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Safety Analysis for Korean Fusion DEMO Plant

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1. Introduction

In accordance with the Korean fusion technology roadmap, the demonstration fusion power plant is scheduled to be constructed around 2030. The National Fusion Research Institute (NFRI) of Korea initiated the engineering R&D programs to make fusion technologies practical forward in 2010 [1, 2]. Although the design of fusion reactors seems to enter an engineering phase, the regulatory requirement for fusion reactors is still in its infancy due to the fact that many of the important design parameters for fusion power plant are technically pending issues. This research provides the preliminary results on the Failure Mode and Effects Analysis (FMEA) for the Engineering Safety Features (ESFs) of Korean Fusion DEMO Plant (KFDP), which ultimately aims at supporting the design and regulatory requirements of the ESFs.

2. Methods and Results

2.1Overview of the Design Process

To embrace a wide range of issues and uncertainties in selecting design parameters at the conceptual design stage of KFDP, we first developed the function tree which hierarchically presented the bare-bone systems related to electricity generation using Tokamak and power conversion systems.

In order to take the synergetic benefits of both methodologies in achieving safety goals, we performed the deterministic and probabilistic safety analyses.

The preliminary Fault Trees (FTs) were constructed by converting the function tree, and FMEA were performed to determine the list of initiating events and scenarios. The terminals in the function tree correspond to the design parameters and their failure modes can affect the performance as well as the safety on the entire power plant [3]. To select the list of initiating events for an individual design parameter, the failure mode analysis should be conducted, and their effects were also evaluated in a qualitative manner by engineers' judgment.

Concerning the specific properties of the KFDP utilizing water-cooling system, the most extreme conceivable accidents were selected and prioritized. For example, a total loss of active cooling water during the burn, a structure breakdown by abrupt plasma disruption, the hydrogen generation and explosion, and lithium firing could be considered as the most severe cases potentially. For the initiating events, the quantitative simulations were performed to decide the needs and feasibility of the associated ESFs. In this study, we are primarily focusing on thermo-hydraulic analysis and structural integrity while another research is attempting to estimate the radioactive hazards.

2.2Result of Bare-bone system design

We start first consider the top Functional Requirement (FR) and Design Parameter (DP) for a bare-bone system, as follows [1];

FR0: Generate electric power
DP0: Demonstration fusion power plant

The sub-FRs of DP0 can be considered as the requirements to convert fusion energy to thermal energy (FR1) and to convert fusion energy to thermal energy (FR2). The respective DPs of FR1 and FR2 constitute the fusion reaction system and shutdown cooling system. There are various thermodynamic cycles and working fluids for DP2, for example, water, gas or liquid metal. In this study, the Rankine cycle with light water which has similar operation conditions with commercial pressurized water reactors was chosen. This process continued to identify all significant design parameters. The final function tree [1] is ready to be converted into a FT.

2.3 Result of FMEA

In the FMEA, the weakness from the viewpoint of system's reliability is analyzed for determining the strategies of accident prevention and/or mitigation. During this process, the function tree is useful for generating a FT because they have complementary characteristics. The development of the FT is almost completed as long as the logic gates in the function tree are converted in an appropriate manner [4]. The whole set of potential initiating events were analyzed by the FMEA and its subset is shown in Table I.

Table I. Results of FMEA for candidate lists of initiating events

Design Parameters	Potential Events	Effects
DP 1.2.3 Fuel supply system	Structural failure System failure	Release of Tokamak dust including tritium and activated corrosion products Isotope separation system failure
DP 1.2.4 Heat removal system to power conversion system	Structural failure System failure	Loss of heat removal / flow / heat sink /In-cryostat coolant ingress /Ex-vessel coolant ingress/Simultaneous coolant ingress in VV and vault / into plasma chamber and cryostat

Figure 1 is a piece of the results from the fault tree analysis. The initiating event in this figure, 'pump trip' occurring within a divertor coolant circuit is obvious to cause the 'failure of divertor cooling loop to power conversion system,' which corresponds to DP1.2.4.1, which can threaten a tokamak system in a fatal manner.

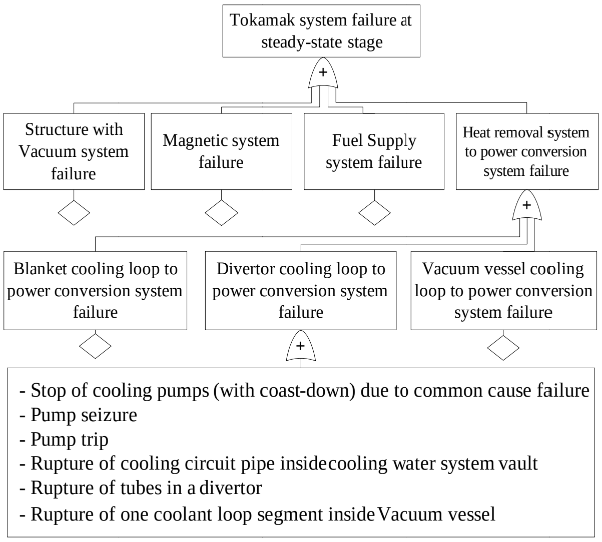

Fig.1. Fault tree for KDFP

We are able to propose an accident preventive method by adding a stand-by train for enhancing the reliability of this pump. In the same manner, other accident scenarios can be explicated. Several the loss of coolant accidents (LOCAs) occurring inside and outside a vacuum vessel were analyzed to evaluate the severity of initiating events. Their schematic diagram is represented in Figure 2.

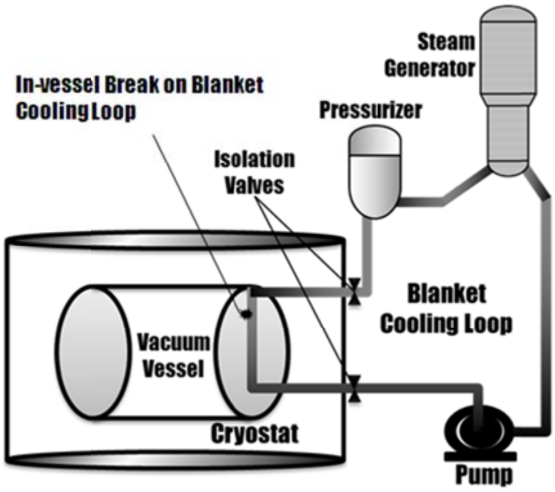

Fig.2. Schematic diagram for LOCA simulation

This illustrates the leaked blanket coolant flows into plasma-facing side of the vacuum vessel. The large pressure difference between the structure and the coolant pipes will produce large amount of steam, and it will build up great pressure in the inner wall of the structure. Consequently, the pressure rise can threaten the integrity of the vacuum vessel.

By using MARS [5] code, this event was simulated. The internal pressure buildup turned to be over 1,000 kPa so the current design of the vacuum vessel would be broken; ultimately, it was likely for radioactive material to be released outside and consequently to the environment. We regarded this initiating event as an accident and suggested an ESF. In Figure 2, the location of the isolation valves are indicated. The simulation results assuming isolating capability showed that the pressure buildup of the vacuum vessel turned to be less than 300 kPa so the current design is satisfactory to maintain radioactive material not to be released to the environment.

3. Conclusions

This study was to overview the design processes for the KDFP and to identify backup materials prioritizing the safety-associated researches on the Korean fusion technology roadmap. We have cooperated with other institutions for the development of regulatory frameworks and the calculation related to radiation affection. The detail direction and methodology of safety analysis has been also controlled by the results of the conceptual design, which NFRI is leading. By the safety analysis in this design stage, prioritizing R&D needs for the engineering phase of, particularly, ESFs can be conducted and researched, which is expected to contribute to optimizing the design of the KDFP.

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