GEN IV International Forum[SM]

DESIGN, SAFETY FEATURES & PROGRESS OF HTR-PM

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Meet the Presenter

Dr. Dong is a Professor in Nuclear Engineering at the Tsinghua University, Beijing, China, where he earned his PhD degree in Nuclear Reactor Engineering and Safety. Since 1997, he has worked to develop advanced nuclear reactors at the Institute of Nuclear and New Energy Technology, INET, Tsinghua University. He has served as the Head of the Division of Reactor Thermal-Hydraulic Calculation, and Head of the Division of Reactor Physics, Thermal-Hydraulics and System Simulation. In 2006, he was responsible for the Division of General Design of High Temperature Gas-cooled Reactor (HTGR).

Currently, he is the Deputy Director and Deputy Chief Engineer of INET in charge of HTGR projects. In addition, he has also been appointed by the National Energy Administration to be the Deputy Technical Director of the HGTR Nuclear Power Plant Project, which is one of the National Science and Technology Major Projects. He is actively involved in planning the System Arrangement of VHTR as a member of the System Steering Committee in the frame of GIF.

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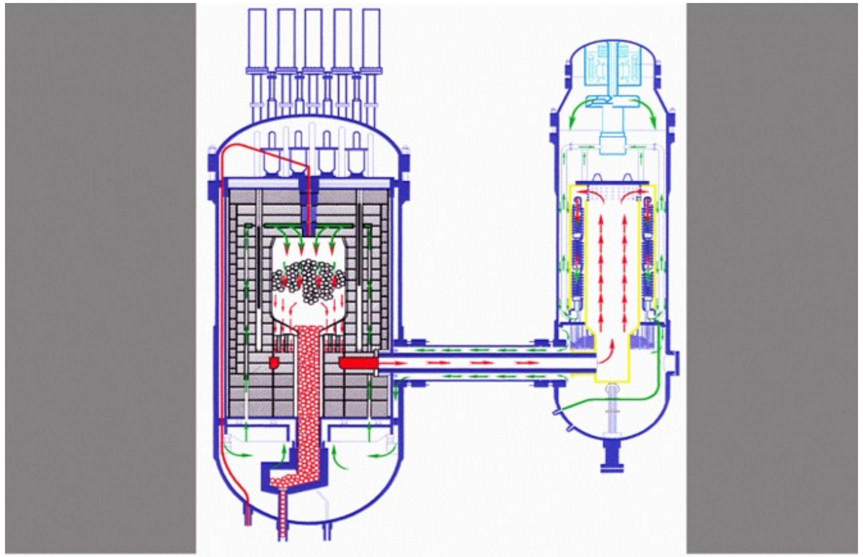
OUTLINE

- Design
- Safety
- Pre-construction
- Demonstration tests
- Procurement of components
- Construction
- Fuel
- Follow-up project

Basis of HTR-PM

- 1986: R&D work on design and component technologies under the support of national high technology program
- 1992: Government approved to construct the 10 MW high temperature gas cooled reactor (HTR-10)
- Jun 1995: Reactor construction started
- Dec 2000: First criticality achieved
- Jan 2003: Full power operation



HTR-10

Technical Goals of HTR-PM

- Keep inherent safety
- Achieve economic competitiveness
- Realize standardized design
- Use proven technology as much as possible
  - HTR-10 proven technology
  - Global experience
  - Steam turbine
  - Global purchase of some key components

HTR-PM: High Temperature Reactor- Pebble-bed-Module

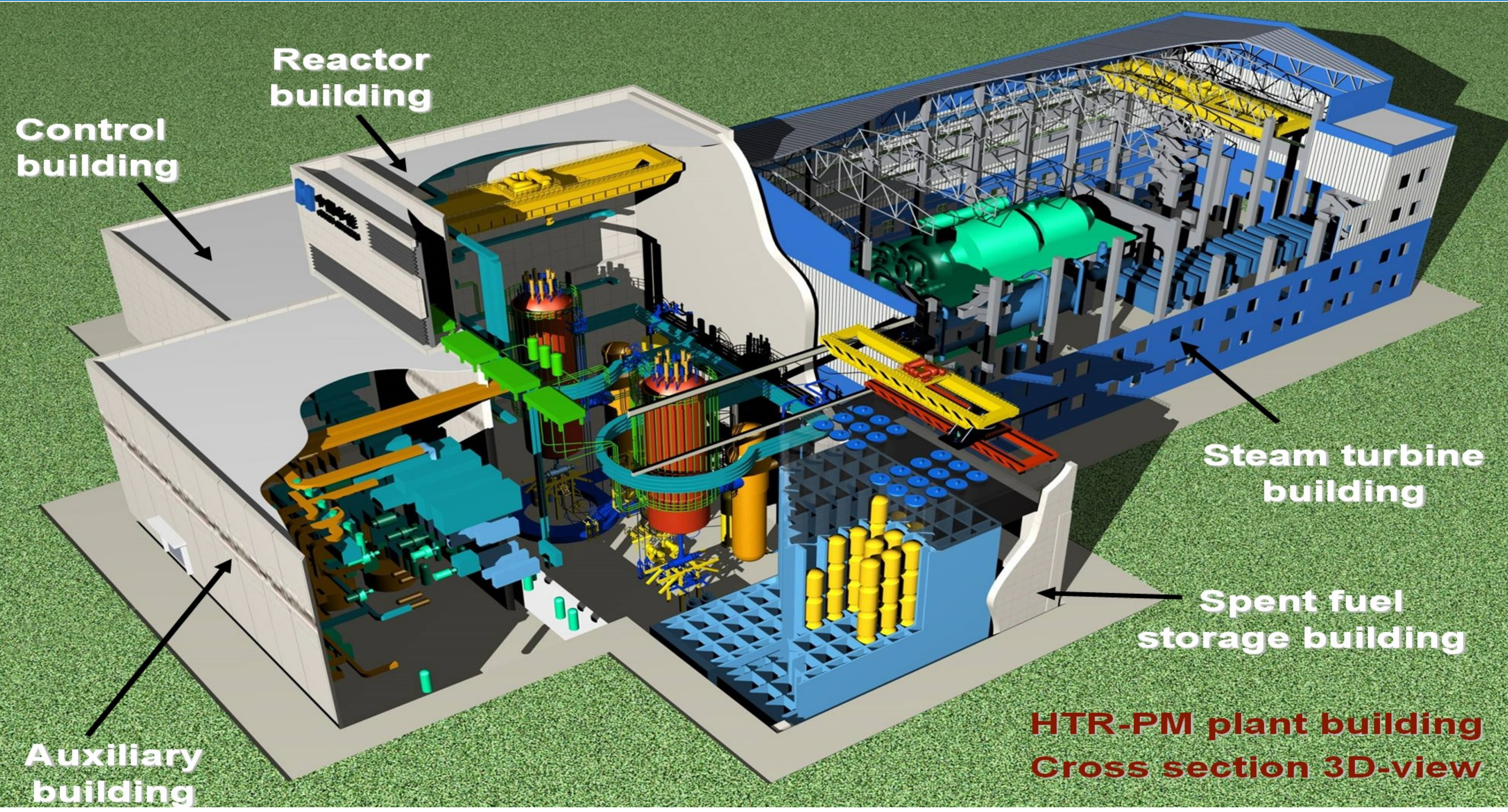
Comparison of Designs

Since 2004, INET cooperated with CHINERGY and Shandong Electric Power Engineering Consulting Institute for developing a standard design of HTR-PM, focus on:

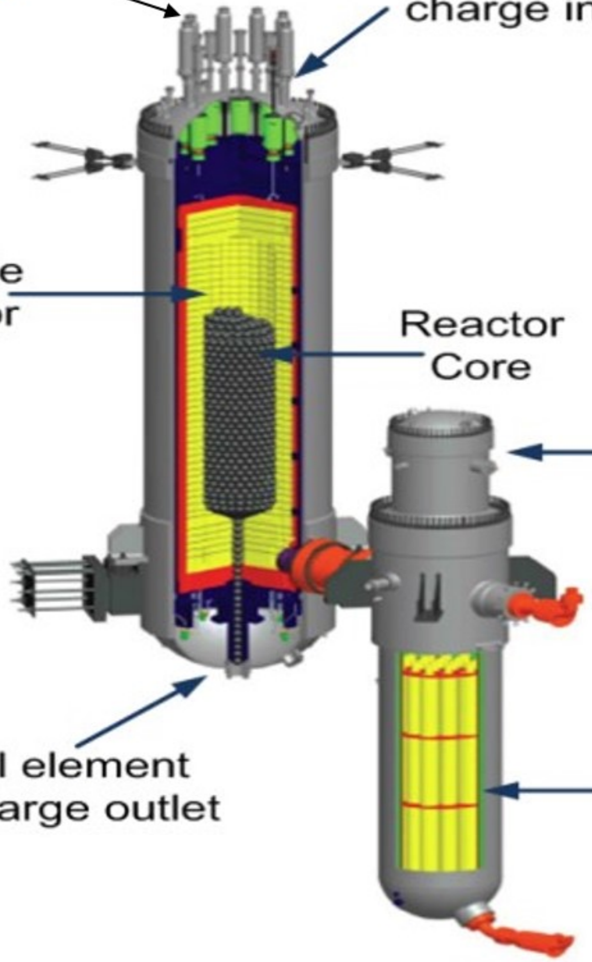
- Studied annular core with power of 458MWth, cylindrical core of 250MWth
- Compared annular cores with different central graphite columns: dynamic and fixed
- Compared different steam cycles: reheating and non-reheating

Features of Final Design

- Steam turbine cycle
- Two NSSS with one turbine
- Non reheating in second circuit
- Cylindrical core
- Multi-pass charge continually


Reactor building
Control building
Steam turbine building
Spent fuel storage building
Auxiliary building
HTR-PM plant building
Cross section 3D-view

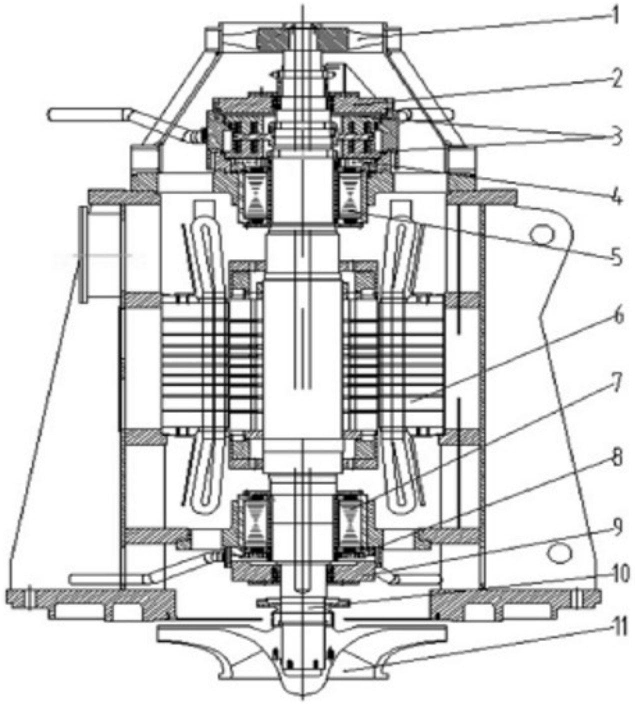
Overview of Design



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, ℃	567

Blower Design

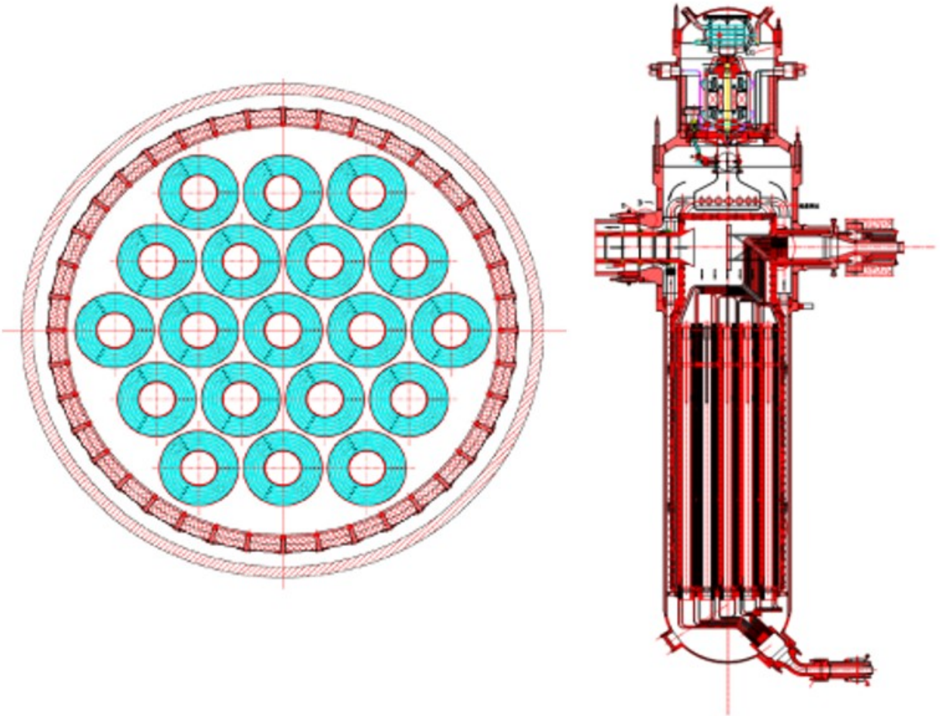
- Internal, Vertical layout
- Driven by high speed, frequency control electrical motor
- Single stage, centrifugal impeller
- Active magnetic bearing (AMB)



Parameter	Unit	Value
Pressure rise	kPa	200
Temp. of helium	℃	250
Rotation speed	rpm	4,000
Electrical power	kW	4,500

Steam Generator Design

- Vertical, counter flow, once-through type, helical tubes
- Middle size, multi-layer helical tube assemblies
  - In-service inspection (ISI) feasible
  - Flow distribution, testable



Parameter	Unit	Value
Power	MW	253
No. of Units		19
No. of tubes per unit		35
Total No. of Tubes		665

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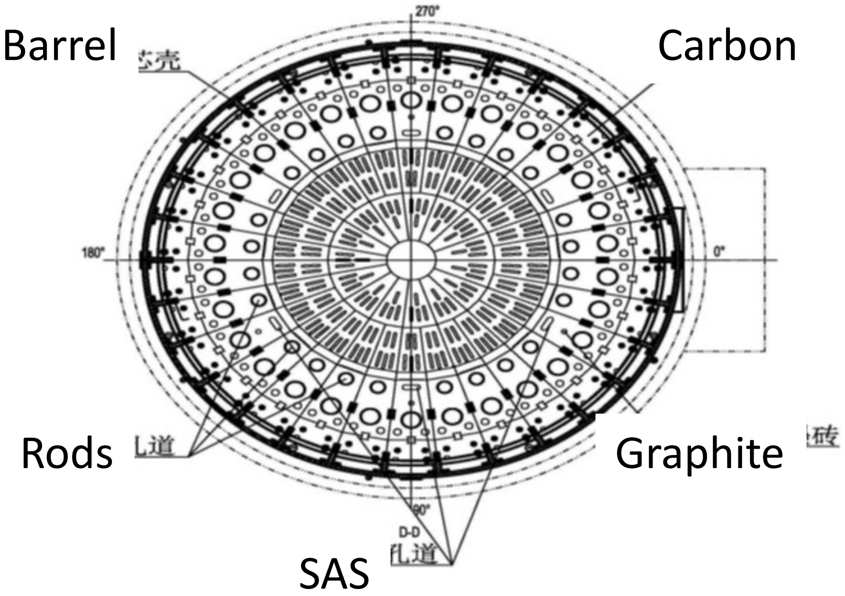
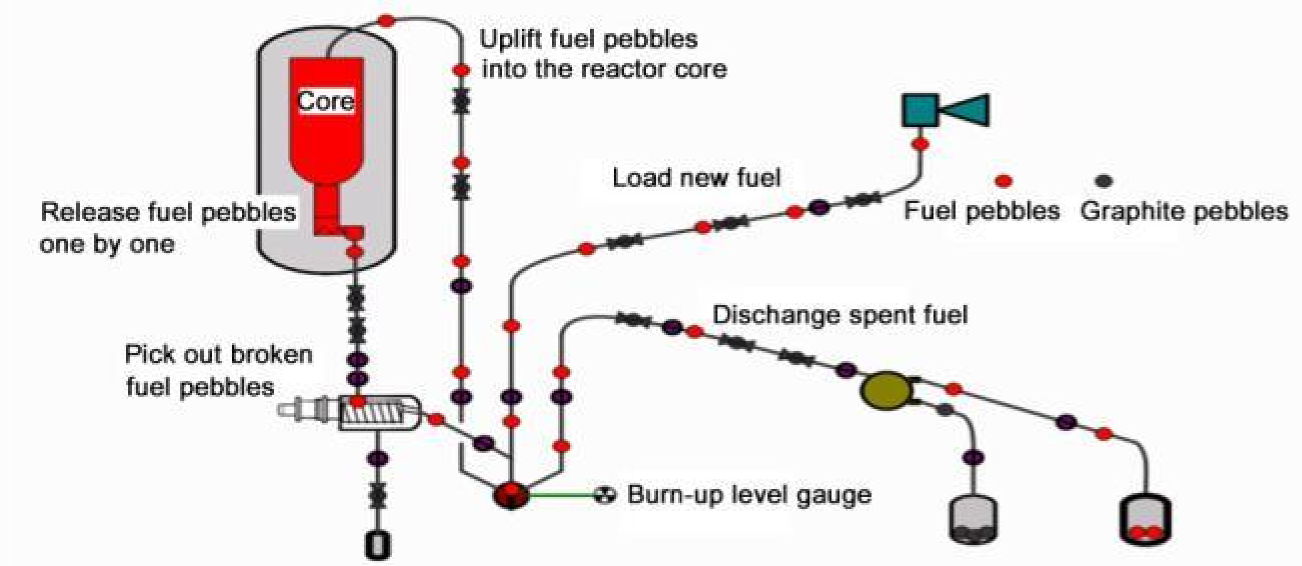
Reactivity Control Systems

- Two independent systems: rods plus small absorber spheres (SAS), located in side reflector
  - Primary: rods, 24, motor driven
  - Secondary: SAS, 6 , falling by gravity, pneumatic conveyance



Fuel Handling System

- Charge and discharge fuel elements on line
- Separating out the broken fuel elements
- Measure burn-up of fuel element and screening out spent fuel
- Transfer spent fuel elements to storage tank



Safety of HTR-PM

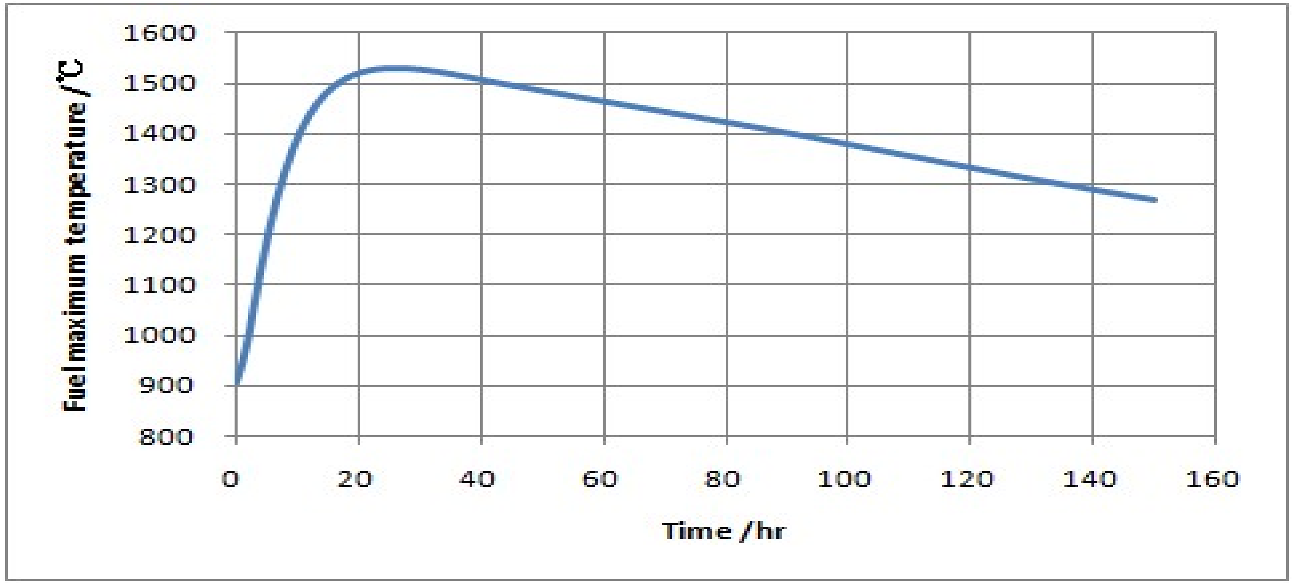
- Fulfillment of fundamental safety functions
  - Control of reactivity
  - Removal of heat from the reactor and from the fuel store
  - Confinement of radioactive material, shielding against radiation and control of planned radioactive releases, as well as limitation of accidental radioactive releases

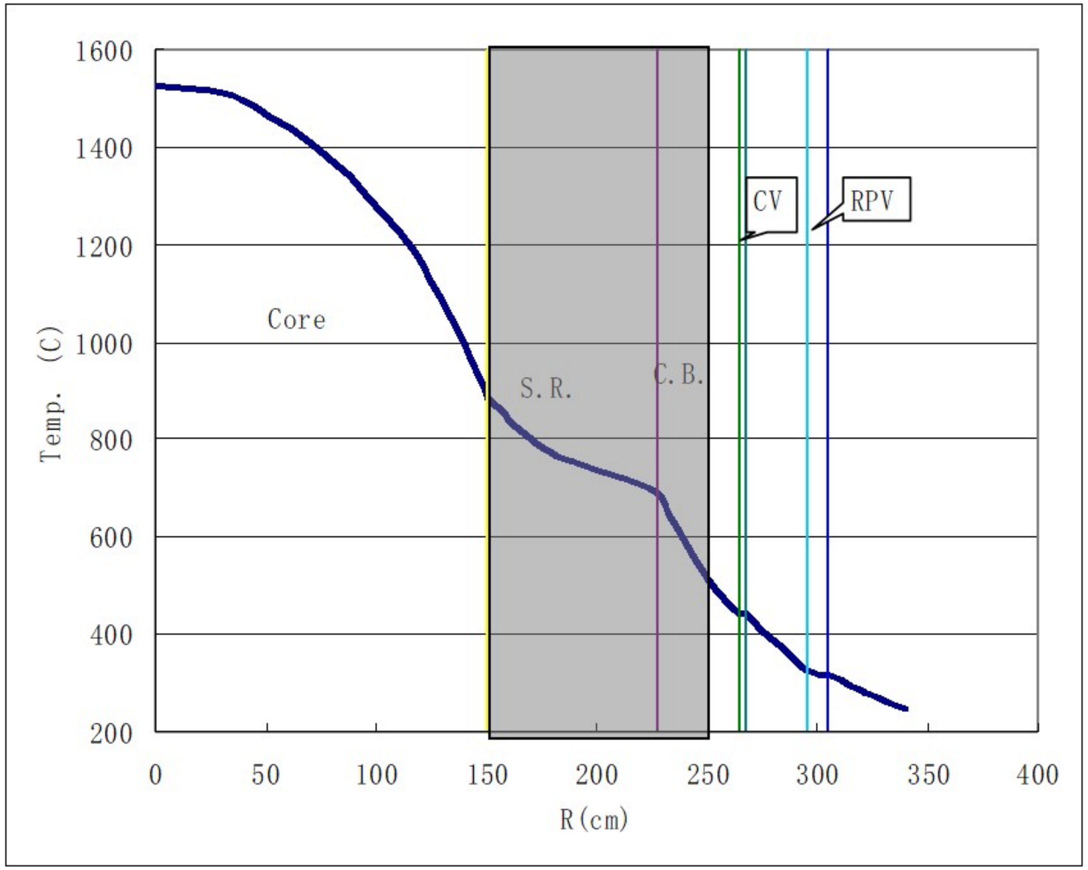
Control of Reactivity

- Small reserved reactivity due to continuous fuel load: nearly no insertion of control rods in normal conditions. Only reserved reactivity for power regulation is balanced by control rods.
- Helium is transparent to neutrons.
- Full scope negative temperature feedback (Coefficient -5×10^{-5}), large temperature margin (500℃-1500℃), reactor shutdown automatically depending on negative temperature feedback
- Insertion of positive reactivity related to accidents （e.g. water ingress) can be compensated by negative temperature feedback

Removal of Decay Heat

Max. fuel temperature is lower than the limit temperature of materials during loss of coolant

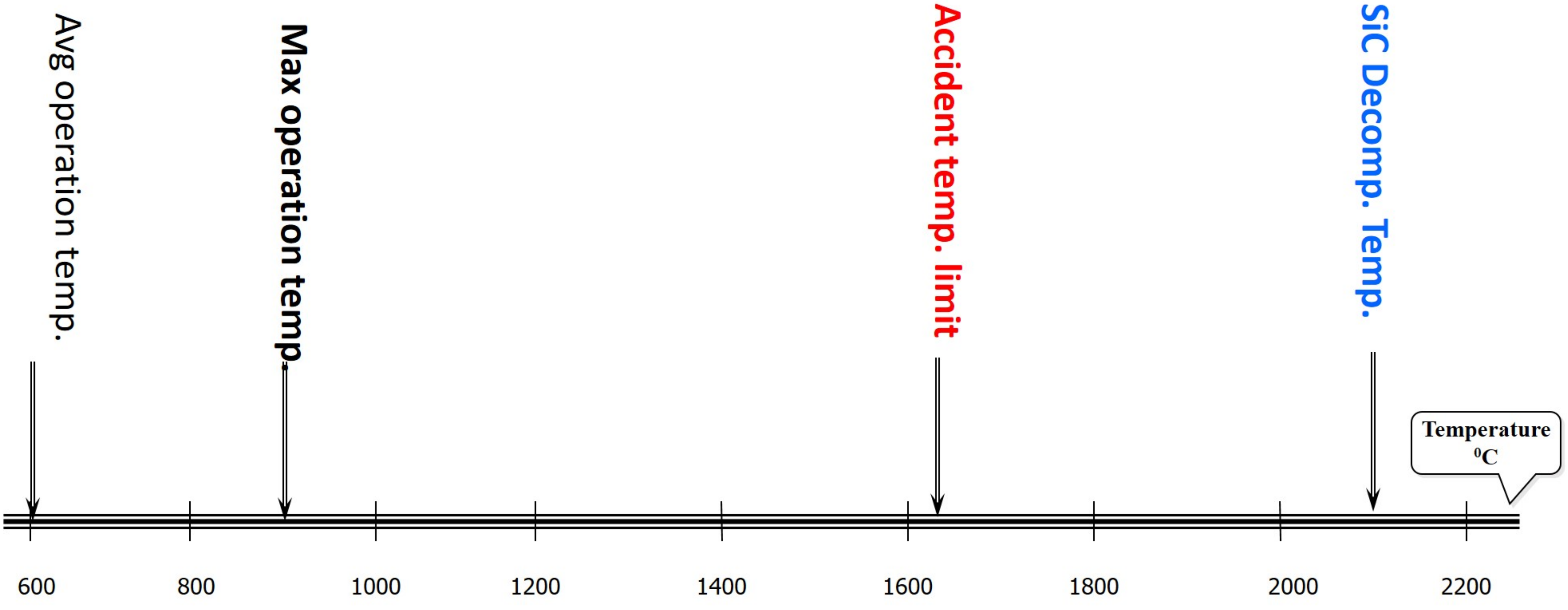




Confinement of Radioactive Materials

- No of CP: 4×10^5 FE, 4×10^9 CP
- Failure rate in manufacture and operation $<10^{-4}$
- No likelihood of massive failure in accidents
- SiC can resist intrusion of external water and air

Excellent Performance of CP



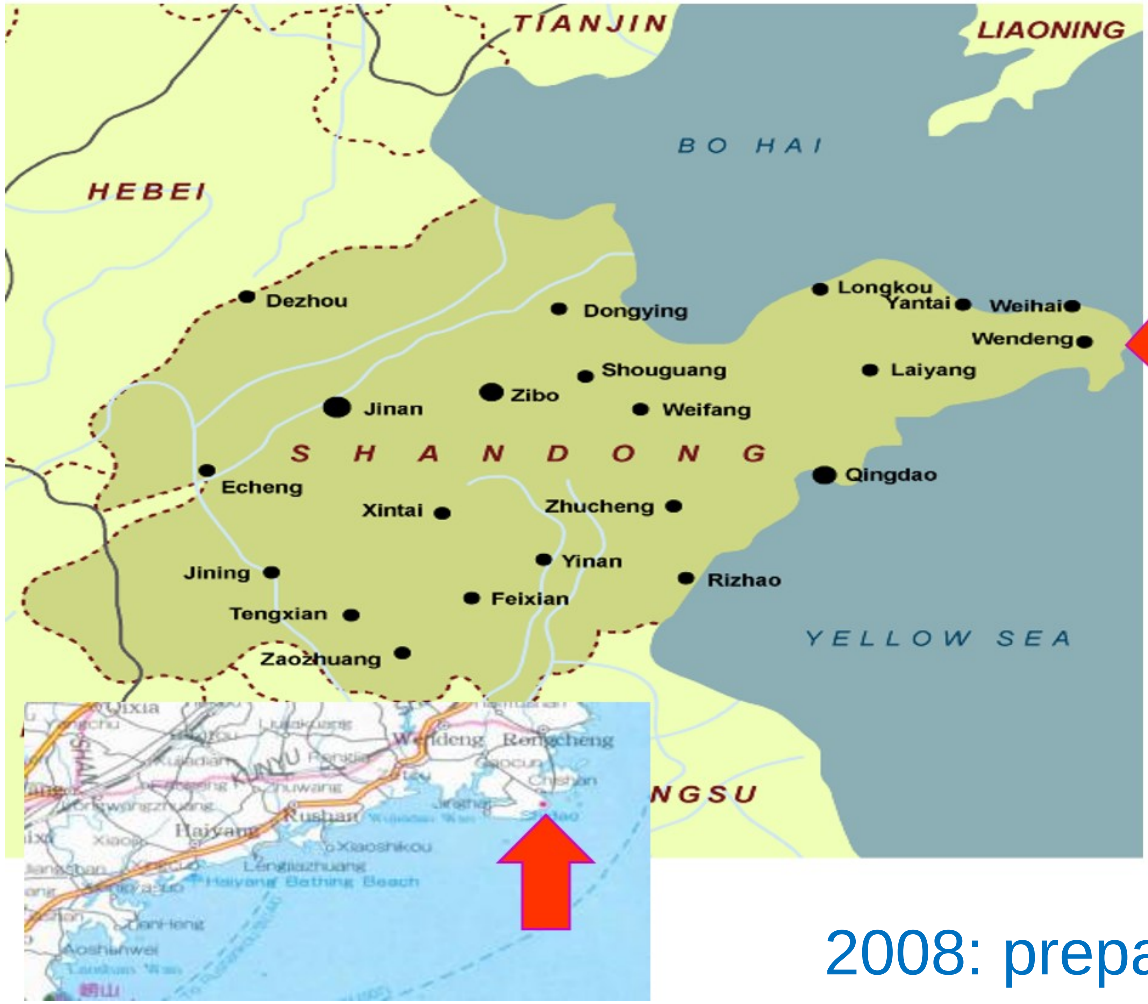
HTR-PM Project

- From 2001, on the basis of the success of HTR-10, HTR-PM conceptual design started
- In 2006, Listed by the central government as one of the key projects in Outlines of National Medium-term Science & Technology Development Program (2006-2020)
- In 2008, Implementation planning approved, including target, schedule, funding, R&D programs
  - *Completing 200 MWe HTR-PM demonstration plant, and providing sound foundation for the further development of Generation IV nuclear system.*

Organization

- INET R&D Technical responsibility
  - *Institute of Nuclear and New Energy Technology*
- CHINERGY EPC main contractor of NI and its BOP
  - *China Nuclear Engineering Group Corporation(CNEC); Tsinghua Holdings; China Guangdong Nuclear Power Holdings (CGN)*
- Huaneng Shandong Shidao Bay Nuclear Power Co.,Ltd (HSNPC) Owner for construction and operation
  - *China Huaneng Group (CHNG); China Nuclear Engineering Group Corporation (CNEC); Tsinghua Holdings*

Site Preparation



The HTR-PM site is in Rongchen City of Shandong Province.

2008: preparation in site was started, excavation of nuclear island buildings

HTR-PM Project Feasibility, Basic Design & PSAR

- In 2007, feasibility study was finished; feasibility study report was checked by consultancy in 2008; Environment Impact Report (at feasibility study stage), Site Safety Analysis Report were approved by National Nuclear Safety Administration.
- In 2008, basic design of HTR-PM demonstration plant was finished; basic design documentations and drawings were reviewed in 2009.
- In 2008, the PSAR was submitted; the PSAR was approved by NNSA in 2009.

Engineering Laboratory

Started construction in 2009 and finished in 2010

The laboratory overview

The facility is ready for test

Large-scale helium loop

- power：10 MW
- tempt.：750 ℃
- pressure：7 MPa
- coolant：helium

Full scale, under HTR-PM helium conditions

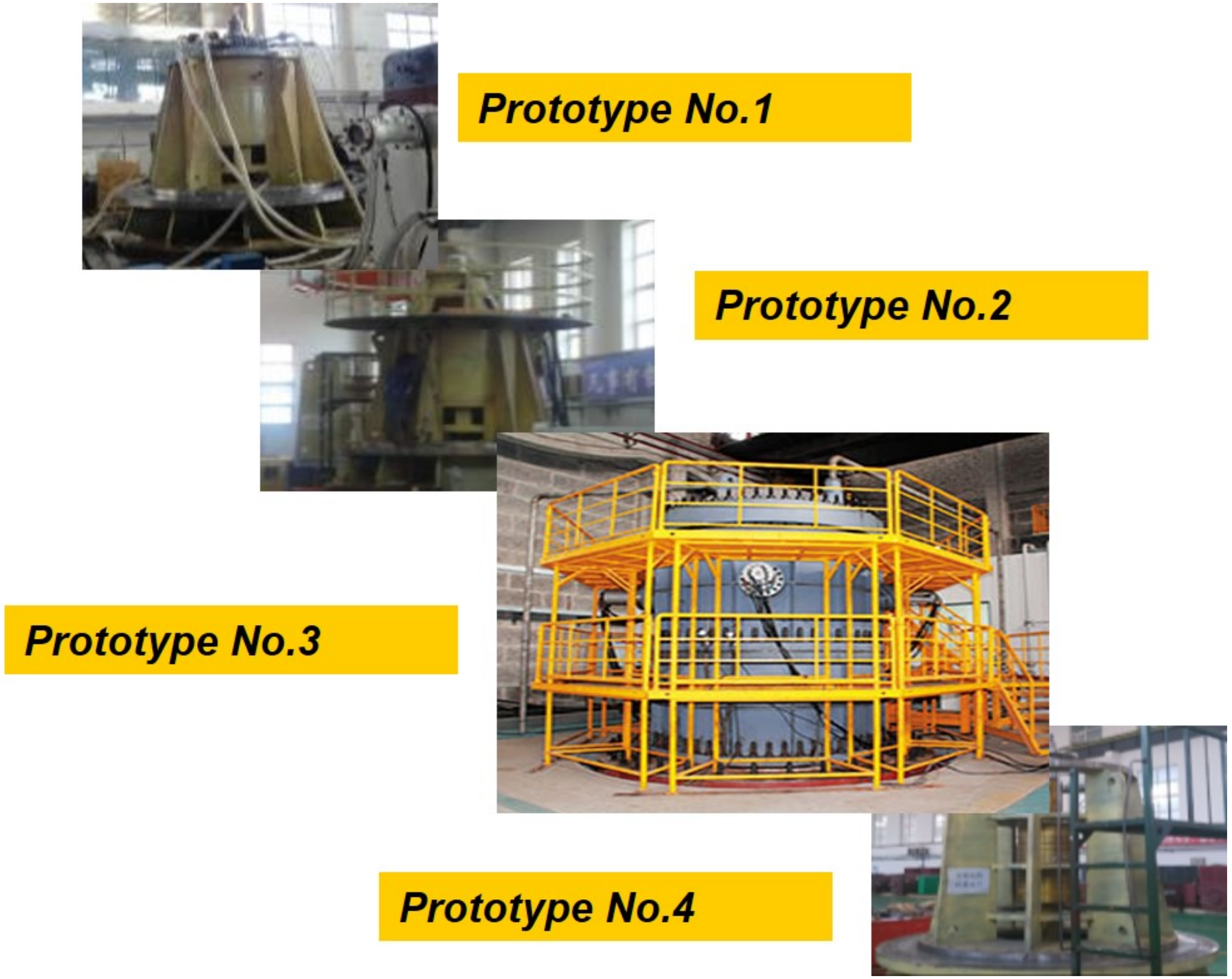
- steam generator, one of the 19 units
- helium circulator
- fuel handling system
- control rods driving system
- small absorber balls reserve shutdown system
- helium purification system
- reactor protection system and control room

Demonstration Tests

- Control Rods Driving Mechanism, finished
- Small Sphere Absorption System, finished
- Control Room, finished
- Helium Circulator, finished
- Spent fuel canister, finished
- Fuel Handling System, finished
- Steam Generator, finished

Helium Circulator with AMB

- Prototype No.1: full scale motor with oil lubrication bearing
- Prototype No.2: motor with domestic magnetic bearing
- Prototype No.3: full scale helium circulator with domestic bearing
- Prototype No.4: full scale motor with the magnetic bearing of the final product, tests the catch-down capability.



Full Scale Helium Circulator Test

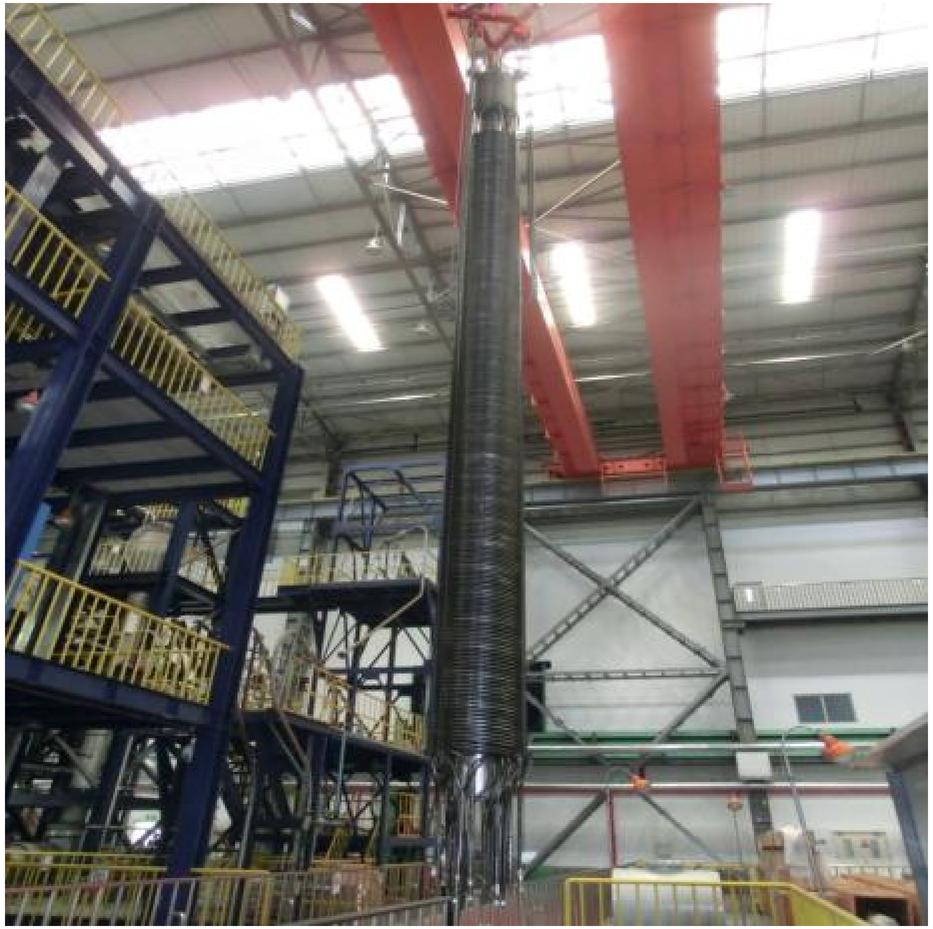
- 100 hours, Nitrogen, 2014, Shanghai
- 500 hours, Nitrogen, 2014, Shanghai
- 50 hours, Helium, 2015, INET
- 50 life cycles, Helium, INET, 2016
  - Every cycle, from cold to hot, experienced 10 transients. The tests take totally 500 transients and 6 months
- Extreme condition, Helium, INET, 2016

Fuel Handling System

- Full scale engineering tests finished
  - 500h, automatic operation
  - 7MPa helium, hot

SG Engineering Test

- Hot test of an assembly, finished, 2017/07
  - 10 MW thermal power
  - Helium:750℃, 7 MPa
  - Steam: 570 ℃, 14 MPa



Delivery of Components

By the end of 2008: main components were ordered

- Reactor Pressure Vessels, on site
- Metallic reactor internals, on site
- Full Scope Simulator, on site
- Distributed Control System, on site
- Reactor Protection System, on site
- Control Rods Driving Mechanisms, on site
- Small Sphere Absorption Systems, on site
- Helium Circulators, in schedule
- Fuel Handling System, on site
- S/G, delayed, in final installation


国家科技重大专项一华能石岛湾核电厂高温气冷堆示范工程压力容器胜利出厂
发展绿色电力 奉献清洁能源
上海电气
全球首台HTR-PM压力容器
华能石岛湾高温气冷堆示范工程

Main Control Room

FSS

HTR-PM Supply Chain

- Main Components Suppliers:
  - Shanghai Electric: RPV, Metallic Reactor Internals, CRDMs, SASs, Steam Turbine, Helium Circulators
  - Harbin Electric: Steam Generator, Generator
  - Toyo Tanso: Graphite
  - CGNPC: DCS, Simulator
- Nuclear island EPC Contractor: CHINERGY
- R&D, NSSS and main NI system Engineering: INET
- Other components: companies inside and outside China

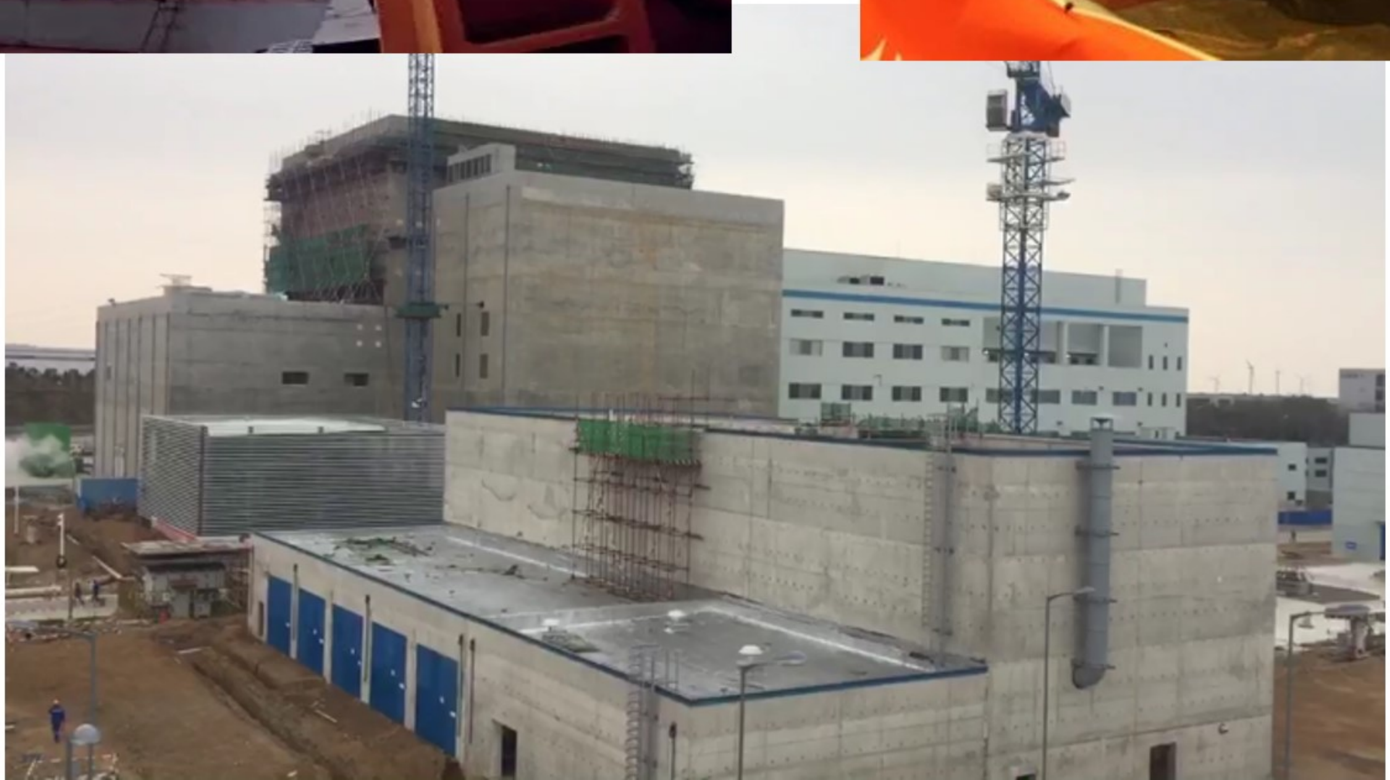
Milestone of Construction

- 2012/12/09：FCD
- 2015/06/30：Reactor plant
- 2015/12：Full scope simulator
- 2016/03/20：1st RPV installed
- 2016/09：2nd RPV installed
- 2016/10：Inverse transmission power
- 2017/06: 1st ceramic internals installed
- 2017/09: 1st graphite pebbles loaded
- 2017/12: 1st head of RPV hosted in place


展中核二三铁军风采
安全优质建设高温
中核二四
中核二

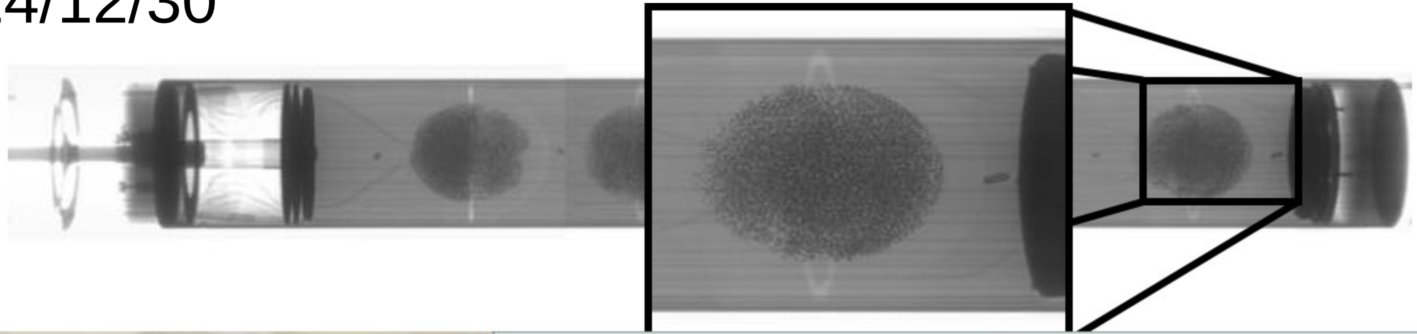

铸精品工程 建世界首堆 攀世界高峰
高起点规划 高标准建设 高水平管理 高效率产出
无证人员
禁止入内

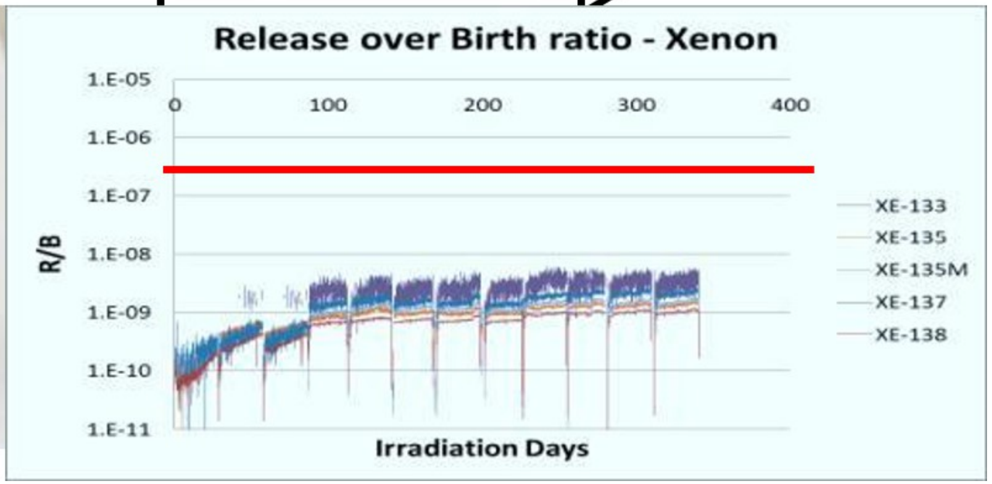

精心施工建精品 与时俱进
服务业主 稳中求进 创建精品



Fuel Irradiation Test

- INET demo production facility, 100,000/a, 2010/10
- Irradiation test of fuels, Petten, The Netherland,
  - From 2012/09/08/ to 2014/12/30
  - 351 EFPD





Fuel Fabrication

- Commercial fuel plant, 300,000/a, Baotou, CNNC fuel plant
  - 2013/03/ started construction
  - 2016/03/ finished plant installation and commission
  - 2016/08/ started production
  - 2017/12/ 300,000 fuel pebbles produced

HTR-PM600

- 6 reactor modules connected to one steam turbine, **650 MWe**
  - the same safety features,
  - the same major components,
  - the same parameters,
  - comparing with HTR-PM demonstration plant;
- the same site footprint and the same reactor plant volume comparing with the same size PWRs.
- Plant Owner: China HUANENG Cor. , China Nuclear Engineering Cor.(CNEC) , China General Nuclear Power Cor.(CGNPC)
- Feasibility study of sites:
  - ***Sanmen,Zhejiang****; Ruijin, Jiangxi; Xiapu, Fujian; Wan'an Fujian; Bai'an, Guangdong*

Concluding Remarks

- HTR-PM, pebble-bed modular HTGR, inherent safety, cylindrical core, steam cycle, electricity generation
- Key components and technologies, tested and verified
- Most components, delivered on schedule
- Construction, smoothly going
- Fuel factory, put into operation successfully
- Next, 6-module unit (HTR-PM600), commercial 600 MWe unit can be deployed, as supplement to PWRs, such as replacing coal-fired power plant, co-generation of steam and electricity

GEN IV International Forum℠

Upcoming webinars

21 February 2018	Gen IV Reators' Materials and Their Challenges	Dr. Stu Maloy, LANL, USA
21 March 2018	SCK•CEN's R&D on MYRRHA	Prof. Dr. H.C. Hamid Ait Abderrahim, SCK-CEN, Belgium
18 April 2018	Russia BN 600 and BN 800	Dr. Iurii Ashurko, Institute of Power and Engineering, Russia

An international training course supported by GIF ETTF

The course is targeting scientists already involved in Gen IV systems activities or planning to work in such areas. The course covers the 6 systems, and cross-cutting aspects (energy conversion, materials, safety, and fuel cycle).
It offers lectures by renowned subject matter experts in the various areas, as well as tutorials (how to "design" a fast neutron reactor using simple calculations).

Generation 4, Nuclear reactor systems for the future
June 18-22, 2018
INSTN/CEA-Saclay, France

CONTACT
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claude.renault@cea.fr

General Objective is to provide participants with an up-to-date basic knowledge on the six concepts selected for the 4th generation of nuclear systems (SFR, LFR, GFR, VHTR, SCWR, MSR)

The course will be held at the National Institute for Nuclear Science and Technology located at the CEA Saclay center (20 km from Paris, France), in the frame of the European Nuclear Energy Network (ENEN). Number of participants limited to 20. Course fee includes lectures, documentation, lunches and coffee breaks.

INSTN is Collaborating Centre of IAEA

The Generation IV International Forum (GIF) and 4th generation systems
- General context, evaluation criteria, the six concepts selected
- Increased performance for energy conversion: innovative cycles
- Materials issues and development of advanced components
- Safety aspects of 4th generation reactor concepts

Sodium-cooled Fast reactors (SFR)
- Principles, past and existing reactors, and background knowledge
- SFR core design, performance and safety
- The choice of sodium coolant: impact on design and operation
- The ASTRID prototype reactor

High Temperature and Very High Temperature Reactors (HTR and VHTR)
- Historical development of HTRs
- HTR core physics

Gas-cooled Fast Reactors (GFR)
- GFR core and system design, preliminary safety evaluation
- The ALLEGRO demonstration reactor

Lead-cooled Fast Reactors (LFR)
- Status of LFR development

Supercritical Water Reactors (SCWR)
- SCWR principles, characteristics and challenges

Molten Salt Reactors (MSR)
- Physics of MSR in the thorium fuel cycle

Fuel cycle of 4th generation systems
- Closed nuclear fuel cycle and transmutation