4.28E-11
									SUM	3.37E-08