Use of Beryllium in the ITER Project

C.K. Dorn

Be4FUSION LLC

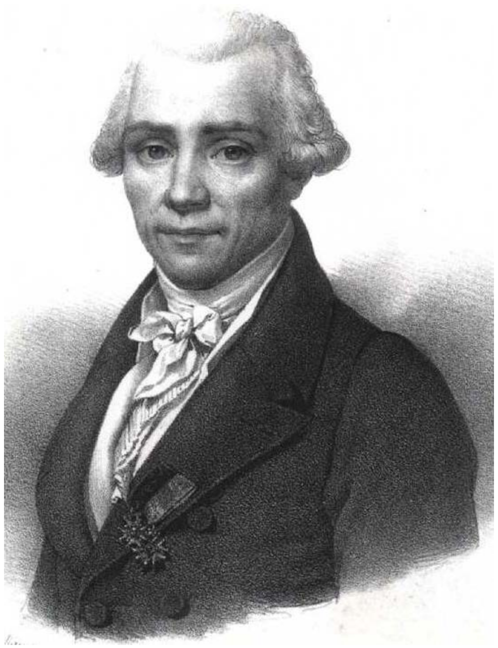
Project Associate for Beryllium Activities
Blanket Section
Tokamak Engineering Department
ITER Organization

With contributions from:

J. van der Laan, M. Merola, A.R. Raffray, V. Barabash & R. Eaton

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

- History & Status of the ITER Project
- Use of Beryllium in the ITER Blanket First Wall
- Summary

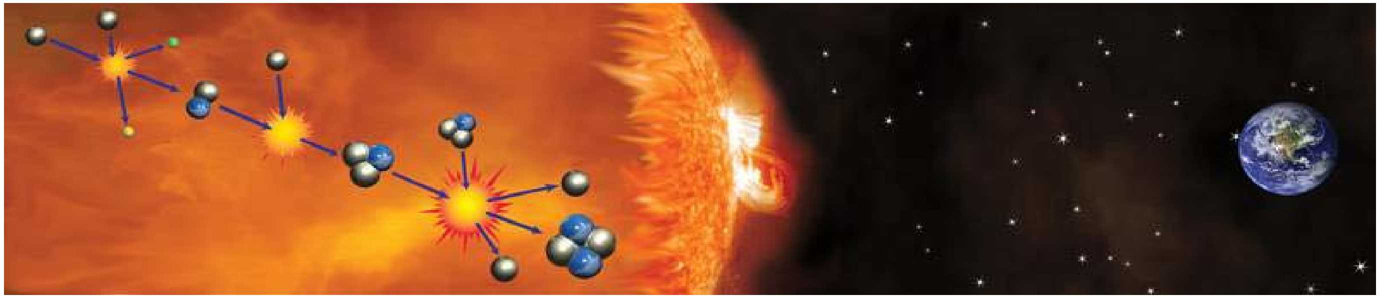


Louis Nicolas Vauquelin
(Discovered beryllium in 1798)

bēryllos (βήρυλλος)

Fusion Powers the Sun and the Stars

"…Prometheus stole the fire from the heaven"



On Earth, fusion could provide:

- Essentially limitless fuel, available all over the world
- No greenhouse gases
- Intrinsic safety
- No long-lived radioactive waste
- Large-scale energy production

The idea for ITER originated from the Geneva Superpower Summit on 21 November 1985, when the Russian Premier Mikhail Gorbachev and the US-President Ronald Reagan proposed that an international project be set up to develop fusion energy "as an essentially inexhaustible source of energy for the benefit of mankind."

"All the News That's Fit to Print"

The New York Times

Late Edition

VOL.CXXXV.. No. 46,601 — NEW YORK, FRIDAY, NOVEMBER 22, 1985 — 30 CENTS

Text of the Joint U.S.-Soviet Statement: 'Greater Understanding Achieved'

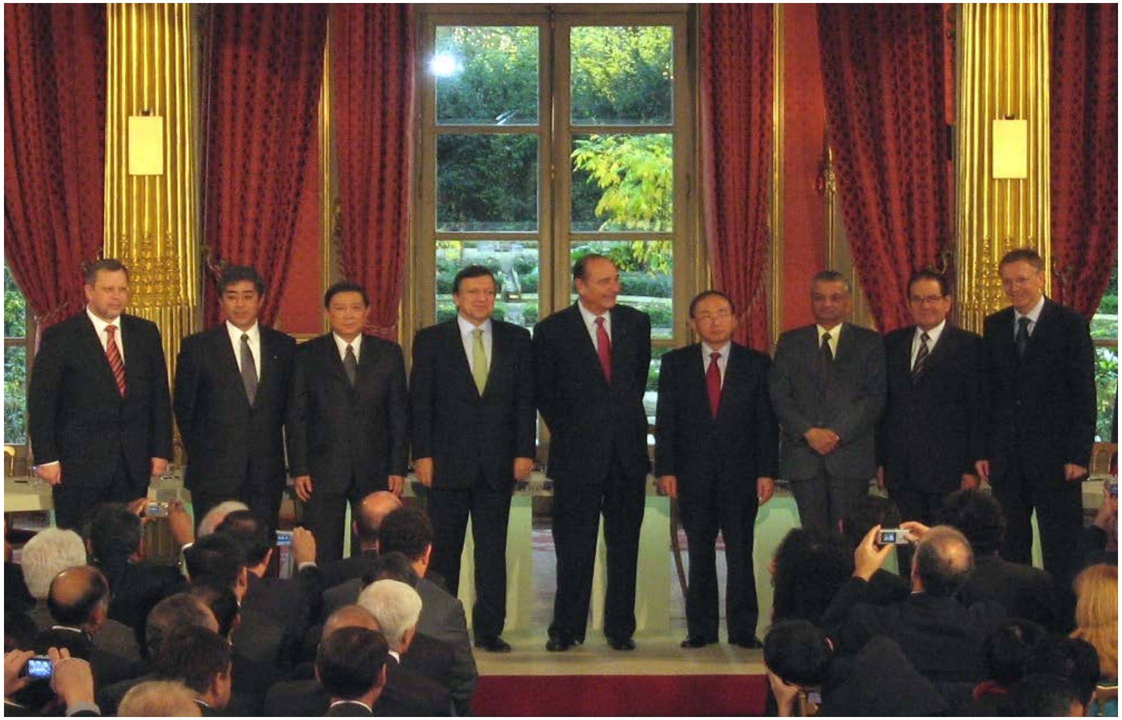
Fusion Research

The two leaders emphasized the potential importance of the work aimed at utilizing controlled thermonuclear fusion for peaceful purposes and, in this connection, advocated the widest practicable development of international cooperation in obtaining this source of energy, which is essentialy inexhaustible, for the benefit for all mankind.

Fusion Research

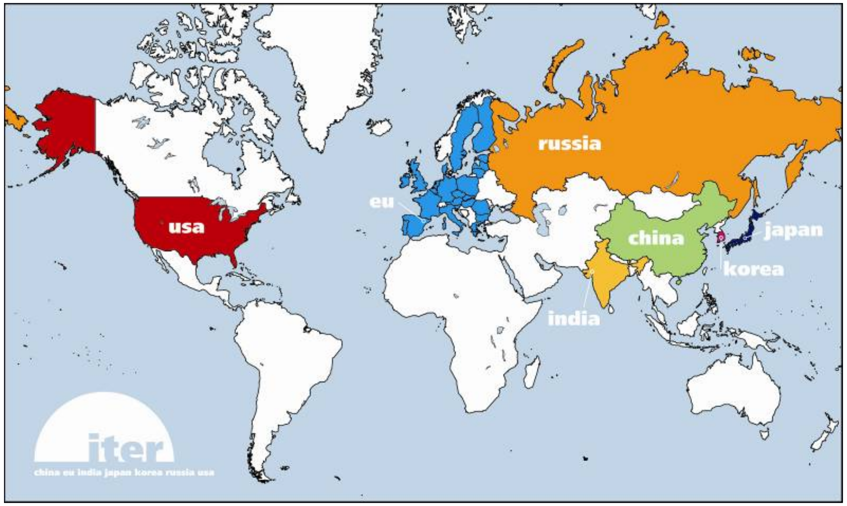
ITER Agreement

- The agreement was signed on the 21st November 2006 at the Elysée Palace in Paris.
- International Organization started.



ITER – International Partnership

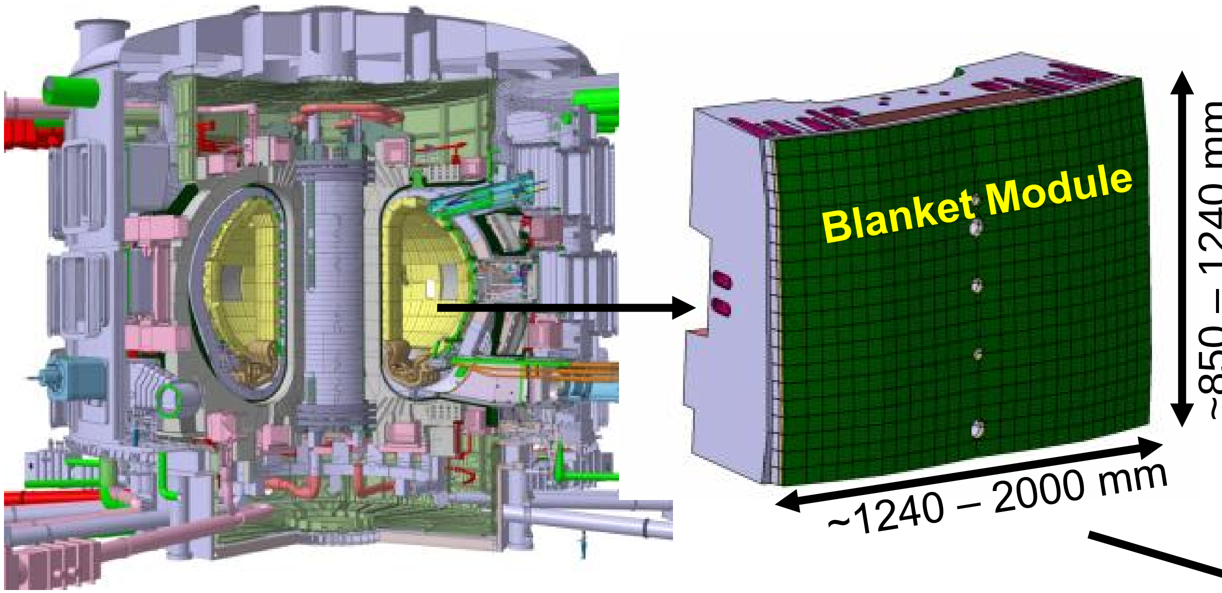
- **With the ITER project, seven parties (China, European Union, India, South Korea, Japan, Russia and the USA), representing more than <u>half of the world population</u> and more than <u>80% of the world gross domestic product</u>, have agreed to pool their financial and scientific resources to prove the viability of fusion as an energy source.**



- **ITER is not only one of the major scientific and technological challenges of the 21st century, but also an unprecedented model for international research collaboration.**

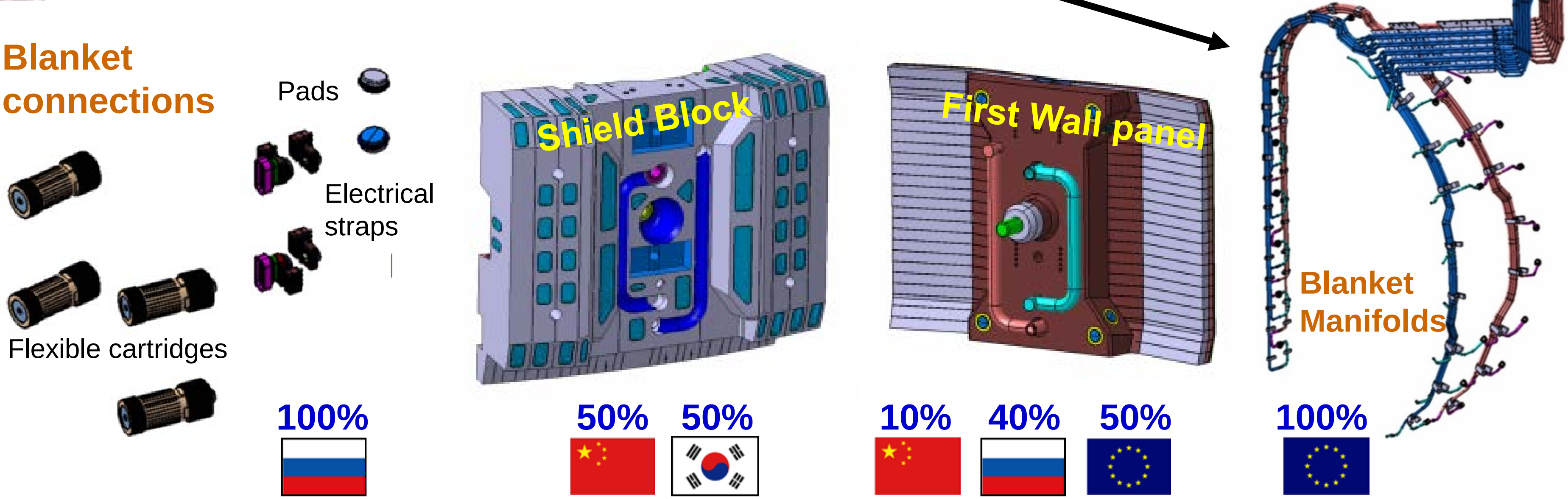
- **The ITER Project creates a new collaborative culture contributing to the world peace.**

ITER Blanket System



Main Functions:

- Exhaust the majority of the plasma power.
- Contribute in providing neutron shielding to superconducting coils.
- Provide limiting surfaces that define the plasma boundary during startup and shutdown.
- Provide passage for and accommodate interface requirements of the plasma diagnostics

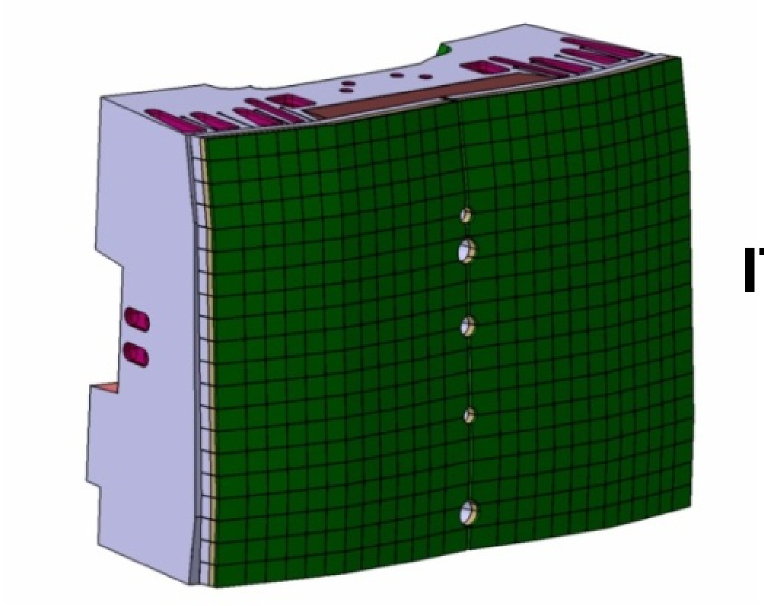


Heat Flux onto the ITER Blanket System

Facing the Plasma → High Heat Fluxes

Summer sunny day
1 kW/m^2

Space shuttle (re-entry)
500 kW/m^2



ITER Blanket First Wall
~5,000 kW/m^2

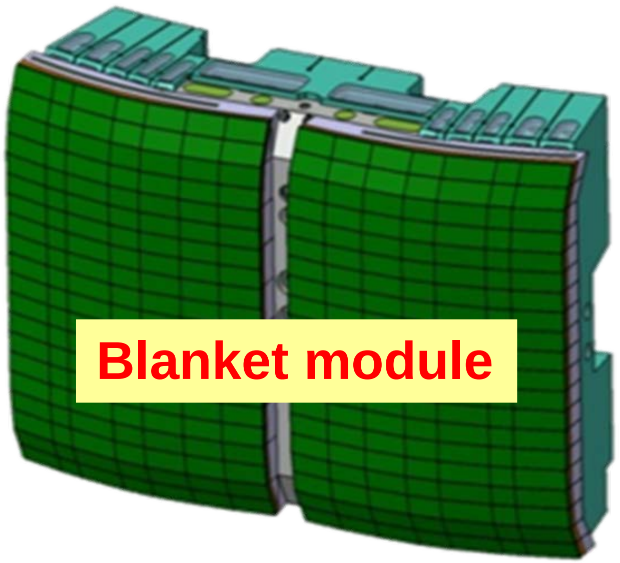
Beryllium Armor for the First Wall

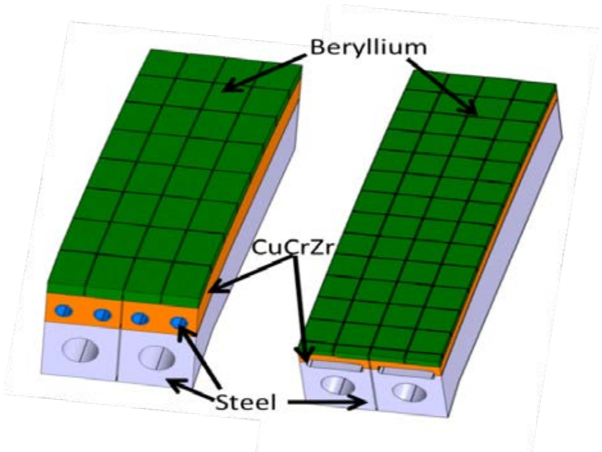
- **Plasma-facing material (PFM) shall address plasma compatibility, tritium retention, and heat removal capability.**

- **Beryllium is considered as PFM for the ITER First Wall since the beginning of the ITER Engineering Design Activity phase in 1994 for the following main reasons:**
  - **Oxygen gettering capability**
  - **Low atomic number**
  - **Absence of chemical sputtering**
  - **High thermal conductivity**

- **Current Beryllium Tile Designs**
  - **Thicknesses: 8mm and 10mm**
  - **Sizes: 12 x 12mm, 25 x 25mm, 50 x 50mm, etc.**

- **Total Amount of Beryllium**
  - **Net Weight ~12 tons**





Normal heat flux panels 2 MW/m²

Enhanced heat flux panels 4.7 MW/m²

Selection of Be Grades for the ITER First Wall

❖ **Beryllium grades differ with regard to the impurity levels, grain size, methods of production, and thermo-mechanical treatments.**

❖ **Materials shall have appropriate and sufficiently characterized properties for all the foreseeable operating conditions during scheduled lifetime (taking into account changes of material properties during manufacturing cycle and during operation).**

❖ **Material compositions shall follow As Low As Reasonably Achievable (ALARA) requirements on radiation protection (maximum uranium content is 0.0030 wt.% [30ppm] to limit the impurity content of alpha-emitter radionuclides).**

BERYLLIUM FACTS

- Symbol = Be
- Atomic weight = 9.012
- Density = 1.85 g/cm3 - 1.85 times that of water
- Hardness = 6 to 7 on the Mohs scale
- Melting point = 1287°C (2349°F)
- Boiling point = 3000°C (5432°F)

WHERE IS BERYLLIUM FOUND?

Two thirds of the world's beryllium is mined and extracted in Utah. It is also found in Russia.

Source: https://materion.com/Products/Beryllium.aspx

Selection of Be Grades for the ITER First Wall

- **In the ITER Final Design Report 2001, two beryllium materials have been identified as reference grades:**
  - **S-65C Vacuum Hot-Pressed (VHP) from Brush Wellman Inc. (USA) – Note: the "C" in the designation indicated the specification revision**
  - **DShG-200 from the Russian Federation**

- **These grades were selected based on excellent thermal fatigue and thermal shock behavior, high ductility, low impurity content, availability, and existence of a comprehensive information database.**

- **RF and CN Domestic Agencies proposed additional grades in 2006.**

- **US Domestic Agency proposed a new grade in 2017.**

- **A qualification program was established to characterize and formally qualify these new grades:**
  - **Composition requirements (BeO, U content, etc.)**
  - **Main physical and mechanical properties**
  - **Thermal performance (thermal shock, fatigue, VDE)**

Beryllium Grades & Qualification Program

- **The following beryllium materials have now been qualified for ITER FW application:**
  - **S-65 Vacuum Hot-Pressed (VHP) from Materion Brush (USA)**
  - **DShG-200 from the Russian Federation**
  - **TGP-56FW from the Russian Federation**
  - **CN-G01 from China**
  - **LM-30U “Legacy Material” through Peregrine Falcon Corp. (USA, qualified in April 2018)**

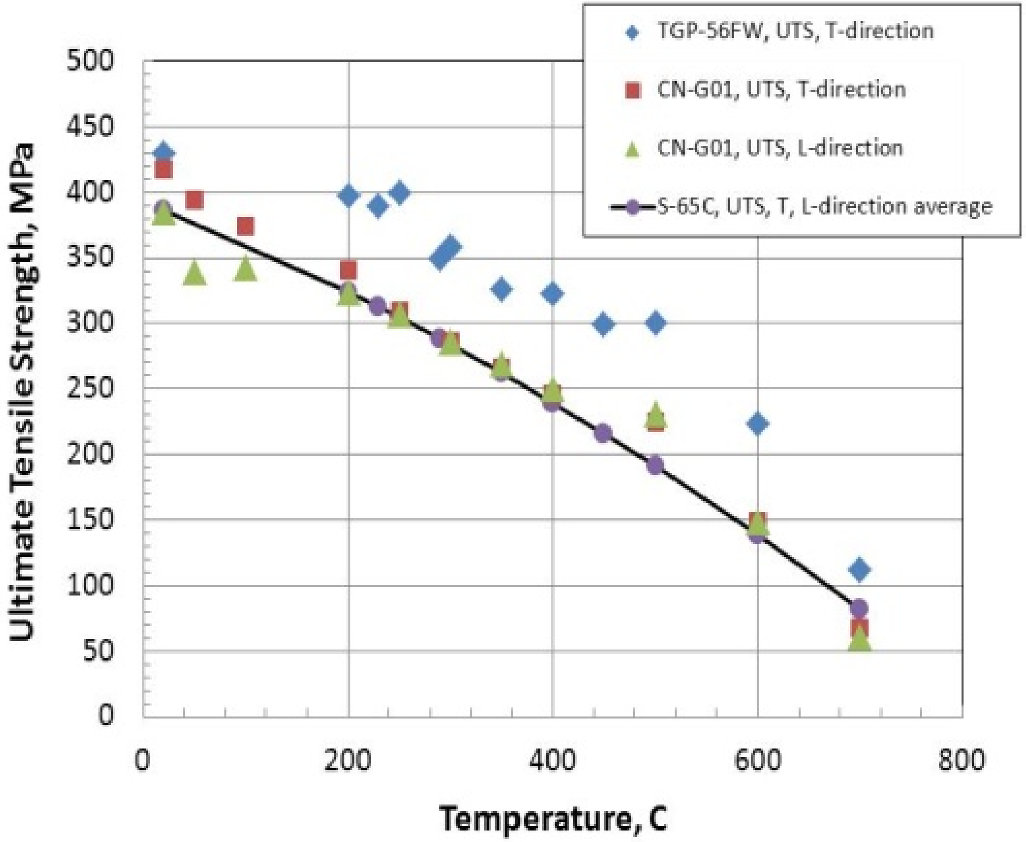
Physica Scripta T145 (2011)

Phys. Scr. T145 (2011) 014007 (6pp)

Summary of beryllium qualification activity for ITER first-wall applications

V Barabash[1], R Eaton[1], T Hirai[1], I Kupriyanov[2], G Nikolaev[2], Zhanhong Wang[3], Xiang Liu[4], M Roedig[5] and J Linke[5]

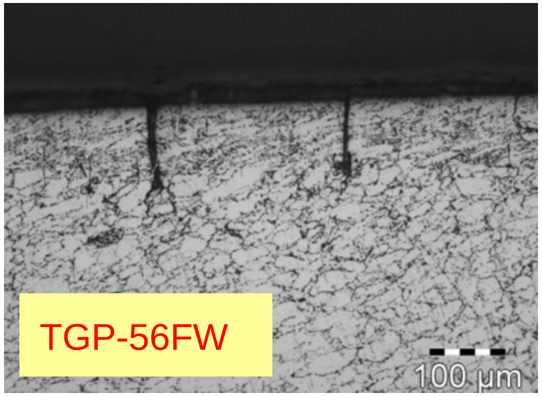
Beryllium Characterization

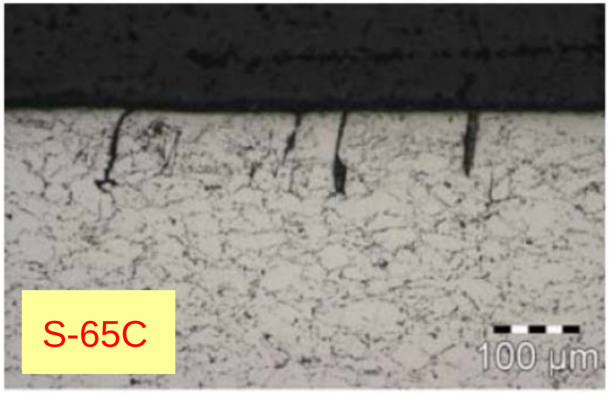


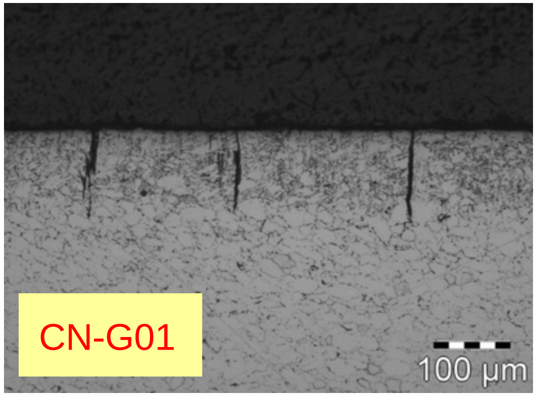
- ❖ Ultimate Tensile Strength of S-65, TGP-56FW, and CN-G01 grades, with T – transverse and L – longitudinal to vacuum hot-pressing direction.
- ❖ Strength is very similar for all grades (TGP-56FW is slightly higher due to BeO content).
- ❖ Chemical Composition Requirements
  - BeO <1.0 wt.%
  - U <0.003 wt.% (30ppm)
- ❖ Density >99.0% of theoretical
- ❖ Grain Size 20-25µm

Thermal Performance Qualification

- **A Comparative Study of TGP-56FW, CN-G01 and S-65 Beryllium Grades for Thermal Shock Resistance was performed at the Electron Beam Facility JUDITH-1 (FZJ).**
- **Samples were loaded in a single-shot mode between 1.2 and 2.4 MJ/m^2 with a step of 0.3 MJ/m^2 and also at 3 MJ/m^2 and 5 MJ/m^2 (5mm x 5mm, pulse 5ms).**
- **No significant weight change was observed.**
- **Metallographic sectioning perpendicular to the loaded surface for the different beryllium grades loaded at 3 MJ/m^2 shows comparative behavior.**

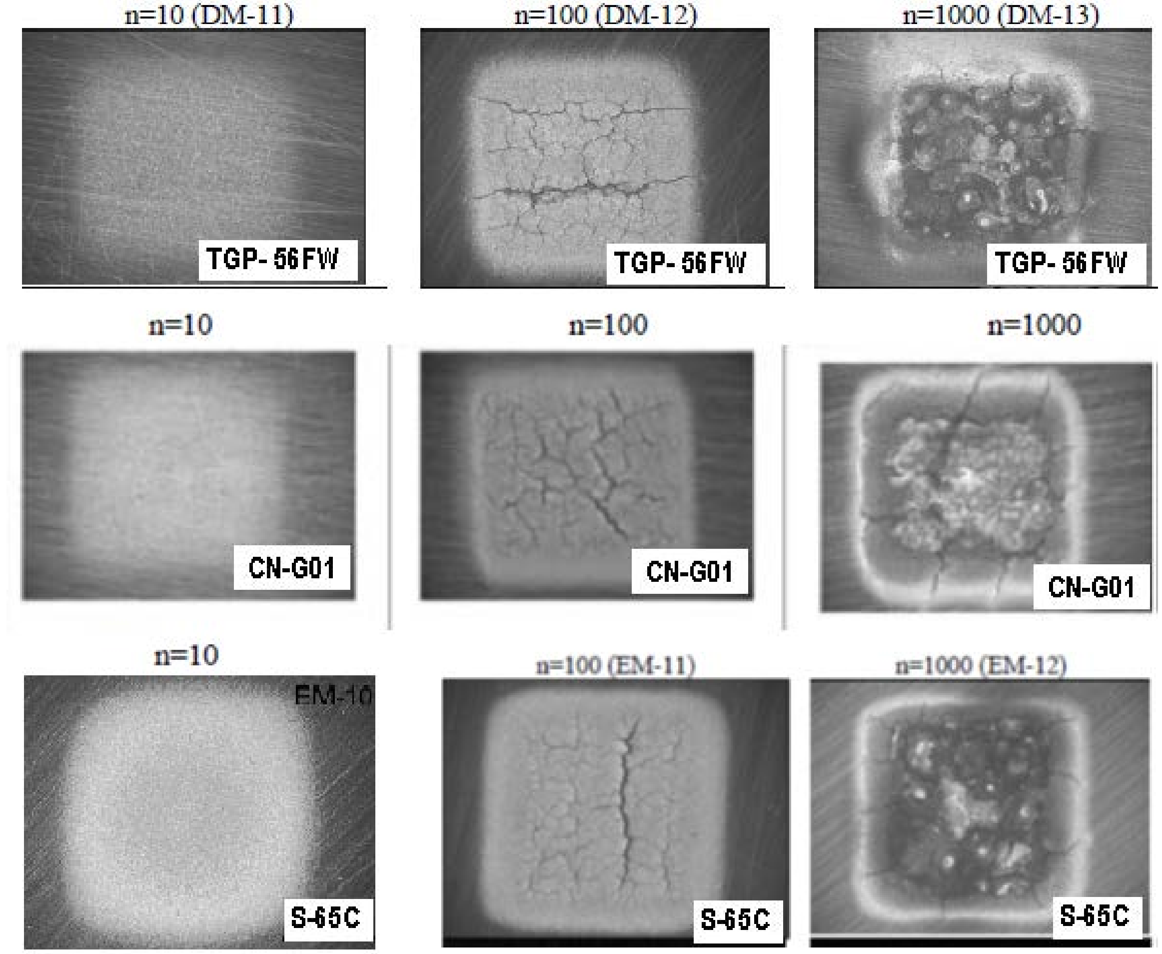




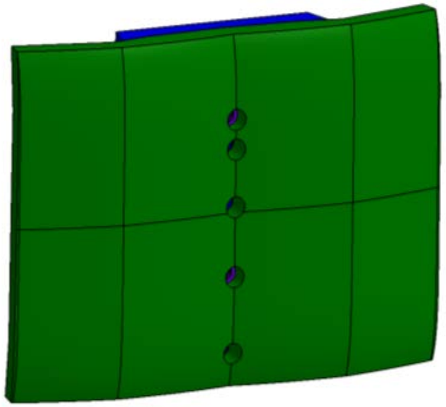


Thermal Performance Qualification

- **Surface view of three beryllium grades after multiple-shot exposures at 1.5 MJ/m^2, (n = number of cycles) with preheated beryllium samples up to 250ºC.**
- **A similar behavior can be noticed. Crack formation is observed after 100 cycles and some melting occurs on the surface after 1000 pulses.**

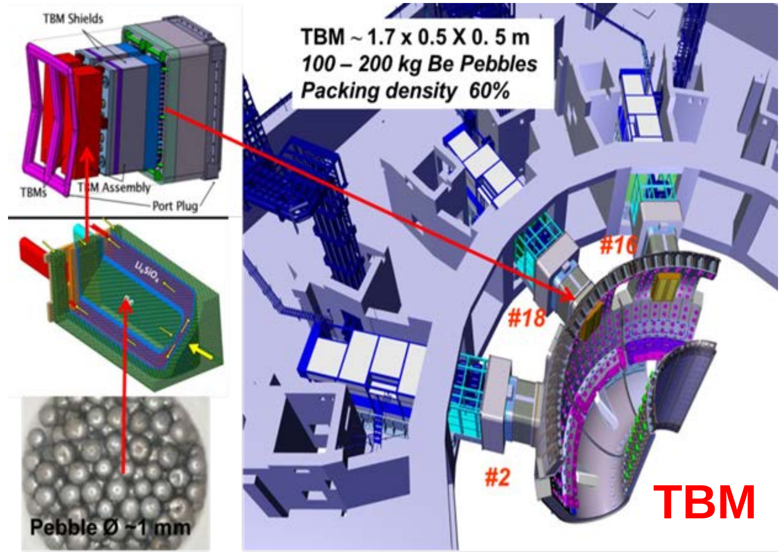


Range of ITER Components using Beryllium

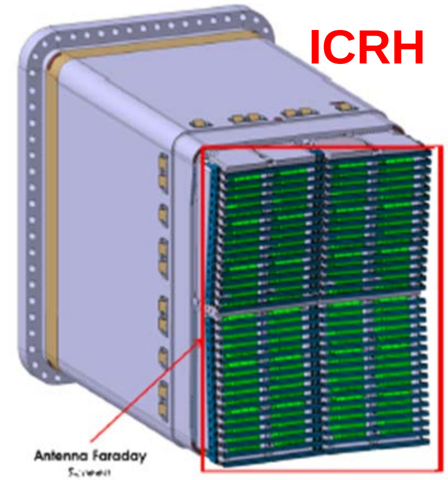


Blanket FW

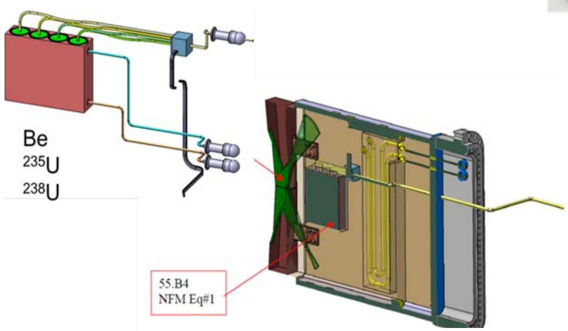
About 12,000kg

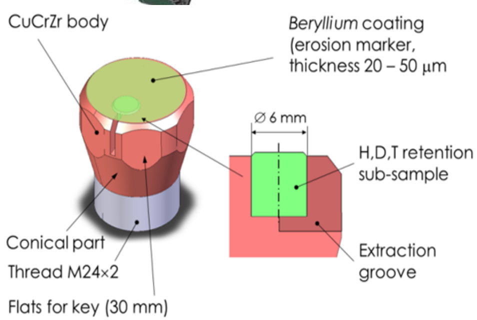


100-200kg of 1mm-diameter Be pebbles (per TBM) to be used as neutron-multiplier

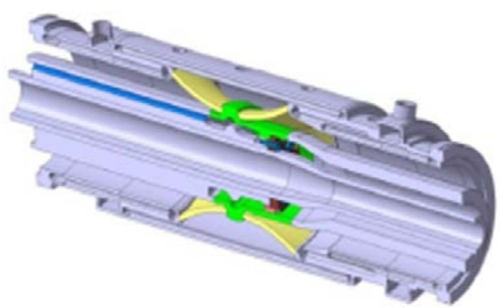


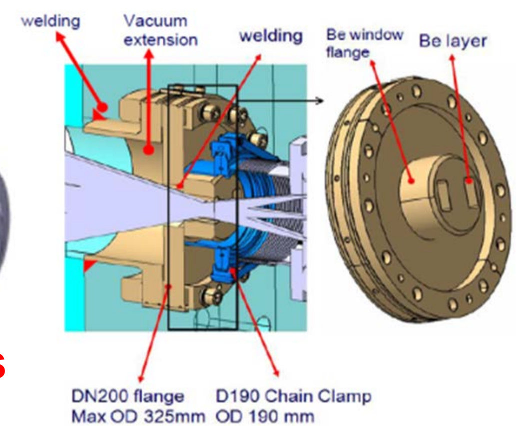
Faraday Shields
40kg of beryllium





Diagnostic Systems

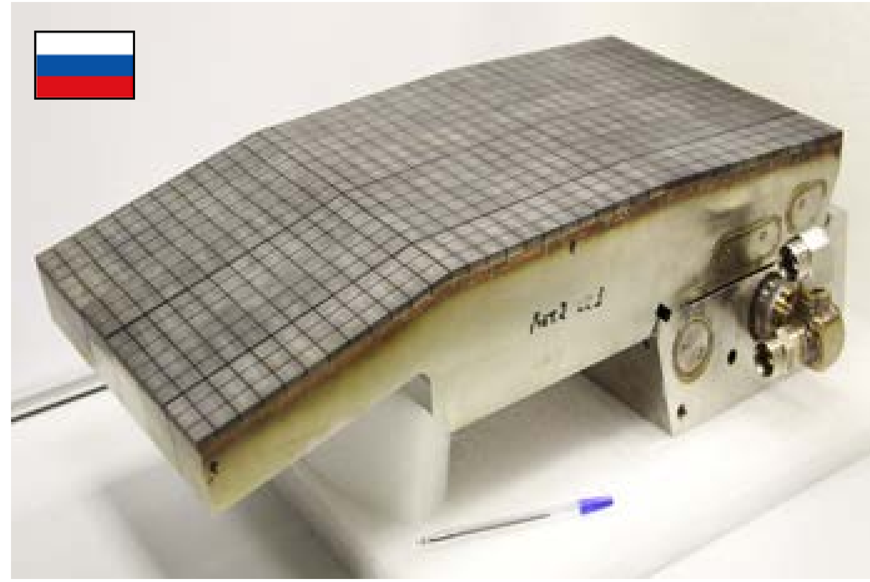


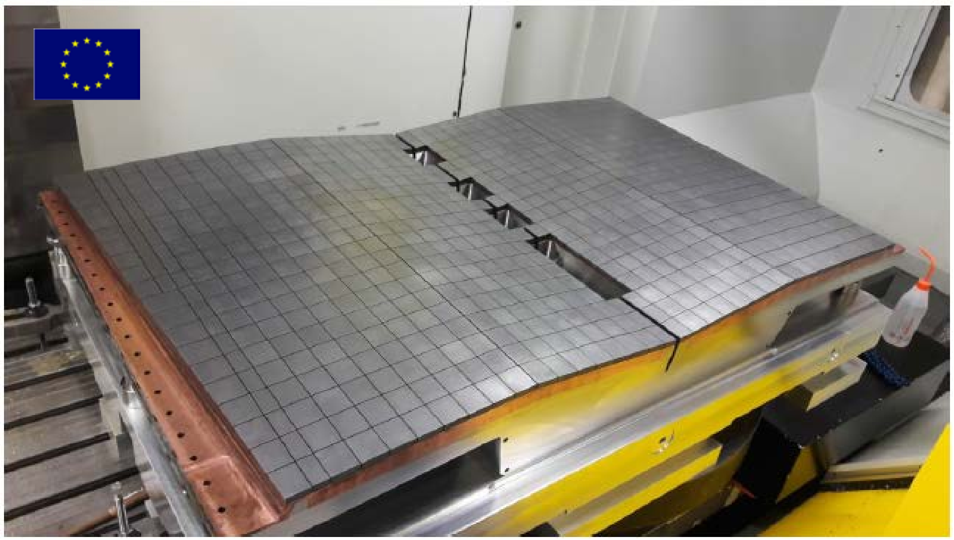


RF Windows

Blanket First Wall Panel Production Status

- ❖ **FW Semi-Prototypes: RF & CN**
- ❖ **FW Full-Size Panel: EU**





Normal Heat Flux Panel:
Nearing completion (98%), then
Factory Acceptance Tests (6 months)

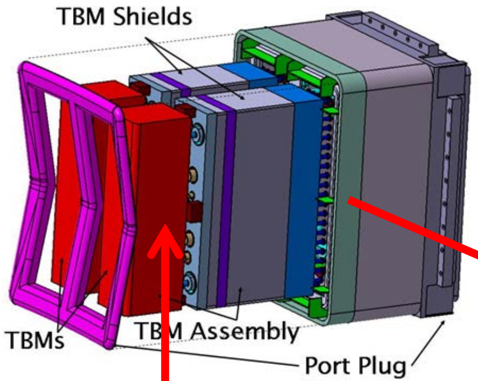
Enhanced Heat Flux Panel, tested at:
4.7 MW/m^2 for 7500 cycles
5.9 MW/m^2 for 1500 cycles

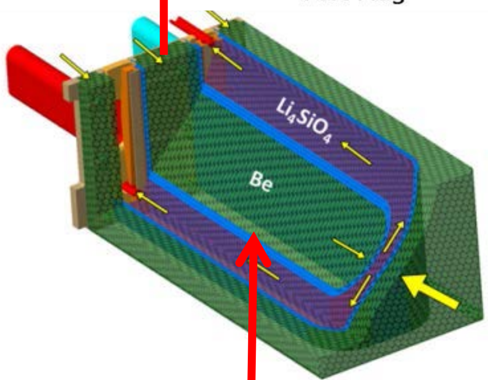
Beryllium in the Test Blanket Modules (TBMs)

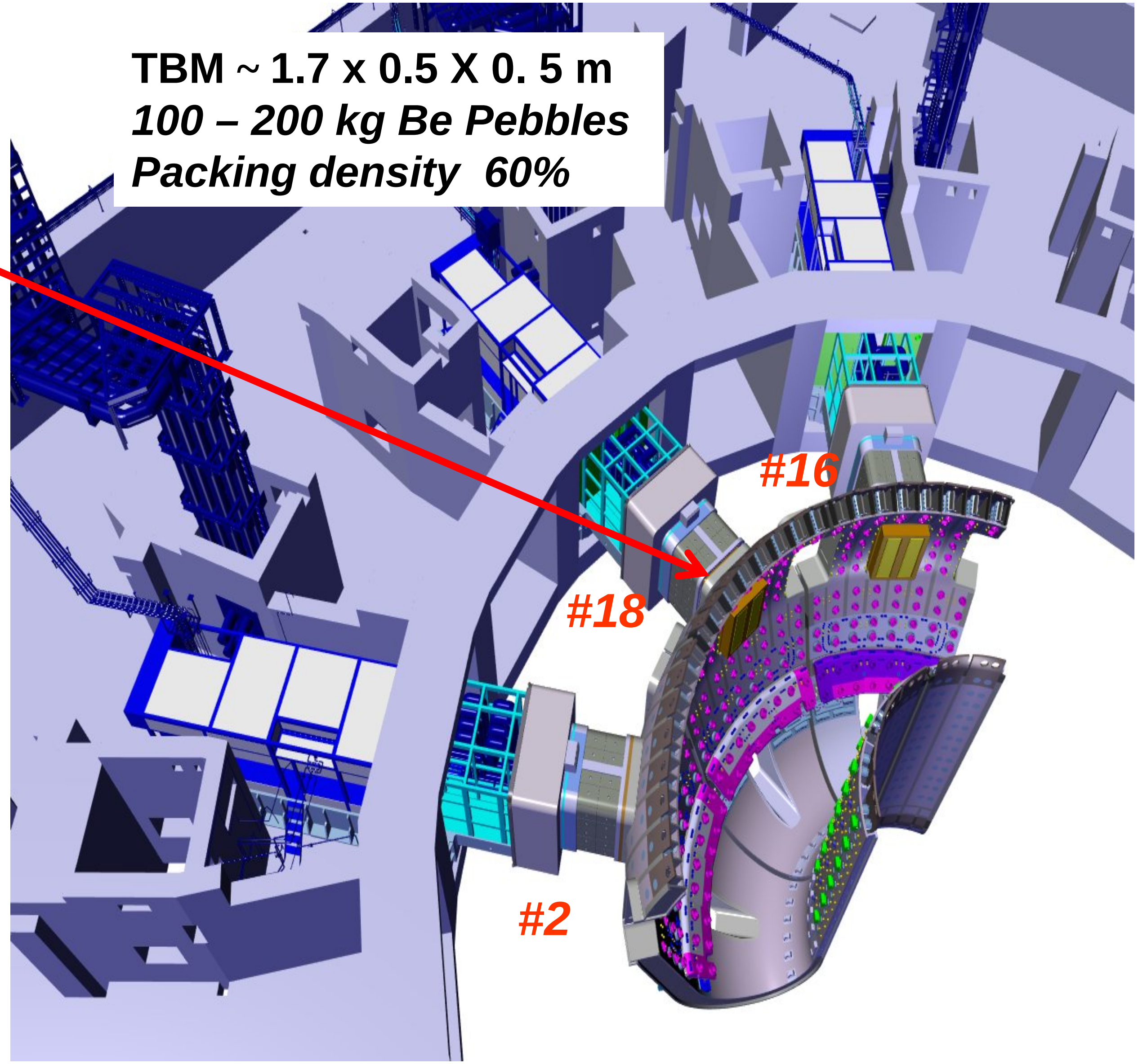
TBM ~ 1.7 x 0.5 X 0. 5 m

100 – 200 kg Be Pebbles

Packing density 60%







TBM Status & Considerations

- **Original plan is to have testing of 6 TBMs in ITER, of which 4 are based on ceramic breeder pebble-beds, with Be as the neutron multiplier. Testing starts after Assembly Phase III.**
- **The thermo-mechanical behavior of pebble-beds is complex, resulting in a relatively large uncertainty in the heat transport properties, as well as in the behavior of the pebbles, and consequently on the pebble-bed integrity.**
- **Tritium inventory: tritium generated in Be typically remains in the material at T < 600°C, which impacts the safety cases and waste management.**
- **A linked issue is the presence of dust inside the pebble-bed zone, including its generation during operation (e.g. from pebble friction, fragmentation, corrosion, etc.). Dedicated filters are required to prevent such dust from contaminating purge gas lines connected to Tritium Extraction System (TES).**
- **Be toxicity slightly impacts the manufacture & TBM assembly activities and their supervision, and further cross-contamination risks may apply for maintenance operations, handling of transports casks, and dismantling.**
- **Be produces hydrogen at T > 600°C when interacting with water/steam, which gives a safety concern ($Be + H_2O \rightarrow BeO + H_2$) for some specific accident scenarios. The future use of *beryllides* (e.g. $TiBe_{12}$) may alleviate this specific issue significantly.**

Managing Beryllium Activities at ITER (1)

- The initial step was the formation of the ITER Beryllium Management Committee (IBMC) in 2015
- IBMC comprises stakeholders from both IO-CT (ITER Organization Central Team) and Domestic Agencies
- Typically 2 main meetings are planned/held each year
- Objectives of the IBMC
  - Identification of all activities involving beryllium
  - Overall supervision of all applicable legislation and regulations
  - Identification of best practice safety standards
  - Prepare incident response procedures for on-site and off-site activities
  - Implementation and coordination of the activities

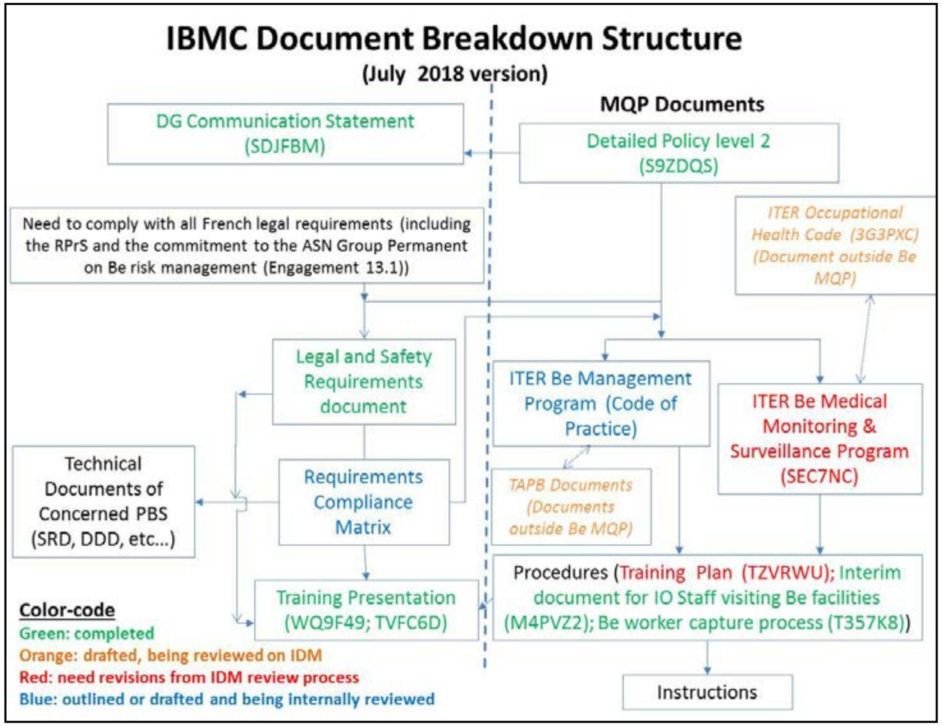
Managing Beryllium Activities at ITER (2)

❖ Activities Completed

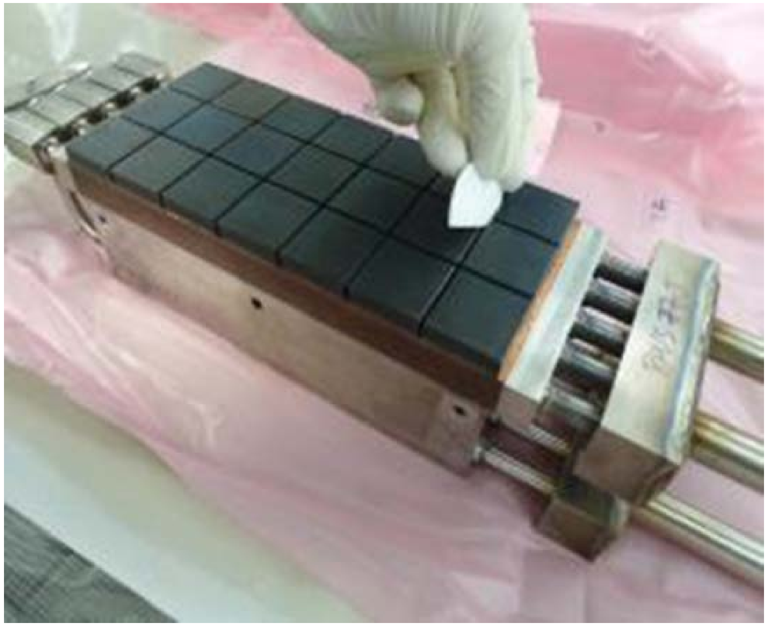
- **Conduct ITER Beryllium Workshop on Health & Safety (Jun-2017).**
- **Hire IPA for Beryllium Activities (Apr-2018).**
- **ITER Be Worker Training Program.**
  - **First training sessions performed at CCFE in 2017.**
  - **All other sessions to be performed in Cadarache starting from the June 2018 session.**
  - **Current activities: IO staff visits to DA & supplier sites.**

❖ Activities in Progress

- **Follow up on "Document Breakdown Structure".**
- **Write and implement relevant procedures and standards.**
- **Create "ITER Beryllium Management Plan" or "ITER Beryllium Code of Practice" - now started.**
- **Identify all beryllium components and produce lifecycle documentation.**



Managing Beryllium Activities at ITER (3)



❖ Activities in Progress (cont'd)

- **Tokamak Ass'y Prep (TAP) Bldg.**
  - Purpose: Receiving & Storage of Be FW Panels when they arrive at IO.
  - Trial Fit of Blanket First Wall Panel with Shield Block.
  - Preliminary/Final Design Reviews: Oct-2018.
  - Beryllium Phase to begin Dec-2024.

- **Technical Activities**
  - R&D Plan to gather data from DAs and suppliers to determine typical Be surface particle concentration levels.
  - Effects that the Plan will Consider
    - » Scale-Up from MU to FSP.
    - » Transportation & Packaging.
    - » Storage Conditions: Relative Humidity & Temperature.
  - Potential Need for Test Specimens.
  - Ongoing Support Contract (JET).

Summary

- A brief overview of the ITER project & Blanket System has been provided.
- Selected ITER beryllium grades have been qualified by means of an extensive characterization program.
- Relevant mock-ups and prototypes for the Blanket have been manufactured and tested.
- An ITER Beryllium Management Committee has been established to coordinate all the beryllium related activities.
- An ITER Project Associate for Beryllium Activities has been hired. His initial focus includes producing a Be Code of Practice and an R&D Plan on Surface Cleanliness.
- Recent accomplishments include: ITER Beryllium Workshop held in June 2017 and new close-to-site ITER Beryllium Worker Training course held in June 2018.

Thank you for your attention