Impact of Pre-Initiators on PSA in Research Reactor

Chimedtseren OCHIRBAT[a] and Sok Chul KIM[b]
Department of Nuclear and Quantum Engineering , Korea Advanced institute of Science and Technology (KAIST)
[a]291 Daehak-ro (373-1 Guseong-dong), Yuseong –gu, Daejeon 305-701
[b]Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon 305-338, jupiter@kins.re.kr
**Corresponding author: chimedtseren.o@gmail.com*

1. Introduction

After TMI and Chernobyl Accident, Probabilistic Safety Assessment (PSA) or Probabilistic Risk Analysis (PRA) has been emerged crucial tool for safety evaluation process for nuclear installations. Most of nuclear power plants had already conducted PSA work to examine their plant safety for identifying vulnerability and preparing the mitigating strategies for severe accident.

However, the PSA for research reactor has been conducted limitedly comparing with nuclear power plants due to lack of awareness and resources.

Most of PSA results demonstrated that human failure events (HFEs) take a major role of risk contributor in terms of core damage frequency. HFEs are categorized as the following three types: pre-initiating event interaction (e.g., maintenance ~~of~~ errors, testing errors, calibration errors), initiating event related interactions (e.g., human error causing loss of power, human error causing system trip), and post-initiating event (e.g., all action actuating manual safety system backup of an automatic system)[1]. In general, pre-initiating events has been modeled as a part of system or components failures.

Especially, most of research reactor demands human interaction frequently during the reactor operation and utilization process. Lack of resources and utilization of research reactor calls a vicious circle in terms of safety degradation. The safety degradation poses the vulnerability of human failure during research reactor utilization process.

Typically, evaluation of pre-initiators related to test and maintenance are not taking into account in PSA for research reactors. This paper aims to investigate the impact of pre-initiating events related to test and maintenance activities on PSA results in terms of core damage frequency for a research reactor.

For the case study, we developed event tree and fault tree for 5MW pool-type TRIGA research reactor as a target facility.

2. Methodologies and Results

PSA model for this study was built with AIMS PSA software developed by KAERI. For the evaluation of human reliability related to pre-initiating events, the Technique for Human Error Rate Prediction (THERP) was introduced.

THERP is a systematic approach to evaluate HEP (Human Error Probability) with identifying, modeling, and quantifying the human errors to be evaluated.

THERP approach is comprised of following five steps:

1) Plant familiarization for gathering necessary data information related to target consequences
2) Defining the task to be analyzed
3) Discomposing action steps related to the task based on procedures
4) Building HRA model
5) Quantifying HRA model and incorporate into system PSA model

2.1 General description of TRIGA research reactor and PSA model.

A pool type TRIGA research reactor with 5MW thermal power was chosen as the target reactor for evaluating impact of pre-initiating events. The reactor core consist of 33 LEU fuel elements and 5 control rods with Ag, Cd, and reactor primary circuit include 2 pumps and 2 heat exchangers. The maximum thermal and fast neutron flux reach up to 1×10^{14} n/ m^2s and 4.5×10^{13} n/ m^2s, respectively. As emergency core cooling system, storage tank containing 250m^3 cooling water provides cooling water into primary circuit by gravity, which is located 30m height above reactor pool.

We considered following initiating events: LOCA, Loss of Offsite Power (LOOP), Loss of owing to Butterfly valve closure, Fuel Channel Blockage, Loss of Flow (LOFA) owing to both Primary Pumps failure, Loss of Flow owing to Butterfly valve closure, and Insertion of Excess Reactivity.

Fig.1.An example of event tree for LOOP

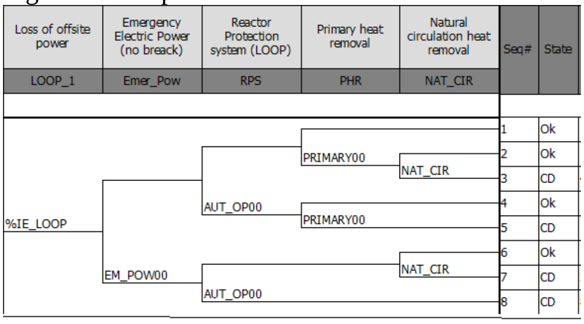
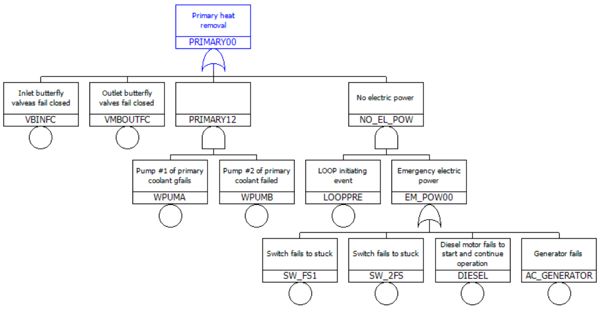


Figure 1 demonstrates the Event Tree model considered in this case study. The headings events include the following mitigating functions: Reactor Protection System (RPS), Primary Heat Removal (PHR), Natural Convection, and Emergency Core Cooling System (ECCs). For each head event Fault trees were developed. For example, developed PHR fault tree is shown in Fig.2.

Through the preparatory analysis, reactor protection system was identified as the most significant contributor to core damage frequency at TRIGA research reactor. Based on these results, the operator's activities related to test and maintenance for reactor protection system was selected as a target human failure regarding pre-initiating event. The research reactor RPS consists of two safety channels: safety circuit with scrams, interlocks, alarms and magnet power supply [3].

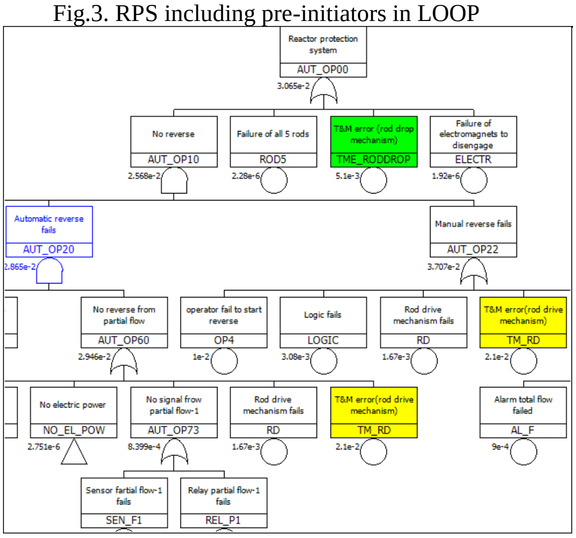
Fig.2. Example of fault tree for PHR system



2.2 Identification of significant pre-initiator of HFE in LOOP event of research reactor

In order to identify influential HFEs in terms of test and maintenance to system risk, a base calculation has been done with assigning 0.01 of HEP conservatively for all human actions as assuming occurrence of LOOP event of research reactor.

Fig.3. RPS including pre-initiators in LOOP



As a result of the base calculation, T&M for checking control rod drop and rod drive mechanism were identified as a major contributor to core damage frequency in LOOP event. The pre-initiators included in fault tree are shown in Fig.3. For more specific evaluation, HEP of the HFE was evaluated by THERP method in the next steps.

2.3 Developing HRA event tree for the significant HFE

To develop HRA event tree, firstly, errors have been identified, quantified and diagrammed in event tree using checklist of maintenance and testing procedure taken from ORNL-TM-506. Basic HEP as the nominal values was obtained from NUREG/CR1273. The HEP can be calculated with consideration of PSF (Performance Shaping Factors) which is characterized by expertise level, procedures, and working environment and so on.

The developed HRA event tree for checking control rod drive mechanism was built as shown in Fig.4, and BHEPs applied are provided in Table.1. Eq.(1) demonstrates how to get the Basic Human Error Probability (BHEP) for checking one control rod drive mechanism with THERP methodology:

$$BHEP=A+aB+abC+abcD+\ldots..=0.2088, \quad (1)$$

where, the capitalized alphabet is failure branch of HRA event tree and the small alphabet is success branch of HRA event tree.

In case of operator fail to test control rod drop mechanism, BHEP was calculated as the follow using event tree in Fig.5 and data in Table.2:

$$BHEP=A+aB=0.001+0.05=0.051, \quad (2)$$

2.4 Quantification of HEP

The BHEP can be modified by several factors that express specific situations during the task performing. First, the BHEP is modified by Performance Shaping Factor (PSF) that influences human performance in specific situation. In our case, the plant activity specific PSF is normal, i.e. PSF=1, assuming:

- Step by step work;
- Task was made by skilled person
- Stress level is normal
- Written procedure or check off is available
- Test and maintenance conducted by operator
- Procedure is considered long list
- Zero dependence, because, in our case, there was not two HEP in a minimal cut set

Another factor that influences the task performance is the Recovery Factor (RF), which is action that negates error. Assuming checker failed to detect error; nominal HEP is equal to 0.1, found from NUREG/CR1273. HEP can be expressed as the following equation:

$$HEP=BHEP*PSF*RF, \quad (3)$$

The calculated HEP values for the aforementioned two pre-initiators are as shown in Table.3.

Table.3. HEP results for the two pre-initiators

	Pre-initiator	PSF	RF	HEP
1	HFE for testing control drop	1	0.1	5.1E-3

	mechanism			
2	HFE for checking control rod drive	1	0.1	2.1E-2

2.5 PSA results

In order to investigate the impact of the pre-initiators on PSA for TRIGA research reactor, core damage frequency was evaluated with two cases as shown in Table 4. Core damage frequencies for two T&M errors related to control rod drive mechanism and rod drop function were evaluated for initiating events as shown in Table.4.

Table.4.The results of quantification of CDF for HEF regarding test and maintenance error.

Initiating event	Event freq. /years	Base case	with pre-initiators	ΔCDF
LOOP	1.0E-4	4.2E-8	1.2E-7	7.8E-8
LOCA	1.2E-4	1.5E-6	2.1E-6	0.6E-6
Excess reactivity	1.0E-3	1.4E-6	6.5E-6	5.1E-6
LOFA, both Primary Pumps failure	1.0E-7	1.1E-7	1.6E-7	0.5E-7
LOFA, Butterfly valve closure	1.0E-7	1.5E-7	1.6E-7	0.1E-7
LOFA owing to Flapper opening	1.0E-8	1.4E-8	6.5E-8	5.1E-8
Fuel channel blockage	1.0E-2	1.4E-4	1.6E-4	0.2E-4

As results, we found that some HEFs regarding the pre-initiator give significant impact to CDF in LOOP event. Table 5 shows influence of consideration of HEF related to test and maintenance to total core damage frequency.

Table.5. Comparison results of PSA Level-1

	Base case	without pre-initiators	ΔCDF
PSA Level-1	1.2E-4	1.71 E -4	0.5E-4

3. Conclusion

Last few decades, PSA in NPP has been increasingly performed in worldwide to identify the vulnerability of systems and to strengthen their safety systems since TMI and Chernobyl accident. However, research reactor has left behind because research reactor has been regarded as extremely low risk. Also, lack of awareness and resources make rare trials of PSA work for research reactors. The PSA considering pre-initiators for research reactor has not been conducted. Notwithstanding, enquiring more frequent human intervention and test and maintenance than nuclear power plant, research reactor has not pay attention to impact of HEF regarding test and maintenance.

In this research, we attempted to assess impact of HFEs regarding test and maintenance on PSA results for research reactor.

In this study, we considered HFEs regarding test and maintenance error as the pre-initiators; T&M errors for checking of control rod drive and drop mechanism. The THERP method as a tool for HRA was applied to evaluate HEP s related to those of pre-initiators.

CDF was evaluated using AIMS code in the following two case; base case without T&M error and with case.

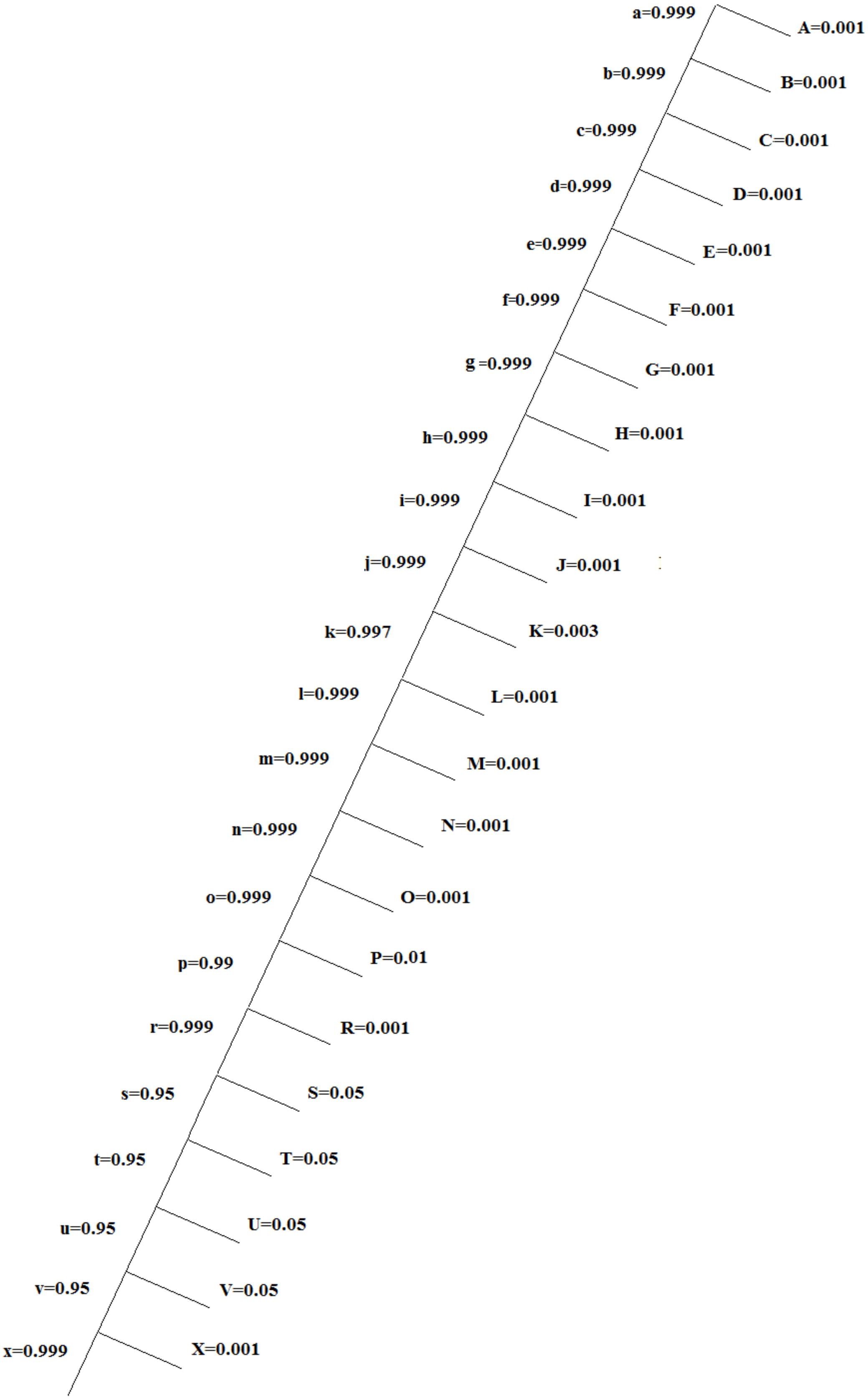
As a results, we found that test and maintenance error provide meaningful contribution to PSA results in terms of CDF as shown in Table 5. We can drew the conclusion that HFE regarding pre-initiator such as test and maintenance error should be taken into account for PSA for research reactor. More investigation should be given for identify impacts on HEFs regarding pre-initiator with various types of research reactor and pre-initiators.

REFERENCES

[1] R. Barati, S. Setayeshi, Human Reliability Analysis of the Tehran Research Reactor using the SPAR-H Method, Vol.27, No.3, pp.319-332,2012.
[2] NUREG/CR1273
[3]O.N. Aneziris, C.Housiadas, I.A.Papazogloglou, M.Stakakis, Probabilistic Safety Analysis of The Greek Research Reactor, Institute of Nuclear Technology and Radiation Protection Greece, 2001.
[4] IAEA, Research reactor instrumentation and control technology, IAEA-TECDOC-973, Report of a Technical Committee meeting held in Ljubljana, 4-8 December, 1995.
[5] IAEA, Generic Component Reliability Data for Research Reactor PSA, IAEA-TECDOC-930, Vienna, 1997.

APPENDIX

Fig.4. HRA event tree for checking control rod drive mechanism



.

Table.1. Definition of events in Figure.1

	Procedure Tasks	Human error	Table (Swain)	Nominal HEP	EF
A	Observe that S.R Drive stops UL Light comes on.	Misreading status lamp	20-11(8)	0.001	3
B	Observe that S.R. Drive stops and LL Light comes on.	Misreading status lamp	20-11(8)	0.001	3
C	Record distance between the S.R Drive magnet and magnet keeper	Error of recording	20-10(9)	0.001	3
D	Record selsyn position (unplugged the drive motor)	Error of recording	20-10(9)	0.001	3
E	Record the selsyn position Indication (unplugged the drive motor)	Error of recording	20-10(9)	0.001	3
F	Record the selsyn position indication.(unplugged the drive motor)	Error of recording	20-10(9)	0.001	3
G	Checking the recocking spring to insure it is not fully compressed (Normal position)	Error of checking	20-11 (1)	0.001	3
H	Drive stops and CLUTCH Light goes off	Misreading status lamp	20-11(8)	0.001	3
I	Record selsyn position indication (Normal position)	Error of recording	20-10(9)	0.001	3
J	Record the selsyn position Indication (Normal position)	Error of recording	20-10(9)	0.001	3
K	Disconnect Clutch switch	Error of omission	20-7(2)	0.003	3
L	Record the approximate distance the legs of the recocking tripod extend below the housing.	Error of recording	20-10(9)	0.001	3
M	Record the Selsyn Position-Indication.	Error of recording	20-10(9)	0.001	3
N	Record the difference between the readings obtained k and l task	Error of recording	20-10(9)	0.001	3
O	Check the recocking spring to insure that it is not fully compressed.	Error of checking	20-11 (1)	0.001	3
P	Check to see no gap exists on any S.R. Drive.	Error of checking	20-12 (1)	0.1	5
R	Observe that insertion is prohibited and Seat Light comes on.	Misreading status lamp	20-11(8)	0.001	3
S	Checks for Mechanical Tightness of U.L.S	Error of checking	20-12 (1)	0.05	5
T	Checks for Mechanical Tightness of L.L.S	Error of checking	20-12 (1)	0.05	5
U	Checks for Mechanical Tightness of Seat Switch	Error of checking	20-12 (1)	0.05	5
V	Checks for Mechanical Tightness of Magnet Housing –Top Section	Error of checking	20-12 (1)	0.05	5
X	Record the S.R. Drive position at U.L.S	Error of recording	20-10(9)	0.001	3

Fig.5. Event tree for checking control rod drop mechanism

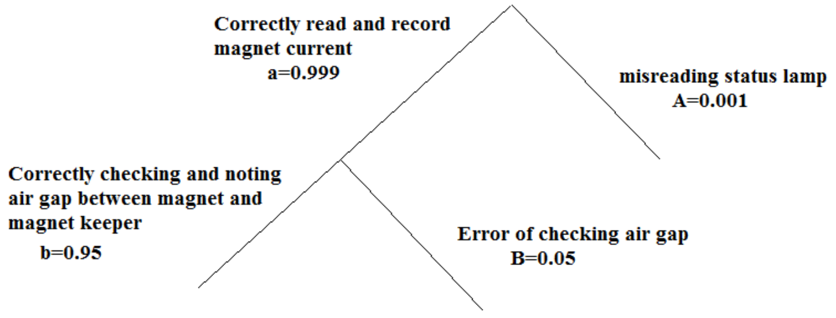


Table.2. Definition of event tree for checking control rod drop mechanism

	Procedure Tasks	Human error	table	HEP	EF
A	Read and record the magnet current after drive unit have "run down" and rerocked.	Misreading status lamp	20-11(8)	0.001	3
B	Check and note the air gap between magnet and magnet keeper after the clutch switch has made up and coast down has terminated	Error of checking	20-22(10)	0.05	5