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Parameter study of Hydrogen and dust explosion risk of Korean fusion demonstration reactor type using MELCOR

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1. Introduction

The fusion reactor has researched as one of the future generation energy sources and can get a lot of energy from fusion reactions of deuterium and tritium in a vacuum. So far, safety analysis of nuclear fusion reactors has not progressed much, and it is needed to study that the accident analysis of nuclear fusion is different from fission reactors cases. Although the design of fusion demonstration reactor (DEMO) has not been determined perfectly, it is expected to be built on the basis of the ITER design. Analyzing accident scenarios that may cause radioactive release may contribute to a better DEMO design.

Of these, leakage from the tritium in a vacuum vessel (VV) to the outside is considered most important in the accident analysis of the fusion reactor. Tritium inventories inside VV changes during operation and some of the tritium are burned from the plasma and some are kept inside and deposited, which in ITER undergoes periodic recovery and elimination of tritium. The reason for periodic evaluation and elimination of the inventory of tritium deposited inside the VV before reaching the safety limit is that there is a hydrogen/dust explosion issue.

One of the major accident phenomena in the fusion reactor is the dust/hydrogen explosion. Hydrogen may catch on fire or explode if it is mixed with oxygen as a with a very low flammable points compared to other gases. The Fukushima Daiichi accident showed the importance of hydrogen explosions in safety analysis, which about 65 to 120 kg of hydrogen in the Unit1 could shock the containment due to the explosion [1]. Moreover, it should be noted that, as assessed by ITER RPrS (Preliminary safety report) [2], hydrogen explosions can act as a catalyst for dust explosions. Hydrogen explosion is induced when air enters a VV as a result of a broken tube causing the flow between the VV and the port cell. Pressure increase after the vacuum is lost due to the flow of hydrogen and dust isotopes to the VV, which forms a mixture of hydrogen and air, resulting in an explosion. As air enters the VV and the pressure increases, tritium and tungsten dust are generated, and the effects of hydrogen explosions can provide enough energy to cause dust explosions, leading to severe impacts and release of radioactive materials to buildings connected to the VV [3].

In this paper, hydrogen/dust explosion risk analysis were carried out in various accident scenarios of the hypothetical DEMO reactor. The system analysis code was used to analyze and evaluate the probability of hydrogen explosion through the Shapiro diagram and the amount of radioactive leakage in the event of an explosion.

2. Safety analysis methodology

MELCOR version 1.8.6 [4] was used to analyze the different accident scenarios of a fusion reactor. The MELCOR code is widely used to evaluate accident simulation and source term analysis.

Based on the design of the ITER, the nodalization for the safety analysis is as shown in Fig. 1. and major parameters as shown in Table I, which applied lumped blanket model for ease of interpretation. VV pressure suppression systems, detritiation system and HVAC (heating, ventilation and air conditioning) isolation systems were used for the safety system, which was referred to the ITER safety system and the volume of each system determined to fit the proportion of VV in demonstration reactor.

The accident scenarios selected an event that could cause the most radioactive material to be leaked out referred to the BDBA of ITER RPrS. The scenarios of loss of vacuum condition, loss of coolant, station blackout, which can result in the pressure increasing vacuum vessel, were selected to perform the hydrogen risk calculation using Shapiro diagram. Each accident description is described in Table II, assume that all accidents starting at 0 second.

Table. I: Parameter value of System control volume [3]

Reactor type	Hypothetical DEMO reactor
Vacuum vessel volume	598m^3
Suppression tank volume	835.95m^3
Suppression tank pool volume	416.5 m^3
NBI cell volume	74 m^3
Port cell volume	810 m^3
Gallery volume	26701.96 m^3

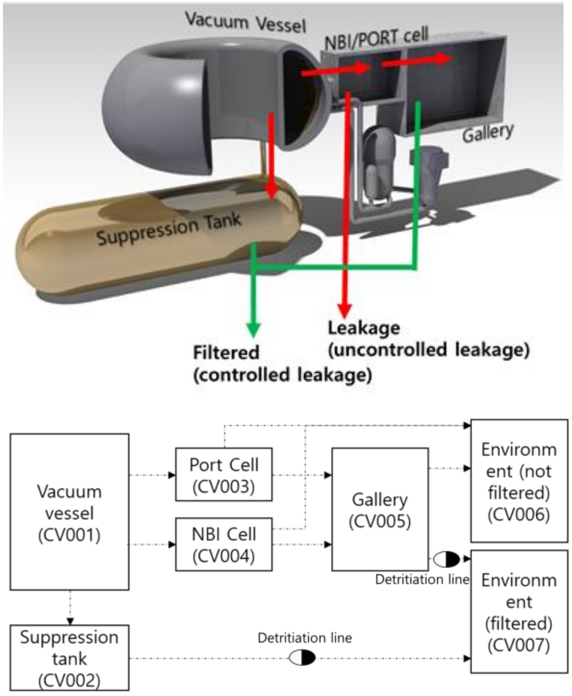

Fig. 1. Hypothetical DEMO reactor and Nodalization for the safety analysis [3]

Table. II: Description of the initial events and accident scenarios

Accident scenarios	Event description
Loss of vacuum accident	0.02m^2 area penetration between vacuum vessel and port cell
Loss of coolant accident	Outboard first wall coolant channel guillotine break and plasma disruption from LOVA damages first wall
Station black out	Detritiation systems, vent systems, pumps are not activated during 2hours blackout

For the assessment of possibility of hydrogen explosion, Shapiro diagram is used as shown in Fig. 2. Several hydorgen risk assessment studies have conducted using Shapiro diagram [5]–[7]. The Shapiro diagram is one of the methodologies for calculating hydrogen risk. There are three types of air gas in this diagram and the main composition of air is oxygen and nitrogen. The explosion and combustion limits can be estimated in terms of the volume fractions of combustible gases.

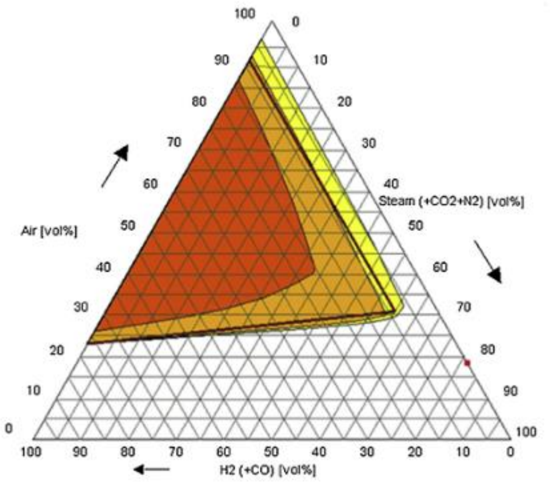

Fig. 2. Shapiro diagram for estimate hydrogen risk. [7]

3. Summary and Future work

Using the ITER safety analysis report and the relevant nuclear fusion reactor accident analysis report, the safety analysis will perform on hydrogen/dust explosion risk due to accident scenario on the nuclear fusion reactor to be built in Korea. The selected safety system changed volume in consideration of DEMO's VV size, and the selected accident scenario assumed three BDBAs that caused VV pressure rise.

In MELCOR, there is not a model for hydrogen detonation calculation and hydrogen production for fusion reactor. It needs some assumption like sudden pressure increasing as shown in Fig. 3. In this paper, the parameter study will conduct about how hydrogen production affects the explosion risk and radiative leakage.

In the case of demonstration reactor, it is expected that high power and large amounts of radioactive materials will be generated as source term upon accident more than ITER, so the possibility of explosion through Shapiro diagram and the amount of radioactive leakage will be performed from a conservative perspective using MELCOR.

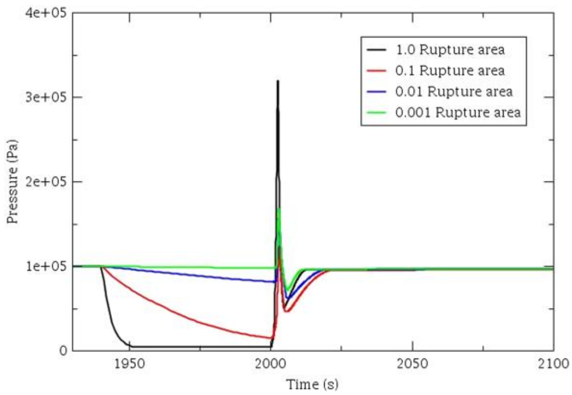

Fig. 3. Sudden pressure increasing for modeling hydrogen explosion at t=2000s [3]

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