

# Update on SINAP TMSR Research

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MSR Workshop 2016  
ORNL, Oct.4-5 2016

# Outline

 **Project overview**

 **Highlight-2016**

- **Th-U fuel cycle**
- **Materials**
- **Reactor engineering**

 **Summary**

# Outline

## **Project overview**

## Highlight-2016

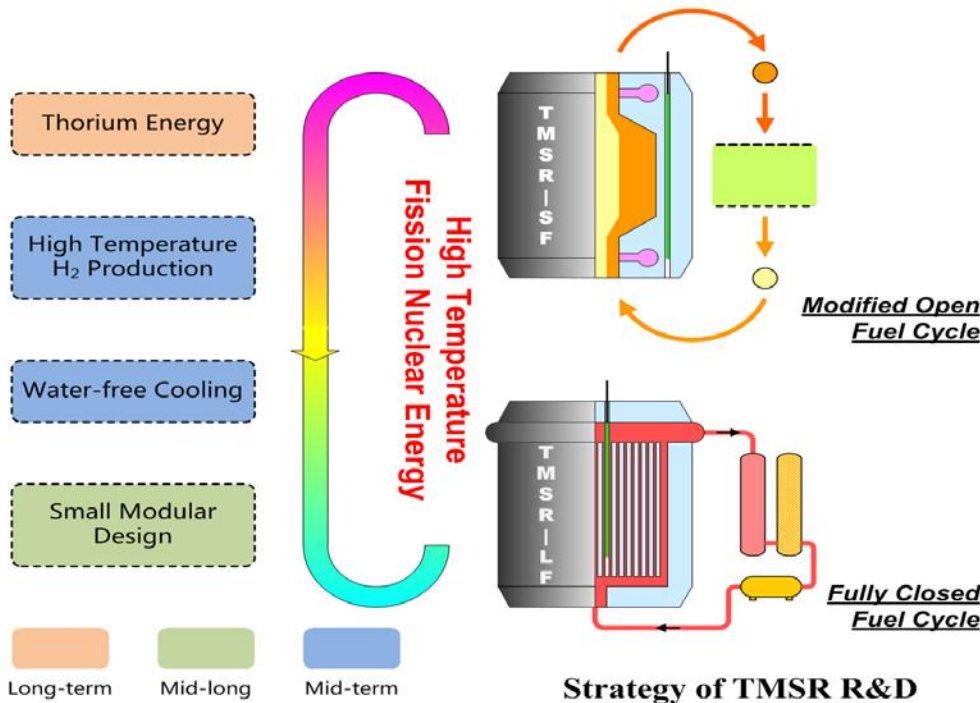
-  Th-U fuel cycle
-  Materials
-  Reactor engineering

## Summary

## China's TMSR Project

-  **TMSR: Thorium Molten Salt Reactor Nuclear Energy System.**
-  **Long term goal: Develop TMSR for Thorium utilization and Low-C energy application in 20-30 years.**
-  **The phase I program (so called pioneer program) was initiated by the Chinese Academy of Sciences (CAS) in 2011.**

## TMSR Reactors and Applications



### Th Energy :






- Long-Term Supply of Nuclear Fuel

### MSRs :

- Elevated Safety
- Higher fuel efficiency
- H-T nuclear energy

- **TMSR-LF (Liquid-Fuel):** Optimized for utilization of Th with Pyro-process.
- **TMSR-SF (Solid-Fuel):** Optimized for high-temperature based hybrid nuclear energy application.

## Goals of TMSR Pioneer Program

-  Develop Th utilization scheme based on MSR and pyro-process. Develop pyro-process flow sheet.
-  Design, construct 2 test reactors (2MW liquid fuel, TMSR-LF1, 10MW solid fuel, TMSR-SF1).
-  Develop materials, salts, fuel, components, instrumentations etc. for test reactors.
-  Licensing and site selection of test reactors.
-  Build up R&D platform and Experienced team for future TMSR research and development.

## Summary of R&D Activities up to Now

### Engineering developments

- Test reactors design, safety analysis and licensing. Test reactor components and instrumentations. Tritium control technique.
- Materials (alloy, graphite, C-C, Fluoride salts, fuel,  $^7\text{Li}$  etc.) fabrication, processing and qualification.
- Molten salt related mechanics, test loops.
- Pyro-process techniques and equipment.
- High temperature nuclear hybrid energy system design, hydrogen production prototype.

### Researches

- Physics of Th-U fuel cycle, Neutronics, T-H, reactor modeling, basic data, codes developments; design study of small modular MSR.
- Basic sciences behind material fabrication, processing and performance (e.g. mechanic strength, molten salt corrosion, radiation damage), and chemical separation.

Major R&D progress had already been presented in the workshop held last October.



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Project overview



**Highlight-2016**

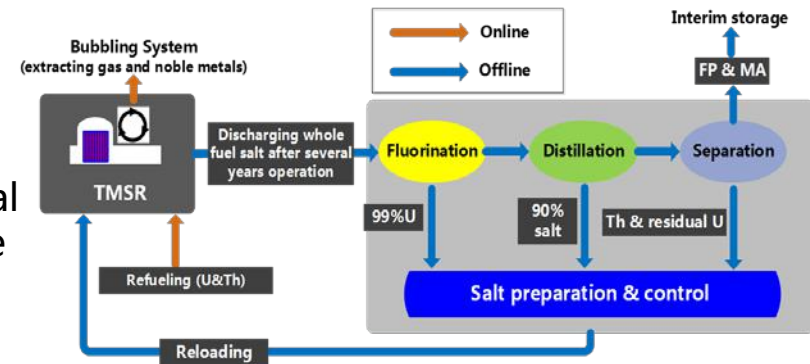
- **Th-U fuel cycle**
- **Materials**
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Summary

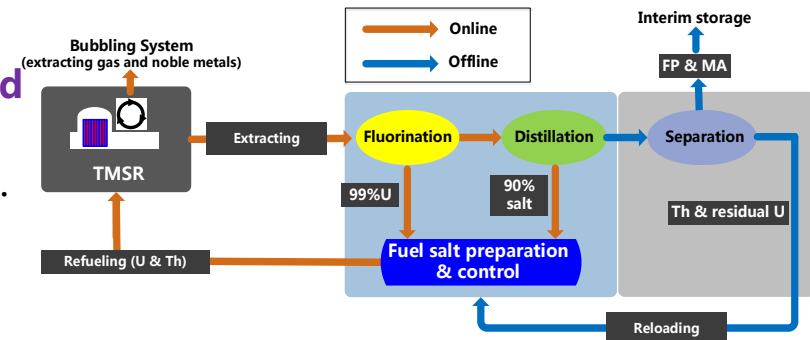
## ➤ Step1: Offline batch process

- Fuel loading: LEU+Th (transition to Th cycle); U3+Th (future standard fuel)
- Online refueling and remove gaseous FPs. After several years' operation, discharge whole core fuel salt, offline extract U&Th and reload to core for operation.
- FP&MA for temporary storage.



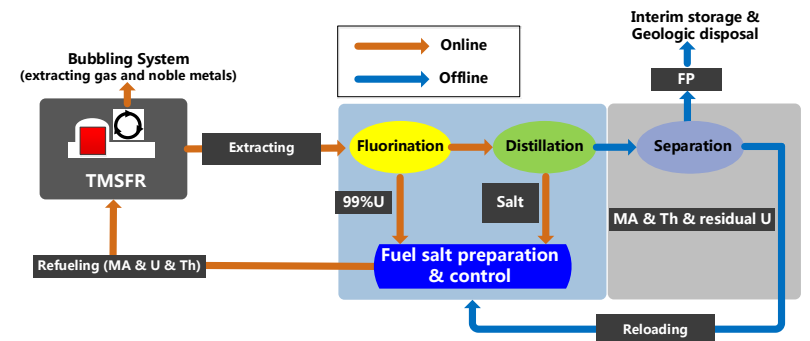
## ➤ Step2: Online process, quasi closed cycle

- Online remove gaseous FPs. **Online extract and reload U to enhance fuel utilization ratio.**
- Offline batch process to recycle salt, residual U and Th.
- FP&MA for temporary storage.



## ➤ Step3: Fully closed fuel cycle

- Online remove gaseous FPs.
- Online extract and reload U.
- **Offline extract TRU and reload to reactor.**
- **Recycle mode: Breeders / Burners. All heavy elements are recycled.**
- Geologic disposal: only FPs and a small amount of U and MA loss from reprocessing



## Target performance of “three steps”

Characteristics	Step 1	Step 2	Step 3
Fuel reprocessing	Batch processing	Continuous processing	Continuous processing + MA re-injected
Fuel utilization efficiency (%)	1~5	~45	55~100
Radiotoxicity (Sv/GW.y)	$\sim 1.0 \times 10^7$	$\sim 5 \times 10^6$	$1 \times 10^5$
Th fission fraction (%)	~24	50 - 100	100
Convert Ratio (CR)	0.6-0.8	0.8-1	$\geq 1$
TRU transmutation rate (%)	/	/	> 95

The third step can fully incinerate the MA from the previous two steps, realizing the fully closed fuel cycle.



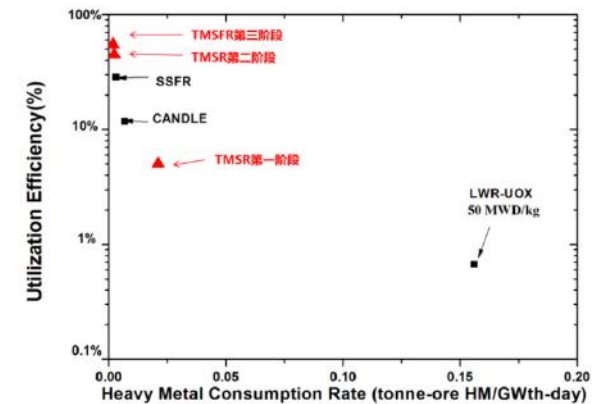
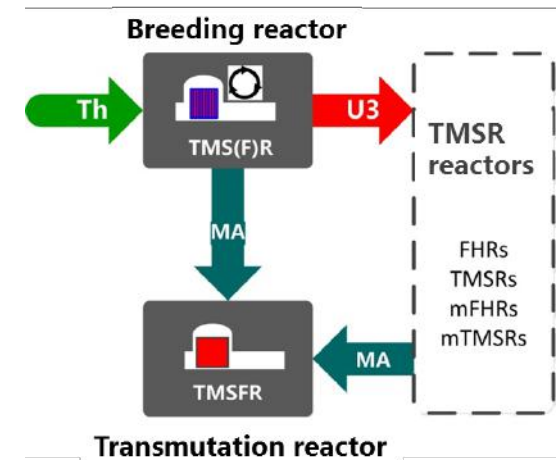
## The breeder reactors supply U233 for series of commercial reactor fleets

- High breeding, ensuring the sustainable utilization of Th for the TMSR family;
- The fuel utilization efficiency of each generation can reach 40%-60%.

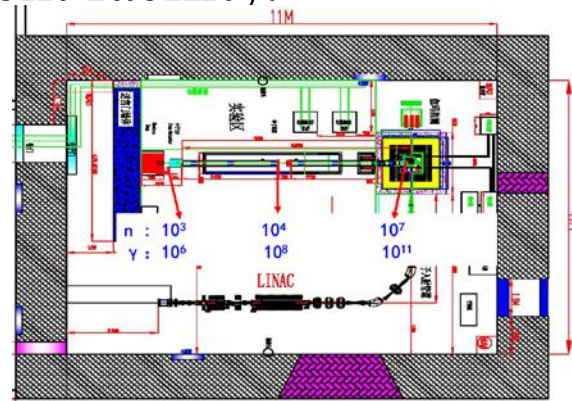
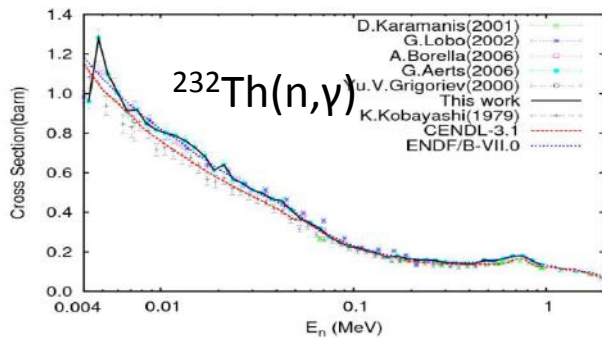


## The transmutation reactors clear up the wastes from the commercial reactors

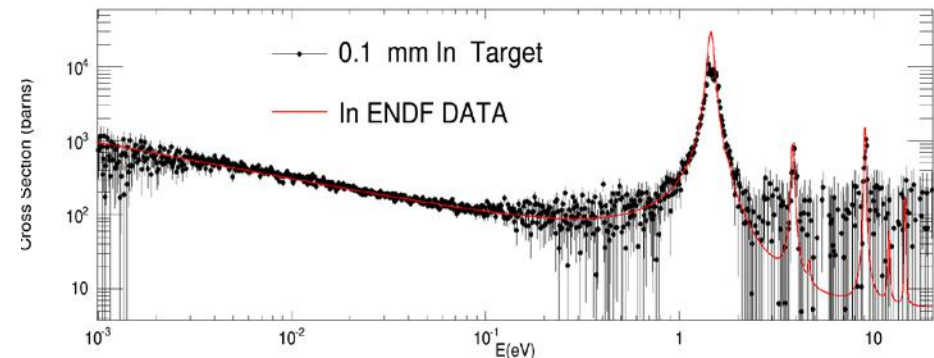
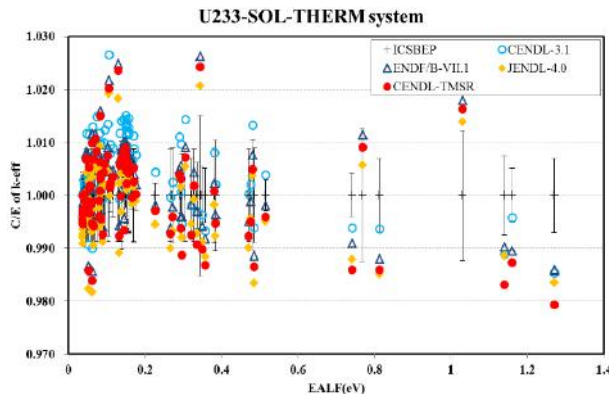
- The transmutation rate can reach to 95%
- After multi-generations, the fuel utilization efficiency can approach to 100% and with minimum radiotoxicity emission.

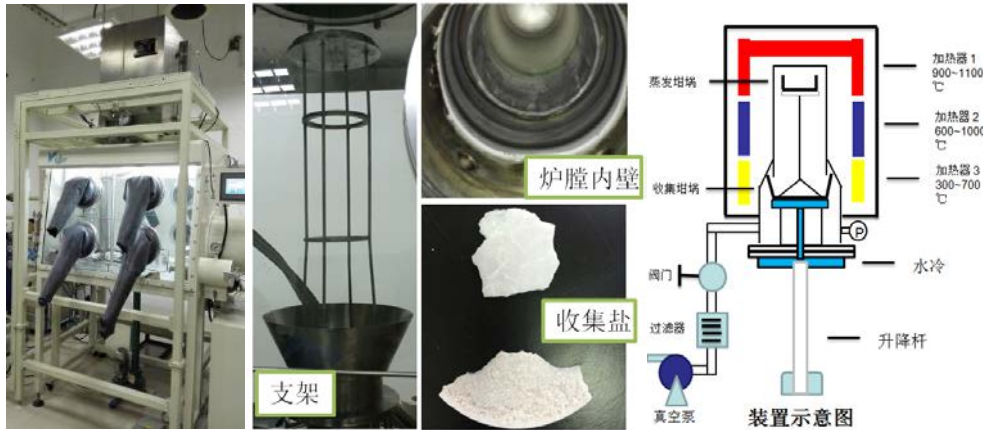


- Establish the special nuclear data library for TMSR(CENDL-TMSR-V1), which includes 403 nuclides.
- Commissioning of electron LINAC neutron source and nuclear data measurement facility.



	设计指标
平均流强/mA	0.1
电子能量/MeV	15
功率/kW	1.5
靶	钨
脉冲频率/Hz	1-266
中子脉冲宽度/ns	3-3000
飞行距离/m	1-5
分辨(@MeV)%	<1
中子通量/ $s^{-1}cm^{-2}$	$10^5$
中子产额 $10^{13}/s^{-1}$	0.4



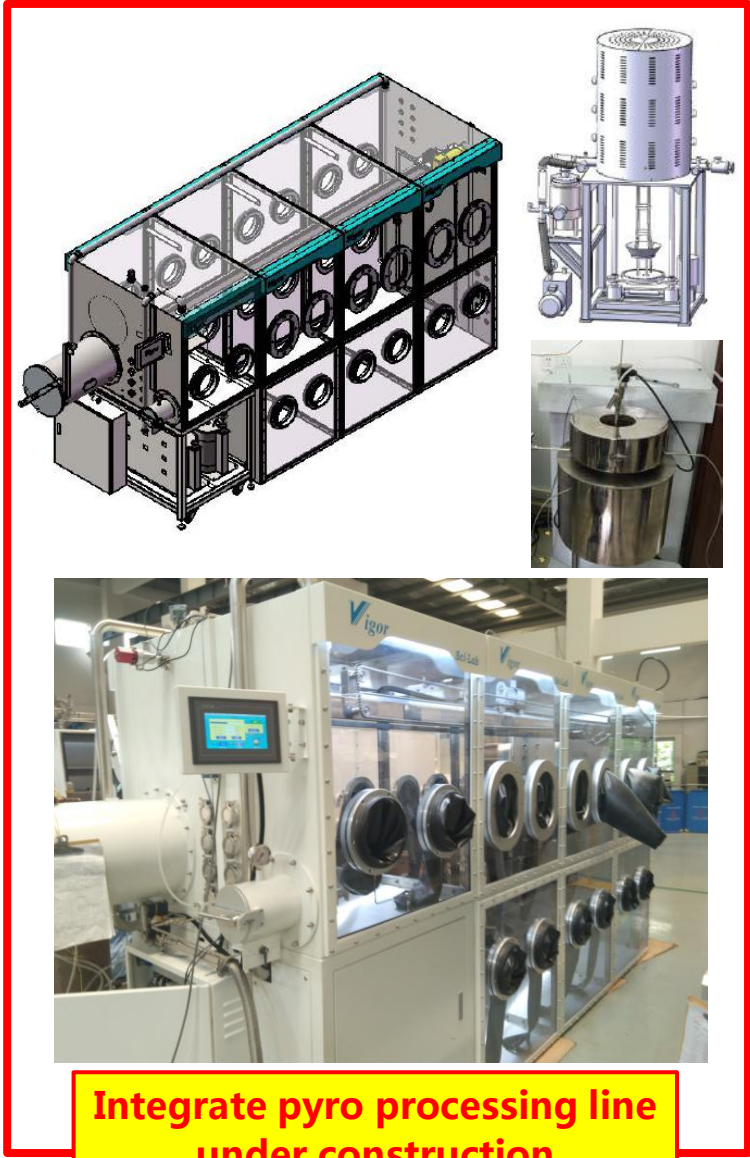


**Molten salt distillation facility designed for FLiBe, kg level, salt recovery rate > 98% for Flinak**



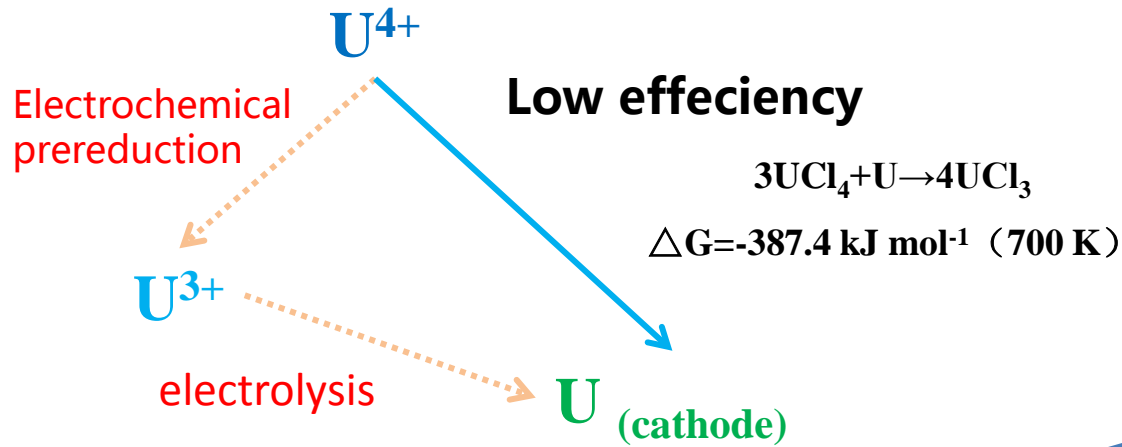
**F<sub>2</sub> supply    Fluorination monitors    Product recovery    Tail gas**

**High temperature fluorination facility, kg level U recovery recovery rate >95%**

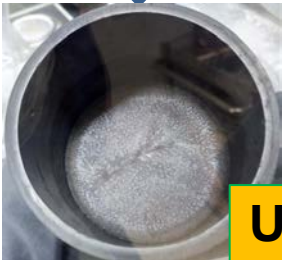


**Integrate pyro processing line under construction**

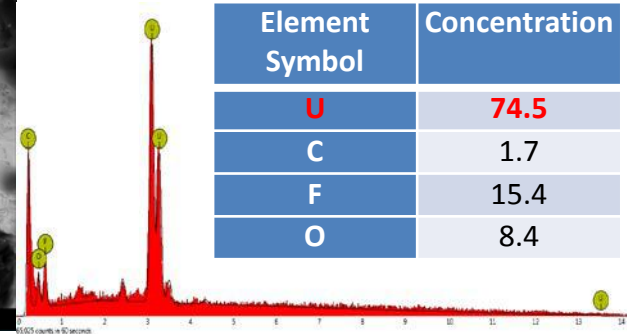
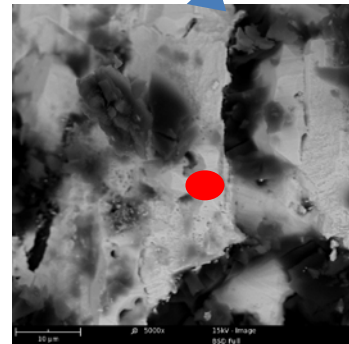
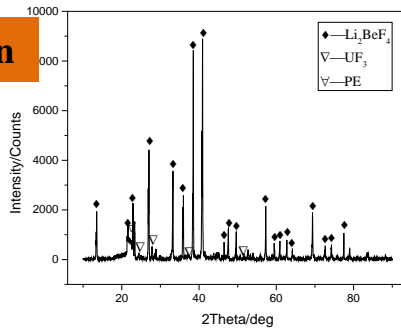
Solve the direct reduction problem of  $U^{4+} \rightarrow U$  by prereduction method. Dendritic U metal was obtained.



Li metal Prereduction

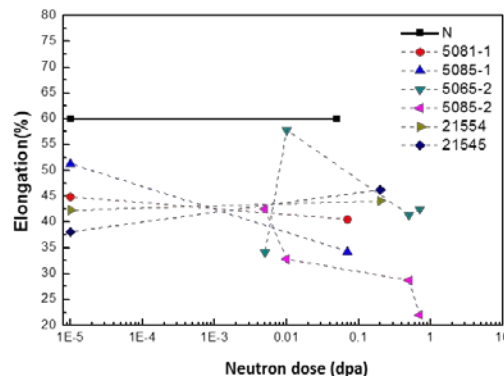
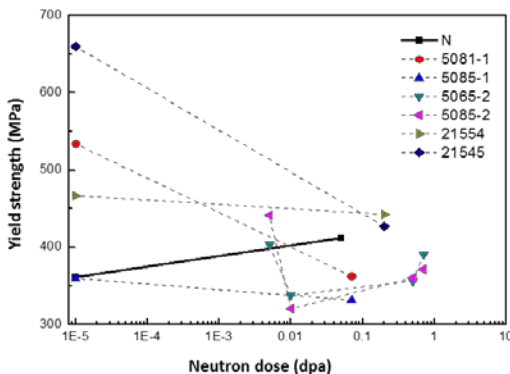
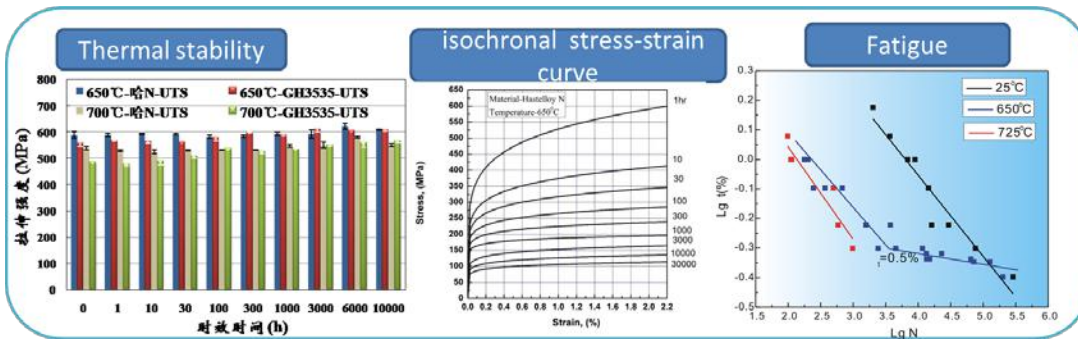


**UF<sub>3</sub>**






**GH3535 fabrication, processing:** 10t ingot and 3-m diameter ring rolled piece manufactured, welding procedure fixed.

**Material data base** is in construction. Extensive experiments are in progress to produce long time mechanical performance data (**>10000h up to now**). Irradiation tests are also in progress.



PIE at room temperature



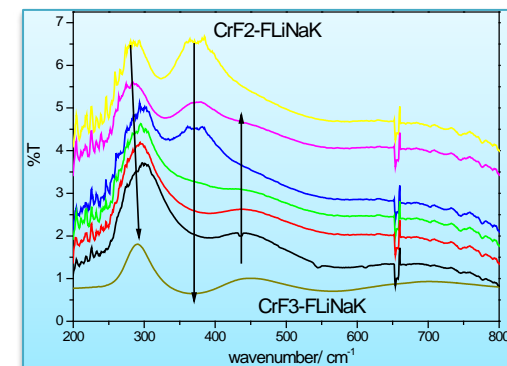
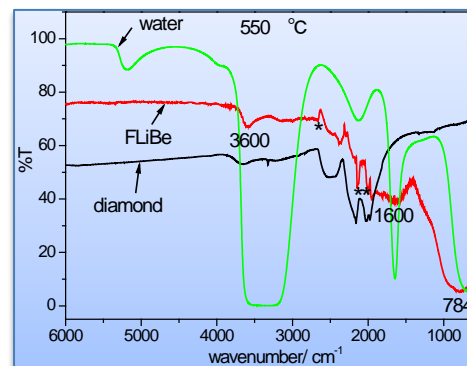
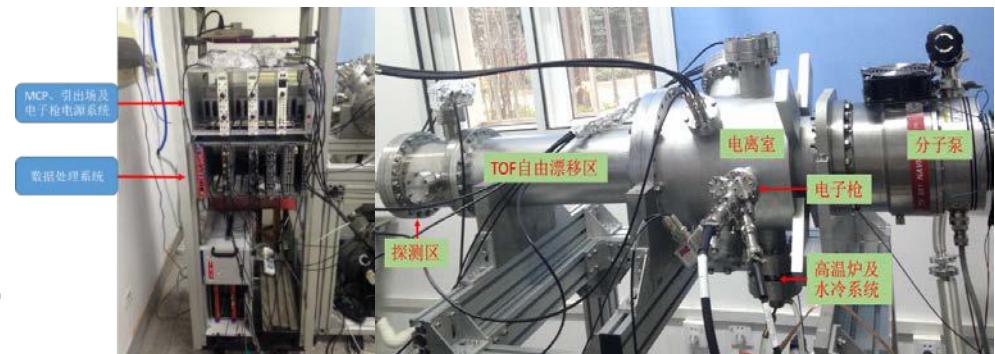
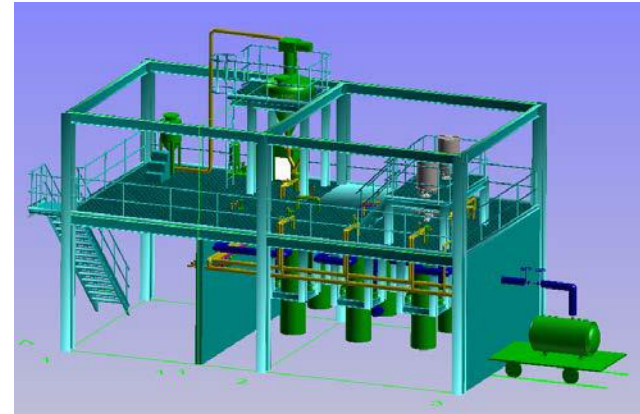
-  Fabrication technology progress: improve rate of finished products, improve fracture toughness, fabricate larger block (1400X600X350mm)
-  Material Irradiation tests and performance tests after irradiation have been planned. The irradiation will be start soon in high flux reactor of China.
-  Experimental study for graphite irradiation together with molten salt will be carried out in collaboration with MIT Reactor Lab.

Mass production of high purity FLiNaK salt: A production line able to produce 10t salt per year has been constructed.

Facility for kg level FLiBeThU fuel salt production has been designed.

Experimental facility for study molecular and cluster structure of salt vapour.

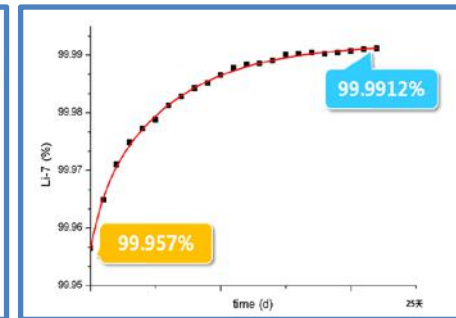
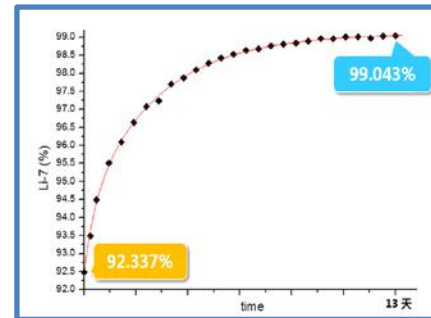
New results of spectroscopy study.



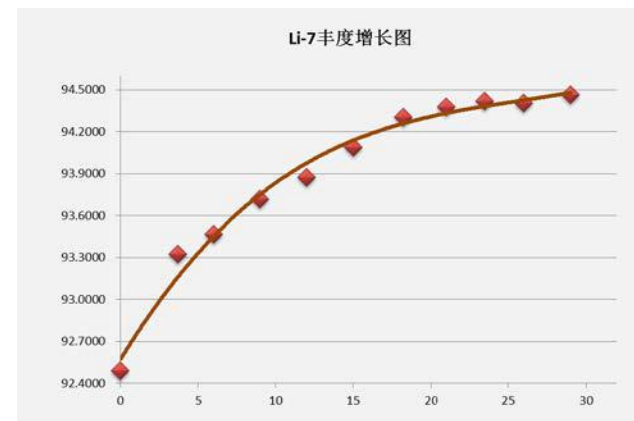
📖 2011-2014: Develop new methods, small scale demo in laboratory. 160 cascade stages,  $\phi 20\text{mm}$  centrifugal extractor. 99.99%  ${}^7\text{Li}$  can be produced.



📖 2015-2016: Mid scale (20kg  ${}^7\text{Li}/\text{a}$ ) demo and test. 40 cascade stages,  $\phi 100\text{mm}$  centrifugal extractor.  ${}^7\text{Li}$  abundance increased from 92.49% to 94.46%.



📖 The plan of large scale factory (tone/a) in under evaluation.



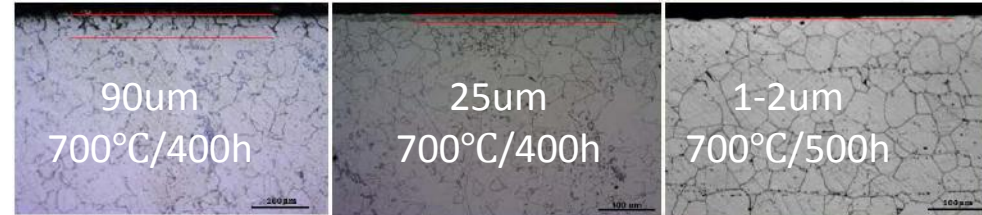
Corrosion rate about 2um/a was observed for N alloy in highly purified FLiNaK molten salt (static).

Corrosion behavior and mechanism

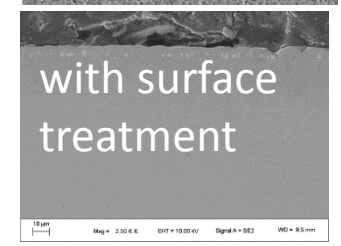
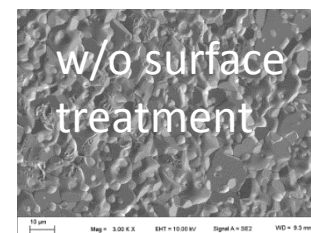
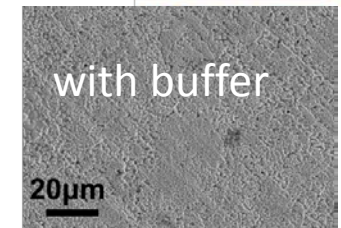
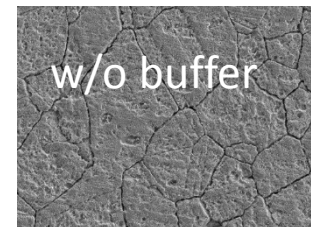
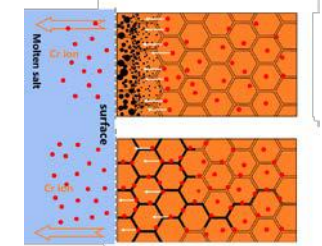
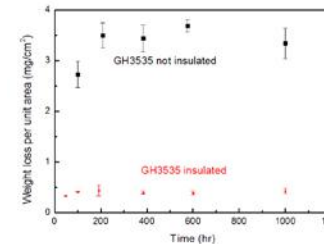
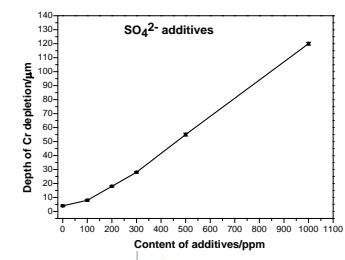
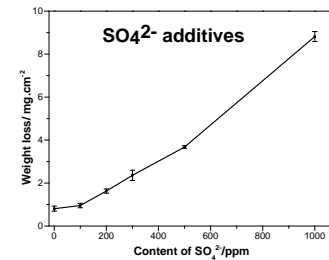
- Cr diffusion.
- Contamination effects:  $SO_4^{2-}$ , metal ions.
- Corrosion acceleration of alloy with graphite? Electric dipole corrosion, contaminants effects.

Corrosion protection for SS316

- Different corrosion mechanism of N-alloy and SS. Uniform diffusion vs. grain boundary diffusion
- Corrosion protection by adding "buffer pair" in salt.
- Corrosion protection by surface treatments.



Depth of Cr diffusion layer, different salt purity



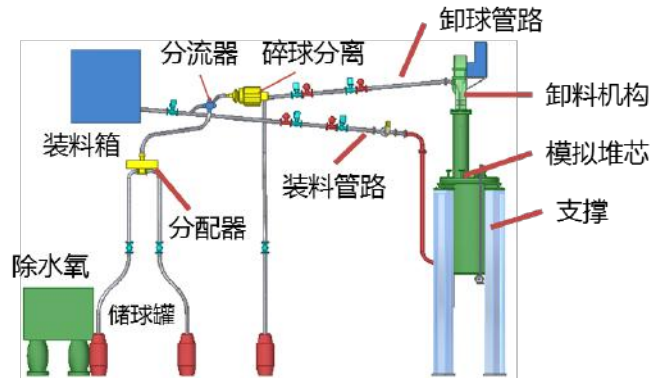
Changed to predictable uniform diffusion

Comprehensive test platform has been designed and in construction, for non-nuclear testing of MSR materials, components, instrumentation and test reactor design.

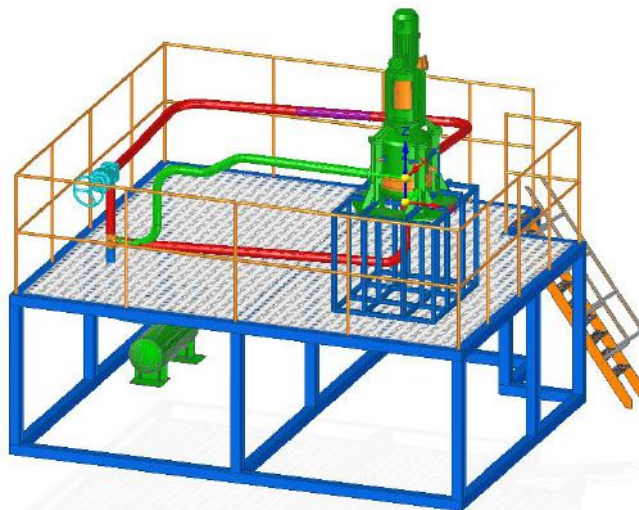
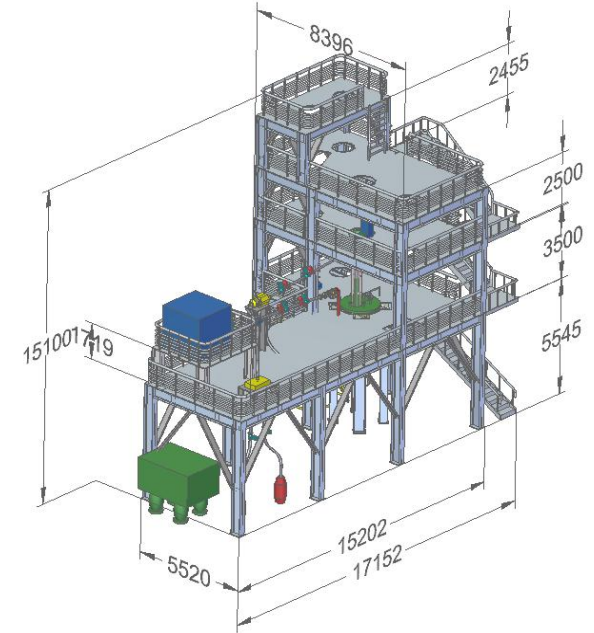
- Test benches for TMSR-SF1 components: Molten salt pumps, Control rod systems, fuel pebble circulating system etc,
- Test benches for MSR instrumentation: temperature, level, pressure, flow rate and neutron detectors.
- Simulate reactor (TMSR-SF0) based on TMSR-SF1 design.



Control rod test bench. Simulate design and service condition in TMSR-SF1



Fueling, defueling and pebble circulating simulation in molten salt condition.

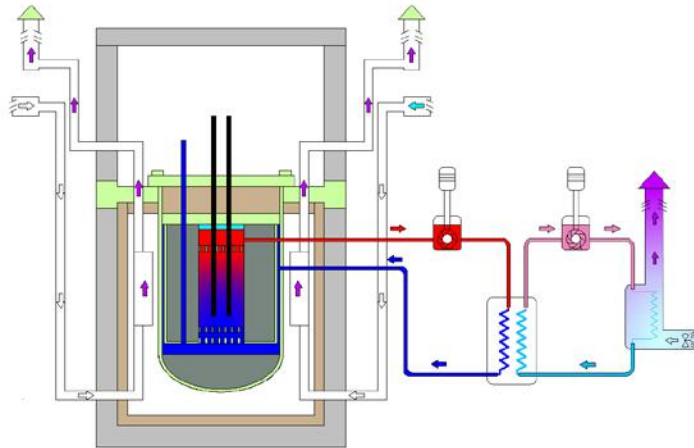


Salt pump test bench

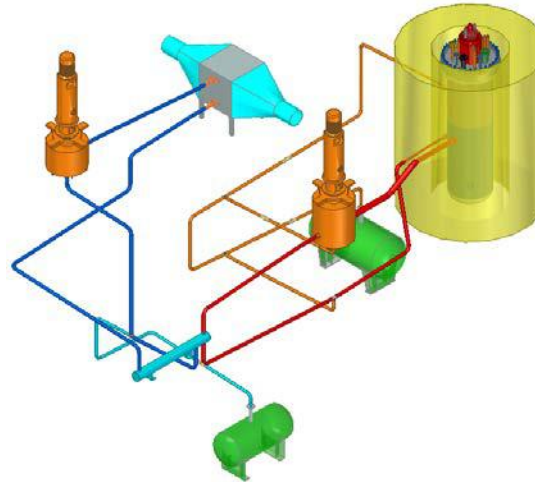
Working medium	FLiNaK molten salt
Temperature	500~700°C
Flow rate	≤500 m <sup>3</sup> /h
Pump lift	≤40m
Power	≤150kW
Pressure	1MPa

**TMSR-SF0 is a simulator of TMSR-SF1 (1:3 in geometry), with various purpose:**

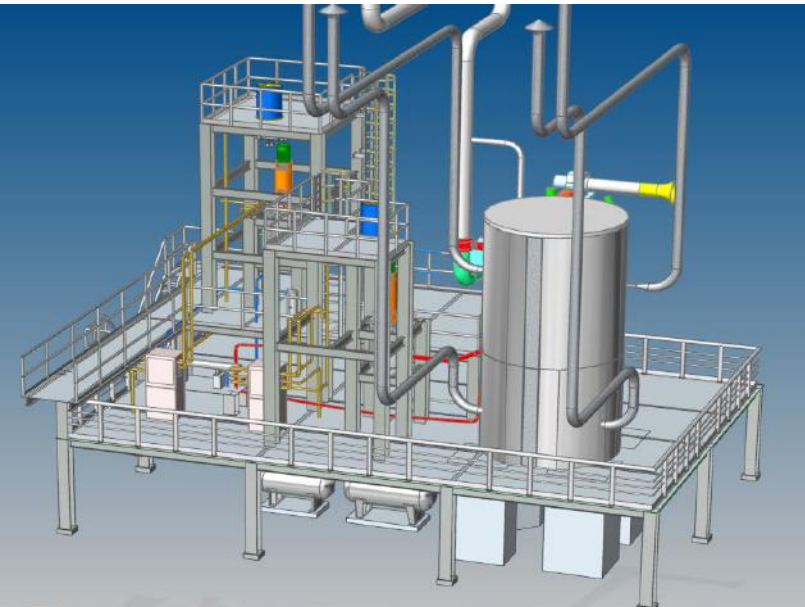
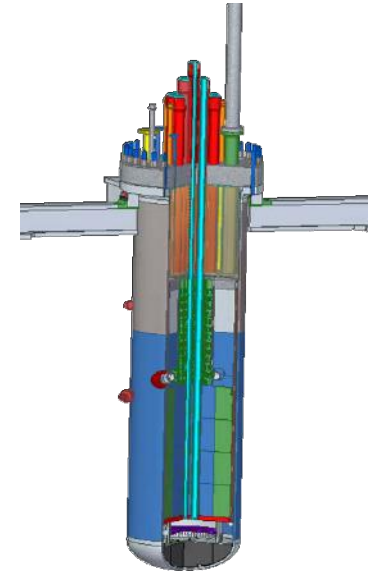
- **Verification** test of the T-H design and safety design of TMSR-SF1;
- Test the feasibility of some SF1 engineering designs and the reliability of design calculations;
- To **benchmark** the validation of T-H and safety analyzing **codes** for TMSR-SF1 and future FHR.
- To study the steady and transient behavior of FHR by simulating various event of SF1.
- To be a **comprehensive demonstration and testing platform** for materials, component and system techniques that TMSR developed during past years.
- To be a **training platform** for TMSR-SF1 operation.



Schematics of principle



System layout



Overall installation drawing

## TMSR-SF0 Design Parameters

Electric Heating Rated Power @ Core	370kW	Design Temperature @ Main Vessel	700 °C
Temperature of Molten Salt @ Reactor Inlet	600 °C	Design Pressure @ Main Vessel	0.5MPa
Temperature of Molten Salt @ Reactor Outlet	650 °C	Design life	10 year
Mass Flow of Molten Salt @ Primary Loop	0-10.0 kg/s	Mass Flow of Molten Salt @ Second Loop	0-12.2 kg/s
Cover Gas @ Primary Loop	Ar	Rated Power of Passive Exhaust System	12.8 kW
Molten Salt @ Primary Loop	FLiNaK	Molten Salt @ Second Loop	FLiNaK



# Outline



Project overview



Highlight-2016



Th-U fuel cycle



Materials






Reactor engineering



**Summary**

# Summary and Outlook

-  TMSR Project has made big progress in wide range of basic research and engineering development. However, the plan to build test reactors is postponed, instead, a simulate reactor will be built.
-  The recent announced 13<sup>th</sup> five-year plan of CAS requires to build a 2MW molten salt test reactor for Th-U fuel cycle experiments.
-  Chinese government will continue to support the long term R&D of Th utilization.
-  SINAP is making new plan towards TMSR commercialization, and making effort for industrialization of molten salt related techniques.



**Thanks**



**for  
your  
attention!**