CHINESE FAST REACTOR TECHNOLOGY DEVELOPMENT†

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Abstract

The basic research work of the Fast Reactor Technology was started in the middle-end of 1960's in China. In the framework of the High-Technology Program, as the first step of the Chinese Fast Reactor development, the Chinese Experimental Fast Reactor (CEFR) is under its detail design stage right now. Its preliminary safety analysis report is still under reviewing by the China National Nuclear Safety Administration, but it is near completion. It is estimated that the construction commission for the CEFR is going be issued in two months. It is envisaged that the CEFR construction completion will be in the year 2004.

As the second step of Chinese Fast Reactor development, the Prototype Fast Breeder Reactor will be started to design in the year 2001 as preliminarily planned.

Introduction

As a developing Country, China has a very large population and rather poor conventional energy resources per capita, but there is a vast territory. The nuclear energy is a new energy which could be developed in large scale and much suitable to the Country. It is illustrated by the operation of Qinshan-1 and Daya Bay Nuclear Power Stations and the construction of four new nuclear power stations, that nuclear energy has been becoming a complementary energy for regions lack of conventional energy and electrical power. Looking for ward to the future, considering that the large scale application of fossil fuels will induce serious pollution and heavy transportation problems, fossil fuel resources will be exhausted year by year, as raw material of chemical industry, these carbohydrogenates should be taken a conservation strategy and as to the hydraulic power relatively concentrated in the west and south west, the expensive long distance transmission of electricity will be met, so, it is believed that the nuclear energy will become an important component in the Chinese future energy supply.

In the year 1998 the electricity generation capacity in the whole country has reached 300GWe. If the nuclear power plays an important role in the future total capacity, it will be a very big value as shown in Table 1. However the uranium resource is limited. So, the fast breeder reactors should be developed and deployed. Considering

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the treatment and disposition of long-life nuclear wastes, based on the envisageable technology, to use fast burner reactor to burn out them will be reasonable. Due to these reasons China is interested in the fast reactor technology for a long time.

Table 1 Envisaged Electricity Capacity Development in China [1-3]

Year	Total Capacity (GWe)	Nuclear Capacity (GWe)
1994	199	2.1
1998	300	2.1
2002		2.7
2003		4.9
2004		8.6
2010	590	20-23
2020	800	40-50
2050	1200	240

Research and Development

Basic Research (1968-1987)

Since the middle-end of 1960's the fast reactor technology basic research has been started in China, the emphasis was put on neutronics, thermal hydraulics, materials and sodium technology. During this period, about 12 sodium loops and test facilities in small scale have been established including the fast neutron zero power facility containing 50 kgU-235.

Basic Research (1987-1993)

Taking 65MWt experimental fast reactor as the target, in this period the basic research rearranged. The emphasis was aimed at sodium technology, materials and fuels, safety and fast reactor design study, about 20 sodium loops and test facilities have been built and studied.

Design Test Demonstration (1995-now)

After the conceptual design of the Chinese Experimental Fast Reactor (CEFR), the design test demonstration was started. Some important test demonstration have been completed:

(1) Blockage test with 19 pins bundle (in CIAE)
(2) CEFR pool water simulation test for decay heat removal based on CEFR conceptual design(in CIAE) .
(3) Hydraulic pressure drop test of fuel S.A.(in CIAE)
(4) Sodium Purification Mockup (in CIAE)
(5) Core physics Mockup (in Russia)

Other design test demonstrations of about 30 items have been arranged

The important test facility for design demonstration have been established in the CIAE as shown in Table 2

Table 2 Test Facilities for CEFR Design Demonstration

NO	Name	Main parameters
1	Sodium Purification facility in middle scale	0.3t/d Ca≤8PPm,0≤20PPm
2	Material corrosion sodium loop	2-5m/s 650_
3	Core S.A. test sodium loop (ESPRESSO)	110m3/h 600_
4	Large scale test sodium loop (CEDI)	$320m^3/h$ 650_
5	Cleaning facility for sodium components	N_2 and steam
6	S.A. dimension measuring meter	4m. ±0.02mm
7	H-meter test sodium loop*	1.5 m^3/h 600_

* in Tsinghua University

CEFR Design

Timetable

1990 - 1992.7 Conceptual design
1992.7 - 1193.12 Modification to the conceptual design
1994.12 - 1996.12 Preparation for preliminary design
1995.2 - 1997.8 Preliminary design
1998.1-now Detail design, components ordering started
1998.5 Submit CEFR Preliminary Safety Analysis Report to CNNSA

Main Technical Selections and Design Boundary Conditions

Thermal power: 65MWt;
Sodium pool type;
$(Pu,U)O_2$ as fuel, UO_2 as first loading;
Maximum linear power of fuel element: 430W/cm;
Nominal sodium outlet temperature from the core: 530°C;
Permitted maximum cladding temperature at normal operation: 700°C;
Maximum burn-up for first loading: 60MWd/Kg;
Nominal steam Parameters: 480°C, 14MPa;
Loop number of coolant circuit: 2;
Fuel handling concept:

1. spent fuel primary storage in the periphery of the core;
2. straight moving fuel handling machine with double rotating plugs
3. transportation of new and spent fuel S.A. through fixed port;

No independent irradiation loops, but irradiation capsules will be equipped;
Safety features:

1. two independent shut down systems;
2. the core designed with neutronics self-stability;
3. passive decay heat removal systems;
4. the primary systems never out of the containment.

CEFR Design Characteristics

The CEFR is a bottom support pool type sodium reactor, as shown in Fig 1, its primary circuit is composed of 2 main pumps, 4 intermediate heat exchangers (IHX) diagrid plenum, reactor core and pipings immersed in the main vessel which contains 260 t sodium as primary coolant. The main vessel made of 304ss and 316ss has the diameter of 8010 mm with the thickness of 25-50mm, protected by the guard vessel made of same material which diameter is 8235mm with the thickness of 25-50mm, In the normal operation the reactor core inlet mean temperature is 360°C, the outlet temperature 530°C. Mixed with the hot pool sodium, it will be 516°C when entering to the IHXs. When the primary sodium leaves from IHXs, the temperature will decrease to 353°C. After mixing, 360°C sodium is inhaled by pumps and delivered to the diagrid plenum.

The fuel subassembly (S.A.)with the external across flat 59mm contains 61 fuel pins, each one has 6 mm diameter, 0.3mm thickness and 0.95mm diameter wire wrap as its radial positioning. The general structure of the S.A. is shown in Fig. 2.

The CEFR core, as shown in Fig. 3, is composed of 81 fuel S.A.s, 3 compensation S.A.s, 2 regulation S.A.s and 3 safety S.A.s. The former 5 control S.A.s are used as the first shut-down system, The drop down time of each S.A. from top to bottom is 1.5 seconds, and the 3 safety S.A.s are taken as second shut-down system, its drop-down time is 0.7 second.

The secondary circuit is composed of 2 loops, each one has, besides two IHXs, secondary sodium pump, expansion tank, superheater, evaporator valves and pipings. The inlet temperature of secondary sodium at superheaters is 495°C, 310°C at outlet of Evaporators. The supply water to the tertiary circuit has the inlet temperature of 190°C. The steam parameter is 480°C and 14MPa. The steam from two sets of steam generators is incorporated into one turbine-generator with the 25MWe capacity.

The straight moving fuel handling machine with a double rotating plugs and two fixed port in the reactor vessel are used for in-core fuel handling. Spent fuel S.A.s are primarily stored in the periphery shielding region for two cycles, totally 56 positions for them. After two cycles decay the S.A.s are one by one moved out of reactor vessel to the washing plant and then stored in water pool which could contain fuel S.A.s equivalent to 11.5 cores.

The main parameters of CEFR is given in Table 3.

CEFR Safety Evaluation

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 4.

Table 3. 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%)
Fuel, First Loading		UO_2
UO_2(enrichment)	Kg	417(64.4%)
Linear Power max	W/cm	430
Neutron Flux $(Pu,U)O_2$	$n/cm^2 \cdot s$	3.7_10^{15}
Burn-UP, target max.	MWd/t	100000
Burn-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
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

Table 4. 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.

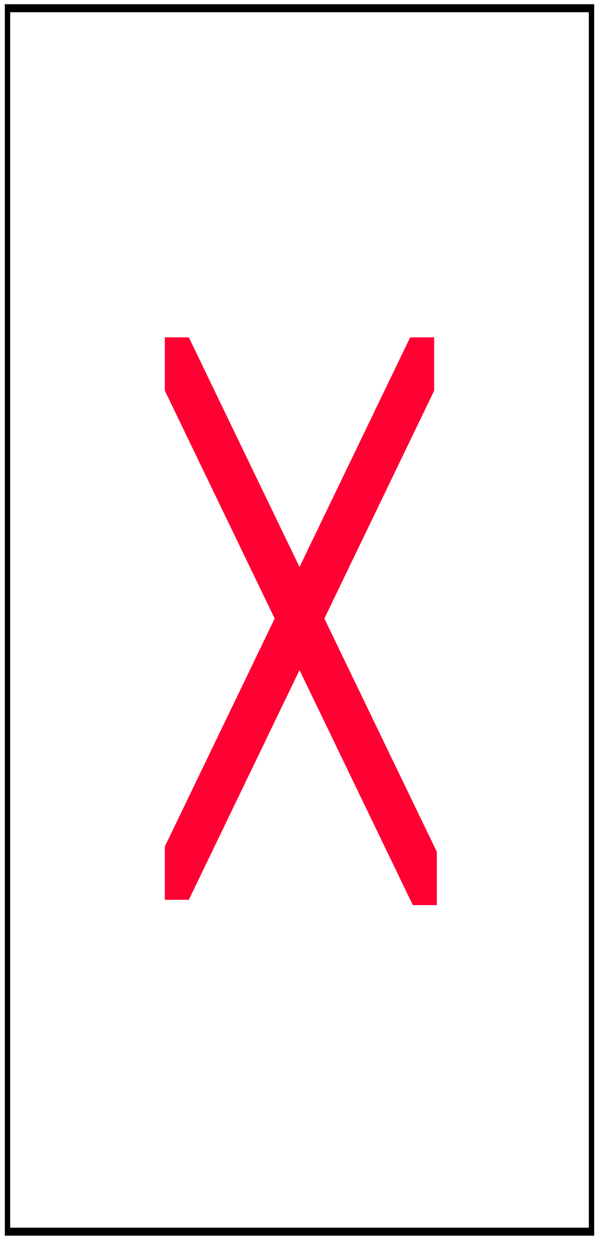

Fig. 1 **CFR Reactor Block**

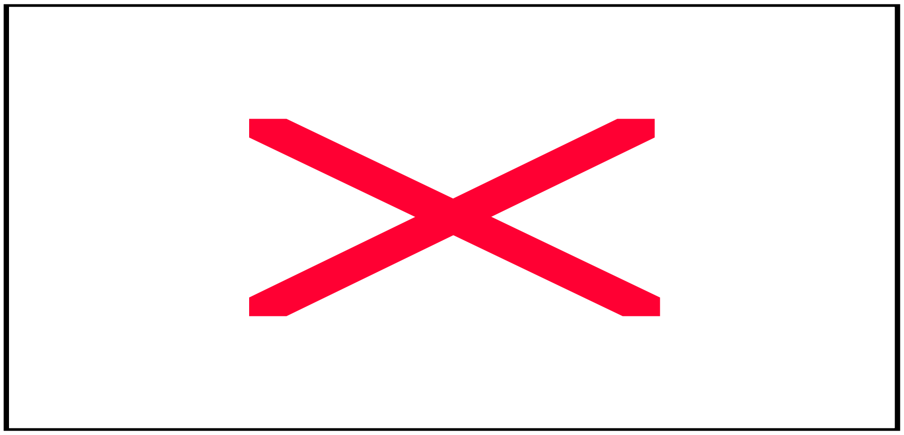

Fig. 2 CEFR fuel sub-assembly

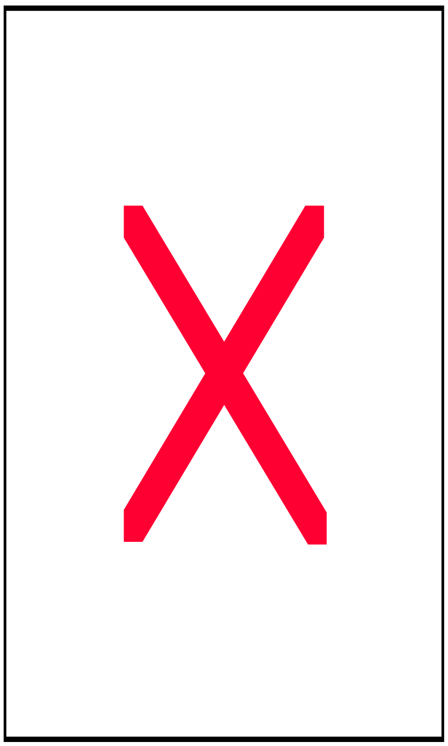

Fig. 3 CEFR core

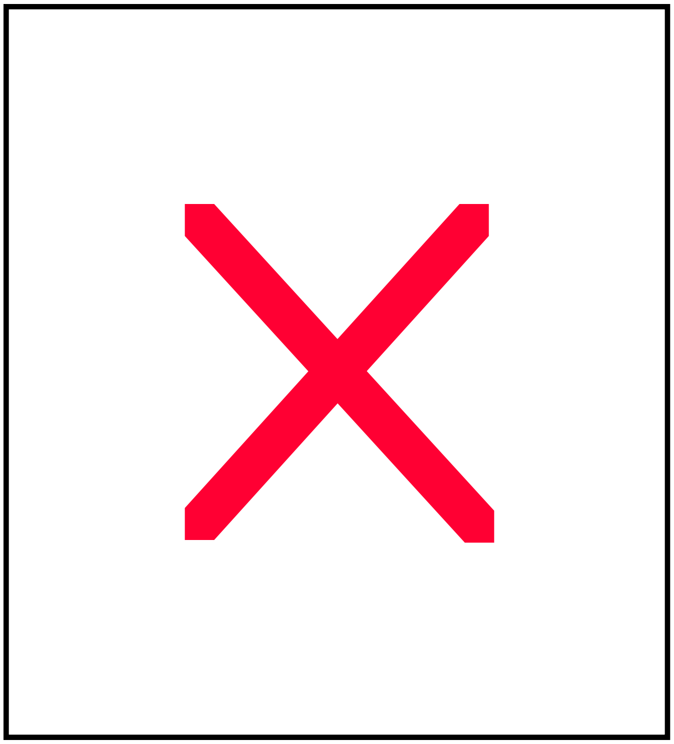

Fig. 4 **Decay heat removal system. 1: Air cooler, 2: Sodium pipe, 3: Decay heat exchanger (DHX)**

The CEFR is a small reactor which has a 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.

MOX core, average: (250°C-360°C)-4.19 Pcm/°C

UOX core, average: (250°C-360°C)-4.00 Pcm/°C

And negative power coefficients:

MOX core, average: (0-65MWt)-8.69 Pcm/MWt

UOX core, average: (0-65MWt)-7.83 Pcm/MWt

Therefore, the CEFR has its neutronics selfstability. And sodium bobble coefficients anywhere are negative. The reactivity effect of whole core sodium lost is:

MOX core: -5.195%ΔK/K

UOX core: -5.194%ΔK/K

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 (Fig. 4 shows one system). Each one is rated to a thermal power of 0.525MWt under the nominal 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 5 gives the parameters of the DHRS, of the CEFR.

Table 5. Parameters of one 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 °C		
Inlet at DHX	516	516
Outlet at DHX	444	490
Secondary Na Temperature °C		
Inlet at Air cooler	514	515
Outlet at Air cooler	373	485
Air Temperature °C		
Inlet at Air cooler	50	50
Outlet at Air cooler	264	496
Secondary Na Pressure MPa	0.6	0.402

*) DHX-Direct Heat Exchanger in DHRS

Table 6. Maximum Dose Equivalent Value (mSv)

no. of accidents	Grid lost	Shut down failed	DHRS failed	Dose calculated	Dose limitation
BDBA-1	∨	∨		0.12	5
BDBA-2	Purification pipe leaked and check valve failed,1372kg Na			0.0692	5
BDBA-3	∨		∨(10%kept)	Negligible	5
BDBA-4	Regulation S.A. unexpected raised	∨		Negligible	5
BDBA-5	Two check valves in primary circuit closed			negligible	5
BDBA-6	Main and guard vessels leaked successively			0.00414	5
BDBA-7	∨	∨	∨	1.22	5
DBA-1	Main vessel leaked			Negligible	0.5
DBA-2	Purification pipe leaked and check valve O.K. ,40kg Na			0.0013	0.5
DBA-3	Cover gas leaked			Negligible	0.5
DBA-4	Ar decay tank leaked			0.003	0.5

In the preliminary safety analysis report (PSAR) 16 initial events and DBAs and

9 BDBAs have been analized. The calculation results show that the maximum public effective dose equivalent values at the periphery of the site are all lower that the dose limitation during these accidents. The main results is introduced in the Table 6.

Conclusion

During the past less than 10 years we started, based on self-reliance with some international cooperation, to design and build an experimental fast reactor, even though we have prepared this technology for a long time, but we are still lack of experiences on this field. It reflects especially the schedule always delayed. But it is sure that the safety of the reactor and environment can be assured based on our efforts. And especially the CNNSA is very rigorous to any nuclear facility, it goes without saying to the CEFR which is the first fast reactor in China and located only 40km far away from 10 million people City. The safety reviewing standard of nuclear power plants has been adopted for the CEFR. Concerning the PSAR almost thousand questions and answers have been carried out since last May, but the construction permission is still not issued up to now. It is estimated that it will be realized in May.

Now , the site has been prepared, the ordering of the components is started. It is envisaged that the construction completion will be in the year 2004.

As the second step of Chinese fast reactor development, the prototype fast reactor will be started to design in the year 2001.

References

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