Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-19, 2017

Beyond-design-basis Accident Analysis using Bayesian Network: Application to Research Reactor

Shinyoung Kwag [a*], Jinho Oh [a], Jong-Min Lee [a]
[a] *Research Reactor Mechanical Structure Design, Korea Atomic Energy Research Institute, Daejeon, ROK*
[*] *Corresponding author: kwagsy@kaeri.re.kr*

1. Introduction

The research reactor can be subjected to an internal accident during the design lifetime. Especially, a loss of primary coolant system (LOPCS) flow is one of significant threats to the safety of pool-type research reactor [1]. This failure is possibly extended to the direct core damage (CD) of the reactor. Under this background, the objective of this paper is to perform the beyond-design basis accident analysis based on a Bayesian network (BN) instead of utilizing the standard fault tree (FT) analysis. Such a BN analysis can facilitate any evidence/assumption within its formalism unlike FT analysis [2,3]. For this purpose, the BN for LOPCS leading to the CD is developed based on an event tree (ET) and fault trees (FTs) related to the LOPCS. Then, the BN analysis is conducted under an assumption that the CD accident occurs. The analysis results reveal the updated risks of all events, and the most vulnerable scenarios and basic events. Finally, the BN is expected to be utilized for identifying the real-time risk status and to aid in making risk-informed decisions.

2. Internal Initiating Events for Research Reactor

In the safety perspective, the safety functions and corresponding systems to prevent core damage in research reactors can be described as: (1) controlling reactivity: RT(Reactor Trip System) (Here, RT consists of RPS(Reactor Protection System)/APS(Alternative Protection System) & CRDM(Control Rod Drive Mechanism)/SSDM(Second Shutdown Drive Mechanism)), (2) maintaining the coolant inventory: SBVs(Siphon Break Valves) & EWSS(Emergency Water Supply System), and (3) removing the core decay heat: PCS(Primary Cooling System) & FVs(Flap Valves)/SBVs & EWSS. Based on the responses of the corresponding safety functions and systems, the initiating events can be selected as follows: (a) LOEP (Loss of Electric Power), (b) RIA (Reactivity Insertion Accident), (c) LOPCS (Loss of Primary Cooling System), (d) LOSCS (Loss of Secondary Cooling System), (e) LOCA (Loss of Coolant Accident), and (f) GT (General Transient). The Level 1 PSA is generally conducted to evaluate CD-level risk based on all these postulated initiating events. However, this study is solely focused on a LOPCS initiating event since this event is governing overall safety of research reactor in this particular example.

3. ET-FT Linking Approach

An ET for the LOPCS constitutes the probable scenarios caused from the postulated initiating event of loss of PCS flow. The event tree model for the LOPCS is represented in Fig. 1. The detailed FTs are described in Fig. 2. The descriptions of all events are summarized in Table 1. The CD consequence of ET and related FTs can be transformed into a single integrated FT in the ET & FT linking approach. The Fig. 3 illustrates the integrated FT for LOPCS inducing CD. The analysis results using FT analysis are summarized in Table 1.

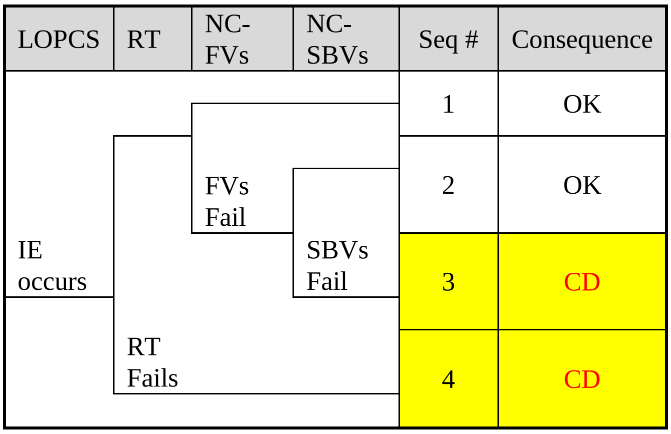
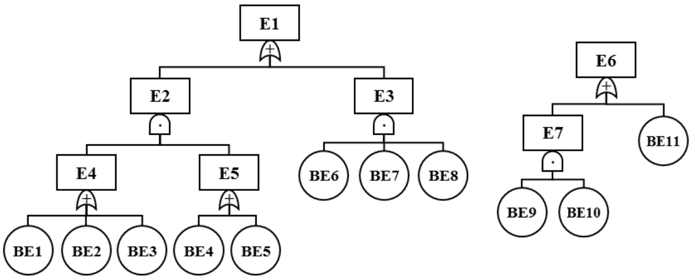
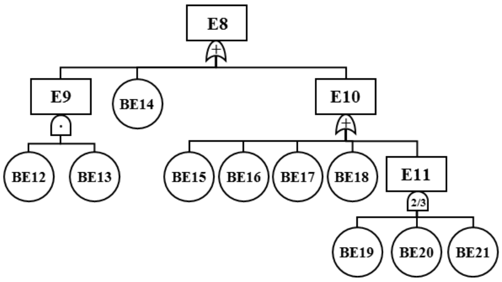


Fig. 1. Event tree model for LOPCS



(a) RT

(b) NC-FVs



(c) NC-SBVs

Fig. 2. FTs for RT, NC-FVs and NC-SBVs

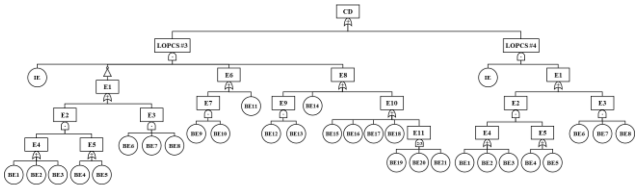


Fig. 3. Integrated FT for LOPCS inducing CD

Table 1: Descriptions of basic events of LOPCS

Events		Annual probabilities	
		FT	**BN**
IE	Loss of PCS flow	4.26e-1	4.26e-1 (9.70e-1)
BE1	Failure of RT due to mechanical failure of CAR #1	2.13e-8	2.13e-8 (2.95e-7)
BE2	Failure of RT due to mechanical failure of CAR #2	1.01e-8	1.01e-8 (1.40e-7)
BE3	Failure of RT due to mechanical failure of CAR #3	5.58e-8	5.58e-8 (7.74e-7)
BE4	Failure of RT due to mechanical failure of SSR #1	2.86e-6	2.86e-6 (3.93e-6)
BE5	Failure of RT due to mechanical failure of SSR #2	1.41e-7	1.41e-7 (1.94e-7)
BE6	Electrical Failure of RPS	2.82e-4	2.82e-4 (9.47e-1)
BE7	Electrical Failure of APS	7.83e-3	7.83e-3 (9.48e-1)
BE8	Failure of RPS/APS recovery by operator	1.00e-1	1.00e-1 (9.53e-1)
BE9	Flap valve V003 fails to open	5.00e-4	1.50e-3
BE10	Flap valve V004 fails to open	5.00e-4	1.50e-3
BE11	Flap valves V003 & V004 fail to open due to CCF	1.29e-5	5.15e-2
BE12	Siphon Break Valve AV-101 fails to open	4.00e-3	4.90e-3
BE13	Siphon Break Valve AV-102 fails to open	4.00e-3	4.90e-3
BE14	SBVs AV-101 & AV-102 fail to open due to CCF	9.24e-5	5.30e-3
BE15	CCF of FT-001A/FT-001B Flow Transmitter	1.11e-4	6.38e-3
BE16	CCF of FT-001A/FT-001C Flow Transmitter	1.11e-4	6.38e-3
BE17	CCF of FT-001B/FT-001C Flow Transmitter	1.11e-4	6.38e-3
BE18	CCF of FT-001A/FT-001B/FT-001C Flow Transmitter	2.37e-4	1.36e-2
BE19	Failure of FT-001A Flow Transmitter	9.20e-3	1.86e-2
BE20	Failure of FT-001B Flow Transmitter	9.20e-3	1.86e-2
BE21	Failure of FT-001C Flow Transmitter	9.20e-3	1.86e-2
CD	Core damage event	9.93e-8	1.00

*BEs: basic events, (-): values for LOPCS#4

4. Accident Analysis using BN

Let us perform the beyond-design-basis accident analysis using the BN. For this purpose, as a first step, the FT in Fig. 3 is mapped into a BN. The Fig. 4 shows the mapped BN from the FT. Then, the accident condition is implemented by starting with the assumption that a CD accident occurs which can be represented by the occurrence probability for event CD to be equal to unity within the BN structure. Based on this postulated accident, updating is performed to calculate the posterior probabilities. The BN analysis is conducted using GeNIe 2.1 software [5]. The updated results are represented in Table 1. The critical path is described in Fig. 4. These updated results cannot be obtained within the conventional FT analysis framework. Using a BN analysis aids in selecting the weakest links under the occurrence of the CD accident and in adopting an efficient risk improvement strategy by allocating additional preventive provisions to the most vulnerable events. Furthermore, new data reflecting the behavior of actual physical system can be utilized for accurate assessment of probabilistic safety in the system, and effective plan for mitigating the risk.

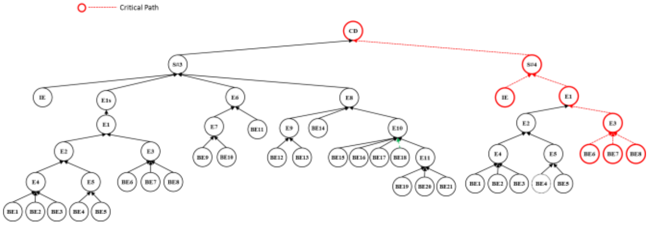


Fig. 4. BN for LOPCS inducing CD and critical scenarios evaluated from BN analyses

5. Summary and Conclusion

This study focuses on the beyond-design-basis accident analysis of LOPCS of research reactor. The concept of a BN is applied for probabilistic safety assessment method instead of utilizing the standard FT analysis for a systems analysis. Unlike the standard FT analysis, the BN enables an analyst to explore scenarios subjected to beyond-design-basis accident. This is because the Bayesian inference facilitates the updating of prior probability information about all events based on the evidence. The numerical result shows that the BN finally assists in the identification of important events that lie on an updated critical path.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support provided by the Ministry of Science, ICT and Future Planning of Korea.

REFERENCES

[1] KAERI, Final Probabilistic Safety Report for JRTR, Rev. 0, 2015.
[2] S. Kwag and A. Gupta, Bayesian Network Technique in Probabilistic Risk Assessment for Multiple Hazards, Proceedings of 24th International Conference on Nuclear Engineering (ICONE 24), June 26-30, 2016, Charlotte, NC, US.
[3] S. Kwag and A. Gupta, Probabilistic Risk Assessment Framework for Structural Systems under Multiple Hazards using Bayesian Statistics. Nuclear Engineering and Design, Vol. 315, p. 20-34, 2017.
[4] GeNIe 2.1 version, http://www.bayesfusion.com.