Overview of GEN IV Demonstration Projects in China

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Main Outlines

- *VHTR - SSC Signatory*
- *SFR - SSC Signatory*
- *SCWR - SSC Signatory*
- *MSR - Observer*
- *LFR - Observer*

Outlines — VHTR

- *Overview*
- *HTR-PM project in China*
- *Prospects for VHTR*

The Content of This Part is Provided by Institute of Nuclear and New Energy Technology, Tsinghua University.

1. Overview

- *China has large investment and activities on VHTR*
  - *HTR-PM is a demonstration of power plant*
  - *HTR-PM will be operated in 2020*
  - *China will continue the development of VHTR, HTR-PM600 will be followed*
- *China joined all PMBs in VHTR*

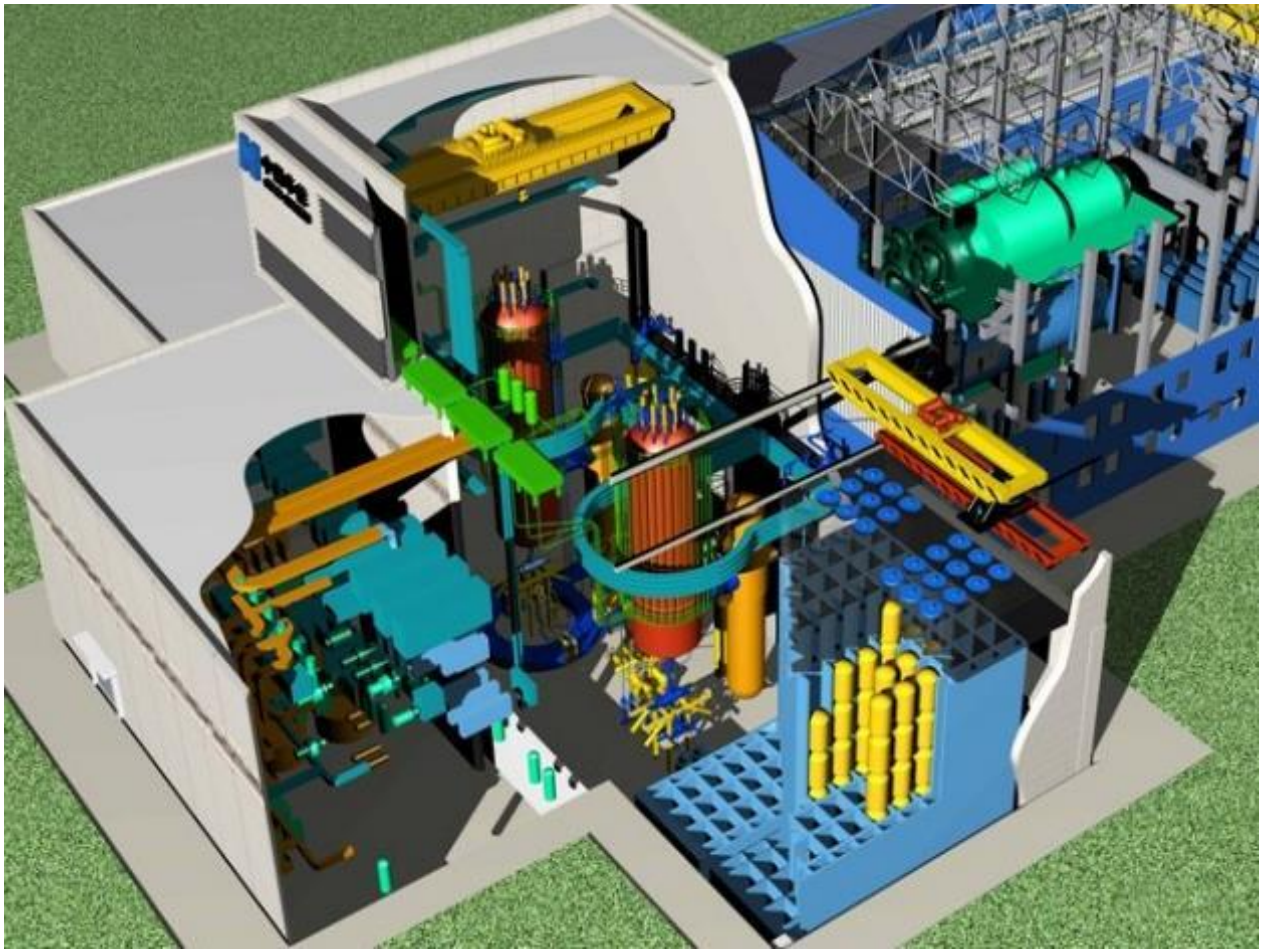
2. HTR-PM project

- *HTR-PM is a power plant demonstration, supported by central government, main milestones:*
  - *Feasibility study began in 2003*
  - *Design was fixed in 2006*
  - *FCD was taken place on Dec.9,2011*
  - *Full power operation is scheduled in 2020*

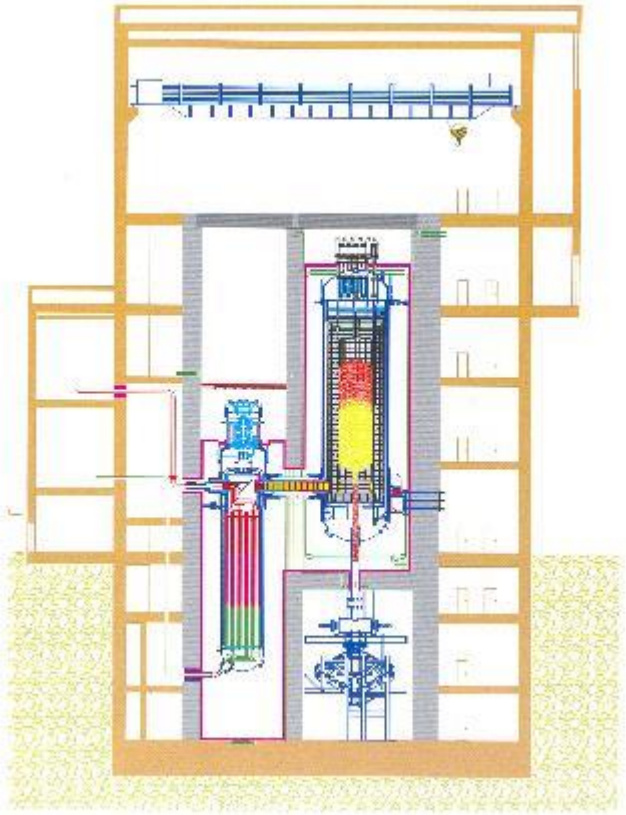
2. HTR-PM project

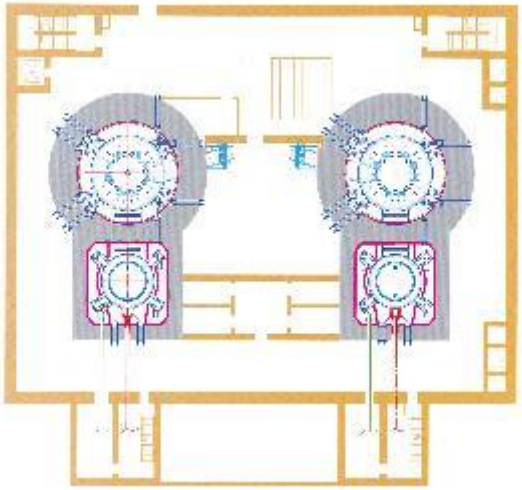
- *HTR-PM design features:*
  - *Single zone, pebble bed*
  - *Steam cycle*
  - *Standardized reactor with 250MWt*
  - *Two NSSS modules coupled with one 200MWe steam turbine*
    - » *HTR-PM600 will have 6 NSSS modules, has capacity 600MWe,*
    - » *The reactor modules is same as that in HTR-PM*

2. HTR-PM project

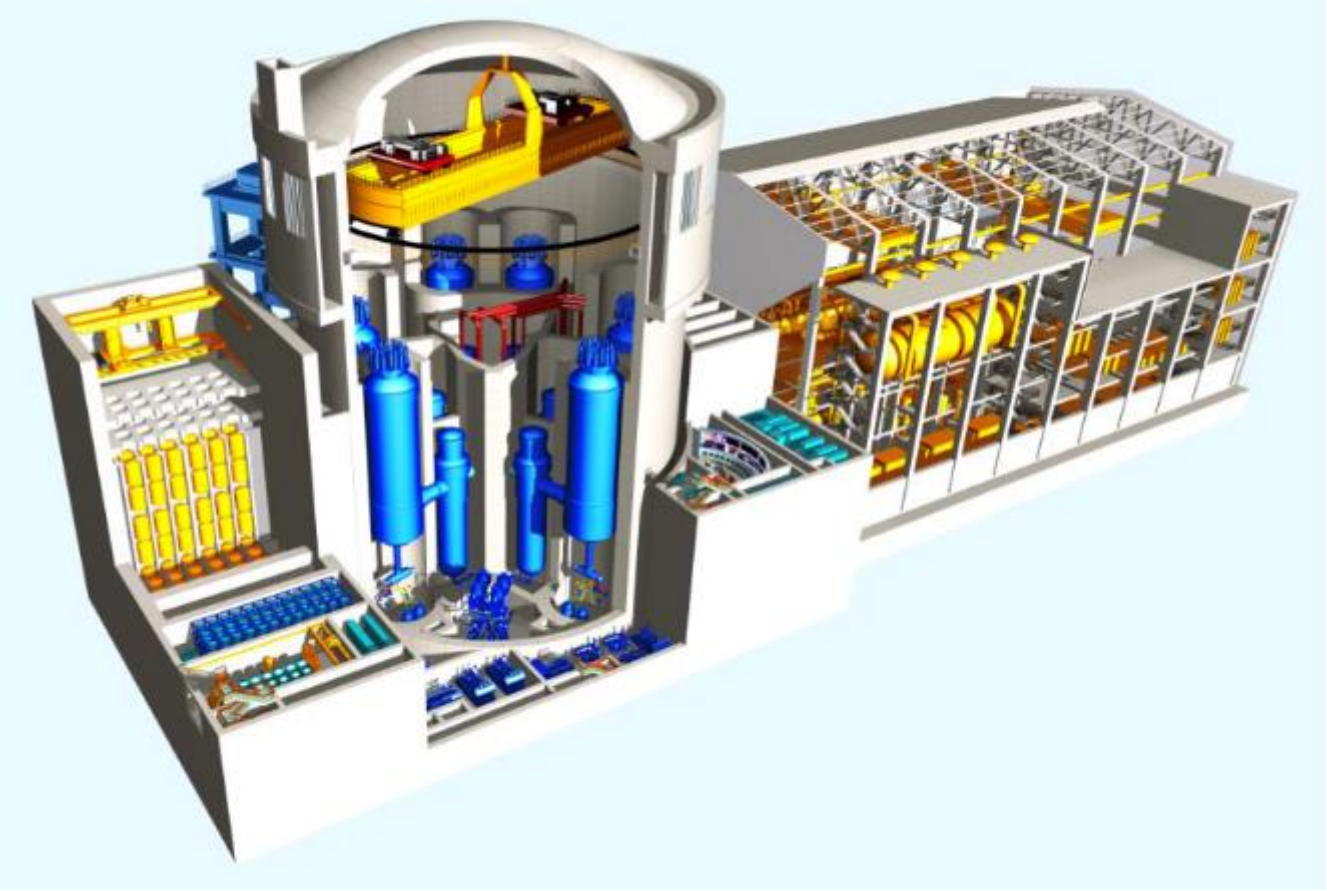


2. HTR-PM project - *Twin reactors configuration*





2. HTR-PM project - *HTR-PM600*



2. HTR-PM project - HTR-PM600

- *Design improvement*
  - *Same key components demonstrated in HTR-PM*
    - » *Same reactor modules used in HTR-PM*
  - *Single unit arrangement for standardization*
  - *Modular construction*
  - *Reduce the construction time*
  - *60 years lifetime*
  - *Capability to withstand commercial airplane crash*
  - *Compact arrangement inside the buildings*
  - *Simplify the auxiliary system further*

2. HTR-PM project - HTR-PM600

- *HTR-PM600 progress*
  - *First version of design was finished in September 2017*
  - *Economy feature will be improved than HTR-PM*
  - *Same components used in HTR-PM, less volume in building, simplified system configuration*

3. Prospects for VHTR

- *Highlights of VHTR:*
  - *High efficiency*
  - *Versatile applications: electricity, cogeneration, process heat,…*
  - *Inherent safety*
  - *Relatively mature*
    - » *HTR-PM is a good demonstration for VHTR future*

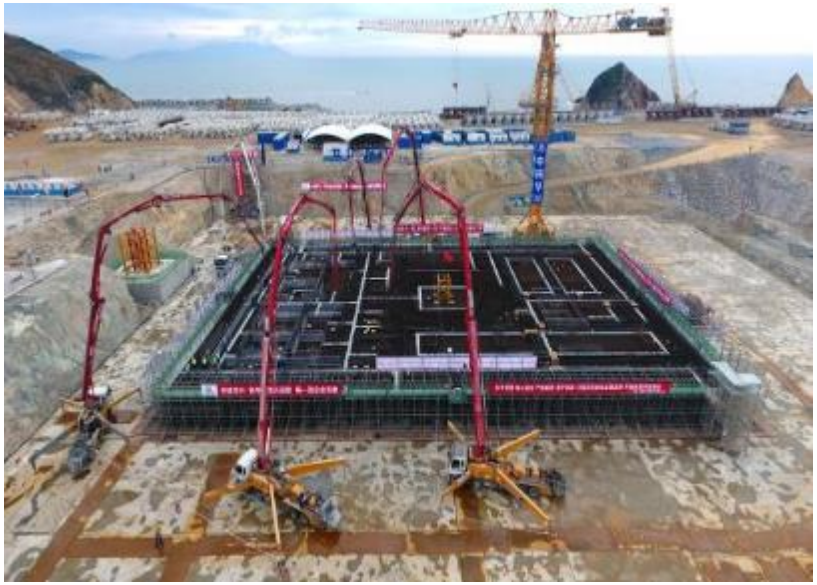
Outlines — SFR Demo plant

- *Preliminary plan of CFR600*
- *Main design parameters of CFR600*
- *Fuel and Material Development*
- *MOX Fuel*

***The Content of This Part is Provided by China Institute of Atomic Energy, CNNC.**

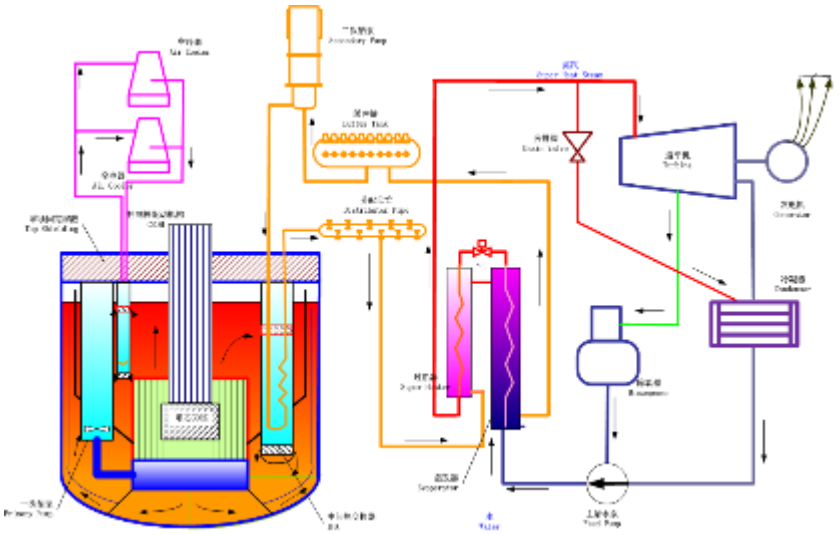
1. Preliminary plan of CFR600

- *2015.12, Concept design*
- *2016.12, Preliminary design*
- *2017.12, Detail design, FCD*
- *2023.12, Put into operation*



2. Main design parameters of CFR600

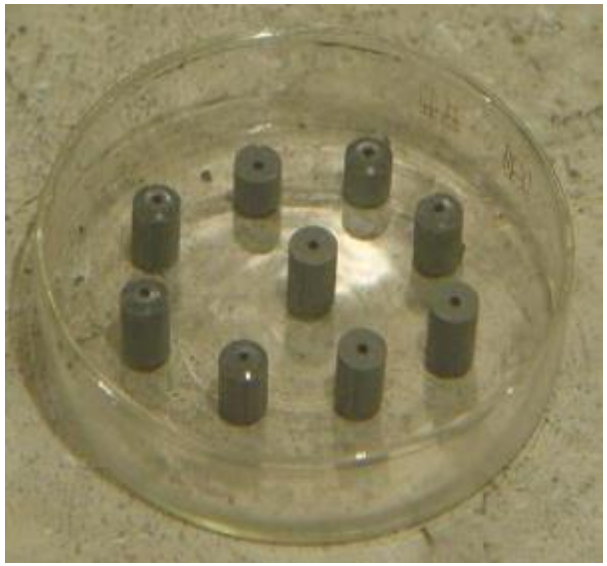
Parameters	Value
Thermal power, MW	1500
Electricity Power, MW	600
Efficiency	40%
Design Load Factor	80%
Fuel	MOX
Burn up (max), MWd/kg	98
BR	1.15
Circuit Number Per Circuit	2
CDF	$<10^{-6}$
LRF	$<10^{-8}$

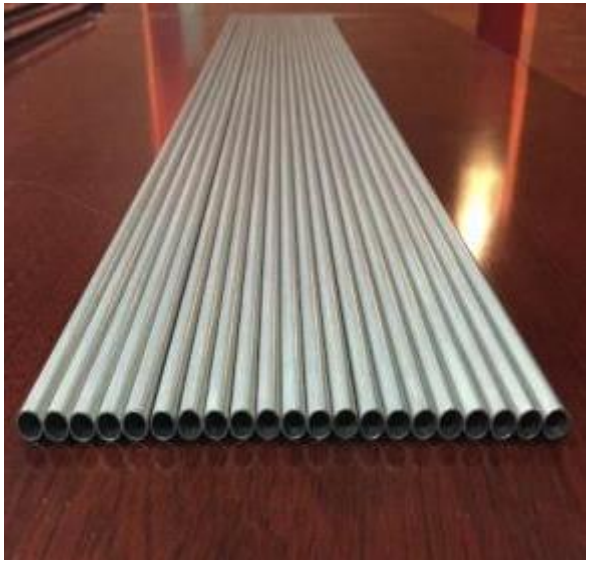


3. MOX Fuel - Significant progress

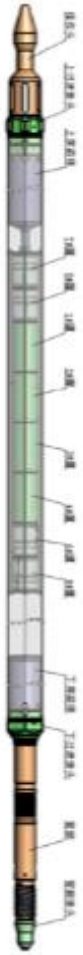
- *MOX fuel pellet specimens has been fabricated in laboratory scale.*
- *Domestic 15-15Ti (CN-1515) structural materials including cladding and wrapper has been fabricated.*
- *MOX fuel subassembly production line in laboratory scale has been achieved, the manufacturing process tests of MOX fuel subassembly are ongoing.*
- *The construction of MOX fuel subassembly production line in industrialization scale is under way.*

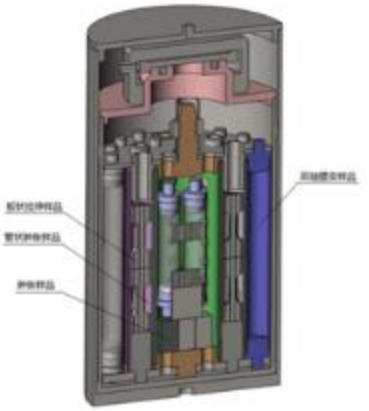
3. MOX Fuel – pellets, cladding and wrapper





4. MOX Fuel - Further Work





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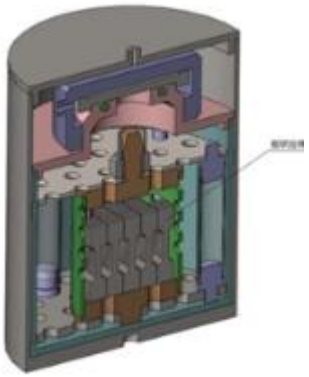

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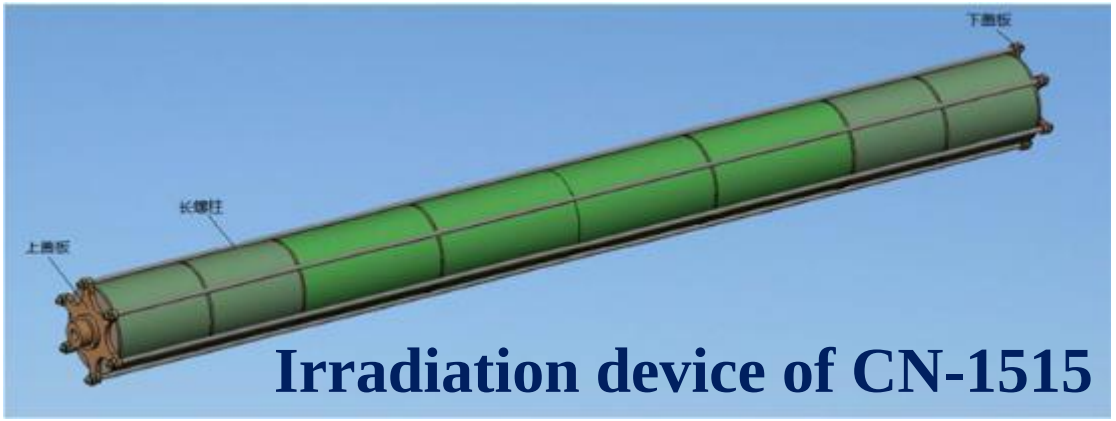


Irradiation device of CN-1515

Outlines —— SCWR

- *Introduction*
- *System Design*
- *Thermal Hydraulics*
- *Materials and Water Chemistry*

***The Content of This Part is Provided by Nuclear Power Institute of China, CNNC.**

1. Introduction

- *In 2003, Research on SCWR with a strategic R&D plan completed and proposed*
- *In 2007, China Minister of Science and Technology (MOST) supported the basic research project named "Study on scientific problems of SCWR"*
- *In 2009, CAEA supported the first technology research project named "R&D on SCWR technology (phase I)" to propose up the China SCWR design*
- *In 2014 , China joined the SCWR System Arrangement, signed SA extension in 2016 and joined the SCWR TH&S and M&C PMB in July 2017*

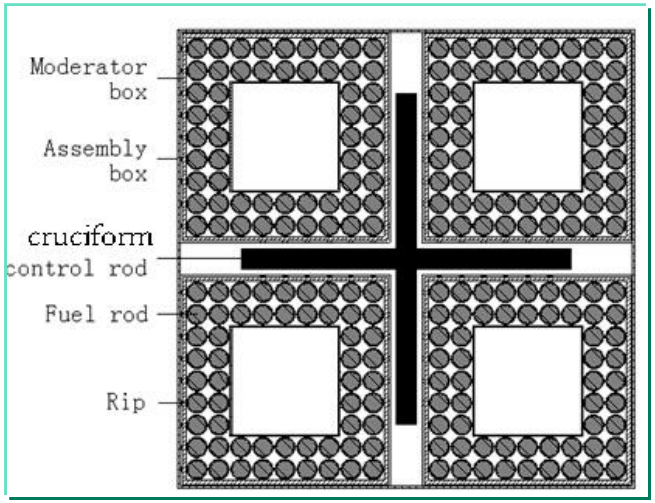
2. System Design - Parameters

- Based on abundant fundamental research achievements, a SCWR conceptual design named CSR1000 has been established with the following features:
  - Pressure vessel
  - Thermal neutron spectrum
  - Light water as moderator
  - Two flow-pass of coolant in core
  - Direct once-through cycle

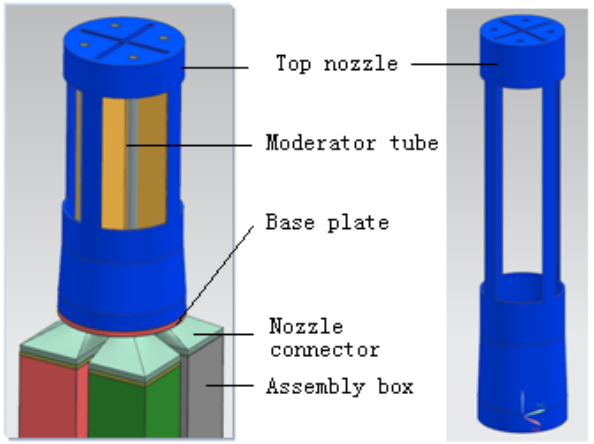
CSR1000 design parameters

Parameters	Value
Thermal power	2300MW
Electric power	～1000MWe
Efficency	～44%
System pressure	25.0MPa
Design pressure	27.5MPa
Reactor coolant inlet temp.	280℃
Reactor coolant outlet temp.	500℃
Coolant mass flow rate	1190 kg/s
Loop number	2
Neutron spectrum	Thermal
Cycle	once-through
Design lifetime	60 years

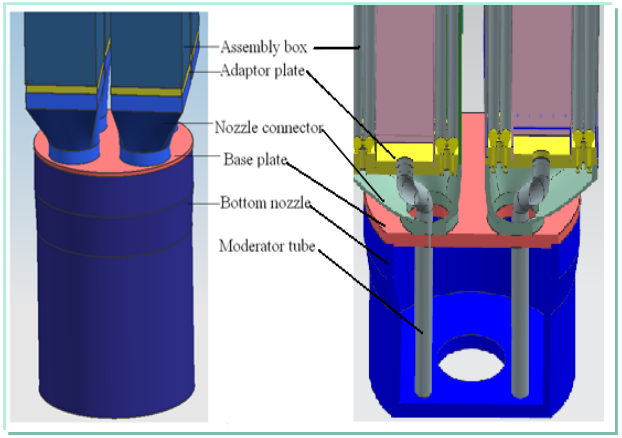
2. System Design - FA Design



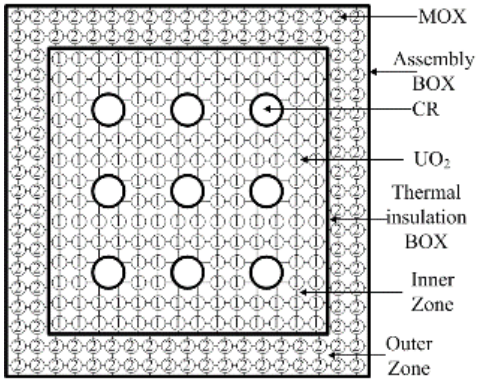
Structure

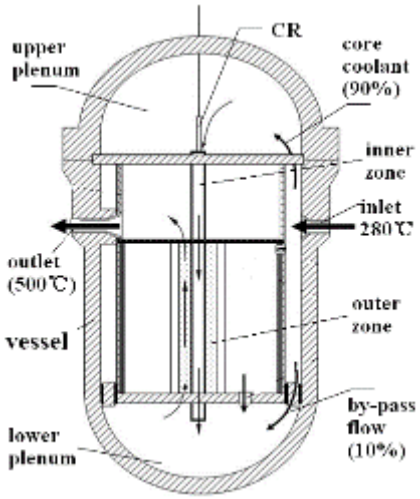


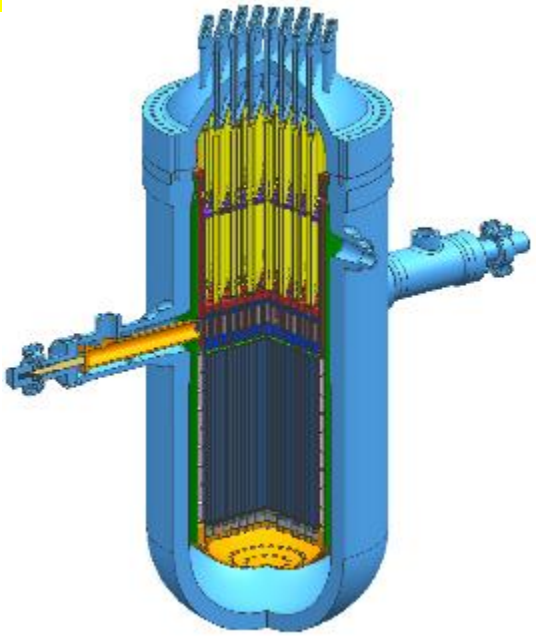
- A square FA with two-row FRs and a central moderator box
- 4200mm active length; Φ9.5 RD
- SiC cladding; Cruciform control rod
- Assembly box thickness:2mm
- Moderator box thickness:0.8mm

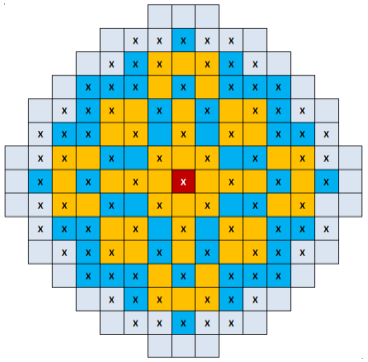


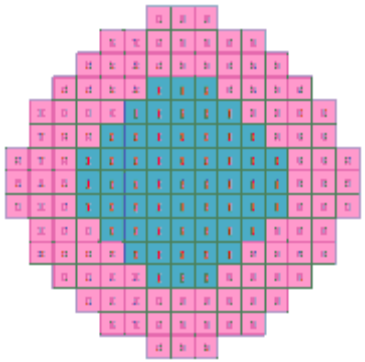
2. System Design – Core Design









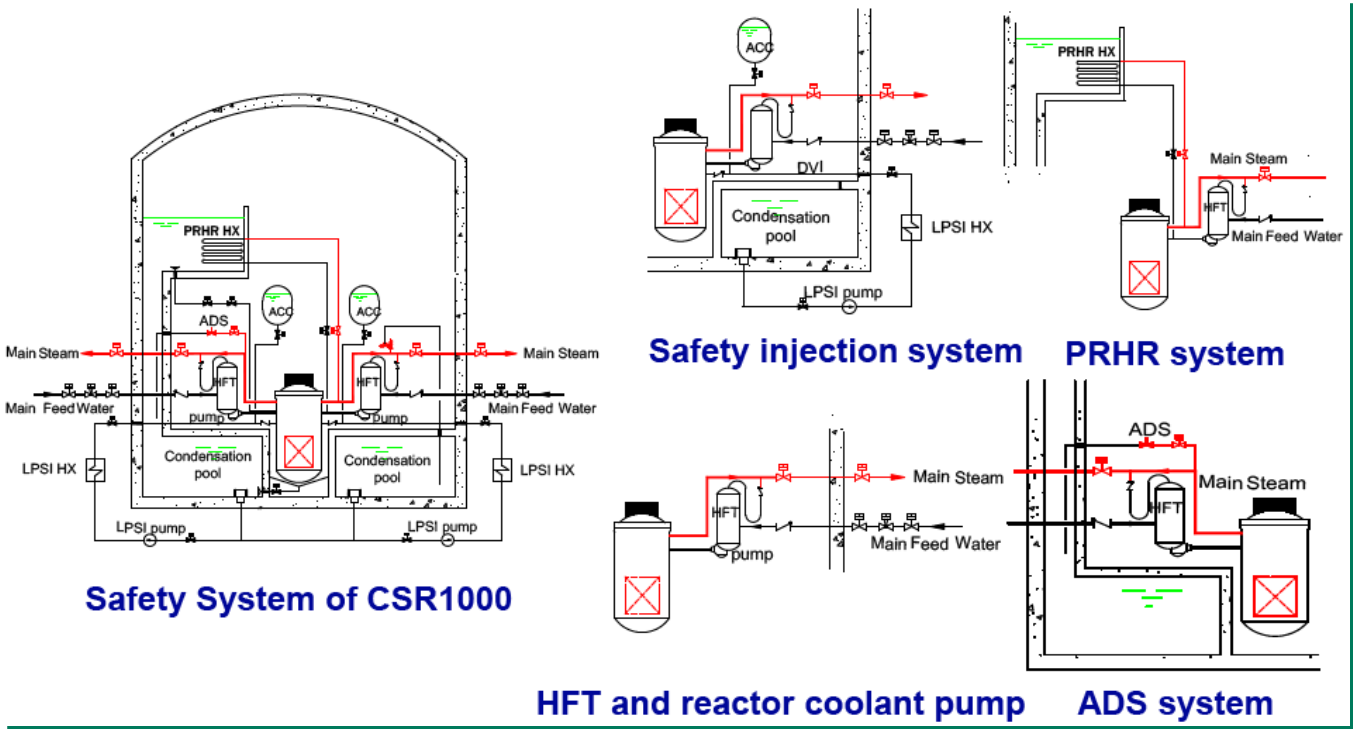


- Height 16.0m
- O.D. 5.3m
- thickness 0.44m
- Material 508III (T.D.)

Radial Zone Distribution of flow path **Radial Zone Distribution of control rod**

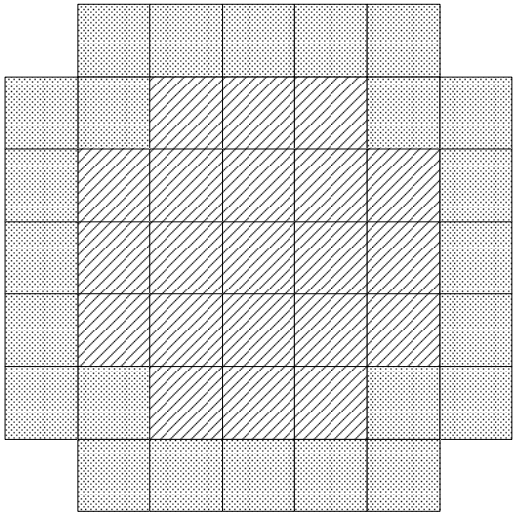
2. System Design - Safety Design

- *Conceptual design of safety system of CSR1000 has been accomplished, including passive safety system and active safety system*



2. System Design - CSR150 Design

- *Based on CSR1000, the conceptual design of the technical demonstration CSR150 has been proposed*



CSR150 design parameters	
Parameters	Value
Thermal power	375MW
Electric power	150MWe
Efficency	～40%
System pressure	25.0MPa
Inlet/outlet temp.	280℃/500℃
Coolant mass flow rate	193.7 kg/s
Neutron spectrum	Thermal
Coolant flow scheme	tow-pass
^{235}U Enrichment	5.7&7.2
Average power density	~60MW/m^3
Active core height	2.5m
Cladding material	310S

3. Thermal Hydraulics

- *The SCWR thermal hydraulics research in China includes four major aspects:*
  - *Heat transfer and flow tests of SCW in tubes, annular channel and simple rod bundles*
  - *Safety performance related tests including natural circulation, critical flow, CHF near critical pressure*
  - *Flow stability research of SCW in parallel Channels*
  - *Assessment and applicability of analysis codes*
- *Based on the above research work, a T-H database of SC fluid has been established, and some thermal hydraulic characteristics of SC fluid have been obtained*

3. Thermal Hydraulics - T/H Facilities

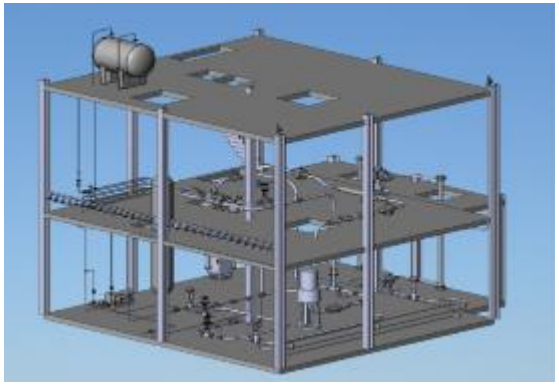
- *Up to now, China has setup some SCW test facilities, from small scale to larger scale, to fulfill the R&D request*

Loop	LSWT	SSWT	SNCL	XJHPWL-X	XJHPWL-M	XJHPWL-S	SWAMP
Organization	NPIC	NPIC	NPIC	XJTU	XJTU	XJTU	SJTU
Pressure(MPa)	32	30	30	40	40	40	30
Flowrate(t/h)	30	0.5	Natural Circulation	4.5	1.0	0.2	5
Heating Power	5MW	0.32MW	0.1MW	Sharing with electrical heating power 1.4 MW, Recover about 50% to 70% with a heat exchanger			1.2MW

3. Thermal Hydraulics - T/H Facilities

SNCL, operation in 2012

SSWT, operation in 2009



LSWT, operation in 2012

3. Thermal Hydraulics - T/H Facilities

XJHPWL-X

XJHPWL-M

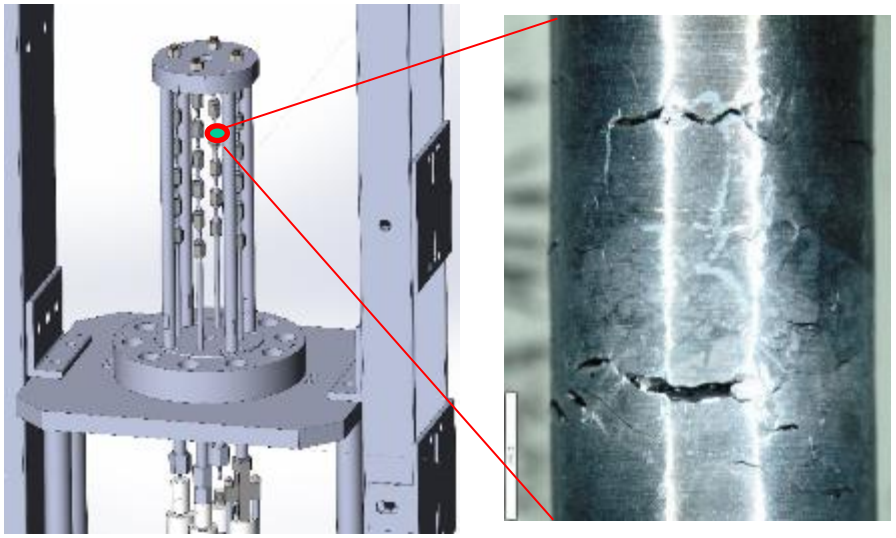
XJHPWL-S

SWAMP

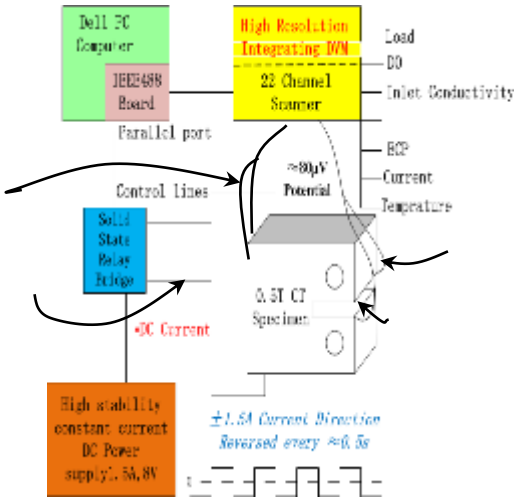
4. Materials and Water Chemistry

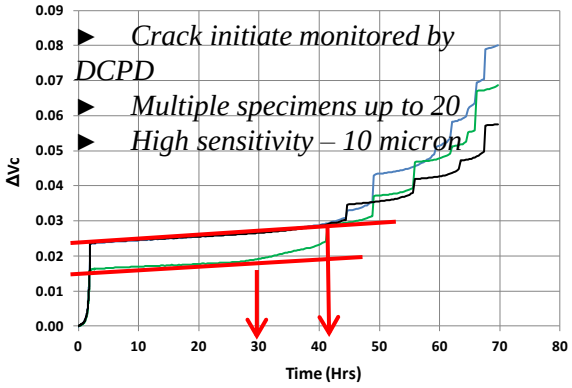
- *The SCWR material research in China includes four major aspects:*
  - *Screening of major candidate materials for fuel cladding and internal component*
  - *Mechanical property study of major candidate materials for fuel cladding and internal component*
  - *Corrosion property study of major candidate materials for fuel cladding and internal component*
  - *SCC property study of major candidate materials for fuel cladding and internal component*
- *Preliminary property assessments of several kinds of candidate materials have been obtained, and a material database of out-of-pile performances has been set up*

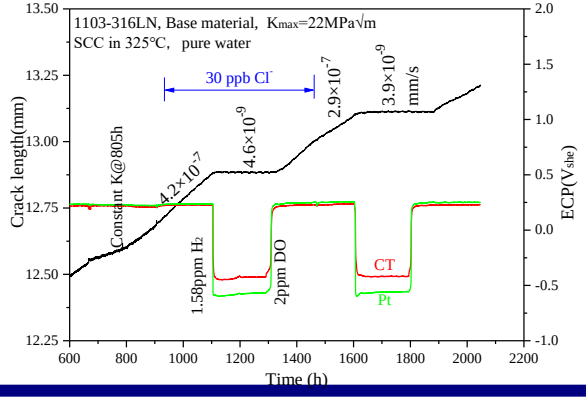
4. Materials and Water Chemistry - Some Results

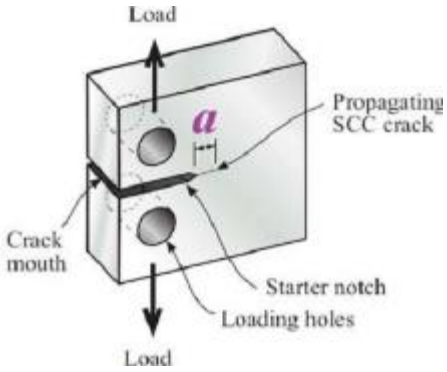


Multi axis/section/channel crack growth facility





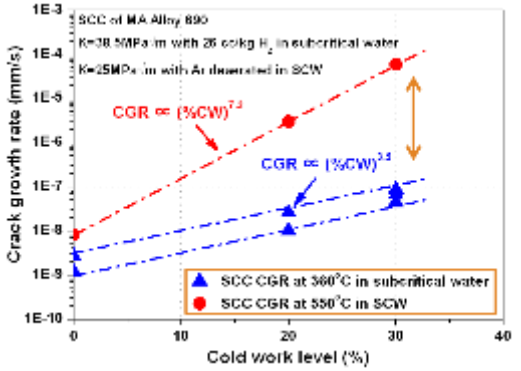


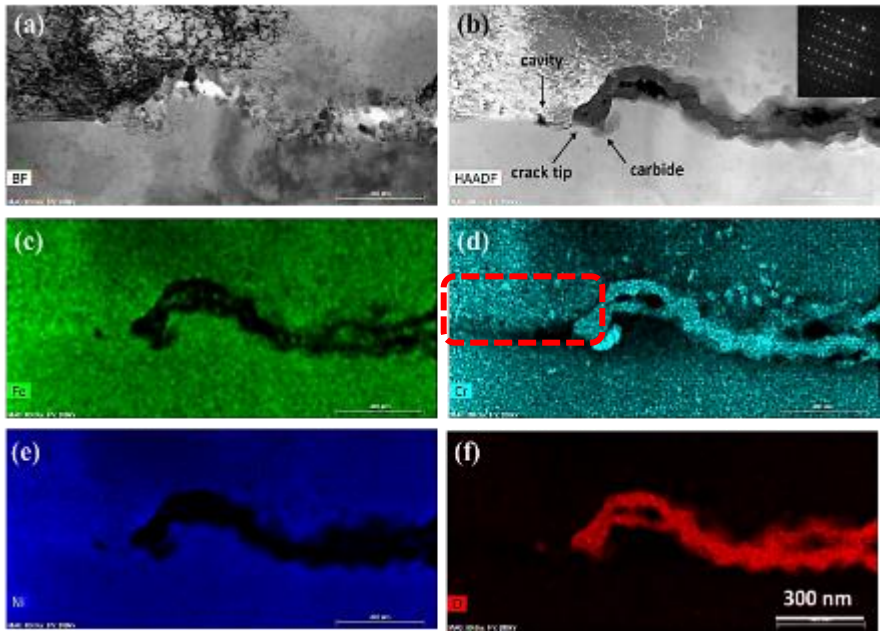


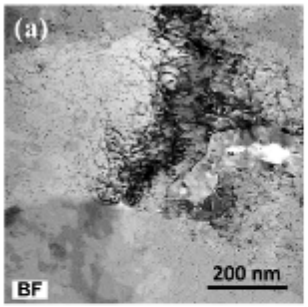
DCPD crack length measurement

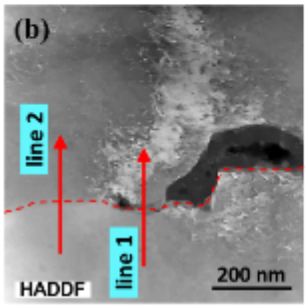
4. Materials and Water Chemistry - Some Results

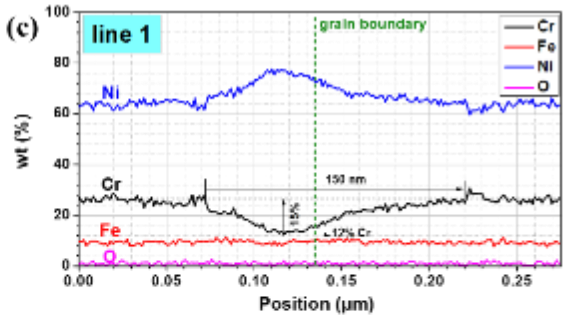
- *The sensitize of 690 Alloy SCC*
  - *Low content Cr at the crack boundary*
  - *Sensitization accelerates crack growth*
  - *SCC is more sensitive to cold work*

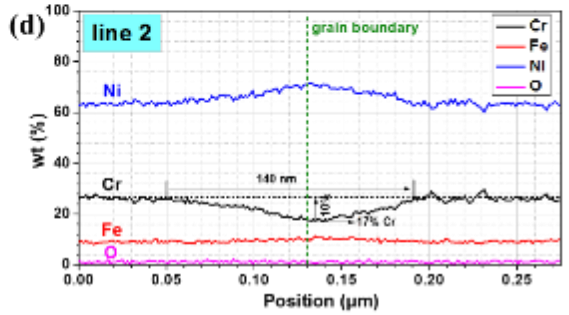












Outlines —— MSR

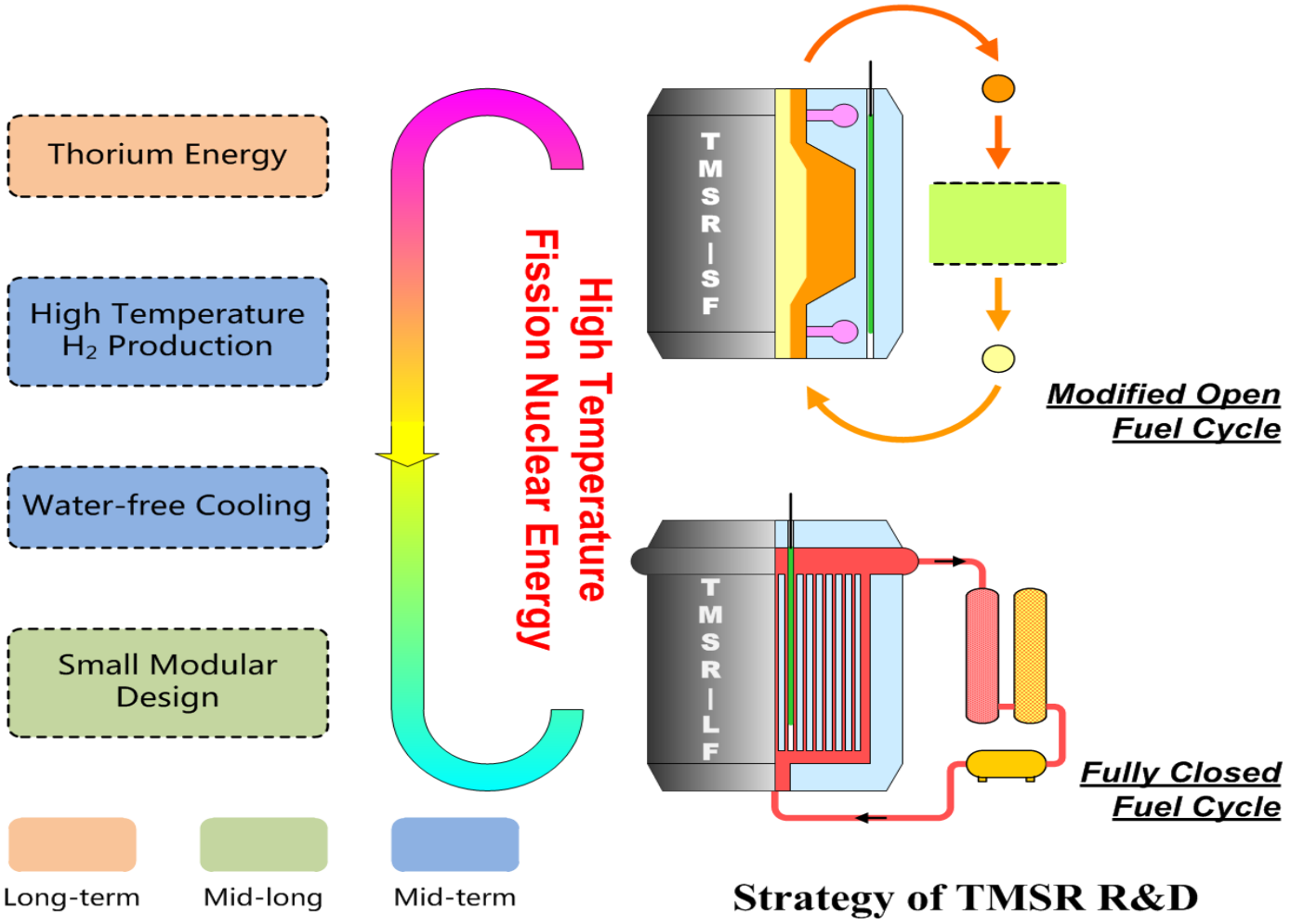
- *Introduction*
- *Systems and Techs of TMSR*
- *TMSR Design*

The Content of This Part is Provided by Shanghai Institute of Applied Physics, Chinese Academy of Sciences.

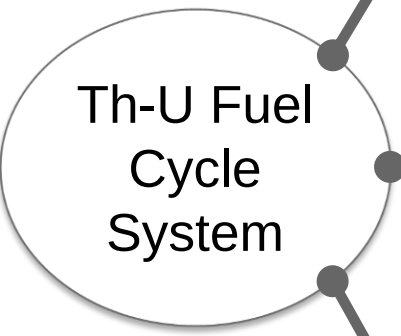
1. Introduction

- *TMSR is to develop the TMSR-LF and TMSR-SF in the next 20 to 30 years*
  - *Use thorium fuel and closed fuel cycle*
  - *Nuclear heat application*
- *TMSR-LF, a liquid fuel molten salt reactor or MSR*
- *TMSR-SF, a solid fuel molten salt reactor or FHR*
- *Program was initiated by the Chinese Academy of Sciences (CAS) in 2011*

1. Introduction - *TMSR Fuel Cycles and Applications*



2. Systems and Techs of TMSR - *Thorium-Uranium Fuel Cycle*



Fuel cycle mode

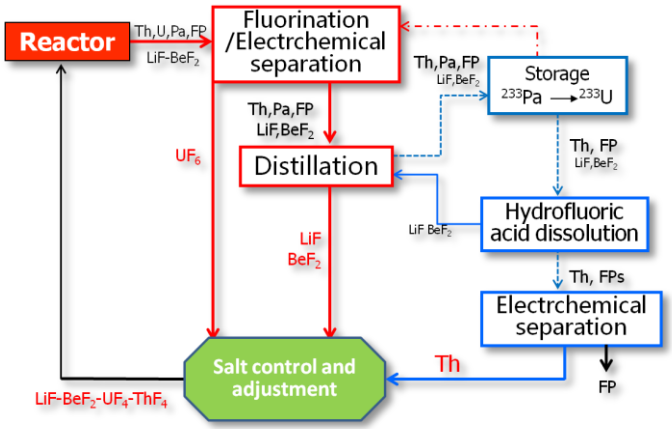
Thorium utilization strategy in MSRs
- ^{235}U to ^{233}U transition
- Minor actinides transmutation

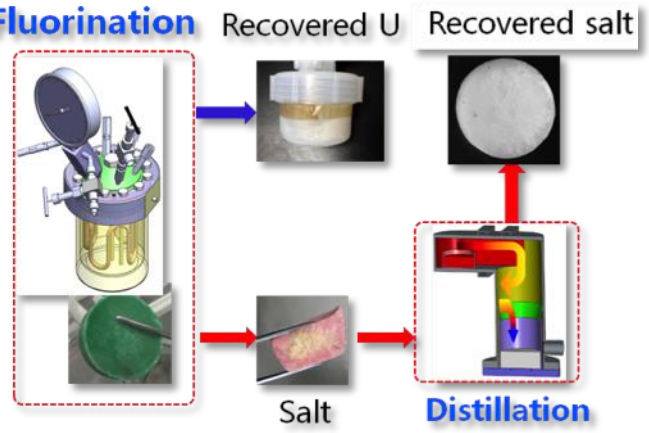
Flow sheet design

Flow sheet combines on-line and off-line processing
- On-line for U and carrier salt
- Off-line for Th and minor actinides

Process Consist.

Consistency of on-line reprocessing in cold, lab-scale
- Recovery rate of U > 95%
- Recovery rate of carrier salt > 90%





2. Systems and Techs of TMSR - *Reactor Design and Components Development*

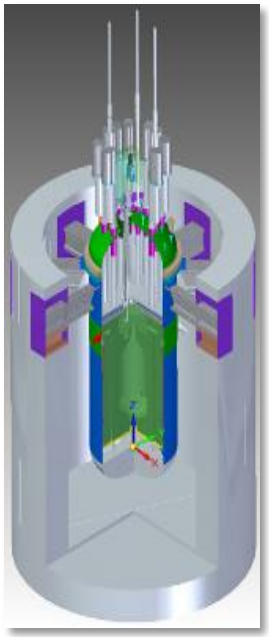
- Development of design and analysis methods and tools
- Development of technology and equipment used for high-temperature fluoride salts
- Design of the 2 MW TMSR-LF1 and the 10 MW TMSR-SF1
- Design of the “simulator” TMSR-SF0

- Development of design and analysis tools
- Evaluation of H-T nuclear data
- Thermal hydraulics experiments
- Reactor core modeling and analysis

Conceptual Design

Preliminary Design

Engineering Design



- Vessel and core structure design
- Control rods
- Fueling and defueling machine
- Neutron detectors
- H-T Flowmeter, pressure sensor, thermometer, level gauge
- Digital reactor protection and control system

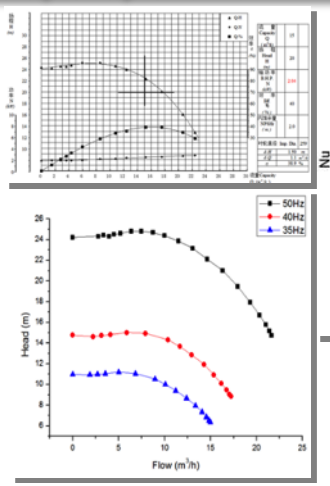
2. Systems and Techs of TMSR - *Fluoride Salt Loops*

- Constructed high-temperature fluoride salt loops.
- Developed equipment to be used with fluoride salts, e.g., pump, heat exchanger, valve, seal, pressure meter, etc.

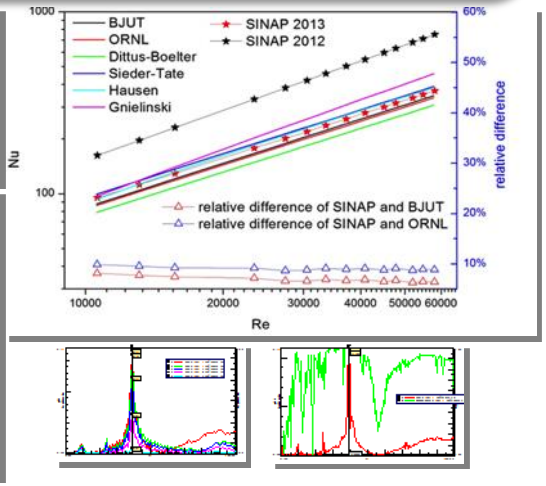
- Design and analysis methods for high-temperature fluoride salt loops
- Prototypes for pump, valve, heat exchanger, etc.
- Experience of loading and unloading of fluoride salts
- Experience of high-temperature fluoride salt loops operation and maintenance

High-temperature fluoride salt experimental loop

Prototypes of equipment

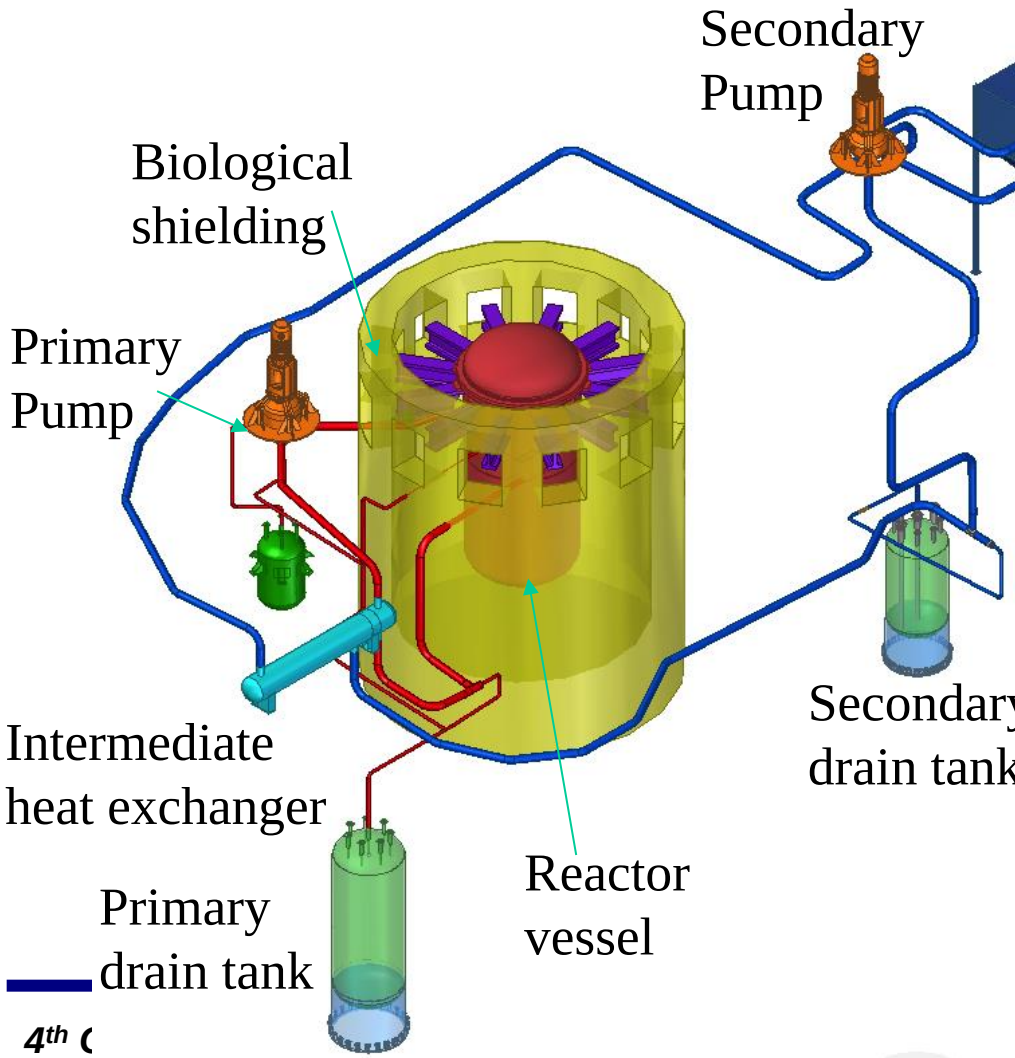


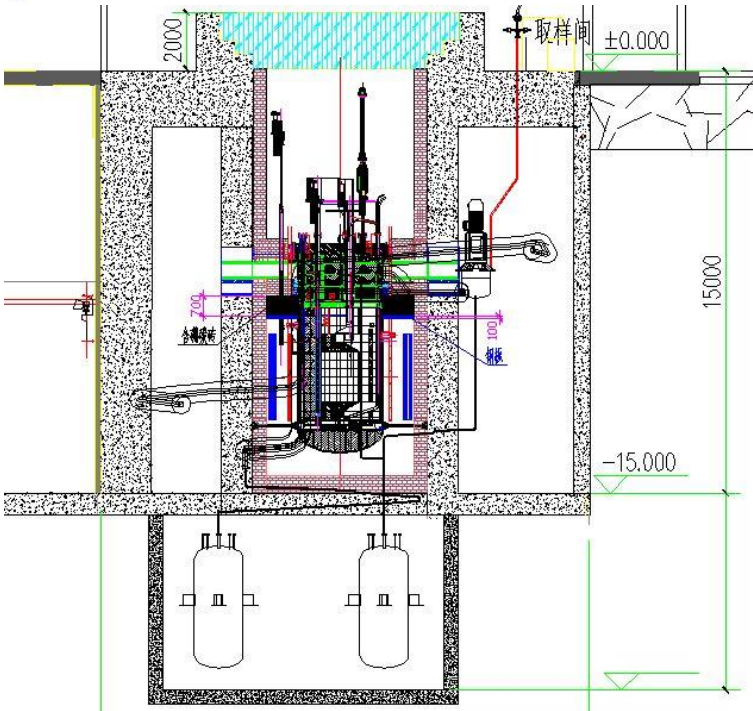
Hydraulic test of molten salt pump



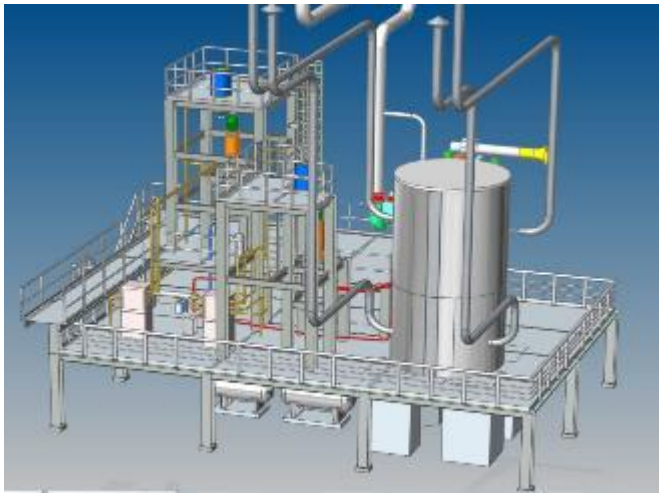
Thermal hydraulic & mechanical test of loop

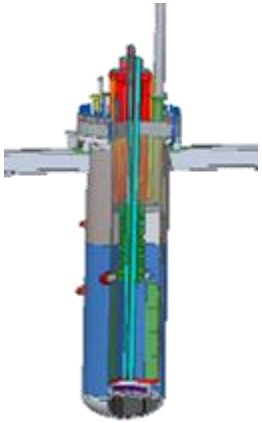
3. TMSR Design - Completion of the TMSR-SF1 Design





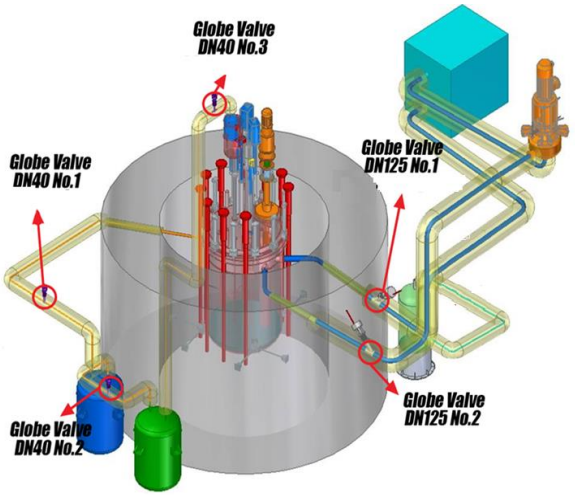
3. TMSR Design - *Progress of the TMSR-SF0 Construction*

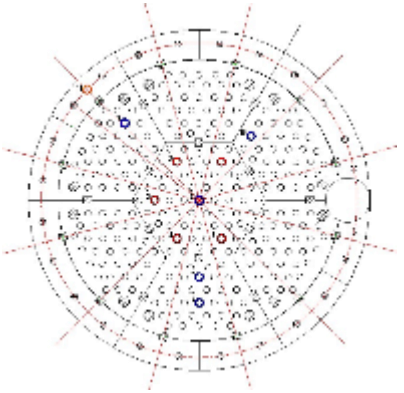


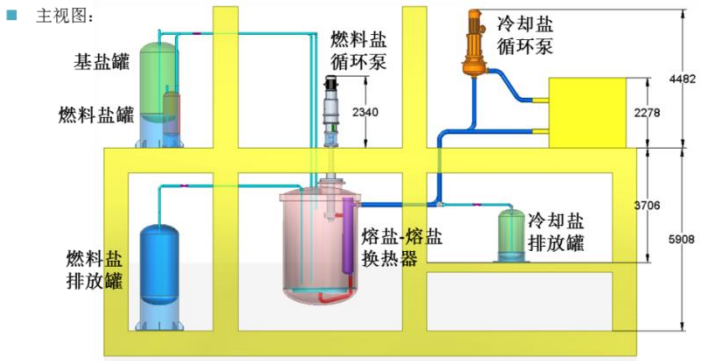


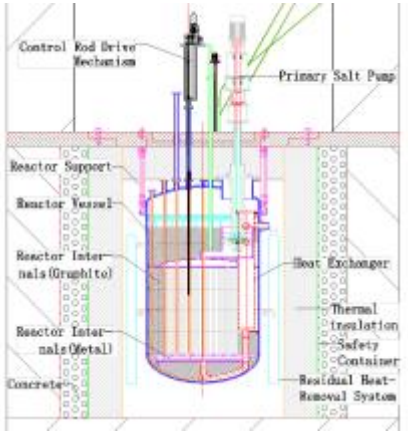
- The engineering design was complete and major components was ordered
- Steel frames were constructed
- Installation of major components is expected to start in mid of 2018
- A practice for the future test reactor construction

3. TMSR Design - Progress of the TMSR-LF1 Design









3. TMSR Design - Site Evaluation and Preparation

- *NNSA evaluation and approval*
  - *Environmental impact and site safety reports submitted in 12/2017*
    - *121 Q1s were generated in 02/2018*
    - *Reviewers and applicants met in 03/2018 to resolve most Q1s*
    - *Reviewers to visit candidate site in 04/2018*
    - *Remaining Q1s &Q2s to be reviewed by NNSA committee in 07/2018.*

Outlines —— LFR

- *Introduction*
- *Key Technologies*
- *Three Integrated Test Reactors*
- *Engineering Implementation Activities*

The Content of This Part is Provided by Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences.

1. Introduction - Roadmap Proposal

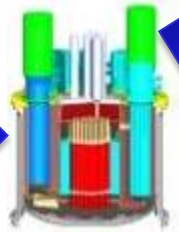
2020 2030 2040

CLEAR-0

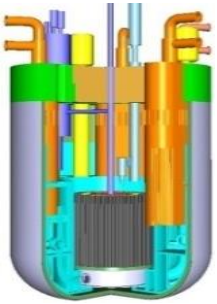
CLEAR-S

CLEAR-V

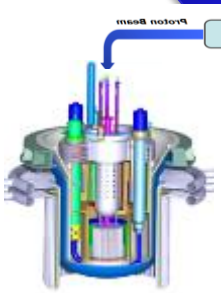
M1x



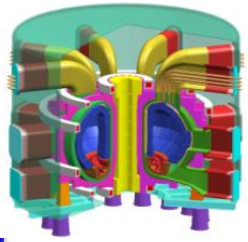
CLEAR-M
(Small)



LFR (large)



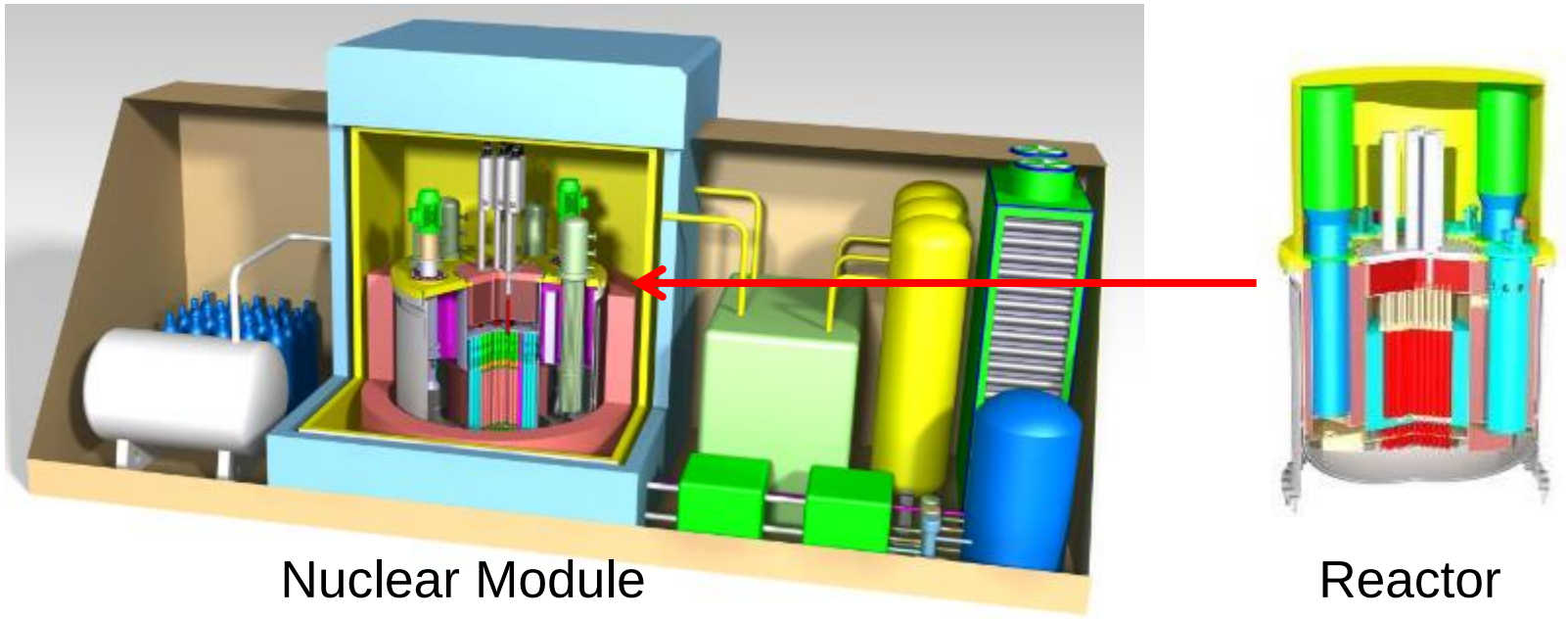
CLEAR-I/A
(New concepts)



Fusion Reactor

1. Introduction - CLEAR-M10d Design

- *10MW Class Lead-based Mini-Reactor*
  - *Small modular and compact, easy to transport and install*
  - *Inherent safety, no severe accident*
  - *Long duration, better economy, environmentally friendly*



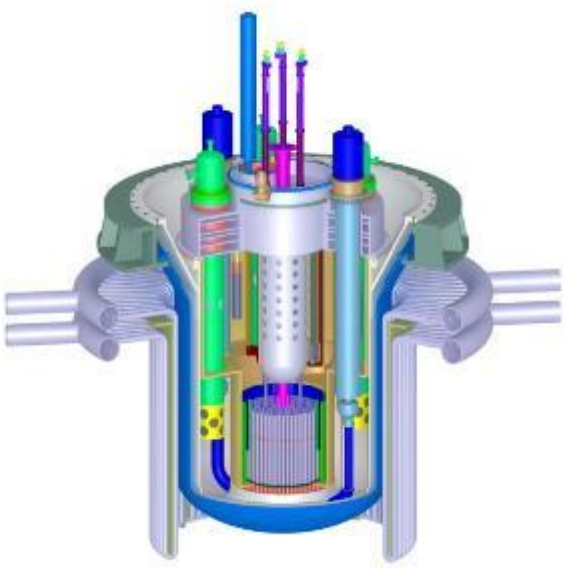
Nuclear Module

Reactor

1. Introduction - ADS Reactor for Transmutation CLEAR-I

- *Objective: ADS/ Lead-based Reactor technology validation*
- *Design status: the detailed conceptual design has been done*

1. **Nuclear Design**
2. **Thermo-hydraulic Design**
3. **Coolant System**
4. **Reactor Structure**
5. **Reactivity Control System**
6. **Refueling System**
7. **LBE Process System**
8. **Fuel Assembly**
9. **Safety System**
10. **I&C System**
11. **Application System**
12. **Radiation Protection System**
13. **Auxiliary System**
14. **…**



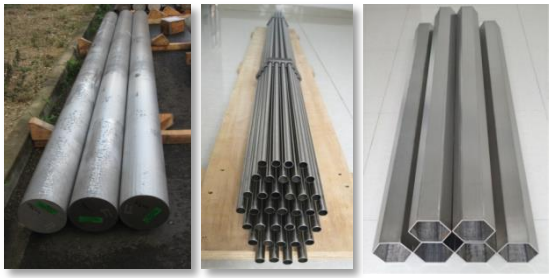
Parameter	Values
Thermal power	10MW
Fuel (enrichment)	UO_2(19.75%)
Primary coolant	LBE
Inlet/Outlet Temp.	~300/385℃
Second coolant	Water
Cladding	15-15Ti/316Ti
Structure	316L

CLEAR-III is designed as commercial ADS reactor for nuclear waste transmutation, which has the transmutation performance of $TSR_{LLMA} > 10$

2. Key Technologies

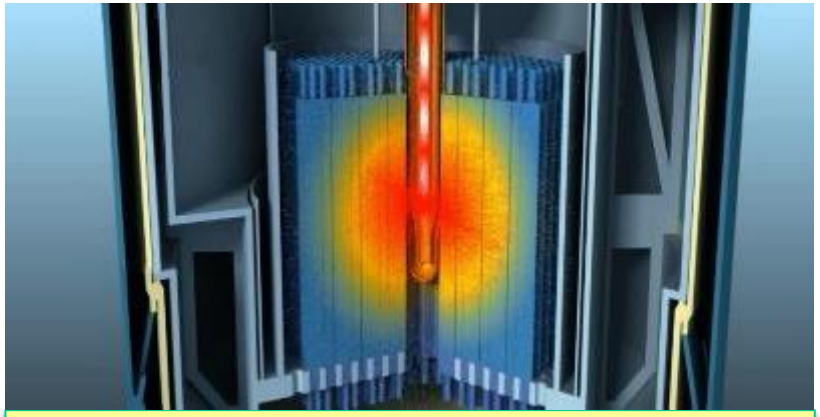
- Coolant Technology
- Key Components
- Materials and Fuel
- Operation and Control

>30,000h operation



1:1 scale prototype components, tested under lead alloy condition

3. Three Integrated Test Reactors



Digital Simulation CLEAR-V

Multi-physics integrated simulation by ~30 codes

Physics Test CLEAR-0

Critical and subcritical duel-mode

Engineering Validation CLEAR-S

2.5MWth, >200t LBE pool type facility

4. Engineering Implementation Activities

- ✓ Industrial park for lead-based reactor
  - ~700,000 m^2 laboratory under construction
- ✓ China Industry Innovation Alliance of Lead-based Reactor (CIIALER)
  - over 100 enterprises
  - president member INEST,CAS

THANKS

Any Questions?