Fast Reactor Development for a Sustainable Nuclear Energy Supply in China

For the International Conference on Fast Reactors and Related Fuel Cycles- Challenges and Opportunities (FR09)
December 7～11, 2009, Kyoto, Japan

XU MI
China Institute of Atomic Energy

2009-11-20

Contents

1 Introduction

Recent years the national economy development and the primary energy production increasing have a rather quick speed in China. Their average annual increasing rates are about 10% for more than ten years.

Nuclear Energy is a new member of the energy resource family in China, but only sharing less than 2% by now.

Status of NPPs in China Mainland

Site	Capacity/Type	Grid Date	Load factor (%)								
			2000	2001	2002	2003	2004	2005	2006	2007	2008
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
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
-2	900MW/PWR	1994.02.07	84.9	89.1	81.6	84.5	73.6	79.44	99.68	88.29	86.39
Qinshan II -1	600MW/PWR	2002.02.01			74.9	81.0	82.2	92.76	55.20	65.69	87.38
-2	600MW/PWR	2004.03.11						85.19	90.30	90.70	86.48
Lingao -1	984MW/PWR	2002.04.05			92.0	76.8	87.76	82.69	89.16	82.65	90.79
-2	984MW/PWR	2002.12.15				85.0	79.9	90.57	91.89	87.31	84.56
Qinshan III -1	700MW/PHWR	2002.11.10				90.2	77.3	84.05	98.20	88.35	93.48
-2	700MW/PHWR	2003.06.12				90.4	94.0	81.05	88.70	99.87	89.34
Tianwan -1	1000MW/PWR	2006.06								65.59	74.43
-2	1000MW/PWR	2006.12								78.76	85.50
Total	8.6GWe										

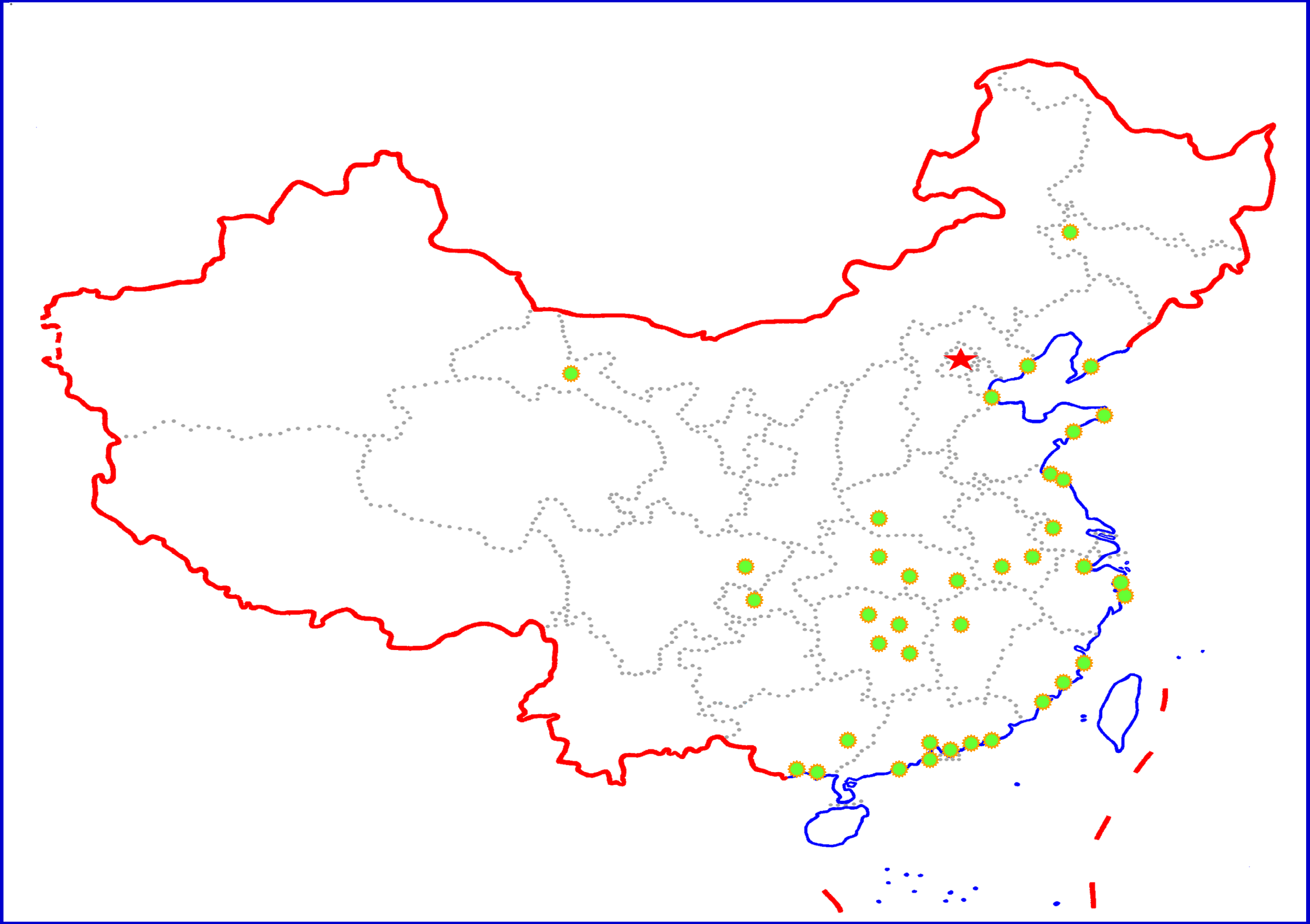
The average load factor over 67 unit ·years is 85.8%.

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.

Right now:

19 units with ～ 20GWe under construction.

7 units with ～7GWe under preparing for construction.



Envisaged NPP Sites in Future

From Mr. Pan Ziqiang's PPT on 2007 Chinese Nuclear Society Annual Meeting

The future capacity scale of PWR will depend on Uranium available internal and external. Uncertainty is obviously unavoidable.

2. The Strategy Study of China FBR Development

Envisaged Primary Energy Production in China for 2050

	1991 Envisaged			2005—2007 Envisaged	
Energy	Exploitable In 2050	Standard Coal Equivalent (billion tsce)	Total Requirement (billion tsce)	Standard Coal Equivalent (billion tsce)	Total Requirement (billion tsce)
Oil	0.1×10^9t	0.45		0.5	
Gas	1500×10^9m^3			0.3	
Hydraulic	260～370GWe	0.65		0.6	
Coal	3.4×10^9t	2.50		2.5	
Nuclear	240GWe	0.60		0.6	
Others		0.30		0.5	
Total		4.5	4.5	5.0	5.0

For such huge capacity 240 GWe NPPs it is impossible to use only PWRs due to the Uranium resources technically and economically exploited are limited in China or in the world.

And also considering:

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

(2) to decrease the emission of green-house gas.

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	600～900	2007	2018～2020
	CCFR	n×800～900	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	600～900	1000～1500	n×600～900
Coolant	Na	Na	Na	Na
Type	Pool	Pool	Pool	Pool
Fuel	UO_2 MOX	MOX Metal	Metal	MOX+Ac 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

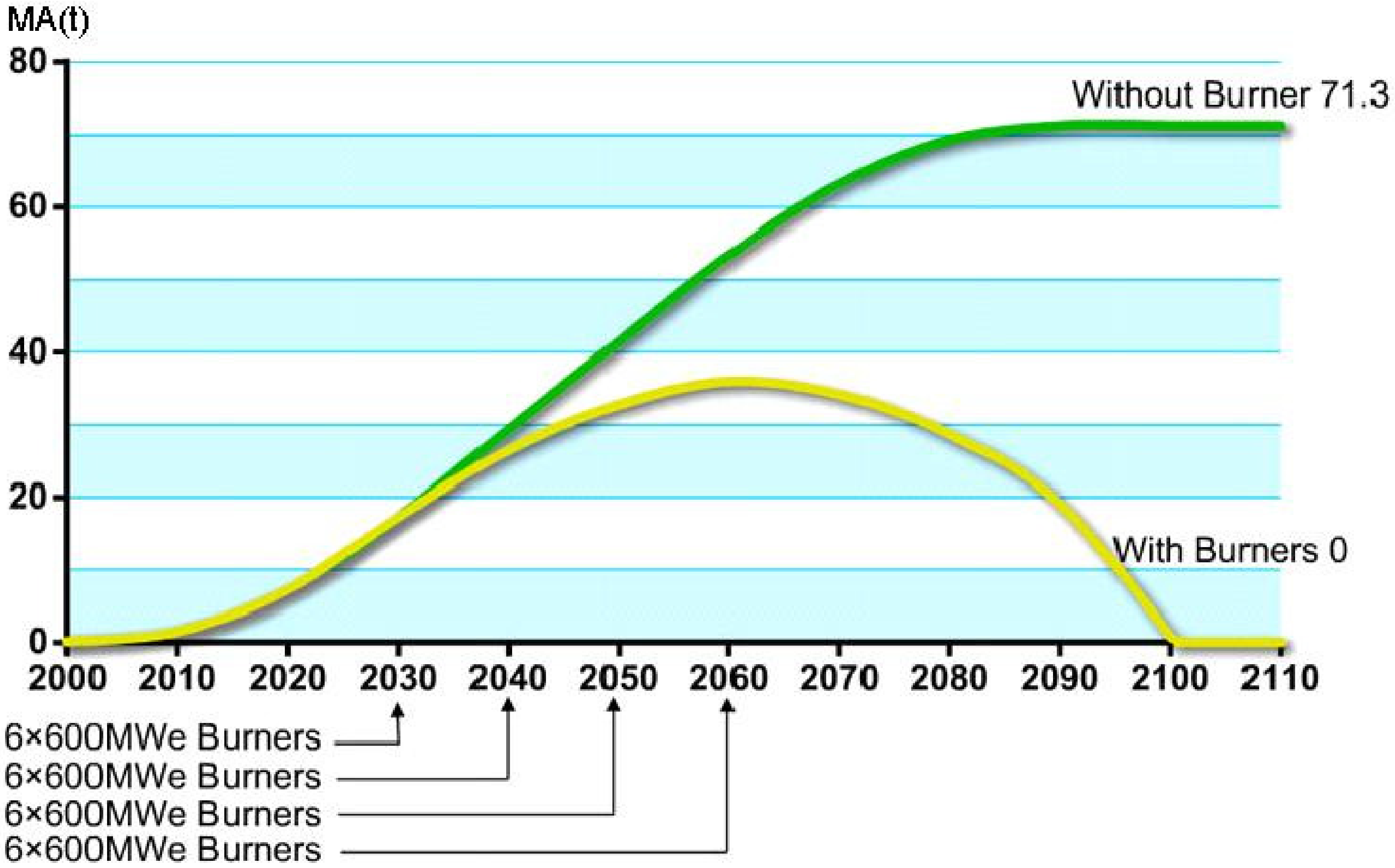
IVPS: In-Vessel Primary Storage

WPSS: Water pool Secondary Storage

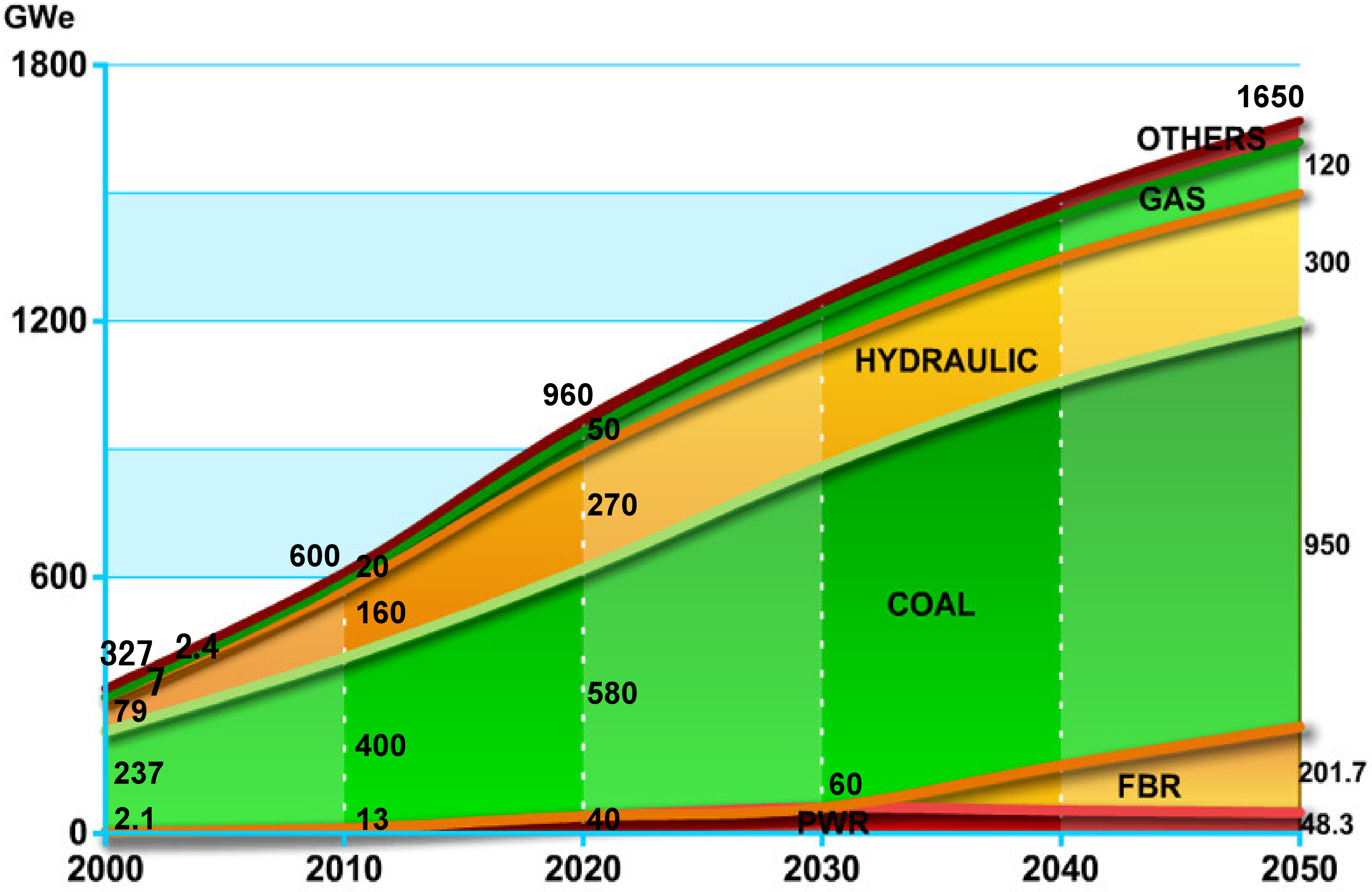
ASDS: Active Shut-Down System

PSDS: Passive Shut-Down System

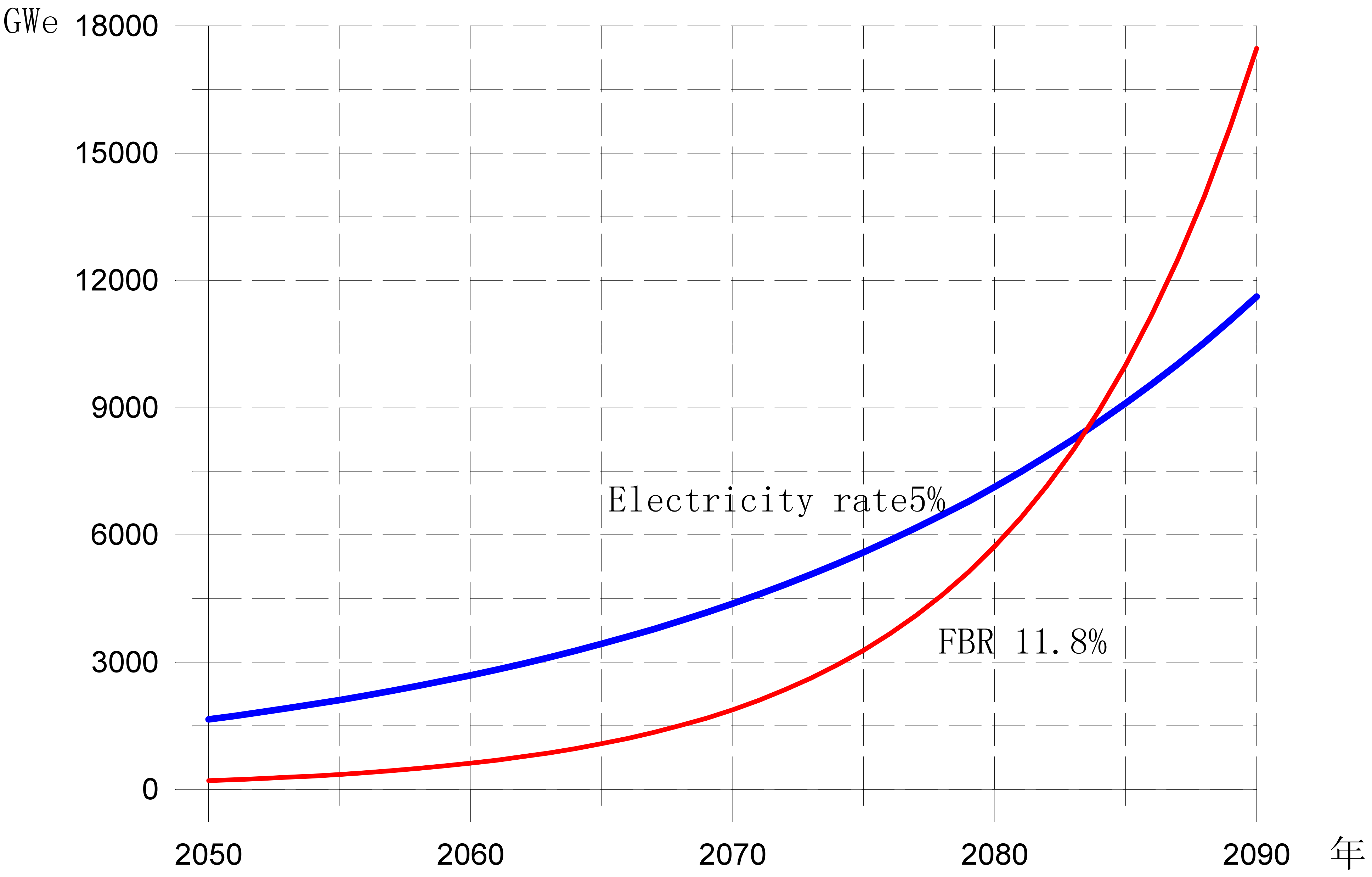
PDHRS: Passive Decay Heat Removal System



MA Transmutation Strategy



Electric Capacity Development Envisaged In China



National electricity and FBR annual increasing rate

Three Strategy Targets:

- 2030　600～900 MWe FBR deployment and operation to support PWR reaching power capacity expected .
- 2050　nuclear capacity will reach 240 GWe or more, sharing around 16% at that year.
- 2050～2100　Nuclear will in large scale replace fossil fuel.

3. Status of China Experimental Fast Reactor

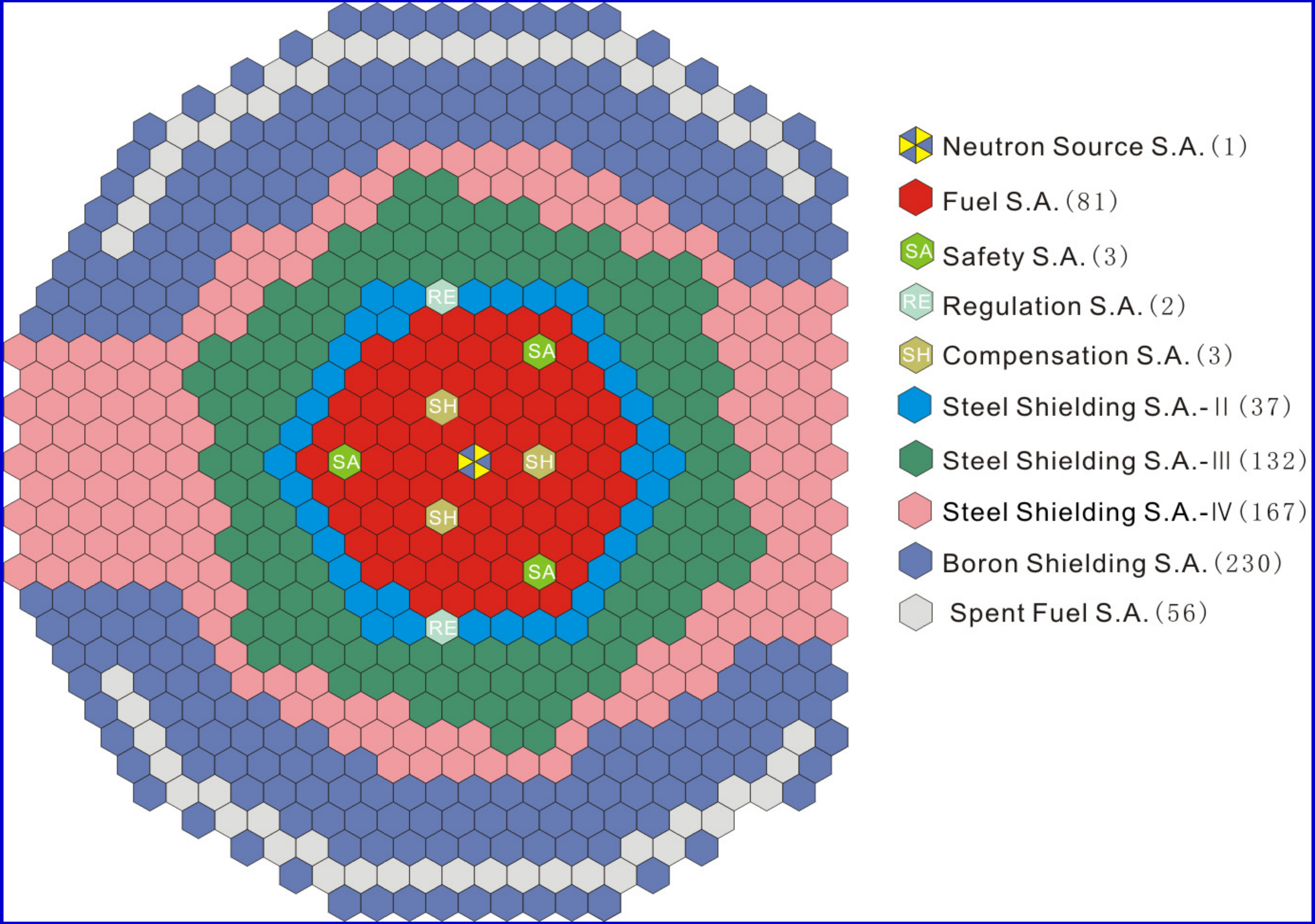
In the framework of the National ‘863’ High-Tech Program the China Experimental Fast Reactor has been executed since 1990.

CEFR timetable

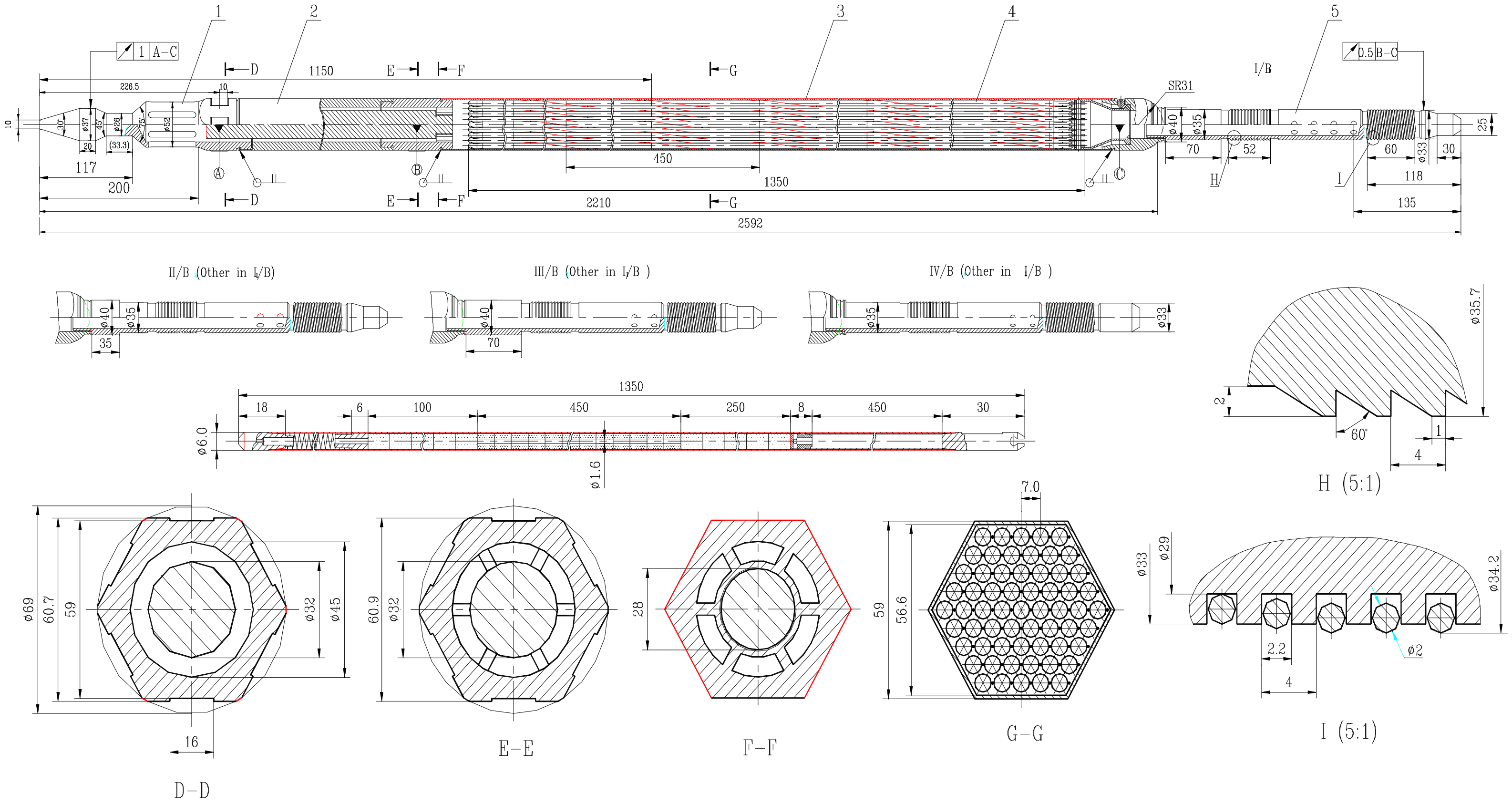
Conceptual Design	1990～1992.7
Consultation with Russian FBR Association and Optimization	1993
Technical Co-Design with R-FBR-A	1994～1995
FBR R&D cooperation with France	1995～Now
Preliminary Design	1996～1997
Ordering Components	1997～2004
Detail Design	1998～2003

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 Systems	**2009.5**

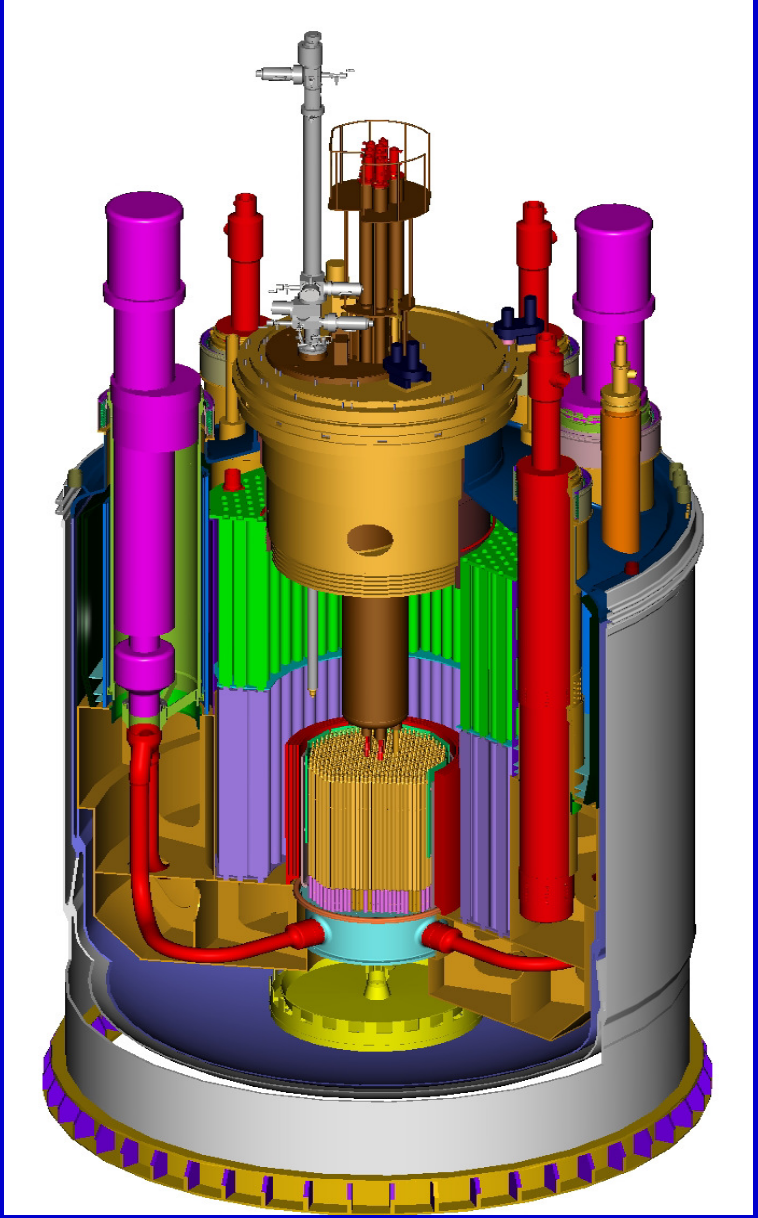
CEFR Introduction



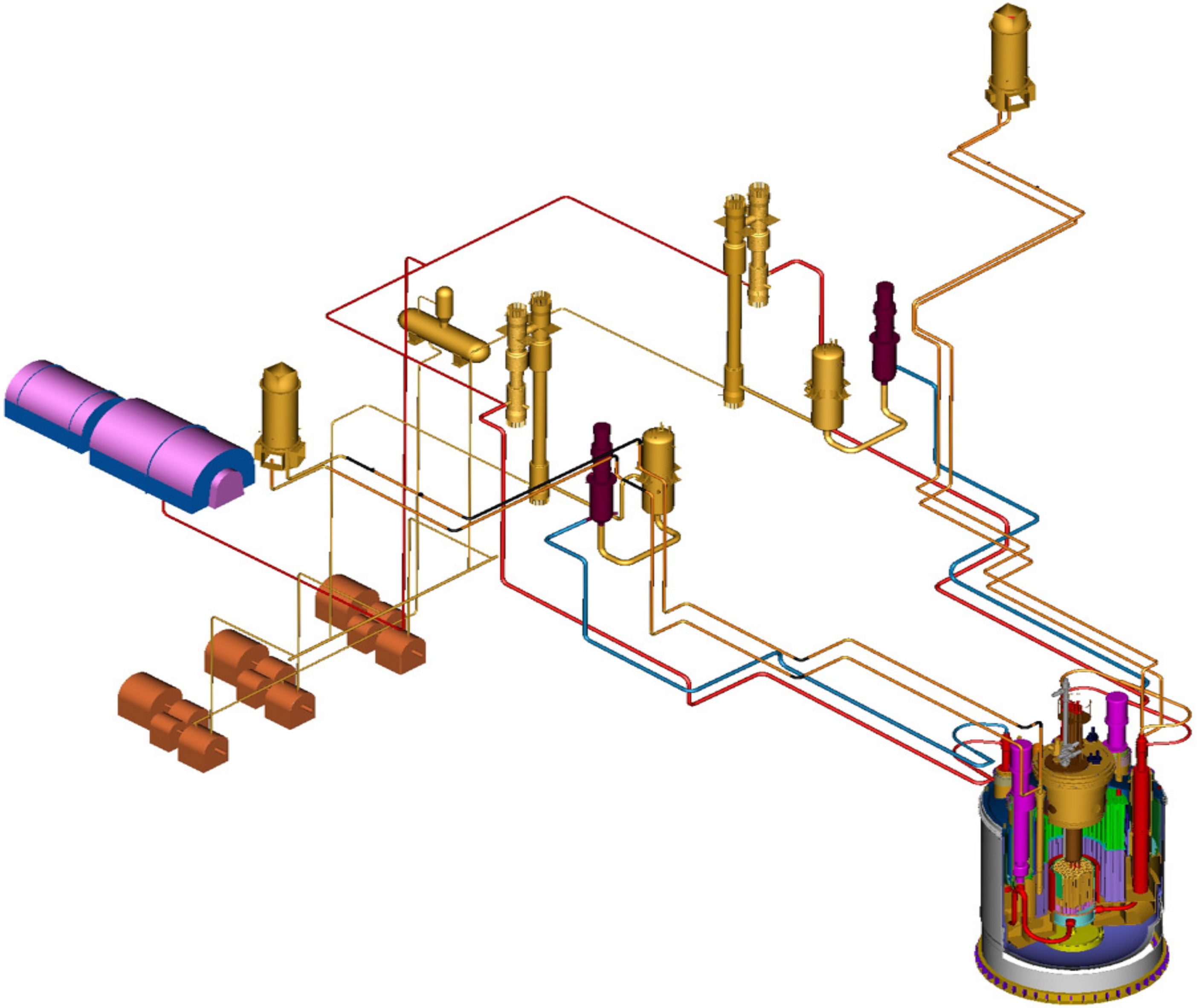
The core of CEFR



CEFR Fuel Subassembly



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	$n/cm^2 \cdot s$	3.7×10^{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

Recent Status of CEFR：

- Installation is completed.
- Pre- operation- cooled and hot testing of more than 98% systems has been completed .
- 336.6t nuclear grade sodium has been transported and filled into reactor block and secondary circuit, purified to about 2 ppm. Their hot testing before fuel loading is finished.
- Now the license by NNSA for physical start-up has been issued in 29th, September,but physical start- up was delayed dut to a public letter.

And planned originally that it will incorporated to the grid with 40% full power in June, 2010, may be need 3 months delay.

Summary on CEFR Safety Characteristics

1）Temperature reactivity effect (250－360ºC) －0.62 β_{eff}

Power reactivity effect (360ºC 0%－100% power）－0.55 β_{eff}

Sodium void reactivity effect (all fuel and upper) －3.9 β_{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	Regulation
Normal operation	0.05 mSv/a	0.25 mSv/a
DBA	0.5 mSv/accident	5 mSv/accident
BDBA	5 mSv/accident	100 mSv/accident

PRA: core molten probability 4×10^{-7}/reactor.a

no requiring site response at any accident,

CEFR Reactor Building Completion Ceremony (2002.08.15)

Nuclear Grade Sodium Receiving System

Reactor block and Main Vessel under Installation

Evaporator Moving to Reactor Building (2005.03)

Sodium Purification plant (2005.10)

Core Reflector Subassembly moving to the core (2008.02.26)

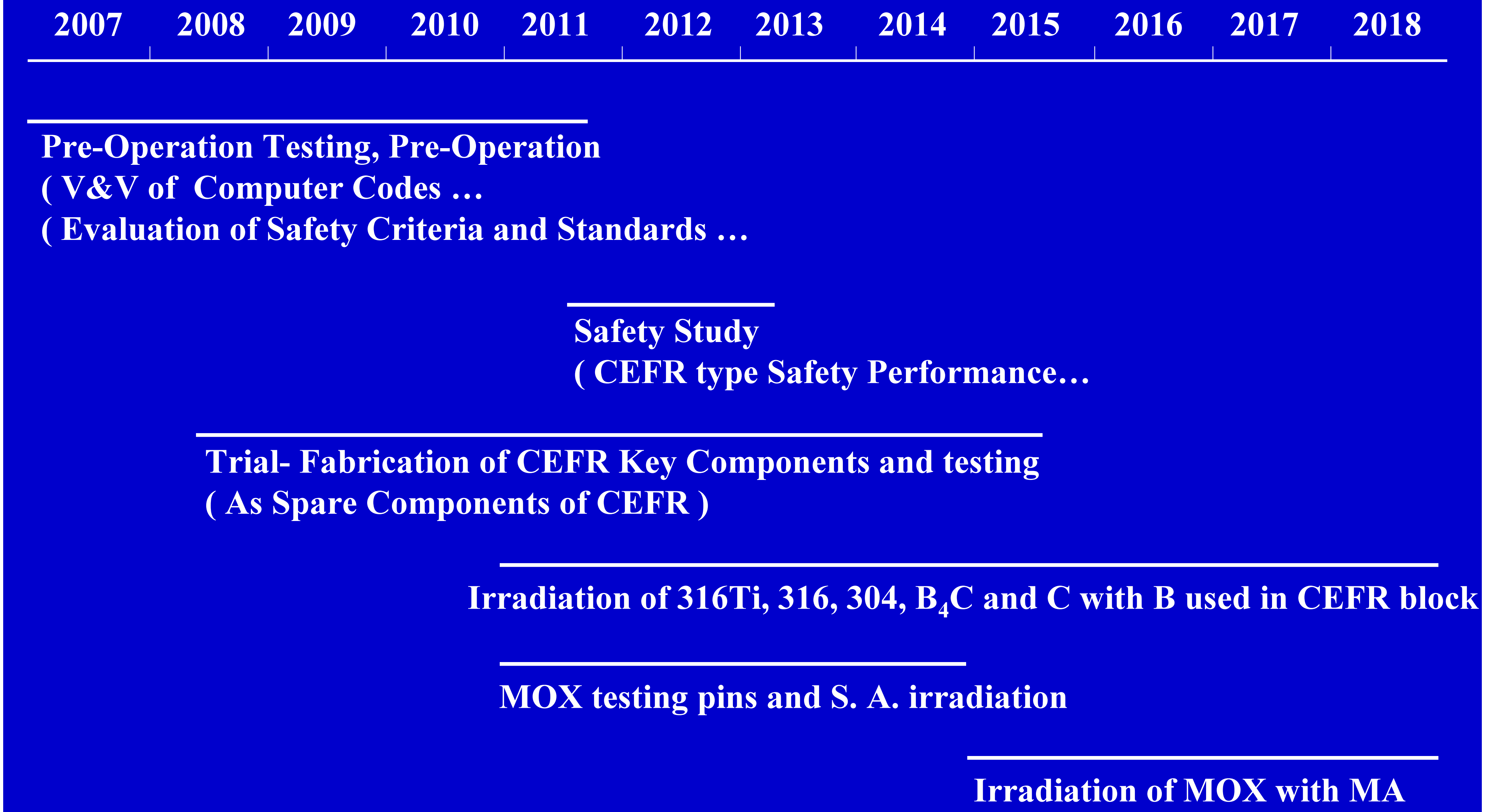
Small rataling plug under installation (2003.03.22)

Turbine under installation (2005.07.21)

CEFR Outside view (2007.10.10)

National Grid comes to the site (2007.01.28)

R&D Activities on CEFR



2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

Pre-Operation Testing, Pre-Operation
(V&V of Computer Codes …
(Evaluation of Safety Criteria and Standards …

Safety Study
(CEFR type Safety Performance…

Trial- Fabrication of CEFR Key Components and testing
(As Spare Components of CEFR)

Irradiation of 316Ti, 316, 304, B_4C and C with B used in CEFR block

MOX testing pins and S. A. irradiation

Irradiation of MOX with MA

4. China Demonstration Fast Reactor

After pre-conceptual design for 600MWe CPFR core It was started to pre- conceptual design for a 800 MWe CDFR.

The general design demands: (1)the safety properties should reach the recommendation for SFR design by IAEA-TECDOC-1083;

(2) the reliability should meet commercial nuclear power plants target; and

(3) the economy should be accepted.

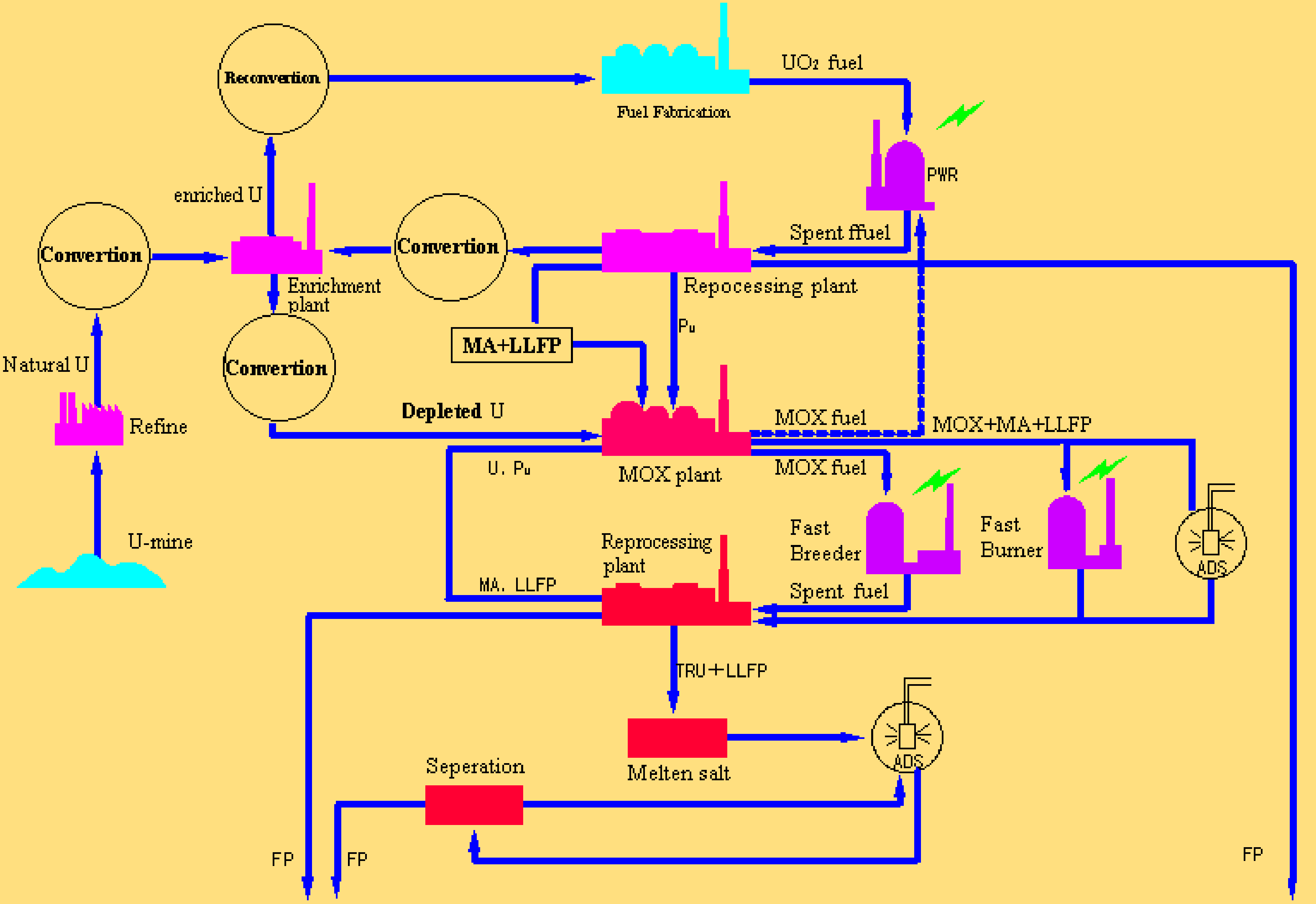
Design Boundary Condition for CDFR

	unit	value
Power	**MWe**	**800**
Fuel		**PuO_2-UO_2**
Outlet Temp. of Primary Na	**℃**	**550**
Linear Power	**W/cm**	**450**
Breeding Ratio		**～1.1**
Burn-up, Target max.	**MWd/kgH**	**120**
First Loading, max.	**MWd/kgH**	**100**
Mean Length of Reactor Run	**d**	**300**
Seismic Intensity, Design	**MSK-64**	**7**
Safety Requirements		
Reactor core Molten Probability		**$<10^{-6}/a$**
Dose Limit at the Site Boundary Not Requiring Short-term of Site Response		**$<10^{-7}/a$**
Frequency of Loss of Shut-down Function		
Frequency of Loss of Decay Heat Removal Function		**$<10^{-7}/a$**
Load Factor	**%**	**>80**
Reactor Life	**a**	**40**

5. 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



Reconvertion

Fuel Fabrication

UO2 fuel

PWR

enriched U

Convertion

Enrichment plant

Convertion

Repocessing plant

Spent ffuel

Natural U

Convertion

MA+LLFP

Pu

Refine

Depleted U

MOX fuel

MOX+MA+LLFP

U. Pu

MOX plant

MOX fuel

U-mine

Reprocessing plant

Fast Breeder

Fast Burner

ADS

MA. LLFP

Spent fuel

TRU+LLFP

Melten salt

ADS

Seperation

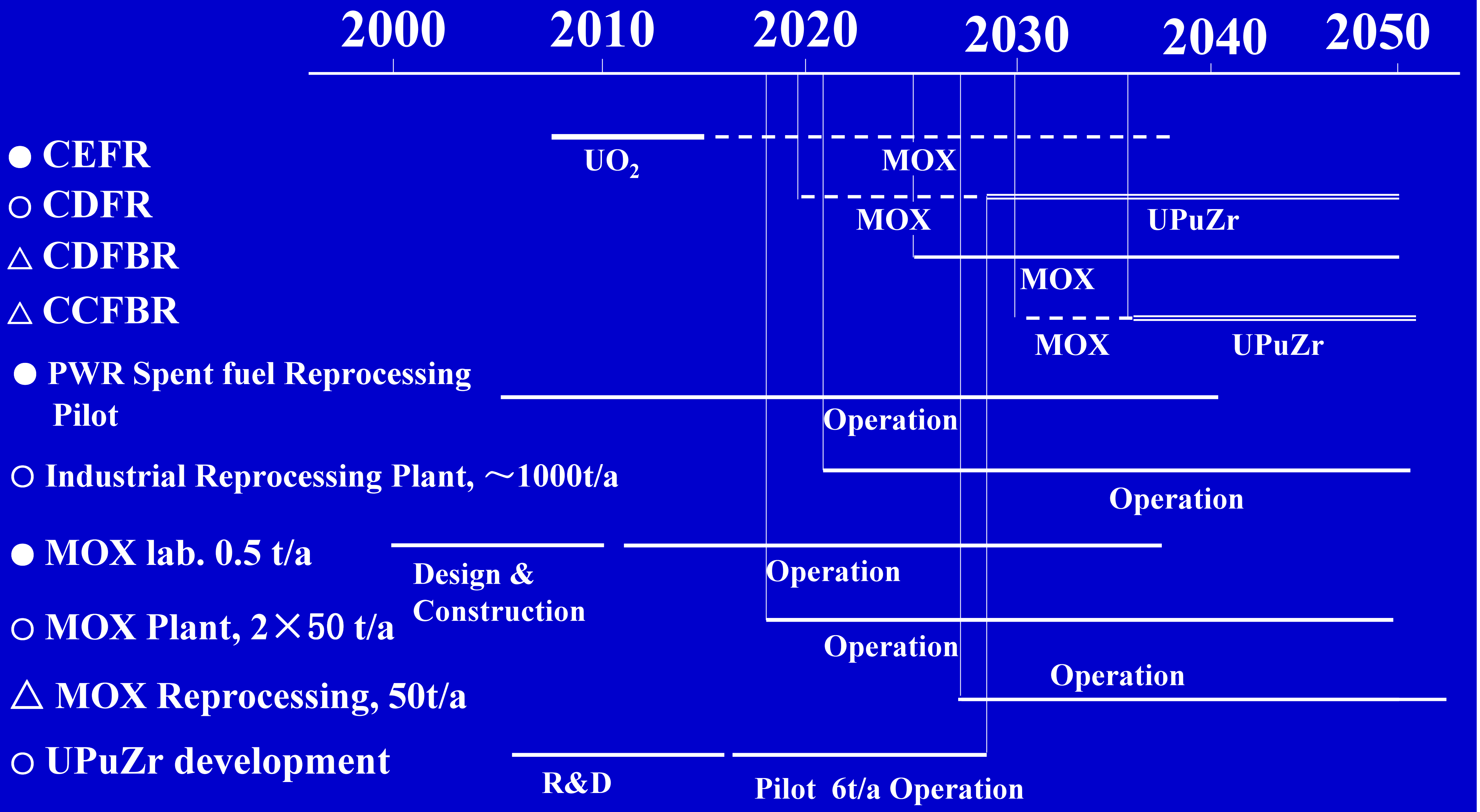
FP

FP

FP

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.



● Execution ○ Application △ Consideration

6. 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.