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Thorium Energy R&D in China

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Outline

Why TMSR

Th-E @ TMSR

Status and Progress

Outline

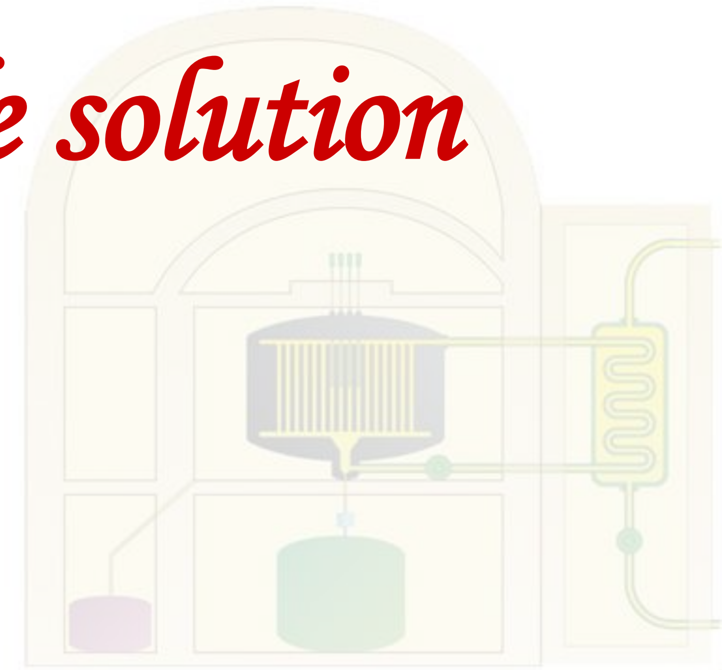
Why TMSR

Th-E @ TMSR

Status and Progress

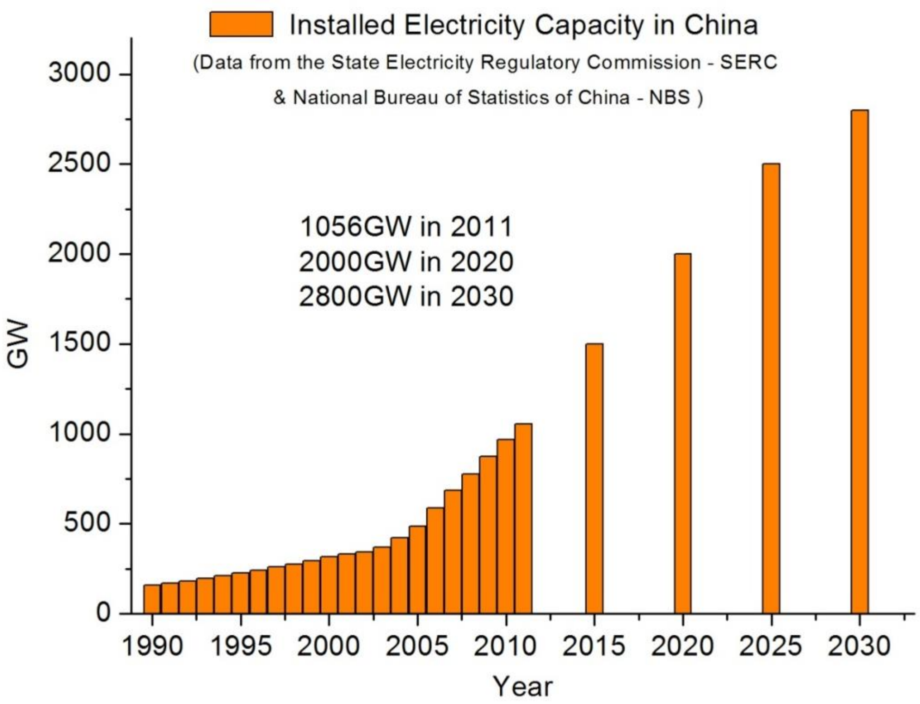
The Challenges to China

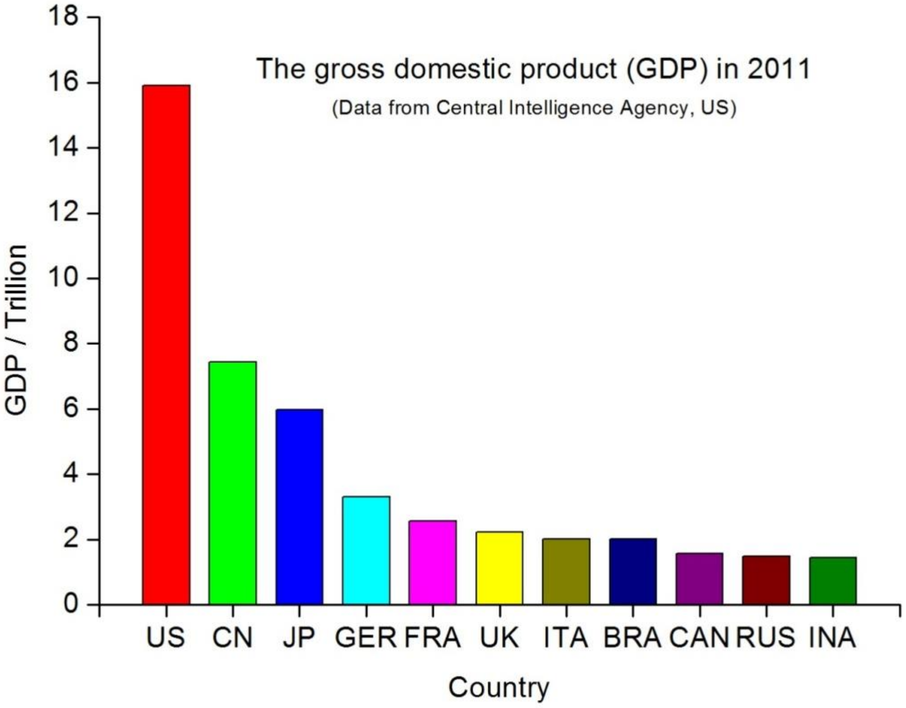
And one possible solution



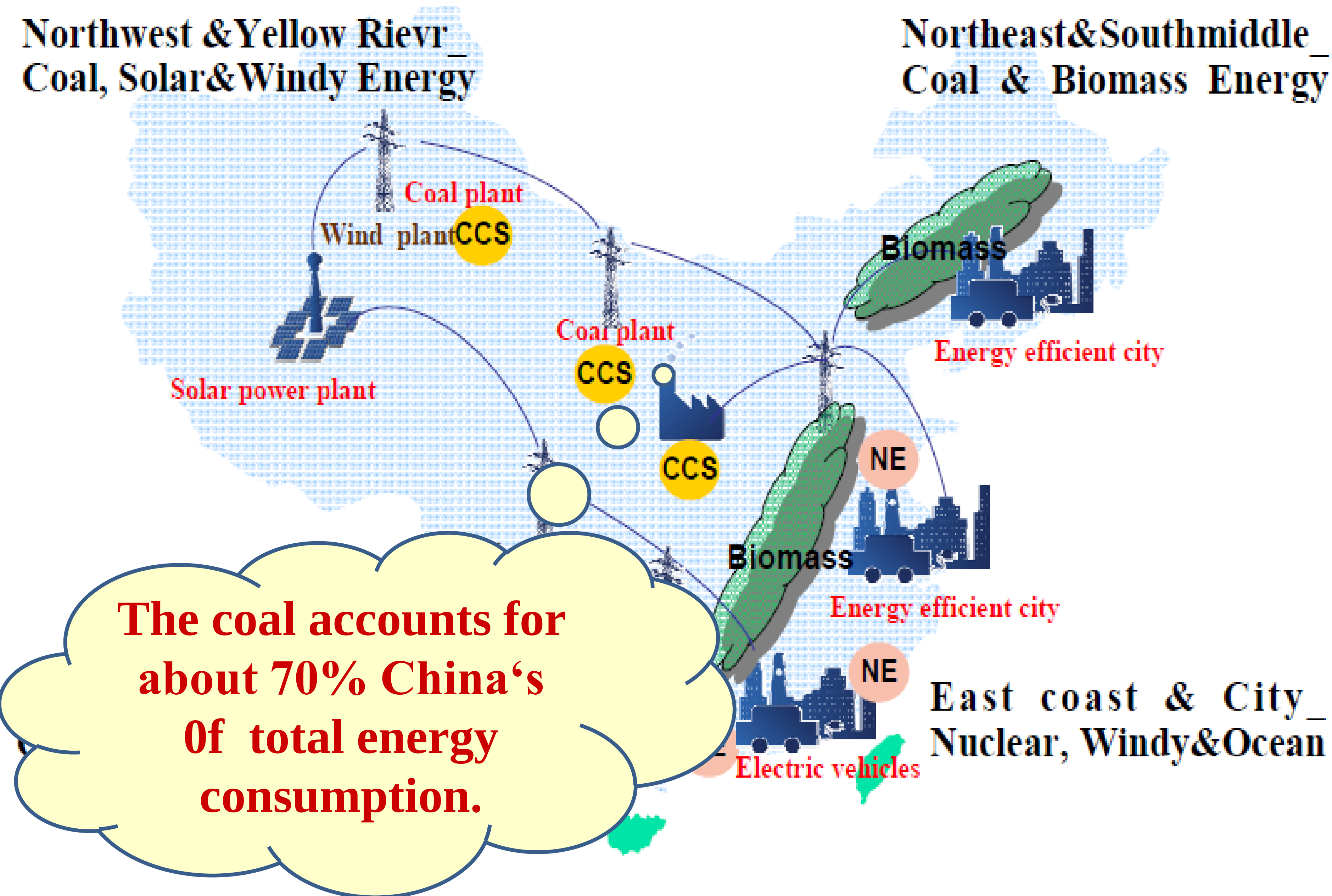
China's Energy Challenge

- Analysis and forecast on national electric power in China: In 2030, the electricity demand of per person will be about 2KW, total generation capacity will reach about 3000GW, the MW - level power stations will need 3000.





Localized Energy Resource in China



The coal accounts for about 70% China‘s 0f total energy consumption.

List of countries by 2011 emissions estimates

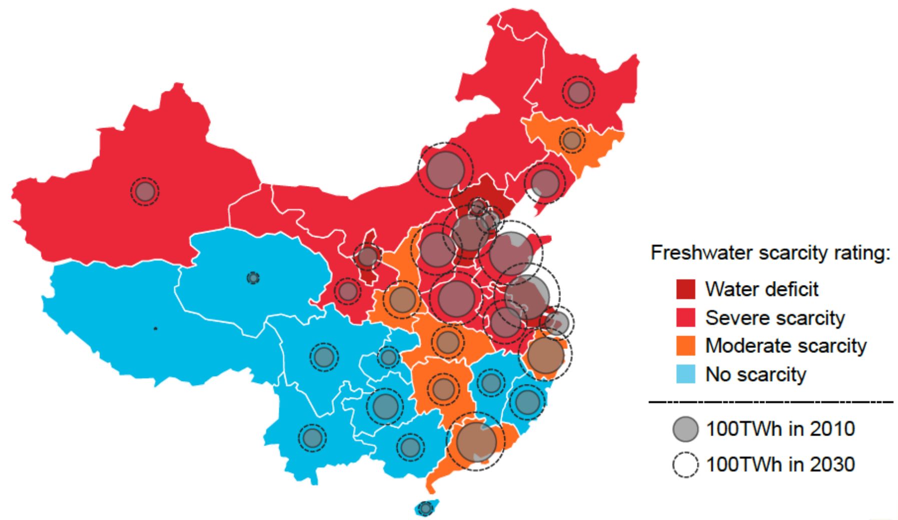
	Country	CO_2 emissions	Area (in km^2)	Population	Emission / Person
	World	33,376,327	148,940,000	6,852,472,823	4.9
	China	9,700,000	9,6[illegible]	[illegible]252	7.2
	United St[illegible]	5,420,0[illegible]	[illegible]	[illegible]	17.3
	India	1,9[illegible]	[illegible]	[illegible]	2
	Russia	1,83[illegible]	[illegible]	[illegible]	12.8
	Japan	1,24[illegible]	[illegible]	[illegible]	9.8
	Germany	810,000	[illegible]	81,799,600	9.9
	South Korea	610,000	100,210	48,875,000	12.6
	Canada	560,000	9,984,670	34,685,000	16.2

China's
Environment
Challenge

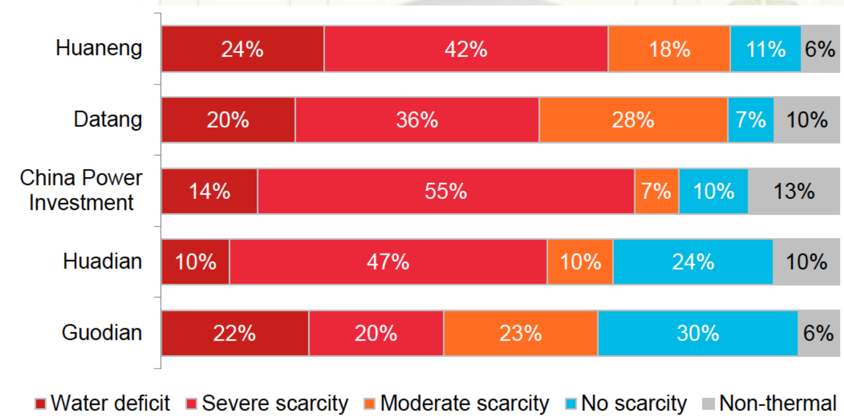
EDGAR (database created by European Commission and Netherlands Environmental Assessment Agency) released 2011 estimates. The following table is lists the 2011 estimate of annual CO2 emissions estimates (in thousands of CO2 tonnes) from these estimates along with a list of emissions per capita (in tonnes of CO2 per year) from same source.

Water Scarcity Threats China's Thermal Power Plants

- China's "Big Five" power utilities exposed to water disruption in their 500GW of plants;
- Their thermal plants used 102bn m^3 of water for cooling in 2010 and forecasted to use even more in 2030;
- Most thermal (Coal) plants in China are located in water deficit region;
- Retrofitted to air-cooling uses less water but decreases efficiency by 3-10% and costs $20bn per 100GW to current plants;
- Adopting non-water cooled power generation technology is a viable solution.



Power generation vs. water scarcity by province in China



China Big Five's capacity in water scarce region

Data and pictures from Bloomberg New Energy Finance Report, March 25, 2013

Essays

Alternative Energy Sources

Beyond Oil and Gas: The Methanol Economy**

*George A. Olah**

Keywords:
environmental chemistry · hydrocarbons · hydrogen · methanol

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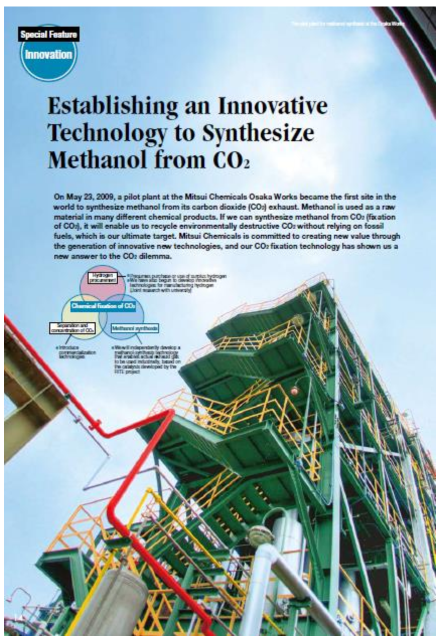
Anthropogenic Chemical Carbon Cycle for a Sustainable Future

George A. Olah,* G. K. Surya Prakash, and Alain Goeppert

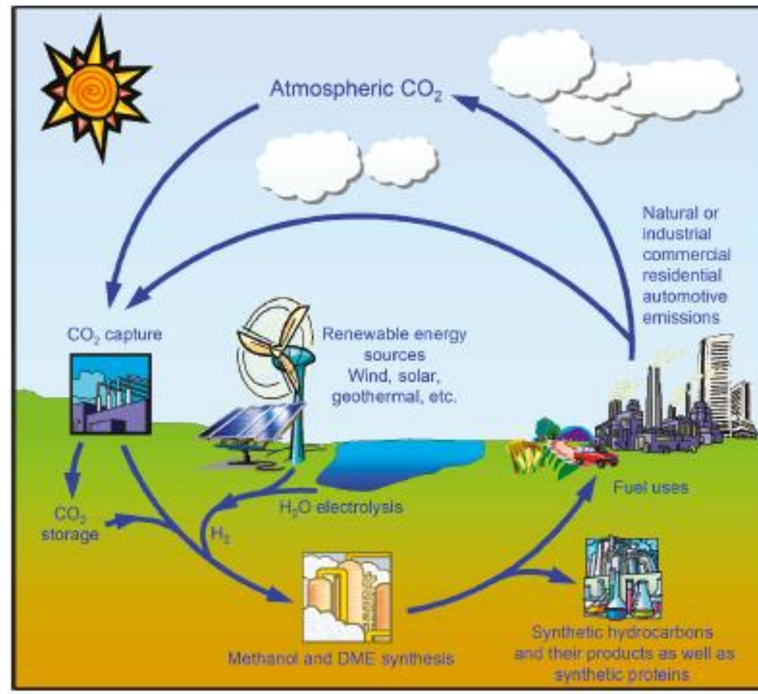
Loker Hydrocarbon Research Institute and Department of Chemistry, University of Southern California, University Park, Los Angeles, California 90089-1661, United States

Hydrogen Production Using Nuclear Energy and Carbon Dioxide Hydrogenation to Methanol


Special Feature
Innovation

Establishing an Innovative Technology to Synthesize Methanol from CO_2

On May 23, 2009, a pilot plant at the Mitsui Chemicals Osaka Works became the first site in the world to synthesize methanol from its carbon dioxide (CO_2) exhaust. Methanol is used as a raw material in many different chemical products. If we can synthesize methanol from CO_2 (fixation of CO_2), it will enable us to recycle environmentally destructive CO_2 without relying on fossil fuels, which is our ultimate target. Mitsui Chemicals is committed to creating new value through the generation of innovative new technologies, and our CO_2 fixation technology has shown us a new answer to the CO_2 dilemma.



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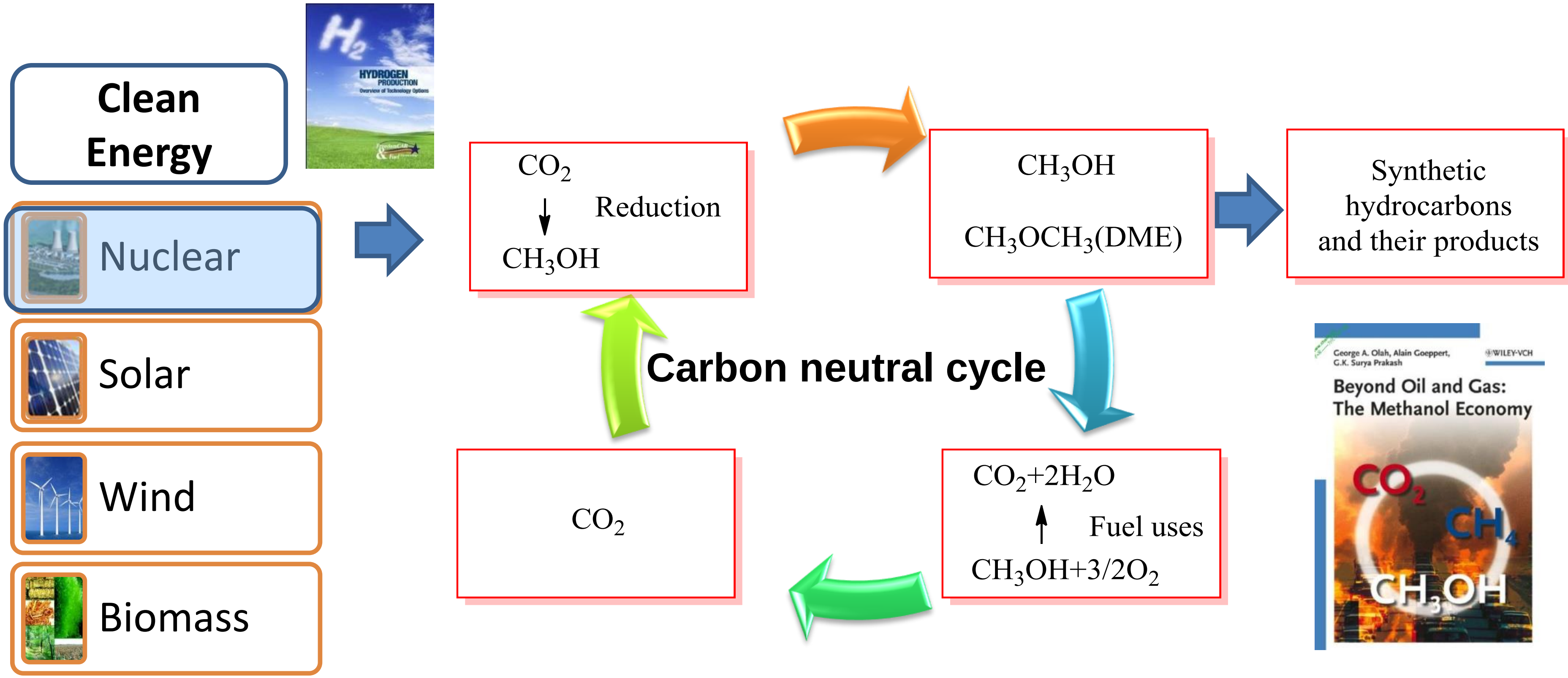
Methanol Economy: Carbon Neutral Cycle



George Andrew Olah
1994 Nobel Prize in Chemistry

1. Carbon neutral cycle based on methanol is one way to solve energy and environment problems.
2. Methanol producing from CO_2 and H_2 is the optional technology.
3. Hydrogen does not exist naturally, should get from clean energy without CO_2 emission.
4. The efficiency of methanol production from CO_2 should be improved.

Generations of Nuclear Energy

Generation I

Early Prototypes

- Shippingport
- Dresden
- Magnox

Generation II

Commercial Power

- PWRs
- BWRs
- CANDU

Generation III

Advanced LWRs

- CANDU 6
- System 80+
- AP600

Generation III+

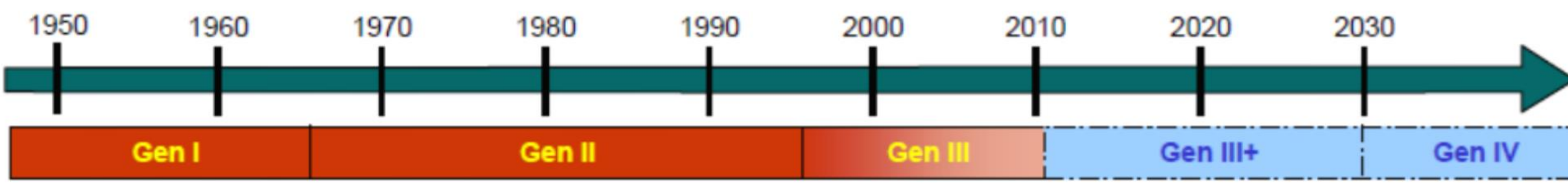
Evolutionary Designs

- ABWR
- ACR1000
- AP1000
- APWR
- EPR
- ESBWR

Generation IV

Revolutionary Designs

- Safe
- Sustainable
- Economical
- Proliferation Resistant and Physically Secure



Overview of the Generation IV Systems

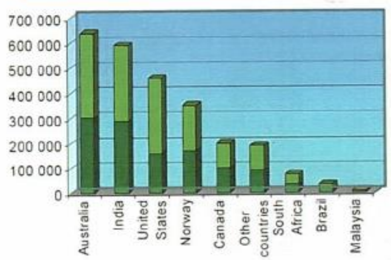
System	Neutron Spectrum	Fuel Cycle	Size (MWe)	Applications	R&D Needed
Very-High-Temperature Reactor (VHTR)	Thermal	Open	250	Electricity, Hydrogen, Process Heat	Fuels, Materials, H_2 production
Supercritical-Water Reactor (SCWR)	Thermal, Fast	Open, Closed	1500	Electricity	Materials, Thermal-hydraulics
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

Why G IV

- Safe：
  - **Residual heat** will be removed with active cooling system in GIII ；
  - **Residual heat** will be removed with passive cooling system in GIV (natural cycle), aiming to inherent safe.
- Substanable：
  - Fuel availability is 1～2% in GIII;
  - Fuel availability is large than 10% in GIV, aiming to fully fuel cycle.
- Economic:
  - Output heat is about 300℃ in GIII， Efficiency of therm/electr is about 33%;
  - Output heat is > 500℃ in GIV， the thermoelectric conversion efficiency will be higher， and the hybrid application will be possible.
- Non-proliferation：
  - The proliferation is comtrolled by man-power (politic, economic , military) in GIII;
  - Proliferation resistance is physical in GIV.

About Thorium

India's thorium reserves stimulate its thorium power development.



India's nuclear strategy
1. Heavy water reactors for unenriched, limited uranium reserves.
2. Fast breeder reactor for plutonium from spent fuel uranium
3. Thorium fast breeder reactor.

India has 13 heavy water reactors plus 4 under construction.

The CANDU-like technology allows breeding U-238 to Pu-239 and Th-232 to U-233.

India already has reprocessing facilities and a developmental breeder reactor.

Kamini reactor tests U-233 from Kalpakkam experimental breeder.

0.5 GW fast breeder reactor is under construction, due 2010.

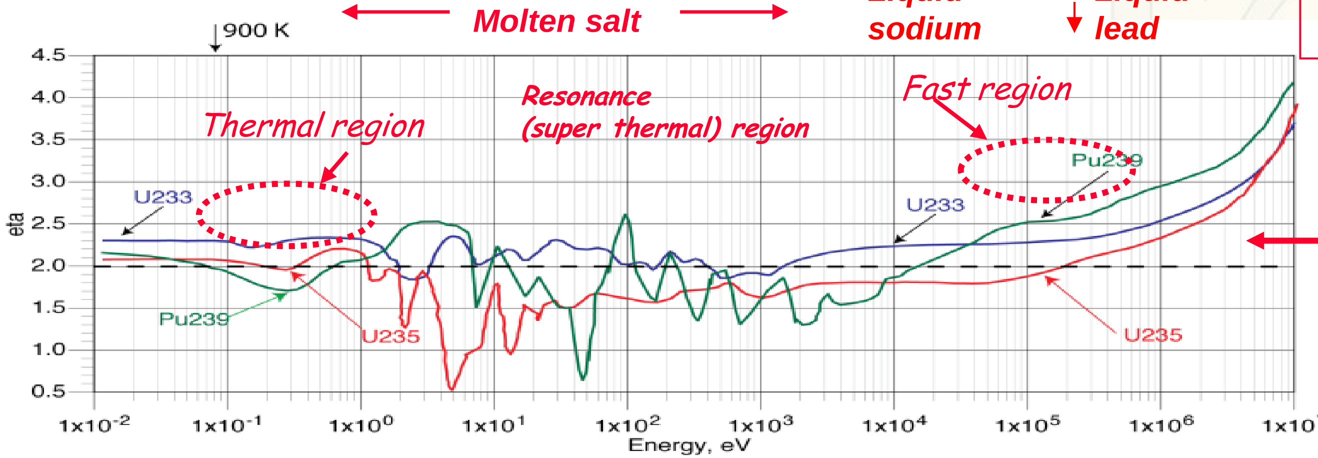
20 GW of U and Th power by 2020. 30% of electricity from Th by 2050.

India has little uranium, which has been difficult to obtain, because India did not sign the Nuclear Non-proliferation Treaty.

India's thorium power reactor development uses solid fuel, not liquid fluoride salts as the LFTR uses.

CONCLUSION –C.Rubia

Unlike other energy sources, China's reserves of Thorium, may ensure the major domestic energetic supply for many centuries to come. For instance the whole China's today electricity (3.2 Trillion kWh/year) could be produced during ≈20'000 years by well optimized Th reactors and 8,9 million ton of Th, a by-product of the China's REE basic reserves.



Possible Th232/U233 methods

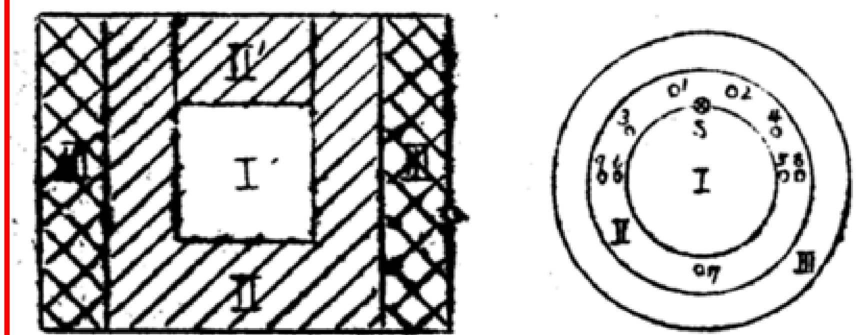
$\eta = 2$

only fast neutron is suitable to U238/Pu239

TMSR

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.

1972-1975, in SINAP about 400 scientists and engineers designed the Qinshan 300 MWe (Qinshan NPP-I), which has been operating since 1991.

Thorium Molten Salt Reactor Nuclear Energy System - TMSR

- The Aims of TMSR is to develop Th-Energy, Non-electric application of Nuclear Energy based on TMSR(LF) and TMSR(SF) during coming 20-30 years.
- The program initiated by CAS from 2011
- TMSR(LF) 液态燃料钍基熔盐堆 --- MSRs
- TMSR(RF) 固态燃料钍基熔盐堆 --- FHR s

Thorium Molten Salt Reactor nuclear energy system

Th-based fuel

Abundant
Minimized n-waste
Non-proliferation

Thorium/ MSR

TMSR-SF: partly utilization of Thorium
TMSR-LF: Realize full close Th-U cycle

Thorium Molten Salt Reactor nuclear energy system

Fluoride-coolin

Safety
High Temp.
Water-Free

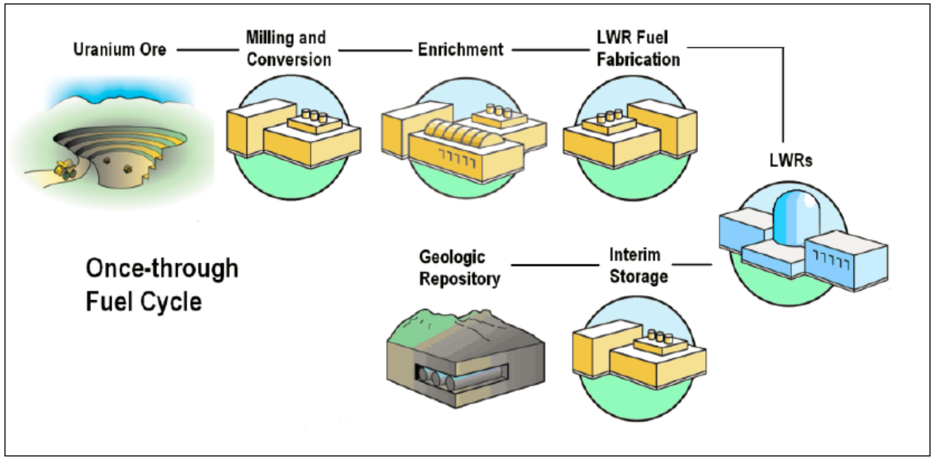
Outline

Why TMSR

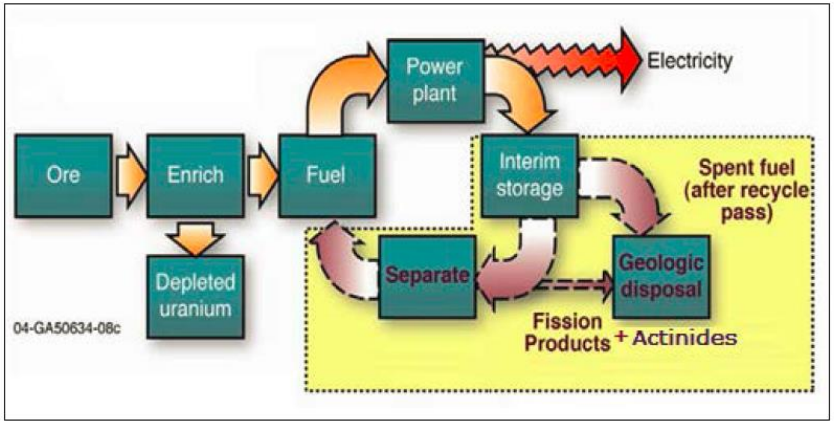
Th-E @ TMSR

Status and Progress

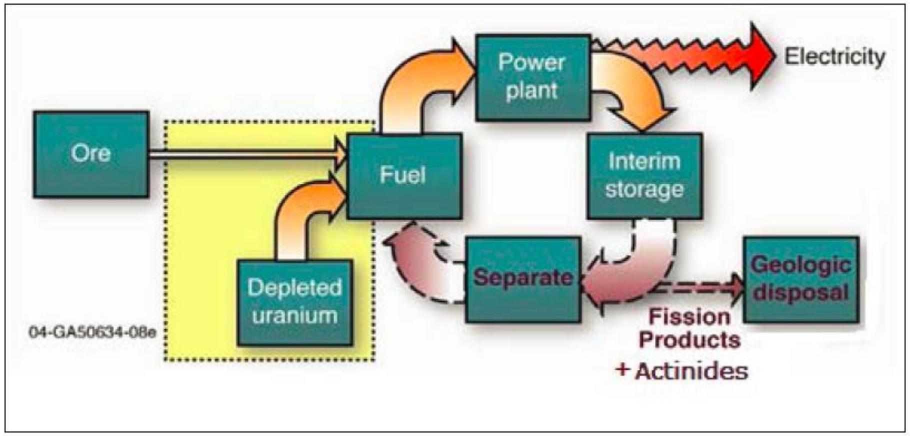
Nuclear Fuel Cycle Modes



- ***The Once-Through Fuel Cycle***
- ***Alternate Once-Through Fuel Cycles***



Modified Open Fuel Cycle



Fully-Closed Fuel Cycle with (Sustained) Recycle

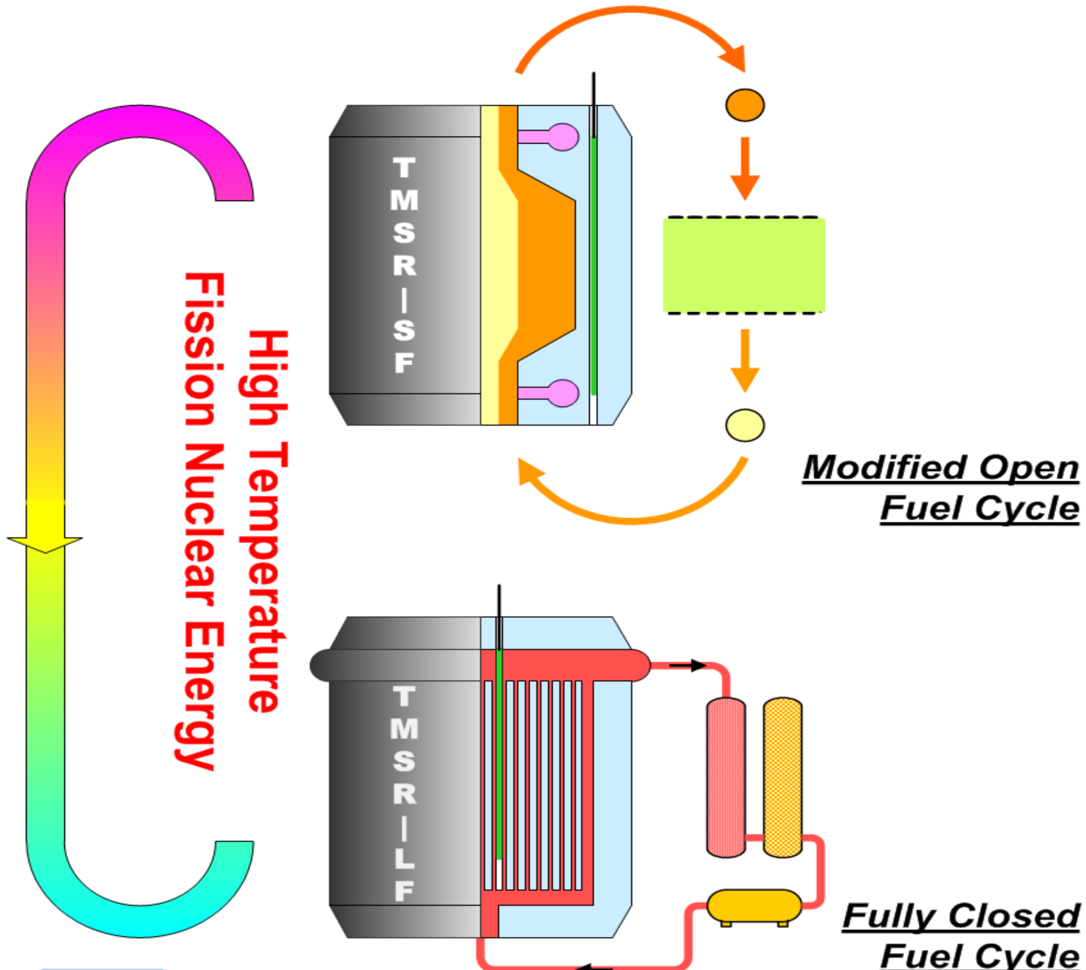
Reactors and Applications

Thorium Energy

High Temperature H_2 Production

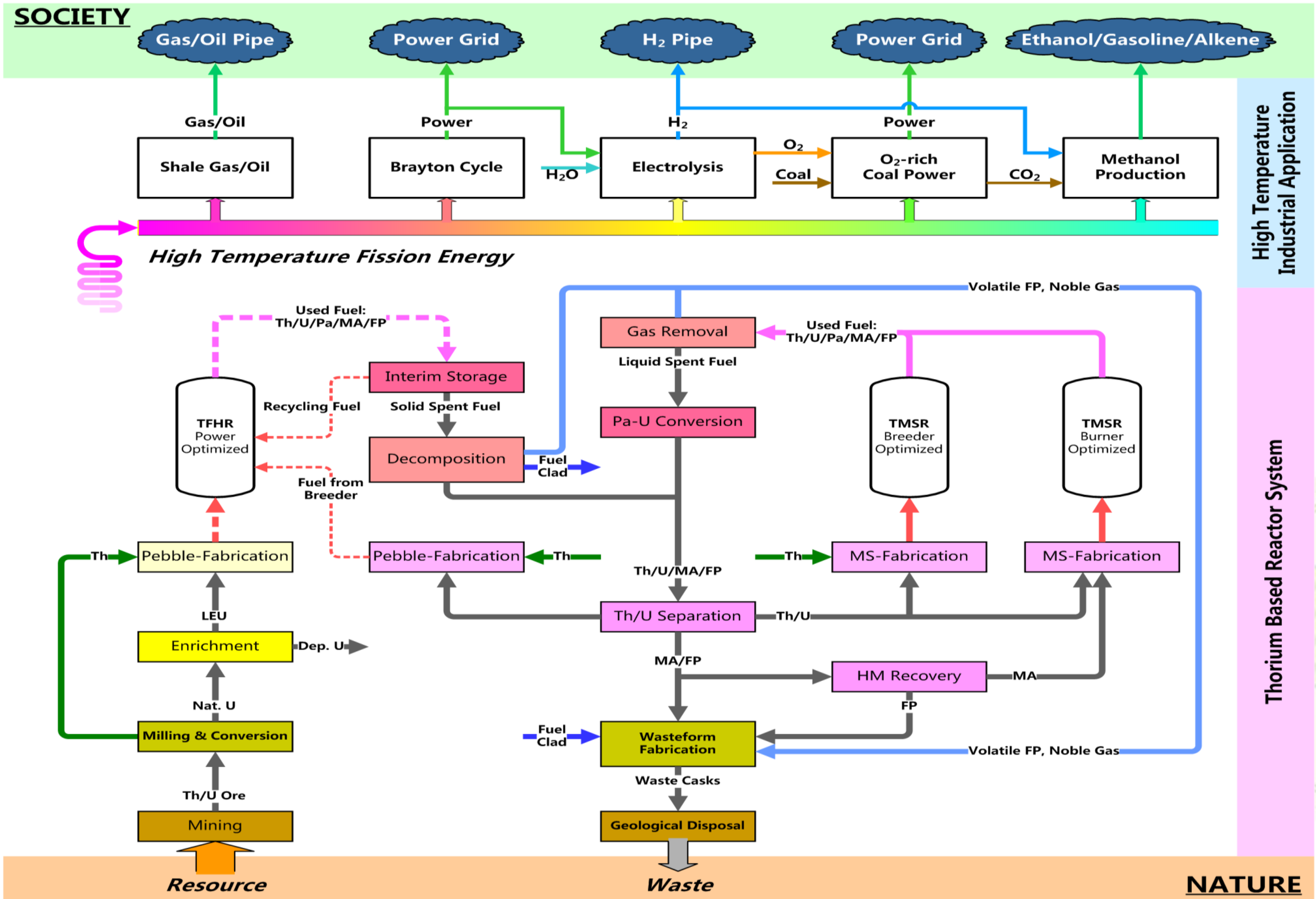
Water-free Cooling

Small Modular Design



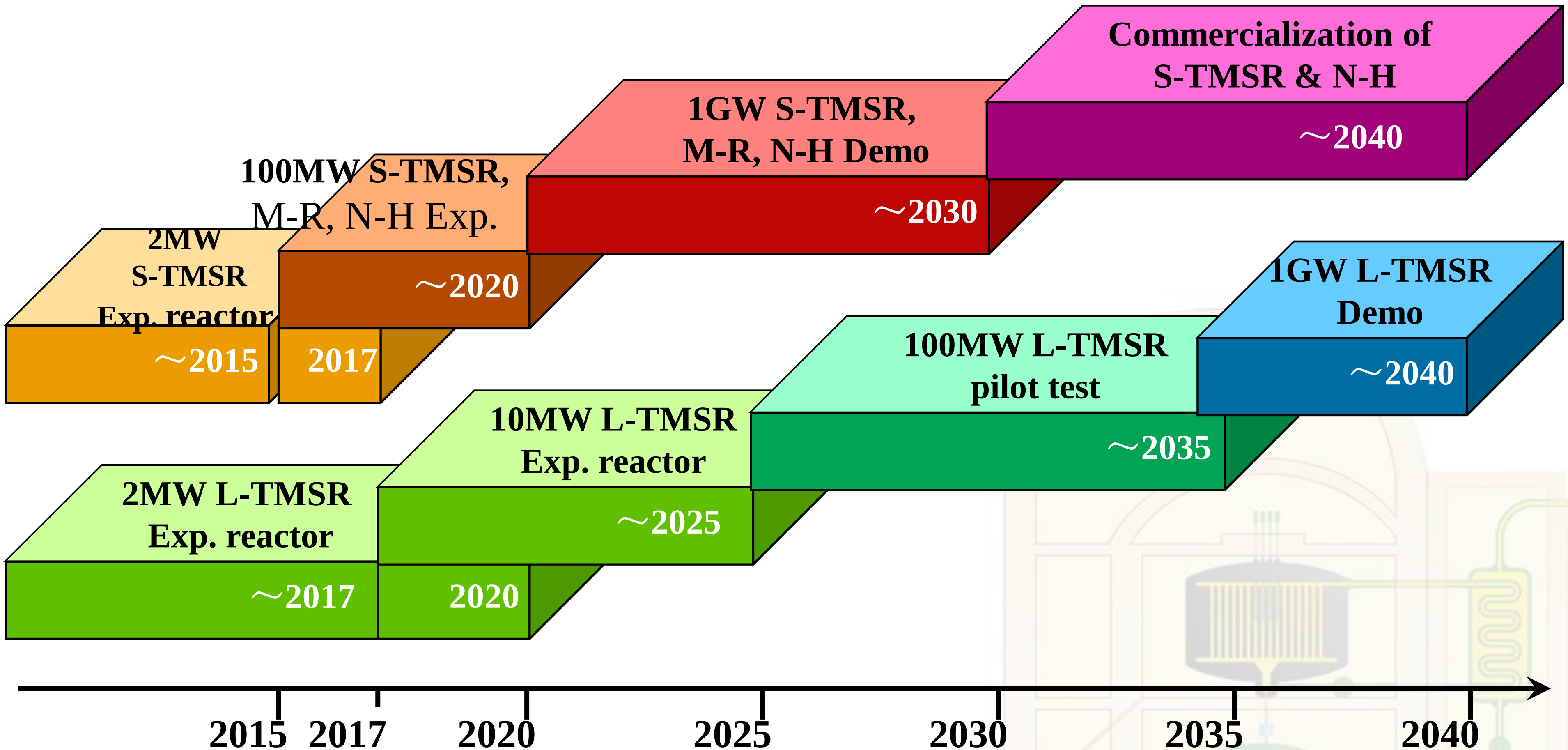
Long-term | Mid-long | Mid-term

Strategy of TMSR R&D


SOCIETY
Gas/Oil Pipe
Power Grid
H₂ Pipe
Power Grid
Ethanol/Gasoline/Alkene
Gas/Oil
Power
H₂
Power
Shale Gas/Oil
Brayton Cycle
H₂O
Electrolysis
O₂
Coal
O₂-rich Coal Power
CO₂
Methanol Production
High Temperature Industrial Application
High Temperature Fission Energy
Volatile FP, Noble Gas
Used Fuel: Th/U/Pa/MA/FP
Gas Removal
Used Fuel: Th/U/Pa/MA/FP
Interim Storage
Liquid Spent Fuel
TFHR Power Optimized
Recycling Fuel
Solid Spent Fuel
Pa-U Conversion
TMSR Breeder Optimized
TMSR Burner Optimized
Decomposition
Fuel Clad
Fuel from Breeder
Th
Pebble-Fabrication
Pebble-Fabrication
Th
Th
MS-Fabrication
MS-Fabrication
Th/U/MA/FP
LEU
Th/U Separation
Th/U
Enrichment
Dep. U
MA/FP
HM Recovery
MA
Nat. U
FP
Fuel Clad
Wasteform Fabrication
Milling & Conversion
Volatile FP, Noble Gas
Th/U Ore
Waste Casks
Mining
Geological Disposal
Resource
Waste
NATURE
Thorium Based Reactor System

FHRs Can Be Considered A Precursor to MSRs

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



Th-U cycle

Nuclear power plant

MS coolant

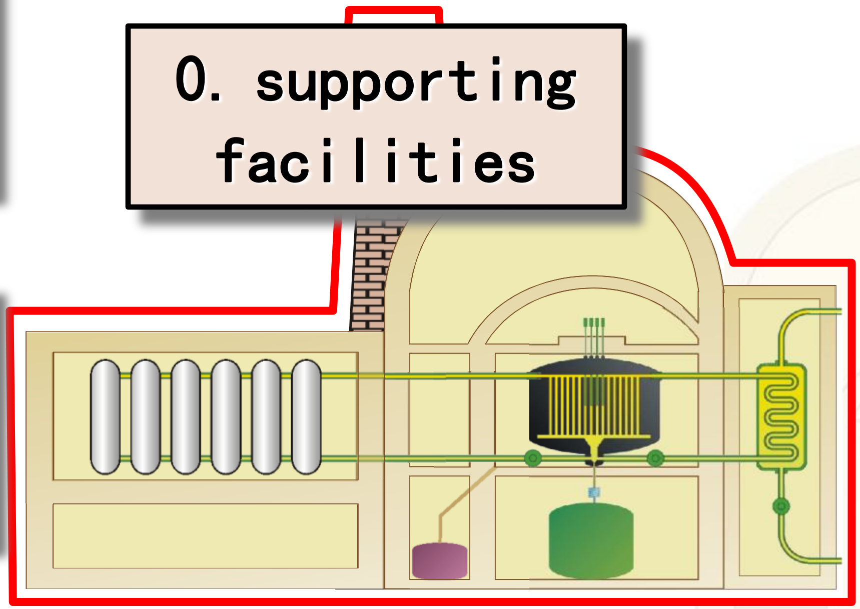
Hydrogen production with high temperature nuclear power

TMSR WBS (0)

1. Reactor Phys. &Eng.

2. Molten-Salt Chem. &Eng.

0. supporting facilities



3. Th-U Radioactive Chem. &Eng.

4. Nuclear Power Material & Eng.

5. Th-U Security & Eng.

Reactor Modeling

Thermal-Power Cycle

Nuclear Hydrogen& CO_2/Carbon Utilization

R&D abilities –I for TMSR deveopment

- **TMSR reactor design and development.**
  - Reactor core design: neutron physics, thermal hydraulics...
  - Engineering design and construction.
  - Key technologies and components.
- **Developing safety codes and licensing**

R&D abilities -II for TMSR deveopment

- **Molten salt manufacturing techniques and molten salt loop techniques**
  - Separation of ^{7}Li.
  - Purification of fluoride salt.
  - Design and construction of molten salt loops.
  - Development of key components for molten salt loop.

Materials for TMSRs

- Production, processing and testing of structure materials TMSR (Hastalloy-N, Graphite etc.).
- Carbon-based structure materials and components for TMSR
- Effect and mechanism of material degrading under service condition.

Th/U fuel and Pyro-process techniques

- Production of nuclear-grade Thorium fuel (both fluoride and oxide).
- Triso fuel manufacturing
- Pyro-process techniques for on-line (or in-site) off-line) chemical separation of actinides and fission product for Th/U fuel cycle).

Techniques of Nuclear Hybrid Energy system

100kW CSP (the salt is absorber and heat storage media)

- Techniques for hydrogen producing
- Methanol producing from CO2 and H2
- CSP techniques

Outline

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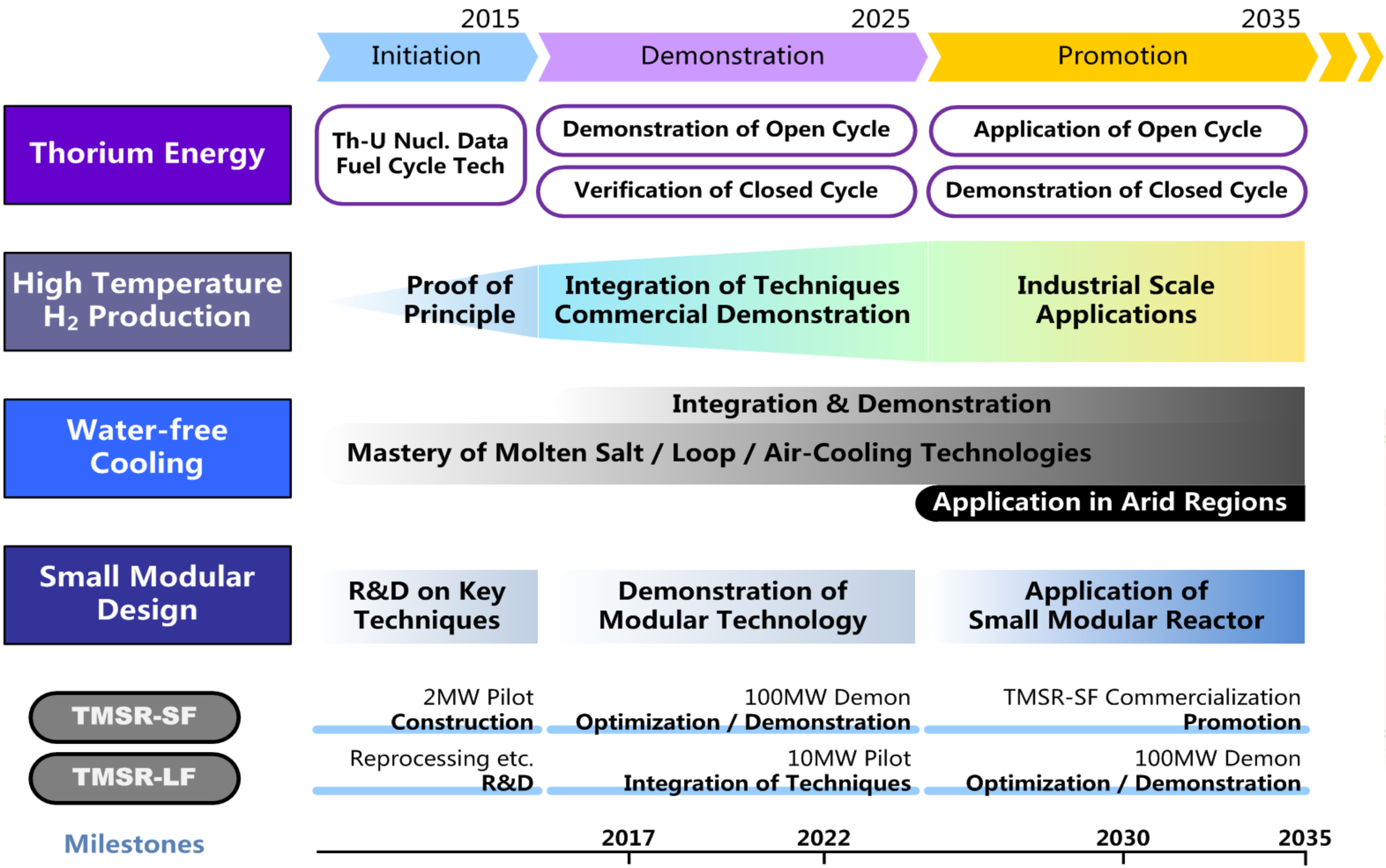
Th-E @ TMSR

Status and Progress

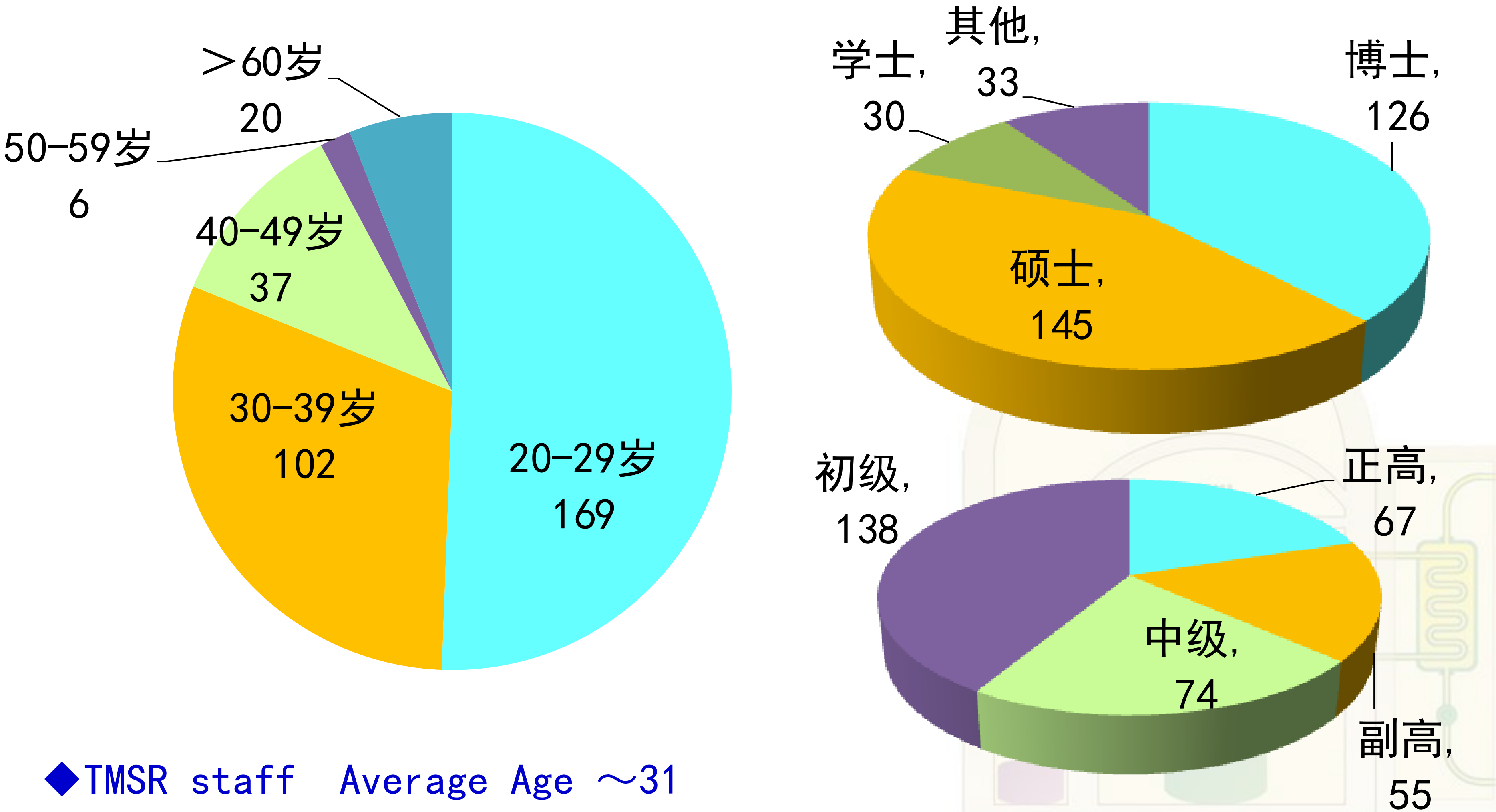
TMSR Schedules



Team and Organization

- Basic team –from SINAP (some have the experiences of SSRF construction). It take time for them to be professional researchers
- Young scientists and engineers are majority – for the future.
- To attract the exellent younger and experienced scientists both from domestic and abroad.

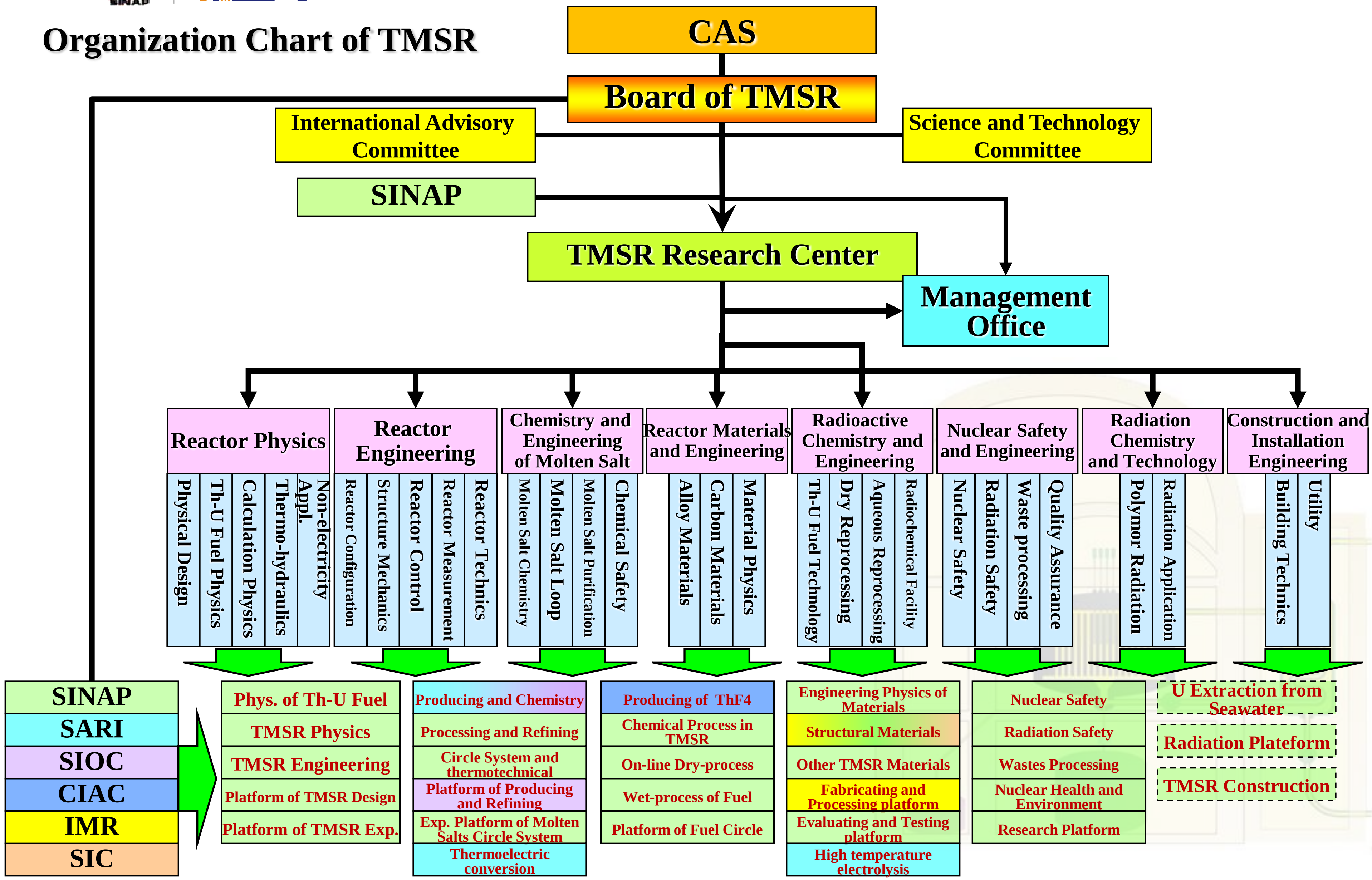
Team Structure of TMSR（）400）



◆TMSR staff Average Age ～31

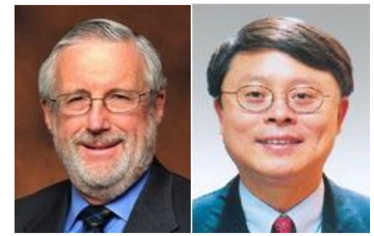
◆Key personnel Average Age ～38

Organization Chart of TMSR



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) 江绵恒
U.S. – Peter Lyons (DOE)

Technical Coordination Co-Chairs

China – Zhiyuan Zhu (CAS) 朱志远
U.S. – Stephen Kung (DOE)

Nuclear Hybrid Energy Systems *

- Zhiyuan Zhu (CAS) 朱志远
  Yuhan Sun (SARI,CAS) 孙予罕
- Steven Aumeier (INL)

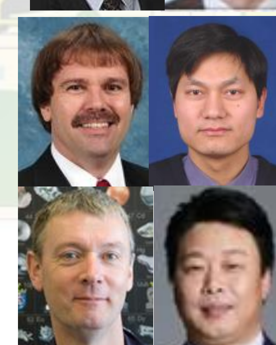
* Work scope governed by DOE-CAS Science Protocol Agreement

Molten Salt Coolant Systems

- Hongjie Xu (SINAP, CAS) 徐洪杰
  Weiguang Huang (SARI,CAS) 黄伟光
- Cecil Parks (ORNL)
  Charles Forsberg (MIT)

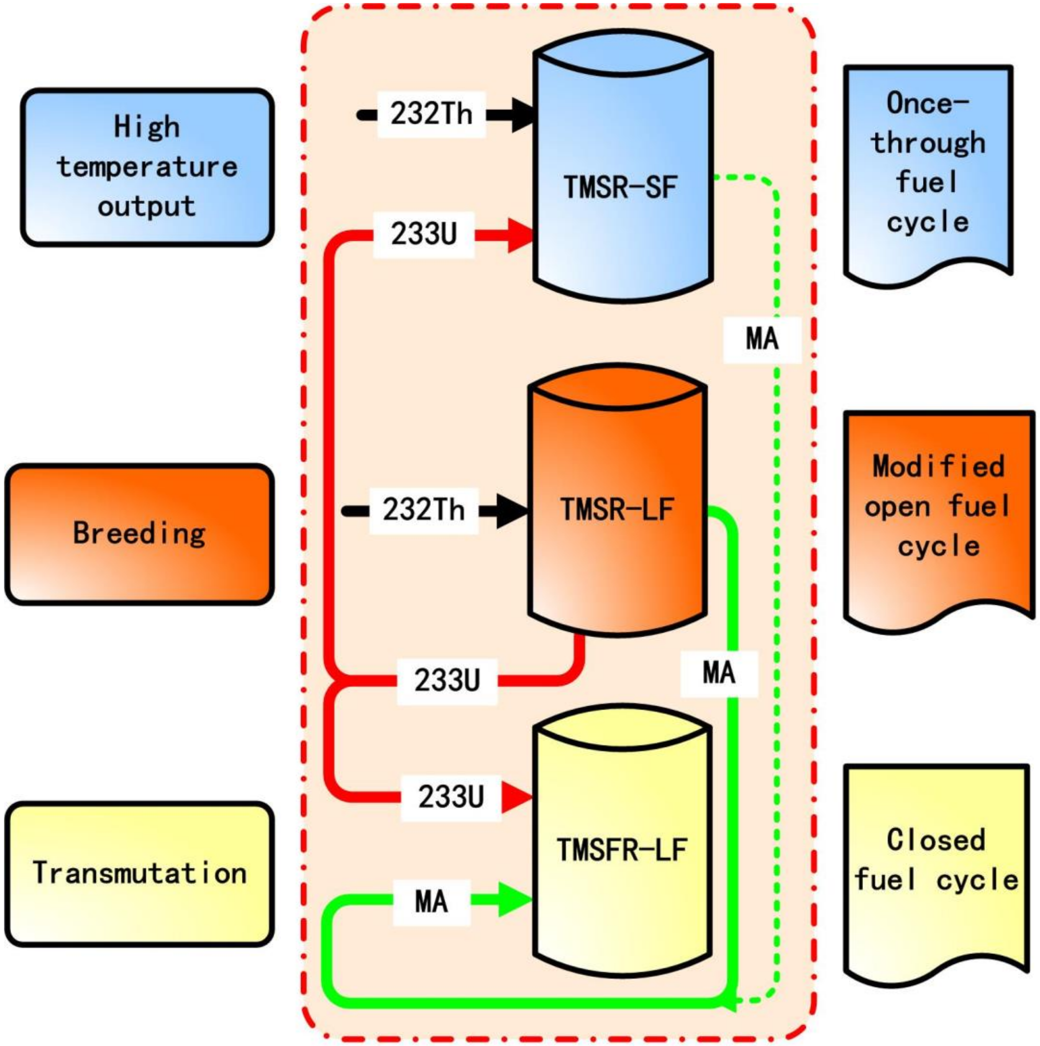
Nuclear Fuel Resources

- Zhimin Dai (SINAP, CAS) 戴志敏
  Biao Jiang (SARI,CAS) 姜标
- Phil Britt (ORNL)
  John Arnold (UC-Berkeley)



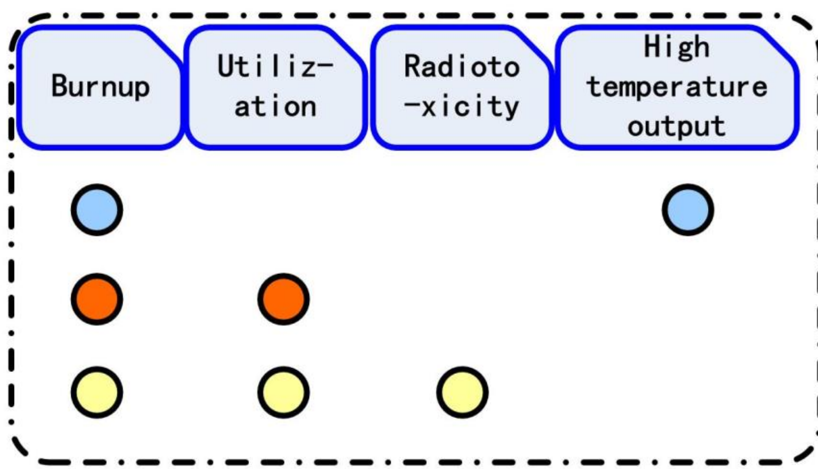
SINAP :Shanghai Institute of Applied Physics
SARI: Shanghai Advanced Research Institute
ORNL: Oak Ridge National Laboratory
INL: Idaho National Laboratory
MIT: Massachusetts Institute of Technology
UC-Berkeley: University of California at Berkeley

Ⅰ、Preliminary Physical Analysis of Th/U Fuel Cycle Based on MSR (1GWth)

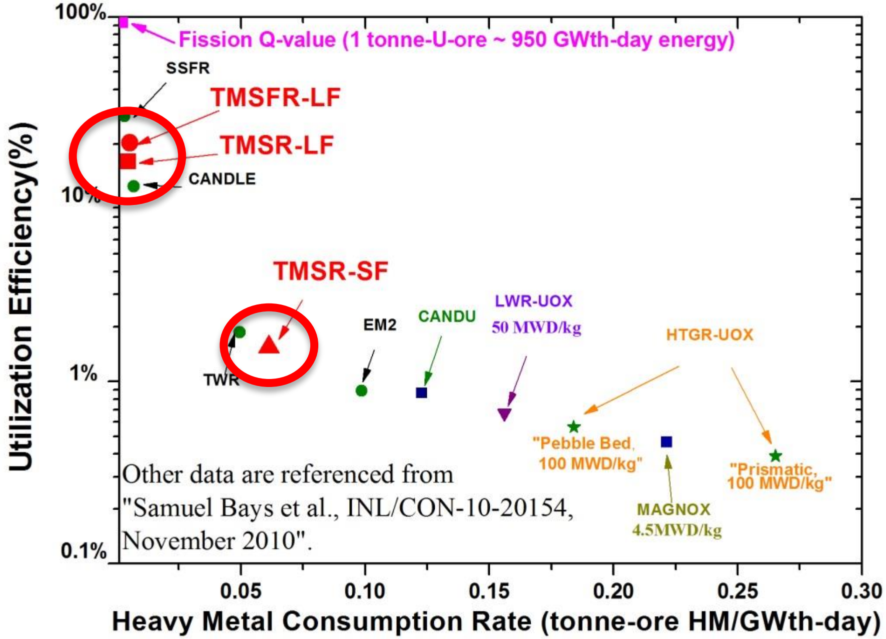


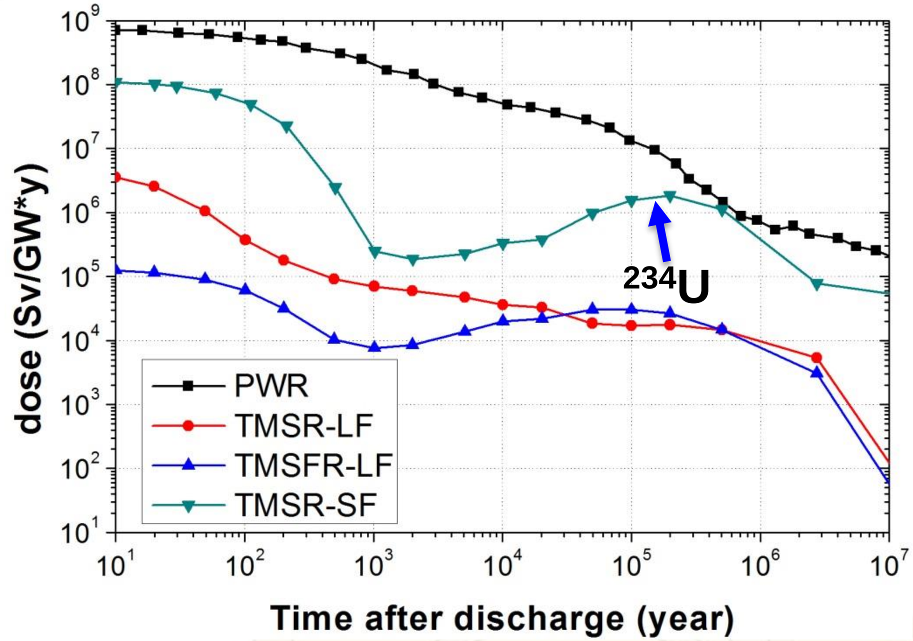
Application of Th-U fuel cycle in TMSR (**1GWth**)

- TMSR-SF: thorium utilization with high burnup
- TMSR-LF: breeding of ^{233}U
- TMSFR-LF: transmute spent nuclear fuel



Fuel utilization and radiotoxicity





TMSR-LF with online processing can significantly improve the fuel utilization.

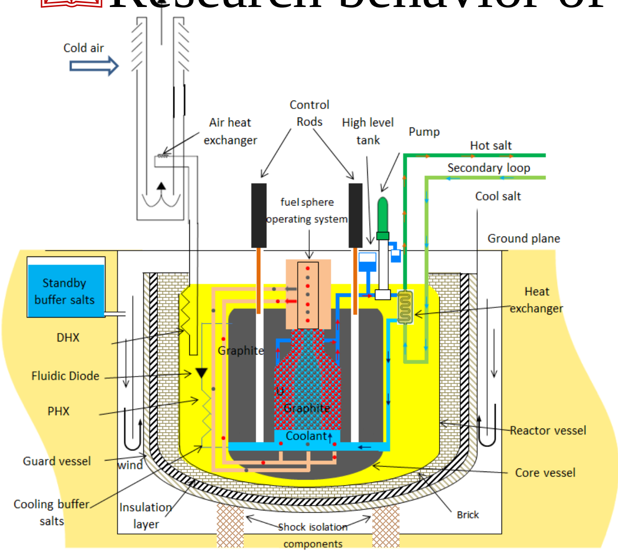
TMSR-SF has far higher radiotoxicity than TMSR-LF, but still lower than traditional PWR.

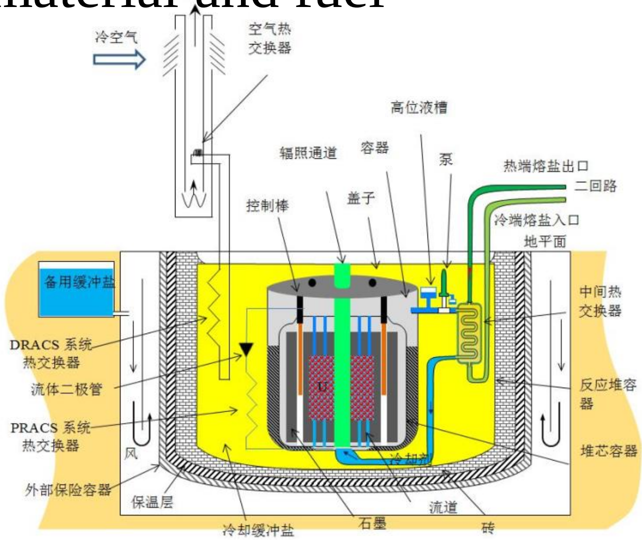
- **Higher burnup of TMSR-SF to save uranium resource.**
- **TMSR-LF and TMSFR-LF to realize self-sustaining and produce U-233.**
- **TMSFR-LF is optimized for transmutation.**

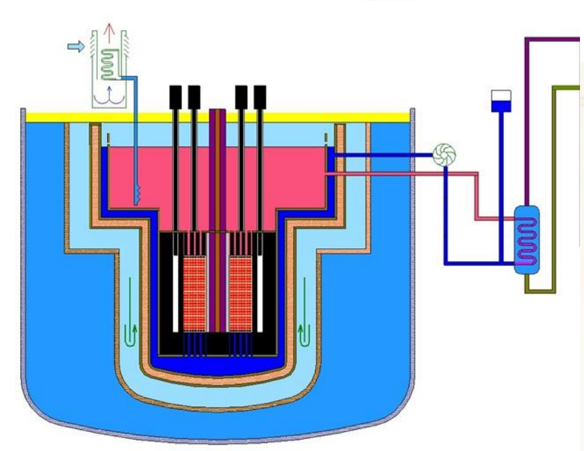
A Combination of TMSRs to realize self-sustaining Th-U fuel cycle and nuclear waste minimization.

II、Goals and physical design for TMSR-SF1

- Form abilities for design: physics design, thermal-hydralics design, safety system design and engineer design
- Form abilities for integration, operation and maintenance.
- Verify characteristics of FHR: physics behavior, safety behavior and thermal-hydralics behavior
- Research behavior of material and fuel



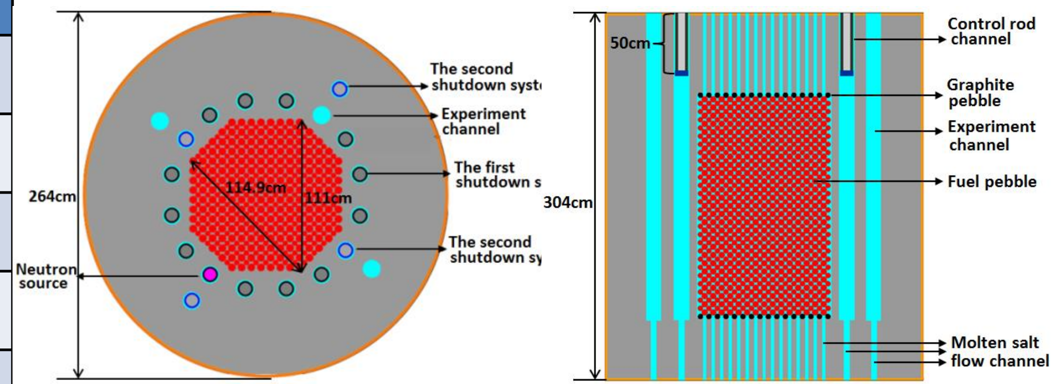




From partition flow pebble bed design to No-partition ordered pebble bed design

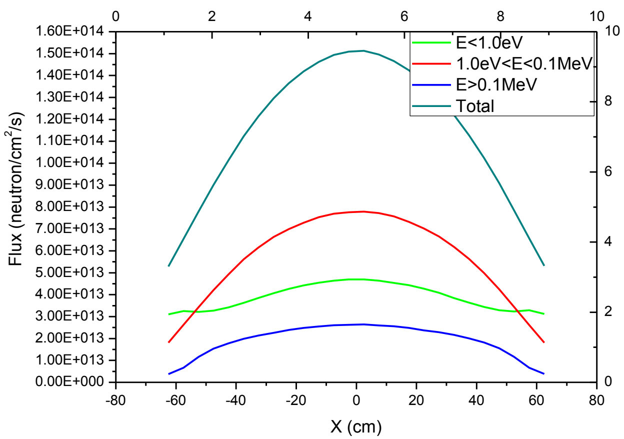
Core geometry of TMSR-SF1

Parameters	Value
Fuel Pebble diameter	6.0 cm
Number of Fuel Pebble	11043
Number of Graphite Pebble	432
Height of active core	185 cm
Side by side distance of active core	111cm 114.9 cm
Height of reflector	300.0 cm
Diameter of reflector	260.0 cm
Thickness of upper reflector	65.0 cm
Thickness of bottom reflector	50.0 cm
Thickness of side reflector	73.5 cm

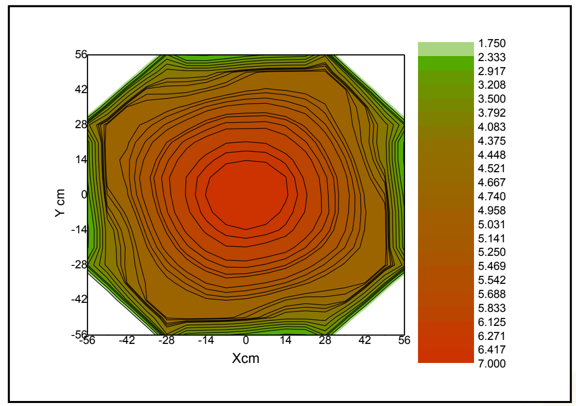


- Ordered-bed active core.
- Control rods: 12 regulating rods , 4 safety rods.
- Other channel:1 neutron source channel, 3 experimental channels.

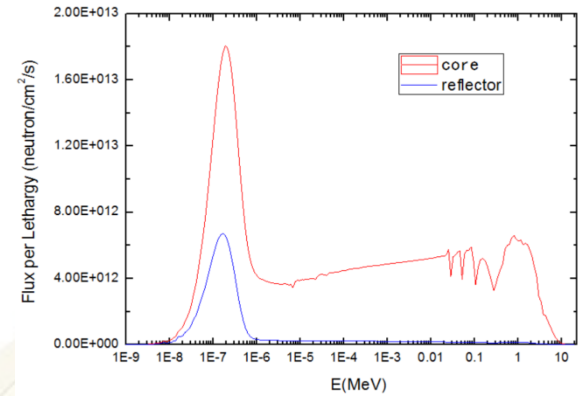
Neutron flux and power distribution



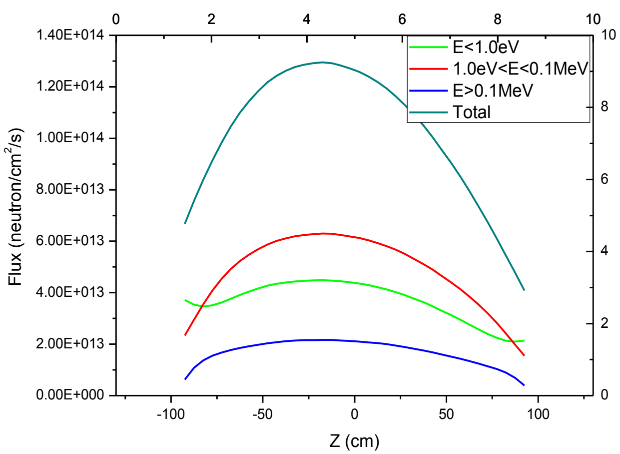
Radial neutron flux distribution



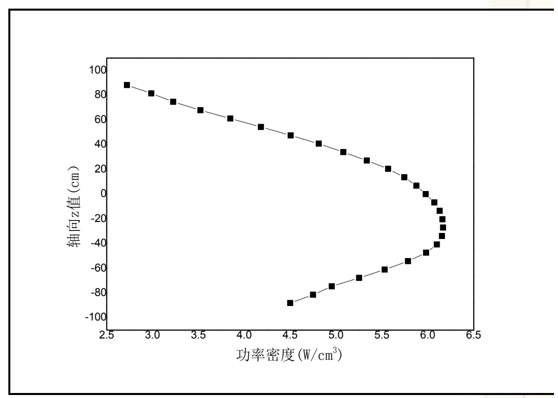
Horizontal power distribution



Neutron Spectra



Axial neutron flux distribution

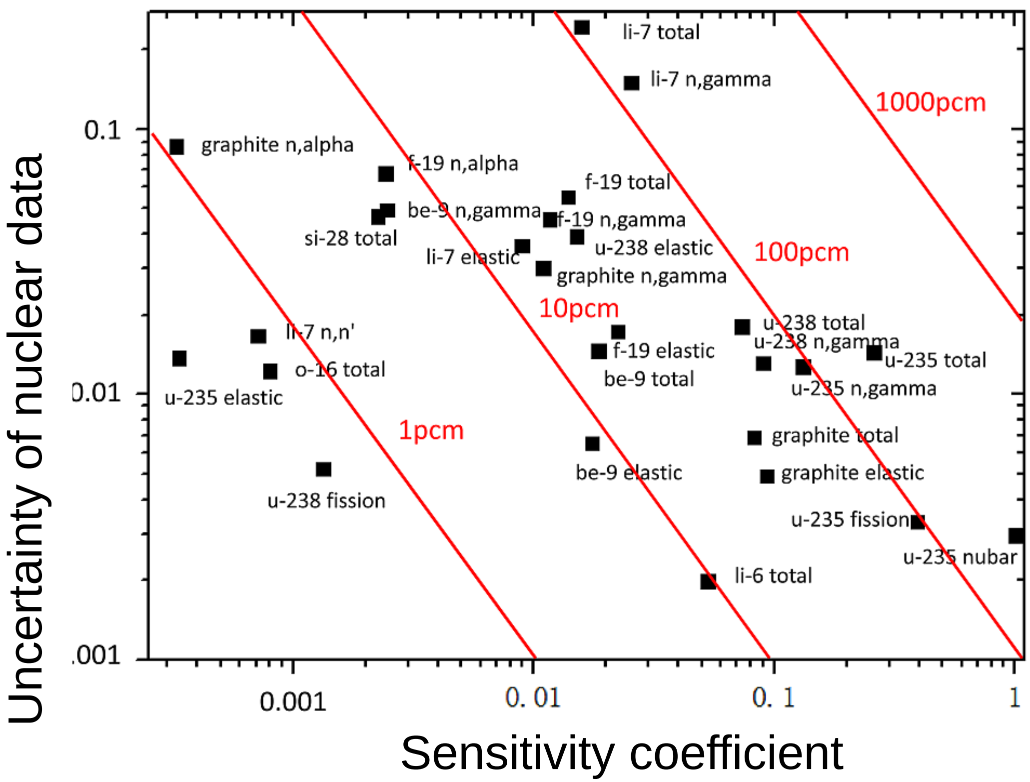


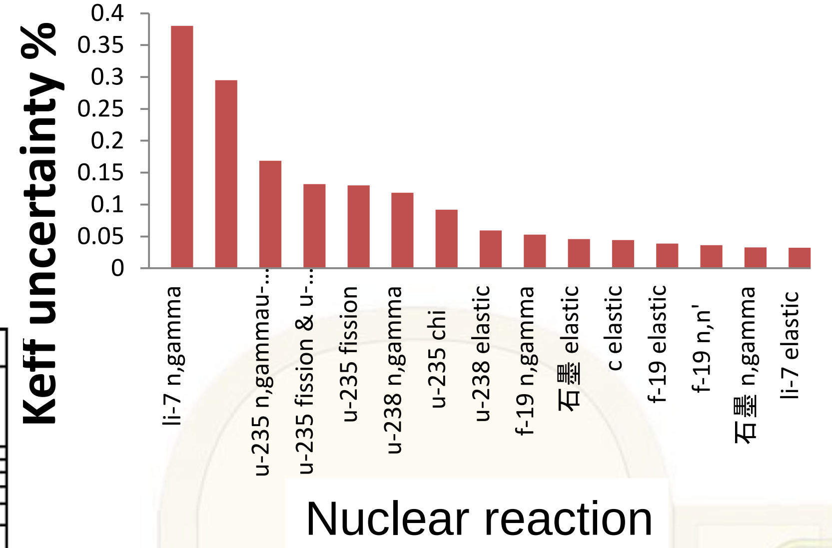
Axial power distribution

- Thermal neutron flux raised near reflector.
- Fast neutron flux dropped very fast near reflector.
- Because control rod is inserted, peak of power and flux shifts to the lower active core.

Uncertainty and sensitivity

- Uncertainty of keff caused by uncertainties of nuclear data is about 0.58%
- Li7 (n, γ) cross-section causes max uncertainty of keff, about 0.38%.

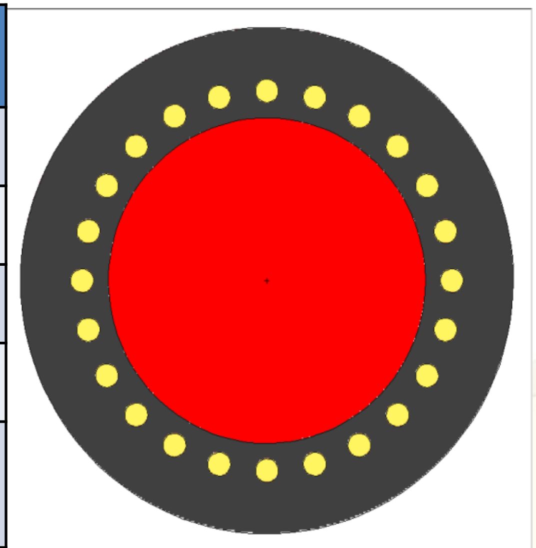


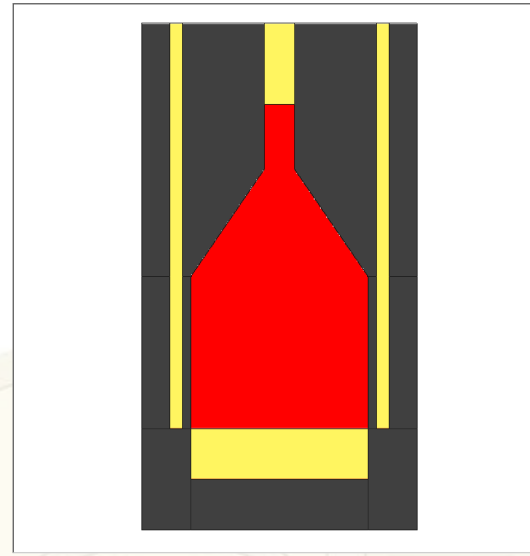


- Uncertainties of nuclear data, uncertainty of keff, sensitivity coefficient and their relations are demonstated in the left figure.

Pre-conceptual design of 100MW demonstrated reactor

Parameters	Value
Thermal Power	100 MW
Electric Power	45 MW
Power density	20 MW/m^3
Pebble diameter	3 cm
Coolant of primary loop	$2LiF\text{-}BeF_2$
Core in/out T	650℃ /700℃
Mass of heavy metal	470 kg
U235 enrichment	15%
Volume of active core	4.9 m^3
Height of active core	1.9 m
Diameter of active core	1.8 m



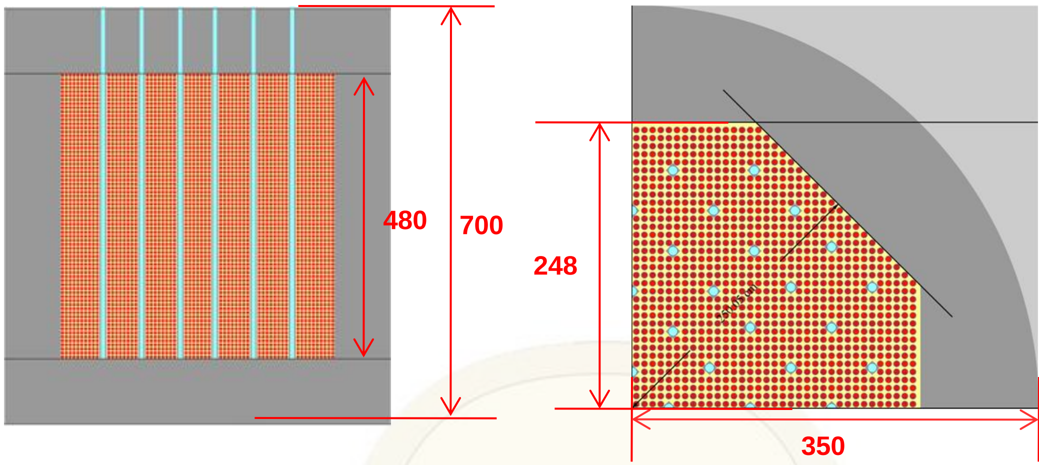


Consideration

- Economic demonstation
- Safety demonstation
- Technology R&D
- Ability of design, building, operation and management

Pre-conceptual design of 1GW order-bed reactor

Parameters	Value
Thermal Power	1 GW
Electric Power	45 MW
Power density	10.1 MW/m^3
Pebble diameter	6 cm
Coolant of primary loop	$2LiF\text{-}BeF_2$
Core in/out T	600℃ /710℃
Mass of heavy metal	7 t
U235 enrichment	13.5%
Volume of active core	99 m^3
Height of active core	4.8 m
Diameter of active core	~5 m
Max burnup	98 GWD/tU



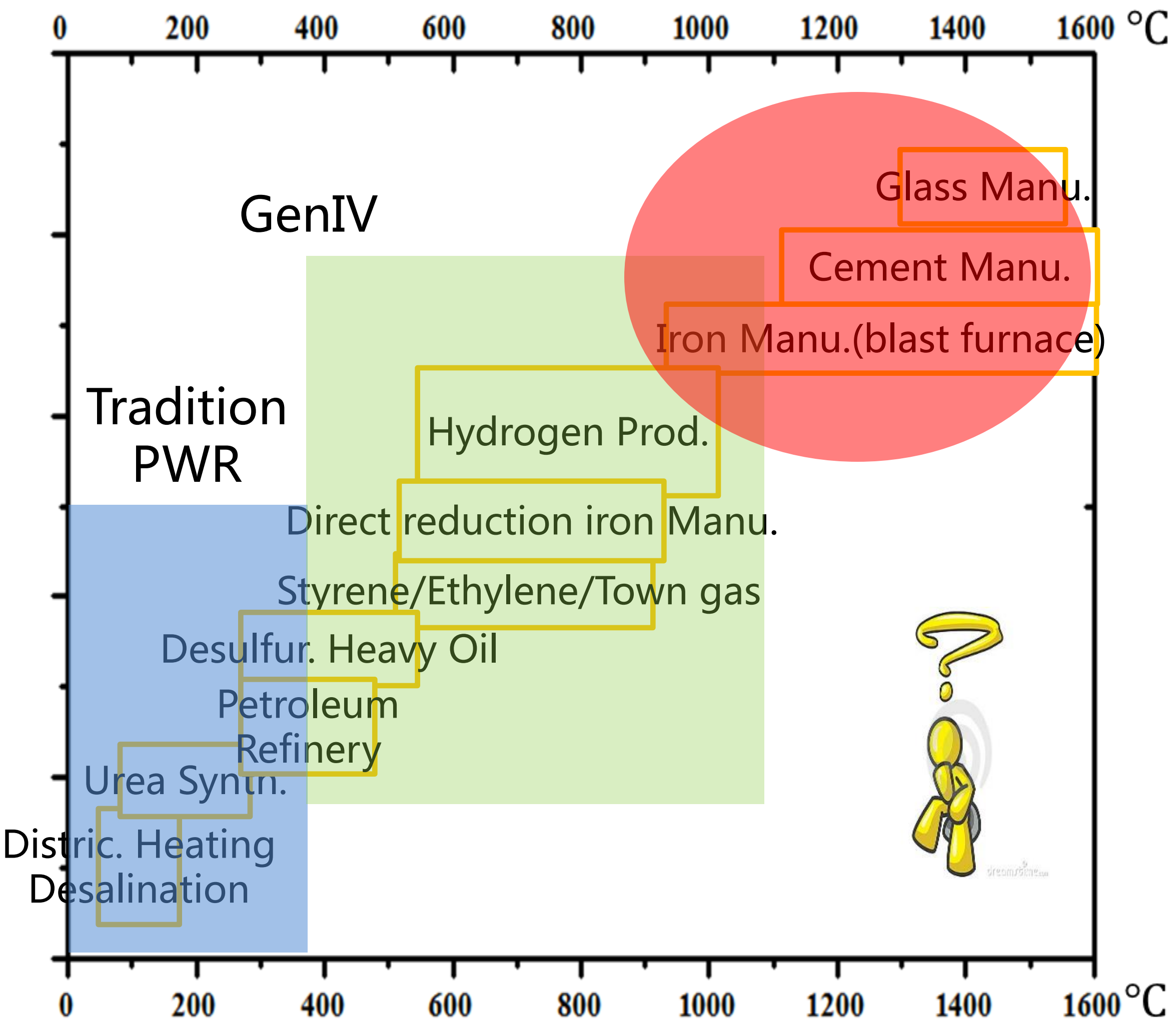
📖Consideration

- Ordered-bed
- Utilize current fuel pebble
- Use via hole formed in ordered-bed for reactivity control system

III、Development Plan of Th-based fuel

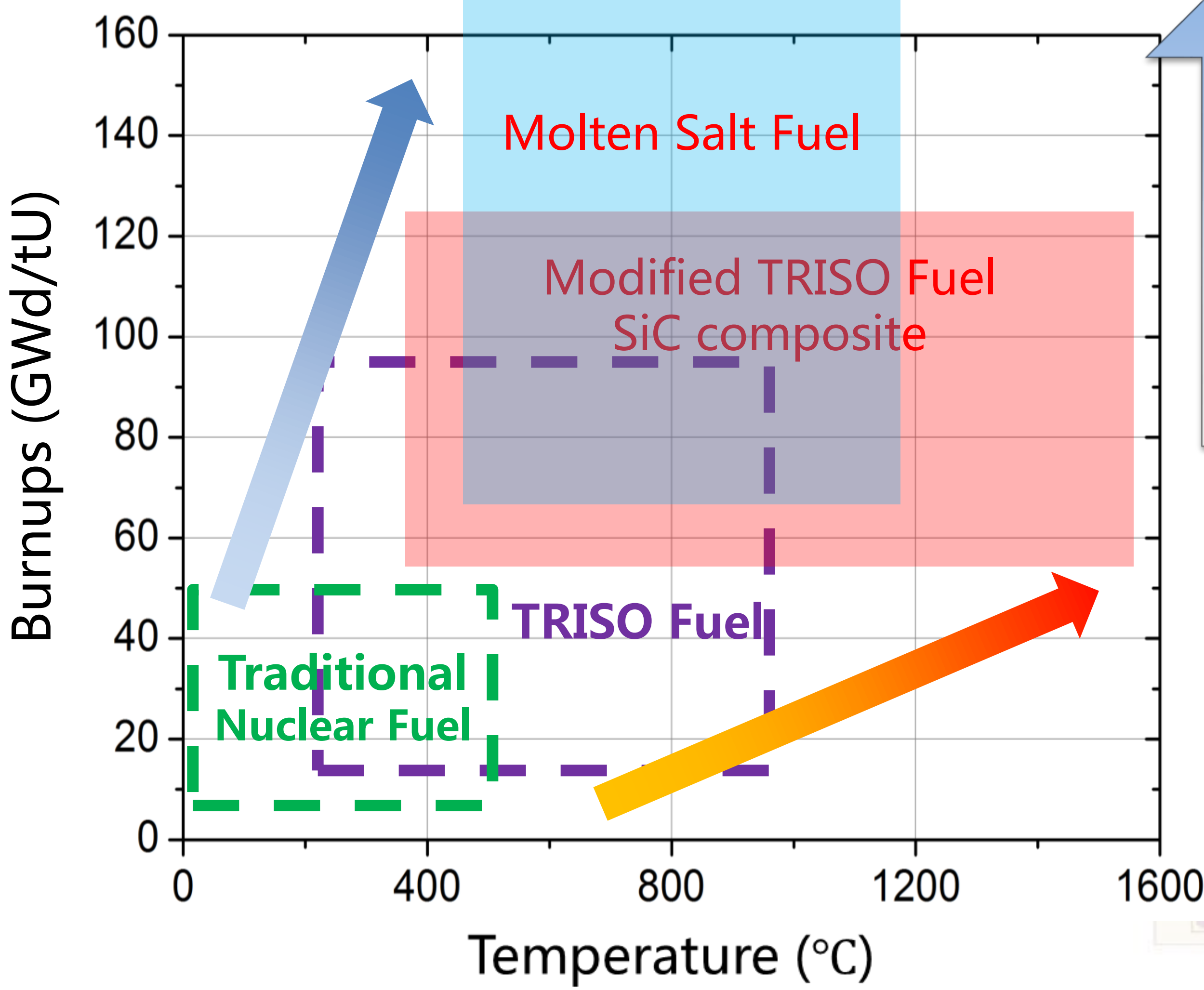
- Near-term
  - Establish standard specification of nuclear-grade ThF_4 and ThO_2 applicable to MSR
  - Establish the preparation process of nuclear-grade ThF_4 and ThO_2
  - Test Th fuel in molten salt reactor
- Mid-term
  - establish a process line with tons class for nuclear-grade ThF_4 and ThO_2
  - Establish Th-U fuel cycle system

Challenges facing by Nuclear fuel



Challenge	Demand
Higher Temp	Stable at HT
Deeper Burnup	Radiation Resistance
Higher Power Density	Better Eco.
Limited Uranium	Fuel cycle Th utilization

Advanced Fuel Development Map



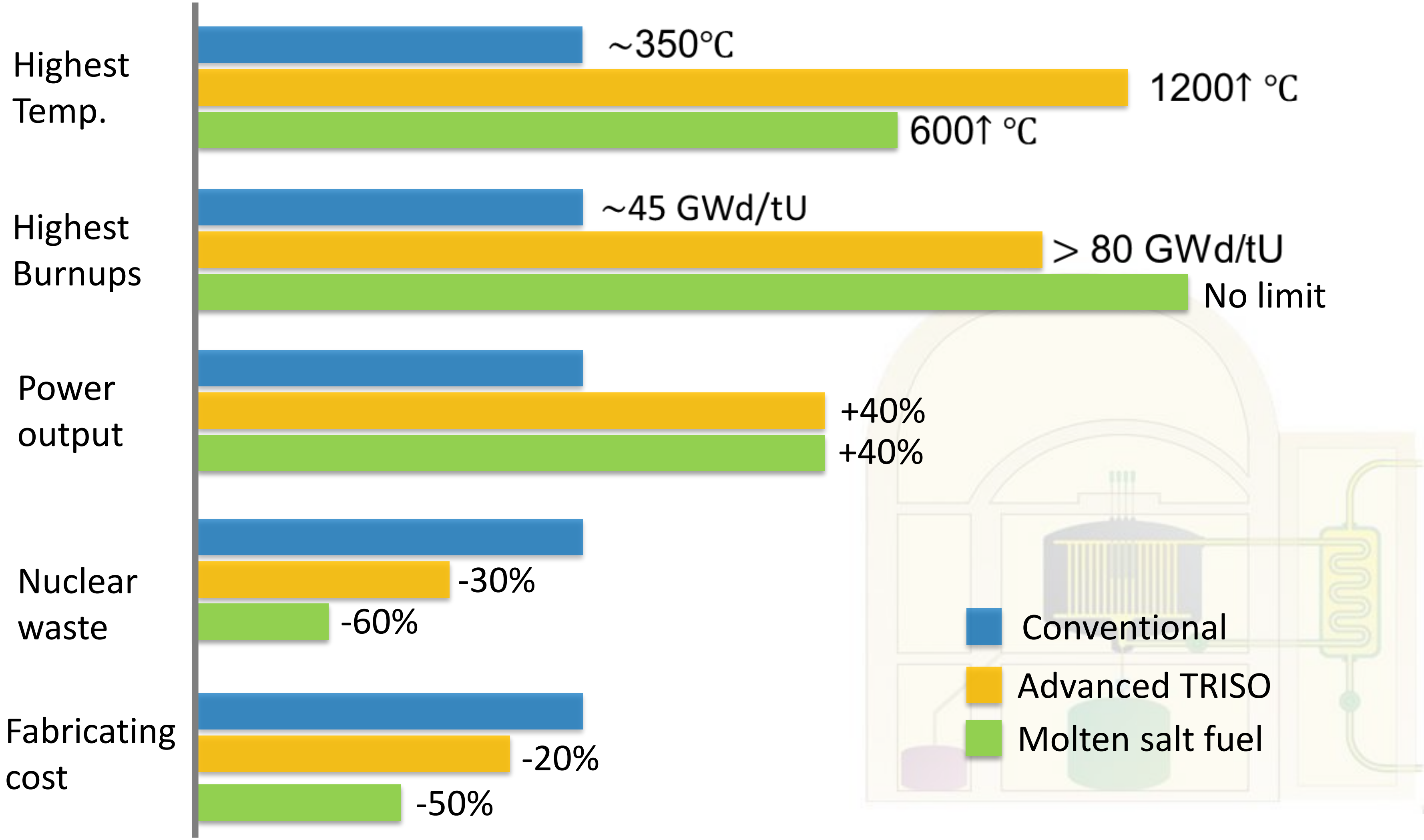
Molten salt fuel

- Fuel carrier and coolant
- No radiation damage
- In-pile fueling
- Flexible fuel-cycle

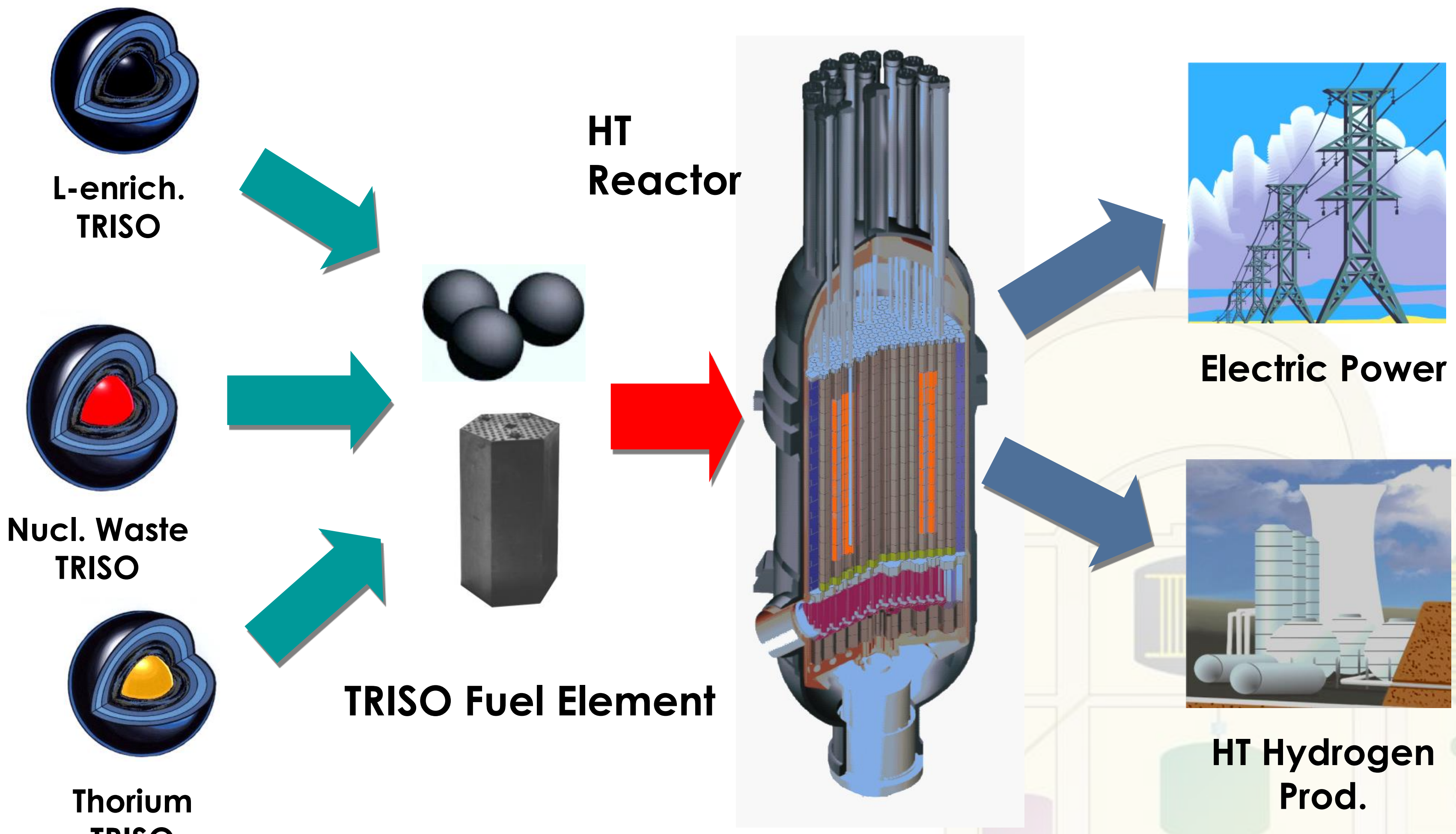
Advanced Solid Fuel

- Modified TRISO
- Fully ceramic
- Radiation resistance
- Higher temp. resist.
- Higher Burnups

Aims of Advanced Fuel

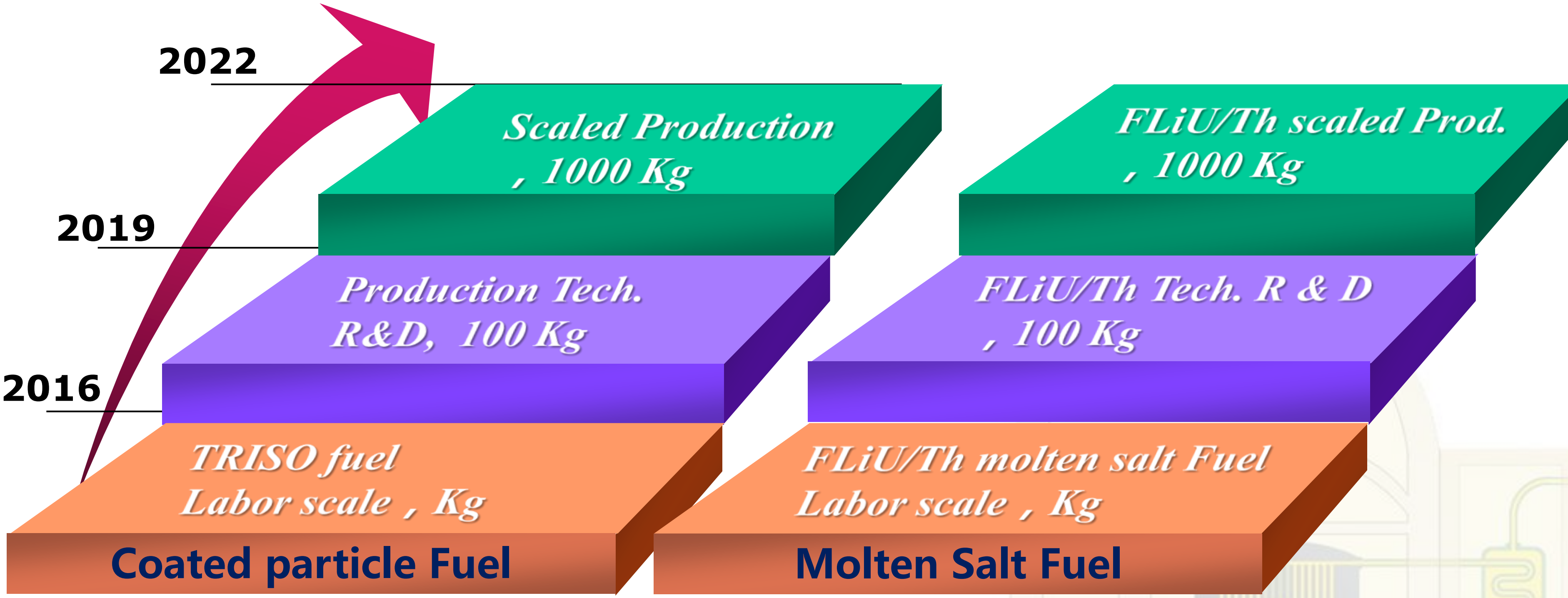


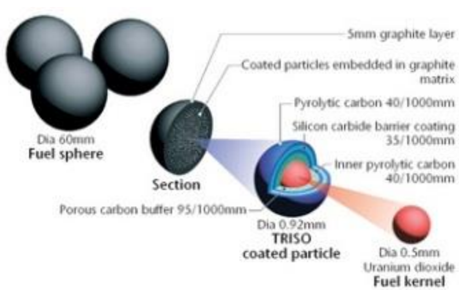
TRISO Fuel： Stand High Temp. and Flexible



Key Tech： TRISO coated fuel

Development planning for Advanced Fuel





A scheme for the preparation of ultra-pure thorium compounds

Thorium oxalate 95%

↓ calcination

Thorium oxide 95%

↓ dissolution

Thorium nitrate solutions

↓ extraction

Thorium nitrate >99.99%

↓ Ion exchange

Thorium nitrate solutions >99.999%

② deposited with HF → Thorium fluoride → Filtrate, washing, dryness → anhydrous thorium fluoride

① Thorium oxalate → calcination → Thorium oxide >99.999%

The scheme might be modified to meet the need of standard specification of nuclear grade ThF_4 and ThO_2 applicable to MSR.

Key techniques developed for ultra-pure thorium compounds preparation

Cascade centrifugal extractors

（50-100g/h)

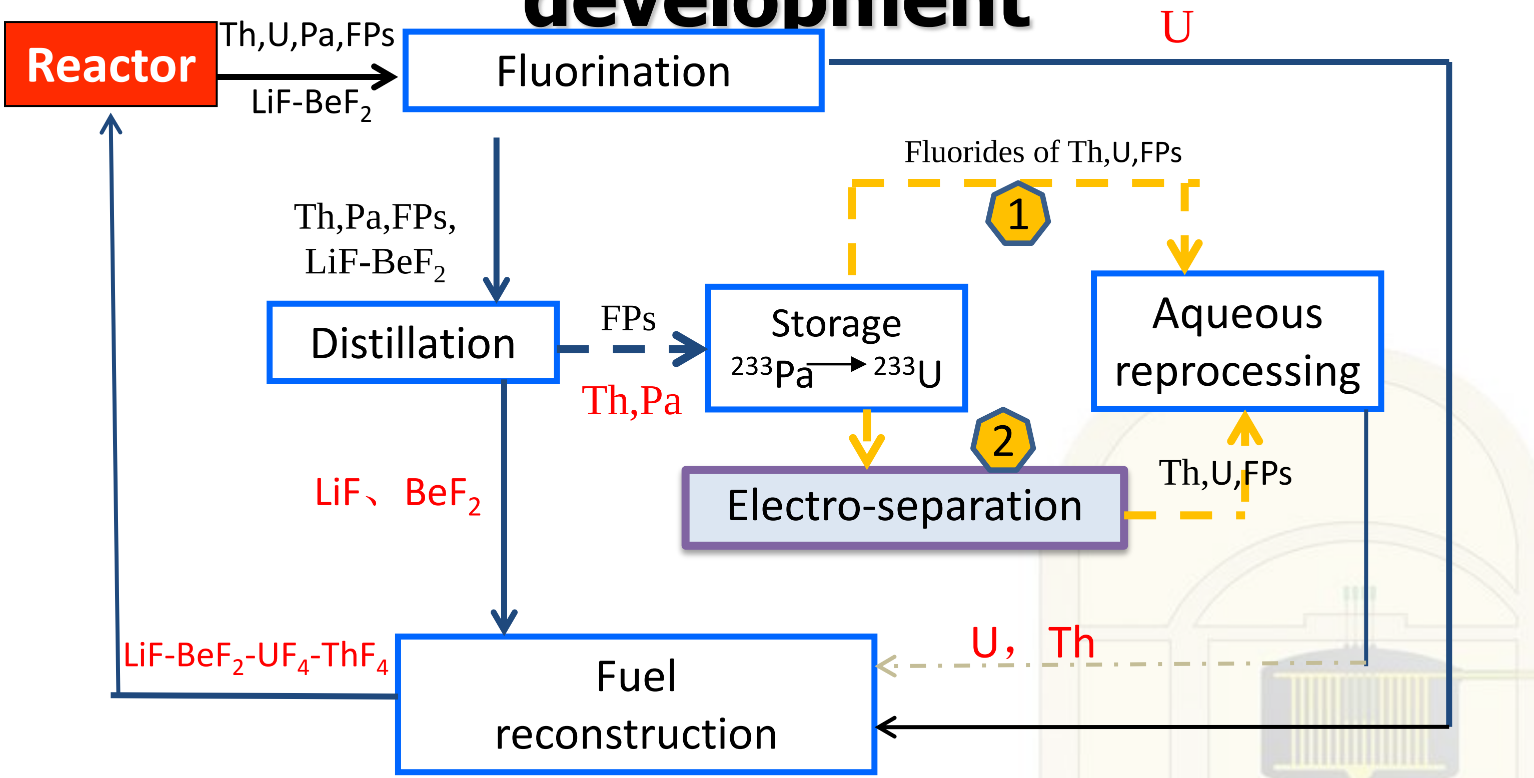
（99.99%）

Ion exchange column separation system

（200g/h)

（99.999%）

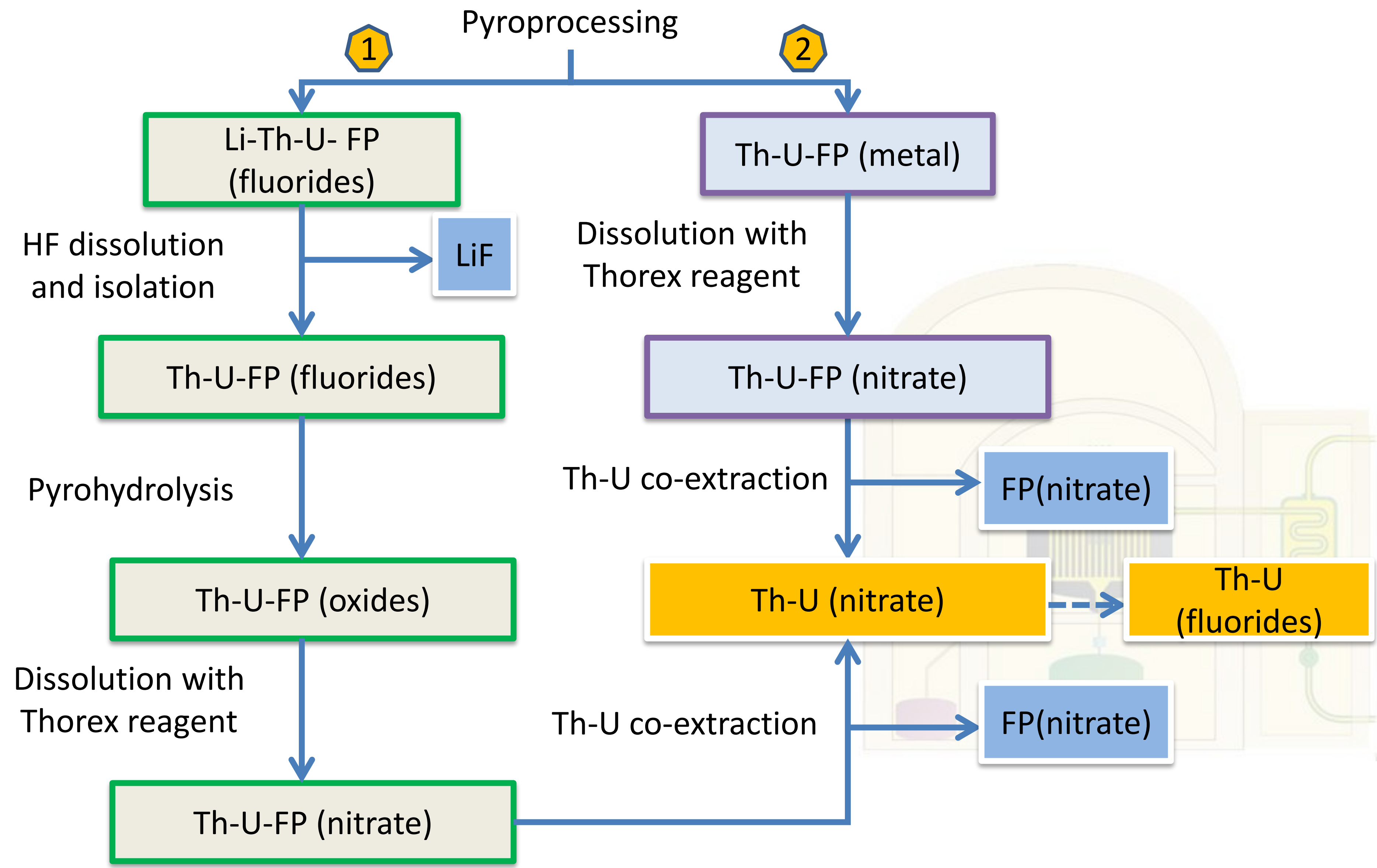
IV-Flow-sheet of TMSR fuel cycle under development



Main advantages:

- ☐ Recycle U and carrier salt as soon as possible base on pyroprocessing to minimize the out-of-reactor inventory and maximize the utilization of fuel
- ☐ Simplify the process by combining with aqueous processing methods
- ☐ **Proliferation risks are negated by co-extracton of Th an U**

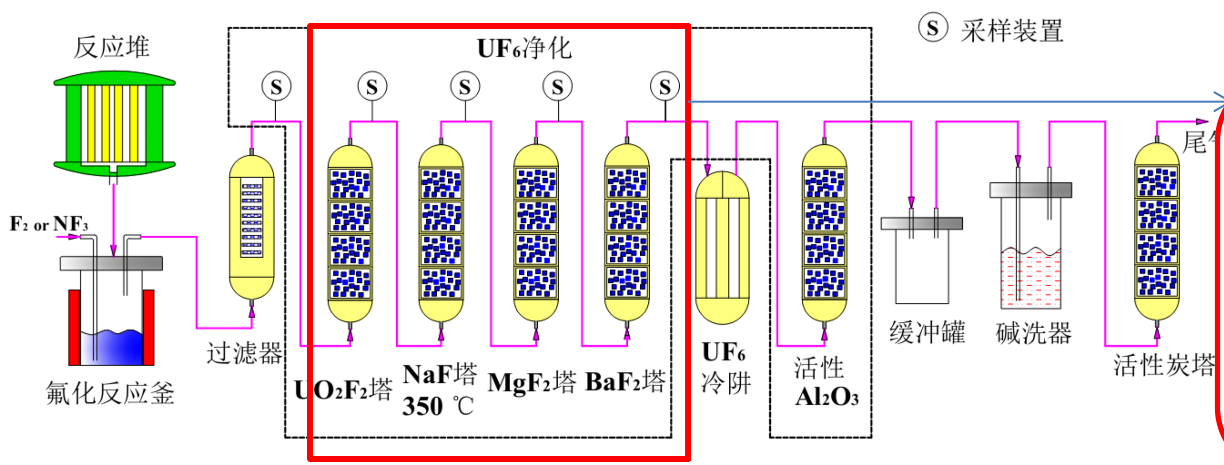
Aqueous Flow-Sheet Following Pyroprocessing



Feasibility study of fluoride volatility process

Key design features

- Main material: HC-276
- Volume: 1L
- Max. Temperature: 600℃
- F_2 flow: 10ml～1l/min
- Main constituents:
  - Gas supply system
  - Gas preheater
  - Fluorinator
  - absorb traps
  - Off-gas system



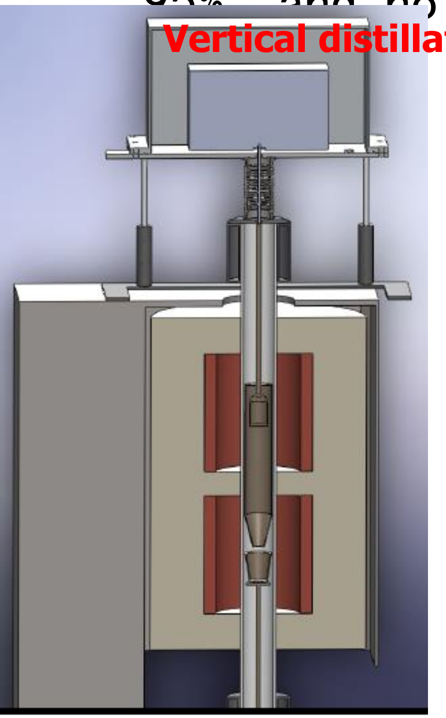
Purification of UF_6

- UO_2F_2 trap (150 ℃) for Pu removal
- NaF trap (350℃) for Ru and Nb
- MgF_2 trap (125℃) for Nb, Mo and Sb
- BaF_2 trap (125℃)for Ru and Mo

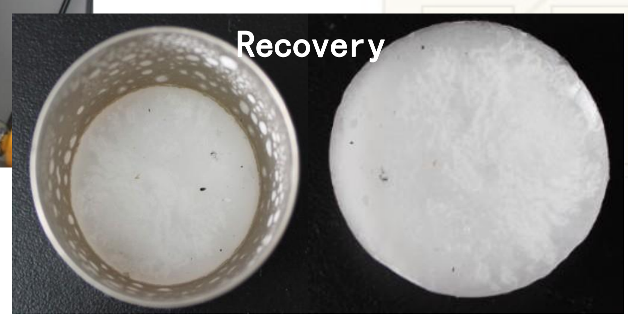
Feasibility study of distillation process

- Primary results using a simple distillation device showed that carrier salt and rare earth fluorides could be separated efficiently
- In present conditions, the highest recovery ratio was about 95%, and no significant corrosion was observed

Vertical distillation device



	NdF_3 residue (%)	Relative volatility of NdF_3 to LiF*
FLiNaK-NdF_3 0.2wt%	83	2.7×10^{-2}
FLiNaK-NdF_3 1.6wt%	74	1.3×10-2
FLiNaK-NdF_3 3.0wt%	45	2.0×10^{-2}



Feasibility study of electrochemical separation process

- Obtaining a series of electrochemical data for REs, and determination the primarily feasibility of the electrolytic separation for Th and Ln in molten salt

	Reaction	E^0（V）vs. Ni/NiF_2	$D/cm^2.s^{-1}$	Separation?
Gd	$Gd^{3+}+3e^- \rightarrow Gd^0$	-2.02	3.2×10^{-4}	Yes
Y	$Y^{3+}+3e^- \rightarrow Y^0$	-1.96	5.4×10^{-6}	Yes
Nd	$Nd^{3+}+3e^- \rightarrow Nd^0$	-1.95	1.1×10^{-5}	Yes
Th	$Th^{4+} +4e^- \rightarrow Th^0$	-1.90	8.4×10^{-7}	Yes
Zr	$Zr^{4+} +4e^- \rightarrow Zr^0$	-1.86	3.1×10^{-6}	Yes
Zr	$Zr^{4+} +3e^- \rightarrow Zr^+$	-1.66	----	---
Sm	$Sm^{3+}+e^- \rightarrow Sm^{2+}$	-1.65	7.4×10^{-6}	No
Eu	$Eu^{3+}+e^- \rightarrow Eu^{2+}$	-1.03	9.6×10^{-6}	No

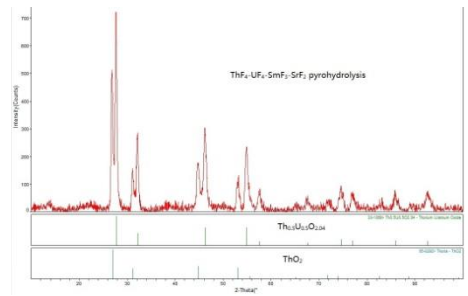
Feasibility study of aqueous process

^{7}Li recycling by HF Dissolution

Fluorides	Solubility in 90% HF (mg/g)
LiF	90
ThF_4	＜0.03
UF_4	0.005~0.010

TRE decontamination >500

Pyrohydrolysis



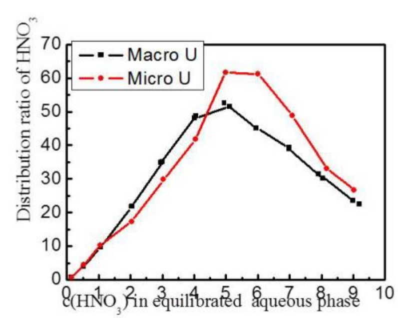
XRD analysis of pyrohydrolysis products of ThF_4-UF_4-SmF_3-SrF_2

ThF_4, UF_4 can be completely converted to oxides @450 °C while RE and Sr, Cs can not.

ThO_2 and Th Metal Dissolution with Thorex reagent

Dissolution of ThO_2 and Th metal with 12-13 M HNO_3 with 0.03-0.05 M fluoride as catalyst is a well known method and has beensuccessfully performed in our lab.

Th-U co-extraction



>99.9% of Th and U can be extracted together with 30% TBP from their solution in 3 M HNO_3 with a decontamination factor of 1E4.

Thank you for your Attention!