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The GAMMA Code Assessment of the HTR-10 Safety Demonstration Experiments – LOFC ATWS

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1. Introduction

KAERI's thermo-fluid and safety analysis tool, the GAMMA (GAs Multicomponent Mixture Analysis) code [1], can calculate reactor power transients by solving the point-kinetic equations with six-group delayed neutrons, by considering the reactivity change caused by the effect of Xenon transients, the core temperature change and the intentional reactivity insertion such as the control rod withdrawal.

The GAMMA code is applied for the assessment of a LOFC ATWS (loss of helium flow without reactor scram) against the HTR-10 experiment [2]. The HTR-10 LOFC ATWS test was conducted at 30% rated power conditions. The detail test data are provided by the KAERI and INET joint project [2]. The GAMMA code has already demonstrated the steady state temperature distribution of the HTR-10 full power initial core (FPIC) with good overall predictions of less than a ±10% deviation [3]. This calculation uses the same calculation model of the HTR-10 reactor system as that of the steady state calculation.

The sensitivity study of the various coastdown curves is performed first to select the proper flow decreasing rate after the circulator trip. The calculation results of the power response transients after the circulator trip are compared with the experimental data.

2. Description of LOFC ATWS Test

A safety demonstration test of a VHTR, LOFC ATWS, was performed at the HTR-10 reactor. LOFC ATWS test assumes an accident where the helium circulator is suddenly switched off, but the reactor scram does not work and so the shut down control rod does not insert. The objectives of the test are to verify the inherent safety features of the automatic reactor power trip and the power stabilization due to a negative reactivity feedback caused by a rise of the temperature in the core after a LOFC ATWS occurs. These design features are required for the maintenance of a fuel and a reactor structure integrity below a temperature limit during a LOFC ATWS.

HTR-10 LOFC ATWS [2] started at the initial steady state operating conditions with a power of 3315 kW, an outlet helium temperature of 650ºC, an inlet helium temperature of 212ºC and a primary loop pressure of 2476 kPa, respectively.

3. Analysis Method

For the assessment of the LOFC ATWS, we use the same fluid part, solid part and boundary models of the HTR-10 system with the models used in the steady state calculation [3]. Before the LOFC ATWS calculation, the flow and the temperature fields are calculated at the initial steady state conditions. The flow rate of 1.413 kg/s is used to satisfy the outlet helium temperature of 650ºC at the initial steady state conditions.

Simulating the transient power behavior of LOFC ATWS needs not only the point-kinetic parameters but also the time dependent flow conditions such as the flow coastdown, the inlet helium temperature and the outlet helium pressure. The measured data of the inlet temperature and the outlet pressure are directly used as the time dependent boundary conditions because the calculation does not simulate IHX loop in the secondary side. The variations of these parameters are basically small during the transients. A temperature of 50 ºC at the RCCS water cooling tube [3] is used as a fixed boundary condition during the transients.

The temperature coefficients of the fuel, the moderator and the reflector [4] are -2.13×10^{-5}, -16.2×10^{-5} and 7.71×10^{-5} ($\Delta k/k/^{o}C$), respectively. Based on the sensitivity study of the various coastdown curves, the optimum coastdown curve is selected by comparing the power decay curve in a short term with the experimental data. It decreases linearly in proportion to the rotating speed of helium blower in 10 seconds and then rapidly decreases to zero in 150 seconds.

4. Results and Discussions

The calculation results of the power response transients after the circulator trip are compared with the experimental data in Fig.1. The GAMMA code prediction of the power response after the LOFC ATWS is very close to the experimental data of the power decreasing curve in a short term, and the re-criticality time and the power oscillation peak in a long term. The fission power starts to decrease just after the circulator trip due to the negative reactivity feedback in response to the temperature rise of the pebble core, and reaches a zero power in 400 seconds and increases again to a re-criticality power oscillation peak at 4200 seconds. The re-criticality power peak is estimated as about 25% of the initial power, which correlates very well with the experimental data of a 25% power peak at 4400 seconds. After then, the reactor power oscillates due to the reactivity feedback effects by the core temperature changes corresponding to the power oscillation. The magnitude of the power oscillation peak decreases gradually and becomes stable in virtue of the thermal inertia of the graphite structures with a large heat capacity and heat conductivity.

Fig.2 shows the net reactivity behavior together with the reactivity feedback effects of the fuel temperature, the moderator temperature, the reflector temperature, the Xenon concentration and the control rod. The reactivity by the control rod remains a zero level because the control rod does not insert during the LOFC ATWS. The net reactivity decreases rapidly in 240 seconds, then increases slowly, becomes critical again (positive reactivity) at 2900 seconds and reaches to the re-critical peak reactivity at 4000 seconds. The reactivity of the graphite moderator mainly contributes to the net reactivity behavior, but the effects of the fuel, the reflector and the Xenon concentration are small.

ACKNOWLEDGEMENTS

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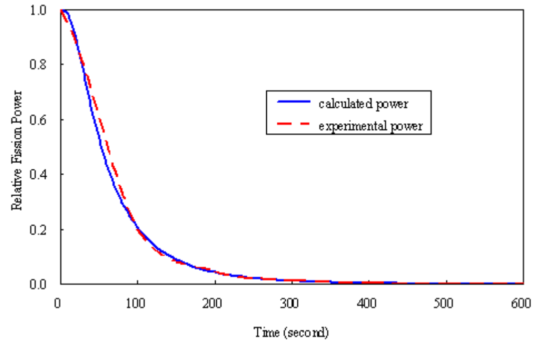
REFERENCES

[1] Hong Sik Lim, Hee Cheon No, "GAMMA Multidimensional Multicomponent Mixture Analysis to Predict Air Ingress Phenomena in an HTGR", Nuclear Science and Engineering 152 (2006) 1-11, 2006

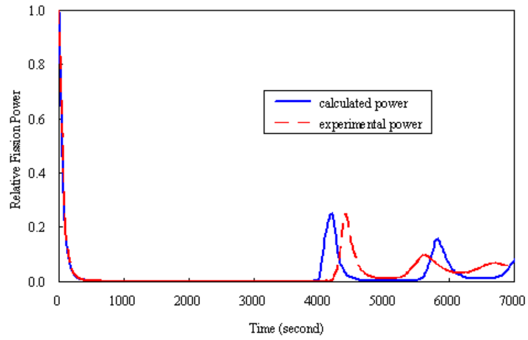
[2] INET, "HTR-10 Experiments Report - Loss of Helium Flow without Reactor Scram", NH-JRC-P1-R06-009, KAERI/INET Internal Report, 2006.5

[3] Ji Su Jun, Hong Sik Lim, Won-Jae Lee, "Final Report of IAEA CRP5 Benchmark Problem of HTR-10 Steady State Temperature Distribution (Rev. 1)", NHDD-KA06-RD011 -01, KAERI Internal Report, 2006.11

[4] IAEA, "Benchmark Problems of the HTR-10 ; Prepared for the IAEA CRP-5 by INET", IAEA-TECDOC-xxx, on going version, 2005. 12.



(a) short term



(b) long term

Fig.1 Power Transient after the LOFC ATWS

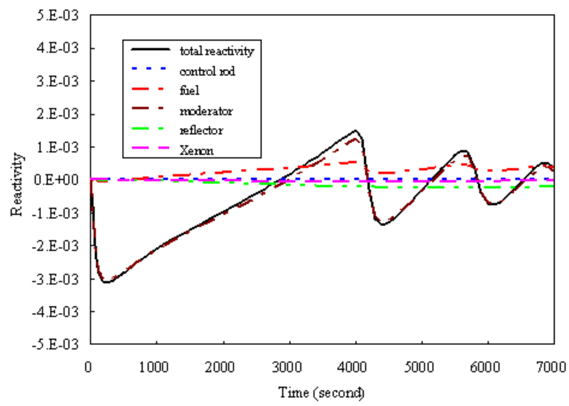


Fig.2 Reactivity Transient after the LOFC ATWS