Radionuclides release possibility analysis of MSR at various accident conditions

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1. Introduction

Radionuclides release at the accident condition is one of the important safety issues of the nuclear power plant. Even though an accident happen, radionuclides contain in the reactor building, problems are restricted to near the reactor. However, if radionuclides are released to environment, it can cause a lot of public health problem. Moreover, recovering is not easy and requires a lot of resources and manpower. There are some accidents which go beyond our expectation such as Fukushima Daiichi nuclear disaster and amounts of radionuclides release to environment, so more effort and research are conducted to prevent it.

MSR (Molten Salt Reactor) is one of GEN-IV reactor types, and its coolant and fuel are mixtures of molten salt. MSR has a schematic like figure 1 and it has different features with the solid fuel reactor, but most important and interesting feature of MSR is its many safety systems. For example, MSR has a large negative void coefficient. Even though power increases, the reactor slows down soon.

In this research, considering safety feature of MSR, accident scenarios of MSR are investigated and how source term acts is reviewed while the safety of nuclear power plant is getting the most important issue after Chernobyl and Fukushima disaster. Moreover, substituting Chernobyl and Fukushima disaster condition to MSR, radionuclides release possibility at severe accident is investigated.

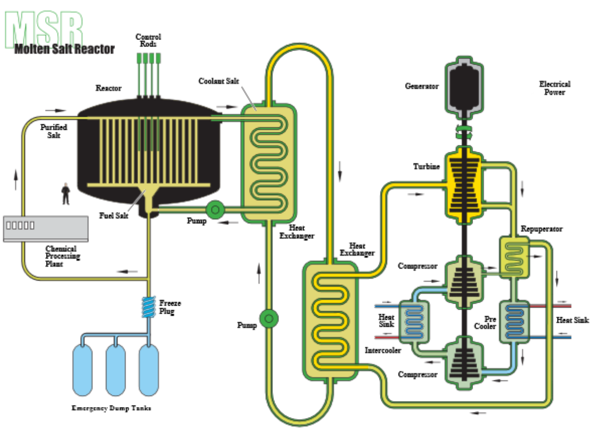

Fig. 1. Schematic of MSR[1].

2. Source term analysis

Based on the NRC definition, "source term" is "Types and amounts of radioactive or hazardous material released to the environment following an accident". In order to evaluate the source term, it is necessary to assume accident scenarios and find behavior of radionuclides.

2.1 Accident scenario of MSR

In the current LWR licensing, all abnormal events are categorized to three types, which are abnormal operating transients (AOT), design basis accidents (DBA), and severe accidents (SA) which are beyond DBA. Although classifications and definitions are prepared for LWR, these are still applicable to MSR until different safety designs for MSR are established.

Abnormal operating transients (AOT) is anticipated events to occur once or more during a plant service lifetime, it can be easily recovered to normal operation and the fuel integrity is preserved.

Design basis accident (DBA) is the event beyond AOT and it can be categorized as 3 major types as power increase accident or RIA (Reactivity Initiated Accident), Flow decrease accident and Fuel-salt leak accident.

Power increase accident or RIA is typically initiated by control rod withdrawal/ejection accident, but the power excursion terminates soon because of the large negative reactivity coefficient of the fuel-salt temperature. Flow decrease accident occurs because of the fuel-salt pumps trip, then a heat removal function is lost and the temperature increases. However, because of the negative reactivity coefficient, the accident is not to extend to the severe accident. Last, fuel-salt leak accident occurs if rupture or break of the vessel, pipes, pumps, heat exchangers, and other small pipes occurs by some reasons. Then, the integrity of the primary loop is lost, and the fuel salt will leak out. However, a leaked salt is caught by a catch-pan, and collected in a drain tank or an emergency drain tank.

2.2 Behavior of radionuclides at DBA

There are lots of possible accident scenarios, but only possible event to release radionuclides to environment is the severe accident. At AOT and DBA the integrity of primary loop is preserved and fuels can contain in the system except fuel-salt leak accident. In case of fuel-salt leak accident, integrity is failed, but the leaked fuel will be catch by catch-pan and go to dump tank. Thus, MSR is unlikely to produce source terms in various scenarios of DBA.

3. Substitution to other severe accident condition

MSR is unlikely to produce source terms in various scenarios of DBA because of many safety systems such as the negative void coefficient and the catch pan. However, the accidents beyond our expectations can occur and be led to severe accidents. Actually, there are some accidents, which a lot of radionuclides are released to environment beyond our expectations, such as Chernobyl and Fukushima disaster. It is hard to define MSR severe accident, but radionuclides from the MSR are not thought to be released to environment due to its property of the radioactivity dump even at Chernobyl and Fukushima disaster condition, hence, it assures that at least severe accidents would not happen.

3.1 Chernobyl disaster condition

Chernobyl disaster is the nuclear accident at Chernobyl nuclear power plant in Ukraine at the April 1986 and caused by flawed Soviet reactor design coupled with serious mistakes made by the plant operators. At the April 1986, the experiment is prepared to test for the electrical supply at the emergency situation. During the test preparation, all control rod is withdrawn except 6~8 which is much below than, minimal number of control rods for safety. RBMK reactor which is the reactor type of Chernobyl nuclear power plant has positive void coefficient so if power increases or flow of water decreases, fission will be increased. In consequence, during the test, power increase rapidly estimated to be 100 times the nominal power output and it causes a steam explosion which destroyed the reactor core. Through the broken reactor core, vast amount of radionuclides release to environment.

Fortunately, 2 safety systems will prevent to repeat this disaster. These characteristics are shown at table 1.

Table I: Safety feature comparison of Chernobyl Power plant and Molten Salt Reactor

	Chernobyl Power plant	Molten salt reactor
Reactivity coefficient	positive	Negative
Explosive material	water	none

MSR has the negative void coefficient, so although the temperature increases, the reactivity become lower and the reactor go stable. At the Chernobyl case, water explode because of boiling from the rapid temperature increasing, but boiling temperature of molten salt of MSR is 1670 °K or more, so it is not possible to molten salt explosion like water. Because of these two safety features, MSR is unlikely to happen to this kind of the accident, and even if the power increases, radionuclides will not release to environment.

3.2 Fukushima Daiichi nuclear disaster condition

Fukushima Daiichi nuclear disaster is the nuclear accident at Fukushima I Nuclear Power Plant in Japan at 2011. At March 11, 2011, a huge earthquake and a tsunami struck Fukushima Daiichi nuclear power plant. Fukushima Daiichi power plant was generating electricity and shut down automatically. However, fission products generated decay heats, and the earthquake caused loss of coolant (LOCA) and offsite power supplied to be lost, and backup diesel generators started up as designed to supply backup power. Thus, the temperature of the reactor start melt down, and a chemical reaction between the fuel's zirconium cladding and high-temperature steam generated large amounts of hydrogen in the containments. The hydrogen leaked from the containments or the venting systems into the reactor buildings and caused large explosions. This explosion damaged reactor walls tremendously, and amounts of radionuclides released to environment.

Observing process of Fukushima Daiichi nuclear disaster, two major factors of this accident are the fuel melting by LOCA and the hydrogen explosion, and MSR has some feature not to worry about those. First, the fuel of MSR is already melted and the reactor is built considering that, so there is no melting problem unlike the solid fuel. Even if the primary system is ruptured or broken and the fuel salt leaked by the huge earthquake and the tsunami, the catch-pan catch the leaked fuel salt and send it to the drain tank safely, so radionuclides can be contained in the building and will not be released to environment.

The melting condition also gives another safety feature. To prevent to contact of a fuel and a coolant, the solid fuel reactor use cladding, and zircaloy is one of cladding materials frequently used. Zircaloy perform well as a cladding material, but zirconium of zircaloy can react with water at the high temperature and produce hydrogen which can explode like Fukushima Daiichi nuclear disaster. However, MSR uses the molten salt which is a mixture of the fuel and the coolant, so there is no cladding use and Zircaloy isn't used in MSR, so the hydrogen explosion isn't happened. ZrF_4 is considered and studied as one of the molten salt material, but it is already compose the salt, so the oxidation reaction will not happen. Therefore, the hydrogen explosion will not occur, and gaseous fission products can contain in the reactor building.

4. Conclusions

Radionuclides release possibility of MSR was analyzed at various accident conditions including Chernobyl and Fukushima ones. The MSR was understood to prevent the severe accident by the negative reactivity coefficient and the absence of explosive material such as water at the Chernobyl disaster condition. It was expected to contain fuel salts in the reactor building and not to release radionuclides into environment even if the primary system could be ruptured or broken and fuel salts would be leaked at the Fukushima Daiichi nuclear disaster condition of earthquake and tsunami. The MSR, which would not lead to the severe accident and therefore prevents the fuel release to the environment at many expected scenarios, was thought to have priority in the aspect of accidents. A quantitative analysis and a further research are needed to evaluate the possibility of radionuclide release to the environment at the various accident conditions based on the simple comparison of the safety feature between MSR and solid fuel reactor.

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