Study of Critical Safety Functions and Conceptual Design of Safety Systems for Korean Fusion DEMO Plant

Kyemin Oh[a], Myoung-suk Kang[a], Gyunyoung Heo[a*], Young-seok Lee[b], Hyoung-chan Kim[b]
[a]*Kyung Hee University, Yongin-si, Gyeonggi-do, 446-701, Korea*
[b]*National Fusion Research Institute, Daejeon-si, 305-333, Korea*
[*]*Corresponding author: gheo@khu.ac.kr*

1. Introduction

This study was performed to propose the defense-in-depth concepts and critical safety functions for the fusion power plants and to design engineered safety features for R&D program through the National Fusion Research Institute of Korea. As a preceding step, the concepts of defense-in-depth, critical safety functions and engineered safety features for present and/or future fission power plants were analyzed. Additionally, the safety systems for ITER and other conceptual fusion power plants are compared with fission power plants, and ultimately the design concepts of safety systems are proposed based on the preliminary results of the failure mode and effects analysis which we have done during the past years.

2. Methods and Results

In accordance with the Korean fusion technology roadmap, the construction of demonstration fusion power plants is scheduled for the investigation of technical and commercial feasibilities around 2030. Even though Korea has started operation of K-STAR for various research activities, but engineering support seems insufficient to construct commercial plants. Among such issues, this paper aims at dealing with nuclear safety and suggesting a design concept for the Korean Fusion DEMO Plant (KFDP) on the basis of analysis of possibly expected accidents in fusion reactors.

2.1 Defense-in-Depth and Critical Safety Functions

The keyword of nuclear safety, defense-in-depth, consists of a hierarchical deployment of different levels of equipment and procedures in order to maintain the effectiveness of physical barriers placed between radioactive materials and workers, and the public or the environment, to deal with the events during in normal operation, anticipated operational occurrences at the plant. Defense-in-depth is practically implemented through design and operation to provide a graded protection against a wide variety of transients, incidents and accidents, including equipment failures and human errors within the plant and events initiated outside the plant [1]. Generally, the probability of the occurrence of the abnormal conditions is very low stochastically; if abnormal conditions are occurred by the equipment failure or operator error, the reactor protection system detects it automatically and prevents the progression to severe accident such as core damage through shutdown safely. Nevertheless, severe accidents may occur, or are likely to occur, necessary safety systems conducting critical safety functions such as emergency core cooling and securing ultimate heat sink should be designed to prevent release of radioactive material.

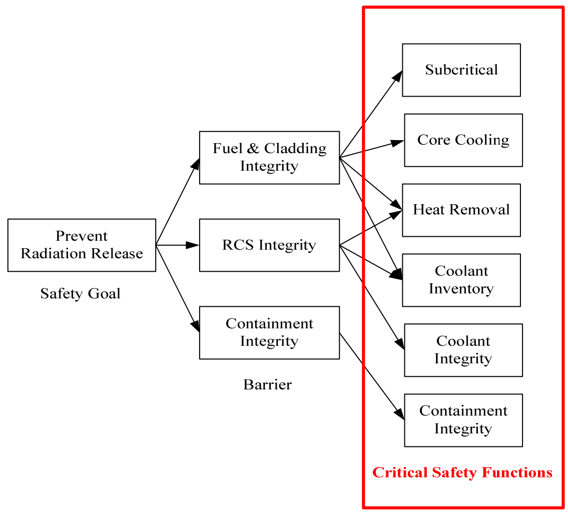

Fig.1 Safety Goal and Critical Safety Functions of Fission Reactors

2.2 Engineered Safety Features of Fission Reactors

Engineered safety features mitigate the consequence of accidents and ultimately prevent the release of radioactive products. The functions of each system are different, but interconnected system is working to cope with accident in timely manner. According to driving mechanism, safety systems are divided into passive and active system.

The representative safety systems of power plants currently operating in Korea are containment, containment spray, safety injection, shutdown cooling, auxiliary feedwater, and safety depressurization systems, and most of them can work with external driving sources. However, studies related to passive systems are actively taking place domestically and internationally because of specific characteristic of passive systems that are vulnerable to supply power in the event of an accident. It is worthwhile to make an attention for passive systems particularly after Fukushima accident.

2.3 Safety System of ITER

In order to control identified hazards, following fundamental function(s) should be fulfilled by the safety systems of ITER: confining the radioactive material and limiting internal and external exposure to ionizing radiations. Some main systems of ITER perform their own particular functions with safety functions at the same time. From a safety viewpoint, the main function of the Vacuum Vessel Pressure Suppression System is to reduce accidental overpressure in the vacuum vessel to an acceptable level in the event of an in-vessel coolant leak. For this purpose, passive devices (e.g. pressure suppression tank, relief pipes, rupture disks and bleed line) can be adopted. Since ITER is not a level of electricity production, safety systems have not been yet developed sufficiently.

2.4 Design of Safety Systems

For the conceptual design of safety systems, consequence analysis for various failure modes should be conducted and there should be a need to define safety goals and critical safety functions. Even though it is true that the design of safety systems is strongly dependent on regulatory guidance, such prerequisites seem indispensable.

2.4.1. Analysis of Fusion Reactor LOCA

In order to acquire numerical data for design concept development for safety system of fusion reactors, we attempted to analyze the scenarios of LOCA occurred in vacuum vessel, cryostat, containment using MARS code [2]. In these cases, the large pressure difference between the structure and the coolant pipes was produced due to large amount of steam and it built a great pressure on the inner wall of the structures, which can make breaches.

2.4.2. Safety Goal and Critical Safety Functions

The designing safety systems for vacuum vessel in a fusion power plant are relatively less important due to negligible decay heat and automatic shutdown of plasma during transients. However, a fusion power plant generates radiological materials; for example, tritium or activated materials so that development of proper confinement systems and maintaining their integrity are required. Moreover, some external events can affect the integrity of internal structures so we have to be careful to develop the initial stage of safety systems.

Fig. 2 represents the draft of critical safety functions of fusion power plants. It is under revision upon the consequence results on structure as well as public/environment. Table 1 shows expected safety systems for fusion power plants based on the selected critical safety functions of fission power plants and ITER's safety systems. Some of them are associated with only the integrity of internal systems and structure. The impact of radioactivity should be analyzed in detailed, which is on-going.

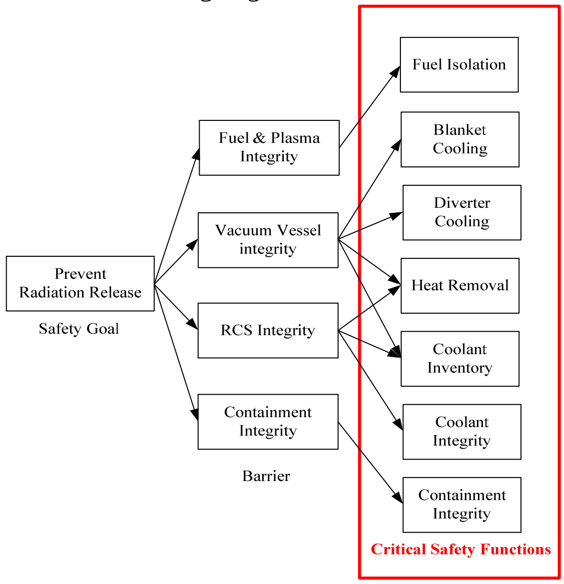

Fig.2 Safety Goals and Critical Safety Function of Fusion Reactors

Table.1. Expected Safety Systems for Fusion Reactors

Barrier	Safety System
Plasma	Tritium Treatment System
Vacuum Vessel	Vacuum Vessel Pressure Suppression System, Coolant Isolation System
Cooling Loop	Auxiliary Coolant System
Containment	Containment System, Containment Spray System, Flammability Control System

3. Conclusions

This paper reviewed the information related to safety systems of fission reactors and ITER. In the future, we will finalize the safety function and conceptual design. We possibly provide quantitative data in designing of suitable safety system for KFDP if the key parameters for a power plant are decided.

ACKNOWLEDGEMENT

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