HTR-PM Project and Nuclear Hydrogen Production

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INET-an overview

Institute of Nuclear and New Energy Technology (INET)

- Founded in 1960 as one of the first nuclear education and research bases in China
- An institute of Tsinghua University, Beijing
- The largest R&D institute under China's state educational system
- ~ 400 faculty and staff members
- Over 300 graduate students
- Equipped with 3 research reactors and a large number of laboratories
- INET campus: ~50km northwest of Beijing downtown

Major R&D milestones on advanced nuclear energy

1964

Swimming pool reactor for shielding test

1989

5MW Nuclear Heating Reactor (NHR-5)

2000

10MW High Temperature Gas-cooled test Reactor (HTR-10)

2022

HTR-PM Demo. Plant

Part 1: HTR-PM Project

High Temperature Gas-cooled Reactor (HTGR/HTR)

- Gen IV reactor
- Helium as coolant, graphite as moderator, fuels with ceramic coatings
- Why HTGR
  - ✓ High temperature (core outlet temperature: 700^{o}C or higher)
  - ✓ Heat applications for industry needs
  - ✓ Nuclear hydrogen production methods with high temperature
- Why Modular HTGR
  - ✓ Inherent safety
  - ✓ Severe accident(core meltdown) practically eliminated
  - ✓ Simplified siting and licensing possible

History and evolution of HTGR

Test Reactor → Large Reactor → Test Modular → Current


PEACH BOTTOM (U.S.A. 1967)


AVR (GERMANY 1967)

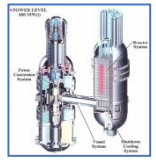

DRAGON (U.K.1966)

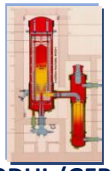

THTR (GERMANY 1986)


FORT ST. VRAIN (U.S.A. 1976)


HTR-10 (CHINA 2000)

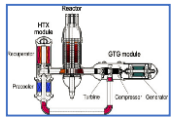

HTTR (JAPAN 1998)

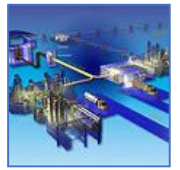

GT-MHR (U.S.A.)


HTR-MODUL (GERMANY)

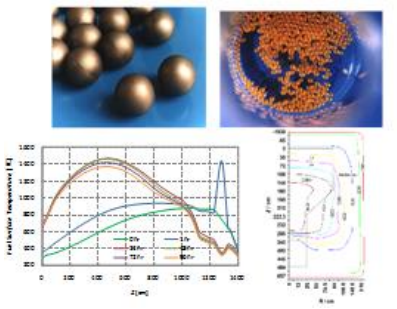

HTR-PM (CHINA 2023)


Xe-100 (U.S.A.)


GTHTR300 (JAPAN)

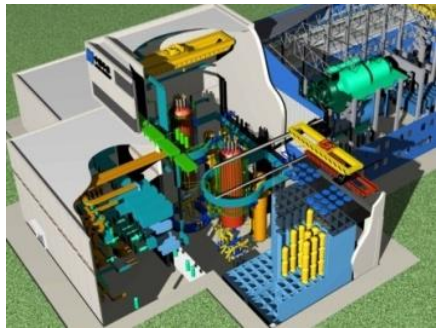

NGNP (U.S.A.)

A HTGR Roadmap in China

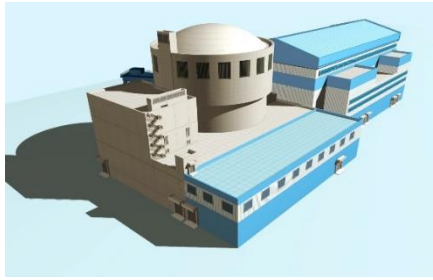


Starting research
(1980s)

Test reactor
(HTR-10, 1986)



Demo. Plant
(HTR-PM, 2001)



Commercial plant
(HTR-PM600, 2014)

China chooses the pebble-bed modular HTGR.

HTR-10

Basic Info.

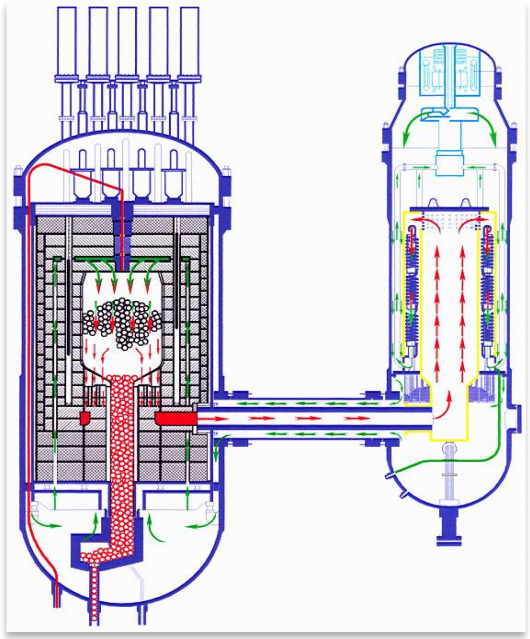
- A 10MWth pebble-bed modular HTGR
- Core outlet temp. : 700°C
- Electricity / heat co-generation

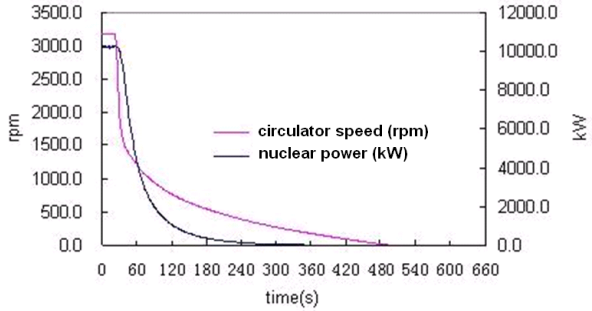
Milestones

- 1995: Construction started.
- 2000: Reaching first criticality.

Achievements

- Inherent safety demonstrated (e.g., loss of forced cooling + no action of control rods).
- Knowledge of “know-how”.
- R&D / fuel facilities established.





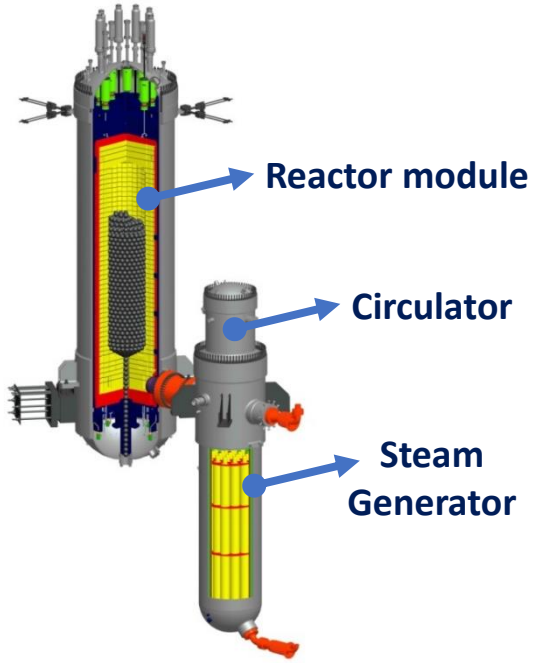
HTR-PM (High Temperature Gas-cooled Reactor Pebble-bed Module)

Basic Info.

- A 211MW_e commercial demonstration NPP
- 2 x 250MW_{th} pebble-bed HTGR modules coupling one steam turbine.

Demonstration Objectives

- Inherent safety
- Economical competitiveness
- Proven technology
- Modularization (scalable HTGR modules)



Parameters	Values
Helium Pressure (MPa)	7.0
Core outlet Temp. (°C)	750
Fuel enrichment (%)	8.5
Steam Temp. (°C)	540
Steam Pressure (MPa)	13.24

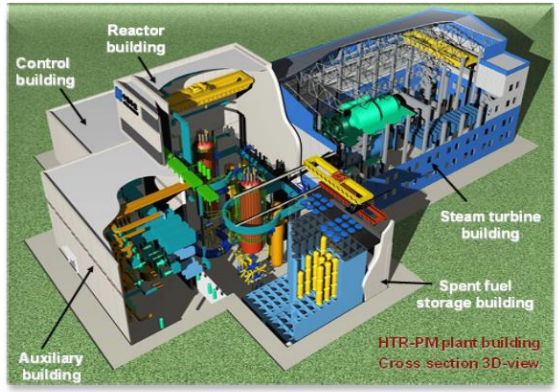
HTR-PM (High Temperature Gas-cooled Reactor Pebble-bed Module)

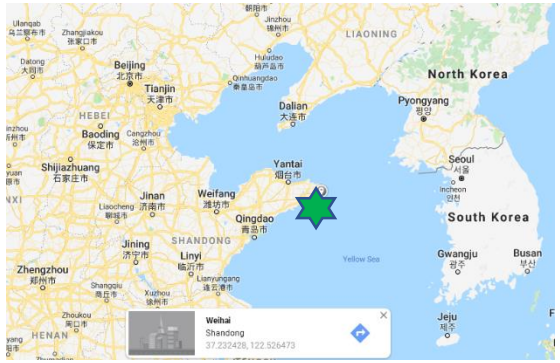
Organization

- China HUANENG Group (Owner & Operator)
- CNNC (EPC Contractor)
- Tsinghua University (R&D, NSSS Designer)

Milestones

- 2006: One of the 16 top level state projects.
- 2008: Preliminary design completed.
- DEC 2012: Construction started.
- 2016: Fuel production started, first RPV.
- 2021: First criticality, connected to grid.
- 2022: Initial full power, two modules.
- DEC 2023: Safety demonstrations completed, commercial operation started.





First concrete pour

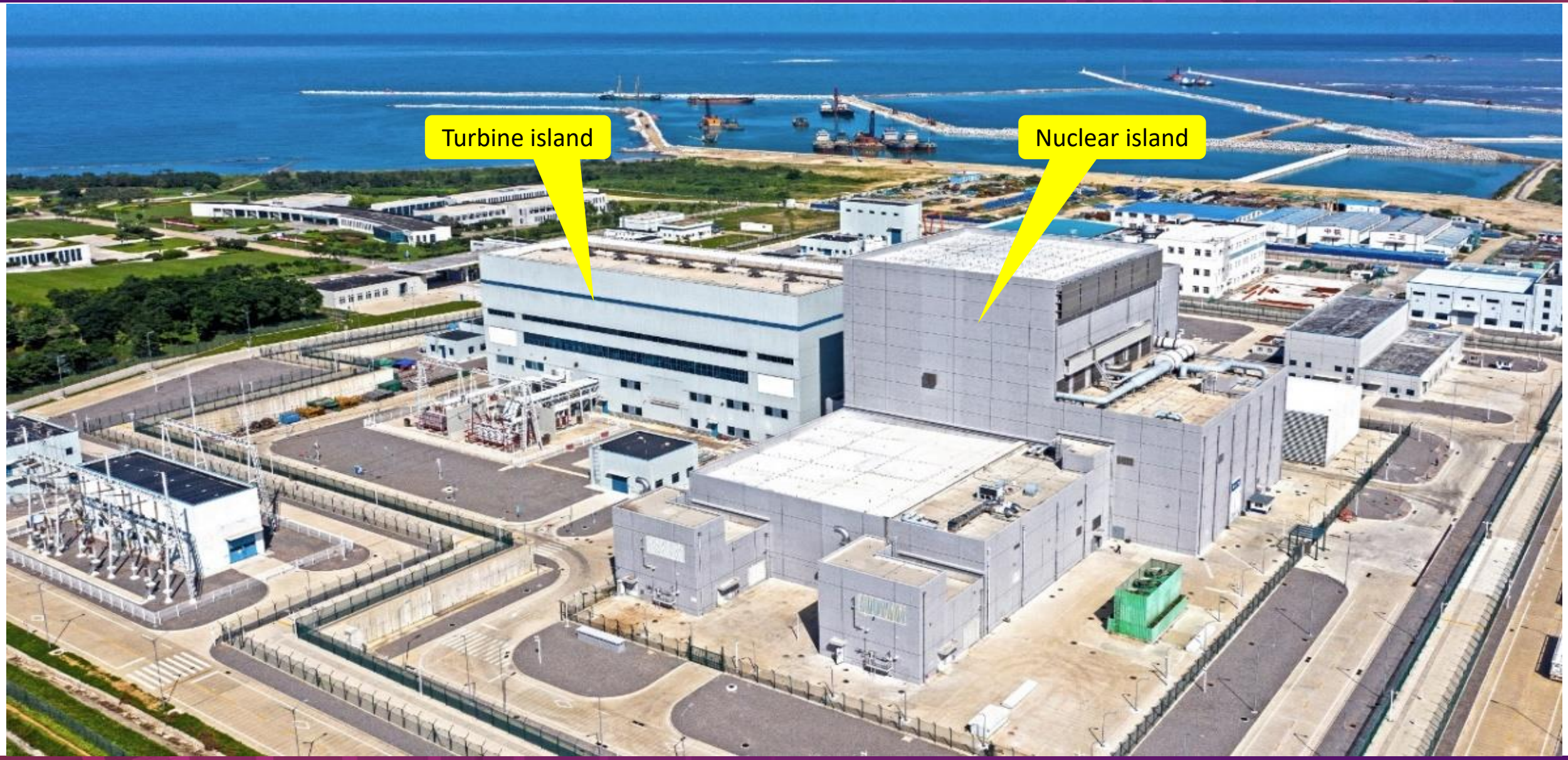
Civil work of nuclear island

Reactor pressure Vessel

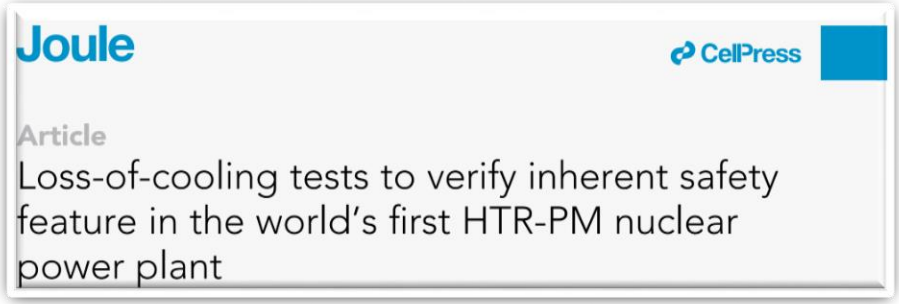
Steam generator

Main control room

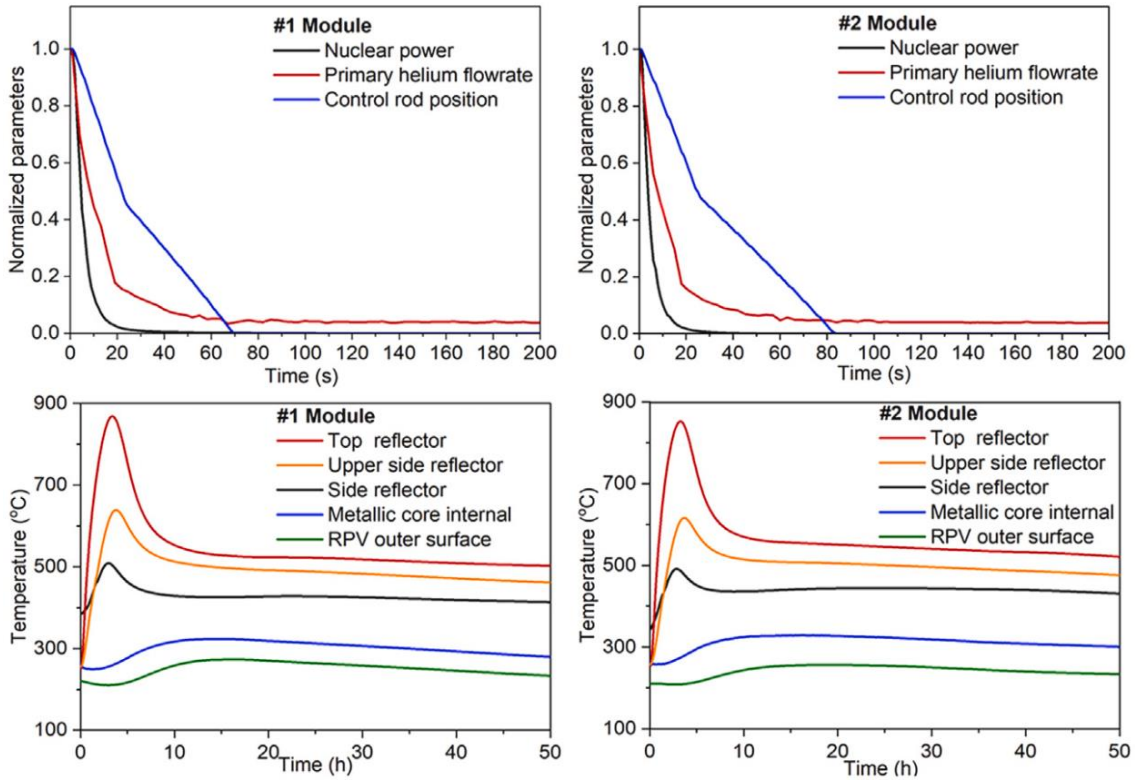
Fuel manufacture


Turbine island
Nuclear island

Safety tests on HTR-PM



- The loss-of-cooling tests were performed on the two reactors of HTR-PM nuclear power plant in August and September of 2023 respectively.
- The tests showed for the first time that commercial-scale nuclear fission reactors can be cooled down naturally without emergency core cooling systems.



The 10MWth Helium Test Facility at INET

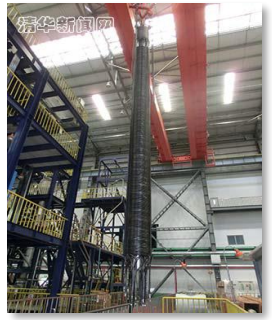
Control Rod Driven System

Small Absorber Sphere

Helium Circulator

Fuel Handling System

Main Control Room



Steam Generator

Engineering Verification Tests

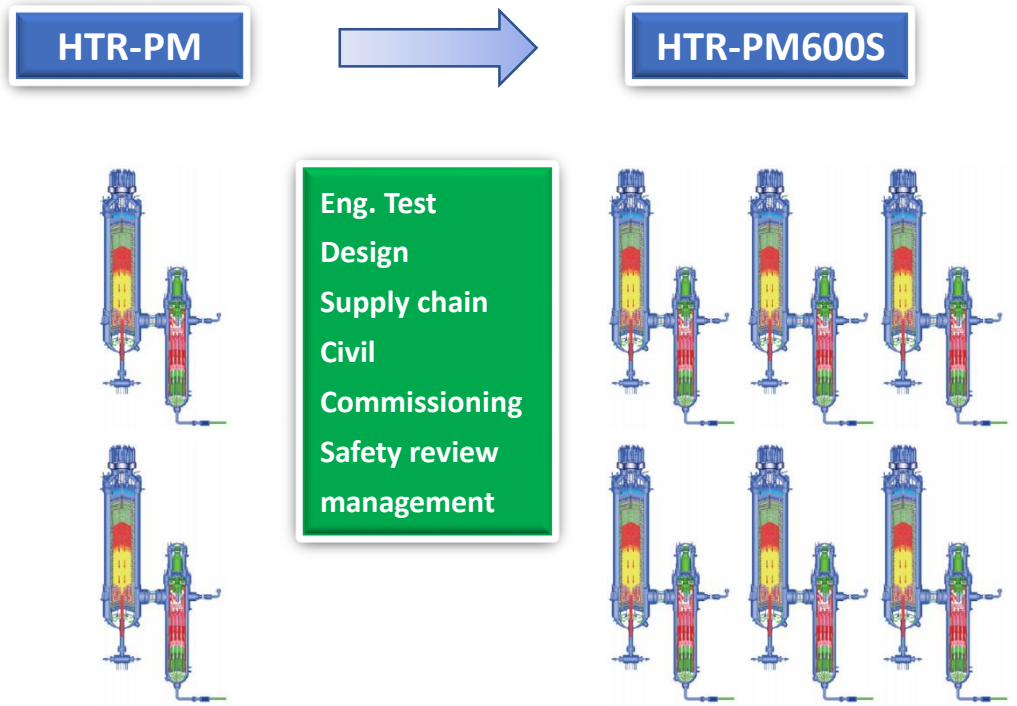
Supply Chain of HTR-PM

Key components / systems	Manufacturer
Fuel	China National Nuclear Corporation (CNNC)
Reactor Pressure Vessel	Shanghai Electric
Steam Generator	Harbin Electric
Graphite internal	Toyo Tanso, Japan
Carbon internal	China FANGDA Group
Metallic internal	Shanghai Electric
CR drives	Shanghai Electric
Main helium circulator	Harbin Electric & Shanghai Electric
DCS & Simulator	China General Nuclear Power Corporation (CGN)

Next step: HTR-PM600S

Basic Info.

- A ~600MW_e (1500MW_{th}) commercial NPP with six 250MW_{th} pebble-bed HTGR modules
- Closely referencing the HTR-PM design
  - The same safety features
  - The same major components (e.g., the same HTGR module)
  - The same parameters



Next step: HTR-PM600S

Recent News (AUG 2024)

- China has approved five new nuclear power projects, including 11 nuclear power units.
- The project in Xuwei, East China's Jiangsu province, is world's first nuclear power plant that couples high temperature gas-cooled reactors with pressurized water reactors, focusing on industrial heating and electricity supply.
- After completion, the project will provide large-scale high-quality, low-carbon industrial heat to the petrochemical park in Jiangsu province.

Part 2: Nuclear Hydrogen Production with HTGRs

H_2: A clean energy to secure our future

- Carbon free: $H_2 + O_2 \rightarrow H_2O$
- Excellent energy carrier: high energy content by weight
- Full applications to all economic sectors

Mature markets

Conventional industry

- Petroleum refining
- Petro-chemical

Rapid increasing

Transportation:

- Fuel cell vehicles

More future

Clean steelmaking

- H_2 to replace Carbon as reductant

Hydrogen production in China

- Currently, China is already the world largest producer and consumer of hydrogen.
- China produced > 35 million tonnes of hydrogen in 2022, which amounted to ~30% of the world's total.
- About 2/3 of China's hydrogen is produced from coal. Natural gas & industry by-product ~1/3, electrolysis only ~1%.
- Cost: depending on the technology, the cost of energy used and the cost of feedstock; about 1~2 USD/kg H_2 from fossil fuels (coal, natural gas), 4~8 USD/kg H_2 from electrolysis (significant reduction expected in the long term).

China’s development plan for hydrogen (2021-2035)

Background: China's "dual carbon" target – carbon peaking by 2030 and carbon neutrality by 2060

- Identifying hydrogen as a key clean energy in the future China energy infrastructure.
- Focusing on the development of hydrogen production using renewable feedstock resources, targeting to reach 100,000-200,000 tonnes per year by 2025. (Comparing with > 35 million tonnes total in 2022)
- Targeting to bring 50000 hydrogen fuel-cell vehicles on the road by 2025 and to build a number of hydrogen refuelling stations.
- Besides transport, envisaging the use of clean hydrogen in other sectors: energy storage, electricity generation and industry.
- Addressing R & D of nuclear hydrogen production technologies.
- Addressing R & D of hydrogen in metallurgical processes.

Source: Medium- and long-term development plan for hydrogen industry (2021-2035), National Development and Reform Commission & National Energy Administration of China, DEC 2022.

Trends of H_2 production: CO_2 free

Today's mainstream hydrogen production technologies emit CO_2

Production method	From hydrocarbons: Steam Methane Reforming (SMR)	From hydrocarbons: Coal Gasification	From low-temperature electrolysis of water
Feedstock	Natural gas + water	Coal + water	Water
Energy input	Heat (natural gas as fuel)	Heat (coal as fuel)	Electricity
CO2 emission	YES	YES	☐ YES (electricity from fossil fuel) ☐ No (electricity from renewable)
Level of maturity	High	High	High
Efficiency	High	High	Low (due to thermal to electricity conversion)

Water cracking with electricity from renewable energy would be an attractive CO_2-free option for distributed hydrogen production.

Trends of H_2 production: CO_2 free

Nuclear hydrogen production: considered as a clean substitute for fossil fuels

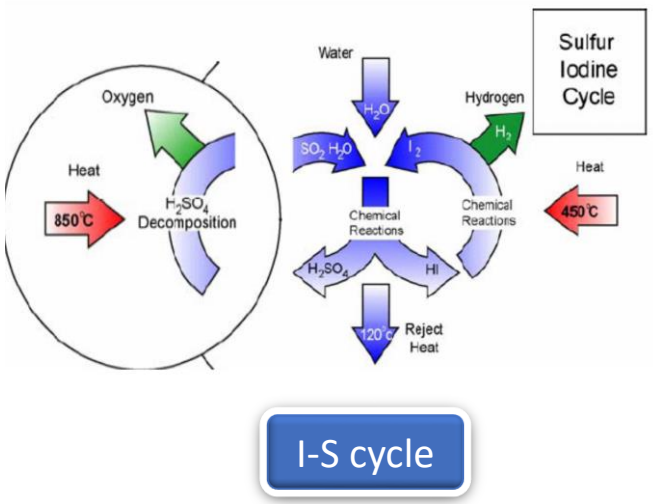
- To provide electricity + heat with no CO_2 emissions
- Hydrogen production in centralized, large scales
- To be coupled with mature hydrogen production technologies
  - To make the energy input CO_2 free
  - Cannot reduce CO_2 from the hydrocarbons as feedstock (natural gas, coal)
- Depending on the reactor type (**basically temp. dependent**)

Reactor type	Coolant	Core temp. (°C)
Lighter water reactor (LWR)	Water	~300
Fast breeder reactor (FBR)	Liquid metal	~550
High temperature gas-cooled reactor (HTGR)	Helium	700~950

High Temperature Gas-cooled Reactor (HTGR)

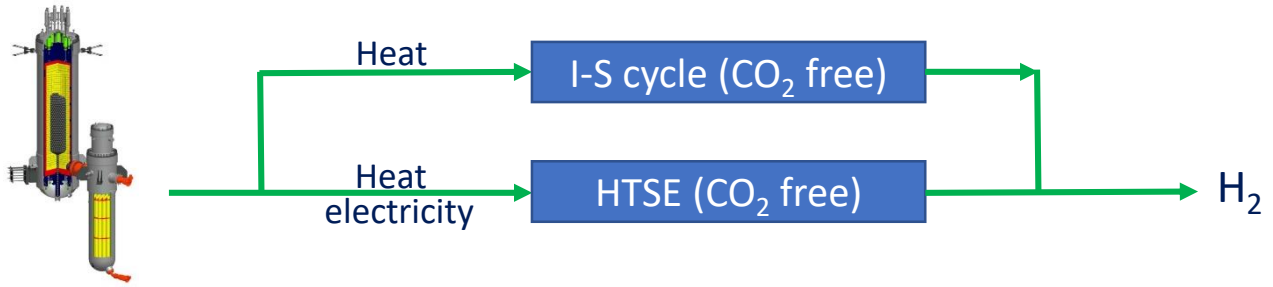
The HTGR is particularly suitable for nuclear hydrogen production due to its unique features:

- High temperature: can provide heat (700~950°C) that meets the temperature need of advanced CO_2-free hydrogen technologies.
  - Thermochemical: Iodine-Sulfur cycle (I-S cycle)
  - Electrolysis: High Temperature Steam Electrolysis (HTSE)
- Inherent safety: easily coupled with the hydrogen plant and feasible to be close to the infrastructure.



I-S cycle

Source: U.S.DOE



A $600MW_e$ ($1500MW_{th}$) HTGR integrated with hydrogen plant can meet energy/gas demand of ~**1.8 Mt** / Year steelmaking, reducing ~**3 Mt** CO_2 emissions.

A view on hydrogen production with HTGR in China

- CO_2 free
  - Medium-term: HTGR + biomass
  - Long-term: HTGR + I-S cycle, HTGR + HTSE
- Cost effective: comparable to coal-based hydrogen production in China
  - Nuclear plant
  - Hydrogen plant
- Targeted market: iron/steel industry
  - H_2 has great potential as a reductant to reduce CO_2 emissions in iron/steel industries
  - In 2023, steel production in China was ~ 1.0 billion tons, accounting for ~50% of the world total.
  - Energy consumption in the sector of “Smelting and Pressing of Ferrous Metals” accounts for ~15% of total energy consumption in China.

Summary

- Hydrogen is going to play an important role in the energy infrastructure of China towards “dual-carbon” goals.
- Nuclear hydrogen production is considered a clean substitute for fossil fuels in the future energy market.
- HTGR is particularly suitable for advanced CO_2-free hydrogen production technologies.
- With HTR-PM starting commercial operation in China, the following commercial-scale HTGRs are coming into reality soon, paving the way to the integration of HTGR with hydrogen plant.

Thank you very much for your attention!

A View of the HTR-PM Site