Status and Challenges in Development of Fusion Reactor Materials for CFETR

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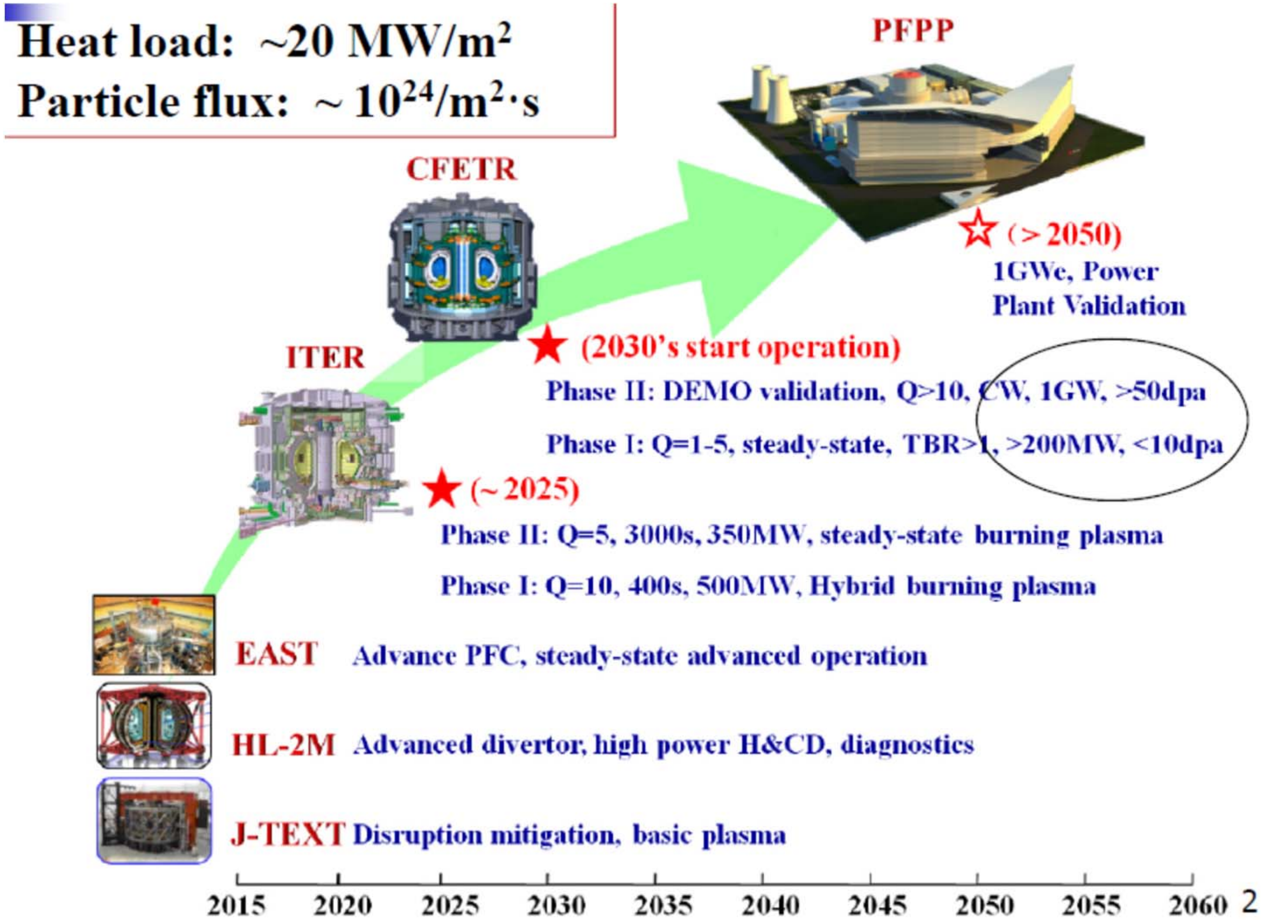
On behalf of the working group for the Roadmap to the Development of Fusion Reactor Material in China

FPCC strategic session, Developments in Materials Research for Fusion, Paris 14 February 2019

Roadmap of Fusion Energy in China



CFETR Missions

Obtained Burning Plasma for fusion power

1. P=200-2000MW
2. Q=1-10，SSO， hours
3. Q=20-30 hours-SSO
4. High energetic α heating

Steady-state operation for fusion energy

5. Hybrid (OH+BS+CD)
6. SSO (Ext H&CD +Higher f_b)
7. PSI on the first wall
8. Heat&particle exhaust on Div.

Breeding Tritium for T self-sustained

9. T-breeding by blanket
10. T-plant: extract & reprocessing
11. Materials & components
12. Reliable and quick RH
13. Licensing & safety

Research of FRM in China

- In China there are about 400 scientists and graduate students from more than thirty institutions doing research work in the field of fusion reactor materials.
- “Forum of Fusion Reactor Materials” holds every year with more than 200 participants.

General Strategy of FRM for CFETR

- The development of fusion reactor materials in China should match and cooperate closely with CFETR design.

- Because of the similarity, the development of FRM will incorporate with the R&D plan in fission energy. Meanwhile, there are important lessons to be learned from the development of fission reactor materials.

- Chinese TBM for ITER will be finished in 2020's. Although the working conditions in ITER are moderate comparing to CFETR, the R&D of some materials for C-TBM is benefit to the development of FRM in blanket for CFETR.

General Strategy of FRM for CFETR

- It's important to emphasize the industrialization of the candidate materials, including issues of fabricability and joining techniques. Direct participation of industry as a main partner is highly recommended.

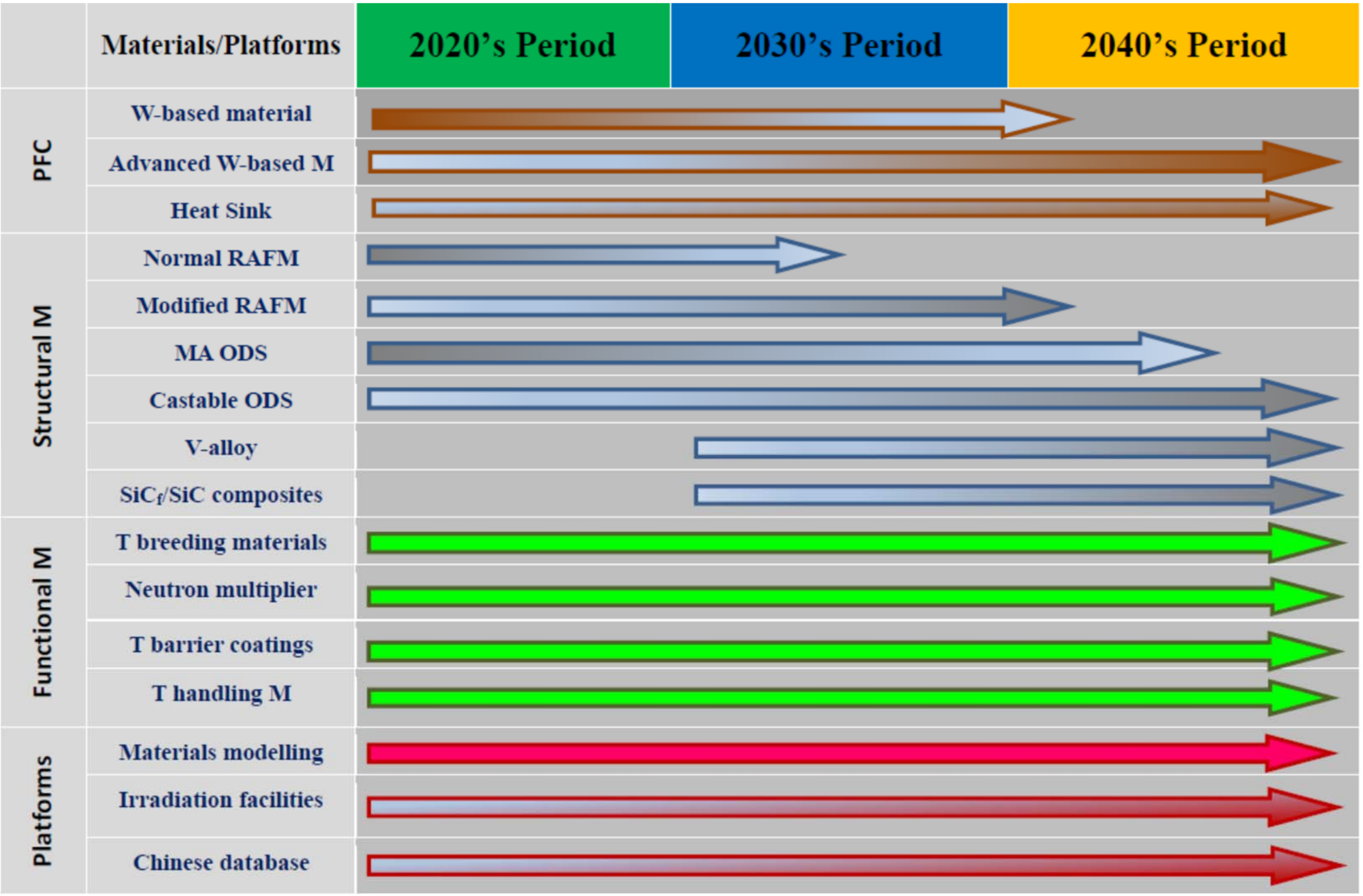
- The selection of various materials for CFETR is on the basis of the testing results of neutron irradiation at different doses.

- Due to the lack of fusion neutron sources, neutron irradiations will be carried out at first with fission reactors (both domestic and international). In addition, CFETR will also be used for components test.

Roadmap to FRM for CFETR

- In order to match the design and construction requirements of CFETR, we try to outline a roadmap of FRM development in China. Based on the R&D situation and applications of materials, the roadmap to fusion reactor materials development in China is divided into four parts:
  - Plasma-facing materials and components;
  - Structural materials;
  - Functional materials (In this roadmap we will focus mainly on tritium breeder, neutron multiplier and functional coatings);
  - Supporting platforms (material modelling, material database and irradiation test facilities).

Roadmap to FRM for CFETR

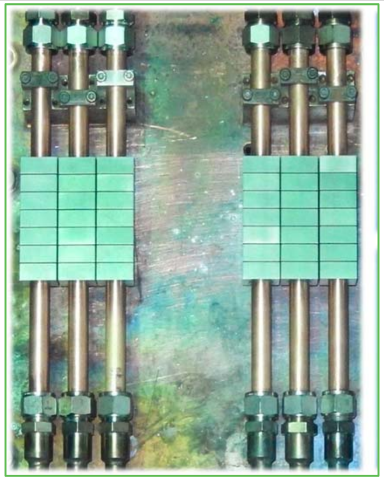


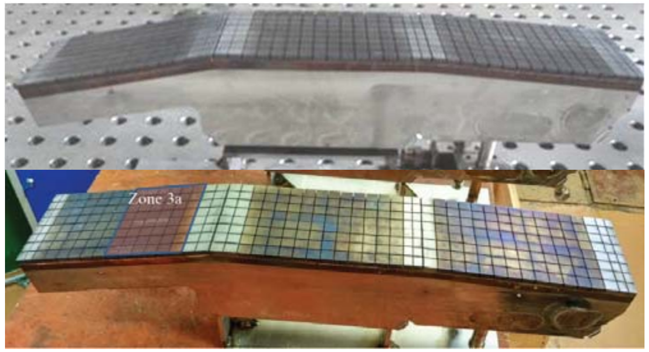
Roadmap to FRM for CFETR-an example

- Plasma-facing materials-divertor/first wall
  - Current Stage: ITER grade pure tungsten, W/steel.
  - Future R&D: Advanced W-alloy or reinforced W.

	Pure tungsten/components	Advanced tungsten-based materials
2020's Period	**PFCs based on ITER grade pure tungsten plates**; PSI: >10^{22} $m^{-2}\cdot s^{-1}$, > 10^{27} m^{-2}) ; HHF：10 MW/m^2; **Neutron irrad. : 1-2 dpa of PFCs.**	**Focus on two or three advanced W-based materials**; complete cold-state thermal properties tests; HHF tests. **Neutron irradiation of ~3 dpa**
2030's Period	Test in ITER together with Chinese TBM	**PSI: > 10^{24} $m^{-2}\cdot s^{-1}$, > 10^{28} m^{-2}** ; **HHF test: 20 MW/m^2;** **Neutron irradiation: ~ 5 dpa**.
2040's Period		Fusion neutron irradiation: > 5 dpa; CFETR tests for W/Cu divertor and W/steel FW components.

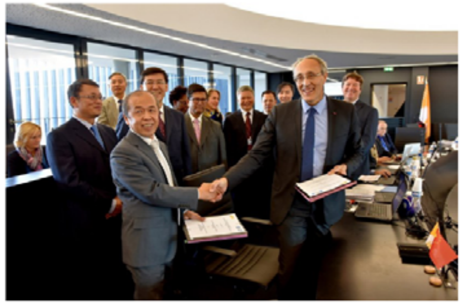
Recent Progresses in FRM in China





The HHF test of FW was successfully completed in 2016.

PA signed on Nov. 16, 2016



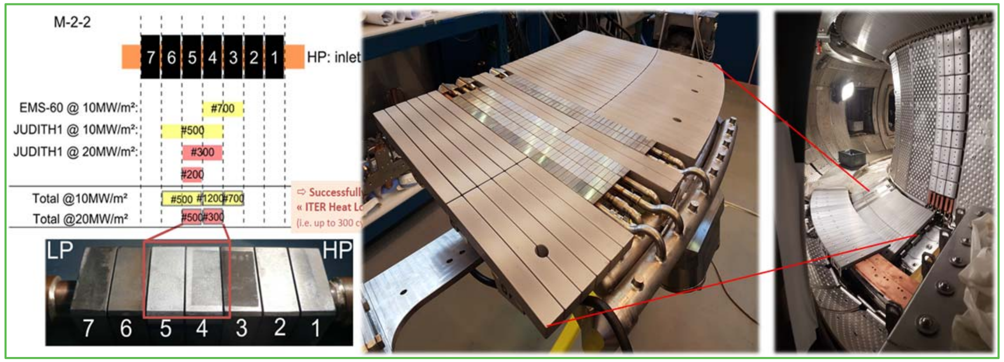
ITER NEWSLINE -

21 Nov, 2016

China signs final Procurement Arrangement

An important milestone was celebrated on the margins of the ITER Council last week when the head of ITER China, Luo Delong, and ITER Director-General Bernard Bigot signed the Blanket First Wall Procurement Arrangement on 16 November. This was the last remaining Procurement Arrangement scheduled for signature by the Chinese Domestic Agency in the context of its "in-kind" procurement commitments to the project.

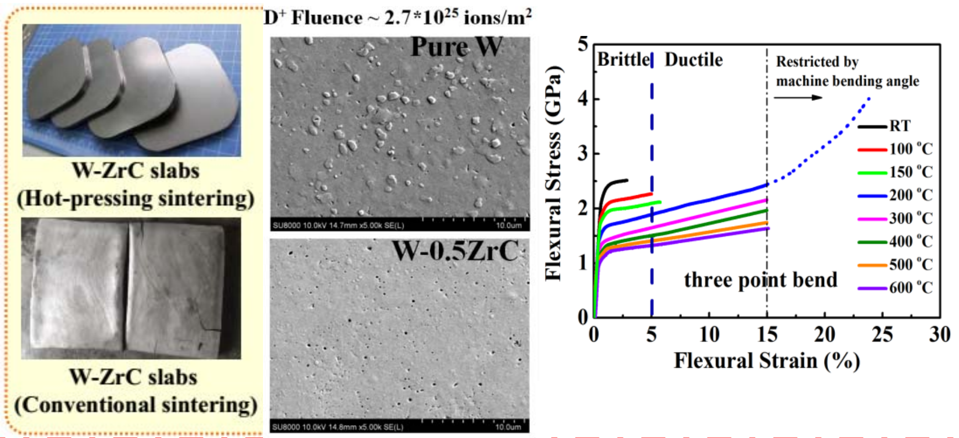
Small scale monoblock mockups passed ITER examination (5000 cycles@10MW/m^2 and 1000 cycles@20MW/m^2) and full size prototype components are under development.

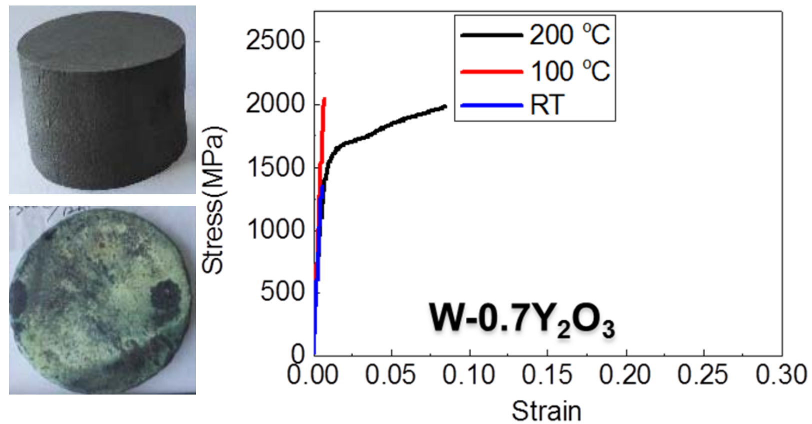


Both monoblock and flat-plate small scale mockups passed CEA high heat flux examination, full size monoblock PFCs installed in WEST for experiments and batch procurement is underway.

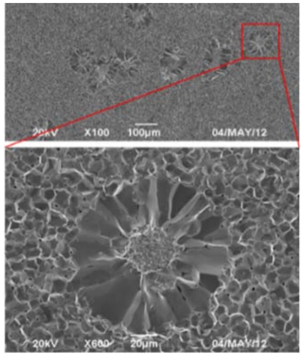
Recent Progresses in FRM in China

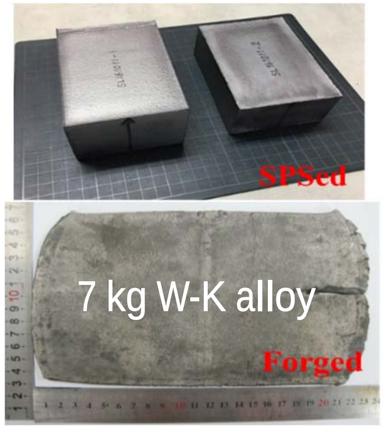
Advanced W-based materials and heat sink



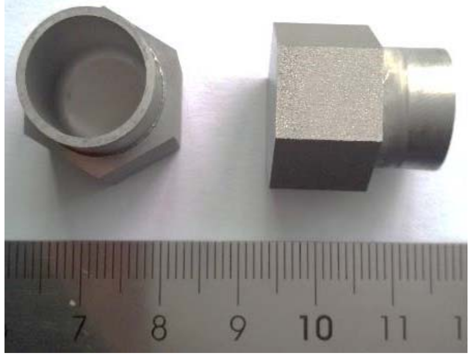


W_f/W composite





Finger with MIM-W-Y_2O_3 + CVD-W.



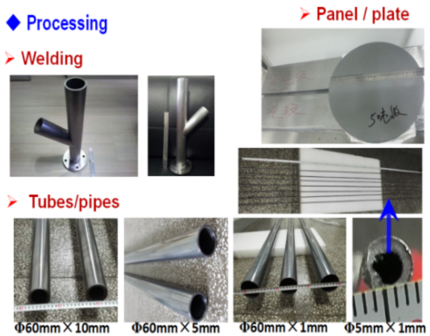
W coatings on CuCrZr

Recent Progresses in FRM in China

Large-scale RAFM production and ODS steel

CLF-1

CLAM



SIMP

MA-ODS

Production of functional Materials

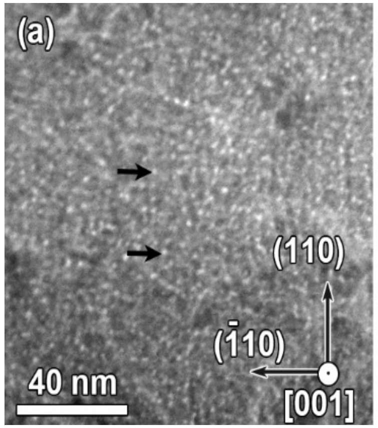
Be pebbles

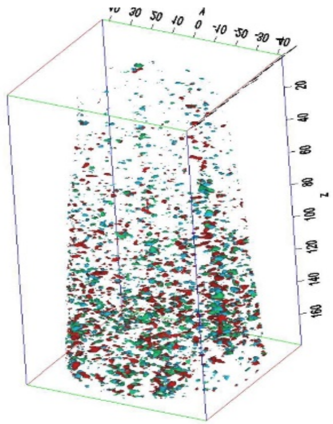
Li_4SiO_4 pebbles

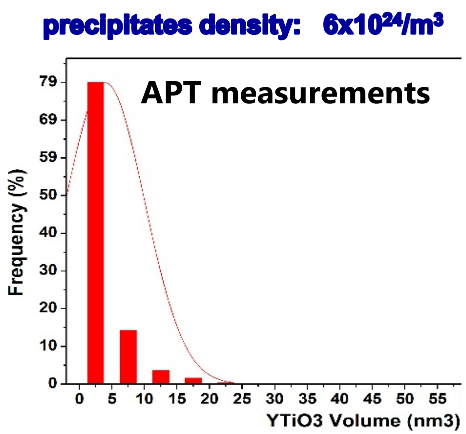
Recent Progresses in FRM in China

Modified RAFM Steel

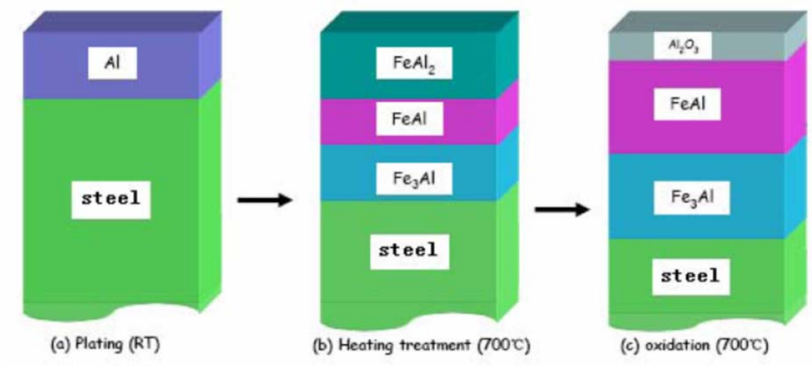
Castable ODS-RAFM Steel

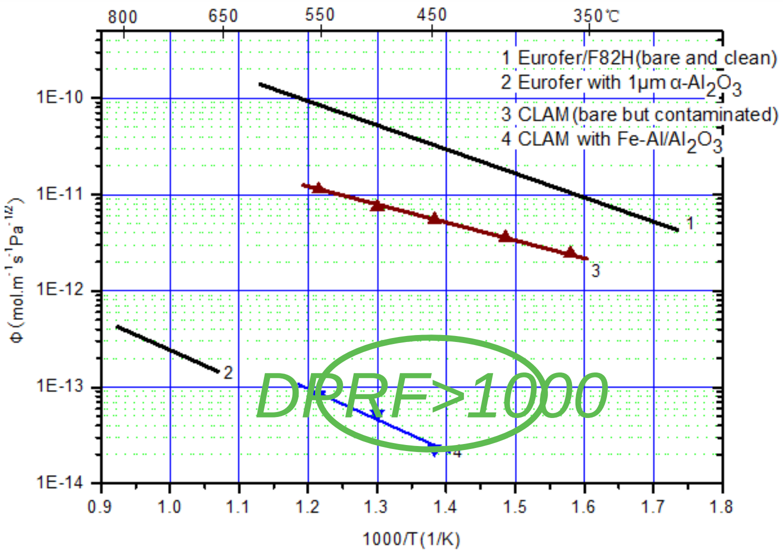




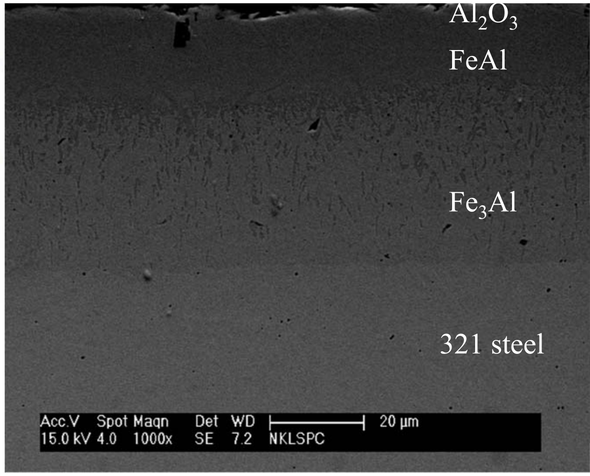


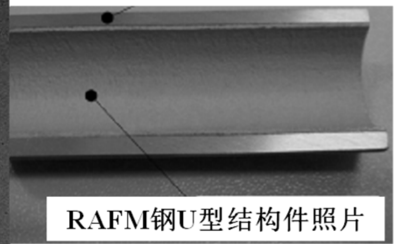
Recent Progresses in FRM in China

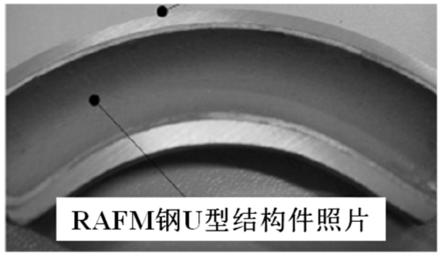




Al_2O_3/Fe_xAl_y coating on steels



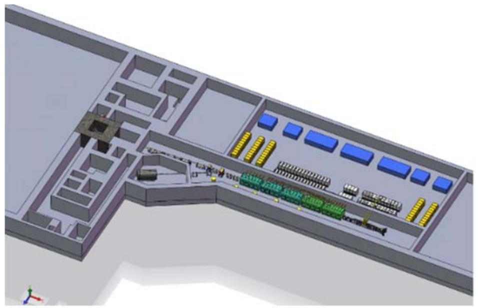


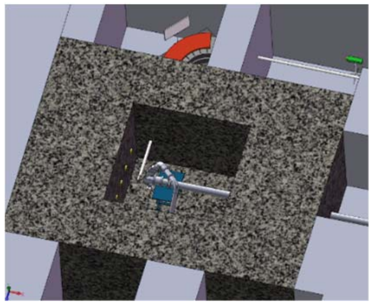


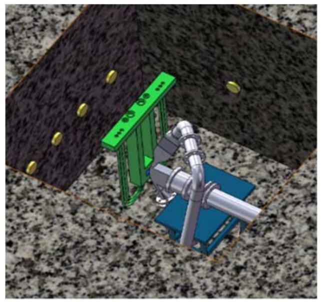
Recent Progresses in FRM in China

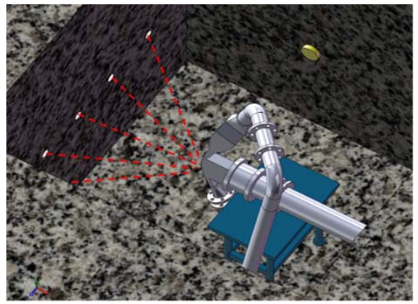
ADS SC Proton Accelerator: E-26 MeV, Pulse-12 mA, CW-2 mA

Proposed BISOL-MAINS: 40 MeV D^+, 10->50 mA, Liquid Li target



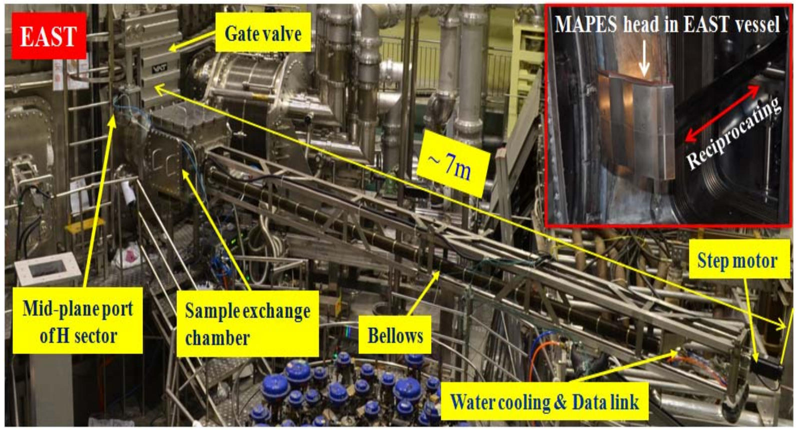




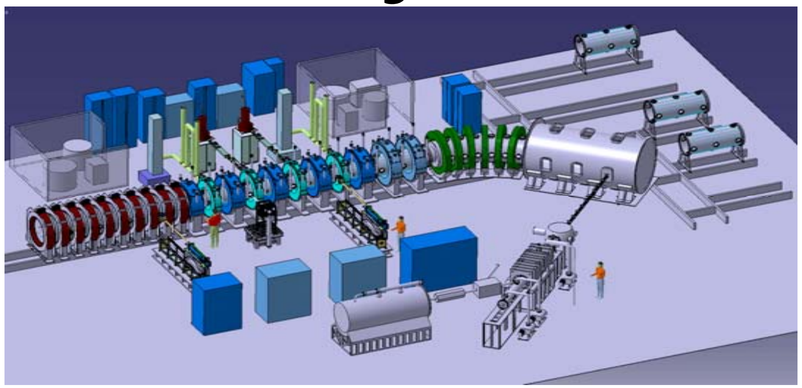


Recent Progresses in FRM in China

Material and Plasma Evaluation System/Linear plasma devices



Plasma source of high flux and low energy

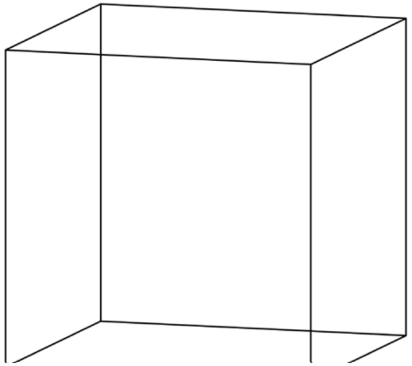


STEP

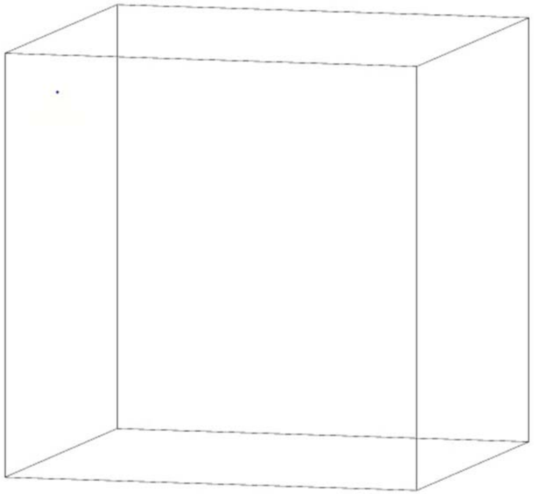
Recent Progresses in FRM in China

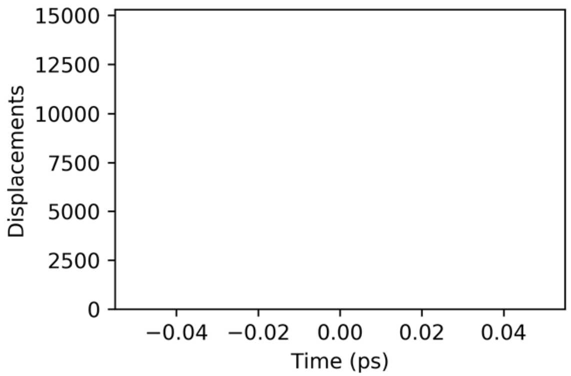
Multi-scale simulation: MD and KMC

Cascade evaluation



Defect evaluation





MD Simulation:
128,000,000 atoms,
240 cores , 56 hours

Simulation Steps	3,311,300,000
Physical Time	~1 s
Computing Time	~9 hours
Open box	$1 \times 1 \times 1\ \mu m^3$
Input cascade	~300 KeV
Temperature	500 K
Dose rate	$\sim 10^{18}\ m^{-2} \cdot s^{-1}$, 37n

KMC Simulation

Challenges of FRM for CFETR

- Plasma-facing materials-divertor/first wall
  - W-based alloys: resistant to 20 MW/m^2 of heat power & 10^{24}/m^2·s of P flux; tritium retention & permeation; transmutation; plasma disruptions
  - Cu-based alloys: high thermal conductance with good mechanical properties and radiation tolerance

- Structural steels-breeding blanket
  - RAFM steels: high radiation resistance
  - ODS steels: large scale production & welding
  - Tritium retention and lack of high dose irradiation with fusion neutrons

Challenges of FRM for CFETR

- Tritium-related Materials-breeding blanket
  - Li-based ceramics and Be-based alloy: high radiation and thermal stability
  - T barrier coating: high radiation resistance
  - T sealing material: radiation resistance

- Fusion neutron irradiation platforms
  - Equivalence: fission/fusion irradiation, ion/neutron irradiation, small/standard sample
  - Fusion neutron source: waiting for approved for IFMIF-like facility

Challenges of FRM for CFETR

- Some other radiation-resistant materials which are needed to be considered and put into the Roadmap
  - Insulating feedthroughs and windows materials for plasma heating systems
  - Window/mirror materials for plasma diagnostics
  - Superconducting materials for superconducting magnet systems
  - ……

Recent Plans of FRM for CFETR

- Chinese TBM for ITER (approved by Chinese government, wait for ITER decision)
  - Fabrication of related materials, including RAFM steel, pure W.
  - Manufacture of TBM components.
  - Irradiation of above materials with fission neutrons at ~3 dpa.

- Tritium Plant (2018-2022)
  - Including R&D of T-breeder (e.g. Li_4SiO_4, Li_2TiO_3) , neutron multiplier (Be alloy pebbles), Al_2O_3 T-barrier coatings and sealing materials.

Recent Plans of FRM for CFETR

- R&D of Advanced Structural Materials for CFETR (2019-2023, approved)
  - Mainly on mass-production of ODS, modified RAFM, ODS-Cu/modified CuCrZr
- High-dose Neutron Irradiation of Domestic Advanced FRM (2019-2023 , approved)
  - 5-50 dpa with fission reactors for structural materials with small samples
- Simulation Platform of Neutron Irradiation of FRM (2019-2023 , approved)
  - Multiscale simulation of pure metals at low dose

Recent Plans of FRM for CFETR

- R&D of Advanced Tritium Barrier Coatings for CFETR (2019-2022, for young scientists)
  - Mainly on advanced T-barrier coatings
- R&D of Advanced PFC Materials for CFETR (2020-2024, in planning)
  - Mainly on advanced W-alloy or reinforced W
- Equivalence of Experimental Simulations of FRM (2020-2024, in considering)
  - Mainly on fission/fusion irradiation, ion/neutron irradiation, small/standard sample
- ……

Summary-Development of FRM in China

- The development of FRM in China is driven by CFETR and its goal is the requirements of design and construction of CFETR.
- D#preliminary roadmap to the development of FRM in China was drawn up to match the engineering design and construction requirements of CFETR.
- In recent years, there are many research progresses in FRM in China.
- Several R&D projects of FRM for CFETR have been launched or been planned.
- The challenges are huge, but we have to face them and find ways to solve them.

Thanks for your attention!