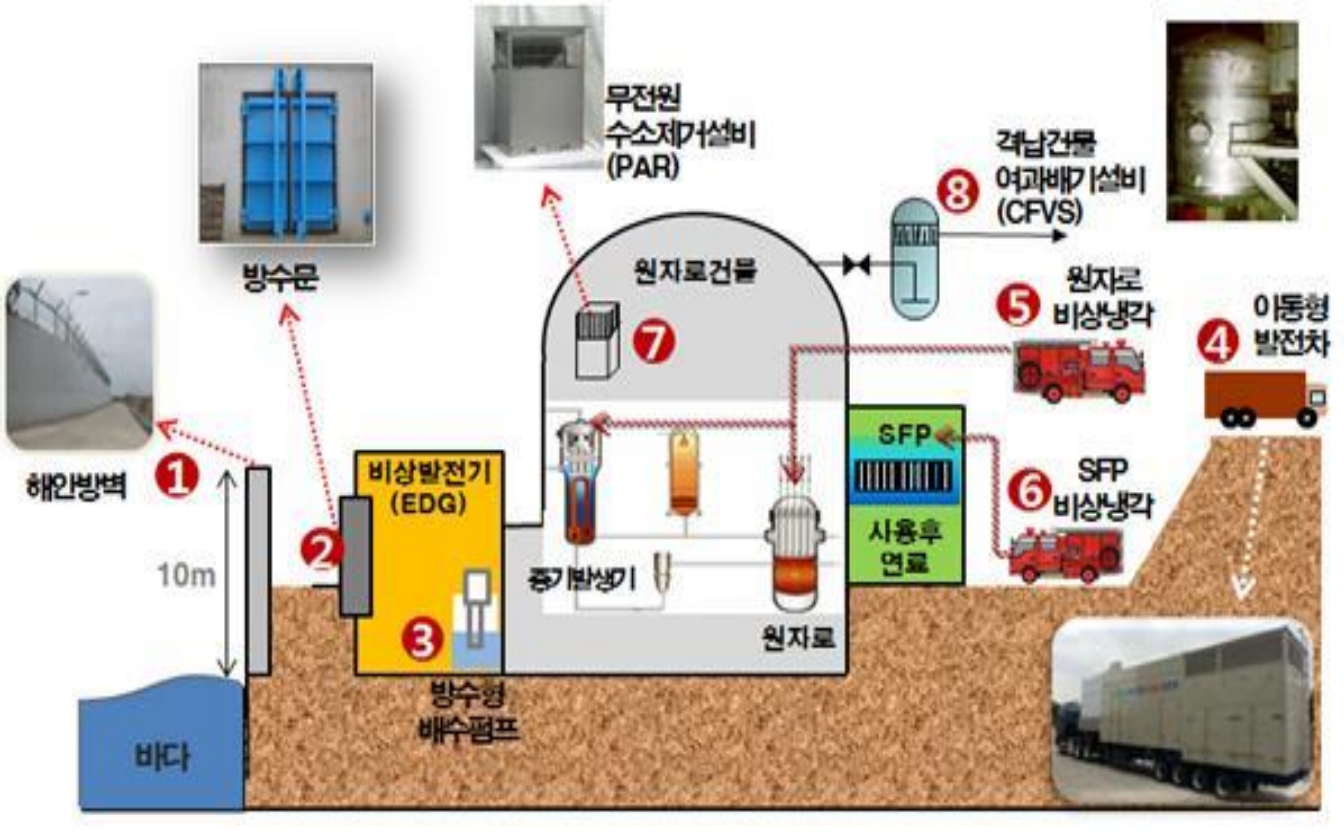
A comparative study of FLEX strategies to cope with Extended Station Blackout (SBO)



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FLEX Objectives

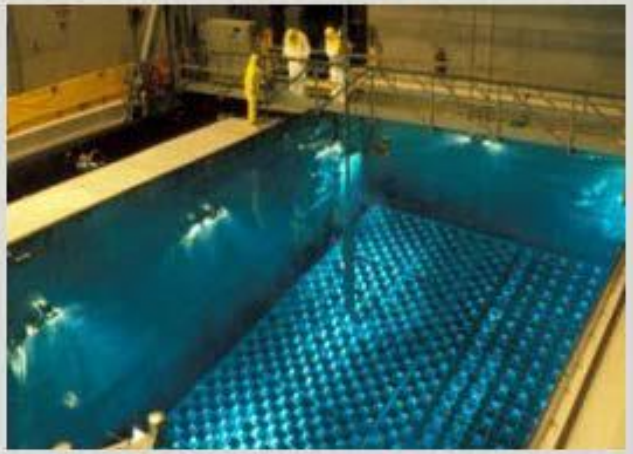
The Objectives of FLEX

To enable a plant to restore and maintain its key safety functions of:

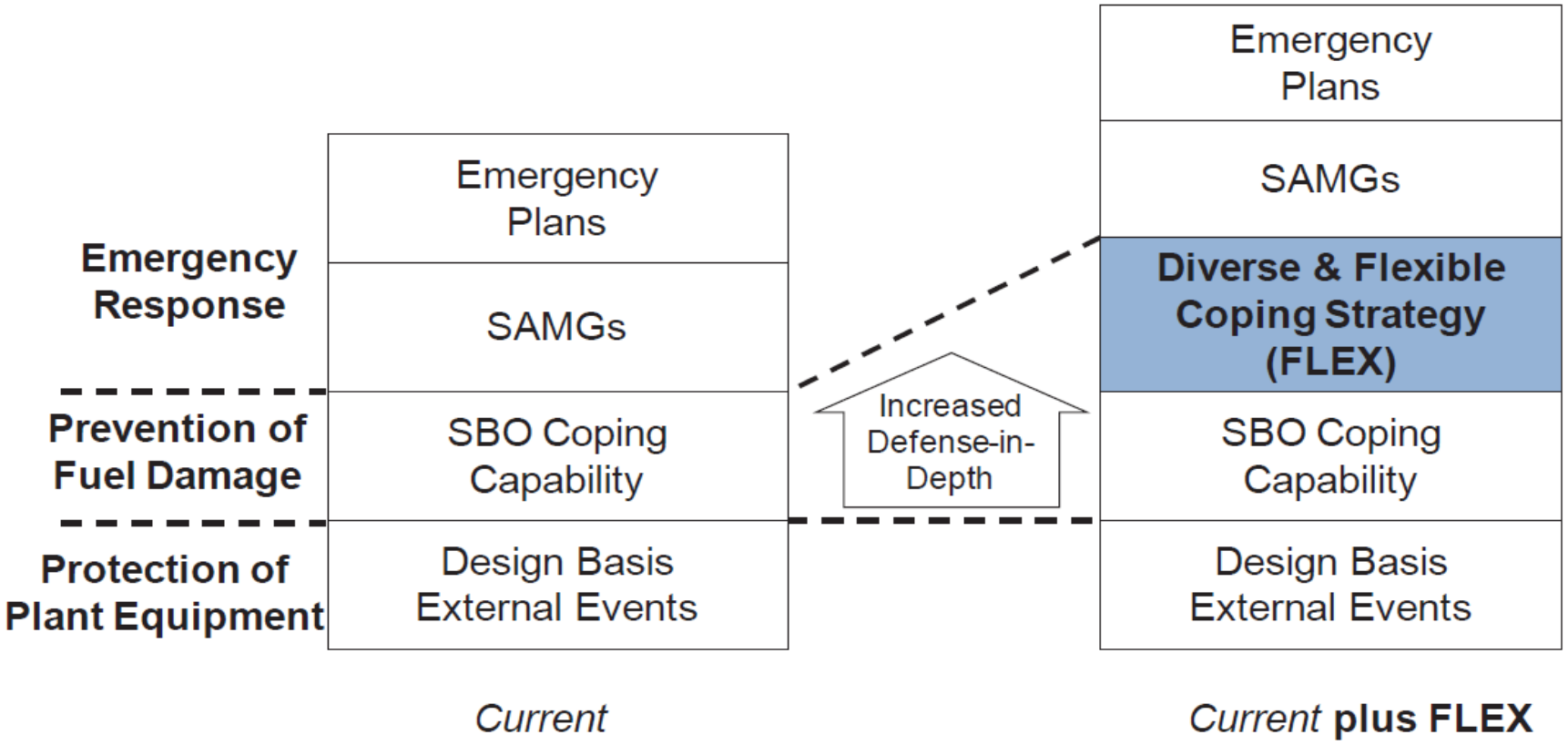
Core cooling

Containment integrity

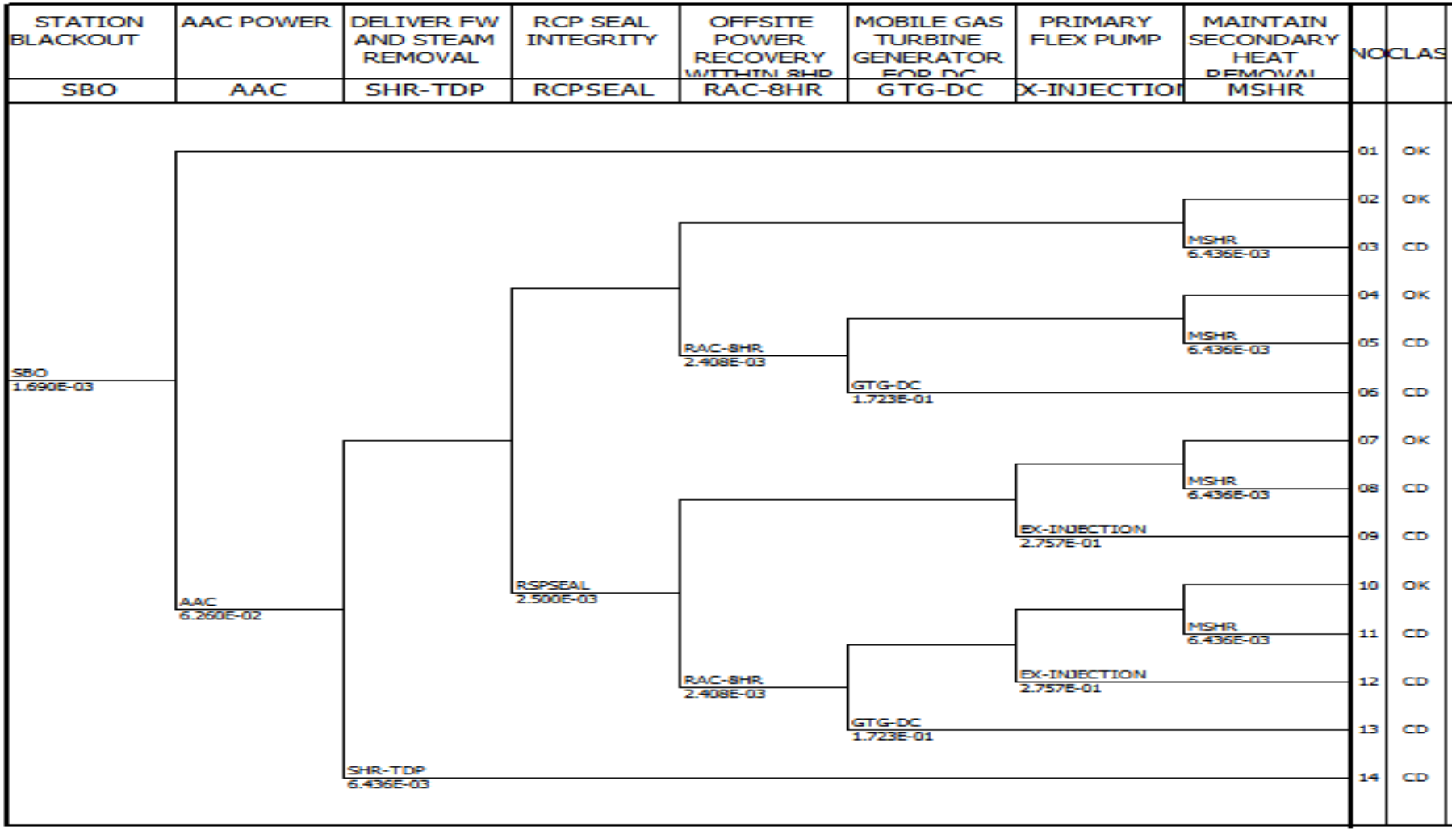
SFP cooling



Enhancement of FLEX



Event Tree for Extended SBO using Small GTG

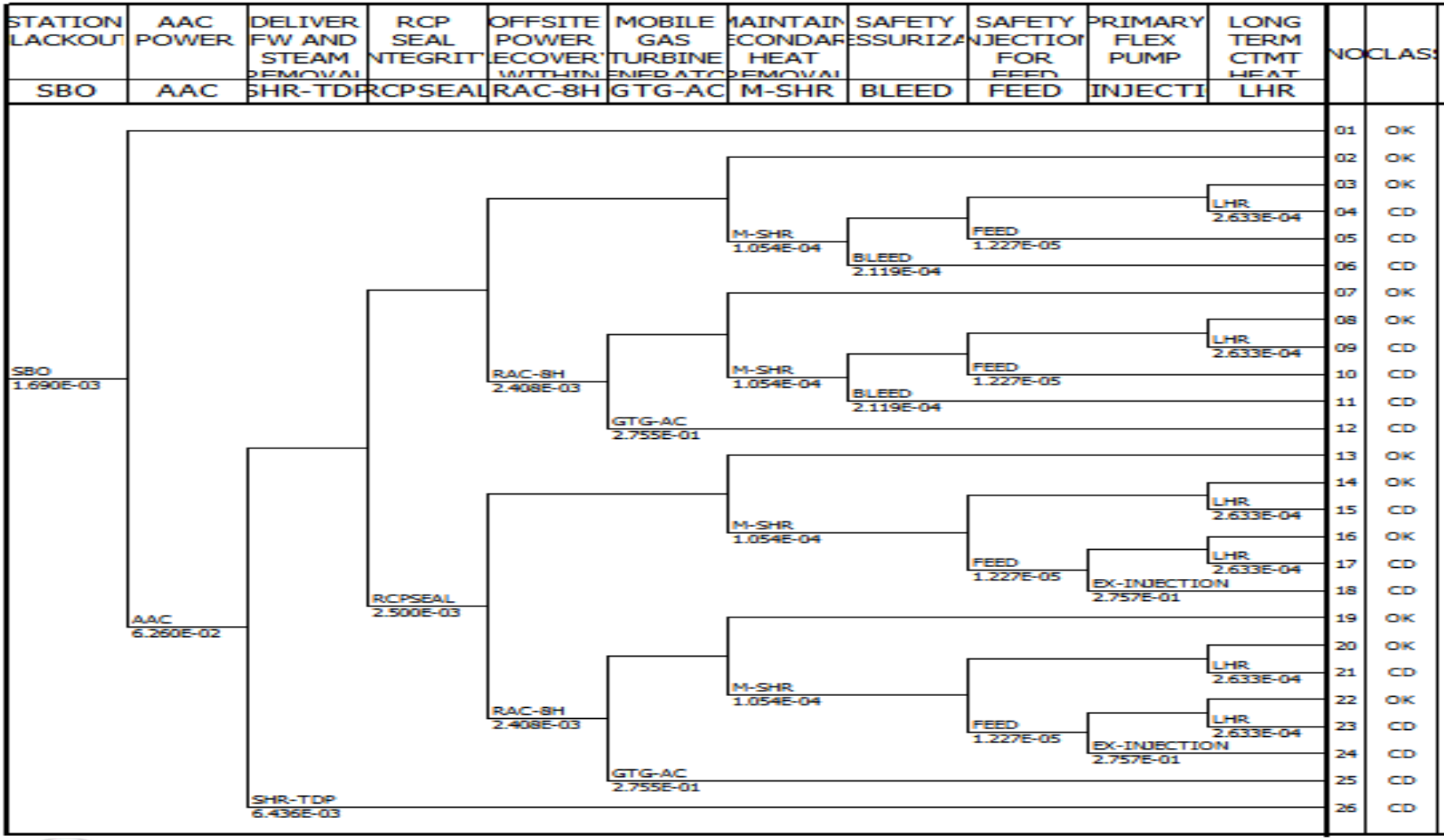


Success Criteria

❑ Success criteria was considered for main function of system and component to mitigate accident

No	Event Name	Description
1	AAC	AAC DG power source aligned to one Class 1E 4.16 kV ac bus
2	SHR-TDP	1 of TDAFPs to associated SG and 1 MSADV or 1 MSSV on associated SG
4	RAC-8HR	Offsite power restored within 8 hours following an LOOP event
5	SHR-MDP	1 of MDAFPs to associated SG and 1 MSADV or 1 MSSV on associated SG
6	GTG-DC	dc power restored within 8 hrs following battery depletion
7	EX-INJECTION	Primary FLEX pump injects sufficient water to RCS inventory
8	M-SHR	AFW flow from AFWST after depletion of battery to associated SG and 1 MSADV or 1 MSSV on associated SG

Event Tree for Extended SBO using large GTG



Success Criteria

- Accident scenario was considered for main function of system and success criteria with mission time was confirmed by thermal-hydraulic analysis

No	Event Name	Description
1	AAC	AAC power source aligned to one Class 1E 4.16 kV ac bus
2	SHR-TDP	1 of TDAFPs to associated SG and 1 MSADV or 1 MSSV on associated SG
3	RCPSEAL	RCP seal remains intact given RCP seal injection or auxiliary charging pump provides seal cooling
4	RAC-8HR	Offsite power restored within 8 hours following an LOOP event
5	GTG-AC	AC power resorted within 8 hour following battery depletion which is aligned to 4.16kV safety class 1 AC bus.
6	M-SHR	AFW flow from AFWST after depletion of battery to associated SG and 1 MSADV or 1 MSSV on associated SG
7	BLEED	2 of 4 POSRVs need to open
8	FEED	1 of 4 SI pumps provides DVI injection.
9	EX-INJECTION	Primary FLEX pump injects sufficient water to RCS inventory
10	LHR	1 of CS (containment spray) pumps to associated CS nozzle and 1 of SC (shutdown cooling) pumps to associated IRWST cooling

➢ Fault Tree for FLEX Equipment's

- ❑ The modeling of portable equipment in a PRA is very similar to modeling of installed equipment
- ❑ Fault tree of portable equipment include random failure of equipment, fail of maintenance and HRA.
- ❑ Data : Portable equipment is not set up to nuclear power plant and there is no experience data for the portable pump. But there is data on the same type equipment in NUREG/CR-6928.

Mitigating Strategies of Small Mobile GTG in PRA

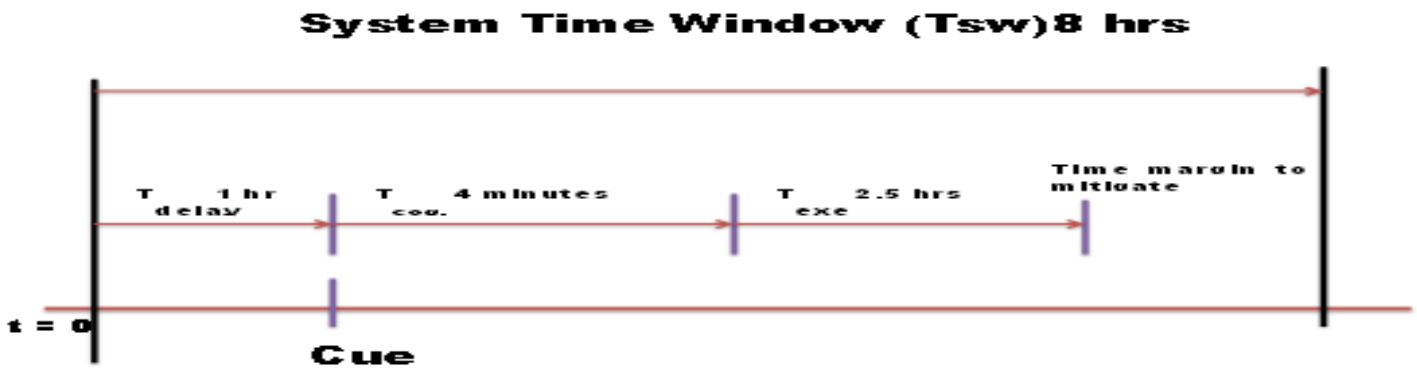
- TDAFW pump is required for the first 8 hours of the scenario to provide sufficient time to deploy the FLEX equipment
- Small Mobile GTG connected to 480 V of mobile generator to recover dc power and instrumentation & control.
- Cable reel from small mobile GTG connected to the connection box of plant
- small mobile GTG deployment from a storage building to in front EDG room

Mitigating Strategies of Large Mobile GTG in PRA

- Large mobile GTG can be connected to the 4.16 KV class 1E safety bus to recover ac power.
- Deployment and staging of large GTG
- After equip. staged installation of GTG
- Pre-operational check of large mobile GTG can be done before re-energized the bus.
- Energized bus from large GTG

- **calculation of human error probability (HEP)**
  - cognitive portion of human error probability (Pc) with recovery, and
  - execution portion of human error probability (Pexe) with performance shaping factors and recovery

➢ Structure of Timing Analysis for Mobile GTG



- ❑ Td= 60 mins. diagnose the situation and begin the deployment of the mitigati ng strategies equipment, measured from the time of initiating event.
- ❑ Tcog= 4 mins. action of detection, diagnosis and decision making
- ❑ Texe= 150 mins. mobile GTG implementation to deployment, staged installation, the time to pre-operational check, and time to start re-power the buses

- **cognitive portion of human error probability (Pc)**
  - Detection, diagnosis, and decision making phase of procedure guides
  - To facilitate the identification of Pc is made into failures of the plant in formation-operator interface and failures of the operator- procedure interface

➢ cognitive portion of human error probability (Pc) (CBDTM)

Cognitive analysis		
Pc Failure Mechanism	Branch	HEP
Pea: Availability of Information	a	N/A
Pcb: Failure of Attention	h	N/A
Pec: Misread/miscommunicate data	a	N/A
Ped: Information misleading	a	N/A
Pee: Skip a step in procedure	e	2.00E-03
Pcf: Misinterpret Instructions	a	N/A
Peg: Misinterpret decision logic	l	N/A
Pch: Deliberate violation	a	N/A
Initial Pc (without recovery credited)		2.00E-03

➢ cognitive portion of human error probability (Pc)

Cognitive Recovery				
	Initial HEP	Dependency level	Multiply by HEP	Final value
Pca	N/A	N/A		
Pcb	N/A	N/A		
Pcc	N/A	N/A		
Pcd	N/A	N/A		
Pce	2.00E-03	MD	1.45E-01	2.90E-04
Pcf	N/A	N/A		
Pcg	N/A	N/A		
Pch	N/A	N/A		
Final Pc with recovery				2.90E-04

- **execution portion of human error probability (Pexe)**
  - deployment and staging of portable equipment,
  - installation of hoses or cables,
  - pre-operational checks, electrical rotation checks, and/or alignments, and
  - reenergized of bus from portable equipment.

  - Moreover, Errors of omission and errors of commission with performa nce shaping factors are considered in each part of execution

➢ execution portion of human error probability (Pexe)

Execution Uncovered							
procedure		Error type	THERP		HEP	Stress factor	Override
Step no.	Instruction (action)		Table	Item			
01	Deployment and staging of large GTG	EOM	20-7	1	3.0E-03	high	
		EOC	20-13	1	1.3E-03	high	
		Total step HEP					2.15E-02
02	After equip. staged installation of GTG	EOM	20-7	2	1.0E-02	high	
		EOC	20-12	13	1.3E-02	high	
		Total step HEP					1.15E-01
03	Pre-operational Check of large GTG	EOM	20-7	2	1.0E-02	high	
		EOC	20-22	9	1.0E-03	high	
		Total step HEP					5.50E-02
04	Energized bus from large GTG	EOM	20-7	2	1.2E-02	high	
		EOC	20-12	11	5.0E-03	high	
		Total step HEP					7.50E-02
		Total HEP					2.66E-01

➢ execution portion of human error probability (Pexe)

Execution Recovered					
Step No.	Action	Initial HEP	Dep.	Cond. HEP	Total for step
01	Deployment and staging of large GTG	2.15E-02	MD	1.45E-01	3.11E-03
02	After equip. staged installation of GTG	1.15E-01	LD	6.24E-02	7.17E-03
03	Pre-operational Check of large GTG	5.50E-02	MD	1.45E-01	7.97E-03
04	Energized bus from large GTG	7.50E-02	ZD	6.24E-02	4.68E-03
	Total Uncovered	2.66E-01	Total Recovered		1.96E-02

➢ THE HEP OF SMALL GTG AND LARGE GTG

HEP Summary				
		Pcog	Pexe	Total HEP
Large Mobile GTG	Without Recovery	2.00E-03	2.66E-01	1.99E-02
	With Recovery	2.90E-04	1.96E-02	
Small Mobile GTG	Without Recovery	2.00E-03	1.18E-01	5.35E-03
	With Recovery	2.90E-04	5.06E-03	

Results

➢ RESULT FOR EXTENDED SBO WITH SMALL MOBILE GTG

Sequence Number	Sequence	Core Damage Frequency Contribution (events/year)
ESBO-06	(SBO)(failure of AAC)(successful delivery of feedwater using turbine driven pumps)(RCP Seal intact)(failure of recovery offsite power within 8 hours)(failure of mobile GTG for dc power recovery)	4.67E-08
ESBO-09	(SBO)(failure of AAC)(successful delivery of feedwater using turbine driven pumps)(RCP Seal leakage)(success of recovery offsite power within 8 hours)(failure of primary injection of RCS inventory by primary FLEX pump)	8.20E-08
ESBO-12	(SBO)(failure of AAC)(successful delivery of feedwater using turbine driven pumps)(RCP Seal leakage)(failure of recovery offsite power within 8 hours)(success of mobile GTG for dc power recovery)(failure of primary injection of RCS inventory by primary FLEX pump)	1.96E-10
ESBO-13	(SBO)(failure of AAC)(successful delivery of feedwater using turbine driven pumps)(RCP Seal leakage)(failure of recovery offsite power within 8 hours)(failure of mobile GTG for dc power recovery)	1.16E-10
ESBO-14	(SBO)(failure of AAC)(failure of delivery of feedwater using turbine driven pumps	6.93E-07
	Total	**8.21E-07**

Results

➢ RESULT FOR EXTENDED SBO WITH LARGE MOBILE GTG

Sequence Number	Sequence	Core Damage Frequency Contribution (events/year)
ESBO-05	(SBO)(failure of AAC)(successful delivery of feedwater using turbine driven pumps)(RCP Seal intact)(success of recovery offsite power within 8 hours)(failure to maintain secondary heat removal)(Safety dep. For bleed OK)(safety injection for feed fails)	6.48E-14
ESBO-06	(SBO)(failure of AAC)(successful delivery of feedwater using turbine driven pumps)(RCP Seal intact)(success of recovery offsite power within 8 hours) (success of mobile GTG for ac power recovery)(failure to maintain secondary heat removal)(Safety dep. For bleed fails)	1.03E-10
ESBO-11	(SBO)(failure of AAC)(successful delivery of feedwater using turbine driven pumps)(RCP Seal intact)(failure of recovery offsite power within 8 hours)(failure to maintain secondary heat removal)(Safety dep. For bleed fails)	1.49E-13
ESBO-12	(SBO)(failure of AAC)(successful delivery of feedwater using turbine driven pumps)(RCP Seal intact)(failure of recovery offsite power within 8 hours)(failure of mobile GTG for ac power recovery)	8.06E-08
ESBO-13	(SBO)(failure of AAC)(successful delivery of feedwater using turbine driven pumps)(failure of RCP Seal)(successful of recovery offsite power within 8 hours)(failure to maintain secondary heat removal)	2.7E-07
ESBO-25	(SBO)(failure of AAC)(successful delivery of feedwater using turbine driven pumps)(failure of RCP Seal)(failure of recovery offsite power within 8 hours)(failure of mobile GTG for ac power recovery)	2.01E-10
ESBO-26	(SBO)(failure of AAC)(failure to delivery of feedwater using turbine driven pumps)	6.93E-07
Total		**7.74E-07**

Conclusion

- **In comparative study of FLEX strategies**
  - SBO model with small mobile GTG and SBO model with large mobile GTG have been modelled and compared
  - The result of station blackout core damage frequency has been compared.
  - Based on the comparative study results, the Core damage frequency (CDF) of SBO with small mobile GTG is reduced.
  - The opportunity to improve response times, simplify required manual actions, and utilize robust equipment in robust locations can be justified by employee this small mobile GTG to as a mitigating strategy of extended SBO
  - sensitivity analysis can be performed that would be provided a deeper insight into the risk analysis, add to credibility of the results



Thank you for your kind attention