Research Progress of TMSR design

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Outline

- TMSR Project
- Progress of TMSR design
- Perspective of TMSR project

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TMSR Project (Chinese Academy of Sciences)

中文名称：钍基熔盐堆核能系统

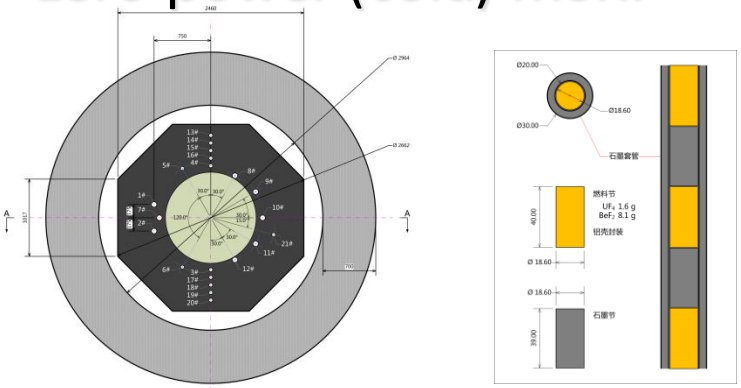
英文名称：Thorium Molten Salt Reactor Nuclear Energy System

Abbr. ：TMSR

Aims ：Develop Th-Energy, Non-electric application of Nuclear Energy based on TMSR during coming 20-30 years.

Early Efforts for MSR in China

1970 - 1971, SINAP built a zero-power (cold) MSR.



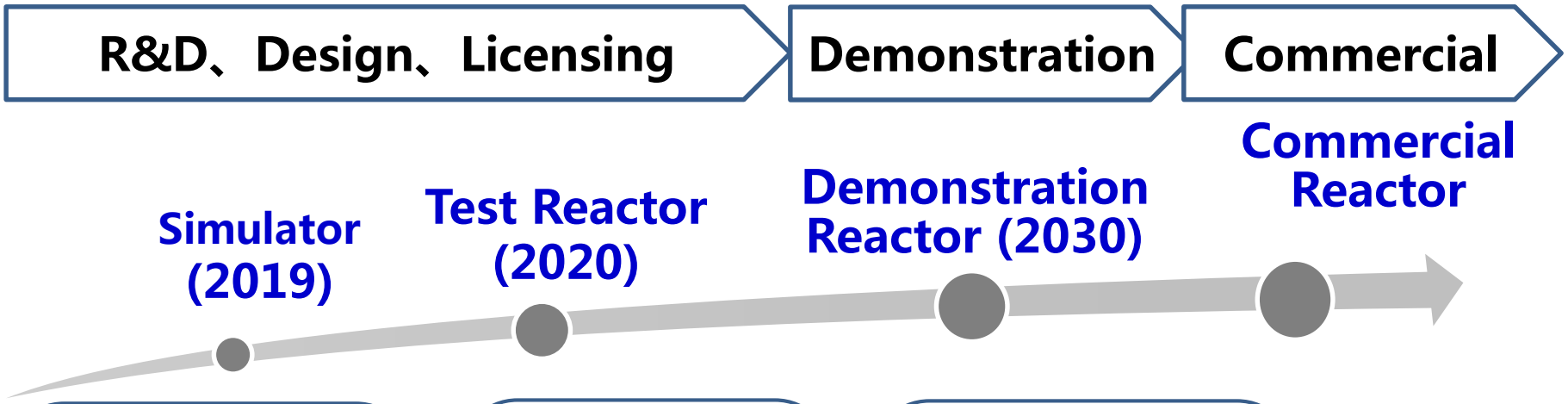
Ⅰ - core
Ⅱ- reflector
Ⅱ'- reflector cover
Ⅲ- protection wall
S- neutron source (100mCi Ra-Be)

1-2- safety rod
3- regulating rod
4- shim rod
5-6- backup safety rod
7-8-9- BF_3 neutron counter

1972 - 1973, SINAP built a zero-power LWR.

1970~1975, in SINAP about 400 scientists and engineers studied on the nuclear power plant. the original goal is to build 25 MWe TMSR
1972-1975, the goal was changed to the Qinshan 300 MWe (Qinshan NPP-I), which has been operating since 1991.

TMSR Development Plan



Key technology and component development, Simulator (mock-up) (TMSR-0)

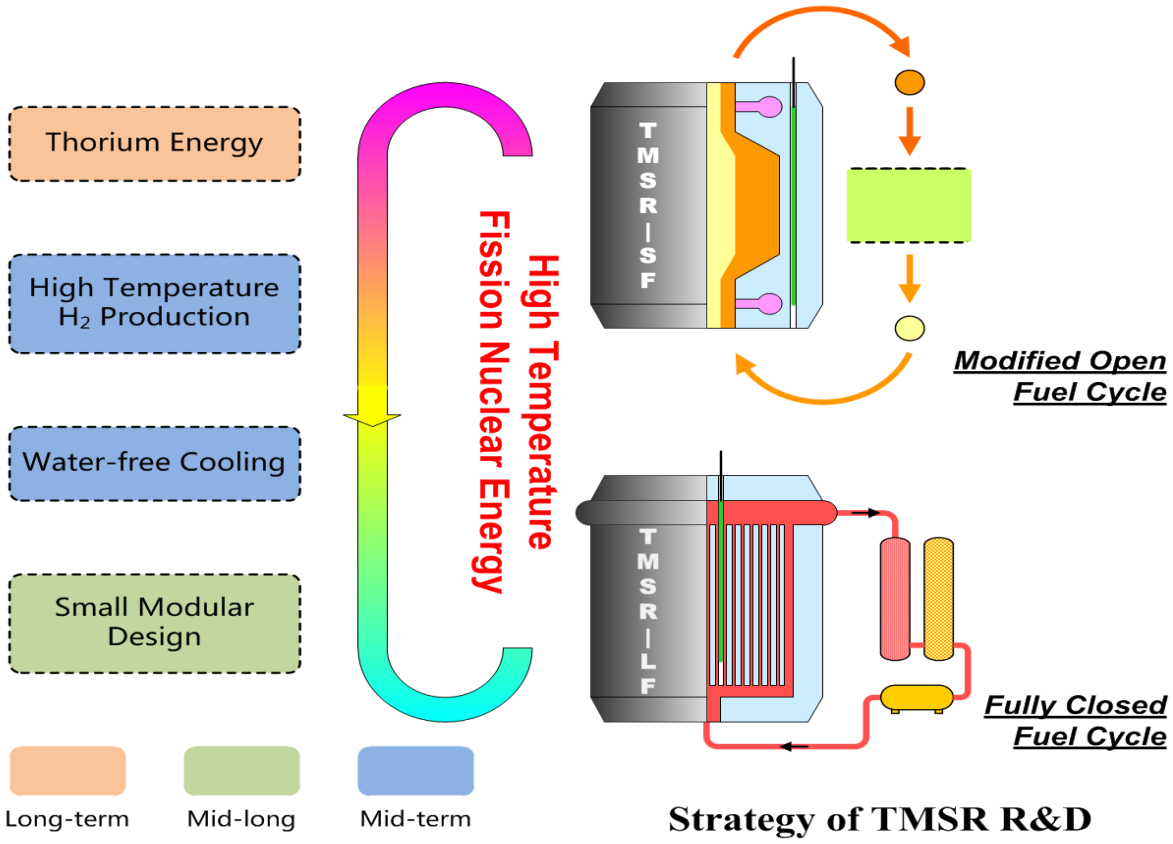
2MWth liquid-fuel test reactor (TMSR-LF1)

100MWe liquid-fuel demonstration reactor (TMSR-LF2)

100MWe solid-fuel demonstration reactor

Funding resource:
CAS TMSR Project (2011-2020);

TMSR Reactors and Applications



Strategy of TMSR R&D

Th Energy :

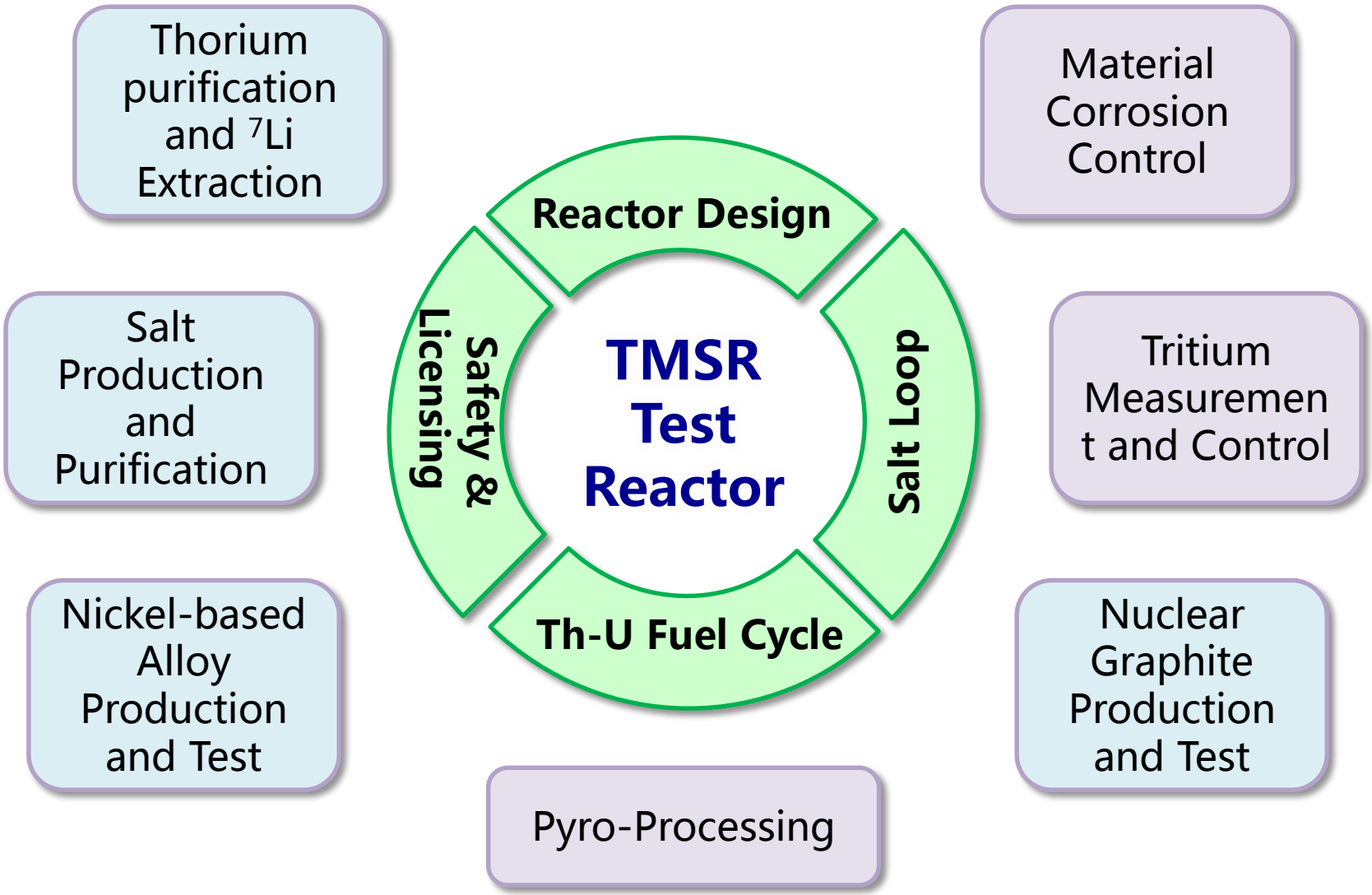
Long-Term Supply of Nuclear Fuel

MSR :

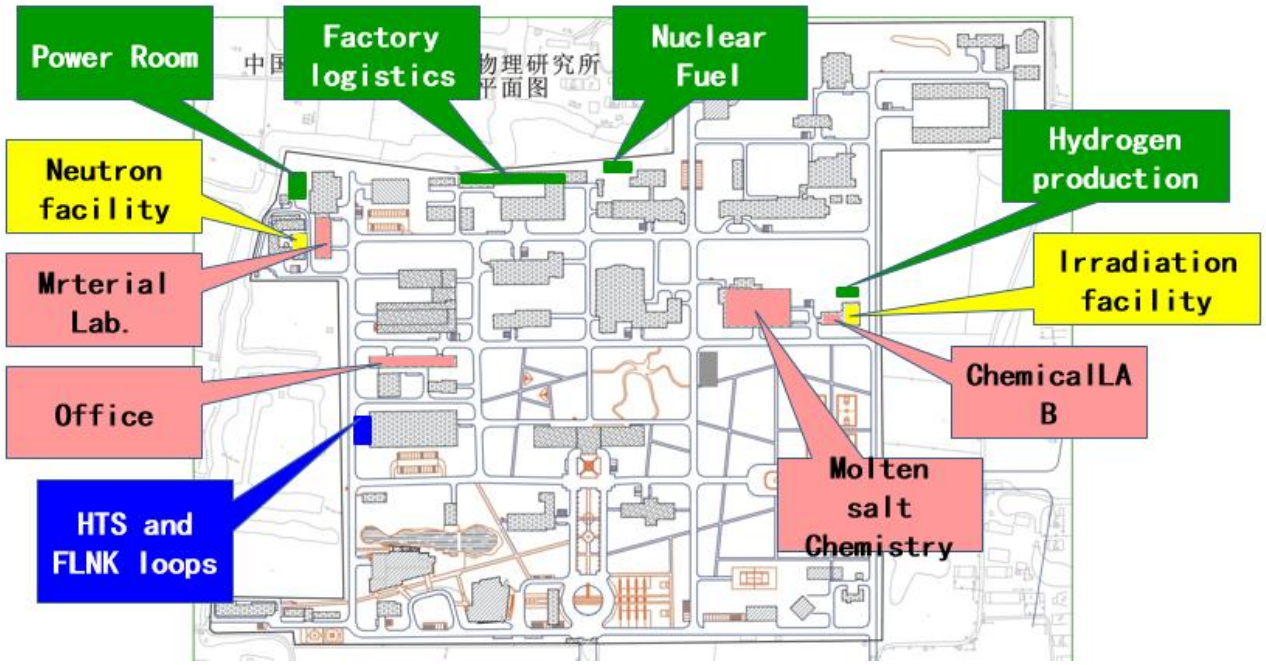
Elevated Safety
Efficiency
Nonproliferation

- **Optimized for high-temperature based hybrid nuclear energy application.**
- **Optimized for utilization of Th with Pyro-processing.**

Systems and Techs of TMSR



Setup Fundamental Research Base



Super Computer

Hot Cells

Material Testing Labs

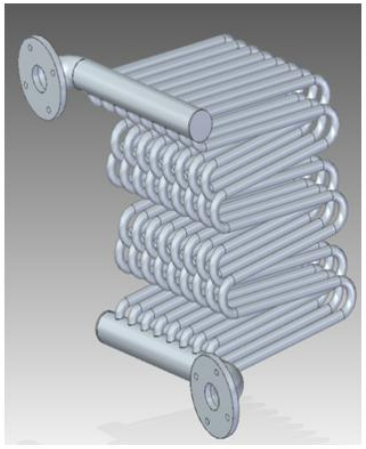
Salt Properties Labs

β Irradiation Facility

R&D of Components

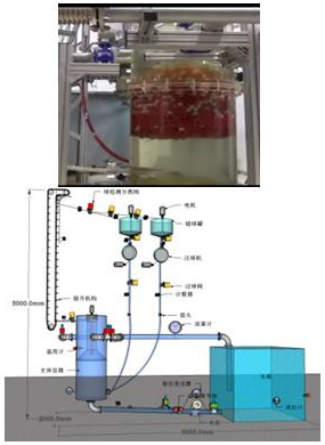
Salt pump

Freezing valve



Heat exchanger

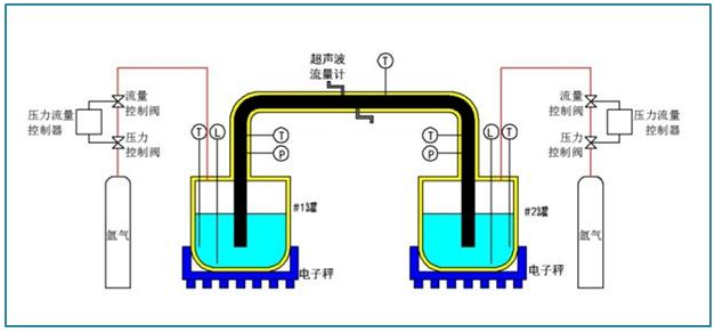
Control rod test facility



Fuel sphere Loading facility

Graphite structure test facility

Pressure meter film



Ultrasonic flowmeter benchmark platform

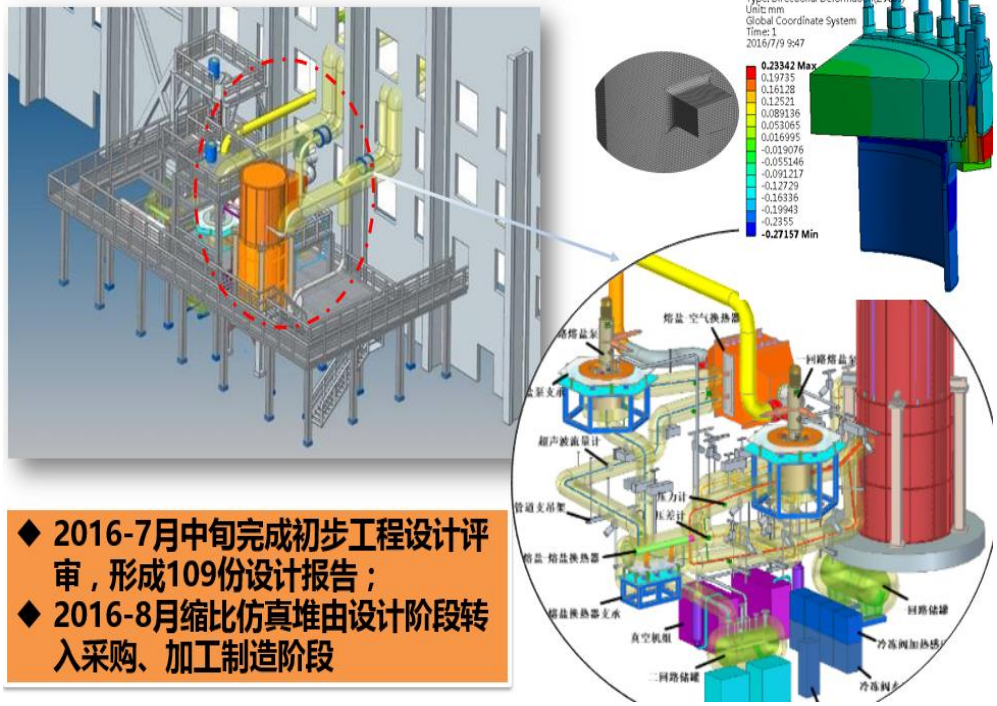
Outline

- TMSR Project
- Progress of TMSR design
- Perspective of TMSR project

1、TMSR-0(simulator)

- Integrated facility via scaling methods
- Key facility for design validation and licensing
- Simulation for operation and training operators.

TMSR缩比仿真堆



- 2016-7月中旬完成初步工程设计评审，形成109份设计报告；
- 2016-8月缩比仿真堆由设计阶段转入采购、加工制造阶段

	SF1	TMSR-0
Coolant	FLiBe	FLiNaK
Temperature	600℃-650℃	
Size ratio	1:3	
Area ratio	1:9	
Volume ratio	1:27	
Power	10 MW	370 kW
Heating	nuclear	electricity

Construction of TMSR - 0

- A practice for the future test reactor construction
- Installation of is finished in June. 2019
- Verification experiment of 2MW TMSR-LF1 design will be done.

Vessel body

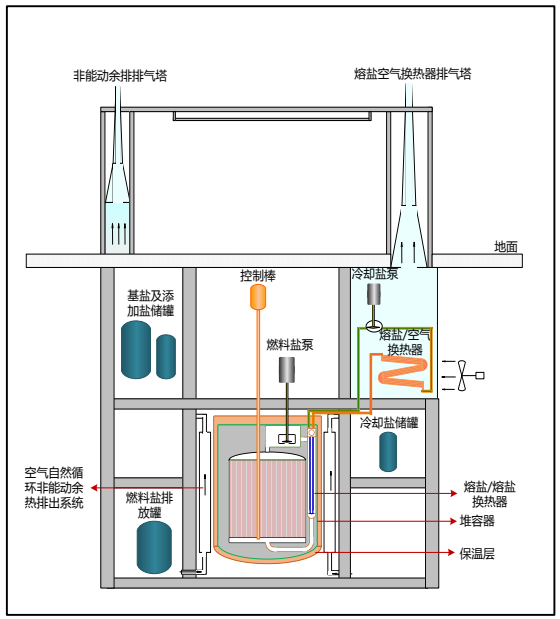
Graphite Components

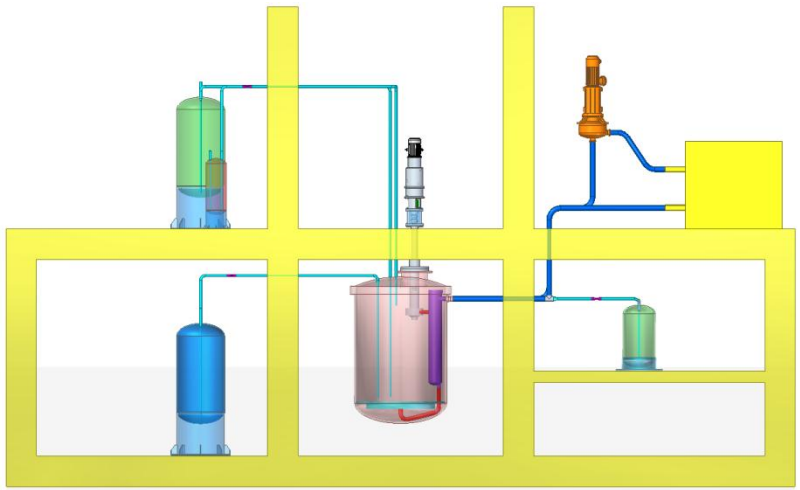
Graphite Core

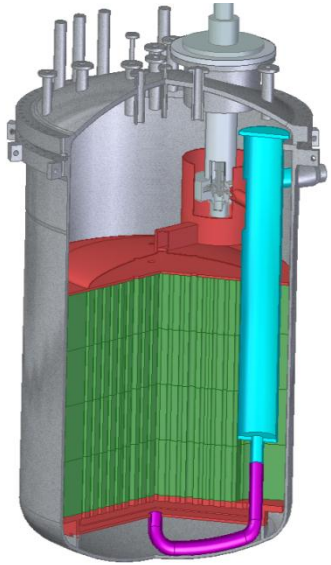
2、2MW TMSR-LF1

- **Demonstrate concept of MSR with liquid fuel and pyroprocessing.**
- **Demonstrate Th-U cycle and its features.**
- **Platform for future reactors and Th-U cycle R&D.**

Power	2MW
Temperature	630 ℃ / 650 ℃
Type	Integrated design
Fuels	$LiF-BeF_2-ZrF_4-UF_4-ThF_4$
Residual heat removal	Passive air natural circlation system







Challenges and Design Basis

📖challenges:

- Limited Funding, limited time (3 years after site be determined, 2020), high safety level.

📖Design basis :

- TMSR previous R&D on materials, components and analysis system.
- Engineering experience from loops and TMSR-0 design and construction.
- Knowledges and experience from MSRE.

Previeous R&D and Experience

- **Materials**: Produce, test and evaluation of fuel salt, coolant salt, alloy and graphite;
- **Analysis system**: Neutronics and Thermal-Hydraulics analysis system, with liquid fuel flow issues. Mechanics analysis and evaluation system under high temperature molten salt and irridation environment.
- **Components**: vessel, graphite core, pump, heat exchanger, measurement and instrumentations, etc.
- **Loops and Simulator**: breed industrial community for manufacture chain. Gain experience for integration, installation. Used in verification for design.

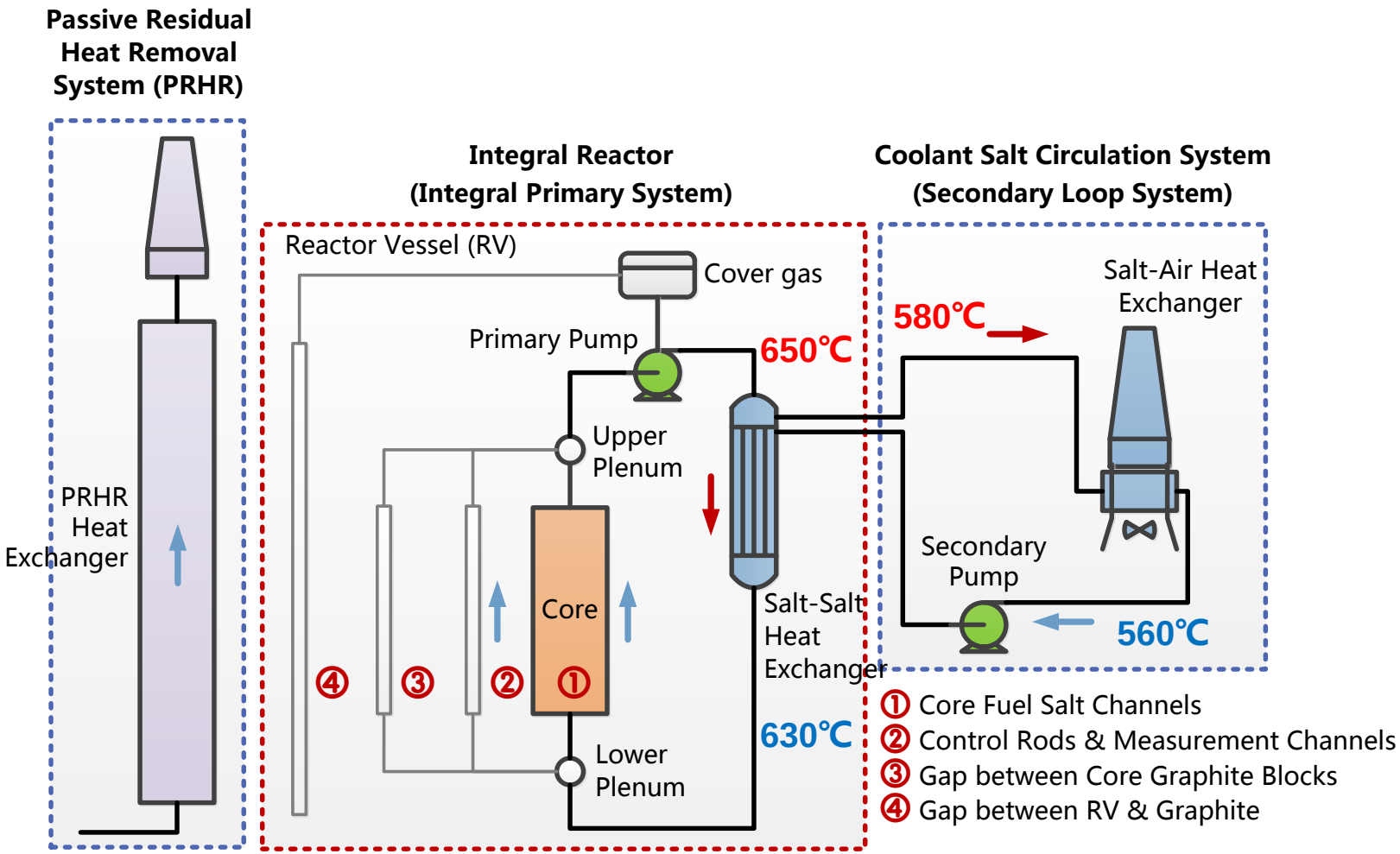
Regulatory Design Criteria of LF1

1) Maintain control of radionuclides
2) Control heat generation (reactivity)
3) Control heat removal
4) Control liquid fuel and coolant inventory
5) Maintain core and reactor vessel geometry
6) Maintain reactor building structural integrity

General Description

- **Fuel**： $LiF\text{-}BeF_2\text{-}ZrF_4\text{-}UF_4$ $(+ThF_4)$,
- **Structural Materials**: UNS N1003 alloy , superfine particle graphite made in china.
- **Systems**：
  - Heat generation (reactor body)
  - Heat transfer (loops, air cooling system)
  - Cavity: structure support and maintain
  - Cover gas and off-gas processing system
  - Controlling and instrumentations
  - Etc.

TMSR-LF1 FLOW SCHEMATIC

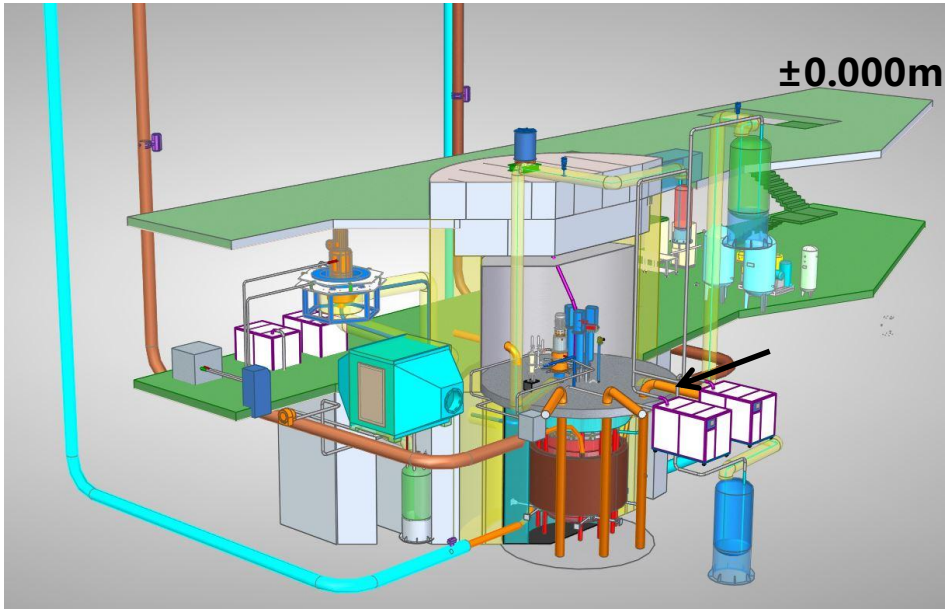


Progress of the TMSR-LF1 Construction

Preliminary design review

- Complete the preliminary design and pass the expert review organized by the Bureau of Major Tasks, CAS in Jun. 2018.
- Start up the processing and manufacturing of key materials and equipment, and determine the manufacturer.
- Design of equipment construction drawings was completed jointly with manufacturers in Feb. 2019.

Expert review meeting



equipment construction drawings

Safety review & construction

- Site Selection Work Completed, Site Assessment Report was approved.
- Preliminary safety analysis report (PSAR) and its Q1&Q2 has been finished. FSAR will be completed in August 2019.
- Construction of Wuwei campus has started.

PSAR symposium

Wuwei campus

Progress of the TMSR-LF1 Construction

New Candidate Site of the TMSR-LF1

- The candidate site is located in Wuwei (武威), Gansu Province, about 2000 Km from Shanghai, the annual precipitation is 128 mm and the annual average temperature is 8.3 °C.

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TMSR Roadmap

Combination of batch-scale pyro process treatment and on-line fission production removing, 80% energy contribution from Th-based fuel, basically achieve U-Th cycle

2040s JIUQUAN+WUWEI

Build batch-scale pyro process demonstration facility, 40% energy contribution from Th-based fuel

2040 JIUQUAN

Build 100MWe small module TMSR, 20% energy contribution from Th-based fuel

2030 WUWEI

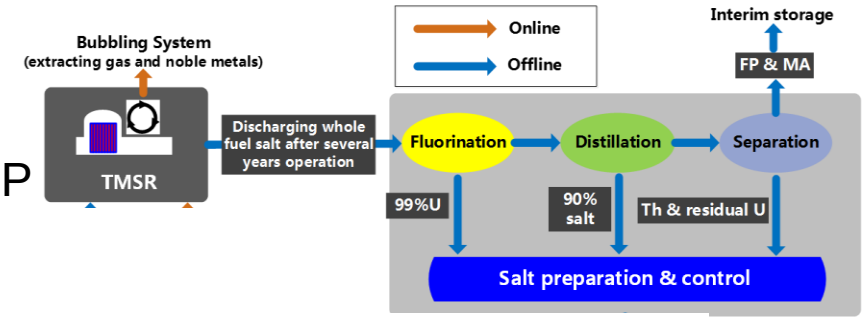
Build 2MWt TMSR-LF1 and Low Carbon Clean Energy Demonstration System

2020 WUWEI

A 3-step Strategy for Th-U Fuel Cycle

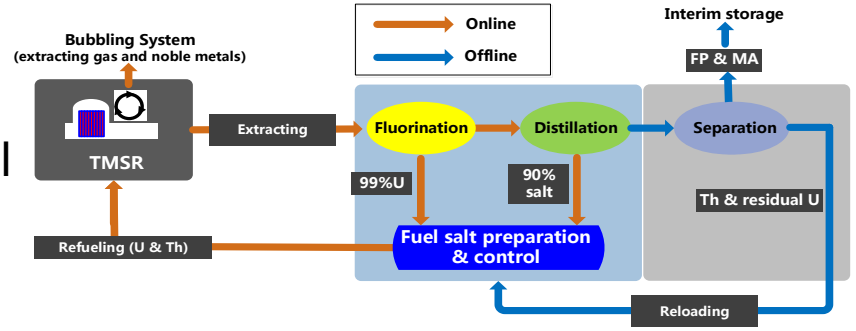
Step 1: batch process

- Fuel: LEU+Th
- Online refueling and removing of gaseous FP
- Discharge all fuel salt after 5-8 years
- Extract U , Th and salt
- FP and MA for temporary storage



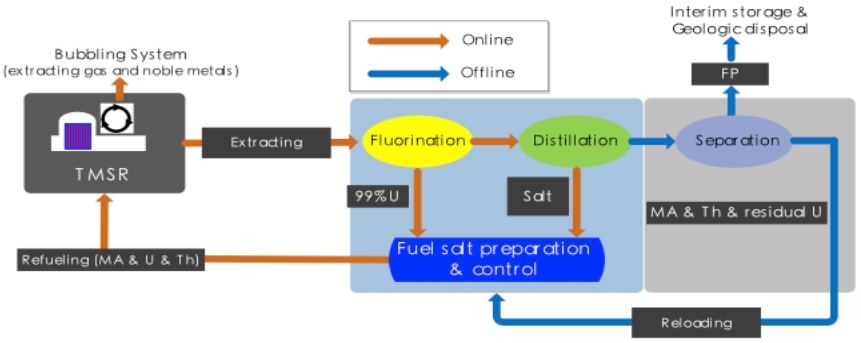
Step 2: step1 + fuel reload

- Reloading of U and Th to realize thorium fuel cycle



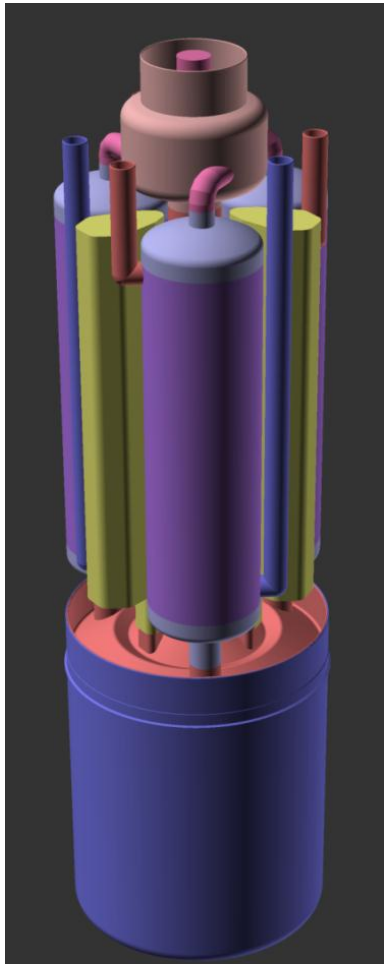
Step 3: step 2 + continuous process

- Continuous process to recycle salt, U and T
- FP and MA partly separation



	Step 1	Step 2	Step 3
Th fission fraction (%)	~ 20	~ 40	~ 80

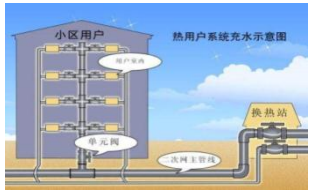
Small modular TMSR : nuclear electricity →nuclear energy



Modularization
Distributed
High efficiency
Water free
Multi-purpose

High efficiency Electricity generation

High temperature hydrongen production

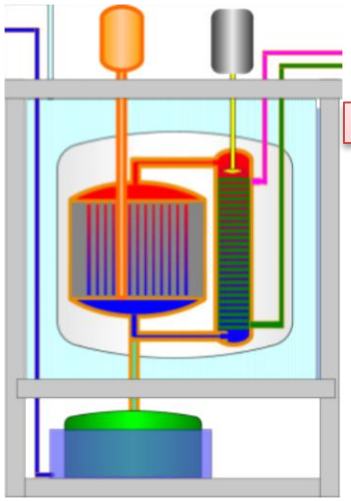


High temperature heat deliver

Sea water deslinatio n

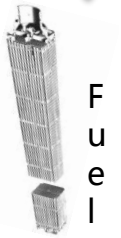
Materials for small modular TMSR

Changed periodly : deployment in the near future

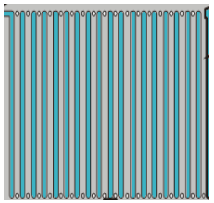


Key materials

Vessel

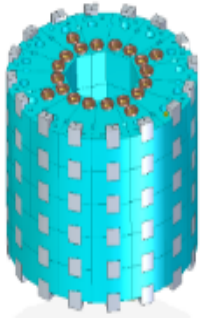


Fuel



moderate

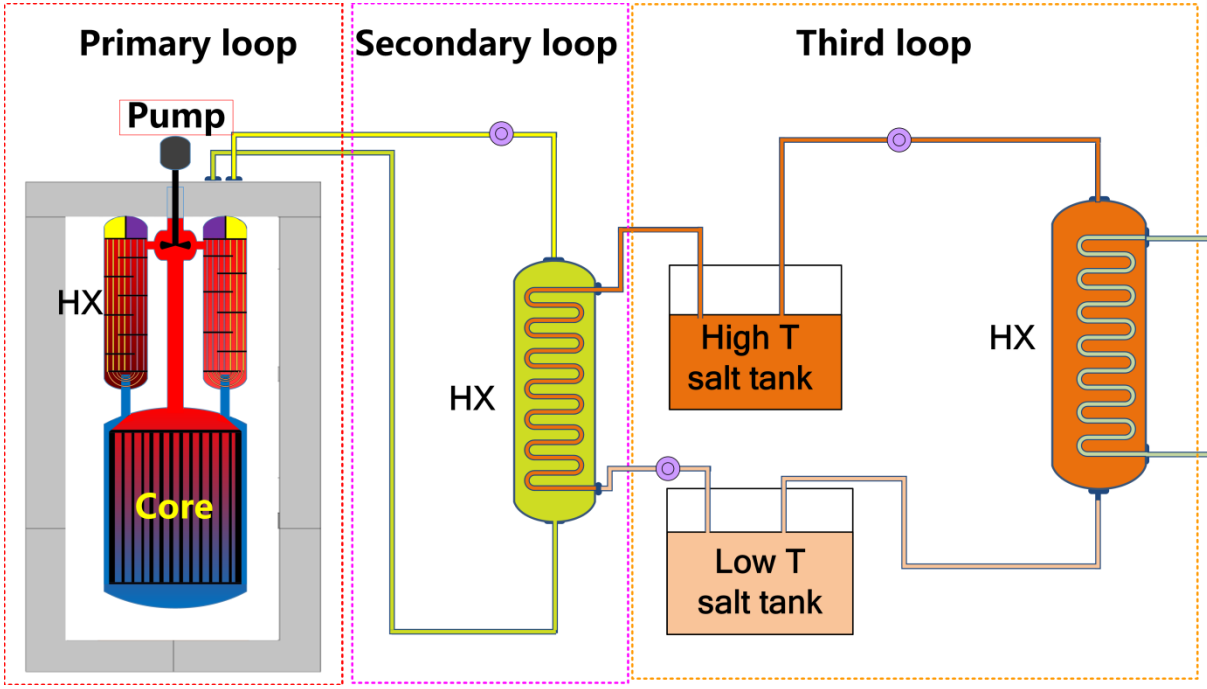
Nickle based alloy



Nuclear graphite

Main concept of TMSR-LF150

- A modular design combined with compact loop design and integratal design
- Combined with heat storage system for adpating net demand, wind energy and solar energy.



Utilizations :

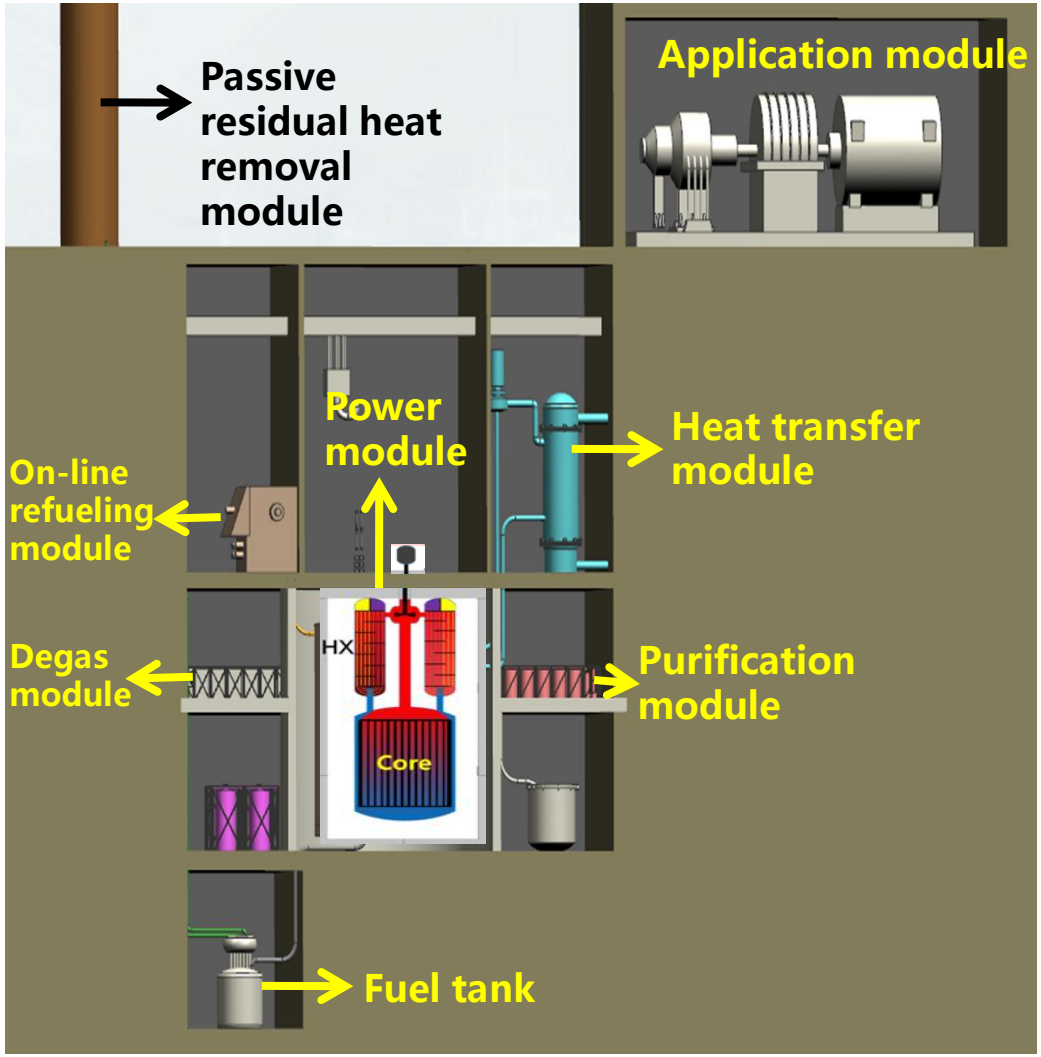
- Hybrid-energy system
- Arid area
- Remote area
- High temperature heat

Different Applications

1、Air Braytron Cycle
2、Super Critical CO2 Braytron Cycle
3、Helium Brayton Cycle
4、Hydrogen production
Etc.

Bing-chen Zhao, Mao-song Chenga, Zhi-min Daia, etc. Conceptual design and preliminary performance analysis of a hybrid nuclear-solar power system with molten-salt packed-bed thermal energy storage for on-demand power supply, Energy Conversion and Management, 166 (2018) 174-186

TMSR Small Modular layout



☐Key modules

power , heat transfer , heat storage, passive residual heat removal , on-line refueling

☐Application modules

generator, hydrogen production, distillation, etc.

Main parameters

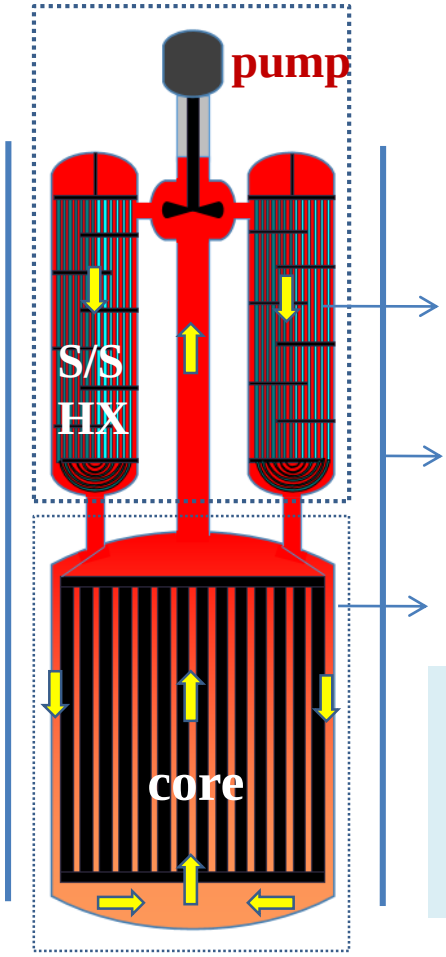
Parameters	Value
Thermal Power	150MW
Electricity Power	60MW
Life time of power station	60-80 y
Modular replace period	10 y
Fuel batched processing period	10 y

Parameters	Value
Fuel	U, Th or TRUs
Burnup	≥250GWd/tU
Power of Thorium	≥20%
Temperature of core in/out	600℃/700℃
Load factor	≥95%

Nuclear power unit

- The nuclear power unit is the combination of the loop mode with the integration mode.
- Based on mainly TMSR research results.

Power	150MWt/60MWe
Temperature (in / out)	600℃/700℃
Size of vessel (D×H)	3.8 m×5.0 m



1. This modular design decrease difficulties for each module and coupling points. And increase reliability for equipments.

First loop module

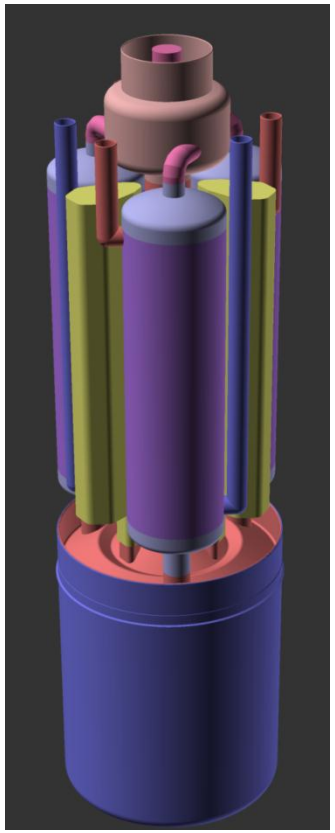
Passive Residual heat removal system (*by radiation , natural circulation***)**

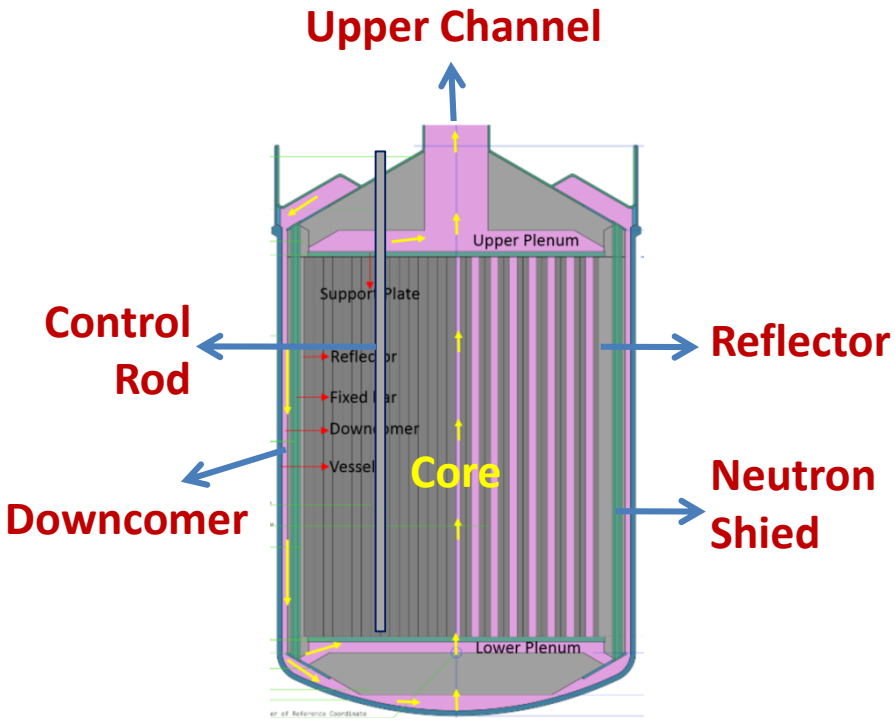
Reactor core module

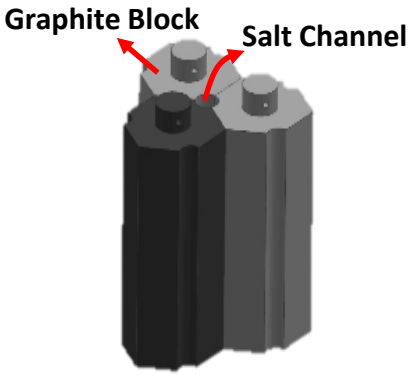
2. Fluid flow, power distribution, deacy heat removal and volume of fuel salt is more controllable than integral design.

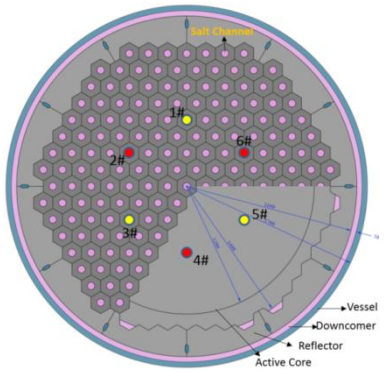
Core design

- **Hexagonal Graphite Block：** low radiation stress, fluid in gaps can easy flow.
- **Materials irridation:** 1) Long Graphite irradiation life，~10 year; 2) Composite material for control rod tube； 3) Reflector to slow-down fast flux, and neutron absorbed shielding for protecting main vessel.





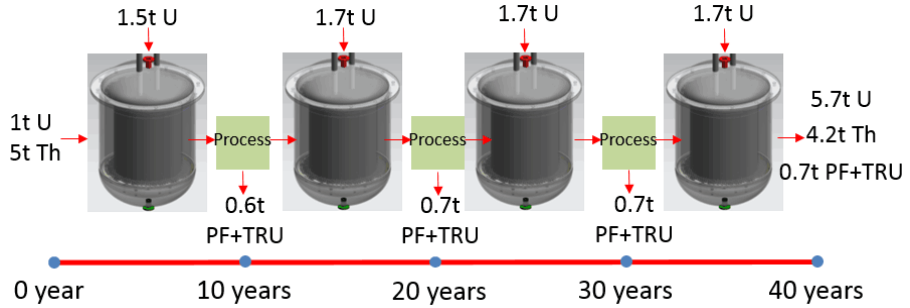




Fuel cycle

- **Baseline fuel cycle type: Th+U**
- **Different options for various applications with a modified core (*liquid fuel is more easy restructured than solid fuel*): U, TRU, TRU+Th, ect.**
- **Batched reprocessing (off-line): easily deployment at present, benefit for burnup and temperature reactivity coefficient, etc.**

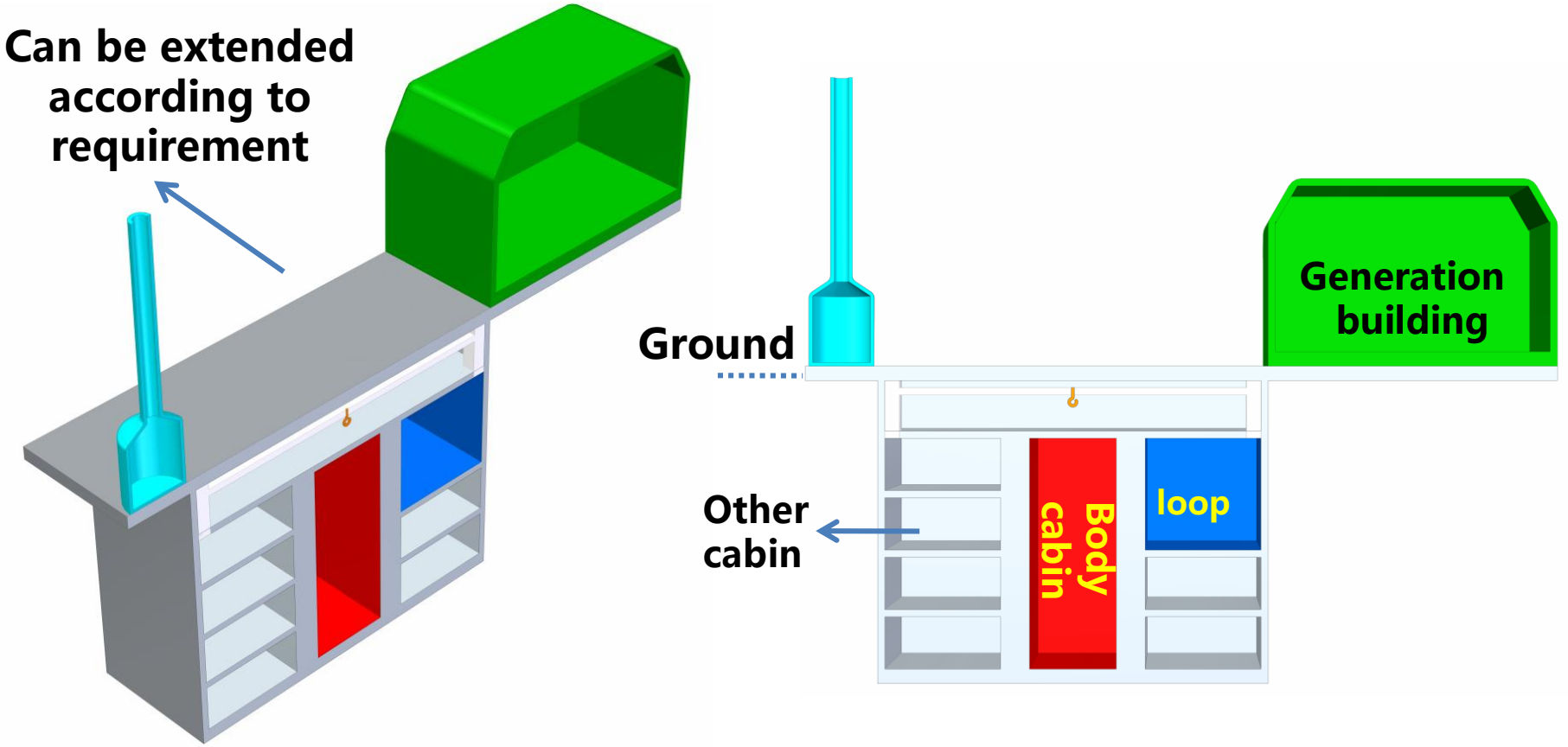
Th+U：19.75% U-235，equivalent burnup is about 280 MWd/kgU



Fuel type	Features
Th+U	Th application High equivalent burnup
U	High temperature heat application
TRU	Burn TRUs
TRU+Th	Burn TRUs + produce U233

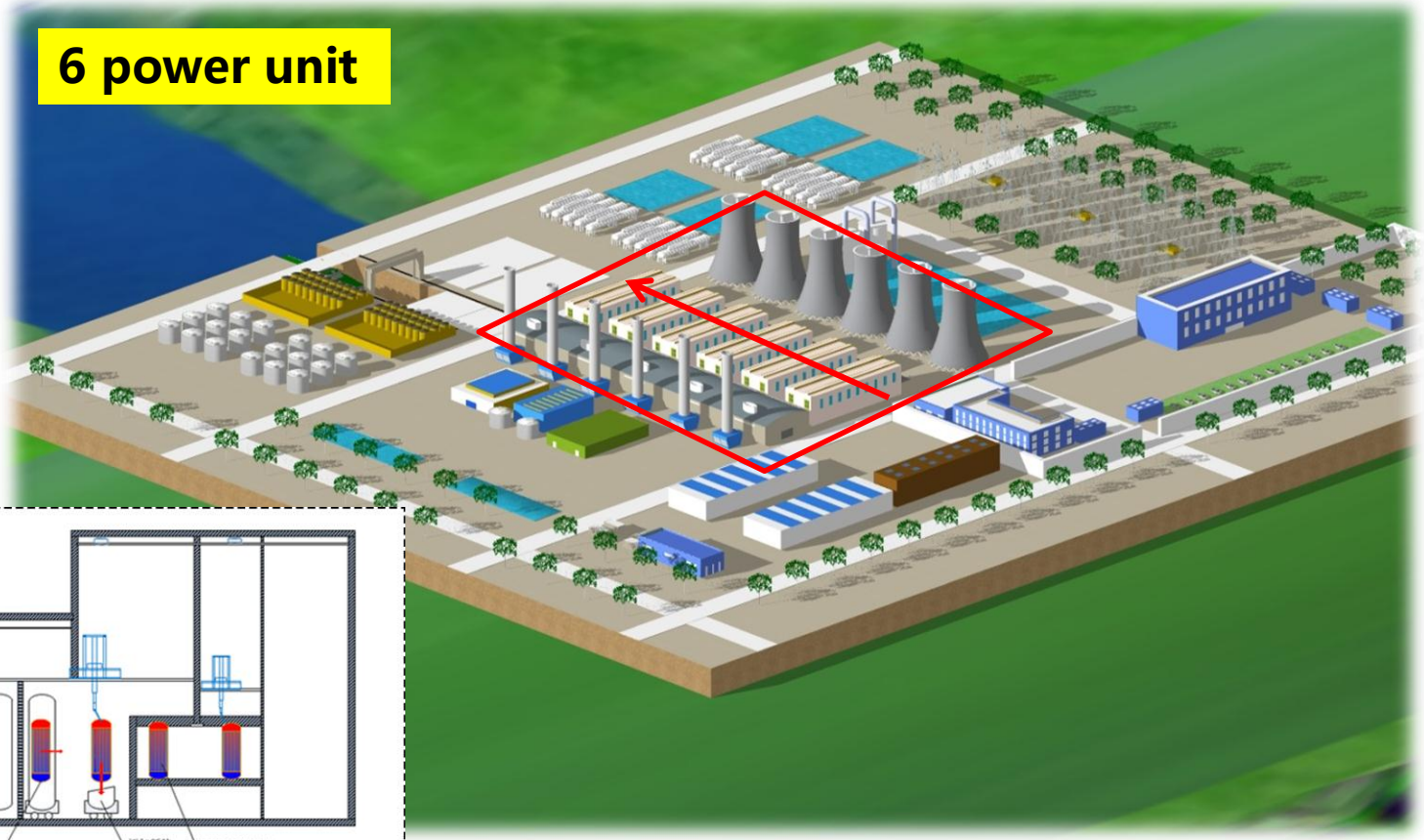
Modular building and cabin

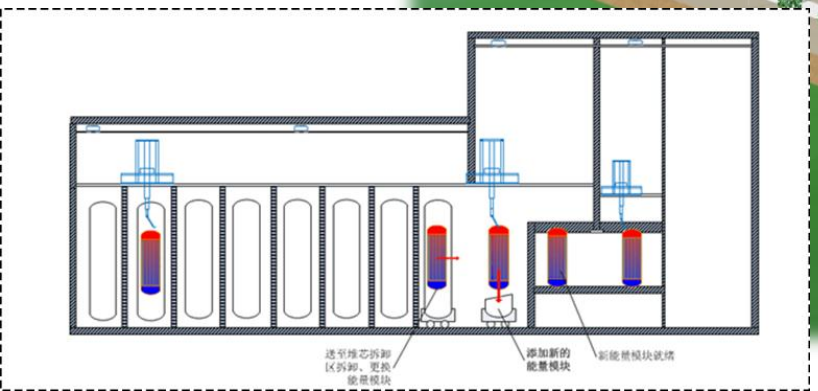
- Without complex and high pressure containment
- Building and installation can be separated to save time and cost



Modular extension

- Options: one unit, or multi-units
- Decrease investment door sill and finance cost





Summary

- MSR is a Gen-IV reactor with many advantages, such as safety, high temperature deliver, Thorium utilization, and fuel cycle etc.
- There is also a obvious technology gap to demonstration reactor, such as materials, salt fuels, fuel reprocessing, and components etc.
- In physics, T-H and safety analysis, a new code system for demonstration MSR is required for the different key issues from LWR, such as delay neutron, internal heat source, and multi-physics effect etc.
- Small modular reactor is a new and feasible route for MSR, which matches the requirement of future energy system, and decrease the requirement of materials, components.

Thank you for your attention