

RAHP News Letter

No.18

**High Temperature
Gas Cooled Reactor (HTGR)
Developments in the World
~ Present Status and Future Plans ~**

March 2019

**Research Association of
High Temperature Gas Cooled Reactor Plant
(RAHP), Tokyo, Japan**

1. Introduction:

This News Letter is a brief summary of “High Temperature Gas Cooled Reactor (HTGR or HTR)” plant developments in the world, including their backgrounds, targets, present status and future plans, as of March 31, 2019. It is annually reviewed and issued by Research Association of HTGR Plant (RAHP), which is structured by Japanese industry (utility companies and nuclear plant vendors, etc.) and academia, as a part of promotion activities on HTGR reactor plants, for industry, government, academia and the general public of Japan and abroad. The News Letter of this year has been summarized to modify the letter of last year (No.17).

2. Backgrounds, targets and current trends of HTGR developments:

In the world now, policy, economy, society and environment are becoming unstable,

(a) energy security and

(b) global warming restriction is the common subjects to be solved.

As their major countermeasures, “Unconventional fossil fuel” such as oil sand and shale gas, and “Low carbon and clean energy” such as nuclear energy and hydrogen (H₂), are under energetically development. “Nuclear energy”, in particular, is reviewed in light of its sustainability, cleanliness and diversity, and even after “Fukushima Daiichi Accident” happened in 2011, although some countries became “Away from nuclear”, many countries are promoting nuclear energy renewed development and/or its introduction, through enhancement of safety under Severe Accident conditions. “HTGR”s are under development by advanced countries, and large demand and resource countries as well, from the following viewpoints, in addition to the above mentioned common characteristics of nuclear energy.;

- 1) Inherent (or natural) safety, high temperature energies (about 750-1,000 deg.C, electricity generation, hydrogen (H₂) production, industrial process heat applications (such as H₂ power generation, fuel cell, fertilizer production, synthetic fuel production from fossil resources, biomass, regional heat supply, sea water desalination, etc.), nuclear non-proliferation (burning of surplus plutonium, etc.), effective utilization of resources, industrial promotion, export, etc.. Recent noticeable trends on HTGR plant development are as follows;
- 2) In China, a demonstration reactor plant (HTR-PM) is under construction, and commercial reactor plant programs are practically in progress.
- 3) Introduction of HTGR is planned in Poland. Japan supports the plan with international cooperation.
- 4) In US and Canada, development programs are in process, utilizing French, German and/or S. African technologies.
- 5) Some development programs are terminated or slowing down.
- 6) In Japan, national and strategic discussions are being argued on how to develop the HTGR and their road maps. HTTR interconnected Gas Turbine power generation & Hydrogen generation system demonstration program is being considered.
- 7) HTGRs in pursuit are all of “Small Modular Reactor (SMR)s” with less than 300MWe(eq.)/module, and the development steps considered are in general, taking

technologies and demands into account, (1) In near future, High Temperature Gas Cooled Reactor (HTGR) (750 deg.C class, steam cycle, power generations and mid-low temperature heat applications) and (2) In future, Very High Temperature Gas Cooled Reactor (VHTR) (higher than 850 deg.C class, gas cycle, high efficiency power generations and high-mid-low temperature heat applications, such as high efficiency H₂ production.

8) UK, Canada and USA are planning to introduce SMR including HTGR.

World current status of HTGR developments is summarized below on country basis. Tables 1-2 show the latest topics on Poland, Chinese HTR-PM and Xe-100, and research trends based on typical conferences.

3. Development Status on country basis:

3.1 USA

(1) Xe-100 Program:

In 2013, X-energy raised a HTGR development program, targeting treatment and disposal of LWR spent fuels and process heat applications, etc.. The Xe-100 reactor adopted pebble bed type fuel, multi-path fuel loading system and 200MWt of thermal output. In 2016, DOE decided to grant 40M\$/5yr funding for the development. In September 2018, X-energy said that its design was about 50%, and that it hoped the full design would be finalized by 2022 or 2023. Centrus Energy Corp and X-energy are to proceed with the preliminary design of a facility to fabricate advanced nuclear fuels based on X-energy's uranium oxycarbide tristructural isotropic (TRISO) fuel forms in November 2018. In November 2017 the company signed an agreement with Jordan Atomic Energy Commission to consider building the Xe-100 in Jordan.

(2) Next Generation Nuclear Plant (NGNP) Program:

- 1) In 1993, USA (Department of Energy (DOE), General Atomics (GA) and Oakridge National Laboratory (ORNL), jointly with Russia (Minatom; presently Rosatom, and OKBM), started “Gas Turbine Modular Helium Reactor (GT-MHR)” program for nuclear non-proliferation (incineration of surplus plutonium (Pu) from weapon dismantling) and power generation. The joint program was terminated in 2013, but the developmental fruits are utilized in US and Russian HTGR programs to follow.
- 2) DOE has been promoting “Next Generation Nuclear Plant (NGNP, actually HTGR plant)” development and demonstration program, based on Energy Policy Act (EPA-2005) and the public-private partnership principle described there. On its way, taking into account of demand trend and technological maturity. The NGNP’s main purpose and target temperatures have been changed from “Hydrogen (& power) generation” to “Heat applications (& power generation)”, and from “above 950 deg.C” to “about 750-800 deg.C for the time being”.
- 3) Works of “Phase 1 (2005-2010; plant conceptual design, technological selection)” had almost been finished, but it was decided not to proceed to originally programed “Phase 2 (2011-2021;

plant detailed design, construction and demonstration)”, taking into account of program completion cost, prospect of the said public-private partnership, etc. and presently R&D works are under way with reduced scale. Manufacturing and irradiation characterization of coated particle fuels (CPFs) and high quality graphite materials are continuing by mainly Idaho National Laboratory (INL). During Phase 1, US and international industries participated and cooperated to the program. GA proposed advanced versions of above GT-MHR, such as “Hydrogen production MHR (H2-MHR)”, “Steam cycle MHR (SC-MHR)” and “Deep burn MHR (DB-MHR)”, Westinghouse (WH) proposed an advanced version of S. African “PBMR”, and Framatome Inc. (-USA) proposed an advanced version of Antares “Steam Cycle HTGR (SC-HTGR)”, respectively. Japanese Mitsubishi Heavy Industries (MHI), Toshiba and Fuji Electric participated and cooperated in those proposals.

- 4) In March 2016, International Prismatic Block HTGR Commercial Deployment Meeting was held by participation of governments and industries of US, Europe, Japan and S. Korea. This international collaboration is called PRIME for Polygeneration Reactor with Inherent safety, Modularity, and Economic competitiveness. The NGNP program works are continuing under DOE’s new program “Advanced Reactor Technology (ART)” or “Small Modular Reactor Licensing Technical Support (SMR-LTS)”.

(3) MMR-5/10 Program

Ultra Safe Nuclear Corporation (USNC) in New Mexico has a ‘micro-modular reactor’ HTR with the fuel in prismatic graphite blocks and operating at 12 MWt/5 MWe in the MMR-5 version. There is also an MMR-10 with a double power of the MMR-5. Phase 1 of a pre-licensing vendor design review by the Canadian Nuclear Safety Commission (CNSC) began in December 2016.

(4) StarCore Program (Canada, USA)

This is a small (20 MWe) concept design of helium-cooled graphite block-type reactor from StarCore Nuclear in Quebec, designed for remote locations (displacing diesel and propane) and with remote control system via satellite. The company has applied to the CNSC to start the pre-licensing vendor design review process.

3.2 Europe

Member countries of European Union (EU), such as France and Holland, are deploying nuclear energy joint development strategy, composed of 3 pillars of Next Generation LWRs, Fast Reactors and HTGRs (for H2 production and heat applications).

So far, they have been promoting a series of HTGR programs, such as “European Sustainable Nuclear Energy Technology Platform (SNETP)”, “Reactor for Process Heat, Hydrogen and Electricity Generation (RAPHAEL)”, “End User Requirements for Industrial Process Heat Applications with Innovative Nuclear Reactors for Sustainable Energy Supply (EUROPAIRS)” and “Advanced Reactor for Cogeneration of Heat & Electricity R&D (ARCHER)”. Based on the above fruits, “Nuclear Cogeneration Industrial Initiative (NC2I)” has been implemented. And now, NC2I, USA-NGNP Alliance, Japan and S. Korea are promoting a

cooperative research and development project for developing HTGR's cogeneration system in Europe, as "GEMINI+ project".

In France, in addition to the above EU activities, Areva has been developing an advanced French version of GT-MHR "AREVA New Technology based on Advanced gas cooled Reactor for Energy Supply (ANTARES)" and then, the Framatome Steam Cycle – High Temperature Gas-Cooled Reactor (SC-HTGR) is being developed to serve a variety of markets with high temperature

steam for process heat, electricity production, and cogeneration applications.

German company Siemens/HTR GmbH had sold "HTR-M" technology to Rosatom of Russia.

In Poland, the government has a plan to introduce a research reactor with 10MWt by 2025 and a commercial reactor with 165MWt by 2031. Moreover, it anticipates demand of 10 – 20 HTGRs in Poland and 100 – 200 HTGRs in Europe by 2050.

The U-Battery consortium established mainly by the joint venture of uranium enrichment (Urenco) among UK/Holland/Germany has started R&D on small HTGR plant for remote and heat & power "Uranium Battery Reactor (U-Battery)". The U-Battery was awarded the budget of the advanced modular reactor (AMR) project from the UK government in 2018.

3.3 South Africa

(1) Pebble Bed Modular Reactor (PBMR)" program:

Since 1993, as a part of national energy strategy, national electricity supply company (ESKOM) had been promoting PBMR development & demonstration program, based on German modular HTGR design (HTR-M) technology, and globally affecting to "Generation 4 (Gen.4) Reactor" and/or "SMR" developments. The program itself, however, had been placed under care and maintenance in 2010, due to "Lehman Shock" related financial crisis. Possibilities of its restoration or reutilization are in pursuit, while maintaining the developmental test facilities and intellectual properties. In 2016, they began R&Ds of AHTR-100 with a reactor outlet temperature of 1200 °C.

(2) Thorium High Temperature Reactor (TH-100) program:

In 2011, Steenkampskraal Ltd. (STL), one of thorium (Th) mining companies in S. Africa, started Thorium fueled HTR TH-100" program to use Th as fertile material in a pebble bed reactor together with a fissile driver such as uranium (U) . Th is one of the by-products of Rare-Earth (RE) mining in the country, and the program is positioned for its effective usage, or supplement/ alternative of U fuel in future. Already finished its reactor plant conceptual design, a consortium is under establishment for its detailed design, construction and operation. In 2014, a conceptual design of Th fuel production facility was executed.

(3) High Temperature Module Reactor (HTMR-100/25) program:

A joint venture company HTMR, established in Hong Kong by above-mentioned STL and Neopanora, is, deriving from TH-100 and mainly aiming at heat & power market in Asia, etc.,

developing HTMR-100/25, using Low Enriched Uranium (LEU), Th or Pu as fuel and for electricity generation or heat & power co-generation.

3.4 China

(1) High Temperature Reactor Test Module (HTR-10) program:

HTGR development is positioned as one of the important items in national energy strategy. As a part of it, the HTR-10 program is in progress. Phase 1 (Steam Turbine Cycle: HTR-10ST) is continuing, and transitional works towards Phase 2 (Gas Turbine Cycle: HTR-10GT) are under way. From July, 2007 to October, 2014, a series of equipment maintenance, and so on, had been carried out. At the end of November, 2014, HTR-10 was restarted.

(2) High Temperature Reactor Pebble Bed Module (HTR-PM) program:

Goals of this program are of HTGR plant demonstration and commercialization, based on experiences of HTR-10. At first, HTR-PM demonstration plant composed of 2 reactor modules (HTR -PM200) [see Fig.7] started its construction in 2012 in Shidao Bay, Rongcheng City, Shandong Province, after passing safety review after “Fukushima Daiichi Severe Accident” in 2011. Connection to grid is planned in 2020.

In 2014, a conceptual design of HTR-PM600 plant for commercialization, composed of 6 reactor modules/unit and 2 units/plant, was completed. Its higher temperature version reactor (HTR-PM+), H₂ production, Th fuel reactor, etc. are under study for future deployment.

(3) HTGR Plant Installation Programs:

In 2013, China Construction & Nuclear Engineering Group Co. (CNEC) and Putian City in Fujian Province, announced on HTGR plant installation plan of HTR-PM600, as one of major economic development programs in the provincial center city. Targets of the plan are promotion of employment, coal gasification/liquefaction (CTG/CTL), water desalination, plant exportation, etc..

In 2015, Ruijin City in Jiangxi Province announced on a similar HTGR plant installation plan, of construction will start in 2017 and operational start is planned in 2021.

In Ningde, Xiapu County in Fujian Province, a HTR-PM600 is planned to be constructed.

In Wan-an, Fuzhou City in Fujian Province, a plan is proposed to construct a HTR-PM600. A detailed review was carried out by experts in April, 2016. They agreed the site satisfied conditions for construction of a nuclear reactor.

In Sanmen, Taizhou City in Zhejiang Province, there is a plan of construction of HTR-PM600. Technical review of the site was carried out in November, 2017. The site passed through the examination.

Similar plant programs are also in Guangdong, Hubei and Hunan Provinces.

3.5 South Korea

(1) Nuclear Hydrogen Development & Demonstration (NHDD) program:

The objectives of the development are system design, construction and demonstration of

hydrogen production by NPP. The performance of the system is 200MWt of thermal output, 950 deg.C of the coolant temperature of the core outlet. The history of NHDD program is as follows.

- 1) KAERI proposed the NHDD program in 2004,
- 2) AEC of Korea approved the NHDD program in 2008.
- 3) At present, the R&D is in the stage of point design of a NHDD plant and feasibility study of the NHDD demonstration project.

As a part of national energy strategy, this program is in progress. Nuclear Hydrogen Alliance (NHA) was established in 2009. Companies of utilities, heavy industries, steels, etc. are participating in the alliance, and NGNP Industry Alliance (NIA) in US has also participated since 2013.

3.6 Indonesia

(1) Multi Purpose Power Reactor (MPPR) / Indonesian Experimental Power Reactor (I-EPR) program:

In 2010, “Nuclear Co-generation Reactor” is situated in National Mid-term Energy Development Program. Since then, National Nuclear Energy Agency (BATAN) is promoting MPPR development plan, and I-EPR settlement program to initialize the plan.

International competitive bidding was done in 2015 for the I-EPR conceptual design, and Rosatom (Russia) made a success for it. Japan, China, S. Africa (/Hong Kong), etc. are also in cooperation or under proposal for the programs. Due to a governmental announcement on nuclear energy policy change, made at 2015 year end, the program future prospects are becoming unclear.

In the end of 2015, the conceptual design of 10MW HTGR pebble bed type, known as Reaktor Dava Eksperimental (RDE), performed by RENUKO (Nukem, Roastom, Rekayasa, KOGAS). BATAN started the detailed design of RDE in March, 2018.

3.7 Japan

Since 1970's, HTGR has been under continuous development, centered in Japan Atomic Energy Agency (JAEA), and in cooperation by nuclear reactor vendors, fuel maker, etc., and from view point of multi-purpose utilization of nuclear energy such as nuclear steel making, etc., including execution of basic R&D, design, construction and operation of High Temperature Engineering & Test Reactor (HTTR) and a series of safety demonstration tests using the reactor.

At present, Japan is at the world front end in its key technologies, such as CPF production, high quality graphite structural material production, helium (He) gas turbine design, H₂ generation (Iodine & Sulfur (IS) process), large size steel forgings for reactor vessel, etc..

Although Japan at present has no HTGR commercial deployment plan as for national program, its international cooperation in HTGR development programs, and leadership in technology development are required. Cooperation to US NGNP in plant design proposal, Chinese HTR-10 and HTR-PM in graphite structural material supply, and to Kazakhstan KHTR program, Indonesian MPPR/I-EPR program is continuing. Japan has begun to cooperate with National Center for Nuclear Research (NCBJ) in the Republic of Poland and URENCO in the UK in HTGR

technologies in May, 2017. At the end of January 2019, the first HTGR Technology Seminar was held in Poland.

After “Fukushima Severe Accident” in 2011, Democratic Party in power at that time declared “Zero Nuclear Energy Policy”, and the situation became confused. In 2014, after changing to Liberal Democratic Party & New-Komeito Coalition, however, “New Strategic Energy Plan” was established, and “Nuclear power stations are to re-start operation after the safety is confirmed” and “R&D on HTGR is to be promoted under international cooperation” were described in it, and in the fifth Strategic Energy Plan the same policy was also shown. In 2014, national discussions have started on what and how to develop and its road map on the subject HTGR plant.

(1) HTTR program:

HTTR reactor plant (30MWt, 850 deg.C rated operation and 950 deg.C for high temperature operation) have been enforced to be shut down since Fukushima Accident in 2011. HTTR is confirmed by the Nuclear Regulation Authority of Japan comply with new safety criteria aiming for resuming operation at an early stage. At present, “OECD/NEA Loss of Forced Cooling International Collaboration Test (HTTR-LOFC)” program in use of HTTR is in progress, and “Gas Turbine & H₂ Production Demonstration Test” program in use of HTTR (HTTR-GT/H₂) had started.

(2) Small Steam Cycle HTGR (HTR50S, MHR-50/100)/ Gas Turbine HTGR (GTHTR300, MHR-100GT) / Naturally Safe HTGR (NSHTR) / Clean Burn HTGR (CBHTR) programs:

On the other hand, JAEA, Mitsubishi Heavy Industries (MHI), Toshiba, Fuji Electric, etc. are, independently or jointly, promoting conceptual designs of reactor plant, of steam cycle of 750 deg.C class or gas cycle of 850 deg.C class, market survey, and developmental tests on anti-oxidation CPFs and graphite materials, from new viewpoints of a variety of global and huge heat & power needs, incineration treatment of Pu and TRUs to be derived from Light Water Reactor (LWR) spent fuels, pursuit of ultimately safe reactor which is capable to respond even under Severe Accident (SA) conditions, such as water and/or air ingress to reactor, taking Fukushima Accident into consideration.

In these reactor plant designs, GTHTR300 series (such as (-X) for power generation, (-H) for H₂ generation, (-C) for co-generation and (-A) for water-free plant), HTR50S, MHR-50/100, NSHTR, CBHTR and MHR-100GT are included.

4. Information Sources:

- (1) International conference papers: ICAPP2018(USA), ICONE26(England), HTR2018(Poland), 2018 meetings of Atomic Energy Society of Japan, etc..
- (2) WEB keywords: HTR, HTGR, VHTR, SMR, Gen.4 reactor, nuclear heat applications, hydrogen production, etc..
- (3) RAHP News Letter of No.17 (2018), Home pages of WNN, etc..

5. Inquiries to:

Research Association of HTGR Plant (RAHP)
 Office: The Omon Innovation Research, Inc.,
 7-6-41-302, Akasaka, Minato-ku, Tokyo, Japan, 107-0052:
 E-mail: omonrahp@jcom.zaq.ne.jp

6. Abreviation:

BI	Block (type)
Co-gen.	(Heat & Power) Co-generation
CPF	Coated Particle Fuel
GT	Gas Turbine
H ₂	Hydrogen
He	Helium
HTGR	High Temperature Gas Cooled Reactor
HTR	High Temperature Reactor
Md	Module
Pe	Pebble-bed (type)
Pi	Pin-in block (type)
Pu	Plutonium
RE	Rare Earth (Element)
SMR	Small Modular Reactor
ST	Steam Turbine
Th	Thorium
U	Uranium
VHTR	Very High Temperature Reactor

Table 1 Current HTGR topics on Poland, HTR-PM and Xe-100

Poland	On May 18, 2017, Japan-Poland Foreign Ministers' Meeting. The two ministers signed the "Action Plan for the Implementation of the Strategic Partnership between the Government of Japan and the Government of the Republic of Poland", where encouraging cooperation toward R&D of HTGR between the JAEA and NCBJ. http://www.mofa.go.jp/press/release/press4e_001593.html
	JAEA: Launching cooperation with Poland and the United Kingdom concerning the High Temperature Gas-cooled Reactor (HTGR) technologies (18 May, 2017) - Toward international deployment and standardization of Japan's HTGR technologies - https://www.jaea.go.jp/english/news/press/p2017051901/
	Department of Energy opens the report from the special team which considers introduction of HTGR in Poland. (http://www.me.gov.pl/node/28011) Ostatnia aktualizacja: 2018-01-30
	Around 100 industry leaders and decision makers will come together in Warsaw on 20 November 2018 for World Nuclear Spotlight Poland https://www.eiseverywhere.com/ehome/368628
	The draft document - titled Polish Energy Policy until 2040 (PEP2040) - was released by the Ministry of Energy on 23 November. http://www.world-nuclear-news.org/Articles/Nuclear-included-in-Poland-s-draft-energy-policy
HTR-PM	China starts mass production of HTGR fuel elements. (18 July, 2017) (http://english.gov.cn/news/top_news/2017/07/18/content_281475735868940.htm)
	On April 5, 2017, the first of the graphite moderator spheres was loaded within the reactor's. http://www.world-nuclear-news.org/NN-Fuel-loading-starts-at-Chinese-demonstration-HTGR-0704175.html
	The pressure vessel head was installed on unit 2 of the HTR-PM on 27 December. It's expected to begin to operate the nuclear reactor in 2018. http://www.world-nuclear-news.org/NN-First-HTR-PM-vessel-head-in-place-0401185.html
	The first steam generator for China's demonstration high-temperature gas-cooled reactor plant (HTR-PM) has completed air pressure tests, confirming its integrity. (02 October 2018) http://www.world-nuclear-news.org/Articles/HTR-PM-steam-generator-passes-pressure-tests
Xe-100	X-energy Contracts with Centrus to Support Advanced Nuclear Fuel Fabrication Facility Work https://www.centrusenergy.com/news/x-energy-contracts-with-centrus-to-support-advanced-nuclear-fuel-fabrication-facility-work/
	NRC Holds First Public Meeting for X-energy's Proposed TRISO-X Fuel Fabrication Facility https://www.prnewswire.com/news-releases/nrc-holds-first-public-meeting-for-x-energy-s-proposed-triso-x-fuel-fabrication-facility-300702783.html
	Centrus Energy Corp and X-energy are to proceed with the preliminary design of a facility to fabricate advanced nuclear fuels based on X-energy's uranium oxycarbide tristructural isotropic (TRISO) fuel forms. http://www.world-nuclear-news.org/Articles/US-companies-collaborate-on-TRISO-fuel-facility

Table 2 HTGR's research trends based on the current typical conferences

	Name of conference			Total
	ICAPP2018 ^{*2}	ICONE26 ^{*3}	HTR2018 ^{*4}	
Fuel	0	3	32	35
Graphite	2	5	11	18
Metal	1	7	10	18
Kinetic	1	2	17	20
Heat flow/safety	4	6	28	38
Others	1	8	26	35
Heat utilization	0	3	4	7
Topics	USA : 5 China : 3 Bangladesh : 1	- related to HTR-PM:12 - digital I&C	- 16 countries and 3 international organizations - Many papers from China, USA and Japan - Pu burner series ^{*5} - Trends in Poland	China : 64 USA : 42 Japan : 21 Korea : 7 Indonesia : 7 Other countries : 30
Research trend and so on	<p># As global research trends, numerous achievements in the fields of fuel and heat flow / safety are presented.</p> <p># Japan: Advance research of HTGR technology is promoted.</p> <p># China: Research results concerning with HTR-PM.</p> <p># USA: Research results in the field of fuel and heat flow/safety. Progress of the Xe-100 project.</p> <p>*1) A research field is classified into fuel, graphite, metal/high temperature component, kinetic/nuclear design, heat flow/safety, others related to nuclear reactor, and heat utilization by considering the feature of HTGR.</p> <p>*2) The International Congress on Advances in Nuclear Power Plants, April 8-11, 2018, Charlotte, NC, USA</p> <p>*3) The 26th International Conference on Nuclear Engineering, July 22-26, 2018, London, England</p> <p>*4) 9th International Topical Meeting on High Temperature Reactor Technology, October 8-10, 2018, Poland</p> <p>*5) Development of security and safety fuel for Pu-burner HTGR(Japan)</p>			