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Technologies of HTR-PM Plant and its economic potential

Prof. Dr. Yujie Dong

INET/Tsinghua University Beijing, China

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Contents

- **HTR-PM:** ***High Temperature gas-cooled Reactor Pebble-bed Module***
  - ***HTR-PM DPP : twin-module demonstration power plant, a unit with power of 200 MWe***
  - ***HTR-PM 600: Hexa-module commercial unit with power of 600 MWe***
- ***HTR-PM DPP: basis, design, progress***
- ***HTR-PM 600: design, features***
- ***Analysis of economic potential***

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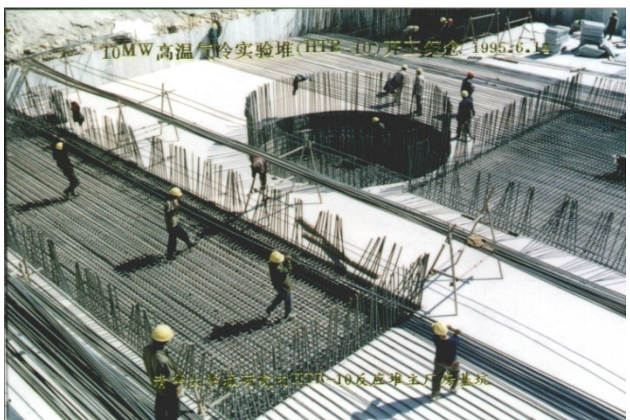
HTR-10 – basis of HTR-PM

- *1986: “National High Technology Program(863)”*
- *1992: Approved*
- *1995: Started construction*
- *2000: Reached first criticality*
- *2003: Operated in full power*



HTR-10 in 1995

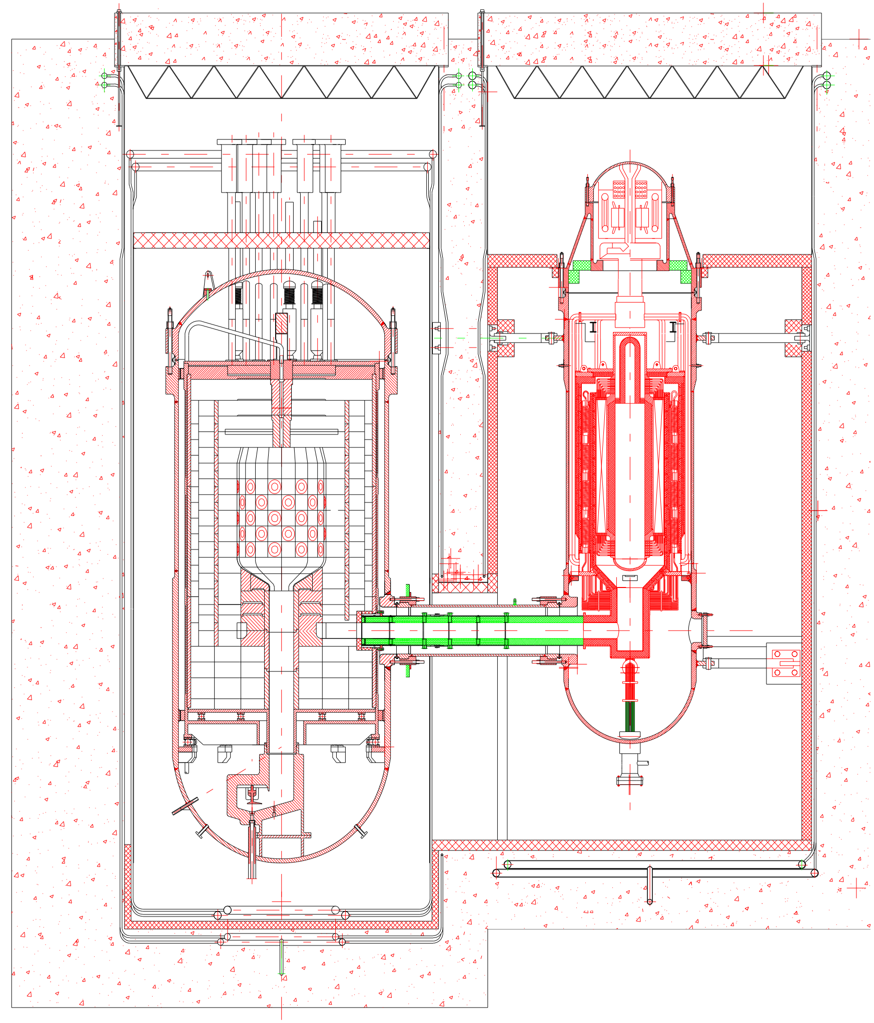
HTR-10 in 1997

HTR-10 in 2000

Design of HTR-10

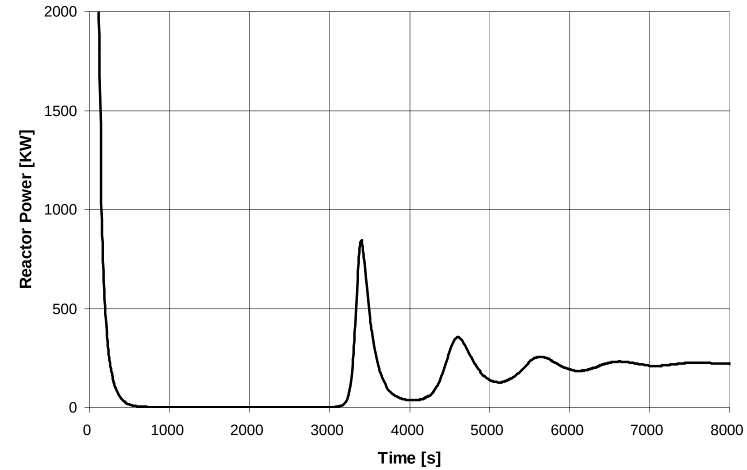
Reactor Power, MWth	10
Pressure, MPa	3
Reactor Inlet Temperature, ℃	250
Reactor Outlet Temperature, ℃	700
Fuel Elements Number	27000

- *Spherical fuel elements*
- *Max fuel elements temp. < 1600° C*
- *Passive residual heat removal*
- *Multi-pass charging mode*
- *Side by side arrangement*
- *All control rods in side reflectors*



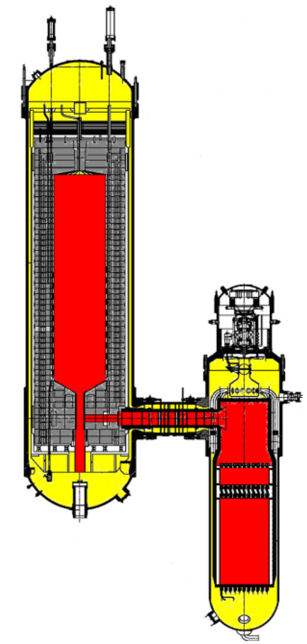
Tests on HTR-10

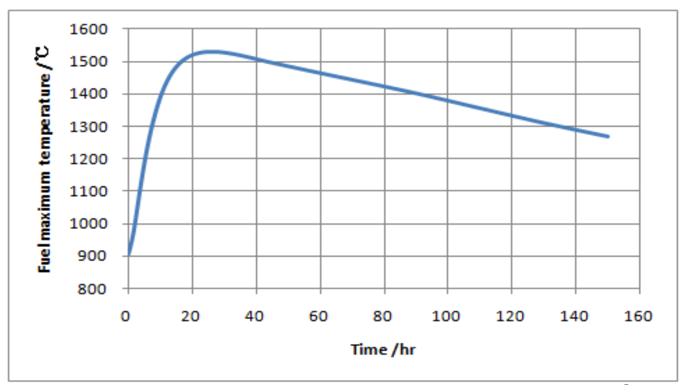
- Loss of helium flow
- Turbine trip
- Loss of off-site power supply
- Helium blower trip without scram
- Reactivity insertion without scram
- Helium blower trip without closing outlet cut-off valve
- ……



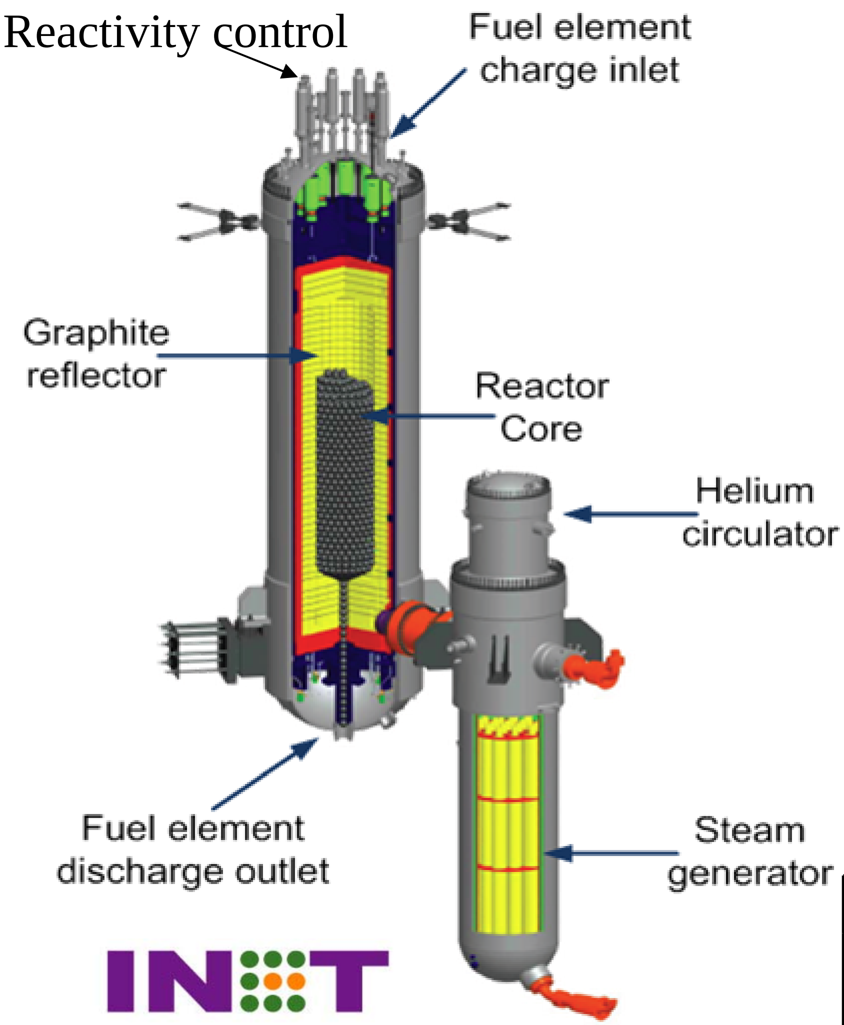
Technical Objectives of HTR-PM

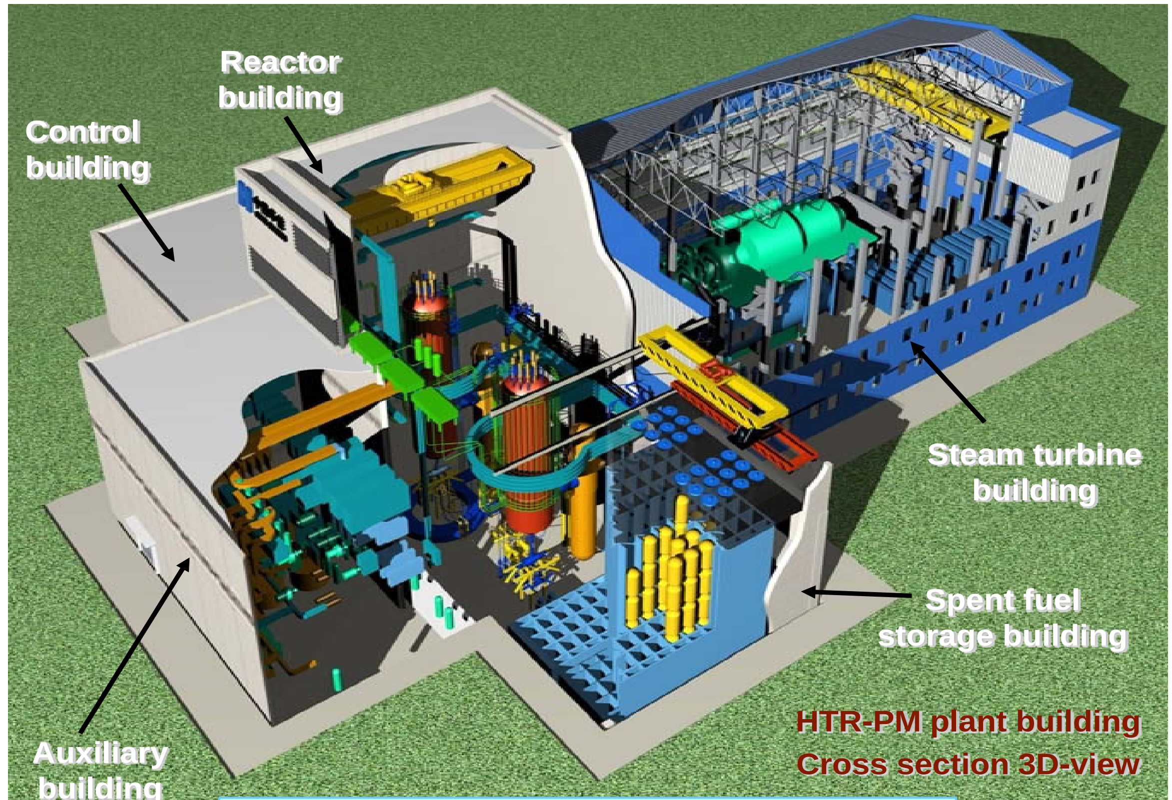
- ***Demonstration of inherent safety features***
  - ***Practically exclude the need for off-site emergency plan***
- ***Demonstration of cost competitiveness***
- ***Standardization and modularization***
- ***Confirmation of proven technologies***





Overview of HTR-PM Design





Final technical solution in 2006

Reactor & SG	***2 X 250 MW***	***Fuel enrich.***	***8.5%***
Primary helium	***250/750°C, 7 MPa***	***Avg. burn-up***	***90 MWd/tU***
Plant life-time	***40 a***	***Main steam***	***567 °C/13.25 MPa***

Engineering Tests

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 helium conditions

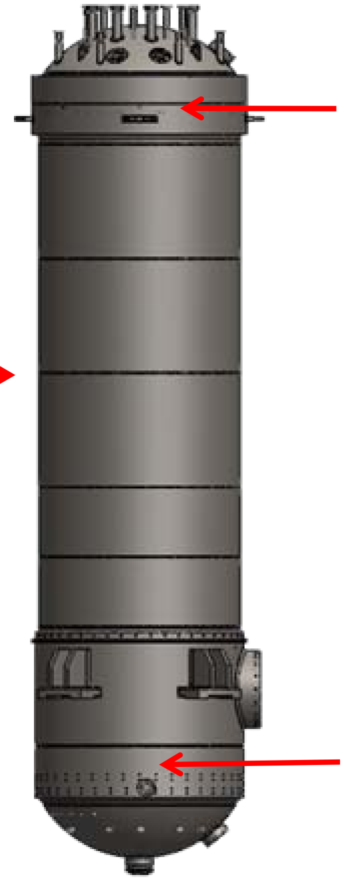
- *steam generator, one of the 19 units*
- *helium circulator*
- *fuel handling system*
- *control rods driving system*
- *small absorber balls reserve shutdown system*
- *helium purification system*
- *reactor protection system and control room*

Reactor Pressure Vessel

(Bottom vessel I)

- Height: 25m
- Diameter: 5.7m
- The key difficulty is the forge, with a weight 460 tons.

Pressure vessel

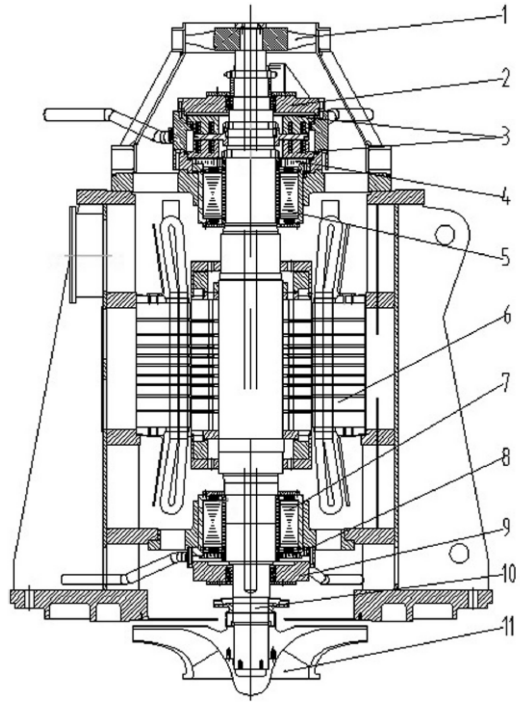


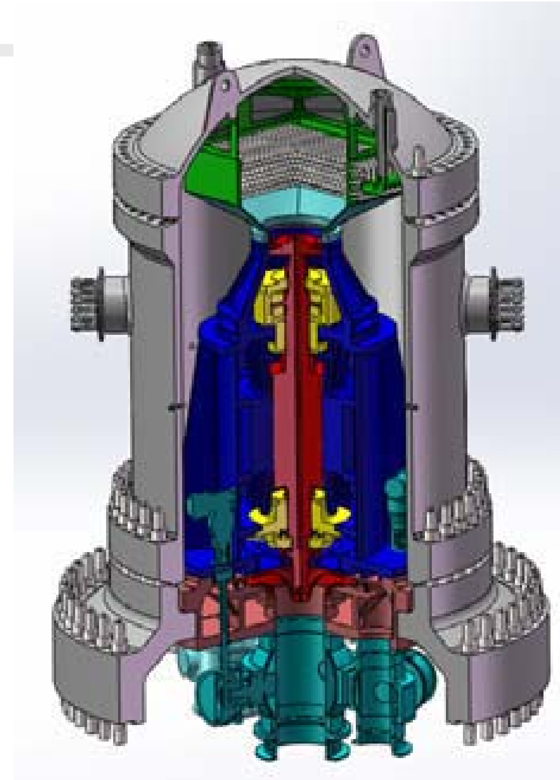
(Top head)

(Bottom head & bottom vessel II)

Circulator design

- *Vertical layout*
- *Driven by electrical motor*
- *Single stage, centrifugal impeller*
- *Active magnetic bearing (AMB),*
  - *no shaft penetration of vessel, no lubrication*



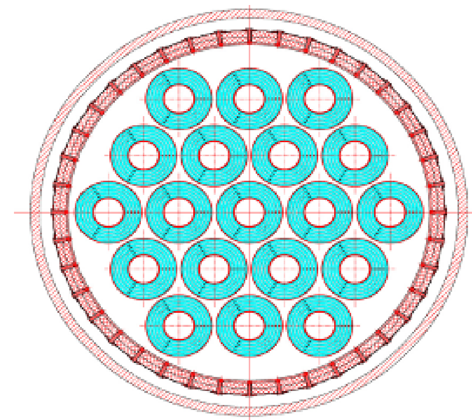


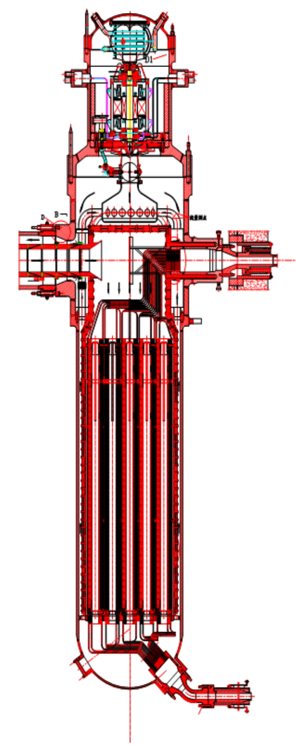
Parameter	Unit	Value
Pressure rise	kPa	200
Temp. of helium	℃	250
Rotation speed	rpm	4,000
Electrical power	kW	4,500

Steam Generator

- ***Vertical, counter flow, once-through type, helical tubes***

- ***Middle size, multi-layer helical tube assemblies***

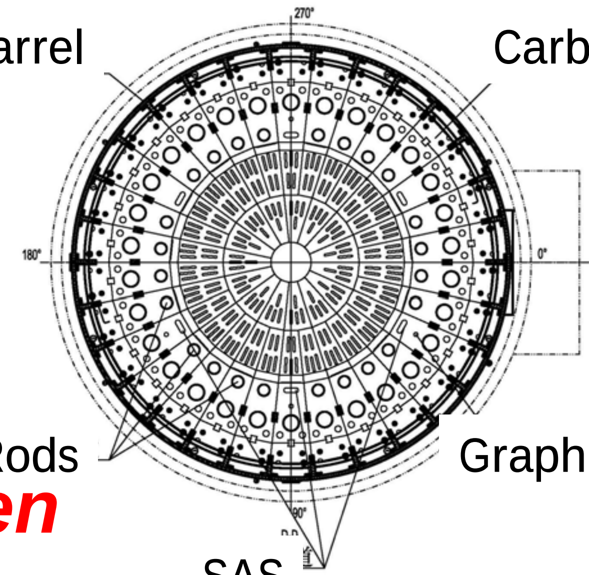




Parameter	Unit	Value
Power	MW	253
No. of Units		19
No. of tubes per unit		35
Total No. of Tubes		665

Reactivity control systems

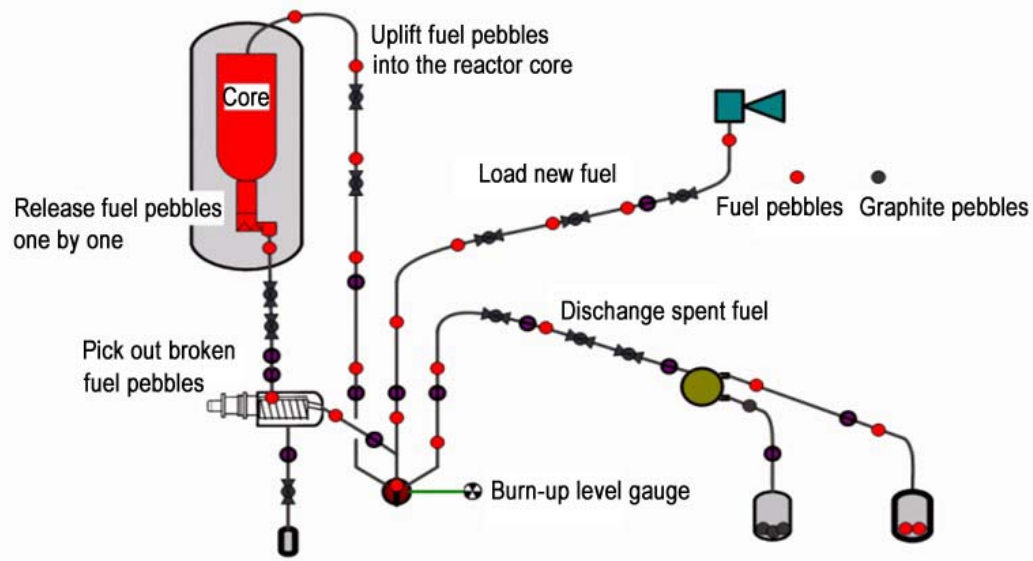
- ***Two independent systems: rods plus small absorber spheres (SAS), located in side reflector***



  - ***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 FEs
- Measure burn-up of FE and screening out spent fuel
- Transfer spent FEs to storage tank



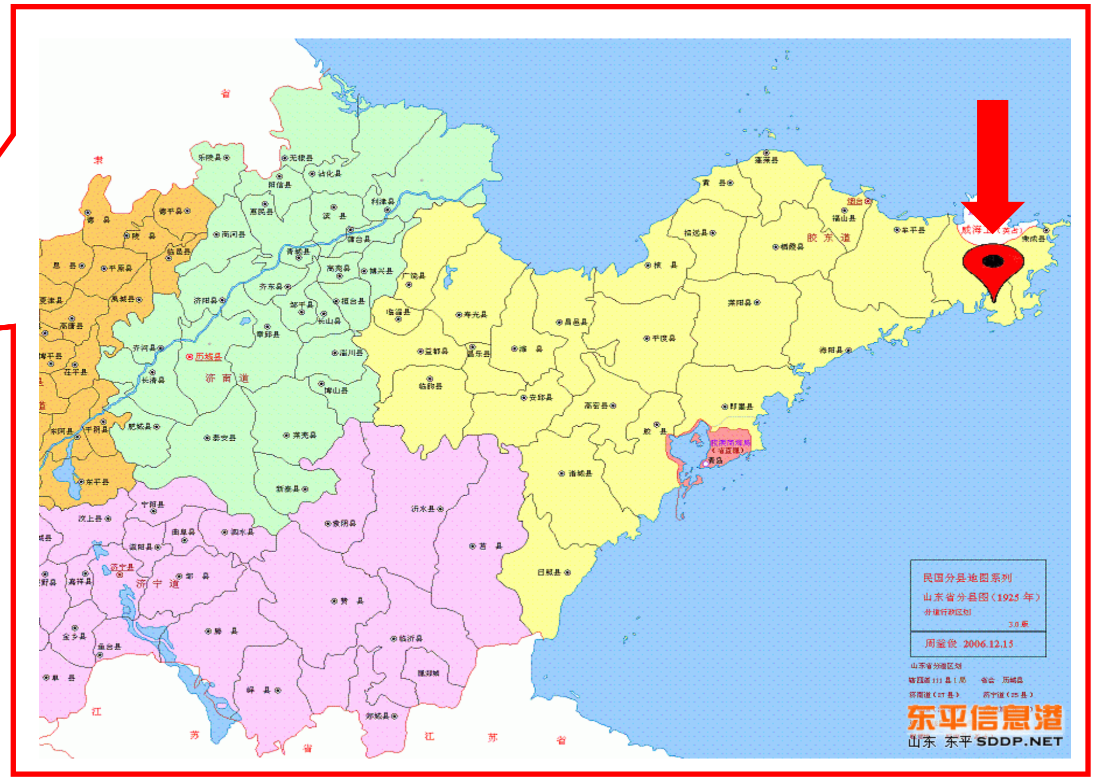
Progress of HTR-PM DPP

FCD, Dec. 2012.

The target to connect grid is 2017

HTR-PM project location

Shidao Bay, Rongcheng City, Shandong Province, China.



Progress of HTR-PM DPP

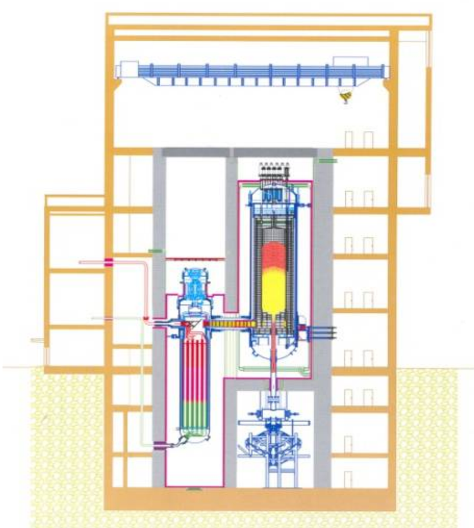
- Engineering design, nearly finished
- Procurement, more than 95% finished
- Civil engineering, nearly finished
  - NI: reactor building, nuclear auxiliary building, spent fuel building, electrical building
  - CI:T/G building
- Installation engineering, ongoing
  - Installation of heavy components will start soon, RPV, CI, SG , blowers, in succession

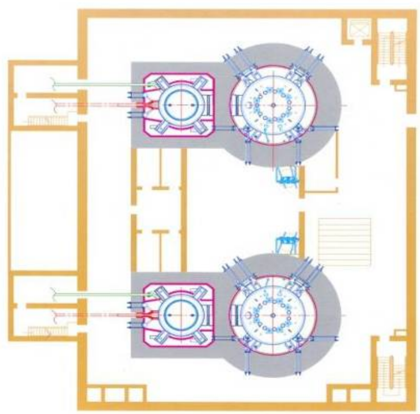
Fuel fabrication

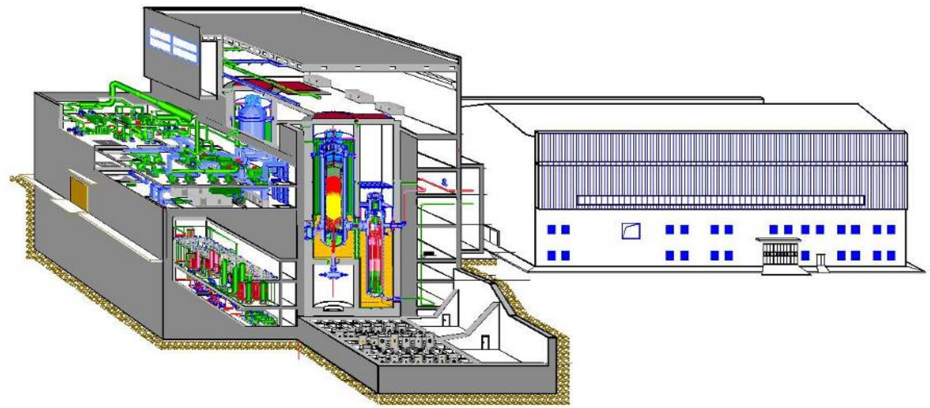
- ***In 2010, INET demo production facility, 100k/a, finished the first production***
- ***In the end of 2014, irradiation test of fuels, Petten, Netherlands, finished, results are good***
- ***Commercial fuel plant, 300k/a, commissioning test, to start production this year***

Deployment of HTR-PM

HTR-PM: multi-module reactor steam turbine plant to properly address safety, cost and technology feasibility







Demo. plant

- Each reactor module 100 MWe
- two module in one reactor plant
- Connect to one steam turbine, 200MWe

Comm. plant

- Each reactor module 100 MWe
- Multi-module in one reactor plant
- Connect to one steam turbine, 200, 300, 600 MWe

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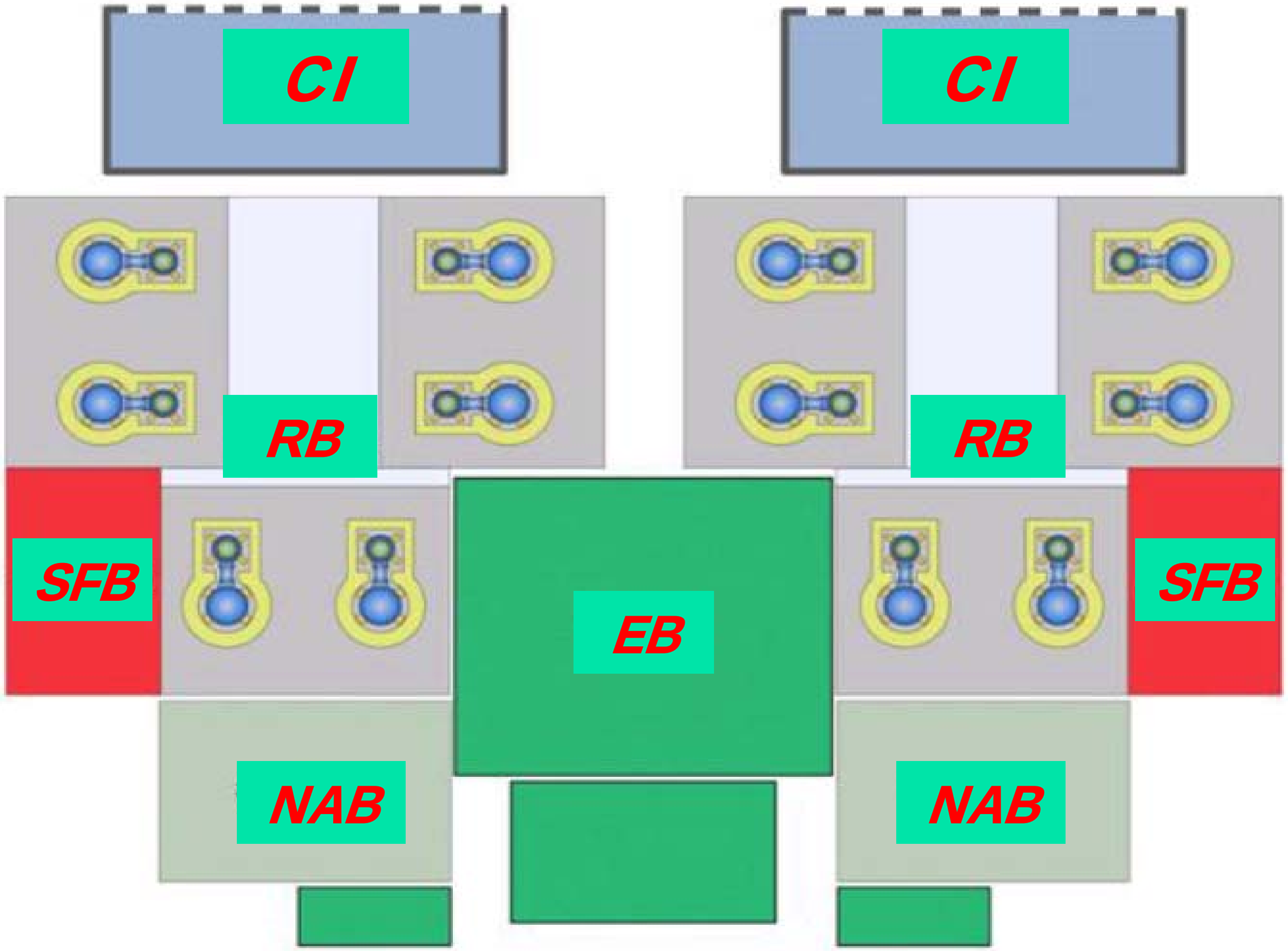
Overall design of HTR-PM 600

- Each NSSS module, identical to those in DPP in order to use proven SSC in DPP and realize standardization.
- 6 NSSS identical modules, coupled to one steam turbine for generation, forming one unit.
- Maximally, auxiliary systems are shared by multiple modules.
- Two unit at a single site.
- Cogeneration is possible through steam extraction.

Layout of HTR-PM 600



Nearly the same site footprint of PWR 600 plants.

Configuration of systems

- ***Systems non-shared among modules , i.e. one-to-one***
  - ***NSSS (RPV, CI, SG, HGD, Blower, CRDM, SAS)***
  - ***ESF (e.g. pressure relief system)***
  - ***Auxiliary system (main steam and feedwater, helium purification)***
  - ***Nuclear measurement, reactor protection,***
  - ***Emergency power supply***

Configuration of systems

- Systems shared among modules
  - HVAC in NI
  - FHS, Fresh fuel supply, Spent fuel storage
  - Other auxiliary process systems
  - Miscellaneous systems
  - MCR and DCS
  - Normal power supply

Analysis of economic potential

- ***Technical advantages of HTR-PM 600***
  - ***Inherent safety (no core meltdown)***
    - ***Capacity of emergency power supply system is small and allowed start-up time is longer***
    - ***Elimination or simplification of emergency response, enhanced security***
    - ***……***
  - ***Simplicity: due to enhanced safety, safety-related systems and auxiliary systems are eliminated or simplified.***
  - ***Use beyond electricity generation: unique feature***

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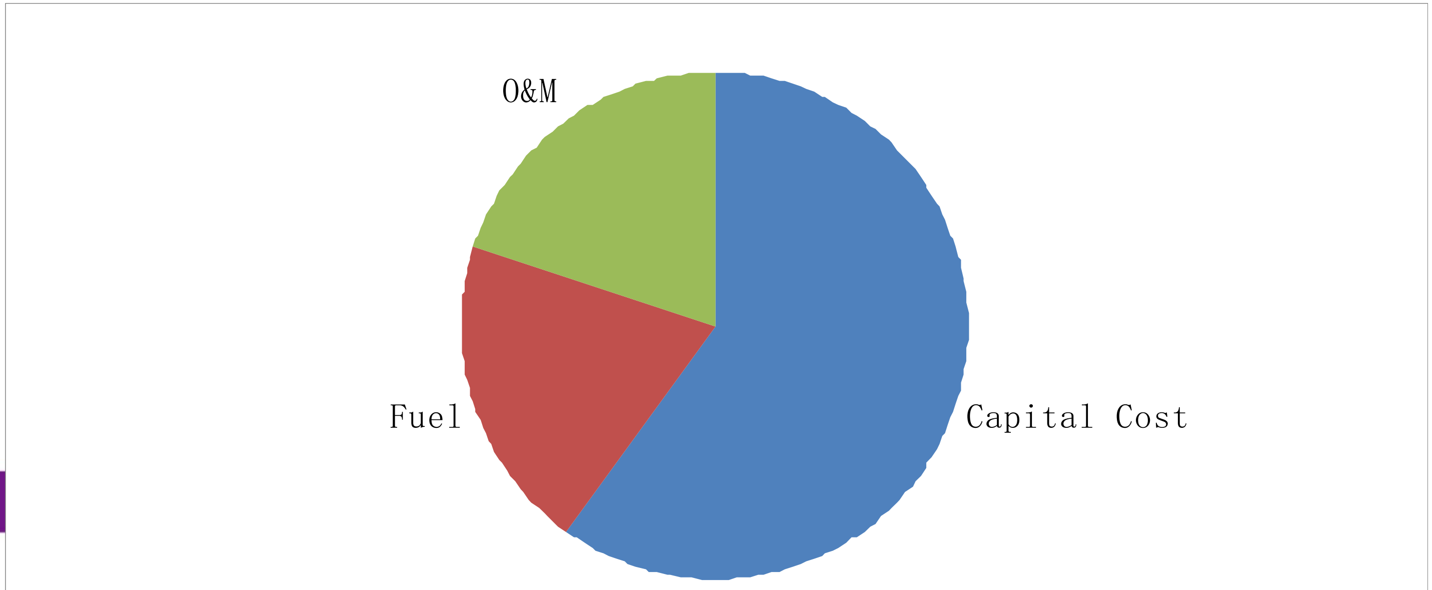
Purpose of this analysis

- ***Try to answer the question based on Chinese practice of HTR-PM DPP***
  - ***Can HTR-PM 600 compete with normal PWR? Commercially feasible?***

Cost competiveness

- Generally, capital cost is the most important factor influencing the generation cost of electricity.
- So, primarily focusing on the capital cost of HTR-PM 600.



Input for economic analysis

- ***Analysis has been done based on detailed costs databank for HTR-PM DPP and also the China's PWR 600 (Generation II+ technology)projects***

Economy-related characteristics

- ***Disadvantage or negative factors***
  - ***Economy of scale***
  - *The Size of module is limited by safety requirements*
    - ***SCC = Cost($)/Size(kWe)***
  - ***For HTR-PM 600, due to low power density, RPV is larger and heavier than that of PWR.***

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Economy-related characteristics

- ***Advantages or positive factors***
  - ***Economy of experience （mass production, replication）:***
    - ***Learning curve. The curve will flatten out after about the 6-8 module. “On site” learning for civil and installation are remarkable***
    - ***Bulk ordering. For a two unit plant, 12 PRV needed. When the number increases, the specific fixed cost decreases.***
    - ***Serial fabrication of components.***

Capital cost breakdown structure

- ***Direct cost***
  - ***NI (civil, equipment, installation)***
  - ***CI (civil, equipment, installation)***
  - ***BOP (civil, equipment, installation)***
- ***Indirect and other cost***
- ***First load of fuel***
- ***Contingencies***
- ***Taxes, etc.***

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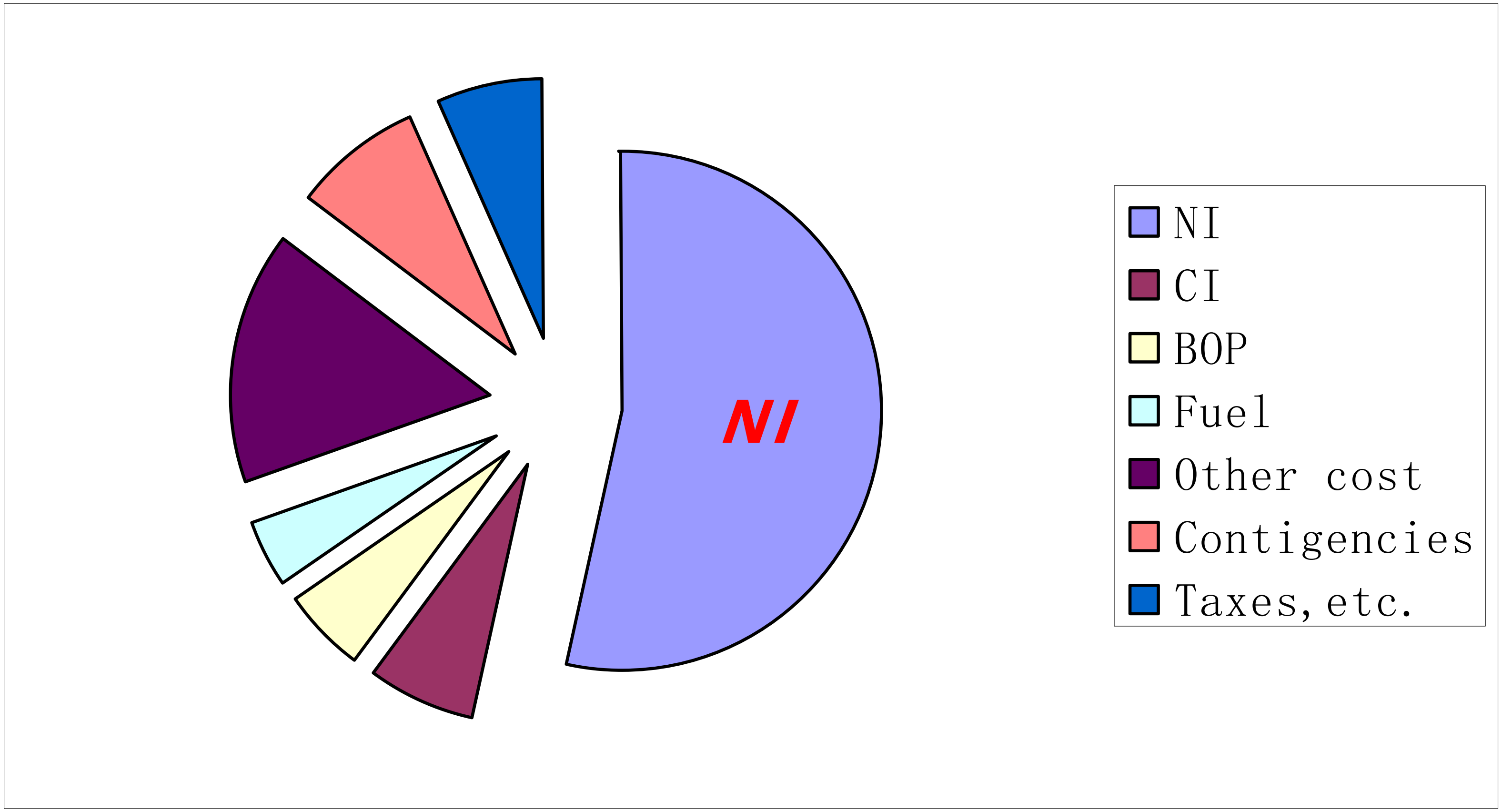
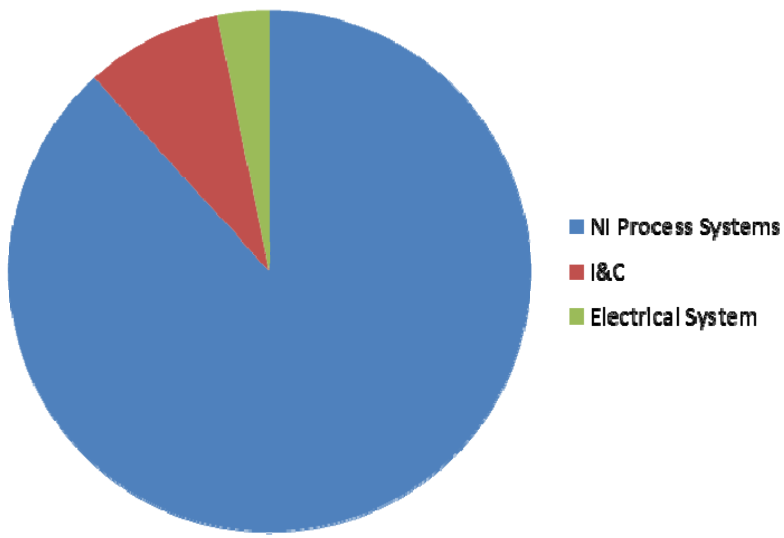
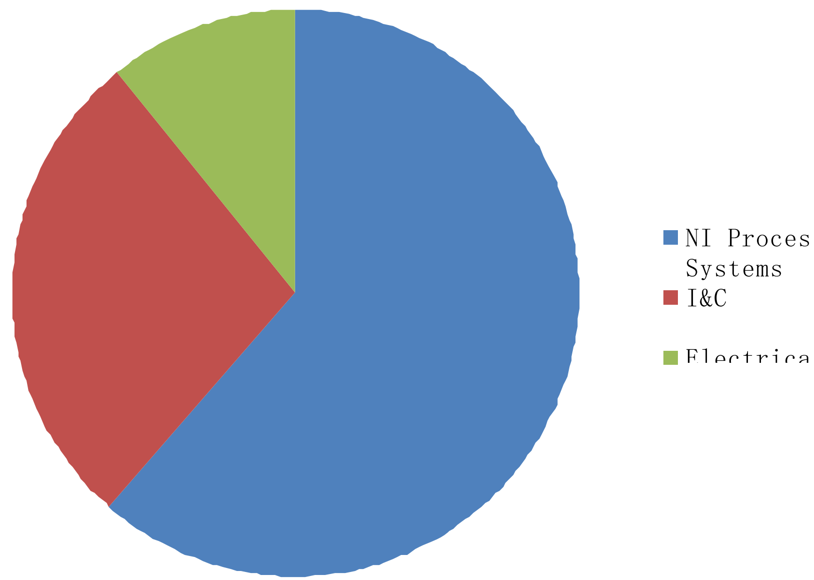
Elements of capital cost of HTR 600



In the total capital cost, more than 50% coming from NI

Composition of equipment in NI





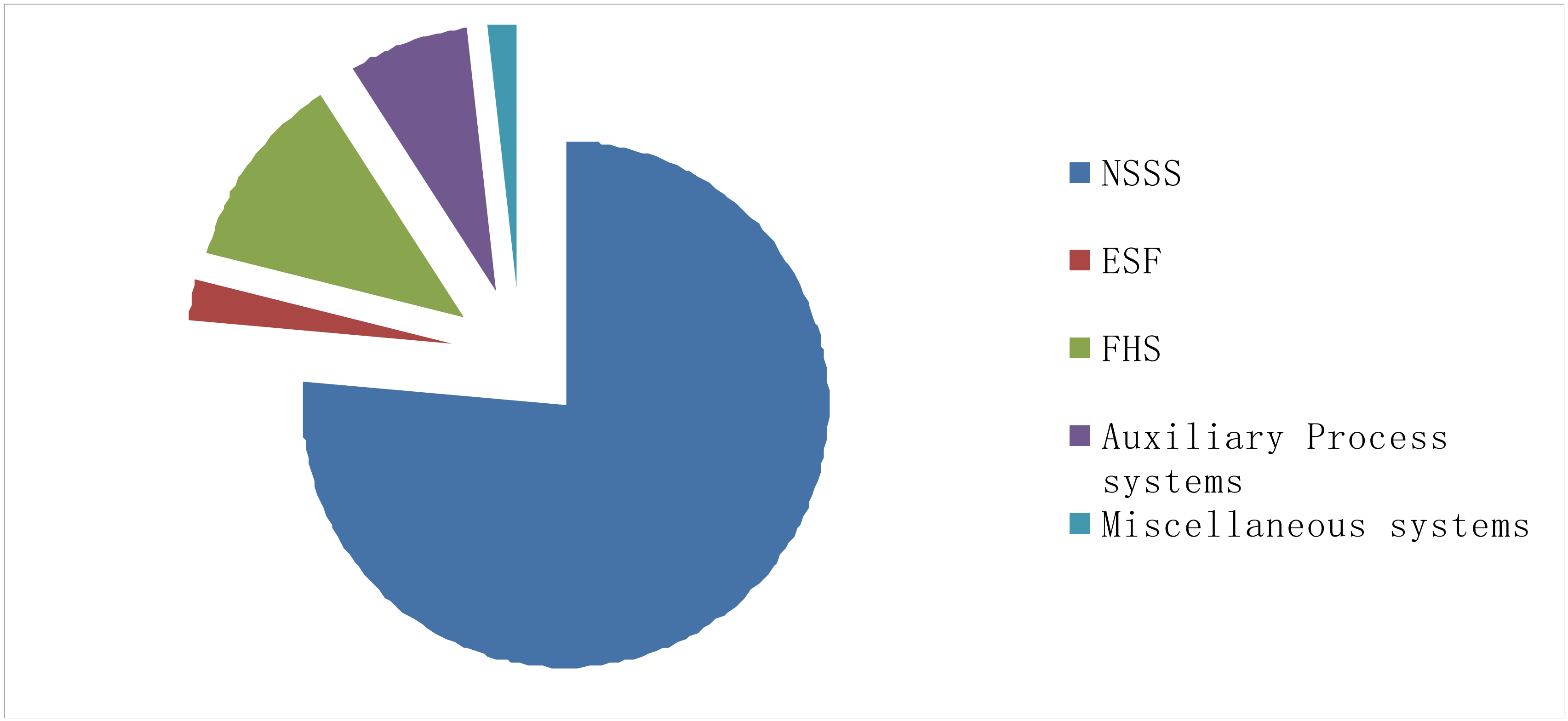
NI process system: ~85%

HTR-PM 600

PWR 600

NI process system: ~60%

Composition of NI process systems of HTR 600



More than three quarter contributed by NSSS

Main equipment of NSSS

- ***RPV***
- ***SG (internals & vessel)***
- ***Core internals (metal, graphite, carbon)***
- ***Blower***
- ***FHS***
- ***CRDM***
- ***SAS***

Potential to reduce cost of NSSS equipment

- ***Bulk ordering, 5-10%***
- ***Increase of suppliers, 10 - 20%***
- ***Domestic production, 20 - 30%***
  - ***Graphite material***
  - ***AMB, electrical penetration, valves, etc.***
- ***Simplification and optimization, 5 - 10%***
- ***Appropriate standards or codes***

Evaluation of NSSS equipment cost

- ***Cost of equipment in DPP multiplied by factors based on actual shared/non-shared situation***
- ***Revised the cost***
  - ***taking commercial factors into account, such as bulk ordering, etc.***
  - ***taking account of the technical progress for cost reduction which is realistic in near future, e.g. domestic production, etc.***

Estimation of total capital cost

- Aspects much different from PWR
  - Main equipment cost, especially NSSS (addition)
  - Equipment cost of auxiliary systems (subtraction)
- Aspects similar to PWR
  - NI civil work, installation work (based on man-hour, difficulty factor)
  - CI, BOP
  - First fuel (actual amount), contingencies
  - Other cost
  - Capacity factor, etc.

Evaluation result of total capital cost

- Based on above evaluation of main equipment costs, total capital cost can be estimated:
  - Specific capital cost of HTR-PM 600 is higher than PWR 600 (Generation II+). However, the difference is only about 15%.
  - Further sensitivity analysis show that，increase of 10% for the main equipment cost in NI will result in an increase of about 4% for total capital cost.
  - Taking account of the uncertainty of main equipment cost, the difference is still lower than 20%.

Concluding remarks

- ***HTR-PM DPP is being built in China and the conceptual design of HTR-PM 600 has been finished.***
- ***Based on the cost data of HTR-PM DPP, analysis of economic competitiveness of HTR-PM 600 has been done. For the case of pure electricity generation, although the capital cost of HTR is higher than that of PWR, the difference is less than 20%.***

Thank you for your attention!