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Study on the Transient Evolution of Precursors near an IHX from a Failed Fuel Assembly in KALIMER-600

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1. Introduction

If a fuel assembly in a sodium-cooled fast reactor (SFR) is failed, the precursors which can generate delayed neutrons are released into the coolant from the gap of a fuel assembly and, hence, the amount of delayed neutrons from the precursors will be increased in the primary coolant.[1] When the concentration of the delayed neutrons in the hot pool is over a pre-defined threshold, it can be supposed that there are some failed fuels in the core.

The precursors released from the failed fuel are mixed in the core channel and transported to the intermediate heat exchanger (IHX) in the hot pool. We assume that the precursors are transported to IHX along the flow of sodium coolant. So, the fuel failure can be detected from the change of the amount of delayed neutron generated from the precursors near IHX. We analyzed the transportation of precursors from failed fuel to IHX. In this research, the COMMIX-1AR/P code[2] was utilized as a thermo-dynamic analysis for KALIMER-600 during normal operation. We analyzed the flow path from the locations of failed fuel assemblies of the core and traveling time of sodium flow from the core outlet to IHX through hot pool of the SFR.

Then, we analyzed the averaged characteristics of the precursors in the hot pool with the traveling time. Otherwise, the transient evolution calculation was calculated in order to estimate the decay out of the precursors while they were traveling in the pool.

2. Transient Evolution of Precursors in Hot Pool

In the present calculation a quarter of the reactor geometry was modeled in a cylindrical coordinate system, which includes a quarter of a reactor core and a UIS, a half of a DHX and a pump and a full IHX. The lower concave region under the reactor core was simplified to be a flat one. Number of grids was decided to be 31, 14 and 39 in the X, Y and Z directions respectively, by considering the degree of the flow field resolution and practical restrictions such as the computing time and storage limitations caused by various calculation conditions. The information related to the calculation under a steady state condition can be found in the reference [3].

From the results of thermodynamic analysis of KALIMER-600, the locations of failed fuel assembly were assumed as shown in Fig. 1. Since the core in the thermodynamic model was modeled as porous media, we could not match the locations of failed fuel assembly with the exact its location, respectively. However, the locations were assumed to cover all fuel assemblies in the core. Also, the precursors from the failed fuel assembly were immediately transported to the core outlet.

Then, we analyzed the transport of the precursors along the sodium flow in the hot pool. Some representative results were shown in Fig.2. Fig. 2 shows the streamline of flow vectors from the core outlet to the inlet windows of IHX in the analysis model. From these results, we can analyze the transport path of the precursors from the failed fuel assembly and the traveling time to the IHX from the core outlet according to the locations of failed fuel assembly.

We assumed that the transport of those in sodium pool 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. That is to say, the transport of the precursors is only governed by convection in the view of the velocity field in the hot pool. Table 1 shows the traveling time data from each location of core outlet to IHX. The traveling time was different according to the location of failed fuel assembly because the flow path and velocity of core outlet was different along the locations of the fuel assemblies.

From the analysis results, we can calculate not only the traveling time but also the traveling path. The path information can give the location and number of required detectors in order to count the delayed neutrons of precursors released near IHX from the failed fuel. We assumed the precursors directly transported from core outlet to IHX were detectable because the concentration of precursors was diffused in whole pool and decayed out after returning cold pool through primary pumps.

The averaged half life of all precursors is 7.04 sec and the total yield fraction from the fission rate is 0.0351 in a typical SFR like KALIMER-600. [4] So, we can count the averaged concentration of precursors after traveling to IHX windows and the traveling time of the assumed locations of the failed fuel are shown in Table 1. The maximum traveling time was about 15.3sec and the concentration of precursors reached to the IHX was decreased to about 1/4 of those of the failed fuel assembly. Also, we can conclude that more than 2 detectors are required in order to detect the precursors because the flow paths were different according to the location of failed fuel assemblies as shown in Fig. 2. Otherwise, 1 detector can not cover all the flow of precursors near IHX from failed fuel assemblies of the core.

From rough estimation of fission rate of the KALIMER-600, the averaged concentration of delayed neutrons 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 the averaged concentration would be released into the coolant from the failed fuel. To detect the delayed neutron in a very hot condition like the hot pool of KALIMER-600 (about 545 ℃), a fission chamber of FC538 manufactured in Centronic Co. in England can be used and it is designed for operation up to 550 ℃ and the standard chamber is the FC538 coated with 1000 μg/cm^2 U-235.

4. Conclusions

We have studied the transient evolution of the precursors which can generate delayed neutron originating from a failed fuel in a pool in order to develop a fuel failure detection algorithm. We examined the transport time and path with the decay out process of the precursors in the hot pool of KALIMER-600. These results will be used in order to develop the detection algorithm for the fuel failures in KALIMER-600.

REFERENCES

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Table 1 Traveling time of precursors

stream no.	location of failed fuel	time(sec)
1	Inner core	6.86
2	Inner core	8.42
3	Inner core	12.68
4	Inner core	9.31
5	middle core	7.82
6	middle core	15.29
7	middle core	8.98
8	middle core	14.61
9	outer core	9.63
10	outer core	10.33

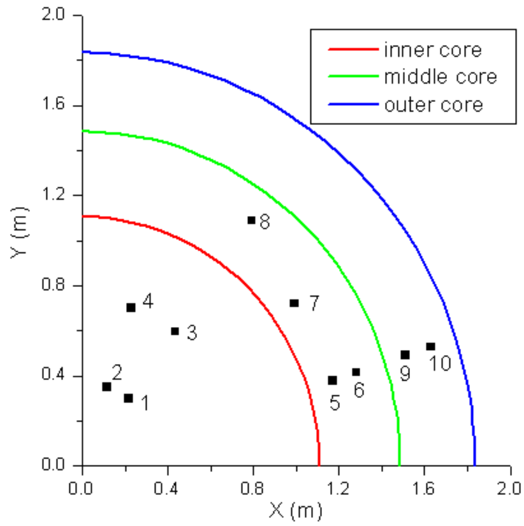

Fig. 1 Locations of assumed failed fuel assembly

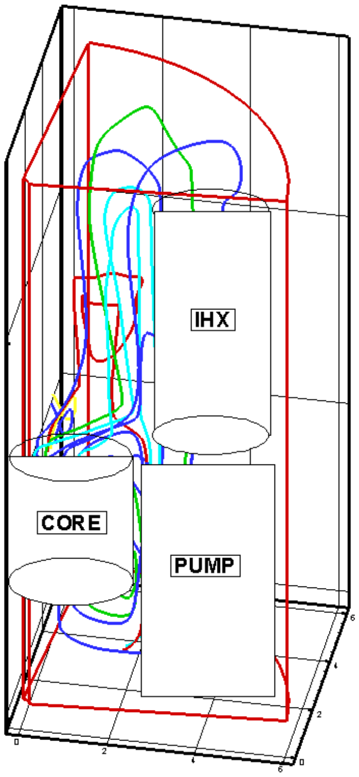

Fig. 2 Streamlines of precursors travel in hot pool