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

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1. Introduction

This paper describes the GAMMA code [1] assessment of the HTR-10 safety demonstration experiments for the control rod withdrawal (CRW) without a reactor scram (ATWS) event. The HTR-10 CRW ATWS test was conducted at 30% rated power condition by INET [2] in China.

The GAMMA code has already demonstrated the steady state temperature distribution of the HTR-10 full power initial core (FPIC) with overall good predictions with less than a 10% deviation [3]. In addition, the code predicted the power response transients after the loss of flow circulator (LOFC) in HTR-10 [4] very well.

This calculation uses the same code model for the HTR-10 reactor system as that of the steady state calculation. The coastdown curve after the circulator trip of the LOFC ATWS calculation is applied identically for the CRW ATWS. The calculations are applied for two kinds of CRW ATWS: 1mk and 5mk positive reactivity insertion by control rod withdrawal, respectively. The calculation results of the power response transients after a CRW are compared with the experimental data.

2. Description of CRW ATWS Test

A safety demonstration test of VHTR, CRW ATWS, was performed at the HTR-10 reactor. The CRW ATWS test introduces a positive reactivity insertion into the core to simulate an accident of an unexpected control rod withdrawal. Like the LOFC ATWS, the CRW ATWS assumes an accident where the helium circulator trips by the overpower trip signal after the control rod withdrawal, but the shut down control rod is not inserted into the core in order to simulate the ATWS. The reactor power is increased unceasingly until the negative reactivity feedback effect in the core is larger than the inserted reactivity.

HTR-10 CRW ATWS started at the initial steady state operating conditions with the power of 3315 kW, the outlet helium temperature of 650ºC, the inlet helium temperature of 212ºC and the primary loop pressure of 2476 kPa. The test data are provided by a joint project between KAERI and INET [2].

The reactivity insertions were made by two kinds of experiments. For a small reactivity insertion test, the withdrawal of a 1mk control rod was finished in 20 seconds. 4.9762 mk reactivity was slowly inserted by withdrawing a 5mk control rod in 128 seconds for a large reactivity insertion test.

3. Analysis Method

The assessment of CRW ATWS uses the same fluid part, solid part and boundary models of the HTR-10 system with those of the steady state calculation [3]. A flow rate of 1.413 kg/s is used to adjust the initial steady state condition. A temperature of 50 ^{o}C at the RCCS water cooling tube [3] is used as a fixed boundary condition through the transients.

The temperature coefficients of the fuel, moderator and reflector [5] are -2.13×10-5, -16.2×10-5 and 7.71×10-5 (Δk/k/ºC), respectively. Based on the sensitivity study for the various flow coastdown curves in the LOFC ATWS calculation [4], the optimum flow coastdown curve was selected by comparing the power decay curve for a short term with the experimental data. The helium flow rate decreases linearly in proportion to the rotating speed in 10 seconds and then rapidly decreases to zero in 150 seconds. This flow coastdown curve is applied identically for the CRW ATWS calculation. In the case of CRW ATWS calculation, it is noted that the circulator trip starts when the reactor power reaches 3.96 MW at a 120% overpower level when compared to the initial power of 3.3 MW.

4. Results and Discussions

Fig.1 compares the results of the power response behavior after withdrawing the 1mk control rod with the experimental data. The reactor power rapidly increases due to the positive reactivity insertion by the control rod withdrawal and reaches a 120% overpower in 12 seconds. After the circulator is switched off, the reactor power continuously increases due to the increase of the reactivity insertion and reaches a peak power of a 142% overpower in 30 seconds. The result of the rapid power uprising and the decay curve for a short term is very close to the experimental data, which shows a peak power of a 149% overpower in 22 seconds. The reactor power starts to decrease due to the negative reactivity feedback corresponding to the rise of the fuel and the moderator temperatures by the power increase and the flow decrease. Then, the fission power is decreased rapidly to a zero power in 400 seconds, and the reactor is in a sub-critical state for a long time. The re-criticality power peak occurs at 4100 seconds with about 28% of the initial power, which is very close to the experimental data of a 25% power peak at 4200 seconds. After this, the reactor power oscillates due to the reactivity feedback effects by the core temperature changes corresponding to the power oscillation. The power oscillation peak is decreased and stabilized by a stable thermal performance of the graphite structures with a large heat capacity and heat conductivity.

Fig. 2 shows the total reactivity behavior including the reactivity feedback effects of the fuel temperature, moderator temperature, reflector temperature, xenon density and control rod after withdrawing the 1mk control rod. The reactivity of the control rod is only an input data. The total reactivity reaches a peak at 20 seconds due to the reactivity insertion of the control rod, and then it decreases to below zero at 40 seconds when the negative reactivity feedback becomes greater than the inserted reactivity. It decreases continuously in 280 seconds, then increases slowly, becomes critical again (positive reactivity) at 2900 seconds and reaches a re-critical peak reactivity at 4000 seconds. Compared to the small effects of the fuel, the reflector and xenon density, the reactivities of the graphite moderator and the control rod mainly contributes to the total reactivity behavior.

Fig.3 compares the results of the power response behavior after withdrawing the 5mk control rod with the experimental data. The results of the power response behavior are also close to the experimental data. The result shows the occurrences of a 120% overpower in 7 seconds and a 216% peak power in 30 seconds. The peak power is slightly less than the experimental data of a 241% overpower in 30 seconds. The fuel reactivity effect of a 5mk-CRW ATWS is obviously greater than that of a 1mk-CRW ATWS because the temperature gradient of the 5mk-CRW ATWS is higher than that of the 1mk-CRW ATWS.

5. Conclusions

This calculation result shows good agreement with the experimental data of the CRW ATWS in HTR-10. It is concluded that the GAMMA code is useful for the ATWS assessment to simulate the reactor power response by solving the point-kinetic equations for a VHTR design.

ACKNOWLEDGEMENTS

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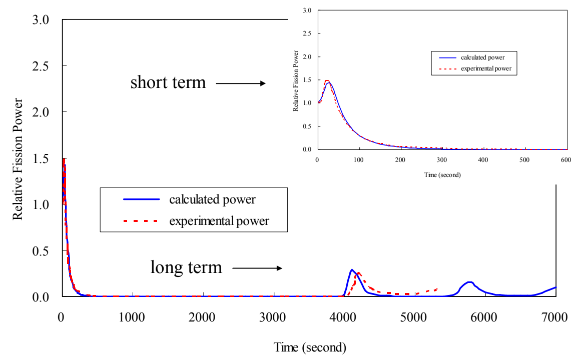

Fig.1 Power Transient after the 1mk-CRW ATWS

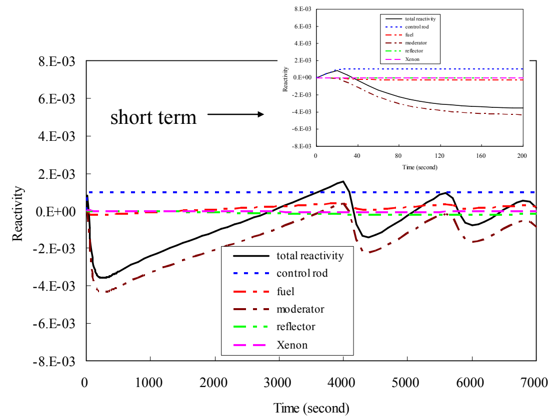

Fig.2 Reactivity Transient after the 1mk-CRW ATWS

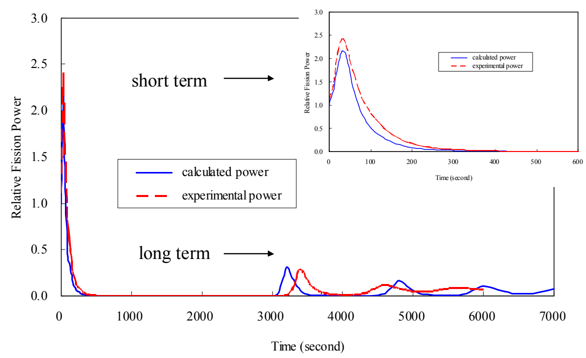

Fig.3 Power Transient after the 5mk-CRW ATWS