

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

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XU MI

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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,

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 growing 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	UO₂ MOX	MOX Metal	Metal	MOX+Ac Metal+Ac
Cladding	Cr-Ni	Cr-Ni, ODS	Cr-Ni, ODS	Cr-Ni, ODS
Core Outlet Temp.°C	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

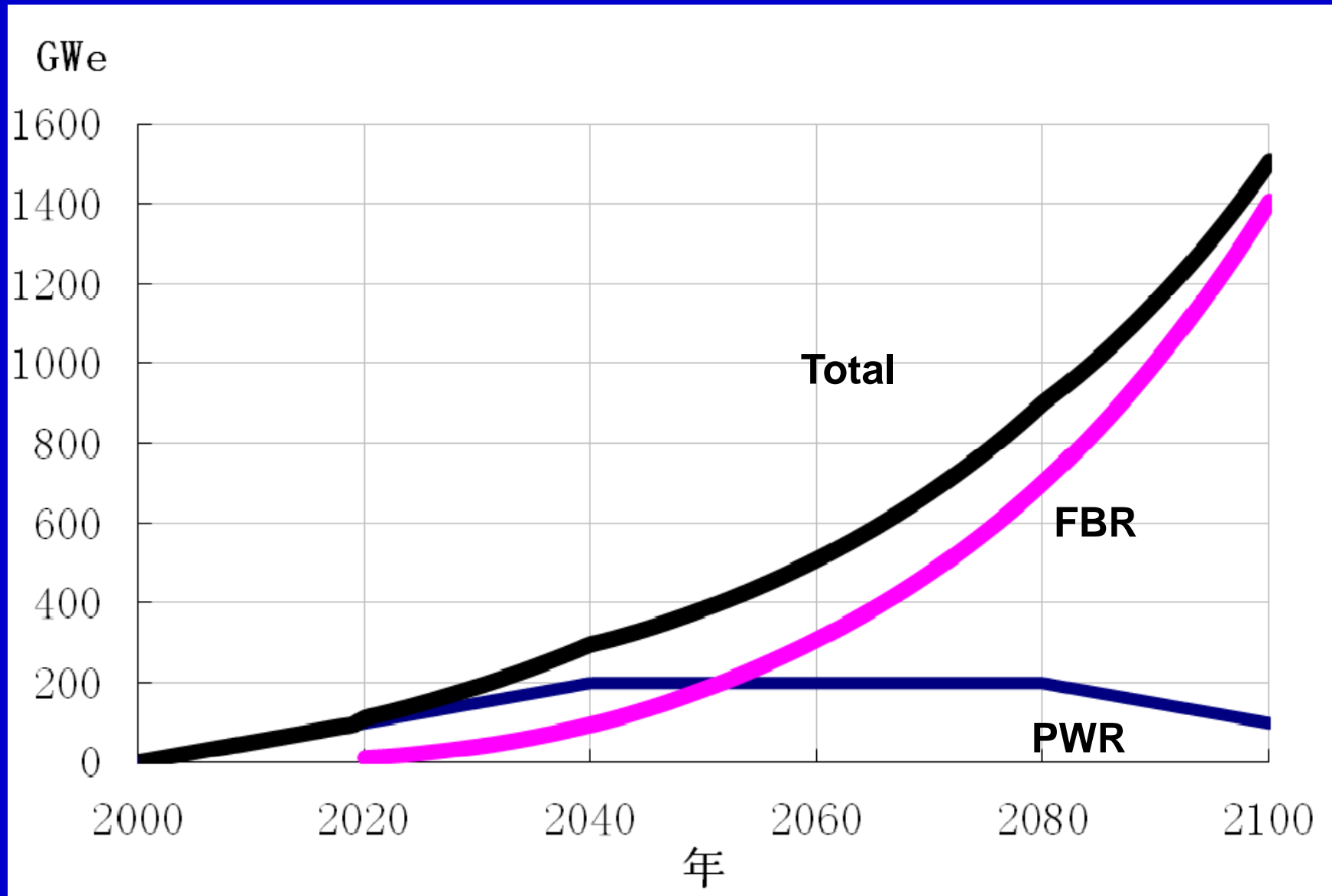
WPSS: Water pool Secondary Storage

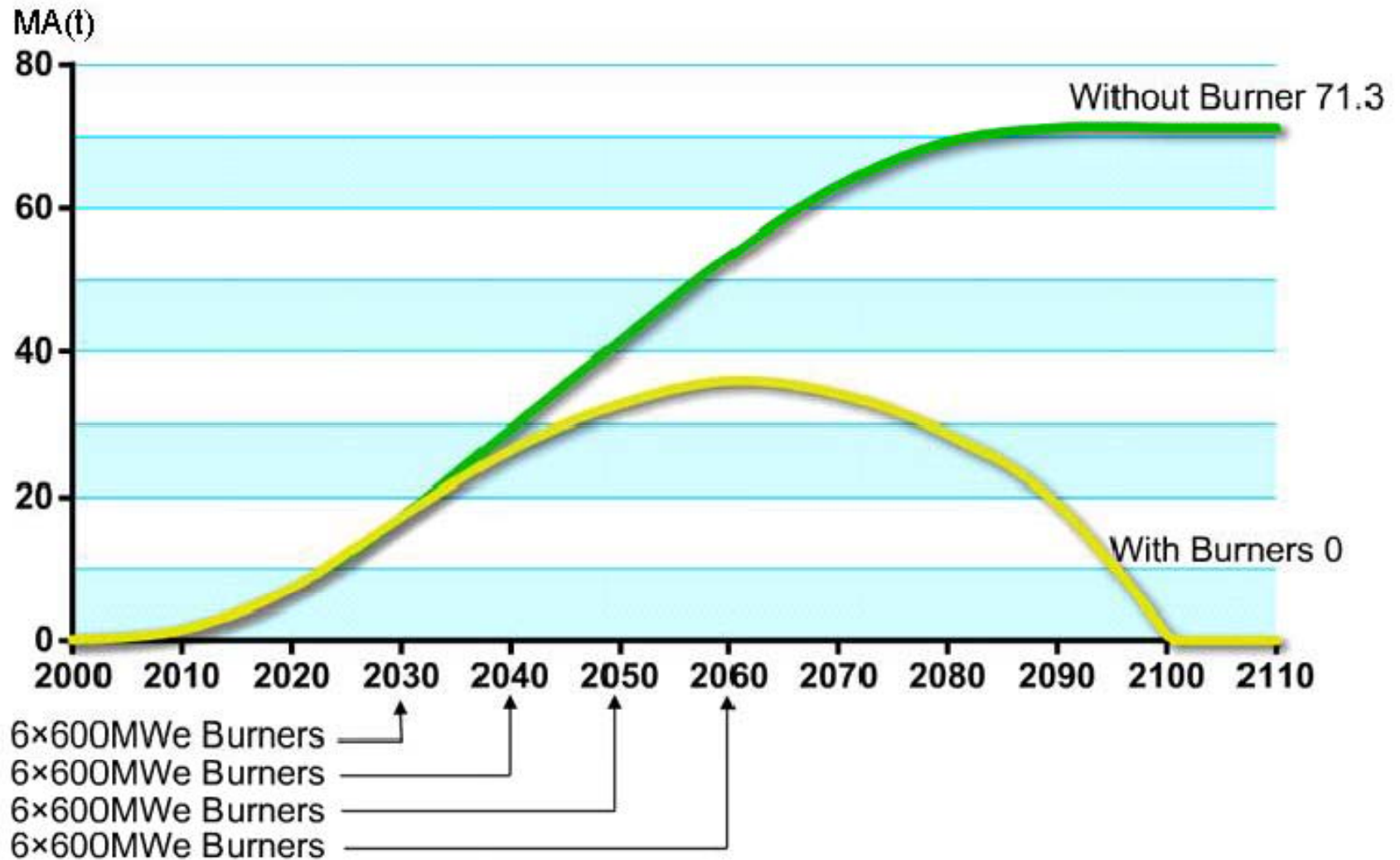
ASDS: Active Shut-Down System

PSDS: Passive Shut-Down System

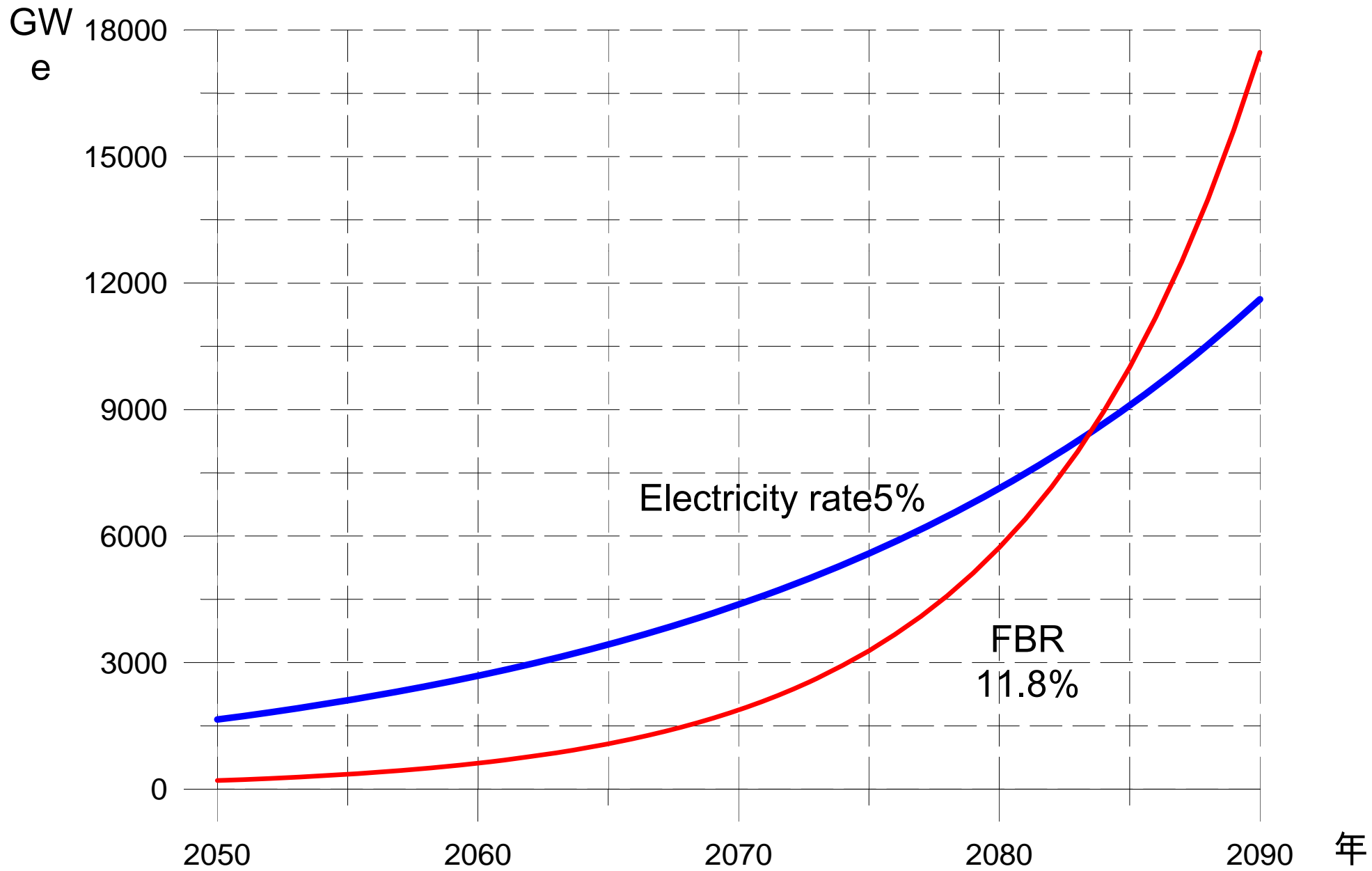
PDHRS: Passive Decay Heat Removal System

- Uranium:3000 kt ,
- FBR:MOX、BR:1.2 , Reprocessing:4a





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

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

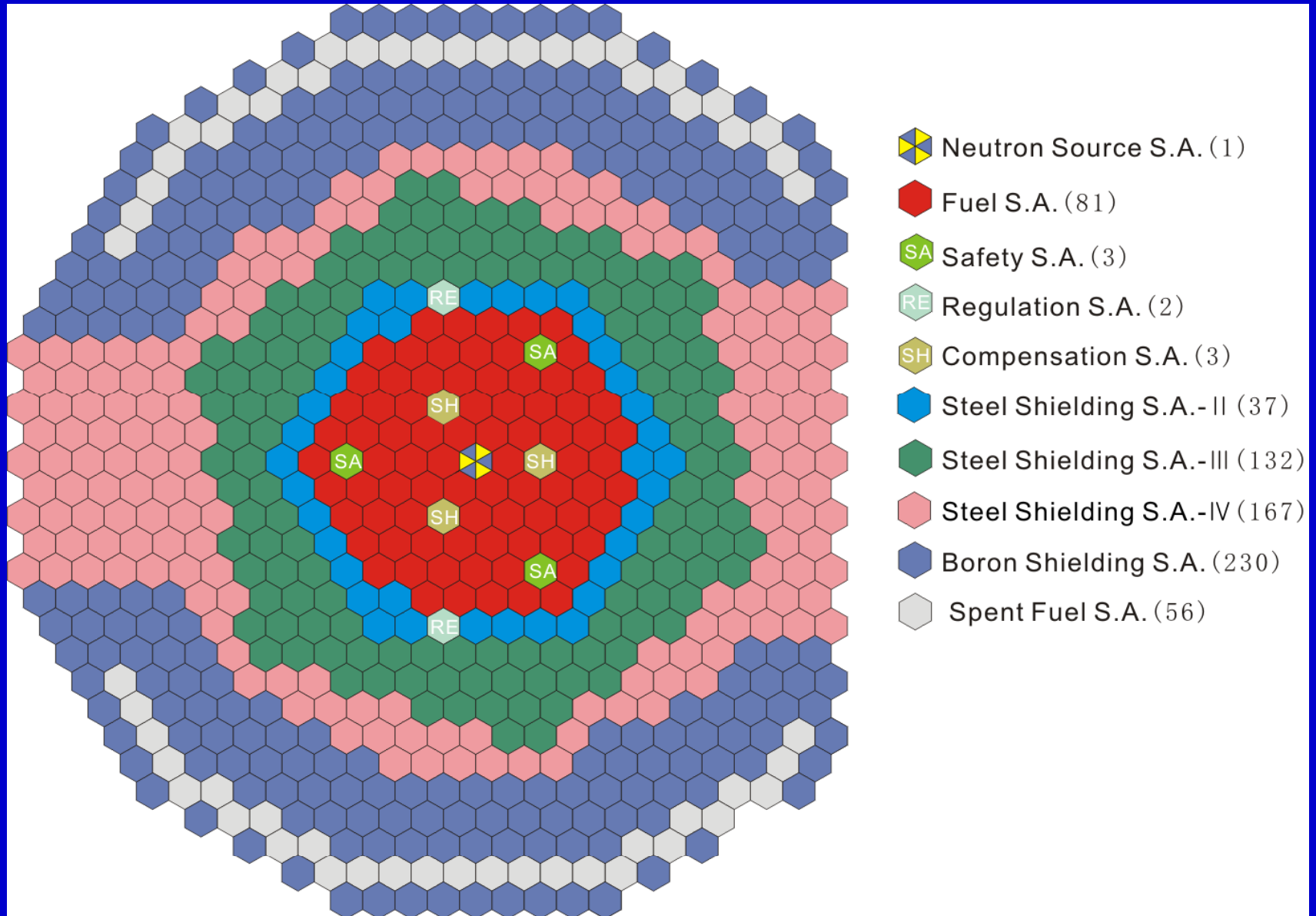
Fuel loading license issued 2009.9

One public letter

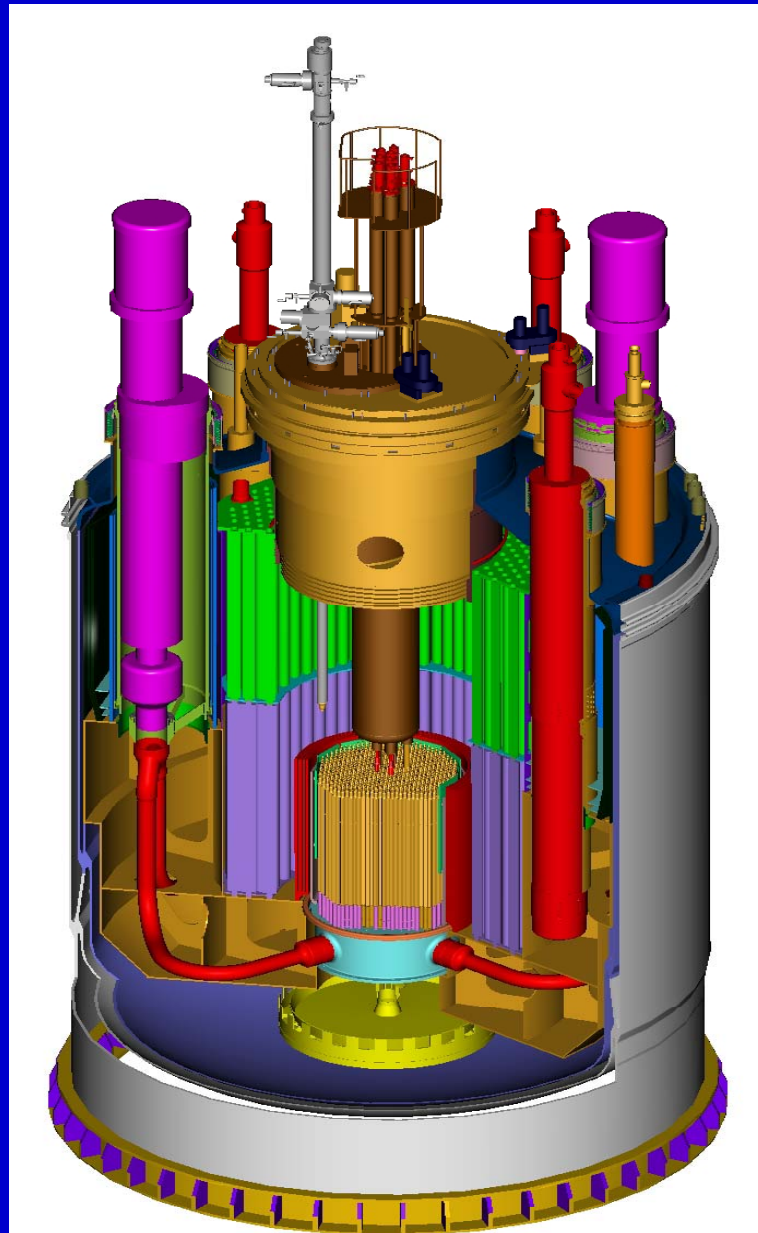
One public letter

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)

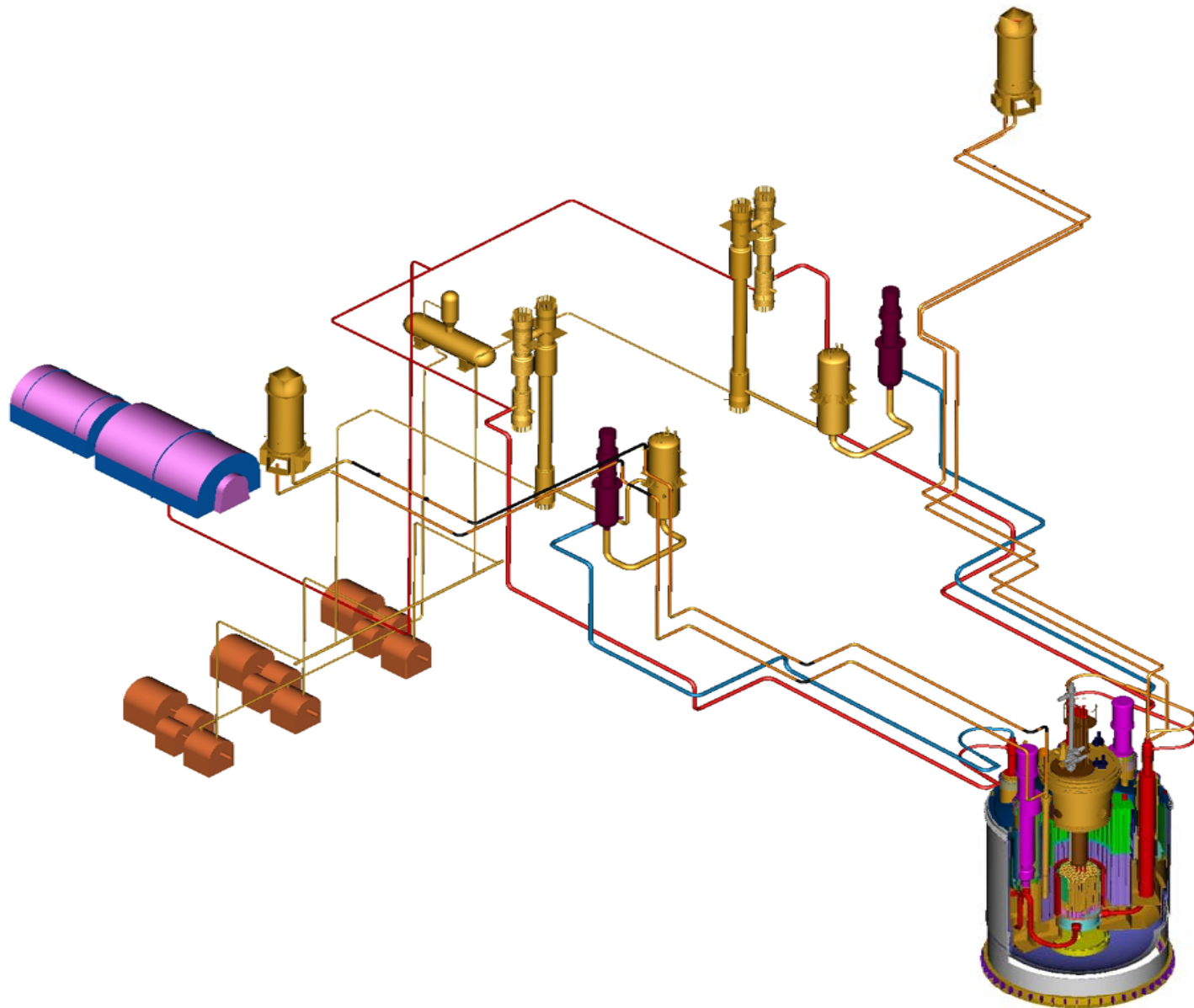
CEFR Introduction



The core of CEFR



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) O₂ / UO₂
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/cm²·s	3.7×10¹⁵
Bum-up, target max.	MWd/t	100000
Bum-up, first load max.	MWd/t	60000
Inlet Temp. of the Core	°C	360
Outlet Temp. of the Core	°C	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	°C	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 - 360°C) - $0.62\beta_{eff}$

Power reactivity effect (360°C 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°C less than boiling
temperature 920°C at the situ pressure, for only ~ 15 sec.**

Max. cladding temperature: 920°C 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 4×10^{-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: ≥ 40 a**











CDFR-1000 Main parameters

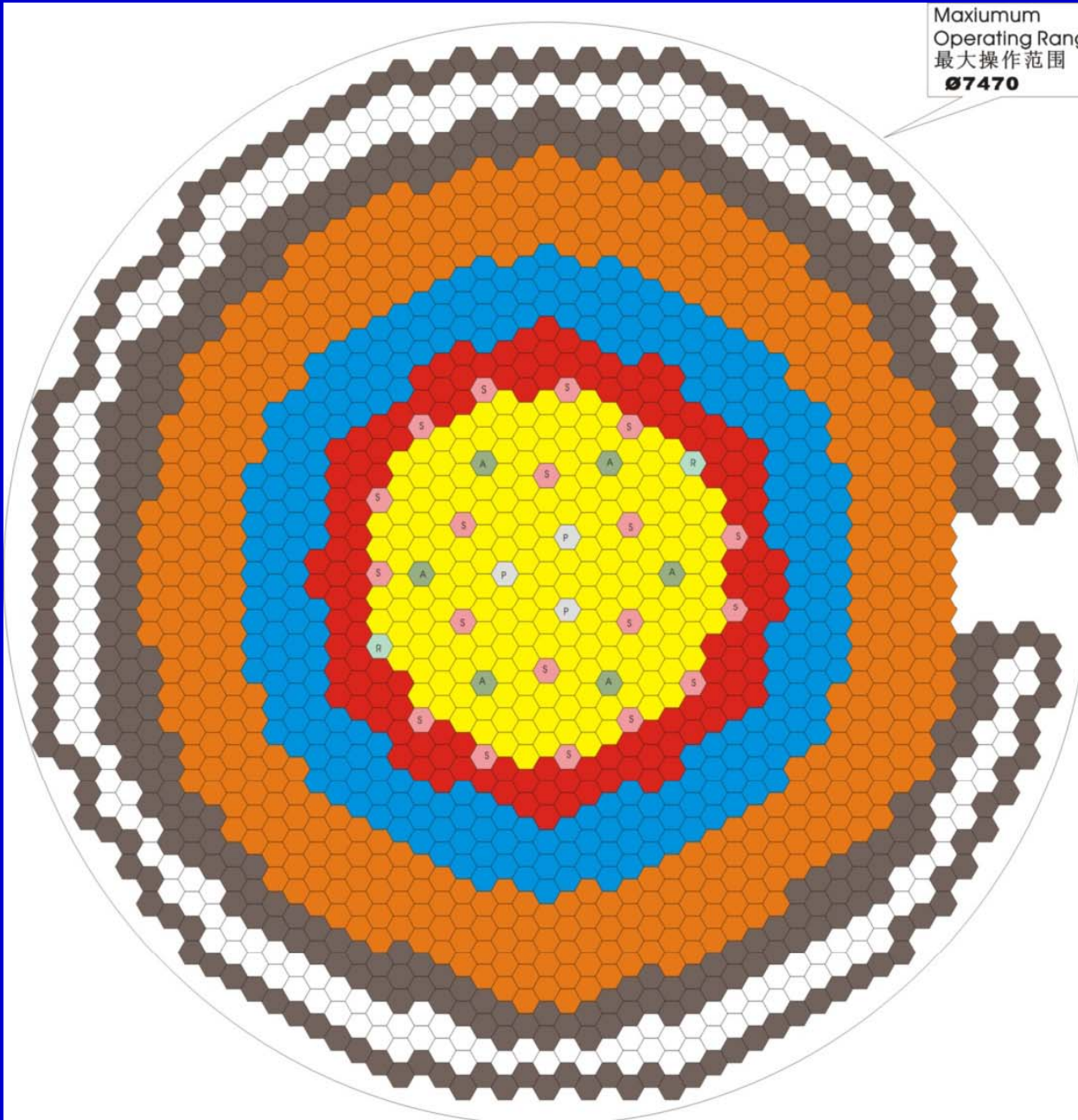
Parameter	Value
Thermal power	2500 MWt
Electric power	1000 MWe
Efficiency	40%
Capability factor	80%
Plant life	≥40
Fuel	MOX
Coolant	Sodium
Primary structure	Pool
Burn-up av.	66 MWd/kg
Burn-up max.	100 MWd/kg
BR	1.2
Fuel S.A. inner/outer	184/132
Pu content, inner/outer	15.3%/19%
Linear power, av./max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

Parameter	Value
Total control rod	30
Safety/Shim/Regulation rod	6/19/2
Passive shut-down rod	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°C
Outlet/Inlet temperature of primary sodium	544/352°C
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

Maximum
Operating Range
最大操作范围
Ø7470

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
	Shim Rod 补偿棒	19
	Regulator ASSEMBLY 调节棒	2
	Passive Shutdown Rod 非能动停堆棒	3
	Safety Rod 安全棒	6



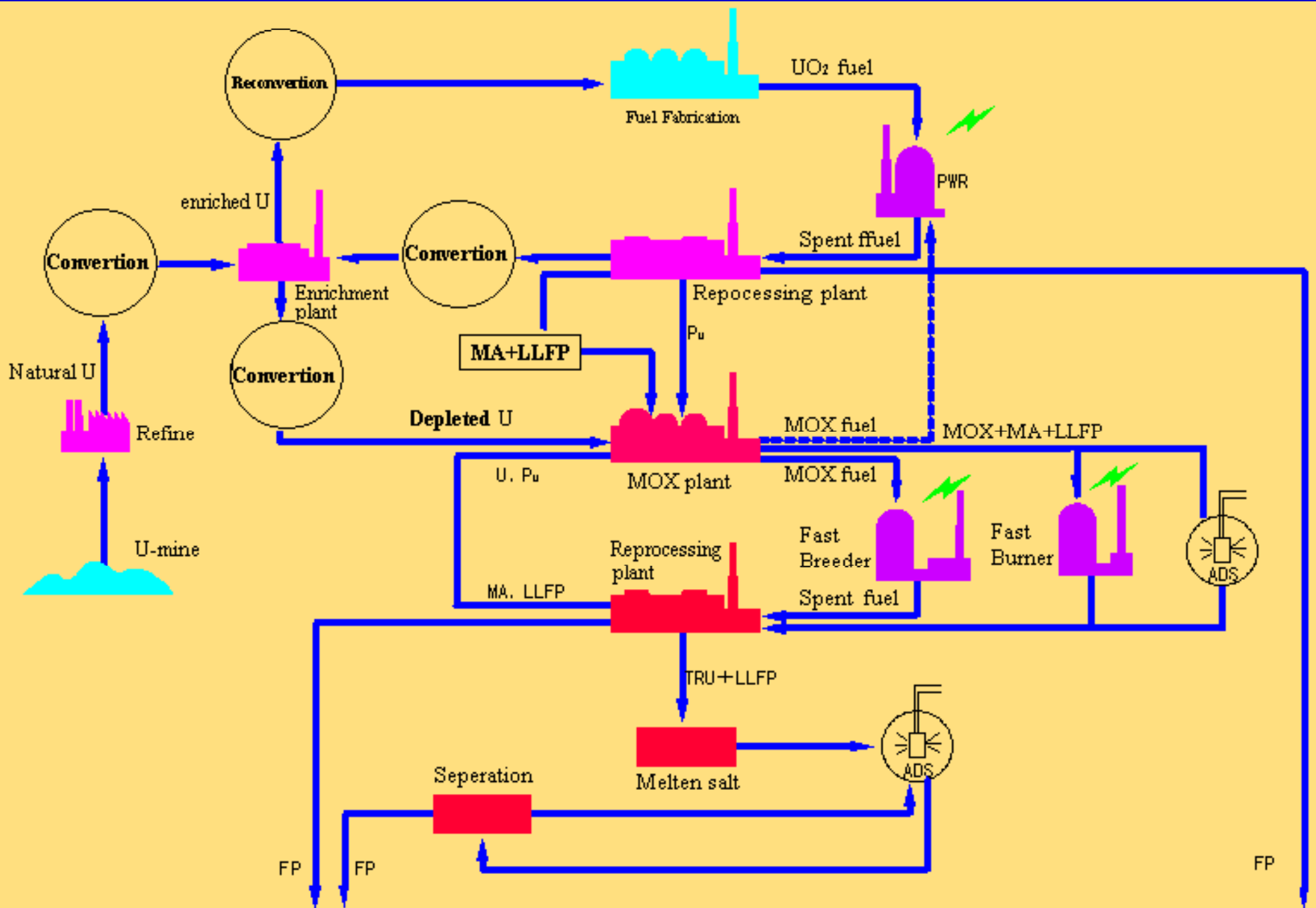
5 China Demonstration Fast Breeder Reactor

- 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**

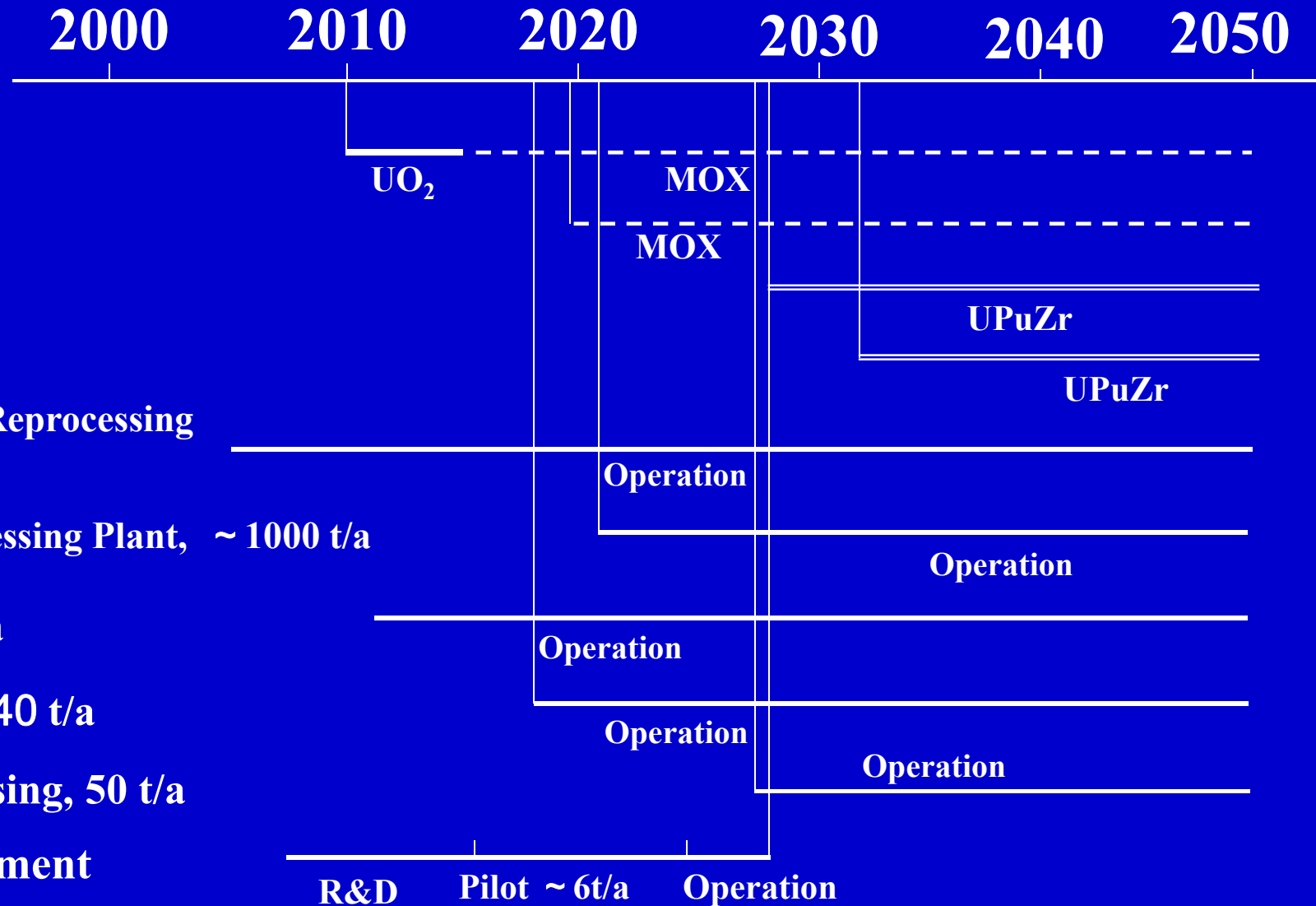


Closed Fuel Cycle Envisaged

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.



- **CEFR**
- **CDFR**
- △ **CDFBR**
- △ **CCFBR**
- **PWR Spent fuel Reprocessing Pilot, 100 t/a**
- **Industrial Reprocessing Plant, ~ 1000 t/a**
- **MOX lab. 0.5 t/a**
- **MOX Plant, 2×40 t/a**
- △ **MOX Reprocessing, 50 t/a**
- **UPuZr development**

● **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.