China's TMSR programme

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Outline

Program Overview

International collaboration

Research Progress

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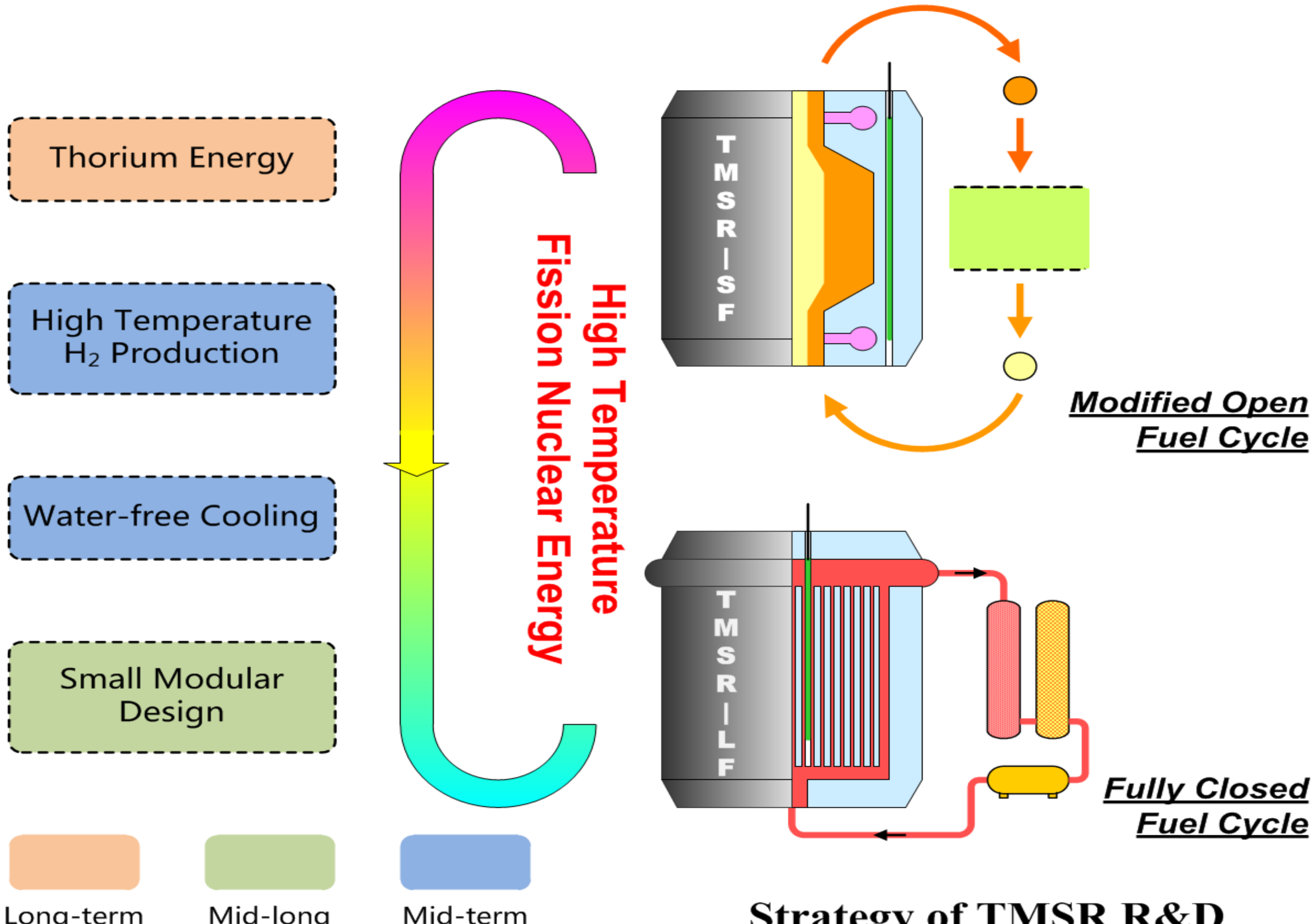
Thorium Molten Salt Reactor Energy System - TMSR

- The aim of TMSR is to develop Th-Energy, Non-electric application of nuclear energy based on TMSR-LF and TMSR-SF in next 20-30 years.
- The program initiated by CAS in 2011
- TMSR-LF 液态燃料钍基熔盐堆 --- MSRs
- TMSR-RF 固态燃料钍基熔盐堆 --- FHRs

FHRs May Be Considered as Precursors to MSRs

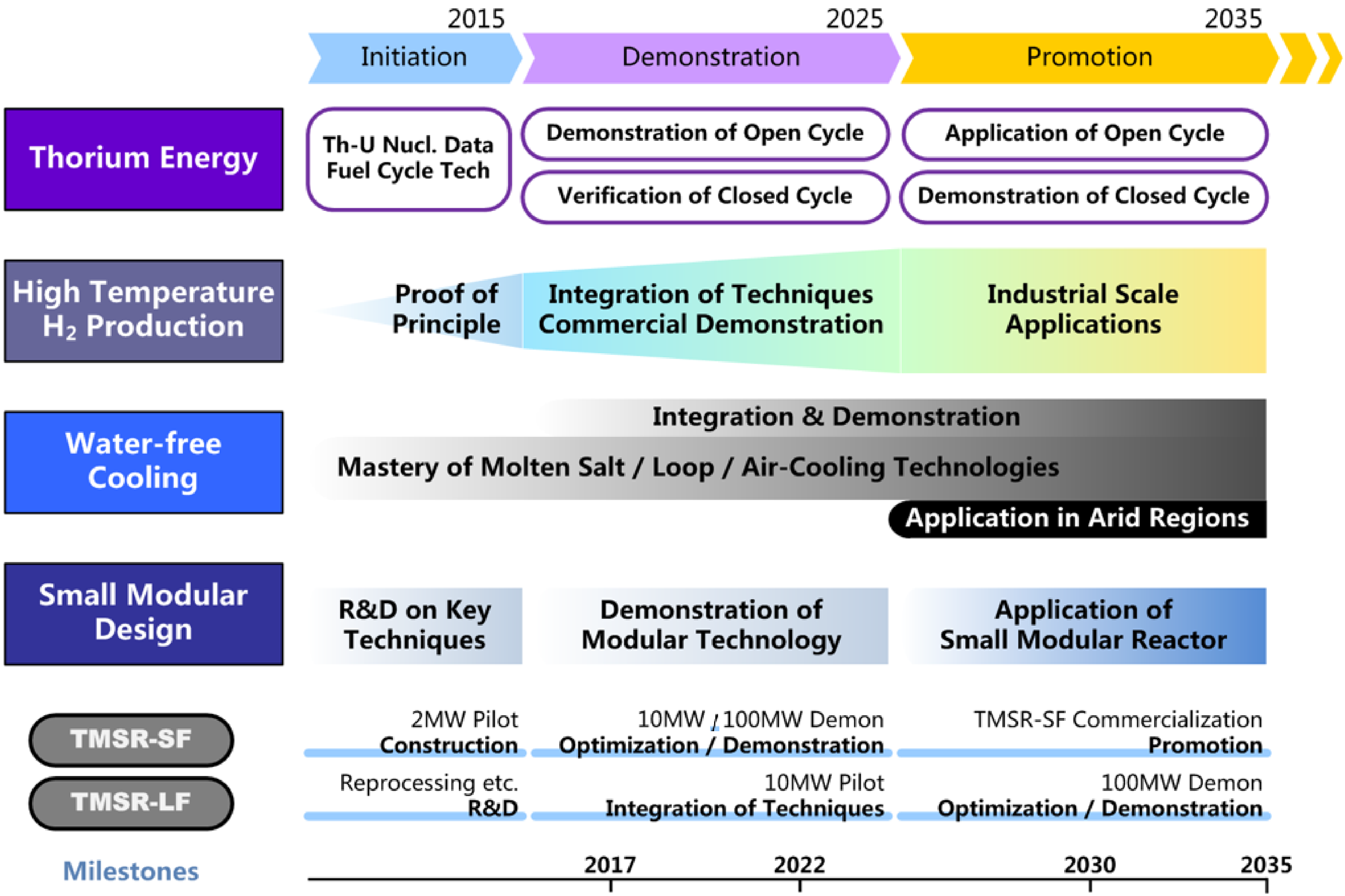
- MSR development requires all of the technologies required by an FHR (such as materials, pumps, heat exchangers, salt chemistry and purification, and power conversion) except for coated particle fuel.
- FHR deployment does not require some of the MSR longer-term development activities (such as reprocessing of highly radioactive fuel salts). FHRs can be deployed much earlier than MSRs.

Reactors and Applications



Strategy of TMSR R&D

TMSR Road Map



The Milestones of TMSR

100MW Liquid-Fuel TMSR-D (TMSR-LF1) +Demo. Th-U Cycle

Long Term (～2030)

100MW Solid-Fuel TMSR-D (TMSR-SF1)

10MW Liquid-Fuel TMSR-E (TMSR-LF1) +Demo. Th-U Cycle

Middle Term (～2025)

10MW Solid-Fuel TMSR-R (TMSR-SF1)

2MW Liquid-Fuel TMSR-E (TMSR-LF1) +Demo. Th-U Cycle

Near Term (～ 2020)

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TMSR International Cooperation

- Th Utilization, Reactor Tech.
- Material, Molten Salt Tech,
- Pyro-processing
- Nuclear Safety Standards

Organizational Overview

The Chinese Academy of Sciences (CAS) and U.S. Department of Energy (DOE)
Nuclear Energy Cooperation Memorandum of Understanding (MOU)

MOU Executive Committee Co-Chairs

China – Mianheng Jiang (CAS)
U.S. – Pete Lyons (DOE)

GEN IV International Forum

Australia

ansto
Nuclear-based science benefiting all Australians

Future

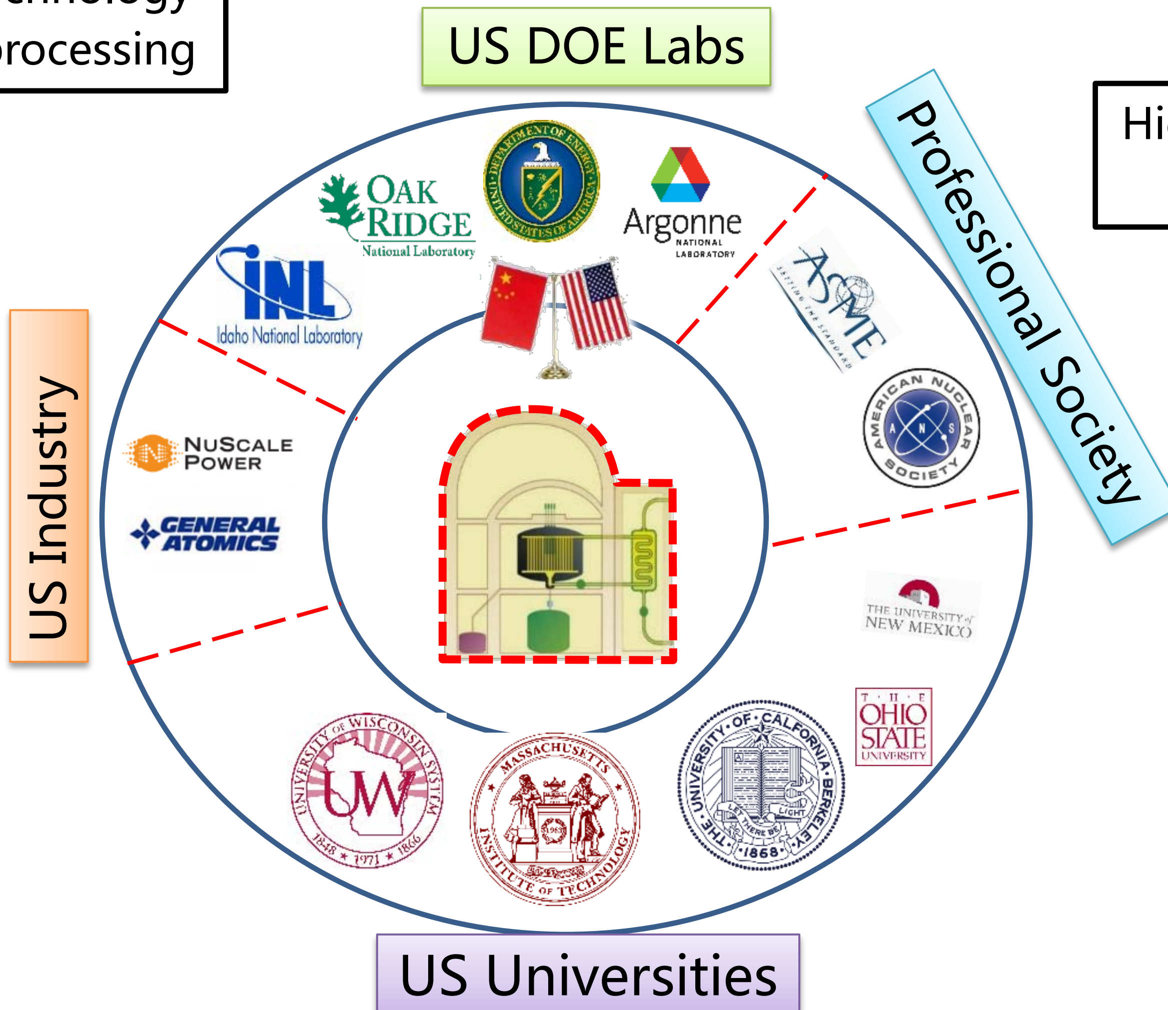
- Russia
- EU
- Korea
- Japan

Collaboration with USA-I

FHR technology
Pyro-processing

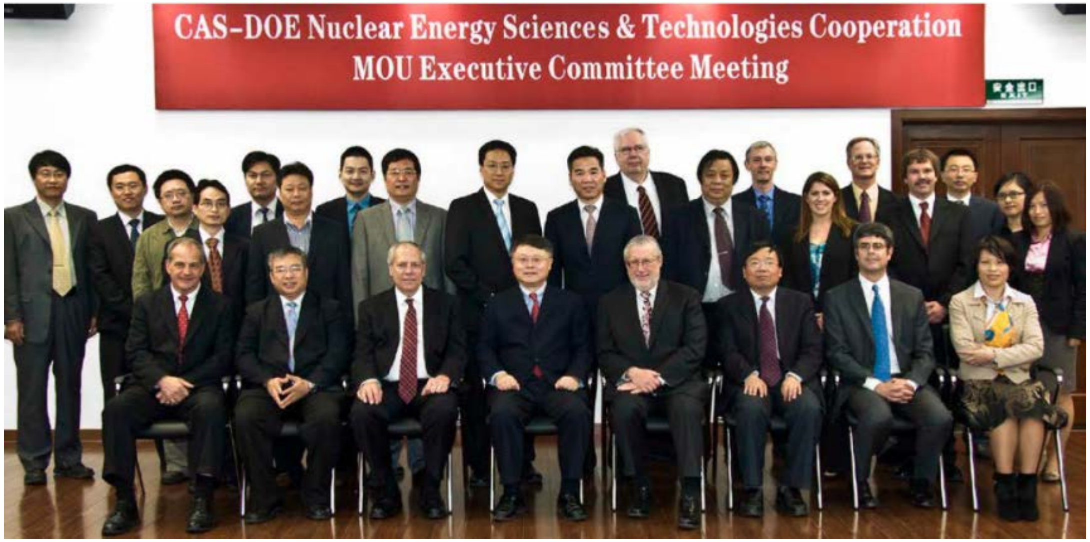
FHR Safety Standards
ANSI/ANS-20.1

High-tem. Material
ASME



Collaboration with USA-II

The Chinese Academy of Sciences (CAS) and U.S. Department of Energy (DOE) Nuclear Energy Cooperation Memorandum of Understanding (MOU)



CRADA between TMSR and ORNL signed in July 2014

TMSR-MIT Agreement
(Signed in March 2015)

- Commercialization Basis for High-Temperature Reactors
- Tritium Control and Coolant Salt Cleanup
- FHR Test Reactor Design and Safety analysis
- Flibe Salt and Materials In-Pile Irradiations
- MSR material simulation

UCB is part of the SINAP-ORNL CRADA.

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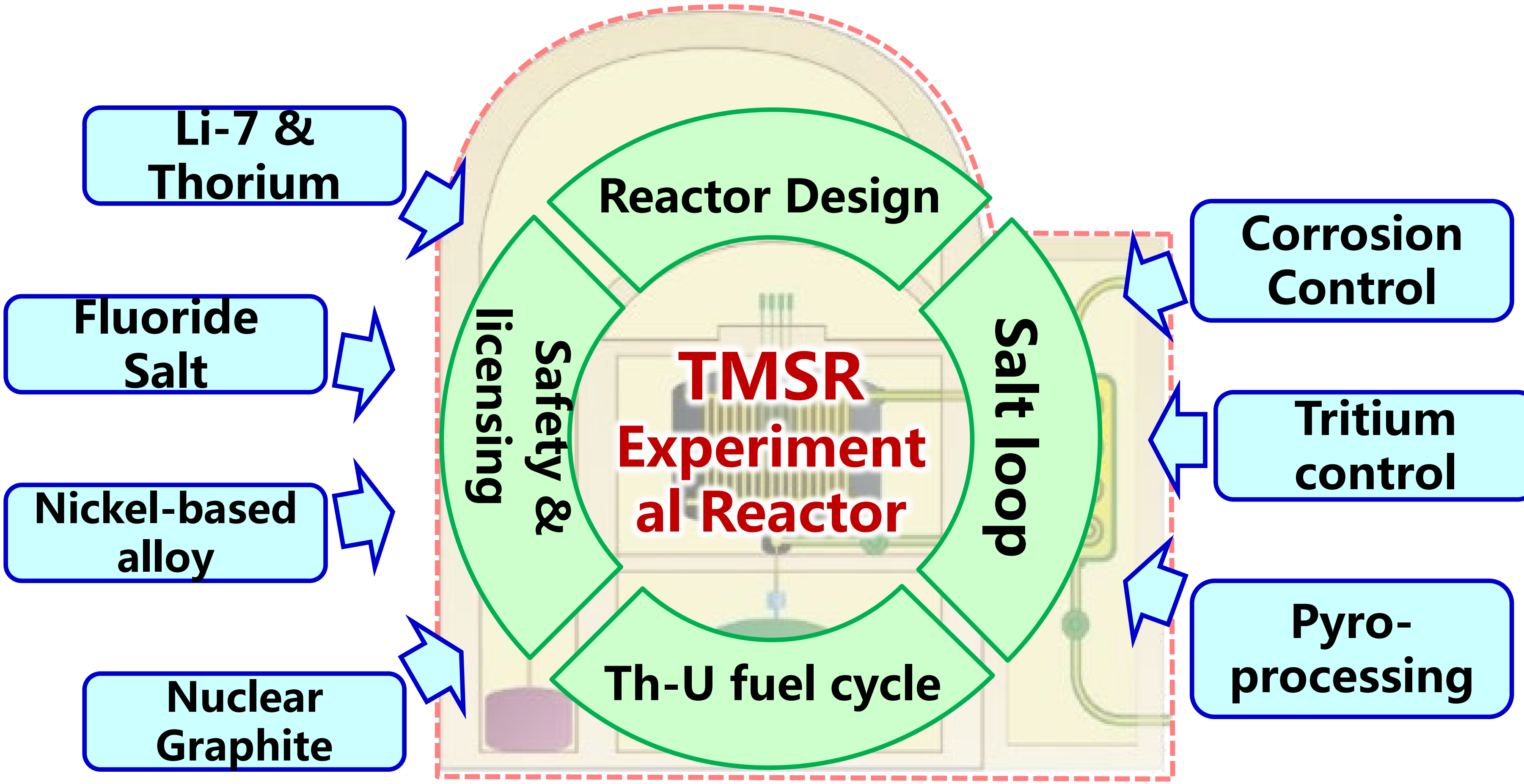
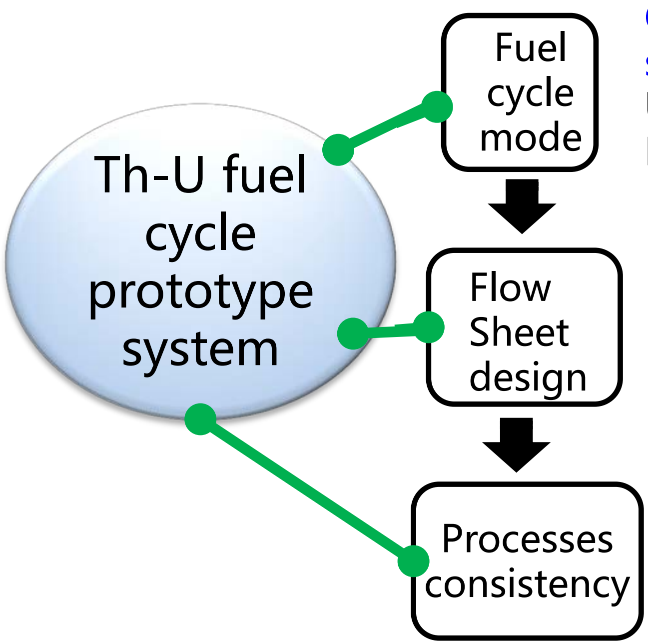
Prototype Systems and Key Techs @ TMSR



Prototype System 1 : Th-U fuel cycle

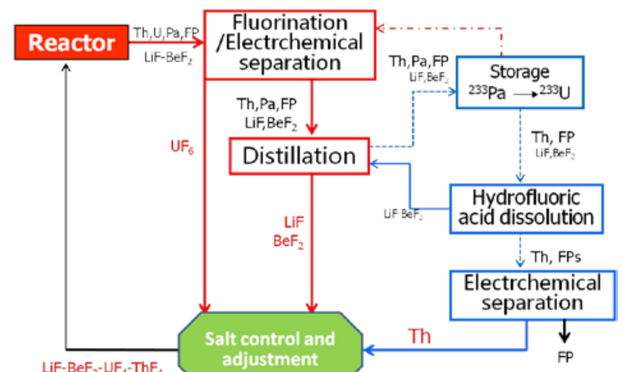
Established a comprehensive Th fuel utilization strategy in MSRs by evaluating the Th-U fuel cycle performances; based on the above strategy, created an innovative reprocessing flow sheet and demonstrated it in cold, lab-scale facilities.

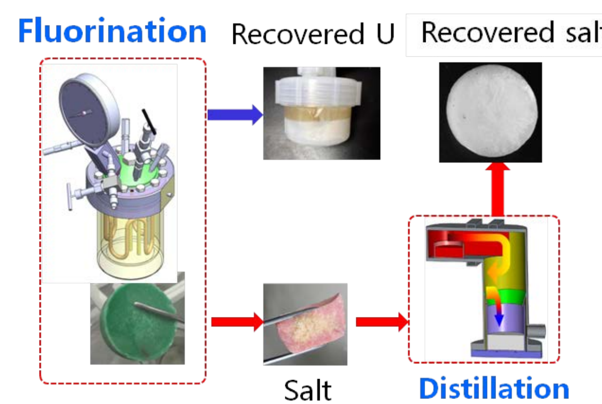


Comprehensive Th utilization strategy in MSRs
U5-U3 transition in MSRs
MA transmutation in MSRs

Innovative flow sheet combines on-line and off-line processing
On-line for U and carrier salt
Off-line for Th and MA

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





Prototype System 2 ：Reactor design of TMSR-SF1

R&D of design tools & methods, key technology & equipment, and related experimental verifications for TMSR-SF1. Preliminary design of 10MW solid fuel molten salt test reactor (TMSR-SF1)

Reactor Physics

- Development of design and analysis tools and methods, validation and verification;
- Nuclear data evaluation, H-T data measure-ment and evaluation;
- Reactor core modeling and experimental study.

Reactor Design

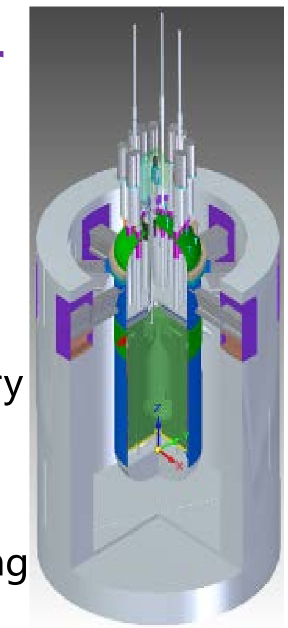
Concept design

↓

Preliminary design

↓

Engineering design



contents

Reactor core;
Reactivity control;
Fuel management;
Inner structure;
Main vessel;
Instrumentatio n;
Rector control and protection

Reactor Engineering

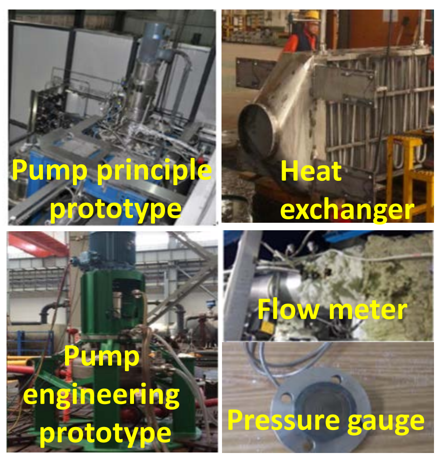
- Reactor mechanics under high-T molten salt condition: vessel, inner structure, support, seal etc.…
- Key equipment, from principle experiment to prototype:
  - Control rod system;
  - Fueling and defueling;
  - In core neutron measurements;
  - Digital reactor protector and DCS

Prototype System-3 ：High-temperature molten-salt experimental system

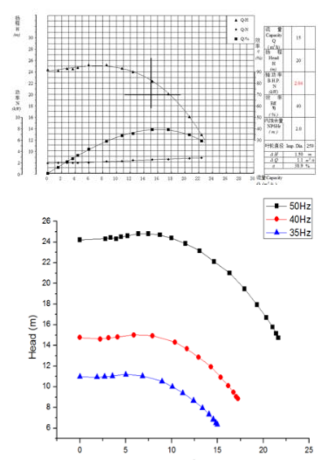
Developed the key equipments such as high-temperature molten-salt pump, heat exchanger, pressure gage, etc.
Constructed the high-temperature molten-salt experimental system.

- Developed design method and key technology for high-temperature molten-slat loop, including high temperature seal, measurement and control, et.al.
- Completed the set of prototypes for pump, valve, heat exchanger prototypes for fluoride system, et.al.
- Constructed the high-temperature molten-salt experimental system and gained the operation experience and important thermal hydraulics data.

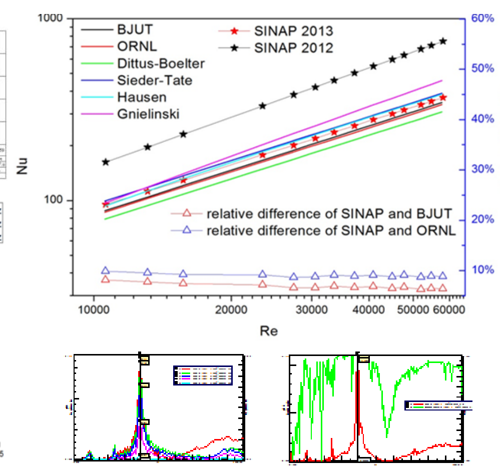
High-temperature fluoride salt experimental loop



Prototypes of key equipment



Hydraulic test of molten salt pump



Thermal hydraulic & mechanical test of loop

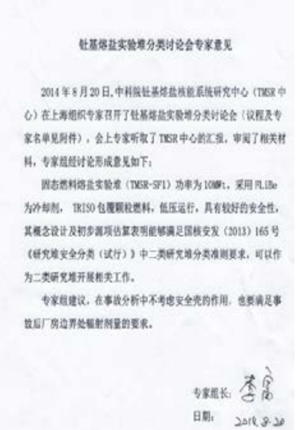
Prototype System 4：Nuclear Safety and Licensing

Developed safety analysis methods, developed safety design criteria for TMSR-SF1, participating in the development of *General Design Criteria* for FHR (ANSI/ANS-20.1), complete a salt natural circulation test loop for safety code validation

- **Scientific design/assessment criteria**: Seismic design criteria & Reactor classification as Class II
- **International safety standards** :development of ANSI/ANS-20.1
- **Reliable safety analysis**: Improve and verify accident analysis codes for molten salt, condition categories & SSC Classification
- **Specific safety V&V**：complete a salt natural circulation test loop for safety code validation

基于安全分类的研究堆选址和抗震设计标准研讨会

会议纪要



钍基熔盐实验堆分类讨论会专家意见

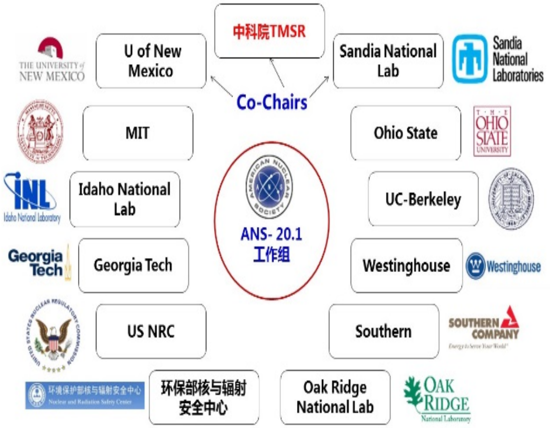
2014年8月20日，中科院钍基熔盐核能系统研究中心（TMSR中心）在上海组织专家召开了钍基熔盐实验堆分类讨论会（议程及专家名单见附件），会上专家听取了TMSR中心的汇报，审阅了相关材料，专家组经讨论形成意见如下：

固态燃料熔盐实验堆（TMSR-SF1）功率为10MWt，采用FLiBe为冷却剂，TRISO包覆颗粒燃料，低压运行，具有较好的安全性，其概念设计及初步源项估算表明能够满足国核安发（2013）165号《研究堆安全分类（试行）》中二类研究堆分类准则要求，可以作为二类研究堆开展相关工作。

专家组建议，在事故分析中不考虑安全壳的作用，也要满足事故后厂房边界处辐射剂量的要求。

专家组长：

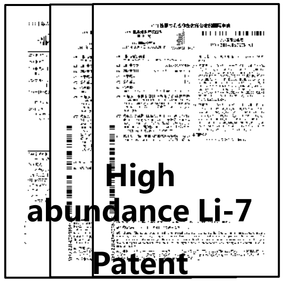
日期：



Core technology 1：Extraction and separation

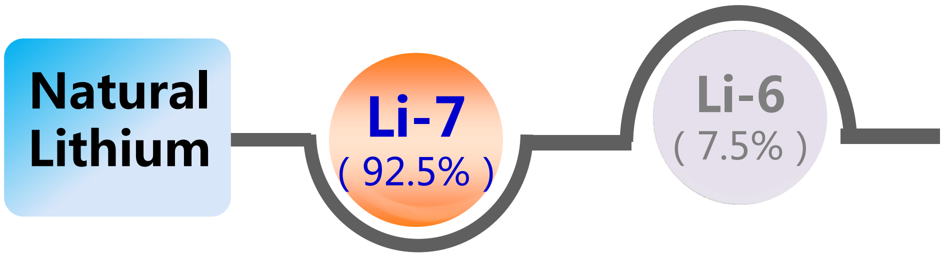
Succeed in obtaining nuclear grade thorium and high abundance Li-7 using extraction technology

- **High abundance Li-7**: As a green technology, centrifugal extraction method was developed instead of mercury method to obtain Li-7. Counter current extraction experiment was achieved and 99.99% Li-7 was obtained for the first time. High efficient extractants were synthesized.
- **Nuclear grade thorium**: High efficient extraction system was developed for the separation and preparation of the nuclear grade thorium. The 99.999% purity thorium was obtained in batches.



WO2014/067278A1
WO2014/201890A1，
CN104140379A， CN104147929A

ZL 2011 1 0074345.8，ZL 2012 1 0552752.X，ZL 2012 1 0453853.1，201210552752.X



- **PWR pH control（abundence≥99.9%）**
- **MSR coolant（abundence≥99.99%）**

Core technology 2 : High quality molten salts

Master the technology for high purity FLiNaK preparation, characterization, purification and batch production. Master the technology of the synthesis of FLiBe and beryllium control method. Established FLiBe-Th-U fuel salts thermodynamics database.

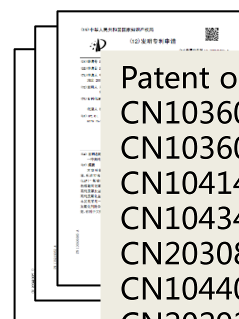
- ☐ Nuclear grade FLiBe (with boron equivalent < 2ppm) synthesis technology
- ☐ High purity FLiNaK (with total oxygen < 100ppm) purification technology
- ☐ High purity FLiNaK batch production (10ton/y)
- ☐ Ability for the physical properties determination and evaluation for fluoride molten salt
- ☐ Established a FLiBe-Th-U fuel salts thermodynamic database

Molten salt

Prototype for molten salt production (10ton/y)

FLiBe

Physical properties determination lab



Patent obtained : CN103219052A, CN103606385A,CN203440069U, CN103601222A,CN104147929A, CN104140379A,CN103572318A, CN104344120A,CN104214420A, CN203083132U,CN104089917A, CN104407011A,CN202460640U, CN202926703U,CN102878109A

15 Chinese patents

Key Tech. 3：Nickel-based alloy

Mastering key technologies for the smelling, processing, and welding of a Nickel-based superalloy （UNS N10003, GB standards GH3535）

GH3535： A nickel-based alloy with an outstanding corrosion resistance in molten salts

- Technologies for smelling (6 tons), processing & welding; performance comparable to Hastelloy N
- Deformation processing technologies for nickel-based alloys with high Mo, the largest UNS N10003 seamless pipes.

hot extrusion

pipe processing

Welding

Capability	China	US Haynes
Pipe Diameter	141.3mm	<88.9mm

seamless alloy pipes for the primary loop of MSR

Performance Test Report

Chinese Patent CN103966476 A (under review)

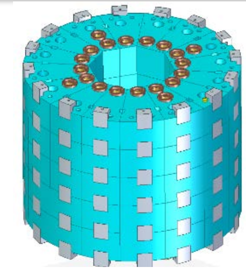
Component（head）

Key Tech. 4 : Nuclear Graphite

Development of the ultrafine grain nuclear graphite for MSR, deeply involved in the establishment of ASME code of MSR nuclear graphite

Nuclear graphite : moderator/reflector

- Industrial production technologies of Chinese ultrafine-grain nuclear graphite **NG-CT-50**
- Pore diameter<1μm, ensured better infiltration resistance than existed nuclear graphite
- Establishing database of its performance & deep involvement in Intl. Std. for MSR nuclear graphite

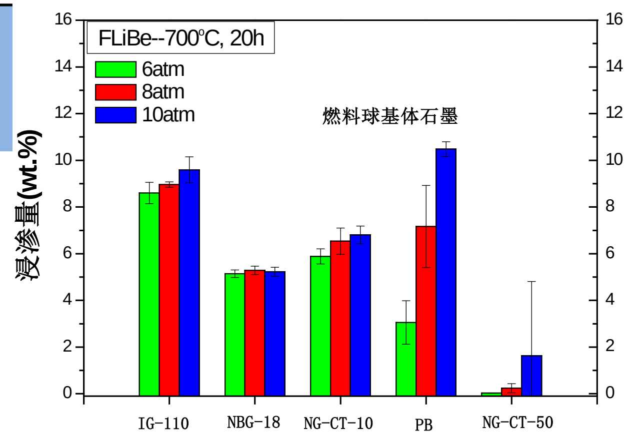


Graphite Core

Ultrafine grain Nuclear Graphite

Parameters	NG-CT-50 (China)	IG110 (Japan)
Pore Dia. (μm)	0.74	2
B Equiv. Cont. (ppm)	<0.05	0.1

Comparison between different nuclear graphite



Molten Salt Infiltration in nuclear graphite


ASME
SETTING THE STANDARD

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August 21, 2014

Zeng Guang Li
SINAP
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Jiading District, Shanghai 37831
People's Republic of China

Dear Dr. Zeng,

The ASME BPV III Subgroup on Graphite Core Components intends to consider the improvement of the provisions for fine-grain graphite in ASME BPV Section III, Division 5. As a research organization prominent in the field of nuclear graphite material, the Shanghai Institute of Applied Physics (SINAP) is positioned to assist the Subgroup in this endeavor.

Provision for ASME code

Key Tech. 5 : Corrosion Control

Solving the Corrosion Issue of Structural Material by Developing Corrosion Control Technologies (Design Optimization, Salt Purification and Surface Modification),

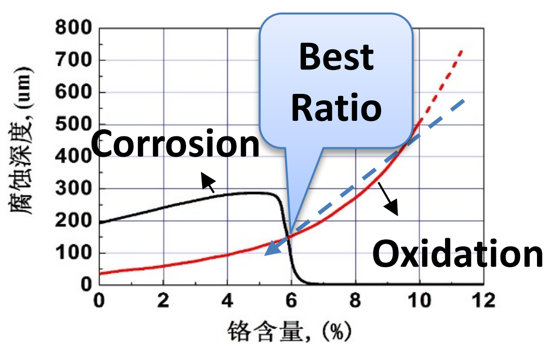
Investigating Corrosion Mechanism

- Salt impurities;
- Elements diffusion;
- Mass transfer;

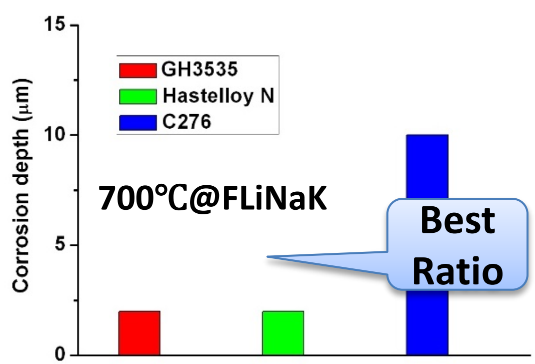
Developing Corrosion Control Technology

- Design Optimization : Optimize the composition of alloy, degrade diffusion of Cr;
- Salt Purification: Modify purification technology, control the impurities content;
- Surface modification: FTD coating, improve the corrosion resistance;

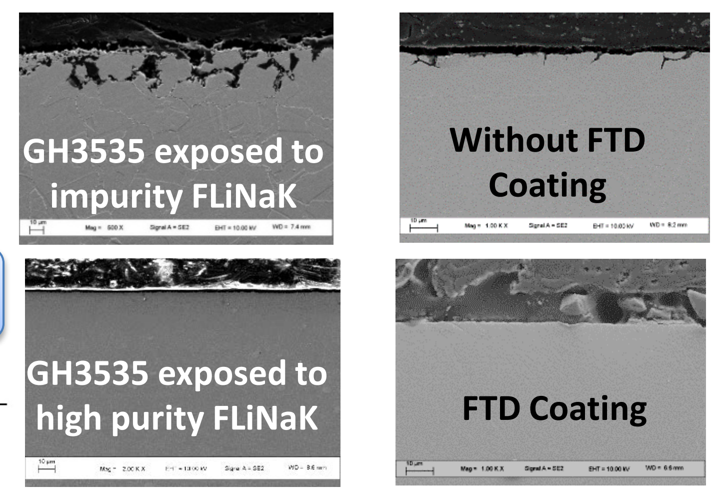
Solving the corrosion control in fluoride salt （ GH3535 static corrosion rate < 2μm/y ）！



Composition Optimization of Alloy (Cr)



Corrosion Depth (μm/y)

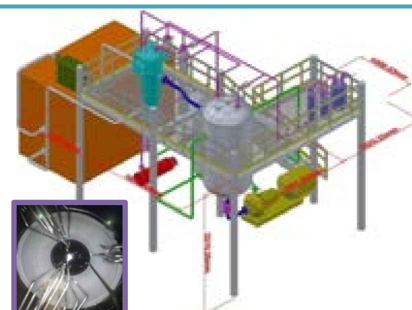


Key tech. 6 : Pyro-processing tech.

Full verification of fluorination and distillation based on fluorides salt with simulated material, and taking the lead in developing fluorides electrochemical separation process.

- **Fluorination for U recovery**
  --Verification of process at cold condition equipped with in-situ monitoring;
  -- Creation of frozen-wall tech dedicated to solving the corrosion problem derived from high temperature, F_2 and liquid fluorides melt.
- **Distillation for carrier salt purification**
  -- Creation of a controllable and continuous distillation device, the distillation rate is about 6 kg/h, and the DF is >10^2 for most neutron poison FP.
- **Fluorides electrochemical separation for U recovery**
  --Electro-deposition of U metal from FliBe-UF_4 melt for the first time, and the U recovery is >92%

Fluorination experimental set-up



Frozen-wall tech. experimental set-up

Distillation experimental set-up

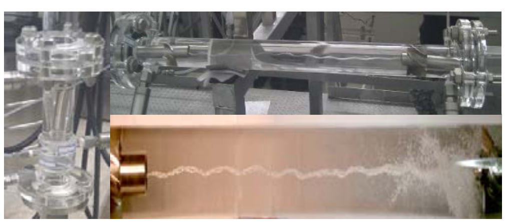
Electrochemical experimental set-up

China patent： CN 103143308 B；CN103143184 B； 201410339236.8；201410414660.4；201410339218.X；201510427482.3；ZL 2013 2 0023881.X；201410158185.9

Core technology 7: Tritium control

Master the key technologies of tritium control in the molten salt reactor such as tritium extraction with bubbling, tritium separation with cryogenics, on-line tritium monitoring and so on .

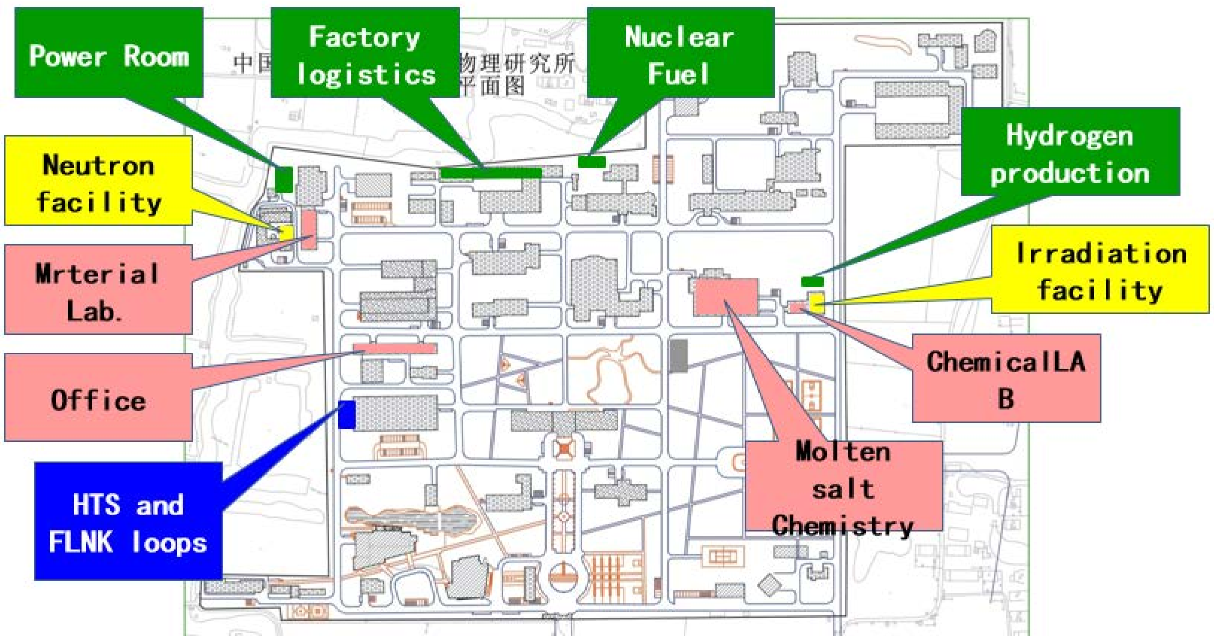
Tritium extraction with bubbling	Tritium separation with cryogenics	Tritium alloy-storage	Tritium sampling	On-line tritium monitoring
Bubble-size control, Degassing efficiency >95%	Concentration of Kr\Xe < 1ppb, H_2 < 1ppm in the exhaust gases	Zr_2Fe alloy (Hydrogen partial pressure ratio <0.1ppm)	Sampling HTO, HT and CH_3T simultaneously；Collecting efficiency >95%	On line monitoring of HTO, HT and Kr, Xe, simultaneously






10 patent applications： CN202471554U，CN203465122U，CN203350089U，CN203465125U ，CN104771937A ，CN104772055A ，CN104678047A，CN102608001A，201510500470.9，201510500762.2，

Fundamental research base in Jiading




Super Computer


Hot Cell

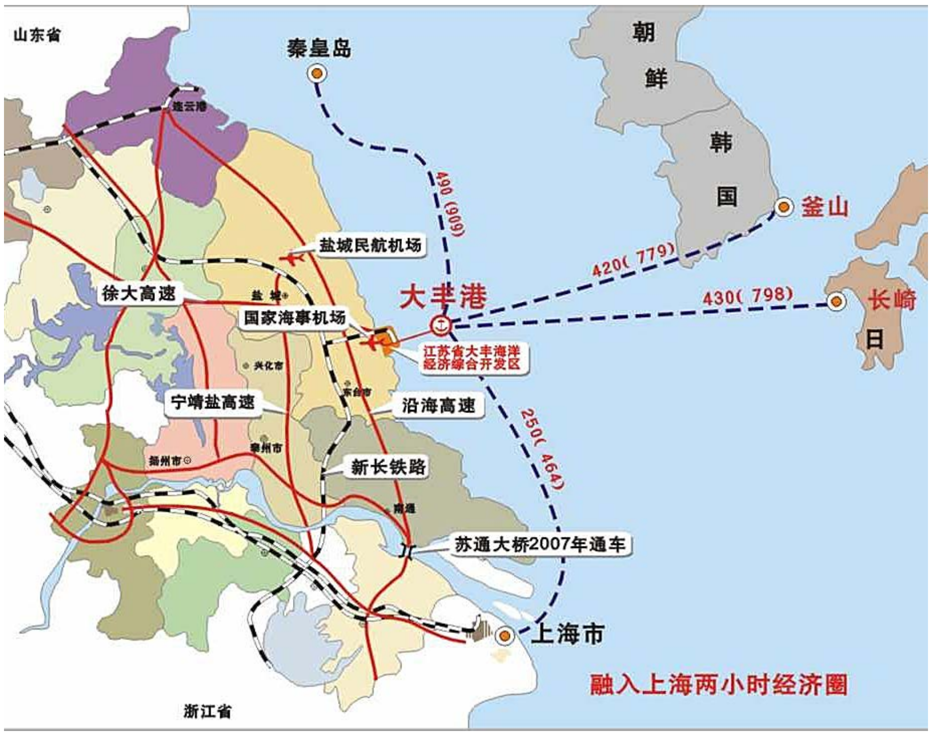

Material test Labs

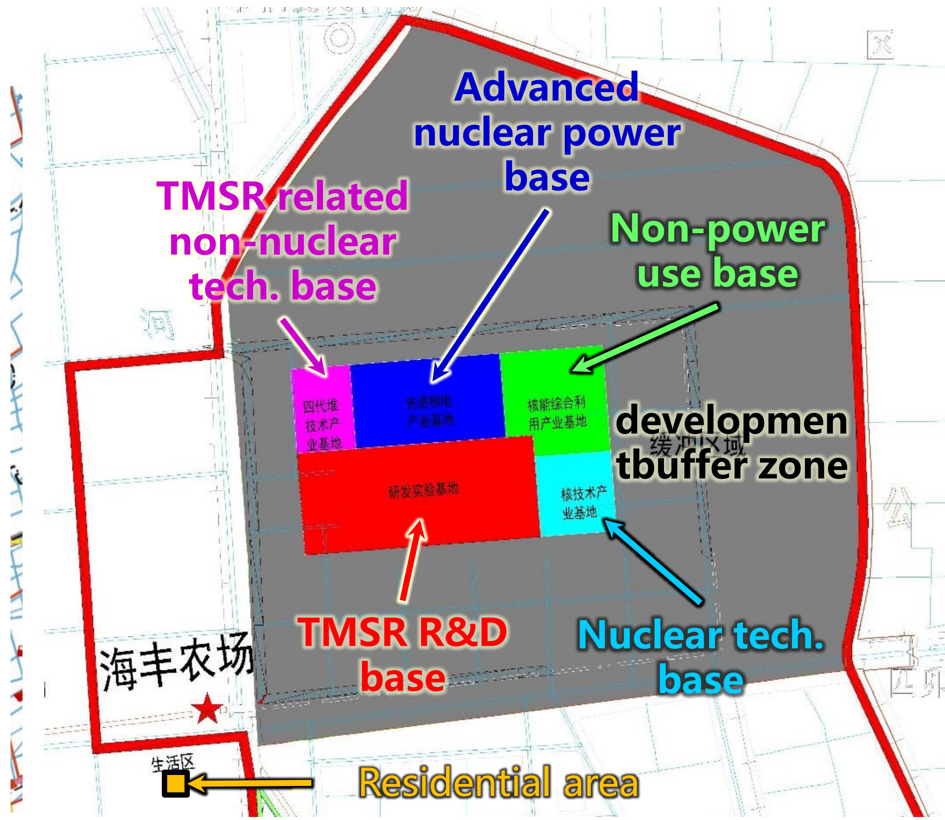

Molten salt measure Labs


β Irradiation Facility

TMSR Reactor Site

Shanghai and Jiangsu support, MEP NNSA agrees in principle





Thank you for your Attention!