# RAHP News Letter

## No.15

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

### ～Present Status and Future Plans～

**March 2016**

**Research Association of**

**High Temperature Gas Cooled Reactor Plant**

**(RAHP), Tokyo, Japan**

## ■ 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, 2016.

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.

## ■ 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 (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 view points, in addition to the above mentioned common characteristics of nuclear energy.;

- 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;

- In China, a demonstration reactor plant is under construction, and commercial reactor plant programs are practically in progress.

- In US and Canada, development programs are in process, utilizing French, German and/or S.African technologies.
- Some development programs are terminated or slowing down.
- In Japan, national and strategic discussions have started on how to develop the HTGR s and their road maps. HTTR interconnected Gas Turbine power generation & Hydrogen generation system demonstration program has started.
- 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.

World current status of HTGR developments is summarized below on country basis. And development programs are shown in Tables 1-3 on stage basis, and reactor plant concepts and development status are shown in Fig.s 1-14 on example basis.

## ■ Development Status on country basis:

### (1) USA

#### (1-1) Next Generation Nuclear Plant (NGNP) Program :

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.

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, its 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" [see Fig.1].

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.

And "NGNP Industry Alliance (NIA)" established by nuclear plant vendors, utilities, chemicals, etc., has independently selected above-mentioned SC-HTGR as most desirable plant design for initial stage, investigated customer's requirements, potential market and potential sites for demonstration plant. 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)".

### (1-2) 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. In 2016, DOE decided to grant 40M$/5yr funding for the development. Design certification application under plan in 2017 [see Fig.2].

## (2) Canada: StarCore Pebble Bed Reactor (SPB) program:

StarCore (Canada and US) is promoting this program mainly targeting on remote, dispersed and/or cool land demands (small towns, mines, military strategic bases, etc.). And it is under preparation of licensing application to Canadian Nuclear Safety Commission (CNSC), targeting construction and operational start of a pilot plant composed of 2 modules by 2018. Remote operation of nuclear reactor by means of satellite, plant settlement by means of lease method, etc. are proposed. The program is now in alliance with Areva-US and B&W [see Fig.3].

## (3) Russia

### (3-1) Gas Turbine Modular HTR (GT-MHR) program:

Russia is continuing R&D of an advanced version of GT-MHR (refer to 1-1), including developments of power conversion system (PCS) equipments and CPFs.

### (3-2) MHR-T (=MGR-T) program:

Based on the GT-MHR (refer to 1-1 and 3-1) technology, Rosatom and OKBM are deploying its new version MHR-T in series, aiming at electricity generation, oil refinery, H2 production, etc., and evaluating its potential market, constructing a public-private partnership, and searching for practical customers.

### (3-2) HTR-M program:

Rosatom, bought German technology of High Temperature Reactor Module (HTR-M) (refer to 4), is proposing for an Indonesian program (refer to 9), based on the technology.

## (4) 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)". And now, based on the above fruits, it is promoting "Nuclear Cogeneration Industrial Initiative (NC21)" (see Fig.4). 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 (refer to 1-1) "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 (refer to 1-1).**

**German company Siemens/HTR GmbH had sold "HTR-M" technology to Rosatom of Russia (refer to 3-3).**

**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.**

## (5) South Africa

### (5-1) "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.**

### (5-2) Thorium High Temperature Reactor (TH-100) program:

**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 [see Fig.5].**

### (5-3) 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 [see Fig.6], 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 (refer to 9).**

## (6) China

### (6-1) 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 [see Fig.7].**

**(No recent activities are reported.)**

### (6-2) High Temperature Reactor Pebble Bed Module (HTR-PM) program:

**This program is of HTGR plant demonstration and commercialization, based on experiences of HTR-10 (refer to 6-1 above). At first, HTR-PM demonstration plant composed of 2 reactor modules (HTR-PM200) [see Fig.8] 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 [see Fig.8].**

**In 2014, a conceptual design of HTR-PM600 plant for commercialization, composed of 6 reactor modules/unit and 2 units/plant, was completed [see Fig.9].**

**Its higher temperature version reactor (HTR-PM+), H2 production, Th fuel reactor, etc. are under study for future deployment.**

### (6-3) 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 start in 2017 and operational start in 2021.

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

## (7) South Korea: Nuclear Hydrogen Development & Demonstration (NHDD) program:

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 (refer to 1-1) is also participating since 2013. Plant operation & demonstration are planned to start after 2028.

## (8) Kazakhstan: Kazakhstan HTR (KHTR) program:

This is a series of HTGR Experiment & Demo. Reactor and Commercial Reactor programs, and in process as part of national strategy of introduction & domestic fixation of foreign advanced technologies as collateral of exportation of natural resources such as U, iron ore, REs, etc.. Japan (Japan Atomic Energy Research and Development Agency (JAEA), Toshiba, Fuji Electric, Nuclear Fuel Industries (NFI), etc.) is fully supporting this program in terms of technology, plant design and education. (No recent activities are reported.)

## (9) Indonesia: 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, see 3-3) made a success for it [see Fig.10]. Japan, China, S.Africa (/Hongkong), etc. are also in cooperation or under proposal for the programs (see 5-3 and 10). (Due to a governmental announcement on nuclear energy policy change, made at 2015 year end, the program future prospects are becoming unclear.)**

## (10) 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) (refer to 10-1 below) 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 (refer to 1-1) in plant design proposal, Chinese HTR-10 and HTR-PM (refer to 6-1 and 6-2) in graphite structural material supply, and to Kazakhstan KHTR (refer to 8), Indonesian MPPR/I-EPR (refer to 9), etc. have been or 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.**

### (10-1) 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 [see Fig.11].

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 [see Fig.12].

## (10-2) 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 [see Fig.13], CBHTR and MHR-100GT [see Fig.14] are included.

## ■ Information Sources:

(1) International conference papers: IAEA meetings (TWG-GCR, Tech. Meetings (TM)), ANS SMR-2013 (USA), HTR-2014 (China), ICONE-2015 (Japan), ANS-2015 Winter Meeting (US), --.

(2) WEB keywords: HTR, HTGR, VHTR, SMR, Gen.4 reactor, nuclear heat applications, hydrogen production, synfuel, --.

## ■ 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:

*Tel/Fax: +81-3-3583-0370, E-mail: ishizuka.fuyuki@jcom.home.ne.jp*

## ■ Abreviation:

| | |
|---|---|
| Bl | Block (type) |
| Co-gen. | (Heat & Power) Co-generation |
| CPF | Coated Particle Fuel |
| GT | Gas Turbine |
| H2 | Hydrogen |
| He | Helium |
| Hi.Temp. | High Temperature |
| HTGR | High Temperature Gas Cooled 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. "Experiment/Test/Research Reactor Programs" at a glance (as of Mar. 2016)

**(Objects: Experiment/Test/Research programs, using nuc. reactor plant)**

| Name, Organ, Country | Background, Purpose, Parameter | Present status, Future plan |
|---|---|---|
| HTTR :<br>Hi. Temp. Eng'g & Test Reactor<br>＜JAEA＞<br>＜Japan＞<br>[Fig. 11-12] | ◆ Nuc. ene. multi-purpose utilization (power gen., nuc. steel making, H2 gen.--)<br>◆ Test & res. of HTGR<br>◆ Oarai, Ibaragi Pref.<br>◆ Pi-type, 30MWt, 850C (950C for short period) | ◆ Reactor under shut down, ope. re-start in FY'16 under planning<br>◆ OECD/NEA Loss of Forced Cooling Safety Demo. Test (HTTR- LOFC) program, and equipments & H2 gen. development under way<br>◆ Demo. program of Gas Turbine / H2 gen. interconnected to HTTR (HTTR-GT/H2) under rise-up |
| HTR-10 :<br>Hi. Temp. Reactor Test Module<br>＜INET＞<br>＜Chaina＞<br>[Fig. 7] | ◆ Plenty of nat. resources (coal, Th,--), Nuc. ene. multi-purpose use<br>◆ Test & res. of HTGR<br>◆ Outskirt of Beijing<br>◆ 10MWt/2.6MWe, (-ST): 700C, (-GT): 750-900C | ◆ Phase-1 ( -ST) : R&D is continuing<br>◆ Phase-2 (-GT): under prep. (dev't of magnetic bearing, --)<br>◆ H2 gen., etc. under development<br>◆ (No recent activities are reported) |
| I-EPR (=RDE) :<br>Indonesian Experimental Power Reactor<br>＜National. Nuc. Energy Agency (BATAN)＞<br>＜Indonesia＞<br>[Fig. 10] | ◆ Experimental reactor for dev't of Multi-Purpose Power Reactor (MPPR), targeting export of nat. resources (coal, nat. gas, Al, Zr, Th--) with added value, co-gen., sea water desalination—<br>◆ BATAN Serpong site<br>◆ Pe-type, U(&Th in future) fuel,-10-30MWt /3-10MWe | ◆ '07/'10: Development of nuc. co-gen. reactor was situated in National Mid-term Ene. Development Program<br>◆ Reactor plant conceptual study and candidate construction site investigation started<br>◆ '14: Coop. agreement concluded between BATAN & JAEA (Japan). Contacted with Russia, China, S.Africa/Hongkong, as well<br>◆ '15: Conceptual design based on HTR-M tech., which Rosatom (Russia) bought from Siemens/HTR GmbH (Germany)<br>◆ '20: I-EPR operation start (plan) -(Program prospects became unclear, due to a governmental announcement on nuclear policy change made at '15 end) |

## Table 2. “Proto-type/Demo/Commercial Reactor Programs at a glance” (1/4) (as of Mar. 2016)

**(Objects: Proto/Demo/Commercial reactor programs, in which plant siting and/or funding base are clearly indicated)**

<table>
<tr><th>Name, Organ, Country</th><th>Background, Purpose, Parameter</th><th>Present status, Future plan</th></tr>
<tr><td>NGNP :<br>Next Gen. Nuc. Plant<br>＜DOE＞<br>＜USA＞<br>[Figs. 1]</td><td>◆ Plentiful nat. resources (coal, oil sand, oil shale,--), ene. demand & CO2 release remarkable<br>◆ Ene. independence, clean ene. (H2,--),nuc. heat apps. (syn-fuels from coal, oil sand, --), dev’t of Gen.4 reactors and SMRs<br>◆ HTGR plant dev’t & demo.<br>◆ Idaho (or other site) -600MWt/??MWe/Md, 750-800C</td><td rowspan="2">◆ Phase-1 (’05-’10: plant concept design, tech. selection): mostly finished. Various plant designs proposed by WH (PBMR-USA), GA and Areva-USA, with coop. by Japan (MHI, Toshiba, Fuji Elec.)<br>◆ Did not enter Phase-2 (’01-’21: plant detail design, construct., demo. ope.), due to lack of pub.-private alliance and funding. R&D works under way with reduced scale<br>◆ NGNP Industry Alliance (NIA: WH, Areva, Entergy, Dow, Toyo Tanso,--) under independent investigation on plant design (Areva’s SC-HTGR selected), candidate plant site (Louisiana, Kentucky, Ohio, Alberta (Canada)) and economy<br>◆ Mar.’16: Int’l Prismatic Block HTGR Commercial Deployment Meeting was held by participating of governments and industries of US, EU, Japan and S.Korea</td></tr>
<tr><td>SC-HTGR :<br>Steam Cycle HTGR<br>＜Areva-USA＞<br>＜France/USA＞</td><td>◆ Advanced version of Antares (France) for US-NGNP, co-gen.<br>◆ Bl-type, UCO fuel, ST, 625MWt/Md, 750C</td></tr>
<tr><td>Xe-100 :<br>X-Energy HTGR<br>＜X-energy/ BWXT/SGL/ INL/ORNL/-/- (Aerotherm/ Stellenbosch Univ.＞<br>＜USA＞<br>[Figs. 2]</td><td>◆ Disposition of LWR spent fuels (incineration of Pu/TRUs), power gen., H2 gen., heat applications<br>◆ Pe-type, 125MWt/50MWe/Md(200 MWe/4Md/Std. plant), 850C</td><td>◆ ’09: Company established<br>◆ Under study on its applicability to Coal to Gas (CTG) process<br>◆ ’15: Under study on plant siting within existing coal fire power plant site, and its economic feasibility, in collaboration with S.Carolina Gas & Electric<br>◆ ’16: DOE decided to grant 40M$/5yr funding for the development<br>◆ ’17: Design Certification App., and ’35: Demo plant operation start (plan)</td></tr>
</table>

Table 2. “Proto-type/Demo/Commercial Reactor Programs at a glance” (2/4)
(as of Mar. 2016)

**(Objects: Proto/Demo/Commercial reactor programs, in which plant siting and/or funding base are clearly indicated)**

| Name, Organ, Country | Background, Purpose, Parameter | Present status, Future plan |
|---|---|---|
| SPB :<br>Star Core Pe. Reactor<br>＜Star Core/ Areva-USA＞<br>＜Canada/ France/US＞<br>[Figs. 3] | ◆ Demo.& commercialization of HTGR plant for dispersed demands in remote/cold area(mines, small towns, strategic bases, --)<br>◆ Reactor core in silo underground, remote ope. using satellite. Plant construction/ope. on lease basis<br>◆ 30MWt/10MWe/Md, 2Md.s/standard plant | ◆ Pre-licensing app. to Canadian Nuc. Safety Commission (CNSC)<br>◆ ’15: Alliance with Areva<br>◆ ’18: Construction and operation of Pilot plant to start (plan) |
| PBMR :<br>Pe. Md. Reactor<br>＜PBMR＞<br>＜S.Africa＞ | ◆ Md. reactor plant demo., based on German HTR-M tech.<br>◆ U fuel. Power gen., H2 gen., heat apps. (coal to gas/liquid (CTG/CTL), etc.)<br>◆ Koeberg<br>◆ Pe-type, U fuel, 400MWt/160MWe/Md, 900C for power gen, 200MWt/80MWe/Md, 750C for heat apps. | ◆ ’93-: Feasibility study, ’95-: Detail Design<br>◆ ’10: Dev’t stopped due to financing difficulty and the program was placed in “Care and maintenance” mode<br>◆ Under pursuit of program restoration, while maintaining test facilities & intellectual properties |

## Table 2. “Proto-type/Demo/Commercial Reactor Programs at a glance” (3/4) (as of Mar. 2016)

**(Objects: Proto/Demo/Commercial reactor programs, in which plant siting and/or funding base are clearly indicated)**

| Name, Organ, Country | Background, Purpose, Parameter | Present status, Future plan |
|---|---|---|
| HTR-PM200/600 :<br>HTGR Pb.Md.<br>＜Huaneng Shidaowan Nuc. Power Co. (INET-Tsinghua Univ./Huaneng/ China Nuc. Eng’g & Const. Grp.(CNEC))＞<br>＜Chaina＞<br>[Fig. 8-9] | ◆ Demo.& commercialization of HTGR plant, based on HTR-10 technology<br>◆ Pe type, U fuel, ST<br>＜HTR-PM200 (Demo Reactor)＞<br>◆ Shidao Bay, Shandong Province<br>◆ 500MWt(=250MWt/Md×2 Md)/200MWe/unit, 750C<br>＜HTR-PM600 (Commercial Reactor)＞<br>◆ 1,500MWt (=250MWt/Md×6Md)/600 MWe/unit, 750C | ＜HTR-PM200＞<br>◆ ’11-12: Safety review after “Fukushima Accident”<br>◆ ’12: Plant construction started<br>◆ ’16: Reactor Pressure Vessels etc. under installation<br>◆ ’17: Plant operation to start<br>◆ Fuel handling, steam gen., etc. are under system demo.. Fuel production facility completed<br>◆ Graphite fuel pebbles and graphite structural materials are to be imported from Germany and Japan, respectively<br>＜HTR-PM600＞<br>◆ ’14: Plant conceptual design completed, based on HTR-PM200 |
| HTGR Introduction :<br>＜CNEC/ Putian City/ Ruijin City /--/--＞<br>＜China＞ | ◆ HTGR plant introduction programs as part of economic deployment in local center cities (Coal gasification/liquifaction, water desalination, promotion of employm’t and export)<br>◆ Putian City (Fujian Prov.)/Ruijin City (Jiangxi Prov.)/Zhejiang/--/--(Guang dong/Huber/Hunan Prov.s)-600MWe (HTR-PM600?) | ◆ ’13: Introduction programs announced by CNEC/Putian City and CNEC/Ruijin City, respectively<br>◆ (Ruijing) ’17: Construction, ’21: Operation to start<br>◆ Similar programs continuously reported in both coastal and inland areas |

## Table 2. “Proto-type/Demo/Commercial Reactor Programs at a glance” (4/4) (as of Mar. 2016)

**(Objects: Proto/Demo/Commercial reactor programs, in which plant siting and/or funding base are clearly indicated)**

| Name, Organ, Country | Background, Purpose, Parameter | Present status, Future plan |
|---|---|---|
| KHTR : Kazakhstan HTGR ＜National Nuc. Center (NNC)＞ ＜Kazakhstan＞ | ◆ Export of natural re-sources (iron ore, U, Th, RE,--), introduction & domestic fixation of foreign advanced technologies<br>◆ HTGR dev’t (power gen., regional heating, H2 gen.--)<br>◆ Kurchatov City<br>◆ Pi type, 50MWt/15MWe/Md, 700C (950C in future) | ◆ Japan (JAEA/Toshiba/Fuji Elec./NFI/--) is fully cooperating (tech., plant design, education,--)<br>◆ ’15～: Feasibility study under preparation<br>◆ ’23: Ope. to start<br>◆ Phase-1: ST power gen., regional heating, --, Phase-2: H2 gen.—<br>◆ (No recent activities reported) |

## Table 3. "Other R&D Programs at a glance" (1/4) (as of Mar. 2016)

| Name, Organ, Country | Background, Purpose, Parameter | Present status, Future plan |
|---|---|---|
| GT-MHR :<br>GT Md. He Reactor<br>＜DOE/GA/ORNL/ Rosatom/OKBM＞<br>＜USA/Russia＞ | ◆ Nuc. non-proliferation (incineration of weapon dis-mantled & surplus Pu) and efficient GT power gen.<br>◆ BI type, Pu fuel, 600MWt/Md, 850C | ◆ '93-'13: US/Russia Joint R&D<br>◆ Deploying to H2-MHR, SC-MHR, DB-MHR,-- in US (refer to 1-1), and to MHR-T (=MGR-T) in Russia (refer to 3-2), respectively |
| H2-MHR :<br>Md. Reactor for H2 gen.<br>＜GA＞<br>＜USA＞ | ◆ US adv'd version of US/Russian GT-MHR<br>◆ H2 generation<br>◆ BI type | ◆ Designs proposed for NGNP Phase-1 (refer to 1-1) |
| SC-MHR :<br>Md. Reactor for Steam Cycle<br>＜GA＞<br>＜USA＞ | ◆ US adv'd version of US/Russian GT-MHR<br>◆ Steam cycle (power gen., heat apps.)<br>◆ BI type | |
| DB-MHR :<br>Deep Burn Md. Reactor<br>＜DOE/GA＞<br>＜USA＞ | ◆ US adv'd version of US/Russian GT-MHR<br>◆ Nuc. waste (Pu, TRUs) management, power gen., heat apps.<br>◆ BI type | ◆ Conceptual design finished<br>＜Based on this technology, Gas Cooled Fast Reactor (GFR; EM2) is under design separately＞ |
| GT-MHR :<br>GT HTGR<br>＜Rosatom/ OKBM＞<br>＜Russia＞ | ◆ Russian adv'd version of US/Russian GT-MHR<br>◆ BI type, Pu fuel, 600MWt/Md, 850C | ◆ New design Coated Particle Fuel (CPF) and turbo machines are under development<br>◆ Russian market under survey, and searching for customers<br>◆ Under cooperation to Kazakhstan<br>＜Under plan to connect the technology to Gas Cooled Fast Reactor (FGR) development＞ |
| MHR-T(=MGR-T) :<br>Md. He Reactor Tech<br>＜Rosatom/ OKBM＞<br>＜Russia＞ | ◆ MHR series design (-GT for GT power gen., (-OR) for Oil refinery<br>◆ SMC for H2 gen. by Steam Methane Conversion, (-HTE) for H2 gen. by Hi. Temp. Electrolysis<br>◆ BI type, U fuel, 600MWt/Md, 950C | |

## Table 3. “Other R&D Programs at a glance” (2/4)<br>(as of Mar. 2016)

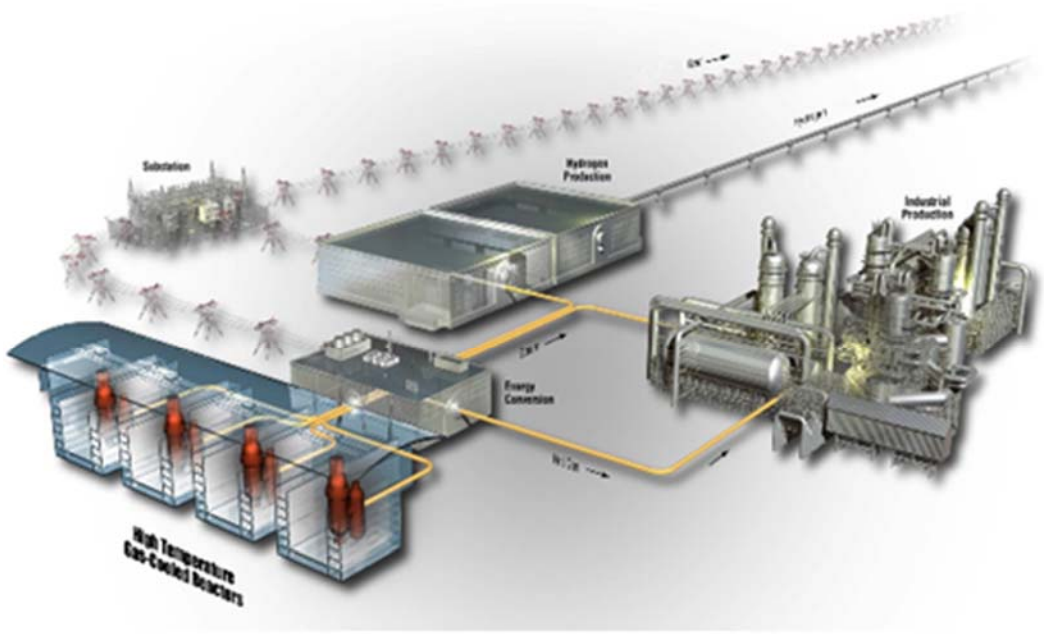
| Name, Organ, Country | Background, Purpose, Parameter | Present status, Future plan |
|---|---|---|
| HTR-M :<br>High Temp.<br>Reactor Md.<br>＜Rosatom/<br>OKBM＞<br>＜Russia＞ | ◆ Md. HTGR (Tech. bought from Nukem (Germany))<br>◆ Pe type | ◆ Under cooperation on conceptual design of I-EPR (Indonesia)(refer to 9) |
| SNE-TP :<br>Sustainable Nuc.<br>Ene. Tech. Platform<br>＜EC＞<br>＜EU＞ | ◆ EU co-strategic deployment. Sorting and construction of nuclear tech. co-development platform | ◆ Under co-study on EU common nuc. ene. dev’t target, strategy, requirements, schedule-- (reactor type, user’s requirements, feasibility of int’l demonstrator)<br>◆ Activities in process, with relaying fruits of “Reactor for Process H’t, H2 and Electricity prod.(RAPHAEL)”, “End-user Requirem’ts for Process H’t App.s (EUROPAIRS) ”, Advanced Reactor for Co-gen. of Heat and Electricity R&D (Archer), --<br>◆ Under alliance with NGNP Industry Alliance (NIA) (US) (refer to 1-1) |
| NC21 (R) :<br>Nuc. Co-gen.<br>Industry<br>Initiative 21st<br>Century<br>＜EC＞<br>＜EU＞<br>[Fig. 4] | ◆ (Research) activities on nuc. co-gen. int’l demo plant construction in Europe | |
| ANTARES :<br>Areva’s New Tech.&<br>Adv’d GCR for Ene.<br>Supply<br>＜Areva＞<br>＜France＞ | ◆ HTGR dev’t (power gen., H2 gen., heat apps.)<br>◆ Bl type, 600MWt/Md, 850 deg. C | ◆ Its adv’d version (SC-HTGR) proposed for NGNP (US) by Areva<br>◆ USA, and selected by NIA as most desirable plant design for initial NGNP (refer to 1-1)<br>◆ (Activities in France terminated) |
| HTR-PL :<br>HTR-Poland<br>＜AGH/NCBIR＞<br>＜Poland＞ | ◆ Feasibility study on HTGR construction in Poland | ◆ Mining and Metallurgy Academy (AGH), National Devt. Center (NCBIR), National Nuc. R&D Center (NCBI) are cooperating in program managem’t, funding, etc. |
| TH-100 :<br>Thorium<br>＜Steenkamps<br>-kraal＞<br>＜S.Africa＞<br>[Fig. 5] | ◆ Utilization of Th (by-product of REs mining)<br>◆ Dev’t & Deploym’t in S.Africa & USA<br>◆ Pe type, 100MWt/35MWe/Md, 750C | ◆ ’11: Program raised, conceptual design, ’12-: Settlement of consortium for devt & promotion<br>◆ ’14: Conceptual design of Th fuel commercial production facility<br>◆ ’22: FOAK plant ope. to start<br>◆ (refer to HTMR-100/25) |

## Table 3. "Other R&D Programs at a glance" (3/4)<br>(as of Mar. 2016)

| Name, Organ, Country | Background, Purpose, Parameter | Present status, Future plan |
|---|---|---|
| HTMR-100/25 :<br>High Temp. Md. Reactor<br>＜HTMR＞<br>＜S.Africa/ Hongkong＞<br>[Fig. 6] | ◆ Advanced version of TH-100 (S.Africa) for Asian market<br>◆ Reactor semi-under-ground<br>◆ Pe type, LEU, Th/LEU or Th/Pu fuel, 750C<br>◆ HTMR-100: 100MWt/35MWe/Md for power gen., HTMR-25: 25-30 MWt/7-9MWe/Md for co-gen., 750deg.C | ◆ HTMR established by STL (S.Africa), Neopanora, etc.<br>◆ A series of HTMR-100/25 designs under development<br>◆ Under cooperation or proposal for MPPR/I-EPR (Indonesia) (refer to 9) |
| NHDD :<br>Nuc. H2 Dev't & Demo.<br>＜KAERI＞<br>＜S.Korea＞ | ◆ H2 ene. dev't as part of national strategy<br>◆ Dev't & demo. of water/H2 gen./power gen. by nuclear<br>◆ Bl type, 200MWt/Md, 750 (950 in future) deg.C | ◆ Korea Adv'd Inst. of Science & Tech. (KAIST) and Korea Inst. of Ene. Res.(KIER) are cooperating on H2 gen. dev't<br>◆ Utility, heavy industry, steel --(KEPCO, Hyundai, POSCO -- ) areparticipating in alliance<br>◆ '13-: NIA (US, refer to 2-1) is participating in alliance<br>◆ '28-: Plant demo. & operation |
| GTHTR300 :<br>GT HTGR<br>＜JAEA＞<br>＜Japan＞ | ◆ GT HTGR series development; (-X) for power gen., (-C) for co-gen., (-H) for H2 gen., (-A) for water-free plant, respectively<br>◆ Pi type, U fuel, 600MWt/Md, 850C | ◆ Concept. design and economic evaluation in progress<br>◆ Under a series of safety demo test on Severe Accident, using HTTR (refer to 10-1) |
| HTR50S :<br>Steam Cycle Small HTGR<br>＜JAEA/ Toshiba/ Fuji Electric/--＞<br>＜Japan＞ | ◆ Dev't of small HTGRs for developing countries (for power gen., steam supply)<br>◆ Pi type, U fuel, 750C<br>◆ Near future: 50MWt/(13.5-17.2MWe/Md, Future: 50MWt/10.3MWe (ST)+6.9MWe (GT)/Md | ◆ Concept. design (plant basic specifications, system concept) finished<br>◆ Market survey under way |

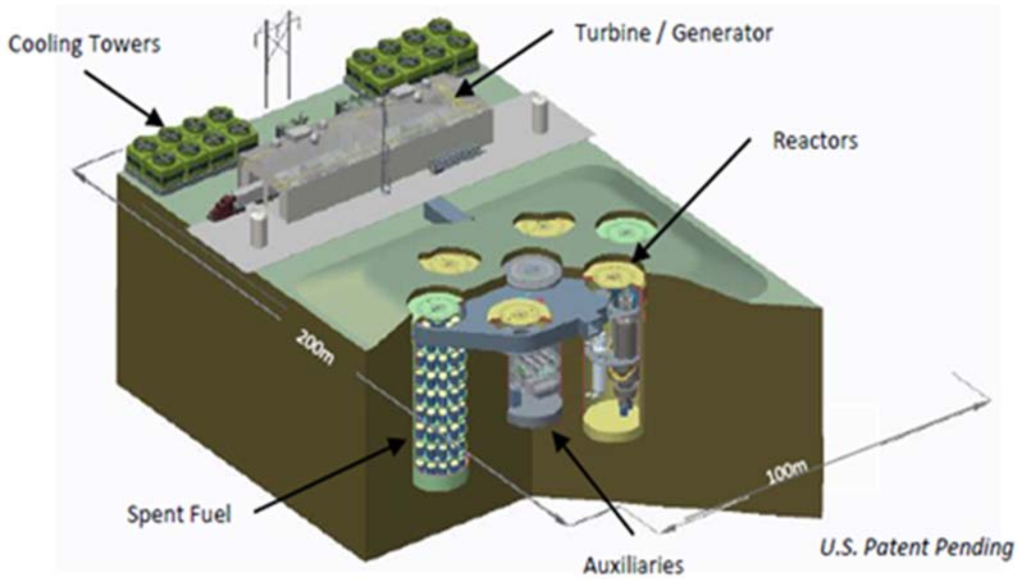
## Table 3. "Other R&D Programs at a glance" (4/4) (as of Mar. 2016)

| Name, Organ, Country | Background, Purpose, Parameter | Present status, Future plan |
|---|---|---|
| NSHTR :<br>Naturally Safe HTGR<br>＜JAEA＞<br>＜Japan＞<br>[Fig. 13] | ◆ Dev't of HTGR capable to protect people and environment only by natural & physical phenomenon (heat conduction/convection/radiation, moderator temp. effect,--)<br>◆ Pi type | ◆ Plant concept. design and related oxidation-resistant fuels and graphite materials under development |
| CBHTR :<br>Clean Burn HTGR<br>＜JAEA＞<br>＜Japan＞ | ◆ Incineration of Pu & TRUs to be derived from LWR spent fuel<br>◆ Pi type, Pu fuel | ◆ Concept. design under way |
| MHR-50/100 :<br>Mitsubishi<br>Small HTGR<br>＜MHI/JAEA＞<br>＜Japan＞ | ◆ Dev't of steam cycle small HTGR plant<br>◆ (-is): Improved safety version<br>◆ Pi type, U fuel<br>◆ (FOAK): 120MWt/50MWe/Md, (NOAK): 250MWt/100MWe/Md, 750C | ◆ Concept. design, market & economic survey finished<br>◆ Safety design was revised, taking into account of lessons learned from Fukushima Severe Accident |
| MHR-100GT :<br>Mitsubishi HTGR GT<br>＜MHI＞<br>＜Japan＞<br>[Fig. 14] | ◆ GT (water free) version of MHR-100(is)<br>◆ Pi type, U fuel, 250MWt/100MWe/Md, 850C | ◆ Under plant conceptual design and cost evaluation |



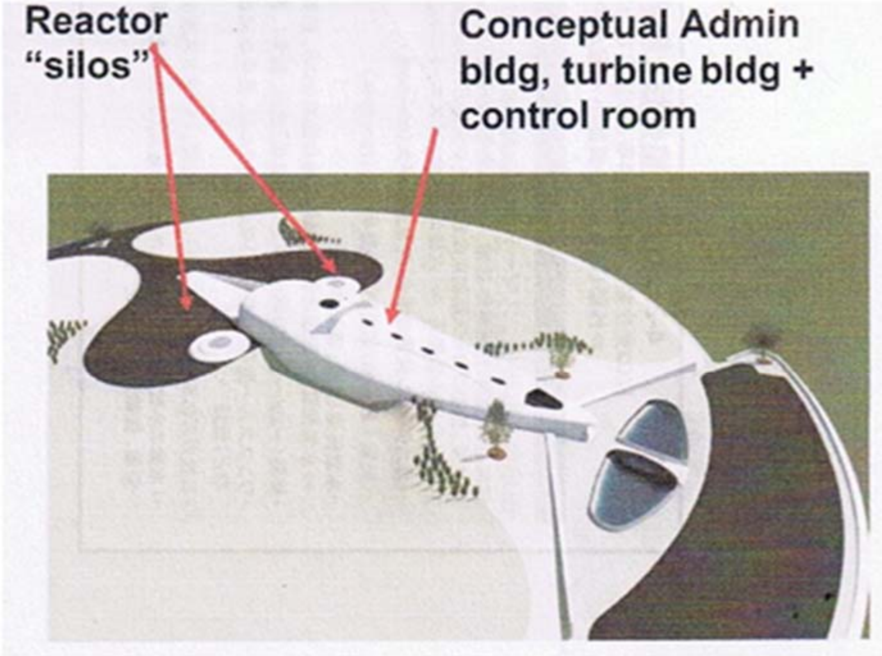

(NGNP Public Documents - HP, 2015.10.7)

Fig.1 (US) Next Generation Nuclear Plant (NGNP) Program




(X Energy HP, 2015.2)

Fig.2 (US) X-Energy HTGR (Xe-100) Program




(Marcel de Vos (CNSC), "A Licensing Discussion: SMRs in Canada", Presentation to CNNC Delegation, Ottawa, Ontario, 2013.6.27)

**Fig.3 (Canada) StarCore Pebble Bed Reactor (SPB) Program**

## Overview of HTR-MODULE 250 Design Inputs

| Parameters | NC2I Reference |
|---|---|
| Configuration | 2 x 250 MWth |
| Overnight costs | 1862 €/kWth |
| O&M costs | 6,23 €/MWth |
| Lifetime | 40 years |
| Reference gas price | 35 €/MWh<br>+ 10 €/t $CO_2$ |
| Design development costs | Excluded |
| Technical basis | Near-term applications (750°C outlet temperature, SG, plug-in market) |

(P-M.Plet, D.Janin (e-on), "First Conclusion on HTR Economics", IAEA TM on Economics of HTGRs and SMRs, 2015.8.25-28, Vienna, Austria)

**Fig.4 (EU) Nuclear Cogeneration 21st Century (NC21) Program**

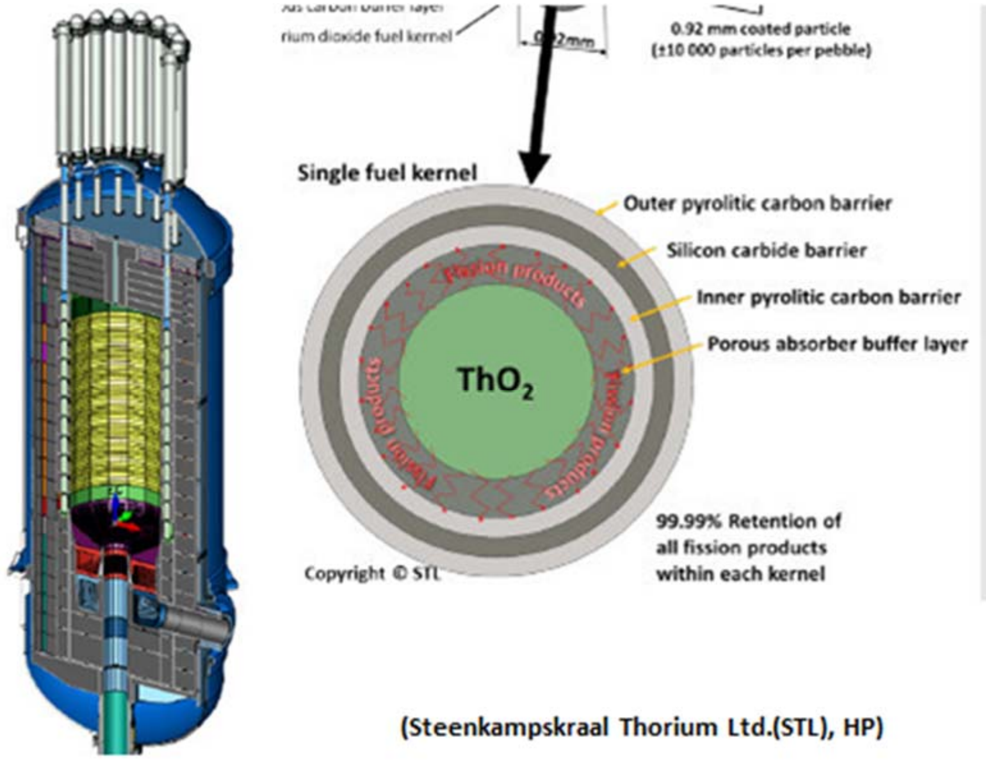



**Fig.5 (S.Africa) Thorium HTGR (TH-100) Program**

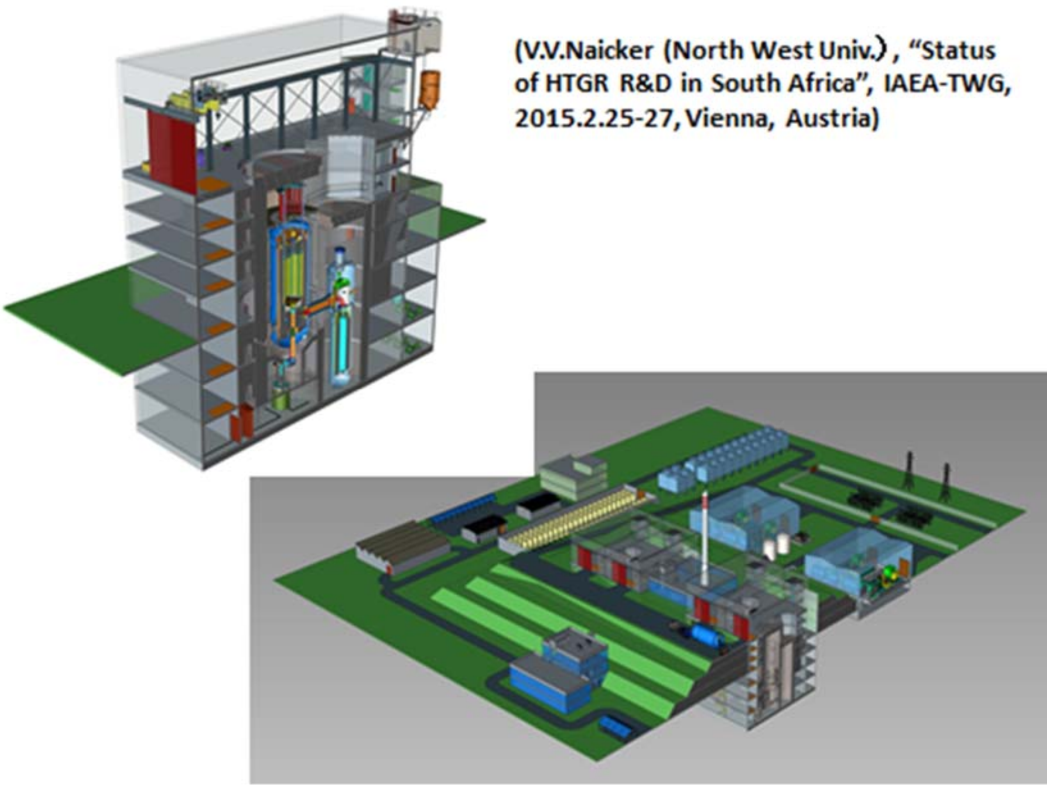
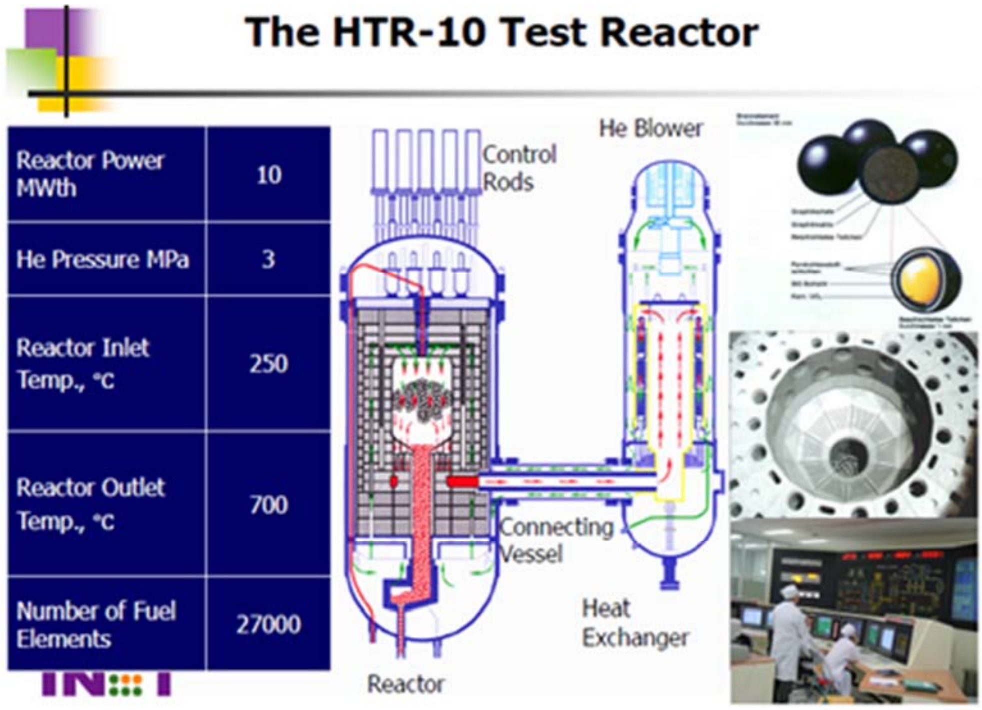



**Fig.6 (S.Africa/Hong Kong) Modular HTGR (HTMR-100/25) Program**




(Y.Sun (INET), "Development of Modular HTGR and other Advanced Reactor Technologies in China", PBNC-2014, Vancouver, Canada, 2014.8)

**Fig.7 (China) High Temperature Reactor Test Module (HTR-10) (Existing)**

(HSNPC-HP, hsnpc.com.cn; Photo, 2015.8)

**Fig.8 (China) High Temperature Reactor Pebble Bed Module (HTR-PM200) (Demonstration Reactor) (Under Construction)**

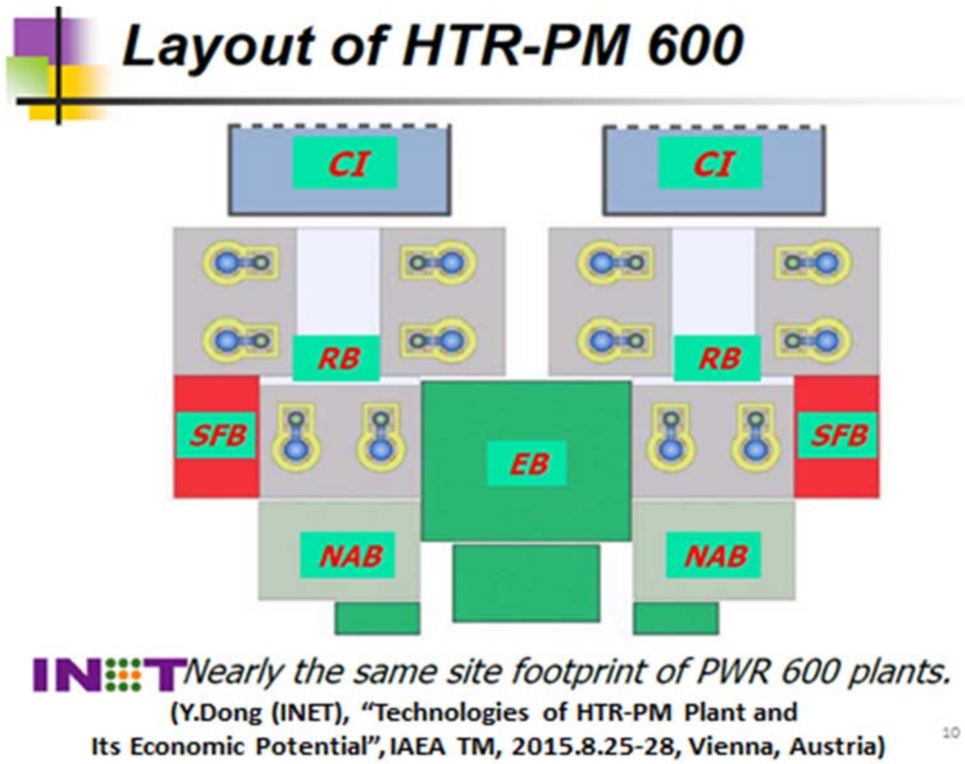



Fig.9 (China) High Temperature Reactor Pebble Bed Module (HTR-PM600) (Commercial Reactor Plant) (Under Construction Plan)

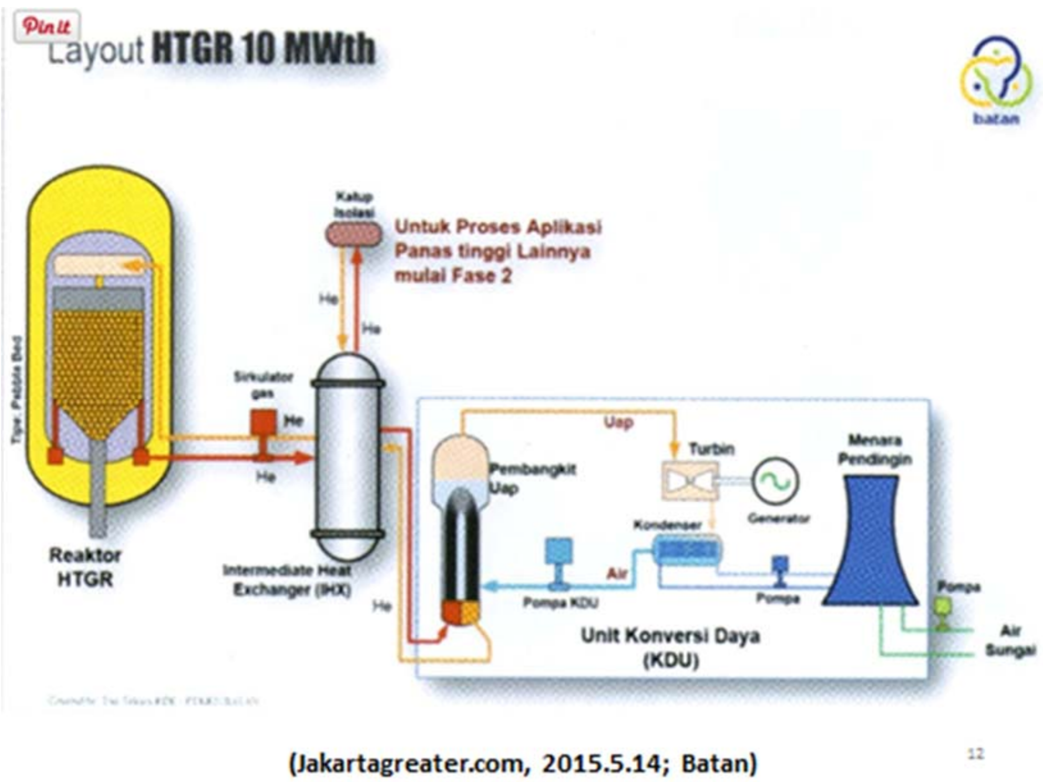
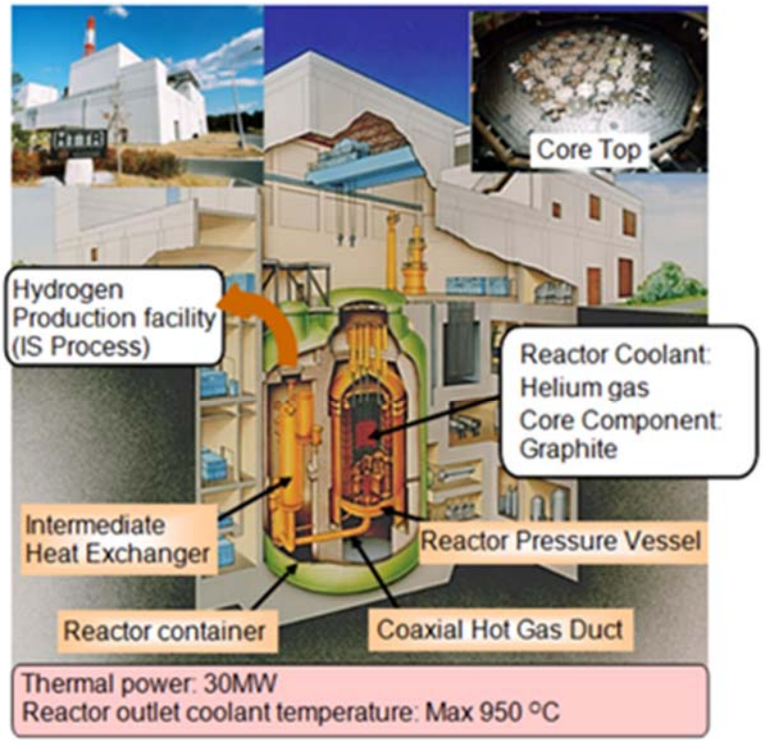
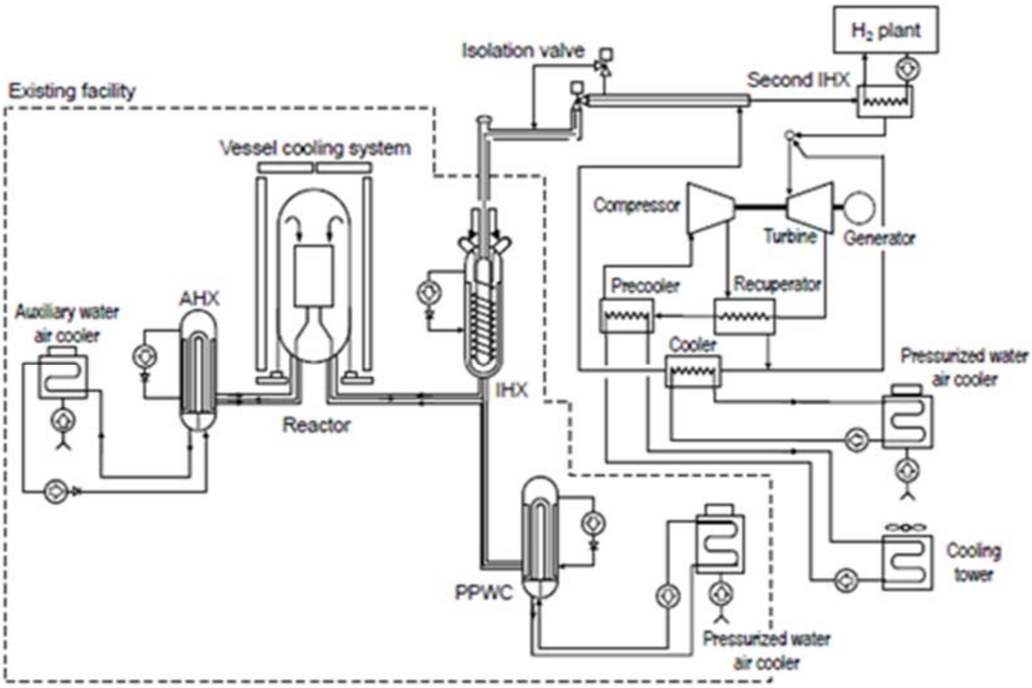



Fig.10 (Indonesia) Experimental Power Reactor (I-EPR) Program



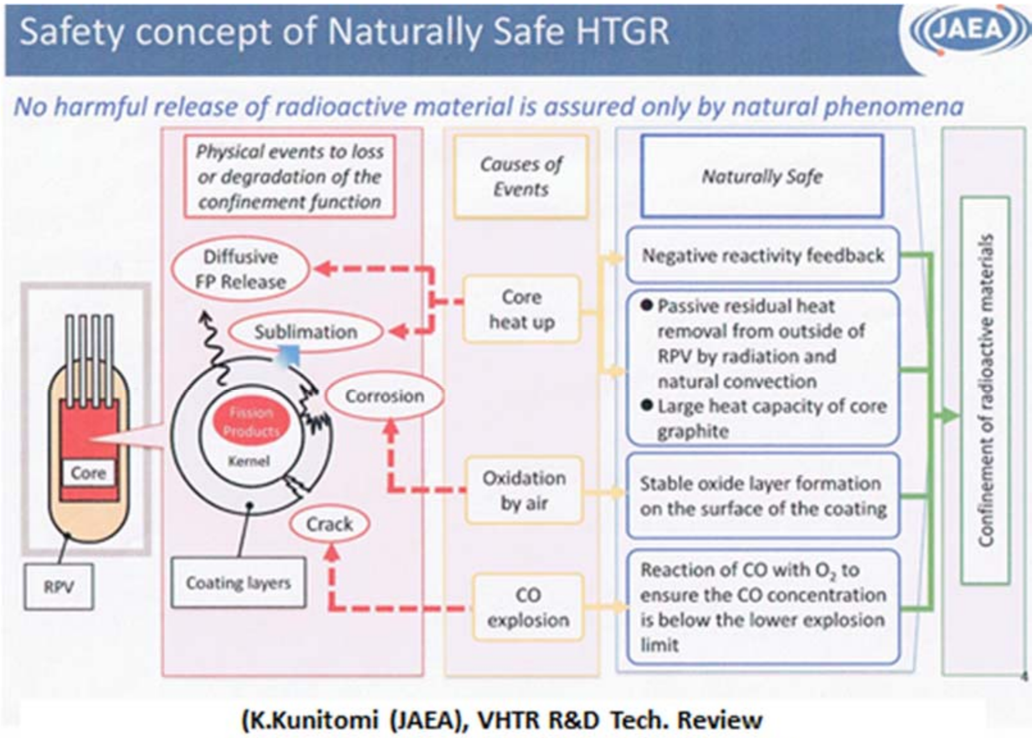

(JAEA HP, HTTR, 2016.1)

**Fig.11 (Japan) High Temp. Eng'g & Test Reactor (HTTR) (Existing)**



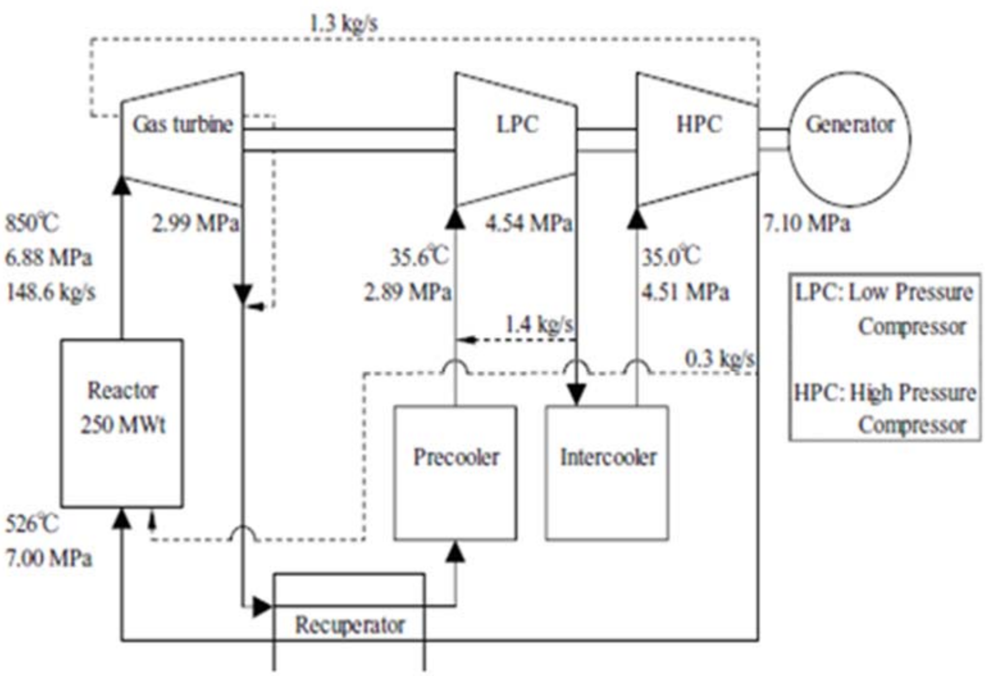

(Hiroyuki Sato, et al. (JAEA), ICONE23-1459, 2015.5.17-21, Chiba, Japan

**Fig.12 (Japan) HTTR Gas Turbine/Hydrogen Production Test (HTTR-GT/H2) Program**




(K.Kunitomi (JAEA), VHTR R&D Tech. Review Meeting, 2012.5.22-24, Salt Lake City, Utah, USA)

**Fig.13 (Japan) Naturally Safe HTGR (NSHTR) Program**




(I.Minatsuki, S.Oyama (MHI), ANS 2015 Winter Meeting, 2015.11.8-12, Washington DC.)

**Fig.14 (Japan) Mitsubishi Gas Turbine HTGR (MHR-100GT) Program**