JAPANESE HTTR PROGRAM FOR DEMONSTRATION OF HIGH TEMPERATURE APPLICATIONS OF NUCLEAR ENERGY

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Abstract

Construction works of the HTTR started in March 1991 in order to establish and upgrade the HTGR technology basis, to carry out innovative basic researches on high temperature engineering and to demonstrate high temperature heat utilization and application of nuclear heat. This report describes the demonstration program of high temperature heat utilization and application.

Introduction

Consumption of a huge amount of fossil fuels resulted from human activities since the industrial revolution causes an enhanced global warming. Concerning about global warming due to emission of CO_2, it is essentially important to make efforts to obtain more reliable and stable energy by extended use of nuclear energy including high temperature heat from nuclear reactors, because it can supply a large amount of energy with little amount of CO_2 emission during their plant life.

First Japanese R&D program on HTGR-heat utilization system for demonstration of the direct steel making and multi purpose such as hydrogen production and steam reforming had performed since 1969. In this program, the following R&D was done ; design of experimental very high temperature reactor (VHTR), research of reactor physics, development of fuels, materials of graphite and heat resistant alloys, high temperature components and etc.. Unfortunately this program was discontinued in 1980 for the reason that industries did not require the direct steel making at that time.

Next program for demonstration of high temperature application of nuclear energy was decided by Japan Atomic Energy Commission in 1987 and recommended of early construction of test reactor of VHTR which is High Temperature Engineering Test Reactor (HTTR).

Construction works of the HTTR started in March 1991 in order to establish and upgrade the HTGR technology basis, to carry out innovative basic researches on high temperature engineering and to demonstrate high temperature heat utilization and application of nuclear heat.[1]

This report describes the demonstration program of high temperature heat utilization and application.

Outline of the HTTR

The HTTR is a test reactor with thermal output of 30MW and outlet coolant temperature of 850°C at rated operational condition and of 950°C at the high temperature testing condition. The HTTR plant is composed of a reactor building, a spent fuel storage building, a machinery and so on. The HTTR reactor building is 48m × 50m in size with two floors aboveground and three floors underground. A reactor vessel, an intermediate heat exchanger and other heat exchangers in cooling system are installed in the reactor containment vessel. The major specification of the HTTR are listed in Table 1.

Table 1 Major Specifications of the HTTR

Thermal power	30MW
Outlet coolant temperature	850°C/950°C
Inlet coolant temperature	395°C
Fuel	Low enriched UO_2
Fuel element type	Prismatic block
Direction of coolant flow	Downward
Pressure vessel	Steel
Number of cooling loop	1
Heat removal	IHX and PWC (parallel loaded)
Primary coolant pressure	4MPa
Containment type	Steel containment
Plant lifetime	20 years

Block type fuel element such as pin-in-block is adopted since it has the advantage of fuel zoning, controllability of coolant flow rate in each column, operability of control rods, etc.. The core consist of 30 fuel columns and 7 control rod guide columns as shown Fig. 1 and is cooled by helium gas of 4MPa flowing downward. Replaceable reflector blocks including 9 control rod guide columns and 3 irradiation test columns surround the core. The core and replaceable reflector blocks are installed within the permanent reflector blocks fixed by the core restraint mechanism. These core structure components are placed on the graphite core support structures and the metallic core support structures as shown Fig. 2.

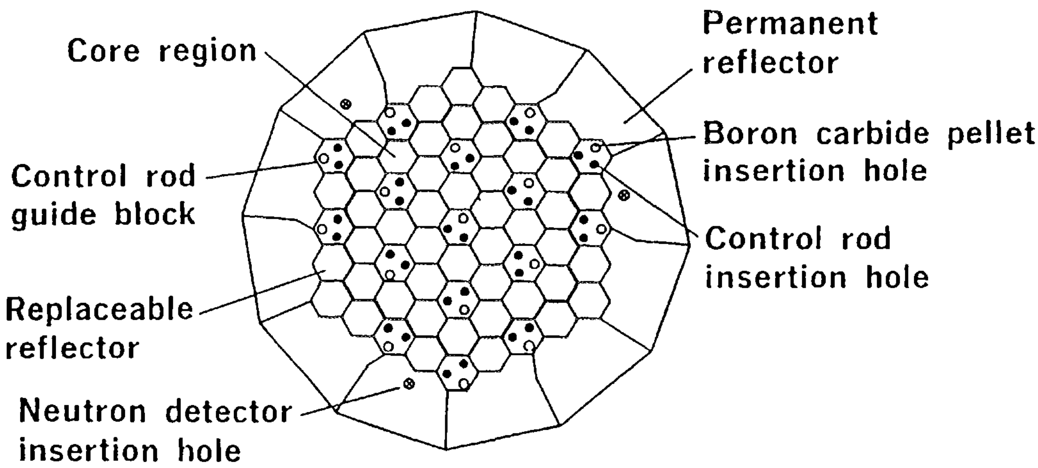


Fig. 1 Cross Section of the HTTR Core

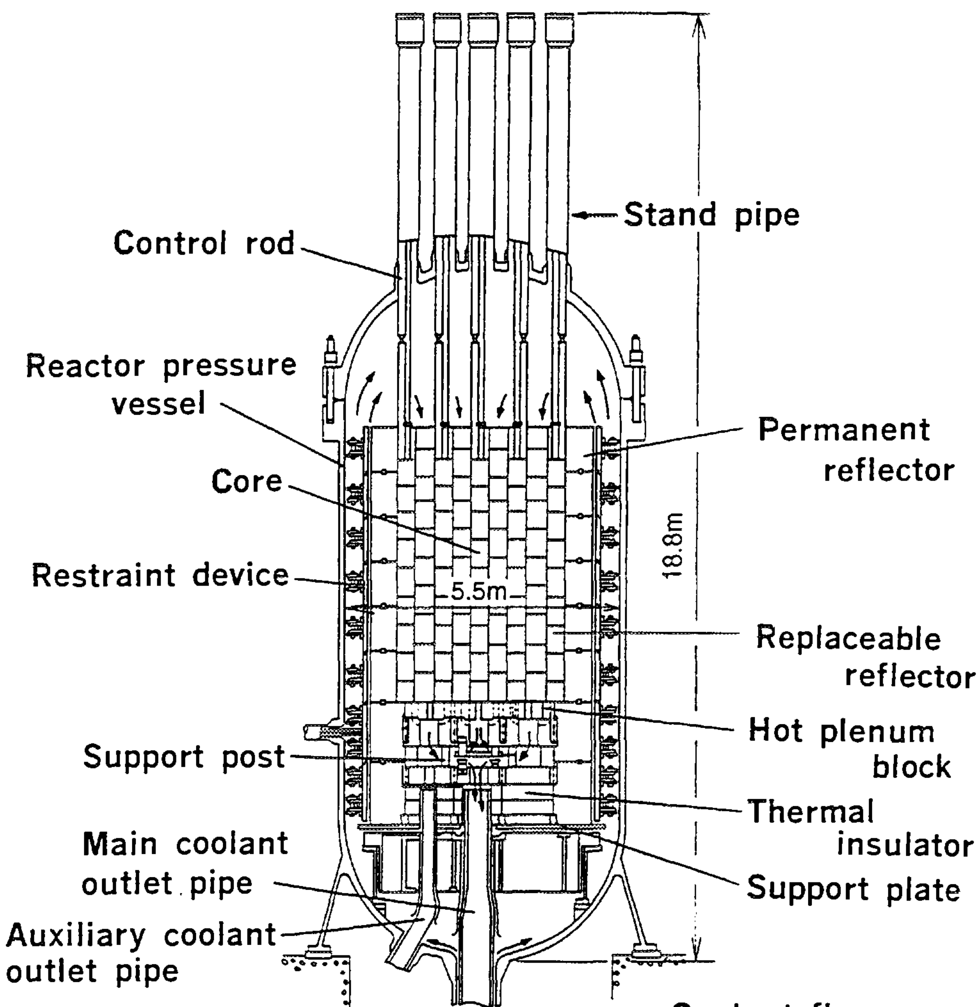


Fig. 2 Vertical Section of the HTTR Reactor Vessel

Flow diagram of cooling system in the HTTR is shown in Fig. 3. The main cooling system of the HTTR is composed of a primary cooling system, a secondary helium cooling system and a pressurized water cooling system. Two heat exchanger such as a He-He intermediate heat exchanger (IHX) and a primary pressurized water cooler (PPWC) are installed on the primary cooling system. The heat from the core is transferred to the IHX and PPWC through the concentric hot gas duct in which outlet helium gas at temperature of 850°C/950°C flows inside the inner tube and inlet gas of 400°C flows in the annular path. Pressurized water is cooled by air cooler.

The HTTR is planed to be operated in two loading modes. One is a parallel loaded operation in which the IHX and the PPWC are operated simultaneously. Their heat removal rate are 10 and 20MW, respectively. The other is single loaded operation in which the PPWC is only operated and remove the heat of 30MW.

Auxiliary cooling system (ACS) is operated to remove the residual heat from the core at reactor scram.

Heat utilization system will be connected to the IHX. The nuclear heat of 10MW at temperature of 905°C and pressure of 4.1MPa is transported to the heat utilization system.

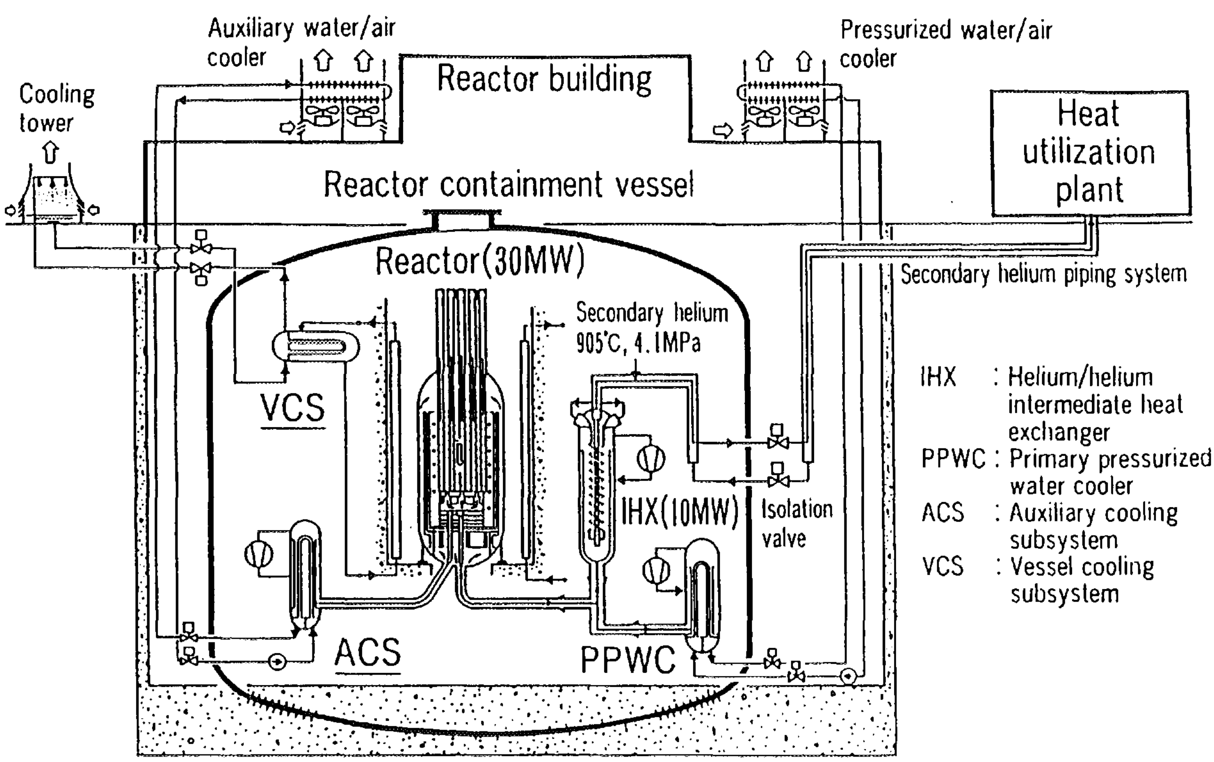


Fig. 3 Simplified Flow Diagram of Cooling System in the HTTR

The construction of the HTTR started in March 1991 as shown Table 2. A functional test operation of the reactor cooling system has been performed since May 1996. Fuels will be loaded into the core around in September 1997 and first criticality is expected in December 1997.

HTTR heat application

Top priority objective for development the heat utilization system connected to the HTTR is to demonstrate technical feasibility of a nuclear process heat utilization system for the first time in the world. From a technical point of view, the following feasibility and reliability should be demonstrated.

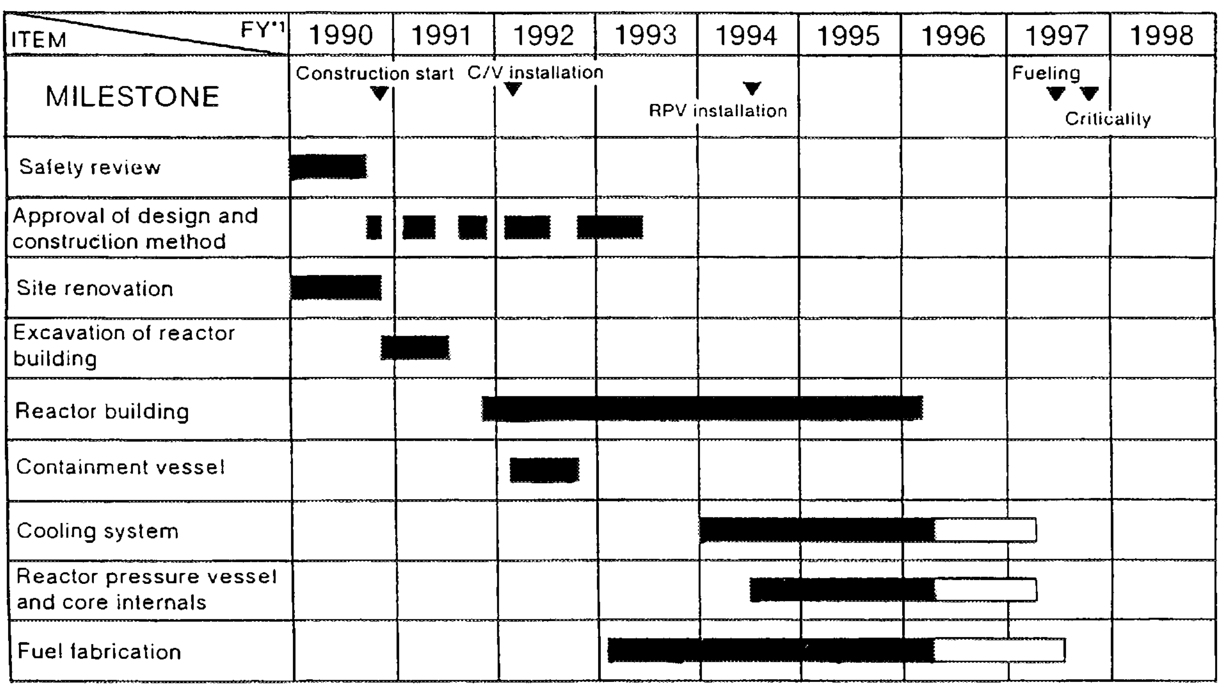
(1) Feasibility of control design concept for the total system including start-up and shutdown procedure.

(2) Feasibility of safety design concept for the total system including interface concept.

(3) Reliability of helium-heated components.

The primary candidate of the first HTTR heat utilization system must have the universality of control and safety design concepts to be demonstrated. Because basic features of these design concepts shall be applicable to other candidates of nuclear process heat chemical systems. And technologies of helium-heated components must have been proven in order to demonstrate the first HTTR heat utilization system as soon as possible.

Table 2 Construction Schedule of the HTTR



*1 Fiscal year of Japan starts in April and ends in March

We have chosen the steam reforming system as the primary candidate because the steam reforming system has a similarity to other candidate systems with respect to the system arrangement and the heat of endothermic chemical reaction. Candidate systems have high temperature endothermic reactor plus steam generator (SG), and the their heat of reaction are as high as 200kJ/mol. And Helium-heated steam reformer has been basically developed in the former project. Furthermore the steam reforming system is an economical and a mature technology. Then technical solusions demonstrated in the HTTR will contribute to other candidates.

At a preliminary design conducted from 1990 through 1995, we has developed a framework of the HTTR-steam reforming system. Key design achievements were as follows.[(2)]

(1) By applying a new concept of steam reformer (SR) and by optimizing arrangement of helium-heated components and related heat-material balance conditions of the system, high heat utilization efficiency of 78% is achieved and is competitive to the efficiency of 80-85% of a fossil-fueled plant of steam reforming.

(2) A SG was allocated downstream the SR to achieve sufficient system controllability. At start-up of the system, helium gas temperature increses in proportion to reactor power. On the other hand, in an endothermic chemical reaction, a heat input enough to cause the reaction dramatically increses with incresing reaction temperature due to the Arrenhius type temperature dependence of reaction rate. It is necessary to balance such a quite difference in thermal dynamics between the nuclear reactor and the chemical reactor at start-up condition without reactor scram. We found that the outlet temperature of the SG is not depend on the outlet temperature of the SR and inlet of the SG due to a large latent heat of the hold up water in the SG as shown in Fig. 4. It is possible to control the feed gas flow rate to balance the difference of thermal dynamics. The SG can adsorp the quite difference in thermal dymanics so that the safety and stable start-up of the system would be performed.

The conceptual and detail design will be carried out for the safety review and construction of the heat utilization system. The draft plan of the HTTR-steam reforming system development is shown Table 3.

International cooperation

In order to promote the HTGR R&D efficiently, the JAERI has proceeded with international cooperation with research organizations in China, Germany,

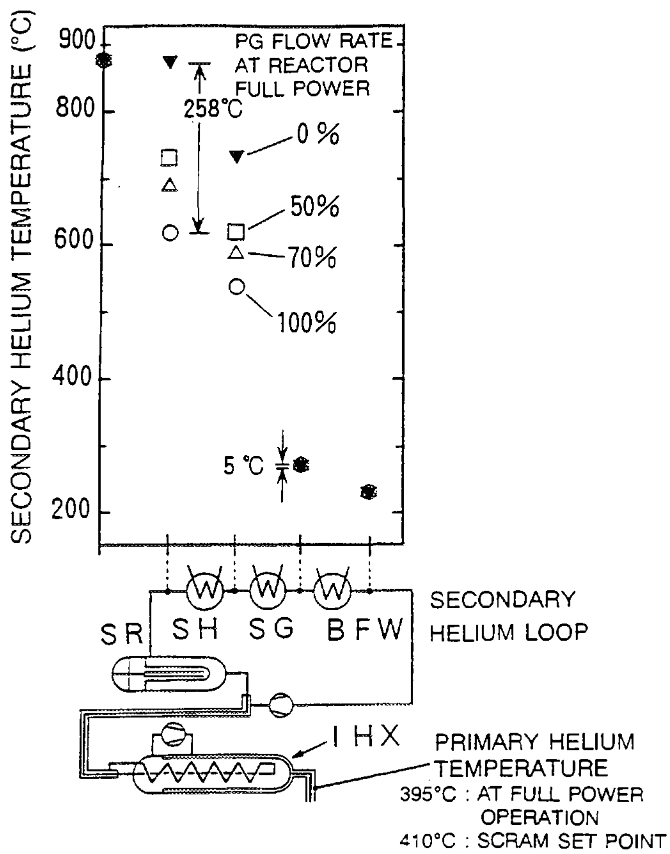


Fig. 4 Helium Temperature Variation in the Hydrogen Production System

Table 3 Draft Plan of the HTTR-Steam Reforming Hydrogen Production System Development

Item	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16
1. HTTR	Construction		Criticality (▲)	Ascent-to -power	Initial core			Second core		
2. Design and construction of hydrogen production system (Steam reforming system)	Conceptual design		Detailed design		Safety review	Construction		Demonstration test		
3. Out of pile demonstration test	Design	Construction		Test						
4. IAEA CRP-4	Conceptual design and safety evaluation			Next CRP (Demonstration tests at out-of-pile test facility and at the HTTR)						

United Kingdom and USA. In these R&D cooperation, we have exchange the technology information, irradiation test and heat utilization test, and we will be able to transfer the R&D results to be obtained in the HTTR and HTTR-steam reforming system. We have positively contributed and will contribute to the International Working Group on Gas-cooled Reactors and the Coodinated Reserch Programs organized by the IAEA.

REFERENCES

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(2) Design of steam reforming hydrogen and methanol co-production system to be connected to the HTTR, K.Hada, N.Fujimoto, Y.Sudo, IAEA TECDOC 761