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A Qualitative Accident Scenario Analysis for a Very High Temperature Reactor

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1. Introduction

The Very High Temperature gas-cooled Reactor (VHTR) is one of the six technologies classified by the Generation Ⅳ International Forum as a high-energy heat source for nuclear hydrogen generation. The motivation on the VHTR concept stems from the high outlet temperatures. The high outlet temperature affords high efficiency electrical generation and the use of nuclear power for potential process heat applications.

In order to prepare for the licensing of the VHTR demonstration reactor, it is necessary to develop a methodology for assessing the VHTR safety. The current licensing technology for nuclear facilities, however, is mainly for LWRs. Due to the inherent and passive features of the VHTR, the approach to modeling initiating events and event sequences should be modified in terms of size and complexity in comparison to that in a LWR model. These adjustments must not diminish the quality of the PRA, but facilitate the capability to model more accurately the VHTR features, events, and plant response [1]. This paper, therefore, presents an accident sequence analysis methodology for the possible initiating events.

2. Methods and Results

2.1 Methodology

Master Logic Diagram (MLD) was used to identify initiating events occurring in the VHTR, and ensure to a high degree of the completeness of the analysis. It is a top down approach that starts with the top event. This event is subsequently subdivided in all possible scenarios that can lead to this event. The events at the lowest level are candidates for the initiating events [2].

An event tree approach was used to define risk-related sequences. Event trees are constructed for each initiating event grouping. The event trees are system-based, and consider failures of those systems and functions capable of providing protection given each initiator. Event trees are used to describe sequences associated with the failure of functions provided to mitigate the effects of these initiators.

2.2 Selection of Initiating Events

Initiating events were selected through the MLD method which addressed systems and structures which are required to maintain control of radionuclide release. Fig. 1 shows the process to define initiating events based on three function failures: failure of control heat generation, failure of decay heat removal, and failure of chemical attack control.

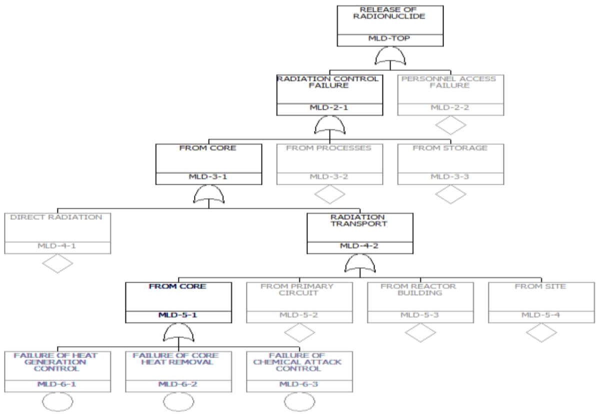

Fig.1. Initiating events selection process through MLD

Initiating events ultimately selected are things causing the three function failures. Table I shows the initiating events for each failure.

Table I: Initiating events selected for each failure

Failure of heat generation control	Failure of core heat removal	Failure of chemical attack control
Anticipated transient without scram	Loss of HTS cooling	Steam generator leak
Steam generator leak	Loss of offsite power	Primary coolant leak
Loss of offsite power	Primary coolant leak	Earthquake
Control rod withdrawal	Earthquake	
Earthquake		

As shown in Table I, the 7 initiating events similar to those typically addressed in LWR PRAs were chosen for analyses. Also, the initiating events cover the scenarios which are known to must be analyzed, as indicated in the Fort Saint Vrain Final Safety Analysis Report (FSAR) [3].

2.3 Accident Sequences

Accident sequences from the 7 initiating events were developed using the event tree analysis. There are some important safety systems. Vessel System (VS) contains the primary coolant and supports the reactor core and other vessel internals. Heat Transport System (HTS) is a forced circulation core cooling system which generates the steam to drive the turbine. When the reactor is shutdown, the HTS normally removes core residual and decay heat. Shutdown Cooling System (SCS) is a forced circulation core cooling system which removes core residual and decay heat when reactor trips and the HTS is unavailable. Reactor Cavity Cooling System (RCCS) is a passive air cooling system, external to the reactor vessel, which removes core residual and decay heat when reactor trips and both the HTS and the SCS are unavailable. Although the primary purpose of the Helium Purification System (HPS) is to control chemical impurities in the helium, the HPS efficiently removes both gaseous and metallic fission products from the helium at a rate determined by the gas flow rate through the purification system [4].

2.3.1 Primary Coolant Leak

A primary coolant leak encompassing the range of leak sizes can be a challenge to the function of controlling chemical attack and removing core heat [5]. This leak fails the primary coolant pressure boundary to retain the helium. The event tree for the primary coolant leak accident sequence is shown in Fig.2.

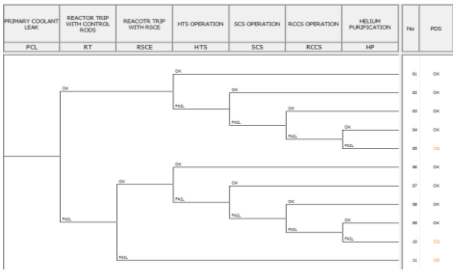

Fig.2. Event tree for primary coolant leak

2.3.2 Loss of HTS Cooling

A secondary cooling system failure may cause the loss of HTS cooling. Although the primary coolant pressure boundary maintains in sound condition, pressure transient of the primary system can occur due to the secondary cooling system failure. The event tree for the HTS cooling loss is shown in Fig.3.

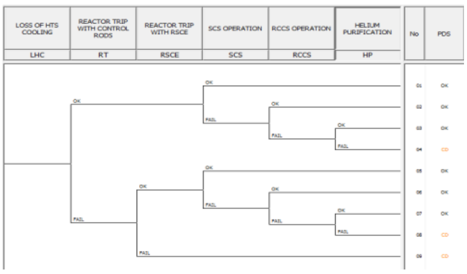

Fig.3. Event tree for HTS cooling loss

2.3.3 Earthquakes

Plant response to an earthquake may vary depending upon the seismic intensity and the impact range. For small ground accelerations, system failures are not expected and reactor trip may not be required. For large earthquakes, the forced cooling systems may be lost and the plant may be damaged. These can be challenges to the functions of removing core heat and controlling heat generation. Fig.4 shows the event tree for earthquakes.

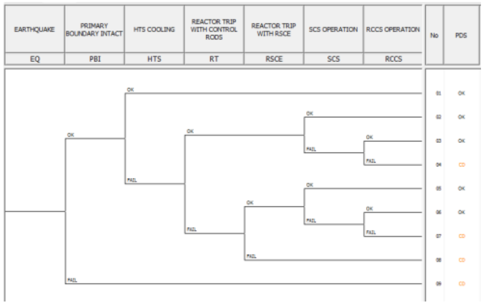

Fig.4. Event tree for earthquake

2.3.4 Loss of Offsite Power

If the offsite power is lost, the electrical loads are supplied by the turbine generators. Either turbine generator set is capable of sustaining house loads. The Loss of offsite power and an inadvertent turbine trip causes loss of all ac power. The DC battery power is available to supply the uninterruptible power sources until standby generators start. If the backup generators fail to supply the power SCS cooling, these results in a loss of all forced cooling failures as shown in Fig.5.

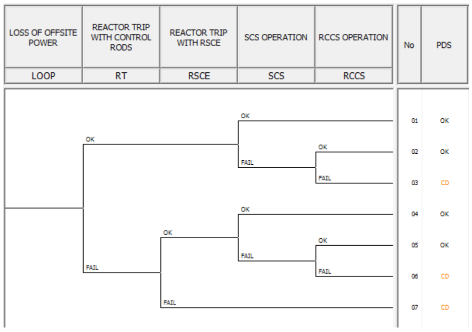

Fig.5. Event tree for loss of offsite power

2.3.5 Anticipated Transient without Scram

The most common transients requiring a reactor trip involve failures that inhibit the ability of the plant to sustain power production. Failure to insert control rods successfully could be from a control system fault, mechanical failure in the control rod drive mechanisms, or the scram contractors failing closed. Fig.6 shows the event tree for anticipated transient without scram.

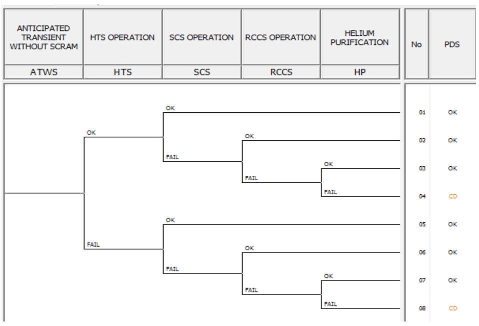

Fig.6. Event tree for anticipated transient without scram

2.3.6 Control Rod Group Withdrawal

The spurious uninhibited withdrawal of an outer reflector control rod group without reactor power setback action can result in a reactivity transient producing excess power above normal levels and increased core temperatures. If residual heat removal fails, core temperatures could gradually increases unless forced circulation cooling is restored. The most likely cause of spurious rod withdrawal is a failure of the neutron flux controller to operate properly. A spurious uninhibited withdrawal would result in an outer control group being withdrawn from the core. Fig.7 shows the event tree for control rod group withdrawal.

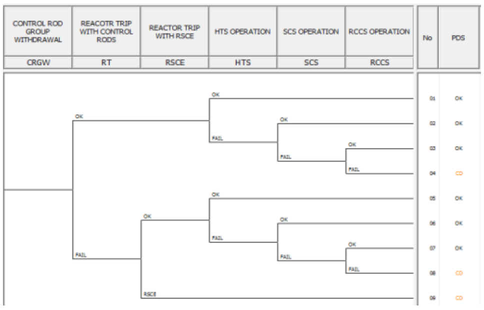

Fig.7. Event tree for control rod group withdrawal

2.3.7 Steam Generator Leak

A leak in the steam generator tubes can result in moisture inleakage into the primary coolant. High moisture levels can cause an automatic trip of the main circulator of the HTS and the startup of the SCS. For a moisture inleakage event, the potential exists for graphite oxidation and fuel hydrolysis. The event tree for steam generator leak is shown in Fig.8.

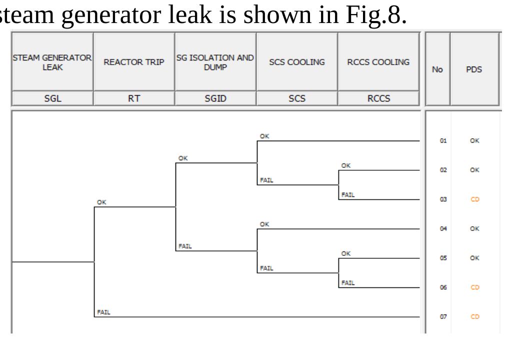

Fig.8. Event tree for steam generator leak

3. Conclusions

Initiating events which may occur in VHTRs were identified through MLD method in this study. For the possible initiating events, the accident sequences were developed with event tree modeling. The results will be the baseline accident scenarios for the future probabilistic risk analysis. After analyzing the probability data of each heading in the event tree using reliability data analysis, it is possible to quantify the VHTR risk and identify the significance of the accident sequences. The results shown in this study might contribute to designing the VHTR to be constructed in future.

Acknowledgement

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