Progress of TMSR in China

Sept. 27, 2018. Shanghai

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TMSR Center of CAS/ SINAP

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Perspective on TMSR

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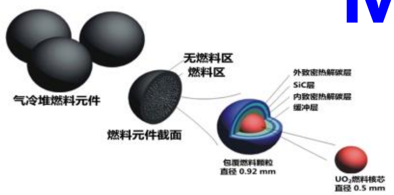
Overview of the Generation IV Systems

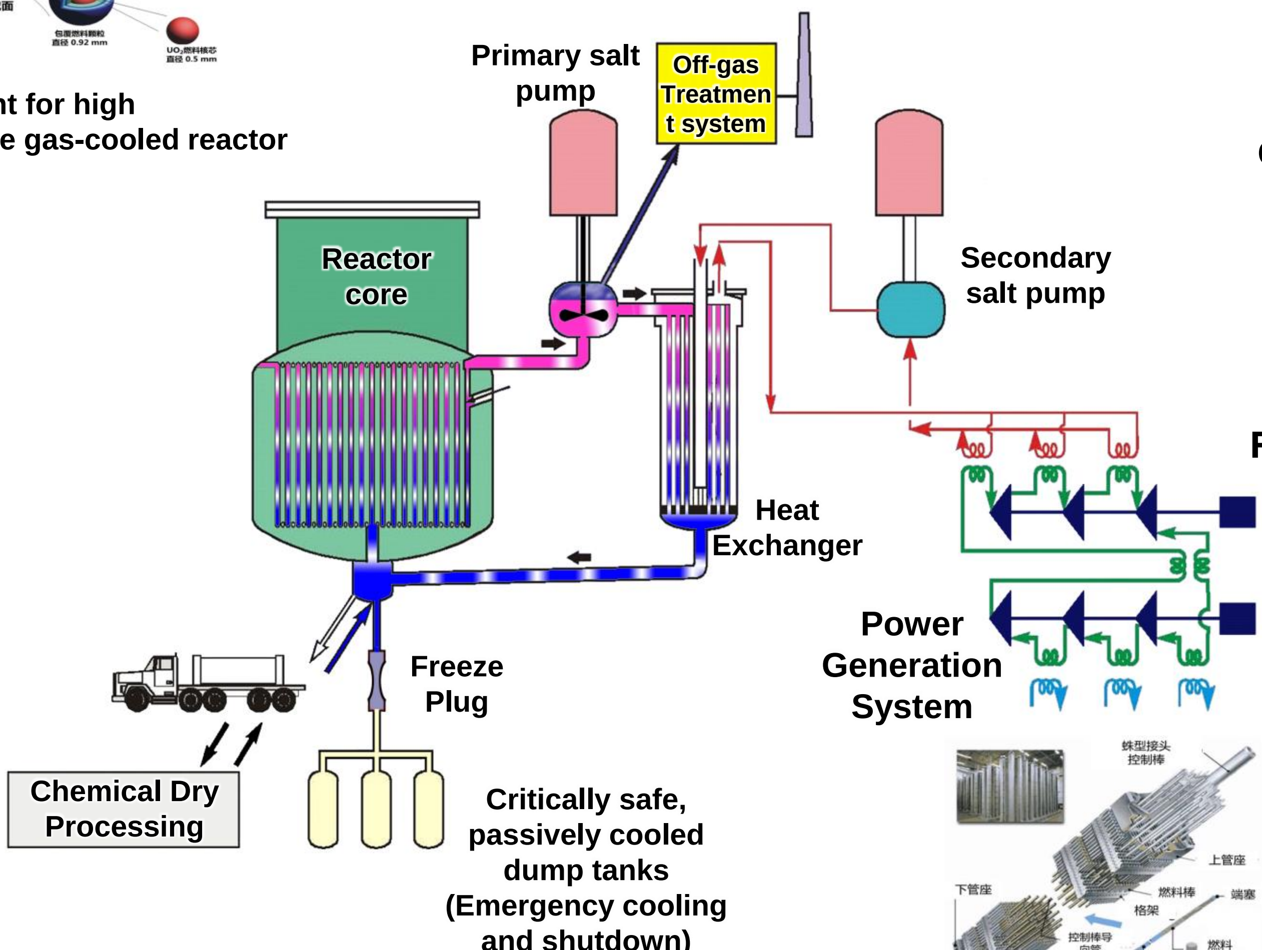
System	Neutron Spectrum	Fuel Cycle	Size (MWe)	Applications	R&D Needed
Very-High-Temperature Reactor (VHTR)	Thermal	Open	250	Electricity, Hydrogen, Process Heat	Fuels, Materials, H_2 production
Supercritical-Water Reactor (SCWR)	Thermal, Fast	Open, Closed	1500	Electricity	Materials, Thermal-hydraulics
Gas-Cooled Fast Reactor (GFR)	Fast	Closed	200-1200	Electricity, Hydrogen, Actinide Management	Fuels, Materials, Thermal-hydraulics
Lead-Cooled Fast Reactor (LFR)	Fast	Closed	50-150 300-600 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

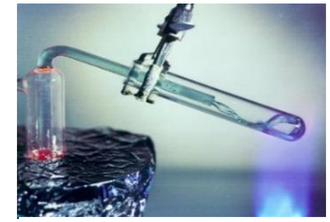
http://www.gen-4.org/Technology/systems/index.htm

Molten Salt Reactor (MSR)



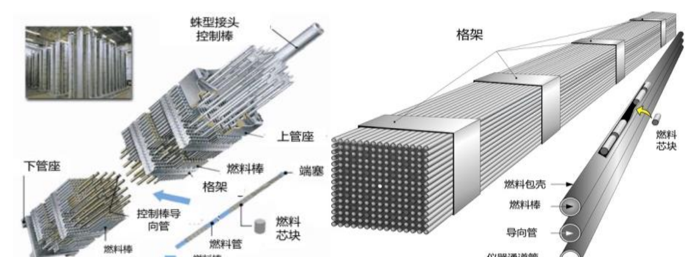
Fuel element for high temperature gas-cooled reactor (HTGR)





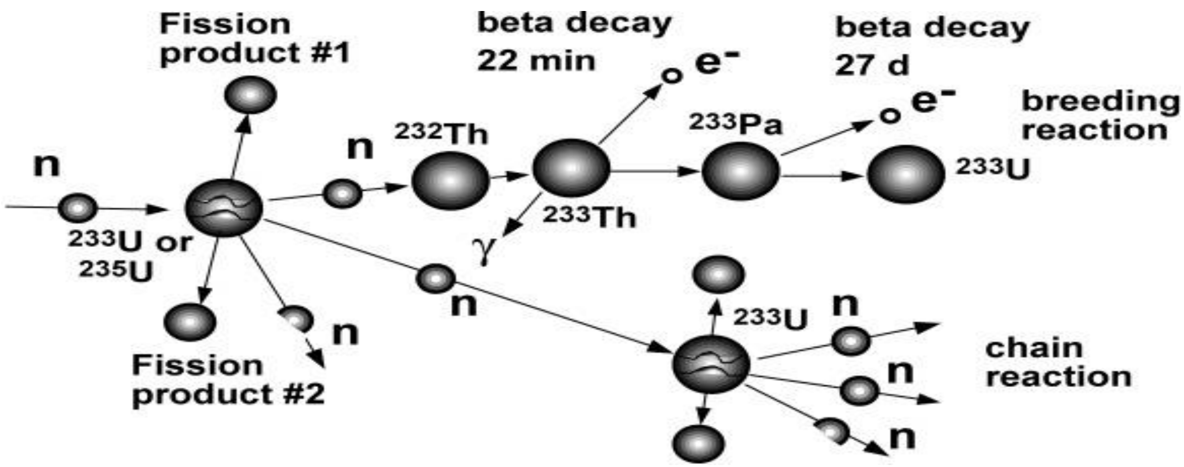
Carrier salt: $LiF\text{-}BeF_2$

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



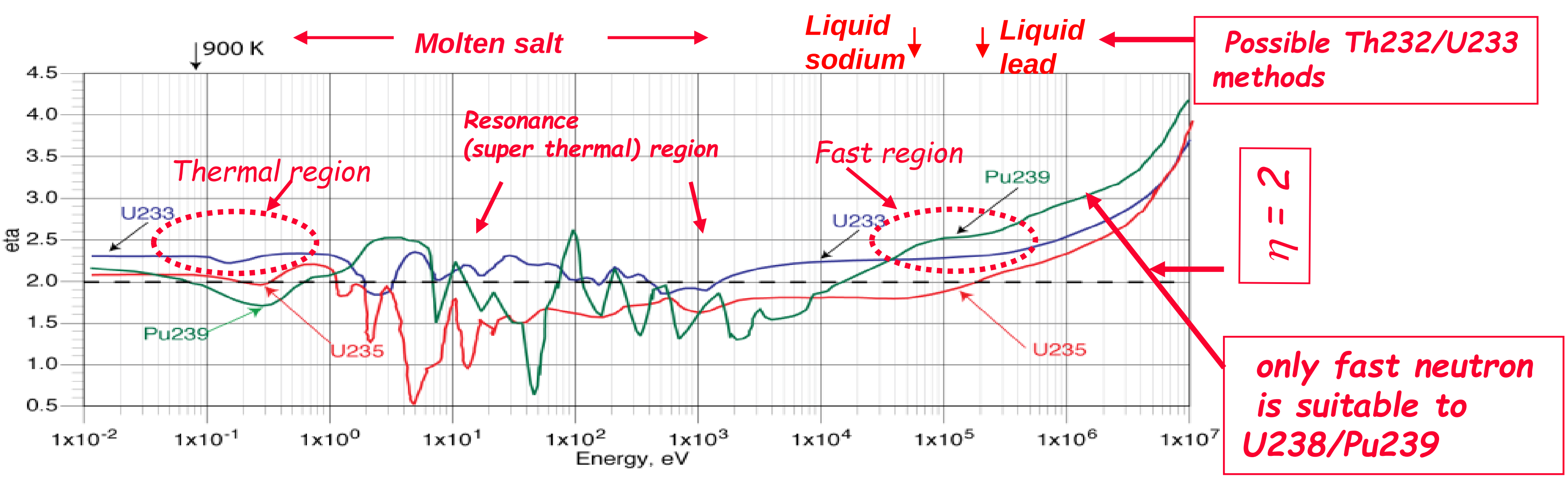
Fuel pin for Pressurized Water Reactor (PWR)

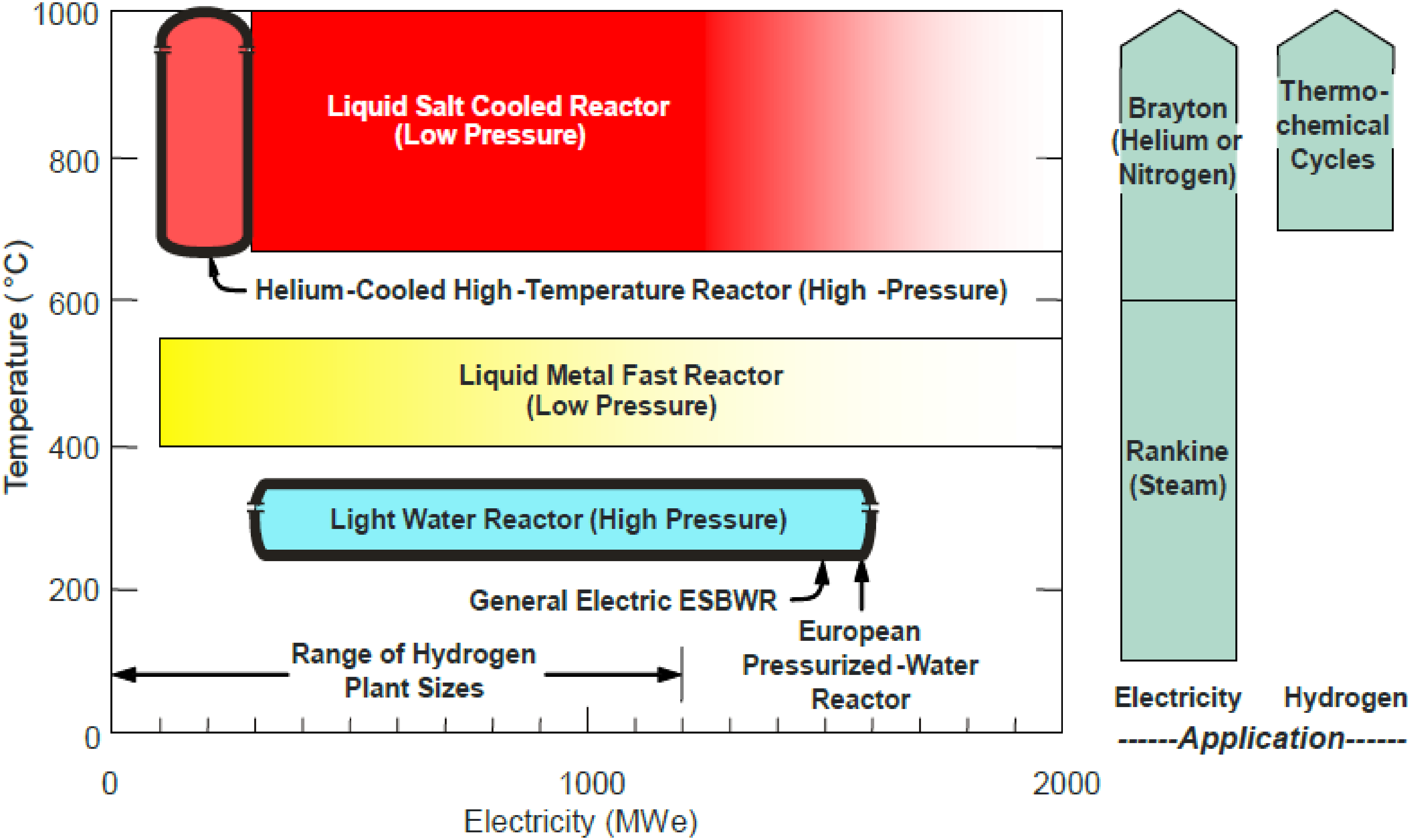
Th232/U233 and U238/Pu239 fuel cycles



Mean released neutron number per fission η

η = 2 is the required condition for a sustain reactor




Temperature (°C)
1000
800
600
400
200
0
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
0
1000
2000
Electricity (MWe)
Brayton
(Helium or
Nitrogen)
Rankine
(Steam)
Thermo-
chemical
Cycles
Electricity
Hydrogen
------Application------

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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

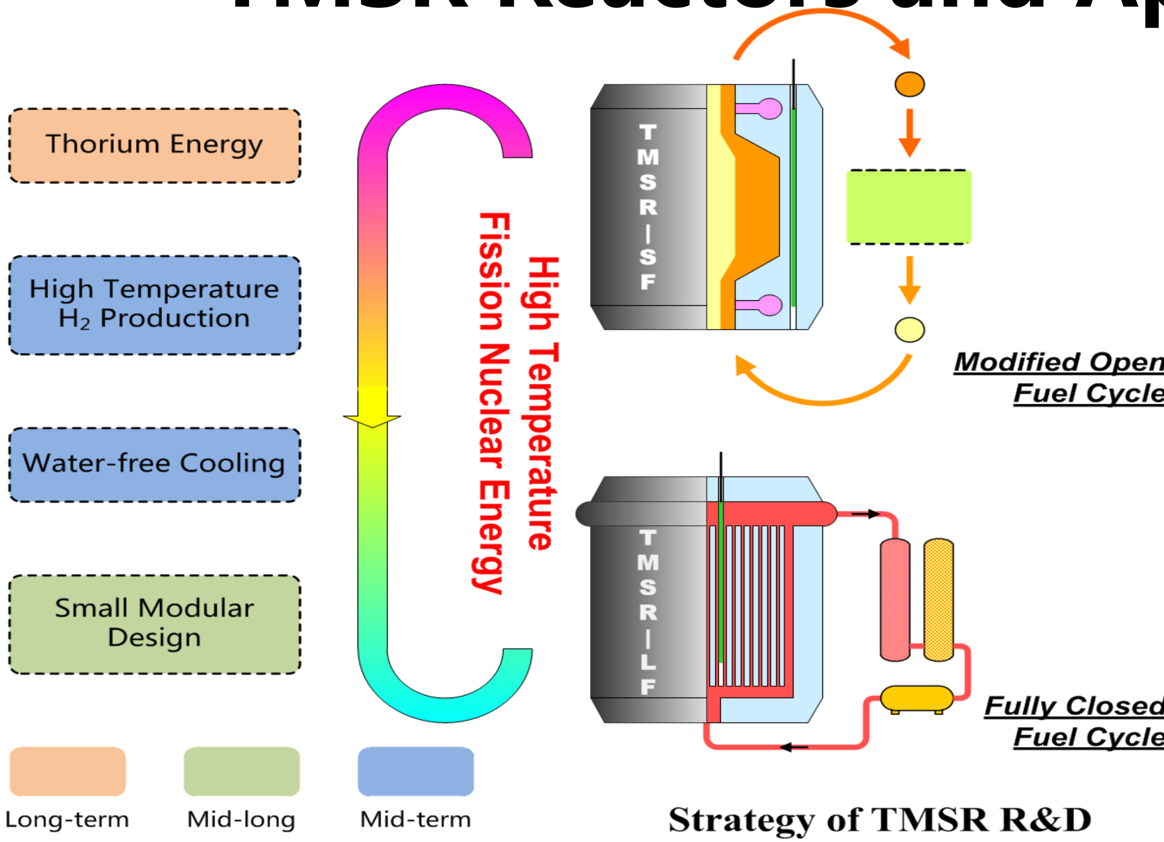
英文名称：Thorium Molten Salt Reactor

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



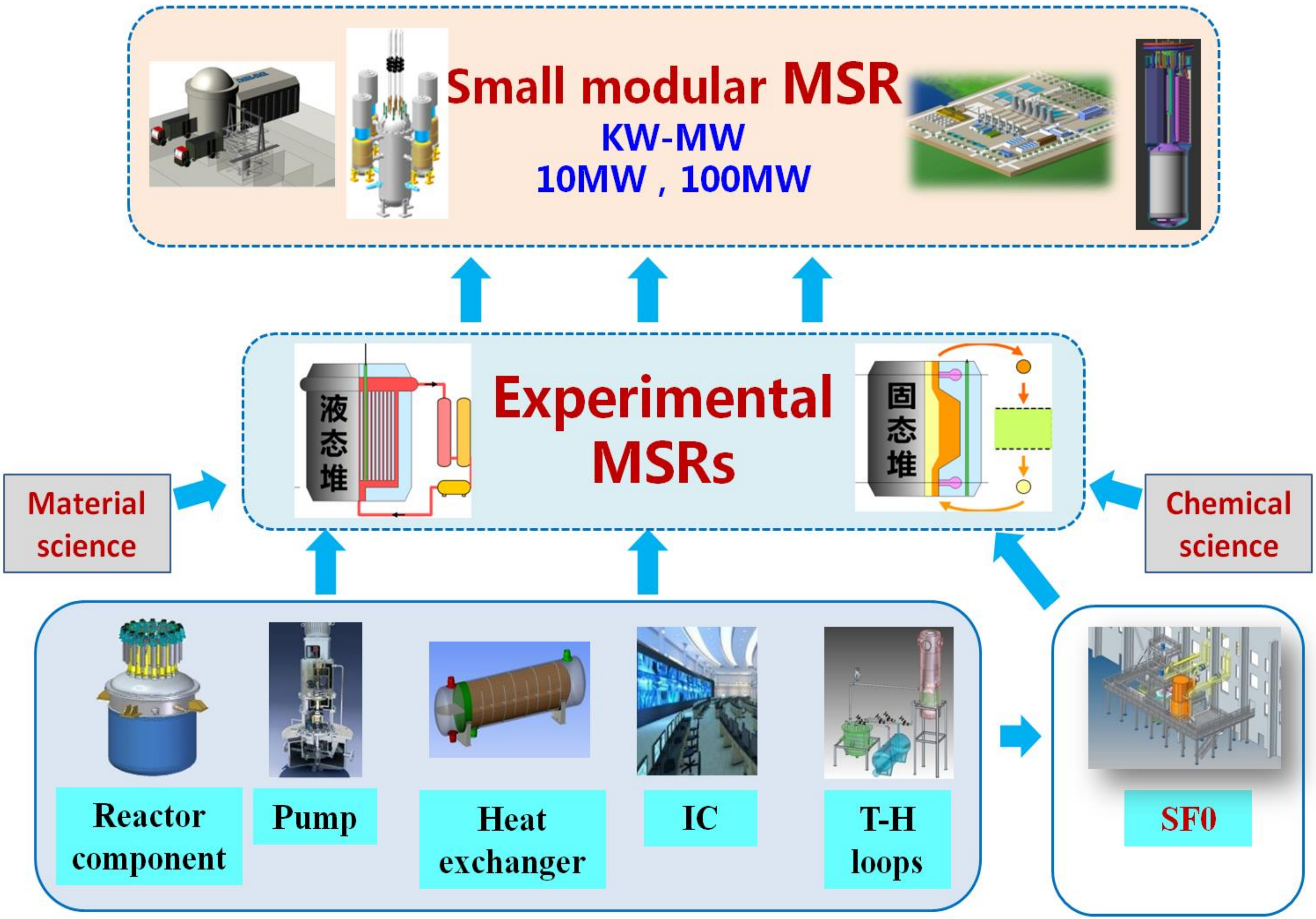
Strategy of TMSR R&D

Th Energy:
Long-Term Supply of Nuclear Fuel

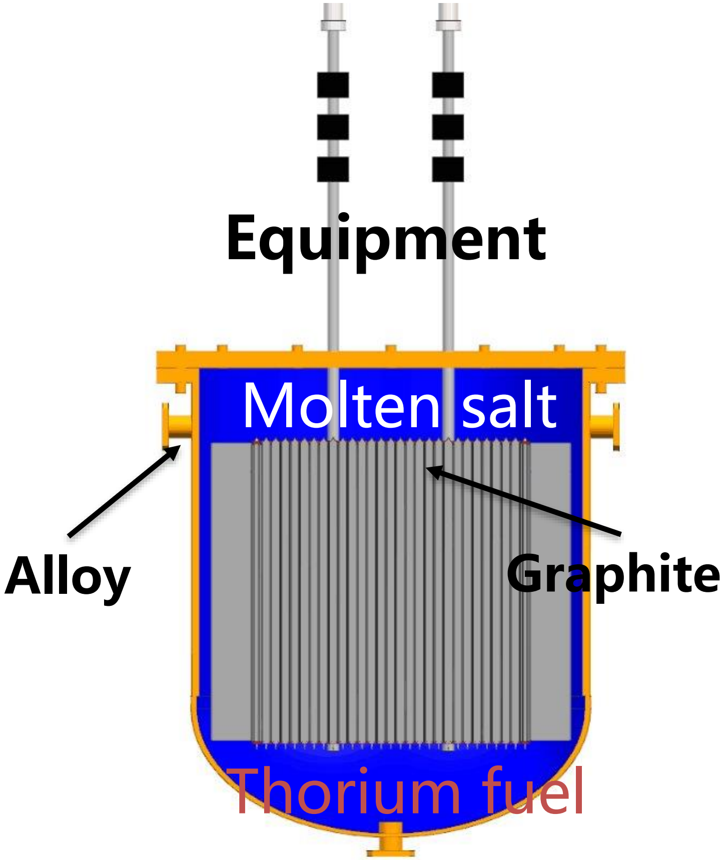
MSR:
Elevated Safety
Efficiency
Nonproliferation

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

Roadmap of Technologies R&D



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

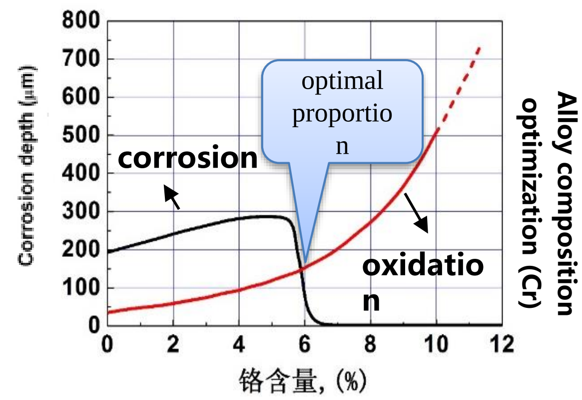
Material	Domestic original foundation	Domestic level after TMSR program implementation	Major breakthrough (World first class of the same kind)
Hastelloy N alloy (Nickel based)	➢ Property data is blank ➢ 6 tons level of cast ingot (nickel based) ➢ Processing technology is blank	➢ The properties meet the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

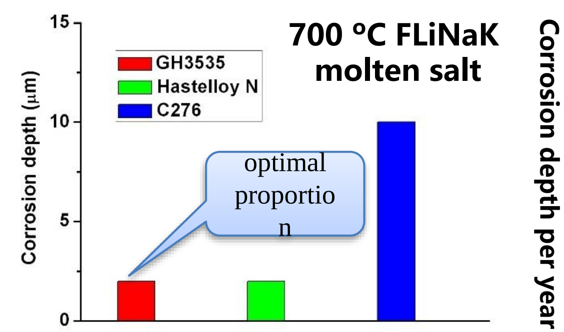
Molten salt corrosion control technology

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

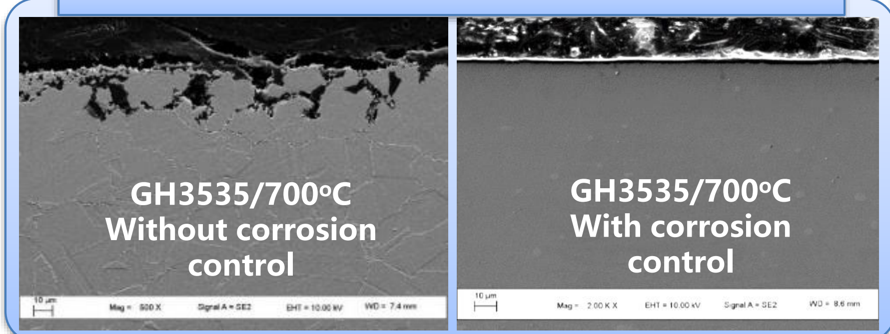
- **Solved the strong corrosive problem of molten salt in application of MSR , thermal and energy storage.**

  - 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

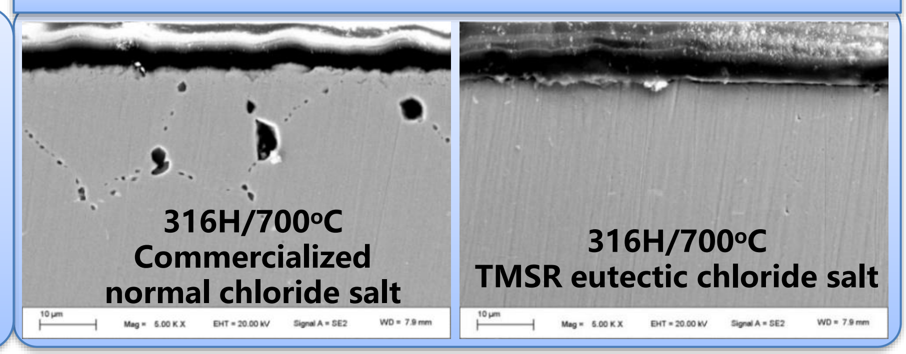




Fluoride corrosion control in molten salt reactor



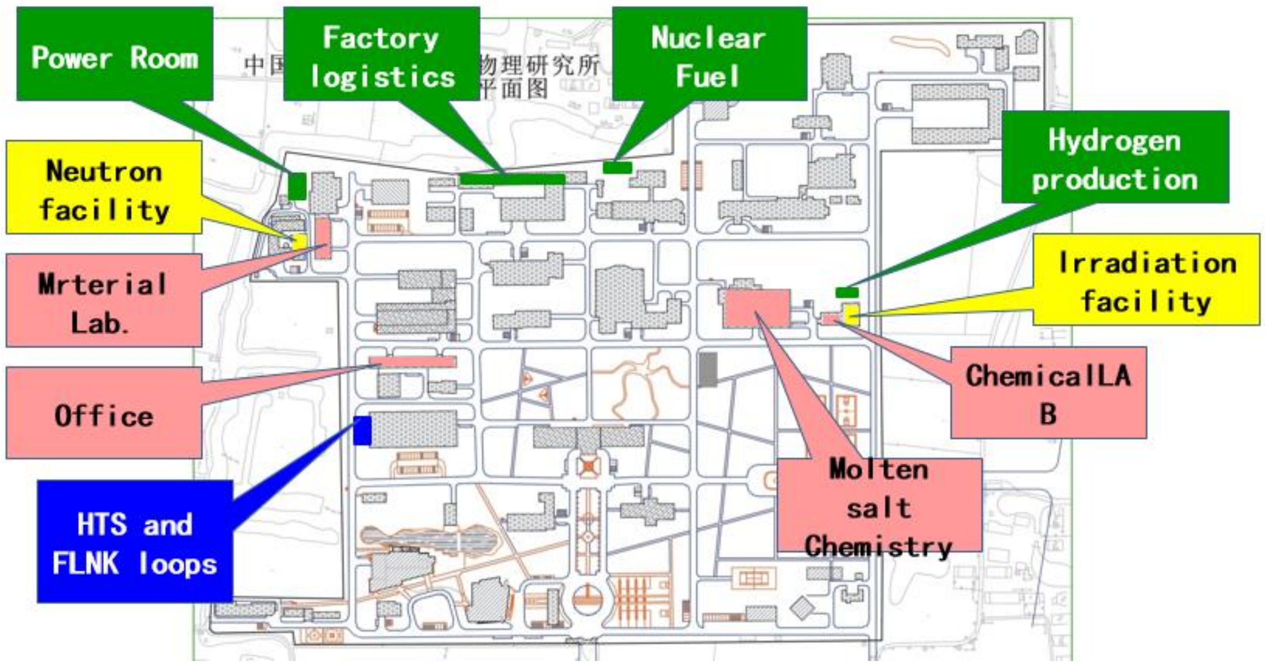
Chloride corrosion control in thermal and energy storage



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 °C)	● Finished the development of molten-salt pump (10 m^3/h, 650 °C) ● Finished the design of reactor pump (300 m^3/h, 700 °C), being processed ● 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 ● 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 ● Built cryogenic valve experimental platform ● 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 1m^3 storage tank ● Designed main vessel (700 °C, 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 °C	● 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 ● Used in molten salt loop and simulation reactor at 650 °C 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

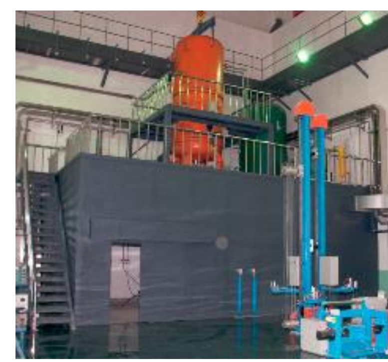


Super Computer

Hot Cells

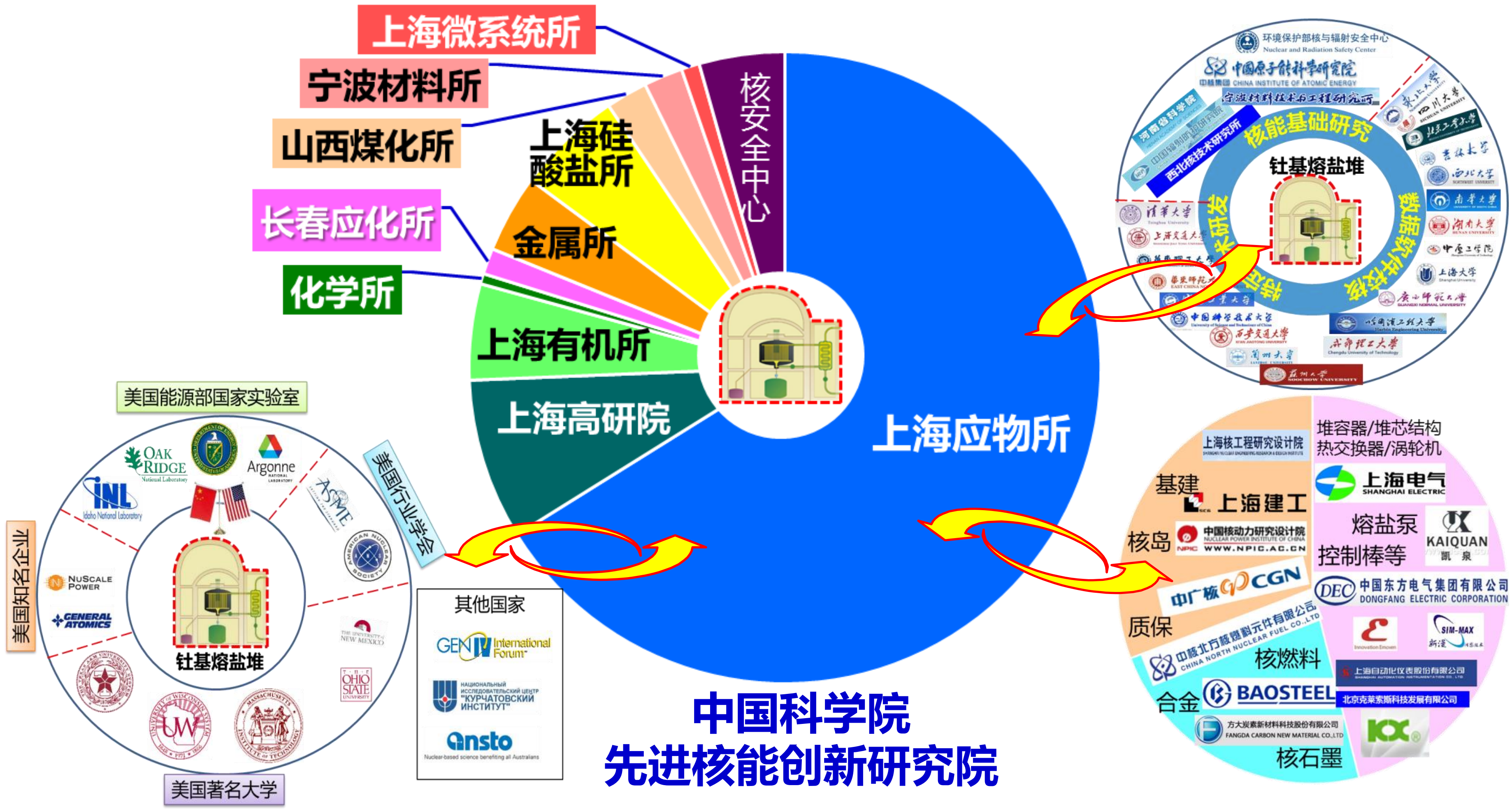
Material Testing Labs

Salt Properties Labs



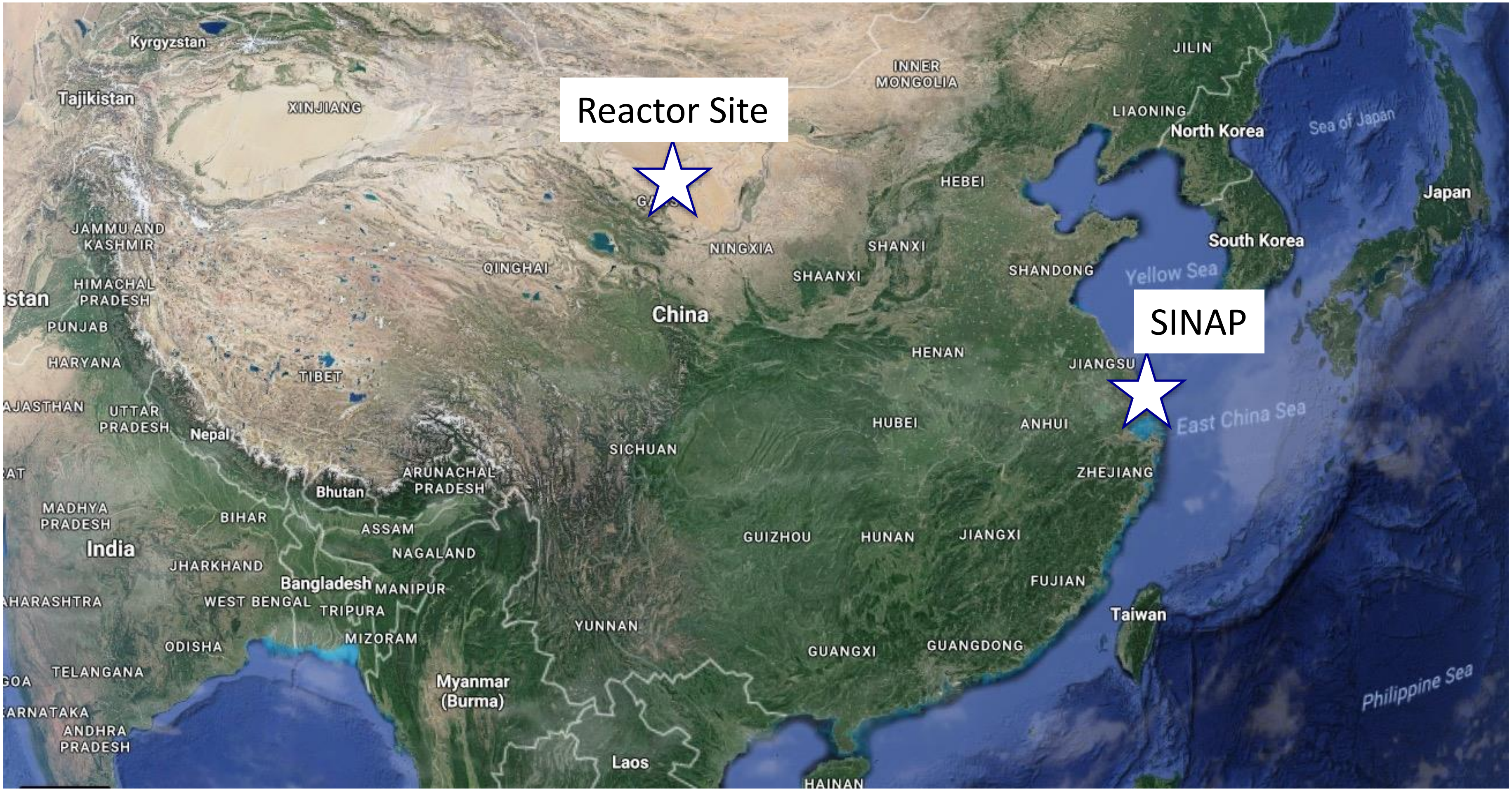
β Irradiation Facility

International and Domestic Collaborations



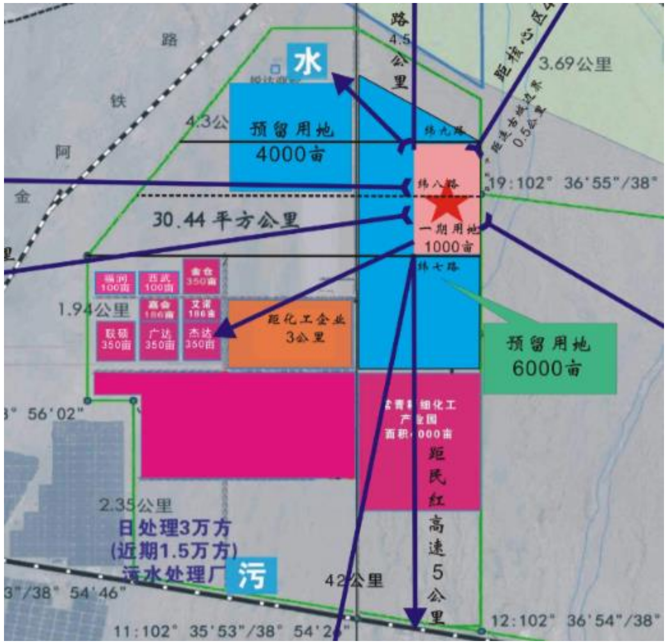
TEAMS: Staffs ～600; Graduate students ～200

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.

国际评价

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.

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

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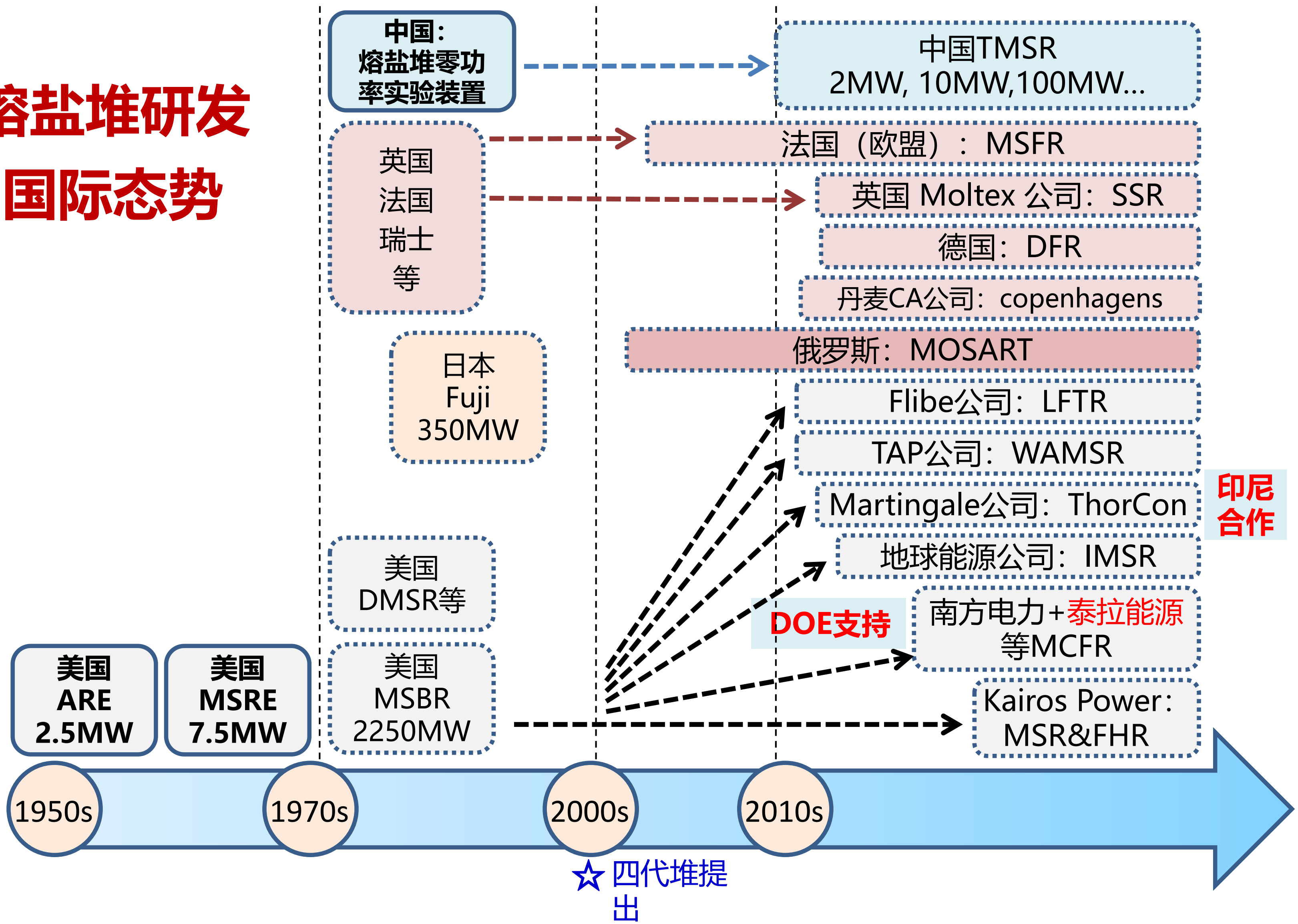
熔盐堆研发国际态势

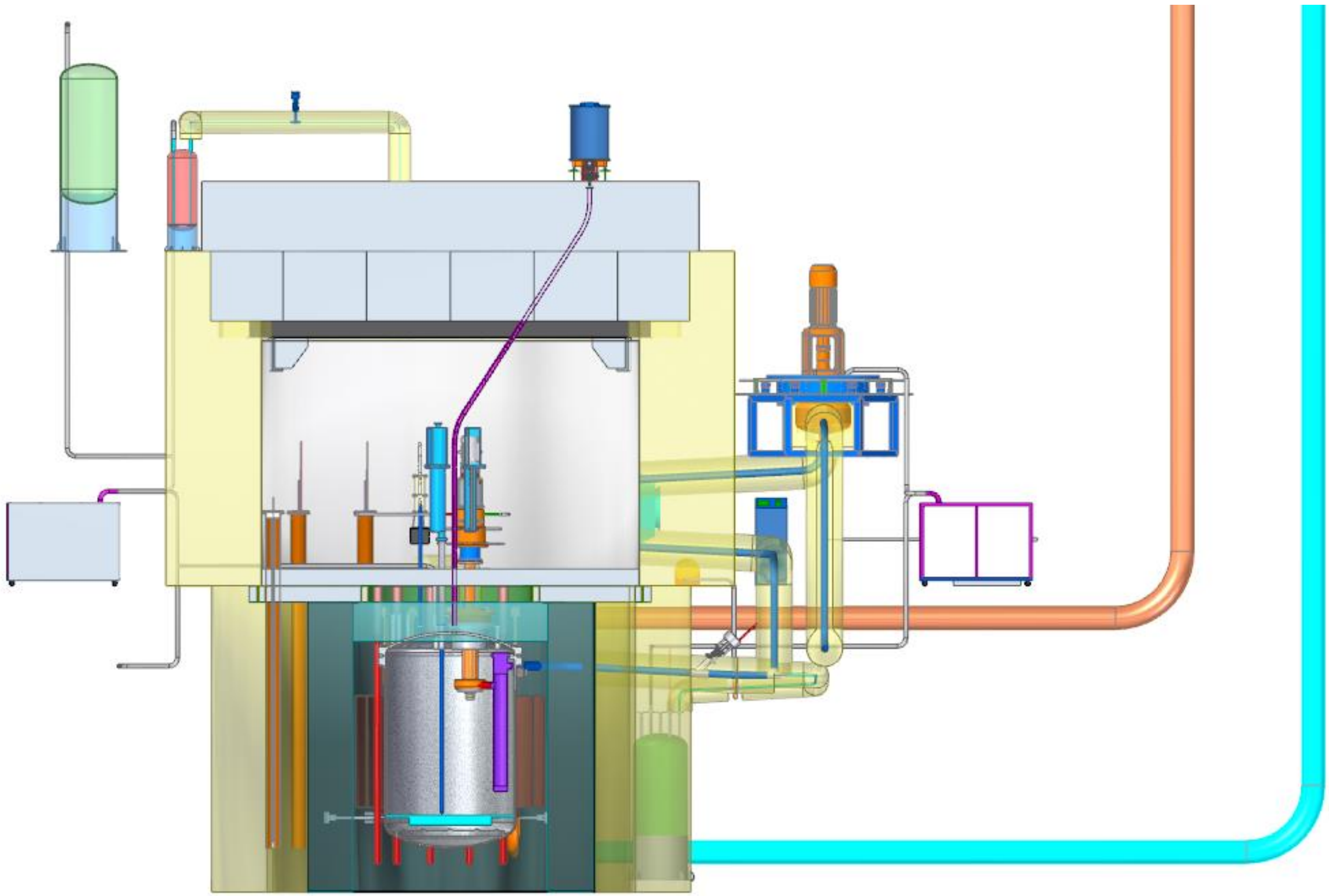


中国：熔盐堆零功率实验装置
中国TMSR
2MW, 10MW,100MW...
英国
法国
瑞士
等
法国（欧盟）：MSFR
英国 Moltex 公司：SSR
德国：DFR
丹麦CA公司：copenhagens
日本
Fuji
350MW
俄罗斯：MOSART
Flibe公司：LFTR
TAP公司：WAMSR
Martingale公司：ThorCon
印尼合作
地球能源公司：IMSR
美国
DMSR等
DOE支持
南方电力+泰拉能源等MCFR
美国
ARE
2.5MW
美国
MSRE
7.5MW
美国
MSBR
2250MW
Kairos Power：MSR&FHR
1950s
1970s
2000s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



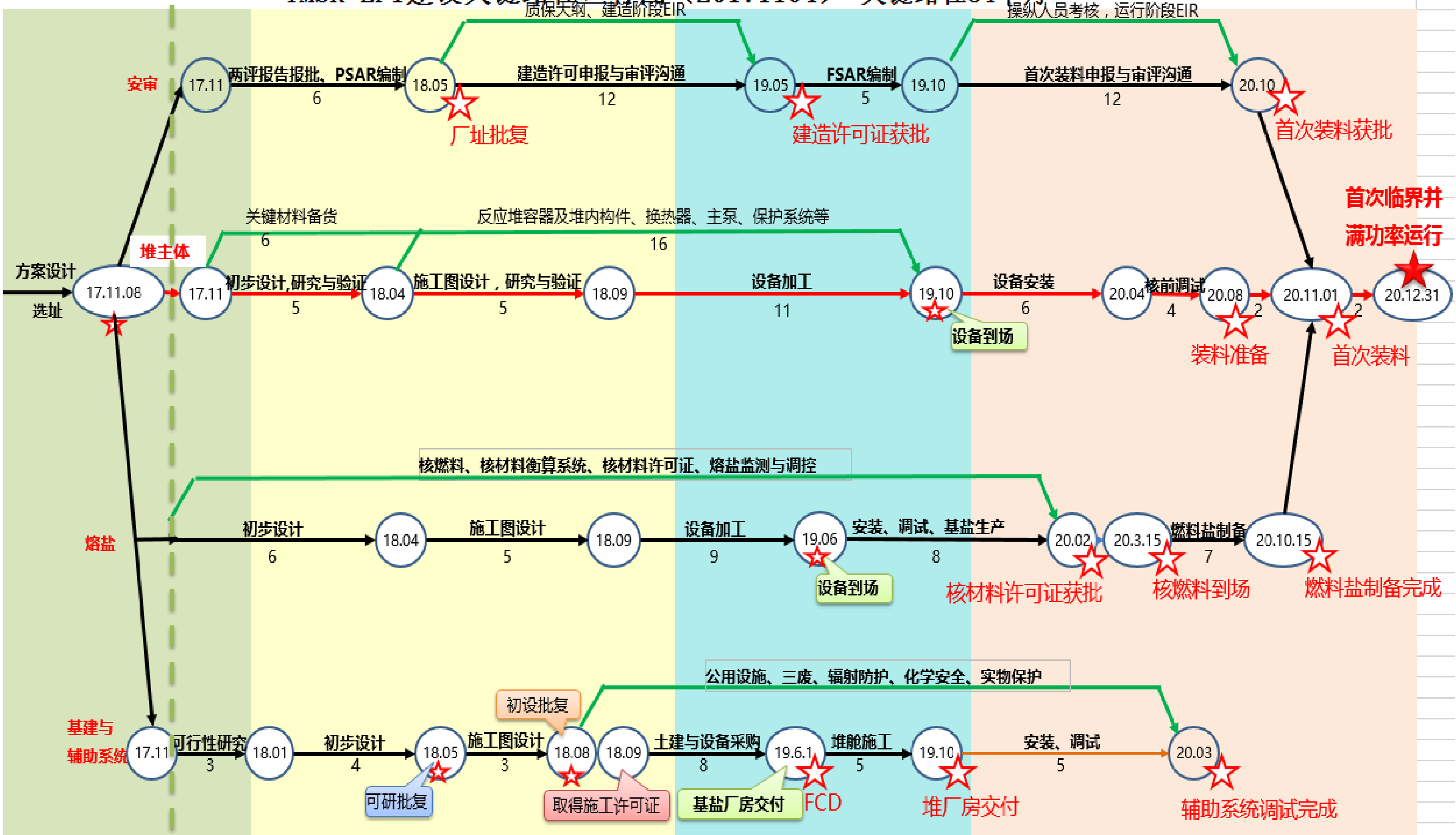
Main Parameters

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	$LiF-BeF_2-ZrF_4-UF_4$ ($+ThF_4$)
U-235 Enrichment	19.75wt%
Coolant salt	$LiF-BeF_2$

TMSR-LF1 Design

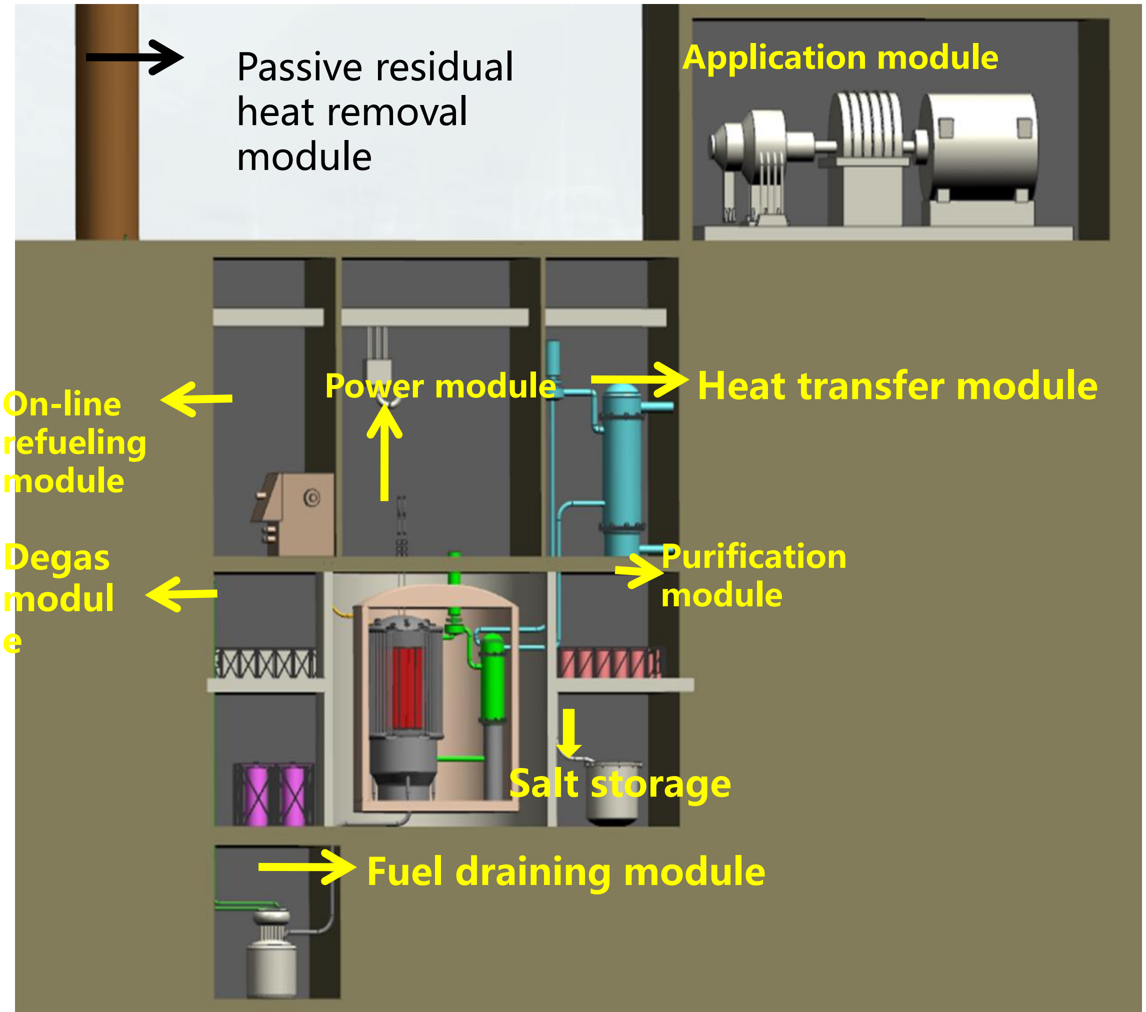
Fuel Loading / discharging	Ar gas + capsule
Reactivity Control	Control rods
Mass flow rate (fuel salt)	~50 kg/s
Mass flow rate (coolant salt)	~42 kg/s
Residual heat removal	1. Loop 2. Air natural circulation Passive residual heat removal system
Alloy	UNS N1003
Graphite	Superfine particle graphite
Cover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

TMSR-LF1建设关键路径鱼骨图（20171104）-关键路径34个月



TMSR-LF150

TMSR-LF Small Modular Demo-Reactor

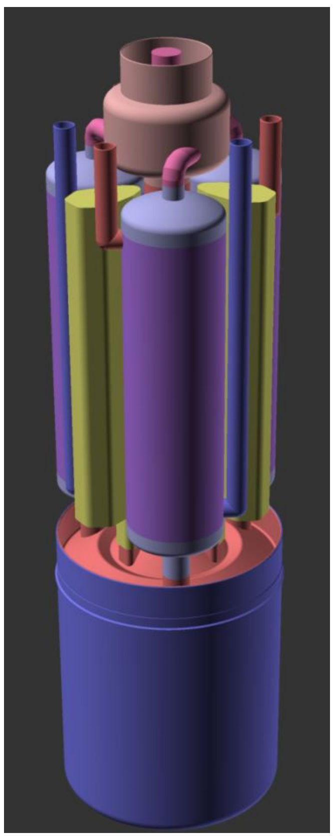


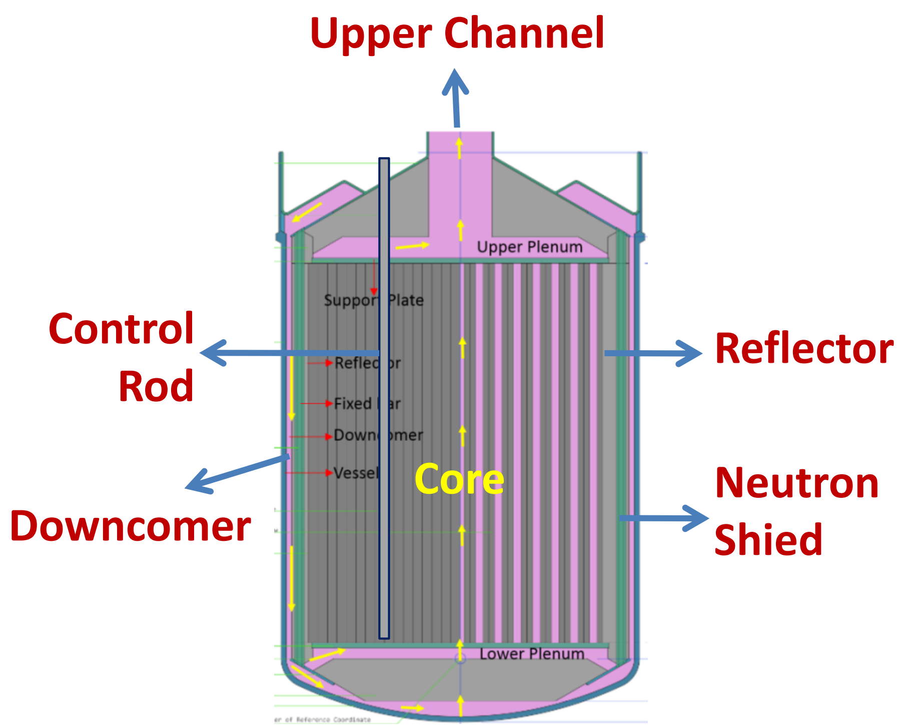
- **Key modules**：power、heat transfer、fueling draining、Passive residual heat removal、on-line refueling
- **Application modules:** generator、hydrogen production、Changed、etc.(Changed with goals)

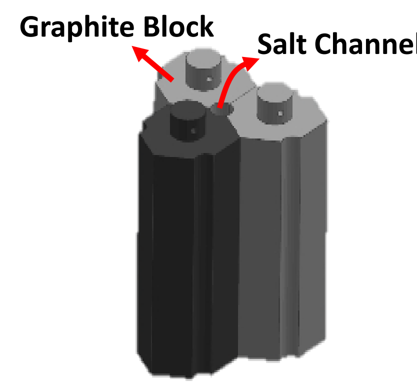
Power	150MWt
Temperature	600 ℃ / 700 ℃
Efficiency	40%-50%
Th power	>=20%
Main vessel	5.2m×6.0m (D×H)
Safety	Passive residual heat removal system
Economics	Cheaper than coal

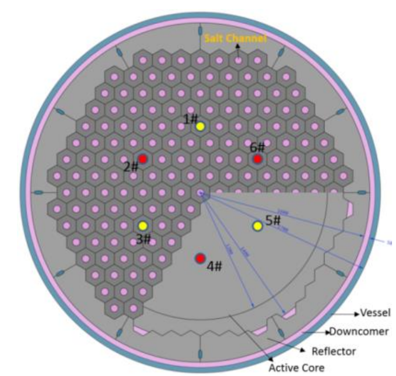
Core design

- **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.





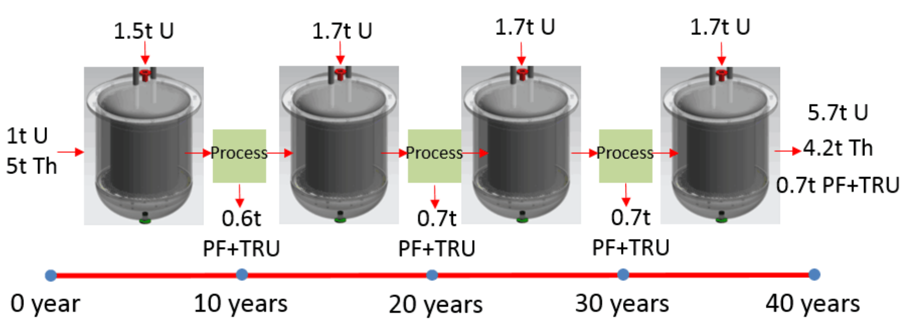




Fuel cycle

- 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.

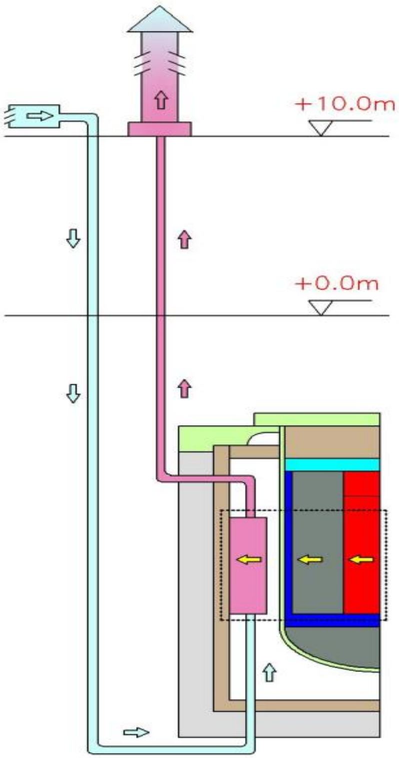
Th+U：19.75% U-235，equivalent burnup is about 280 MWd/kgU



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

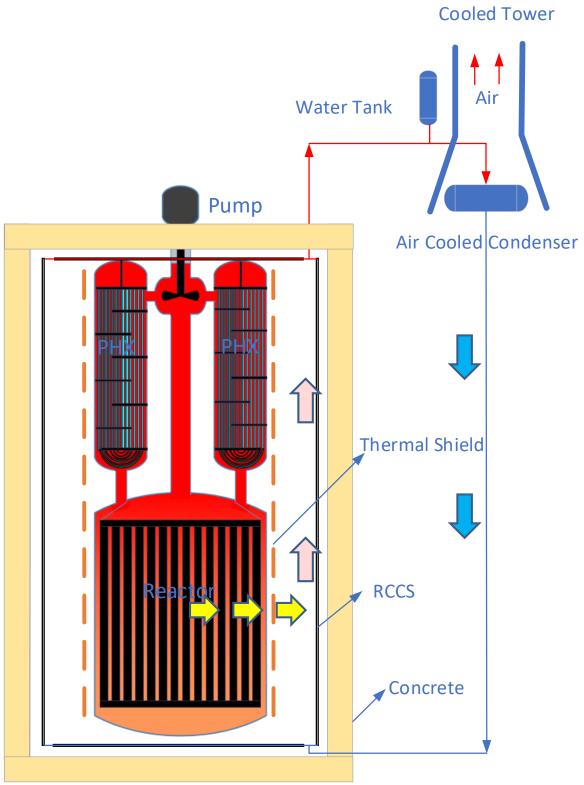


TMSR-LF1

Unlimited time heat removal

High realiable passive system

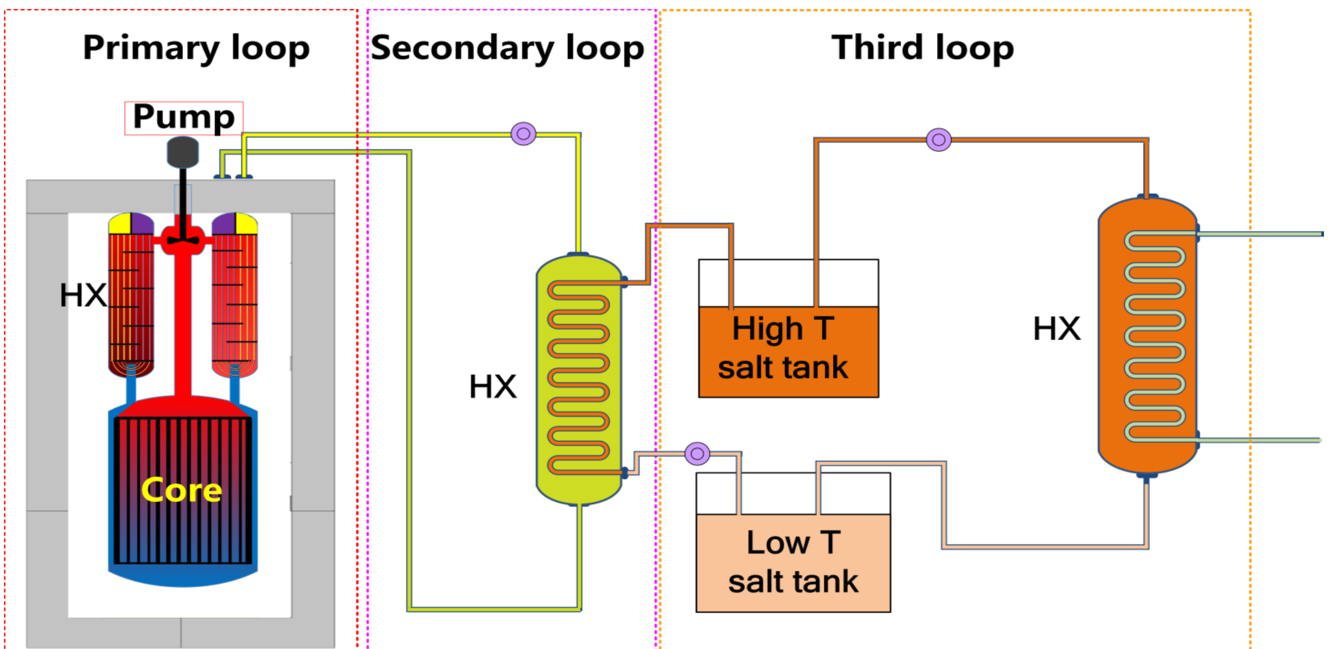
Water layer also as shieding layer



TMSR-LF150

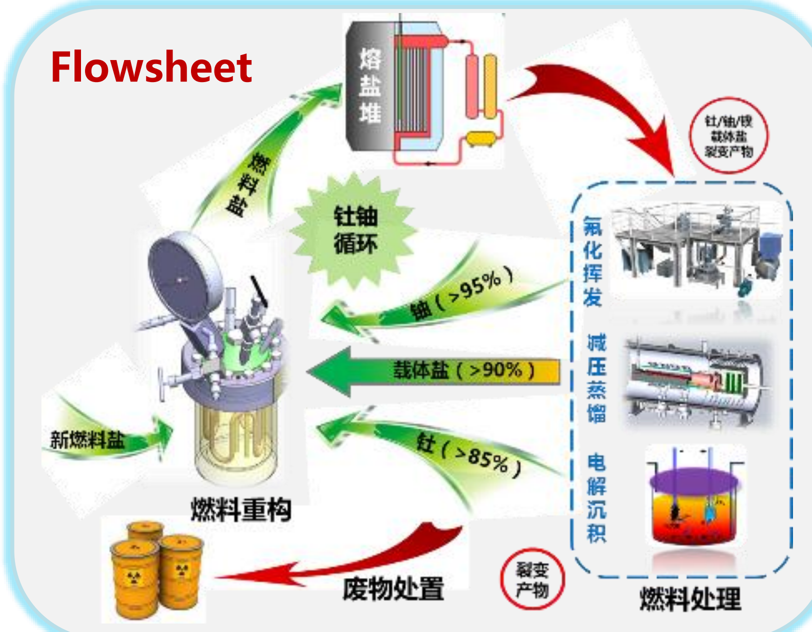
Heat transfer and storage

- 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.



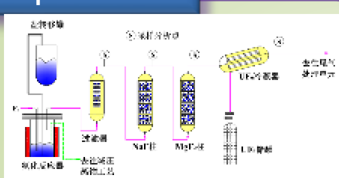
Facility for dry process of Th-U fuel cycle

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

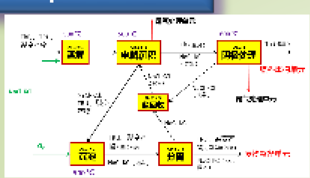
Fluorination



产品收率95~99%
总β和γ去污系数10^7

Th seperation

Electroysis



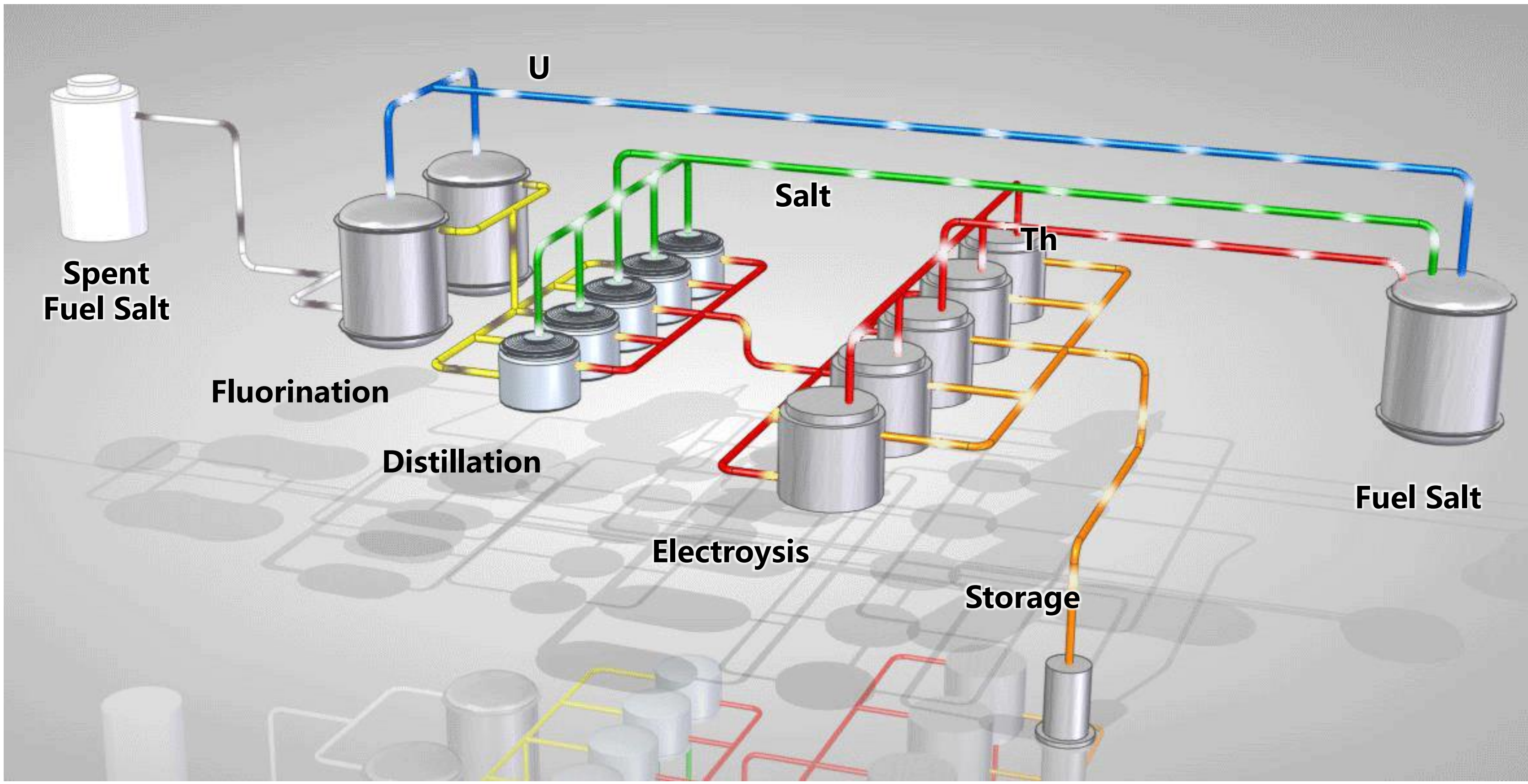
产品收率85~90%
总β和γ去污系数10^2

Salt seperation

Distillation

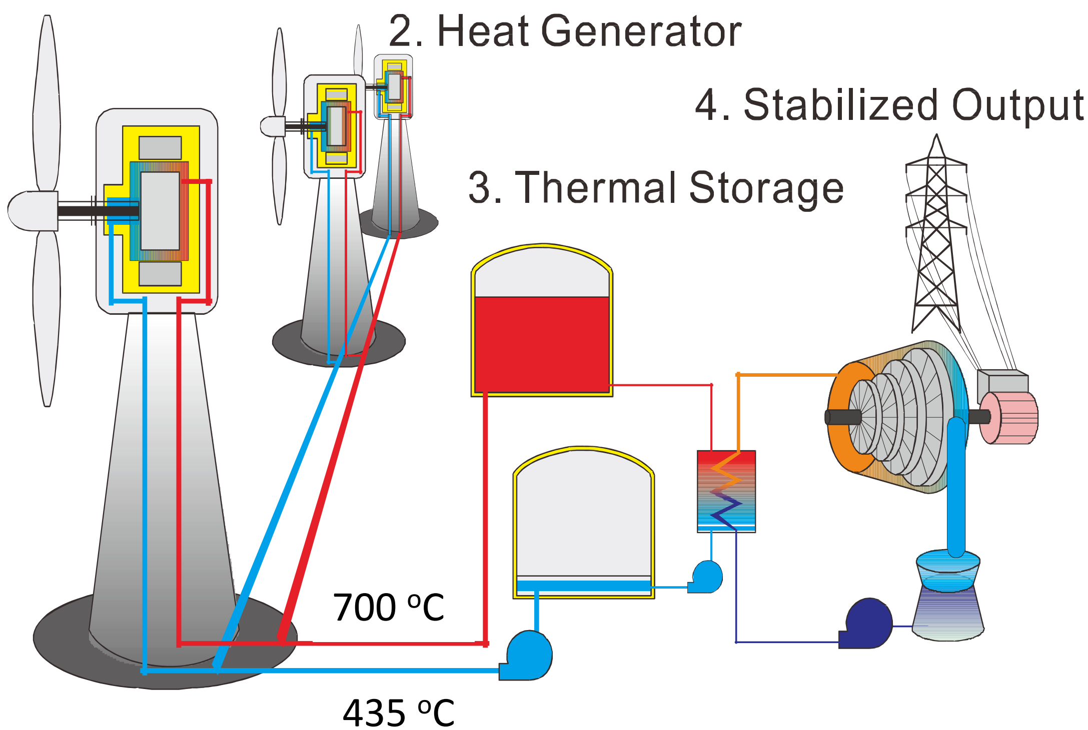
产品收率90~95%
总β和γ去污系数10^4

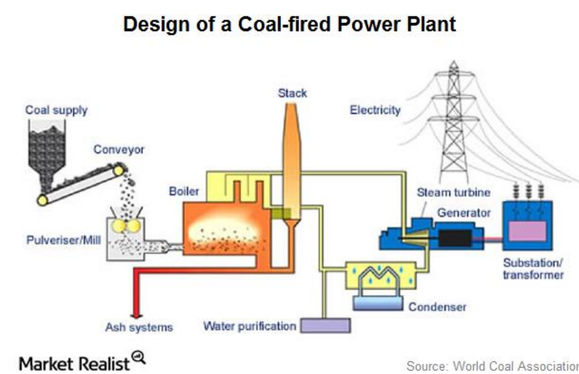
Batch pyroprocess Facility

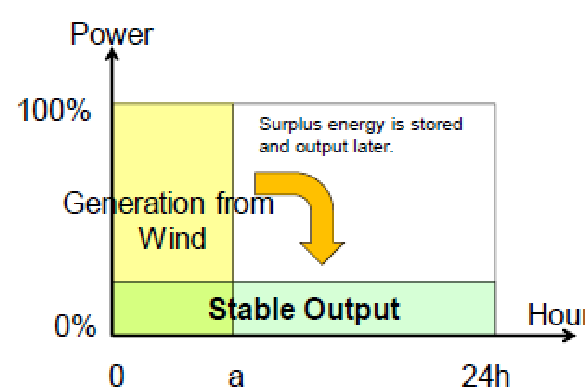


Wind Thermal Power System

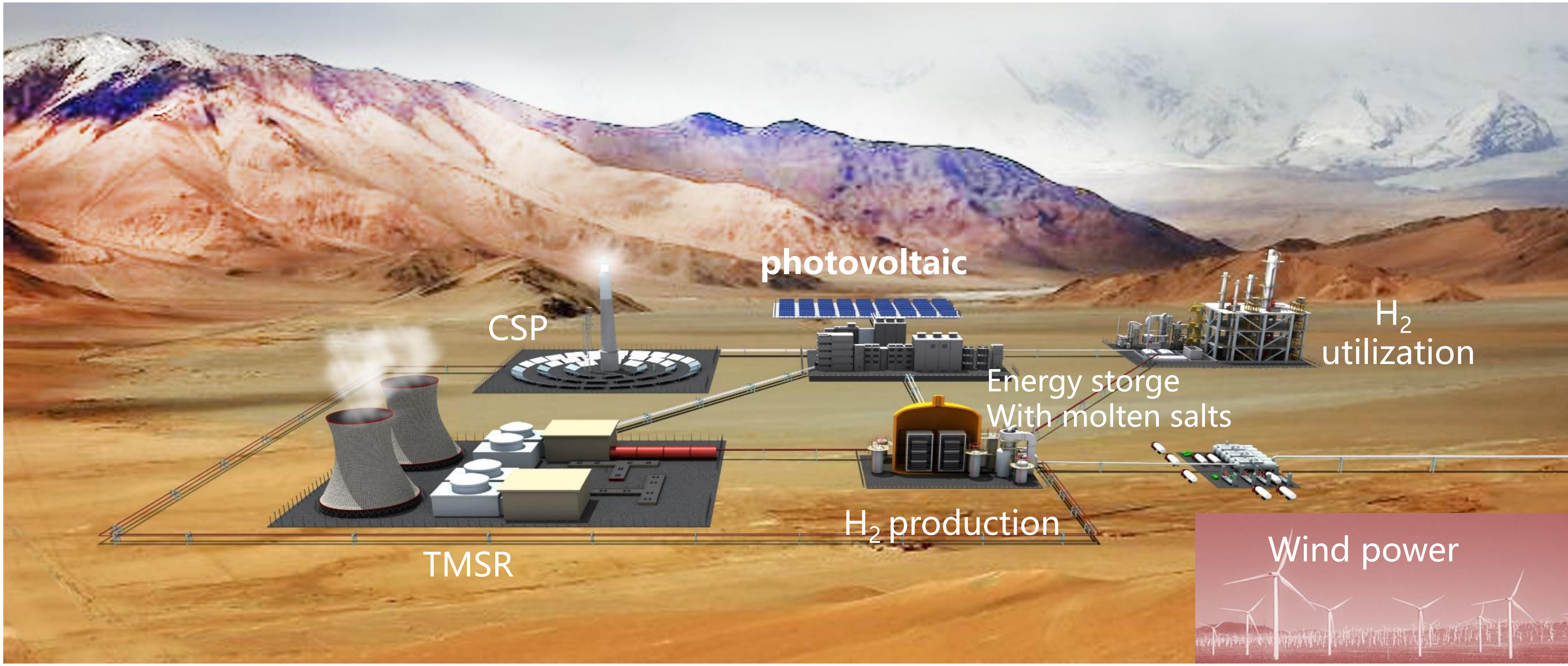
1. Intermittent Input





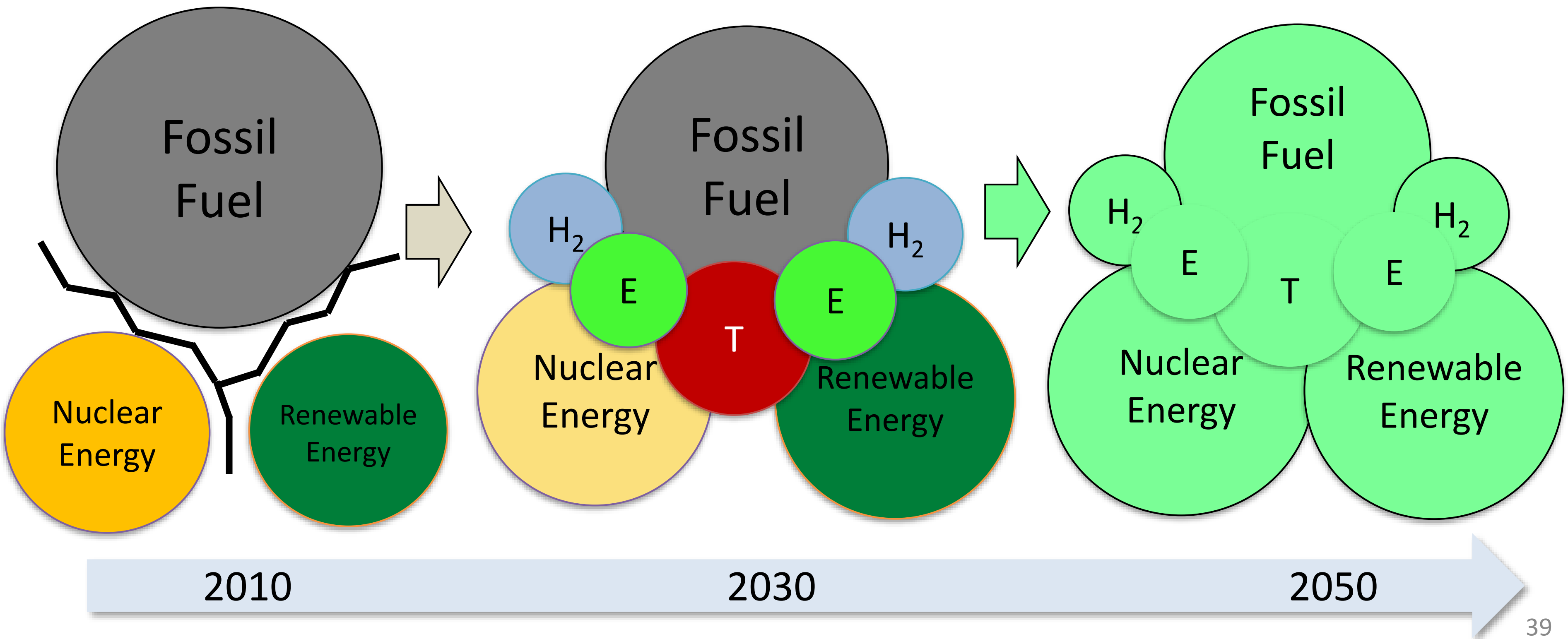


TMSR Innovative Hybrid-energy Park



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!