BIO of Hongyi YANG

- Graduated from Xi'an Jiaotong University and major in nuclear reactor engineering 1993.7
- Got the MA and PhD degree in nuclear energy science and technology from CIAE 1996.7 and 2004.7
- Took part in the R&D of CEFR and organized the detailed design of CEFR.
- Have the expertise in the thermal hydraulics, accident analysis and PRA of FR
- Be responsible for the R&D of the small modular FR.
- Vice President of CIAE and in charge of the R&D of the nuclear science and technology
- Member of Senior Industry Advisor Panel (SIAP) of GIF

Current Status of China Fast Reactor Development

Hongyi YANG

China Institute of Atomic Energy

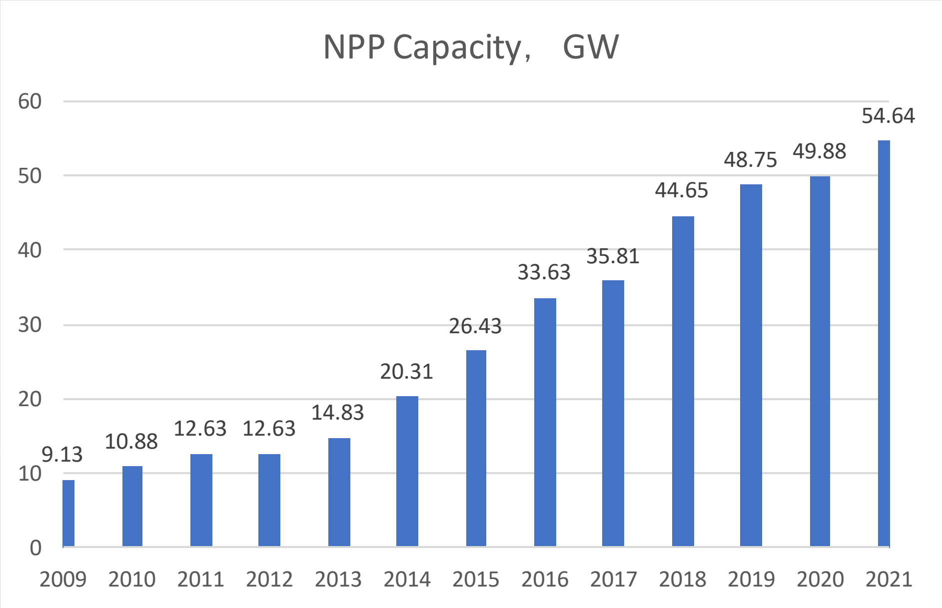
April 19, 2022

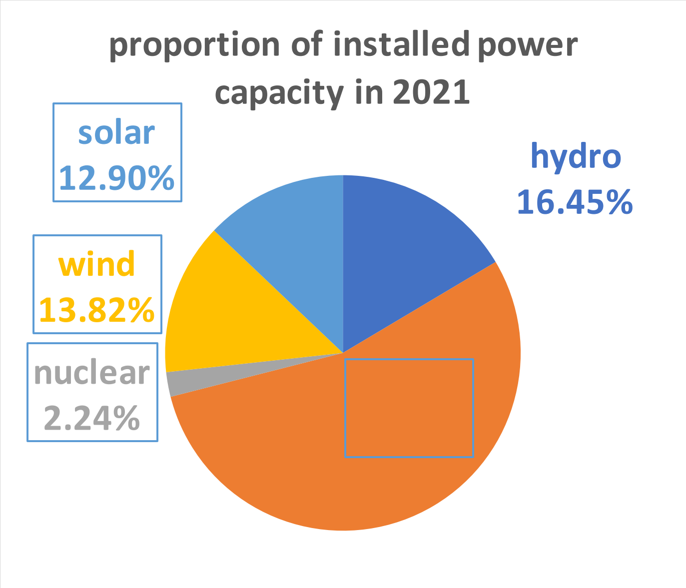
Contents

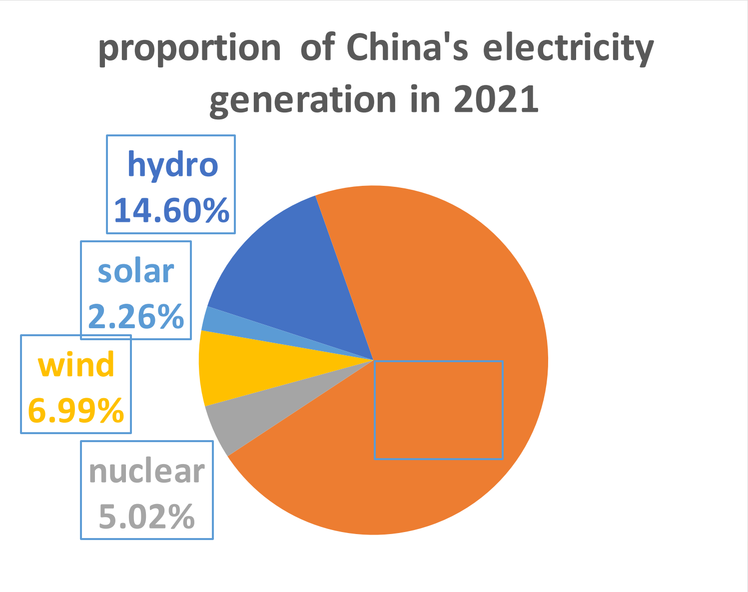
1. Overview of nuclear energy in China(1/3)

Energy production structure

- The cumulative on-grid nuclear power was 382.084 billion kWh in 2021, increasing 11.17% from the same period in 2020.
- The utilization hours of installed nuclear power were 7777.85 hours, and the average unit capacity factor [7] was 92.27%.
- Compared with coal power, nuclear power reduced the burning of standard coal by 115,5805 million tons and reduced CO_2 emissions by 302,820,900 tons, sulfur dioxide by 982,400 tons, and nitrogen oxide by 855,300 tons.

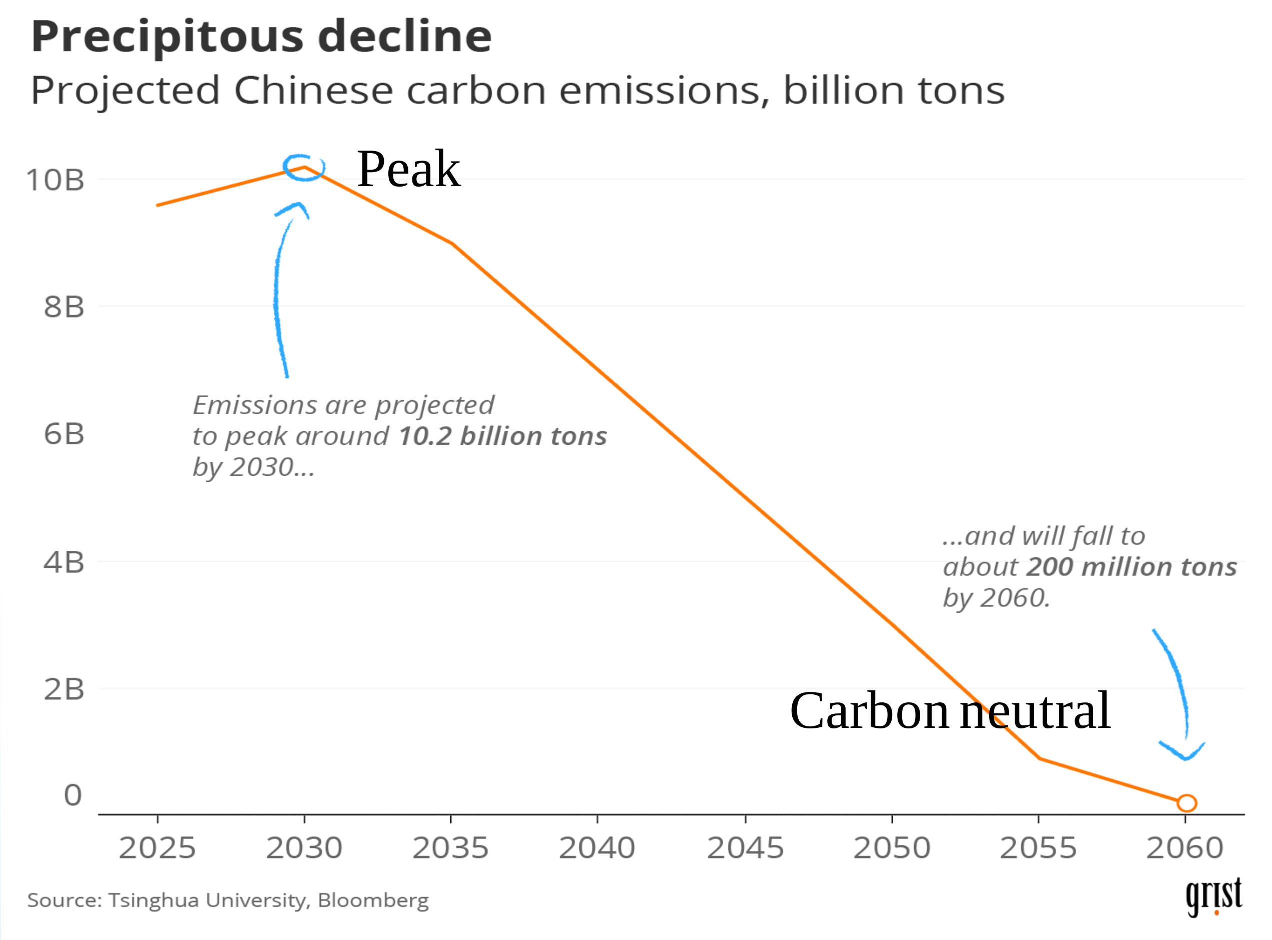






1. Overview of nuclear energy in China (2/3)

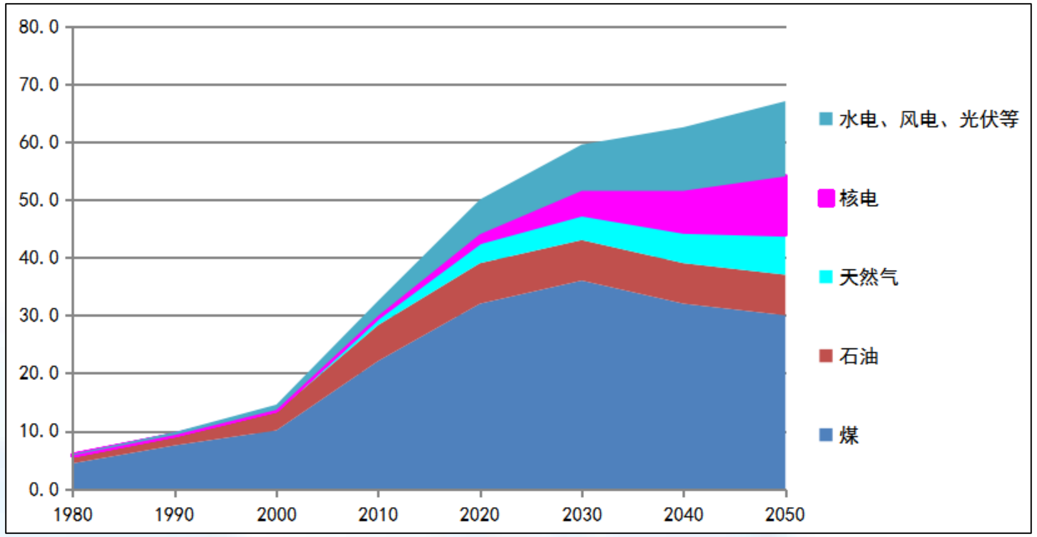
China's commitment to carbon reduction

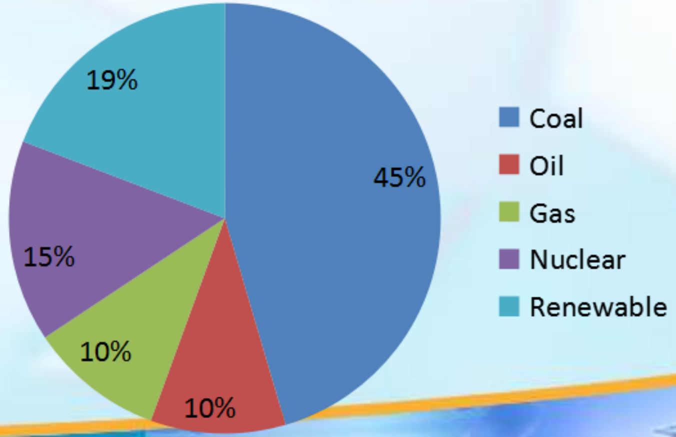


- China promised in Paris Climate Summit that "Non-fossil Energy in China will account for about 20% of Primary Energy consumption". It is expected that nuclear power will have much greater development by 2030.
- Chinese President Xi Jinping promised at the UN general conference in Sep 2020 that "China will improve independent contributions and adopt more powerful policies and measures to make carbon dioxide emissions peak by 2030 and become carbon neutral by 2060."
- Nuclear energy is an important approach for China to carry out the international commitment of reducing carbon emission.

Nuclear Energy Development Prospect

- In 2021, nuclear power generation was account for *2.2%* of the total power generation.
- Till September 2021, the nuclear power installed capacity of china arrived 53.26GW, it is the 3rd place in the world.
- China's nuclear power generation capacity will increase from the current 4.8% to 10% by 2035. It is estimated that China's nuclear power installed capacity will reach 150GW around 2035. It is estimated that China's nuclear power installed capacity will reach 150GW around 2035, and over 300GWe by 2050.





Content

2. Fast Reactor Strategy (1/2)

Nuclear energy policy and tasks of Fast Reactor

➢ Nuclear energy policy

- The nuclear energy must be developed safely and high efficiently.
- PWR is currently the main force of power reactors.
- The strategy is to develop with three steps: thermal reactors, fast reactors, and fusion reactors.
- Fuel cycle will be developed along with nuclear power stations in parallel.

➢ Tasks of Fast Reactor

- Support the sustainable development of nuclear energy
  - Improve the utilization of uranium resource
  - Transmutation of long life radioactive material

2. Fast Reactor Strategy (2/2)

Fast Reactor Development Strategy

Experimental reactor	Demonstration reactor	Commercial reactor
CEFR	CFR600	CFR1000
2011	~ 2025 (2 units)	~2030

➢ **R&D of Small modular fast reactor is under developing parallel.**

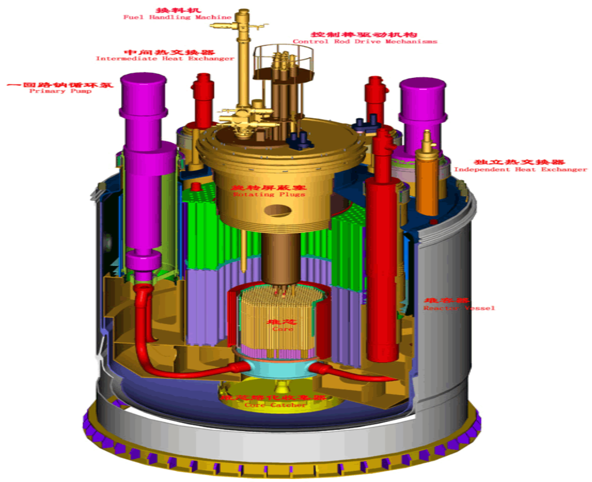
- **1-3MWe small modular SFR is the development focus for the remote territory power supply.**
- **1MWe small modular lead based FR under development, and the material, physics and component R&D activities aimed at the engineering goal are ongoing**
- **7.5MWth Lead based subcriticality FR under the CiADS project will be constructed in Guangdong province.**

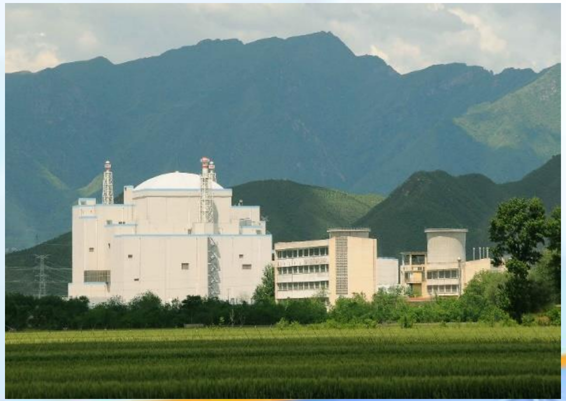
Content

3. SFR：CEFR (1/2)

Main parameters and general design selection

Parameter	Unit	Value		Parameter	Unit	Value
Thermal Power	MW	65		Primary Circuit		
Electric Power, net	MW	20		Number of Loops		2
Reactor Core				Quantity of Sodium	t	260
Height	cm	45.0		Flow Rate, total	t/h	1328.4
Diameter Equivalent	cm	60.0		Number of IHX per Loop		2
Fuel		MOX (first loading is UO_2)		Secondary Circuit		
Linear Power max.	W/cm	430		Number of Loop		2
Neutron Flux	$n/cm^2 \cdot s$	3.7×10^{15}		Quantity of Sodium	t	48.2
Bum-up, first load max.	MWd/t	60000		Flow Rate	t/h	986.4
Inlet/outlet Temp. of the Core	℃	360/530		Tertiary Circuit		
Diameter of Main Vessel(outside)	m	8.010		Steam Temperature	℃	480
Design Life	A	30		Steam Pressure	MPa	14
				Flow Rate	t/h	96.2





3. SFR：CEFR (2/2)

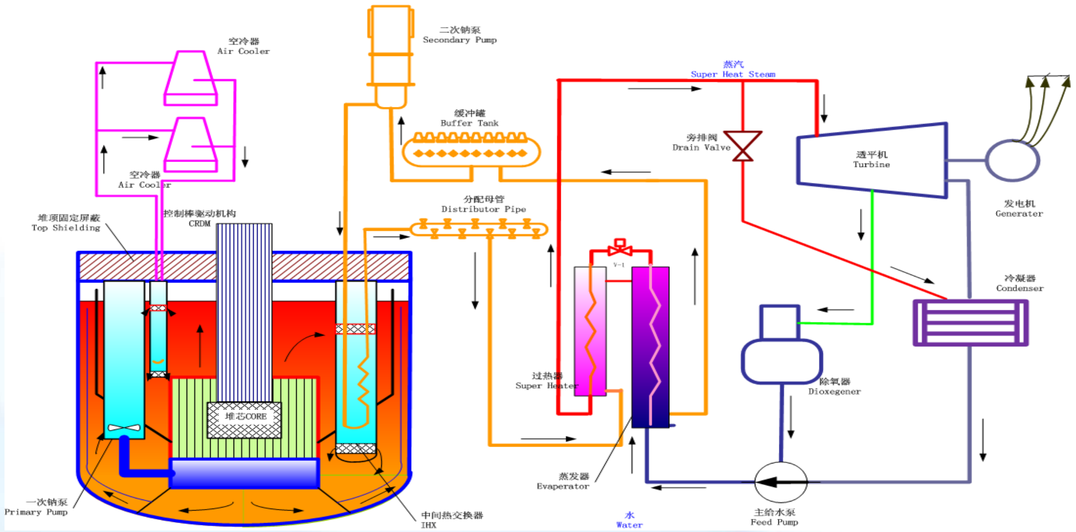
Operation Maintenance of CEFR

- Since the first criticality of CEFR, it has been operating for *101.2 days* and generating about *24.8 million KWh*. On July 31, 2020, CEFR successfully completed all power tests and commissioning projects in phase C. The first refueling was completed on December 31, 2020.
- From 2019 to 2020, *192 maintenance tasks* are planned in the second cycle overhaul window of CEFR, including *130 preventive maintenance tasks* and *60 corrective maintenance tasks*. At present, the overhaul work has been completed on schedule and met the requirements for the next stage of reactor startup.
- Up to the end of Mar 2022, CEFR has been operated for about 21.5 EFPDs. Now it is at the state of shutdown and refueling.

3. SFR：CFR600 (1/2)

Main parameters and general design selection

Parameters	Value
Thermal Power, MW	1500
Electrical Power, MW	600
Efficiency	40%
Design load factor	80%
Fuel	MOX
Burnup (max), MWd/kg	98
BR	1.15
Circuit Number per loop	2/2
IHX number per circuit	2
CDF, per year	$<10^{-6}$
Frequency of large radio active release, per year	$<10^{-7}$



3. SFR：CFR600 (2/2)

Design and Construction of CFR600

- The CFR600 is a typical pool type SFR with 2 symmetry circuits and 8 modular SGs in every circuit. The power is 1500MWth and 600MWe.
- **Design:** the detail design of unit#1 has already completed; the preliminary design of unit#2 has 30% completed.
- **Fuel & Material:** the core cladding material is under development and the first batch of irradiation SAs have already been loaded in the CEFR core.
- **Component:** all the components are under fabrication.
- **Installation:** ongoing

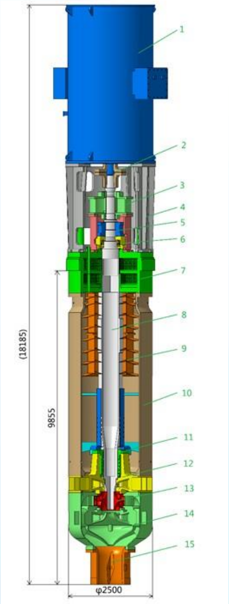
The First SG unit fit to its position successfully last week!

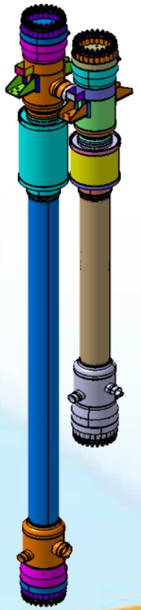
- **Commissioning:**

Under preparation

CN-1515 cladding

CN-FMS duct tube





3. SFR：R&D (1/6)

Development of SFR core materials

- Three kinds cladding material are under developing:
  - 316Ti
  - 15-15Ti(CN-1515)
  - ODS
- Three kinds hexagon duct material are under developing:
  - 316Ti
  - 15-15Ti
  - Ferrite - Martensitic steel(CN-FMS)

CN-1515 cladding

CN-FMS duct tube

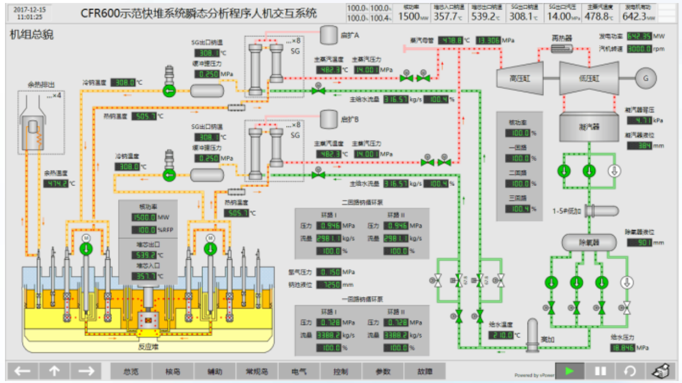
enriched B_4C pellet

R&D of out-of-pile of CN-1515 cladding tube and CN-FMS wrapper tube has been completed, and the structural and absorber materials irradiated subassemblies have started irradiation in CEFR.

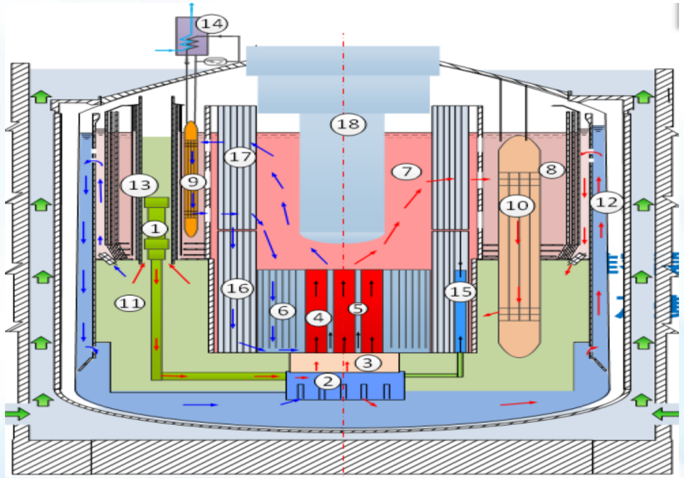
3. SFR：R&D (2/6)

Computer code development

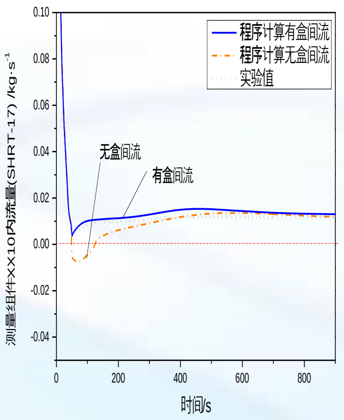
➢ The computer codes requested by the SFR design and safety analysis have already developmental especially for CFR600 and the V&V task are ongoing



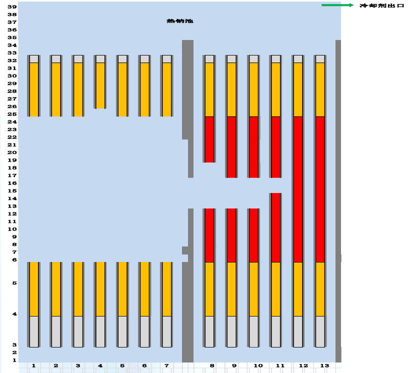
1. System Analysis Code



2. Core and Primary Circuit Thermal-Hydraulic Design code



3. Decay Heat Removal Capability Analysis Code

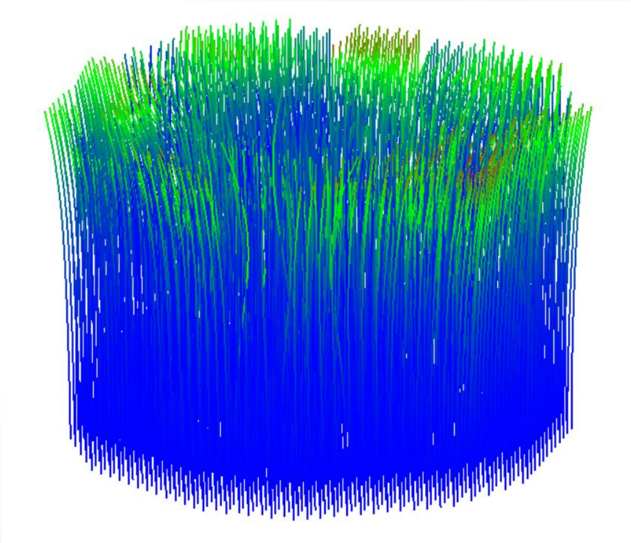


4. Severe Accident Analysis Code

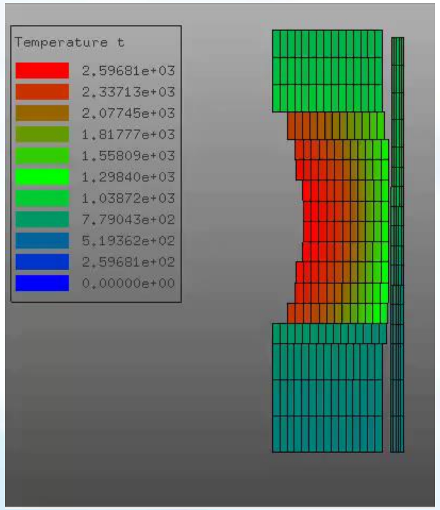
3. SFR：R&D (3/6)

Computer code development

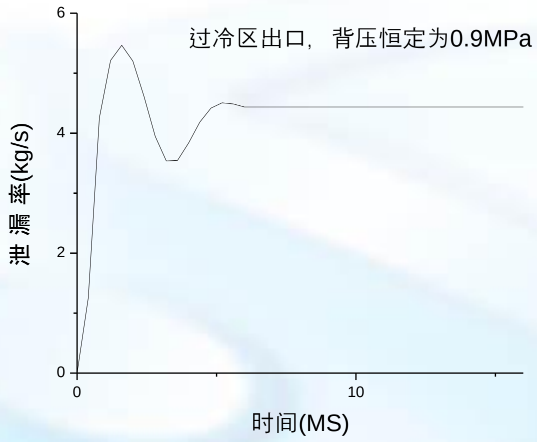
- The computer codes requested by the SFR design and safety analysis have already developmental especially for CFR600 and the V&V task are ongoing



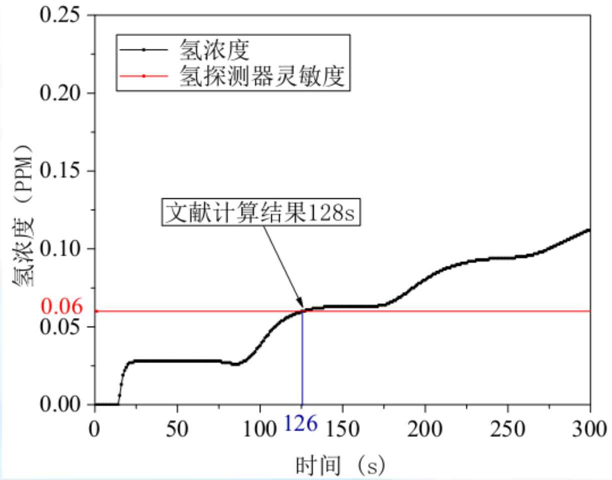
5. Fuel Subassembly Deformation Analysis code



6. MOX fuel performance analysis code



7. Large Sodium-Water Reaction Analysis Code

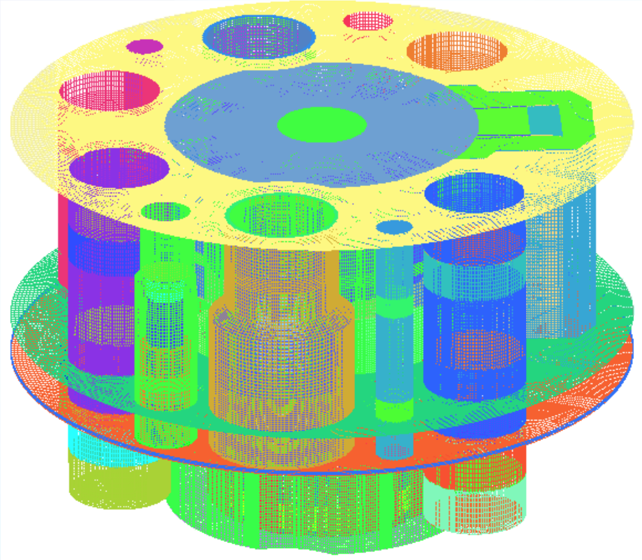


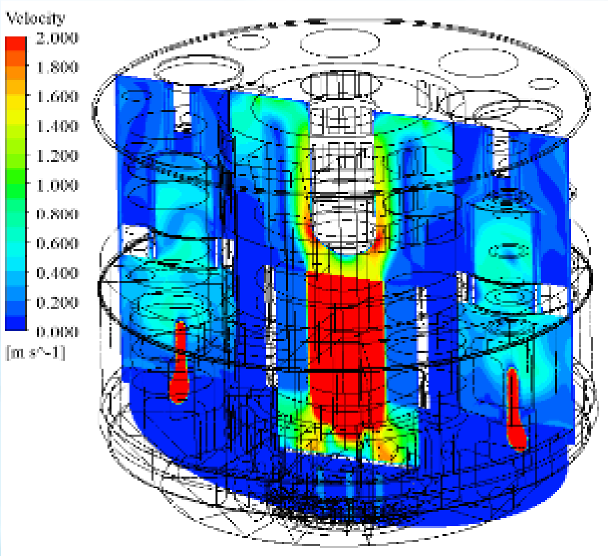
8. Small Sodium-Water Reaction Analysis Code

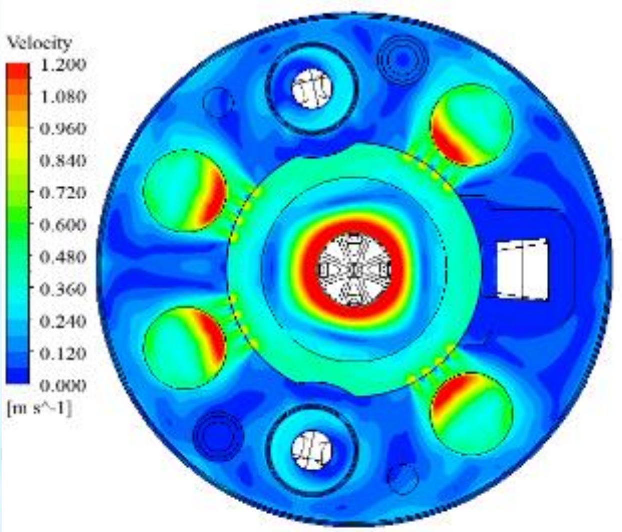
3. SFR：R&D (4/6)

Thermal hydraulic analysis of primary system

1. Design Transients under different power level
2. Integrated model and meshing and 3D simulation methodology
3. Under super computer calculation



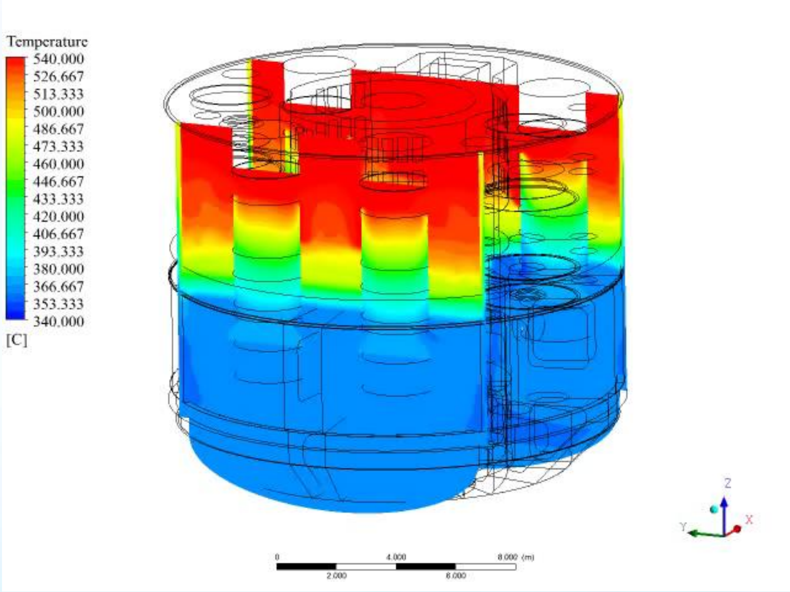


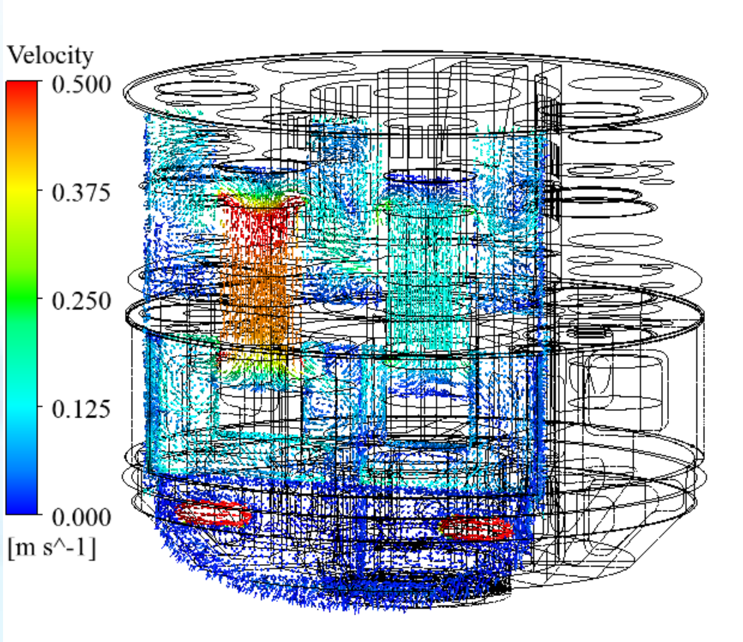


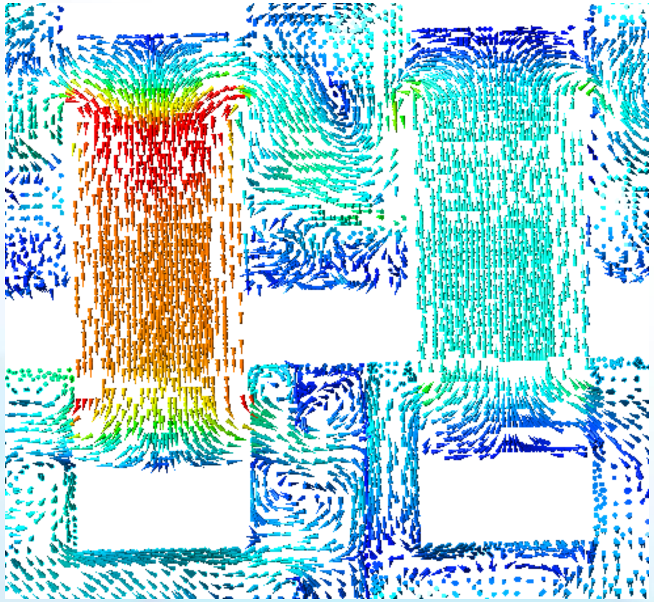
3. SFR：R&D (5/6)

Thermal hydraulic analysis of primary system

1. Special Transients analysis. Primary pump locked rotor







3. SFR：R&D (6/6)

Thermal-Hydraulic verification test of primary system

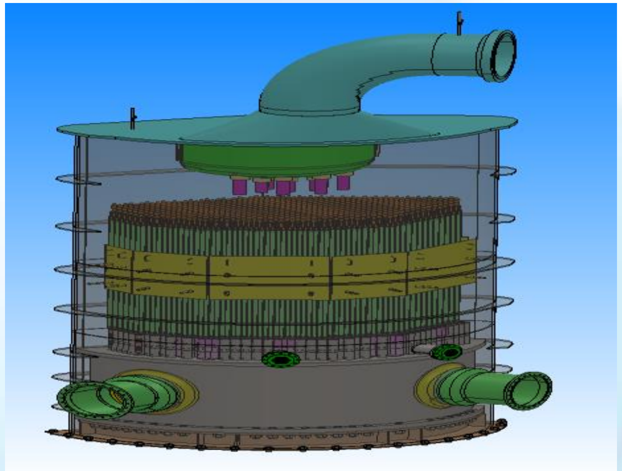
➢ **Typical hydraulic characteristic test**

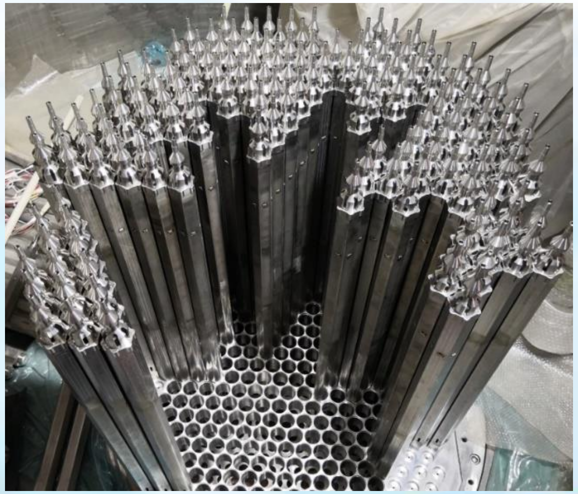
- Separate experiment
  1. hydraulic characteristic experiment of fuel assembly bundle
  2. hydraulic characteristic experiment of assemblies, including：
  3. hydraulic characteristic experiment of small gird header
  4. flow distribution experiment of small gird header
- Integrated experiment (scale 1:1, angle 152°)
  1. flow distribution experiment of the entire core

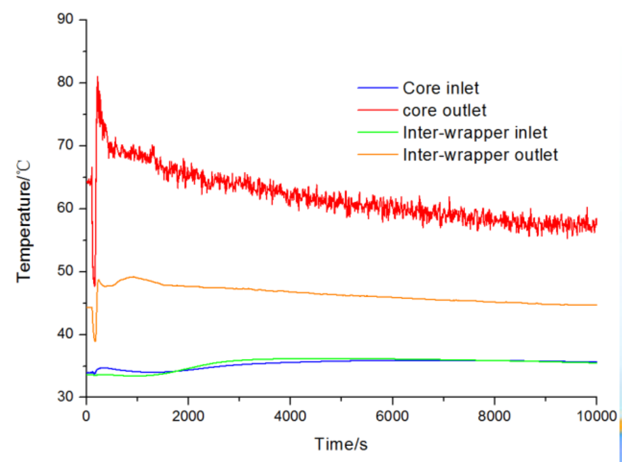
➢ **Natural Circulation Experiment of Primary Circuit**

- 1:5 360◦ water model 。

2. Core：
3. IHX：
3. IHX：
4. Pump：







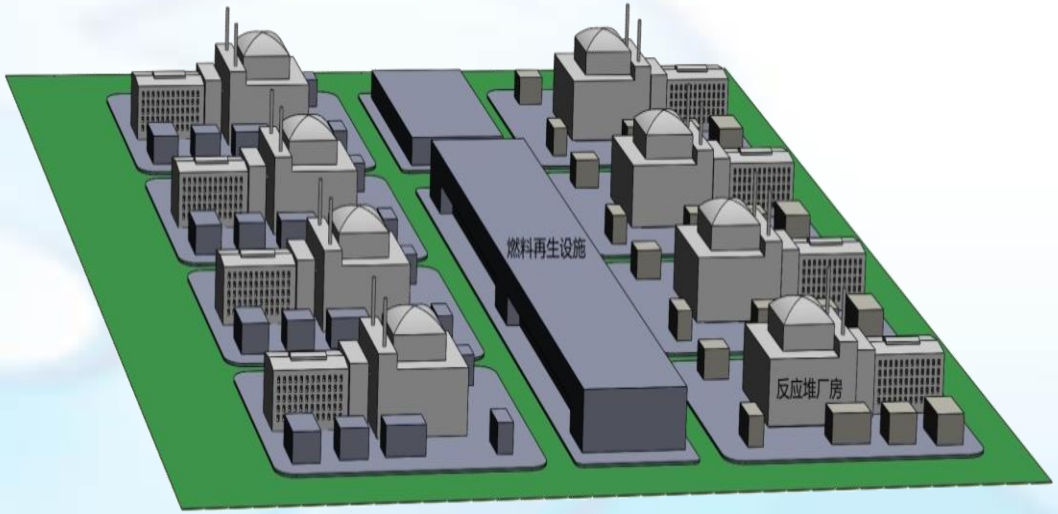
Content

Basic Concepts of IFRES

IFRES is composed of several fast reactors and one fuel regeneration facility, it can be constructed at the same site.

- **Fast reactors and fuel regeneration facility are designed at the same site to integrate closed fuel cycle processes.**
- **Fast reactor can realize three functions: power generation, fuel breeding and transmutation.**
- **Fuel regeneration facility integrate pyro processing and fuel production line for fuel reprocessing and regeneration.**

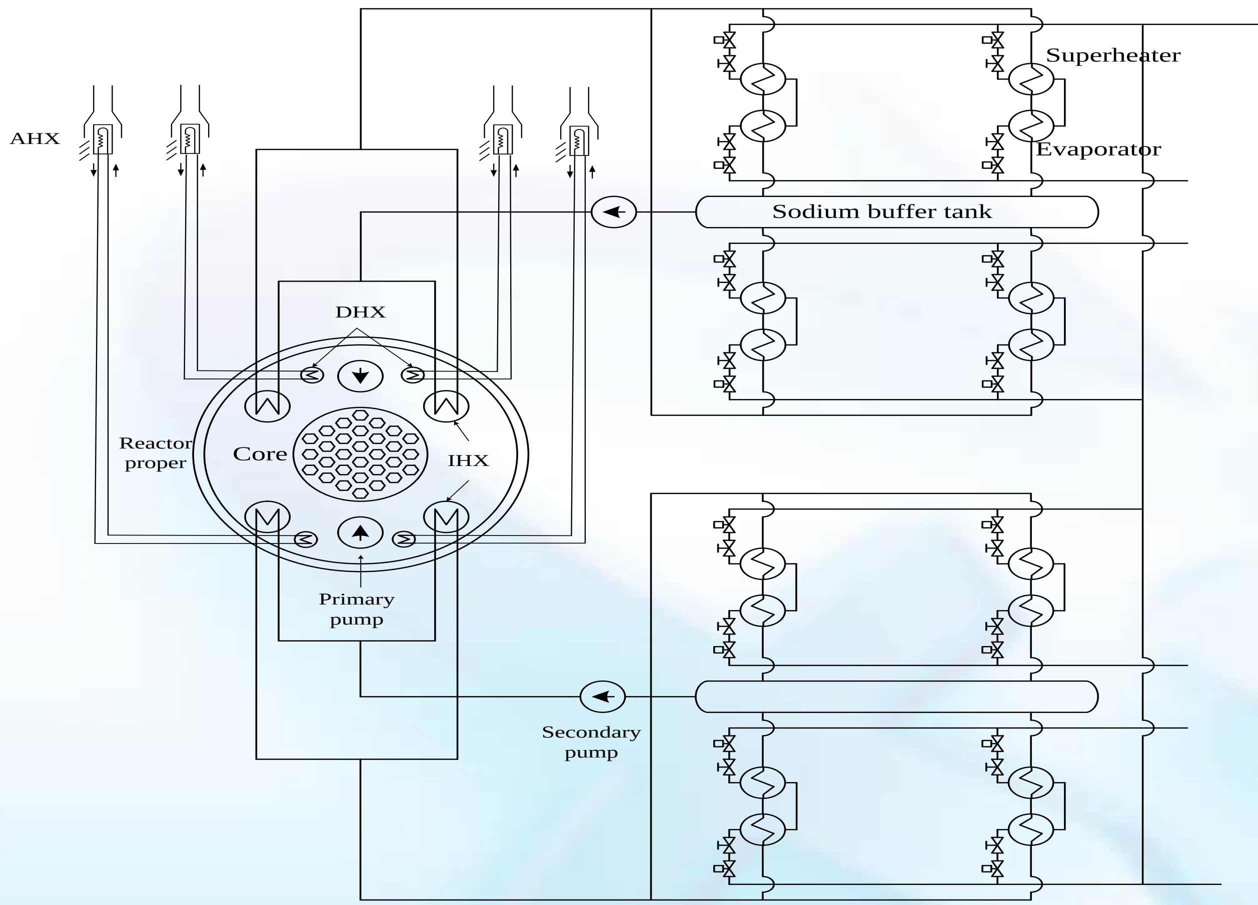
Parameter	SFR in IFRES
Resource demand	1.2tDU/a
Fuel regeneration capacity	20t/a
HLW in need tens of thousands of years of supervision	~0
Spent fuel inventory	~0
Safety	Inherent safety No need for off-site emergency
Economy	Reactor investment ratio 17000 RMB/kW, Full-life cost of fuel cycle facility is less than the fuel cost



Reactor building
Fuel regeneration facility

4. IFRES (2/3)

Technical configuration of SFR coupled with **IFRES**



Parameter	Value
1) NPP Type	SFR
2) Coolant type	Na-Na-H_2O
3) Electric power	1000～1200MWe
4) Thermal efficiency	>40%
7) Fuel type	MOX/Metal Fuel
8) Cladding material	HT9
9) Breeding ratio	>1.1
10) transmutation support ration	4.0
11)Maximum fuel burnup	>150000MWd/tHM
12) Refueling cycle	>12 months
13) Availability	> 80%
14) SSE	0.15g
15) CDF	$<1\times10^{-7}$
16) LERF	$<1\times10^{-8}$
17) Design life	60 years
18) Construction cycle	<60 months

R&D Work in the Future

- **Key technologies to realize advanced features**

advanced closed fuel cycle, reactor core fit for full actinide cycle, fuel technology, and pyro processing technology.

- **Key technologies to realize economy**

increase of reactor power, long life core design, high burnup fuel, cladding materials, large SG, built-in cooled trap, seismic isolation of nuclear island building.

- **Key technologies to realize safety**

negative feedback core design, minor backup reactivity, curie point passive shut-down system, passive residual heat remove system, AI specialist system.

Conclusion

- The nuclear energy of China has significant developed. But there are still some challenges：Inland site ；Economy ；many new reactor option are under development parallelly.
- The closed nuclear fuel cycle is necessary from the perspective of sustainable development of nuclear energy. FR will play a very important role in the fuel cycle in China.
- SFR have a greatly development while the CFR600 get into its operation and new integrated FR nuclear energy system will be the possible future.

Thank you for your attention!