RAHP News Letter

No.14

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

～Present Status and Future Plans～

March 2015

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, 2015.

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, population is growing and people's level of life is increasing, and then,

- **Security of energy (electric power, heat, fuels for transport, etc.), water and foods**
- **Protection of global environment**

are becoming the common subjects to be solved.

As the 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, diversity and cleanliness, and even after "Fukushima Daiichi Accident" happened in March 2011, although some countries became "Away from nuclear", many countries are promoting nuclear energy development and/or its introduction, through enhancement of safety under Severe Accident conditions.

HTGRs are under development by advanced countries, and large demand and resource countries as well, in light of ;

- **Inherent (or naturally) safety, high temperature energies (800-1,000 deg. C, highly efficient electricity generation, hydrogen (H2) production, industrial process heat applications), nuclear non-proliferation, effective use of natural resources, industrial promotion, etc., in addition to the above mentioned common characteristics of nuclear energy.**

Recent notable trends on HTGRs are as follows;

- **In China, "Demonstration reactor plant for electricity generation" is under construction, and "Commercial reactor programs" are in progress.**
- **In Indonesia, "Experimental & Prototypical and Commercial reactor programs" for multi-purpose use are in process.**
- **In Japan, national strategic discussions have started on how to develop HTGR s and their road maps, and HTTR interconnected Gas Turbine power generation & Hydrogen generation test program has newly started.**

HTGRs, in present pursuit, are all of "Small Modular Reactor (SMR)s", less than 600MWt/300MWe/module, and their target demands are, taking into account of marketability and technological maturity;

- **<In near future> Demands at about 750 deg.C: Steam cycle power generations and mid-low temperature heat applications, such as coal reforming, oil sand recovery & reforming, sea water desalination, etc.**
- **<In future> Demands at above 850 deg.C: Gas cycle highly efficient power generations and high-mid-low temperature heat applications, such as highly efficient H2 production, fertilizer production, fuel cell vehicle (FCV), steel make by H2 reduction, etc.**

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 process heat applications are shown in Figures 1-16 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 were utilized in US and Russian 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".

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)", due to the reasons below, 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.

- **Potential demand is great in North America, such as heat & electricity co-generation, H2 generation, oil-sand recovery & reforming (synthetic fuel for transportation), but completion of the program needs further 3-4B US$.**
- **The public-private partnership needs to be strengthened, such as participation of plant suppliers, owners, operators and end-users.**
- **Core design, construction site, completion date, etc. need to be selected and reviewed.**

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 South 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)" by nuclear plant vendors, utilities, chemicals, etc., sorted customer's requirements, showed potential market

survey results, such as about 800 reactor modules in North America, and requested for the government on national strategic promotion of the NGNP plant demonstration program. And independently of the government, it selected above-mentioned SC-HTGR as most desirable plant design for initial stage, and is selecting sites for plant construction, targeting design certification application in 2015.

This NGNP program is currently under execution of DOE "Advanced Reactor Technology (ART) "program, integrating the "NGNP", "Small Modular Reactor (SMR)" and other programs.

(1-2) National Project Management Corp. (NPMC) Pebble Bed Modular Reactor Gas-Turbine Deep Burn (PBMR-GT-DB) Program:

In 2013, NPMC, in alliance with South African PBMR (refer to 5-1), started PBMR-GT-DB Program. It is targeting treatment & disposal of LWR spent fuels (incineration of Plutonium (Pu) and Transuranic elements (TRUs), which US is presently confronted with, and power generation, H2 production and process heat applications as well. And it is situated to support and supplement already running DOE programs of NGNP, Global Nuclear Energy Partnership (GNEP) and Advanced Fuel Cycle Initiative (AFCI).

New York State and Oswego City, etc. have already promised to fund in several hundred M$ scale. Its development in South Africa utilizing World Bank finance, and equipments manufacturing and commercialization in USA are assumed. In July 2013, it was applied to DOE for SMR development support.

(1-3) Xe-100 Program:

Similarly with the above, X-energy has raised a HTGR development program, in collaboration with South African PBMR, targeting treatment and disposal of LWR spent fuels and process heat applications, etc.. At present, its applicability study on Coal to Gasification (CTG) is under way, taking a process model of South African national coal to gas/liquid company SASOL.

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

StarCore (Canada and USA) is deploying this program mainly targeting on remote, dispersed and/or cool land demands (small towns, minings, strategic bases, etc.), and is under preparation of licensing application to Canadian Nuclear Safety Commission, targeting initial deployment in 2015. Remote operation & control of nuclear reactor by means of communication satellite is proposed.

The program is in process in alliance with Areva.

(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 Coated Particle Fuel (CPF)s.

(3-2) MHR-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, aiming at electricity generation, oil refinery, H2 production, etc., and evaluating its potential market of several hundred reactor modules in Russian economic domain.

(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 now, based on the above fruits, they are promoting "Advanced Reactor for Cogeneration of Heat & Electricity R&D (ARCHER)" and "Nuclear Cogeneration Industrial Initiative (NC21)".

In France, in addition to the above co-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).

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

(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" development programs. The program itself, however, had been terminated in 2010, due to "Lehman Shock" related national bankruptcy.

Possibilities of its restoration or reutilization are in pursuit, while maintaining its fuel fabrication facility, developmental test facilities and intellectual properties. In relation to this PBMR, NPMC/PBMR-GT-DB and Xe-100 (USA) and TH-100 (S.Africa) programs (refer to 1-2, 1-3 and 5-2, respectively) are currently under proposal or already in process.

(5-2) Thorium (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 fuel (fertilizer) in place of uranium (U) fuel in PBMR. Th is one of the by-products of Rare-Earth (RE) mining in the country, and is positioned in this program as one of its effective usages and/or supplement or alternative of U fuel in future.

Already finished its reactor plant conceptual design, it is under establishment of a consortium for its plant detailed design, construction and operation. In 2014, a conceptual design of Th fuel production facility is in process. Its first reactor module plant operation is assumed to start in about 2022 in USA.

(5-3) High Temperature Module Reactor (HTMR-100/25) program:

A joint venture company HTMR, established in Hongkong by above-mentioned STL, Neopanora, etc. is, deriving from TH-100 of STL and mainly aiming at Asian market, developing HTMR-100, using Low Enriched Uranium (LEU), Th or Pu as fuel, for electricity generation, and HTMR-25 for heat & electricity co-generation.

It is under design proposal for Indonesian MPPR 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.

(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 (HTR-PM200) started its construction in December 2012 in Shidao Bay, Rongcheng City, Shandong Province, after passing safety review after "Fukushima Daiichi Severe Accident" of March 2011. Its operational start is scheduled in late 2017.

In 2014, HTR-PM600 conceptual design was completed for commercialization.

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

(6-3) Putian and Ruijin HTR Programs:

In 2013, China Construction & Nuclear Engineering Group Co.(CNEC) and Putian City in Fujian Province, announced on HTGR plant introduction 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 introduction plan.

(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 after 2028.

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

This is a series of HTR 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.

(9) Indonesia

In 2010, "Nuclear Co-generation Reactor" is situated in National Mid-term Energy Development Program. Since then, National Nuclear Energy Agency (BATAN) is promoting conceptual designs and candidate site investigations for its Experimental & Prototypical reactor (EPR) and Commercial Reactor (RGTT200K) of Multi-Purpose Power Reactor (MPPR).

International competitive bidding is scheduled in 2015 for the plant basic design, and Japan, China, S.Africa (/Hongkong), etc. are deemed to tender.

(10) Japan

In Japan, since 1970's, HTGR has been under continuous development, centered in JAEA, 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.

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

Although Japan has no HTGR commercial deployment program at present, its cooperation in HTGR development programs, such as NGNP in USA (refer to 1-1), HTR-10 & HTR-PM in China (refer to 6-1 and 6-2), KHTR in Kazakhstan (refer to 8), Indonesian program (refer to 9), etc., and international leadership in technology development are required.

After "Fukushima Daiichi 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 become in operational re-start after the safety is re-confirmed and "R&D on HTGR" is to be promoted under international cooperation".

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:

The reactor plant had been enforced to be in shut-down condition since Fukushima Accident. JAEA, however, is under preparation of its operational re-start in FY2015.

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 Demo Test " program in use of HTTR (HTTR-GT/H2) has newly started.

(10-2) Gas Turbine HTR (GTHTR300), Small Steam Cycle HTR (HTR50S, MHR-50/100), Naturally Safe HTR (NSHTR), Clean Burn HTR (CBHTR) programs:

JAEA, Mitsubishi Heavy Industries (MHI) and Toshiba, etc. are, independently or jointly, promoting conceptual designs of reactor plant, 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 safely 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 of GTHTR300 series (such as (-X) for power generation, (-H) for H2 generation, (-C) for co-generation and (-A) for water-free plant), small steam cycle HTR (HTR50S, MHR- 50/100), NSHTR, and CBHTR are included.

■ Information Sources:

(1) International conference papers: IAEA HTGR related meetings (TWG-GCR, Technical Meetings (TM)), ICONE20 (2012)(USA), HTR-2012 (Japan), ANS SMR-2013 (USA), HTR-2014 (China), --.

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

■ Inquiries to:

Research Association of HTGR Plant (RAHP), in The Institute of Applied Energy (IAE), Tokyo, Japan:

Tel: +81-3-3508-8891, Fax: +81-3-3501-1735, E-mail: rahp1@iae.or.jp

Table 1. "Test & Research Reactor Programs at a glance"
(as of Mar. 2015)
(Objects: Test and research programs, using actual nuclear reactor)

Name, Organ, Country	Background, Purpose, Parameter	Present status, Future plan
HTTR : Temp. Eng'g Test Reactor ＜JAEA＞ ＜Japan＞ [Fig. 1-2]	◆ Nuc. ene. multi- purpose utilization (nuc. steel making, --) ◆ Test & res. of HTGR ◆ Oarai, Ibaragi Pref. ◆ 30MWt, 850C (950C for short period)	◆ Reactor under plan of operation re-start in FY'15 ◆ Under execution of OECD/NEA Loss of Forced Cooling Safety Demo. Test (HTTR-LOFC) program, and equipments & H2 production development ◆ Under start of new demo program of Gas Turbine/H2 production interconnected to HTTR (HTTR-GT/H2)
HTR-10 : HTR Test Reactor ＜INET＞ ＜Chaina＞ [Fig. 3]	◆ Natural resources (coal, Th, etc.) ◆ Nuc. ene. multi- purpose utilization ◆ Test & res. of HTGR ◆ Outskirt of Beijing ◆ 10MWt/2.6MWe, (-ST): 700C, (-GT): 750-900C	◆ Ph.1 (Steam turbine: -ST) : R&D is continuing ◆ Ph.2 (Gas turbine: -GT): under prep. (dev't of mag. bearing, --) ◆ H2 production, etc. under development

Table 2. "Prototypical & Demonstration Reactor Programs at a glance" (1/3) (as of Mar.2015)

(Objects: Proto./Demo. reactor programs, in which reactor plant siting and funding base are clearly indicated)
(Md: Module, U: Uranium, Pu: Plutonium, Th: Thorium, RE: Rare Earth, P-type: Pebble Bed type reactor, B-type: Block type reactor)

Name, Organ, Country	Background, Purpose, Parameter	Present status, Future plan
NGNP : Next Generation Nuclear Plant ＜DOE＞ ＜USA＞ [Figs. 4-6]	◆ Nat. resources (coal, oil sand, oil shale,--) ◆ Ene. demand & CO2 release remarkable ◆ Ene. independence, clean ene. (H2, etc.), nuc. heat apps. (syn-fuels from coal, oil sand, --), dev't of Gen.4 reactors, SMRs ◆ HTGR plant dev't & demo ◆ Idaho (or other site) ◆ 600MWt/ ??MWe/Md, 750-800C	◆ Ph.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 Electric), -- ◆ Did not enter Ph.2 ('01-'21: plant detail design, construct., demo. ope.) due to lack of public-private alliance and funding. R&D works under way with reduced scale ◆ NGNP Industry Alliance (NIA: WH, Areva, Entergy, Dow, Toyo Tanso,--) independently selected Areva's design (SC-HTGR) as most desirable one for initial NGNP. Idaho alternative candidate sites (Lousiana, Alberta (Canada), etc.) under Investigation ◆ '15 (target): Licensing start
SC-HTGR: ＜Areva-USA＞ ＜France/USA＞	◆ Advanced version of ANTARES for US-NGNP, co-generation ◆ B-type, UCO fuel, steam turbine, 750C	
NPMC-PBMR-GT-DB : National Prj. Mgmt Corp. Pebble Bed Reactor Gas-Turbine-Deep Burn ＜NPMC＞ ＜USA/S.Africa＞	◆ Disposition of LWR spent fuels (incineration of Pu/TRUs), power gen., H2 gen., heat app.s. based on S.African PBMR tech. and use of World Bank finance ◆ Demo plant in Koeberg (S.Africa) and commercialization deployment in US-P-type	◆ '13: applied for SMR development support ◆ '13: NY State, Oswego City, etc. promised to fund in scale of 300M$, etc.

Table 2. "Prototypical & Demonstration Reactor Programs at a glance" (2/3) (as of Mar.2015)

(Objects: Proto./Demo. reactor programs, in which reactor plant siting and funding base are clearly indicated)
(Md: Module, U: Uranium, Pu: Plutonium, Th: Thorium, RE: Rare Earth, P-type: Pebble Bed type reactor, B-type: Block type reactor)

Name, Organ, Country	Background, Purpose, Parameter	Present status, Future plan
Xe-100 : ＜X-energy/ Aerotherm/ Stellenbosch Univ.＞ ＜USA/S.Africa＞	◆ Disposition of LWR spent fuels (incineration of Pu/TRUs), power gen., H2 gen., heat app.s. , based on S.African PBMR tech. ◆ Demo plant in Koeberg (S.Africa), and comm. deploym't in US ◆ P-type, 100MWt/50MWe/Md, 850C	◆ Under study on its application to Coal to Gas (CTG) process, taking process models of S.African Coal to Liq. (CTL) company SASOL
PBMR : Pebble Bed Modular Reactor ＜PBMR＞ ＜S.Africa＞	◆ Pebble bed type mod. reactor plant demo. ◆ U fuel. Power gen.,H2 gen., heat apps. (CTG/ CTL, etc.) ◆ Koeberg ◆ P-type, U fuel ◆ 400MWt/160MWe/Md, 900C for power gen. ◆ 200MWt/80MWe/Md, 750C for heat apps.	◆ '93-Concept.design, '95-Detail design, '10: Dev't stopped due to financing difficulty ◆ Under pursuit of program restoration, while maintaining a series of test facilities, and intellectual properties (refer to TH-100 (5-2), HTMR-100/25 (5-3), NPMC/PBMR-GT-DB(1-2), Xe-100(1-3))
HTR-PM200/600 : HTR Pebble Bed Module ＜INET/Huaneng/ China Nuc. Eng'g & Construction Grp. (CNEC)＞ ＜Chaina＞ [Fig. 7]	◆ Demo. & commercialization of HTGR plant , based on Test Reactor HTR-10 technology ◆ P-type, U fuel <HTR-PM200 (Demo Reactor)> ◆ Shidao Bay, Shandong Province ◆ 500MWt(=250MWt/Md×2 Md)/200MWe/unit, 750C <HTR-PM600 (Commercial Reactor)> ◆ 1,500MWt(=250MWt/Md× 6Md)/600MWe/unit, 750C	＜HTR-PM200＞ ◆ '11-12: Safety re-viewed after "Fukushima Severe Accident" ◆ '12: Plant construction started ◆ '17(plan): Operation start ◆ Presently fuel handling, steam gen., etc. are under system demo., and fuel production facility near completion ＜HTR-PM600＞ ◆ '14: Plant conceptual design completed, based on HTR-PM200 demo. Plant

Table 2. "Prototypical & Demonstration Reactor Programs at a glance" (3/3) (as of Mar.2015)

(Objects: Proto./Demo. reactor programs, in which reactor plant siting and funding base are clearly indicated)
(Md: Module, U: Uranium, Pu: Plutonium, Th: Thorium, RE: Rare Earth, P-type: Pebble Bed type reactor, B-type: Block type reactor)

Name, Organ, Country	Background, Purpose, Parameter	Present status, Future plan
HTGR Introduction: ＜CNEC/ Putian City/ Ruijin City＞ ＜China＞	◆ HTGR plant introduction programs as part of economic deployment in local center cities ◆ Putian City (Fujian Prov.) and Ruijin City (Jiangxi Prov.), 600MWe (HTR-PM600?)	◆ '13: Introduction programs announced by CNEC / Putian City and CNEC/ Ruijin City, Respectively
KHTR : Kazakhstan HTGR ＜NNC＞ ＜Kazakhstan＞ [Fig. 8]	◆ Export of nat.resources (iron ore, U, Th, --), introduction & fixation of foreign advanced technologies ◆ HTGR dev't (power gen., regional heating, H2 gen., --) ◆ B-type ◆ Kurchatov City ◆ 50MWt/15MWe/Md, 700C (950C in future)	◆ Japan (JAEA, Toshiba, Fuji Elec., NFI--) is fully cooperating (tech., plant design, education,--) ◆ '15～: Feasibility study (FS)(plan) ◆ '23: Ope. start (plan) ◆ Phase-1: Steam turbine power gen., regional heating, -- ◆ Phase-2: H2 gen.--
MPPR (EPR/RGTT200K) : ＜National Nuc.Ene. Agency (BATAN)＞ ＜Indonesia＞ [Fig. 9]	◆ Export of natural resources (coal, natural gas, Al, Zr, Th, etc.) after value added, and HTGR development for co-gen, sea water desalination, marine infra strengthening, -- ◆ P-type, U(&Th in future) fuel <Experimental & Prototypical Reactor (EPR)> ◆ 10-30MWt/3-10MWe ◆ BATAN Serpong site <Commercial Reactor (RGTT200K)> ◆ 200MWt/100MWe/Md	◆ '07/'10: Development of nuc. co-gen. reactor was situated in National/Mid-term Energy Development Program. ◆ Reactor plant conceptual design and candidate construction site investigation started ◆ '14: Cooperation agreement concluded between BATAN and JAEA (Japan). ◆ China, S.Africa/Hongkong, etc. are also under coop. approach ◆ '20: EPR operation start ◆ '31-: RGTT200K commercialization

Table 3. "Other R&D Programs at a glance" (1/4)
(as of Mar.2015)
(Objects: R&D programs other than afore-mentioned "Test & Research Reactor" and "Proto & Demo Reactor" programs)

Name, Organ, Country	Background, Purpose, Parameter	Present status, Future plan
GT-MHR : Gas Turbine Md. Reactor ＜DOE/GA/ORNL/ Rosatom/OKBM＞ ＜USA/Russia＞	◆ Nuc. non-proliferation (incineration of weapon dis-mantled & surplus Pu) and efficient gas turbine power gen. ◆ B-type, Pu fuel ◆ 600MWt/Md, 850C	◆ '93-'13: USA-Russia Joint R&D ◆ Deploying to H2-MHR, SC-MHR, DB-MHR -- in USA, and to MHR-T(=MGR-T) in Russia, Respectively
H2-MHR : Md. Reactor for H2 gen. ＜GA＞ ＜USA＞	◆ US adv'd version of US/Russian GT-MHR ◆ H2 generation ◆ B-type	◆ Designs proposed for NGNP (Phase-1)(refer to 1-1)
SC-MHR : Md. Reactor for Steam Cycle ＜GA＞ ＜USA＞	◆ US adv'd version of US/Russian GT-MHR ◆ Steam cycle (power gen., heat apps.) ◆ B-type	
DB-MHR : Deep Burn Md. Reactor ＜DOE/GA＞ ＜USA＞	◆ US adv'd version of US/Russian GT-MHR ◆ Nuc. waste (Pu, TRUs) management, power gen., heat apps. ◆ B-type	◆ Conceptual design finished ＜Based on this technology, Gas Cooled Fast Reactor (GFR; EM2) is under design＞
SPB : StarCore Pebble Bed Reactor ＜StarCore＞ ＜Canada/ France/USA＞ [Fig. 10	◆ Remote / cold area / dispersed demands (mining, small towns, strategic bases, --) ◆ Reactor core underground ◆ Remote ope. using comm. Satellite ◆ 30MWt/10MWe/Md	◆ Pre-licensing app. to Canadian Nuc. Safety Commission ◆ '15: Initial deployment (plan) ◆ Alliance with Areva started

Table 3. "Other R&D Programs at a glance" (2/4)
(as of Mar.2015)
(Objects: R&D programs other than afore-mentioned "Test & Research Reactor" and "Proto & Demo Reactor" programs)

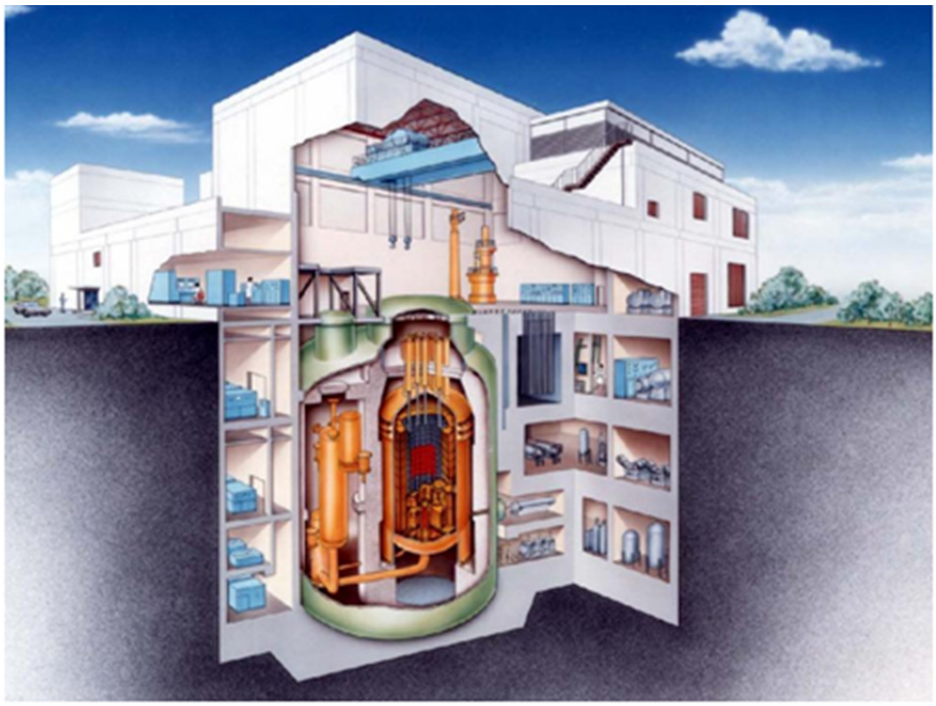
Name, Organ, Country	Background, Purpose, Parameter	Present status, Future plan
GT-MHR : ＜Rosatom/ OKBM＞ ＜Russia＞	◆ Russian adv'd version of US/Russian GT-MHR ◆ B-type, Pu fuel ◆ 600MWt/Md, 850C	◆ New design Coated Particle Fuel (CPF) and turbo machines are under development ◆ Russian market under survey ◆ Under cooperation to Kazakhstan and Indonesian HTR programs ＜Under plan to connect the technology to Gas Cooled Fast Reactor (FGR) development＞
MHR-T(=MGR-T) : ＜Rosatom/ OKBM＞ ＜Russia＞	◆ (MHR-GT) for Gas Turbine power gen. ◆ (-OR) for Oil Refinery ◆ (-SMC) for H2 gen. by Steam Methane Conversion ◆ (-HTE) for H2 gen. by Hi. Temp. Electrolysis ◆ 600MWt/Md ◆ B-type, U fuel ◆ 600MWt/Md, 950C	
SNE-TP : Sustainable Nuc. Ene. Tech. Platform ＜EC＞ ＜EU＞	◆ EU co-strategic deployment, sorting and construction for nuclear technology co-development base	◆ Under co-study on EU common nuc. ene. dev't target, strategy, requirements, schedule-- (reactor type, user's requirements, feasibility of int'l demonstrator) ◆ 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), -- ◆ Under alliance with US-NIA (refer to 1-1)
NC21 : Nuc. Co-gen. Industry Initiative 21 ＜EC＞ ＜EU＞ [Fig. 11]	◆ Activities on nuc. co-gen. demo plant construction in Europe	
ANTARES : Areva's New Tech.& Adv'd GCR for Ene. Supply ＜Areva＞ ＜France＞	◆ HTGR dev't (power gen., H2 gen., heat apps.) ◆ B-type	◆ Its adv'd version (SC-HTGR) proposed for NGNP (US) by Areva-USA, and selected by NIA as most desirable plant design for initial NGNP (refer to 1-1)

Table 3. "Other R&D Programs at a glance" (3/4)
(as of Mar.2015)
(Objects: R&D programs other than afore-mentioned "Test & Research Reactor" and "Proto & Demo Reactor" programs)

Name, Organ, Country	Background, Purpose, Parameter	Present status, Future plan
HTR-PL : HTR-Poland ＜AGH/NCBIR＞ ＜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 : Thorium (Th) PBMR ＜Steenkamps kraal＞ ＜S.Africa＞ [Fig. 12]	◆ Utilization of Th (by-product of Rare Earth (RE)s mining) ◆ Th fuel version of PBMR ◆ Dev't & Deploym't in S.Africa & USA ◆ P-type, 100MWt/35MWe/Md, 750C	◆ '11: Program raised, conceptual design. ◆ '12-: Under settlement of consortium for devt & promotion ◆ '14: Conceptual design of Th fuel commercial production facility ◆ '22: FOAK ope. Start ◆ (refer to HTMR-100/25)
HTMR-100/25 : High Temp. Mod. Reactor ＜HTMR＞ ＜S.Africa/ Hongkong＞	◆ Advanced version of TH-100 (S.Africa) for Asian market ◆ P-type ◆ Reactor semi-under-ground ◆ LEU or Th/LEU or Th/Pu fuel, 750C ◆ HTMR-100: 100MWt/35MWe/Md for power gen. ◆ HTMR-25: 25MWt/5MWe/Md for co-gen.	◆ HTMR established by STL (S.Africa), Neopanora, etc. ◆ A series of HTMR-100/25 designs under development
NHDD : Nuc.H2 Dev't & Demo. ＜KAERI＞ ＜S.Korea＞ [Fig. 13]	◆ H2 ene. dev't as part of national strategy ◆ Dev't & demo. of water, H2 and power gen. by nuclear ◆ B-type ◆ 200MWt/Md, 750C (950C in future)	◆ Korea Adv'd Inst. of Science &Tech. (KAIST) and Korea Inst. of Energy Research (KIER) are cooperating on H2 production development ◆ Utility, heavy industry, steel -- (KEPCO, Hyundai, POSCO --) are participating in alliance ◆ '13-: US NIA (refer to 2-1) is participating in alliance ◆ '28-: Plant demo. & operation

Table 3. "Other R&D Programs at a glance" (4/4)
(as of Mar.2015)
(Objects: R&D programs other than afore-mentioned "Test & Research Reactor" and "Proto & Demo Reactor" programs)

Name, Organ, Country	Background, Purpose, Parameter	Present status, Future plan
GTHTR300 : Gas Turbine HTGR ＜JAEA＞ ＜Japan＞	◆ Gas Turbine HTGR series development; (-X) for power gen.,(-C) for co-gen., (-H) for H2 gen.,(-A) for water-free plant, respectively ◆ B-type, U fuel ◆ 600MWt/Md, 850C	◆ Concept. design and economic evaluation in progress ◆ Under a series of safety demo test on Severe Accident, using HTTR (refer to 10-1)
HTR50S : Steam Cycle Small HTGR ＜JAEA/ Toshiba/--＞ ＜Japan＞ [Fig. 14]	◆ Dev't of small HTGRs for developing countries (for power gen., steam supply) ◆ B-type, U fuel ◆ Phase-1,-2: 50MWt/(13.5-17.2MWe/Md, 750C ◆ Future: 50MWt/10.3MWe(ST)+ 6.9MWe(GT)/Md	◆ Concept. design (plant basic specifications, system concept) finished ◆ Market survey under way
NSHTR : Naturally Safe HTGR ＜JAEA＞ ＜Japan＞ [Fig. 15-16]	◆ Dev't of HTGR capable to protect people and environment only by natural & physical phenomenon (heat conduction/convection/ radiation, moderator temperature effect,--)	◆ Plant concept. design and related oxidation-resistant fuels and graphite materials under development
CBHTR : Clean Burn HTGR ＜JAEA＞ ＜Japan＞	◆ Incineration of Pu & TRUs to be derived from LWR spent fuel ◆ Pu fuel	◆ Concept. design under way
MHR-50/100 : Mitsubishi Small HTGR ＜MHI, JAEA＞ ＜Japan＞	◆ Dev't of HTGR of small and improved safety ◆ U fuel ◆ (FOAK): 120MWt/50MWe/Md ◆ (NOAK): 250MWt/100MWe/Md, 750C	◆ Concept. design, market & economic survey finished ◆ Business plan under study



（JAEA HP）

Fig.1 (Japan) High Temperature Engineering & Test Reactor (HTTR)

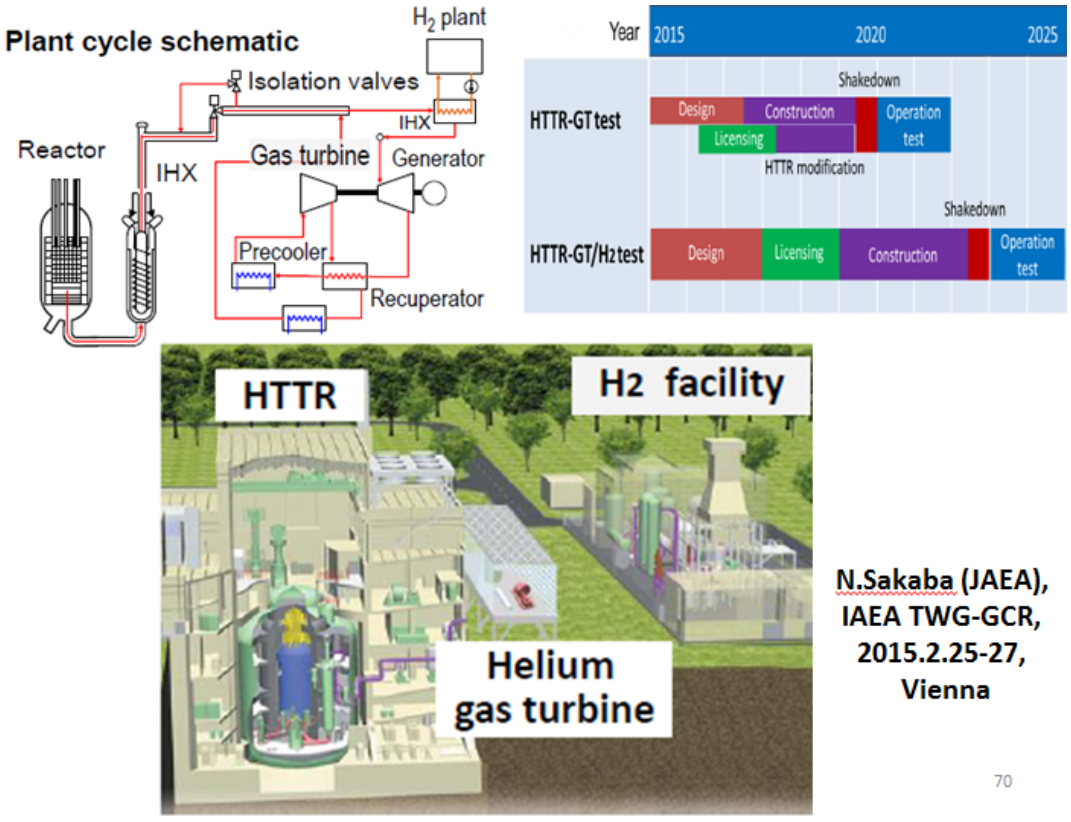
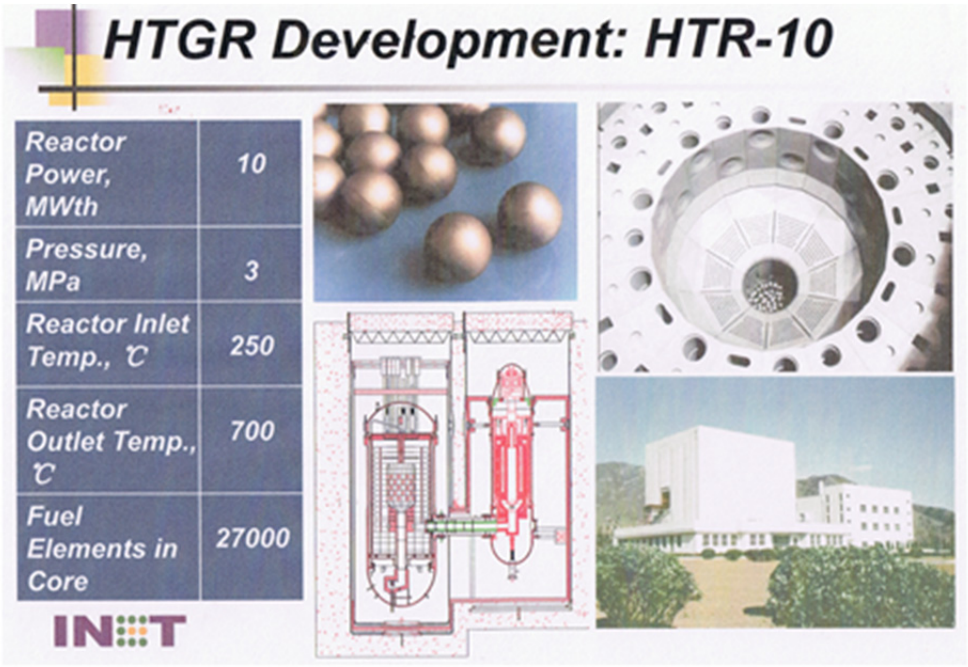
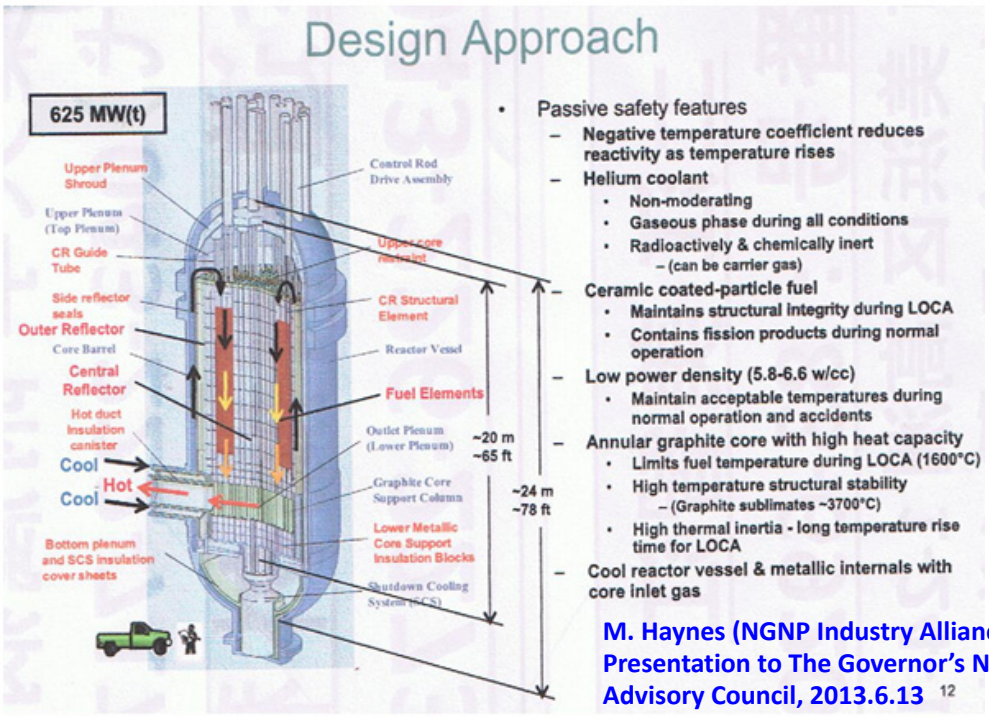


Fig.2 (Japan) HTTR Gas Turbine & Hydrogen Production Test Program （HTTR-GT/H2）



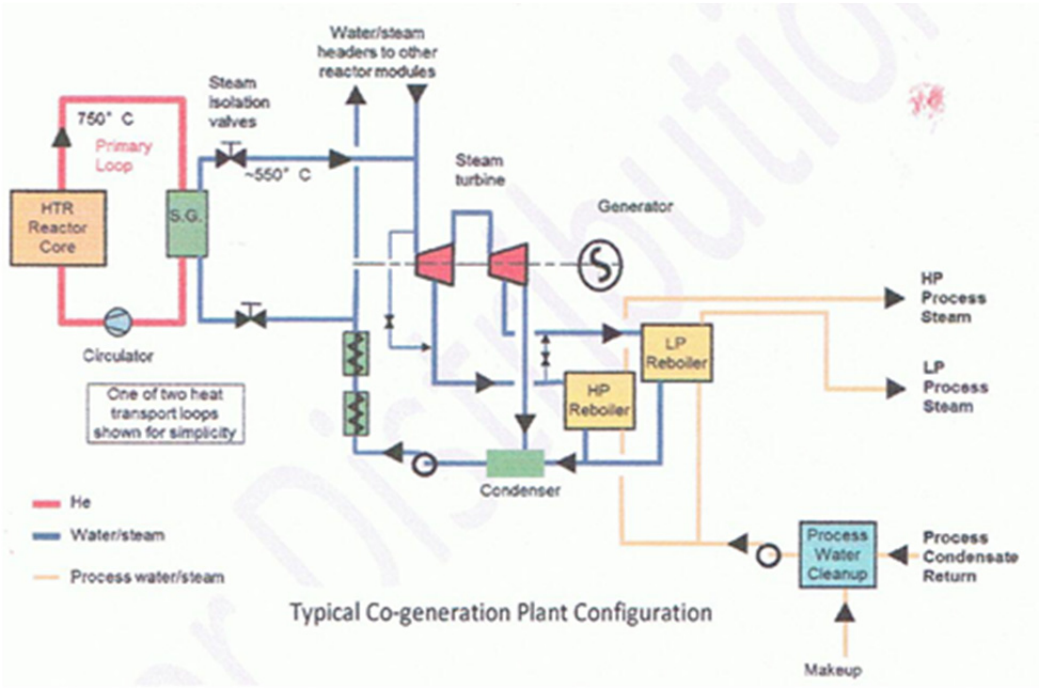
(Sun Yuliang (INET), "Potential Contributions of Modular HTGRs to Energy Supplies in China", IAEA Technical Meeting on Options to enhance Energy Supply Security with NPPs based on SMRs, Oct.3-6, 2011, IAEA, Vienna)

Fig.3 (China) High Temerature Test Module (HTR-10)



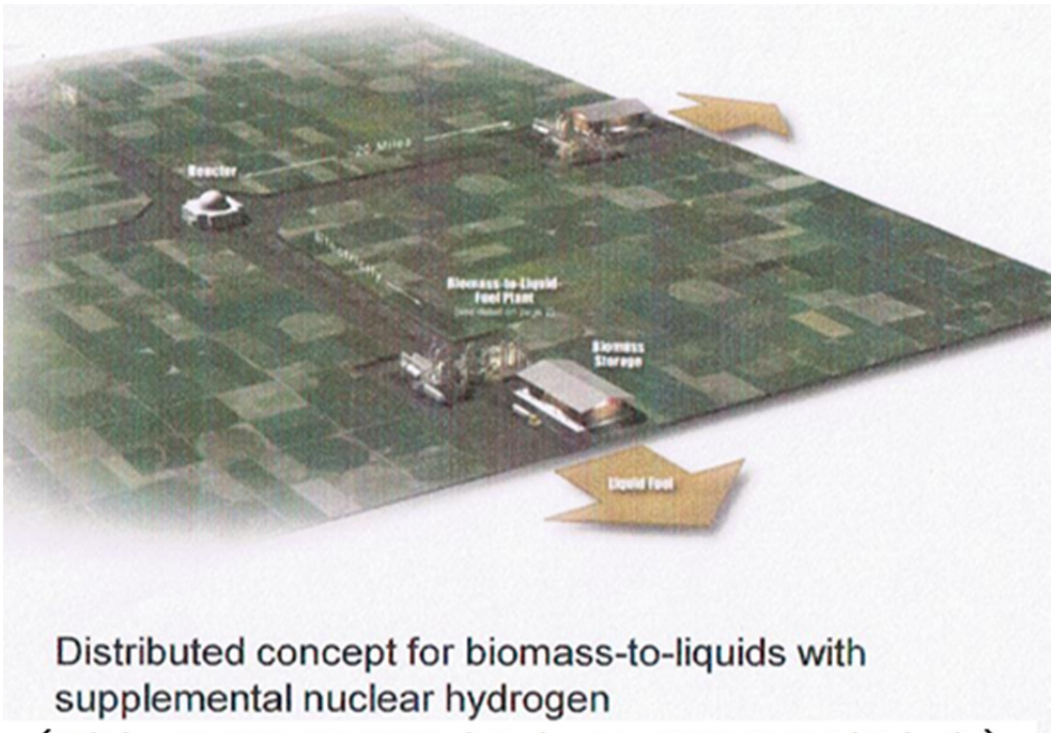
(M.Haynes (NGNP Industry Alliance), Presentation to The Governor's Nuclear Advisory Council, 2013.6.13)

Fig.4 (USA) Next Gen.Nuclear Plant (NGNP) Areva SC-HTGR Design



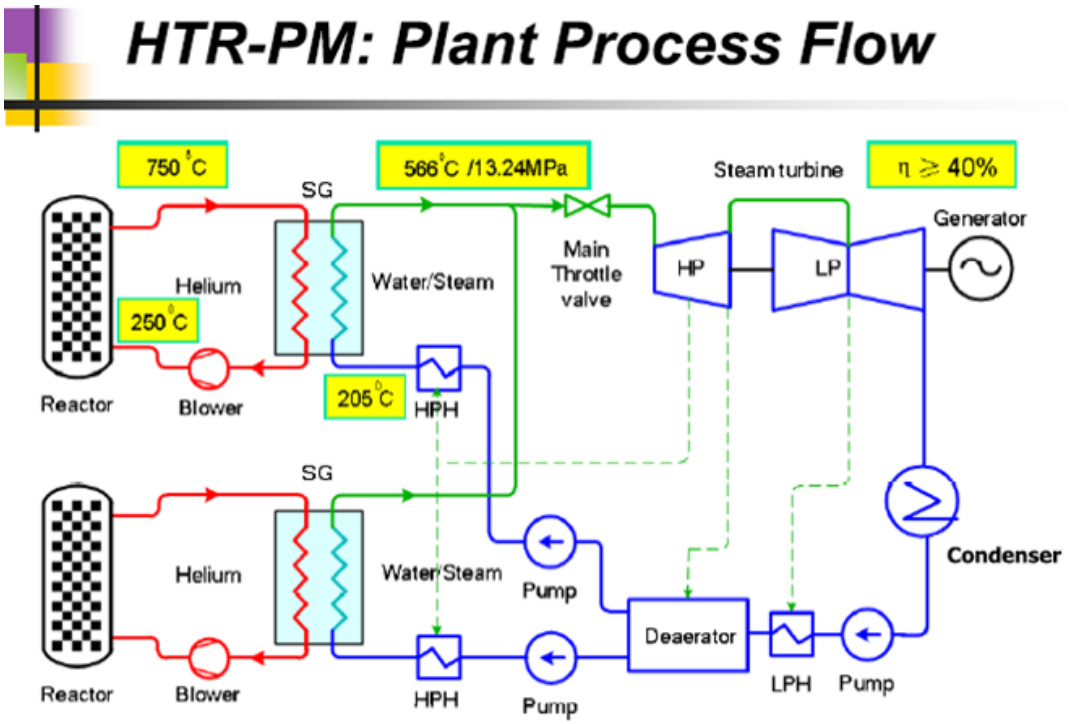
(Summary Decision Paper – Reference Modular HTGR Reactor Design Concept and Plant Configuration for Initial Applications, NGNP Industrial Alliance, 2012.2.7)

Fig.5 (USA) Next Gen.Nuclear Plant (NGNP) Ref. Co-gen Plant Flow



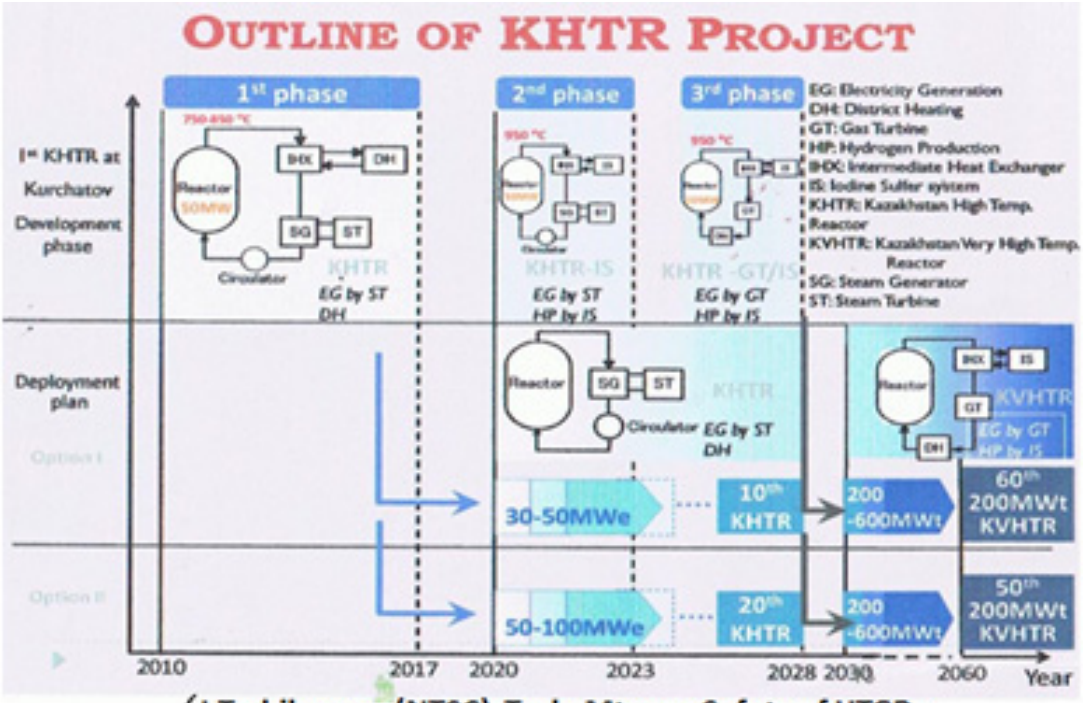
(J.O'Brien, INL; VHTR R&D FY12 Tech. Review Mtg, 2012.5.22-24, Salt Lake City)

Fig.6 (USA) Next Gen. Nuc.Plant (NGNP): H2 & BTL Gen. Concept



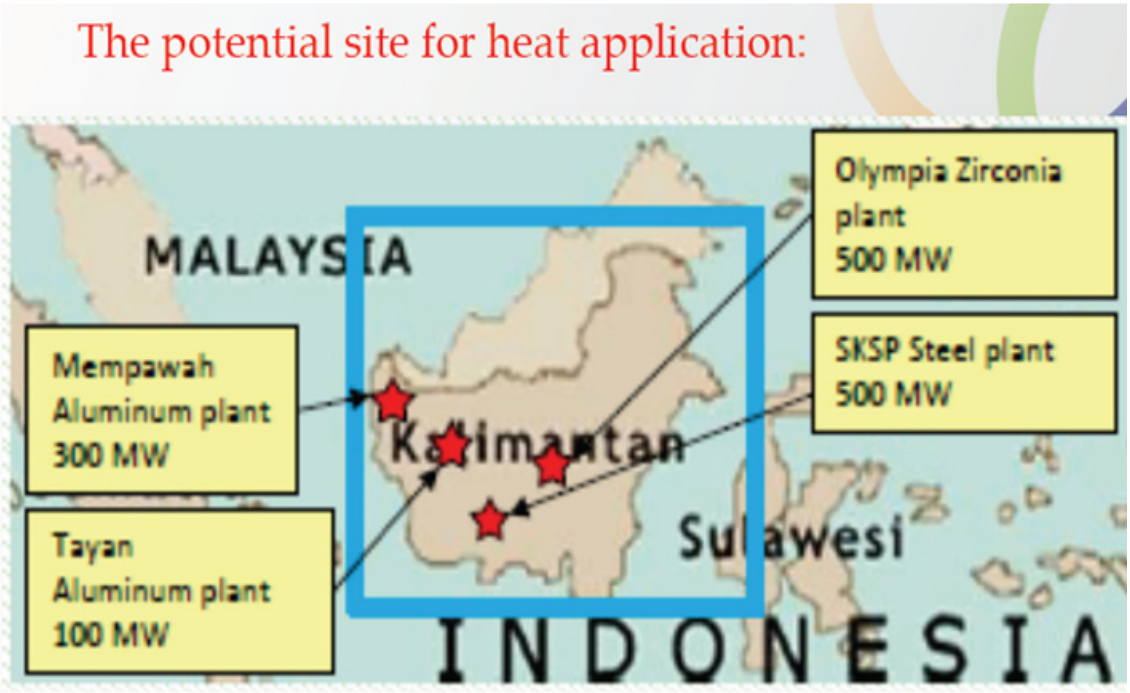
(Sun, Y. (INET), "Potential Contribution of Modular HTGRs to Energy Supply in China", 2011.10.3.6, IAEA, Vienna)

Fig.7 (China) HTR-PM Process Flow



(I.Tazhibayeva (NTSC), Tech. Mtg. on Safety of HTGRs In the light of Fukushima Daiichi Accident, 2014.4.8-11, IAEA, Vienna

Fig.8 (Kazkhustan) KHTR Project Outline



(G.R.Sunaryo (BATAN), IAEA TM on High Temperature Qualification of HTGR Materials, 2014.6.10-13, IAEA, Vienna)

Fig.9 (Indonesia) Potensial Site for Heat Application

Fig.10 (Canada) StarCore Pebble Bed Reactor (SPB) Plant Concept

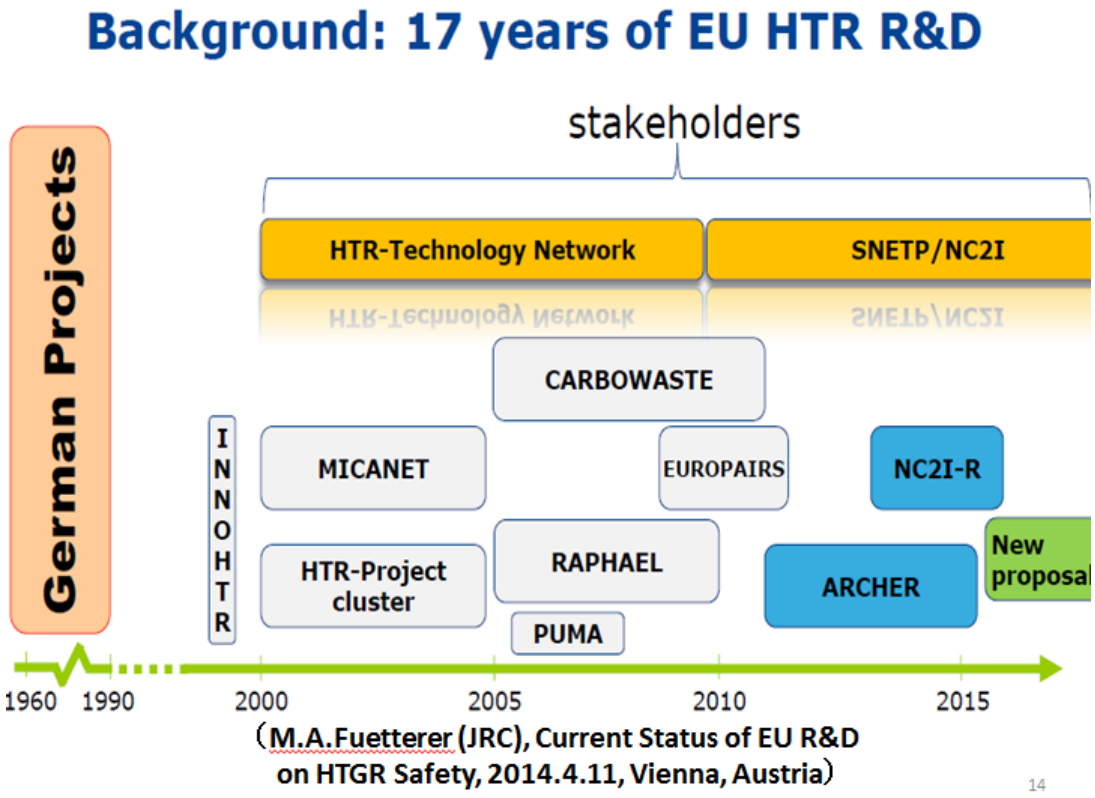


Fig.11 (EU) HTR R&D Flow (Nuclear Cogeneration NC21, etc.)

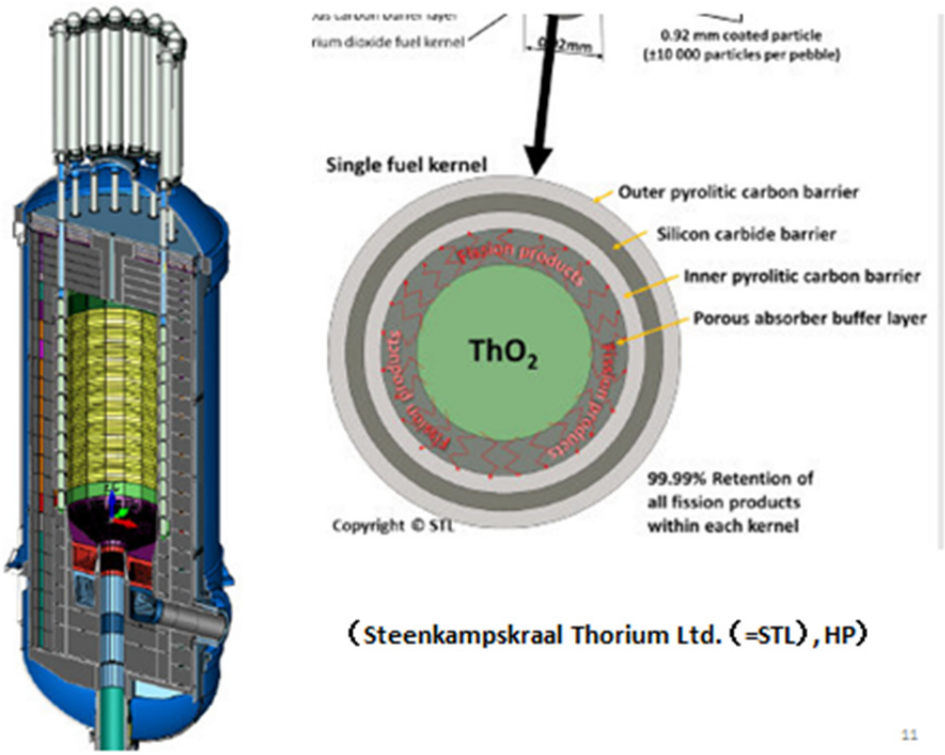
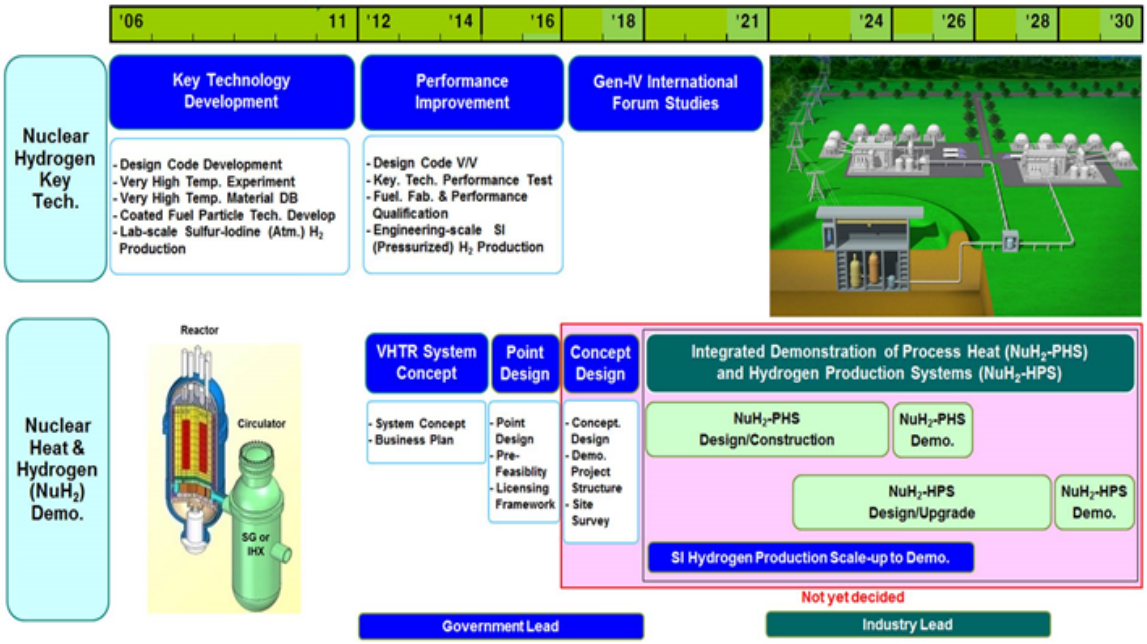


Fig.12 (S.Africa) Thorium Fuel HTR (TH-100)

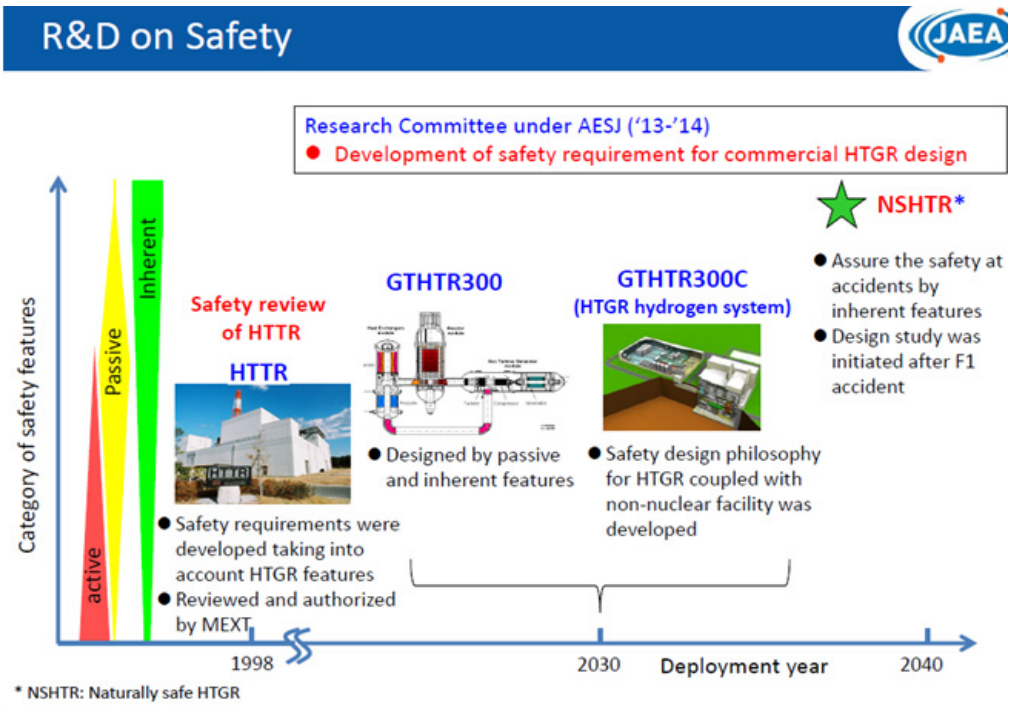


(Eung-Seon Kim (KAERI), "Status of HTGR R&D in Korea, IAEA TM on Hi. Temp. Qualification of HTGR Materials", 2014.6-10-13, Vienna, Austria) (Revised 2015.1)

Fig.13 (S.Korea) Nuclear Hydrogen Development Action Plan

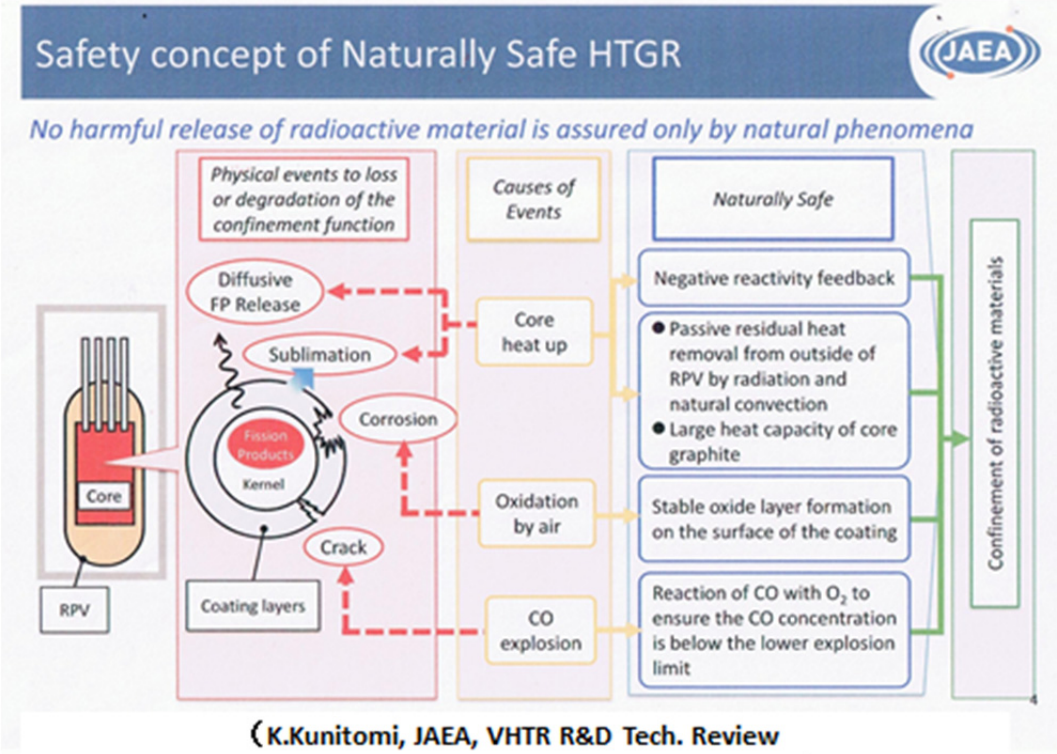
H.Ohashi, Status of HTTR Project in JAEA, TM on Safety of HTGRs in the light of Fukushima Daiichi Accident, 2014.4.7-11, IAEA, Vienna

Fig.14 (Japan) Small HTGR for Co-Generation (HTR50S)



(H.Ohashi (JAEA), Status of HTTR Project in JAEA, TM on the Safety of HTGRs in the light of Fukushima Daiichi Accident, 2014.4.8-11, Vienna, Austria)

Fig.15 (Japan) HTGR Safety R&D Flow



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

Fig.16 (Japan) Naturally Safe HTR (NSHTR) Safety Concept