# Fast Reactor Technology facing nuclear Energy Sustainable development in China

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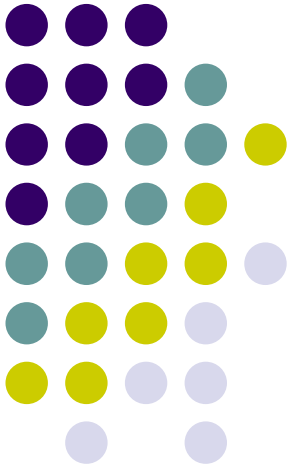
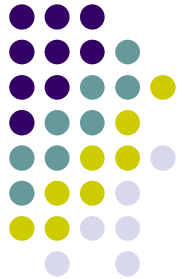
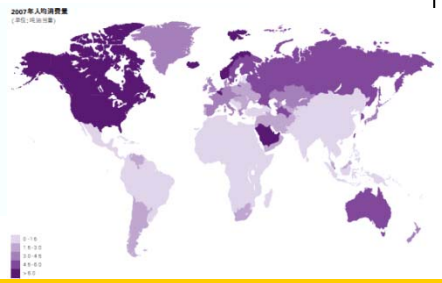


# Content



- Background
- FR and fuel cycle
- FR project in China

# 1. Background



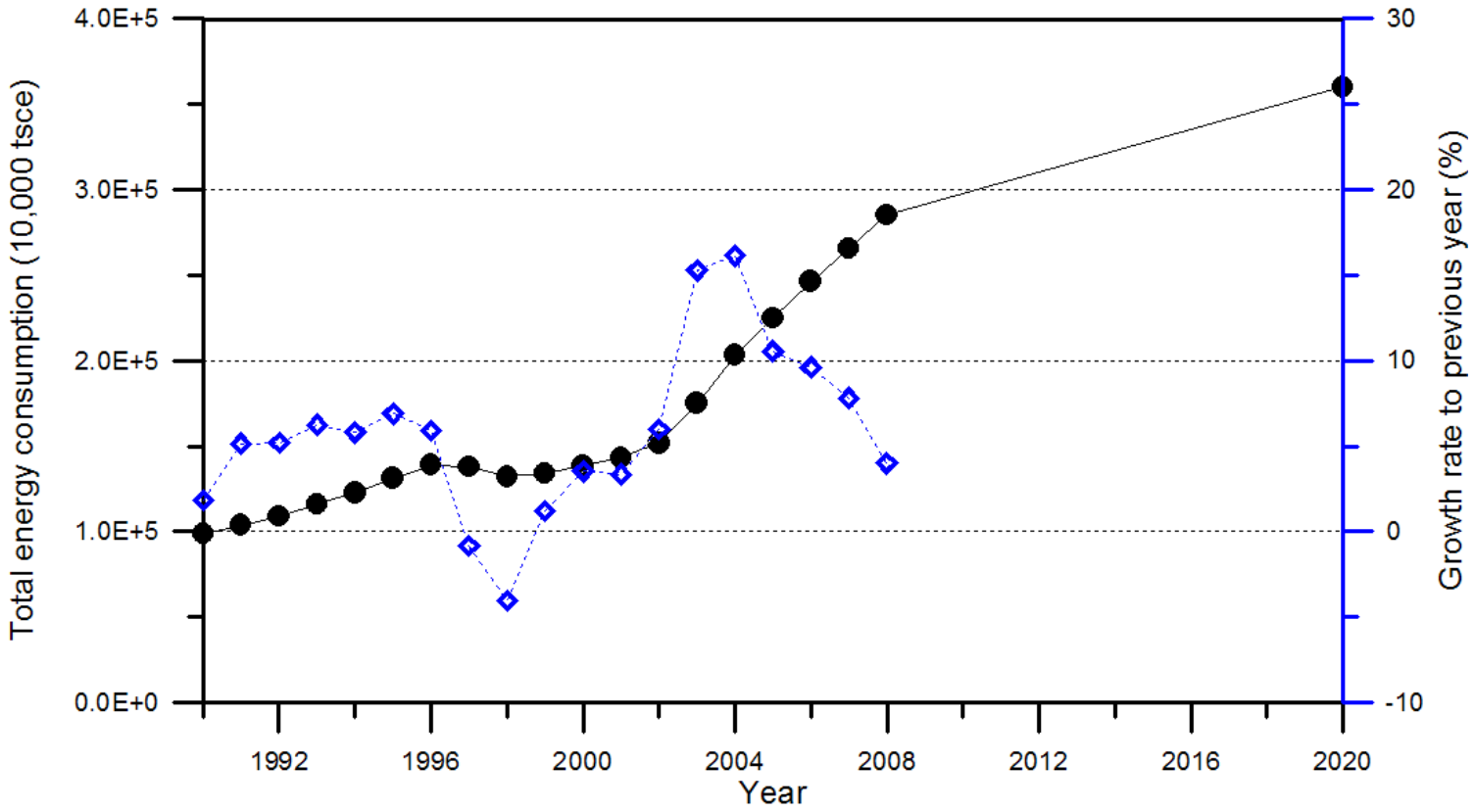
**Country's Destination of China:**
to be a middle-level advanced developed country before 2050

***Some countries' primary energy consumption in 2007***

(Unit: $10^6$ toe)

| | Oil | Natural Gas | Coal | Nuclear | Hydro Electricity | Total | Average per capita (toe) |
|---|---|---|---|---|---|---|---|
| World | 3952.8 | 2637.7 | 3177.5 | 622.0 | 709.2 | 11099.3 | 1.94 |
| U.S.A | 943.1 | 595.7 | 573.7 | 192.1 | 56.8 | 2361.4 | 8.98 |
| Japan | 228.9 | 81.2 | 125.3 | 63.1 | 18.9 | 517.5 | 4.11 |
| Germany | 112.5 | 74.5 | 86.0 | 31.8 | 6.2 | 311.0 | 3.81 |
| U.K. | 78.2 | 82.3 | 39.2 | 14.1 | 2.1 | 215.9 | 3.70 |
| France | 91.3 | 37.7 | 12.0 | 99.7 | 14.4 | 255.1 | 4.36 |
| Korea | 107.6 | 33.3 | 59.7 | 32.3 | 1.1 | 234.0 | 5.22 |
| China | 368.0 | 60.6 | 1311.4 | 14.2 | 109.3 | 1863.4 | 1.50 |

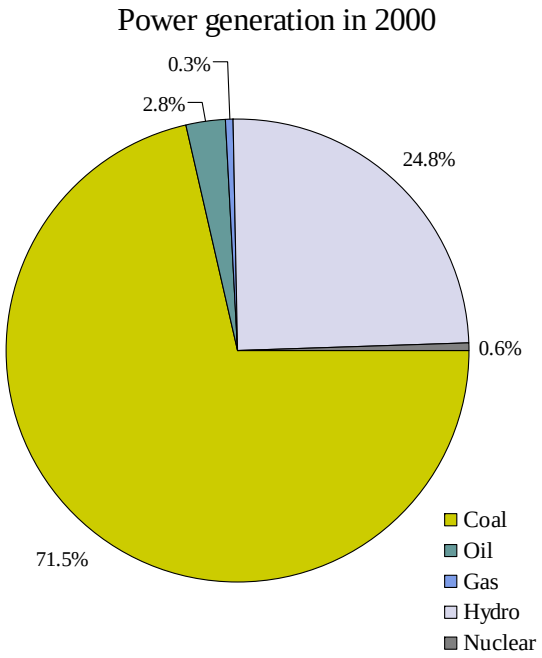
# Energy requirement in the future (~2020)

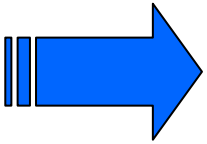


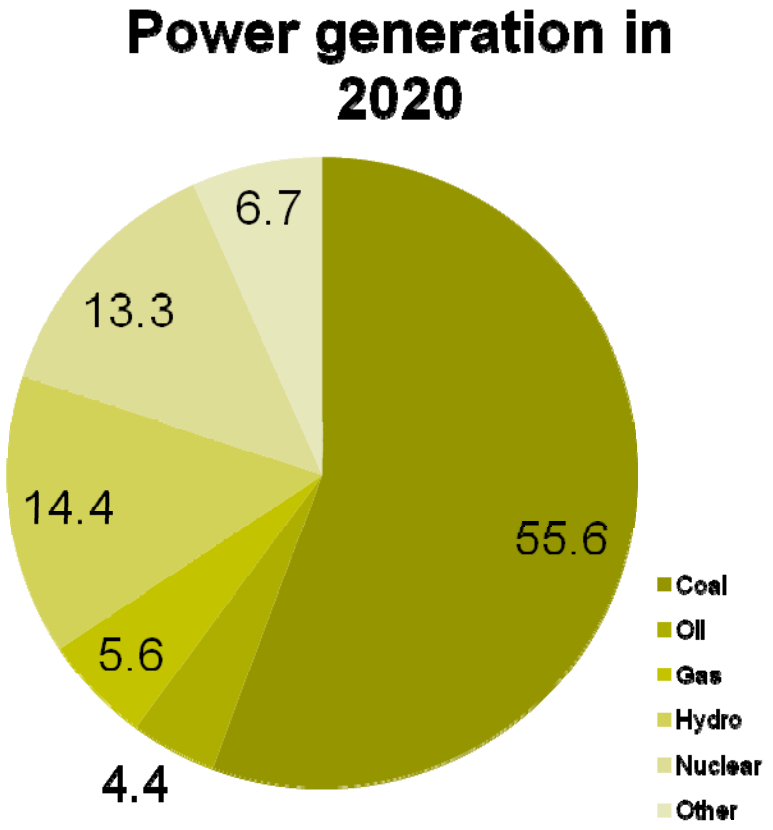
# Envisaged Primary Energy Production in China for 2050

| Energy | Exploitable In 2050 | Standard Coal Equivalent (billion tsce) | Total Requirement (billion tsce) |
|---|---|---|---|
| Oil | $0.1\times10^9$t | 0.45 | |
| Gas | $1500\times10^9$m$^3$ | | |
| Hydraulic | 260～370GWe | 0.65 | |
| Coal | $3.4\times10^9$t | 2.50 | |
| Nuclear | 240GWe | 0.60 | |
| Others | | 0.30 | |
| Total | | 4.5 | 4.5 |

# Energy structure of China

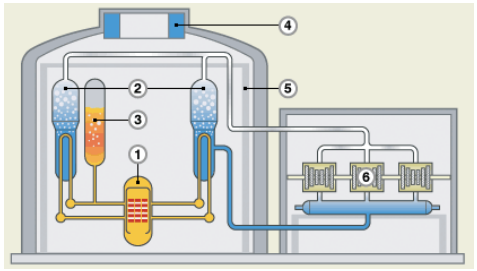


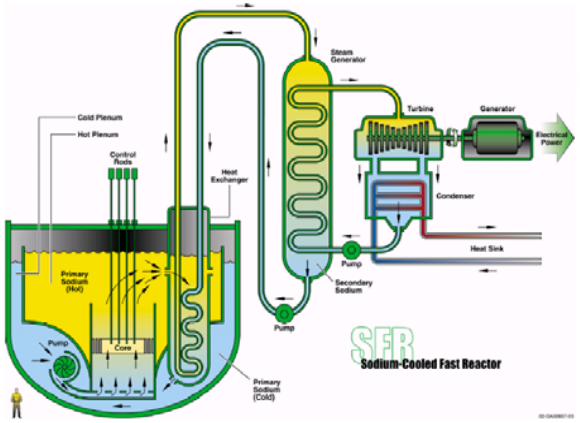



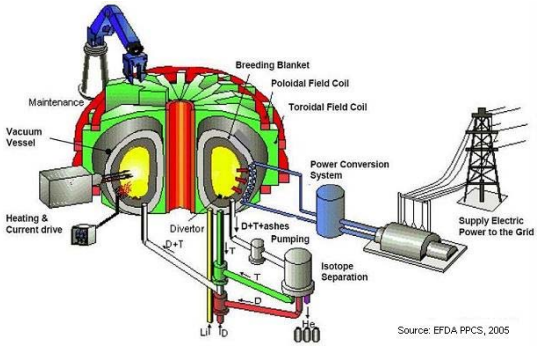


# Strategy of nuclear power development

- PWR-FBR-Fusion is set as the long-term strategy.



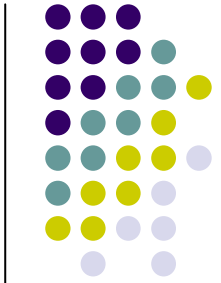




2020 — 2030 — 2050 or later

**>40 GWe** (PWR) — FBR Commercialization — Fusion

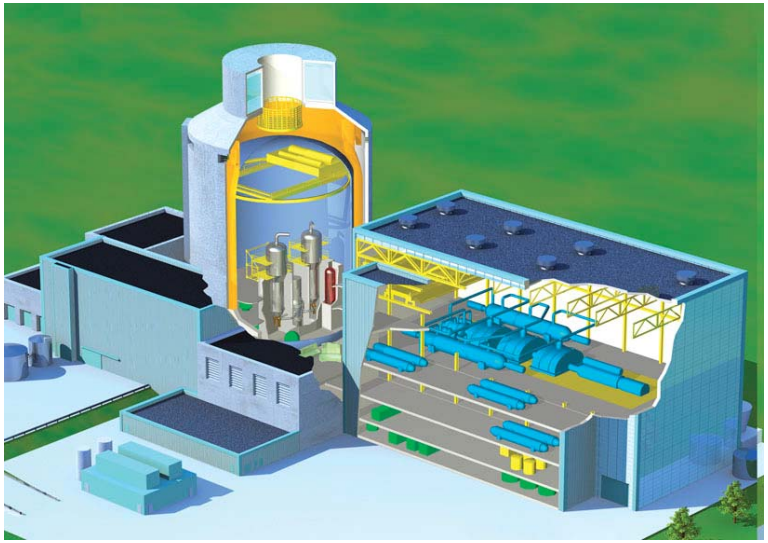
# Current status of nuclear power



| | |
|---|---|
| PWR | 11 reactors are being operated, 24 are under construction. Many NPP sites are under discussion. |
| FBR | CEFR is under construction |
| Fusion | The new fusion facility “EAST” (Experimental Advanced Superconducting Tokamak) was finished and realize the first electricity generation in 2006 |

# “medium- and long-term nuclear power development plan (2005-2020)”

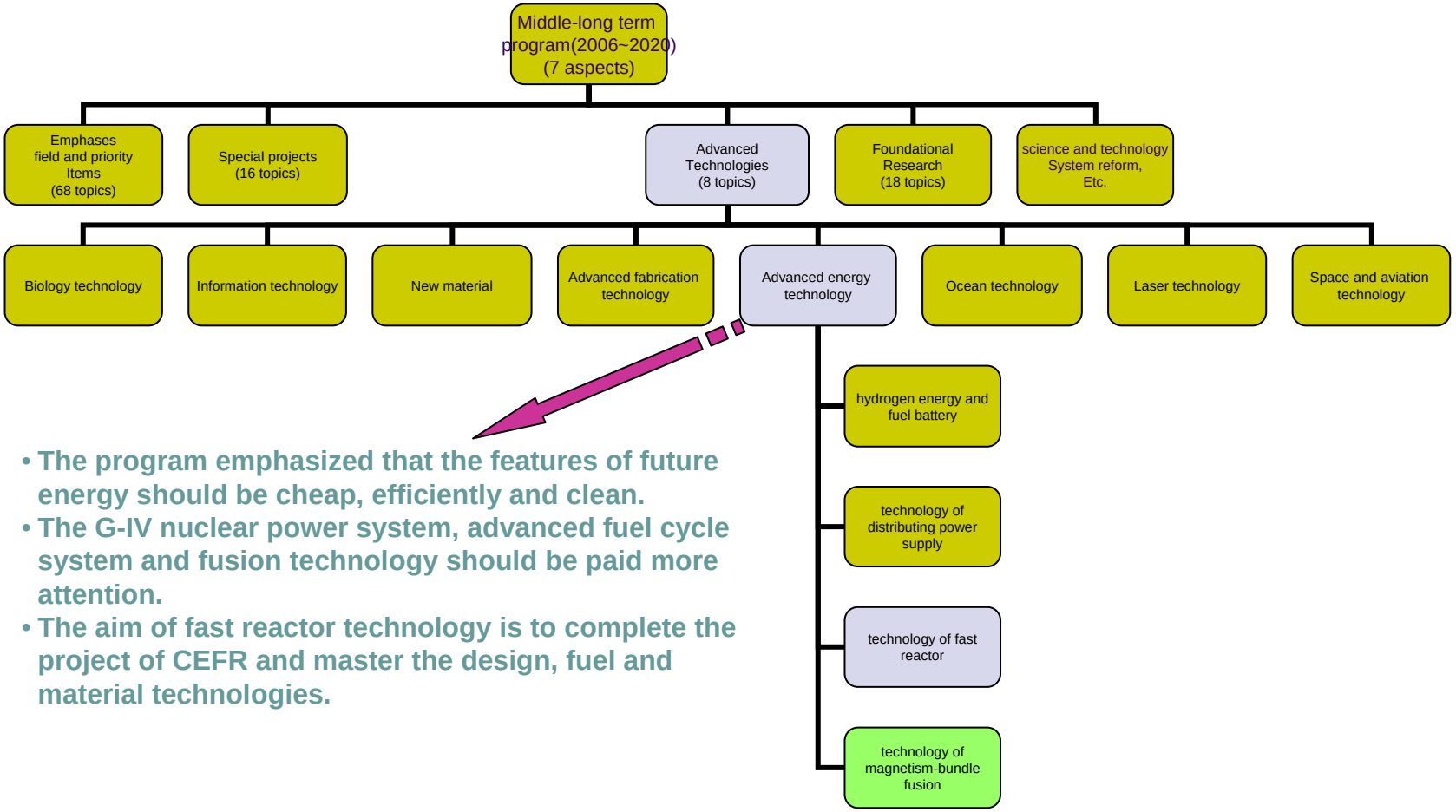
- The plan was passed in principle on March 22, 2006. According to the plan, nuclear power is a strategic energy source and should be actively developed to meet the country's growing demand of energy. The total nuclear power capacity will be up to 40GWe till 2020;
- China has chosen AP1000 as the next generation NPP of China.



# China mainland nuclear power plants

| NPP | Type | Power (MWe) | Status |
|---|---|---|---|
| Qinshan-1 | PWR | 300 | Operation |
| Qinshan-2 | PWR | 2×600 | Operation |
| Qinshan-2+ | PWR | 2×650 | Construction |
| Qinshan-3 | PHWR | 2×720 | Operation |
| Daya Bay | PWR | 2×900 | Operation |
| Lingao | PWR | 2×944 | Operation |
| Lingdong | PWR | 2×1080 | Construction |
| Tianwan | PWR | 2×1000 | Operation |
| Sanmen | PWR | 2×1250 | Construction |
| Yangjiang | PWR | 6×1080 | Construction |
| Hongyanhe | PWR | 4×1080 | Construction |
| Ningde | PWR | 4×1080 | Construction |
| Fuqing | PWR | 2×1080 | Construction |
| Fangjiashan | PWR | 2×1080 | Construction |

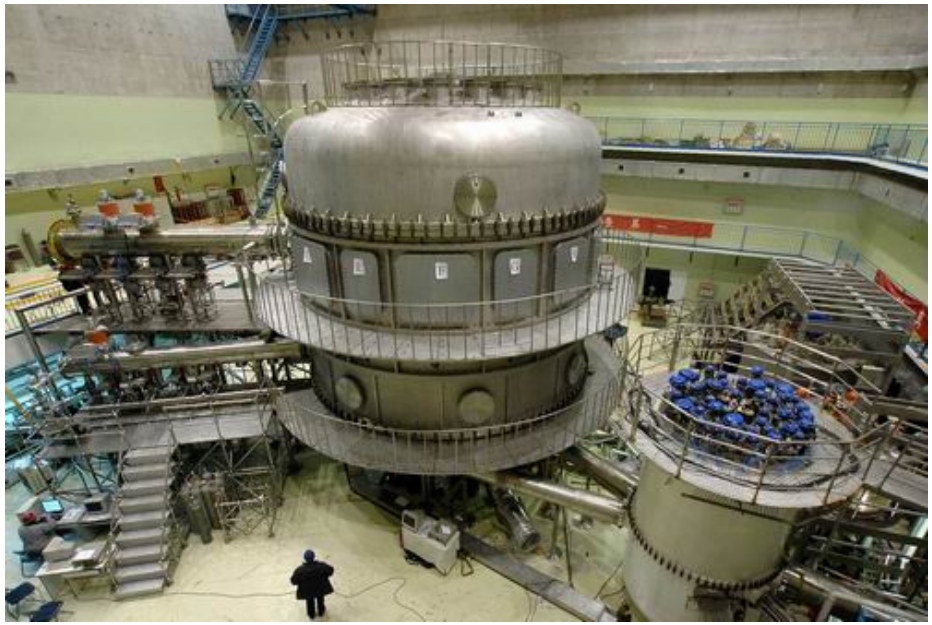
# China National middle-long term science and technology development program(2006~2020)




- The program emphasized that the features of future energy should be cheap, efficiently and clean.
- The G-IV nuclear power system, advanced fuel cycle system and fusion technology should be paid more attention.
- The aim of fast reactor technology is to complete the project of CEFR and master the design, fuel and material technologies.

# Fusion

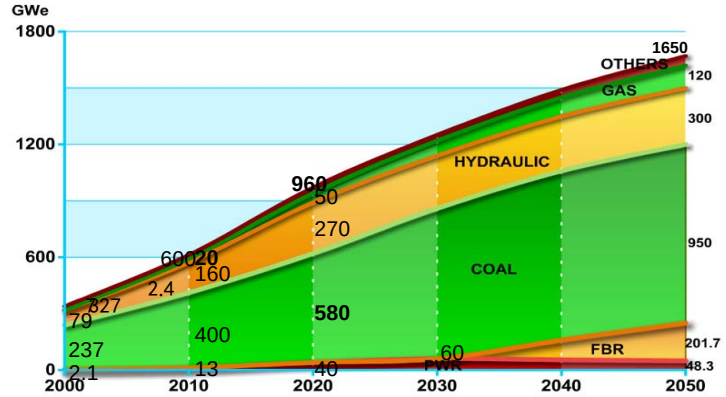
- EAST realized the first electricity generation Sept. 28, 2006 (current>200kA, time>3s);
- Participated the ITER project.



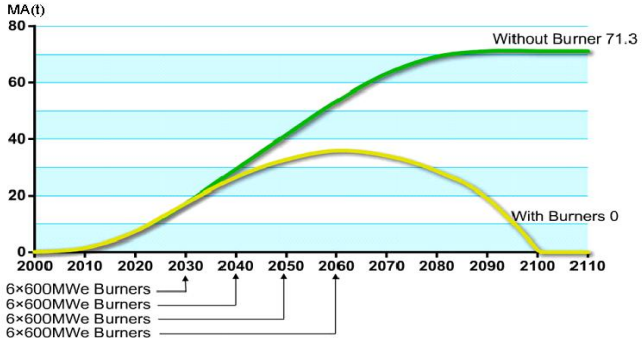
# 2. FR and Fuel Cycle

- The aim of fast reactor technology in China
  - Raise the utility rate of uranium resource;
  - Reduce the amount of long life radioactive waste;
  - Enlarge the capacity of nuclear power as quickly as possible.

# The usage of FBR



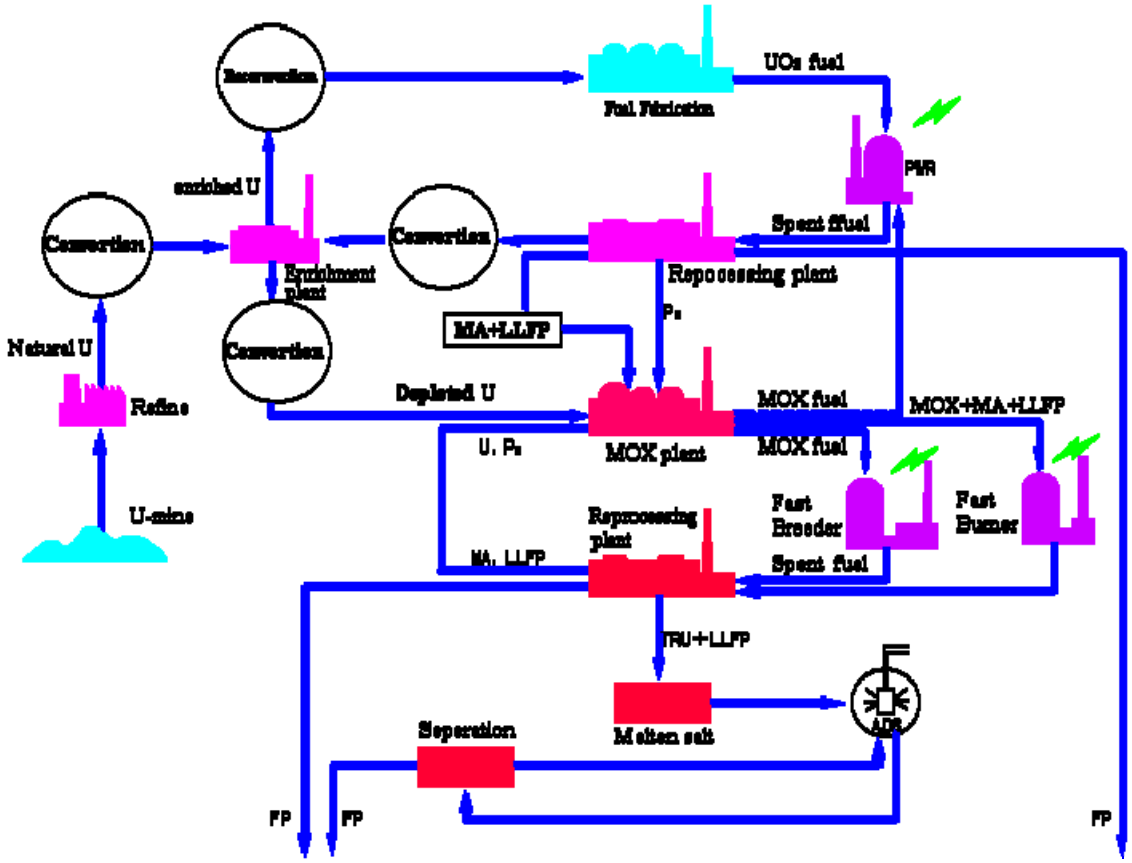

Electric Capacity Development Envisaged In China




MA Transmutation Strategy

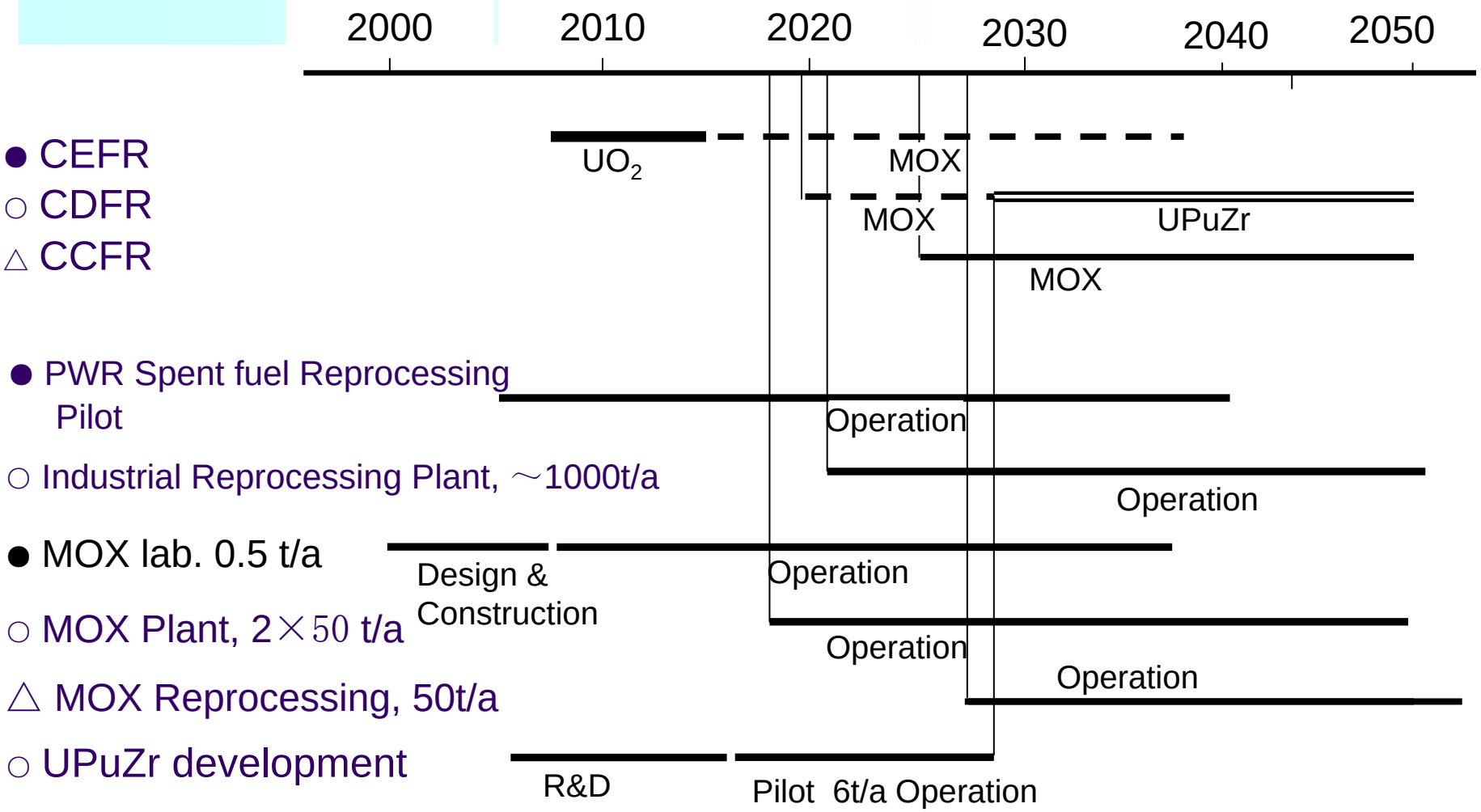
- The nuclear power could grow to 250 GW before 2050 under the co-development of FBR and PWR.
- The MA could be controlled efficiently with FR.

# Closed fuel cycle



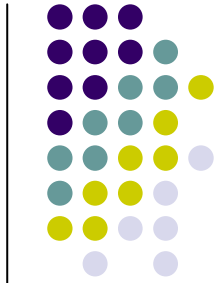

U-Pu cycle

# Fuel Cycle Program and Consideration



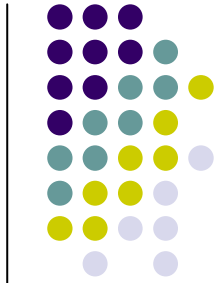

● **Execution** ○ **Application** △ **Consideration**

# 3. FR Project in China



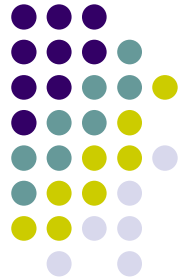
- R&D Project of 8th five-years plan
- CEFR Project of national “863” High-tech Plan
- Roadmap of fast reactor in China

# R&D Project of 8th five-years plan



- The research mainly focused on:
  - Reactor scheme selection study
  - Sodium technology study
  - Thermal Hydraulic and safety study
  - Neutron physics study
  - Structure and material study
  - Fuel study
  - Sodium-water reaction and detection study
  - Important safety related components study
  - Sub-assembly related technical study

# CEFR Project of national “863” High-tech Plan



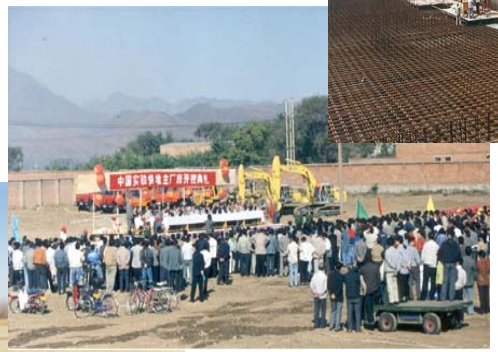
- One of the largest item of China national “863” hi-tech plan.
- The budget is more than 0.325 billion $;
- Milestones:
  - 1995.12.9, project identified;
  - 1997.11.13, preliminary design approved;
  - 2000.5.30, first pour concrete;
  - 2002.8.15, main building finished;
  - 2004.11.30, detail design finished;
  - 2009.12.30, first physical critical;
  - 2010.12.30, connect to the grid.

# Site of CEFR

2005. 8

2002. 8

2000. 5



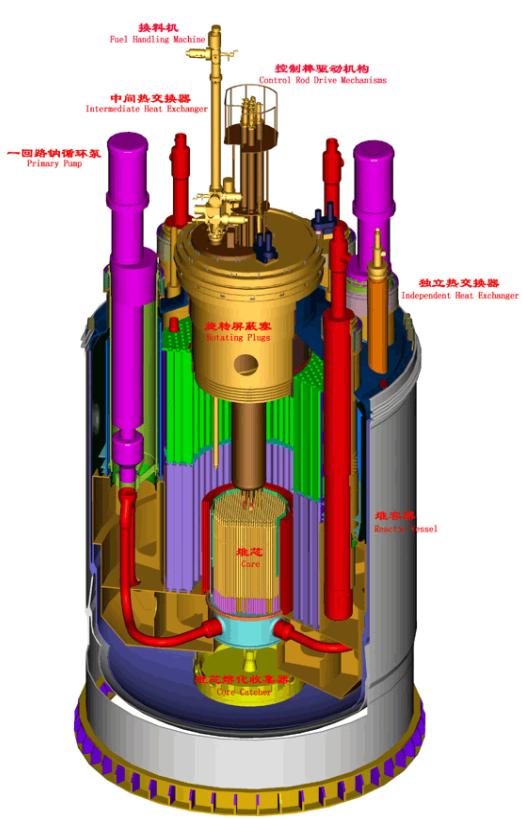
1998. 10

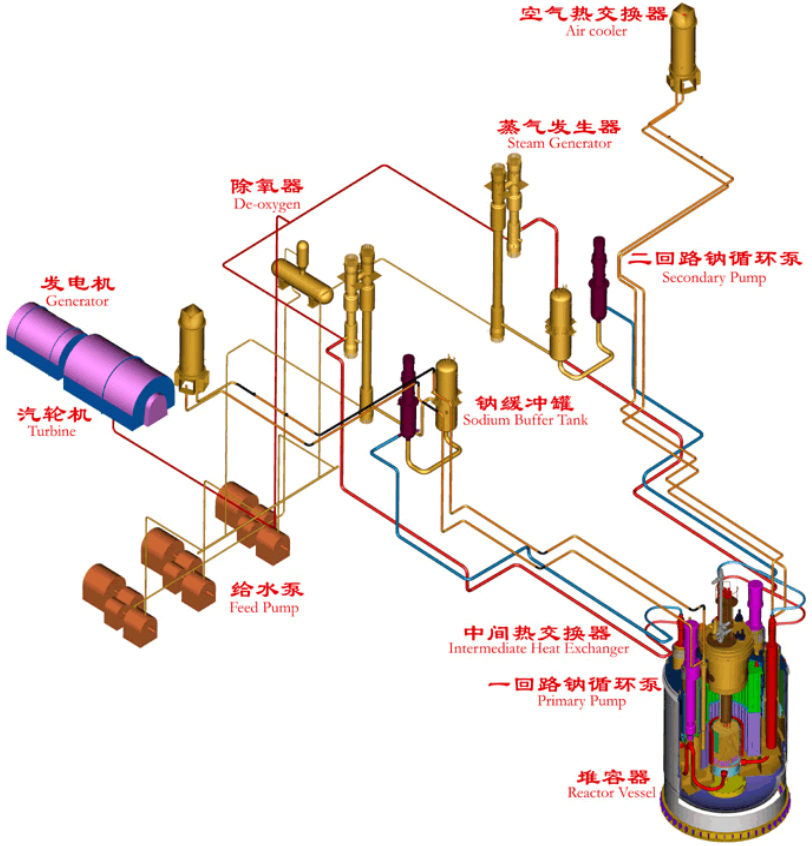
1997

# Main parameters of CEFR

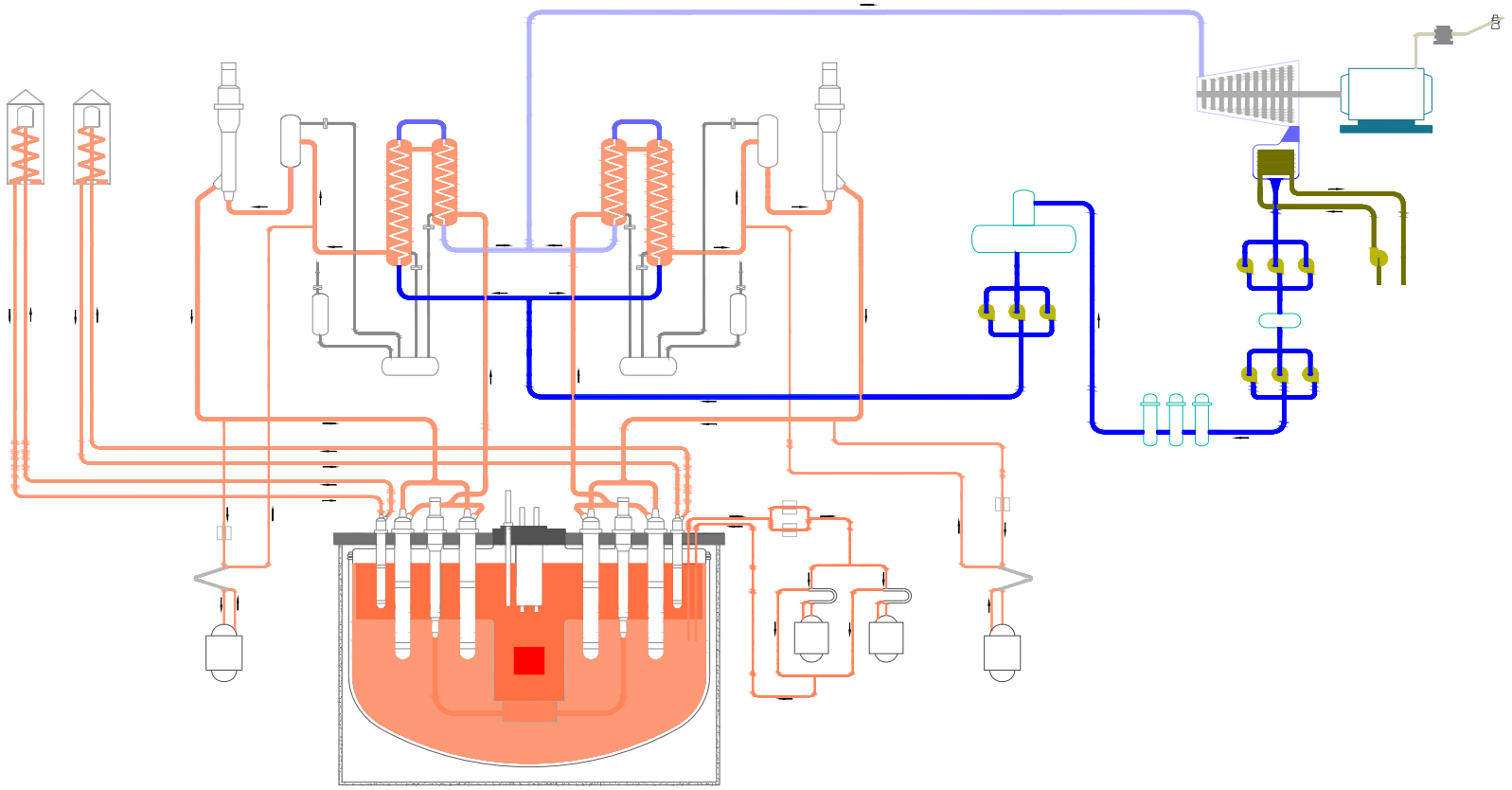
| Parameter | Unit | Value | Parameter | Unit | Value |
|---|---|---|---|---|---|
| Thermal Power | MW | 65 | Primary Circuit | | |
| Electric Power, net | MW | 20 | Number of Loops | | 2 |
| Reactor Core | | | Quantity of Sodium | t | 260 |
| Height | cm | 45.0 | Flow Rate, total | t/h | 1328.4 |
| Diameter Equivalent | cm | 60.0 | Number of IHX per Loop | | 2 |
| Fuel | | $(Pu, U)O_2$ (first loading is $UO_2$) | Secondary Circuit | | |
| Linear Power max. | W/cm | 430 | Number of Loop | | 2 |
| Neutron Flux | $n/cm^2 \cdot s$ | $3.7 \times 10^{15}$ | Quantity of Sodium | t | 48.2 |
| Bum-up, first load max. | MWd/t | 60000 | Flow Rate | t/h | 986.4 |
| Inlet/outlet Temp. of the Core | ℃ | 360/530 | Tertiary Circuit | | |
| Diameter of Main Vessel(outside) | m | 8.010 | Steam Temperature | ℃ | 480 |
| Design Life | A | 30 | Steam Pressure | MPa | 14 |
| | | | Flow Rate | t/h | 96.2 |

# Reactor Block and Main Heat Transfer System

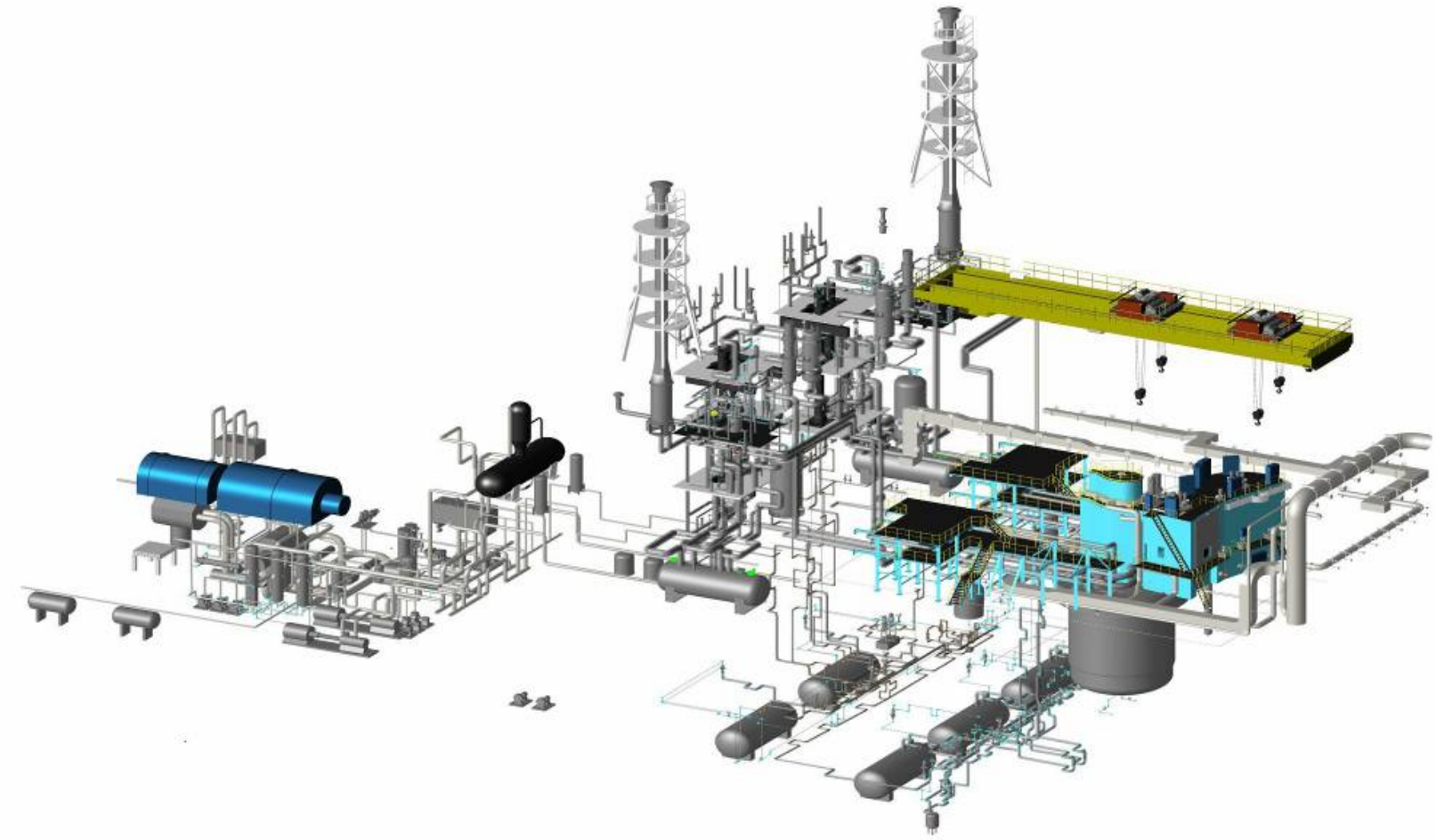


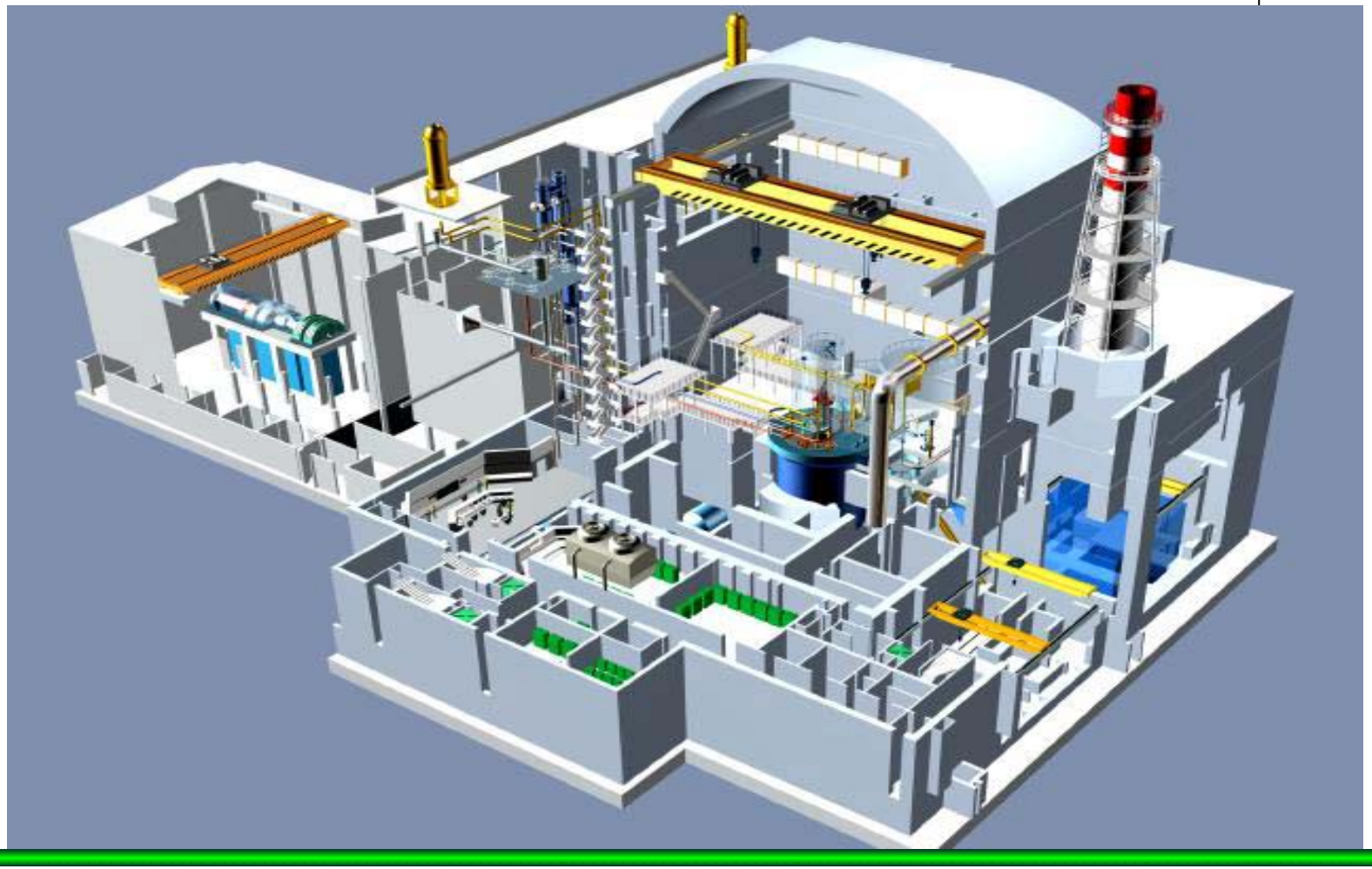
# Main heat transfer system of CEFR



# Main equipments and systems of CEFR



# CEFR



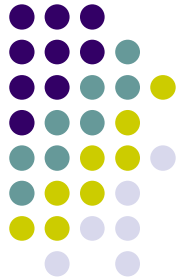
# Technical continuity of Chinese FBRs

| Reactor | CEFR | CDFR | CCFR |
|---|---|---|---|
| Power MWe | 25 | 600~900 | 1000~1500 |
| Coolant | Na | Na | Na |
| Type | Pool | Pool | Pool |
| Fuel | $UO_2$<br>MOX | MOX<br>Metal | Metal |
| Cladding | Cr-Ni | Cr-Ni<br>ODS | Cr-Ni<br>ODS |
| Core Outlet Temp. ℃ | 530 | 500-550 | 500 |
| Linear Power W/cm | 430 | 450-480 | 450 |
| Burn-up MWd/kg | 60-100 | 100-120 | 120-150 |
| Fuel Handling | DRPs<br>SMHM | DRPs<br>SMHM | DRPs<br>SMHM |
| Spent Fuel Storage | IVPS<br>WPSS | IVPS<br>WPSS | IVPS<br>WPSS |
| Safety | ASDS<br>PDHRS | ASDS+PSDS<br>PDHRS | ASDS+PSDS<br>PDHRS |

# The preliminary consideration of demonstration reactor

- The main parameters
  - Power: 2100MWt/800MWe;
  - Fuel: MOX;
  - Design life: 40y
  - Construction cost: ~ 2500$/kW.
  - Safety: Probability of core melt < $10^{-6}$/a;
    For DBA, Maximum public dose < 0.5mSv
    For BDBA, Maximum public dose < 5mSv
  - Loading coefficient: >80%
  - Breeding ratio: >1.1;
  - Fuel handling period: 150d.

# Technical scheme selection



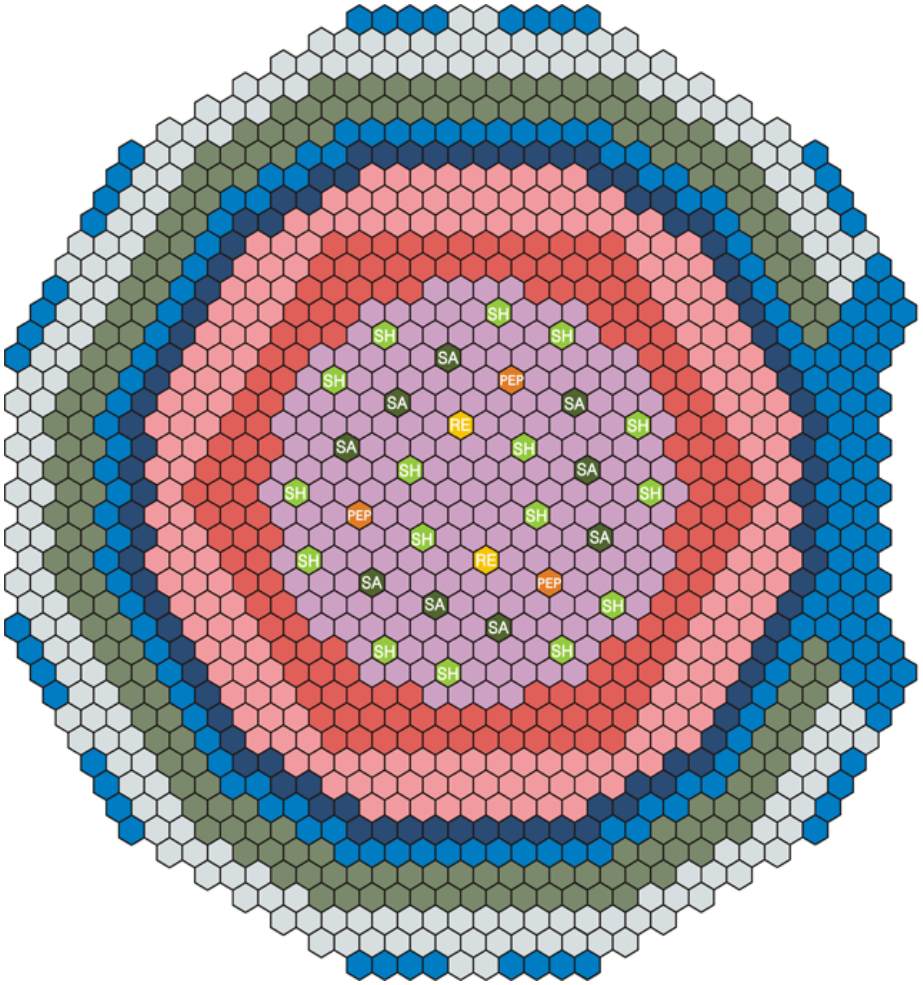
- MOX fuel, clad and structure material adopting 316 austenitic stainless steel;
- Sodium as the coolant;
- The primary loop adopts pool-type;
- The main heat transfer system use the design sodium-sodium-water/steam;
- The primary and secondary loop with 3 circuit respectively;
- The tertiary loop with one turbine;
- Two set of shut down system, and each one could shut down the reactor with enough margin under the case of one control rod stick out of the core;
- Inherent emergency residual heat removal system;
- Containment;
- Primary sodium system set in the bound of containment.

# CDFR Main Parameters (primary)

| Parameters | Design Value |
|---|---|
| Thermal Power | 2100 MWt |
| Electricity Power | 800 MWe |
| Efficient | 38% |
| Load factor | 80% |
| Design life | 40y |
| Fuel type | MOX |
| Coolant type | Sodium |
| Primary Loop type | Pool |
| Average Burn up | 66 MWd/kg |
| Maximum Burn up | 100 MWd/kg |
| Breading ratio | 1.1 |

| Parameters | Design Value |
|---|---|
| Fuel subassembly number (inner/middle/out/total) | 211/156/198/565 |
| Enrich (inner/middle/out) | 19.5%22.1%24.7% |
| Liner Power | 29.3/49 kW/m |
| Diameter of Main vessel | 13000 mm |
| Thickness of Main vessel | 30 mm |
| Sodium temperature (inlet/outlet of reactor core) | 354/547℃ |
| Sodium temperature (inlet/outlet of IHX) | 544/352℃ |
| Flow rate of primary loop | 8700 kg/s |
| Loop number | 3/3 |

# Reactor Core




| 图例 | 说明 | 数量 |
|---|---|---|
| | 内堆芯燃料组件 | 211 |
| | 中间堆芯燃料组件 | 156 |
| | 外堆芯燃料组件 | 198 |
| | 径向转换区组件 | 90 |
| | 钢反射层组件 | 178 |
| | 硼屏蔽组件 | 182 |
| | 堆内储存阱 | 188 |
| SH | 补偿棒 | 16 |
| SA | 安全棒 | 9 |
| PEP | 非能动控制棒 | 3 |
| RE | 调节棒 | 2 |

# THANK YOU FOR YOUR ATTENTION