Progress of Materials R&D in TMSR Project

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中国科学院上海应用物理研究所
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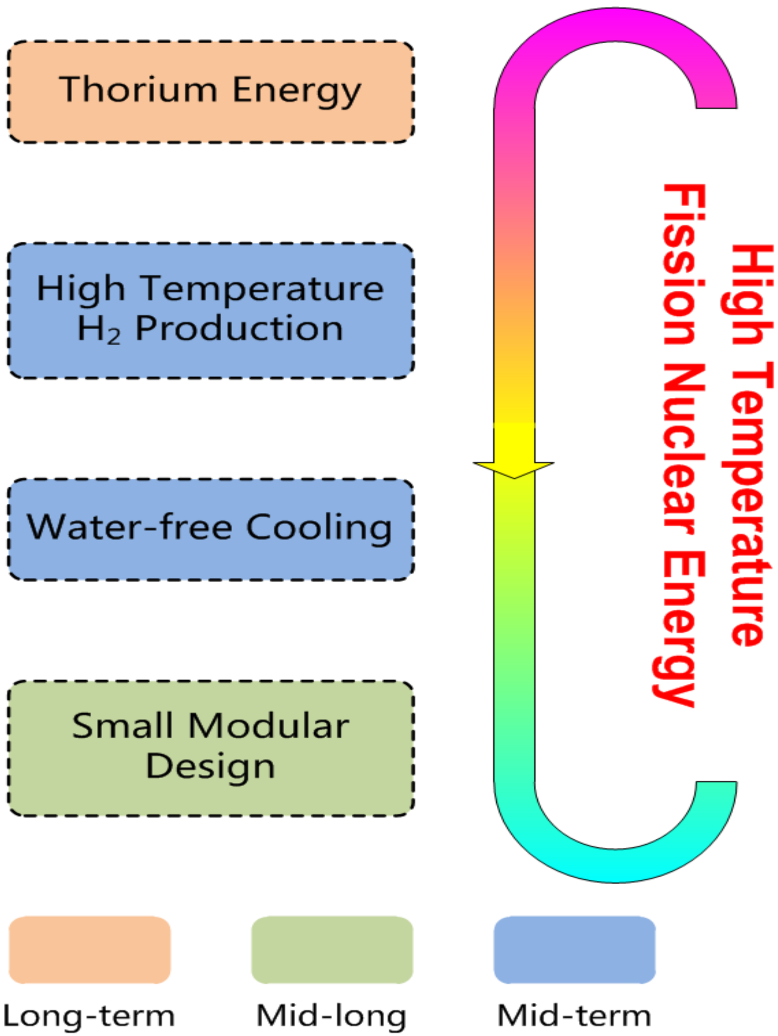
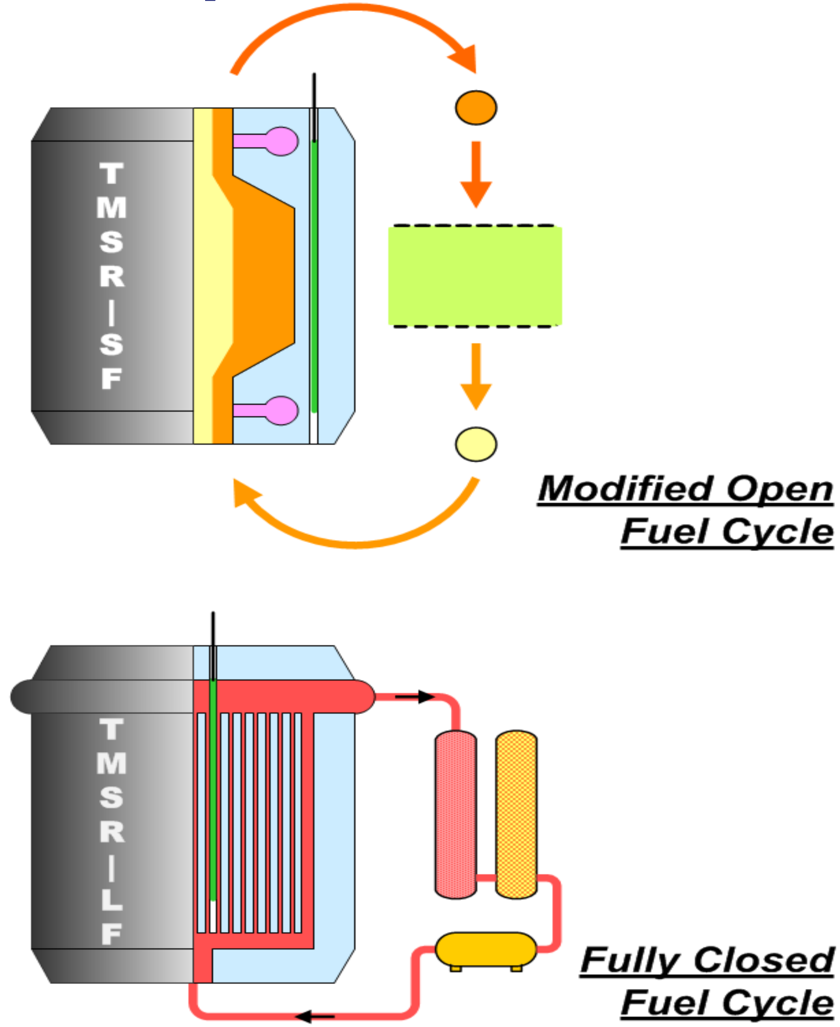
SINAP TMSR

Outline

- **Overview of Thorium Molten Salt Reactor (TMSR) Project**
- **Materials R&D at SINAP**
  - TMSR design and materials overview
  - Challenges and progress on alloy and graphite
  - Database construction
  - Basic science research in progress
- **Summary**

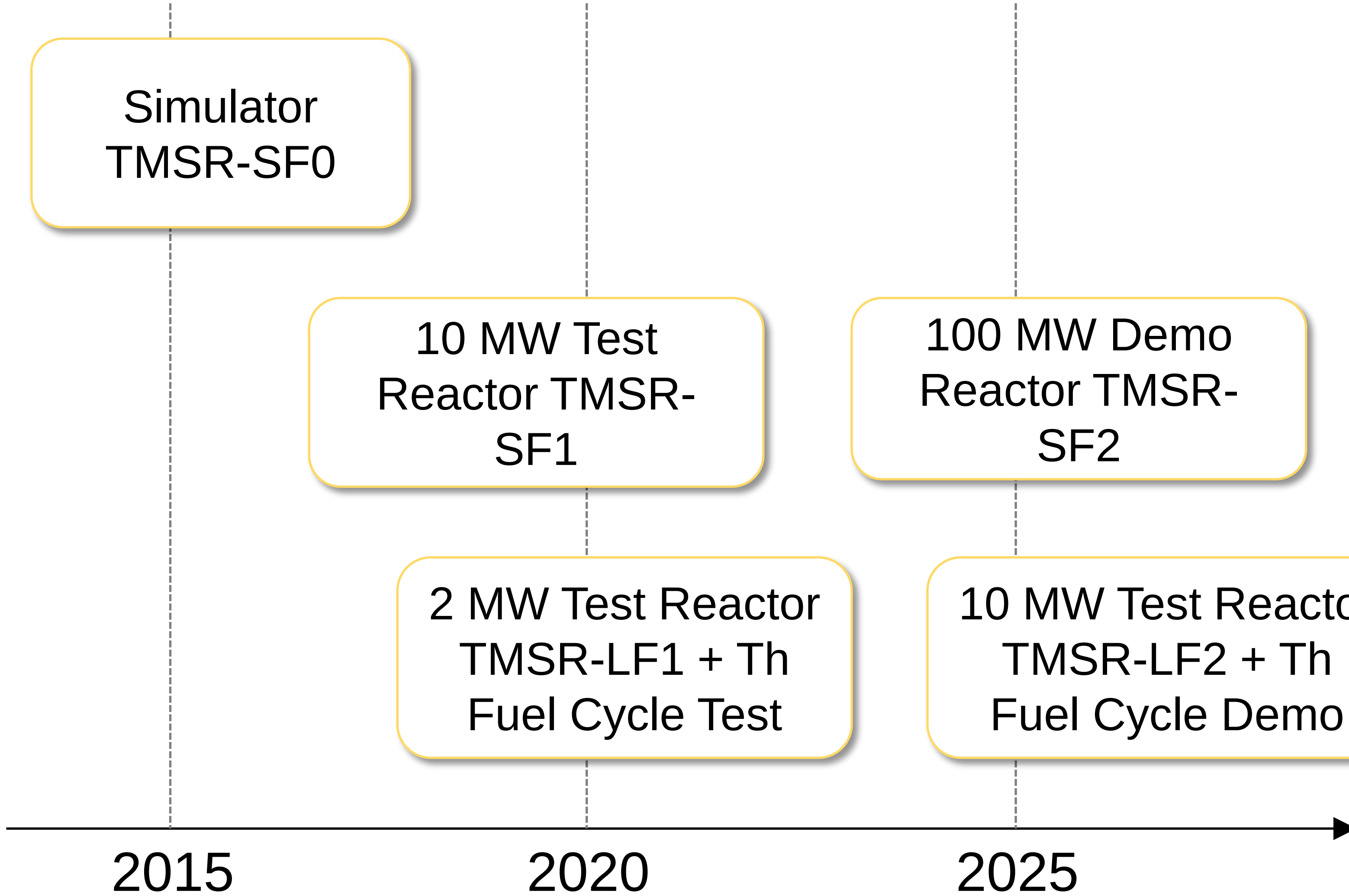
TMSR Reactor Development Plan





Strategy of TMSR R&D

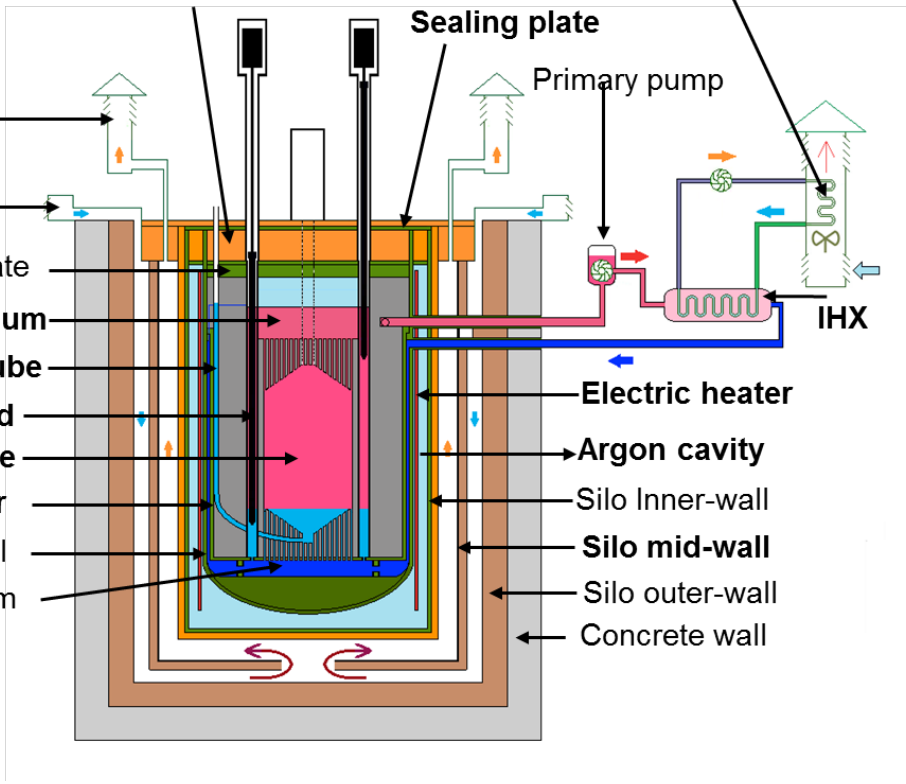
TMSR Reactor Development Plan



SINAP TMSR

Materials

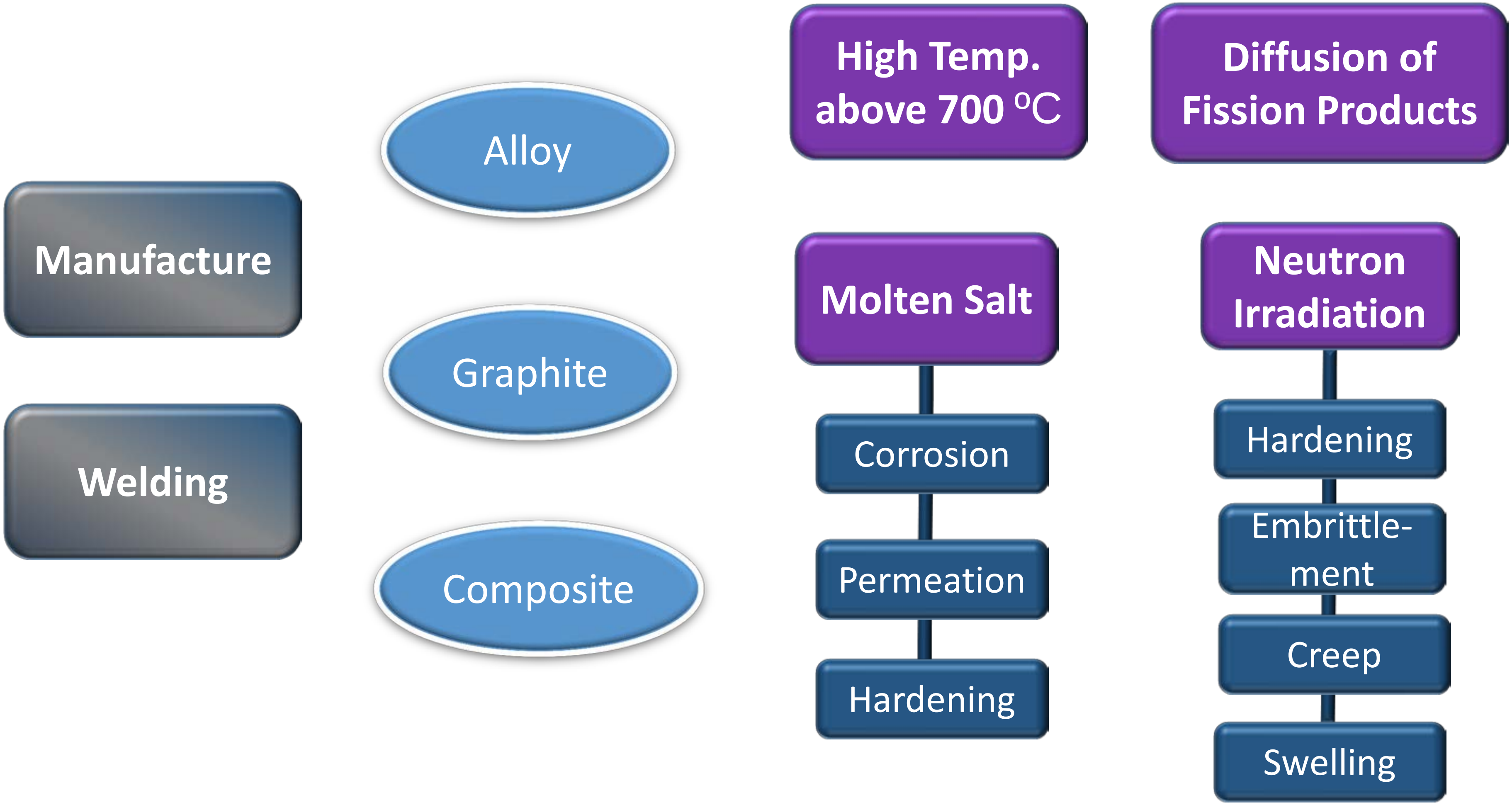
Component	Candidate Materials
Reactor Vessel	N10003
Reactor Vessel Support	SA533
Graphite structure	Nuclear Graphite NG-CT-10
Core barrel	N10003, 316ss
Control Rod System	The rod- N 10003; seal cover-SA-508-3; gears-35SiMn/37SiMnV; spring-50CrVA; Gear box-ZG0Cr18Ni9Ti
Pebble injection Mechanism	N10003, 316ss
Pebble defuel Mechanism	N10003, 316ss



Fuel
TRiSO/ThF4/UF4

Molten Salt
FLiBe /FLiNaK

Challenges to Materials



Materials R&D for TMSR face the challenges from manufacture process as well as the service environments

Challenges to Alloy

Alloy N (UNS N10003) including Hastelloy N and GH3535 is still considered as the best candidate, while 316 is also under review.

- **Scientific challenges**
  - High temperature strength (>700 ºC)
  - Neutron irradiation resistance (He/Te embrittlement, swelling)
  - Corrosion control
- **Technological challenges**
  - Large scale component fabrication
  - Welding procedure development
- **Challenges relevant to code & standard & data**
  - Most of the codes or standards do not exist to support the TMSR/FHR design
  - Alloy N faces big gaps in performance data for the ASME code case application

Progress in Alloy - Manufacture Capability

Current fabrication capacity of Alloy N components

Type of materials	China	USA
Ingot	≦ 10 ton	≦ 3 ton
Plate	width ≦ 2200mm	width ≦ 1800mm
Rolled Ring	diameter ≦ 790mm	under development
Bar	diameter ≦ 240mm	diameter ≦ 240mm
Forging	≦ 1 ton	≦ 1 ton
Pipe	diameter ≦ 168.3mm	diameter ≦ 88.9mm

Capable of fabricating the medium-scale alloy components

Good stability in alloy performance

China has better fabrication capacity

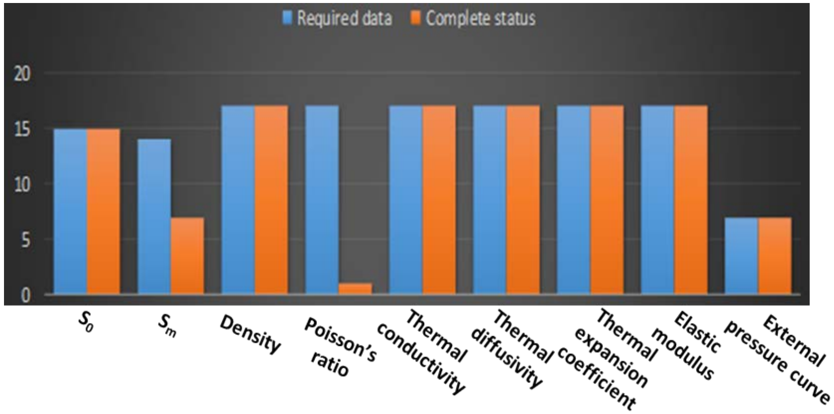
Lack of specifications in processing

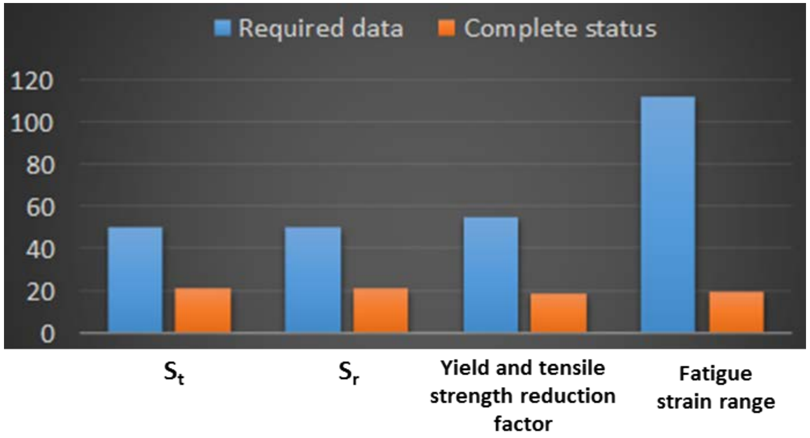
Current technology fails to meet the requirements of lager-scale fabrication

- **Current fabrication ability of SINAP can fulfill the requirements of TMSR SF-1.**
- **The fabrication technology has come to a bottleneck, limiting the component scale.**

Progress in Alloy – Mechanical Evaluation

Property	Requirements in ASME 2015	Data Completeness	Current status	Source
Elastic modulus	25-700℃,50℃interval	Complete	finished	ASMEⅡD,Haynes
Possion rate	25-700℃,50℃interval	Incomplete	1 batch finished	ASMEⅡD
Density	25-700℃,50℃interval	Incomplete	1 batch finished	SINAP
Plastic modulus	25-700℃,50℃interval	Complete	finished	SINAP
Thermal conductivity	25-700℃,50℃interval	Complete	finished	ASMEⅡD
Linear expansion coefficient	25-700℃,50℃interval	Incomplete	Lack of data above 400℃，and 400-900℃MCTEdata	ASMEⅡD,Haynes
Heat capacity	25-700℃,50℃interval	Complete	finished	ASMEⅡD
Base metal S0	25-700℃,50℃interval	Complete	finished	ASMEⅡD
Base metalSm	25-700℃,50℃interval	Complete	finished	ORNL
Base metalSt	450-700℃,50℃interval;Up to 300000h	Incomplete	650℃up to 30000h ; 700℃up to 3000h	SINAP
Base metalSmt	450-700℃,50℃interval;Up to 300000h	Incomplete		
Weldment Smt	450-700℃，50℃interval Up to 300000h	Incomplete	650℃up to 3000h ; 700℃up to 3000h	SINAP
Weldment St	450-700℃，50℃interval;Up to 300000h	Incomplete		
Weldment R	450-700℃，50℃interval;Up to 300000h	Incomplete		
Bolt S0	25-700℃,25℃interval;	Complete	finished	ASMEⅡD
Bolt Smt	450-700℃，50℃interval; Up to 300000h	Incomplete	650℃up to 30000h ; 700℃up to 3000h	SINAP
Isochronous stress-strain curves	450-700℃,50℃interval Up to 300000h	Incomplete	650℃up to 30000h ; 700℃up to 3000h	SINAP
Designed fatigue strain curves	25℃、600℃、650℃、700℃、750℃；Fatigue rupture cycles：$10^3 \sim 10^6$	Incomplete	650℃50% confidential curve，fatigue rupture cycles up to 10^4	SINAP
Creep-fatigue envelop	No defined requirements	Incomplete	650℃, 1% strain	SINAP
Yield stress	25-700℃,50℃interval	Complete	finished	ASMEⅡD, SINAP
Ultimate tensile strength	25-700℃,50℃interval	Complete	finished	ASMEⅡD, SINAP
Yield strength reduction factor	650℃700℃；Up to 300000h	Incomplete	650℃、700℃up to 10000h	SINAP
Ultimate tensile strength reduction factor	650℃700℃；Up to 300000h	Incomplete		SINAP





- Time independent data are nearly complete, except for Poisson's ratio and a few stress data
- Time dependent data are ~ 30% completed

SINAP
TMSR

Progress in Alloy – Irradiation Test

✓ Finish irradiation test on Hastelloy N @ T=650 °C, dose=2.5E19. PIE indicates that after irradiation the yield strength slightly increases, whereas the elongation keeps stable.

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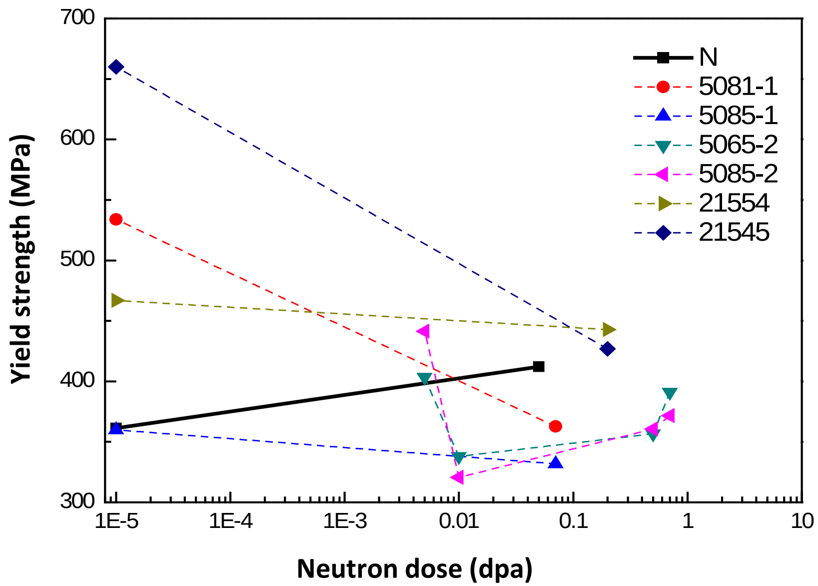

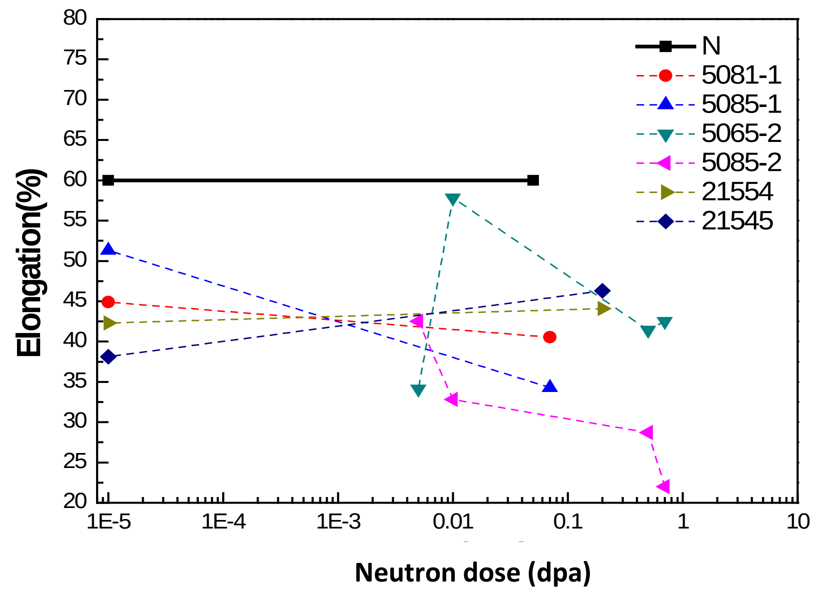

✓ Finish Irradiation test on Hastelloy N and GH3535 (base metal & weld metal) @ T=25 °C, dose=2.5E19 & 1E20

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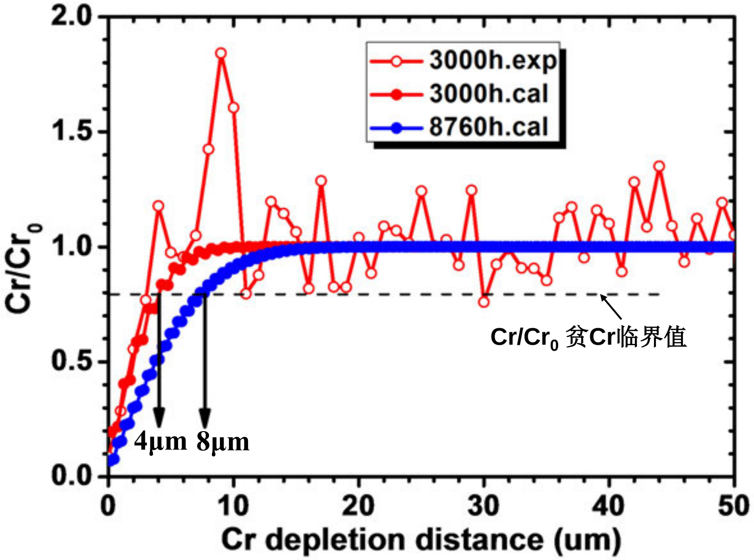
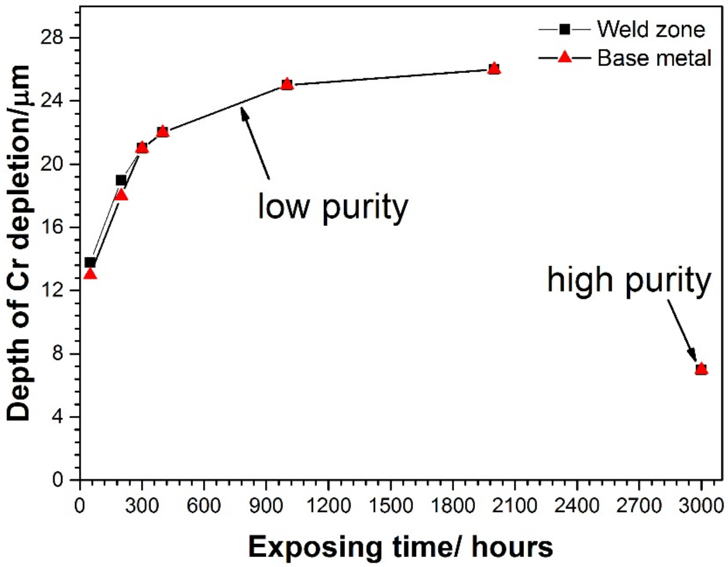
- High Dose (3 -15 dpa) test to be conducted in 2018 @PSI

Progress in Alloy - Corrosion Evaluation





- 3000 hrs static corrosion test suggests corrosion depth of Alloy N in FLiNaK less than 20 um

- Comparison between the base metal and weld zone suggests that the welding process does not affect the corrosion degree of Alloy N in FLiNaK

SINAP TMSR

Challenges to Graphite/Carbon Based Composite

manufacture

- Manufacturing large block of ultrafine grain graphite is challenging.
- The fracture toughness and thermal conductivity need to be improved.
- The uniformity and reproductivity are critical to nuclear graphite.

compatibility

- The infiltration/diffusion of molten salt need to be studied.
- Fission produce/tritium absorption in graphite affects the neutron economy.
- Impurities in salt could enhance the corrosion of graphite.

irradiation

- The irradiation behaviors of ultrafine grain graphite could be different.
- The irradiation data collection is a time and money consuming effort.
- The molten salt and graphite interface could affect the irradiation behavior of graphite.

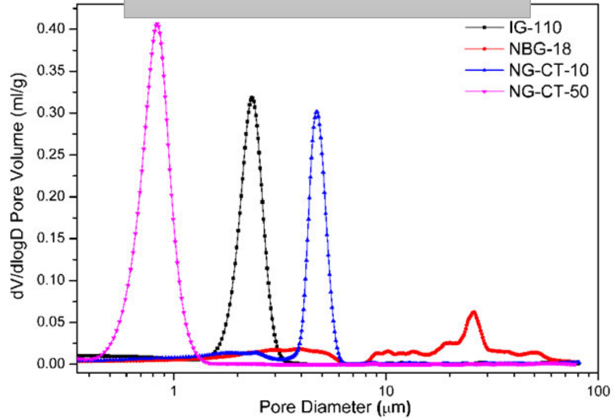
design code

- Design code is needed for commercializing TMSR.
- Fully understanding the behavior of graphite is essential for design code development.

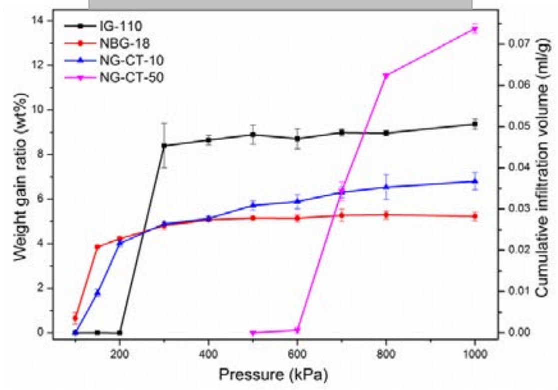
Progress in Graphite – Manufacture & Salt Infiltration

1400×600×350mm

Pore size distribution



FLiBe infiltration curve



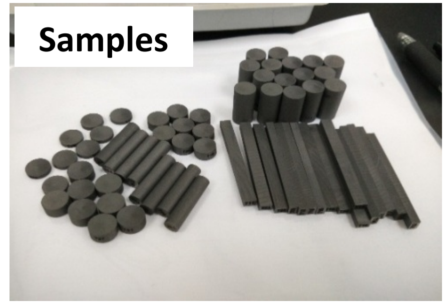
Tests on candidate graphite NG-CT-50

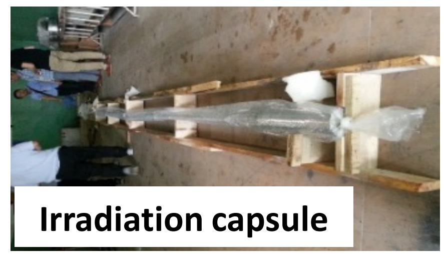
- Manufacture capability – size up to 1400 x 600 x 350 mm
- Smaller size compared to common commercial graphite
- FLiBe infiltration test done – low permeation for molten salt under reactor pressure

Progress in Graphite – Irradiation Test

- Irradiation Test @ T=650 ^{o}C, dose=5E20 to be done by June, 2017. PIE to be done by 2018

Test issues	NG-CT-50	NG-CT-10
Thermal conductivity	24	16
Thermal expansion coefficient	24	16
Splitting tensile	32	16
Compressive strength	24	16
Bending strength	24	16





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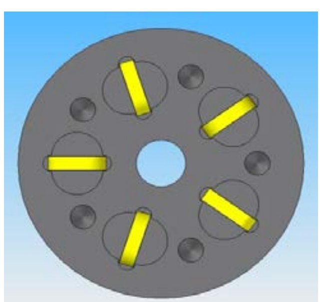
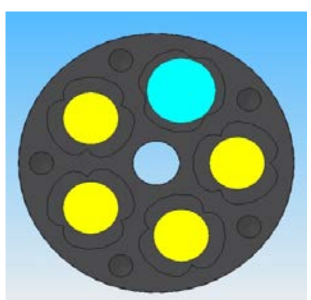
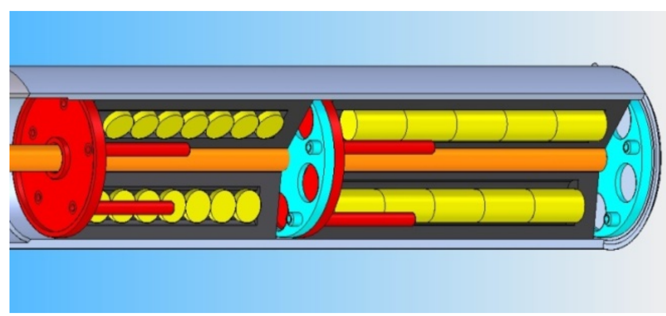
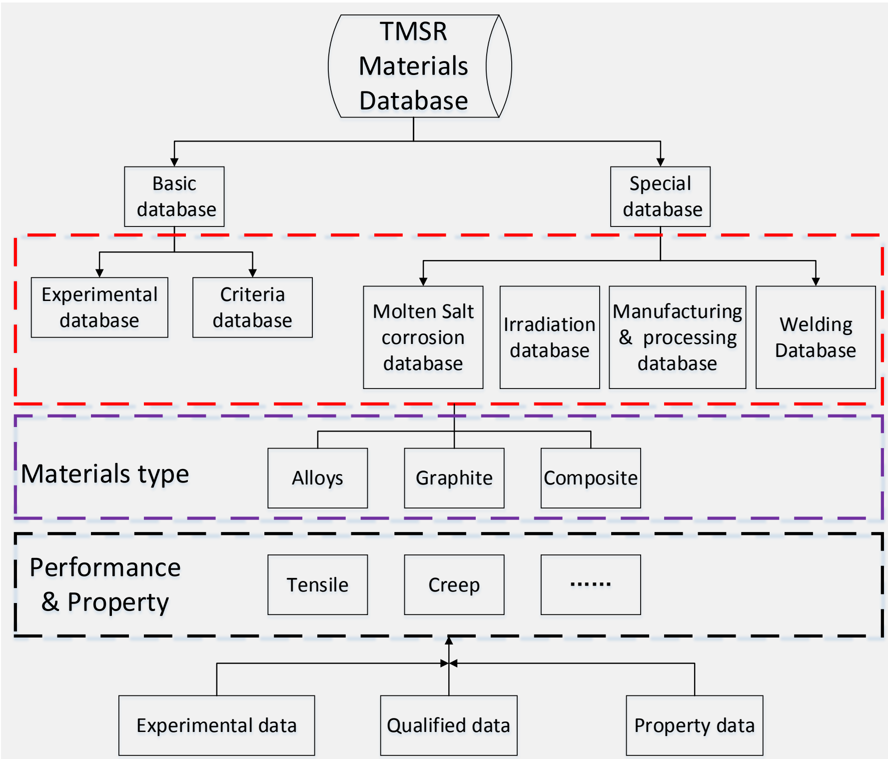
- Irradiation Test in MS @T=700 ^{o}C, dose=4E20 to be done by Dec. 2016. PIE to be done in 2017.

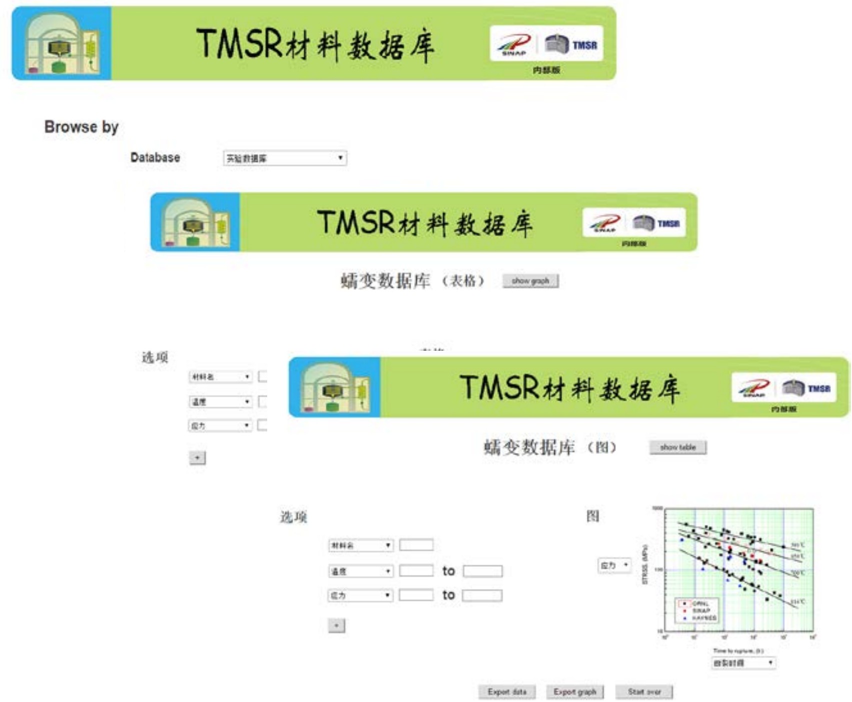






Material Database Construction





- Covers a wide range of materials for TMSR including alloys, graphite, ceramics and composites
- Source includes experimental data by TMSR, qualified data from other expert groups (ORNL etc.), and Journal Publication
- Full traceability from material property data to experimental data and reports

Basic Science Research in Progress

Material Structural Studies Using Synchrotron X-ray

- In situ observing load allocation in alloy
- Molten salt distribution in graphite and composite
- Element tracing in irradiated/corroded samples
- Radioactive material studies with dedicated beam line

Shanghai Synchrotron Radiation Facility

Ion beam simulates neutron irradiation

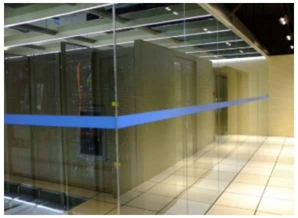
- He embrittlement in Ni based alloy
- Synergy effect of multiple ion species
- New methodology to compare ion and neutron irradiated samples

4MeV Ion Irradiation Facility

Simulation and Modeling

- Irradiation effect on Ni based alloy
- Intergranular embrittlement by fission products
- MD simulation on molten salt and its interaction with materials

Material Test Center



Supercomputer Center

Collaboration to Move MSR Forward

- Material R&D for TMSR benefit from the rich heritage left by MSRE.
- Challenges to Material R&D for modern MSR require the application of modern technologies .
- Collaboration between SINAP and international universities and institutes will propel TMSR/FHR to success.