KINGS KEPCO INTERNATIONAL NUCLEAR GRADUATE SCHOOL

Applying Mobile Equipment Usage to PRA Models (HRA)

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Introduction

- Many nuclear power plants are introducing mobile equipment utilization strategies to cope with severe accidents
- Nuclear power plants also conduct Probabilistic Risk Assessments (PRA) to analyze events that could cause core damage
- Several challenges have been found to apply the newly introduced mobile equipment to PRA
- This poster reviews the proposed solutions and provide additional considerations

Mobile Equipment PRA Modeling and Challenges(1/2)

- PRA Technical Elements for Internal Event (ASME/ANS RA-Sa-2009)
  - Initiating Event Analysis (IE)
  - Accident Sequence Analysis (AS)
  - Success Criteria (SC)
  - Systems Analysis (SY)
  - **Human Reliability Analysis (HR)**
  - **Data Analysis (DA)**
  - Quantification (QU)
  - LERF Analysis (LE)

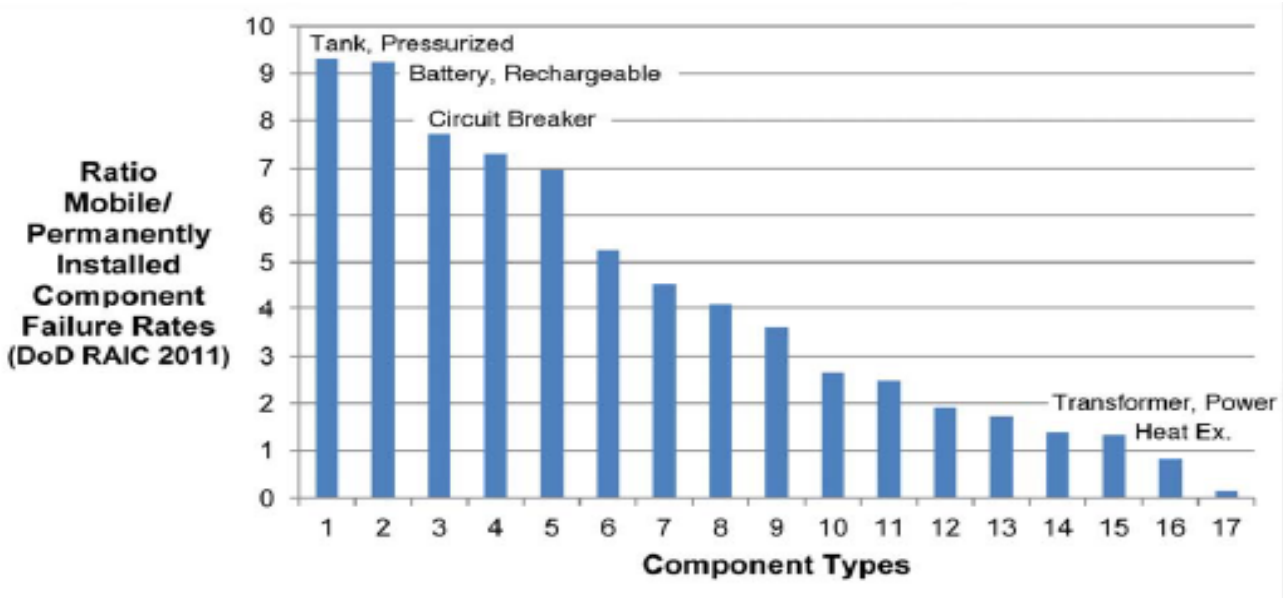
Mobile Equipment PRA Modeling and Challenges(2/2)

- In most cases, the method of modeling mobile equipment in the PRA is similar to the modeling of existing installed equipment
  - Accident Sequence Analysis (AS), Success Criteria (SC), Systems Analysis (SY), Quantification (QU), LERF Analysis (LE)
- Several challenges have been identified
  - Data Analysis (DA)
    - Sufficient industrial data have not been collected to estimate the failure rate for NPP mobile equipment
  - Human Reliability Analysis (HR)
    - Typical HRA methodology of PRA is not designed to address many of the human behaviors needed for mobile equipment

*** Reference : EPRI 3002003151 Incorporating Flexible Mitigation Strategies into PRA Model**

Proposed Solution for Challenges (1/4)

- Data Analysis (DA)
  - The failure rate of mobile equipment in NPP can be estimated by comparing the failure rate of permanently installed NPP equipment with the failure rate of the potable/permanent military equipment
    - Portable military component failure rates are generally higher than permanent component failure rates, but it is less than 10 times



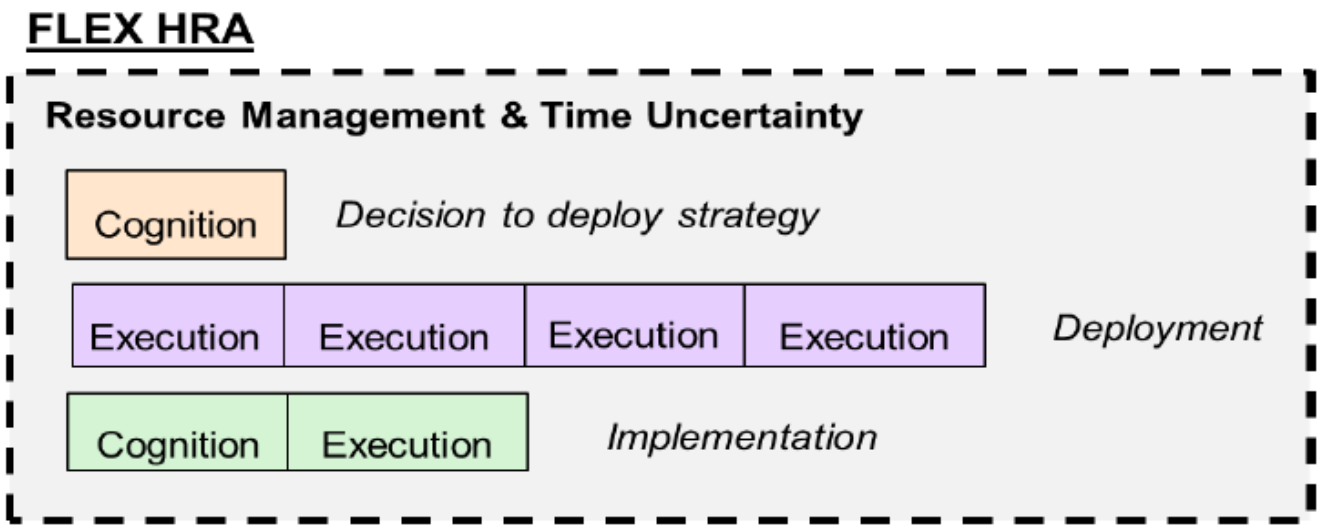
Proposed Solution for Challenges (2/4)

- Data Analysis (DA) (Cont.)
  - Based on engineering judgment, the failure rate can be assumed by considering the weight of the failure rate of the permanent installation equipment of similar functions
    - Failure rate of Permanent equipment : NUREG/CR-6928
    - Deployment Factor : 1 ~ 10
    - Location Factor : 1 ~ 4
    - Water Quality Factor : 1 ~ 10
    - Test/Maintenance Factor : 1 ~ 2

*** Reference : PWROG-14003-P Implementation of FLEX Equipment in Plant-Specific PRA Models**

Proposed Solution for Challenges (3/4)

- Human Reliability Analysis (HR)
  - Cognition
    - The cognition for deployment of mobile pumps and generators is determined by the cognition that declares ELAP
    - After declaring ELAP, no significant additional decisions are required for operators to deploy portable equipment



Proposed Solution for Challenges (4/4)

- Human Reliability Analysis (HR) (Cont.)
  - Execution (THERP method)
    - The operating action is not covered by THERP
      - Use of Supplemental Data
      - Select THERP surrogate value using engineering judgment
        - Choosing the Connecting point → Local valve selection error (T 20-13)
        - Connecting Temporary Hoses → Connector mating error (T 20-12 (13))
        - Operability check of portable pump → Checker fails to detect errors (T 20-22)
    - Too many steps
      - Define the critical tasks at a level and Action Decomposition
      - Recovery modeling

*** Reference : EPRI-3002013018 HRA for Diverse and FLEX and Use of Portable Equipment**

Compare with existing PRA results (1/5)

- Comparison of proposed HRA solutions for mobile equipment with existing HRA
- Comparison
  - Existing Internal Event Activity : Open ADVs Using Hand Wheel
    - Description : After reactor trip, operator should control and maintain SG pressure within post-trip SG pressure control band. it is assumed that TBVs and the remote control of ADVs are not available conservatively. Thus operator controls SG pressure with ADVs in local.
    - Reason for Selection : This action is similar to the deployment and implement of mobile equipment (Not controllable in MCR and requires field operation)
  - Mobile Equipment Strategy Activity : Portable Pump Deploy and Implement
    - Description : transporting the FLEX pump to the staging area, connecting hoses between the source tank and the FLEX pump suction point, and connecting hoses between the FLEX pump discharge point and RHR "A" piping interface point.
    - Reference : EPRI-3002013018, Appendix C and E

Compare with existing PRA results (2/5)

- Existing Internal Event Activity : Fails to Open ADVs Using Hand Wheel

Unit	Method	Cognition	Action type	Stress	Place	Procedure	Recovery
Shin-Kori 3&4	THERP	Time : 20m	**Dynamic**	MH	**Local**	good	Checker Fail Error (T 20-22)
Shin-Kori 1&2	K-HRA	Time : 29m Interest Action : yes **HMI : Mid** Procedure : high **Training : Mid** Burden : 1.0	Step by Step - Complexity : if-then - Procedure : high - Enough Time & Familiar : No	**EH** - Time : < 60m - Severity : Yes - **Step Risk : Local** - **Training : Low**			Time : <60m **HMI : Low** Supervisor : Yes
NPP ONE	CBDTM, THERP (HRA calculator)	Pcd + Pce + Pcg - Information misleading - Skip a step in procedure - Misinterpret decision logic	**High (x5)** - **PSF : Negative (Tools required)** - **Workload : High** * Crew Experience : Experienced		Non MCR		N/A

Compare with existing PRA results (3/5)

- Existing Internal Event Activity : Fails to Open ADVs Using Hand Wheel

Unit	Method	Remark
Shin-Kori 3&4	THERP	Good Procedure and not trained / Harsh Environment → Dynamic and stress
Shin-Kori 1&2	K-HRA	HMI (cognition) : No alarm, Performed by procedure → Mid Training (cognition) : 0.5/year simulator training → Mid Training (execution) : Lack of hands-on practice → Low HMI (execution) : Unable to verify action results in the local → Low
NPP ONE	CBDTM, THERP (HRA calculator)	Cognition : The EOG provides contingency actions which are instructions on how to proceed if the cue states are not as stated → Pcd (b) Stress : This operator action is performed in local. It is expected that this operator action is simple and has not enough time to complete and work environment is not good → High (x5)

Compare with existing PRA results (4/5)

- Mobile Equipment : Portable Pump Deploy and Implement

(EPRI-3002013018 example)

Action	Method	Cognition	Action type	Stress	Place	Recovery	Total HEP
Deploy Portable Pump	CBDTM, THERP (HRA calculator)	Pcb + Pce + Pcg - Failure of Attention - Skip a step in procedure - Misinterpret decision logic (Cognition error is modeled in the ELAP Declaration : 2.7E-03)	**Moderate (x2)** - **PSF : Negative (portable lighting)** - **Workload : low** * Crew Experience : Experienced		Non MCR	Checker Fail Error (T 20-22)	3.2E-02
Implement Portable Pump			**Moderate (x2)** - **PSF : Negative (portable lighting)** - **Workload : low** * Crew Experience : Experienced		Non MCR	Check reading display Error (T 20-11)	1.5E-04

Compare with existing PRA results (5/5)

- Comparison Results
  - Operator fails to ADV open using hand-wheel (KHNP PSA result) : PSF and stress factor are high due to the insufficient field practice and local activity
  - Operator fails to deploy/implement portable pump (EPRI example) : STRESS factor is relatively low on the assumption that there was **sufficient time** available and the number of people required to install mobile pumps was also **trained** once every two years

	ADV open using HW error			EPRI example : Pump Deploy/Implement
	Shin Kori 3&4	Shin Kori 1&2	NPP ONE	
STRESS factor (Multiplication)	X 10	X 10	X 5	**X 2**

Apply to Mobile Equipment HRA (1/4)

- Activity : Mobile Generator Deployment and Implement
- HRA method : CBDTM + THERP
- Procedure progress scenario
  - EOP-09 : EALP Declaration
  - MOG-05 : Site-Status Assessment and Mobile Equipment Deployment
  - OP-3593-01 : Operation of the Mobile Generator
- Assumption
  - Scenario and Time Window : Tsw = 8hr, Td = 10m, Tcog = 20m, Texe = 2hr
  - Manpower Requirement
    - In the early stages of ELAP, the deployment of mobile equipment is carried out simultaneously and the manpower is limited
    - Field operator : 2 (valve manipulation, Mobile Equipment control)
    - Contractor Worker : 15 (electric cable/fuel hose deployment, driving a trailer)

Apply to Mobile Equipment HRA (2/4)

- Assumption (Cont.)
  - All debris on the path has been removed, the HEP for moving is not considered
  - Non-essential load shedding HEP assessment is not considered
- Multiplier Factor

	Plant Response as Expected	Workload	PSF	Crew Experience	STRESS factor
Deployment	Yes	High (Simultaneous installation of many mobile equipment)	Negative (potable Lighting)	Novice (Contract worker)	X 10
Implement				Experience (Shift field Operator)	X 5

Apply to Mobile Equipment HRA (3/4)

Execution Unrecovered

Procedure		Comment				Stress Factor	Override
Step No.	Instruction / Comment	Error Type	THERP Table	THERP Item	HEP		
1.5	connect power cable	EOM	20-7b	1	4.3E-4	High (x10)	
		EOC	20-13	1	1.30E-03		
		EOC	20-12	13	1.30E-02		
	Comment	Performed by Contractor Worker					
	Location:	Out of MCR			Total Step HEP		1.47E-01
1.9	fuel hose connection	EOM	20-7b	1	4.3E-4	High (x10)	
		EOC	20-13	1	1.30E-03		
		EOC	20-12	13	1.30E-02		
	Comment	Performed by Contractor Worker					
	Location:	Out of MCR			Total Step HEP		1.47E-01
1.11	fuel isolation valve open	EOM	20-7b	1	4.3E-4	Moderate* (x4)	
		EOC	20-13	2	3.80E-03		
	Comment	Performed by Field Operator					
	Location:	Out of MCR			Total Step HEP		1.69E-02
1.18	Start generator	EOM	20-7b	1	4.3E-4	Moderate (x4)	0
	Comment	If the step is overlooked, it can be performed later					
	Location:	Out of MCR			Total Step HEP		0.00E+00
1.19	fuel pump test start and check the hose connection	EOM	20-7b	1	4.3E-4	Moderate (x4)	
		EOC	20-22	3	8.10E-02		
	Comment	Performed by Field Operator					
	Location:	Out of MCR			Total Step HEP		3.26E-01
1.22	Mobile generator status check	EOM	20-7b	1	4.3E-4	Moderate (x4)	
		EOC	20-11	1	1.30E-03		
	Comment	Performed by Field Operator					
	Location:	Out of MCR			Total Step HEP		6.92E-03
2.6	close(connect) circuit breaker	EOM	20-7b	2	1.3E-3	Moderate (x4)	
		EOC	20-12	12	3.80E-03		
	Comment	Performed by Field Operator Appendix Lists are Used					
	Location:	Out of MCR			Total Step HEP		2.04E-02

Execution Recovered

Critical Step No.	Recovery Step No.	Action	HEP (Crit)	HEP (Rec)	Dep.	Cond. HEP (Rec)	Total for Step
1.5		connect power cable	1.47E-01				1.02E-03
	1.22	Mobile generator status check		6.92E-03	ZD	6.92E-03	
1.9		fuel hose connection	1.47E-01				4.80E-02
	1.19	fuel pump test start and check the hose connection		3.26E-01	ZD	3.26E-01	
1.11		fuel isolation valve open	1.69E-02				5.51E-03
	1.19	fuel pump test start and check the hose connection		3.26E-01	ZD	3.26E-01	
1.18		Start generator	0.00E+00				0.00E+00
	1.22	Mobile generator status check		6.92E-03	ZD	6.92E-03	
2.6		close(connect) circuit breaker	2.04E-02				2.04E-02
		Total Unrecovered:	3.32E-01			Total Recovered:	7.49E-02

* Stress factor adjusted Individually because the HRA Calculator program does not allow changes to the “Experience Level” of subtask

Cognitive Recovery

	Initial HEP	Extra Crew	STA Review	ERF Review	Dependency Level	Multiply HEP by	Final Value
Pcd	3.00E-03	-	X	-	LD	5.29E-02	1.59E-04
Pce	3.00E-03	X	-	-		5.00E-01	1.50E-03
Pcg	5.94E-03	-	X	-	LD	5.56E-02	3.31E-04
Final Pc (with recovery credited)							1.99E-03

Apply to Mobile Equipment HRA (4/4)

- Considering the STRESS levels applied in ADV local control and the participation of contractor workers (novice crew), the total recovered HEP for mobile generator is 7.49E-02, approximately twice as high as the example in EPRI document
- These results are more consistent with existing domestic HRA processes and assumptions than examples from EPRI

	Calculation value : Mobile generator	EPRI example : Portable Pump
Total HEP (recovered)	7.68E-02 Cognition : 1.99E-03, Execution : 7.49E-2	3.49E-02 Declare ELAP : 2.7E-03, Pump Deployment : 3.2E-02, Pump Implement : 1.5E-04

Conclusion

- The nuclear industry is continuing its efforts to incorporate mobile equipment utilization strategies into the PRA model
- The HRA for mobile equipment requires reasonable engineering judgment and a common consensus among expert groups
- These applications should not deviate from the fundamental methodology of PRA
  - Ex) HR-G6: Check the consistency of post-initiator HEP quantification
- To give credit to mobile equipment operation in the PRA, the conditions applied for HRA in existing PRA should be consistent applied

Thank You