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Design of HTTR-GT/H_2 test plant

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ABSTRACT

The pre-licensing design of an HTGR cogeneration test plant to be coupled to JAEA's existing test reactor HTTR is discussed. The plant is designed to demonstrate the system of JAEA commercial plant design of Gas Turbine High Temperature Reactor for Cogeneration (GTHTR300C). More specifically the test plant (HTTR-GT/H_2) aims to 1) demonstrate licensability of the GTHTR300C system for electricity and hydrogen cogeneration and 2) confirm operation and safety performance of such cogeneration system. With construction planned to be completed around 2025, the test plant is expected to be the first-of-a-kind nuclear system operating on two of the advanced energy conversion systems attractive for the HTGR – closed cycle helium gas turbine for power generation and thermochemical iodine–sulfur water-splitting process for hydrogen production.

1. Introduction

Current Basic Energy Plan of Japan (Basic Energy Plan of Japan, 2014) calls to accelerate research and development on high temperature gas-cooled reactor (HTGR) with the goal of expanding applications while enhancing safety of nuclear energy. Accordingly the Committee advising the Ministry of Education, Culture, Sports, Science and Technology identified five areas for action (Promotion of Future R & D on HTGR Technology, 2014), including:

(1) Demonstrate heat application technologies using the existing test reactor HTTR.
(2) Develop helium gas turbine technologies.
(3) Develop iodine-sulfur (IS) process for hydrogen production.
(4) Establish safety standards.
(5) Develop advanced fuel for commercial use.

Item (1) mainly covers demonstration of high temperature coupling between nuclear reactor and various industrial plants including cogeneration and of safe and economic operation of such plants; Item (2) involves development of component and maintenance technologies required for direct cycle helium gas turbine including gas seal, turbine blade, and equipment scale up; Item (3) develops long-term continuous operation of thermochemical water-splitting IS process; Item (4) establishes safety standards for inherently safe HTGR; and Item (5) develops fuels of increased burnup to 150 GWd/t.

The HTTR-GT/H_2 plant design provides test demonstration to complete part or whole of the specific development Items (1)–(4) whereas Item (5) is being developed separately in parallel in JAEA.

Specifically the HTTR-GT/H_2 test program will design, construct and operate the first-of-a-kind nuclear gas turbine and hydrogen cogeneration plant on the 950 °C operational test reactor HTTR, confirm the licensability of such advanced cogeneration plant, and demonstrate transient system operations including startup and stop, load follow, and loss of load. With completion planned by 2025, the program will complete a key step of system technology development required to develop the lead plant for Japan's Gen-IV GTHTR300C commercial plant series (Yan et al., 2003; Kunitomi et al., 2007).

This paper presents the pre-licensing basic design of the HTTR-GT/H_2 test plant. JAEA is the design lead. Mitsubishi Heavy Industry with its know-how through development of the HTTR and the GTHTR300C as well as in the industrial gas turbine area is the lead industry partner.

2. Design considerations

The HTTR-GT/H_2 test plant consists of a Brayton-cycle helium gas turbine power conversion system, designed to be air-cooled for variable ambient temperatures and produce about 1 MWe electric power output,

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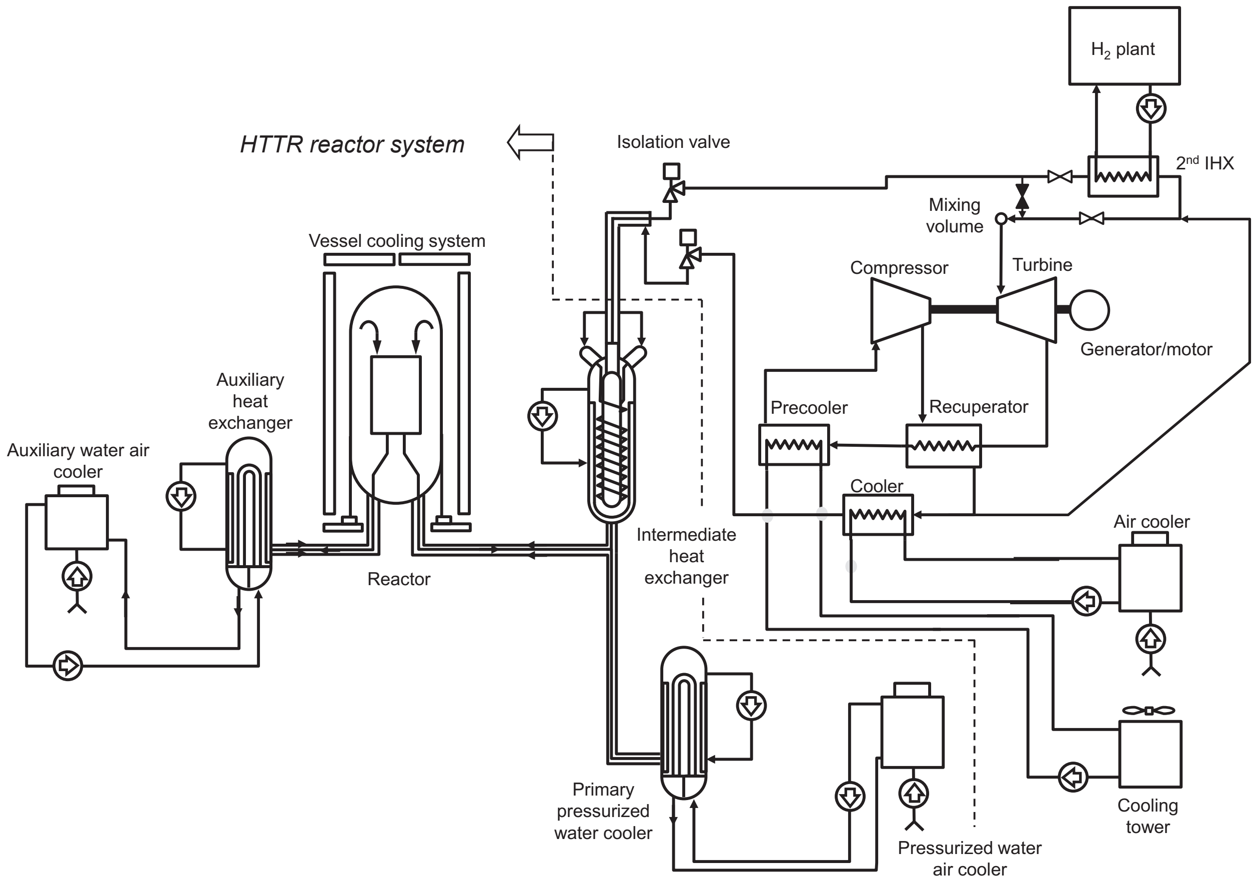

Fig. 1. System configuration of the HTTR-GT/H_2 test plant.

and an IS-process hydrogen cogenerating plant to be built as conventional industrial plant and produce about 30 Nm^3/h hydrogen as well as 15 Nm^3/h by-product oxygen.

Beside the design requirement to connect the test plant to the HTTR having a limited thermal power, other major design considerations to arrive at the final plant configuration shown in Fig. 1 are discussed below.

1) Direct vs. indirect cycle. Due to lack of space in the HTTR containment vessel, the gas turbine is placed outside of primary system and heated by the intermediate heat exchanger (IHX), resulting an indirect cycle. However, the gas turbine follows the design and operation requirements of direct cycle such as component classification, coordinated reactor and turbine temperature and pressure control, and system helium leak tightness. The effect of fission product plate-out related to maintenance of direct cycle turbine is being experimentally studied separately in JAEA.
2) Axial vs. radial gas turbine. The thermal power (10MWt) of the IHX that powers the gas turbine limits the type of turbine and compressor to radial flow. Since basic aerodynamic characteristics of both types of turbomachine are similar such as turbine velocity profile and compressor surge behavior, the choice of machine type doesn't alter the fundamental dynamics of a closed cycle gas turbine system.
3) Coupling high temperature heat application plant to the reactor. The high temperature isolation value and piping technologies previously developed by JAEA are applied. The helium heat transport piping network employs both double and single piping, high temperature bellows to minimize heat and pressure losses as well as construction cost.
4) Licensing considerations include potential issues of reactor and turbine anticipated events and accidents, helium leak tightness of the gas turbine plant, number and placement of isolation valves, and separating distance of the reactor to the hydrogen plant.
5) System operation modes. The system and gas turbine are designed to enable the following three operation modes, the point design of which are given in Table 1:
   a) Power generation including startup, shutdown, rated operation, load follow, and load rejection.
   b) Power and heat/hydrogen cogeneration including load following.

Table 1
Operation modes of the HTTR-GT/H_2 plant.

Operation mode →	a	b	c
Reactor outlet temp, °C	850	950	950
Reactor power, MWt	30	30	30
IHX 2nd side in/out temp, °C	374/570	150/900	150/900
IHX 2nd side flow, kg/s	9.85	2.57	2.57
IHX heat transferred, MWt	10	10	10
PPWC heat transferred, MWt	20	20	20
Turbine inlet temp, °C	568	568	568
Turbine inlet pressure, MPa	4.06	4.08	4.08
Turbine flow, kg/s	9.85	9.15	9.82
Compressor pressure ratio	1.38	1.34	1.34
GT system pressure loss, %	7%	2%	~2%
Reactor bypass flow, %	0	72	74
HT heat to hydrogen plant, MWt	0	0.7	0
Heating temp to hydrogen plant, °C	–	840	840
Power generation, MWe	0.6	0.3	0.7
Hydrogen production, Nm^3/h	0	29.5	0