CHINA INSTITUTE OF ATOMIC ENERGY

# Fast Reactor Technology Development for Sustainable Supply of Nuclear Energy in China

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**XU MI**

**China Institute of Atomic Energy**

# Contents

# 1 Introduction

**China needs very huge energy to keep her national economy development and to improve people's living standard.**

**The nuclear energy is a new member of energy family in China,**

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# Status of NPPs in China Mainland

| Site | Capacity/Type | Grid Date | Load factor (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Qinshan I | 300MW/PWR | 1991.12.15 | 77.2 | 94.1 | 66.9 | 88.6 | 99.8 | 86.72 | 91.44 | 81.62 | 96.39 | 86.98 |
| Daya Bay -1 | 900MW/PWR | 1993.08.31 | 85.2 | 84.9 | 89.6 | 89.6 | 87.2 | 99.79 | 80.31 | 90.85 | 99.60 | 90.20 |
| -2 | 900MW/PWR | 1994.02.07 | 84.9 | 89.1 | 81.6 | 84.5 | 73.6 | 79.44 | 99.68 | 88.29 | 86.39 | 99.76 |
| Qinshan II -1 | 600MW/PWR | 2002.02.01 | | | 74.9 | 81.0 | 82.2 | 92.76 | 55.20 | 65.69 | 87.38 | 84.46 |
| -2 | 600MW/PWR | 2004.03.11 | | | | | | 85.19 | 90.30 | 90.70 | 86.48 | 90.12 |
| Lingao -1 | 984MW/PWR | 2002.04.05 | | | 92.0 | 76.8 | 87.76 | 82.69 | 89.16 | 82.65 | 90.79 | 89.05 |
| -2 | 984MW/PWR | 2002.12.15 | | | | 85.0 | 79.9 | 90.57 | 91.89 | 87.31 | 84.56 | 89.30 |
| Qinshan III -1 | 700MW/PHWR | 2002.11.10 | | | | 90.2 | 77.3 | 84.05 | 98.20 | 88.35 | 93.48 | 93.88 |
| -2 | 700MW/PHWR | 2003.06.12 | | | | 90.4 | 94.0 | 81.05 | 88.70 | 99.87 | 89.34 | 97.30 |
| Tianwan -1 | 1000MW/PWR | 2006.06 | | | | | | | | 65.59 | 74.43 | 77.83 |
| -2 | 1000MW/PWR | 2006.12 | | | | | | | | 78.76 | 85.50 | 85.02 |
| Total | 8.6GWe | | | | | | | | | | | |

**The average load factor over 78 unit ·years is 86.3%.**

**Under the sketch of National Mid-Long Term Science and Technology Development Program (2006 ~ 2020) issued by The State Council ,the Government has decided in 2006 to develop continuously nuclear power with a target of 40 GWe in operation and other 18GWe under construction in 2020. The higher capacity targets are under discussion:**

**2020 70GWe**

**2030 200GWe**

**2050 400-500GWe**

# 2 The Strategy of China FBR Development

Considering the uranium resources are limited internally and in the world, the basic strategy of three steps nuclear energy utilization has been emphasized by the Government:

Thermal reactor-Fast reactor –Fusion reactor

**What is nuclear sustainable supply in China?**

**(1) to develop nuclear capacity in large scale and quick glowing with nuclear resources sufficient utilization.**

**(2) to decrease the quantity of MA and LLFP to be geologically buried, and**

**(3) to replace fossil power plants as early as possible for decreasing green-house gas emission.**

**The basic strategy of PWR-FBR matched closed fuel cycle is under execution step by step.**

# Suggested China FBR Development Strategy

| | Reactor | Power(MWe) | Design Beginning | Commissioning |
|---|---|---|---|---|
| 1 | CEFR | 20 | 1990 | 2010 |
| 2 | CDFR | ≥600 | 2007 | 2018 |
| | CCFR | n× ≥600 | 2015 | 2030 |
| 3 | CDFBR | 1000 ~ 1500 | 2018 | 2028 |
| | CCFBR | 1000 ~ 1500 | 2020 | 2030 ~ 2032 |

# Technical Continuity of Chinese FBRs

| | CEFR | CDFR | CDFBR | CCFR |
|---|---|---|---|---|
| Power MWe | 20 | ≥600 | 1000 ~ 1500 | n× ≥600 |
| Coolant | Na | Na | Na | Na |
| Type | Pool | Pool | Pool | Pool |
| Fuel | $UO_2$<br>MOX | MOX<br>Metal | Metal | MOX+Ac<br>Metal+Ac |
| Cladding | Cr-Ni | Cr-Ni, ODS | Cr-Ni, ODS | Cr-Ni, ODS |
| Core Outlet Temp.℃ | 530 | 550 ~ 500 | 500 | 550 ~ 500 |
| Linear Power W/cm | 430 | 450 | 450 | 450 |

| Burn-up MWd/kg | 60 ~ 100 | 100 ~ 120 | 120 ~ 150 | 120 |
|---|---|---|---|---|
| Fuel Handling | DRPs SMHM | DRPs SMHM | DRPs SMHM | DRPs SMHM |
| Spent Fuel Storage | IVPS WPSS | IVPS WPSS | IVPS WPSS | IVPS WPSS |
| Safety | ASDS PDHRS | ASDS+PSDS PDHRS | ASDS+PSDS PDHRS | ASDS+PSDS PDHRS |

**DRPs: Double Rotating Plugs**

**SMHM: Straight Moving Handling Machine**

**IVPS: In-Vessel Primary Storage**

**WPSS: Water pool Secondary Storage**

**ASDS: Active Shut-Down System**

**PSDS: Passive Shut-Down System**

**PDHRS: Passive Decay Heat Removal System**

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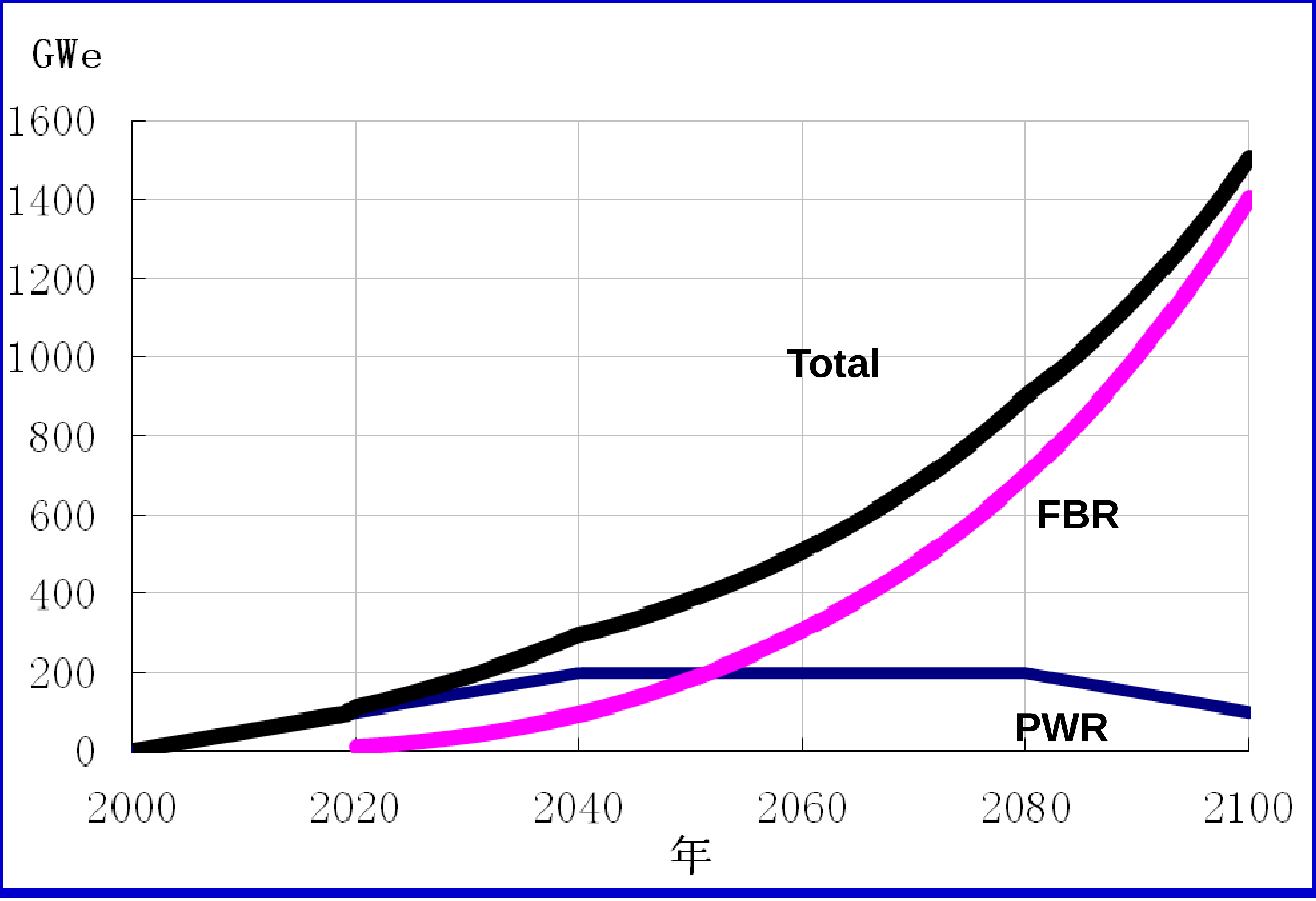
·Uranium:3ooo kt，

·FBR:MOX、BR:1.2，Reprocessing:4a



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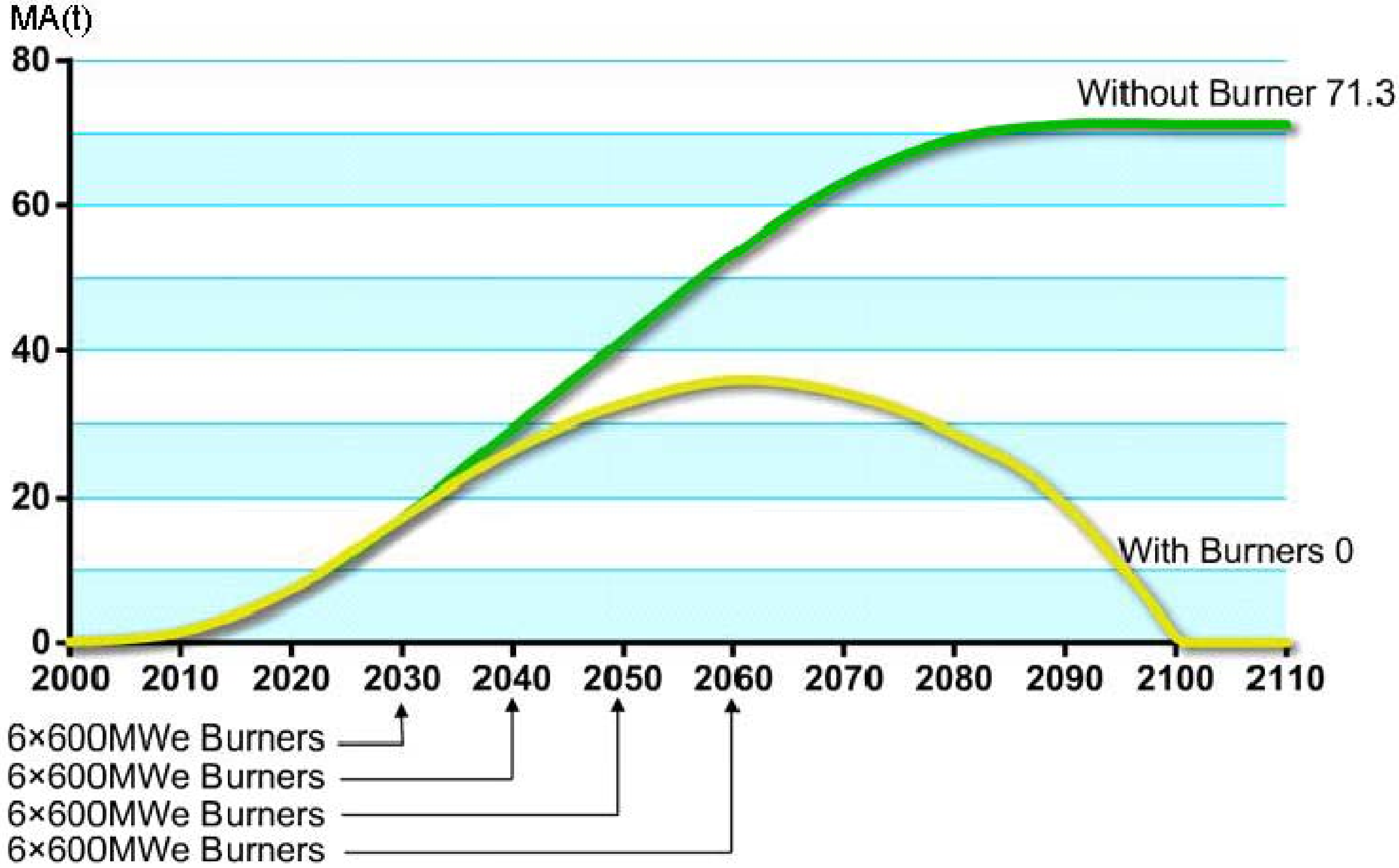
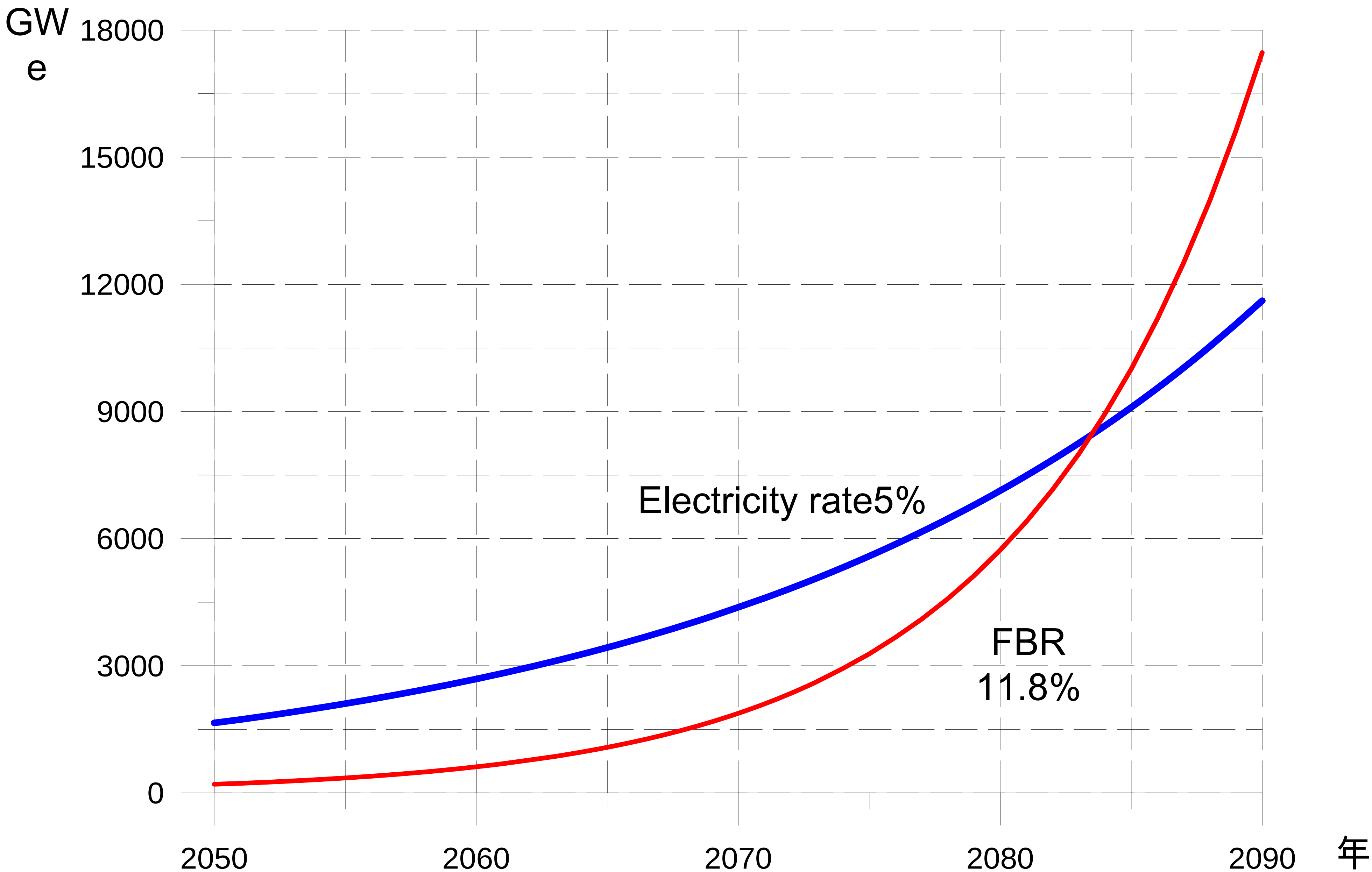



**MA Transmutation Strategy**




**National electricity and FBR annual increasing rate**

**Three Strategy Targets:**

- **2030 ≥600 MWe FBR deployment and operation to support PWR reaching power capacity expected .**
- **2050 nuclear capacity will reach 400 GWe or more, sharing around 20% at that year.**
- **2050～2100 Nuclear will in large scale replace fossil fuel.**

# 3 Status of China Experimental Fast Reactor

In the framework of the National ‘863’ High-Tech Program the China Experimental Fast Reactor has been executed since 1990.

# CEFR timetable

| | |
|---|---|
| Conceptual Design | 1990 ~ 1992.7 |
| Consultation with Russian FBR Association and Optimization | 1993 |
| Technical Co-Design with R-FBR-A | 1994 ~ 1995 |
| FBR R&D cooperation with France | 1995 ~ Now |
| Preliminary Design | 1996 ~ 1997 |
| Ordering Components | 1997 ~ 2004 |
| Detail Design | 1998 ~ 2003 |

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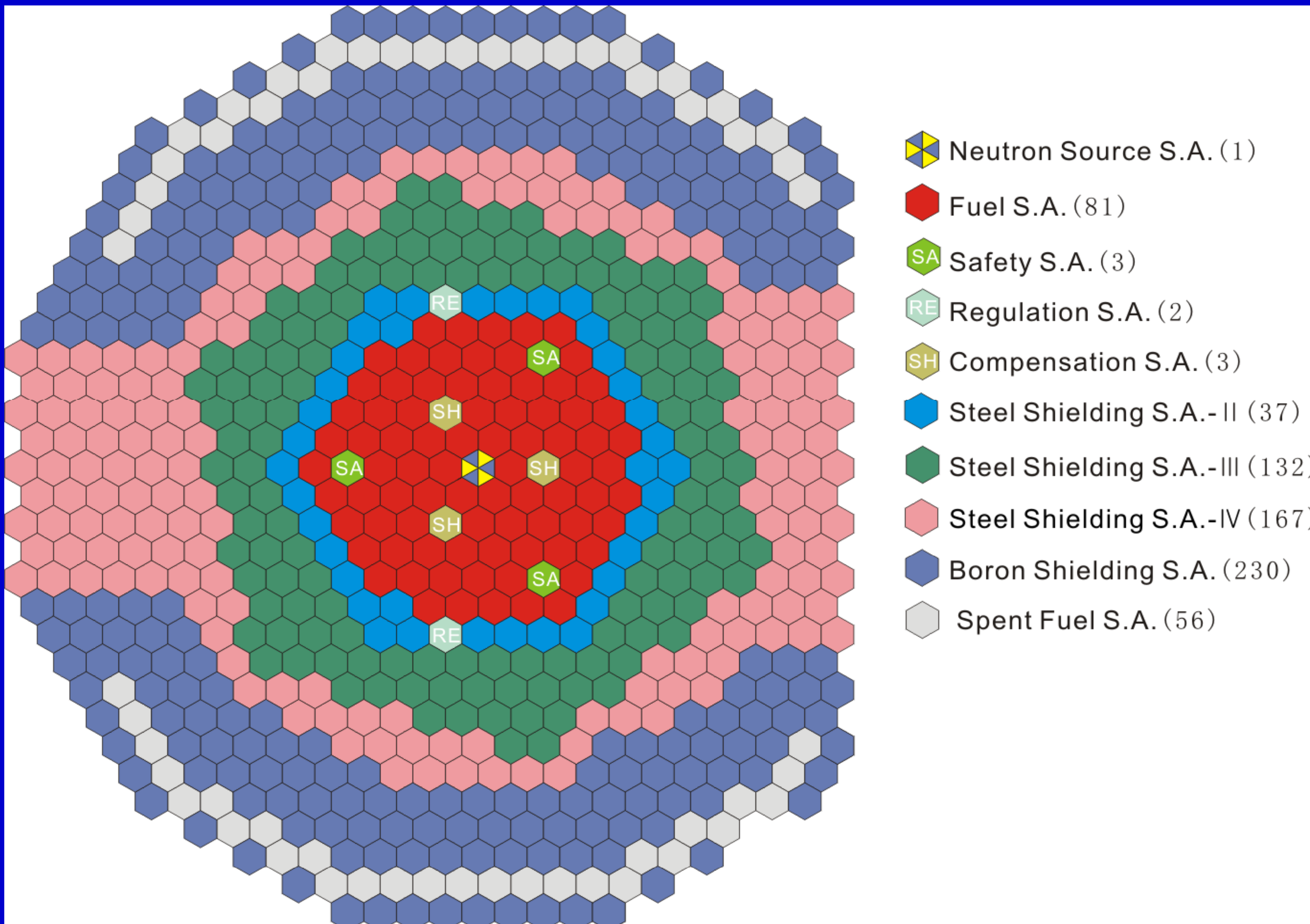
| | |
|---|---|
| Preliminary Safety Analysis Report Review | 1998.5 ~ 2000.5 |
| Architecture Construction (first pot of concrete) started | 2000.5 |
| Reactor Building construction | 2001.3 ~ 2002.8 |
| Installation | 2004 ~ 2007 |
| Pre- Operation Testing | 2006 ~ Now |
| Sodium Loading into Systems | 2009.5 |
| Fuel loading license issued | 2009.9 |

One public letter

## One public letter

| | |
|---|---|
| Fuel loading license re-issued | 2010.6 |
| First criticality | 2010.7.21 |
| Core Neutronics experiments | by now |
| Connected to the grid with 40% | (2011.6) |
| Full power | (2011.12) |

# CEFR Introduction




The core of CEFR

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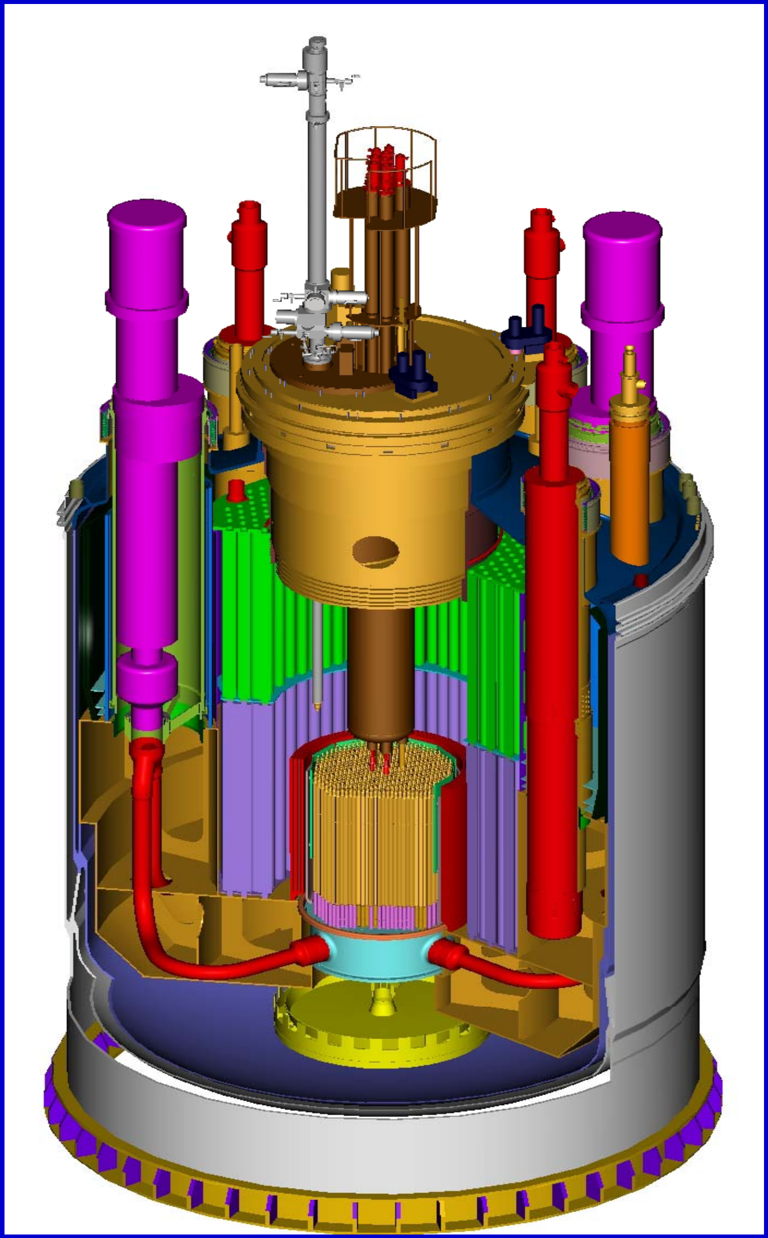
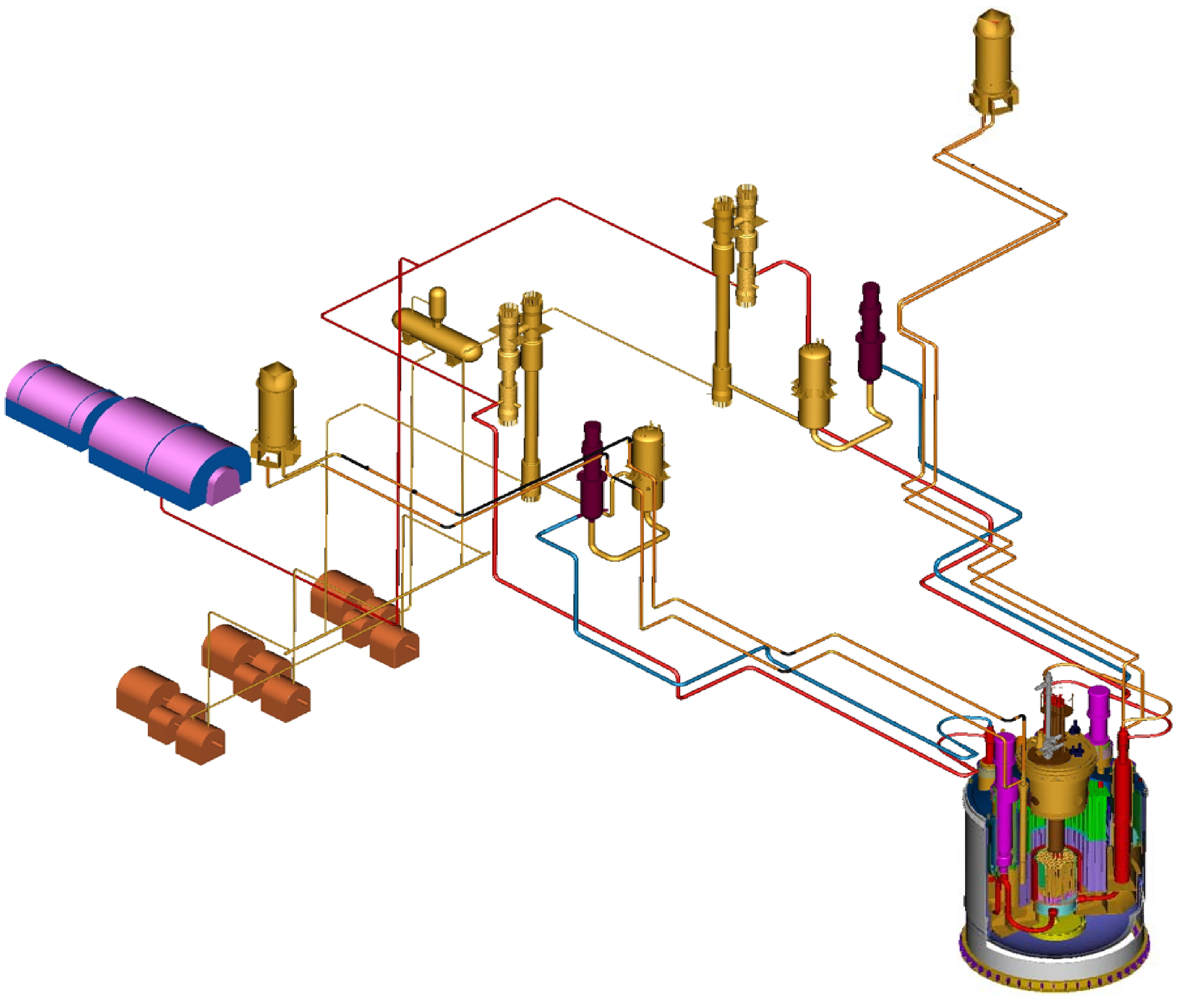


# CEFR Reactor Block



**CEFR Main Heat Transfer System**

# CEFR Main Design Parameters

| Parameter | Unit | Parameters |
|---|---|---|
| Thermal Power | MW | 65 |
| Electric Power, net | MW | 20 |
| Reactor Core | | |
| Height | cm | 45.0 |
| Diameter Equivalent | cm | 60.0 |
| Fuel/First Loading | | (Pu, U) $O_2$ / $UO_2$ |
| Pu, total | kg | 150.3 |
| Pu-239 | kg | 97.7 |
| U-235 (enrichment) | kg | 42.6 (19.6%) / 236.7(64.4%) |
| Linear Power max. | W/cm | 430 |

| Parameter | Unit | Preliminary design |
|---|---|---|
| Neutron Flux | $n/cm^2 \cdot s$ | $3.7 \times 10^{15}$ |
| Bum-up, target max. | MWd/t | 100000 |
| Bum-up, first load max. | MWd/t | 60000 |
| Inlet Temp. of the Core | ℃ | 360 |
| Outlet Temp. of the Core | ℃ | 530 |
| Diameter of Main Vessel (outside) | m | 8.010 |
| Primary Circuit | | |
| Number of Loops | | 2 |
| Quantity of Sodium | t | 260 |
| Flow Rate, total | t/h | 1328.4 |

| Parameter | Unit | Preliminary design |
| --- | --- | --- |
| Number of IHX per loop | | 2 |
| Secondary Circuit | | |
| Number of loops | | 2 |
| Quantity of Sodium | t | 48.2 |
| Flow Rate | t/h | 986.4 |
| Tertiary Circuit | | |
| Steam Temperature | ℃ | 480 |
| Steam Pressure | MPa | 14 |
| Flow Rate | t/h | 96.2 |
| Plant Life | a | 30 |

**Summary on CEFR Safety Characteristics**

**1）Temperature reactivity effect (250 - 360ºC) - 0.62$\beta_{eff}$**

**Power reactivity effect (360ºC 0% - 100% power） - 0.55$\beta_{eff}$**

**Sodium void reactivity effect (all fuel and upper ) - 3.9$\beta_{eff}$**

**2）Passive decay heat removal system**

**Passive siphon effect destruct for primary sodium purification system out of reactor vessel.**

**Passive reactor pressure protection**

**Passive large sodium leakage receiver**

**3）Under BDBA accident as ULOF, ULOHS or UTOP (one Regulation Subassembly drawn off)**

**no sodium boiling, no cladding failure and no fuel molten。**

**4）For BDBA edge accident: no any electricity supply, shut- down system damaged,  decay heat removal system not worked, and no any interference to it for 45 minutes.**

**Max. sodium temperature is 890℃ less than boiling temperature 920℃ at the situ pressure, for only ~ 15 sec.**

**Max. cladding temperature: 920℃ and no fuel molten.**

5）The safety analysis reviewed by CNNSA give the results: CEFR design has met the safety targets of effective dose equivalent much lower than the National Environment Regulation at site boundary 153m.

| | CEFR | GB6249-86 |
|---|---|---|
| Normal operation | 0.05 mSv/a | 0.25 mSv/a |
| DBA | 0.5 mSv/accident | 5-100 mSv/accident2h |
| BDBA | 5 mSv/accident | 250 mSv/accident |

PRA: core molten probability $4\times10^{-7}$/reactor.a

no requiring site response at any accident,

反应堆大厅（2008.11）

主控室（2009.01）

**CEFR外景**

**National Grid comes to the site (2007.01.28)**

# 4 China Demonstration Fast Reactor

**Project One: 1000MWe CDFR 2017 construction**

**2022 commissioning**

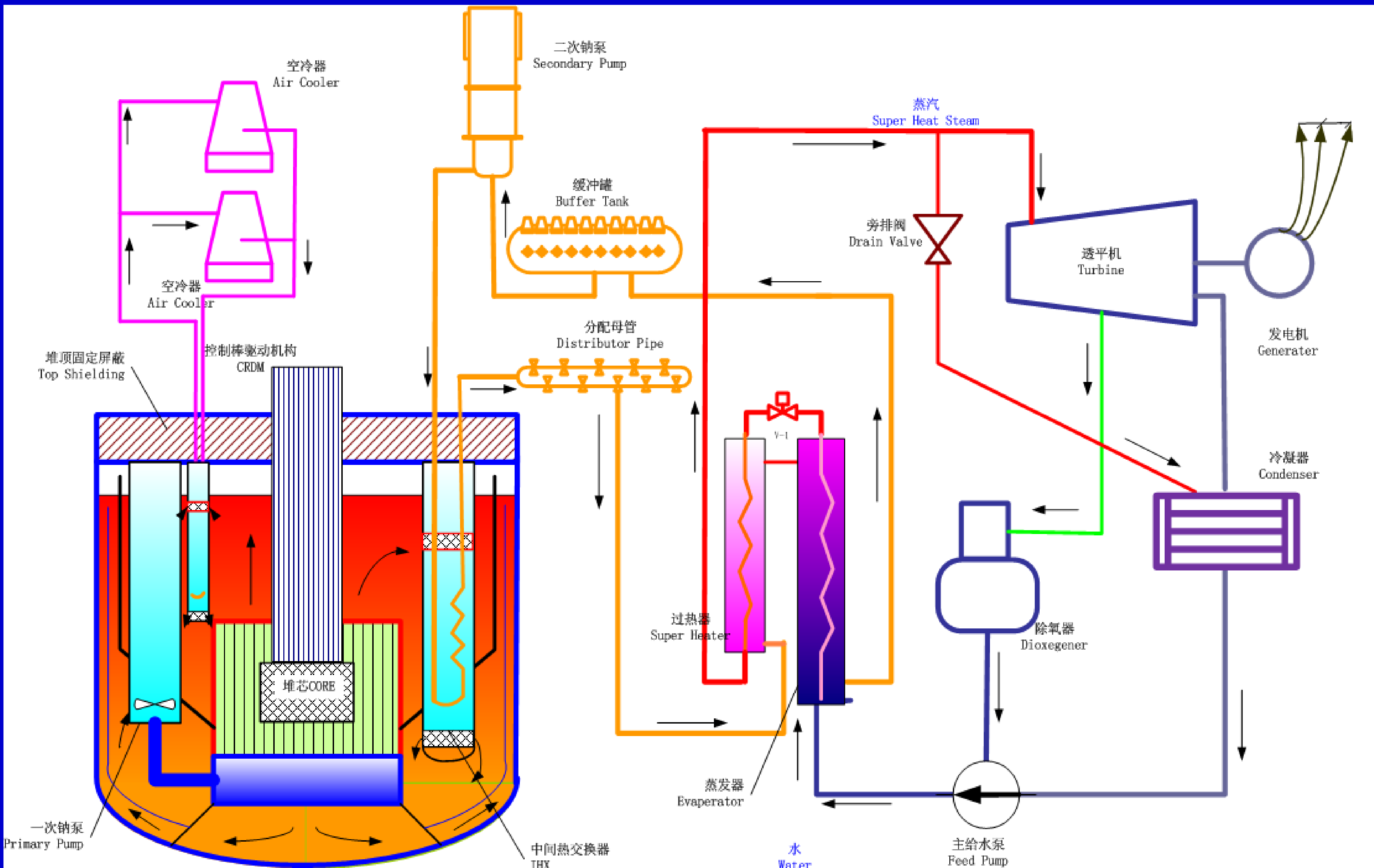
**Project two: 2×800MWe import 2013 construction**

**2018/2019 commissioning**

# CDFR-1000

- Power: 2500MWt/1000MWe
- Fuel: MOX
- BR:1.2
- Sodium
- Number of loops：3
- Turbine generator: 1
- Safety:
  - Core molten probability: $10^{-6}$ reactor a
  - Radioactivity over release；$10^{-8}$reactor a

Plant life: ≥40a



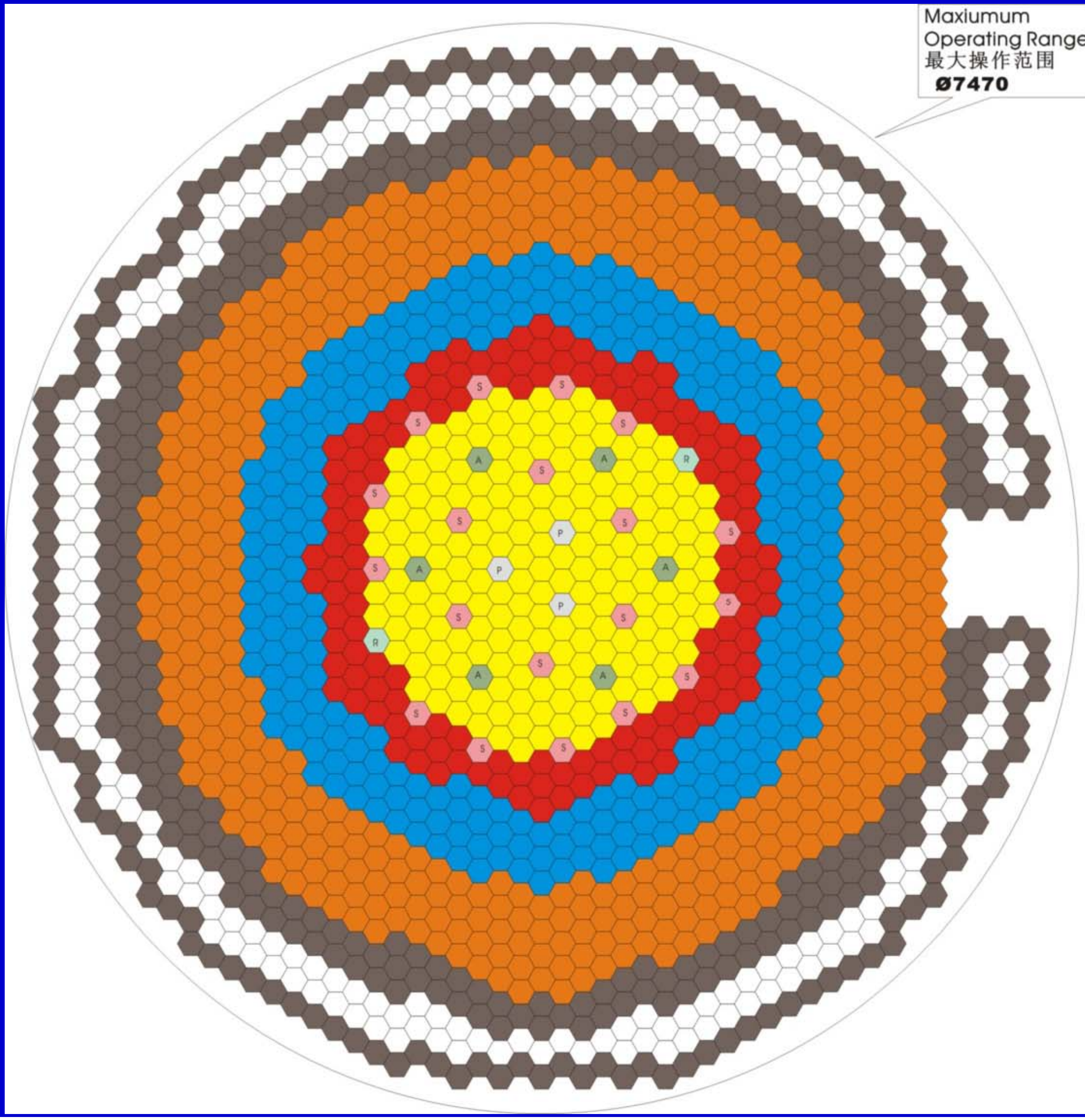

# CDFR-1000 Flowchart

# CDFR-1000 Main parameters

| Parameter | Value |
|---|---|
| Thermal power | 2500 MWt |
| Electric power | 1000 MWe |
| Efficiency | 40% |
| Capability factor | 80% |
| Plant life | ≥40 |
| Fuel | MOX |
| Coolant | Sodium |
| Primary structure | Pool |
| Burn-up av. | 66 MWd/kg |
| Burn-up max. | 100 MWd/kg |
| BR | 1.2 |
| Fuel S.A. inner/outer | 184/132 |
| Pu content, inner/outer | 15.3%/19% |
| Linear power, av./max | 29.3/49 kW/m |
| No. of Fuel S.A. | 316 |
| No. of pins per S.A. | 271 |

| Parameter | Value |
|---|---|
| Total control rod<br>Safety/Shim/Regulation rod<br>Passive shout-down rod | 30<br>6/19/2<br>3 |
| Radial blanket S.A. | 255 |
| No. of reflector S.A. | 426 |
| No. spent S.A. position | 381 |
| Inner dia. of main vessel | 14000 mm |
| Thick of main vessel | 30 mm |
| Outlet/Inlet temperature | 354/547℃ |
| Outlet/Inlet temperature of primary sodium | 544/352℃ |
| Flow-rate of primary Na | 10100 kg/s |
| No. of pri./second. loop | 3/3 |
| pump No. of per loop | 1/1 |
| IHX No. of per loop | 2 |

# CDFR-1000 core




| Fig. 示意图 | Name of Assembly 组件名 | No 数量. |
|---|---|---|
| | Inner Core Fuel Assembly 内堆芯燃料组件 | 184 |
| | Outer Core Fuel Assembly 外堆芯燃料组件 | 132 |
| | Blanket Assembly 转换区组件 | 255 |
| | Reflector Assembly 反射层组件 | 446 |
| | B4C Shielding Assembly 碳化硼屏蔽组件 | 390 |
| | Spent Fuel Storage 乏燃料区 | 211 |
| S | Shim Rod 补偿棒 | 19 |
| R | Regulator ASSEMBLY 调节棒 | 2 |
| P | Passive Shutdown Rod 非能动停堆棒 | 3 |
| A | Safety Rod 安全棒 | 6 |

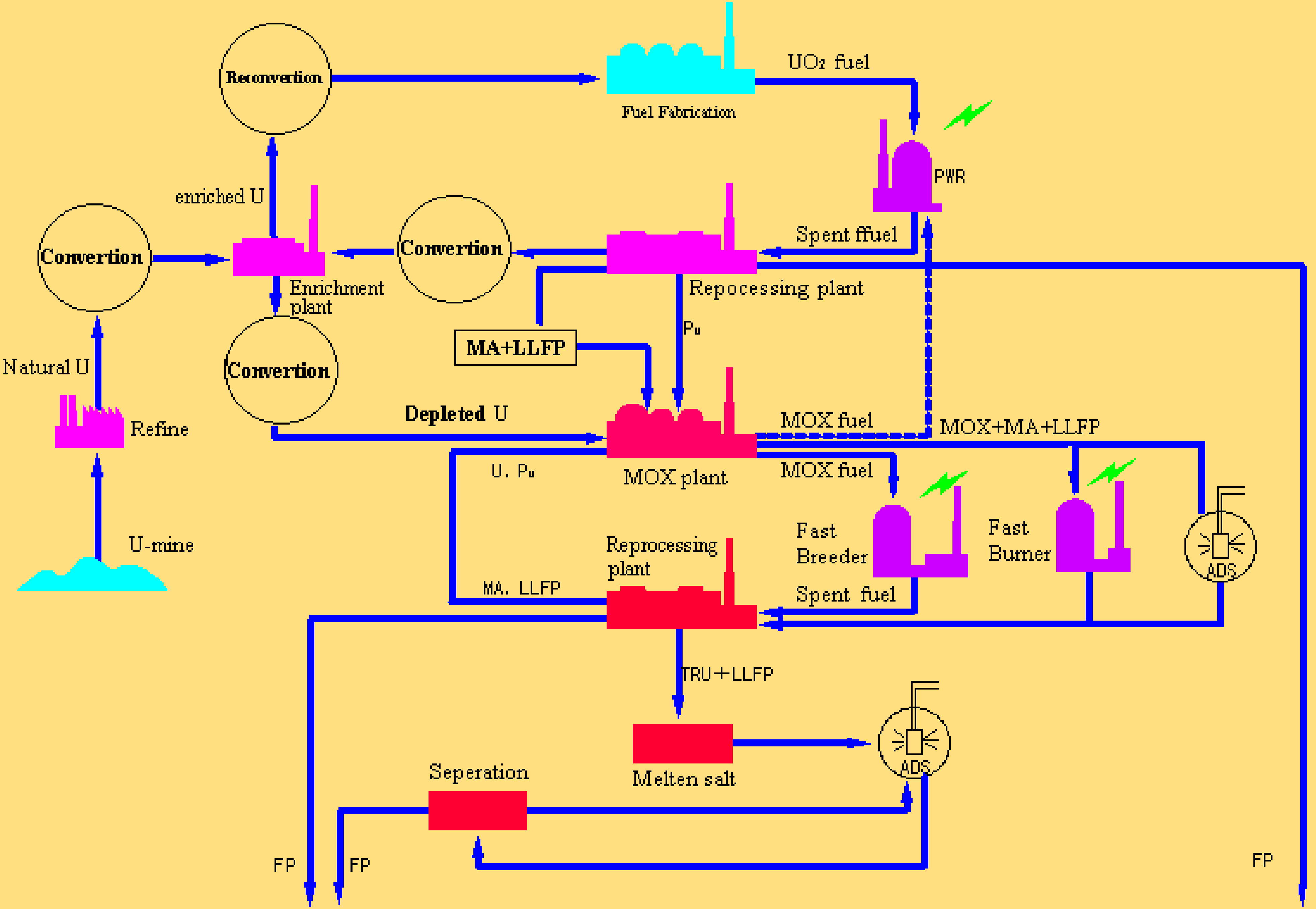
# 5 China Demonstration Fast Breeder Reactor

- **Power： 1200MWe；**
- **Fuel：U-Pu-Zr；**
- **Breeding Ratio:≥1.5；**
- **Following the GⅣ demands.**

# 6 Fast Reactor Fuel Cycle Consideration

## Overall Target

- Uranium resources should be sufficiently utilized including by-products Pu and MA
- The volume of high radioactive wastes to be geologically buried should be as less as possible




# Closed Fuel Cycle Envisaged

**The target fuel cycle for FBR is in-site, metal fuel closed cycle. MOX fuel closed cycle only as transit and standby for Fast Breeders or Burner reactors.**

- **Non-proliferation**

**Multi-reactor units in one site and in-site fuel closed cycle for fast reactors to facilitate enforcing security have been selected in the fast reactor development strategy.**

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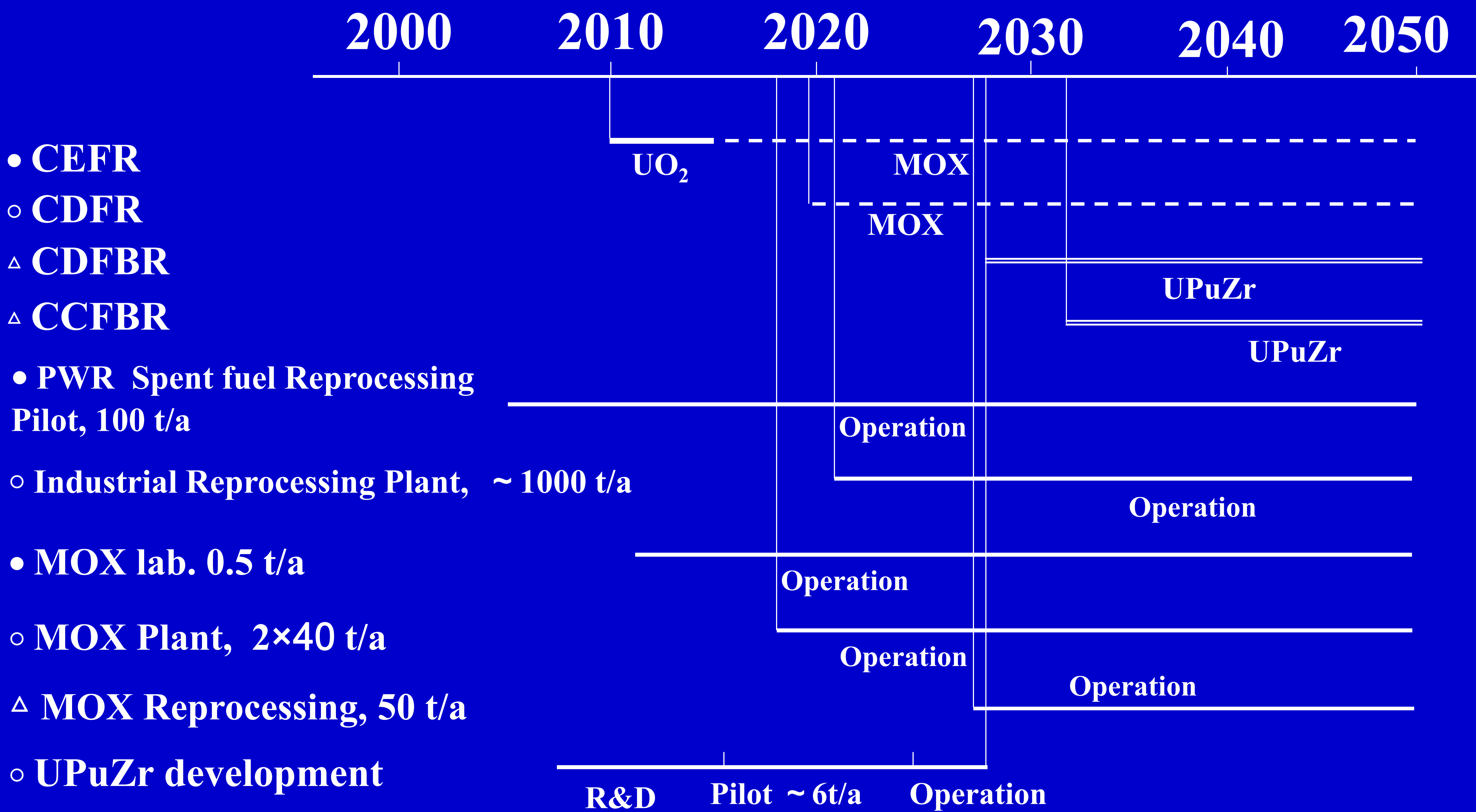


• **Execution** ○ **Application** △ **Consideration**

# 7 Summary

China needs a huge nuclear power capacity in future. Her first phase of nuclear energy application is rather quick for development with PWRs from now, the second phase, i.e. fast reactor development is still at its experimental stage. China has taken part in the INPRO ,GIF and GNEP, and is willing to have more cooperation with IAEA and other countries to share each other the experiences, and to speed up the national nuclear power development.