Big Science Business Forum 2022 – Granada

Session B3: Basic material technologies and advanced manufacturing techniques

Material technologies for the Big Science

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Contents

Introduction

- The largest and most cutting-edge research infrastructures in Europe and the world.
- Boundary conditions: **extreme & unprecedented**.

Environmental conditions

- **Cryogenic temperatures**: fusion & accelerator magnets are operated at extremely low temperatures (-269 ºC) whereas space is also subjected to very cold temperatures.
  - **Metallic materials: FCC** (or HCP) microstructures are privileged

⇐ **Inconel 718** fasteners for the structure of the ITER magnet system. Austenitic microstructure (FCC)

Cold mass of a a single-aperture 11 t Nb3Sn demonstrator dipole for HL - LHC upgrade. **316LN**, austenitic microstructure, welded with 1.4453 filler (austenitic microstructure) ⇒

Environmental conditions

- **Cryogenic temperature**: fusion & accelerator magnets are operated at extremely low temperatures (-269 ºC) whereas space is also subjected to very cold temperatures.
  - Polymeric matrix Composites (**PMC**), carbon fiber reinforced polymer (**CFRP**).

⇑ Carbon fiber filament winding

- Low intrinsic weight
- High strength and stiffness
- Excellent fatigue strength
- High chemical resistance
- Corrosion resistance

Environmental conditions

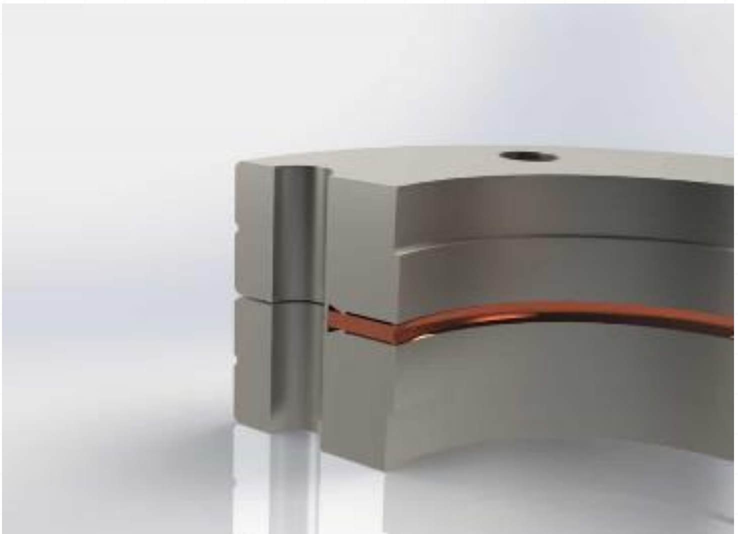
- **Electromagnetic fields:** very high field superconducting magnets used to steer and focus the particle beams on particle accelerators and to confine the plasma.
  - **Materials with very low magnetic permeability**

⇑ ITER tie plate being forged. Material: **FXM-19** (high strength austenitic stainless steel). Length: 15.2 m

⇐ Aluminium shells of MQXF magnets. Material: aluminium **7075 T6**.

Environmental conditions

- **Vacuum and outgassing**
  - UHV required in particle accelerators limits the use of polymers (and PMCs) to its minimum.

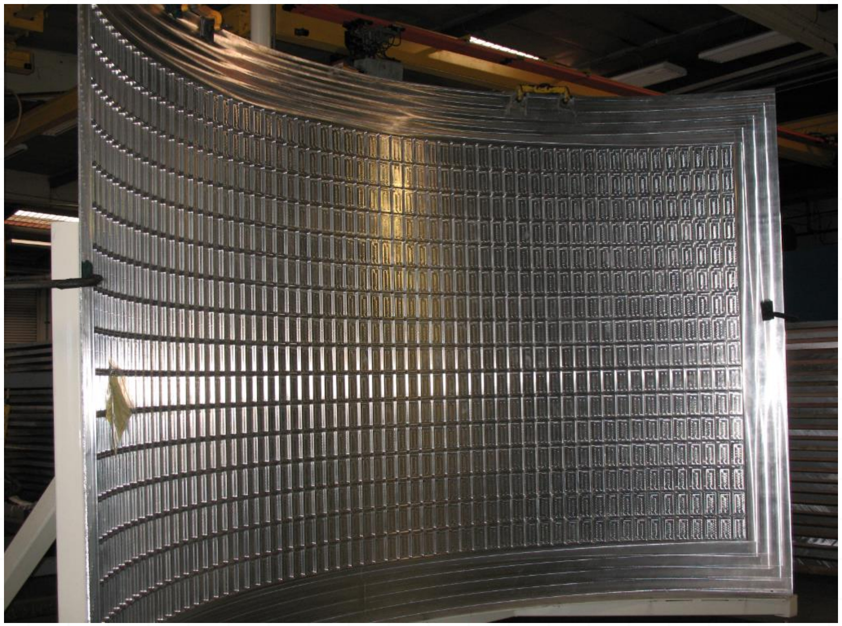


⇐ **OFE – Cu** gasket in a Conflat joint

⇐ NEG coatings (**TiZrV**) capture the last molecules of air, acting like a gigantic pump.

Environmental conditions

- **Vacuum and outgassing**
  - Degassing can also be a problem in space; thus, some structural parts are still fabricated in Ti alloys, austenitic stainless steel and Al alloys (Al – Li, series 2xxx and series 7xxx).

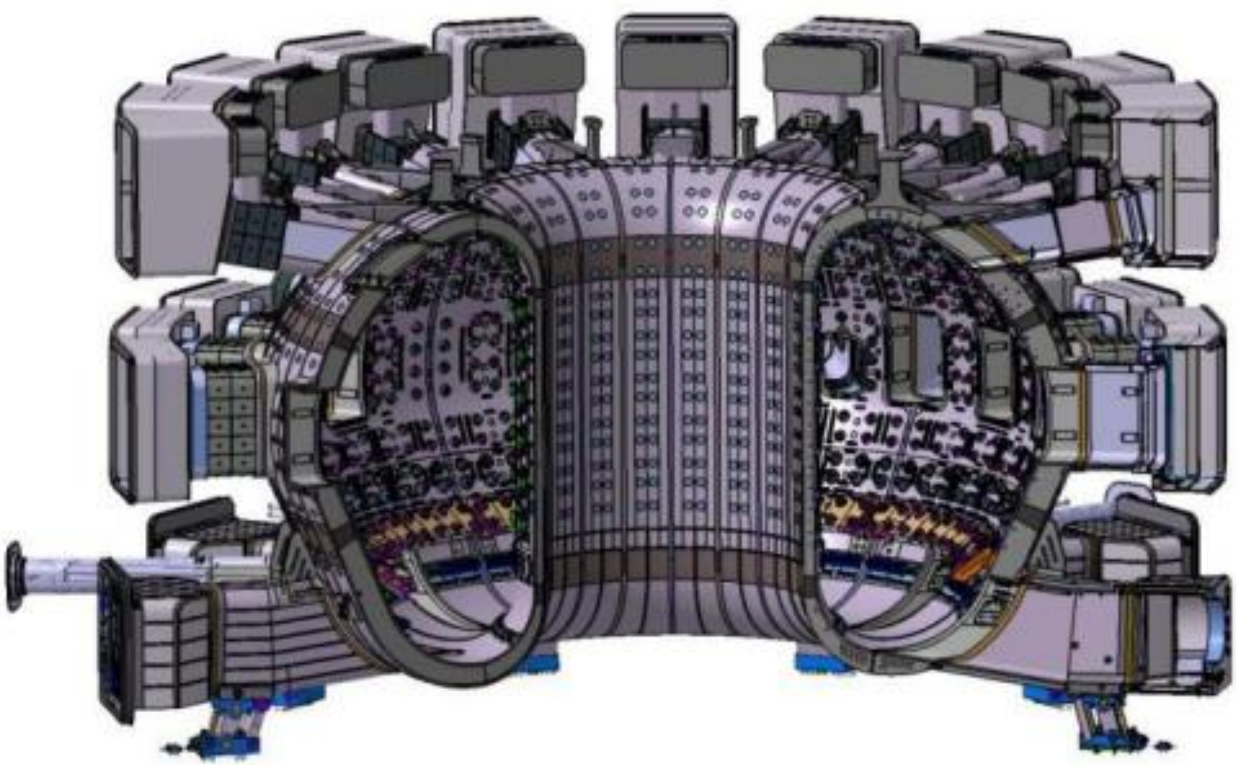


⇐ Aluminium alloy **2050 T8** panel after machining, forming, and artificial aging operations

Al **2050 T34**, CNC machine from a 150 mm thick plate into a nose component ⇒

Environmental conditions

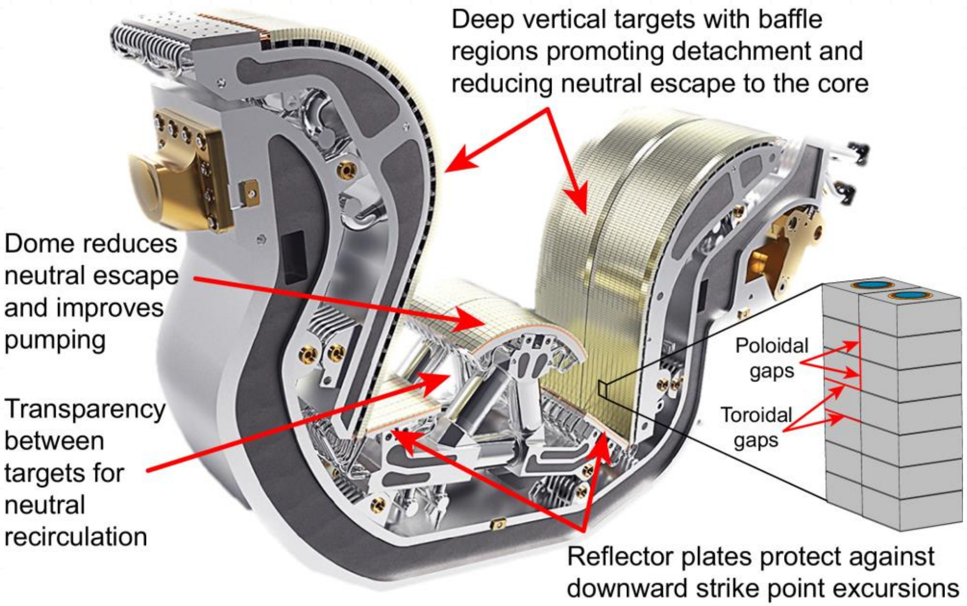
- **Vacuum and outgassing**
  - For the ITER vacuum vessel, **austenitic stainless steel (316LN)** is predominantly used.



⇐ Schematic of the ITER vacuum vessel

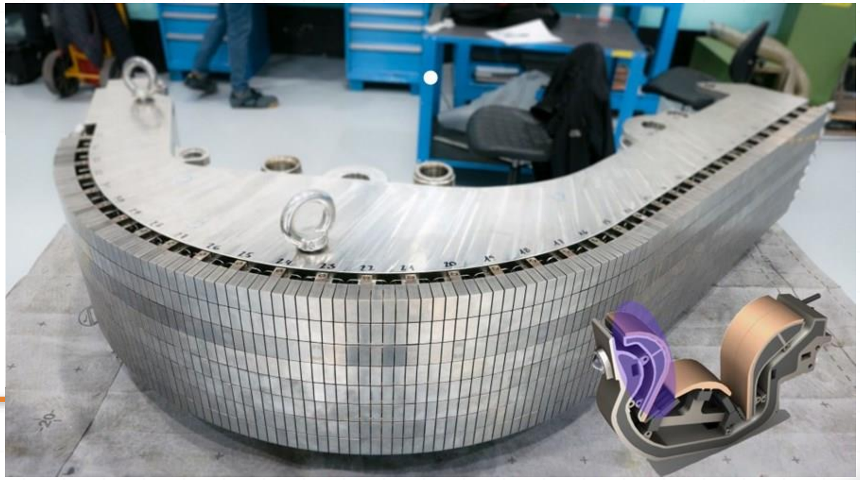
Environmental conditions

- **Elevated temperatures and extreme heat fluxes**
  - The ITER divertor chooses **W** for the plasma facing components (PFC): highest melting point of all metals



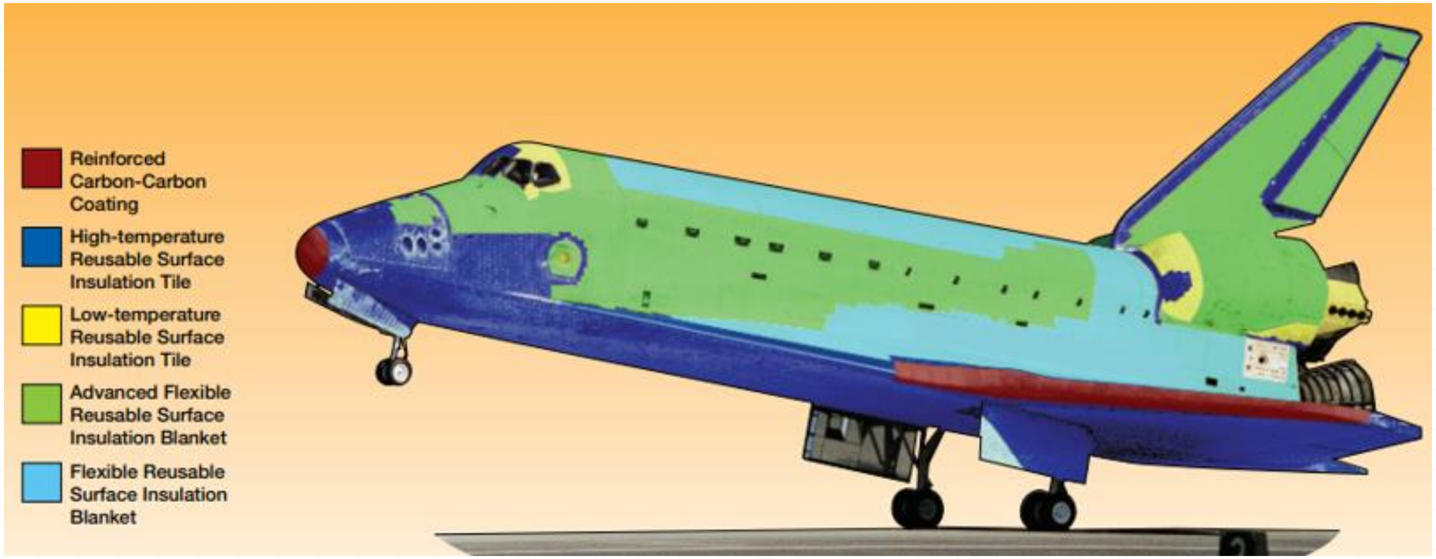
⇐ Schematic of one of the 54 ITER's divertor cassettes. The heat (up to 20 MW/m^2 heat flux) is evacuated from the vertical targets and the dome (PFC) by active water cooling.

Mockup of a vertical target in which the **W tiles** can be clearly seen, as well as the **CuCrZr cooling pipes** ⇒



Environmental conditions

- **Elevated temperatures and extreme heat fluxes**
  - The thermal protection system protect the orbiter at extreme temperatures, primarily during the re-entry into the atmosphere.



- **Reinforced C – C** coating at the nose tip and wing edges.

- The rest are different ceramic tiles typically made of **high purity silica**, with an extremely low thermal conductivity to prevent the heat to transfer to inner layers.

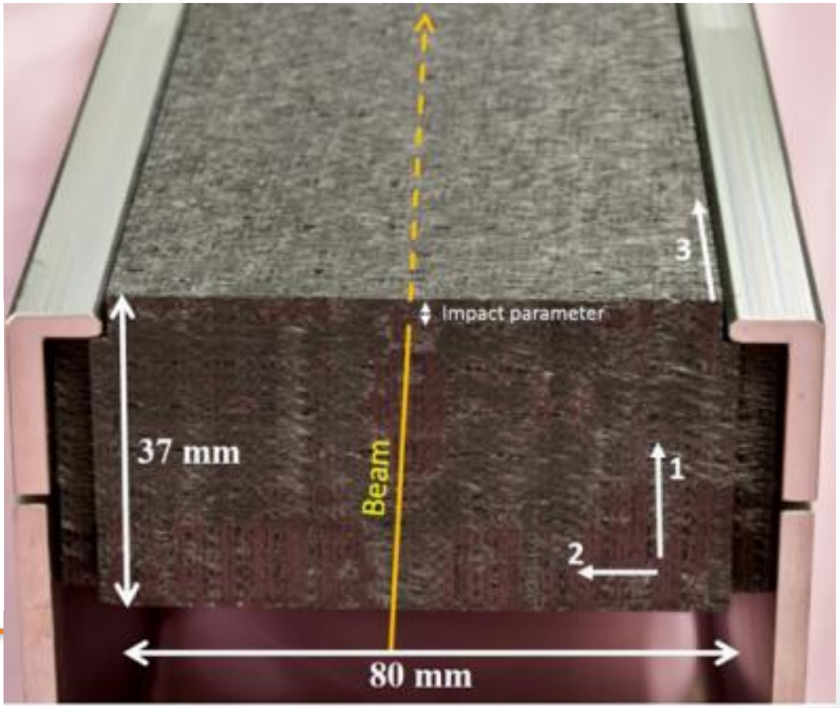
Environmental conditions

- **Elevated temperatures and high strain rates**
  - Beam intercepting devices (targets, dumps, collimators) are complex structures to withstand energetic beam impacts.

⇐ Phase II collimator mockup. The clamping system in **ODS copper** is observed.

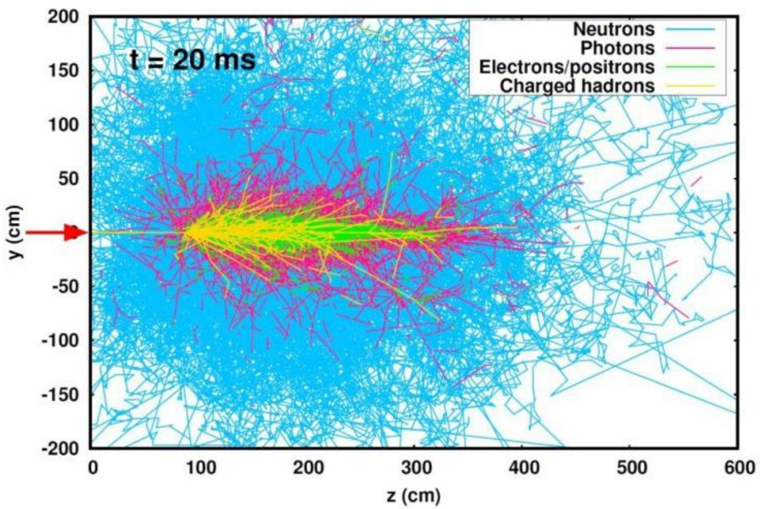
⇑ **Mo – graphite** absorber block

3D C – C composite for beam intercepting devices ⇒



Environmental conditions

- **Radiation:** For particle accelerators, the main challenge in metallic materials is **activation due to beam losses**. For that reason, the **Co content** is strictly limited for components close to the beam.



Radiation shower set up by a single 450 GeV/c proton in Al

Courtesy of R. Garcia Alia

- **Radiation:** For polymeric materials **stiffening and loss of elongation at break** is studied at different dosses.

An important effort is made for cables' sheaths and insulations in the frame of the CARE (Cable Ageing Research) project.

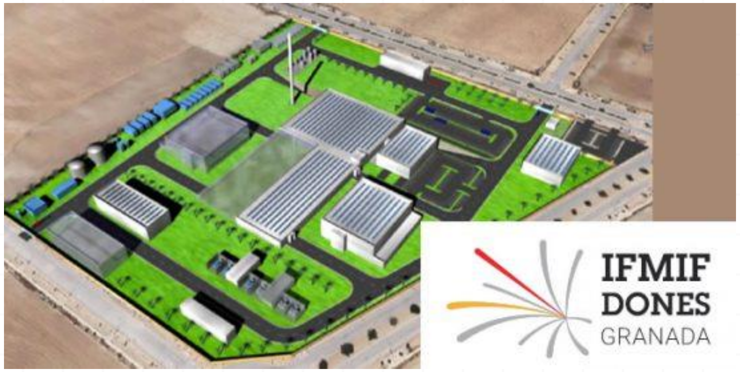
Environmental conditions

- **Radiation:** For fusion reactors, the neutron flux as well as the ɣ rays from the D – D or D – T fusion reaction imposes certain restrictions in the material selection in terms of activation of structural materials.

$$D + T \rightarrow \alpha\ (3.5\ \text{MeV}) + n\ (14.1\ \text{MeV}),$$

$$D + D \rightarrow \begin{cases} T(1.01\ \text{MeV}) + p\ (3.03\ \text{MeV}) \\ {}^3_2\text{He}(0.82\ \text{MeV}) + n\ (2.45\ \text{MeV}) \\ \alpha + \gamma\ (Q = 23.85\ \text{MeV}) \end{cases}$$

- Effects of high displacement per atom (dpa), activation, gas production (swelling) and (grain boundary) embrittlement must be studied.



→ Development and qualification of materials capable of withstanding extreme conditions at which the components of the first wall of future fusion reactors will be exposed to.

Thank-you