RAHP News Letter

No.16

High Temperature Gas Cooled Reactor (HTGR) Developments in the World

～Present Status and Future Plans～

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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, 2017. 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. In these days, nuclear industries are hanging low level, then, little new construction of power plant. Therefore, the News Letter of this year has been summarized to modify the letter of last year (No.15).

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 are 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 (H_2), 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 (about750-1,000 deg.C, electricity generation, hydrogen (H_2) production, industrial process heat applications (such as H_2 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 is under construction, and commercial reactor plant programs are practically in progress.
3) In US and Canada, development programs are in process, utilizing French, German and/or S.African technologies.
4) Some development programs are terminated or slowing down.
5) In Japan, national and strategic discussions have started on how to develop the HTGR and their road maps. HTTR interconnected Gas Turbine power generation & Hydrogen generation system demonstration program has started.
6) 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 H_2 production.

World current status of HTGR developments is summarized below on country basis.

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.. At present, its applicability study on Coal to Gasification (CTG), plant siting possibility studies with a gas & electric company, and CPF strategic commercialization study are under way. 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.

(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.

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 Areva (-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. The NGNP program works are continuing under DOE's new program "Advanced Reactor Technology (ART)" or "Small Modular Reactor Licensing Technical Support (SMR-LTS)".

3.2 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 H_2 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)". And now, based on the above fruits, it is promoting "Nuclear Cogeneration Industrial Initiative (NC21)". Demonstration reactor plant is considered necessary in 10 years.

In France, in addition to the above EU activities, Areva has been developing an advanced French version of GT-MHR "Areva's New Technology and Advanced Gas Cooled Reactor for Energy Supply (Antares)" and then, Areva-USA proposed its further advanced version "Steam Cycle HTGR (SC-HTGR)" for US NGNP program

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

In Poland, government, jointly with university and industry, started a feasibility study program on HTGR construction in Poland (HTR-PL). 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)", and is searching for governmental support.

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.

(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. Its first reactor plant operational start is assumed in about 2022 in US.

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

A joint venture company HTMR, established in Hongkong 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. It is under design proposal for Indonesian Multi Purpose Power Reactor (MPPR)/ Indonesian Experimental Power Reactor (I-EPR) program.

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, this 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 .

(No recent activities are reported.)

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

This program is 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) started its construction in 2012 in Shidao Bay, Rongcheng City, Shandong Province, after passing safety review after "Fukushima Daiichi Severe Accident" in 2011. Its operational start is scheduled in late 2017 .

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+), H_2 production, Th fuel reactor, etc. are under study for future deployment.

(3) Putian/Ruijin/ 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, as one of major economic development programs in the provincial center city. It is targeting promotion of employment, coal gasification/liquefaction (CTG/CTL), water desalination, plant exportation, etc..

Ruijin City in Jiangxi Province announced on a similar HTGR plant installation plan, of construction will start in 2017 and operational start in 2021. Similar plant programs are in Zhejiang, Guangdong, Hubei and Hunan Provinces.

3.5 South Korea

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

The objectives of the development were system design, construction and demonstration of hydrogen production by NPP. The performance of the system were 200MWt of thermal output, 950 of the coolant temperature of the core outlet. The history of NHDD program were as follows.

1) KAERI proposed NHDD program in 2004,
2) AEC of Korea approved NHDD program with 6M$ for 3 years in 2008.

As a part of national energy strategy, this program is in process. Utilities, heavy industries, steels, etc. are participating in alliance, and NIA in US is also participating since 2013. Plant operation & demonstration are planned to start after 2028.

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 (/Hongkong), 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 study performed by RENUKO(Nukem、

Roastom、Rekayasa、KOGAS).

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 basicR&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, H_2 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, Indonesian MPPR/I-EPR are continuing.

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.

In the year, 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 and 950 deg.C for short time) have been enforced to be shut down since Fukushima Accident in 2011. JAEA, however, is under preparation of its operational re-start in FY2016. At present, "OECD/NEA Loss of Forced Cooling International Collaboration Test (HTTR-LOFC)" program in use of HTTR is in progress, and "Gas Turbine & H_2 Production Demonstration Test" program in use of HTTR (HTTR-GT/H_2) 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 H_2 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: HTR2016(USA), ICONE24(USA), ICAPP2016 (USA), IAEA meetings etc..
(2) WEB keywords: HTR, HTGR, VHTR, SMR, Gen.4 reactor, nuclear heat applications, hydrogen production, etc..
(3) RAHP News Letter of No.15 (2016).

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6. Abreviation:

Bl	Block (type)
Co-gen.	(Heat & Power) Co-generation
CPF	Coated Particle Fuel
GT	Gas Turbine
H2	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