High Temperature Gas Cooled Reactor Development in China

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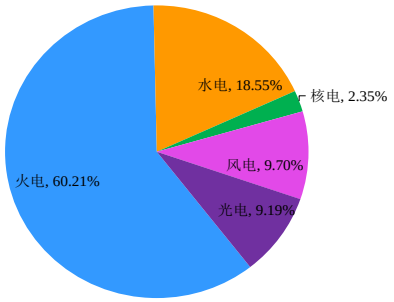
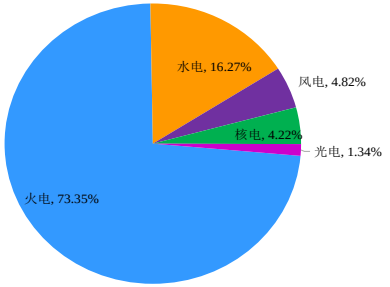
Mainland China Nuclear Power Plants

- By the end of 2018
  - 44 NPP units under commercial operation
  - Installed nuclear capacity: 44.645 GW (2.35% of total)
  - Annual power generation: 294.4 TWh (4.22% of total)
- Until recent in 2019
  - 3 NPP units put into operation
  - 11 NPP units under construction
  - 4 NPP units approved for construction
- Role and prospect of nuclear power
  - Meeting demand, structure optimization, energy security, technology and industry advancement
  - Prospect 2035: 160-170GW, 13-14% of total generated power

End of June'19



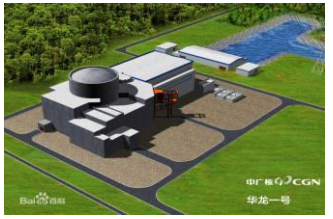
Installed power generation capacity as of end 2018



Power generation in 2018

Development of Advanced Nuclear Power Technologies

- Large PWR technologies
  - CAP1400
  - Hualong-1: China Advanced Gen-III NPP Technology
- Modular HTR technology
  - HTR-10 test reactor constructed around 2000
  - HTR-PM demonstration plant under construction
- Sodium cooled fast reactor
  - CEFR (65MW) achieved initial criticality on 2011-07-21
  - Industrial scale fast reactor plant under development
- Other advanced reactors
  - Small (modular) light water reactors
  - Generation IV advanced types: Molten Salt Reactor (MSR), Lead-cooled Fast Reactor (LFR), ……



HTGR Technology

- **HTGR: High Temperature Gas-cooled Reactor, a thermal nuclear reactor**

	HTGR	LWR
Fuel	UO_2 + Ceramic Coatings and Matrix	UO_2 + Metallic Cladding
Coolant	Helium	Light Water
Moderator	Graphite	Light Water
Core Structural Materials	Graphite	Metal

- UO_2 +Helium + Graphite: allows for much higher temperatures, which again allows for higher power generating efficiency and wider applications
- Graphite as moderator: less compact reactors, large thermal inertia and slow transients

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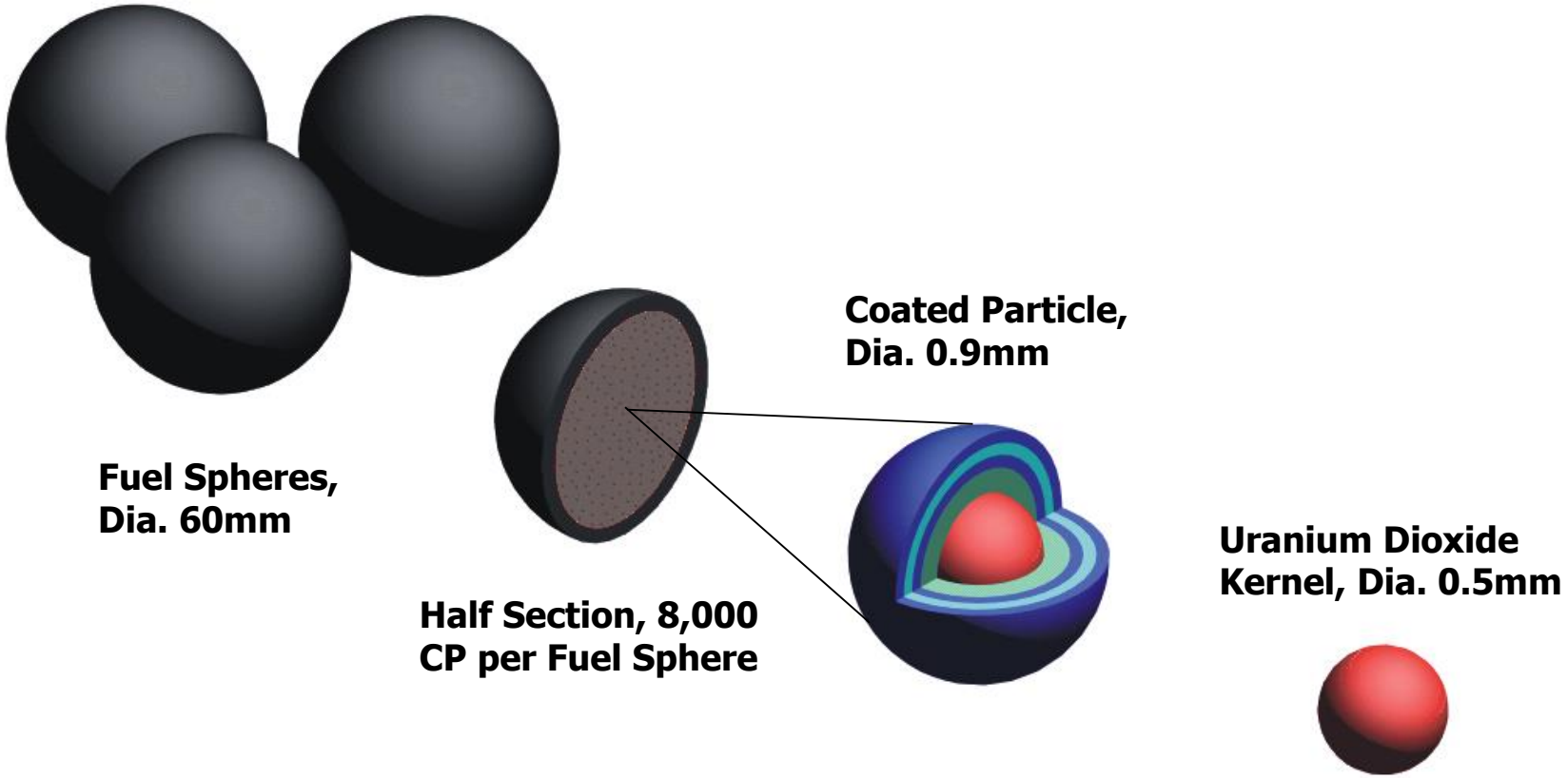
Pebble-bed HTGR Fuel



Coated Particle Fuel Elements

Worldwide HTGR Development

Gen. I
Gen. II
Gen. III
Gen. IV

EXPERIMENTAL REACTORS → DEMONSTRATION OF BASIC HTGR TECHNOLOGY

DRAGON
(U.K.)
1963 - 76

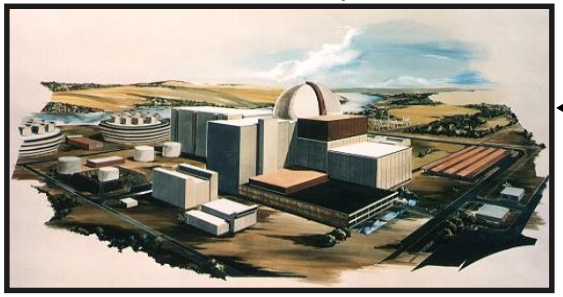
AVR
(FRG)
1967 - 1988

PEACH BOTTOM 1
(U.S.A.)
1967 - 1974

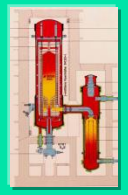
FORT ST. VRAIN
(U.S.A.)
1976 - 1989

THTR
(FRG)
1986 - 1989

LARGE HTGR PLANTS up to 1000MWe



Modular HTGR



Self Shut-down
Self Cool-down

Industrial Demonstration (HTR-PM)

VHTR R&D GIF

EXPERIMENTAL MODULAR REACTORS

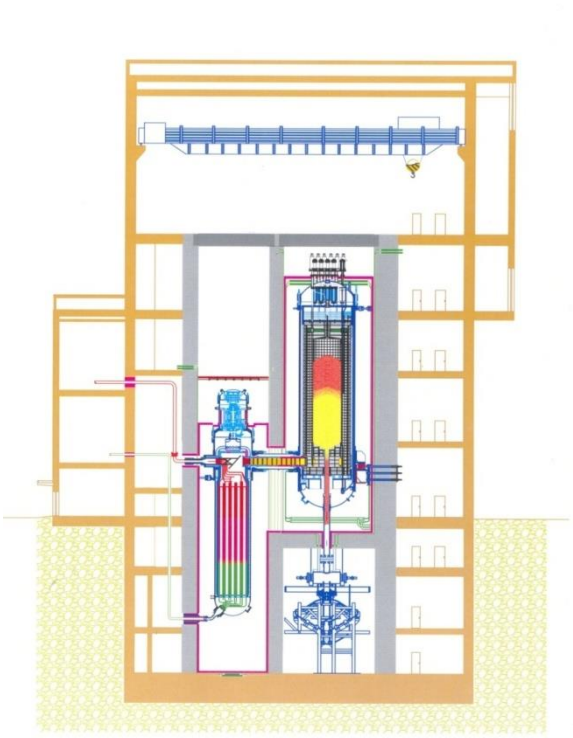
HTR-10

HTTR

6

Modular HTGR advanced features

Typical configuration of modular HTGR designs



1. How **nuclear safety** is achieved with modular HTGR designs:
   - Reactor self-shutdown: (1) strong negative temperature feedback; (2) large span of allowable temperature increase of fuel
   - Self-acting decay heat removal: (1) low power density; (2) selected slim configuration of reactor core
   - Containing radioactivity: (1) strong coatings; (2) limiting temperature simply by material selection and core configuration
   - Safety goal: no off-site nuclear emergency (safety feature of Gen-IV systems)
2. **High temperature** output: 700-950 degree C for steam turbine power generation, process heat applications, even gas-turbine power generation

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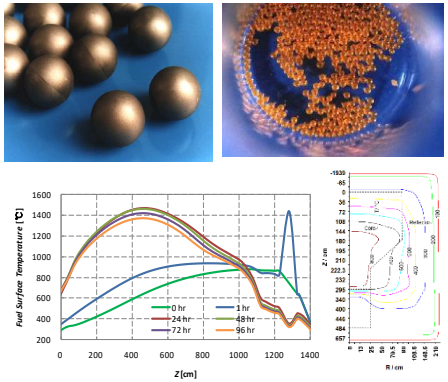
Chinese HTGR development: Roadmap

Three major steps till now, one step yet to follow

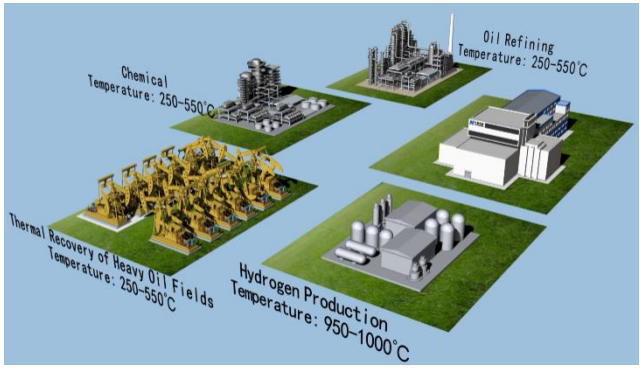


1. R&D on key technologies

2. Construct test reactor

3. industrial demonstration reactor

Electricity generation,
cogeneration, process heat



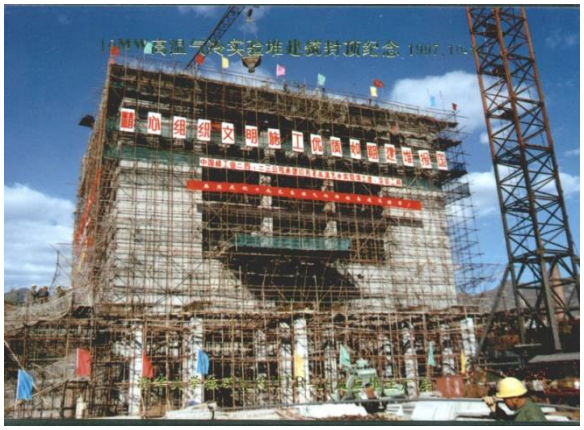
4. Commercial application

Building a Modular HTGR Test Reactor

❑ HTR-10: 10 MWt High Temperature Gas-cooled test Reactor

- 1986: HTGR became one of the key projects in the “National High Technology Program”
- 1992: government approved to construct HTR-10
- 1995: started to construct HTR-10 in INET, Tsinghua University, Beijing
- 2000: HTR-10 reached first criticality
- 2003: HTR-10 operated in full power

HTR-10 in 1995

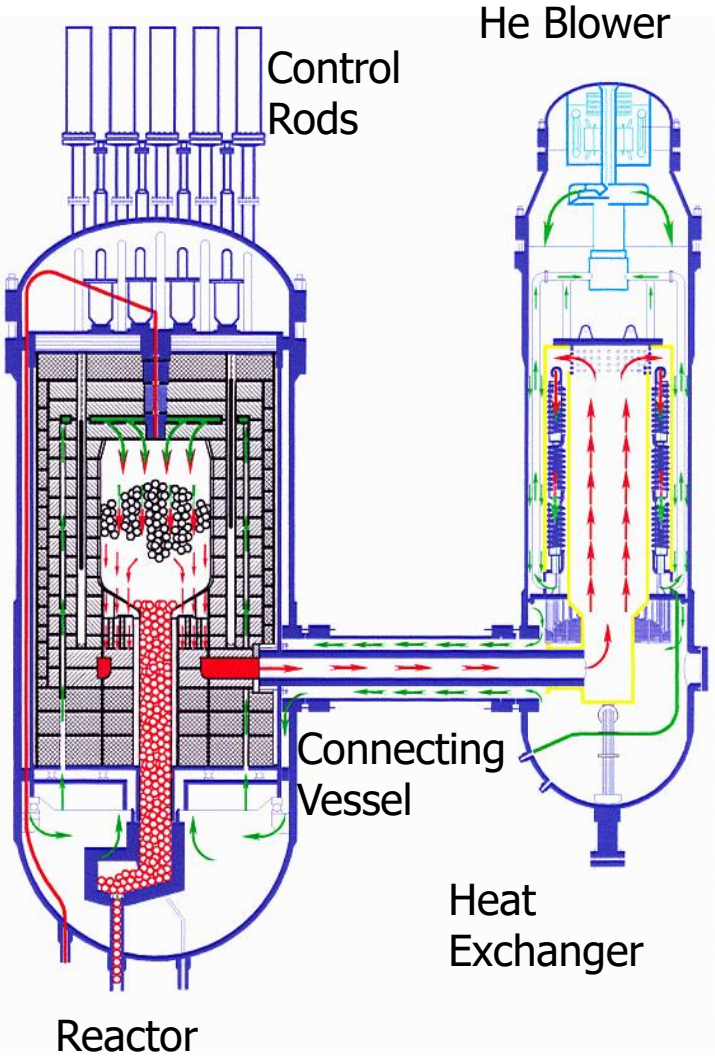


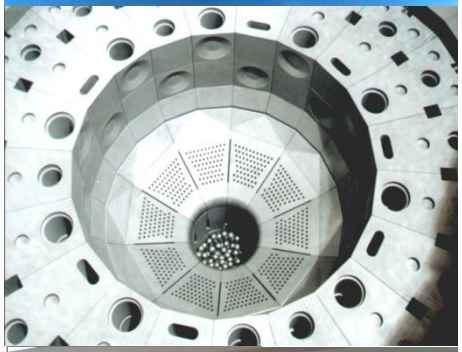
HTR-10 in 1997

HTR-10 in 2000

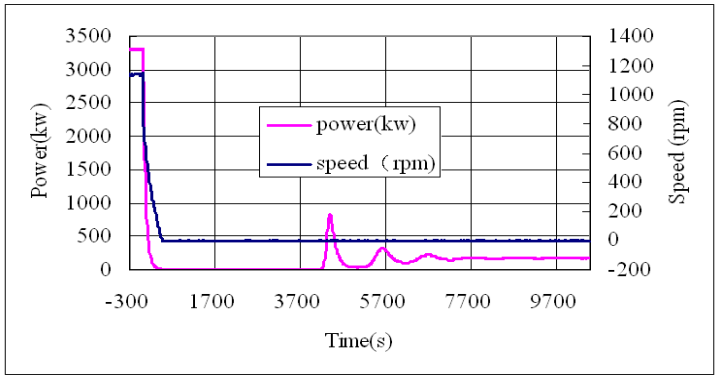
The HTR-10 Test Reactor

Reactor Power MWth	10
He Pressure MPa	3
Reactor Inlet Temp., °C	250
Reactor Outlet Temp., °C	700
Number of Fuel Elements	27000

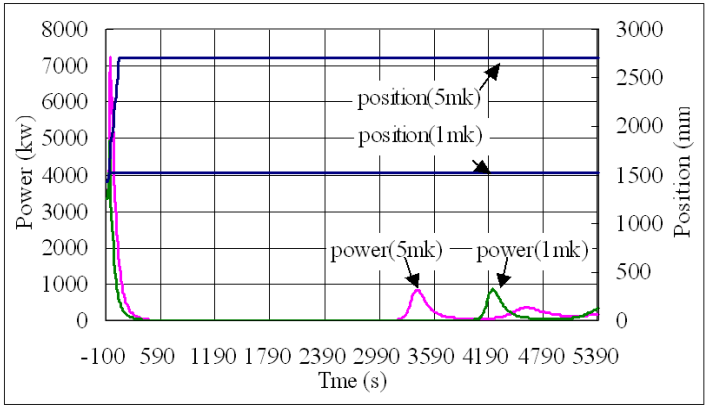




Safety Test with HTR-10



ATWS, Loss of Coolant Flow



ATWS, Control Rod Withdrawal

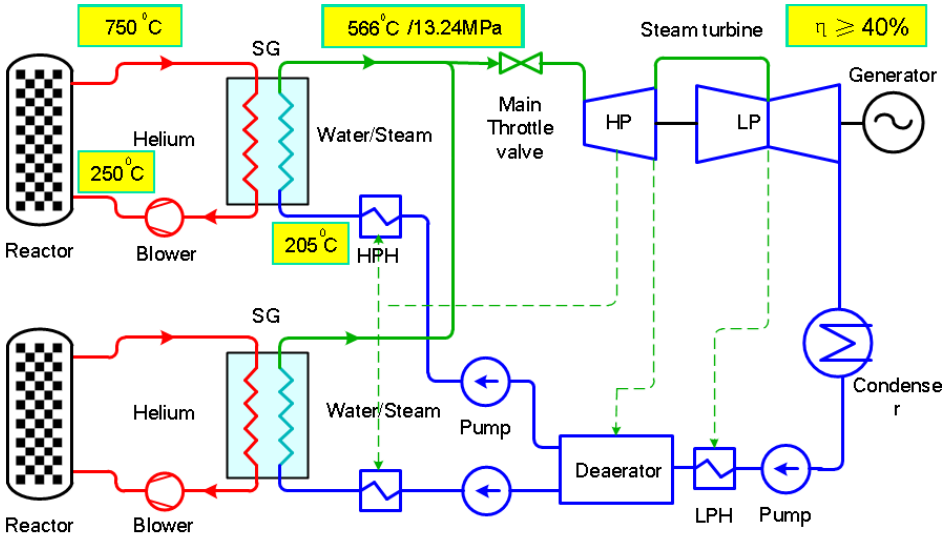
International experts witnessing HTR-10 safety tests

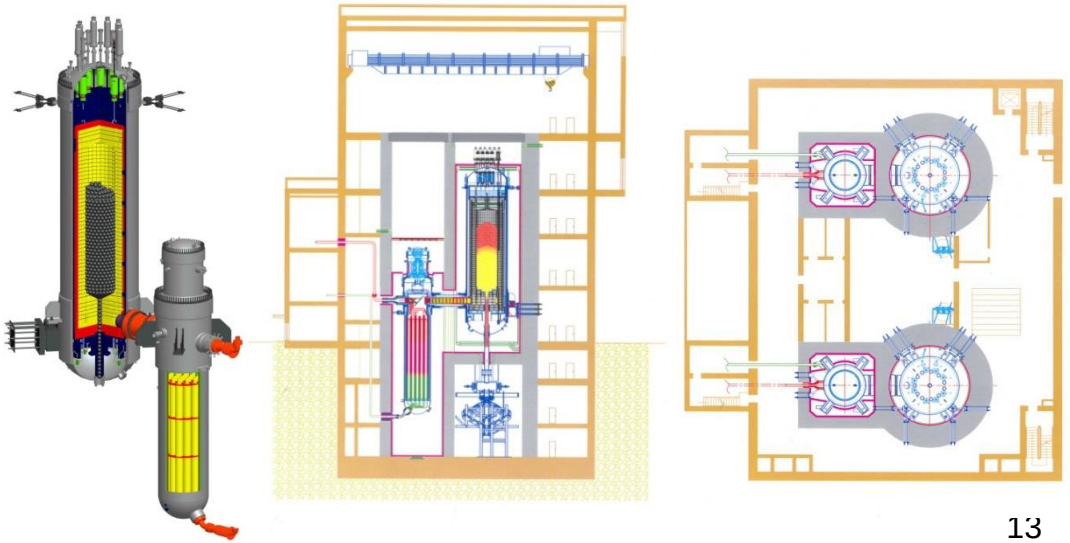
HTR-PM

- It is logic and strategic to build an industrial demonstration plant as the follow-up development step after the success of the HTR-10 test reactor.
- A 200MWe modular pebble bed HTGR demonstration project (HTR-PM) has been initiated and under implementation.
- Since 2006, the project has become one of the national key projects within the 2020 National Science & Technologies Development Program of China.
- HTR-PM has been under construction since 2012.

HTR-PM Process Design

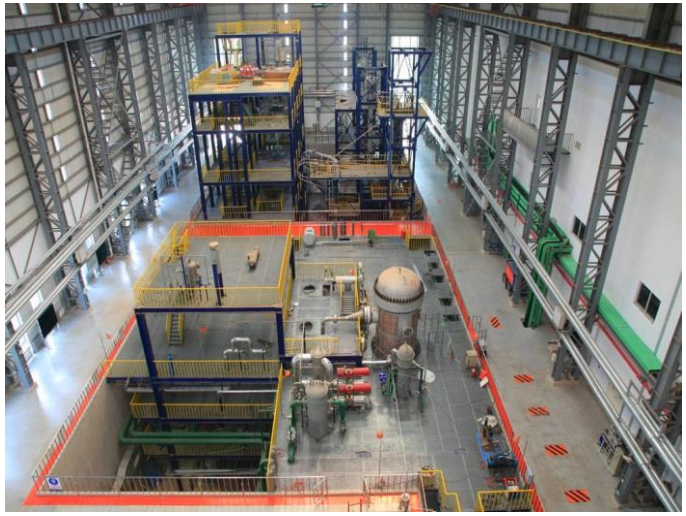
Plant electrical power, MWe	*211*
Core thermal power, MW	*250*
Number of NSSS Modules	*2*
Core diameter, m	*3*
Core height, m	*11*
Primary helium pressure, MPa	*7*
Core outlet temperature, ℃	*750*
Core inlet temperature, ℃	*250*
Fuel enrichment, %	*8.5*
Steam pressure, MPa	*13.24*
Steam temperature, ℃	*566*





Design Verification

- ***The Engineering Lab.***
  - ***Verification of key system and components before installed in the reactors***
- ***10 MW helium test loop***
  - ***Steam generator, one of the 19 assemblies***
- ***Full scale, under reactor helium condition***
  - ***Control Rods Driving Mechanism***
  - ***Small Sphere Absorption System***
  - ***Control Room***
  - ***Helium Circulator***
  - ***Spent fuel canister***
  - ***Fuel Handling System***
  - ***Steam Generator***



Design Verification

Fuel pebbles

Steam Generator

Main Helium Circulator

Fuel Handling System

CRDM

Small absorber ball system

Spent fuel storage system

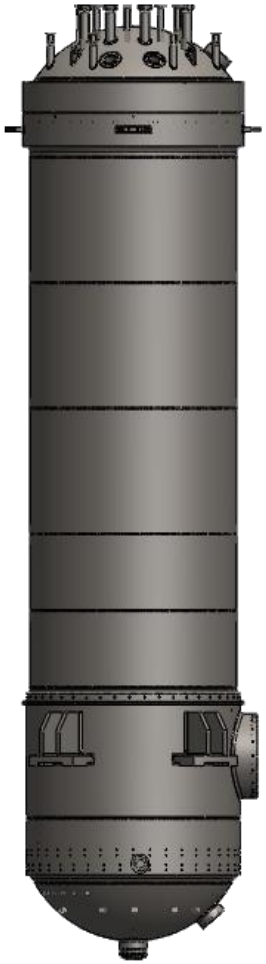
Main control room

Equipment Manufacturing

- ***First of a kind***
- ***Almost all components are manufactured in China, except for graphite and some valves***

Key components / systems	*Manufacturer*
Fuel	*China North Nuclear Fuel Co., LTD*
RPV	*Shanghai Electric*
Steam Generator	*Harbin Electric*
Graphite internal	*Toyo Tanso*
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*

RPV manufacturing



heat treatment of the top head

machined top head

top flange forgings

fine machined top flange

Shanghai Electric Co. 460 tons of large forgings

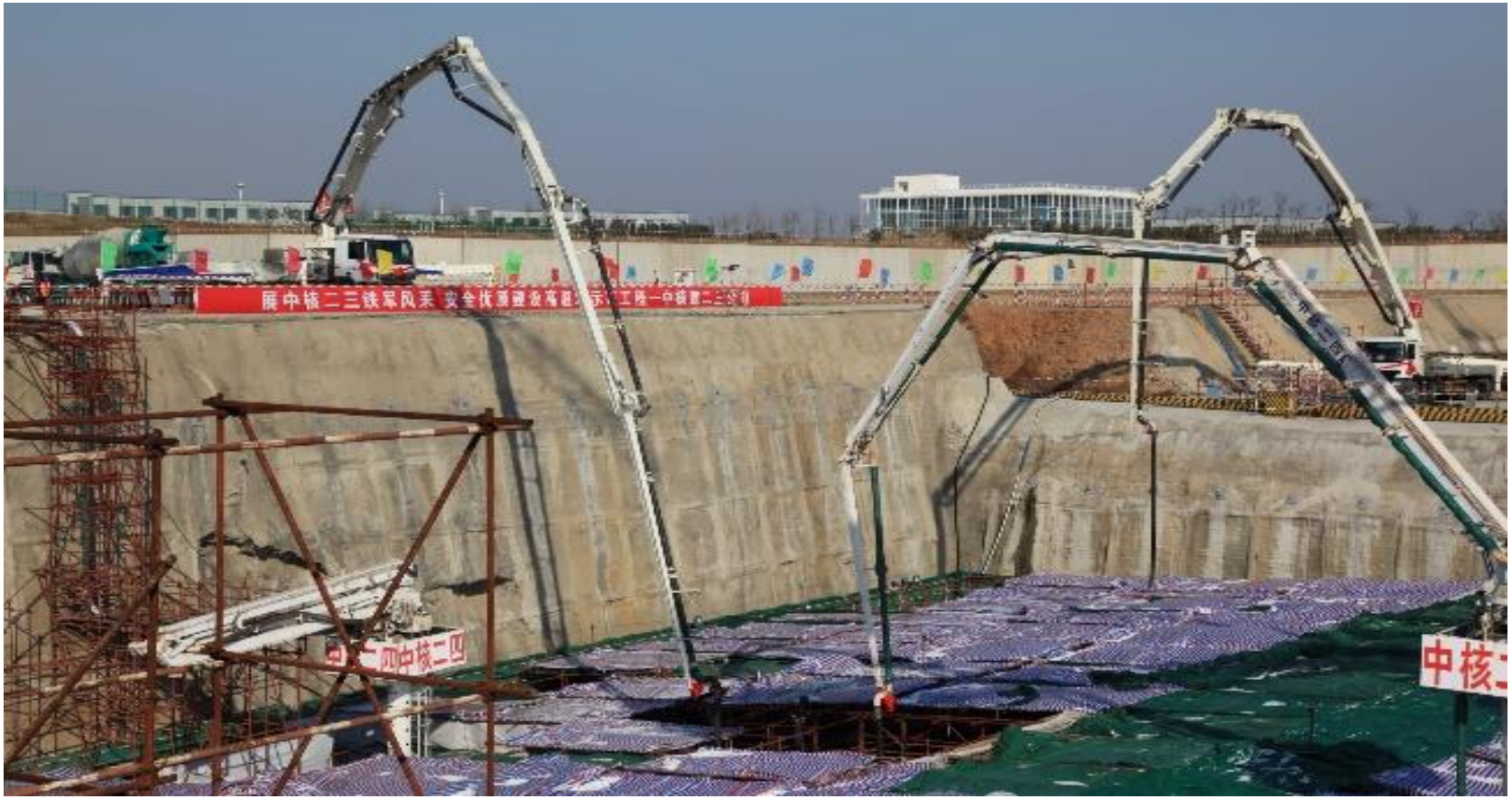
preliminary machined large forgings

2015.11.21

Finish hydrostatic test

Construction Progress

2012.12.09, First Concrete



Construction Progress

2015, Civil work of nuclear island finished

2016.3, Manufacture of fuel elements started

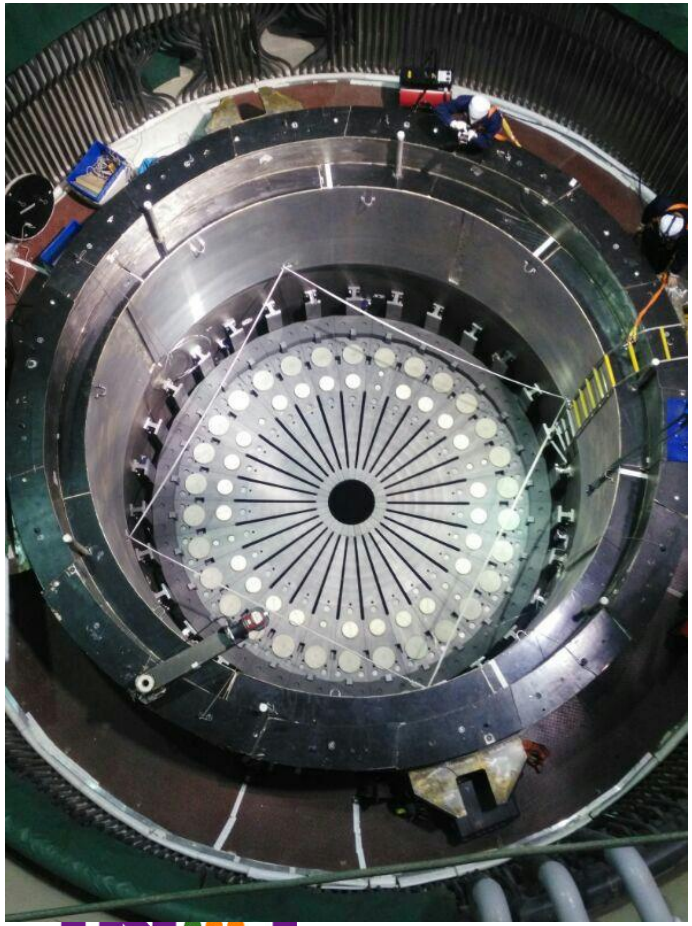
2016, RPVs on site and installed

2015~2016

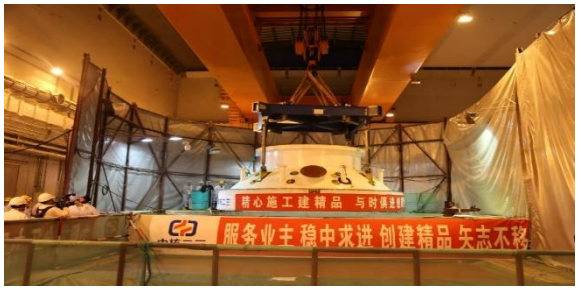
Metallic internal structure, water cooling panel, DCS, full scope simulator

Construction Progress

2017.6, graphite pebbles, ceramic internals finished



2017.12, RPV upper head

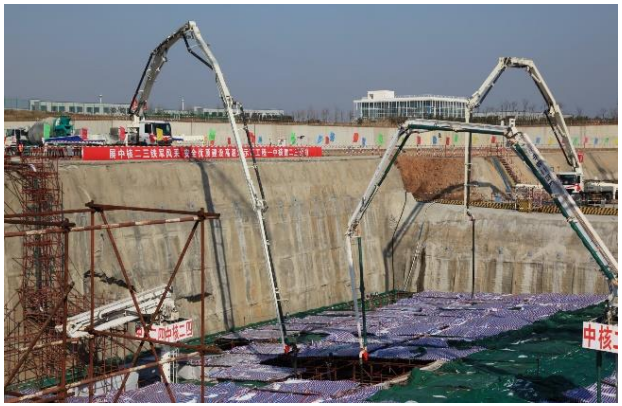


2018.10, 1st SG manufactured, now under installation

Construction Milestones

- *2012/12/09：FCD*
- *2015/06/30：Reactor building*
- *2015/12：Full scope simulator*
- *2016/03/20：1st RPV installed*
- *2016/08：Start fuel production*
- *2016/09：2nd RPV installed*
- *2016/12：main control room*
- *2017/03: steam turbine installed*
- *2017/06: 1st ceramic internals installed*
- *2017/12: 1st head of RPV installed*
- *2018/06: 2nd ceramic internals installed*
- *2018/10: 1st SG delivered*
- *Now: installation and commissioning tests*

HTR-PM in 2008



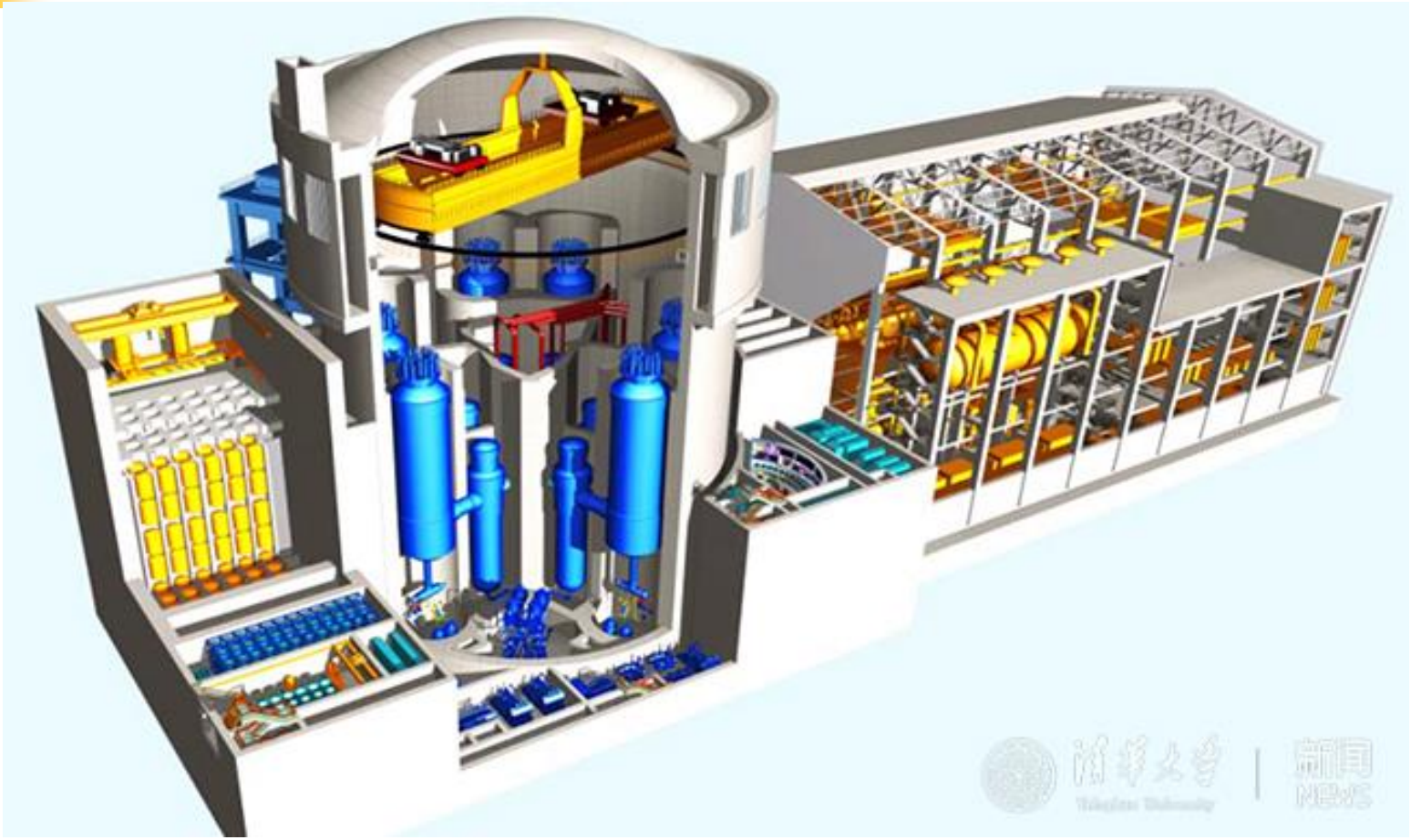
HTR-PM in 2012

HTR-PM in 2014

Next Step

- **Role of HTR-PM in China**
  - **Supplement to PWRs, especially to replace coal-fired power plant to reduce coal share**
  - **Co-generation of steam and electricity, Hydrogen production**
  - **Technology Innovation**

HTR-PM 600



Conclusion Remarks

- HTGR is an important component of advanced nuclear power technology development in China. Modular HTGR is suitable for high efficiency power generation and various heat applications.
- Modular HTGR can play supplemental roles to large LWR for power generation.
- Several reasons for intensive R&D efforts of advanced nuclear power technologies: advanced technical features, new application and market opportunities, high expectations of nuclear potential, innovation-driven strategy ……

THANKS

FOR YOUR ATTENTION !