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Development of Accident Scenarios and Quantification Methodology for RAON Accelerator

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1. Introduction

The RISP (Rare Isotope Science Project) plans to provide neutron-rich isotopes (RIs) and stable heavy ion beams. In recent years, the production of rare isotopes has been emphasized worldwide. By using these rare isotopes, it is expected that many challenging research can be conducted in a broad range of fields in both basic and applied sciences. In order to produce these rare isotopes, various types of accelerator are used.

The accelerator is defined as radiation production system according to Nuclear Safety Law. Therefore, it needs strict operate procedures and safety assurance to prevent radiation exposure. In order to satisfy this condition, there is a need for evaluating potential risk of accelerator from the design stage itself. Though some of PSA researches have been conducted for accelerator, most of them focus on not general accident sequence but simple explanation of accident.

In this paper, general accident scenarios are developed by Event Tree and deduce new quantification methodology of Event Tree.

2. Methods and Results

2.1 Accelerator hazards & Initiating Events

The first one to develop accident scenarios begins with identification of the possible hazards in accelerator facility. The accident divided into two categories. Internal events include radiological and hazardous chemical release, electrical hazards and so on. External events consist of fire, seismic, flood, etc.

In this study, internal accident scenarios are focused and developed by using Event tree which is used widely in PSA.

All possible hazards in the accelerator are identified as, [1]

(1) Ionizing radiation inside accelerator
(2) Ionizing radiation exposure outside accelerator
(3) Exposure to hazardous materials
(4) Electrical hazard
(5) Non-ionizing radiation exposure-RF
(6) Environment pollution
(7) Fire inside accelerator building
(8) Fire in equipment and control areas
(9) Seismic hazard
(10) Flooding inside accelerator

Some Internal accident events which can lead to severe consequences are listed below, [2]

- Beam losses
- Target rupture
- Faulty components causing radiation leak
- Trapping of persons inside high radiation areas
- Failure of bypassing interlock facility

In this study, several initiating events are selected according to their priority as listed below,

- Beam losses caused by loss of power to electromagnetic
- Beam window rupture
- Shielding material rupture
- Vacuum system failure

2.2 Accident scenarios & Event Tree

2.2.1 Loss of power to electromagnetic

Dipoles reflect heavy ion beam in both reflection area (90^o, 180^o) and extraction area for experiment. There are many dipoles in beam line and they divide into 25^o dipoles and 45^o dipoles. To do maintain sound condition, it is essential that electric power is provided to its system. Without supplying sufficient electric, dipoles lose its original function. As a result, heavy ion beam can collide with nearby system and it can be activated. Fig. 1 shows the Event Tree of loss of power to electromagnetic.

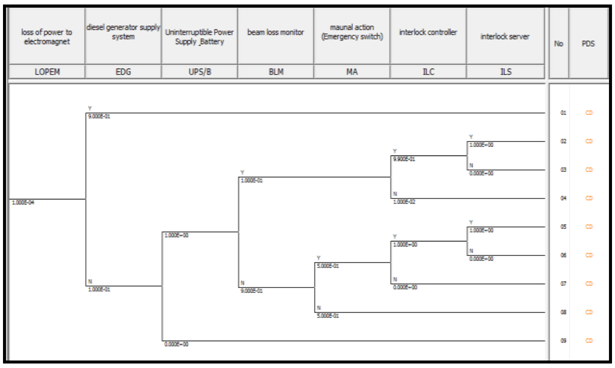

Fig. 1. Loss of Power to Electromagnetic

In order to mitigate loss of power to electromagnetic, there are some emergency electric supply systems. To minimize the cost from an abnormal accident and a power failure, the 5MVA diesel generator which is connected to AC electrical power distribution system supplies the essential power. The 300KW UPS

(Uninterrupted Power Supply) supplies the AC power to important systems such as controls and monitors for supporting the situation which diesel generator fails to operate.

After retaining the emergency power, accelerator must be tripped to prevent more severe accident. Interlock system is used for this purpose. Interlock system consists mainly of four subsystems such as interlock controller, interlock server, software interlock system and beam abort system as described in Fig.2 [3]

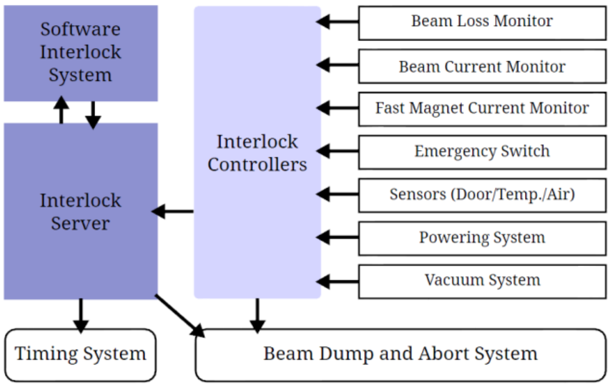

Fig. 2. A conceptual diagram for the RAON safety system

Many of beam loss and beam current monitors are installed around beam line to identify the beam status. If these monitors can't detect any information, operator should judge its situation and push emergency switch. They transport signals to interlock controllers if those monitoring systems detect abnormal condition compared with pre-defined limitation. Then, interlock controller generates the interlock signals and transports them to interlock server. Interlock server judges the situation by the information attained from database. Following this steps, interlock system trip the accelerator. As a result, whole system can be tripped safely.

2.2.2 Rupture of beam window

Accelerated heavy ion beam is transported to experiment area along with beam line. At the end of beam line in experiment area, beam window exists for beam extraction. It requires several mechanical properties which can maintain the sound condition at high temperature and high current. Moreover, it must have thin thickness to reduce the amount of energy loss of beam.

Because of high energy beam and design properties of beam window, it can be ruptured. As a result, this failure causes loss of internal vacuum, contamination of accelerator system and exposed to radiation. Fig. 3 shows Event Tree of rupture of beam window.

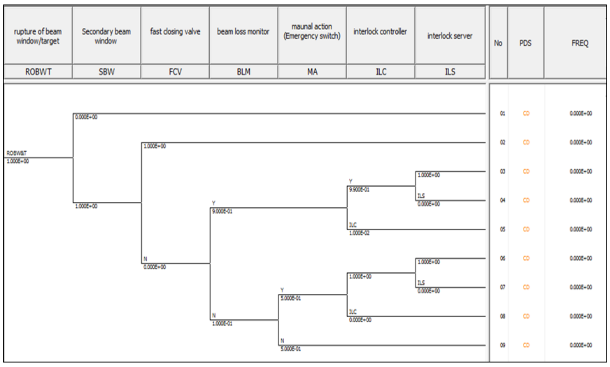

Fig. 3. Rupture of Beam Window

The basic safety systems for beam window rupture consist of secondary beam window and fast closing valve. Secondary beam window keeps the radiation in beam line if first beam window is ruptured. Fast closing valve is equipped to prevent the leakage of radiation from beam window. As mentioned before, interlock system must operate to trip the accelerator. As a result, whole system can be tripped safely.

2.2.3 Rupture of shielding material

Experiment areas where have potential hazard to radiation exposure or machine activation are classified as controlled area according to Nuclear Safety Law.

Therefore, multi-shielding systems which consist of shielding wall, shieling door and the others are adopted to prevent those hazards. Except for low-energy, low-current areas, the walls and the roof of the room are made of thick concrete. If these systems fail to block radiation caused by unexpected accidents or deterioration of systems, those people who are in the controlled area can be exposed more dose. Fig.4 shows Event Tree of rupture of shielding Material.

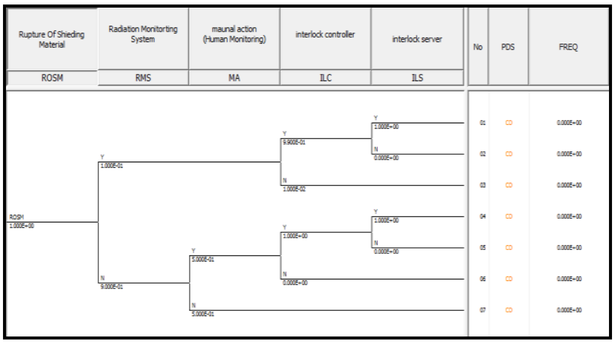

Fig. 4. Rupture of Shielding Material

If the radioactive material leaks to the outside due to cracking of the shielding materials, radiation monitor system detects the elevated radiation level. The measured radiation level is transported to interlock systems and it decides whether it stops or not. As mentioned before, the performance logic of interlock systems are described in Fig. 2.

2.2.4 Loss of vacuum system

Vacuum System can be divided into ultra-high vacuum (UHV) system (10^{-8}~10^{-9} torr) for the beam line and high vacuum (HV) system (~10^{-6} torr) for cryogenic insulation and preliminary pumping of the beam line. In the beam line, UHV condition is needed for preventing contaminations on superconductivity cavities which can cause field emission and lower the acceleration voltage.

Schematic of vacuum system is described in Fig. 5. [4]

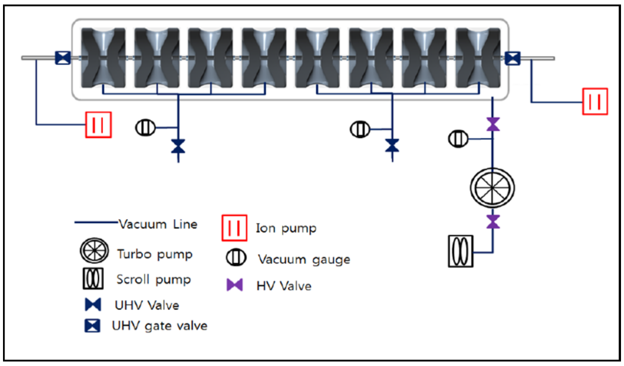

Fig. 5. Schematic of Vacuum System

If a failure occurs in the vacuum system, it is possible to not satisfy the conditions for maintaining the cryogenic condition. Due to the loss of the ability to maintain the vacuum condition, it's possible to lose beam current. In addition, it is possible to cause the activation of peripheral devices and the superconducting loss of beam line resulting from a failure of the drive of the cryogenic equipment. Fig.6 shows Event Tree of loss of vacuum system.

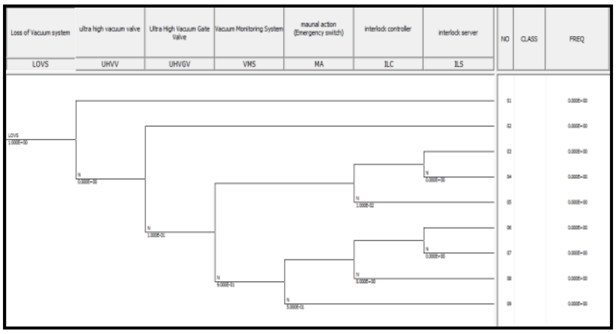

Fig. 6. Loss of Vacuum System

If any failure occurs at pump, valve, gauge which is shown in Fig. 5, vacuum system doesn't operate properly. Vacuum system that has lost vacuum capability can destroy the internal vacuum of the accelerator. It is necessary to maintain the level of vacuum in the accelerator by changing the closed state of Ultra High Vacuum Valve (UHVV) when any failure occurs in the vacuum system. If it succeeds in maintaining the vacuum of the accelerator using UHVV, it can be allowed to recover the vacuum capacity through subsequent actions and maintenance of the vacuum system. Then, the experiment can be continued. If UHVV fails to operate, it is needed to block the superconducting line using Ultra High Vacuum Gate Valve (UHVGV) to prevent loss of vacuum in another superconducting line. If UHVGV also fails, vacuum monitoring system detects a change in beam line and transports signals to interlock system. As mentioned earlier, interlock system shutdowns the accelerator safely.

2.3 Development of quantification methodology in Event Tree using Monte Carlo Method

Existing Event Tree uses a point probability value of each heading. For each event is stochastic phenomena, it is possible that the uncertainty is increased when determining the final frequency using point value. [5] In this study, quantification methodology which can calculate final frequency in the form of distribution is developed. After generating random numbers according to the distribution of each heading, generated values are multiplied each other. The result tends to be similar to point value as the number of sampling is larger. Matlab code is used for this calculation and Monte Carlo sampling.

The Fig. 7 is a simple example of derive final frequency in the form of distribution using the developed quantification method.

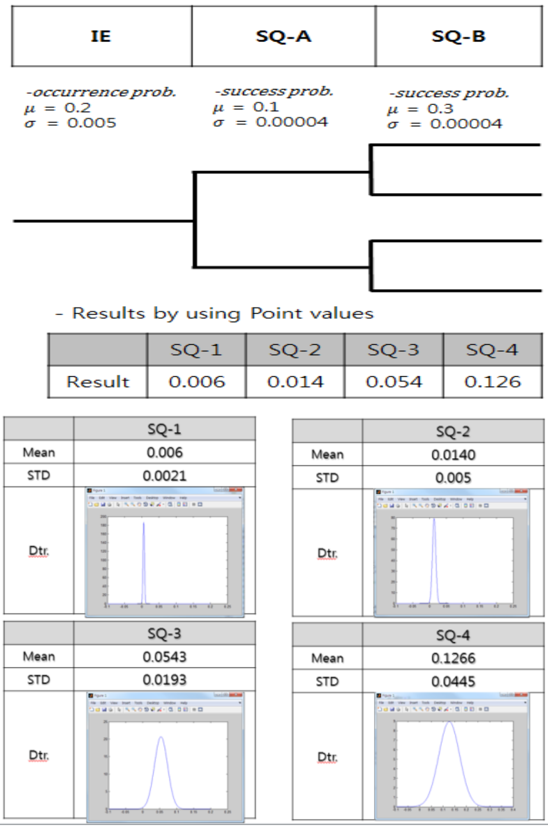

Fig. 7. The Example of Developed Quantification Methodology

After confirming the characteristics of the devices, developed methodology can be used for utilizing the quantification of Event Tree. As a result, it is possible to reduce the uncertainty inherent in the result of the quantification of accident scenarios.

3. Conclusions

In this study, some initial events, which may occur in the accelerator, are selected. Using selected initial events, the accident scenarios of accelerator facility are developed with Event Tree. These results can be used as basic data of the accelerator for future risk assessments.

After analyzing the probability of each heading, it is possible to conduct quantification and evaluate the significance of the accident result. If there is a development of the accident scenario for external events, risk assessment of entire accelerator facility will be completed.

To reduce the uncertainty of the Event Tree, it is possible to produce a reliable data via the presented quantification techniques. This method has an advantage to use the distribution rather than a single value in quantifying step.

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