Status and Prospects of Sustainable Nuclear Power Supply in China

For the GLOBAL 2005 International Conference Nuclear Energy System for Future Generation and Global Sustainability

Oct. 9～13 2005, Tsukuba, Japan

XU MI

China Institute of Atomic Energy, Beijing

2005-09-15

Contents

1. Introduction

Based on the overseas and domestic experiences on nuclear power application, it has been started in China mainland to develop nuclear power plants as a subsidiary role in the regions which are lack of electricity and energy resources.

Status of NPP in China Mainland

Site	Capacity/Type	Grid Date	Load factor (%)				
			2000	2001	2002	2003	2004
Qinshan I	300MW/PWR	1991.12.15	77.2	94.1	66.9	88.6	99.8
Daya Bay -1	900MW/PWR	1993.08.31	85.2	84.9	89.6	89.6	87.2
-2	900MW/PWR	1994.02.07	84.9	89.1	81.6	84.5	73.6
Qinshan II -1	600MW/PWR	2002.02.01			74.9	81.0	82.2
-2	600MW/PWR	2004.03.11					
Lingao -1	984MW/PWR	2002.04.05			92.0	76.8	87.76
-2	984MW/PWR	2002.12.15				85.0	79.9
Qinshan III -1	700MW/PHWR	2002.11.10				90.2	77.3
-2	700MW/PHWR	2003.06.12				90.4	94.0
Tianwan -1	1000MW/PWR	2004.12					
-2	1000MW/PWR	2005.12					

NUCLEAR POWER IN CHINA

Near-Term Program (2005～2006)

— The extension of Qinshan Ⅱ, units 3&4 (2X650MWe), will start construction next year;

— The extension of Lingao, units 3&4 (2X900MWe), will start construction next year.

Mid-Term Program (2007～2015)

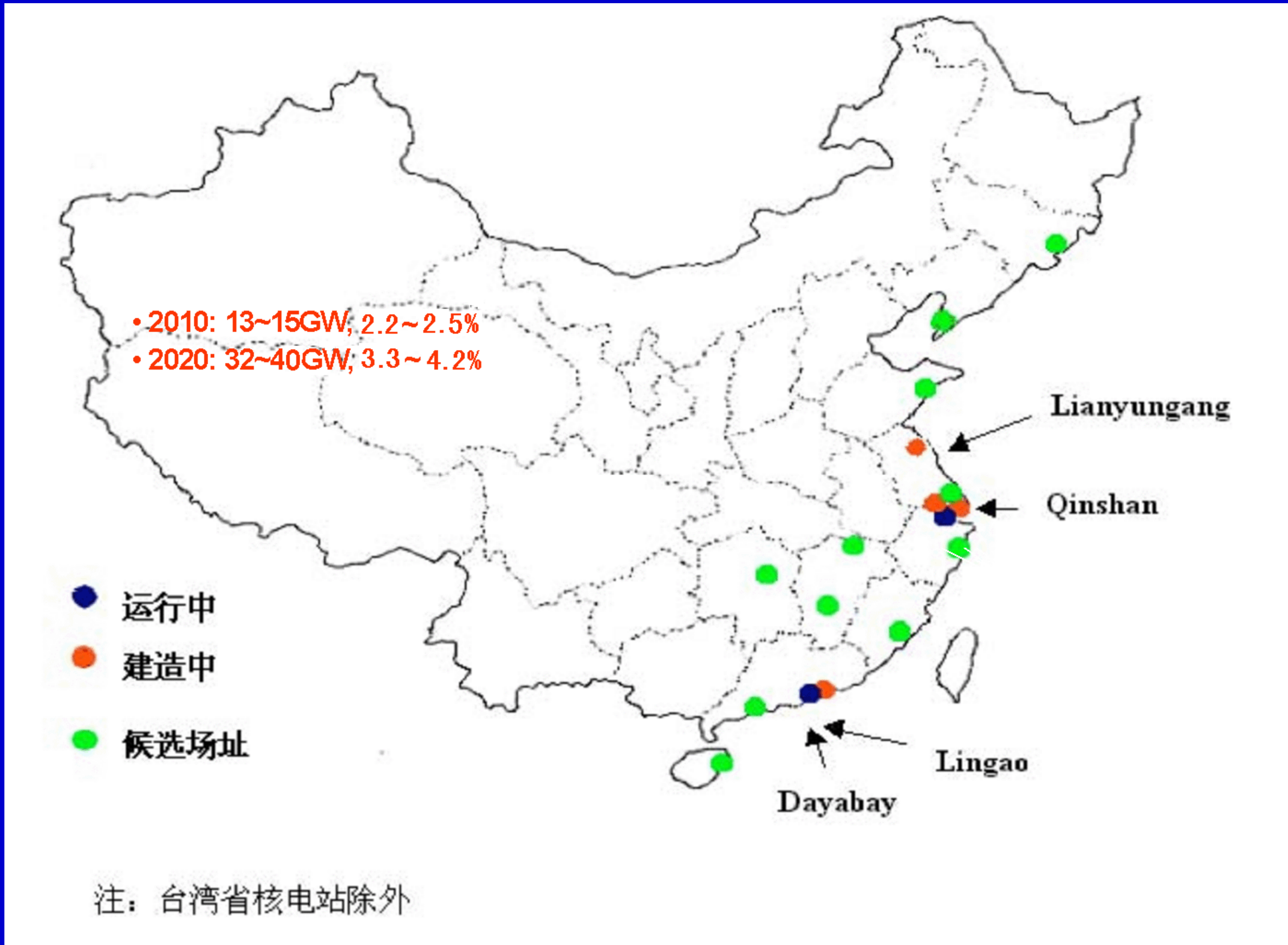
— Tianwan site: 6X 1000～1500MW, PWR;

— Sanmen site: 6X 1000～1500MW, PWR;

— Yangjiang site: 6X 1000～1500MW, PWR.

CHINA INSTITUTE OF ATOMIC ENERGY

NPP Site Resource in China



2. The Strategy Study of China FBR Development

According to the 2006～2020 National Nuclear Development Program Suggestion (to be approved by the Government), the nuclear energy utilization will be further developed in the future:

The total nuclear power capacity will reach 40 GWe in 2020.

Envisaged Primary Energy Production in China for 2050

	1991 Envisaged			2005Envisaged	
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.

In order to estimate the maximum contribution by matched PWR-FBR development, assuming:

(1) the total capacity of PWRs in 2020 and 2030 will reach 32GWe and 50GWe respectively;

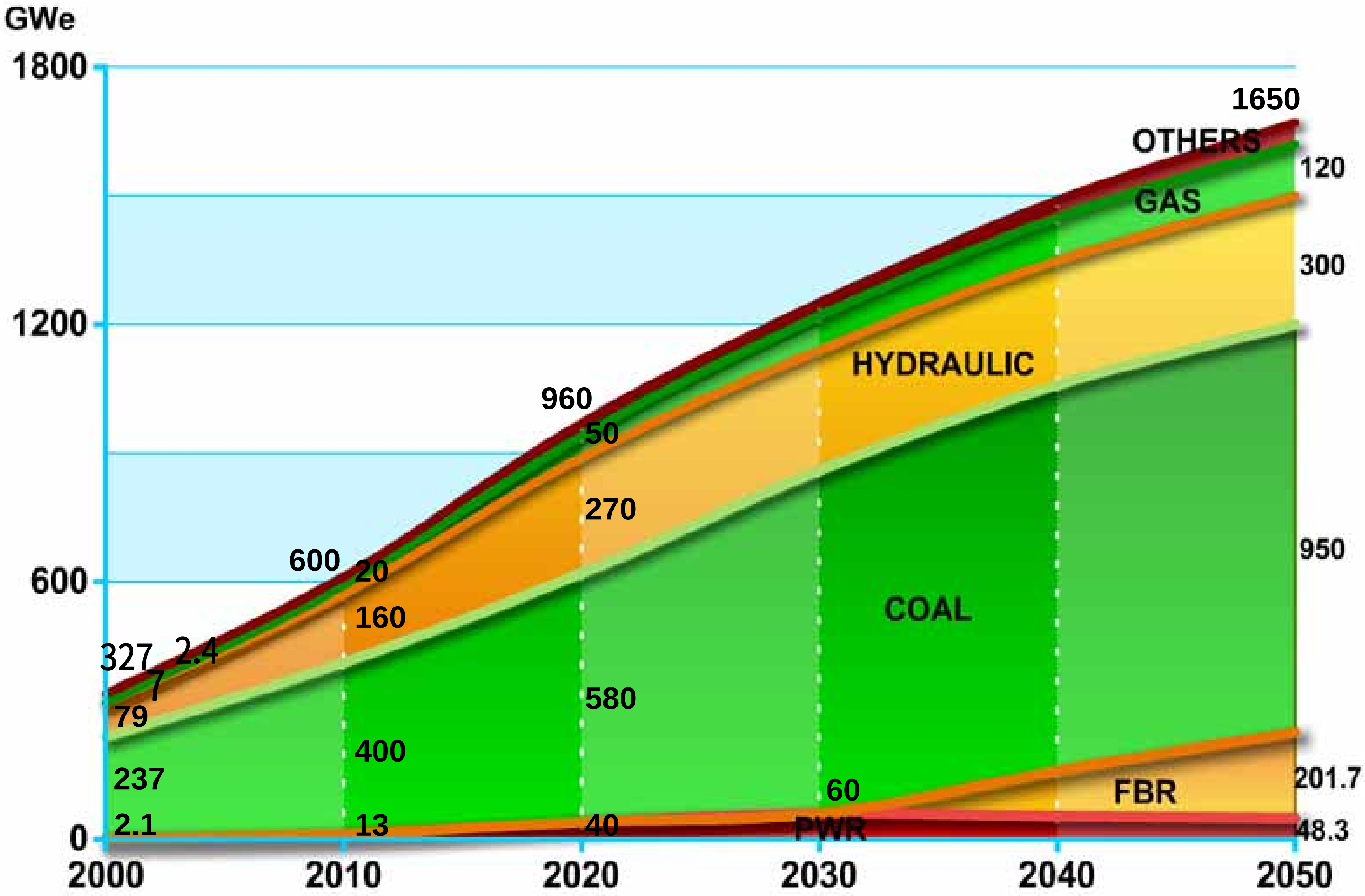
(2) In each period the capacity increases linearly;

(3) Large Fast Breeder Reactors will be deployed from2030, and with metal fuel closed cycle.

Nuclear Electricity Capacity Growth by Matched PWR-FBR

Year	PWRs(GWe)	U Requirement Accumulated(10^3t)	PWR+FBR(GWe)
2005	8.5	5.5	8.5
2010	16.3	16.5	16.3
2020	32	54.9	32
2030	50	117.5	77
2040	47.9	186.0	160
2050	33.7	246.4	386

CHINA INSTITUTE OF ATOMIC ENERGY



Electric Capacity Development Envisaged In China

Along with the nuclear power capacity increase, long lived radioactive wastes should be paied great attention.

The same assuming:

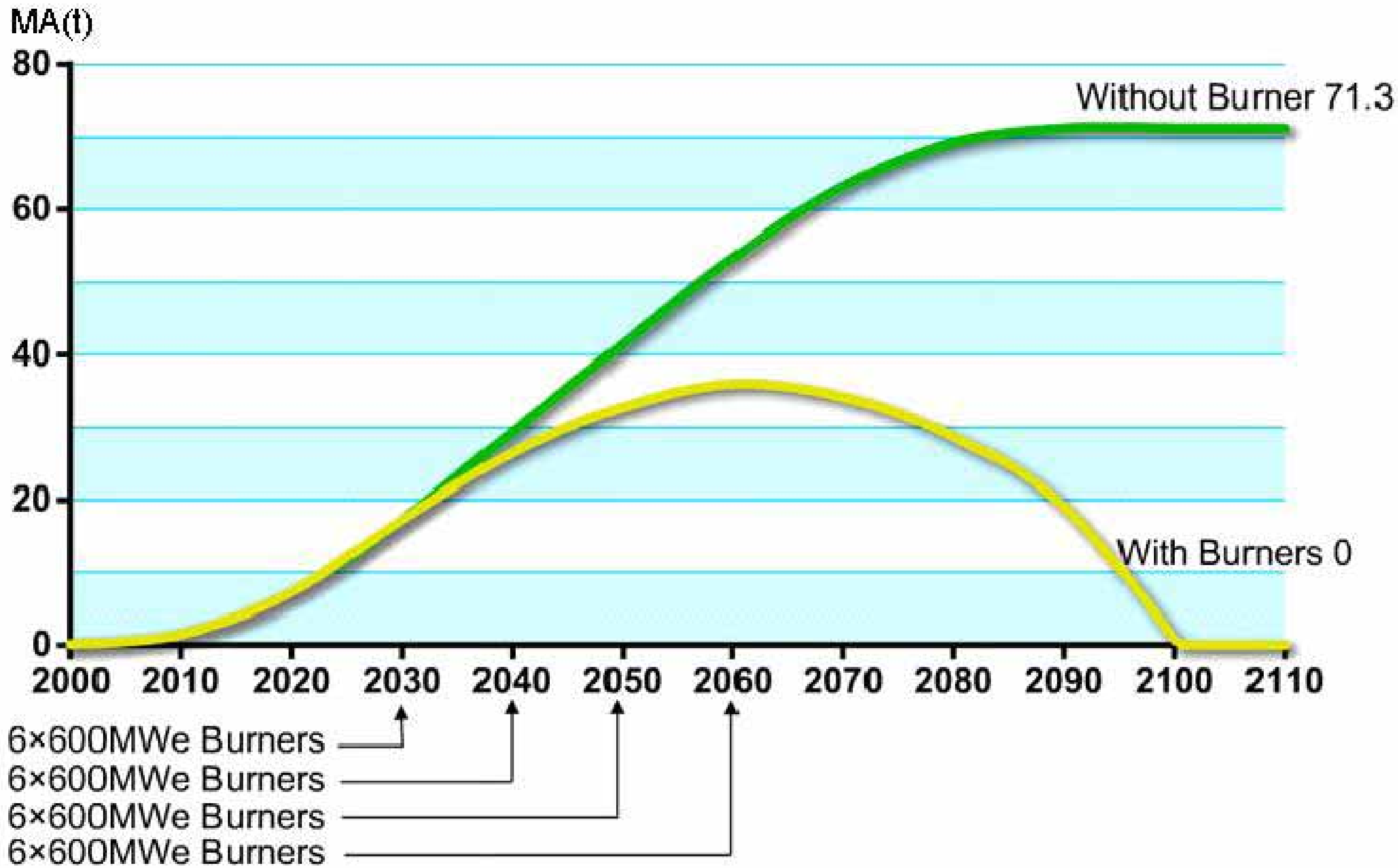
(1) the total capacity of PWRs in 2020 and 2030 will reach 32GWe and 50GWe respectively;

(2) In each period the capacity increases linearly.

Estimated MA and LLFP Accumulation from PWRs

Year	PWRs(GWe)	MA(t)	LLFP(t)
2005	8.5	0.6	1.0
2010	16.3	2.0	3.2
2020	32	7.0	11.2
2030	50	15.4	24.7
2040	47.9	25.0	40.5
2050	33.7	34.0	54.0

Partitioning and Transmutation strategy has been basically decided in China. The fast reactor is a rather realistic burner for MA and LLFP. A preliminary analysis has shown that the 600MWe fast burner was suitable with advantage of safe and dynamic properties not much worse, and the support ratio could be 1:4.



MA Transmutation Strategy

So, by matched PWR-FBR development and their related closed fuel cycle, the fission nuclear energy will be sustainable one to support the national economic development and public living standard improvement, and the nuclear could be really clean energy.

3. China FBR Development Strategy Study

China FBR Development Strategy

Reactor	Power(MWe)	Design Beginning	Commissioning
CEFR	25	1990	2008
CPFR	600	2005	2020
CMFR	n×600	2015	2030
CDFR	1000～1500	2010	2025
CCFR	1000～1500	2018	2030～2035

Technical Continuity of Chinese FBRs

	CEFR	CPFR	CDFR	CMFR
Power MWe	25	600	1000～1500	4～6×600
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	500～550	500	500～550
Linear Power W/cm	430	450～480	450	450

Burn-up MWd/kg	60～100	100～120	120～150	100
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

3.1 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.

3.2 CEFR timetable

Conceptual Design	**1990-1992.7**
Consultation with Russian FBR Association and Optimization	**1993**
Technical Co-Design with R-FBR-A	**1994-1995**
Preliminary Design	**1996-1997**
Detail Design	**1998-2003**

Preliminary Safety Analysis Report Review

1998.5-2000.5

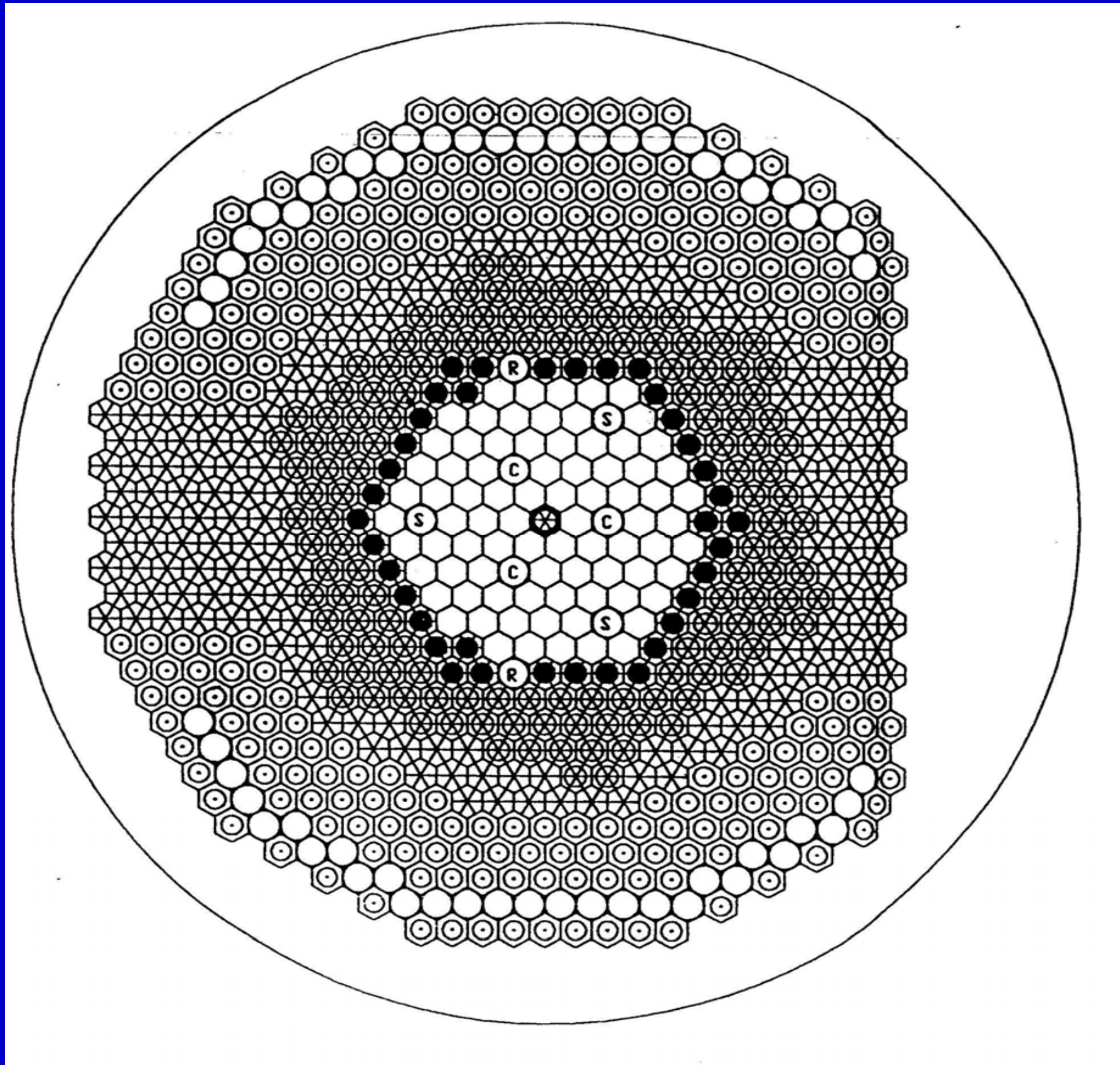
Architecture Construction (first pot of concrete)

started 2000.5

Reactor Building construction completed

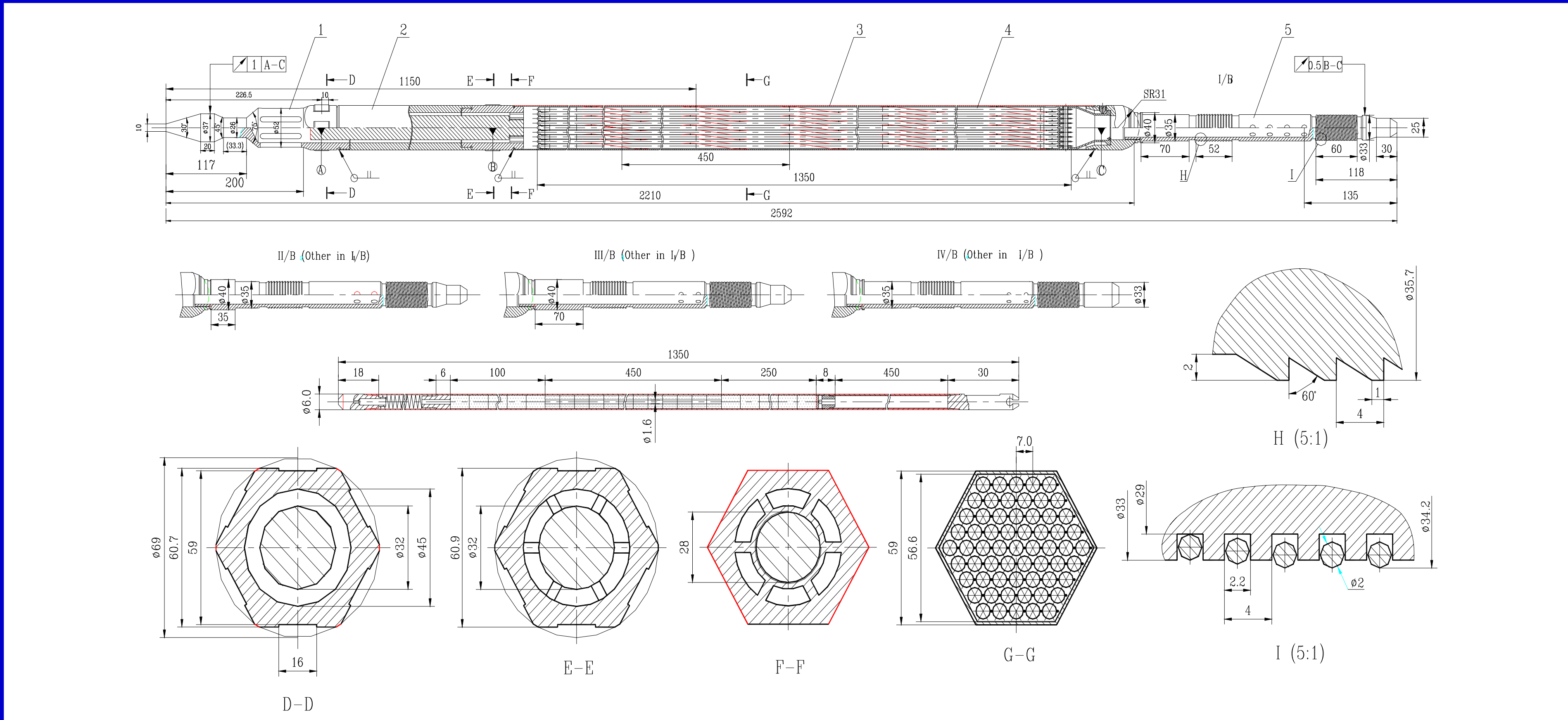
2002.8

3.3 CEFR Introduction

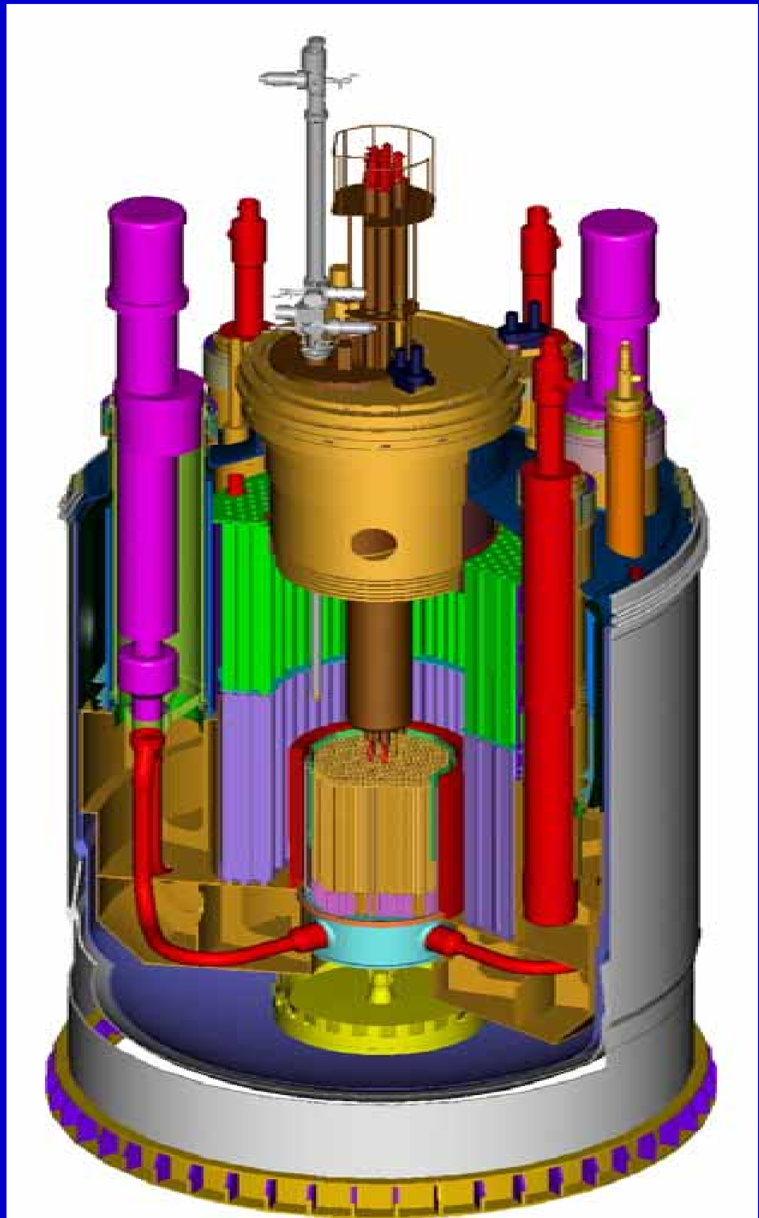


CEFR Core

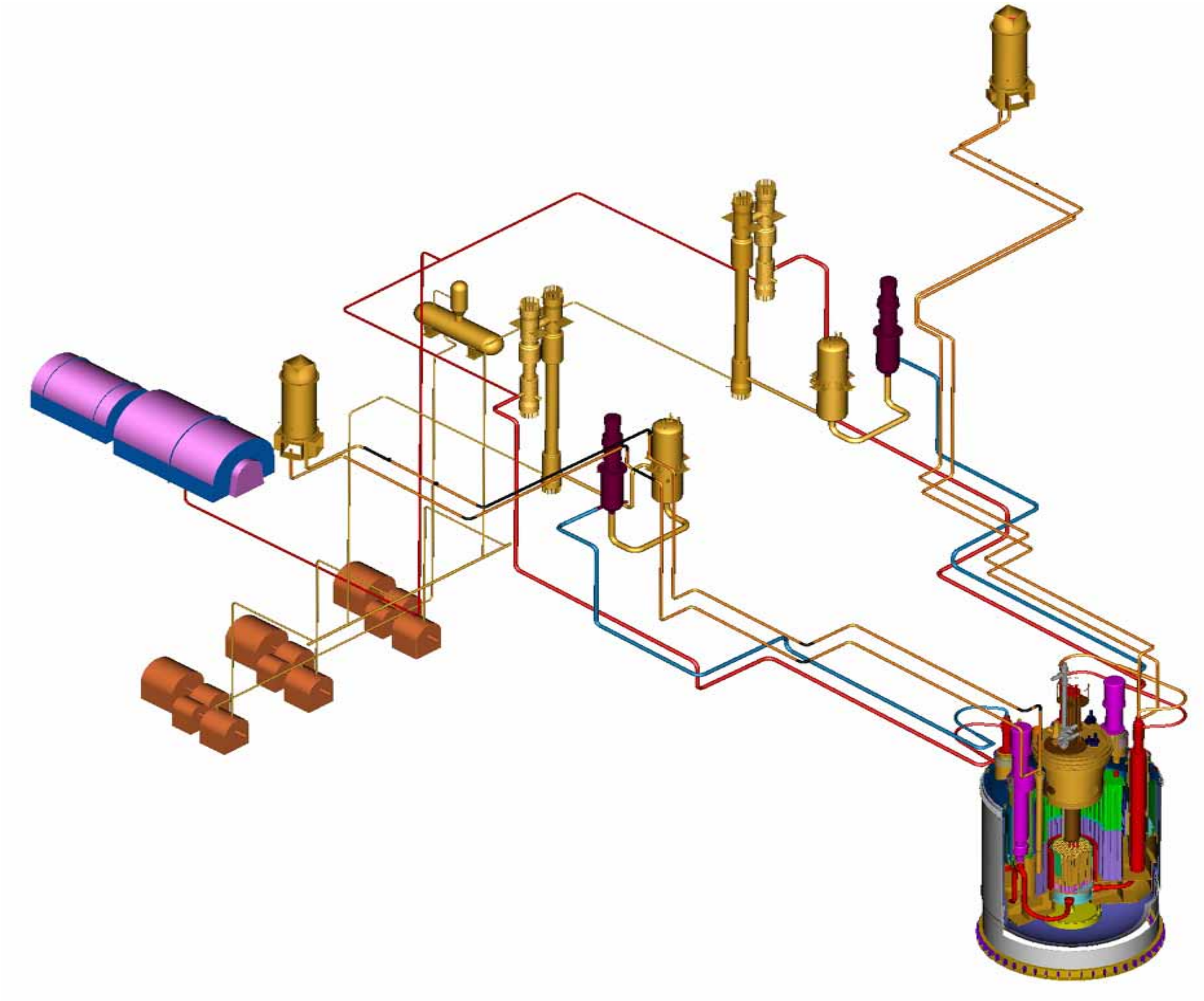
CHINA INSTITUTE OF ATOMIC ENERGY



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	106.87
Pu-239	kg	65.76
U-235 (enrichment)	kg	92.33 (36%) / 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

3.4 Recent Status of CEFR

More than 90% components and systems have been ordered.

More than 400 components have been installed in the building.

70% non-sodium systems have been installed,but for Na systems only 20%.

CHINA INSTITUTE OF ATOMIC ENERGY

CEFR Reactor Building Completion Ceremony (2002.08.15)

CHINA INSTITUTE OF ATOMIC ENERGY

One of Five Sodium Storage Tank (2005.02)

CEFR Hot Cell under Installation (2001.10.26)

CHINA INSTITUTE OF ATOMIC ENERGY

Some Parts of CEFR Main Vessel Moving to Reactor Building (2005.04)

Reactor Pit and Some Parts of CEFR Main Vessel (2005.04)

Evaporator Moving to Reactor Building (2005.03)

CEFR systems installation

Reactor vessel closure under fabrication (in China)

A part of Fuel Transportation Machine (in China)

Planning

2005.8　Starting installation of Reactor Block

2005～2007　Pre-operation testing

2008.6～2008.7　Physics start-up and first criticality

2008.12　40% full power incorporated to the grid

4. Status of ADS Study

1996～1999 ADS Conceptual Study

2000～2005 ADS R&D under the Major State Research Program "973"

2006～2010 1. Construction of an ADS test facility

- 50kW Cyclotron Accelerator (100MeV)
- Keff ～0.95

2. Development of 150 MeV/100 μA, 15 kW beam power Accelerator

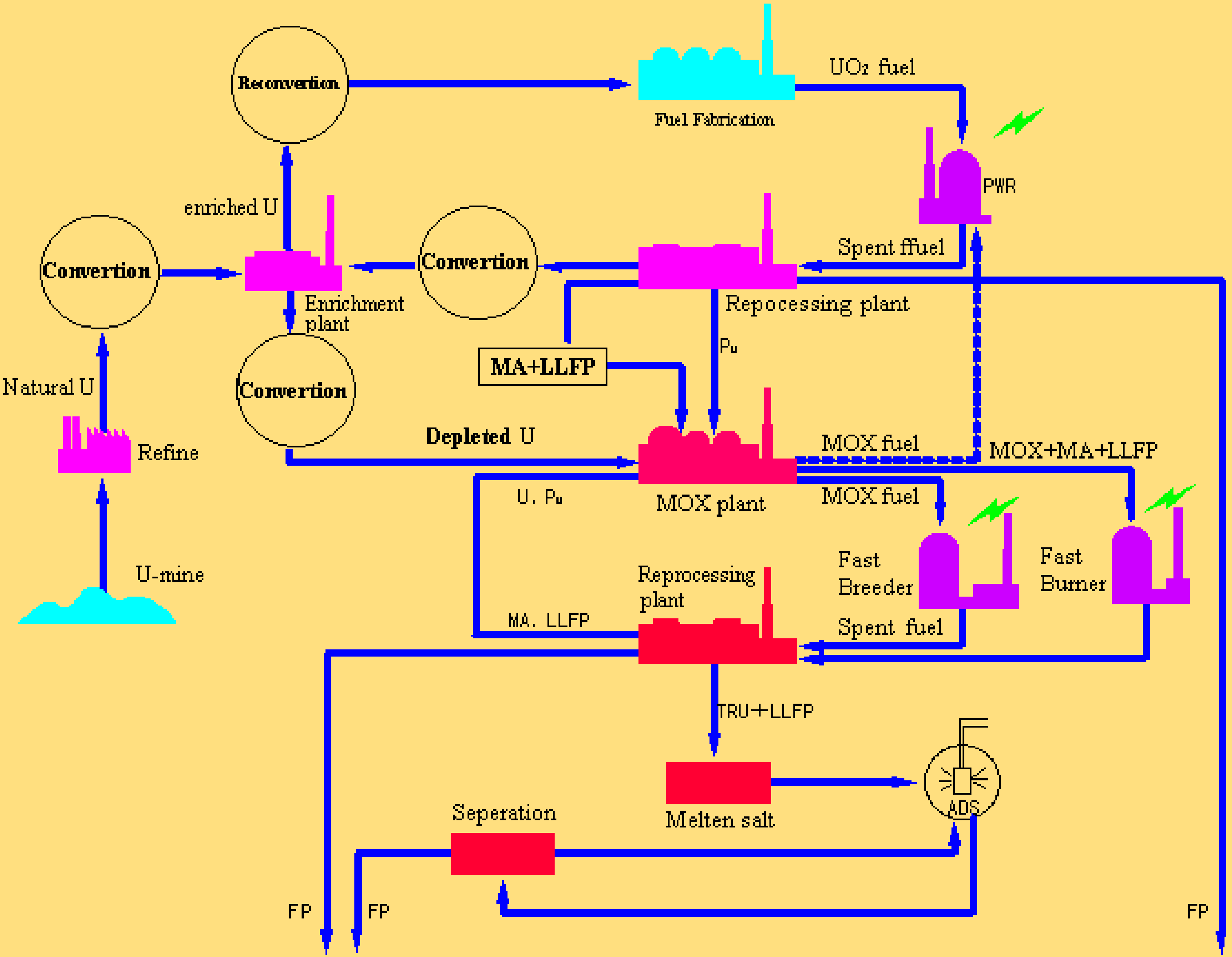
2010～2020 1. Build-up 100MeV/500 μ A, 50 kW beam power Accelerator

2. Build up a Fast Spectrum experimental ADS with 50 MW output power

5. Fast Reactor Fuel Cycle Consideration

5.1 Overall Target

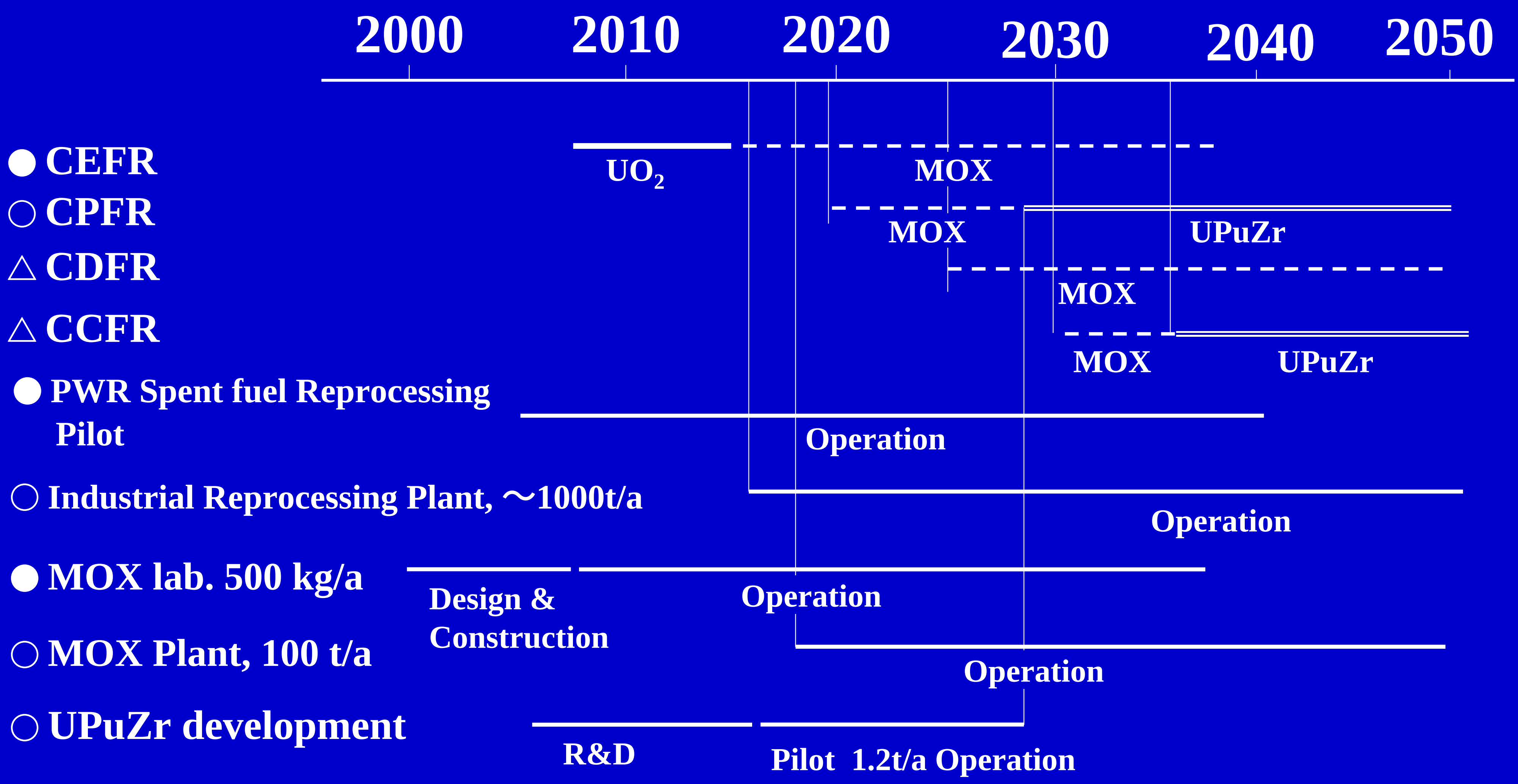
- Uranium resources should be sufficiently utilized including by-products Pu and MA
- The volume of high radioactive wastes to be geologically buried should be as less as possible



Closed Fuel Cycle Envisaged

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

5.2 Fuel Cycle Program and Consideration



● Execution ○ Application △ Consideration

5.3 Some Technical Selections

- **PWR spent fuel reprocessing pilot**

—Matured process PUREX has been selected, UO_3 or U_3O_8 and PuO_2 as Products

—High Activity wastes are temporarily stored and not vitrified to wait the suitable extraction process for Actinides which is under development in CIAE and Tsinghua University.

- **500 kg MOX Laboratory**

－The mechanical mixing of Uranium and Plutonium oxide powders and sintering process is selected.

- **UPuZr development**

—The concept of the Integral Fast Reactor (IFR) Pyroprocess fuel Cycle developed by ANL is very attractive to get good breeding performance of fast reactors and non-proliferation requirement for fuel cycle. It is decided to develop this technology for China Commercialized Fast Breeder Reactors, which includes: electrorefining to extract the U, Pu and other Ac from dissolved fuel; cathode reprocessing to produce metal ingots from the electrorefiner products and injection casting to fabricate new fuel pins.

- **FBR MOX spent fuel reprocessing technology will follow the experiences from PWR spent fuel reprocess and haven't been considered in detail.**
- **Molten salt technology and to directly and continuously extract the fission products is interested, the R&D related will be done in future.**

6. Object Attainability for Innovative Nuclear Systems

- **Sustainability**

China needs a very huge and sustainable nuclear energy supply in future, and nuclear power capacity growth up should be as quick as possible.

So, the main strategy is PWRs matched with FBRs to realize the natural Uranium to be sufficiently utilized, metal fuel and sodium coolant are selected to get high breeding ratio and short doubling time.

- **Safety**

The design targets for FBRs have been set up, as indicated in TECDOC-1083, 1999:

—Frequency of core melt less than 10^{-6}/reactor.a

—Frequency of loss of shut-down function less than 10^{-7}/reactor.a

—Frequency of loss of decay heat removal (DHR) function less than 10^{-7}/reactor.a

—Dose limit at the site boundary not requiring short-term off-site response

Fore the CEFR, based on the PSA analysis with some data from foreign countries, the results are as following:

—Core melt frequency: 4×10^{-7}/reactor.a

—Shut-down function loss frequency:7.6×10^{-10}/requirement

—DHR function loss frequency: 6.7×10^{-7}/ requirement

—During the most serious accident based on the CEFR Safety Analysis Report: lost of site and internal power, loss of shut-down function, loss of DHR function and interferences has happened to shut-down and DHR function after 45 minutes, the site boundary (153 m from CEFR reactor) has a dose less than 5 mSv.

For the CPFR and its followings should be added with Passive Shut Down System to compensate positive sodium void effect and should pursue standardization to a great extent on design, manufacturing, construction, training, operation and maintenance. To decrease sodium leakage and fire and sodium-water reaction. It is suggested to consider some R&D projects for improvements: to simplify primary sodium purification or put it on the top of reactor deck, to replace secondary sodium with Pb-Bi……

- **Environment**

The strategy shows that to decrease the volume of high radioactive wastes to be geologically buried. Two steps would be taken: Fast Burner and ADS with molten salt. For the main type of reactors, which will be built in a large number in China, up to now, we have not considered any new type of reactors which could produce some special harmful isotopes to the environment for example, C-14 and Po-210.

- **Non-proliferation**

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

- **Economy**

Due to the nuclear power application and fast reactor development are still in very preliminary stage in China, the overall economy assessment of FBR with closed fuel cycle is impossible up to now. But it will be done step by step.

Even though the strategy shows a complicated fuel cycle structure including many new technology which need expensive research, development and demonstration, it is expected the profits is still larger than expenses due to a large scale utilization to nuclear energy.

7. Summary

China needs a huge nuclear power capacity in future. Her first phase of nuclear energy application is rather quick development with PWRs, the second phase, i.e. fast reactor development is still at its experimental stage, our experiences are obviously not enough. China is willing to have cooperation with IAEA and other countries to share each other the experiences, and to speed up the national nuclear power development.