Outline

- Introduction
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Introduction

- Lesson learned from Fukushima accident, we need an alternative core cooling method to against severe nature hazard
- Solution - to setup portable equipment, or called FLEX
  - Cheap, Easy to setup
- The effectiveness of FLEX strongly depends on the characteristic of the accident scenario
  - Procedure to lineup portable equipment
  - Hours of temporary core cooling
  - Failure probability of FLEX
- This paper provide an easy and conservative way to show the risk effectiveness of FLEX
- Examples for risk reduction evaluation
  - Estimate CDF reduction for different plant FLEX strategy

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FLEX strategy in Taiwan

- Develop "Ultimate Response Guideline"(URG) to keep fuel from damage during severe accident
- Entry point of URG (any of the follow conditions)
  - Loss of all core cooling ability (except steam driven cooling method)
  - Loss of all AC power including all standby diesel generators and gas turbine
  - Strong earthquake with tsunami alarm
- 3 stages of URG

Stage	Purpose	Action Time
1	Controlled depressurization and provide temporary core cooling (steam driven cooling or fire water)	< 1 hour
2	Provide alternative core cooling	< 8 hours
3	Restore service water system , also long term plant cooling	< 36 hours

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FLEX strategy in Taiwan

- URG is designed to be an event base FLEX Strategy
  - Controlled core depressurization to keep turbine driven pump alive
  - Temporary core cooling to lineup portable long term power supply and cooling water supply
- Success of URG (Plant damage Status)
  - Main control room available for controlled depressurization
  - Temporary core cooling (steam driven cooling or fire water)
  - Good procedure to setup FLEX equipment in time
  - Time to lineup of FLEX equipment (Building damage, road damage)

Risk reduction estimation

- Risk Reduction = $\sum_i (1 - P_i) \times CDF_i$
  - CDF_i : $core\ damage\ frequency\ of\ i^{th}\ accident\ sequence$
  - P_i : $FLEX\ failure\ probability\ for\ i^{th}\ accident\ sequence$

- Steps for risk reduction estimation
  1. Define risk significant initiating events and sequences
  2. Define plant damage status for each sequence
  3. Define proper FLEX probability of each sequence
  4. Calculate risk reduction for each sequence
  5. Summation of risk reduction

Plant damage status categorization

Core Damage Sequence	Main Control Room

Category I~IV : Failure probability of FLEX will be given

Category V : No credit for FLEX strategy

Failure Probability of FLEX

Failure Probability	Remarks
1	No credit for FLEX Strategy
0.4	Generic failure probability form USNRC SECY-15-0085
0.1	Dominate by human error with less time available to lineup FLEX equipment
0.01	Dominate by human error with longer time available to lineup FLEX equipment
0.001	Significant long time available to lineup FLEX equipment. Human error is negligible. Component failure was used.

Risk significant IE

Reactor Type	Internal Events			External Events		
	Transients[1]	Flood	Fire	Strong Wind	Seismic	Tsunami
BWR-4	18.0%	2.2%	28.4%	<0.1%	50.1%	1.3%
BWR-6	19.2%	8.9%	7.5%	<0.1%	64.3%	0.2%
PWR	13.9%	1.1%	4.2%	2.7%	69.7%	8.4%

* This table reflects the risk with no FLEX available;
* BWR: Boiling Water Reactor: PWR: Pressurized Water Reactor
[1] Transients include all kind of loss of coolant accidents and various system failures

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CASE Study

Case	Accident Sequence Category					Note
	I	II	III	IV	V	
Case 1	0.4	0.4	0.4	0.4	1	Generic FLEX failure probability was used
Case 2	**0.01**	0.1	0.1	0.4	1	Plant with pool or unverified FLEX procedure
Case 3	**0.001**	**0.01**	0.1	0.4	1	Plant with high quality FLEX procedure

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Results of risk reduction

- Symptom based FLEX procedure was assumed

By total CDF

Reactor Type	Case 1	Case 2	Case 3
BWR-4	35.6%	50.3%	50.6%
BWR-6	29.7%	44.2%	44.3%
PWR	24.5%	35.2%	35.4%

By CDF of each IE

Case	BWR-4			BWR-6		PWR		
	Transients	Fire	Seismic	Transients	Seismic	Transients	Seismic	Tsunami
Case 1	32.6%	12.9%	54.5%	26.8%	73.2%	16.2%	69.9%	13.9%
Case 2	32.1%	11.4%	56.5%	27.8%	72.2%	13.2%	72.3%	14.5%
Case 3	32.1%	11.8%	56.2%	27.9%	72.1%	13.1%	72.3%	14.5%

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Risk profile wo/w FLEX

- FLEX strategy may change the risk insight of PRA

Without FLEX Strategy

Reactor Type	Internal Events			External Events		
	Transients	Flood	Fire	Strong Wind	Seismic	Tsunami
BWR-4	18.0%	2.2%	28.4%	<0.1%	50.1%	1.3%
BWR-6	19.2%	8.9%	7.5%	<0.1%	64.3%	0.2%
PWR	13.9%	1.1%	4.2%	2.7%	69.7%	8.4%

With high quality FLEX strategy

Reactor Type	Internal Events			External Events		
	Transients	Flood	Fire	Strong Wind	Seismic	Tsunami
BWR-4	3.7%	4.4%	45.3%	<0.1%	43.9%	2.7%
BWR-6	12.2%	16.0%	13.4%	<0.1%	58.1%	0.3%
PWR	14.3%	1.7%	6.5%	4.2%	68.3%	5.1%

Results of other case study

- FLEX strategy is risk effective in all cases

FLEX Strategy was developed only for seismic and tsunami events

Plant with negligible external event risk

Reactor Type	Event Based FLEX Procedure			Negligible External Event Risk		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
BWR-4	19.4%	28.4%	28.4%	34.9%	47.1%	47.7%
BWR-6	21.6%	31.9%	31.9%	41.4%	64.0%	64.5%
PWR	20.5%	30.5%	30.8%	28.7%	33.4%	33.5%

Conclusion

- A simplified methodology was developed in this study to account for the risk effectiveness of different kind of FLEX strategy
- Predict the conservative risk reduction by examining the accident sequences from the event trees of plant specific PRA
- The results suggested that FLEX can significantly decrease CDF no matter it is event based or symptom based
- Even for those plants with negligible external event risk, FLEX is still an effective way to significantly reduce plant risk
- It is important that a specific FLEX procedure should be developed to provide guidance for both reactor operator and other operating crew
- Implementing FLEX may change the risk insight of plant PRA

Question & Comment