4. Reactor Cooling System

4.1 Main Cooling System

The main cooling system (MCS) of the HTTR is composed of a primary cooling system(PCS), a secondary helium cooling system (SHCS) and a pressurized water cooling system (PWCS) as schematically shown in Fig. II.4.1. The PCS, which has gas circulators and two heat exchangers, i.e. a helium-helium intermediate heat exchanger (IHX) and a primary pressurized water cooler (PPWC), removes the heat from the reactor core to the SHCS and PWCS. Primary helium gas is transferred from the core to the IHX and the PPWC through a primary concentric hot gas duct. The SHCS, composed of the secondary pressurized water cooler (SPWC) and a gas circulator, removes the heat from the primary helium gas through the IHX. The PWCS consists of an air cooler and water pumps. The air cooler cools the pressurized water for both the PPWC and the SPWC, and transfers the heat from the reactor core to the final heat sink of atmosphere.

The HTTR is operated in two loading modes. One is a parallel loaded operation in which the IHX and the PPWC are operated simultaneously. Their heat removal rates are 10 and 20MW, respectively. The other is a single loaded operation in which the reactor is cooled only by the PPWC of 30MW.

The IHX is a vertical helically-coiled counter-flow type heat exchanger in which the primary helium gas flows on the shell side and the secondary helium gas in the tube, as shown in Fig. II.4.2. The primary helium gas enters the IHX through the inner pipe of the primary concentric hot gas duct attached to the bottom of the IHX. It flows out to the primary circulator via the upper outlet nozzle of the IHX and flows back to the outer annular space between the inner and outer shells. On the other hand, the secondary helium gas flows downwards in the heat transfer tubes to the hot header and turns upwards through the central hot gas duct (center pipe).

In September 1994, the IHX was installed in the reactor containment vessel. Pressure-proof and leakage tests for the MCS were

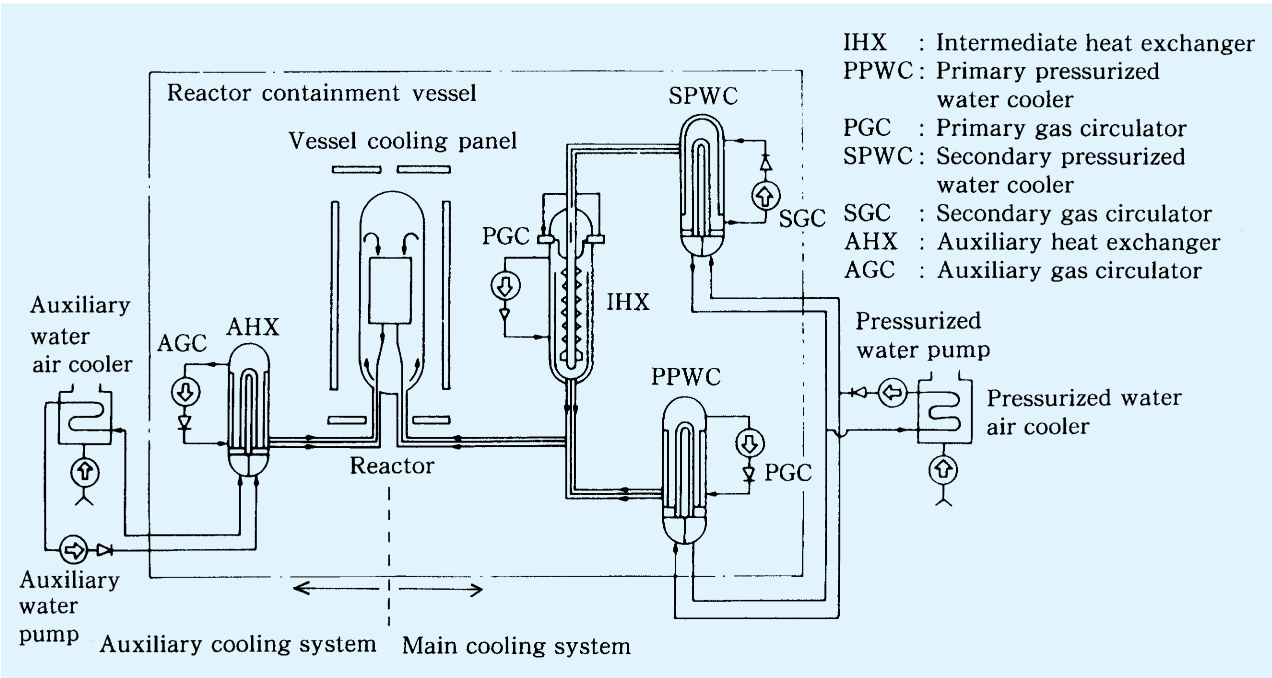

Fig. II.4.1 Cooling system.

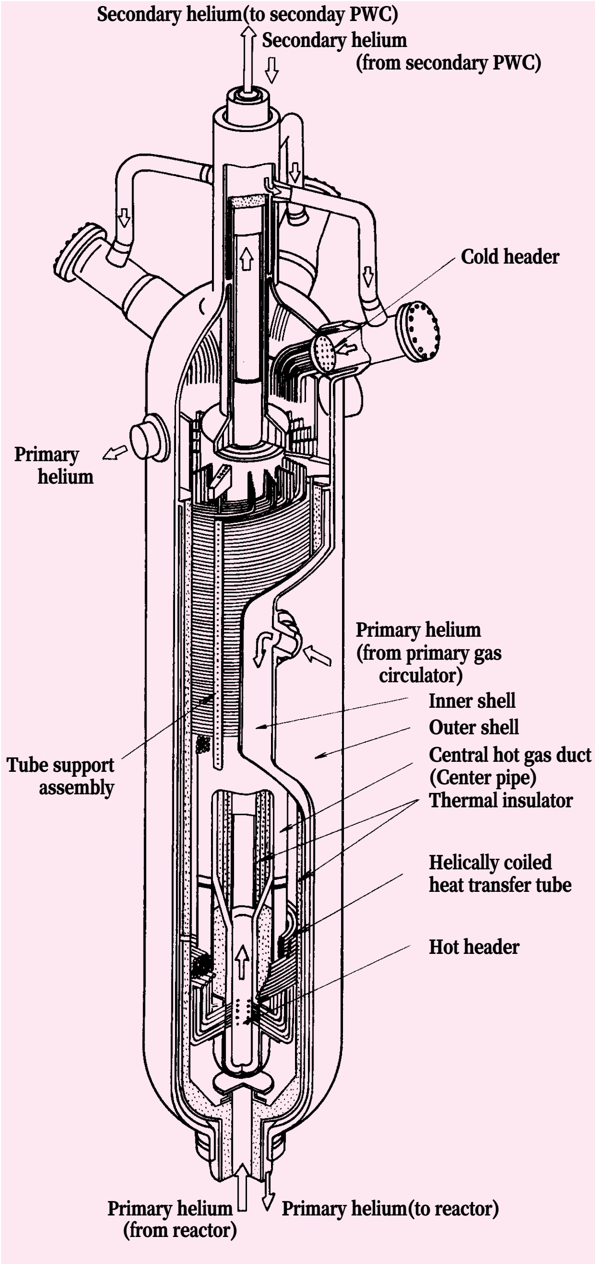

Fig. Ⅱ.4.2 Cutaway view of the He/He intermediate heat exchanger of the HTTR.

carried out in March 1996.

4.2 High Temperature Components

The pressure boundary of the main components, such as the IHX, the PPWC, the SPWC, an auxiliary heat exchanger (AHX) and the primary concentric hot gas duct, operate at a temperature of around 400℃. The pressure boundary between the primary and secondary helium gas, such as the heat transfer tubes of the IHX, is in service at a temperature of approximately 900℃ during the high temperature test operation.

To assure the structural integrity of these high temperature components, the following considerations are introduced:

(i) Usage of several kinds of heat-resistant metallic materials, taking into account the service conditions of the components,

(ii) Application of various countermeasures as shown later for overcoming the severity of the service conditions, and

(iii) Establishment of a reliable high temperature structural design guideline.

For item (i), two commercial materials and a new super alloy, which has been developed for the HTTR, are used as shown below:

- 2¼ Cr-1Mo steel is used for the reactor coolant pressure boundary in service at approximately 400℃,
- Austenitic stainless steels (SUS 321TB and SUS 316) are used for the heat transfer tubes of the PPWC, the AHX and the SPWC,
- Ni-base corrosion- and heat-resistant superalloy, Hastelloy XR, is used for the heat transfer tubes of the IHX and other reactor coolant flow boundaries in service at the highest temperature level of 950℃.

For item (ii), several new ideas are applied especially to the very high temperature components as shown below:

- Adopting co-axial double wall structures for high temperature piping and shells of the heat exchangers, such as the IHX, the PPWC, the SPWC and the AHX, to separate the heat-resisting and pressure-retaining boundaries in order to reduce the temperatures of the pressure-retaining boundary,
- Lowering the pressure difference between the primary and the secondary coolants in order to reduce pressure loads acting on the heat transfer tubes of the IHX. In the case of this IHX, the primary coolant pressure is designed

to be lower by about 0.1MPa than the secondary one.

For item (iii), Table Ⅱ.4.1 shows features of the structural design guideline for the high temperature components.

The high temperature components of the HTTR have been demonstrated to be reliable through the long-term operation of similar types of high-temperature components in the Helium Engineering Demonstration Loop (HENDEL) facility and the high-temperature helium test loop of the Engineering Research Association of Nuclear Steelmaking (ERANS).

Table Ⅱ.4.1 Feature of the high temperature structural design code.

Materials	Feature of code
2¼ Cr-1 Mo Steel Austenitic stainless steel (SUS321 and SUS316)	Design rules are the same as those of high-temperature design code for FBR "Monju" (FBR Code)
Ni-base He corrosion-and heat-resistant superalloy (Hastelloy XR)	Design rules are estsblished on the basis of material properties and component test data referred to the FBR Code

Significant failure modes	Feature of design rules
Creep rupture	Limiting the primary stress intensities
Creep-fatigue failure	Limiting the accumulated creep-fatigue damage by primary + secondary + peak stresses
Loss of function by excessive deformation	Limiting the strain
Creep buckling	Limiting the loads and strains