Information Exchange on HTGR and Nuclear Hydrogen Technology between JAEA and INET in 2009

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July 2010
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Information Exchange on HTGR and Nuclear Hydrogen Technology between JAEA and INET in 2009

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The worldwide interests in the HTGR (High Temperature Gas-cooled Reactor) have been growing because the high temperature heat produced by the reactor can be utilized not only for efficient power generation but also for broad process heat applications, especially for thermo-chemical hydrogen production to fuel a prospective hydrogen economy in future. Presently only two HTGR reactors are operational in the world, including the HTTR (High Temperature Engineering Test Reactor) in Japan Atomic Energy Agency (JAEA) and the HTR-10 in the Institute of Nuclear and New Energy Technology (INET) of Tsinghua University in China. JAEA and INET have cooperated since 1986 in the field of HTGR development, particularly on the HTTR and HTR-10 projects. This report describes the cooperation activities on HTGR and nuclear hydrogen technology between JAEA and INET in 2009.

Keywords: HTGR, HTTR, HTR-10, International Cooperation

* Institute of Nuclear and New Energy Technology of Tsinghua University
日本原子力研究開発機構と中国清華大学核能及新能源技術研究院との
高温ガス炉及び原子力水素製造技術の情報交換に関する報告書（2009年）

日本原子力研究開発機構大洗研究開発センター高温工学試験研究炉部
藤本 望、王 宏*

（2010年3月29日受理）

高温ガス炉から取り出される高温の熱は、高効率発電のみならず、広範囲なプロセス熱利用、特に、熱化学水素製造に用いることができることから、高温ガス炉への関心が世界的に高まっている。現在、世界で運転されている高温ガス炉は2基のみで、1つが独立行政法人日本原子力研究開発機構のHTTR（高温工学試験研究炉）であり、もう1つが、中国の清華大学核能及新能源技術研究院（INET）のHTR-10である。原子力機構とINETは、1986年の覚書締結以来、これまで高温ガス炉分野、特にHTTR計画及びHTR-10計画について研究協力を進めてきた。本報は、2009年の原子力機構とINETの高温ガス炉及び原子力水素製造技術開発に関する研究協力活動についてまとめたものである。
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1. Introduction

The worldwide interests in the HTGR (High Temperature Gas-cooled Reactor) have been growing because the high temperature heat produced by the reactor can be utilized not only for efficient power generation but also for broad process heat applications, especially for thermo-chemical hydrogen production to fuel a prospective hydrogen economy in future. National projects on HTGRs are ongoing in Japan, China, USA, South Africa, Korea, etc., and the VHTR (Very High-Temperature Reactor) is chosen as the most promising Generation IV nuclear reactor system in GIF (Generation IV International Forum). There are presently only two HTGRs operating in the world, HTTR, High Temperature Engineering Test Reactor, in JAEA (see Table 1.1 and Fig. 1.1) and HTR-10 in Institute of Nuclear and New Energy Technology of Tsinghua University (INET) (see Table 1.2 and Fig. 1.2).

Construction of the HTTR was started in 1991 and its first criticality was achieved on November 10, 1998. Then, power-up tests were carried out, and rated thermal power of 30MW at the reactor outlet coolant temperature of 850°C was attained in December 2001. Rated power operation and safety demonstration tests using the HTTR have been conducted since FY2002. After several operational cycles, high temperature test operation of the HTTR to achieve the coolant temperature of 950°C was conducted, and coolant temperature of 950°C at reactor outlet was reached on April 14, 2004.

First criticality of the HTR-10 was achieved at air condition on December 1, 2000, and re-criticality at helium condition was attained in July 2002. Then, power-up tests were conducted, and the first synchronization at 3MWt was achieved in January 2003, followed by full power operation at 10MWt with core outlet temperature of 700°C in February 2003. Safety demonstration tests including helium circulator trip without scram and reactivity insertion without scram were carried out in 2003 and 2005.

INET is also promoting development of Modular High-Temperature Gas-cooled Reactor (MHTGR) named as High Temperature Gas-Cooled Reactor – Pebble bed Module (HTR-PM) (see Table 1.2 and Fig. 1.2), based on the technology and experiences of the HTR-10. The HTR-PM project is under the standard design phase, and the HTR-PM demonstration plant is planned to finish construction by 2013.

JAEA and INET have cooperated in the area of HTGR development, especially on HTTR and HTR-10 projects, since 1986 when a Memorandum of Understanding was exchanged between the two institutes. This report describes cooperation on HTGR development between JAEA and INET and major cooperation activities in 2009.
Table 1.1  Major specifications of HTTR

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal power</td>
<td>30MW</td>
</tr>
<tr>
<td>Outlet coolant temperature</td>
<td>850°C/950°C</td>
</tr>
<tr>
<td>Inlet coolant temperature</td>
<td>395°C</td>
</tr>
<tr>
<td>Fuel</td>
<td>Low enriched UO₂</td>
</tr>
<tr>
<td>Fuel element type</td>
<td>Prismatic block</td>
</tr>
<tr>
<td>Direction of coolant flow</td>
<td>Downward</td>
</tr>
<tr>
<td>Pressure vessel</td>
<td>Steel</td>
</tr>
<tr>
<td>Number of cooling loop</td>
<td>1</td>
</tr>
<tr>
<td>Heat removal</td>
<td>IHX and PPWC (parallel loaded)</td>
</tr>
<tr>
<td>Primary coolant pressure</td>
<td>4MPa</td>
</tr>
<tr>
<td>Containment type</td>
<td>Steel containment</td>
</tr>
<tr>
<td>Plant lifetime</td>
<td>20 years</td>
</tr>
<tr>
<td>Parameters</td>
<td>HTR-10</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Reactor thermal power</td>
<td>MW 10</td>
</tr>
<tr>
<td>Net output power</td>
<td>MW 2.5</td>
</tr>
<tr>
<td>Primary helium pressure</td>
<td>MPa 3.0</td>
</tr>
<tr>
<td>Helium inlet temperature</td>
<td>°C 250</td>
</tr>
<tr>
<td>Helium outlet temperature</td>
<td>°C 700</td>
</tr>
<tr>
<td>Helium mass flow rate</td>
<td>kg/s 4.3</td>
</tr>
<tr>
<td>Main steam pressure</td>
<td>MPa 3.5</td>
</tr>
<tr>
<td>Main steam temperature</td>
<td>°C 435</td>
</tr>
<tr>
<td>Number of spherical fuel elements</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1.2 Specifications of HTR-10 and HTR-PM
Fig. 1.1  Cooling system of HTTR
Fig. 1.2  Figures of HTR-10 and HTR-PM
2. Cooperation on HTGR Development between JAEA and INET

2.1 History of Cooperation

Vice chairman of Atomic Energy Commission of Japan, was requested for collaboration between China and Japan in the area of HTGR research and development during his visit to China in June 1985.

In September 1985, Director of Institute of Nuclear Energy Technology of Tsinghua University (INET) visited HTGR research and development facilities in Japan Atomic Energy Research Institute (JAERI), and discussed exchange of a Memorandum of Understanding (MOU) about cooperation on HTGR research and development.

In December 1985, A JAERI delegation visited INET and discussed exchange of a MOU.

In June 1986, JAERI and INET exchanged the initial MOU.

In June 1988, valid duration of the MOU was extended until June 1990.

In June 1990, the MOU was further extended until June 1995. In addition, Personnel Assignment Agreement was added to the memorandum of understanding.

In June 1995, valid duration of the MOU was extended until June 2000.

In June 2000, the MOU was further extended until June 2005.

In September 2003, Institute of Nuclear Energy Technology of Tsinghua University (INET) changed its full official name to Institute of Nuclear and New Energy Technology of Tsinghua University (INET) to further broaden academic disciplines of the institute.

In June 2005, valid duration of the MOU was once again extended until June 2010.

In October 2005, JAERI and Japan Nuclear Cycle Development Institute (JNC) merged to form Japan Atomic Energy Agency (JAEA).

Since June 1986 until today, information exchange meetings have been held almost every year as shown in Table 2.1, and general information exchange on research and development plan on HTTR and HTR-10 as well as on technologies in the area of HTGRs has been made.

Since the HTR-10 is the only pebble bed type HTGR and the HTTR the only prismatic block type HTGR being operated in the world at present, the information exchange has been beneficial for both JAEA and INET.

Since 1990 when the Personnel Assignment Agreement was added, JAEA has accepted researchers from INET in the field of HTGR safety, nuclear heat utilization, etc.

2.2 Area of Cooperation

The original MOU exchanged in 1986 stipulated the area of cooperation as follows. INET and
JAEA will provide to each other program status and technical outline information such as is generally available at each of their respective facilities relating to their respective programs for research and development of Gas-cooled Reactors. Each party will review the information provided by the other’s programs as a basis for discussions on a future agreement. The subject matter of the information to be exchanged shall include, but not be limited to, the followings:

A) The High-Temperature Gas-cooled Reactor (HTGR), for process heat and cogeneration, including both fuel technology and plant technology.

B) The Very-High Temperature Gas-cooled Reactor (VHTR), for process heat, including both fuel technology and plant technology.

C) (Note: The Very-High Temperature Gas-cooled Reactor (VHTR) here is similar to but not the same as the VHTR selected as a Generation IV nuclear system. The process heat application includes nuclear hydrogen production.)

In 1990, the MOU was amended by inserting that each party may assign its personnel into the facility of the other in accordance with the Personnel Assignment Agreement, and that for the purpose of carrying out the cooperative activities under the MOU, both parties may exchange samples when agreed by both of them. The MOU in 1990 also added a new paragraph: Each party shall make available, at least once a year to the other party reports written in English which have been published by each party.

2.3 Status of HTTR in 2009

In January 2009, HTTR started pre-operational tests of the facility. In the tests, small degradation of gasket in the closure of a standpipe which was located at the top of the reactor pressure vessel. The operation was postponed and a replacement of the gasket was carried out.

In March 2009, pre-operational tests were started again. In the tests, small depressurization was found in the secondary helium circuit. In the investigation, degradation of gaskets at the upper and middle flange of the secondary helium gas circulator.

The replacement work of the gasket in the upper flange was carried out at April. The replacement work of the gasket in the middle flange was carried out in August. To confirm the leak tightness of the secondary helium circuit and other cooling circuit, the HTTR cooling system was operated after the replacement works. The leak tightness of all cooling circuits were confirmed through the operation. During the operation, cold tests of loss of core flow tests and loss of core cooling tests, which will be started in 2010, were carried out to obtain data for pre-evaluation of the tests.

The HTTR was started up at December 2009 for periodical inspection. At the operation, control rod worth, excess reactivity, shutdown margin, etc. were measured and the reactor was shut down.
On January 2009, the HTTR was started up again to pass the periodical inspection and to achieve 50 days full power operation in high temperature test operation mode (about 950 °C of outlet coolant temperature). The long term high temperature operation will finish in March, 2010.

After the 50 days full power operation, test operation to obtain burnup characteristics such as temperature coefficients, fuel performance, etc. and new safety demonstration tests such as loss of core flow tests (all primary gas circulator stop tests) and loss of core cooling tests (all primary gas circulator stop with vessel cooling system stop tests) will be started.

2.4 Status of HTR-10 in 2009

In the year of 2009, the main efforts involved in HTR-10 were made focusing on the preparation of a demonstration test of the passive residual heat removal system (PRHRS), training of operators for HTR-PM project. In the meanwhile, the regular maintenance and check in HTR-10 were conducted including system enhancement and equipment maintenance, regular check and experiment, etc., but no power operation was carried out.

A demonstration test of the passive residual heat removal system (PRHRS) in HTR-10 was scheduled to verify and improve the PRHRS design for HTR-PM. The preparation for the test was carried out in 2009. The necessary measurement sensors and devices were installed. The preparation did not affect its safety function.

In the process of system enhancement and equipment maintenance, analysis and research were made concerning essentially with reducing potential equipment failures. Accordingly, design optimization, technical upgrading, and equipment maintenance were carried out to make sure that HTR-10 will run under stable, reliable and safe conditions to ensure important experiments to be carried out.

Regular check and tests were carried out during the shutdown period to ensure the reliability and safety of operation of HTR-10, in accordance with the Regulations for Periodical Tests and Examinations, and in line with the frequency and requirements prescribed in HTR-10 Technical Specifications.

In 2009, the training program for operating staff is focused on the training of active operators for HTR-PM and maintenance personnel for HTR-10, and the training for license application or renewal.
Table 2.1  Number of people visiting INET from JAEA and JAEA from INET for the purpose of exchanging information on HTGR

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of people visiting INET from JAEA</th>
<th>Number of people visiting JAEA from INET</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1987</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1988</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1989</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1990</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>1991</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1992</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1993</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1994</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>1995</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1996</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1997</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1998</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>1999</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2000</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2001</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2002</td>
<td>1</td>
<td>2</td>
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<tr>
<td>2003</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2004</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>2005</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>2006</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2007</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>2008</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2009</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
3. Major Cooperation Activities in 2009

3.1 Extension of MOU

The present MOU will be expired in June 2010. The future of the MOU was discussed both JAEA and INET. JAEA and INET agreed to extend the MOU until June 2015 without revision of the contents of the MOU except the period of MOU. The procedure for extension of MOU is now proceeding in both side.

3.2 Mutual Visits between JAEA and INET

There is no visit between JAEA and INET during the year 2009. Information on present status of the HTTR and HTR-10, etc. was exchanged by e-mail.
4. Concluding Remarks

This report summarized cooperation on HTGR development between JAEA and INET and major cooperation activities in 2009. The MOU between JAEA and INET is extended for five years. Enhancing future collaboration between JAEA and INET is important, and continuous information exchange on HTGR-related technologies is beneficial for the both institutes.
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国際単位系（SI）

表1. 基本単位

<table>
<thead>
<tr>
<th>名称</th>
<th>記号</th>
<th>定義</th>
</tr>
</thead>
<tbody>
<tr>
<td>長さ</td>
<td>m</td>
<td>フィオット (foott) = 0.3048 m</td>
</tr>
<tr>
<td>質量</td>
<td>kg</td>
<td>ボルトン (ton) = 2.20462 lb = 9.80665 kg</td>
</tr>
<tr>
<td>時間</td>
<td>s</td>
<td>クロック (clock) = 3600 s = 1 hr = 60 min</td>
</tr>
<tr>
<td>電流</td>
<td>A</td>
<td>アンペア (ampere) = 1 C/s = 1 V/A</td>
</tr>
<tr>
<td>温度</td>
<td>K</td>
<td>ベルト (Celsius) = 273.15 K = 248.15 K</td>
</tr>
</tbody>
</table>

表2. 末端単位を用いて表されるSI単位の例

<table>
<thead>
<tr>
<th>名称</th>
<th>記号</th>
<th>定義</th>
</tr>
</thead>
<tbody>
<tr>
<td>フォトン</td>
<td>Φ</td>
<td>フォトン (photon) = 1 J/c = 1 eV</td>
</tr>
<tr>
<td>能量</td>
<td>J</td>
<td>ジュール (joule) = 1 N·m = 1 kg·m/s²</td>
</tr>
<tr>
<td>磁場</td>
<td>T</td>
<td>タンデーソン (tesla) = 1 Wb/m² = 1 V·s/m²</td>
</tr>
<tr>
<td>電荷密度</td>
<td>C/m²</td>
<td>クラウン (coulomb/m²) = 1 A·m² = 1 C/s/m²</td>
</tr>
</tbody>
</table>

表3. 固有の名称と記号で表現可能なSI単位

<table>
<thead>
<tr>
<th>名称</th>
<th>記号</th>
<th>定義</th>
</tr>
</thead>
<tbody>
<tr>
<td>モル</td>
<td>mol</td>
<td>モル (mole) = 1 mol = 6.02214 × 10²³ atoms</td>
</tr>
<tr>
<td>リットル</td>
<td>L</td>
<td>リットル (liter) = 1 dm³ = 10⁻³ m³</td>
</tr>
<tr>
<td>グラム</td>
<td>g</td>
<td>グラム (gram) = 1 g = 10⁻³ kg</td>
</tr>
<tr>
<td>テラグラム</td>
<td>Tg</td>
<td>テラグラム (teragram) = 10¹² g = 10¹² kg</td>
</tr>
</tbody>
</table>

注) SI系組立单位=基本単位と組立単位を組み合わせて表現した単位。

表4. 単位の中で固有の名称と記号を含むSI単位の例

<table>
<thead>
<tr>
<th>名称</th>
<th>記号</th>
<th>定義</th>
</tr>
</thead>
<tbody>
<tr>
<td>ボルト</td>
<td>V</td>
<td>ボルト (volt) = 1 V = 1 W/A</td>
</tr>
<tr>
<td>オーム</td>
<td>Ω</td>
<td>オーム (ohm) = 1 A/V = 1 V/A</td>
</tr>
<tr>
<td>カロリー</td>
<td>cal</td>
<td>カロリー (calorie) = 1 cal = 4.1868 J</td>
</tr>
</tbody>
</table>

注) SI系組立単位=基本単位と組立単位を組み合わせて表現した単位。

表5. SI単位による数値

<table>
<thead>
<tr>
<th>名称</th>
<th>記号</th>
<th>数値</th>
</tr>
</thead>
<tbody>
<tr>
<td>1234567890</td>
<td></td>
<td>1.234567890 × 10¹⁰</td>
</tr>
<tr>
<td>ABCDEFGHIJ</td>
<td></td>
<td>1.234567890 × 10⁻¹⁰</td>
</tr>
</tbody>
</table>

注) SI単位による数値=基本単位と組立単位を組み合わせて表現した単位。

表6. SI単位と基本単位との関係

<table>
<thead>
<tr>
<th>名称</th>
<th>記号</th>
<th>SI単位を用いる場合の数値</th>
</tr>
</thead>
<tbody>
<tr>
<td>ボルト</td>
<td>V</td>
<td>1 V = 1 W/A</td>
</tr>
<tr>
<td>オーム</td>
<td>Ω</td>
<td>1 Ω = 1 V/A</td>
</tr>
<tr>
<td>カロリー</td>
<td>cal</td>
<td>1 cal = 4.1868 J</td>
</tr>
</tbody>
</table>

注) SI単位を用いる場合の数値=基本単位と組立単位を組み合わせて表現した単位。

表7. 国際単位系(JSPS)の定義

<table>
<thead>
<tr>
<th>名称</th>
<th>記号</th>
<th>定義</th>
</tr>
</thead>
<tbody>
<tr>
<td>パルス</td>
<td>pulse</td>
<td>シリーズ中の各パルスを示す</td>
</tr>
<tr>
<td>サンプル</td>
<td>sample</td>
<td>シリーズ中の各サンプルを示す</td>
</tr>
</tbody>
</table>

注) JSPS=国際単位系(日本科学協会)。