The Progress of Fast Reactor Technology Development in China

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SUMMARRY

China, as a developing country with a great number of population and relatively less energy resources, reasonably emphasizes the nuclear energy utilization development. For the long term sustainable energy supply, as for nuclear application the basic strategy of PWR-FBR-Fusion has been settled and envisaged. Due to the economy and experience reasons the nuclear power and technology development with a moderate style are kept in China up to now.

In China mainland apart from two NPPs with the total capacity of 2.1 GWe in operation, four NPPs are under construction and two NPPs are planned for the Tenth Five Year Plan(2001-2005). Also another one or two NPPs are still in discussion. It could be foreseen that the total nuclear power capacity will reach 8.5GWe before the year 2005 and 14-15 GWe before 2010 respectively.

As the first step for the Chinese fast reactor engineering development the 65MWt China Experimental Fast Reactor(CEFR) is under construction. The main components of primary, secondary and tertiary circuits and of fuel handling system have been ordered. The reactor

building under construction has reached the top namely 57m above the ground. More than one hundred components and shielding doors have been installed. It is planned that the construction of reactor building with about 40,000m2 floor surface will be completed in the end of the year 2002 and envisaged that the first criticality of the CEFR will be in the end of 2005.

The second step of the Chinese fast reactor engineering devclopment is a 300MWe Prototype Fast Breeder Reactor which is only under consideration up to now. Some important technical selections have been settled, but its design has not yet started.

INTRODUCTION

Qinshan-1 with a 300MWe PWR, the first self-designed and self-constructed nuclear power plant has passed its 10 years anniversary incorporated to the grid on December 15, 2001 up to when it had generated 16.7 billion kWh of electricity, posting a turnover of 4.9 billion yuan (USD 571.7 million). No any pollution or leaked radiation has been found over the last 10 years.

Daya Bay Nuclear Power Plant with two 900MWe PWRs which was co-funded by Guang Dong and Hong Kong electric companies and imported technically from France and UK has operated from the year 1994. The total electricity generation up to September of 2001 is 99.6 billion kWh with an income of USD 5.8 billion. In the year 2000 it has a load factor of 85% with 14 billion kWh to the south China grid and with the grid price of USD ф5.99/kWh. Daya Bay NPP has won the first place at the nuclear safety match of the French same type NPPs in the year 2000.

Generally speaking the successful operation of these two NPPs has more or less given to the Government and society some encouragement to develop continuously nuclear power application.

Recently four NPPs are under construction. It could be envisaged that in 2005 the total capacity of nuclear power plants in operation will reach 8.5GWe in the mainland as shown in Table 1. Two NPPs (sanmen and Guangsanhe) with total four units of 1 GWe are planned which construction will be started before 2005. Another one or two NPPs are still under proposal and discussion stage.

Table 1 MAINLAND NUCLEAR POWER PLANTS

NPP	Type	Power(MWe)	Commissioning
Qinshan-1	PWR	300	1993
Daya Bay	PWR	2×900	1994
Qinshan-2	PWR	2×600	2002,2003
Lingao	PWR	2×944	2002, 2003
Qinshan-3	PHWR	2×720	2003
Lian yungang	PWR	2×1000	2004
Sanmen	PWR	2×1000	(2010)
Guangsanhe	PWR	2×1000	(2010)

The China Experimental Fast Reactor (CEFR) with the power 65MWt is under construction. The reactor building has reached the top, 57m above the ground. About 80 percent ordering contracts of components have been signed. More than one hundred components and shielding doors have been installed in the un-completed reactor building. About 90% detail design and 80% design demonstration tests have been carried out. The test program after installation of components and systems, physical start-up program and final safety analysis report are all under preparation. The reactor building construction could be finished in the end of 2002. It is envisaged the first criticality of the CEFR will be realized in the end of 2005.

CHINA EXPERIMENTAL FAST REACTOR (CEFR)

INTRODUCTION

After the collection and preparation of necessary computer codes and the decision of main technical selections, the conceptual design of the CEFR was started in 1990 and completed in 1993 including the confirmation and optimization to some important design characteristics. Having spent almost whole 1994 for its preparation, and after finished its technical design cooperation during 1995-1996 with Russia FBR association (IPPE, OKBM and Atomenergoproekt) the CEFR preliminary design was started in the early of 1995 and finished in August 1997. After about another half year for its necessary modification, the detail design is started since the early 1998,and now still continued. Following presentation to this reactor is based on its preliminary design.

The CEFR is a sodium cooled 65MWt experimental fast reactor with (Pu,U)O2 as fuel, but UO2 as first loading, Cr-Ni austenitic stainless steel as fuel cladding and reactor block structure material, bottom supported pool type, two main pumps and two loops for primary and secondary circuit respectively. The water-steam tertiary circuit is also two loops but the superheat steam is incorporated into one pipe which is connected with a turbine. Table 2 is the main design parameters of CEFR.

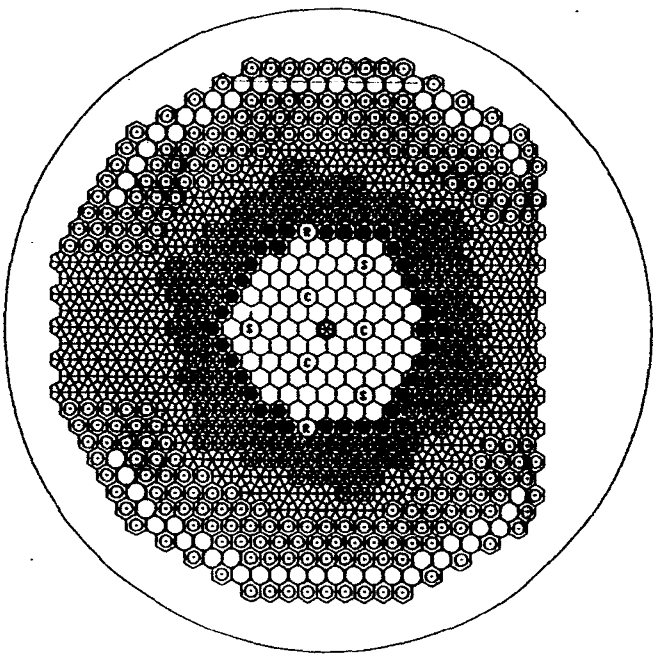
Table 2　CEFR main design parameters

Parameter	Unit	Preliminary design
Thermal Power	MW	65
Electric Power, net	MW	20
Reactor Core		
Height	cm	45.0
Diameter Equivalent	cm	60.0
Fuel		$(Pu,U)O_2$
Pu, total	kg	141
Pu-239	kg	65.76
U-235(enrichment)	kg	92.33(36%)
Linear Power max.	W/cm	430
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
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

REACTOR CORE

The reactor core, as shown in Fig.1, is composed of 81 fuel subassemblies (Fig.2). Three safety subassemblies, three compensation subassemblies and two regulation subassemblies, then 336 stainless steel reflector subassemblies and 230 shielding subassemblies and in addition 56 positions for primary storage of spent fuel



Fuel subassembly	81
Stainless steel rod	1
Stainless steel reflector subassembly	37
Stainless steel reflector rod	132
Stainless steel reflector rod	167
Shielding subassembly	230
Storage position for spent fuel subassembly	56
Safety subassembly	3
Regulation subassembly	2
Compensation subassembly	3

Fig.1 CEFR Core

subassemblies are included. 92%B-10 enrichment B4C is used for safety and compensation absorber. But natural boron B4C (B-10 percent abundance about 20%) for regulation and shielding subassemblies.

The compensation and regulation subassemblies are also as first shutdown system. Three safety subassemblies are as secondary shutdown system. Their drop down time is 1.5 seconds and 0.7 seconds respectively.

REACTOR BLOCK

The CEFR block is composed of main vessel and guard vessel which is supported from bottom on the floor of reactor pit with the diameter 10m and height 12m. The reactor core and its support structure, are supported on lower internal structures. Two main pumps and four intermediate heat exchangers are supported on upper internal

structures. These two structures are sat on the main vessel. Two DHRS heat exchangers are hung from the shoulder of main vessel. The double rotation plugs on

which control rod driving mechanisms, fuel handling machine and some instrumentation structures are supported are sat on the neck of the main vessel. The

CEFR block is shown in Fig 3.

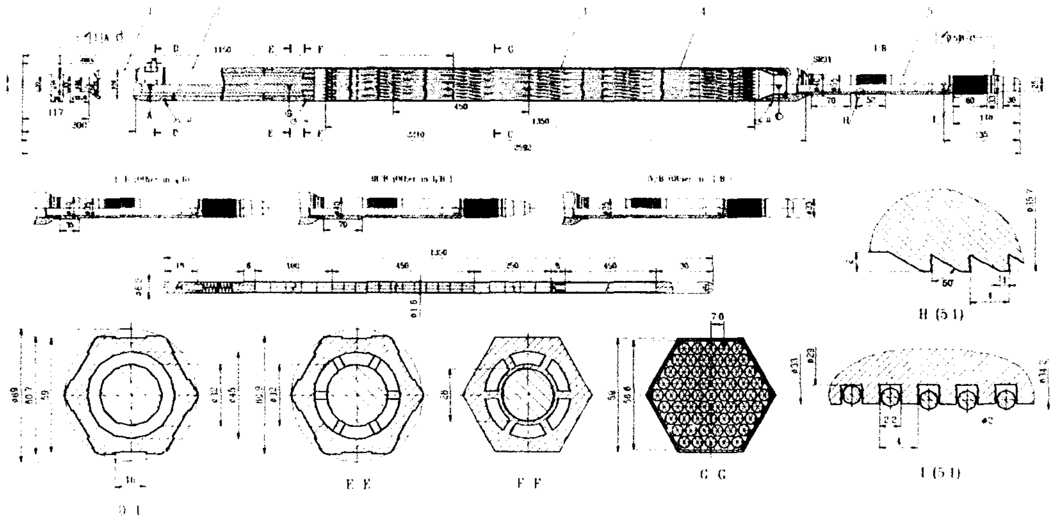


Fig 2 Fuel Subassembly

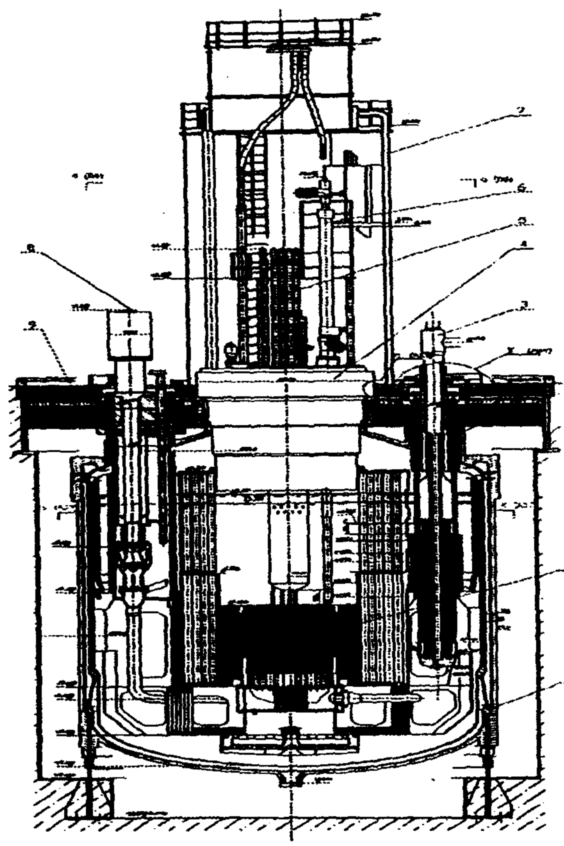


Fig. 3 CEFR reactor block

The main vessel has an outside diameter of 8010mm and a diameter gap of 175mm toward guard vessel. The narrow gap design permits the core still immersed in sodium when the main vessel leak accident has unexpectedly happened. Using 2D Sn computer code, the calculation shows that the neutron fluency in main vessel during 30 years is about 1.0×1022 n/cm2. For main vessel only temperature, strain and sodium leak detection are considered.

In the design a molten core catcher is equipped on the bottom of the vessel even though there is no any serious accident in which the large part of core damage could be happened based on the analysis of all the beyond design basis accidents.

MAIN HEAT TRASPORT SYSTEM

The primary circuit is composed of main pumps, four intermediate heat exchangers, reactor core support diagrid plenum, pipes and cold and hot sodium pools. In cold pool, two primary loops are separated each other, but in hot pool they are linked up. In normal operation the average sodium temperature in cold pool is 360℃ and in hot pool it is 516℃.

The secondary circuit has two loops each one is equipped with one secondary pump, two intermediate exchangers(IHX), evaporator, superheater, expansion tank, and valves. The outlet sodium temperature of secondary circuit from IHX is 495℃. When it leave evaporator it will decrease up to 310℃, and in outlet of superheatert is 463℃.

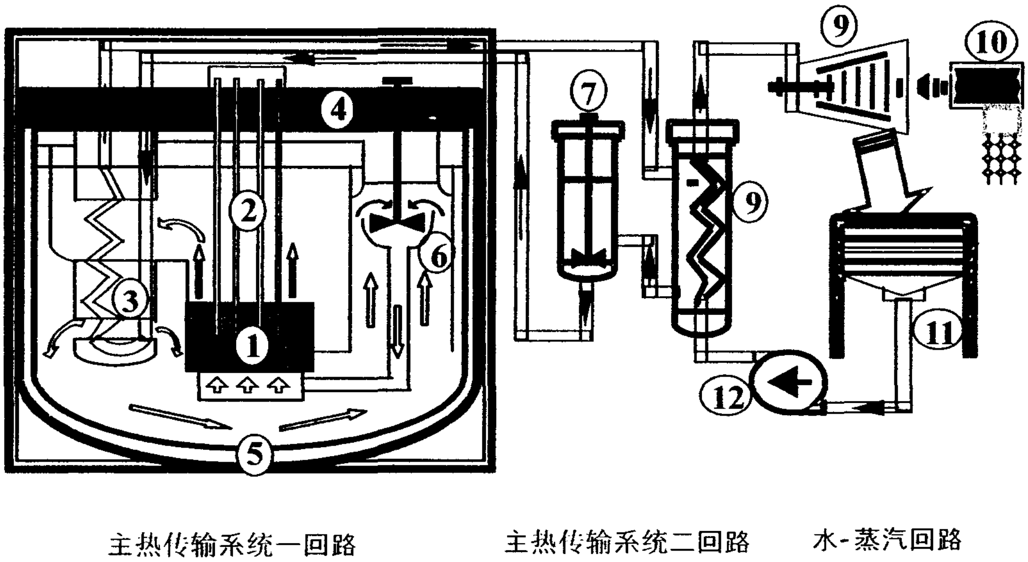


Fig 4 Main heat transfer systems of CEFR

1、Reactor core 2、CRDM 3、IHX 4、Upper shield device

5、Main vessel 6、Primary pump 7、Secondery pump 8、Steam generator 9、Turbine

10、Generator 11、Condenser 12、Feed water pump

The tertiary water steam circuit has one turbine generator, three low pressure heaters, one deoxygenate heater, one demineralization facility and feed water pumps. It provides 480℃/14Mpa superheat steam to the turbine.

Each evaporator is connected with one release-to-air valve and two safety release valves, but for superheater, one release-to-air valve and one safety release valve. And the by-pass de-temperature de-pressure valves equivalent to 67% full power are equipped for discharging the steam to the condenser when the turbine is not in operation. Fig 4 shows the main heat transfer systems of CEFR.

SAFETY CHARACTERISTICS

The CEFR will be located in the China Institute of Atomic Energy (CIAE), about 40 km far away from Beijing City which owns about 10 million inhabitants. According to the raising environment safety consideration, it is stipulated to have more strictly requests to radioactive materials release standards for normal operation, design basis accident (DBA) and beyond design basis accident (BDBA) than related national standards, as shown in Table 3.

Table 3 Maximum Limits of Public Effective Dose Equivalent From The CEFR

States	GB6249-86	CEFR limits
Operational	0.25mSv/a	0.05mSv/a
DBA	5mSv/accident	0.5mSv/accident
BDBA	100mSv/accident	5mSv/accident

No any emergency intervention requirements for residents beyond 153m from the reactor..

The CEFR is a small reactor, which has bigger heat inertia than many other pool reactors due to its relative primary sodium loading per MWt, is larger. The core is designed with negative temperature coefficients, and negative power coefficients.

These feedback properties are shown in Tables 4-7.

Table4 Temperature Reactivity Effect (Pu,U)O2/UO2 CORE, 250-360℃, %ΔK/K

	Cycle	
	Beginning	End
Sodium Density	-0.169/-0.182	-0.170/-0.186
Axial Expansion of Reactor Core	-0.037/-0.034	-0.038/-0.034
Axial Expansion of Lateral Reflector	-0.019/-0.019	-0.020/-0.019
Radial Expansion (diagrid plenum)	-0.204/-0.184	-0.205/-0.188
Doppler Effect	-0.032/-0.022	-0.033/-0.024
Total	-0.461/-0.441	-0.466/-0.451

Table5 Power Reactivity Effect, Hot Standy--Full Power

(Pu, U) O2/UO2 core %ΔK/K

	Cycle	
	Beginning	End

Sodium Density	-0.107/-0.122	-0.112/-0.124
Sodium Volume Fraction Exchange	-0.029/-0.028	-0.034/-0.029
Axial Expansion of Reactor Core	-0.339/-0.259	-0.311/-0.300
Axial Expansion of Lateral Reflector	-0.011/-0.010	-0.011/-0.010
Radial Expansion (S.A. Winding)	-0.020/-0.020	-0.020/-0.020
Doppler Effect	-0.063/-0.034	-0.063/-0.036
Total	-0.569/-0.509	-0.556/-0.519

Table6 Doppler Constant of CEFR Core (Pu, U) O2 /UO2 core 10-3ΔK/K

	kW(with Na)	Kd(without Na)
Fuel:633-1593K Cladding: 633-1000K	-0.878/-0.394	-0.618/-0.113
All Materials 523-633K	-1.574/-1.170	-1.048/-0.519
All Materials 373-523K	-1774/-1.200	-1.142/-0.578

Table7 Reactivity Effect of Sodium Lost (Pu,U)O2/UO2 CORE %ΔK/K

Region Lost Sodium	Cycle	
	Beginning	End
Core (Fuel Section)	-2.366/-2.456	-2.404/-2.504
Core (Fuel section + upper section of S.A)	-3.067/-3.116	-3.110/-3.189
Core (Whole Section of S.A)	-3.737/-3.744	-3.788/-3.836
Whole Core (including central stainless steel Rod, and stainless steel reflector)	-5.196/-5.106	-5.194/-5.282

The reliable removal of decay heat after the shut-down of a nuclear reactor is an important safety criterion. For this reason, two independent passive decay heat removal systems

(DHRS) are designed for the CEFR. Each one is rated to a thermal power of 0.525MWt under the working condition, the decay heat is removed by natural convection and circulation of primary and secondary coolant, and natural draft by air. To have the start-up of DHRS the air dampers of the air cooler stacks are opened by automatic signal of reactor protection system or in case of a lost of any service power mechanically by the operator staff. Except for this procedure the CEFR DHRS is entirely passive. Table 8 gives the parameters of the DHRS. of the CEFR.

Table 8 Parameters of Oone Set of DHRS

Parameters	Working	Stand-by
Transfer Power MWt	0.525	0.052
Primary Na Flow Rate in DHX*) kg/s	5.8	1.66
Secondary Na Flow Rate in DHX kg/s	2.93	1.37
Air Flow Rate in Air cooler kg/s	2.4	0.11
Primary Na Temperature ℃		
Inlet at DHX	516	516
Outlet at DHX	444	490
Secondary Na Temperature ℃		
Inlet at Air cooler	514	515
Outlet at Air cooler	373	485
Air Temperature ℃		
Inlet at Air cooler	50	50
Outlet at Air cooler	264	496
Secondary Na Pressure MPa	0.6	0.402

* : DHX-Decay Heat Exchanger in DHRS

STATUS ON CEFR ENGINEERING

Since March of 2001, getting the full construction permission from the China National Nuclear Safety Administration (CNNSA), the CEFR reactor building with the size 64m×79.59m from the level –4.7m started to be constructed. The reactor building has been coverd in augest of 2002., as shown in Fig 5 and by now more than one hundred equipments including five sodium storage tanks, two fuel subassembly transport channels, hot cell, support structure for whole reactor block, shielding doors.... Have been installed in the un-completed reactor building.

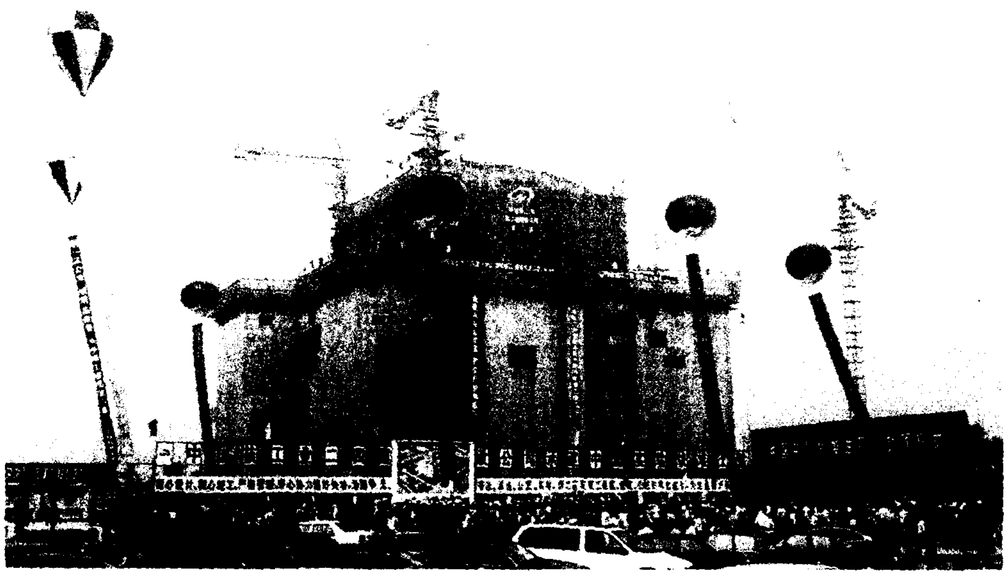


Fig 5 CEFR Reactor Building Covered +57m , Aug.2002

80 percent of ordering contracts for components and equipments have been signed, including main ones of primary, secondary and tertiary circuits and fuel handling system. The large part of components including rotating plugs, reactor main vessel, internal structure and diagrid plenum are ordered from domestic factory. Some equipments are imported from

foreign companies.

The installation of main equipments and systems are started from the begin of this year and will be completed in 2004. The cool tests up to 250℃ without sodium and hot tests with sodium up to 420℃ will be started in October 2004 and September 2004 respectively. It is envisaged to begin fuel loading in September 2005 and the first criticality will be realized before the end of 2005.

CONSIDERATION TO CEFR'S SUCCESSORS

Considering the sustainable energy supply in future and environment protection the prospects of fission nuclear energy application are optimistic in China. According to the preliminary strategy study of fast reactor development, after the CEFR the Program will go to the second step 300MWe Prototype Fast Breeder Reactor (PFBR) which will play as a prototype for next step LFBR, and at same time as a module for Modular Fast Burner Reactor (MFBR) which may be suitable for MA burning .

Table 15 gives the technical continuity of Chinese FBR engineering development and main technical selections.

Table 15 Technical continuity of Chinese FBRs

	CEFR	PFBR	LFBR	MFBR
Power MWe	25	300	1000~1500	4~6×300
Coolant	Na	Na	Na	Na
Type	Pool	Pool	Pool	Pool
Fuel	UO_2 MOX	MOX Metal	Metal	MOX+ MA Metal+ MA
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
6urn-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

Where:

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

Up to now the design of Chinese PFBR has not formally started due to the design team is still engaged in the CEFR construction.

CONCLUSION

For long term nuclear energy development the basic strategy of PWR-FBR-Fusion is kept as pointed out by Mr. XU Yuming[3], Department Director, CAEA at the 2001 Annual Symposium of Chinese Nuclear Society. Due to lack of enough experience, limit nuclear industrial basis and un-sufficient budget, Chinese fast reactor development only with a moderate situation. But the fast reactor technology and its closed fuel cycle will be step by step developed in matching with the PWRs to realize nuclear energy utilization in large scale for the future in China.

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