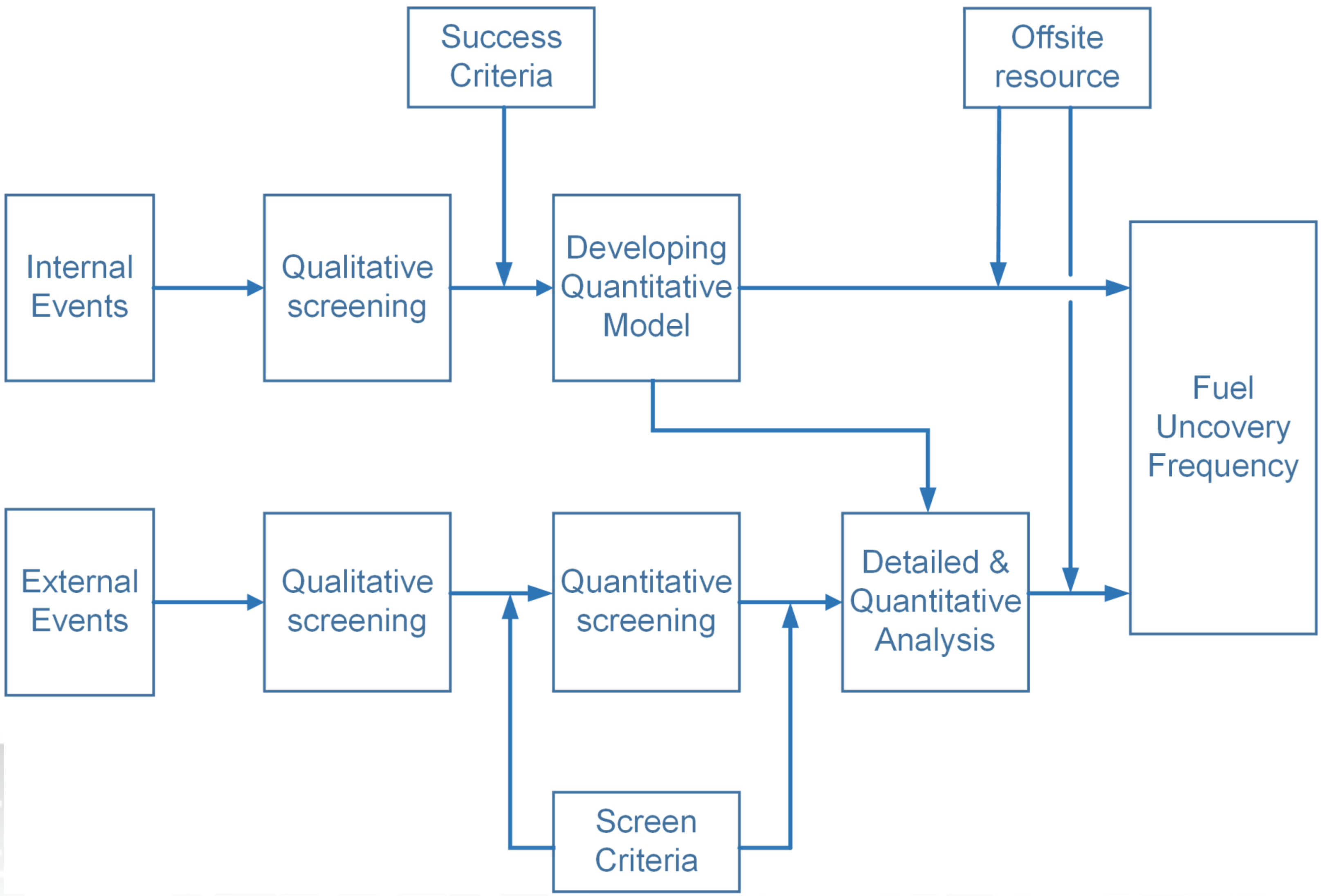
Nuclear Power Plant in Taiwan

NPP	Reactor Type	Commission Date	License Expiration Date
Chinshan	BWR-4	December 1978 (Unit 1) July 1979 (Unit 2)	December 2018 (Unit 1) July 2019 (Unit 2)
Kuosheng	BWR-6	December 1981 (Unit 1) March 1983 (Unit 2)	December 2021 (Unit 1) March 2023 (Unit 2)
Maanshan	PWR	July 1984 (Unit 1) May 1985 (Unit 2)	July 2024 (Unit 1) May 12025 (Unit 2)

- Dry storage facilities of spent fuel is still under planning or construction.
- Spent fuel assemblies are going to respectively remain in spent fuel pools of individual plant site for a decade of time at least.
- The risk of spent fuel pools will be paid more attention after removal of nuclear fuel from reactor vessels.

SFP Risk Assessment Flow Chart



Internal Initiating Events

- Refer to NUREG 1738, “Techincal Study of Spent Fuel Pool Accidents at Decommissioing Plants.”
- Refer to the initiating events from the PRA model of power operating and refueling outage.
- Internal should be take into consideration
  - Fuel Handling Accident
  - Criticality Accident
  - Loss of Cooling
  - Loss of Coolant Inventory
  - Loss of off-site Power
  - Internal Fire
  - Internal Flood
  - Heavy Load Drop

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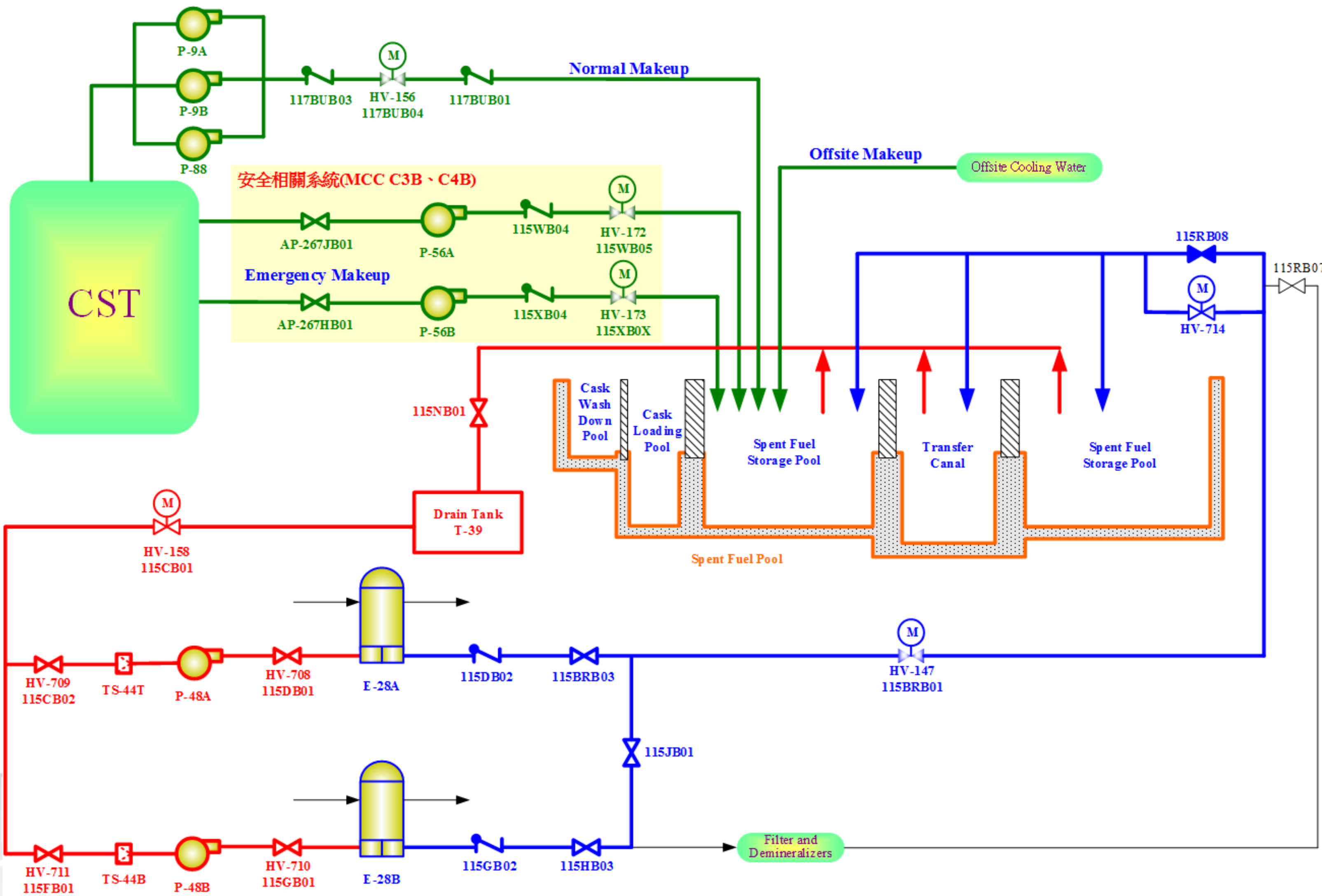
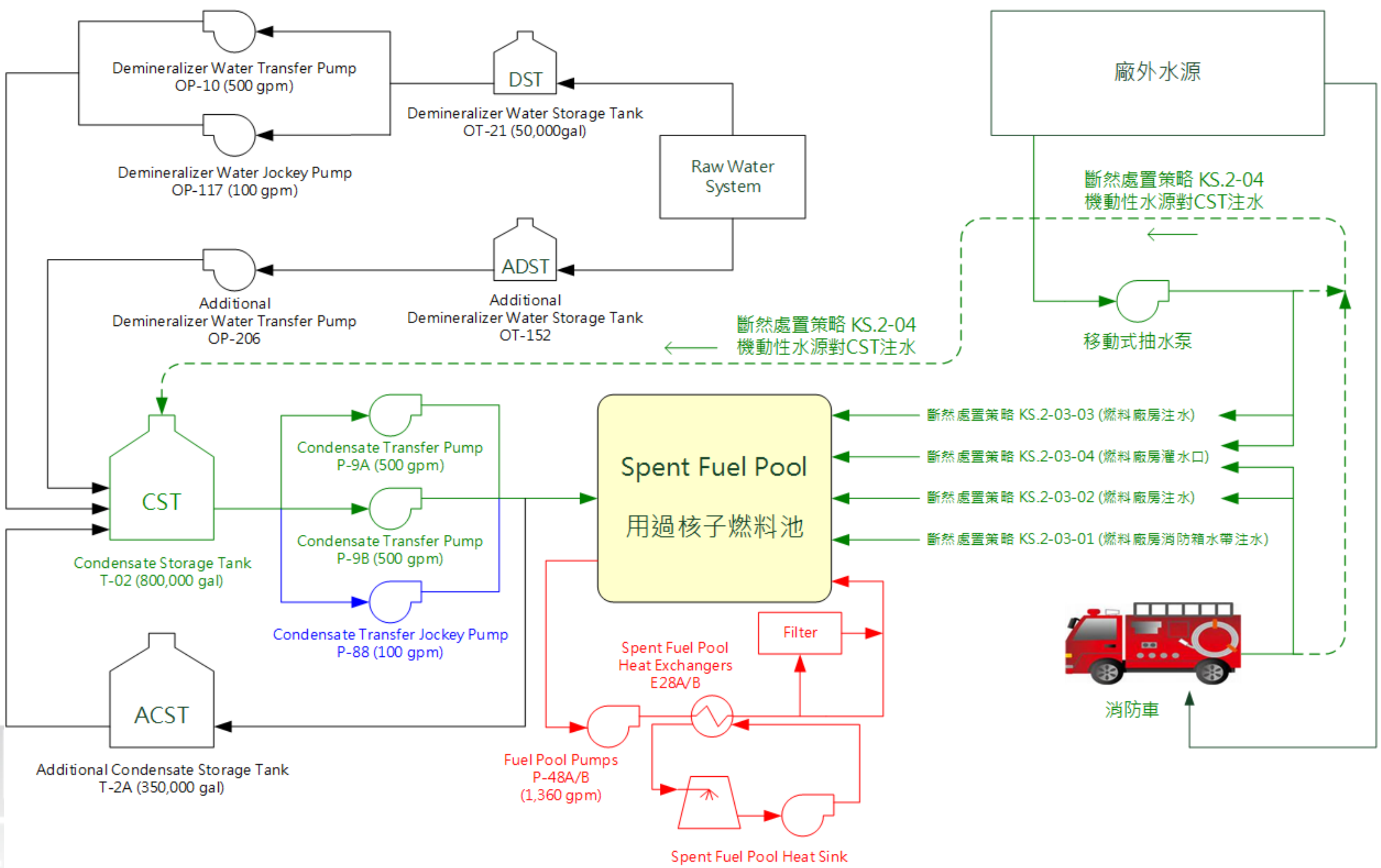
Target Spent Fuel Pool System



Target Spent Fuel Pool System during plant Decommissioning



Success Criteria

- Risk Index
  - Fuel Uncovery Frequency
- Criterion 1: It will could not lead to uncovering of irradiated fuel stored in the spent fuel pool within 72 hours when an event happened.
- Criterion 2: Spent fuel pooling system can be recovered, or any make-up strategies, include on-site and off-site, can be work successfully, which be considered that Criterion 1 could be met, during any events except rapid drain-down event.
- Heat Generation Rate in the Spent Fuel Pool
  - 7 days after reactor permanent shutdown
  - Irradiated fuel could be uncovered in about 3 days during loss of cooling event.

Qualitative screening of Internal IE

Item	Internal Initiating Event	Result
1	Fuel Handling Accident	Screened
2	Criticality Accident	Screened
3	Loss of Cooling*	Further detailed analysis
4	Loss of Coolant Inventory	Screened
5	Loss of off-site Power*	Further detailed analysis
6	Internal Fire	Further detailed analysis
7	Internal Flood	Further detailed analysis
8	Heavy Load Drop	Further detailed analysis

*Two basic events must to be develop their quantitative models which will be used in evaluating following external events.

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External Initiating Events

1	**Aviation impacts**	10	Frost	19	Lightning	28	Seiche	37	Volcanic Activity
2	Avalanche	11	Hail	20	Low lake or river water level	**29**	**Seismic activity**	38	Waves
3	Coastal erosion	12	High tide	21	Low winter temperature	30	snow	39	Boilogical Events
4	Drought	13	High summer temperature	22	Meteorite/ satellite strikes	31	Soil shrink-swell	40	Ship impact
5	External Flooding	**14**	**Hurricane/ Typhoon**	23	Pipeline accident	32	Storm Surge	41	Non-Safety building fires
6	**High Wind or Tornado**	15	Ice cover	24	Precipitation intense	33	Transportation accident	42	Sinkholes
7	**Fire**	16	Industrial or military facility accident	25	Release of chemical from on-site storage	34	Tsunami	43	Heavy-Load Drop
8	Fog	**17**	**Internal Flooding**	26	River diversion	35	Toxic gas	44	Ship stranded
9	Forest Fire	18	Landslide	27	Sandstorm	36	Turbine-generator Missile	45	Landslide dam

From probabilistic risk assessment report of the target nuclear power plant

External Event Screen Criteria

	Power operating for core*		Decommissioning for SFP	
Criterion 1	Core Damage Frequency (1/year)	< 10^{-6}	FUF(1/year)	< 10^{-7}
Criterion 2	External event at annual frequency of occurrence	< 10^{-7}	External event at annual frequency of occurrence	< 10^{-8}

*Follow Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications, ASME/ANS RA-Sa-2009, Part 6, Table 6-2-3(b) Ext -B1 & EXT-B2

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The Events of Quantitative Analysis

- Loss of Cooling
  - Event Tree, Fault Trees, Data and Human Error.
- Loss of Off-site Power
  - Event Tree, Fault Trees, Data and Human Error
- Internal Fire
  - Inventorying components and equipment in every fire compartment related to spent fuel pool system
  - Estimate frequency of fire
  - define the failure of components causing by fire and its consequence
- Internal Flood
  - Inventorying components and equipment in every flood compartment related to spent fuel pool system
  - Estimate frequency of fire
  - define the failure of components causing by fire and its consequence
- Seismic Event
- High Wind
- Aviation Accident

Internal Fire Frequency

- Whole plant fire frequency of target Nuclear Power Plant is from EPRI report, Fire PRA Methodology for Nuclear Power Facilities, EPRI 1011989.

Fire Source	Fire Bin	Fire frequency
Pump	21	2.12E-4
Motor Control Center	16.a	2.49E-6
480V Load Center	16.a	2.49E-6
4.16kV Switchgear	16.b	1.72E-5
Fan	26	1.22E-4

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Fire analysis

- Focusing on the fire scenarios which can cause loss of cooling

Code	Fire scenario	Frequency	CFUP
261A	The two circulating pump of spent fuel pool cooling system both failed	4.24E-4	2.44E-5
218-L1	MCC 0C2C gets fire and cause damage of LCs near 0C2C	2.49E-6	3.24E-5
218-L2	LC 0B2 gets fire and cause damage of MCC and LC near 0B2	2.49E-6	3.24E-5
218-L3	LC 0B3 gets fire and cause damage of MCC and LC near 0B3	2.49E-6	3.24E-5
Cooling tower	The secondary side of spent fuel pool cooling system failed.	6.67E-4	2.44E-5

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Internal Flood Frequency

- Focusing on the flood scenarios which can cause loss of cooling

Flood compartment	Scenario	IE	Frequency*
261A	The two circulating pump of spent fuel pool cooling system both failed	V	Spray: 1.18E-4 Flood: 3.64E-5 Major flood:3.82E-5
257	Condensate transfer pumps failed	X	
260	Valve 714, cooling flow returning to spent fuel pool and normal open, failed	X	
264	No pipe in this room	X	
Outdoor	The secondary side of spent fuel pool cooling system failed.	V	Spray: 1.14E-6

*From ERPI-TR-1013141

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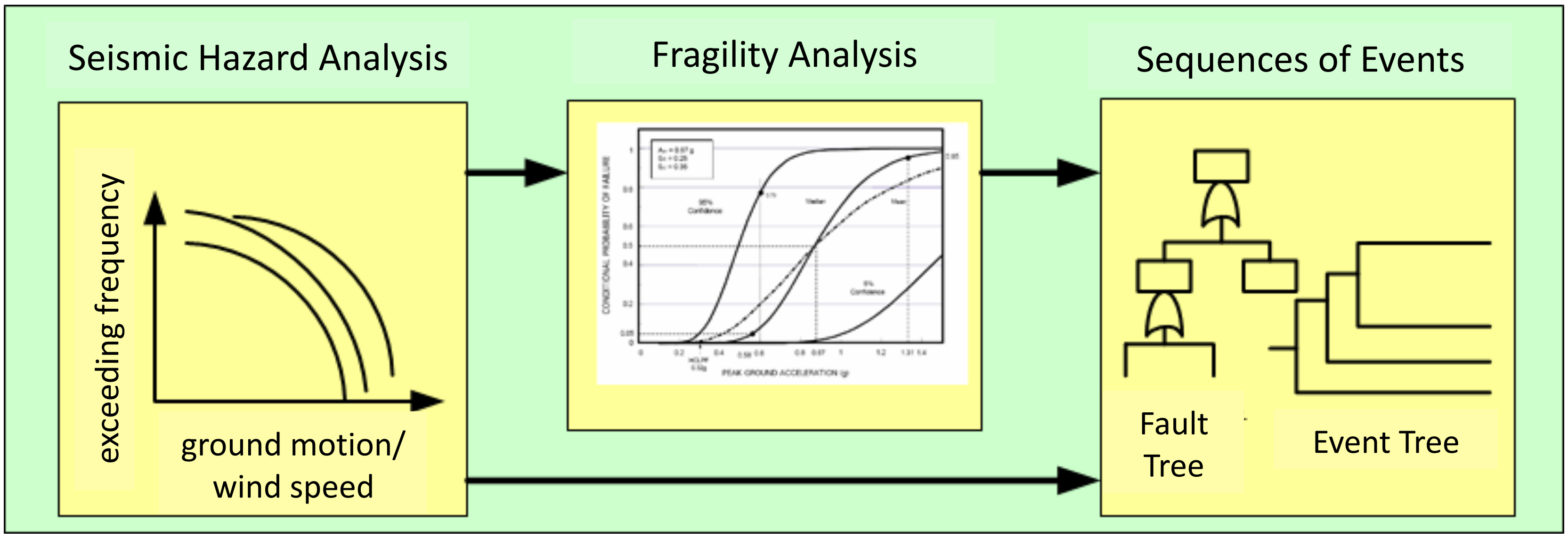
Seismic and Typhoon Events



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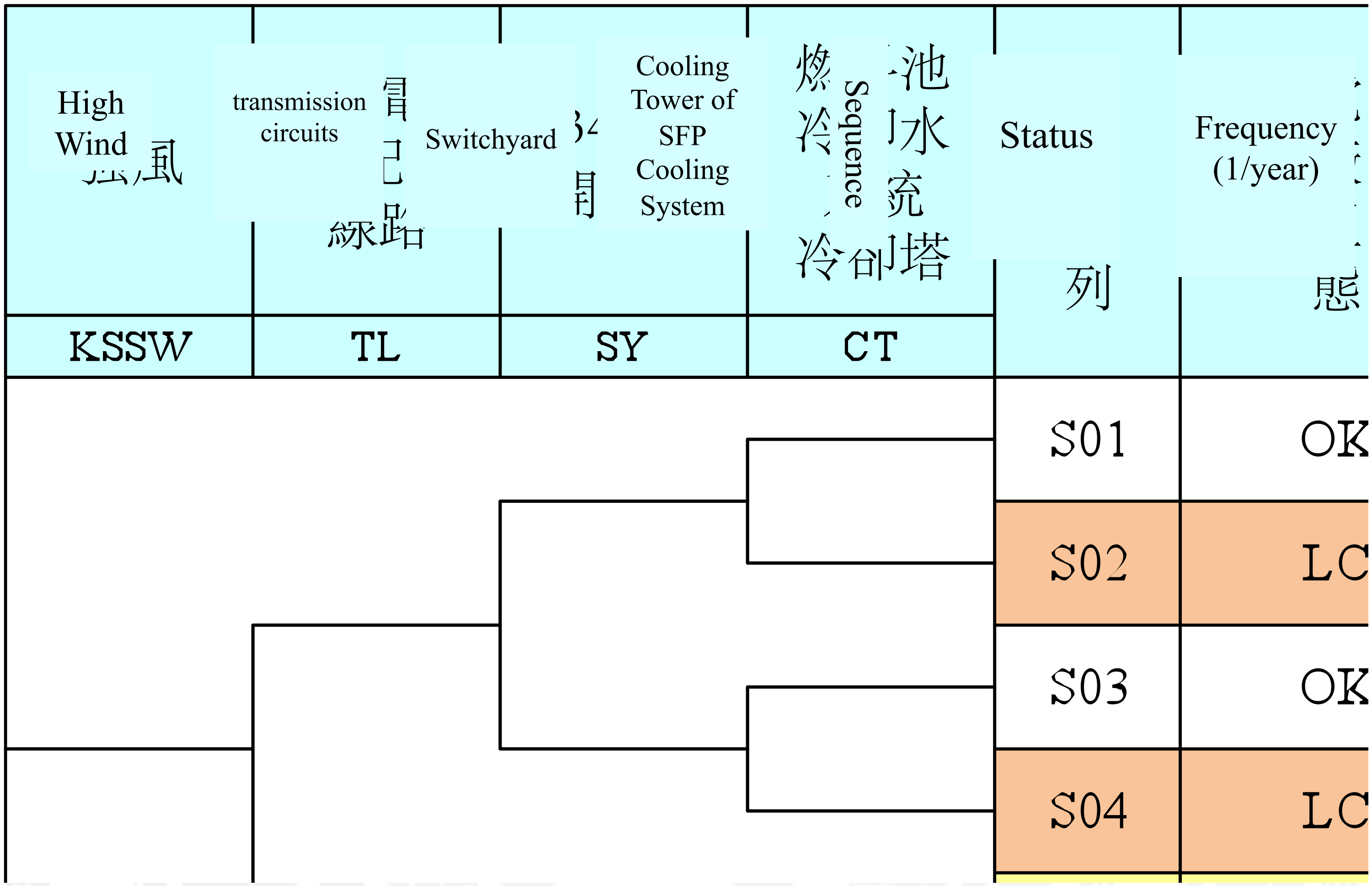
Front end tree for high wind



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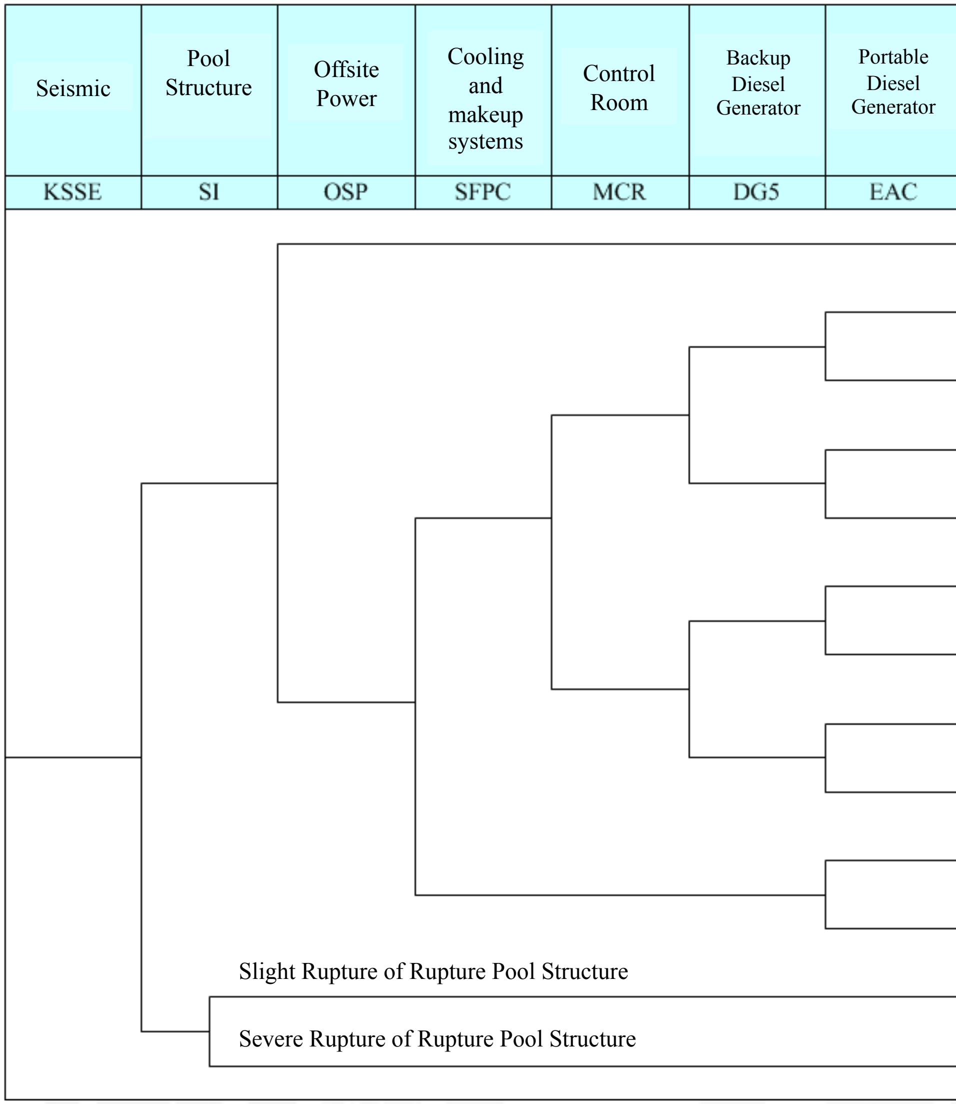
Seismic Front End Tree



Sequence	Status	Frequency (1/year)
S01	OK	-
S02	LOOP	1.59E-03
S03	LOOP	5.28E-08
S04	LOOP	1.45E-05
S05	LC	2.67E-07
S06	LOOP	3.22E-06
S07	LOOP	4.80E-08
S08	LOOP	3.63E-06
S09	LC	5.03E-07
S10	LC	1.61E-06
S11	LC	4.84E-07
S12	LC	8.14E-08
S13	FU	6.42E-08

Aviation Crash

- NUREG-0800 Section 3.5.1.6, Aircraft Hazards and DOE STD-3014-2006, Accident Analysis for Aircraft Crash into Hazardous Facilities
- Taipei Songshan Airport have an effect on target nuclear power plant.
- The aircraft crash impact probability due to takeoff and landing
  - The distance from the airport and the plant is 11.5 miles, so aircraft takeoff and landing have no impact on the plant.
- Aviation crash impact frequency, which includes commercial aircraft crash impact and military aircraft impact, is 4.28E-08/year.

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Failure Probability of Offsite Resource

	Category	Events	Failure Probability	Note
1	Single Failure	Loss of Offsite Power Loss of Cooling	1.00E-03	Random failure of equipment
2	Multiple Failure	Internal Fire Internal Flood Typhoon	1.00E-02	Short recovery time
3	Serious Multiple Failure	Seismic Event Typhoon	1.00E-01	Long recovery time
4	Serious Failure of Structure Failure	Aviation Crash Seismic Event	1	Pool water rapid drain down to TAF

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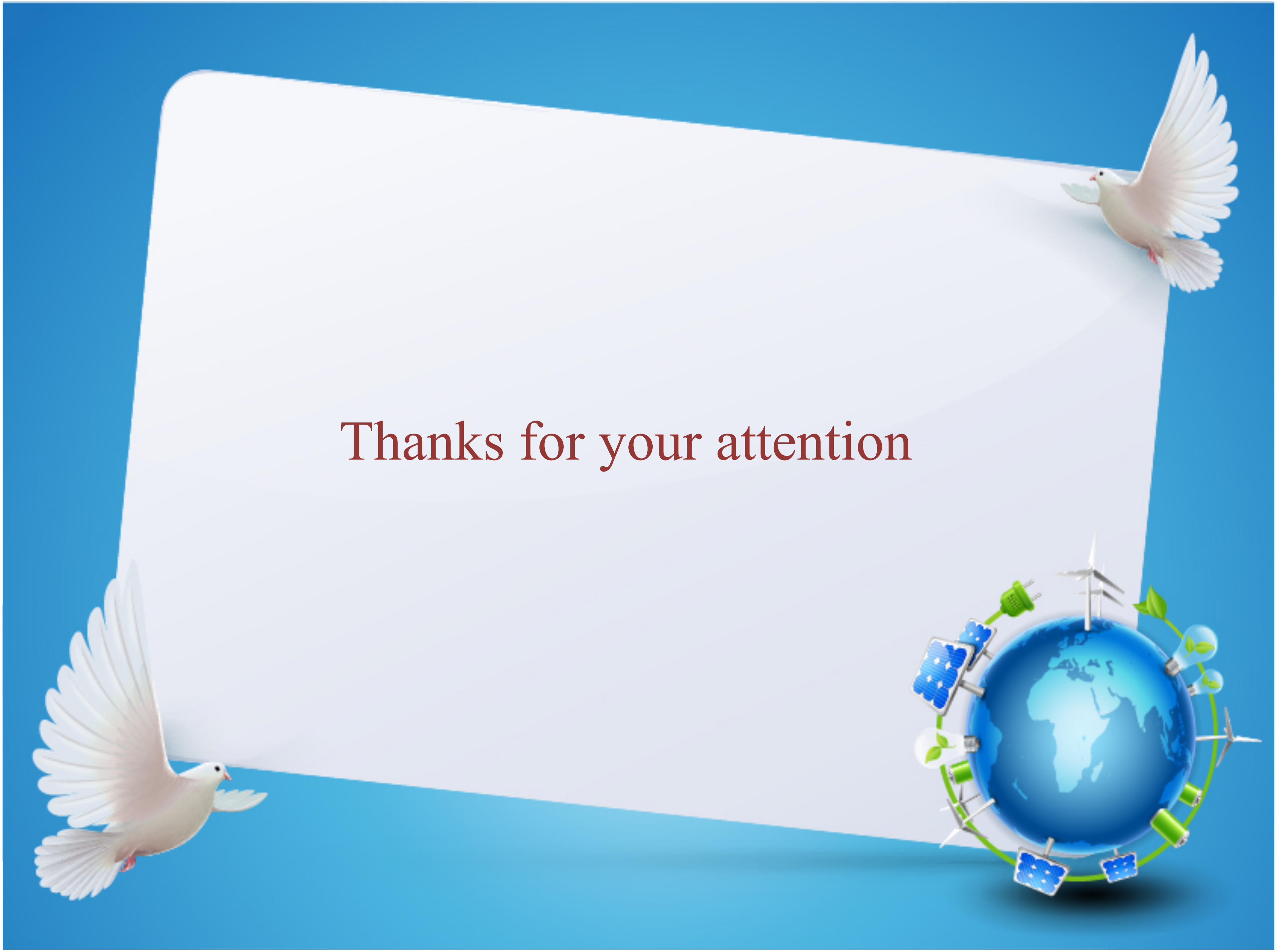
Result

Initiating Event	Fuel uncovery Frequency	Percentage
Heavy drop*	2.00E-07	54.71%
Loss of cooling	1.40E-10	0.04%
Loss of offsite power	4.18E-09	1.17%
Internal Flood	4.74E-11	0.01%
Internal Fire	3.05E-09	0.85%
High Wind	1.54E-09	0.43%
Seismic Event	1.07E-07	28.89%
Aviation Accident	4.28E-08	11.91%

*From NUREG-1738 report

Result & Future

- As expected, the risk of the spent fuel pool during decommissioning is much less than the reactor during operating.
- Except heavy load drop, the seismic event still accounts for the largest and its major contributor is the severe rupture of the pool structure in Taiwan.
- The results can be use to help licensee arrange for decommissioning activities, or provide regulatory body with risk level of spent fuel pool during plants decommissioned.
- This study is a preliminary research in finding the contributors of risk and their significance.
- The risk of the heavy load drop event is an important contributor and should be further evaluated.


Thanks for your attention