PRESENT STATUS OF THE HIGH TEMPERATURE ENGINEERING TEST REACTOR (HTTR)

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ABSTRACT

With growing concerns about global warming due to emission of greenhouse effect gases like CO_2, it is especially important to make efforts to obtain more reliable and stable energy supply by extended use of nuclear energy including high temperature heat from nuclear reactors because they can supply a large amount of energy and its plants emit only little amount of CO_2 during their lifetime. Hence, efforts are to be continuously devoted to establish and upgrade High Temperature Gas-cooled Reactor (HTGR)technologies. It is also expected that conducting basic research at high temperatures using HTGR will contribute to innovative basic research in future. The construction of the High Temperature Engineering Test Reactor (HTTR), which is an HTGR with a maximum helium coolant temperature of 950°C at the reactor outlet, was proposed by the Japanese Atomic Energy Commission (JAEC) in 1987 and is now under way by the Japan Atomic Energy Research Institute (JAERI).

The construction of the HTTR started in March 1991 and essentially completed in 1996. Functional test operations were performed in 1996 and 1997. Some refurbishments have been required to remedy the control rod drive standpipe internal structure heat-up event.

The HTTR will become critical in June 1998. A test program has already been largely defined. Physics tests will concern the first criticality measurements at zero power and during rise to power to confirm the nuclear design and the compliance to regulatory limits. In loading fuel an intermediate stage with an annular core will be created, and some physics tests be carried out. Thermal hydraulics tests will confirm the plant design and validate the respective codes. Safety tests will demonstrate the typical HTGR safety features, and tests at power operation will confirm the integrity of the high temperature components.

INTRODUCTION

A High Temperature Gas-cooled Reactor (HTGR), which is a graphite moderated, helium cooled reactor, can supply high temperature heat as high as 1000°C which offers the potential of obtaining high thermal efficiency as well as high heat-utilizing efficiency. It also has excellent features such as high inherent safety, easy operation and high fuel burnup. From the viewpoint of the global environmental protection and diversification of energy usage, non-electrical application of nuclear energy – for example hydrogen production – is very important. Therefore, in order to establish and upgrade the technological basis for HTGRs and also to use as a tool of basic researches for high temperature and neutron irradiation the Japan Atomic Energy Research Institute (JAERI)has been constructing a 30MWt High Temperature engineering Test Reactor (HTTR)at the Oarai Research Establishment. Since the 10th Pacific Basin Nuclear Conference which was held in Kobe, Japan in October 1996 (Tanaka 1996) construction works of the HTTR have progressed well and have been near the final stage of the functional test in 1997. The first criticality is scheduled in 1998. This report describes the present status of the HTTR.

PRESENT STATUS OF HTTR

The HTTR plant is composed of a reactor building, a spent fuel storage building a machinery building and so on. The reactor building is 48m by 50m with two floors above ground and three below. Major components such as the reactor pressure vessel (RPV) primary cooling system components etc. are all inside the containment vessel. Air cooling towers for the cooling system are located on the roof of the reactor building. The construction of reactor building began in March 1991 and all major components had been installed by March 1996. The major specification of the HTTR is shown in Table 1.

The block type fuel, instead of the pebble-bed, is adopted in the HTTR considering the advantages of fuel zoning, control of coolant flow rate in each column, easy insertion of control rods (CRs), irradiation flexibility in the core. Core components and reactor internals have been installed in the RPV from May to August 1995. Gaps between core components and reactor internals are carefully controlled to maintain the required minimum during the assembling. The installed core arrangement of a upper shield region is shown in Photo 1. The active core is 2.9m in height and 2.3m equivalent diameter and the core is cooled by helium gas of 4MPa flowing downward. The core has 30 fuel columns (with 5 blocks in each column) and 7 CR guide columns, which is surrounded by columns of replaceable reflector blocks and additional CR guide blocks. The reactivity is controlled by the control rods system which consists of 32 control rods (16 pairs) and 16 control rods drive mechanisms. The installation of the system in the RPV started in December 1995 after placing the upper biological shielding structure.

The reactor cooling system is composed of the MCS, ACS and VCS as schematically shown in Fig. 1. The MCS is operated during normal operation condition to remove heat from the core and send it into the environment. The ACS and VCS have incorporated safety features. The ACS is initiated to operate in case of a reactor scram. In addition to the two components of VCS, either one of which has sufficient capacity to remove residual heat, the ACS is provided to cool down the core and core support structure. A helically coiled intermediate heat exchanger (IHX) whose heat-resistant material is Hastelloy-XR developed by JAERI had been installed by September 1994. Primary helium gas is transported from the reactor core to the IHX and primary pressurized water cooler (PPWC) through a concentric hot gas duct. It consists of a pressure tube, an inner tube and an internal insulation reinforced with the liner. The helium gas at temperature of 400°C flows in annular path and of 950°C inside the inner tube. The pressure tube (outer diameter 860mm, thickness 42mm) can contain high pressure helium gas at 4.0MPa. The inner tube, which separates the high and low temperature helium gas paths, supports the pressure difference between the high and low temperature helium gas. The internal insulation is placed between the liner and inner tube. Assembling of T shaped concentric hot gas duct have been carefully conducted with welding taking into account that the RPV is supported with the skirt while the IHX and PPWC are with floating support structures. In March 1996 the pressure-proof and leakage test of the reactor cooling system was carried out with the nitrogen gas at 6.0MPa. No leakage for the nitrogen gas has been confirmed because the amount of helium gas leaking into the atmosphere shall be less than 0.28 percent of the inventory per day.

Functional test operations of the reactor cooling system have been performed since May 1996 and will continue until March 1998. At first the whole reactor cooling system was evacuated by several vacuum pumps and filled with the helium gas. Because of the large volume of the system and the outgases from both the graphite and the ceramic insulation with the temperature increase, a large quantity of chemical impurities in the helium gas are expected, that will be removed by the helium purification system (HPS) to the concentration sufficient to reduce oxidation of the graphite. The helium gas flow rate in the HPS for the primary cooling system (670kg) is 200kg/h. In the copper oxide fixed bed, hydrogen and carbon monoxide are converted to water vapor and carbon dioxide, that are absorbed by a molecular sieve trap. Noble gases, methane, oxygen and nitrogen are absorbed by a cold charcoal trap. At the stage of a functional test without nuclear heating, the helium gas has been heated by gas circulators up to about 200°C at 2MPa. Functional tests of the cooling system has been performed at this operational condition to accumulate operational experience. Plant control systems have been fully checked. During the functional test several improvements in the system have been carried out in terms of securing its safety margin and easy operation. Problems such as excessive helium leakage and local heating of the concrete structure have been assessed. Related with heating operation with gas circulators higher temperature of the helium atmosphere inside the stand-pipe around CR drive mechanisms had been observed in January 1997. This occurred due to the excessive helium bypass leakage between the CR drive internal structure and the stand-pipe. Refurbishments such as to add pressure balance holes at the CR shroud and to provide the seal along the internal structure had been conducted by September 1997. Their performance has been confirmed. Final functional test will be conducted from January to March in 1998.

The fuel fabrication started in June 1995 and completed in November 1997. Refueling is done by replacing the complete fuel assembly in its graphite block. A special refueling machine has been built that can replace one column of fuel blocks at one connection to a standpipe. The blocks are lifted one at a time and moved into a rotating rack in the fuel handing machine and then fresh fuel assemblies are lowered into the core.

Another machine has been provided for replacing control rods. Photo 2 shows HTTR fuel handling area with full handling and control rod handling machines. Placing fuel rods in holes of graphite block of the feel assembly, have been conducted since September 1997 and will end in December 1997. Fuel will be loaded into the core around April 1998 and the first criticality is expected in June 1998. Fuel will be loaded column-wise from the outer fuel column to the inner one and 17 of the total 30 fuel columns will make the reactor critical. Figure 2 shows fuel loading numbers in criticality approach. The first criticality will be attained in a shape of annular core. The excess reactivity and control rod worth will be measured by the Inverse Kinetic method. Preliminary tests to validate the measuring method have been conducted in the Very High Temperature Reactor Critical assembly (VHTRC).

An overview of the physics tests is given in Table 2.

Thermal hydraulics testing will verify the thermal hydraulic layout of the plant and help to further validate the respective codes.

Test conditions

(a) Rise to power (single and parallel loaded operation)

Thermal output	30, 50 and 80% of 30 MW
Coolant inlet temperature	about 180, 241, 334C
Coolant outlet temperature	about 318, 470, 698C
Primary coolant flow rate	12.4 kg/s
Primary coolant pressure	about 2.6, 3.0, 3.6Mpa (gauge)

(b) Rated operation (single and parallel loaded operation)

Thermal output	30MW
Coolant inlet temperature	395C
Coolant outlet temperature	850C
Primary coolant flow rate	12.4kg/s
Primary coolant pressure	4.1Mpa (gauge)

(c) High temperature test operation (single and parallel loaded operation)

Thermal output	30MW

Coolant inlet temperature	395C
Coolant outlet temperature	950C
Primary coolant flow rate	10.2kg/s
Primary coolant pressure	4.1Mpa (gauge)

The tests will address the steady state behavior of the plant and also its response to various simulated disturbances (mild transients). With the automatic control system in operation, these transient tests will investigate the control system performance. With the control system disengaged the transient tests are a prestep to dynamics tests. Real dynamics tests, i.e. with large transients, are conducted as the safety tests.

Other tests within the thermal hydraulics area look at the performance of the ACS after scram shutdown and, in particular at the performance of the VCS at both normal operation and accident conditions.

CONCLUDING REMARKS

The HTTR is a high temperature gas cooled test reactor that has various aims and operational modes. The construction of the HTTR has progressed rather smoothly and its first criticality is expected in June 1998.

The various tests by the HTTR will make a great contribution to confirm the salient characteristics of HTGRs including reliable supply of high temperature heat as high as 950C, high inherent safety and the application of high temperature heat from HTGRs to various fields. It will also contribute to reducing global environmental problems. Furthermore the HTTR has a unique and superior capability for carrying out high temperature irradiation tests not only for development of advanced HTGRs but also for basic research. The HTTR is confidently expected to make a strong contribution to promoting international cooperation in these fields.

REFERENCES

T.Tanaka and et al, “Construction of the HTTR and its Testing Program”, Atomic Energy Society of Japan and Japan Atomic Industrial Forum, 10th Pacific Basin Nuclear Conference Kobe Japan, Proceedings Volume 1, p.811 October 1996.

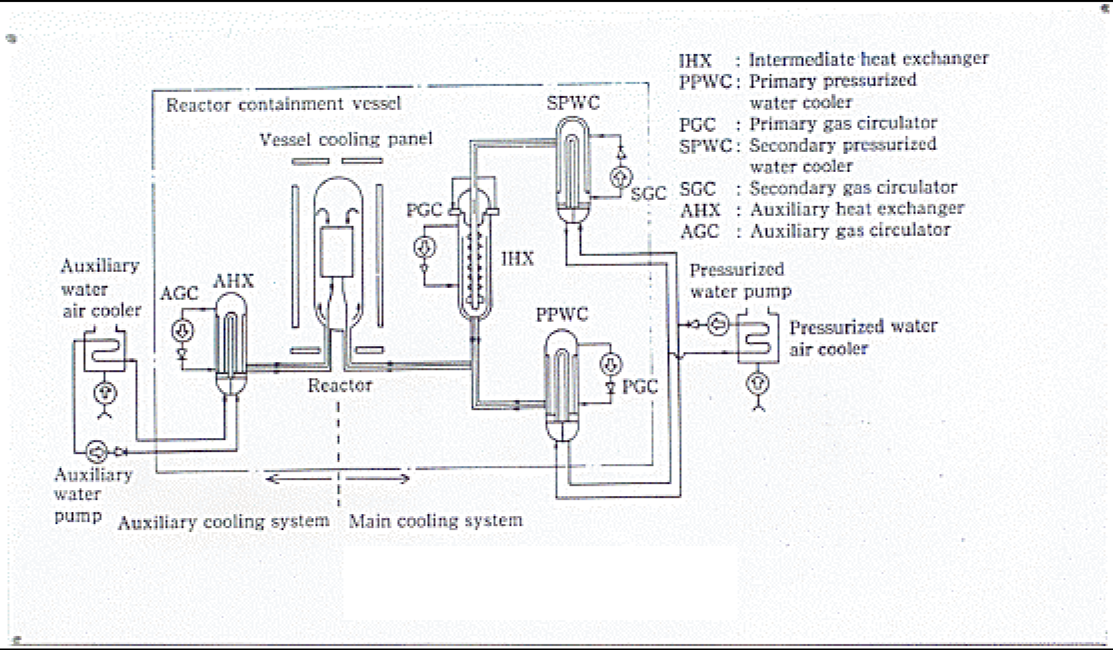

Figure 1 Flow diagram of the HTTR cooling system

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

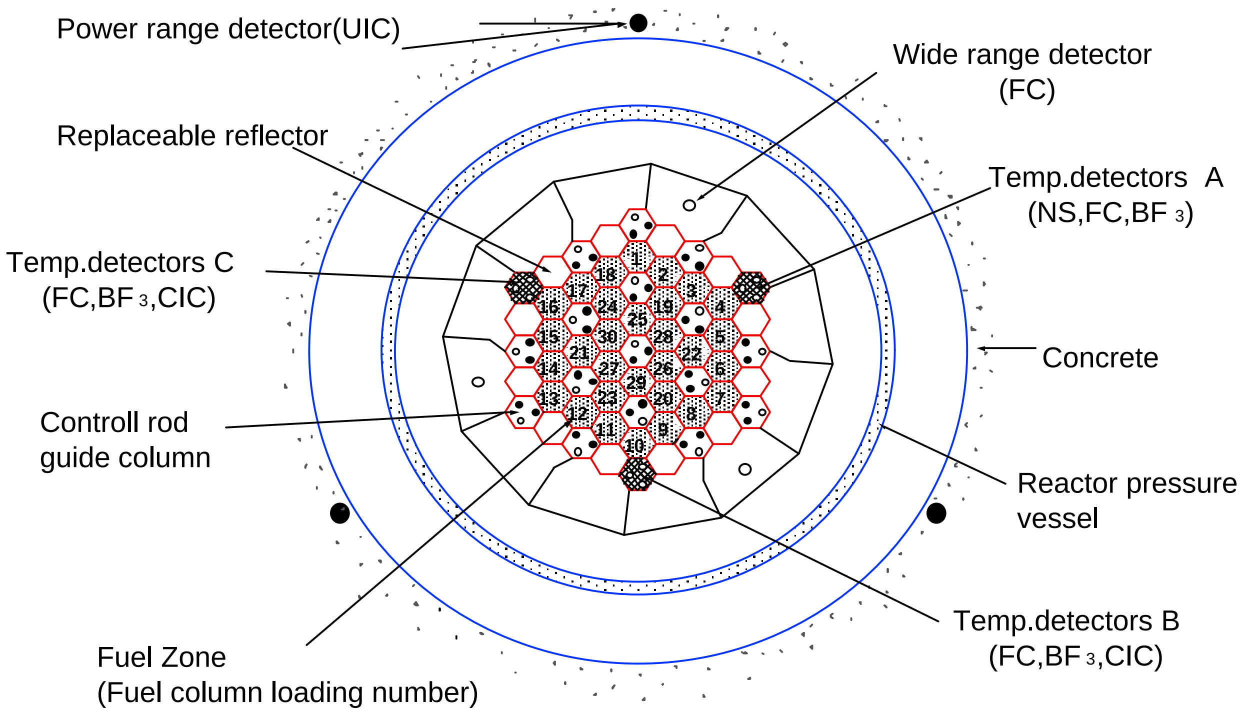

Figure 2 Loading numbers in criticality approach

Table 2 List of HTTR start-up Physics Tests He atmosphere

Item	Purpose	Method	Note
1. Criticality tests Minimum core at room temperature			
1-1 First criticality test	For license	Inverse multiplication method	
1-2 Initial Core Construction test	For license	Measurement of added fuel reactivity by IK method and scram reactivity measurement	Performed from the first criticality to the complete fuel loading
2. Annular core tests 18 columns core at room temperature			
2-1 CR reactivity worth test	For research of annular core physics	Obtain CR worth curves by IK method	Evaluation of correction factor for interaction between CRs
2-2 Measurement of scram reactivity	Same as above	Rod drop method with delayed integral counting (new) and/or IK method	New method test
2-3 Excess reactivity test	Same as above	Fuel addition method and/or Absorption substitution method (from CR worth)	Evaluation of correction factor for interaction between CRs and sum-up effect
2-4 Neutron flux distribution measurement	Same as above	Measurement of axial neutron flux distribution inside reflector by temporary detectors	
2-5 Measurement test for kinetics parameter	Same as above	Reactor noise analysis	
3. Zero-power tests 30 columns core at room temperature			
3-1 CR reactivity worth test	For license	Measurement of CR worth curves by IK method	
3-2 Reactivity control effect test of CRs	For license $>0.18\ \Delta k/k$	Summation of all CR worth obtained in 3-1	Without one pair of CRs. Evaluation of correction factor for interaction between CRs
3-3 Measurement of maximum reactivity insertion rate	For license $<2.4E-4\ \Delta k/k/s$	Evaluation from CR worth curves and CR drawing speed	
3-4 Excess reactivity test	For license $<0.165\ \Delta k/k$	Fuel addition method	Evaluation of correction factor for interaction between CRs
3-5 Reactivity shutdown margin test	For license $>0.01\ \Delta k/k$	Subtraction of value of 3-4 from value of 3-2	Without one pair of CRs
3-6 Measurement of scram reactivity	For research	As 2-2	
3-7 Neutron flux distribution measurement	For research	As 2-4	
3-8 Nuclear power correlation test	Adjustment of the wide range detectors	Reactor noise analysis and/or use of calibrated fission chamber	
3-9 Measurement test for kinetics parameter	Evaluation of b_{eff}/l	Reactor noise analysis	
3-10 Measurement of temperature coefficient of reactivity	For license <0	Reactivity measurement at various core temperatures	Core heated by primary circulator energy
4. Rise-to-power tests 30 columns core at various power and temperature levels			
4-1 Power coefficient measurement	For license <0	Measurement of CR position at various reactor power levels	
4-2 Reactivity Measurement for 2-step scram a) Measurement at first, reflector CR scram b) Subcriticality assessment in the period from first- step to second-step scram c) Measurement at second, core CR scram	For license (Research)	As 2-2	Scram shutdown procedure : Scram of core CRs delayed until coolant outlet temperature < 750°C

CR : control rod pair

Photo 1 Top view of the HTTR internals.

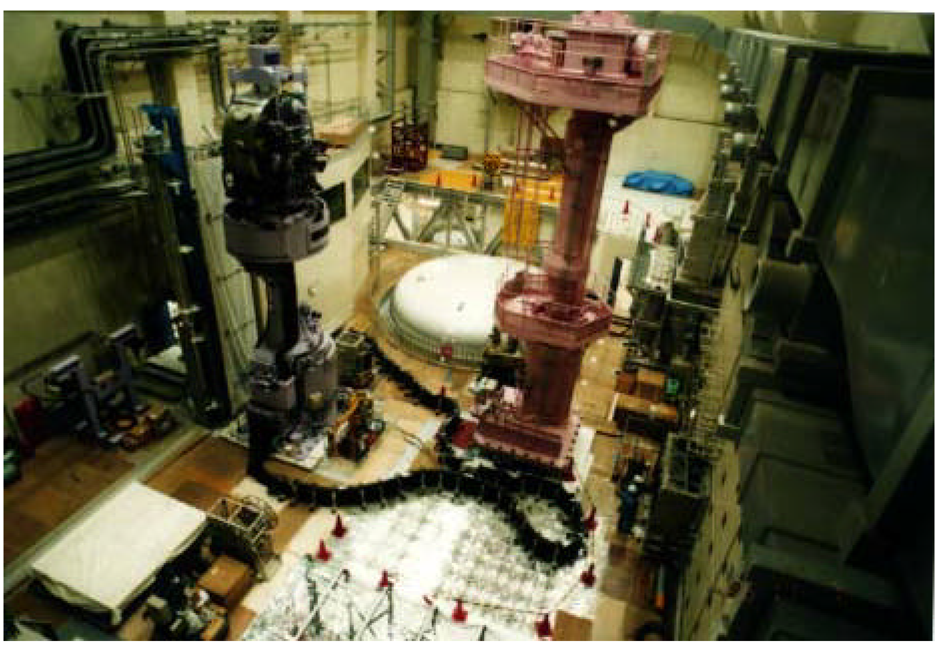

Photo 2 HTTR fuel handling area with fuel handling and control rod handling machines.