Fault Tree Modeling Using CBHRA and SAF Method

Korea Atomic Energy Research Institute
Hyun Gook Kang

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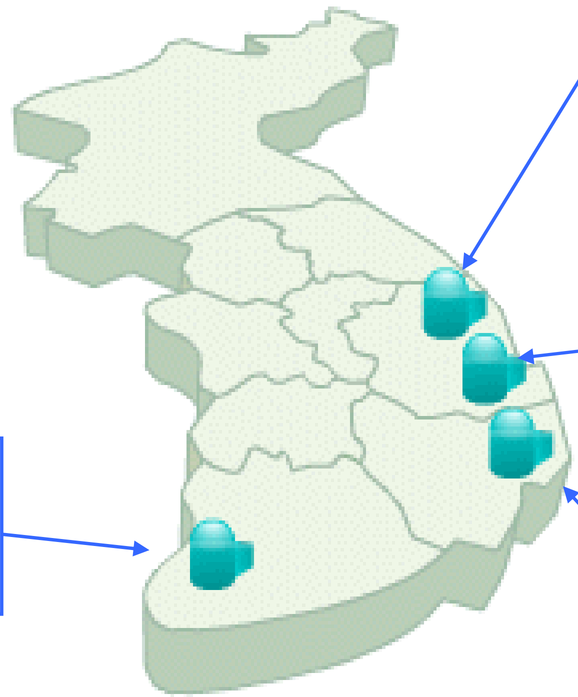

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1. Introduction

- Digitalization of safety-critical functions in NPP
  - DPPS and DESFAS of Korean Nuclear Power Plants
  - Full digitalization in APR-1400

  → Increased importance of the digital I&C PSA
- Safety assessment (PSA) of NPP is essential
- Risk concentration on the digital system
  - Functional diversities might be useless since many functions share the same components and software
  - Redundancy in a digital system might be useless in the case of the CCF of the components
  - Digitalized system provides alarms and indications to the operator (the failure of another redundancy)

1. Introduction

The Status of I&C Systems in Korean NPPs

Systems / Plants	Reactor Trip System	ESFAS Systems	Protection Process	NSSS Control	PCS	Turbine Control	Main Control Board
Kori No. 1	Relay Logic (W/H)	Relay Logic (W/H)	Foxboro H-line	Foxboro H-line	Foxboro H-line	DCS	Conventional
Kori No. 1 (Upgraded in 1998)	Relay Logic (W/H)	Relay Logic (W/H)	Spec200 Spec200m (Foxboro)	Spec200 Spec200m (Foxboro)	Spec200 Spec200m (Foxboro)	DCS	Conventional
Kori No. 2,3,4 YG No. 1,2	SSPS Relay Logic (W/H)	SSPS Relay Logic (W/H)	7300 Analog	7300 Analog	7300 Analog	Mark V (GE)	Conventional
YGN No. 3,4	Relay Logic (ABB-CE)	Relay Logic (ABB-Œ)	Analog (ABB-CE)	Spec200 Spec200m (Foxboro)	ILS (Forney)	Mark V (GE)	Conventional
Ulchin No. 3,4 YG No. 5,6	Relay Logic (ABB-CE)	Relay Logic (ABB-CE)	Analog (ABB-CE)	Spec200 Spec200m (Foxboro)	PCS (Eaton)	Mark V (GE)	Hybrid
Wolsong No. 1,2,3,4	Relay Logic (AECL)	Relay Logic (AECL)	Analog/PDC (AECL)	DCC X/Y Computers Control	Analog/Relay (AECL)	Mark V (GE)	Hybrid
Ulchin No. 5,6	PLC (W/H)	PLC (W/H)	Analog (W/H)	Spec200 (PLC)	PCS (HFC)	Mark V (GE)	Hybrid
Shin Kori No. 1,2	PLC (W/H)	PLC (W/H)	Analog (W/H)	Spec200 (PLC) Ovation(W/H)	Teleperm XP (Siemens)	Mark VI (GE)	Hybrid
Shin Wolsong No.1,2 Shin Kori No. 3,4 (APR-1400)	PLC	PLC	Analog/PLC		PLC		Compact Workstation
HANARO Reactor	Relay Logic (AECL)	Not Applicable	Analog (AECL)	Control Computer	Not Applicable	Not Applicable	Hybrid

Reference: KINS

1. Introduction

- Since 1999, KAERI has performed an initiative research for the safety assessment of digitalized system in order to meet practical needs raised in Korea

- Careful treatment of CCF and HRA is required
  - Simplified alpha factor (SAF) method
  - Condition-based HRA (CBHRA) method

- Concurrent application of CBHRA of SAF methods
  - SAF technique may cause the loss of some information required for CBHRA

- Case study will be presented

2. Simplified Alpha Factor Method

- Alpha factor (Non-staggered test)

$$\alpha_k^{(m)} = \frac{n_k}{\sum_{i=1}^{m} n_i} = \frac{{}_m C_k * Q_k}{\sum_{i=1}^{m} ({}_m C_i * Q_i)}$$

  - Number of CCF events in the fault tree model for m-redundant component: $2^m - m - 1$
  - Multiple redundancy results in an impractically large number of CCF events in the fault tree model
- Simplified alpha factor method
  - Single CCF event represents the unavailability of system due to the CCFs of the specific redundant components
  - Assumption: the probabilities of CCF events are low enough

$$Q_{CCF} = \sum_{k=2}^{m} ({}_m C_k \times p_k Q_k^m) \qquad Q_k^m = \frac{k}{{}_{m-1} C_{k-1}} \cdot \frac{\alpha_k^m}{\sum_{i=1}^{m} i \cdot \alpha_i^m} \cdot Q_t$$

H.G. Kang, et al., The Common Cause Failure Probability Analysis on the Hardware of the Digital Protection System in Korean Standard Nuclear Power Plant, KAERI/TR-2908/2005

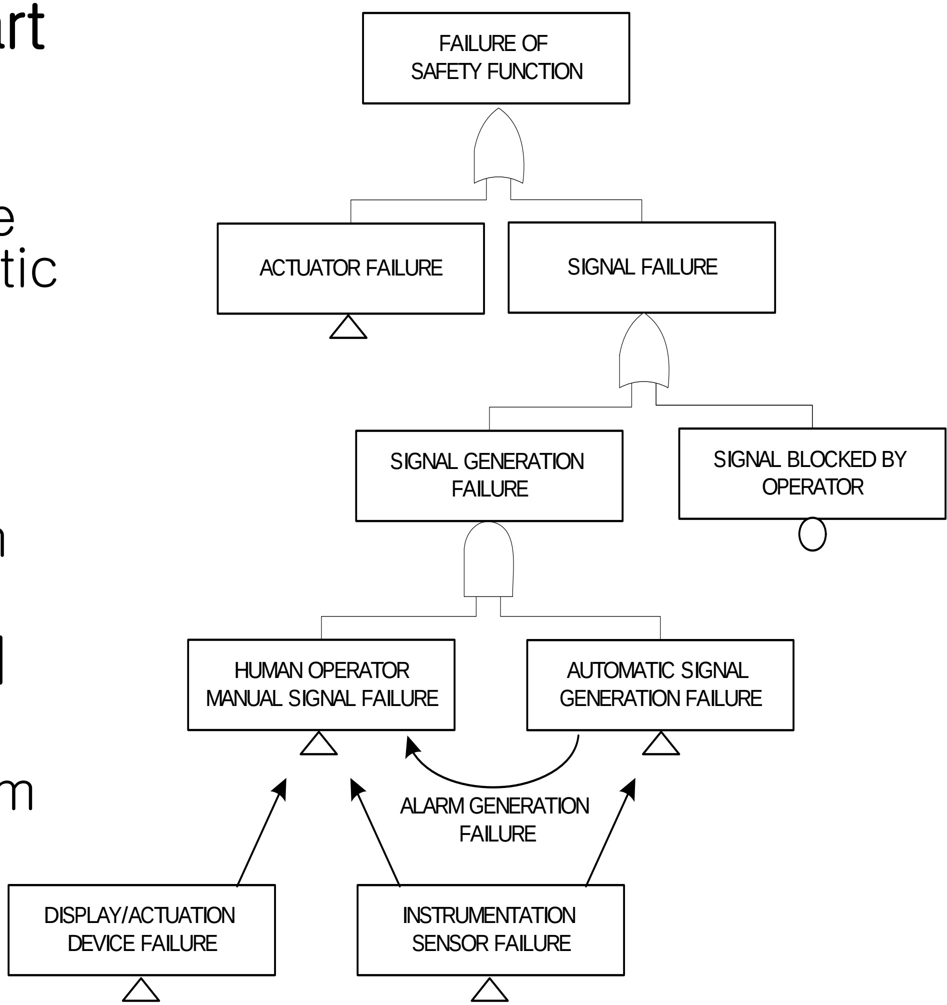
2. Simplified Alpha Factor Method

- Merits of SAF method
  - Complexity reduction of plant or system fault tree model
  - Quantification result is similar to that of detailed model
- Pre-processing for SAF method
  - Detailed success criteria and system design analysis

  → Determination of CCF boundary which causes the unavailability of the system
- Practical than the other methods
  - Simple fault tree than other full CCF event methods
  - Realistic results than other single CCF event methods
- The SAF method may cause the loss of some information required for the post processing of cutsets

3. Condition-based HRA

- Human operators are a part of the signal generation mechanism
  - Manual action plays the role of a backup for the automatic signal generation
  - The HEP of manual signal generation is a conditional probability given that the automatic signal generation fails
- Given condition of manual actuation
  - Failure of processing system
  - Unavailability of process parameters (sensors)



3. Condition-based HRA

- Conventional single event model for human error is not proper for this complicated case
- Condition-based human reliability assessment (CBHRA) method was proposed to address this problem in a practical way
  - CBHRA: A kind of post-processing of minimal cutsets (MCS) for treating the dependencies among the signal generation elements
  - Based on the events in the corresponding MCS, proper HEP which is predetermined is assigned

H.G. Kang and S.C. Jang, "Application of Condition-Based HRA Method for a Manual Actuation of the Safety Features in a Nuclear Power Plant", Reliability Engineering and Systems Safety, In press, 2005.

3. Condition-based HRA

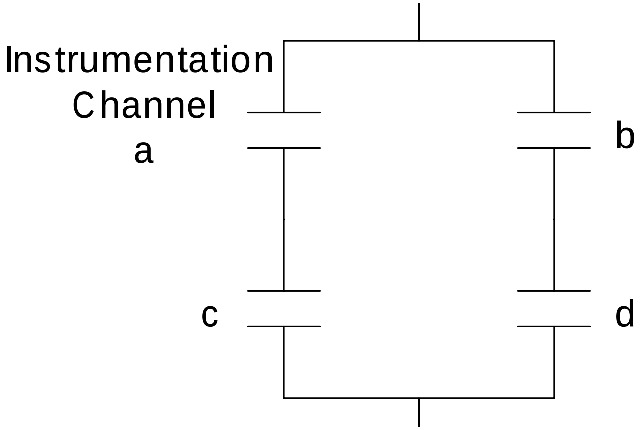
<CBHRA Steps>

(1) Conducting an investigation into possible EFCs
(2) Selecting important EFCs
(3) Developing a set of conditions in consideration of selected EFCs
(4) Estimating the HEP for each condition
(5) Constructing a fault tree which includes one human error (HE) event for each manual action
(6) Obtaining MCS by solving the fault tree
(7) Post-processing of MCSs based on the information from the events in a corresponding cutset

4. Case Study

- Target: DPPS (4-channel processing system)
  - System success criteria: selective 2/4
- Application of SAF method

Conceptual drawing



CCF Coefficient Calculation

No. of CCF channels (k)	${}_mC_k$	No. of system failure CCF (F_k)	p_k ($=F_k/{}_{16}C_k$)	Q_k / Q_t
1	4	0	0.000	-
2	6	2	0.333	0.0129
3	4	4	1.000	0.0092
4	1	1	1.000	0.0678
CCF coefficient (Q_{CCF} / Q_t)				0.1305

- System function failure CCF: {a,c}, {b,d}, {a,b,c}, {a,b,d}, {a,c,d}, {b,c,d}, {a,b,c,d}

4. Case Study

- Application of CBHRA method
  - Consideration of two Error Forcing Contexts (EFC)
    - Unavailability of alarms
    - Unavailability of indication of safety instrumentation channels

  → EFC = unavailability of information

  - Criteria of availability
    - Alarm: 2 or more alarms / 4 alarms
    - Indication: Case study variable
      - Case (A): 3 or more indications / 4 indications
      - Case (B): 2 or more indications / 4 indications
      - Case (C): 1 or more indications / 4 indications

4. Case Study

- Human errors under two different conditions
  - Condition 2: alarm unavailable, but indication available
  - Condition 3: alarm and indication unavailable

Status of instrumentation \ Status of the automated System	Normal	Abnormal
3 or more channels available	Auto. signal: O Indication: O Alarm: O *<Condition 1: EOC>*	Auto. signal: X Indication: O Alarm: X *<Condition 2>*
2 channels available	Auto. signal: O Indication: O/X Alarm: O *< Condition 1*: EOC>*	Auto. signal: X Indication: O/X Alarm: X *<Condition 2/3>*
1 channel available	Auto. signal: X Indication: O/X Alarm: X *<Condition 2/3>*	Auto. signal: X Indication: O/X Alarm: X *<Condition 2/3>*
No channel available	Auto. signal: X Indication: X Alarm: X *<Condition 3>*	Auto. signal: X Indication: X Alarm: X *<Condition 3>*

4. Case Study

- Case (A): 3 or more indications
  - The CCF does not affect on the categorization
  - CCF → <Condition 3>
- Case (B): 2 or more indications
  - The CCFs of {a,c} and {b,d} are included in the single CCF event
  - For the MCS which contains CCF event, two HE events :
    - {a,c} and {b,d} portion → <Condition 2>
    - The other portion → <Condition 3>

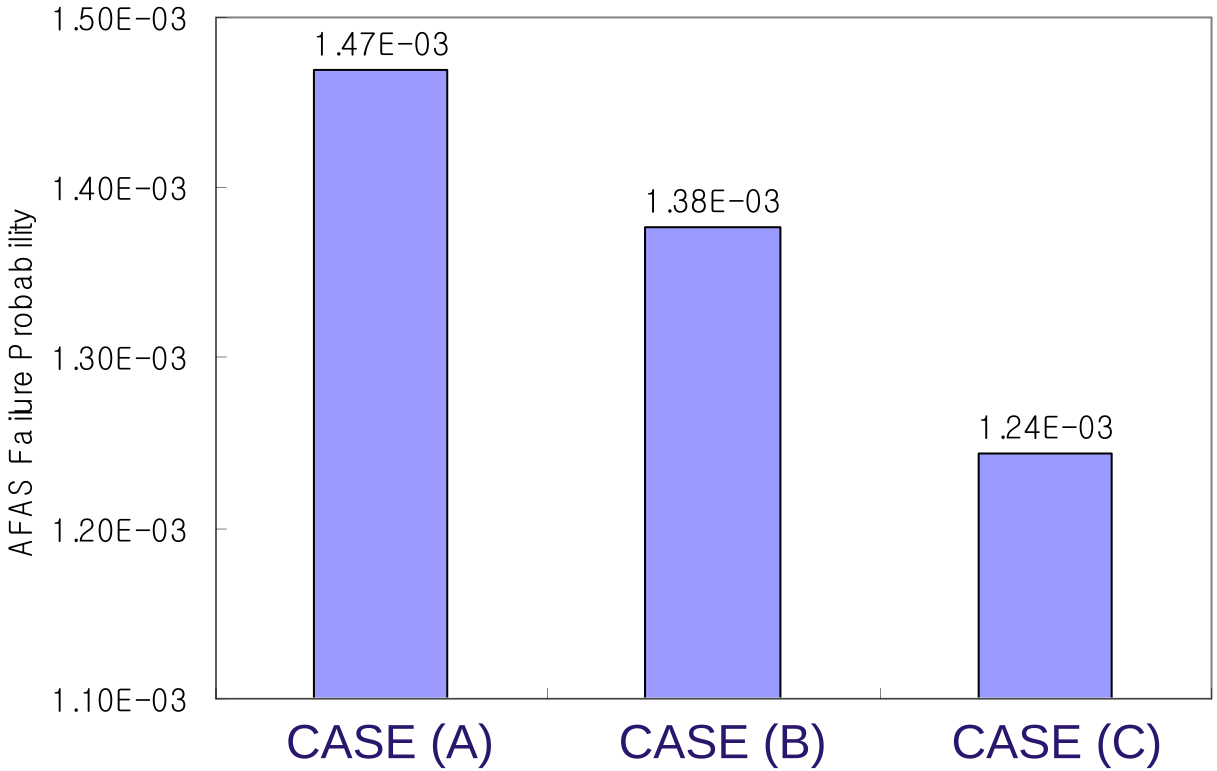
$$Q_{CCF-Condition2} = \sum_{k=2}^{2} ({}_4C_k \times p_k Q_k^4) \qquad Q_{CCF-Condition3} = \sum_{k=3}^{4} ({}_4C_k \times p_k Q_k^4)$$

- Case (C): 1 or more indications
  - {a,c}, {b,d}, {a,b,c}, {a,b,d}, {a,c,d} and {b,c,d}

$$Q_{CCF-Condition2} = \sum_{k=2}^{3} ({}_4C_k \times p_k Q_k^4) \qquad Q_{CCF-Condition3} = \sum_{k=4}^{4} ({}_4C_k \times p_k Q_k^4)$$

4. Case Study

- Results



5. Conclusion

- The single-event CCF modeling technique may cause the loss of system status information which is important in cutset analysis phase
- By using the same number of CCF events as that of human error conditions, the SAF method and the CBHRA method could be concurrently used without loss of accuracy
- The case study of the concurrent application of the SAF and the CBHRA method clearly demonstrates the usefulness of both method and the effect of EFC criteria determination