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Simulation and Analysis of Loss-of-Coolant Accident in Cold Leg of PWR Based on ATHLET and SIMIS

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Abstract. An accident safety analysis of small break loss of coolant is needed in order to avoiding the loss of coolant accident due to inadequate cooling in the reactor core and the leak of radioactive after the small break in primary circuit. We analyze the small break loss of coolant accident in cold leg of PWR primary coolant system by using Daya Bay 1000 MW nuclear power plant simulation system. Then we compare the result with another result which simulated by the software named ATHLET and verify the accuracy about simulation system.

Introduction

In the thought of the possibility of nuclear power plant accident, the circuit of small break loss of coolant accident (SBLOCA) coolant in nuclear power plant is a kind of safety accident which has a large possibility[1]. An accident safety analysis of small break loss of coolant is needed in order to avoiding the loss of coolant accident due to inadequate cooling in the reactor core and the leak of radioactive in the small break in primary circuit. In order to make evaluation on the safety of the reactor and then improve the safety of the reactor design and the safe operation, many calculating program have developed to simulate the typical small break loss of coolant accident for nuclear power plant and analysis the result as the important means of design and review a nuclear power plant.

The SBLOCA in Reactor Primary Circuit

A small break loss of coolant accident in reactor primary circuit may cause the following consequences[2,3,4]， first, it will cause the drop of pressure, the deterioration of core cooling, the leakage of coolant and the potential of radioactive leakage. The influence degree is related to the design of pressurized water reactor, emergency cooling equipment, the size and location of break and specific transient process. Three sizes were introduced which based on the calculation of crevasse type coolant system a loop cold leg small break loss of coolant accident, including 1%, 2%, 5%.

The coolant would flow out directly from the break rather than the pressure vessel when the accident happened in cold leg. In this case it may lead to a drop which into the core of the coolant and decline of cooling capacity. At the same time the injection pipe of safety injection system is connected with the cold leg which cause the same result that the lead to a drop into the core of coolant. Especially the case that the location of break is in the bottom of cold leg.

Softwares and Methods

ATHLET. ATHLET (Analysis of Thermal - Hydraulics of Leaks and Transients) program is made up of technical consulting and security Analysis center GRS (Gesell2 schaft fur Anlagen - und dillenburg Reaktorsicherheit) which was designated by Germany's Nuclear Safety Regulatory for the Analysis of emergency and the loss of coolant accident in the light water reactor[5,6,7,8]. The ATHLET is introduced from GRS by the institute of nuclear and new energy technology of Tsinghua University[9,10,11]. It can make detailed analysis of the flow characteristics inside the reactor. After several improving and enhancing, it becomes one of effective tools for nuclear energy system thermal hydraulics simulation.

The computing simulation program of choice is GRS in the latest version released in August 2006, ATHLET Mod 2.0 Cycle analysis program as A research method to simulated the small break loss of coolant accident and the analysis of accident process parameters change in PWR. It can provide reference basis for small break accident in nuclear power plant primary circuit.

ATHLET programs use the general control module to realize dynamic simulation of nuclear power plant. General control module is used to describe the control system and protection system and auxiliary system module. The user can realize loop or fluid systems control simulation through a series of control module. ATHLET can use the control module to simulate the single side accident, double side breaking accident, flood, and crevasse process.

Fig.1 is the module structure of system.

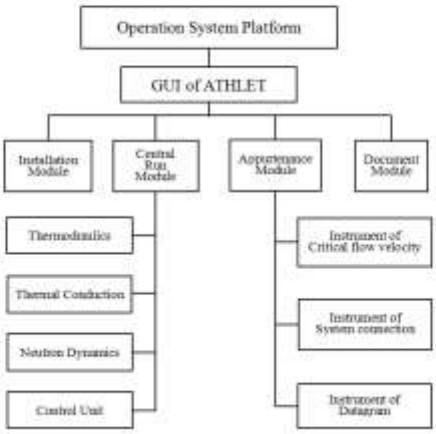


Figure 1. Module structure of ATHLET

SIMIS (Daya Bay 1000 MW nuclear power plant simulation system). Nuclear power plant simulator is based on computers as a work platform using the simulation mathematical model, simulation of nuclear physics, process and control process with computer graphics page as the man-machine interface of simulation system. Simulator simulates the reference plant main control room and the main content of local control which enables the control of simulator to complete unit start-stop, lifting power, accidents and major operating under transient unit. Interface is shown in fig. 2. In this paper, SIMIS is used to simulate the cold leg small break accident.

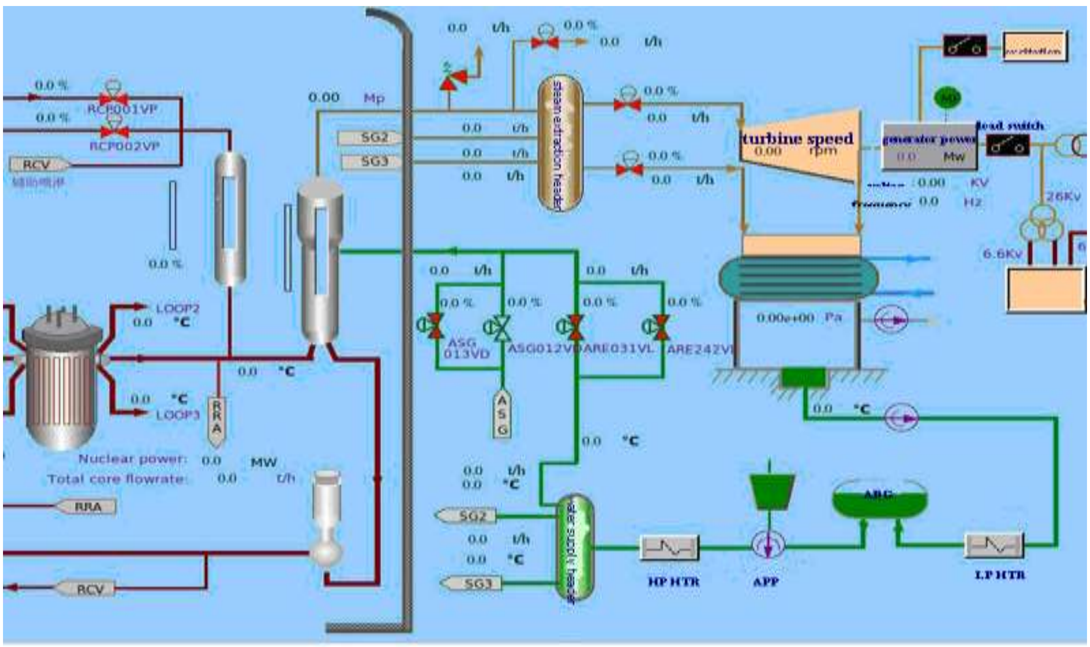


Figure 2. Interface of SIMIS

Result analysis

The temperature is the most intuitive variables to reflect the status of core and safety. So the temperature is an important parameter in this article emphatically analyses. Then the sequence of events after the accident is list, and we analyze the changes of temperature and compare the results from ATHLET and SIMIS.

Event sequence table. Table 1 is the sequence of different sizes of small break in cold leg of PWR.

Table 1 event sequence

Events \ Sizes	1%	2%	5%
Accident happened	10	10	10
Low pressure of PZR	13	12	11
Low level in PZR	20	17	13
Low temperature in filling line	29	26	21
Shut down	66	37	21
High power range rate	67	37	21
Loop DELTA - T high deviation	68	39	13
Loop high average temperature deviation	69	39	23
Water level anomaly in SG	69	40	24
Safety injection system start-up	70	40	23
High temperature in drainage pipe line	83	53	36
ASG pump start-up	91	62	45
Water level anomaly in Deaerator	104	65	52
High pressure in Containment	324	222	113

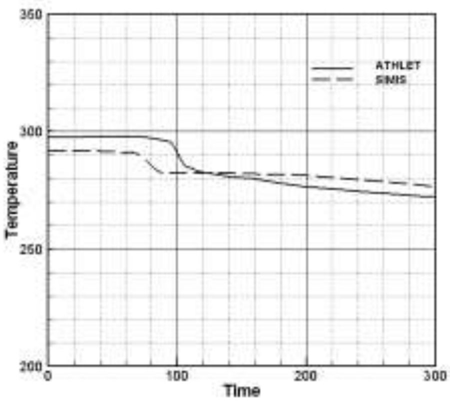


Figure 3. Temperature variation curve of core inlet after 1% small break

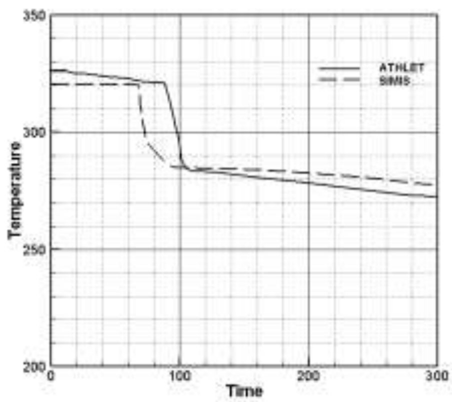


Figure 4. Temperature variation curve of core outlet after 1% small break

The temperature change curve. The inlet temperature change curve after 1% small break to the the cold leg is introduced in figure 3. The accident happened in 10 seconds by setting. It can be seen from the results from SIMIS and ATHLET that the temperature changes are consistent in the overall trend. The initial temperature is relatively stable over a period of time after the accident. Then the temperatures reduce quickly and become gradually declined. But change curve have differences on the point in time. In 80 seconds, the curve begin to drop obviously which the temperature from 295℃ to 280℃ in the case of SIMIS. Then the temperatures still keep falling with a low velocity. In the case of ATHLET, the temperature appears a significant drop which up to 280℃ and become stable. It can be seen from the diagrams; results have a 10 seconds error on time in the progress of temperature drop.

The outlet temperature change curve of 1% break in cold leg is introduced in figure 4. The situation is similar to the inlet temperature change curve. In 80 seconds temperature decline quickly and lowered from 320℃ to 280℃ in the case of SIMIS. While the result from ATHLET is falling start of the 90 seconds which fall to about 280℃.

Thus it can be seen from the pictures that SIMIS accurately simulate the temperature changing trend. But it has the same error in the time like the case of inlet.

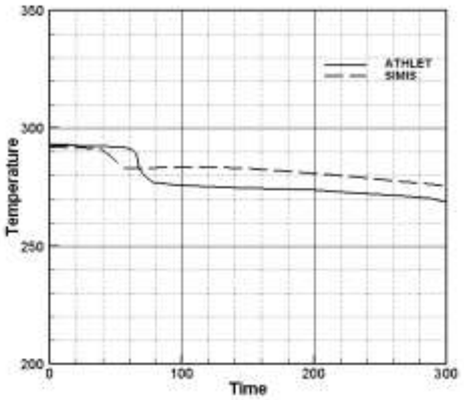


Figure 5. Temperature variation curve of core inlet after 2% small break

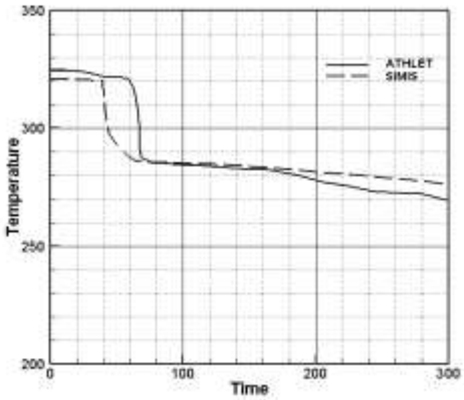
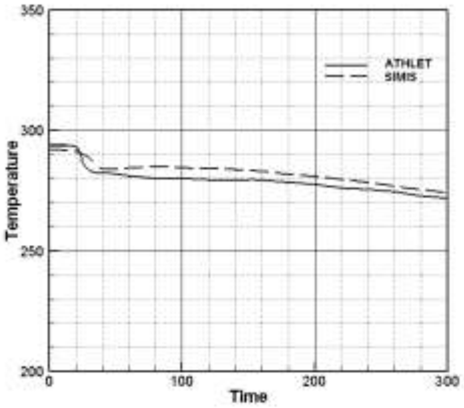


Figure 6. Temperature variation curve of core outlet after 2% small break

As it shown in figure 5, the core inlet temperature variation curve of the accident of 2% break in cold leg, decline obviously after a shorter period of time in this kind of case Compared with 1% of small crevasse. In 50 seconds, the temperature begin falling fast which from 295℃ to 280℃ by simulating with SIMIS. But in the case of ATHLET, it begin to decline rapidly in 60 seconds which fall to 275℃. According to the pictures, a gap of 10℃ exists compared with ATHLET. In addition to the error of time, the SIMIS don`t have an ideal simulation in this kind of circumstance.

The outlet temperature change curve of 2% is introduced in figure 6. In the case of SIMIS ,the temperature reach to 285℃ in 40 seconds and then it become stable. In the case of ATHLET, compared to the result of SIMIS, it began to rapid decline in 60 second which from 325℃ to 285℃ in temperature.

Conclusion can be drawn through the compare about two methods that SIMIS have a better simulation of inlet than the case of outlet, and compared with ATHLET, its temperature decline in a shorter time.



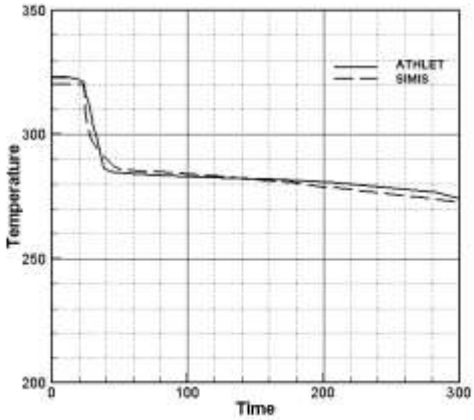


Figure 7. Inlet temperature of 5% break

Figure 8. Outlet temperature of 5% break

The inlet temperature change curve of 5% is introduced in figure 7. In 20 seconds, the curve begin to drop obviously which the temperature from 295℃ to 280℃ in the case of SIMIS and ATHLET. The decline last 20 seconds. Both of them drop to 270℃ in 300 seconds. And conform to the two curves is pretty good.

As it shown in figure 8, it`s the outlet temperature variation curves of the accident of 5% break in cold leg, just like the situation in inlet. The temperature appears a significant drop which up to 280℃ and become stable in the case of both situations.

We can see from pictures that SIMIS can make a ideal simulation to this circumstance.

Conclusion

The change of temperature in small break loss of coolant accident is a complicated progress. In this paper, We analyze the small break loss of coolant accident in cold leg of PWR primary coolant system by using Daya Bay 1000 MW nuclear power plant simulation system(SIMIS). Then we compare the result with another which simulated by the software named ATHLET and verify the accuracy about simulation system. We get the following conclusion.

(1) In this paper, three kinks of accident are simulated and the temperature change trend is obtained. The theory evidence is provide for the handling of accident. It can be used as a reference for handling this kind of accident.

(2) The comparison of the two software results shows that ATHLET has the ability to simulate the temperature change in the small break in primary circuit. At the same time, it can be considered that ATHLET has high accuracy and reliability in simulating this kind of accident. But it also have error within the allowable range in the case of 1% and 2%.

In general, it can be thought that ATHLET can reliably simulate the small break loss of coolant accident in 1000MW nuclear power plant.

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