Review of Advanced Manufacturing Technologies for Fusion Reactor Materials

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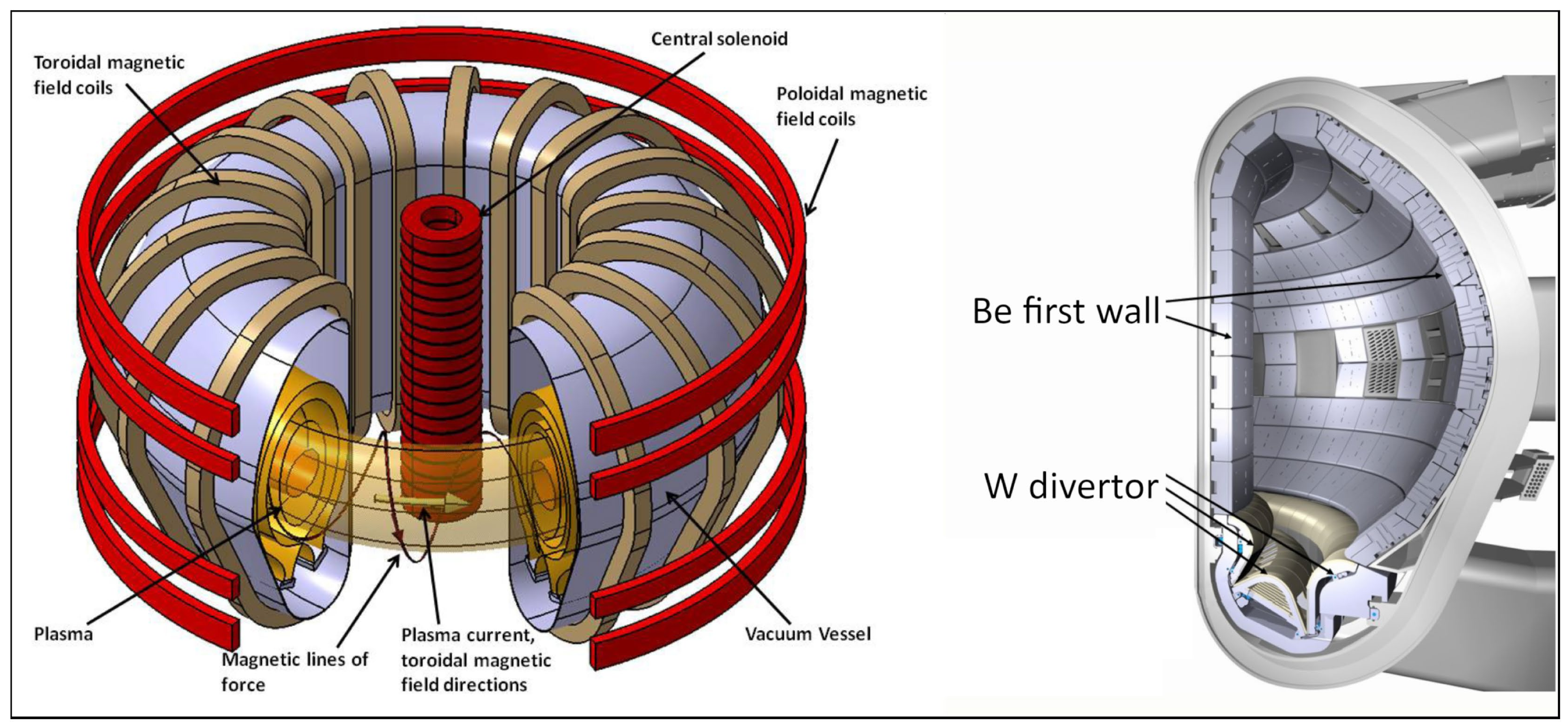
Outline of future-focused research project

- Technical challenges to materials for plasma-facing components (PFCs) for fusion energy systems
- A brief description of the FFR project
- An overview of application of AMTs to fabrication of plasma-facing components
- Key planned activities
- Summary of future plans

Technical challenges to materials for plasma-facing components for magnetic-confinement fusion energy systems

- Extreme operating conditions will require materials with extraordinary thermophysical properties and resistance to radiation damage degradation, e.g. Fabritsiev et al, 2019.
  - Steady-state heat load of 10 to 20 MW/m^2
  - Radiation load of 20 dpa for the first wall and 5 dpa for the divertor plates
  - Cross-section temperature gradient of 300–700°C
- Materials investigated for PFCs, such as the first wall or divertor region of the reactor vessel, have in the past included silicon carbide, molybdenum, niobium, tungsten, beryllium, and graphite.

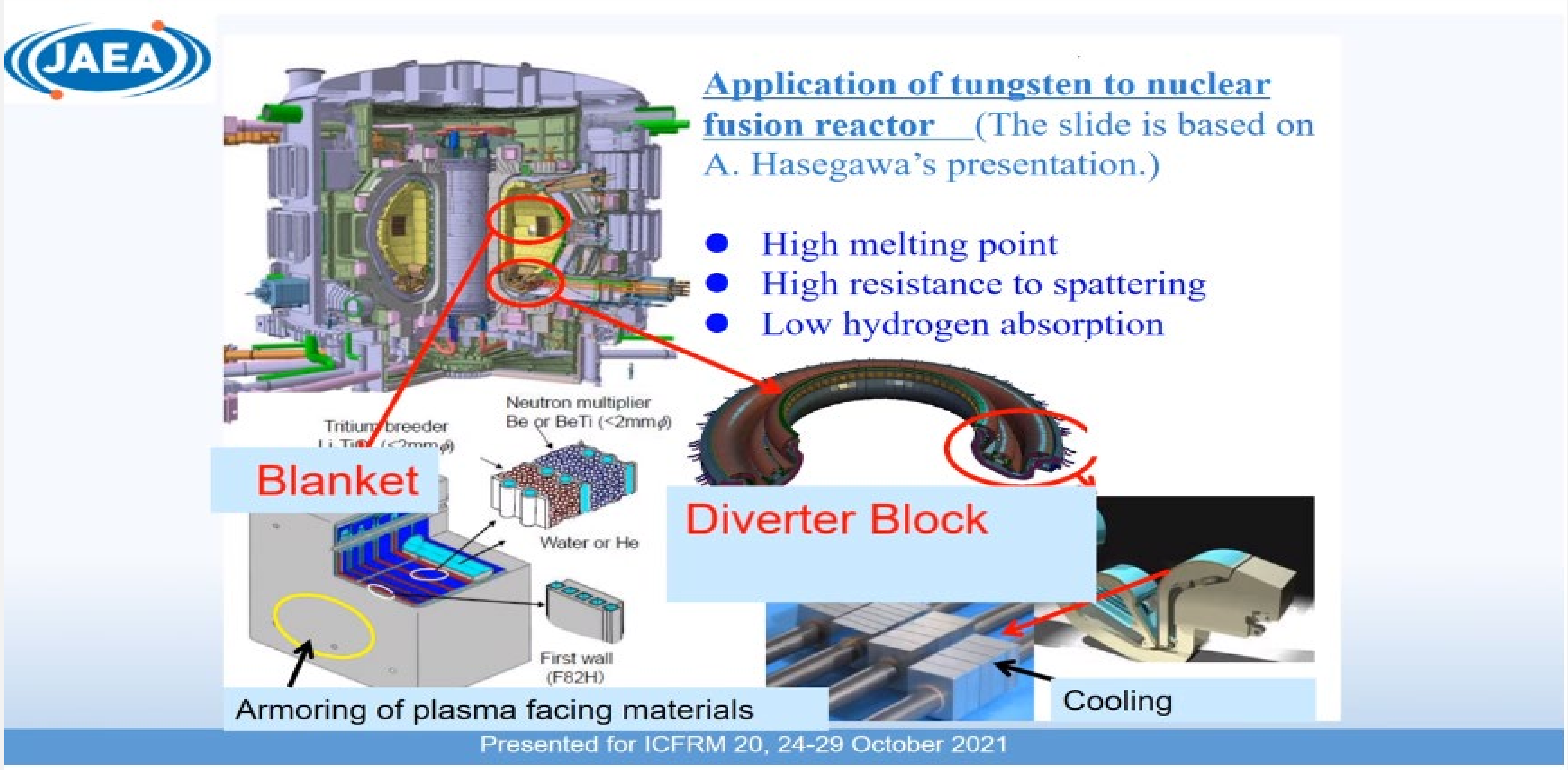
Magnetic fusion reactor schematic; ITER vessel cross-section



Tungsten (W) Armor for Tokamak Beryllium (Be) First Wall, and Divertor,
J. Cizek et al., Coatings, 2019, 9(12), 836.
https://doi.org/10.3390/coatings9120836

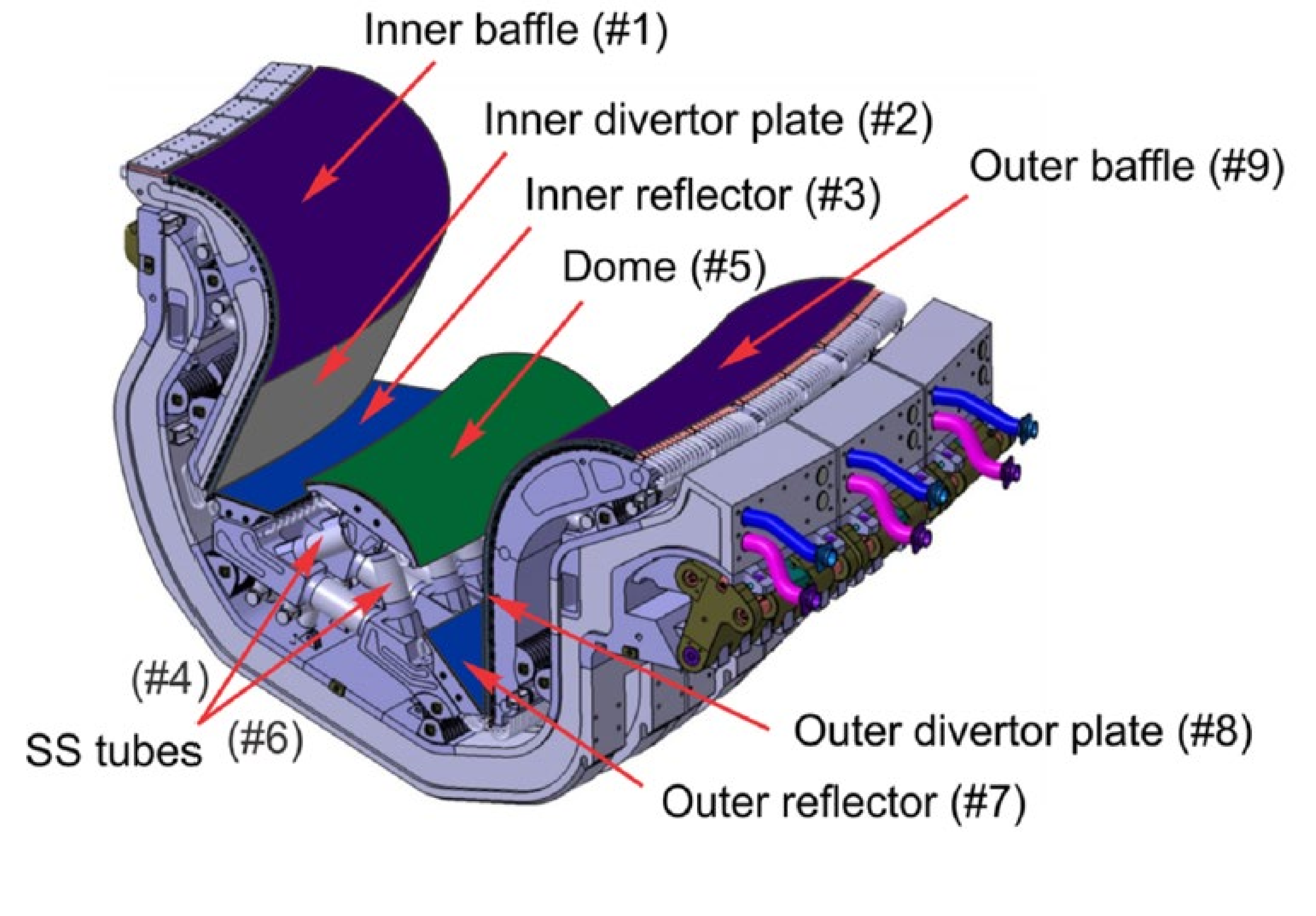
ITER: International thermonuclear experimental reactor being built in France
https://www.iter.org

Tungsten has to be able to withstand very harsh conditions and high thermal conductivity and good mechanical properties are needed



Tomoaki Suzudo, International Conference on Fusion Reactor Materials (2021).

ITER divertor cassette assembly with plates, baffle, reflector and dome surfaces made of tungsten as plasma-facing material, and SS (stainless steel) tubes



Hassanein, A., Sizyuk, V., Sci Rep 11, 2069 (2021).

https://doi.org/10.1038/s41598-021-81510-2

Fifty four (54) divertor cassettes planned for ITER. (https://www.iter.org/newsline/-/3229)

Brief description of FFR project on advanced manufacturing technologies (AMTs) for fusion reactor materials

- Project started in FY 2022
- Identify the technical challenges associated with novel, advanced materials for fabricating plasma-facing components in the context of NRC's current and evolving regulatory framework, including applicable codes and standards, and modeling capabilities.
- Enable NRC staff to broaden their knowledge of state-of-art for fusion reactor materials (FRMs) and specialized AMTs and challenges to their deployment

Examples of AMTs to fabricate plasma-facing components (PFCs)

- Additive manufacturing fabrication of nuclear-grade silicon carbide (SiC).
- CuCrZr/316L bimetallic joint produced by laser power bed fusion (L-PBF) technology
- Electron beam powder bed fusion (EB-PBF) additive manufacturing of refractory metals (tungsten, molybdenum)

Key Planned Activities

- Leverage work presented internationally on FRMs and AMTs to better inform NRC work
- Identify the technical challenges to materials for PFCs in the context of NRC's currently evolving regulatory framework.
- Investigate applications of AMTs to potential materials selected for PFCs
- Assess the likelihood of a licensee using AMT-fabricated PFCs to determine the need to make changes to the current regulatory framework

Summary

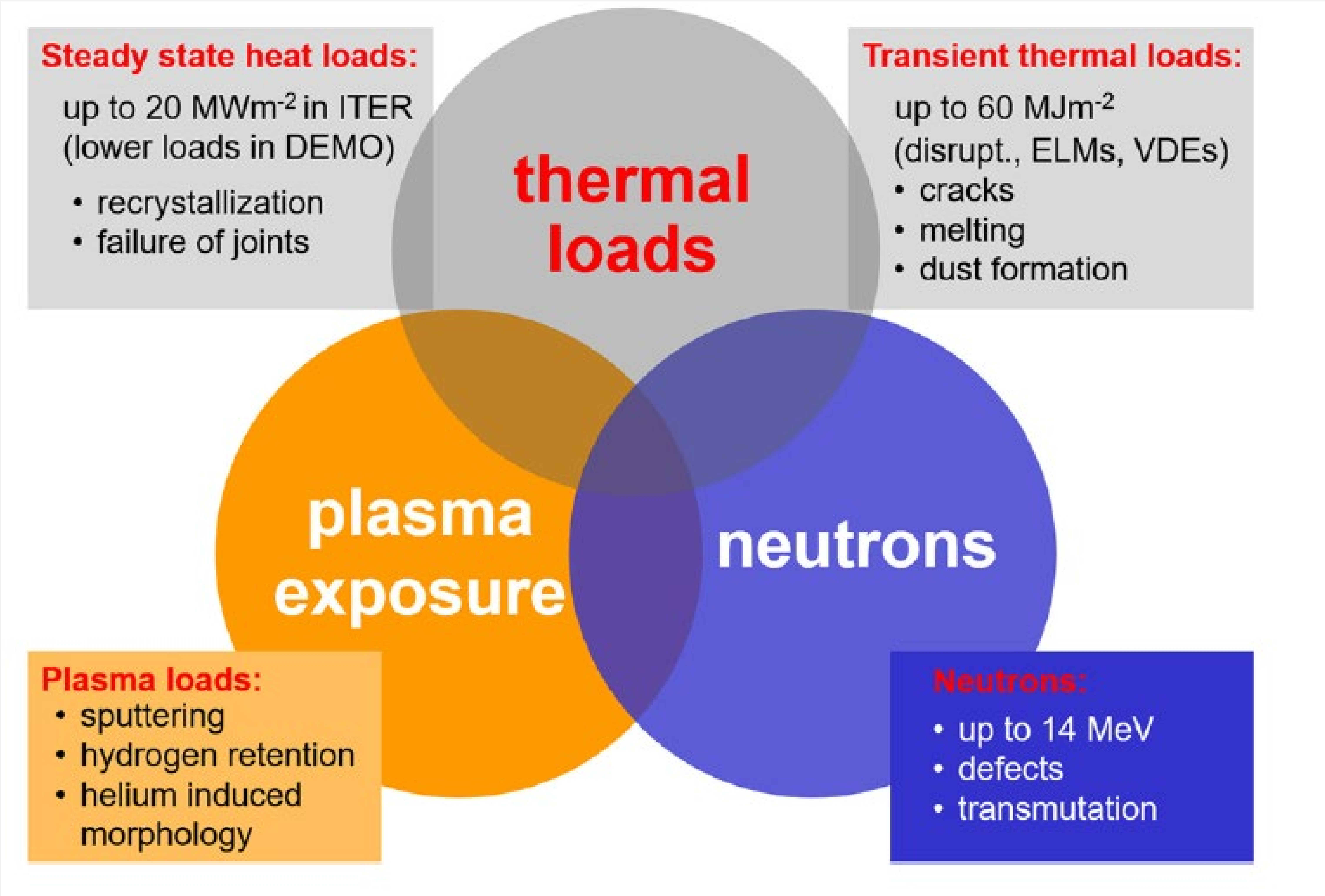
Advanced manufacturing technologies (AMTs) allow overcoming design restrictions and exploiting new problem-solving strategies.

An option for PFC subjected to extreme operating conditions could be based on functionally-graded multilayer structures of dissimilar metals.

Focus on exploring innovative materials and manufacturing technologies to meet materials needs for fusion energy

BACK-UP SLIDES

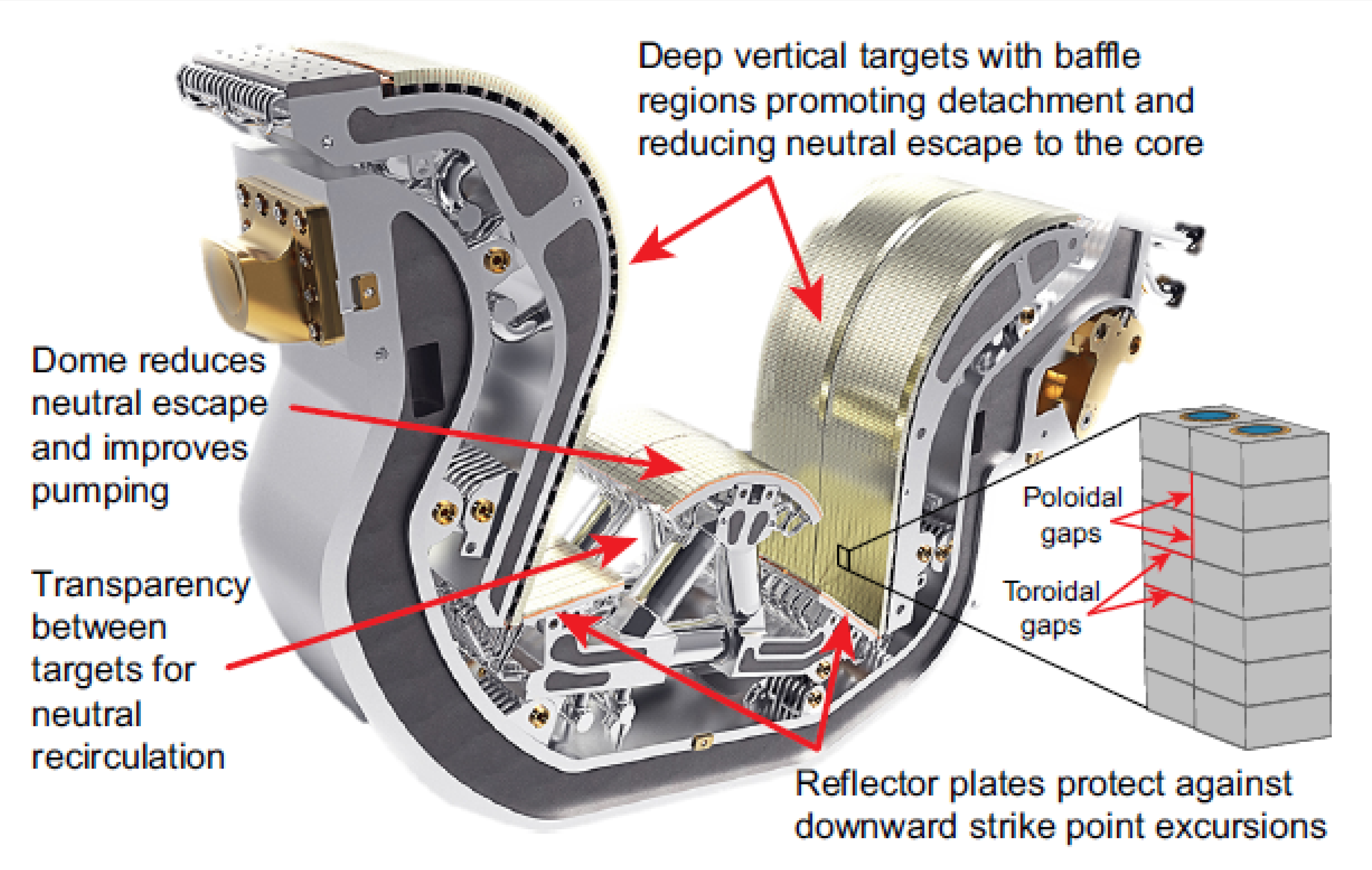
Technical challenges to plasma-facing components in magnetic confinement nuclear fusion devices



Challenges for plasma-facing components in nuclear fusion, J. Linke et al., Matter Radiation Extremes 4, 056201 (2019).

https://doi.org/10.1063/1.5090100

Key physics features in ITER tungsten divertor cassette



Physics basis for the first ITER tungsten divertor, R.A.Pitts et al., Nuclear Materials and Energy, Volume 20, August 2019, 100696.

https://www.sciencedirect.com/science/article/pii/S2352179119300237