# Progress of TMSR in China

**Sept. 27, 2018. Shanghai**

*Hongjie XU*

**TMSR Center of CAS/ SINAP**

# OUTLINE

**MSR & Thorium**

**Progress of TMSR**

**Perspective on TMSR**

# OUTLINE

**MSR & Thorium**

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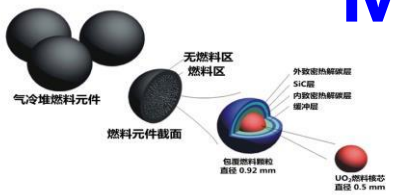
**Perspective on TMSR**

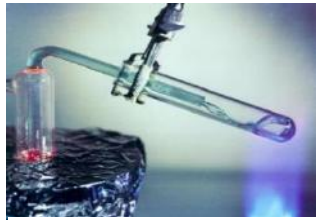
# Overview of the Generation IV Systems

| System | Neutron Spectrum | Fuel Cycle | Size (MWe) | Applications | R&D Needed |
|---|---|---|---|---|---|
| Very-High-Temperature Reactor (VHTR) | Thermal | Open | 250 | Electricity, Hydrogen, Process Heat | Fuels, Materials, $H_2$ production |
| Supercritical-Water Reactor (SCWR) | Thermal, Fast | Open, Closed | 1500 | Electricity | Materials, Thermal-hydraulics |
| Gas-Cooled Fast Reactor (GFR) | Fast | Closed | 200-1200 | Electricity, Hydrogen, Actinide Management | Fuels, Materials, Thermal-hydraulics |
| Lead-Cooled Fast Reactor (LFR) | Fast | Closed | 50-150<br>300-600<br>1200 | Electricity, Hydrogen Production | Fuels, Materials |
| Sodium Cooled Fast Reactor (SFR) | Fast | Closed | 300-1500 | Electricity, Actinide Management | Advanced recycle options, Fuels |
| Molten Salt Reactor (MSR) | Epithermal | Closed | 1000 | Electricity, Hydrogen Production, Actinide Management | Fuel treatment, Materials, Reliability |

# Molten Salt Reactor (MSR)

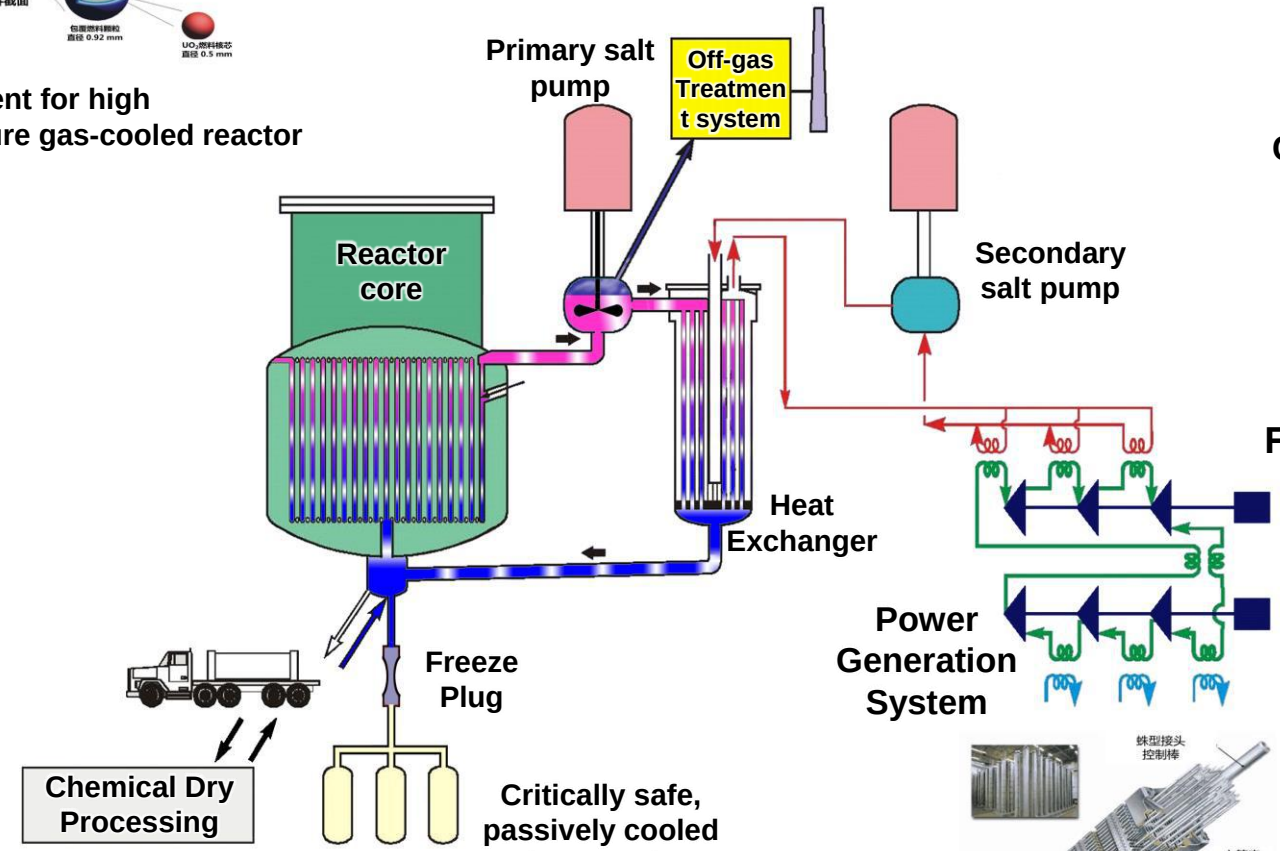


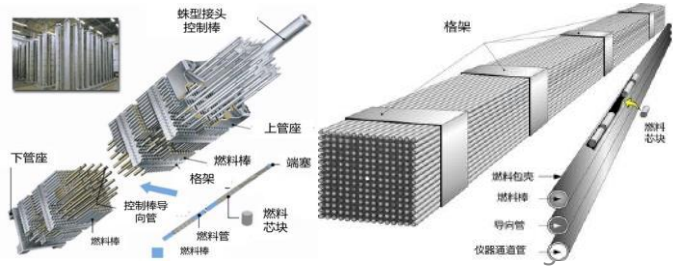

Fuel element for high temperature gas-cooled reactor (HTGR)



Carrier salt: $LiF\text{-}BeF_2$

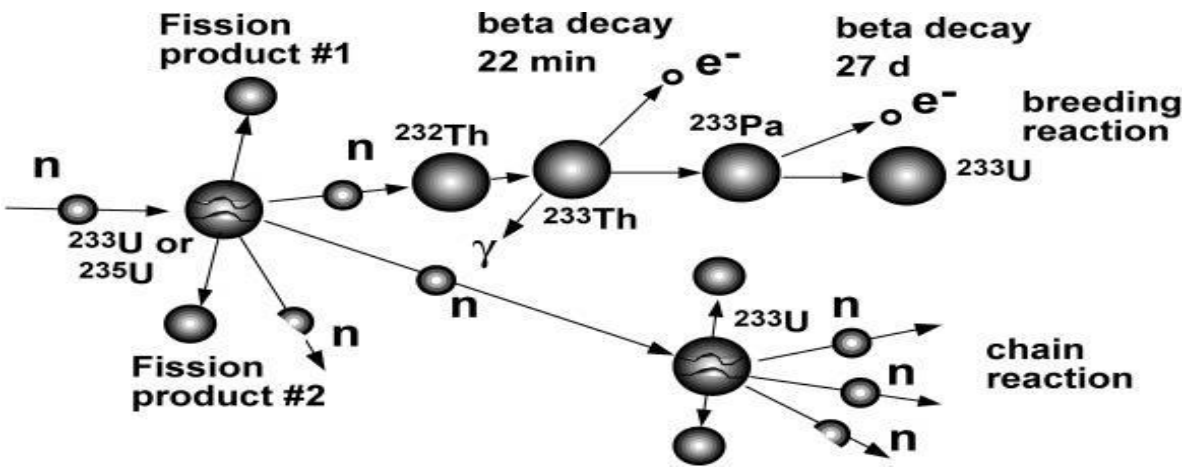
Fuel salt: $LiF\text{-}BeF_2\text{-}UF_4$



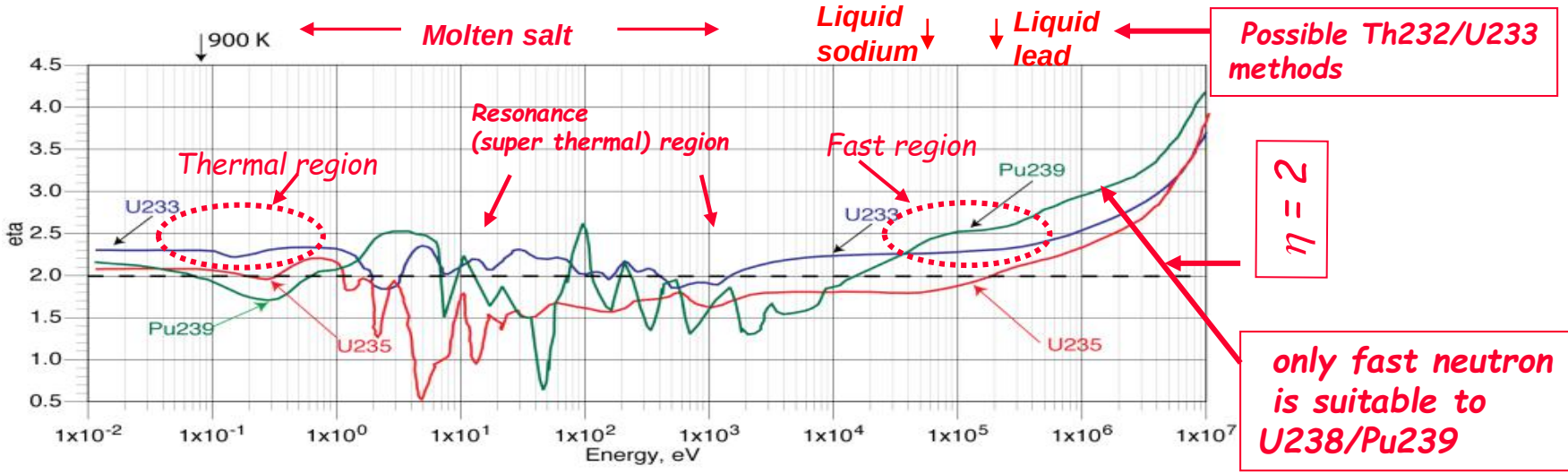

Fuel pin for Pressurized Water Reactor (PWR)

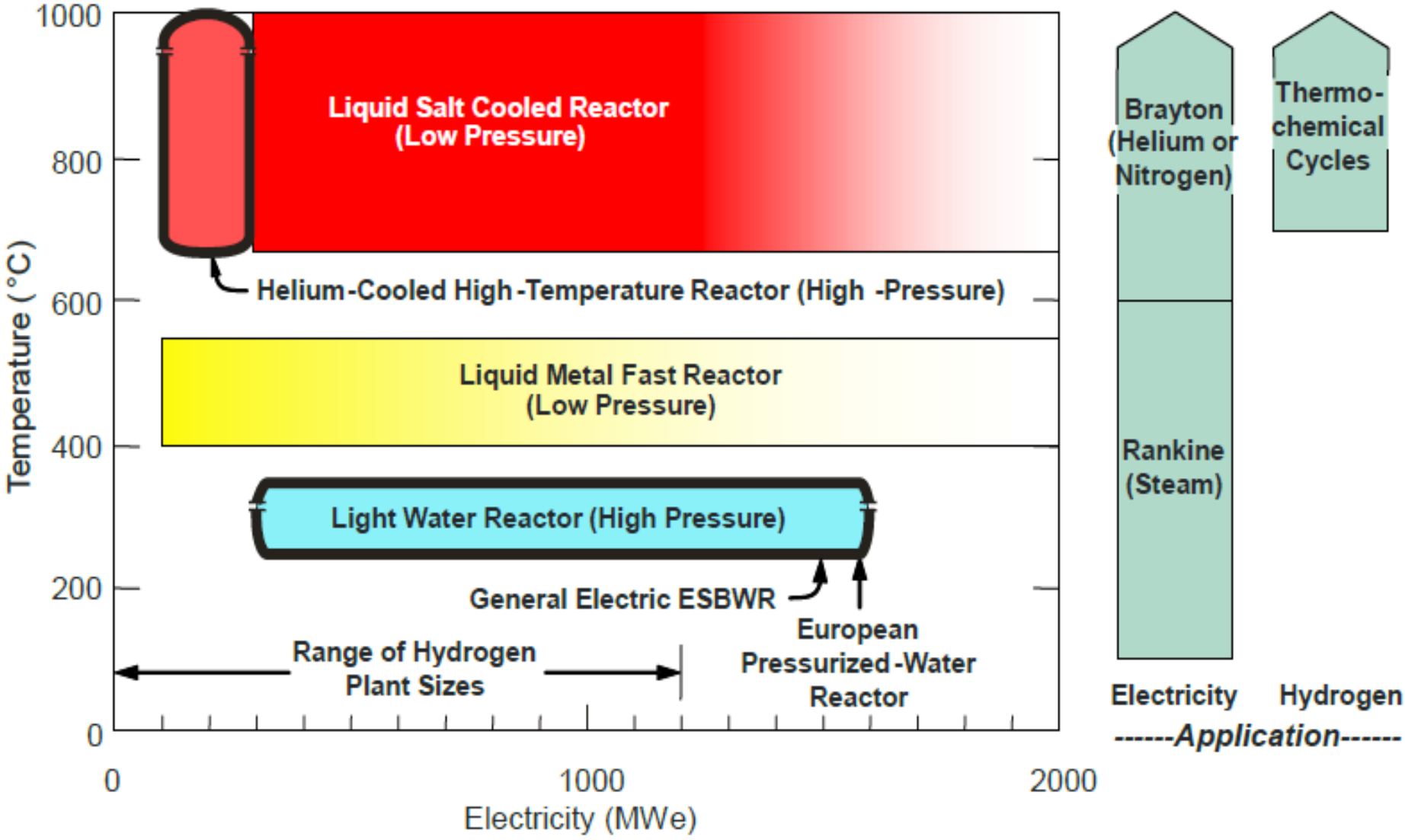
# Th232/U233 and U238/Pu239 fuel cycles




**Mean released neutron number per fission $\eta$**

***$\eta$ = 2 is the required condition for a sustain reactor***




Liquid Salt Cooled Reactor
(Low Pressure)
Helium-Cooled High-Temperature Reactor (High -Pressure)
Liquid Metal Fast Reactor
(Low Pressure)
Light Water Reactor (High Pressure)
General Electric ESBWR
European
Pressurized-Water
Reactor
Range of Hydrogen
Plant Sizes
Temperature (°C)
1000
800
600
400
200
0
0
1000
2000
Electricity (MWe)
Brayton
(Helium or
Nitrogen)
Rankine
(Steam)
Thermo-
chemical
Cycles
Electricity
Hydrogen
------Application------

# OUTLINE

MSR & Thorium

**Progress of TMSR**

Perspective on TMSR

# OUTLINE

What is TMSR

Motivation for TMSR

**Progress of TMSR**

Perspective on TMSR

# TMSR Project (Chinese Academy of Sciences)

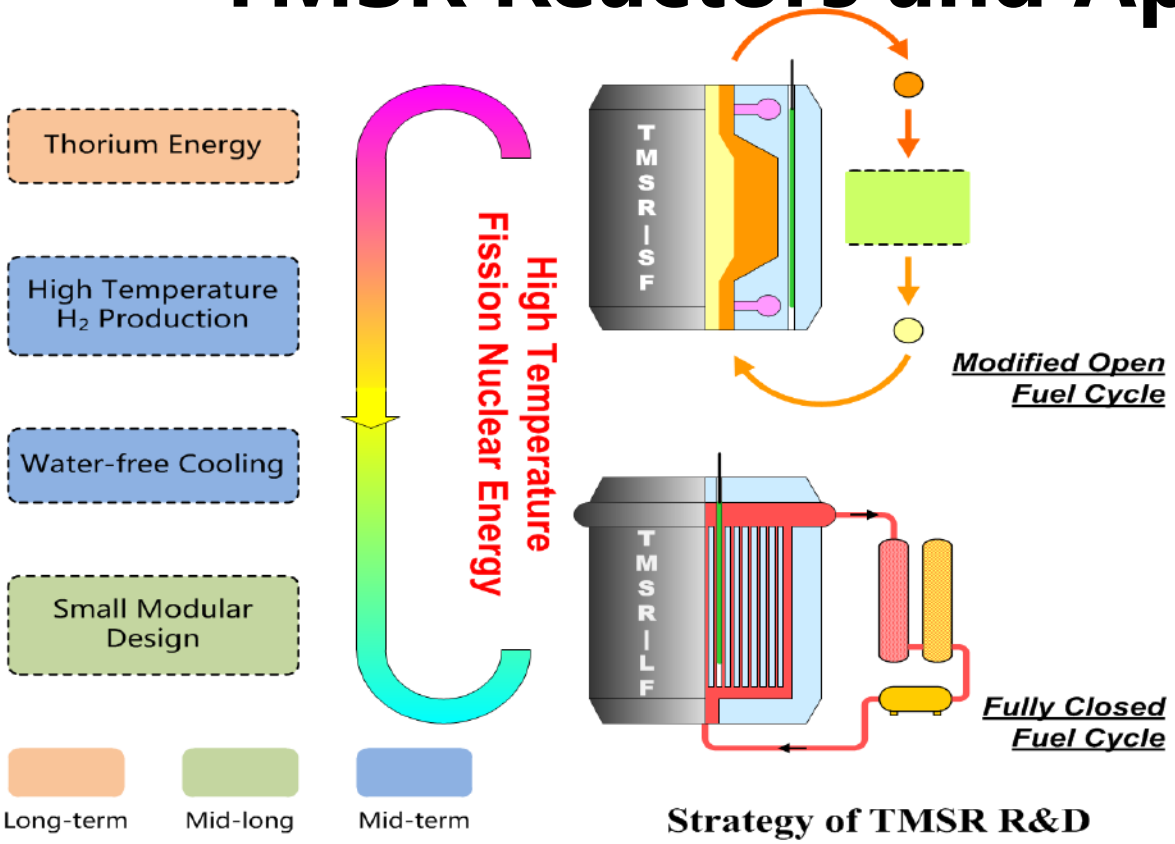
**中文名称：钍基熔盐堆核能系统**

**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.**

# TMSR Reactors and Applications




Strategy of TMSR R&D

**Th Energy:**

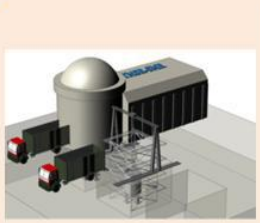
Long-Term Supply of Nuclear Fuel

**MSR:**

Elevated Safety
Efficiency
Nonproliferation

- Optimized for high-temperature based hybrid nuclear energy application.
- Optimized for utilization of Th with Pyroprocessing.

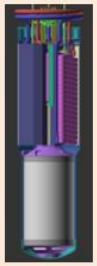
# Roadmap of Technologies R&D

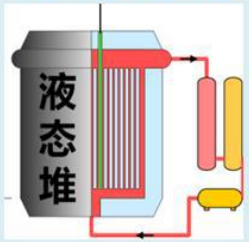


## Small modular MSR

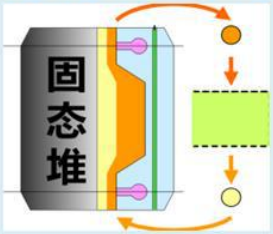
KW-MW

10MW , 100MW






## Experimental MSRs

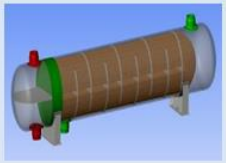



Material science

Chemical science

Reactor component

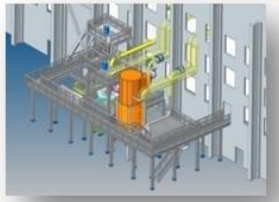
Pump



Heat exchanger

IC

T-H loops



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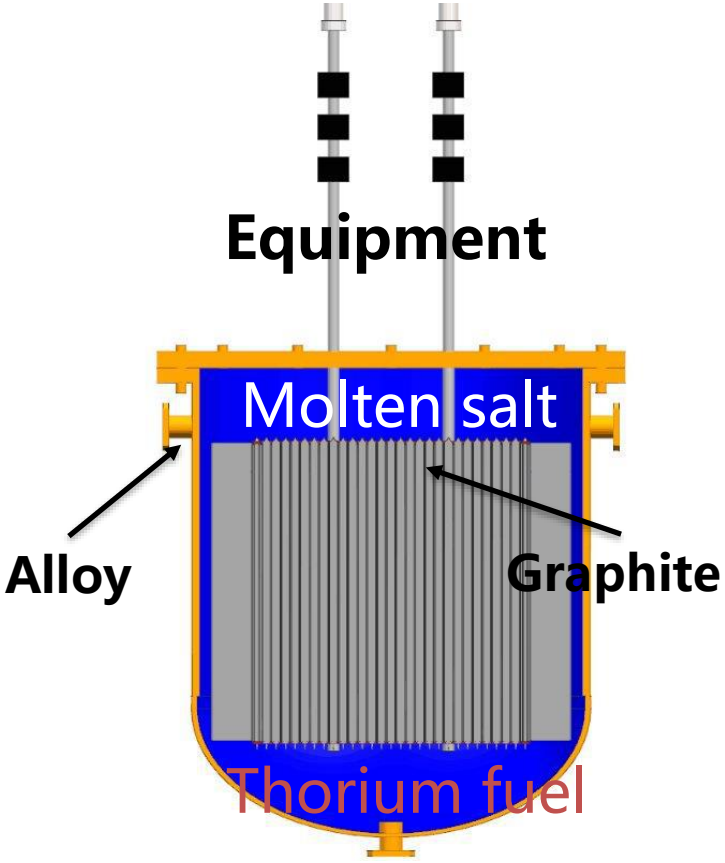
# Key technology of TMSR - Molten salt and thorium fuel related Technologies




Reactor (Operation temperature ≥ 700℃)

## Molten salt

- Synthesis preparation
- Purification
- Material preparation processing
- Corrosion control
- Loop device

## Thorium

- Fuel preparation
- Dry separation offline
- TMSR design and safety
- TMSR Equipment and operation
- Gas separation online

# TMSRs Materials Technology

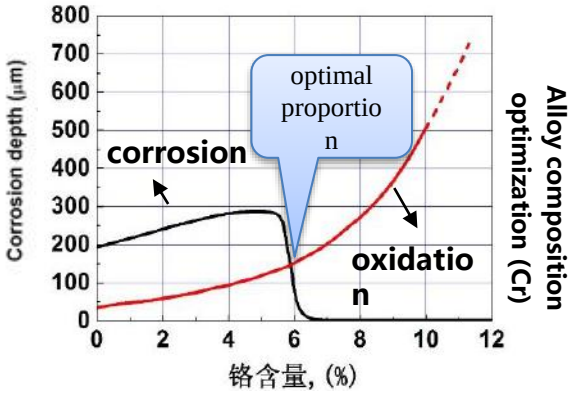
| Material | Domestic original foundation | Domestic level after TMSR program implementation | Major breakthrough (World first class of the same kind) |
|---|---|---|---|
| **Hastelloy N alloy ( Nickel based )** | ➢ Property data is blank<br>➢ 6 tons level of cast ingot (nickel based)<br>➢ Processing technology is blank | ➢ The properties meet the service requirement of Molten Salt Reactor<br>➢ The specification meets the size requirement<br>➢ The technology meets the construction requirements | ➢ High temperature performance test accumulates to 300,000 hours<br>➢ 12 ton level of ingot casting， 8 tons level of wide sheet ， Large size seamless tube<br>➢ Main vessel near molding technology，welding technology |
| **Stainless Steel** | ➢ Mature technology in conventional field<br>➢ Not resistant to high temperature molten salt corrosion<br>➢ No application experience for MSR | ➢ Solved molten salt corrosion problem<br>➢ Reduced cost based on safety | ➢ Bimetal composite board technology<br>➢ Overlaying technology for Main vessel<br>➢ Welding technology for composite board |
| **Nuclear graphite** | ➢ No specialized graphite for molten salt reactor<br>➢ Processing /properties are blank | ➢ The properties meet the service requirement of Molten Salt Reactor<br>➢ The specifications and dimensions meet the requirements of the internal components<br>➢ The first nuclear grade graphite for molten salt reactor | ➢ Anti-melting salt infiltrated fine granular graphite<br>➢ Key data of high temperature molten salt compatibility<br>➢ Large scale up to 350×600×1400 mm |
| **Molten salt** | ➢ Nitrate salt 560℃<br>➢ Fluoride salt/chloride salt technology is blank | ➢ Fluoride salt/chloride salt 700℃<br>➢ The properties meet the service requirement of Molten Salt Reactor<br>➢ The impurity content of molten salt is less than the design requirement<br>➢ Provide products for international peers | ➢ High purity molten salt preparation technology<br>➢ High purity molten salt corrosion control technology<br>➢ International largest scale reactor fluoride salt production equipment<br>➢ Production capacity of fluoride salt reaches 10 tons per year |

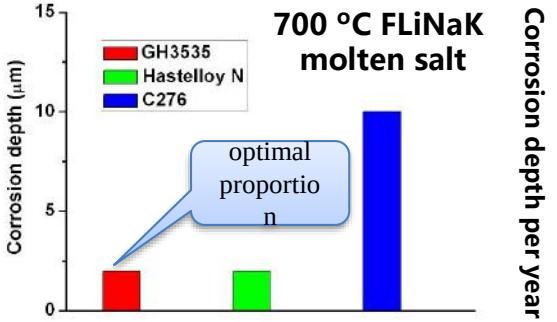
# Molten salt corrosion control technology

**□ Developed an Integrated molten salt corrosion control technology including alloy composition optimization, surface treatment, molten salt purification and potential-modulated.**

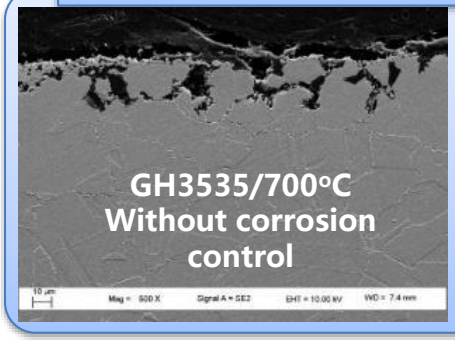
**□ Solved the strong corrosive problem of molten salt in application of MSR , thermal and energy storage.**

- Design optimization：Optimized alloy composition, Reduced Cr diffusion
- Surface treatment：FTD surface modification，Improve corrosion resistance
- Molten salt purification：Preparation of high purity fluorine salt, impurity content control
- Potential-modulated：Add inhibiting elements, Electrochemical control of corrosion



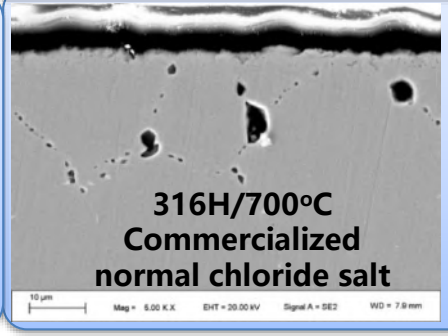



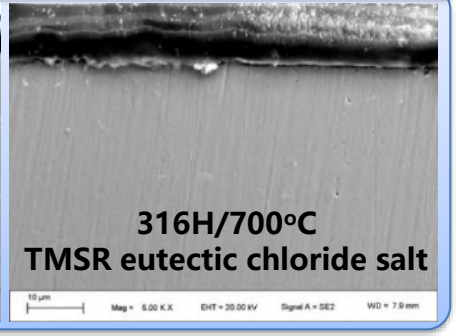

**Fluoride corrosion control in molten salt reactor**





**Chloride corrosion control in thermal and energy storage**

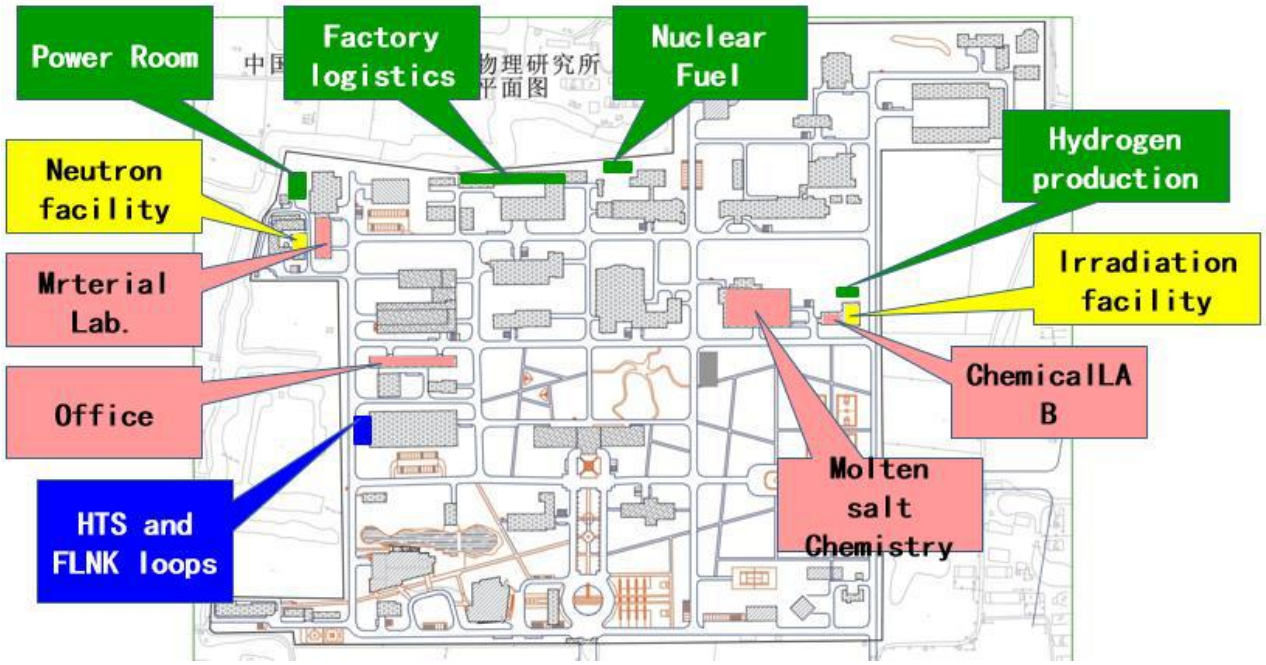


# Key Equipments for TMSR

| Equipment | | Application | Domestic original foundation | TMSR researched progress and results |
|---|---|---|---|---|
| Special and key equipments for MSR | High temperature molten-salt pump | Driving Molten Salt flow at high temperature | Chemical molten-salt pump (< 500 ºC) | ● Finished the development of molten-salt pump (10 $m^3$/h, 650 ºC)<br>● Finished the design of reactor pump (300 $m^3$/h, 700 ºC), being processed<br>● The engineering sample pump test bench is being built |
| | Molten salt heat exchangers | Heat Transfer | No | ● Finished a series of molten salt air heat exchangers for experimental circuits<br>● Finished the design of molten salt molten salt heat exchanger for simulation reactor, being processed |
| | Molten salt valve | Safety protection Flow regulation | No | ● Finished molten salt refrigeration valve for experimental circuit<br>● Built cryogenic valve experimental platform<br>● Finished designs of the mechanical molten salt valve for the simulation reactor |
| | Storage tank, vessels | Reactor vessels etc. | Low temperature molten salt | ● Mastered the design and processing technology and built a 1$m^3$ storage tank<br>● Designed main vessel (700 ºC, 4m) of simulation reactor is being processed |
| | Helium turbine | Power generation | No | ● SARI-CAS built a comprehensive test device for MW helium gas turbines for MSR |
| Molten salt instruments | Molten salt flowmeter | Molten salt flow measurement | < 400 ºC | ● Successfully developed an ultrasonic flowmeter with a working temperature of up to 700 ˚C, a high temperature molten salt flowmeter calibration platform has been built<br>● Used in molten salt loop and simulation reactor at 650 ºC high temperature |
| | Molten salt manometer | Molten salt pressure measurement | No | ● The prototype of the Na-K type molten salt pressures to gauge is successfully developed, and its accuracy can reach 200 Pa at 650 ˚C |

# Fundamental Research Base at Jiading




Super Computer

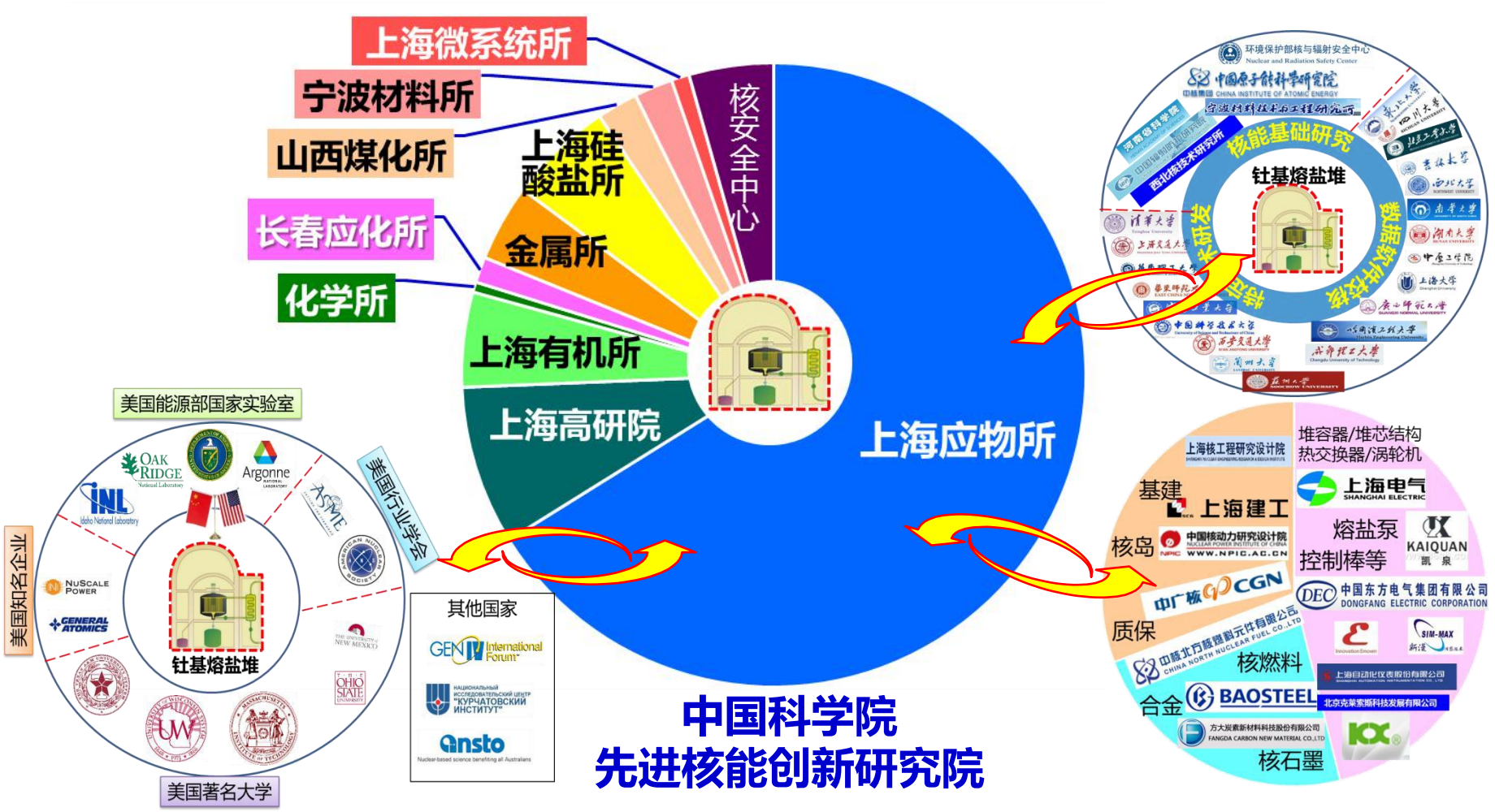
Hot Cells

Material Testing Labs

Salt Properties Labs

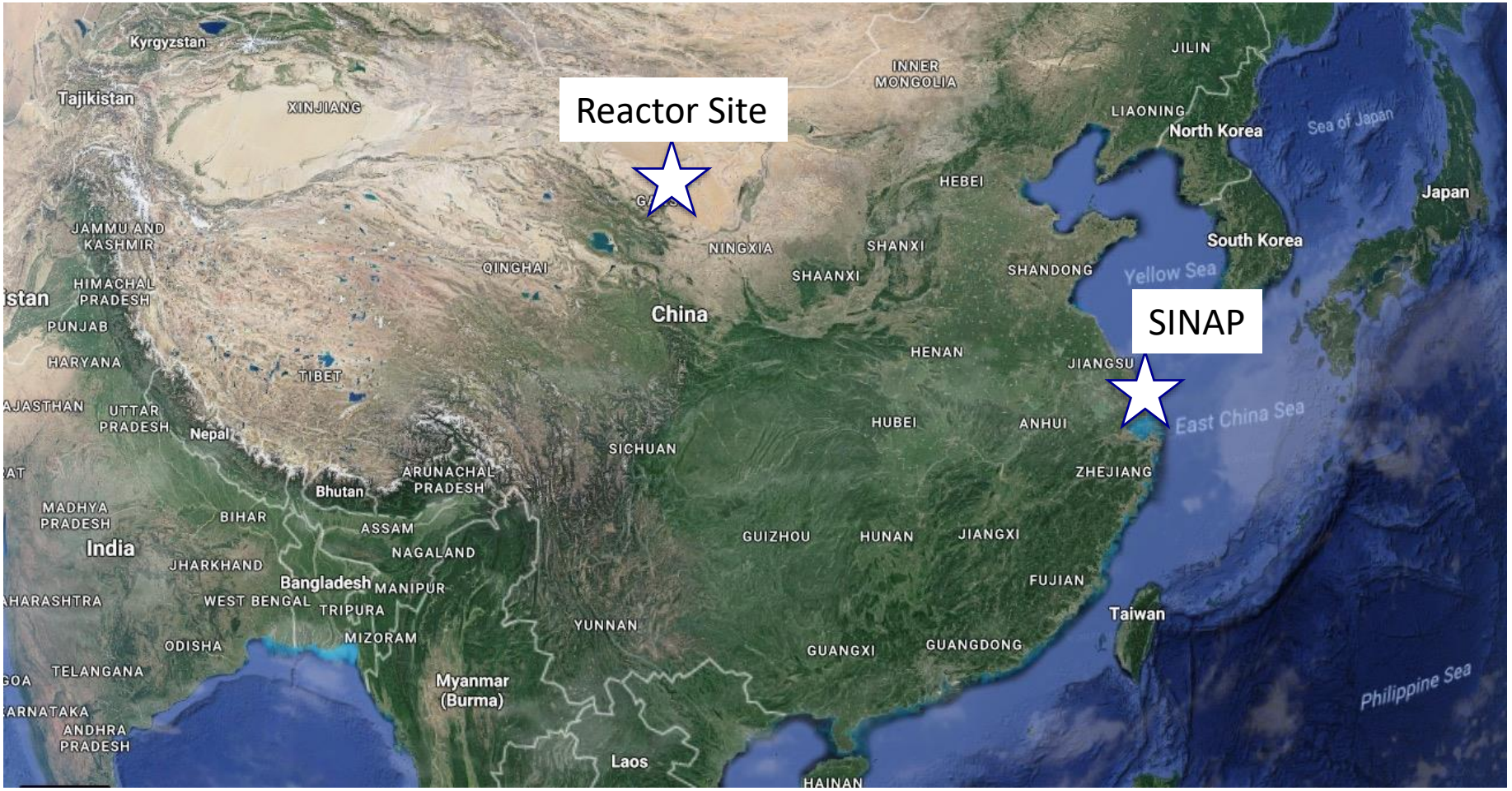
β Irradiation Facility

# International and Domestic Collaborations



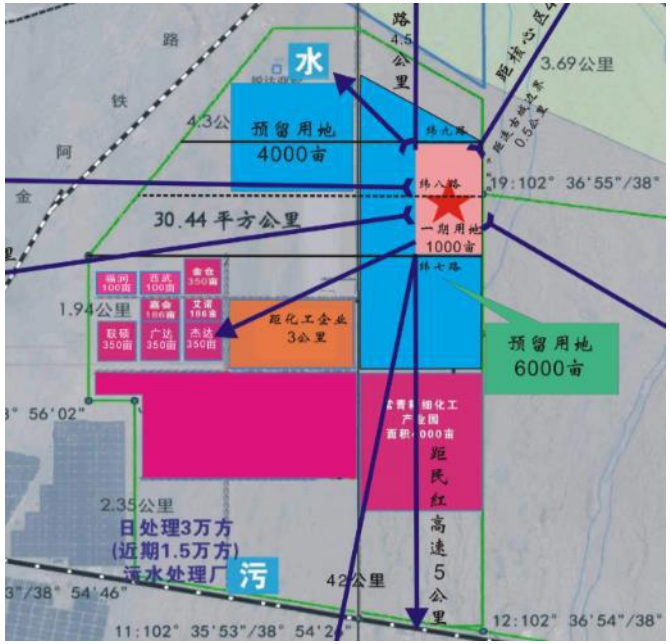

**TEAMS:** Staffs ~600; Graduate students ~200

# New Candidate Site of TMSR test reactor




- 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.

# Survey of the Candidate Site




- Onsite survey completed in August
- Application for the site permit to be submitted to government this year.

WORLD NUCLEAR ASSOCIATION

Home / Information Library / Current and Future Generation / Molten Salt Reactors

# Molten Salt Reactors

*(Updated July 2018)*

- Molten salt reactors operated in the 1960s.
- They are seen as a promising technology today principally as a thorium fuel cycle prospect or for using spent LWR fuel.
- A variety of designs is being developed, some as fast neutron types.
- Global research is currently led by China.
- Some have solid fuel similar to HTR fuel, others have fuel dissolved in the molten salt coolant.

http://www.world-nuclear.org/information-library/current-and-future-generation/molten-salt-reactors.aspx

# ANES have Great Potential for Development in China

MIT Technology Review

The dream of American scientists at Oak Ridge, a half-century ago, is taking shape here， thousands of miles away.

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**Energy**

## Fail-Safe Nuclear Power

Cheaper and cleaner nuclear plants could finally become reality—but not in the United States, where the technology was invented more than 50 years ago.

by Richard Martin August 2, 2016

# OUTLINE

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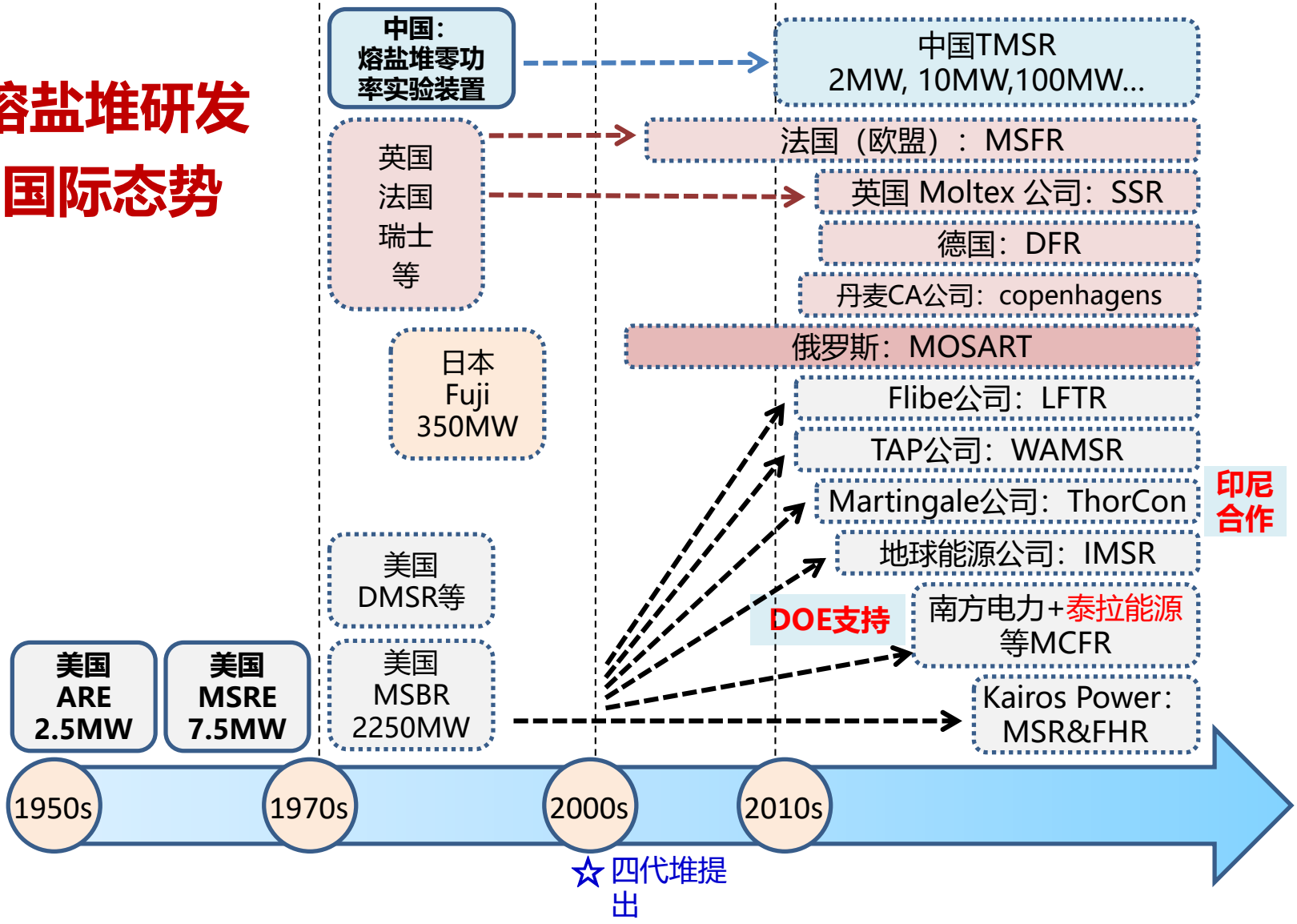
**Perspective on TMSR**

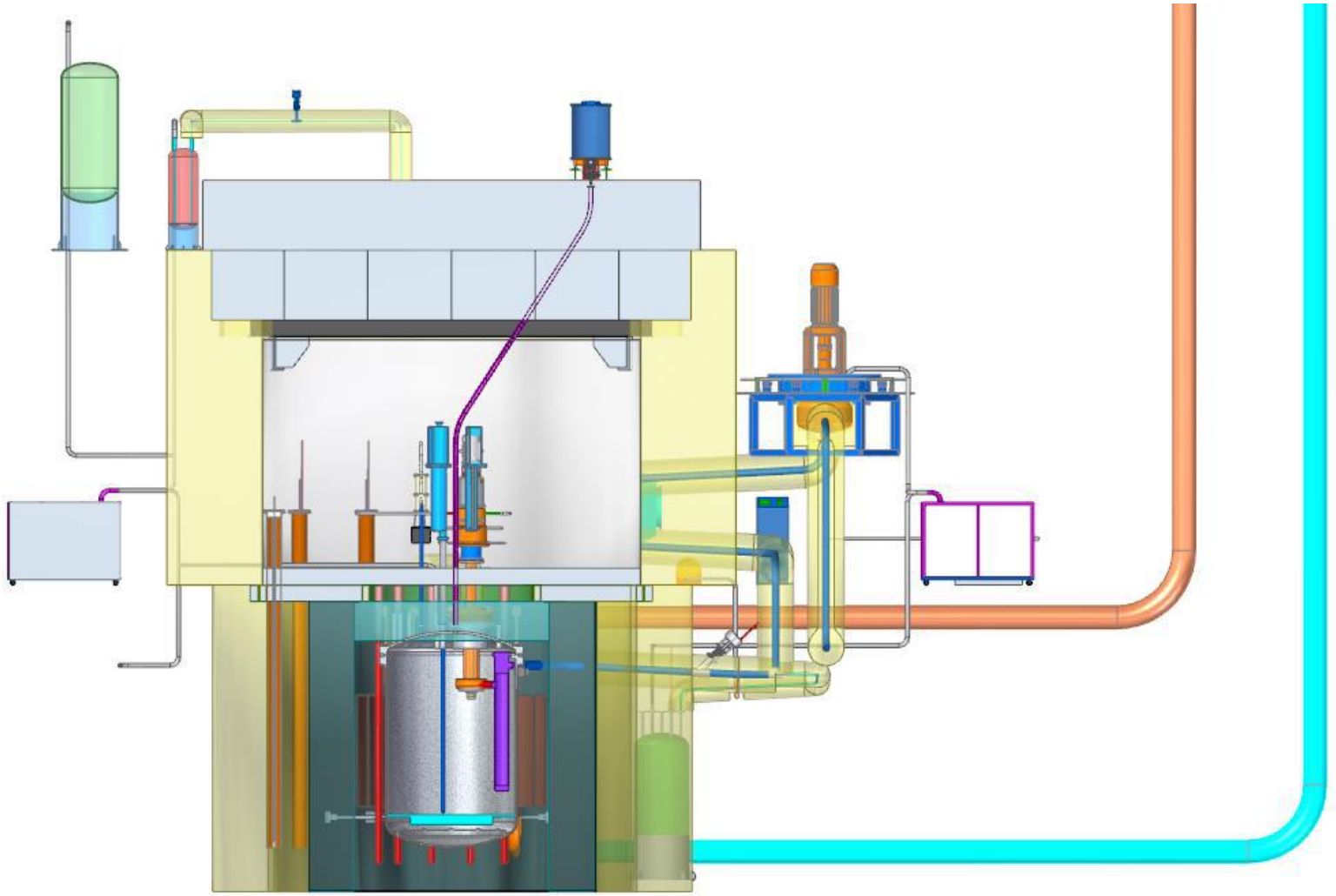
# 熔盐堆研发国际态势


中国：
熔盐堆零功率实验装置
中国TMSR
2MW, 10MW,100MW...
英国
法国
瑞士
等
法国（欧盟）：MSFR
英国 Moltex 公司：SSR
德国：DFR
丹麦CA公司：copenhagens
俄罗斯：MOSART
日本
Fuji
350MW
Flibe公司：LFTR
TAP公司：WAMSR
Martingale公司：ThorCon
印尼合作
地球能源公司：IMSR
美国
DMSR等
DOE支持
南方电力+泰拉能源等MCFR
美国
ARE
2.5MW
美国
MSRE
7.5MW
美国
MSBR
2250MW
Kairos Power：
MSR&FHR
1950s
1970s
2000s
2010s
☆四代堆提出

# Chinese Proposal for TMSR Roadmap

- Base on the technologies have had in Lab-scale during last a few years.,TMSR team propose the roadmap as following:
- To complete the construction of test reactor TMSR-LF1 by 2020
- To complete the construction of TMSR-LF-150 demo-facility by 2030.
- To complete the construct of TMSR fuel salt batch pyro-process demo-facility , and to realize Th-U Fuel Cycle usage by the early 2040s.

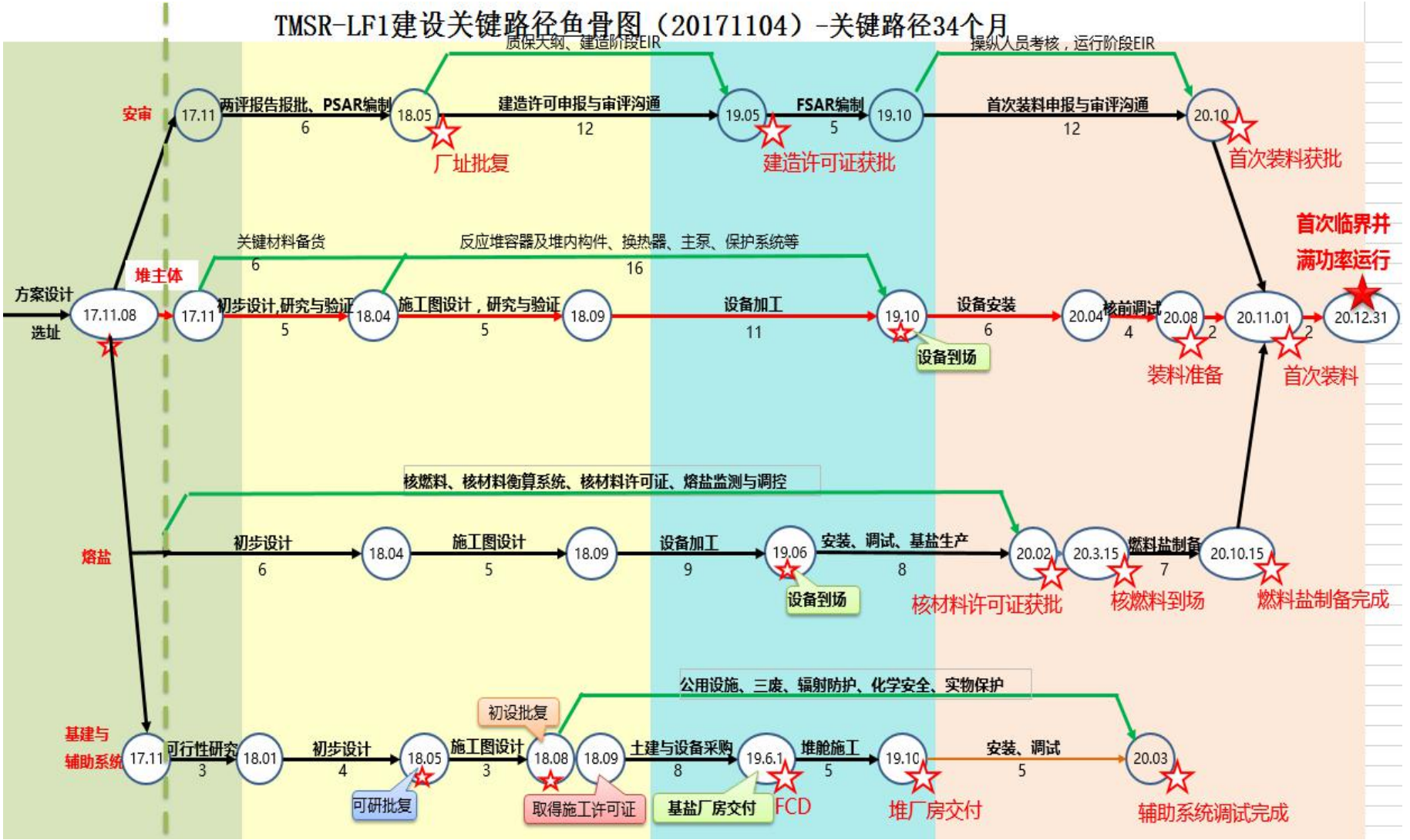
# 3D Graph of Engineering Design



# Main Parameters

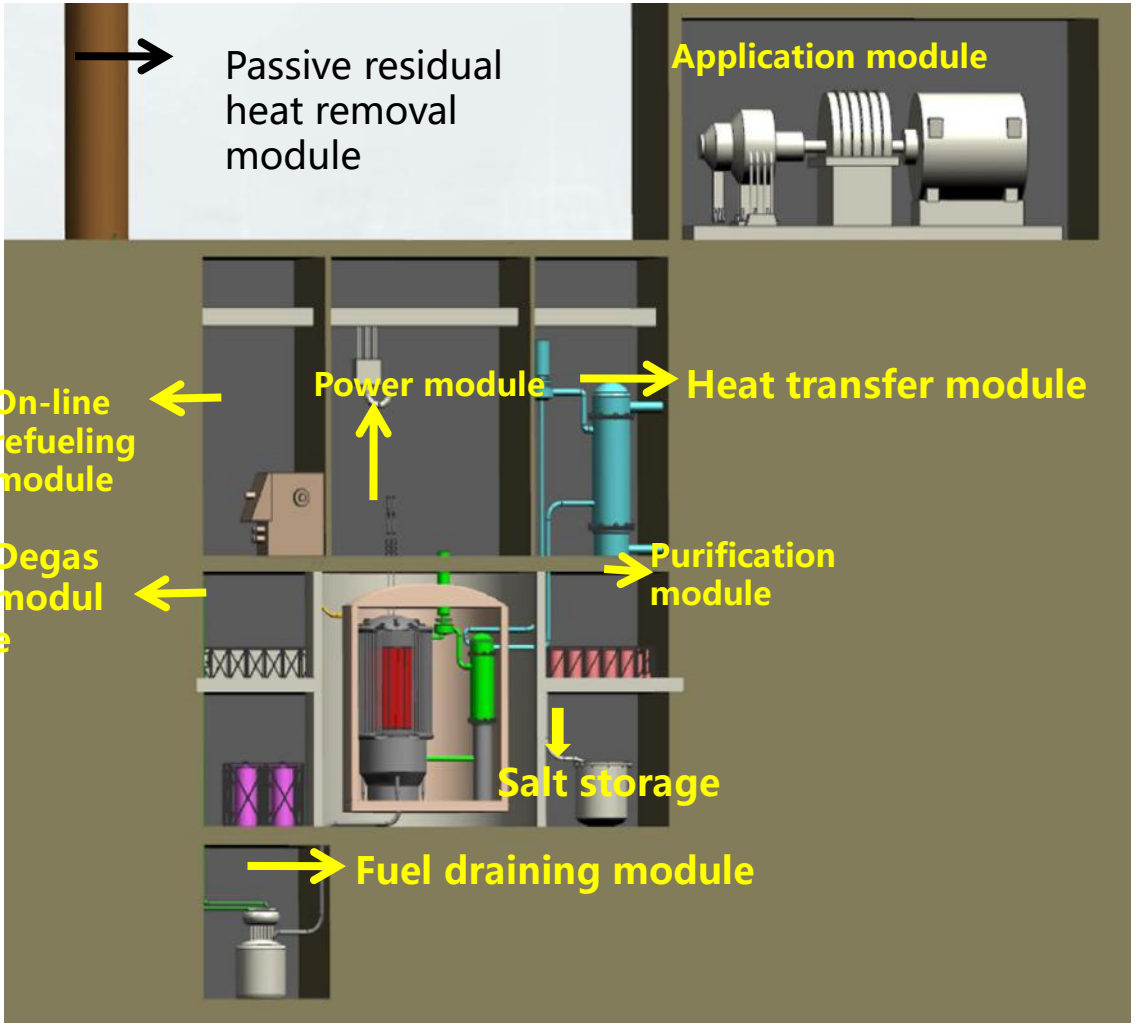
| | |
|---|---|
| Reator type | Liquid-fueled molten salt reactor |
| Power | 2 MW |
| Life | 10 years |
| EFPD | 300 days |
| Max EFPD / year | 60 days |
| Inlet/outlet Temperature (fuel salt loop) | 630℃ / 650℃ |
| Inlet/outlet Temperature (coolant salt loop) | 560℃ / 580℃ |
| Fuel salt | $LiF\text{-}BeF_2\text{-}ZrF_4\text{-}UF_4$ ($+ThF_4$) |
| U-235 Enrichment | 19.75wt% |
| Coolant salt | $LiF\text{-}BeF_2$ |

| | |
|---|---|
| Fuel Loading / discharging | Ar gas + capsule |
| Reactivity Control | Control rods |
| Mass flow rate (fuel salt) | ~50 kg/s |
| Mass flow rate (coolant salt) | ~42 kg/s |
| Residual heat removal | 1. Loop<br>2. Air natural circulation Passive residual heat removal system |
| Alloy | UNS N1003 |
| Graphite | Superfine particle graphite |
| Cover gas | Argon, 0.05 MPa |


TMSR-LF1建设关键路径鱼骨图（20171104）-关键路径34个月
质保大纲、建造阶段EIR
操纵人员考核，运行阶段EIR
安审
17.11
两评报告报批、PSAR编制
6
18.05
建造许可申报与审评沟通
12
19.05
FSAR编制
5
19.10
首次装料申报与审评沟通
12
20.10
厂址批复
建造许可证获批
首次装料获批
首次临界并
满功率运行
堆主体
关键材料备货
6
反应堆容器及堆内构件、换热器、主泵、保护系统等
16
方案设计
选址
17.11.08
17.11
初步设计,研究与验证
5
18.04
施工图设计，研究与验证
5
18.09
设备加工
11
19.10
设备安装
6
20.04
核前调试
4
20.08
2
20.11.01
2
20.12.31
设备到场
装料准备
首次装料
核燃料、核材料衡算系统、核材料许可证、熔盐监测与调控
熔盐
初步设计
6
18.04
施工图设计
5
18.09
设备加工
9
19.06
安装、调试、基盐生产
8
20.02
20.3.15
燃料盐制备
7
20.10.15
设备到场
核材料许可证获批
核燃料到场
燃料盐制备完成
公用设施、三废、辐射防护、化学安全、实物保护
初设批复
基建与
辅助系统
17.11
可行性研究
3
18.01
初步设计
4
18.05
施工图设计
3
18.08
18.09
土建与设备采购
8
19.6.1
堆舱施工
5
19.10
安装、调试
5
20.03
可研批复
取得施工许可证
基盐厂房交付
FCD
堆厂房交付
辅助系统调试完成

# TMSR-LF150

## TMSR-LF Small Modular Demo-Reactor

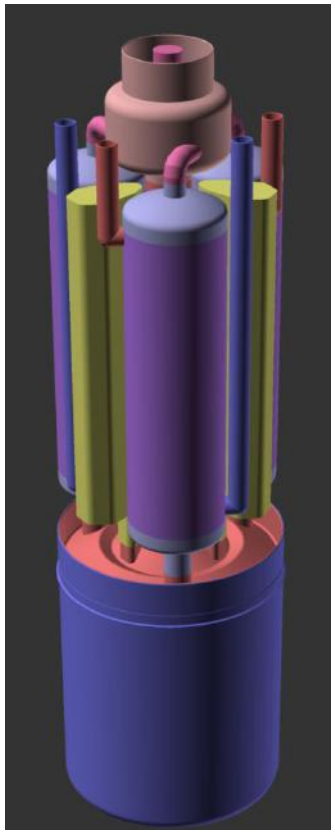


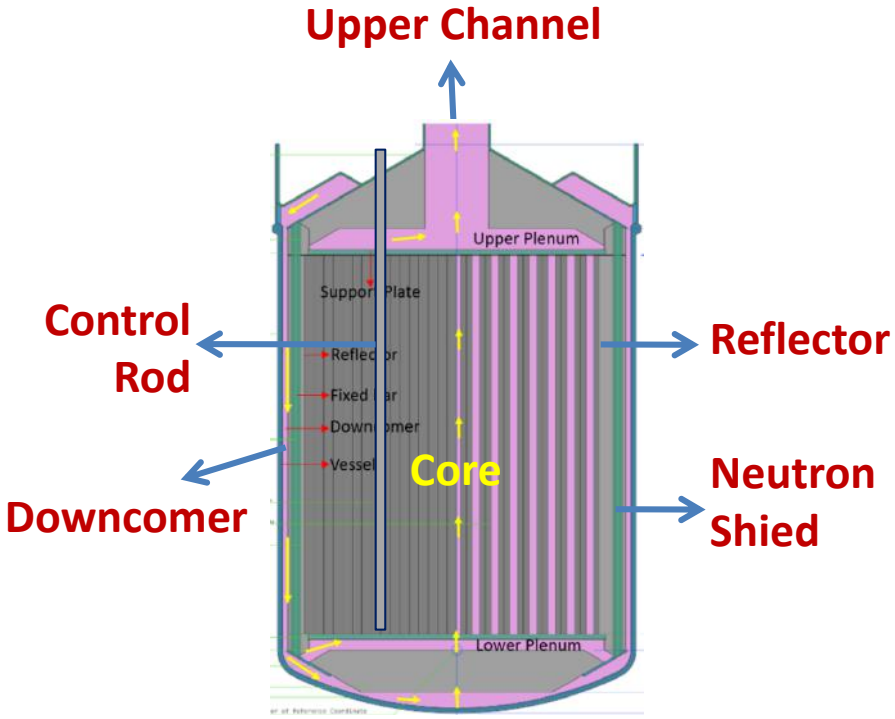

- **Key modules**: power、heat transfer、fueling draining、Passive residual heat removal on-line refueling
- **Application modules:** generator、hydrogen production、Changed、etc. (Changed with goals)

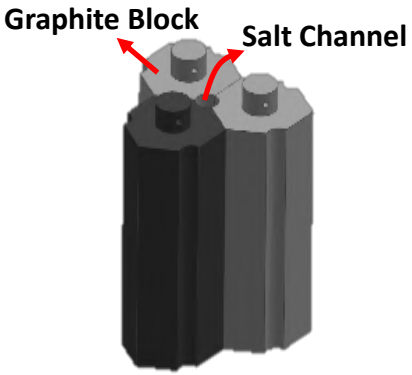
| | |
|---|---|
| **Power** | 150MWt |
| **Temperature** | 600 ℃ / 700 ℃ |
| **Efficiency** | 40%-50% |
| **Th power** | >=20% |
| **Main vessel** | 5.2m×6.0m (D×H) |
| **Safety** | Passive residual heat removal system |
| **Economics** | Cheaper than coal |

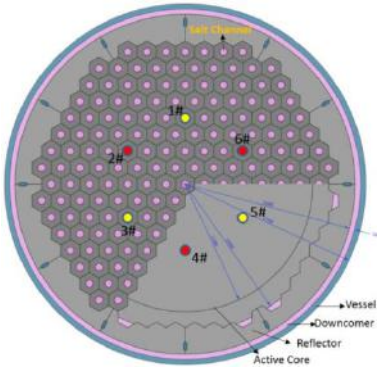
# Core design

- **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.





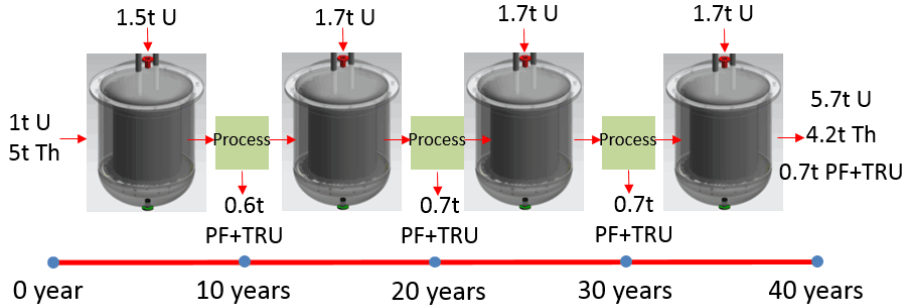



# Fuel cycle

- Baseline fuel cycle type: Th+U
- Keep option for various application (*liquid fuel is more easy restructuring*): U, TRU, TRU+Th, ect.
- Batched reprocessing (off-line): easily deployment at present, benefit for burnup and temperature reactivity coefficient, etc.

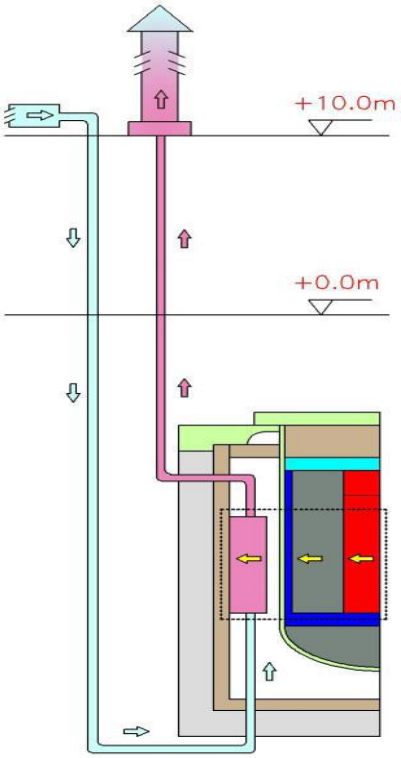
**Th+U**：19.75% U-235，equivalent burnup is about 280 MWd/kgU




| Fuel type | Features |
|---|---|
| Th+U | Th application<br>High equivalent burnup |
| U | High temperature heat application |
| TRU | Burn TRUs |
| TRU+Th | Burn TRUs<br>+ produce U233 |

# Passive Residual Heat Removal System

- **Assure safety as final heat sink in accidents**
- Passive : heat radiation, heat conduction, natural circulation Will be verified on TMSR-LF1. RCCS system is also used in HTR

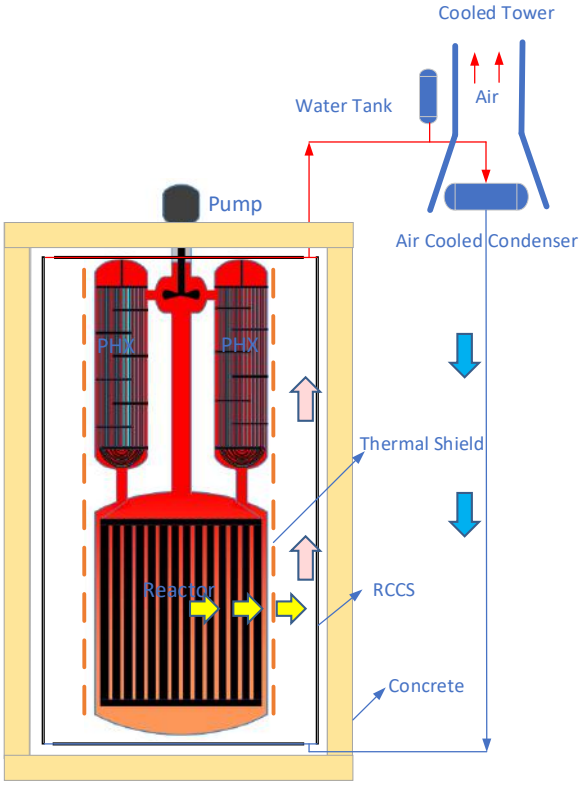



TMSR-LF1

**Unlimited time heat removal**

**High realiable passive system**

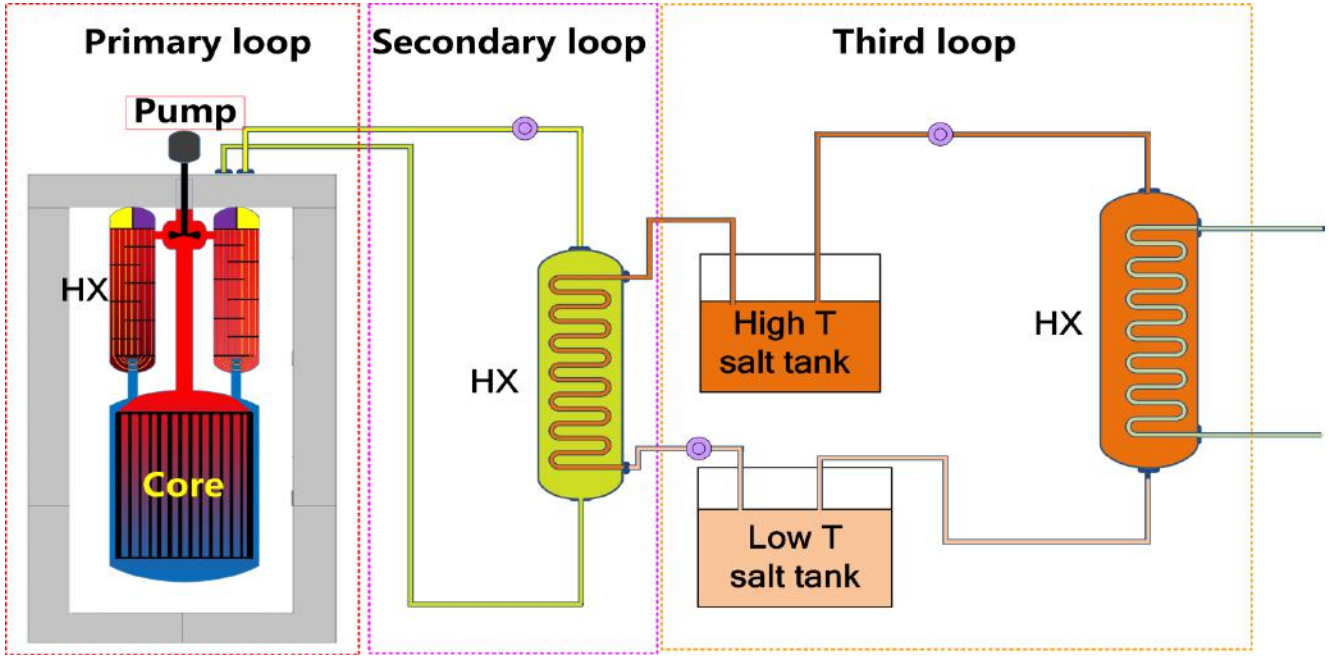
**Water layer also as shieding layer**




TMSR-LF150

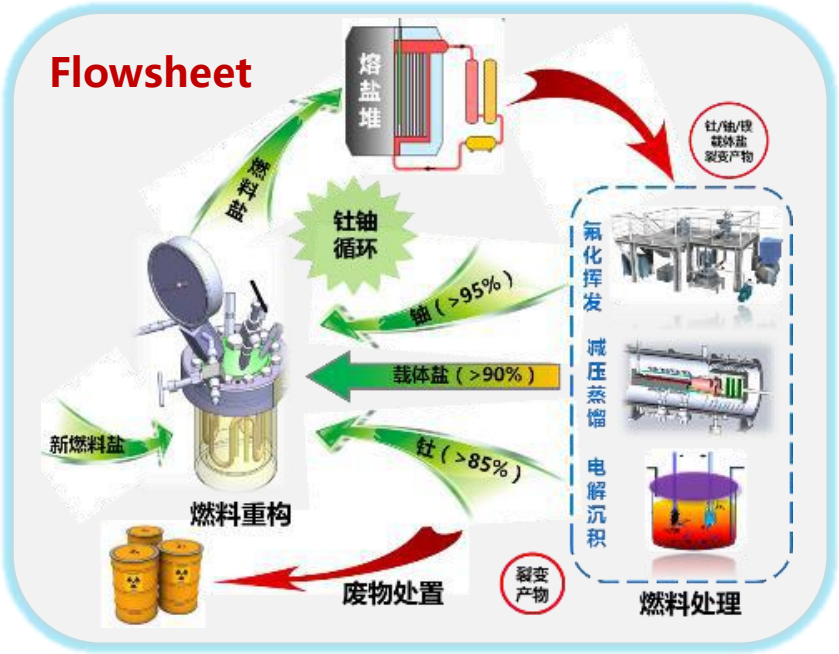
# Heat transfer and storage

- Primary loop is fuel salt loop with one pump and three HX. Well contained.
- Secondary loop is a radioactivity separated loop.
- Heat storage system with chorlide salt (or nitrates) is used to improve load factor and actual max deliver power: MSR can operate at full power in full-time, and heat storage system can deliver variable power following demand of net, wind energy and solar energy.



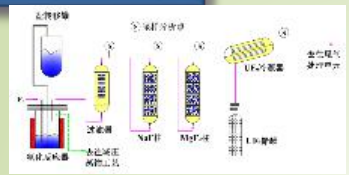
# Facility for dry process of Th-U fuel cycle

| | |
|---|---|
| Goal | Large scale Th utilization |
| Technologies | Fluorination, Electroysis, Distillation |
| Capability | 5m3/batch， 20m3/year |
| Efficiency | U>95%; Th>85% |
| Waste | 10 times lower than current technologies |




**U seperation**

Fluorination



产品收率95~99%
总β和γ去污系数$10^7$

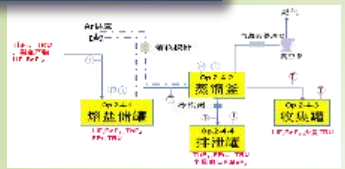
**Th seperation**

Electroysis

产品收率85~90%
总β和γ去污系数$10^2$

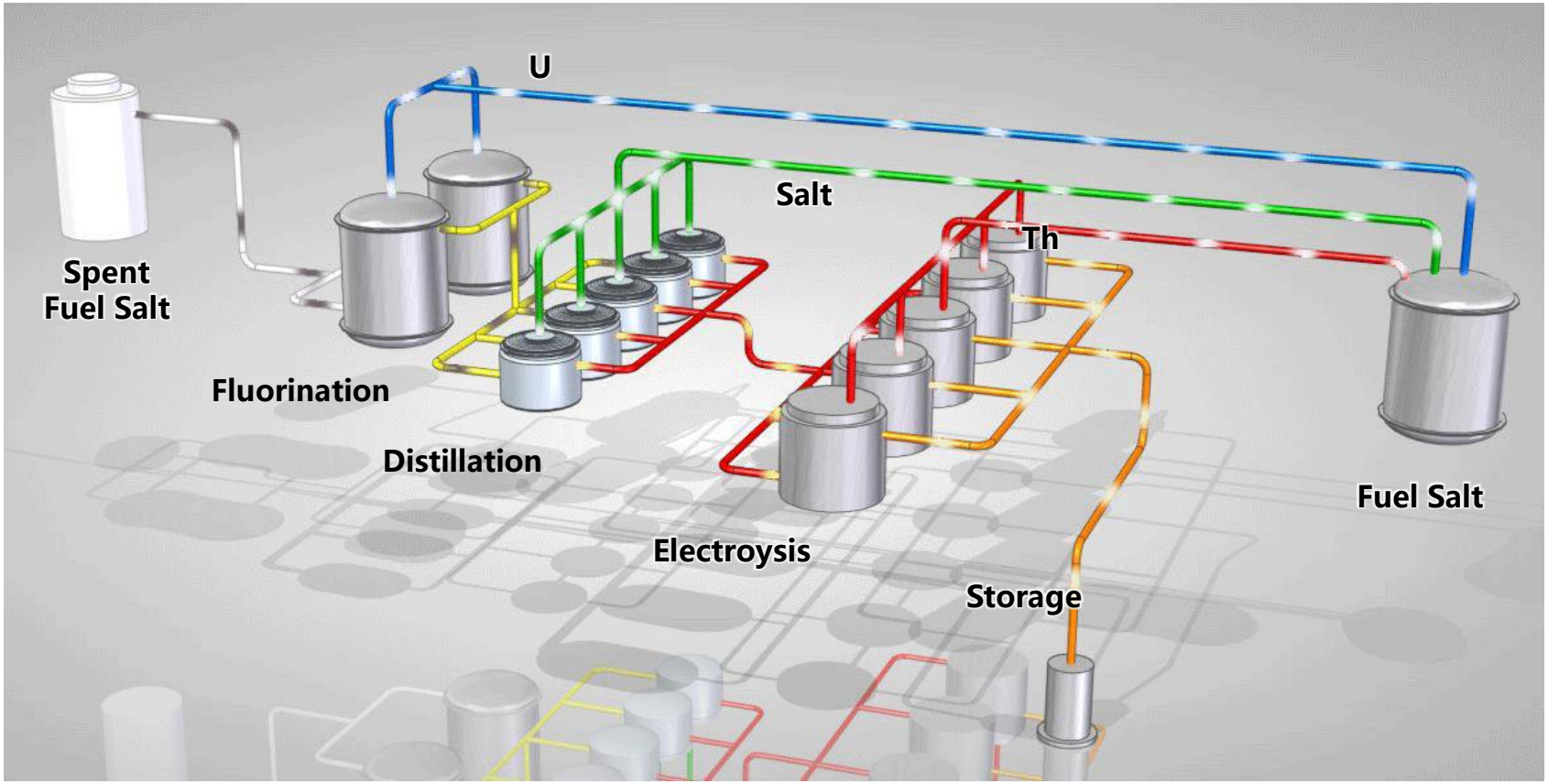
**Salt seperation**

Distillation



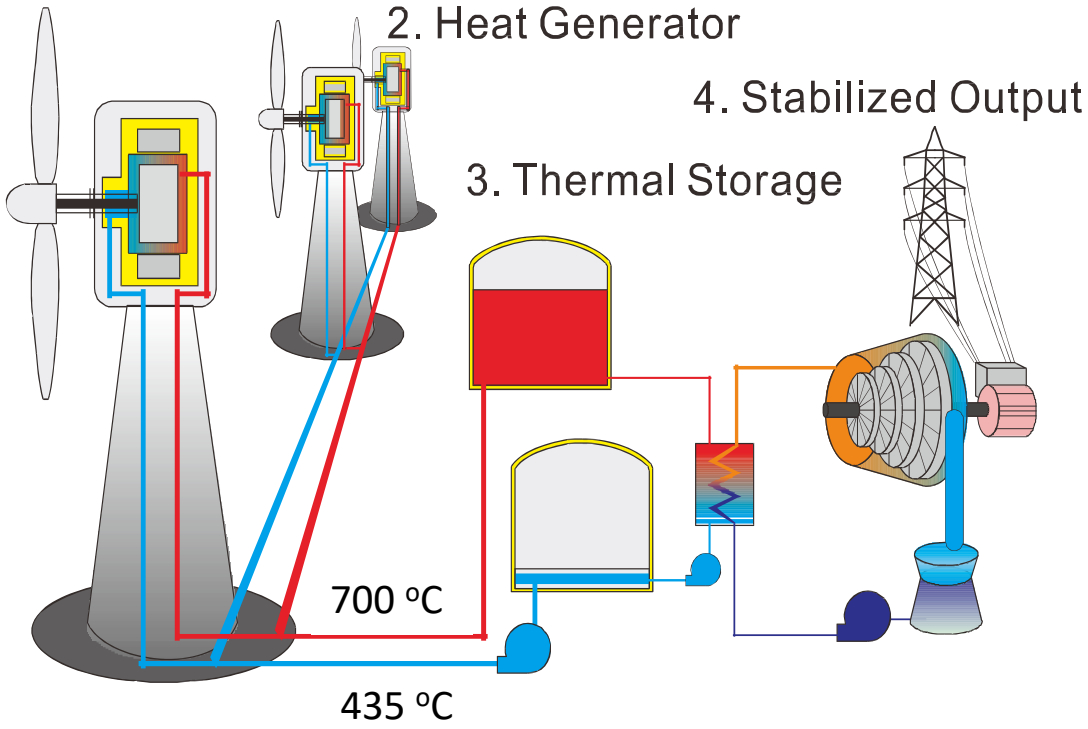
产品收率90~95%
总β和γ去污系数$10^4$

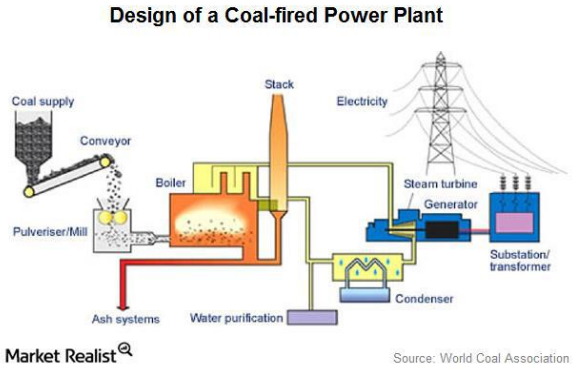
# Batch pyroprocess Facility

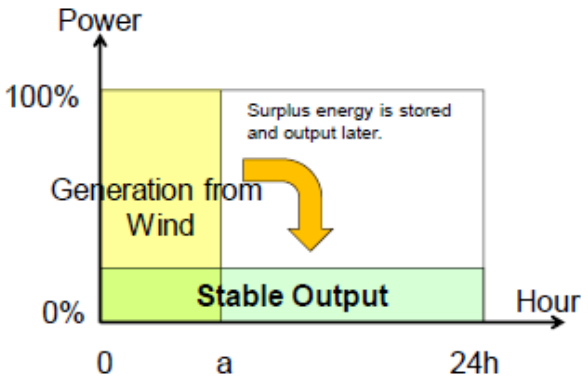


# Wind Thermal Power System

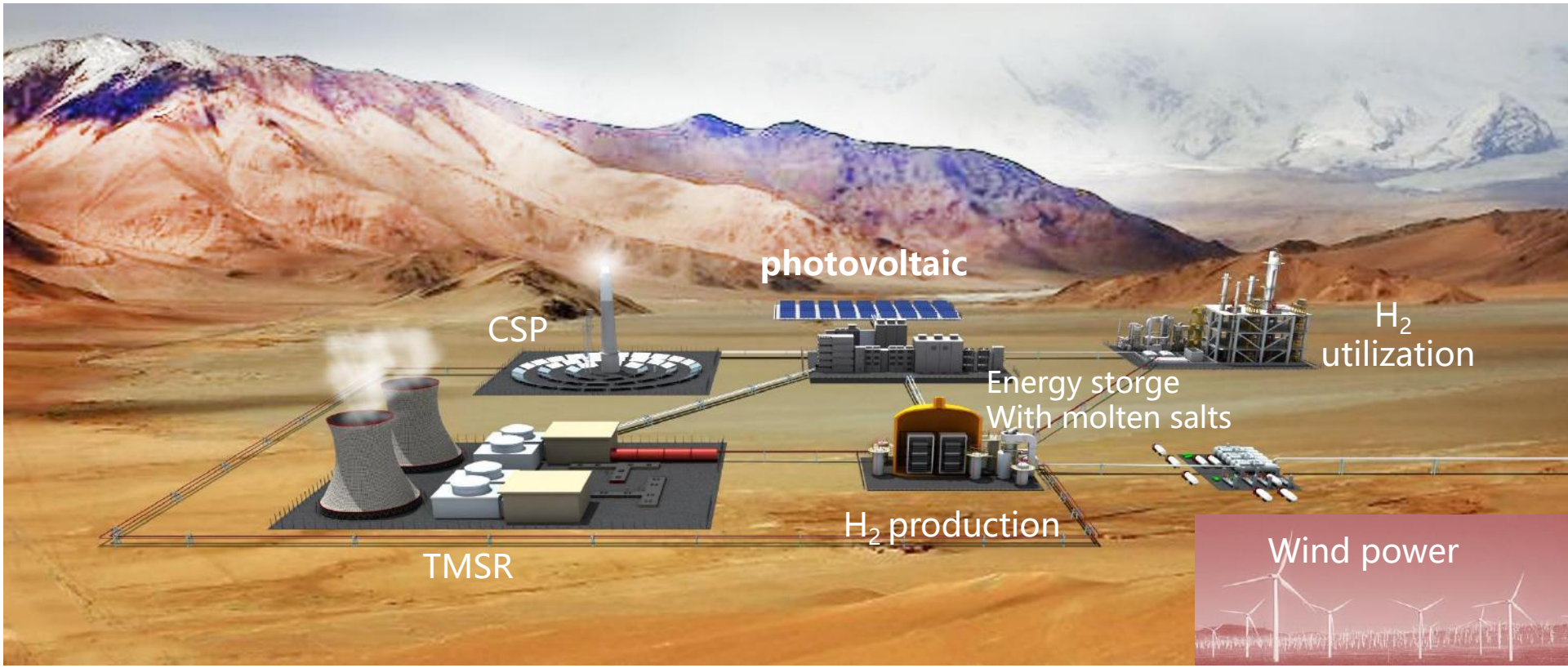
1. Intermittent Input



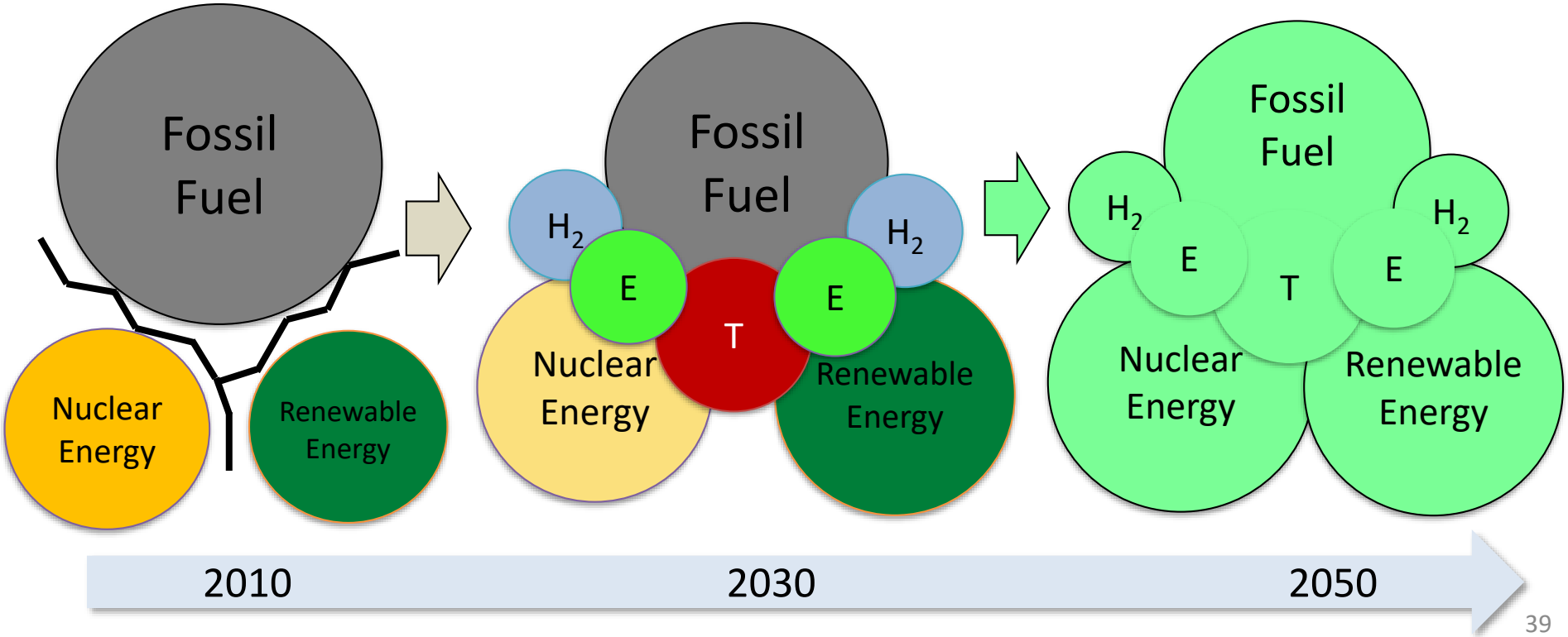



# TMSR Innovative Hybrid-energy Park



# Clean Energy System

Nuclear energy system produces heat and/or electricity; renewable energy system produces electricity and/or heat; both of them can produce hydrogen for energy conversion and storage, which is also used for lower the $CO_2$ emission of fossil fuel.




Thanks for


your attention!