Japanese Development Plan for HTGR

Koji OKAMOTO
The University of Tokyo

okamoto@n.t.u-tokyo.ac.jp

Important Lessons Learned from Fukushima-Accident

Following items were insufficient before Fukushima
At least, they should be improved

- External Event consideration
- Accident Management
  - Countermeasure for Total Station Blackout,
  - Loss of Ultimate Heat Sink and
  - Huge area damage
  - Containment Vessel Protection
- Emergency preparedness

New Nuclear Safety

Protect people and the environment

+ Defense-in-Depth
  - Severe Accident Management
  - Defense-in-Depth to protect environment
+ Graded Approach
  - Risk oriented countermeasure
+ Continuous Improvement
  - Regulatory System
  - Utility Management System

Safety Culture and SAHARA

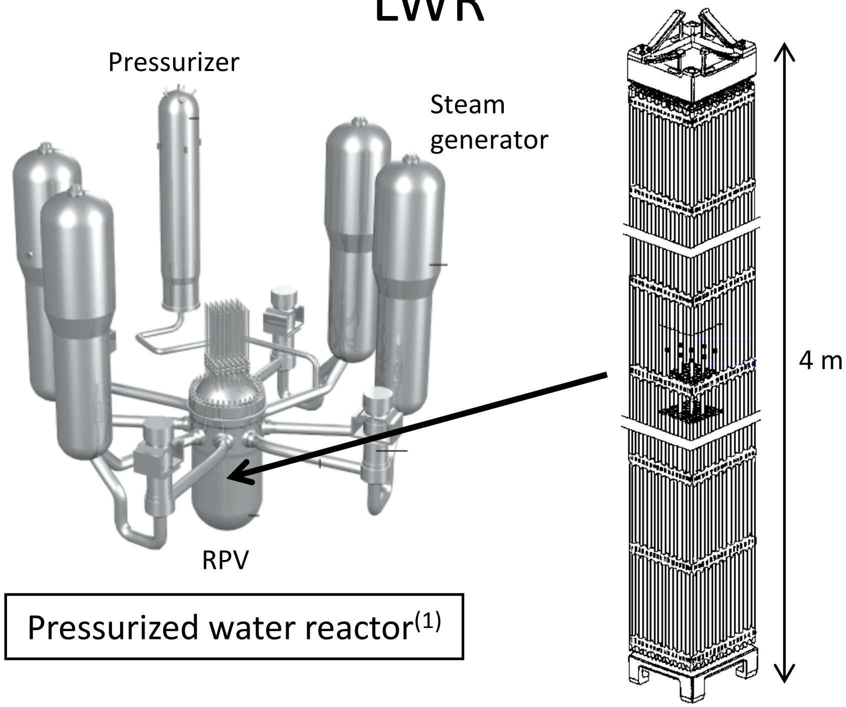
(Safety as high as reasonably achievable)

Nuclear Plant in 2010s

- The Severe Accident should be considered in Design
- Accident Management
  - Long term cooling capability
  - Robustness for SBO/LUHS and so on
  - Robustness for severe external event
  - Education and Practices
- Fuel Cycle and High-level waste
  - Acceptable waste management
  - Pu Fuel

Comparison between LWR & HTGR

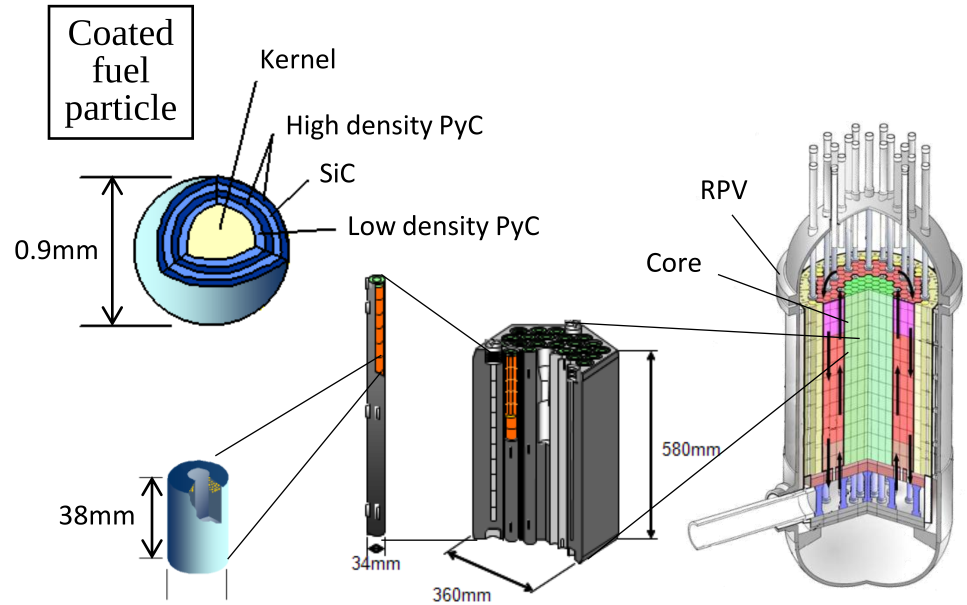
LWR



Pressurized water reactor[1]

Fuel assembly[2] (17x17)

HTGR



- Low enriched uranium (Enrichment 5%)
- Light water moderated, cooled, metallic fuel
- Reactor outlet temperature about 300°C
- Obtain economical competitiveness by increasing scale

- Low enriched uranium (Enrichment 5-15%)
- Graphite moderated, helium cooled, ceramic coated fuel
- Reactor outlet temperature up to 950°C
- Obtain economical competitiveness by simplifying safety system from inherent characteristics

(1) ATOMICA, http://www.rist.or.jp/atomica/data/dat_detail.php?Title_Key=02-04-03-02, accessed on October 15, 2012.
(2) ATOMICA, http://www.rist.or.jp/atomica/data/dat_detail.php?Title_Key=04-06-03-02, accessed on October 15, 2012.

HTTR (High Temperature Test Reactor)
JAEA, Japan

History

- 1991 Start Construction
- 1998 Criticality
- 2001 Full-power 30MW
- 2003 Start Safety Experiments
  - Simulation for RIA
  - Simulation for Loss of Flow.
- 2004 950℃(World Record)
- 2006 Safety Experiments
- 2010 Continuous operation for 50 days
- 2010 Safety Experiments
  - Simulation of Primary Loop LOF
- Future
  - 100% LOF simulation

Thermal Power : 30MW
Coolant Exit Temp. : 950℃ (Highest)
Coolant : Helium Gas
Pressure : 4.0MPa
Power density : 2.5W/cc
Fuel : UO_2
Enrichment : average 6%

Advantages of HTGR

- Safety under severe conditions
  - No Severe Accident may be considered
  - Large negative reactivity feedback
  - Cooling without electricity
  - Confine FP inside the fuel particle
- High temperature heat
  - Desalination, Electricity, Hydrogen, ….
- Stability of high-level waste
  - Spent fuel contains FP stably

Disadvantages of HTGR

- Small Modular Reactor
  - Large plant could not be constructed
    - Large HTGR has no inherent safety feature.
  - For large power, many plants are needed.
  - Huge area for construction
  - Multiple unit issue (like Fukushima)
  - Construction cost

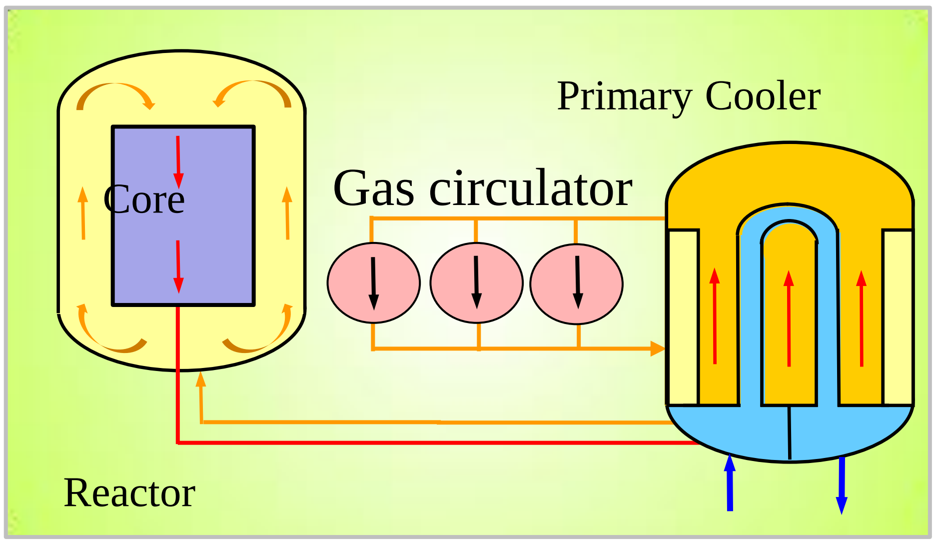
Misunderstandings on HTGR

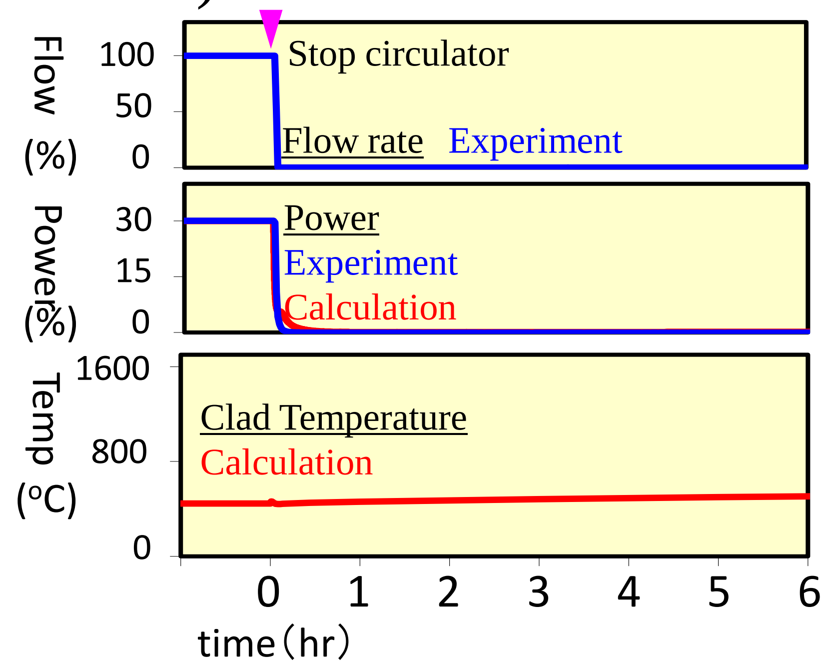
- Under development
  - 750℃-HTGR plant is under construction in China
  - 950℃-HTGR plant needs R&Ds
- Graphite may burn
  - HTGR class pyloric carbon can not burn. Because of small surface and high thermal conductivity, oxidization can not be kept.
  - Carbon mono-oxide may be considered caused by oxidization.
- Week for Earthquake because of Graphite
  - High earthquake resistance had been proved.
  - Out-of-consider huge earthquake may cause damage on core. However, no core melt because of radiation heat cooling
- Expensive for Small Modular Reactor
  - 500 M$ / 300MWe, ~5 ¢ /kWh
- Nonproliferation feature
  - Pu can burn. Inert matrix fuel has strong non-proliferation feature.

Inherent Safety Characteristics of HTGR (1/3)
- Control of Reactivity -

ATWS experiment shows safety stop, HTTR (2010)

- Three circulator had been stopped (Loss of Flow)
- No Control Rods motion, (Without Scram)

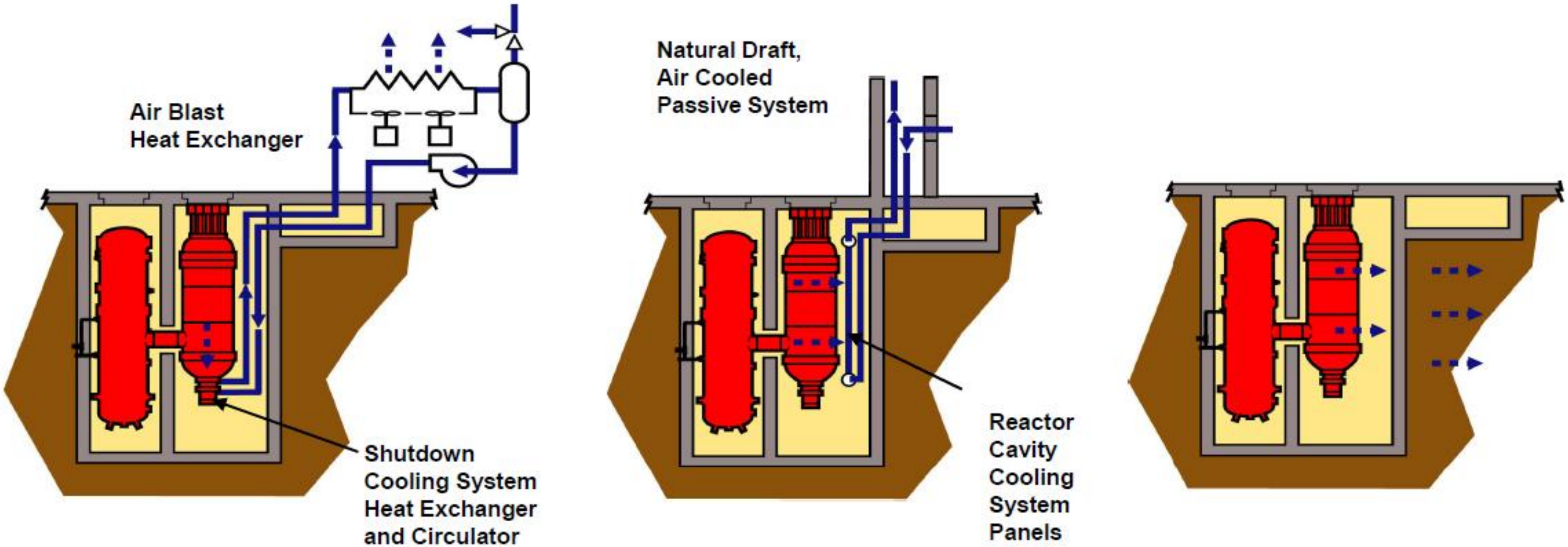




- Date: December 21, 2010
- Reactor Power 9MW (30%) , Outlet Helium Temperature 380℃
- Primary coolant flow rate 12.2 kg/s ⇒ 0 kg/s

Inherent Safety Characteristics of HTGR (2/3)
- Removal of Core Decay Heat -

Decay and residual heat during accident can be removed by natural draft air cooled system



a) Active shutdown cooling system

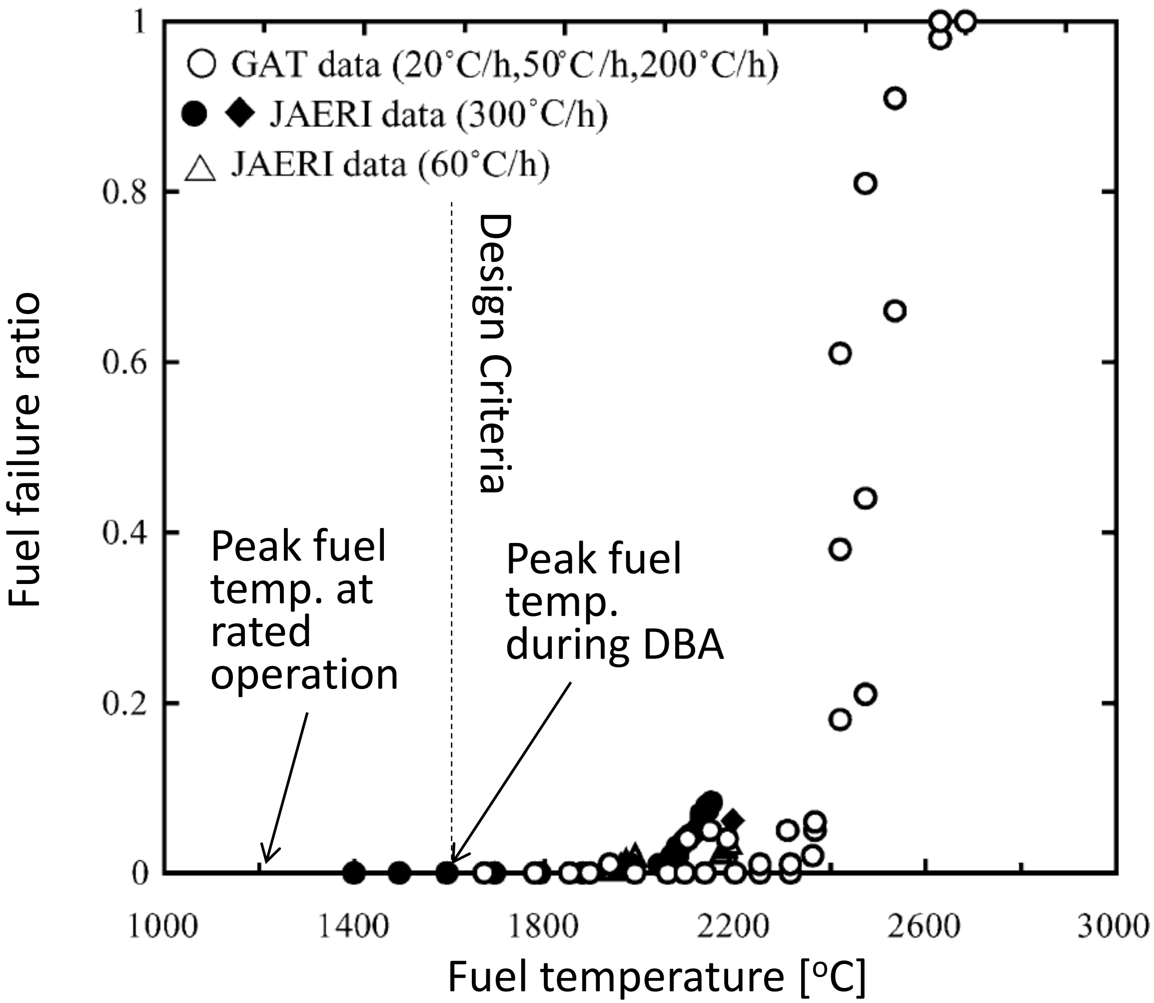
b) Passive reactor cavity cooling system

c) Passive radiation and conduction of heat to reactor building (DEC)

Defense-in-depth buttressed by inherent characteristics*

* INL, HTGR Technology Course for the Nuclear Regulatory Commission, May 24 – 27, 2010.

Inherent Safe Characteristics of HTGR (3/3) - Radionuclides Retention -



Relation between fuel failure ratio and fuel temperature*

- Integrity of fuel is assured under Design Basis Accident (DBA)
- Public dose can meet Top Level Regulatory Criteria without reliance on containment vessel

* K. Sawa et al., Nucl. Eng. Des., 233, 163 (2004).

Summary for HTGR

- Completely Safe Nuclear!!!
  - Fukushima never happens even in long-term total station blackout
  - No operator actions needed
  - Cooling to land. Anyway confine FP.
- Cost is competitive!!!
  - Similar or Cheaper than LWR
  - Electricity + Desalination
- High-level waste can also be confined!!!
  - Spent fuel contains FP stably for long term

Discussion on HTGR in Japan

- 2014 April Energy Strategy in Japan

  3E+S*(Energy Security, Economics, Environment + Safety)*
- 2014 June Japanese Developing Planning 2014

R&D on Nuclear Technology for safety improvement will be promoted under the international collaboration, for example, the HTGR may has advantage on hydrogen generation and inherent safety （Energy strategy in Japan）

2014 June-Sept. MEXT, Working group on HTGR

科学技術・学術審議会　研究計画・評価分科会

原子力科学技術委員会　高温ガス炉技術研究開発作業部会

Current status on HTGR R&D

- 750℃（Steam cycle）
  - Under construction in China(200MWe)
  - As a hypothetical Severe Accident, water ingress from Steam Generator may be considered after Fukushima.
- 850℃（Helium Gas turbine cycle）
  - Almost developed technology, except confirmation on Helium Gas turbine system
  - As a Severe Accident, air ingress should be considered. No need to consider the water ingress, i.e., lower risk.
- 950℃（Gas turbine cycle + Hydrogen Production）
  - Generation IV reactor（Gen-IV）
  - Needs R&Ds, incl. hydrogen(IS), high burnup, and so on

R&D for HTGR Development

Development of multi-purpose HTGR for the hydrogen society and international needs, incl. electricity, hydrogen and so on.

- Summary for R&D items
  - HTGR technology, Safety Improvement, Hydrogen, etc.
- International Collaboration
  - International contribution on Safety concept
  - International Codes and Standards（Safety, Fuel, Material, System, etc.）
- Future Activities
  - Consortium with Industries, Government and Academia.
  - Comprehensive Safety Evaluation (PRA, etc.)
  - Keep the Japanese Advantage on HTGR technology and Human Resource Development

Japanese HTGR Strategy

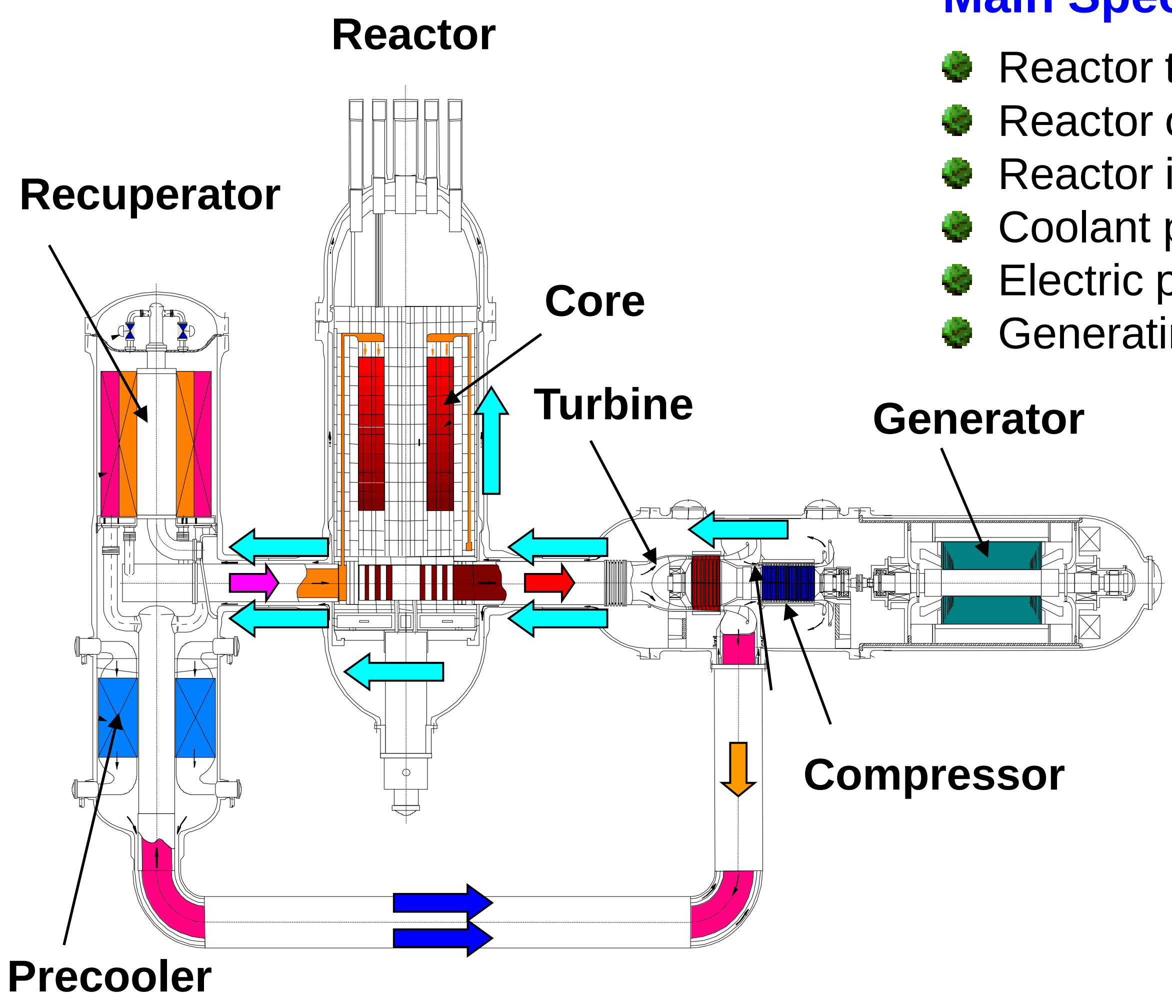
- Export Infrastructure
  - Complete Safe Electric Power Source (850℃-Gas turbine HTGR)
  - Desert Green Fields combine desalinate plant
- Pu burner (PuO_2/MOX)
  - Safe reduction of Pu inventory
- Direct disposal of Spent Fuel
  - Inert matrix fuel keeps Safeguards and Security
- Hydrogen Production
  - CO_2 free Hydrogen with 950℃-HTGR

850℃ Gas turbine HTGR for world export infrastructure

Japanese Advantage

- Anyway Safe!!!
  - Inherent Safety feature
  - Easy treatment for Severe Accident
  - No needs for water ingress Severe Accident
  - No actions needed for several days after accident.
- Electric and Thermal Power
  - Energy, Desalination, Process heat
- R&D for safety confirmation
  - Probabilistic Safety Assessment, External Event responses, Security
  - Spent Fuel（Direct Disposal / Fuel Cycle）

GTHTR300: Gas Turbine High Temperature Reactor 300



Main Specifications

- Reactor thermal power : 600MW
- Reactor outlet temperature: 850ºC
- Reactor inlet temperature : 587 ºC
- Coolant pressure : 7 MPa
- Electric power : 275MW
- Generating efficiency : 45.8%