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Preliminary Study on the Transport and Detection of Delayed Neutrons in the Hot Pool from Failed Fuel Elements of KALIMER-600

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1. Introduction

The early detection for a failed fuel assembly during a normal operation is an important issue for a sodium-cooled fast reactor. If a fuel fails, the safety and operability of a reactor is threatened. If a fuel assembly is failed, the fission products are released into the coolant from the gap of a fuel assembly and, hence, the radioactivity and the delayed neutrons from the precursors will be increased in the primary coolant.[1] When the concentration of the delayed neutrons in the primary coolant is over a pre-defined threshold, it can be supposed that there are some failed fuels in the core.

The concentrations of the delayed neutrons originating from the failed fuel mix into the hot pool are naturally reduced along with time due to the decay process. For analyzing the transport and generation mechanism of delayed neutrons in a hot pool, 3 analyses are required. At first, the generation of the delayed neutrons in the coolant is analyzed. And, then, a thermodynamic analysis is needed in order to calculate the mixing and the transport of fission products which can generate the delayed neutrons in the hot pool along the sodium flow. Lastly, the transient evolution calculation is required in order to estimate the decay of the precursors while they are traveling in the pool.

In this study, we studied the generation of fission products, especially the precursors of delayed neutron, the transport of those in a hot pool, and, then, the decay out of the precursors traveling in the hot pool.

2. Evolution of Delayed Neutron in Hot Pool

2.1 Generation of delayed neutrons

The delayed neutrons in a core have been born from the radioactive decay of fission fragments (precursors) generated from fission reactions. The representative nuclides of the precursors are Br-87, Br-88, I-137, I-138 and so on. For a convenience of the analysis, we assumed an averaged concentration in a whole core. In the common reactor physics, the delayed neutrons can be categorized into 6 groups by the decay constant of precursors. The half life of the first group is more than 51 sec, it of the second group is about 22 sec and those of the other groups are less than 6 sec.[2] Table 1 shows the yield fraction of each 6 group delayed neutron and those half-life in a SFR, respectively. Total yield fraction of the delayed neutrons is 0.00351 and the average half life of all groups of delayed neutrons is 7.039 sec. From rough estimation of fission rate of the KALIMER-600, the averaged concentration of delayed neutrons in the core is 2.0×10^{10} #/cm3-sec and it of each fuel pin is roughly estimated to be 1.8×10^{15} #/cm3-sec. Although the concentration of the delayed neutrons in each fuel pin different according to its power, we supposed an averaged value in every fuel pin and the averaged concentration would be released into the coolant from the failed fuel for a simple analogy in this study.

Table 1 Characteristics of delayed neutron groups

delayed neutron fraction (6 group)	8.129E-5 0.000621235 0.00051927 0.0012635 0.0007487 0.000276
half-life (sec) (6 group)	51.48588 22.39819 5.899379 2.27519 0.806142 0.235568

2.2 Transport and Decay of Delayed Neutrons

If a fuel failure occurs, the precursors of the delayed neutrons leak into the sodium flow in the hot pool, and, hence, all the precursors get transported to the IHX through the pool sodium. Since the path depends on the sodium flow distribution, we analyzed the flow distribution in the pool by using the COMMIX code which can evaluate a 3-dimensional flow distribution in a reactor. We assumed that the transport of those in sodium is not influenced by drag and slip effects which are important in the transport of solid particles because the precursors can be supposed not to cause a significant change in the physical and thermal properties of a coolant.[3] The laminar diffusion and buoyancy effect as well as the release of gaseous precursors to the cover gas region from the coolant through the free surface of the hot pool are neglected in this study. That is to say, the transport of the precursors is only governed by convection in the view of the velocity field in hot pool.

Figure 1 shows some representative streamlines of the sodium flow in the pool from the exit of the inner, middle and outer core to the IHX. As shown in the figure, the paths are complex according to the location of core exit. With those profiles, we analyzed the transport time along the path. The transport time of all the precursors is about 20sec regardless of the location of the fuel pin through an analogy of the streamlines from the inner, middle and outer core, because the exit velocity of the inner core region is a little faster than the other regions although the length of the transport path is longer than others. The transport time is the most important parameter to detect the fuel failures because the response time of the detector is a function of the dilution, decay and path followed by the precursors before reaching the detector.

With the analyzed transport time, we estimated the concentration of the delayed neutron in the detector. It can be easily calculated by a radioactive decay process. The concentration of decreased to the 1/8 of the initial value due to decay out process during transport time in the pool. We did not consider the circulation of the coolant through the cold pool and the core in the reactor because it was perfectly mixed in the cold pool and the transport time is relatively large comparing to the half life of the precursors. So, its influence to the concentrations of the delayed neutrons in the hot pool was supposed to be much less than those directly from the core exit.

3. Detection for Delayed Neutrons in Hot Pool

For detecting the delayed neutron in the hot pool, the fission chamber is supposed to be suitable among several measurement instruments.[4] It counts the delayed neutrons, which are based on the small fission reaction. The coated materials of the detector should be changed from U-235 element to U-239 to be suitable to the energy of the delayed neutron. Since the energy peak in the detector is so high (~167MeV), it can be used in a high energy gamma-ray background and it has a high efficiency to detect neutrons with a small size. Also, all of the fission fragments are confined in the detector because the mass numbers of the fission fragments are very large. So, we will use the fission chamber in order to detect the delayed neutron in the coolant from the failure of the fuels in the reactor and it will be installed near the free space of the intermediate heat exchanger in the hot pool for minimizing the interfere to other components and for improving the detection efficiency with the coolant flow as described in the previous section.

4. Conclusions

We have studied the behaviors of the delayed neutron originating from the fuel failures in a pool in order to develop a fuel failure detection system. We examined the generation, transport and the decay process of the precursors as well as a possible detector for the delayed neutrons in the pool of a sodium-cooled fast reactor. We concluded that it was possible to detect the failed fuel by using the delayed neutron detection system in KALIMER-600.

In this paper, we preliminarily evaluated the detectability for a fuel failure in a sodium-cooled fast reactor with these preliminary analyses. However, some detailed analyses for the generation and transport of the precursors in the hot pool are needed to comprehend the behaviors of the delayed neutron in the pool because the release rate of the precursors is dependent on the size (area) of the fuel failure and the count rate of the delayed neutrons in the detector is strongly dependent on the initial value, transport time and flow path with the decay out process

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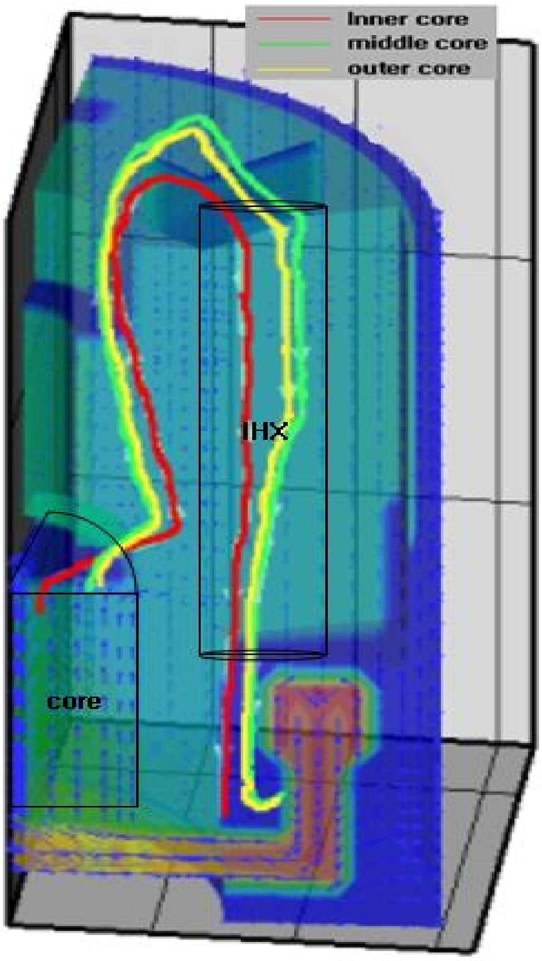

Fig. 1 flow path from core to IHX