Very High Temperature Reactor

LI Fu

GIF VHTR SSC Chair

INET, Tsinghua University, China

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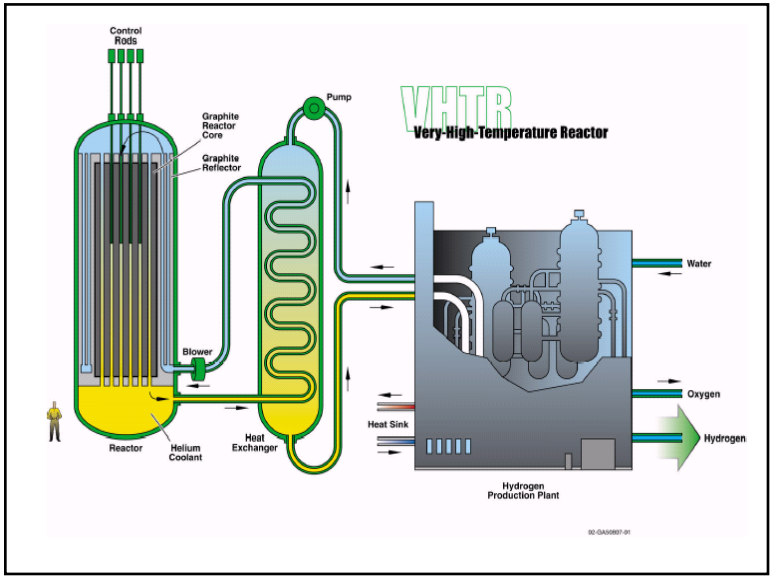
Outline

1. Original VHTR Features
2. Key VHTR Development Targets
3. Reference Configurations and Features
4. Status of VHTR Development
5. Current Vision

Original VHTR features

- *Initial VHTR target was 1000℃ delivered to end-user for high efficiency H_2 production.*
- *TRISO coated particle fuel*
- *Graphite as core structure*
- *Helium coolant*



Very High Temperature Reactor

Key VHTR Development Targets

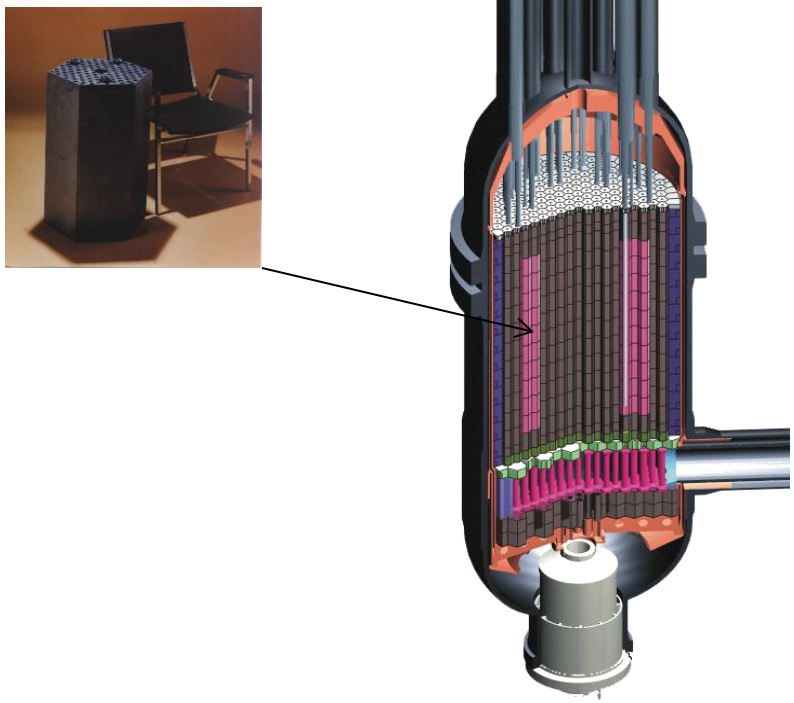
1. Fuel and Fuel Cycle
   - Fuel fabrication process, fuel qualification, fuel model
   - Fuel cycle back-end: spent fuel, irradiated graphite
2. Materials
   - High temperature alloys for vessels, IHX/SG, …
   - Graphite
   - Ceramic composites for control rods, core internals, insulation

Key VHTR Development Targets

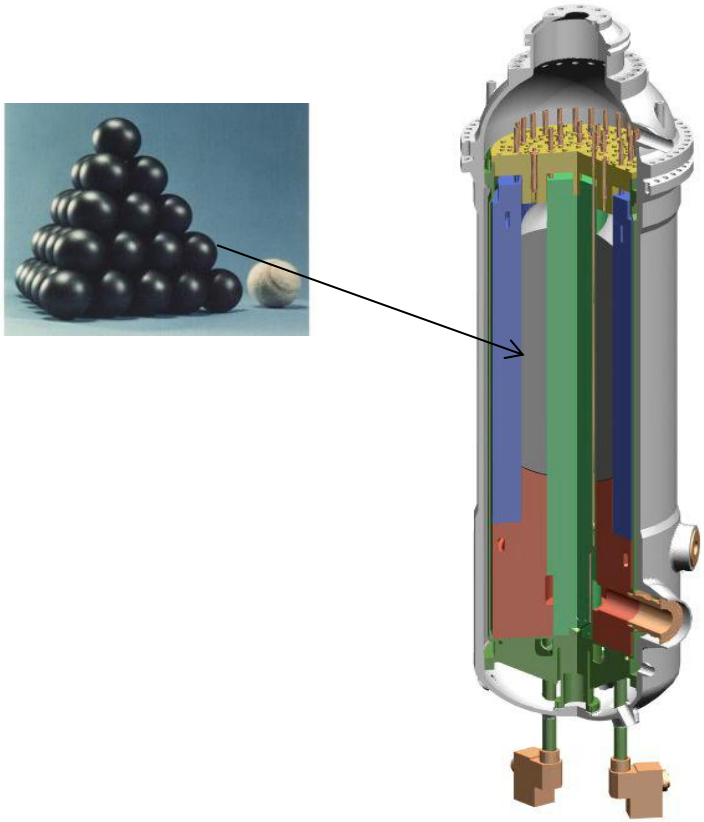
3. Hydrogen Production
   - Two thermo-chemical processes
   - High Temperature Steam Electrolysis

4. Computational Methods Validation and Benchmarks
   - Codes need to be improved for safe design and licensing of VHTR
   - Experiments are used to provide data needed to validate the codes

VHTR Reference Configurations



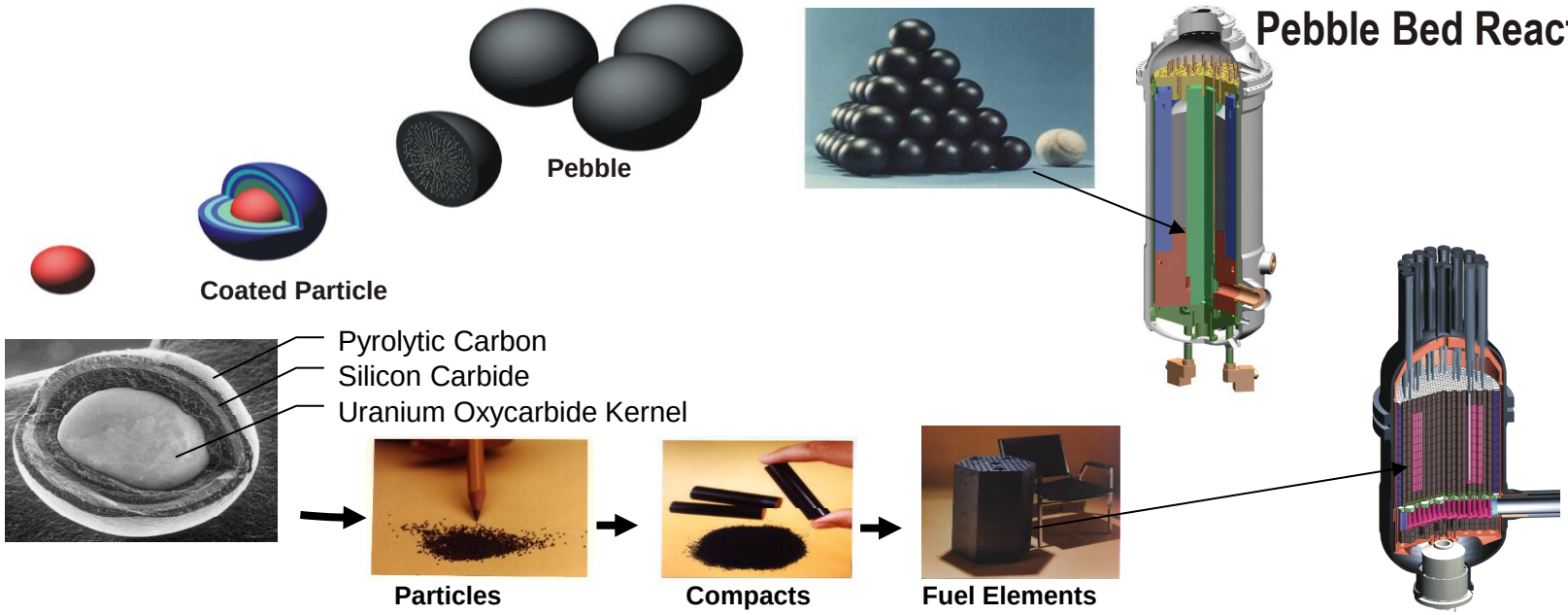
Prismatic



Pebble bed

Features of the Core

- *Fully ceramic (graphite) internals*
- *TRISO coated particles in a graphite matrix*
- *Supports alternative fuel cycles(U, Th, Pu)*



Parameters of Reference GenIV Systems

	LWR	VHTR	SFR	SCWR	GFR	LFR	MSR
Electrical Power (MWe)	600-1000	**100-300**	50-2000	300-700	1000	20-1200	1000
Coolant	water	**helium**	sodium	water	helium	Lead or lead-bismuth eutectic	Fluoride salt
Moderator	water	**graphite**	--	water	--	--	--
System Pressure (MPa)	8-16	**6-9**	0.3	>22	7	0.3	0.6
Coolant Temperature at Outlet	325	**700-1000**	500-550	510-625	750-850	480-570	700-800
Average Core Power Density (W/cm^3)	100	**3-8**	>200	~70	100	70-120	330

Status of VHTR development

- ***National programs***
  - *China, Japan, USA, Euratom, Korea, France, South Africa (until 2010)*
  - *Other interested countries*
- ***GIF Project Members***
  - *China, Japan, USA, Euratom, Korea, France, Canada, Switzerland.*
- ***Project Arrangements in***
  - *Materials*
  - *Fuel and Fuel Cycle*
  - *Hydrogen Production*
  - *Computational Methods Validation and Benchmarks (being reformulated)*

China

- *HTR-10 Engineering-scale reactor (INET)*
  - *10 MWt, operating since 2000*
  - *Test bed for fuel, system, code V&V*
- *HTR-PM demonstration plant*
  - *Mature design: pebble bed, 750℃ outlet temperature, steam cycle, 40% efficiency*
  - *Two 250MWt modules for 210MWe electricity*
- *Technically ready*
  - *PSAR assessment completed*
  - *Key components procured or are being manufactured*
  - *Infrastructure for full scale testing is ready*
  - *First pour of concrete: waiting for government approval*
  - *HTR-PM fuel qualification has started with irradiation in HFR Petten in September 2012*

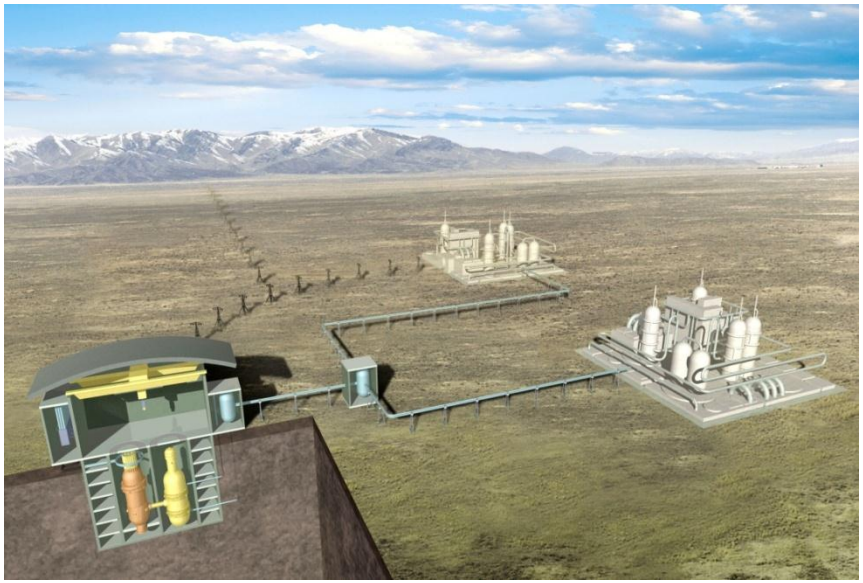
HTR-PM demonstration plant

Japan

- HTTR has operated since 1998. Outlet temperature raised to 950℃ in 2004. 50 days continuous operation at 950℃ completed March 2010
  - 1st safety demonstrations (Loss of Forced Cooling from 30% power) successfully performed in December 2010
  - More safety tests to be conducted under an OECD-NEA LOFC Project started in 2011
- Design of 50 MWth HTGR for electricity, district heating, etc. for developing countries
- Design of Naturally-safe HTGR (NSHTR) with improved inherent safety
- I-S process for hydrogen production

USA

- ***Next Generation Nuclear Plant (NGNP) Project with goal of demonstrating electricity, process heat and/or hydrogen production***
- ***R&D in fuel and graphite qualification, methods development, economic analyses***
- ***H_2 production - Lab-scale high temperature steam electrolysis demonstrated.***



Korea

- ***Two main projects with hydrogen production as the main driver, in particular to reduce CO_2 emissions***
  - ***R&D:*** *Nuclear Hydrogen Key Technologies Development Project (2006-2017). Fuel, materials and high temperature experiments, computer code and hydrogen production.*
  - ***Demonstration:*** *Nuclear Hydrogen Development and Demonstration (NHDD) Project (~2026)*
- ***Industry Alliance for Nuclear Hydrogen:***
  7 nuclear industrial companies or institutes, and
  5 potential end users

Other contributors

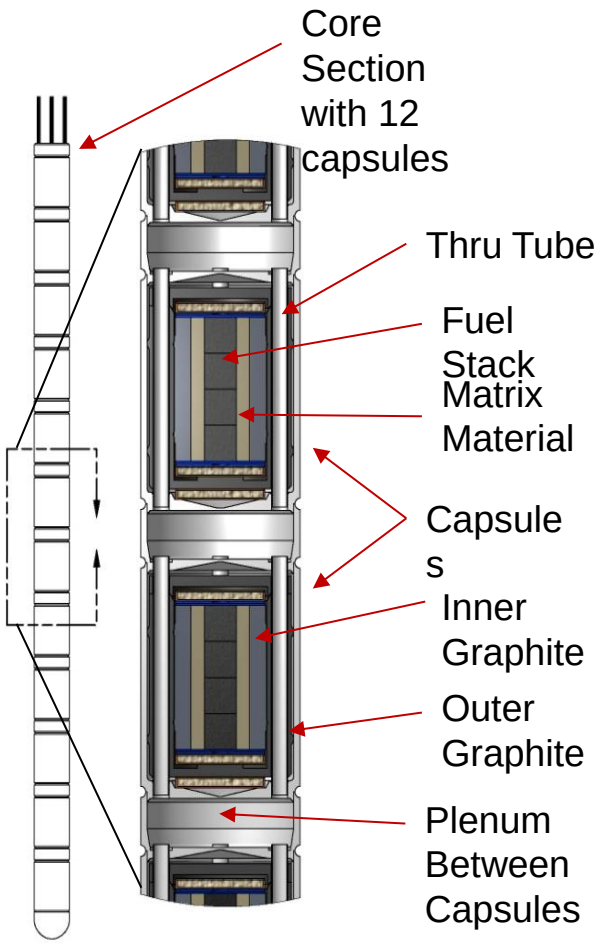
- *Euratom – key support from several EU projects covering fuels, materials, graphite qualification, fuel and graphite recycling, modeling and hydrogen*
- *France – complementary work in GFR; contributions to Hydrogen and Materials PMB*
- *Canada – complementary work in SCWR; contributions to Hydrogen and Materials PMB*
- *Switzerland – contributions to Materials PMB*
- *South Africa – with shutdown of PBMR project, previous contributions to Fuel, Material, and Computational Methods has been suspended*

VHTR Materials Project

- *Successful collaborations*
  - *Metallic materials, graphite, ceramic (composite) materials development*
  - *Irradiation testing in USA, Switzerland, Euratom*
  - *Mechanical testing by all participants*
  - *All data being bundled in the ORNL Material Database*
  - *Development of design codes and standards*
- *Future R&D challenges*
  - *Development of high temperature alloys*
  - *Qualification of new graphite types*
  - *Development of composite ceramic materials*
  - *Crosscut with other GIF concepts*

VHTR Fuel and Fuel Cycle Project

- ***Fuel testing & qualification collaborations***
  - ***AGR-1,2,3,4 (US, F, RSA)***
  - ***KR-HANARO (KR)***
  - ***HFR-EU1bis, HFR-EU1 (EU, CN)***
  - ***PYCASSO-1 and -2 experiment (EU, F, J, KOR)***
  - ***PIE and safety tests on samples of AGR-1, HFR-EU1bis, soon HFR-EU1 (US, EU)***
  - ***Pulse irradiation test (JP)***
- ***Fuel performance modeling: IAEA CRP6***



AGR Fuel Test Train

VHTR Fuel and Fuel Cycle Project

- Waste management (EU, CARBOWASTE)
- Qualification current SiC based TRISO fuel
  - More data prove better fuel performance
  - Better performance achieved in China, US, Japan
- Development of new TRISO fuel (with ZrC coating?)
  - Only for >1000℃ VHTR
- Fuel cycle challenges
  - Options for final disposal of spent fuel
  - Recycling of irradiated fuel and graphite

VHTR Hydrogen Production Project

- *Main Technology directions:*
  - *Iodine-Sulphur*
  - *High Temperature Steam Electrolysis*
  - *Copper Chloride (Canada)*
- *Active contributors:*
  Japan, USA, Korea, Canada, China, EU (tbc)
- *Future challenges*
  - *Integrated process demonstrations*
  - *Coupling reactor to process*
  - *Cost reduction of components*
  - *Commercial scale*

Current vision

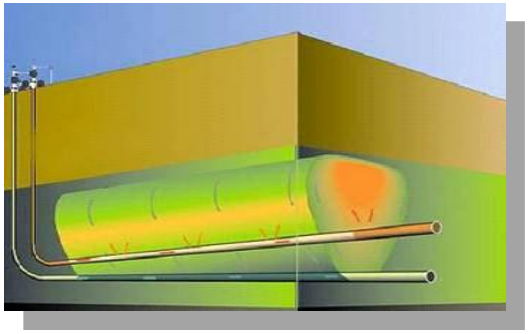
- *The market for process heat based on steam is very large*
- *Outlet temperature*
  - *Current: 700-950℃ (Modular HTGR)*
  - *Maintain long-term goal: 1000℃*
  - *Better denoted as V/HTR*

Mission – Process heat and Cogeneration

- *(Petro) Chemical Industries*
- *Coal Liquefaction*
- *Hydrogen production*
- *As well as electricity generation and desalination*

Hydrogen Production

Petrochemical, ammonia, fertilizer Production



Hydrocarbon recovery

Coal-to-Liquids

Declaration from HTR-2012

- *Tests at the AVR, HTR-10 and recently on the HTTR have demonstrated that HTGR continues to stand out as an exceptionally safe and reliable nuclear energy technology.*

  The HTTR will be employed for even more extensive safety testing soon, which will be useful for strengthening worldwide public confidence and acceptance.

- *HTGR proven up to 950°C coolant outlet promises to be highly efficient and adaptable to both electrical and industrial applications including hydrogen production.*

  Its practical uses can lead to reduction in CO_2 emission from industry.

Declaration from HTR-2012

- *There is confirmed demand for nuclear process heat applications ranging from steam to hydrogen with very high market potential.*
- *HTGR can help cope with problems related to population growth, industrial development and the resulting CO_2 emissions and finite fossil fuel resources.*
- *HTGR is close to commercial deployment, and should be recognized for its value by industry, policy makers, users and investors.*
- *Excellent research and development progress has been made since the last meeting held in Prague in 2010. Completing research and development as well as licensing efforts through private and public cooperation is needed to realize HTGR deployment in the near future.*

Conclusions

- *The original GIF goals for VHTR are largely still valid*
- *Safety, high efficiency, process heat application are well recognized for VHTR*
  - *After Fukushima accident, GIF concepts must be shown to excel in safety*
  - *Process heat application to reduce CO_2 emission is very important*
- *VHTR has two stages of commercial target: 700-950℃, 1000°C of outlet temperature*
- *VHTR with steam cycle has large market potential, is ready for deployment*