The 13th International Workshop on Spallation Materials Technology (IWSMT-13)

Development of SIMP Steel for Accelerator Driven System in China

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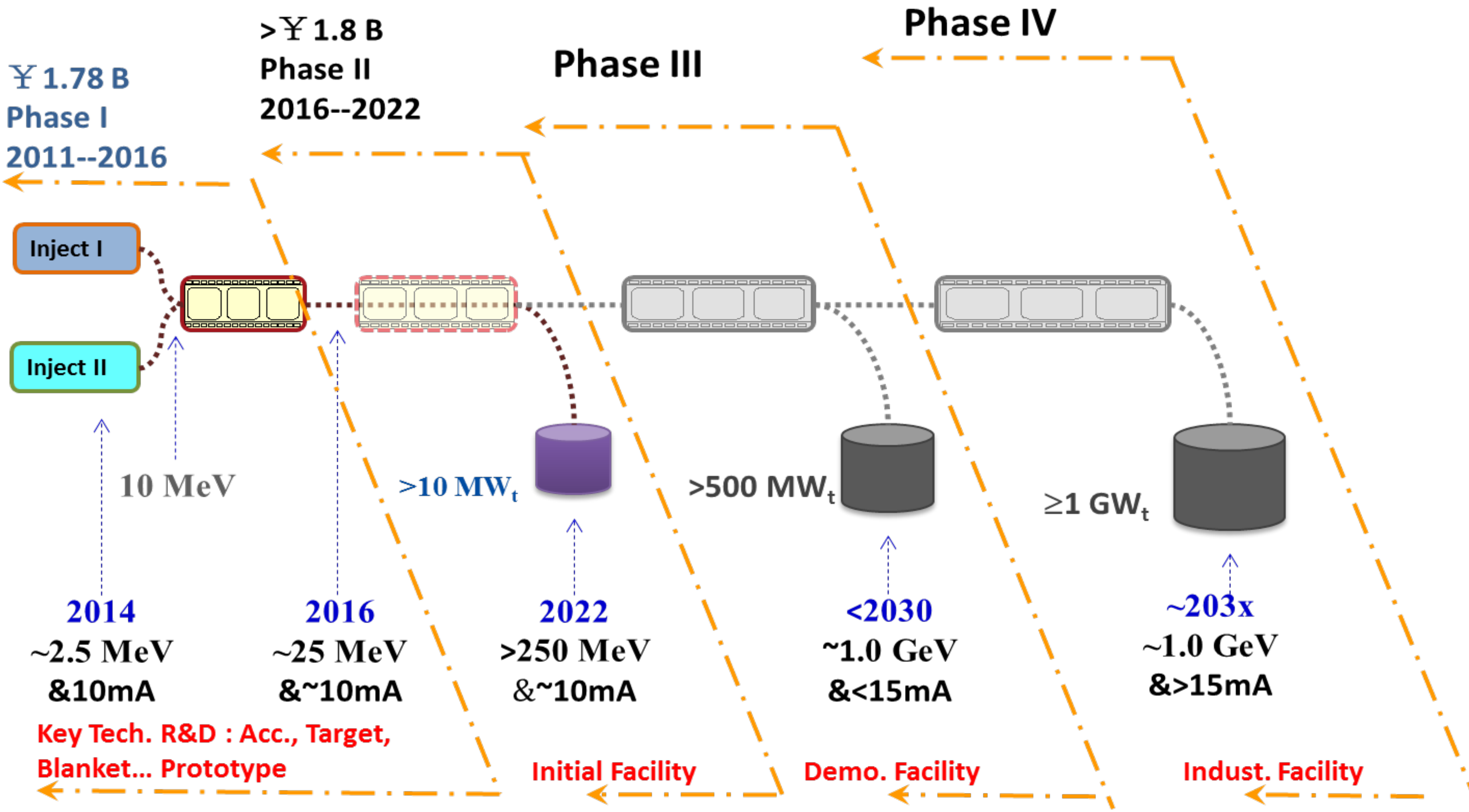
Outline

1. Introduction
2. Experimental Setups
3. Research Progresses
4. Perspectives

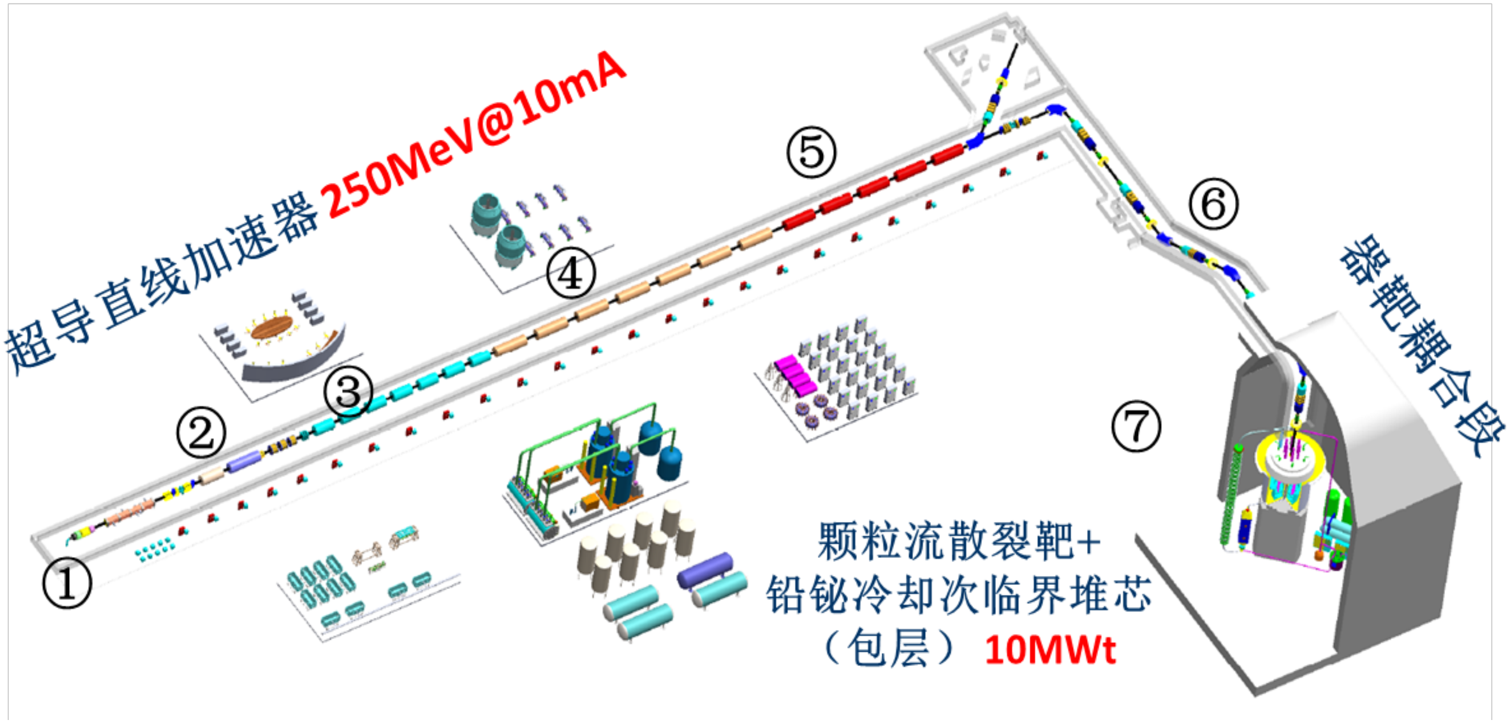
Introduction

ADS Roadmap in China



Introduction

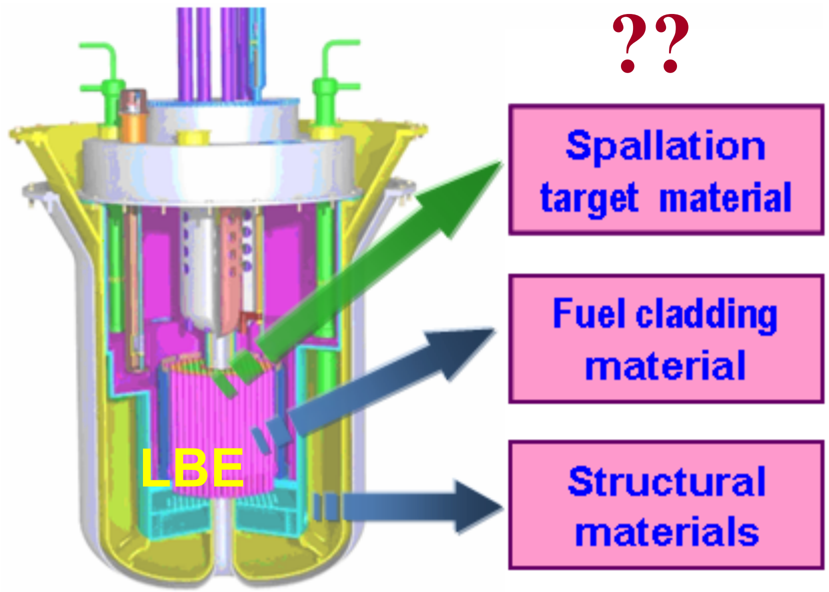
CIADS project 2015.12.31 1.8 B CNY



S -Linac+ Granular target + **sub-critical core (LBE coolant)**

Introduction

Material — Bottleneck for R&D of the system



Challenges for materials:

- Extreme service condition:
  - temperature (300-800℃)
  - thermal flux(~10MW/m^2)
  - irradiation damage(>100 dpa)
  - LBE corrosion(≥100um)
- High He accumulation in targets (up to 100appm/dpa)
- Instantaneous stress

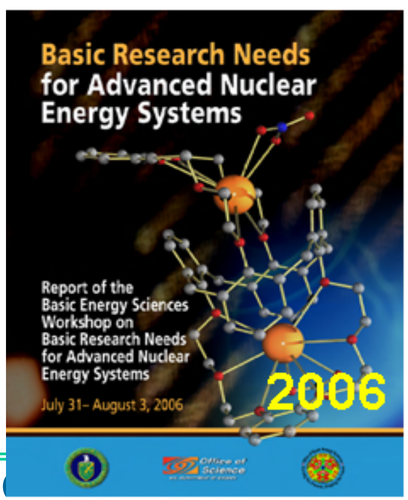
	Thermal neutron fission reactor	Fast reactor	Fusion reactor	ADS
Temperature (° C)	300 - 900	350 - 600	300 - 600	300-800
Damage rate (dpa/year)	Up to 2	20	20 - 30	100
Yield of He (appm/dpa)	Up to 10*	~ 0.2	10 - 15	~100

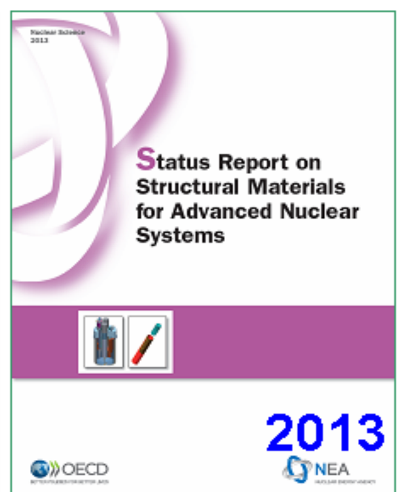
Introduction —— Research Aims

Requirements for ADS system

- **R&D New Material**
  - Structural material for ADS (LBE-cooled)
  - SiC based materials SiCf/SiC composites
- **Evaluation Irrad. Material**
  - New exp. Techniques, setups (synergetic effect)
  - Simulation and Ion irradiation test

Ion beam is a powerful tool for simulating nuclear reactor damage





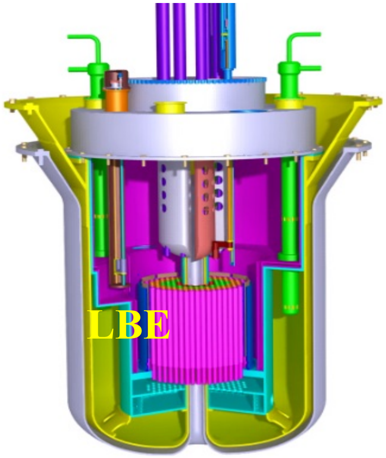
Introduction —— Research Aims

◆ R&D of new material

Aim: Significant tolerance to high-T, dpa, LBE

- Analysis
- Design
- Fabrication
- Processing
- Evaluation

→ **Structural materials for ADS— LBE Coolant**



Status

- Material / LBE compatibility data is limited.
- Synergetic effect of irradiation/LBE/high-T is lack of study.
- The existing reactor materials cannot be directly used as ADS structure material.

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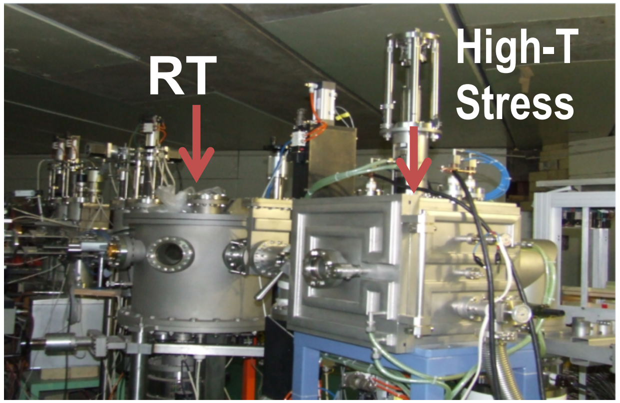
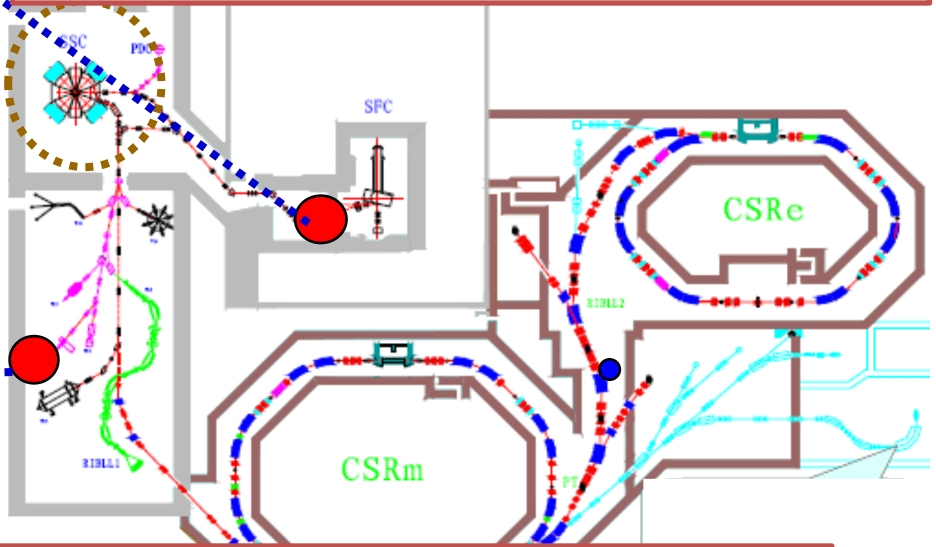
Experimental Setups

E: 10s to 100s of MeV
T: RT -- 600 °C
Coolant: LM (LBE or Pb)
LM flow velocity: 0-2m/s

Study the synergetic effect of irradiation/LM/high-T on material





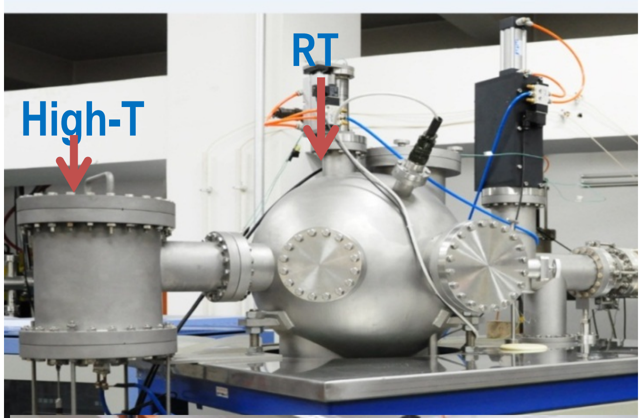
E: 100s of MeV to several GeV
T: RT -- 1200 °C
Applied stress: 0 -- 1 GPa

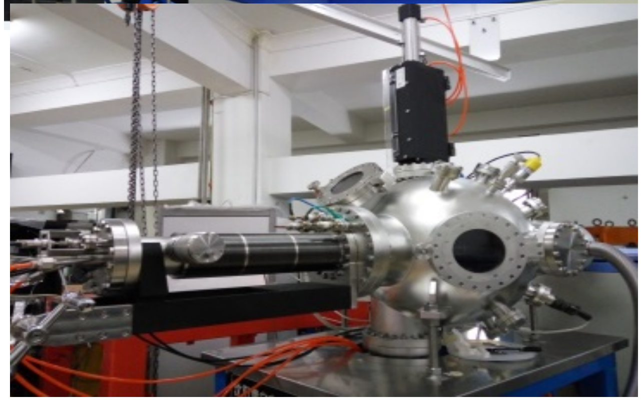
Study the synergetic effect of irradiation/stress/high-T on materials

Experimental Setups

◆ Irradiation set-ups for low-energy ion irradiation/implantation

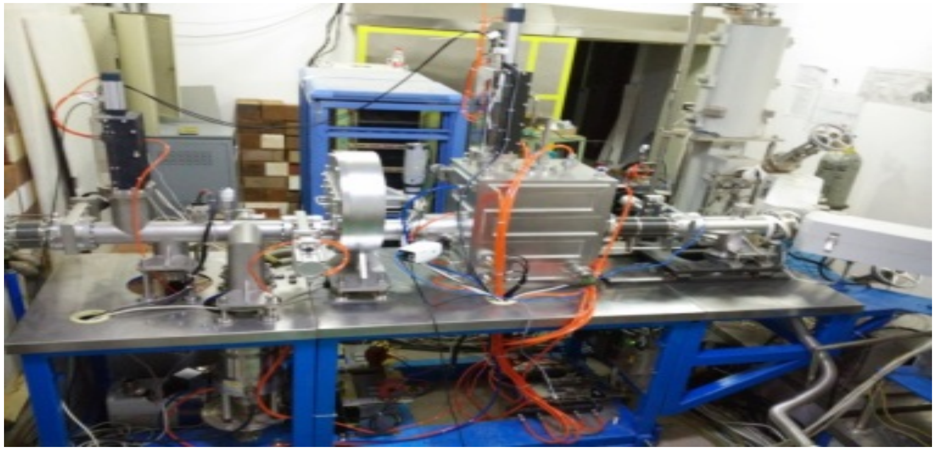
- Multi-samples
- Ion energy: tens of keV to 10MeV
- Irradiation temperature: RT to 800℃





Study the He, H doping effect, microstructural modification, synergetic effect of irradiation/doping in materials

Experimental Setups



Set-up for Irradiation creep test at T < 1000°C

Set-up for embrittlement test LM

Corrosive medium: LBE or liquid Pb

T : RT-800℃

Corrosive medium: LBE or liquid Pb

T: RT-800℃

Rotating speed: 0-300 rpm (maximum linear speed: 4.7 m/s)

Liquid Metal Corrosion Experiment Equipment

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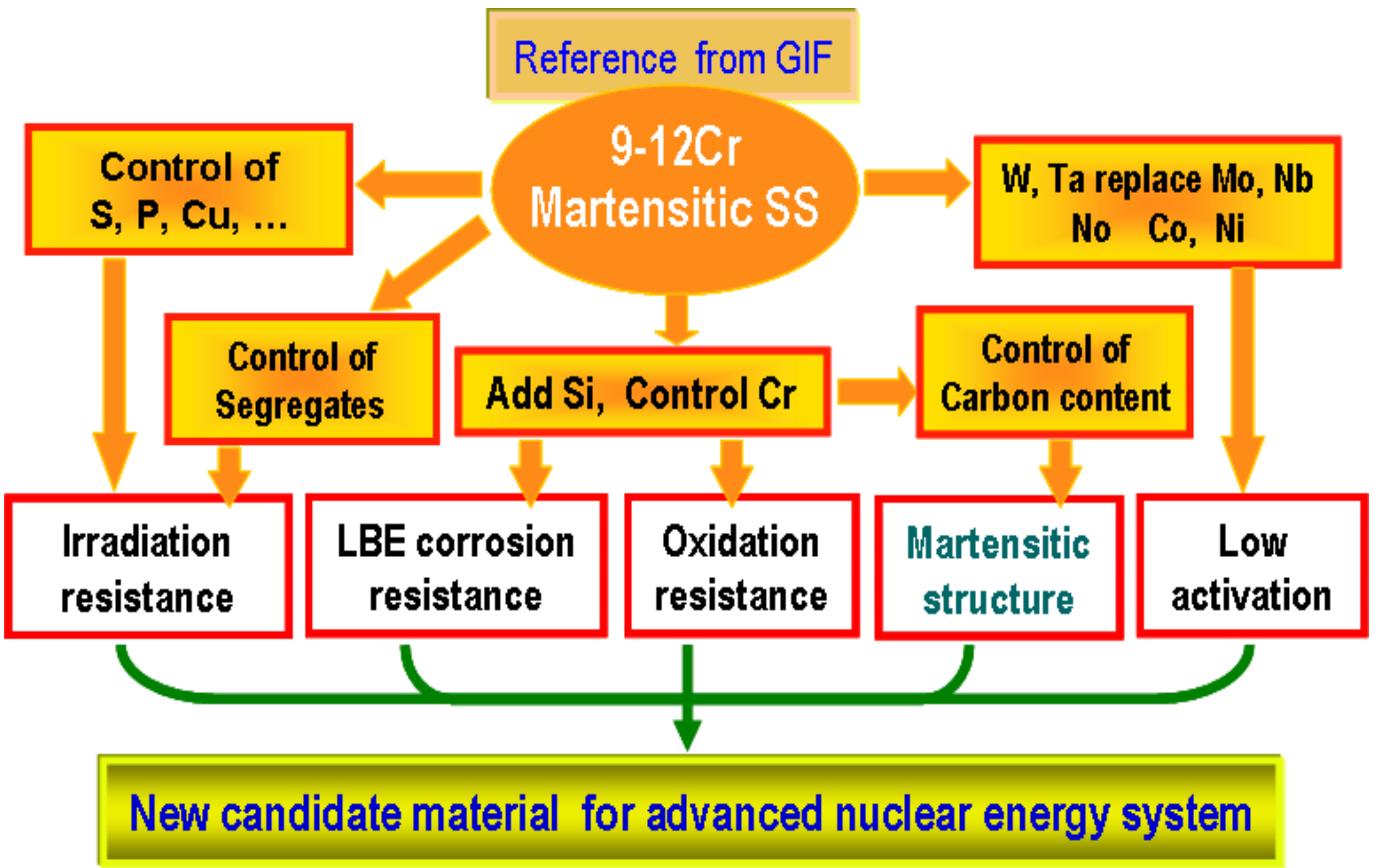
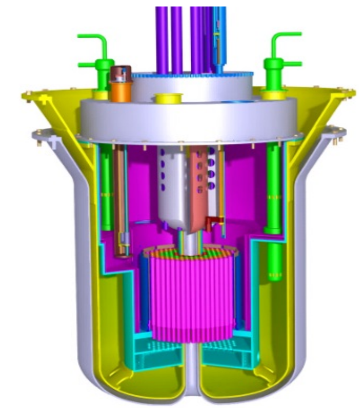
R&D of SIMP steel

◆ Design

Control: elements, phase





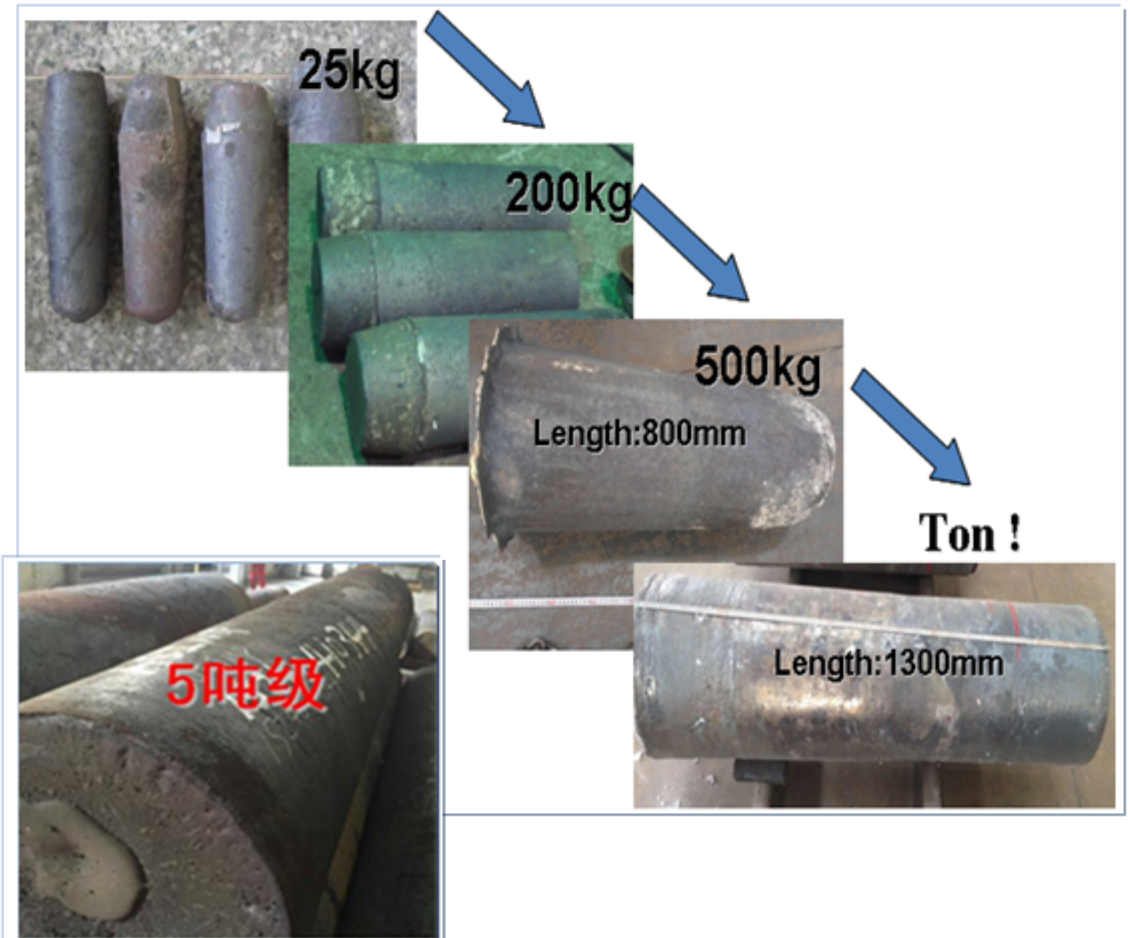
LBE Coolant

Do collaboration with IMR on the fabrication and processing

R&D of SIMP steel

◆ **Smelting & casting**

Control: purity, homogeneity

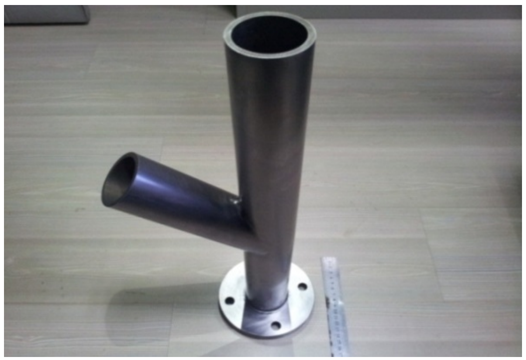


5ton SIMP ingot

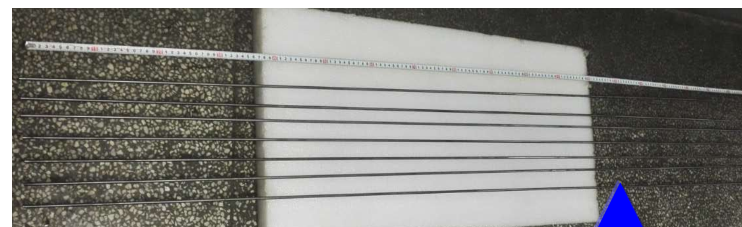
R&D of SIMP steel

◆ Processing

➢ Welding



➢ Panel / plate

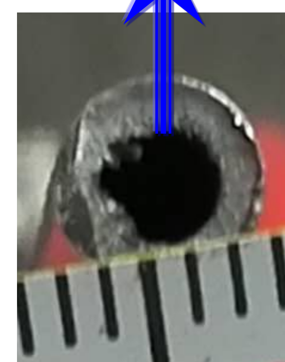


➢ Tubes/pipes

Φ60mm╳10mm

Φ60mm╳5mm

Φ60mm╳1mm



Φ5mm╳1mm

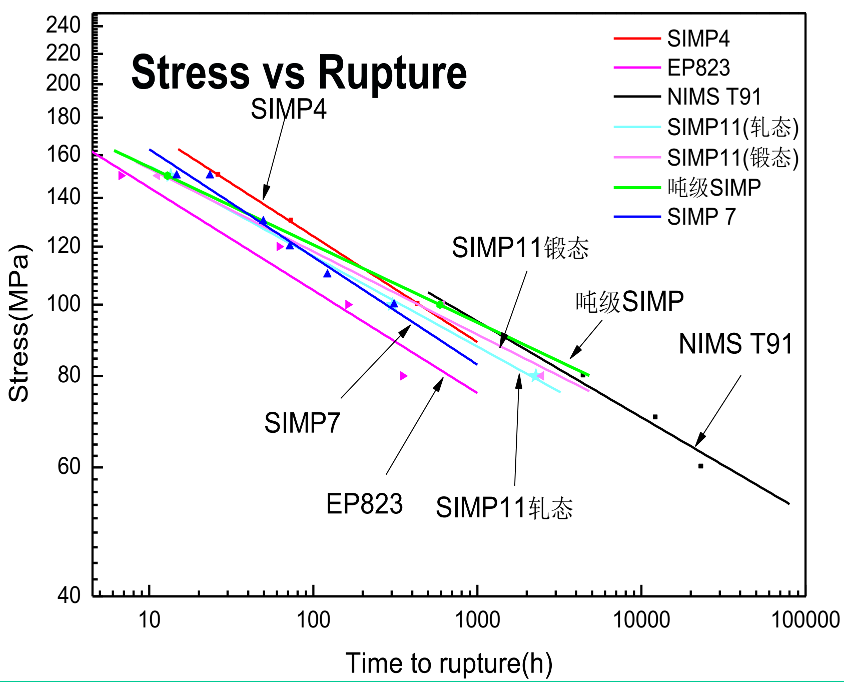
R&D of SIMP steel

◆ Main Properties

	C	Si	Cr	Mn	W	Ta	V	Nb	S	P
SIMP/Tons	0.22	1.22	10.24	0.52	1.45	0.12	0.18	0.01	0.0043	0.0040

Extracted strength after 10^5h (MPa)

	550℃	600℃	650℃
SIMP11 Forged	-	-	44.1
SIMP11 Rolled	154.0	91.7	27.9
SIMP/2T Rolled	Testing	Testing	58
NIMS T91	175.2	99.9	56.1



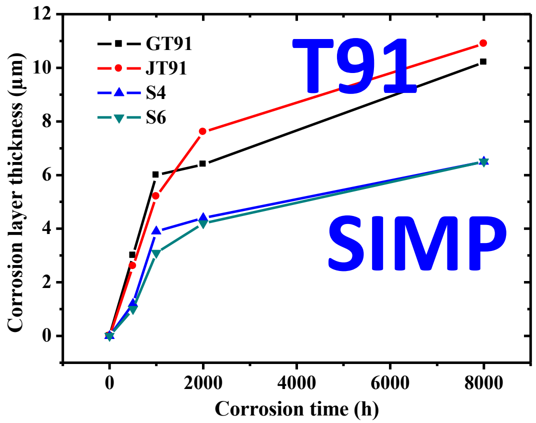
- **Rolled SIMP11 is close to NIMS T91 in 600℃, 550℃;**
- **Rolled SIMP sample (2Ton) is similar as NIMS T91 in 650℃;**
- **Rolled SIMP sample (2Ton) could be similar as NIMS T91 in 600℃、550℃ pre-testing.**
- **5 Ton Sample's is better than 2 Ton's**

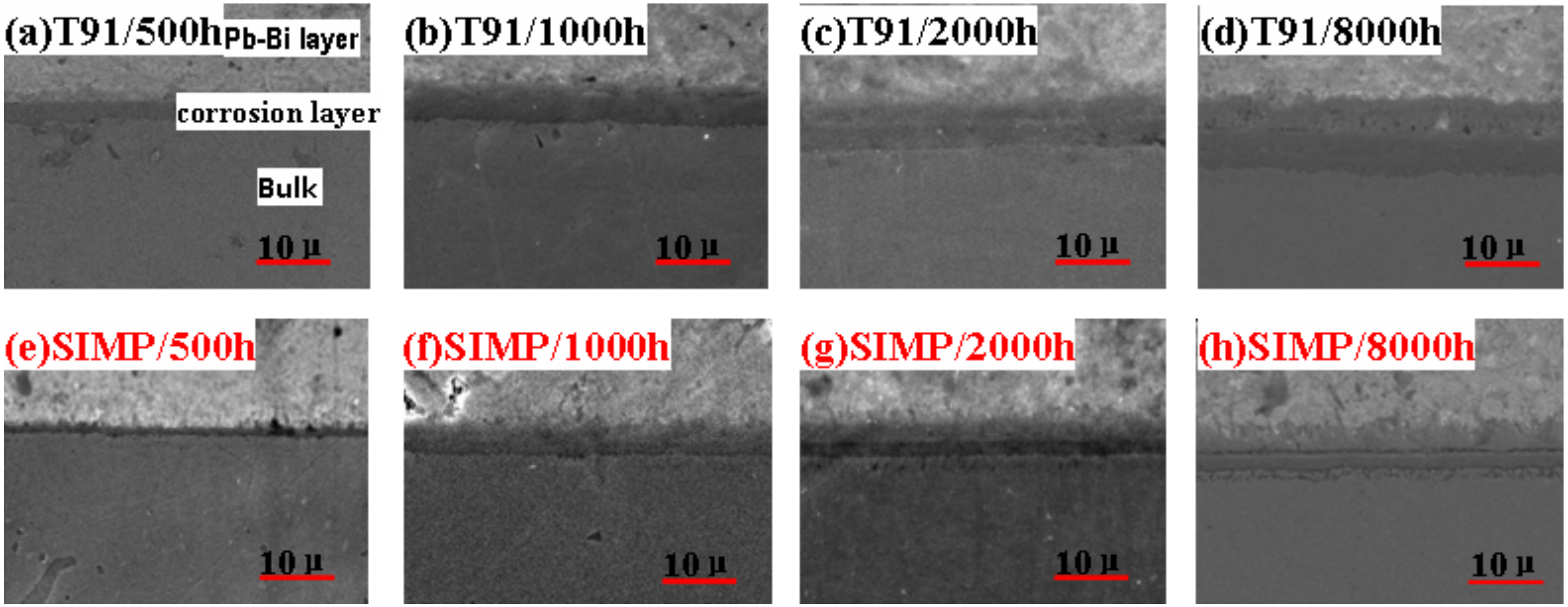
R&D of SIMP steel

◆ Main Properties

Resistance to LBE corrosion

450℃, static, saturation oxygen





Thickness of corrosion layer: SIMP < T91

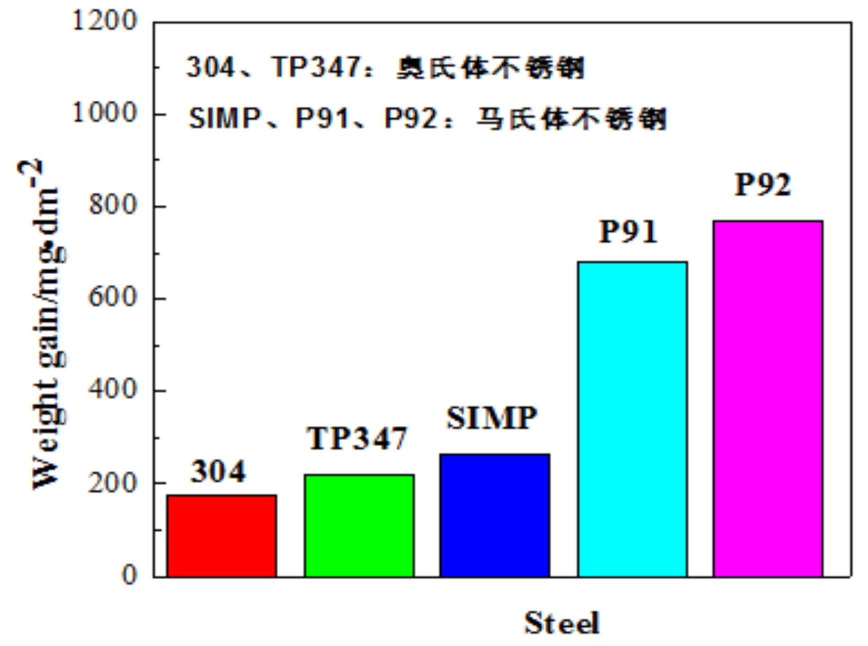
R&D of SIMP steel

◆ Main Properties

Chemical Component (wt%)

Steel	C	Si	Cr	Mn	W	Ta	V	Nb	Ni	Mo	S/ppm	P/ppm
SIMP	0.22	1.22	10.24	0.52	1.45	0.12	0.18	0.01	—	—	43	40
T/P91	0.1	0.26	8.5	0.46	—	—	0.20	0.04	0.17	0.92	20	30
T/P92	0.1	0.38	8.63	0.42	1.59	—	0.164	0.053	0.15	0.37	10	14
TP347	0.08	0.6	18	1.6	—	—	—	0.8	10	—	<30	<40
304	0.09	<0.03	18	<1.0	—	—	—	0.05	9.7	—	<10	<40

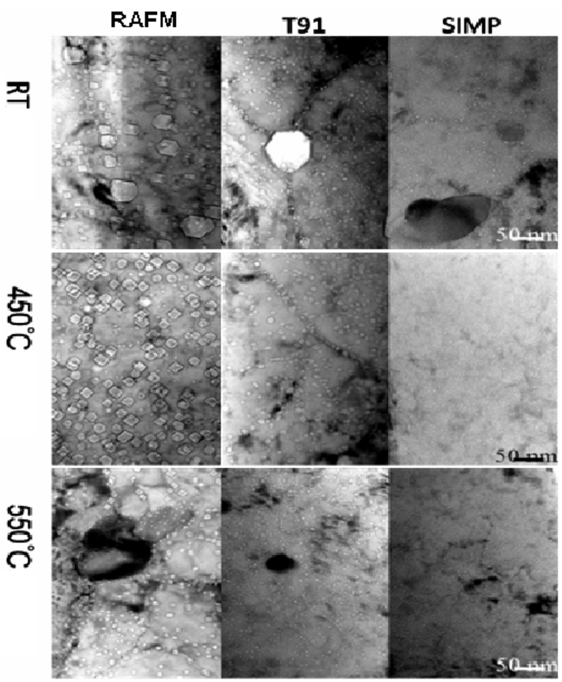
Corrosion Test in SC Water (600℃, 25Mpa, 1000h)

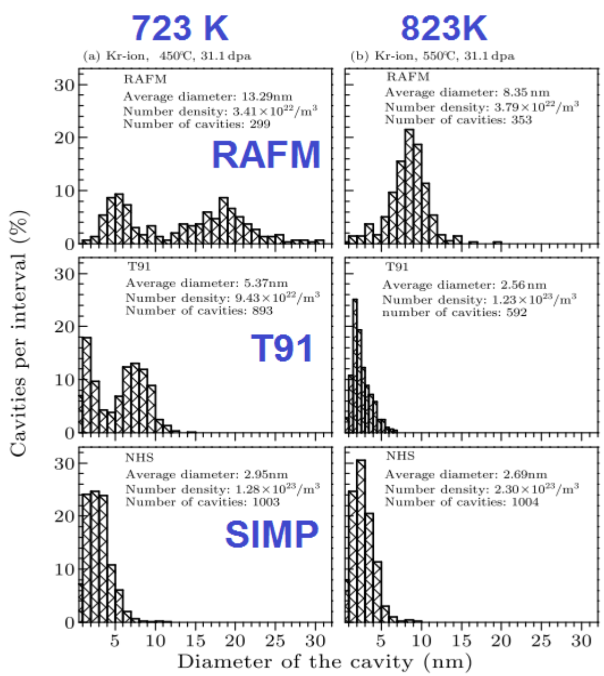


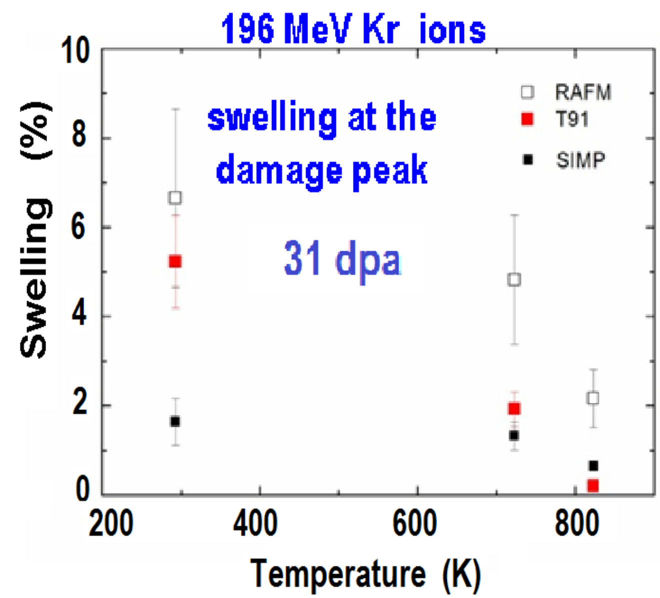
R&D of SIMP steel

◆ Main Properties

irradiation resistance







Irradiation swelling resistance: SIMP > T91 > RAFM steels

R&D of SIMP steel

◆ General —— Primary Evaluation

Comparison

Tests	Result
TS/YS/elongation rate at RT-600℃	SIMP ＞ (EP823, T91, RAFM)
Oxidation resistance at RT-800℃	SIMP ＞ (EP823, T91)
LBE corrosion resistance (600℃, static saturation oxygen）	SIMP ≁ EP823 ＞ T91
LBE corrosion resistance (450℃, static saturation oxygen）	SIMP ＞ T91
Short durability at 600℃ (150 MPa)	SIMP ＞ (EP823, T91)
Durability at 650℃ (100 MPa)	SIMP ≁ T91 ＞ EP823
Ion irradiation resistance at RT- 450℃	SIMP ＞ (T91, RAFM)
Ion irradiation resistance at 550℃	SIMP ≁ T91 ＞ RAFM
SC water corrosion resistance (600℃, 25Mpa, 1000h)	SIMP ≁ TP347, 304 ＞ T/P91, T/P91

SIMP steels irradiated at SINQ-PSI, (n/p, ～20dpa, 2012-2014)

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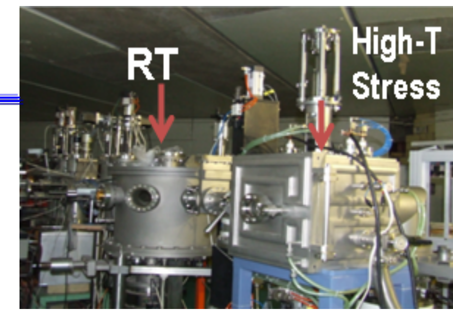
Perspectives

◆ Evaluation —— Synergetic effects in SIMP steel

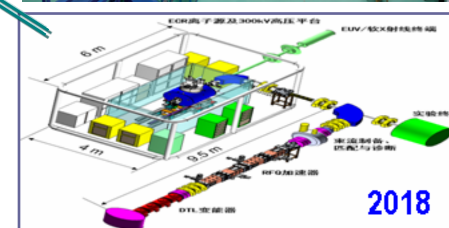
Simulating "true" environment in nuclear energy system

(Dopant, DPA, High-T, Coolant, Stress, …)

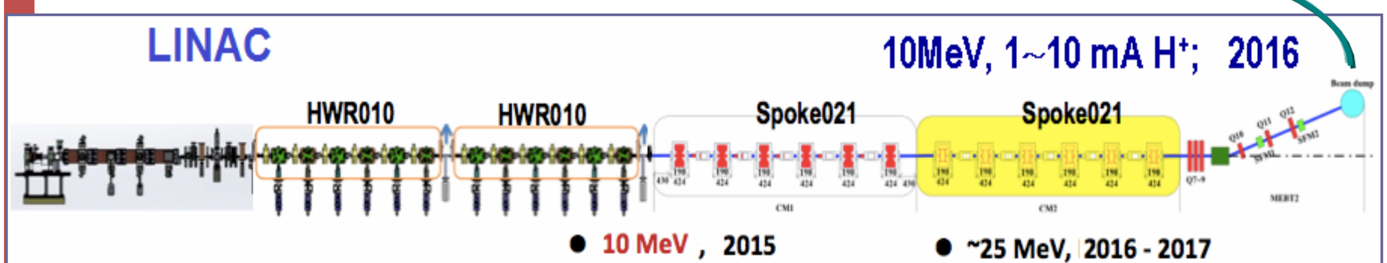
- DPA + Coolant + High-T
- DPA + Stress + High-T
- H (or He) + DPA (self ions) + High-T



- H + He + DPA (self ions) + High-T
- H + He + DPA + Stress + High-T
- H + DPA + Stress + High-T



$H_2^+ + He^{2+} + {}^{58}Ni^{28+}$ $H_2^+ + He^{2+} + {}^{56}Fe^{26+}$	30-50 μA	0.1-100 MeV



Acknowledgement

* Institute of Modern Physics, CAS

Wei Kongfang, Yao Cunfeng, Shen Tielong,

Chang Hailong, Zhang Hongpeng, et al.

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Shan Yiyin, et al.

Thank You !

谢谢！