

**INTERNATIONAL FRAMEWORK FOR NUCLEAR ENERGY
COOPERATION INFRASTRUCTURE DEVELOPMENT
WORKING GROUP MEETING**

Nuclear energy beyond electricity



Chinese HTR Program

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- ***2 Overview of Chinese HTR program***
- ***3 HTR-PM progress***
- ***4 HTR-PM600***
- ***5 Process heat application***

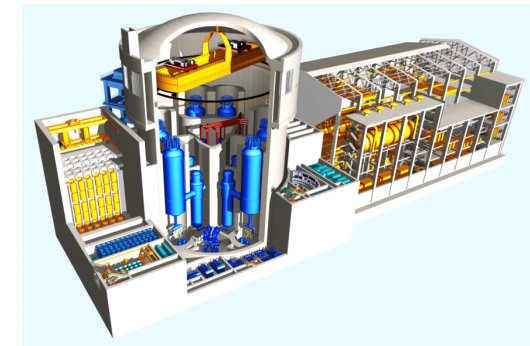
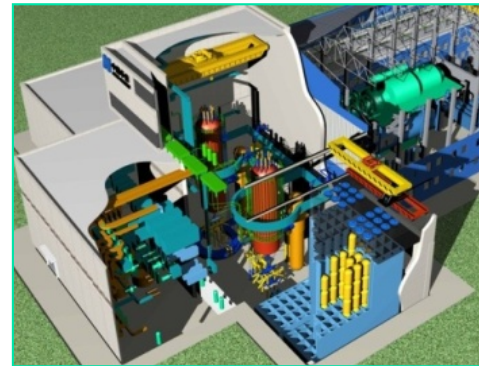


1 Mission of HTR in China

- ***Supplement to PWRs***
 - ***for power generation, especially to replace coal-fired power plant in popular region***
- ***Co-generation***
 - ***of steam and electricity,***
 - ***& Hydrogen production***
- ***Technology Innovation***

2 Overview of Chinese HTR program

- *China chose pebble bed HTR*
- *Research was started in 1970s*
- *Benifited from international cooperation*



Fundamental R&D

Test reactor

Demonstration plant

Commercial plant

1970s

1986-, HTR-10

2001-, HTR-PM

2014~, HTR-PM600



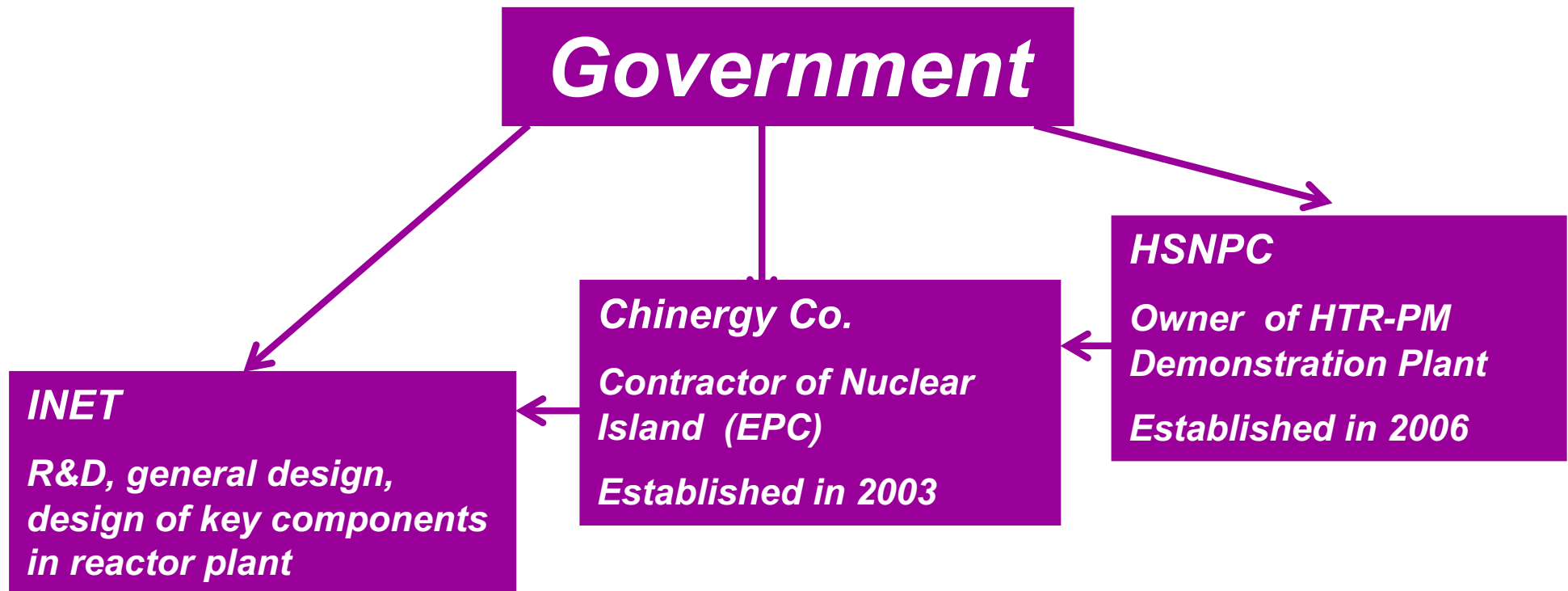
3 HTR-PM progress

- ***HTR-PM: High temperature gas cooled reactor--pebble bed module***

- ***HTR-PM demonstration plant***
 - ***Supported by the Chinese National Key Science and Technology Project (1 of 16 projects)***
 - ***Government support the R&D***
 - ***Commercial operation***
 - ***Located in Shidao Bay, Shangdong Province***

HTR-PM development team

- *As one of national key S&T projects, including research, design, licensing, manufacturing, construction, fuel fabrication, operation, ..., with many partners*



HTR-PM demonstration plant in Shidao Bay, Shandong

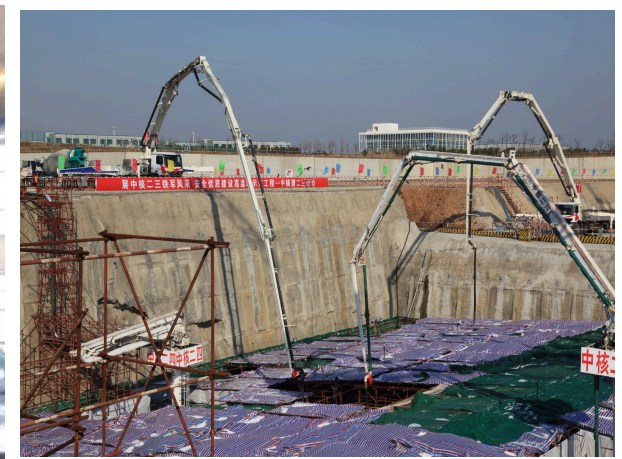


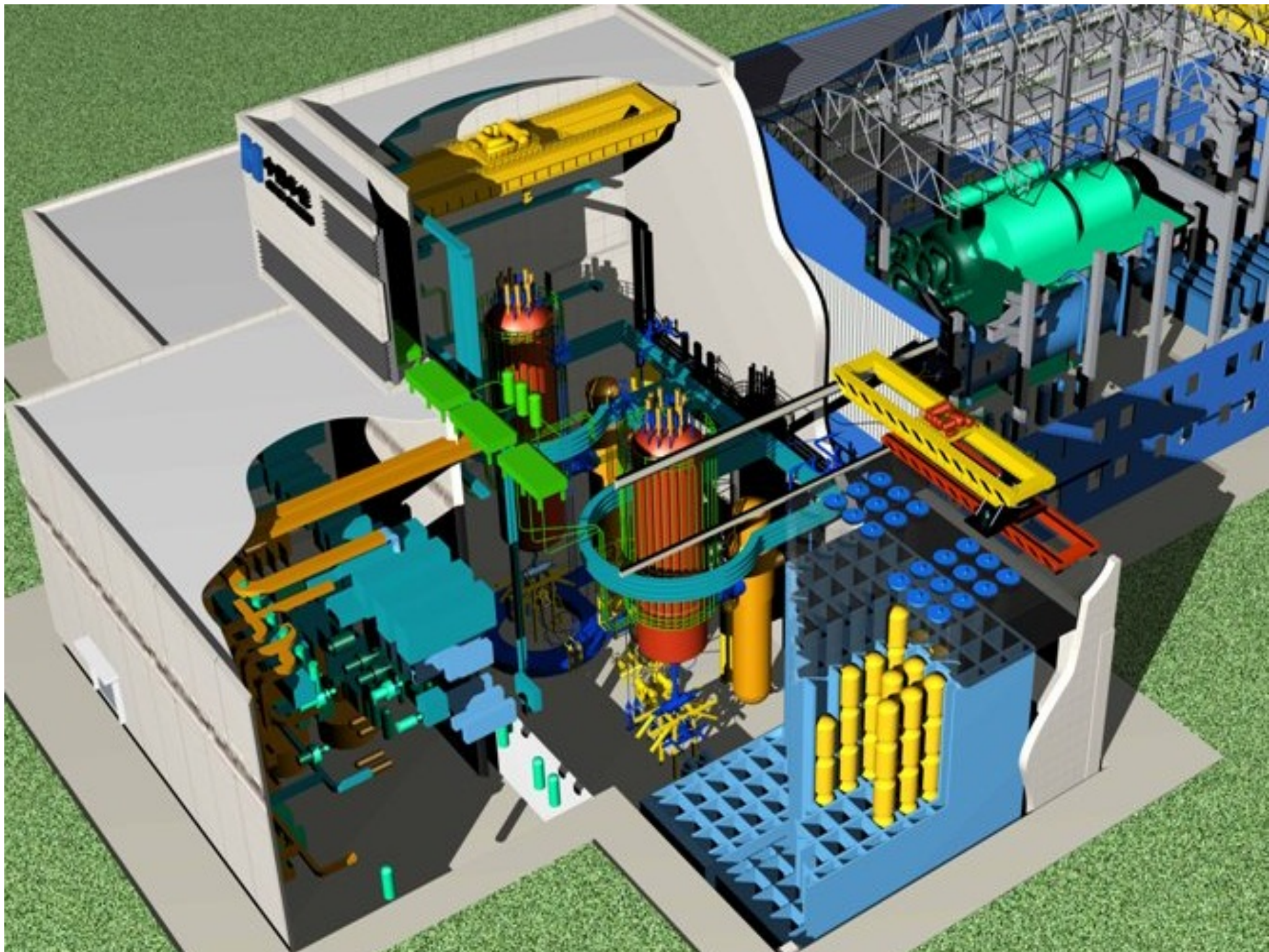
The overview of the HTR-PM site



3 HTR-PM progress

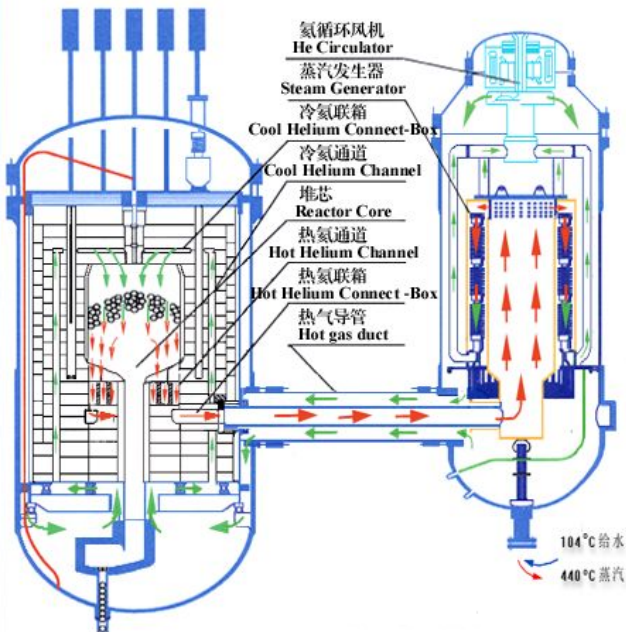
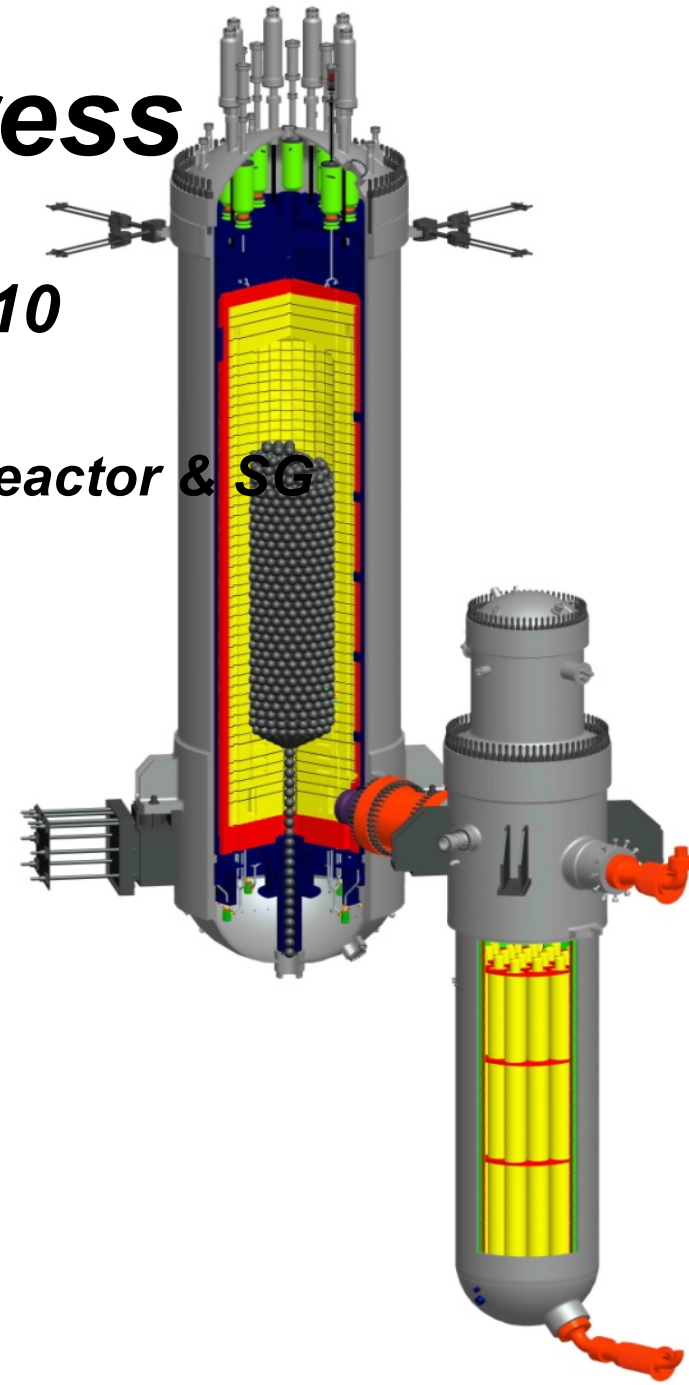
- **Milestones for whole project:**
 - **2003: finished pre-concept design and decided to use steam cycle**
 - **2004: signed industry investment agreement**
 - **2004: start the design of 458MWt with annual core**
 - **2006.01: became a National Key S&T Project**
 - **2006.09: decided to use 2×250 MWt reactors with a 200 MWe turbine**
 - **2008.02: government approved the HTR-PM project**
 - **2008.10: issued procurement contracts of the leading components**
 - **2008.4-2009.9: PSAR review**
 - **2012.12.09: FCD**





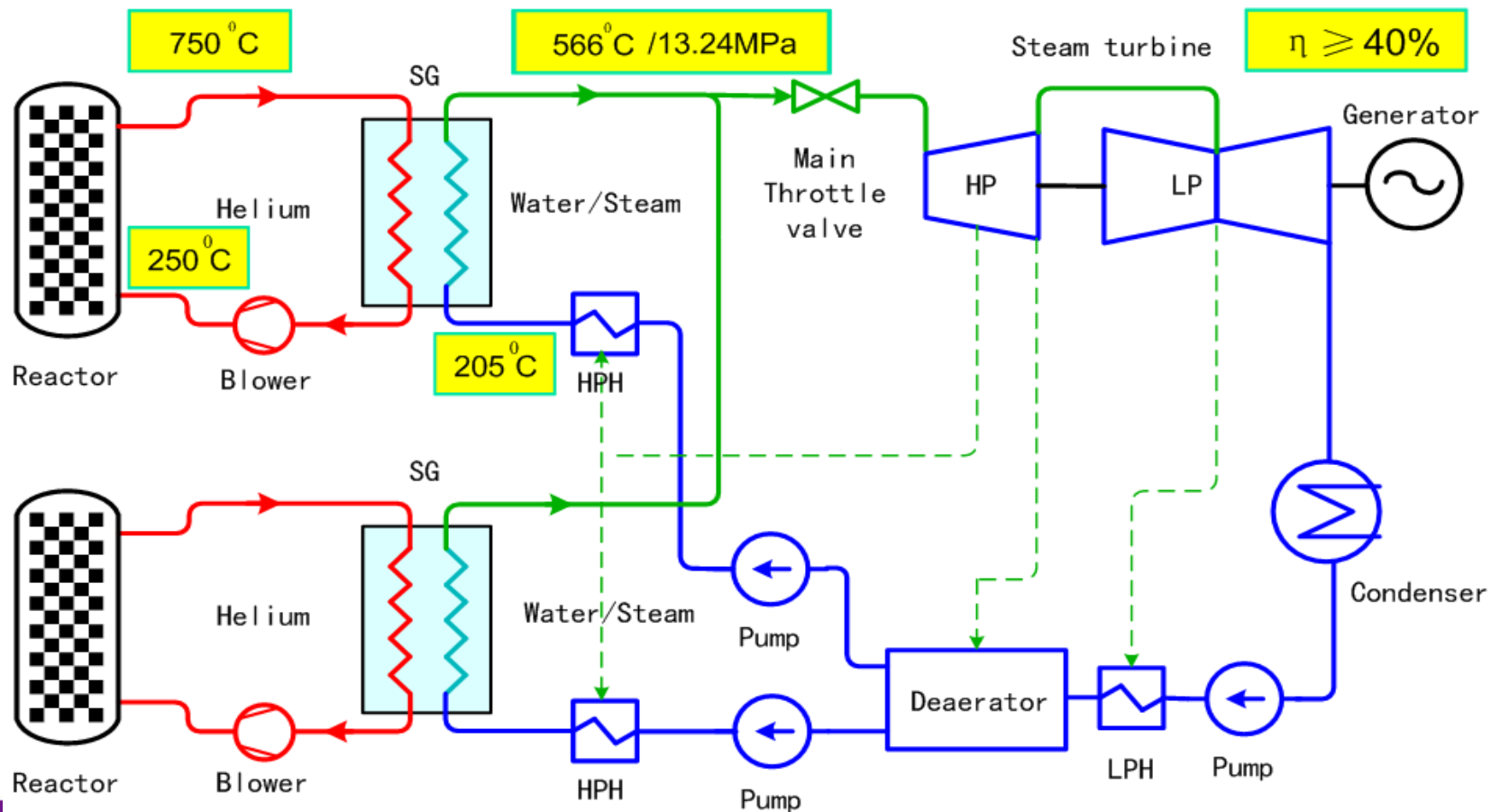
3 HTR-PM progress

- **Technology based on HTR-10**
 - **Single zone core**
 - **Side by side arrangement of reactor & SG**
 - **Super heat steam**
 - **Modular desgin**



3 HTR-PM progress

- 2 NSSS modules connected with 1 turbine in HTR-PM
 - 6 modules will be connected with 1 turbine in HTR-PM600





HTR-PM Design Parameters

<i>Plant electrical power, MWe</i>	<i>211</i>
<i>Core thermal power, MW</i>	<i>250</i>
<i>Number of NSSS Modules</i>	<i>2</i>
<i>Core diameter, m</i>	<i>3</i>
<i>Core height, m</i>	<i>11</i>
<i>Primary helium pressure, MPa</i>	<i>7</i>
<i>Core outlet temperature, °C</i>	<i>750</i>
<i>Core inlet temperature, °C</i>	<i>250</i>
<i>Fuel enrichment, %</i>	<i>8.5</i>
<i>Steam pressure, MPa</i>	<i>13.25</i>
<i>Steam temperature, °C</i>	<i>567</i>



3 HTR-PM progress

- ***Milestones for construction:***
 - ***2012/12/09:FCD***
 - ***2015/06/30: Reactor building***
 - ***2015/12: Full scope simulator***
 - ***2016/03/20: 1st RPV installed***
 - ***2016/08: Start of fuel fabrication***
 - ***2016/09: 2nd RPV installed***
 - ***2019/04: 1st SG installed***
 - ***2019/07: 2nd SG installed***
 - ***...***



3 HTR-PM progress

- **Ongoing work**
 - **Finish installation in this year**
 - **Fix the RPV, HDPV, SGPV soon**
 - **Commissioning test**
 - **Test of auxiliary/supporting system started in 2016**
 - **Criticality and power operation is scheduled in 2020**
 - **Full power operation in 2021**



3 HTR-PM progress

- ***Main achievements***
 - ***Standard NSSS module with full scale test and operation demonstration***
 - ***Experience & team covering design, manufacturing, licensing, construction & installation, commissioning test, operation, ...***
 - ***Licensing framework***
 - ***Test facilities for future development***
 - ***Whole supply chain***
 - ***Fuel fabrication capability***
 - ***Operation experience feedback for future plants***

Test Facilities for HTR-PM Project

ETF-HT	Engineering Test Facility- Helium Technology	10MWt test power, 7.0MPa, 250-750°C, helium	Heat source to verify steam generator	Finished
ETF-SG	Engineering Test Facility- Steam generator	10MWt test power, 13.25MPa, 205-570°C, water	Secondary loop and third loop to verify steam generator	Finished
ETF-HC	Engineering Test Facility- Helium Circulator	4.5MWe, 7.0MPa, 250°C, helium	Full scale verification of helium circulator	Finished
ETH-FHS	Engineering Test Facility- Fuel Handling System	7.0Mpa, 100-250 °C, helium, two chain	Full scale verification of fuel handling system	Finished
TH-FHS	Test Facility- Fuel Handling System	Full geometry size, air, 0.1MPa	Verification of the fuel movement in the FHS system	Finished
ETF-CRDM	Engineering Test Facility- Control Rods Driving Mechanism	1MPa, 100-250°C, helium	Full scale verification of Control Rods Driving Mechanism	Finished
ETF-SAS	Engineering Test Facility- Small Absorber Sphere System	7.0MPa, 100-250°C, helium	Full scale verification of small absorber sphere system	Finished
ETF-SFS	Engineering Test Facility- Spent Fuel System	Full geometry size, air, 0.1 MPa	Full scale verification of major components of spent fuel storage system	Finished
TF-SFCD	Test Facility- Spent Fuel Canister Drop	Full geometry size, Full height (30m), Full weight (17t)	Full scale drop verification of spent fuel canister	Finished
ETF-HPS	Engineering Test Facility- Helium Purification System	7.0MPa, 25-250°C, helium Purification flow rate: 40kg/h	Verification of purification efficiency (greater than 95% and system resistance less than 200kPa).	Finished
TF-PBEC	Test Facility- Pebble Bed Equivalent Conductivity	1600°C, helium/vacuum	Measurement of pebble bed equivalent conductivity	Finished
TF-PBF3D	Test Facility- Pebble Bed Flow 3D	0.1 MPa, room temperature, air	Three-dimensional simulation test for pebble bed flow (1:5 scale)	Constructing
TF-HGM	Test Facility- Hot Gas Mixing	atm, 20-150°C, air	Reduced scale (1:2.5) verification of hot gas mixing at reactor core outlet	Finished
ETF-DCS	Engineering Test Facility- Distributed Control System	Reactor power control system, fuel cycle control system, VDU-based Man-Machine Interface	verification of DCS architecture and major control Systems	Finished
ETF-RPS	Engineering Test Facility- Reactor Protection System	Prototype of Reactor Protect System with 4 channels	Full scale verification of Reactor Protect System	Finished
ETF-MCR	Engineering Test Facility- Main Control Room	1:1MCR control consoles, mimic panels, layouts and inner environments	Full scale verification of Man-Machine Interface	Finished



3 HTR-PM progress

- **HTR-PM Supply chain:**

- **Plant Owner (in China): China HUANENG Corp. , China National Nuclear Corp.(CNNC) , China General Nuclear Power Corp.(CGNPC)**
- **Main Components Suppliers:**
 - **Shanghai Electric: RPV, Metallic Reactor Internals, CRDMs, SASs, Steam Turbine, Helium Circulators**
 - **Harbin Electric: Steam Generator, Generator**
 - **Toyo Tanso: Graphite**
 - **CGNPC: RPS, DCS, Simulator**
- **Fuel supplier: CNNC with INET**
- **Nuclear island EPC Contractor: CHINERGY**
- **R&D, NSSS and main NI system Engineering: INET**
- **Other components : companies inside and outside China**



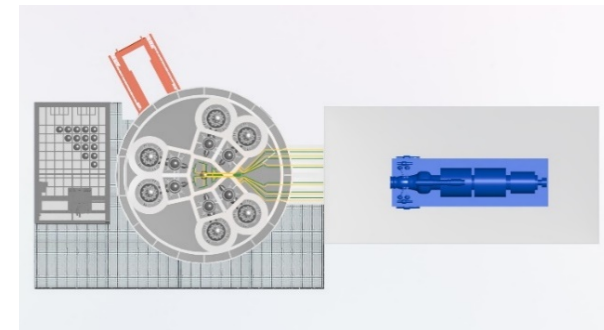
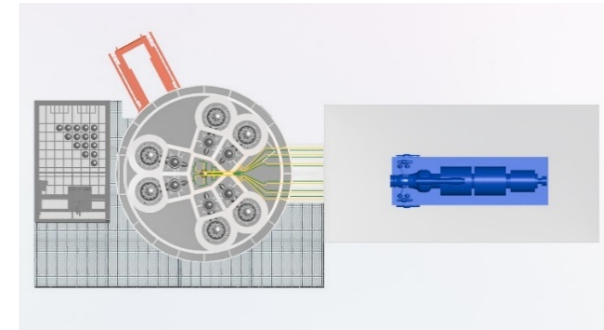
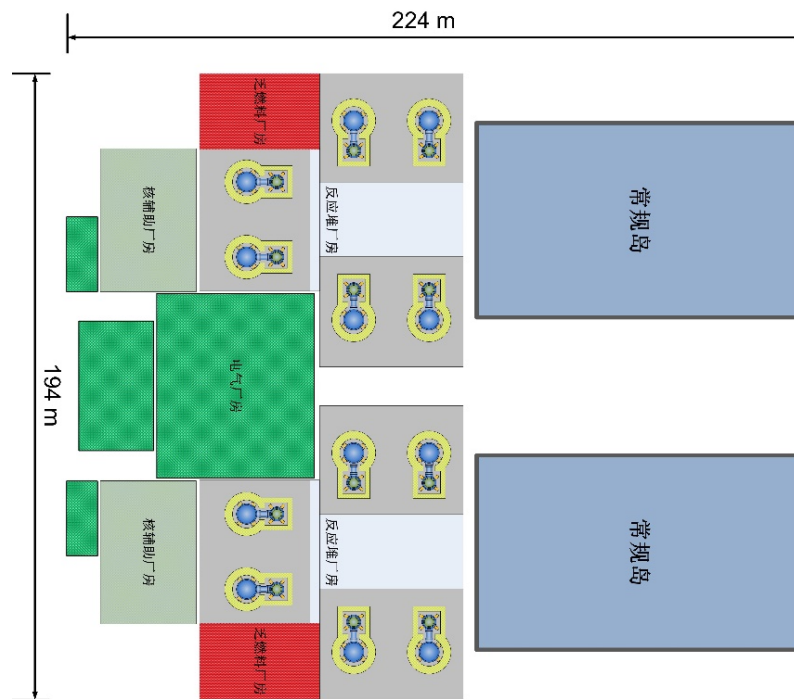
4 HTR-PM600

- ***Batch construction of HTR-PM is possible***
- ***Improved version of HTR-PM600 is designed***
 - ***6 NSSS modules connect to 1 steam turbine, comparing with 2 modules in HTR-PM, with***
 - ***the same safety features,***
 - ***the same major components,***
 - ***the same primary circuit parameters,***
 - ***With the same site footnote and building volume comparing with the same size PWRs.***
 - ***With the interface of steam extraction capability for co-generation***

4 HTR-PM600

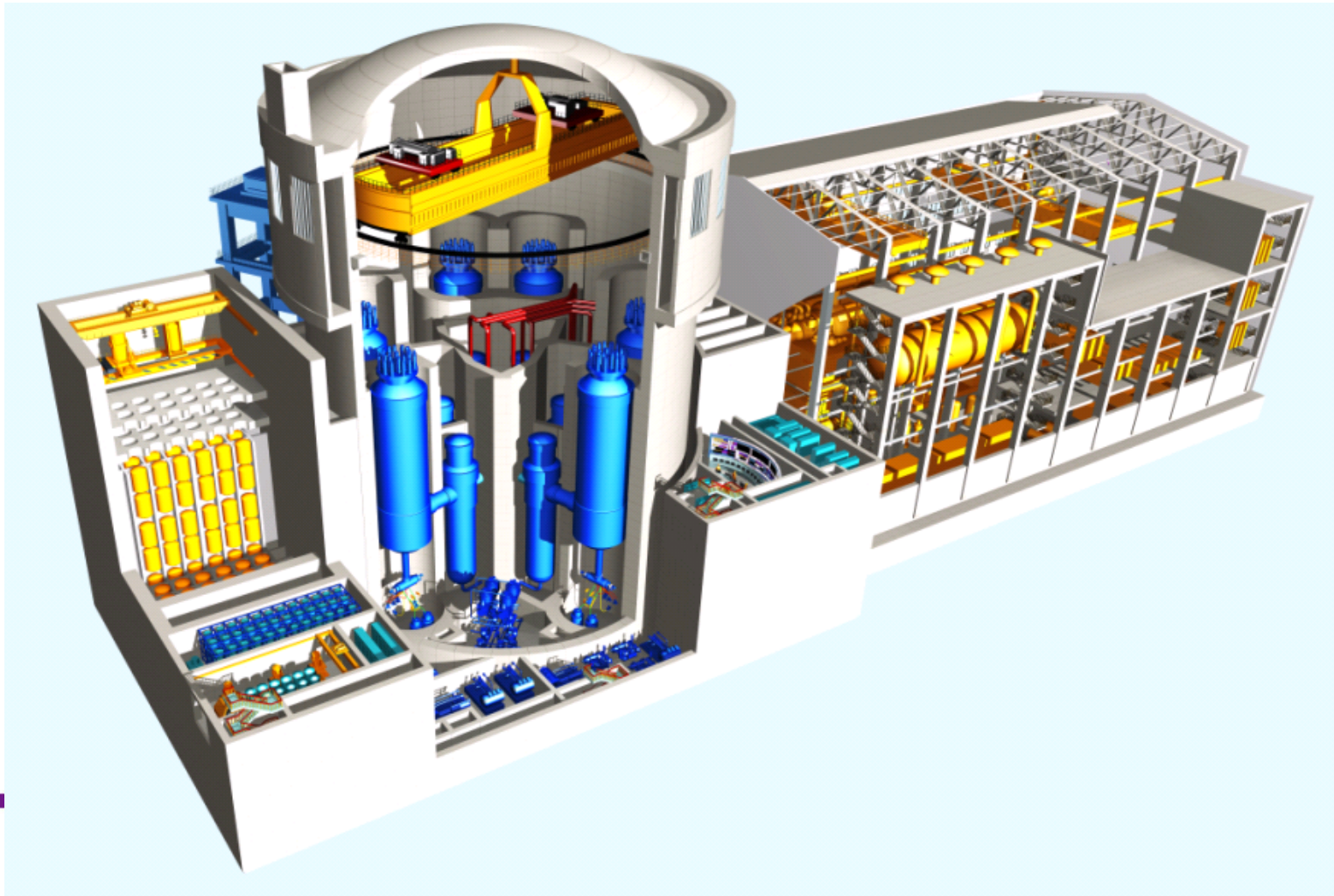
Evolution of HTR-PM600 layout:

*The volume of seismic qualified building was reduced 50%,
the same as PWR*



4 HTR-PM600

- *Optimized layout, economy with proven technology*



4 HTR-PM600

<i>Thermal power of one Reactor Module</i>	<i>MW</i>	<i>250</i>
<i>Reactor Module number</i>		<i>6</i>
<i>Plant thermal power</i>	<i>MW</i>	<i>1500</i>
<i>Plant electric power</i>	<i>MW</i>	<i>655</i>
<i>Pressure of the primary circuit</i>	<i>MPa</i>	<i>7</i>
<i>Reactor inlet temperature</i>	<i>°C</i>	<i>250</i>
<i>Reactor inlet temperature</i>	<i>°C</i>	<i>750</i>
<i>Feed water temperature</i>	<i>°C</i>	<i>205</i>
<i>Steam temperature</i>	<i>°C</i>	<i>566</i>
<i>Steam pressure</i>	<i>MPa</i>	<i>13.24</i>
<i>Power generation efficiency</i>	<i>%</i>	<i>44</i>



5 *Process heat application*

- ***China has a huge process heat market, like worldwide***
 - ***290 Mtoe/yr = 385 GW (60/40 heat/electricity) → 231 GWth***
 - ***15.6% of total primary energy, strongly growing***

 - ***Market for steam (< 650 °C) 138 Mtoe/yr = 183 GWth (doable with conventional HTGR @750 °C, would save 20% of oil imports)***

 - ***District heating in North is also a huge market***

 - ***Currently mainly based on coal***
 - ***Replace with Natural gas & electricity is underway, but expensive***



5 Process heat application

- ***High quality process heat from HTR is straight forward***
 - ***HTR-PM & HTR-PM can provide high temperature steam by extracting from steam turbine/steam generator, with nearly no change to the reactor design***
- ***Hydrogen production with ~900 °C outlet temperature is reasonable***
- ***But harmonization between nuclear island and process heat island need more research and demonstration***
- ***Our strategy is to continuously improve HTR through electricity market, while continuously R&D on process heat application and hydrogen production, and increase of outlet temperature***



Conclusion remarks

HTR-PM will provide:

- ***Proven Technology and Budget: the world first 200MWe pebble-bed modular high temperature gas-cooled reactor demonstration plant (HTR-PM) will soon be operated in China.***
- ***Generation IV Safety: eliminate off-site emergency response through a Meltdown-Proof Reactor.***
- ***Huge Market Potential: provide 200, 600 MWe high efficiency power plant and co-generate steam up to 560 °C.***
- ***Whole supply chain.***



Conclusion remarks

- ***More capability from HTR for process heat application including hydrogen production will be explored and demonstrated, via domestic project and international cooperation.***
 - ***Gen IV International Forum is one of platform***
 - ***All type of international cooperation is welcomed***



***Thanks for listening
&
Thanks for comments!***