Development and Validation of Analysis Method for Reactor Performance and Safety Characteristics of HTGR

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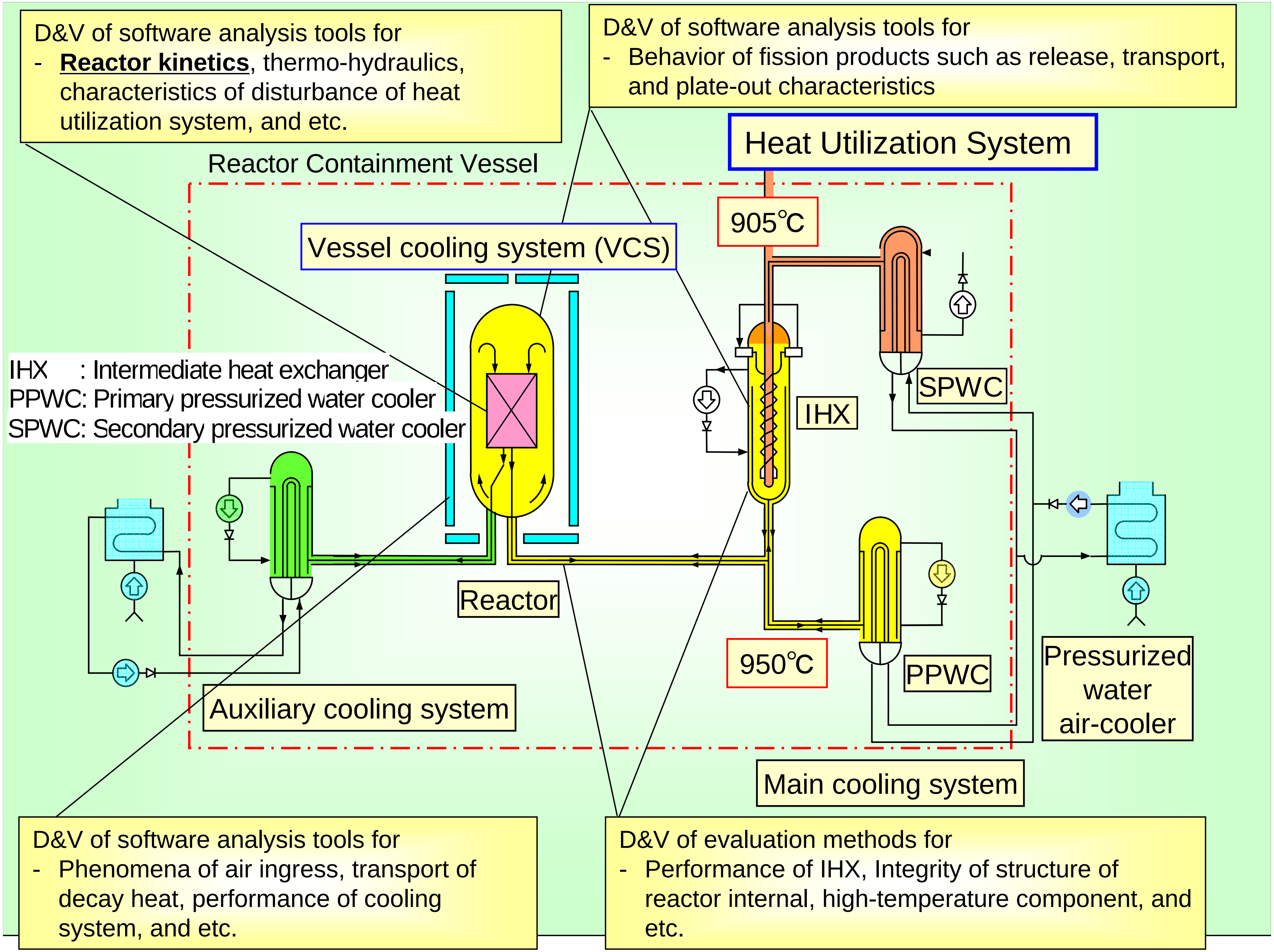

D&V of software analysis tools for
- **Reactor kinetics**, thermo-hydraulics, characteristics of disturbance of heat utilization system, and etc.
D&V of software analysis tools for
- Behavior of fission products such as release, transport, and plate-out characteristics
Heat Utilization System
Reactor Containment Vessel
905℃
Vessel cooling system (VCS)
SPWC
IHX
IHX : Intermediate heat exchanger
PPWC: Primary pressurized water cooler
SPWC: Secondary pressurized water cooler
Reactor
950℃
PPWC
Pressurized water air-cooler
Auxiliary cooling system
Main cooling system
D&V of software analysis tools for
- Phenomena of air ingress, transport of decay heat, performance of cooling system, and etc.
D&V of evaluation methods for
- Performance of IHX, Integrity of structure of reactor internal, high-temperature component, and etc.

HTGR performance & safety demonstration group

Objective is to carry out the following researches using the HTTR (High Temperature Engineering Test Reactor) for establishing and upgrading the VHTR (Very High Temperature Reactor) technologies.

- Enhancement of reactor kinetics evaluation method
- Enhancement of nuclear characteristics evaluation method

Safety demonstration tests have been conducted to demonstrate inherent safety features with abnormal status simulation.

Purpose of our research (1/2)

Objective is to develop and validate an analytical method of reactor kinetics using safety demonstration tests.

- Reactivity insertion test
- Partial loss of coolant flow test (one or two out of three gas circulators trip test)
- Loss of coolant flow test (all gas circulators trip test)

Reactivity insertion test

Problem is that peak power values of analytical results are lager than those of the measured values.

Reason is that an conventional method with one point kinetics can't consider the temperature difference (550 deg C) from the inlet to the outlet of the core larger than that of Light Water Reactor (LWR) and Fast Breeder Reactor (FBR).

Method of solution is to improve the analytical model for considering the distribution of three dimensional temperature coefficients.

Purpose of our research (2/2)

Partial or all loss of coolant flow test

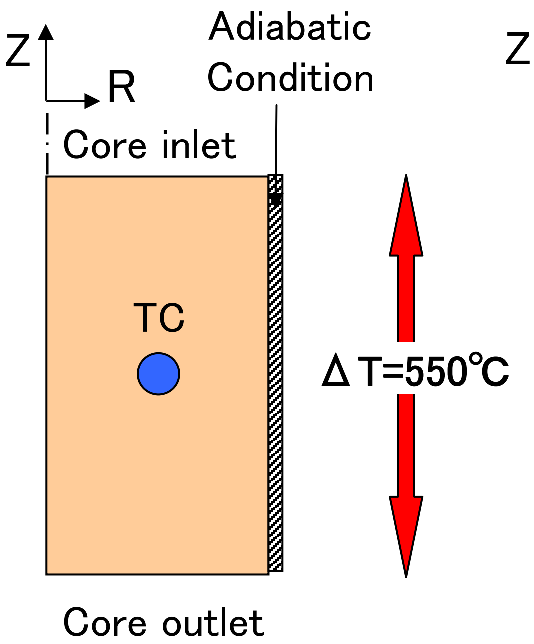
Problem is that an analysis code for constructing the HTTR can't analyze the partial or all loss of coolant flow test with accuracy.

Reason is that an analytical model doesn't contain full core structures and doesn't consider heat transfer from the fuels to the reflector blocks and the RPV.

Method of solution is to improve the analytical model for considering heat transfer from the fuels to the reflector blocks and the RPV.

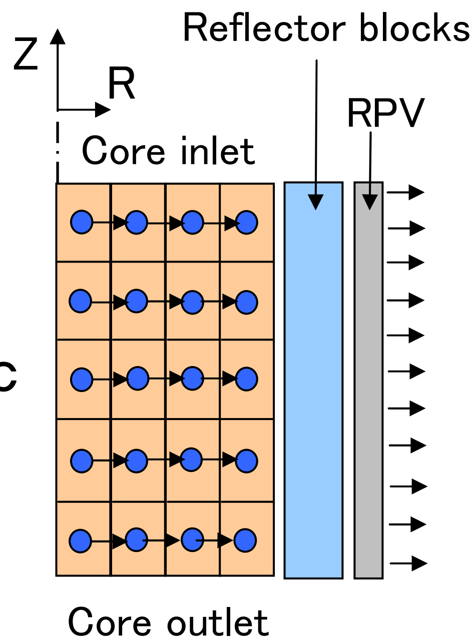
Analytical model

Conventional model
1ch・1TC



$$\rho = \alpha_{\text{single}} \frac{\Sigma \Delta T_i \cdot V_i}{V}$$

Developed model
4ch・20TC



$$\rho = \Sigma \alpha_i \cdot \Delta T_i$$

Consider the distribution of three dimensional temperature coefficients

Analytical method

①One point reactor kinetics
②Multi flow channels
③Region temperature coefficients
④Heat transfer from fuels to Reflector blocks and RPV

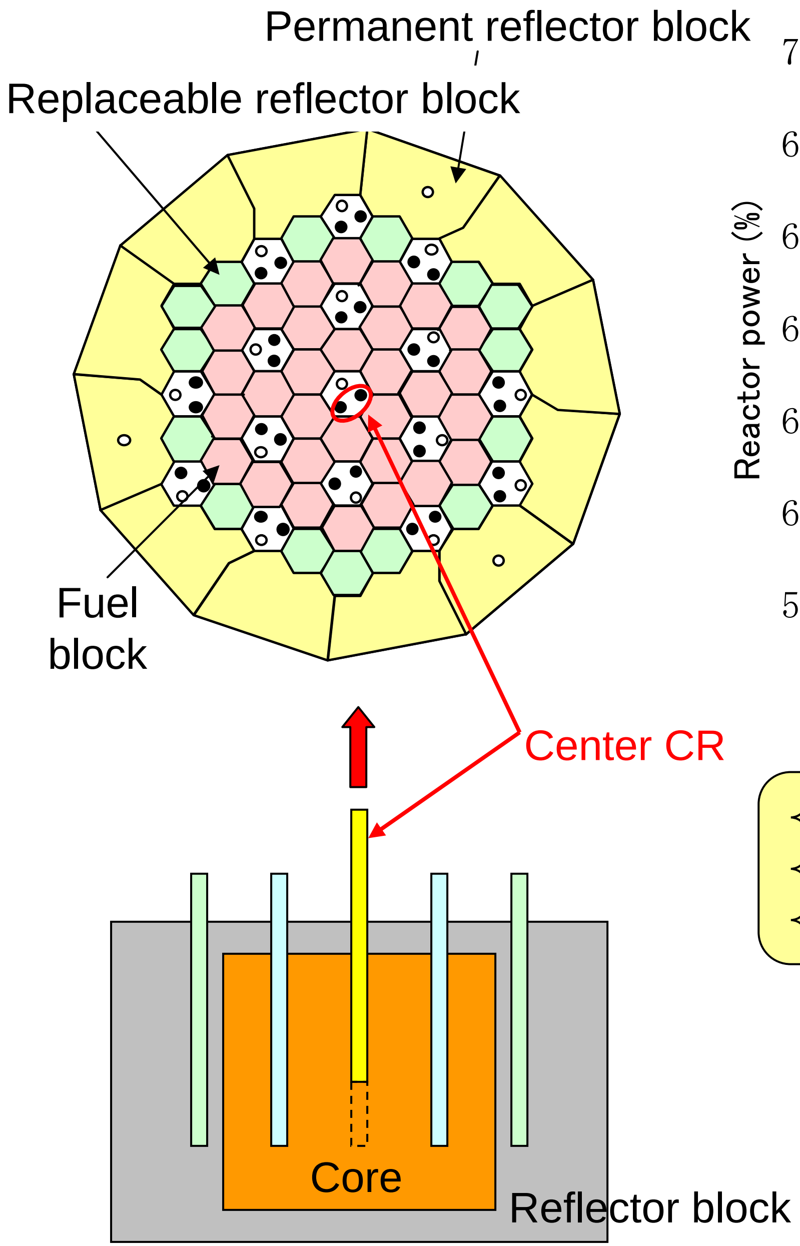
$$\alpha_{\text{single}} = \Sigma \alpha_i = \Sigma \frac{\left(\dfrac{1}{k_{eff} - k'_{eff}} \right)_i}{\Delta T_i}$$

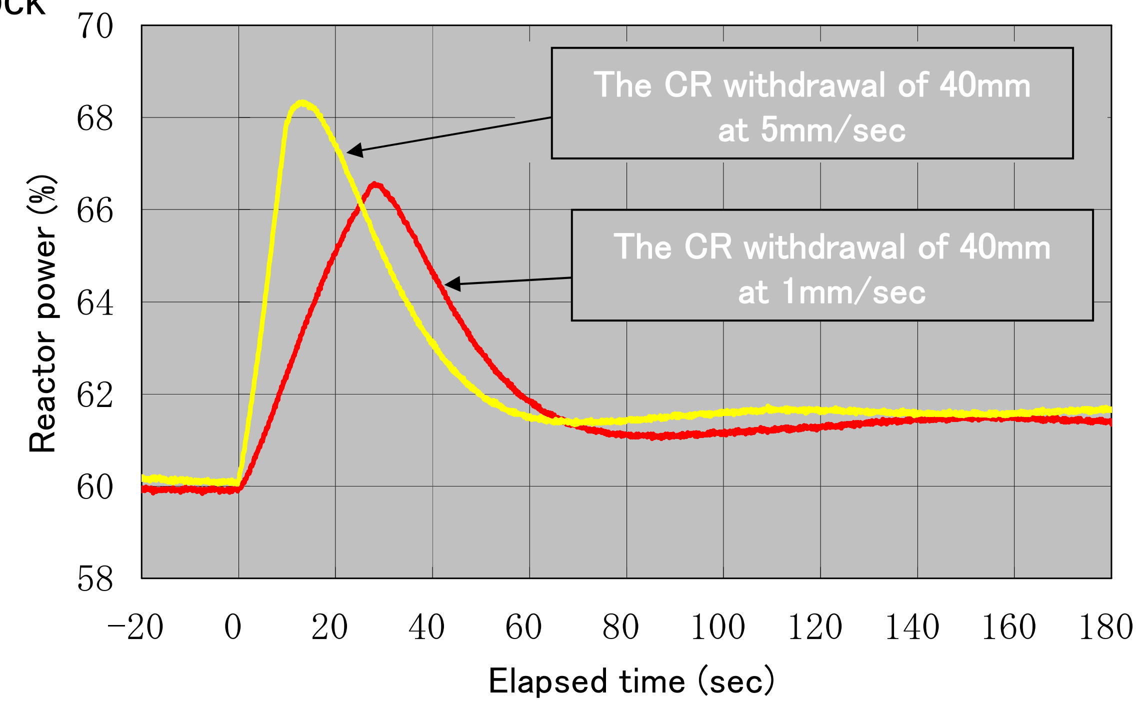
Temperature rise is small (below 20 deg C) during the tests.
Power distribution doesn't change.

ρ : reactivity feedback effect ΔT_i : Region temperature rise

α : Temperature Coefficient (TC) V : Volume i : Region number

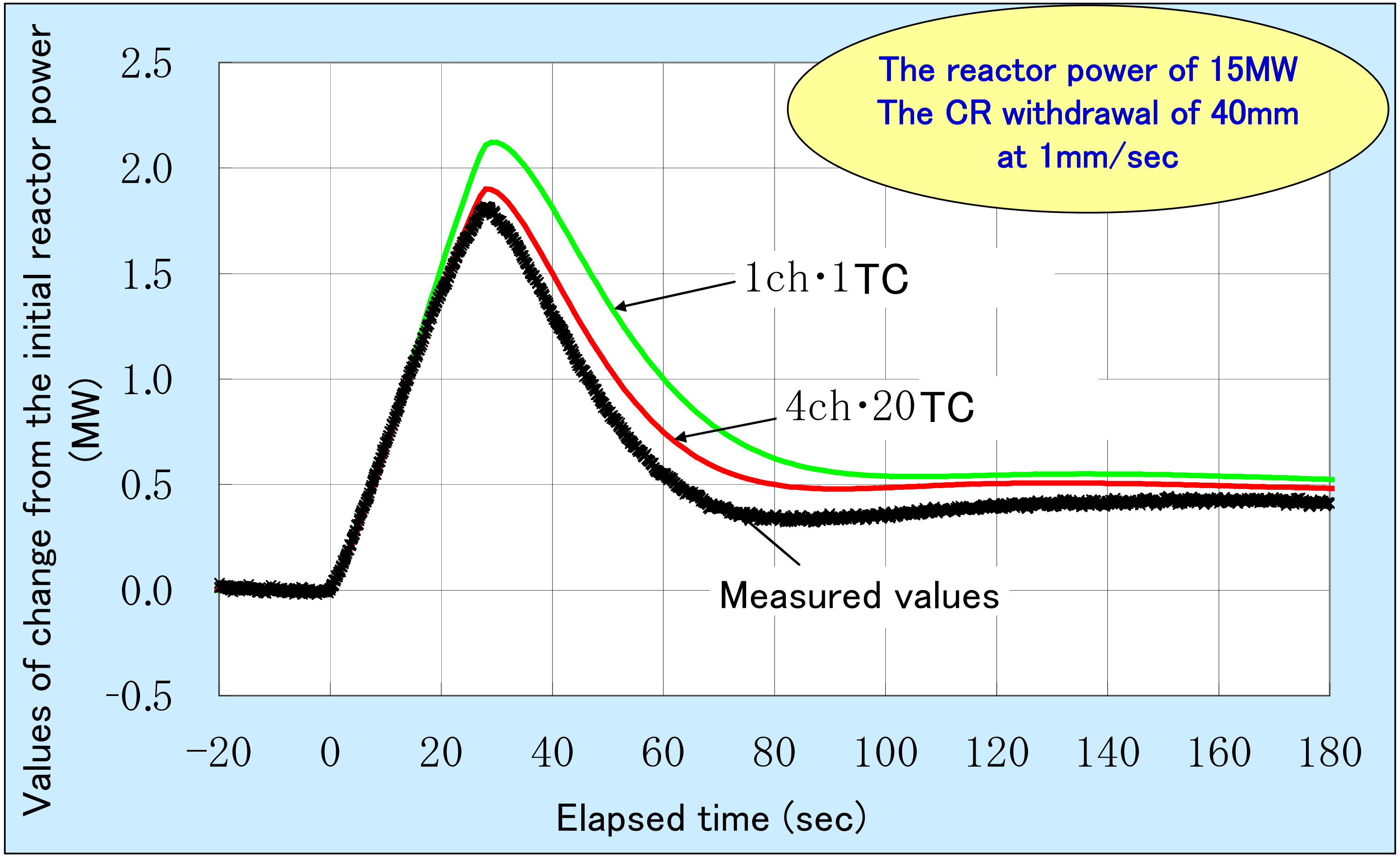
Reactivity insertion test





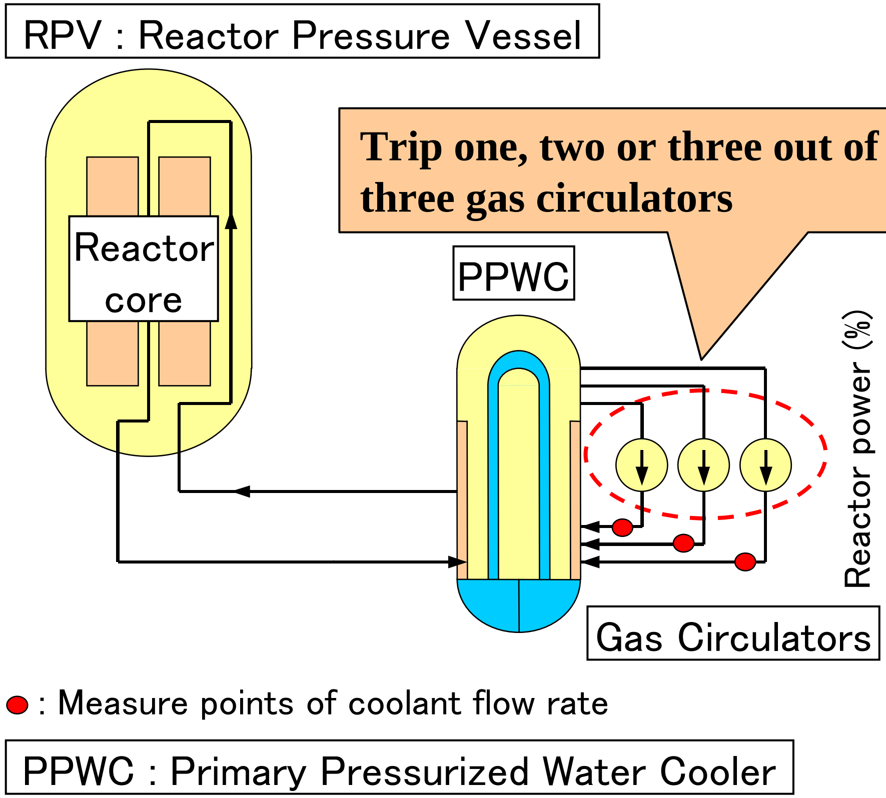
- ✧Withdraw the center control rod
- ✧The reactor power control system is not operational.
- ✧The other control rods are fixed.

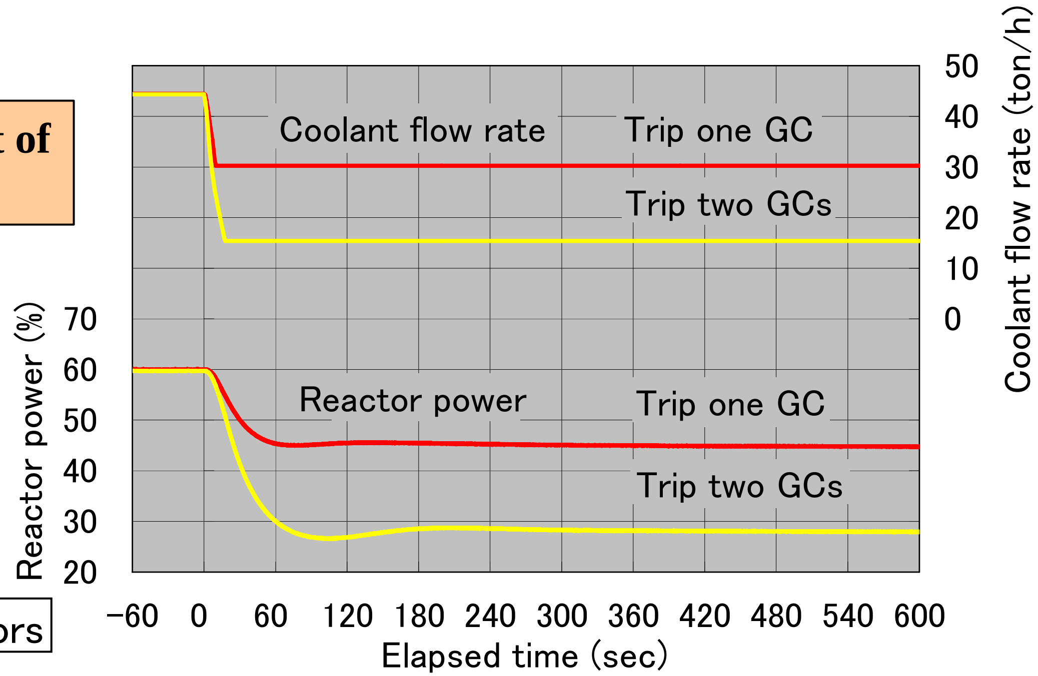
Reactor transient in reactivity insertion test



The analytical results using the 4 ch and the 20 TC can demonstrate the transients of the reactor power better than those using the 1 ch and the 1 TC.

Partial or all loss of coolant flow test

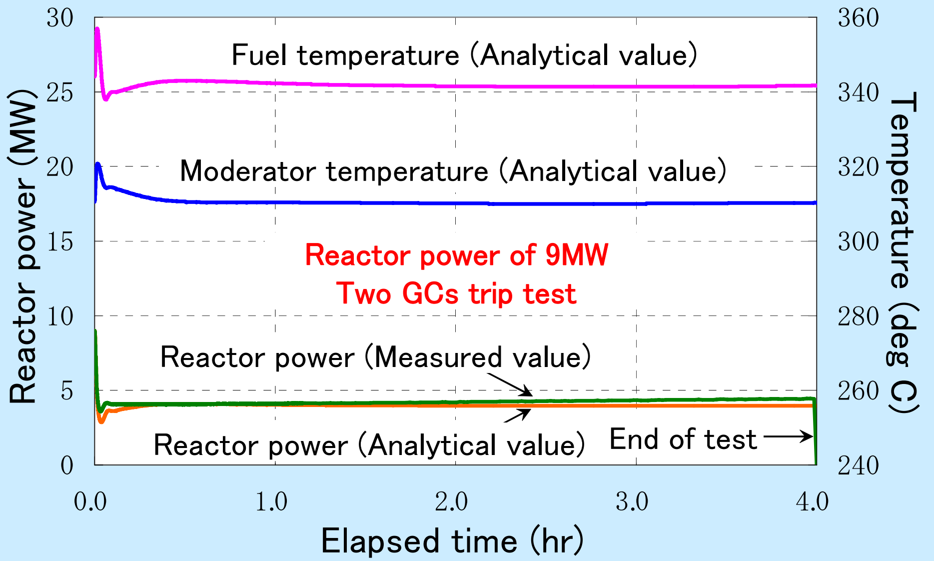


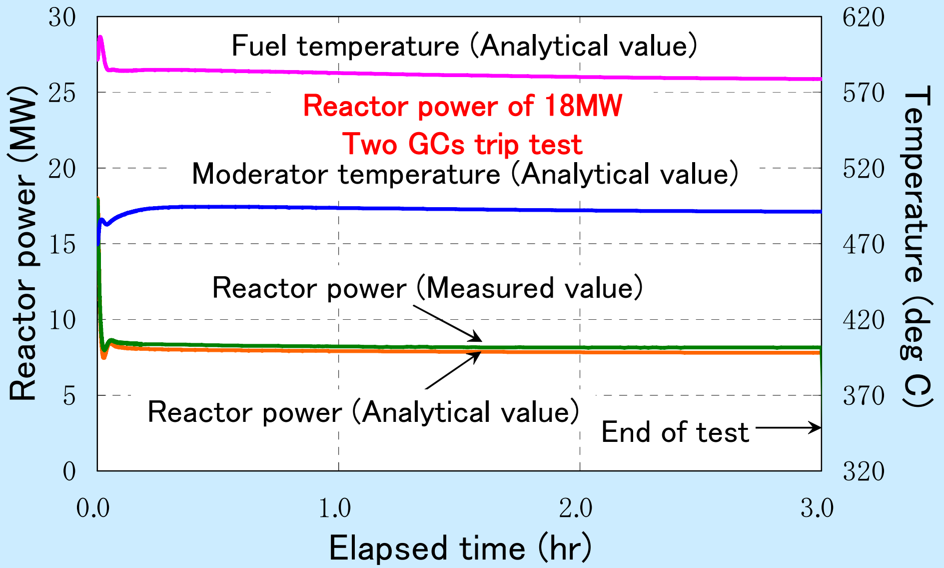


Results of partial loss of coolant flow tests

- ✧**Coolant flow rate**
  - Trip one GC: The flow rate decreases from 100% to 66%
  - Trip two GCs: The flow rate decreased from 100% to 33%
- ✧**Reactor power**
  - Trip one GC: The reactor power decreased from 60% to 45%
  - Trip two GCs: The reactor power decreased from 60% to 28%
- ✧**Anticipated Transient Without Scram**

Reactor transient in partial loss of coolant flow test

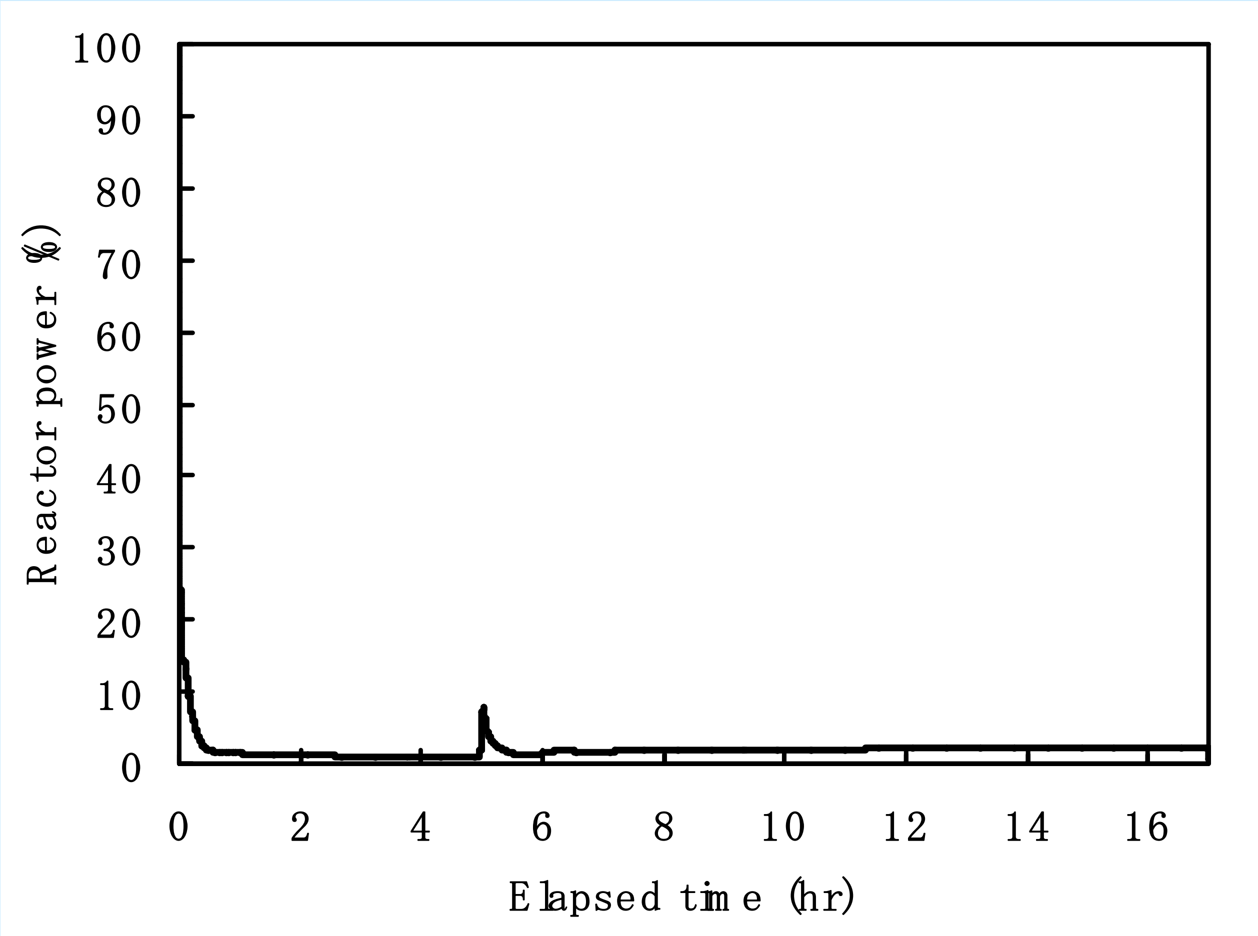




These figures show that the analytical results of transient reactor power are identical to the measured values during the tests.

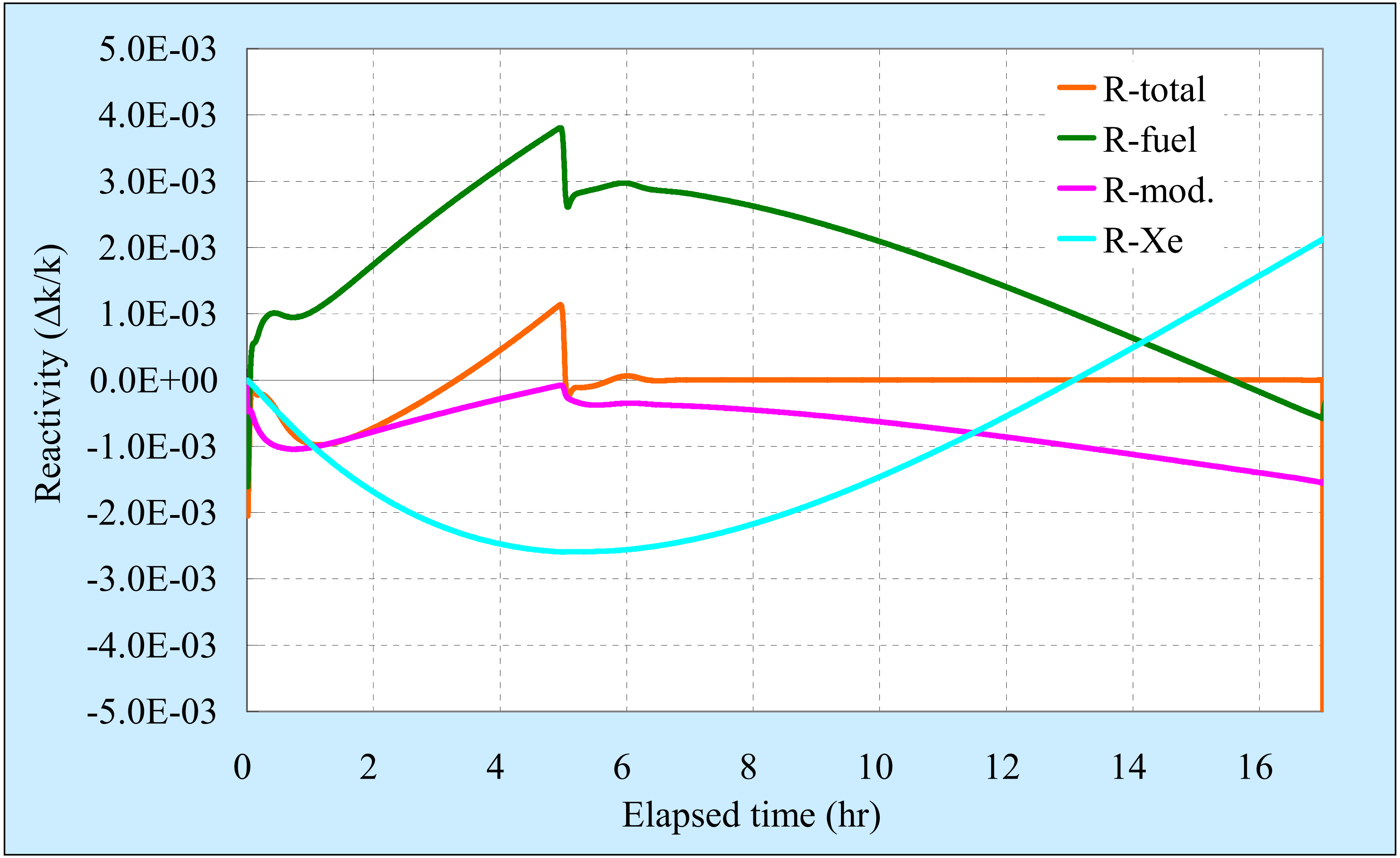
Therefore, it is confirmed that the code is able to simulate the pre-analysis in loss of coolant flow test.

Reactor transient in loss of coolant flow test



Although the reactor power becomes critical again, the peak power value is merely 2MW.
The reason is that the core temperature decreases.

Reactivity transient in loss of coolant flow test



Negative reactivity is inserted as soon as the all gas circulators trip. After that, the total reactivity increases due to the decrease of the core temperature.

Conclusions

- The safety demonstration tests are performed on the HTTR and many valuable data for establishing and upgrading the VHTR technologies have been measured.

- The improvement and validation of the analytical model for considering the distribution of three dimensional temperature coefficients and the radial heat transfer of the core is successful to simulate the reactor transient with accuracy.

- JAEA will provide the HTTR data for development of computational methods and validation for the VHTR system through not only the IAEA CRP but also the GIF VHTR projects.