Diamond window for the ITER EC H&CD Upper Launcher - Status of design, testing and qualification

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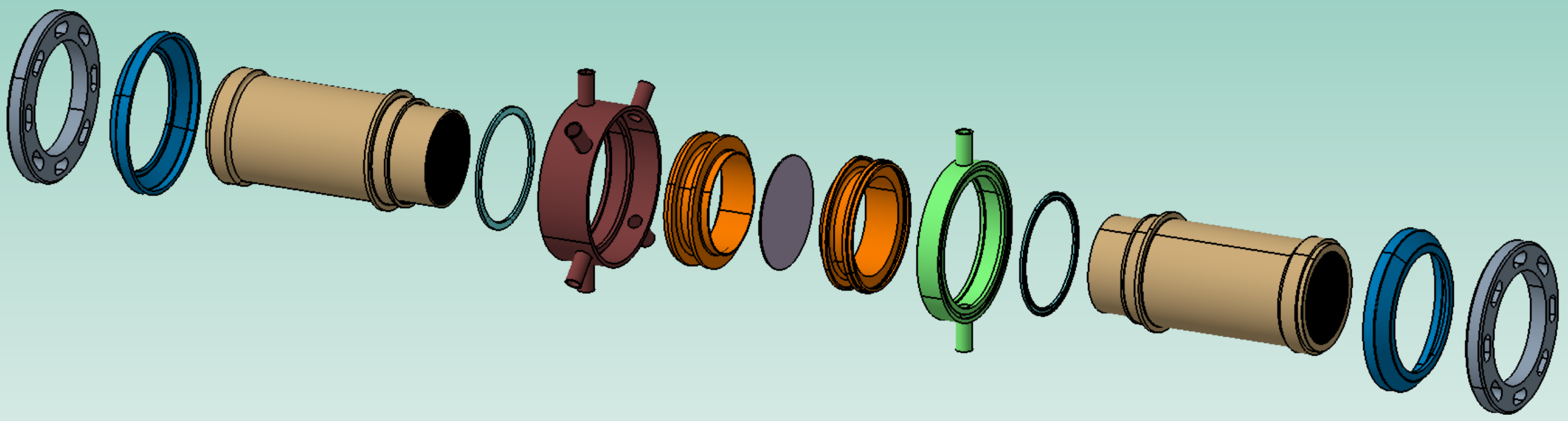
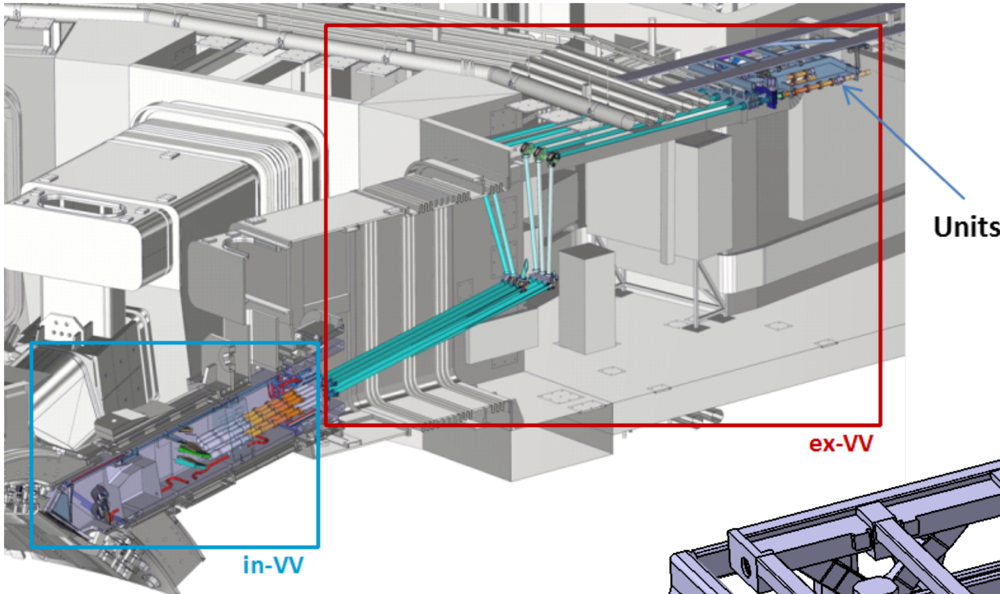


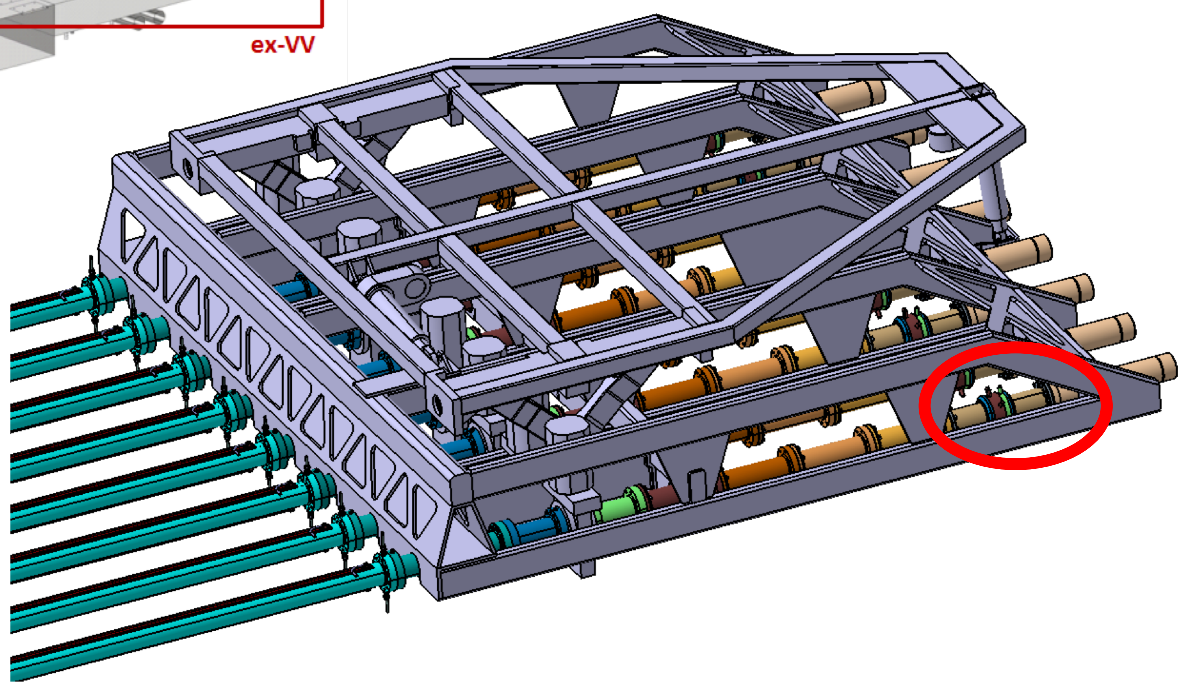
Outline

- The ITER EC H&CD Upper Launcher
- Design philosophy of the window unit
- Design optimized by FEM analyses and ASME code
- Assembling sequence of the unit
- Qualification program
- First results of qualification
- Conclusions and outlook

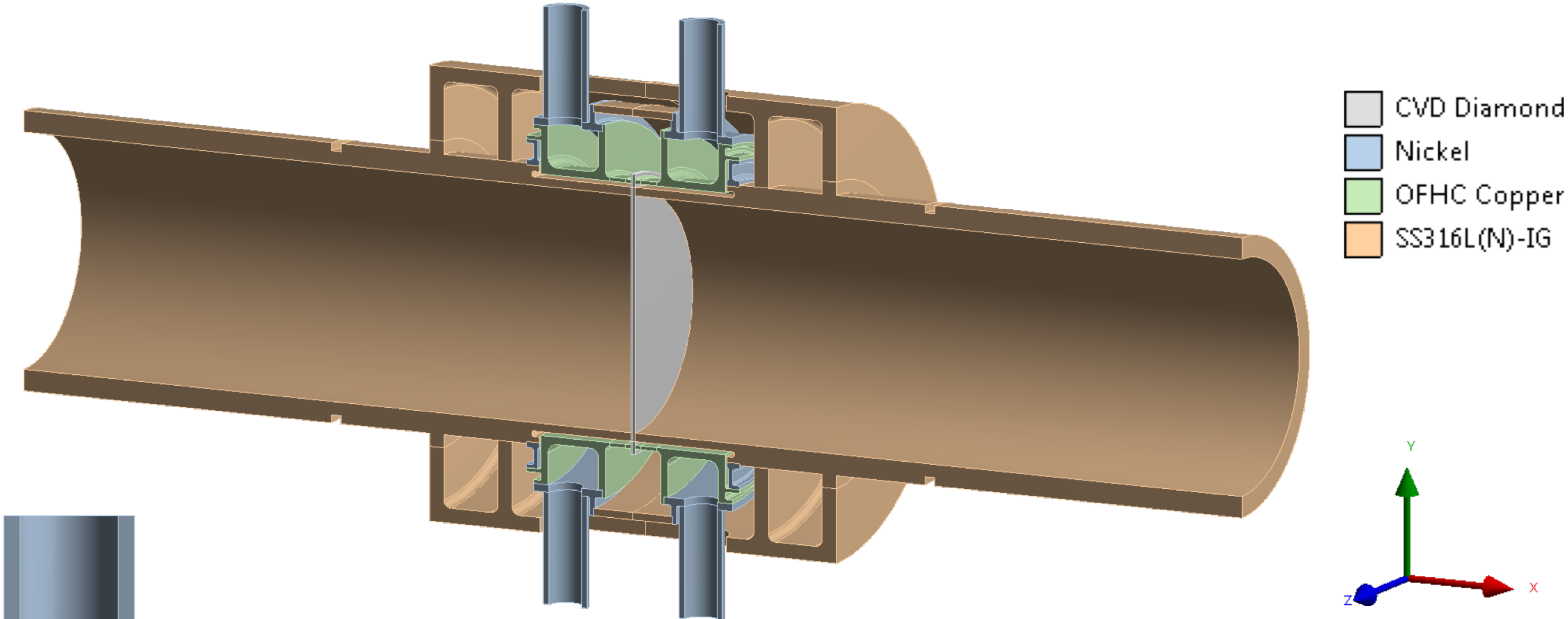
The ITER EC H&CD Upper Launcher

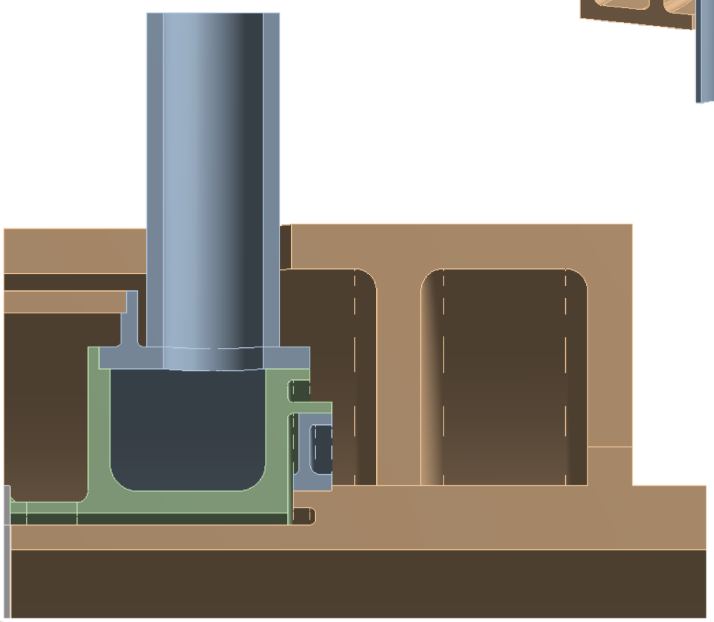


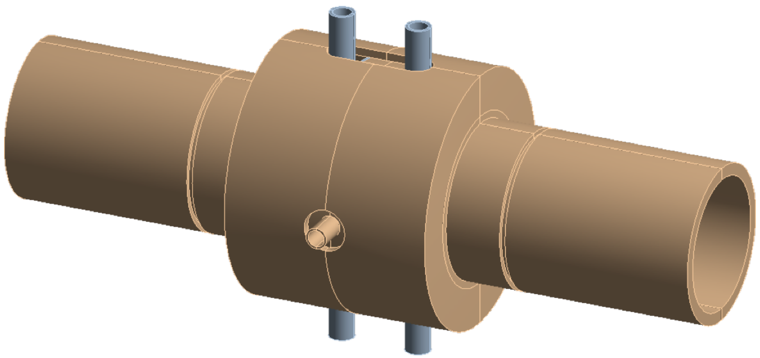
The Upper Launcher consists of an assembly of ex-vessel WGs and an in-vessel port plug.



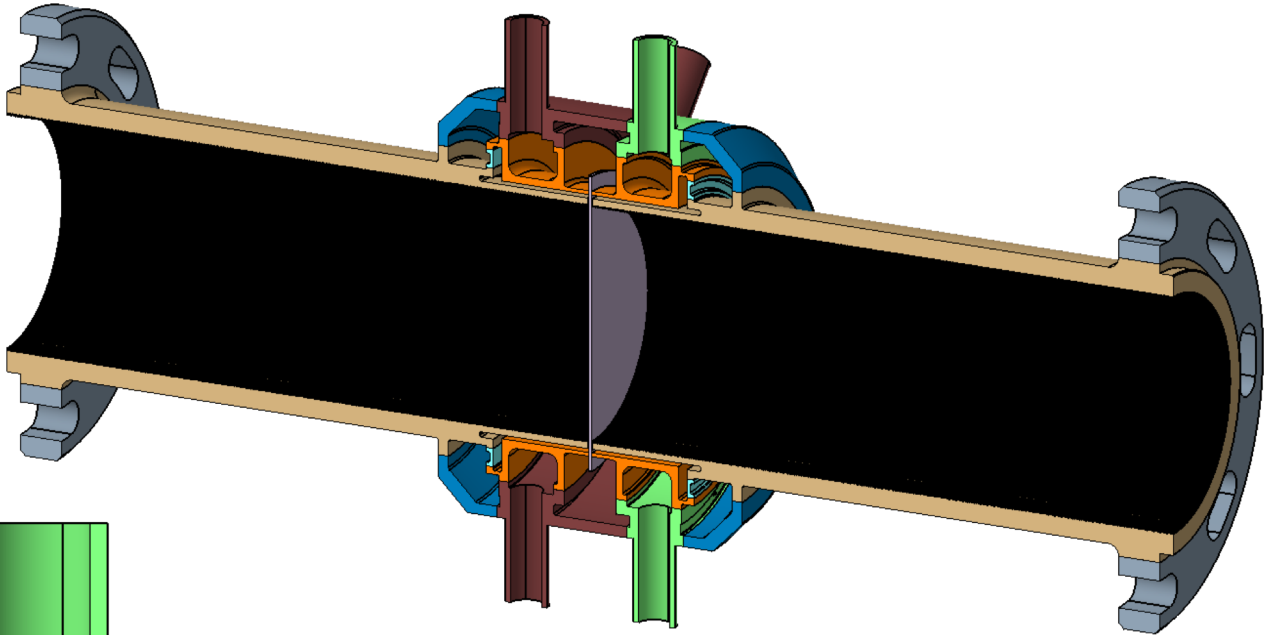
Proposed design in 2013 (Workshop in Speyer)

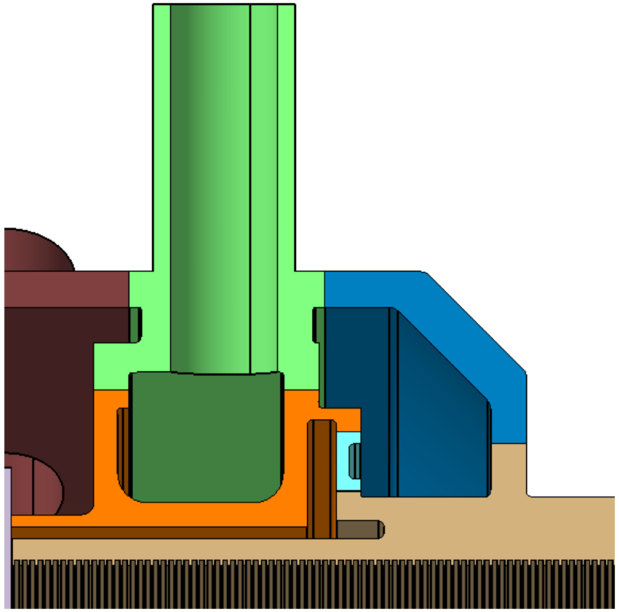


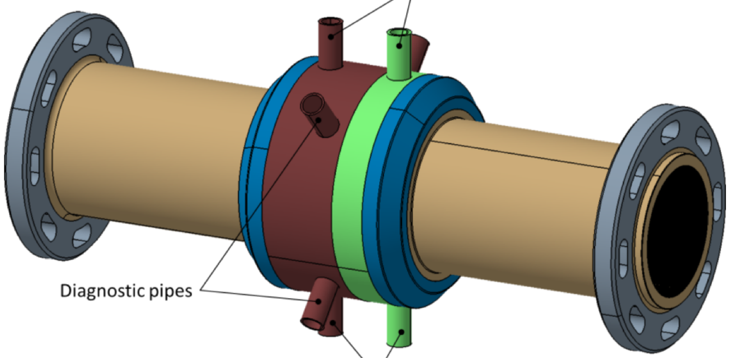




Current design of the window unit

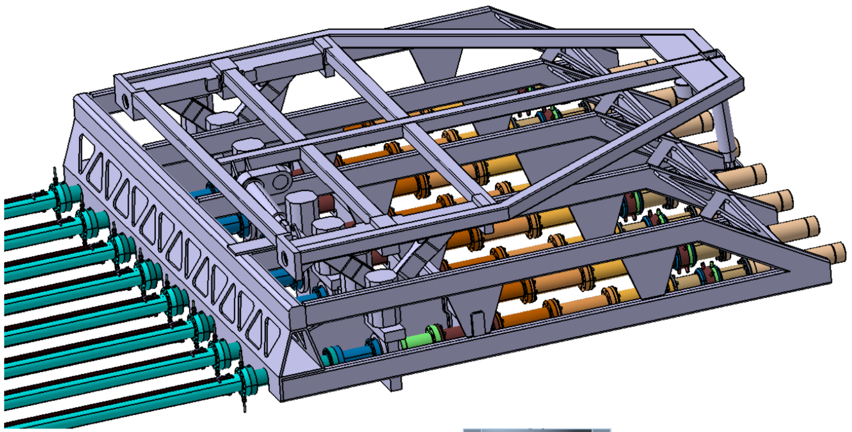


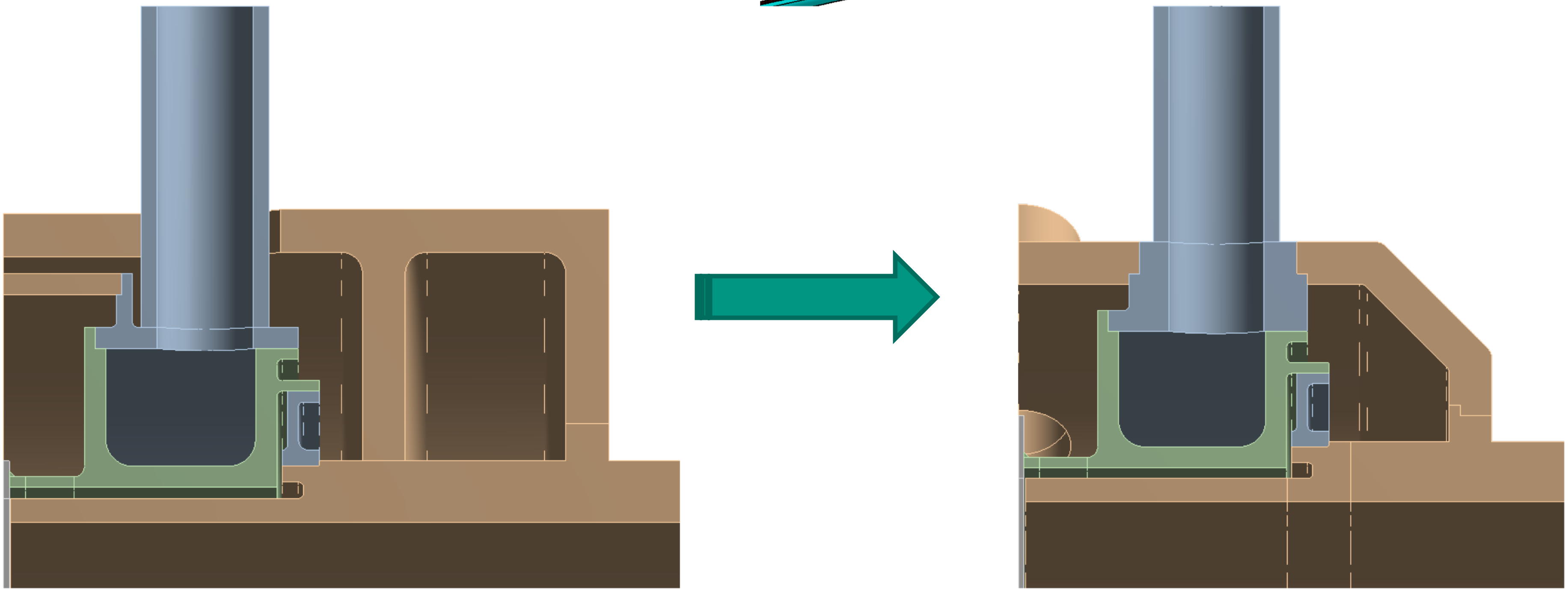




Optimization by FEM analyses

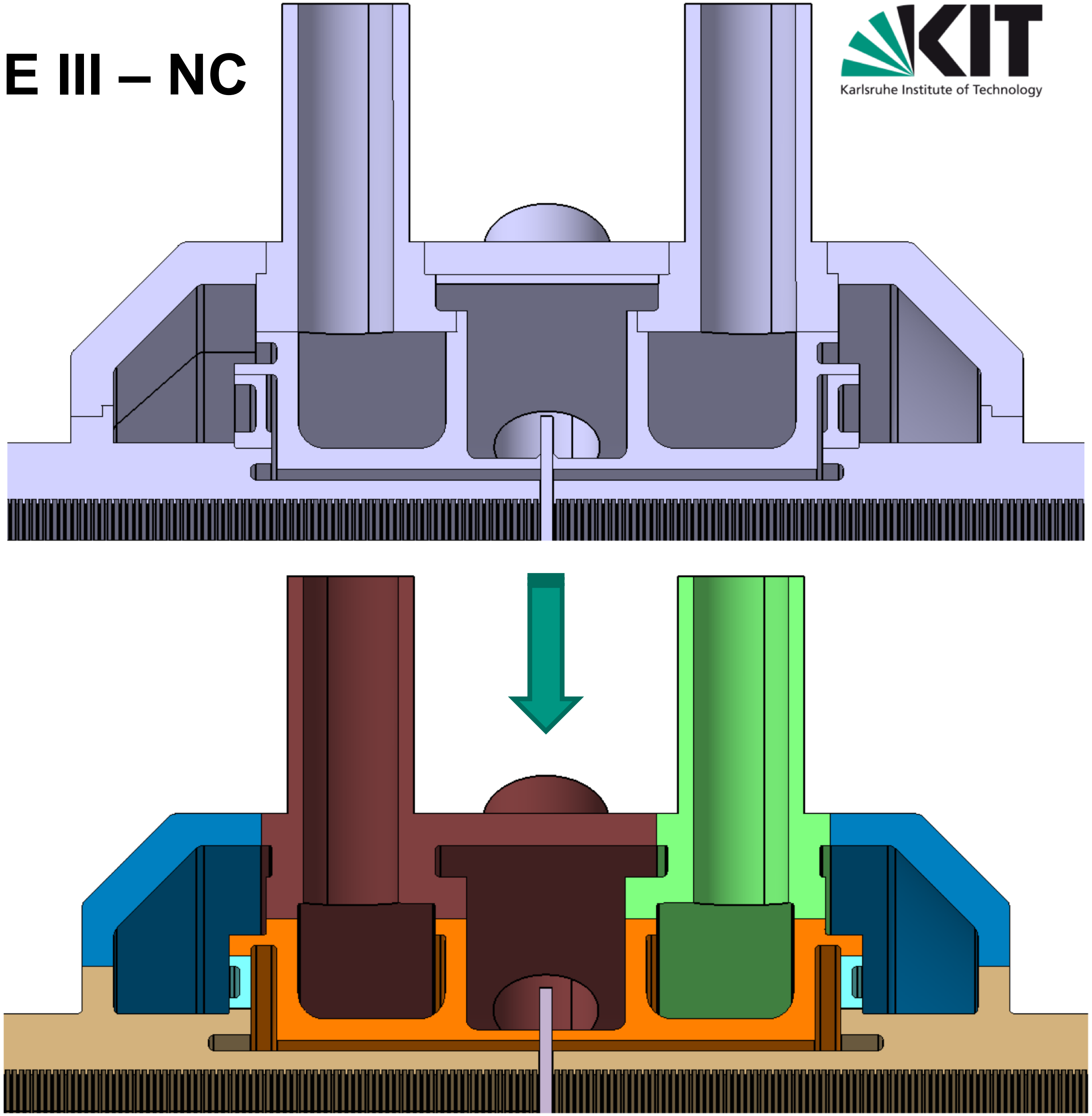
- Lower seismic loads acting on the units.
- Design more compact and feasible to manufacture.
- Second tritium barrier and real-time monitoring of interspaces.



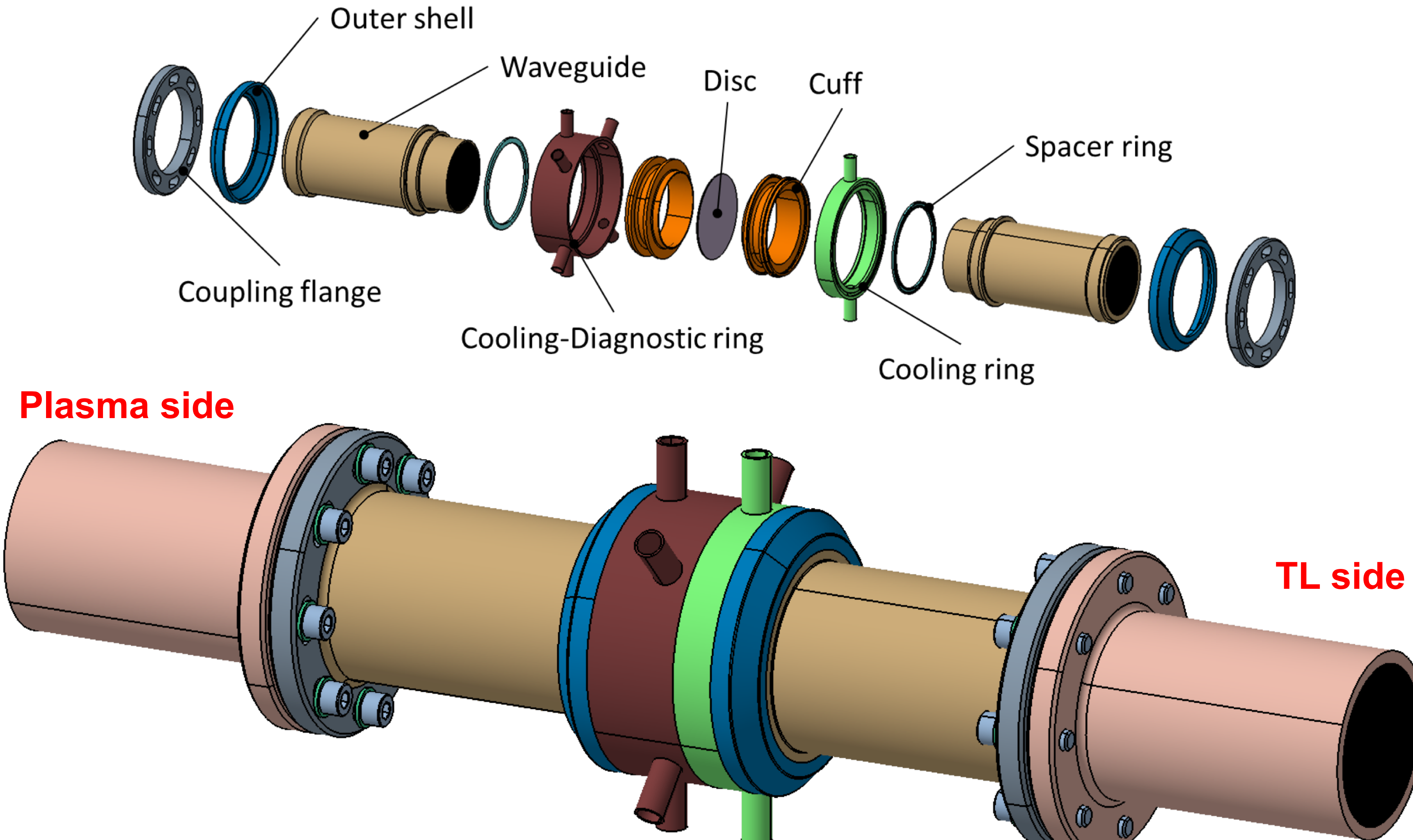


Application of ASME III – NC

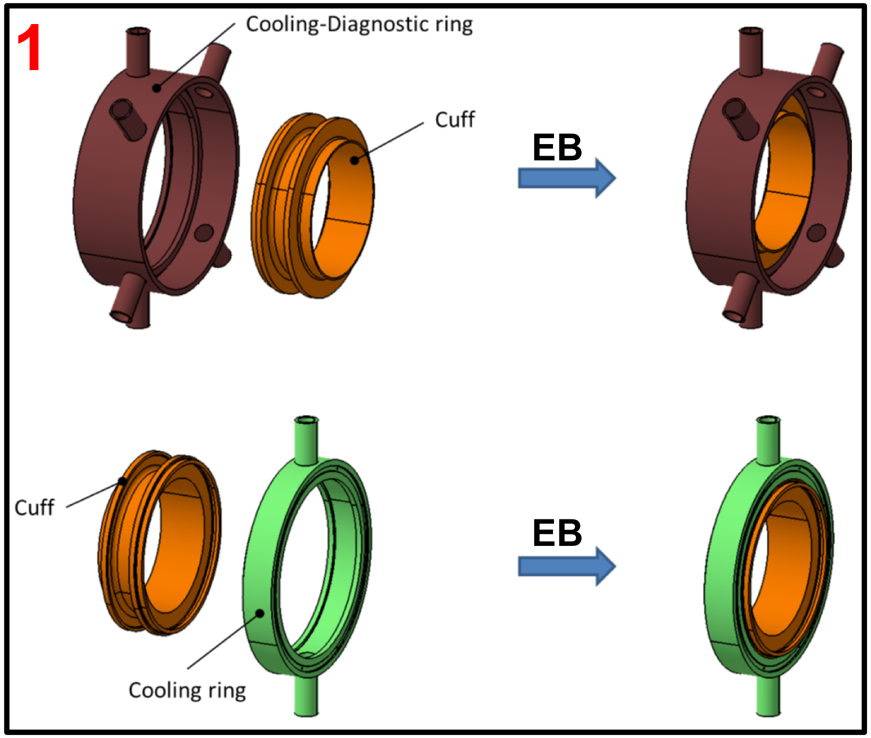
- Lower number of joints.
- No steps at the joint locations (full penetration butt joints).
- Reduction of the EB welding thickness.
- Design affected by the requirements of examination (joints fully radiographed).

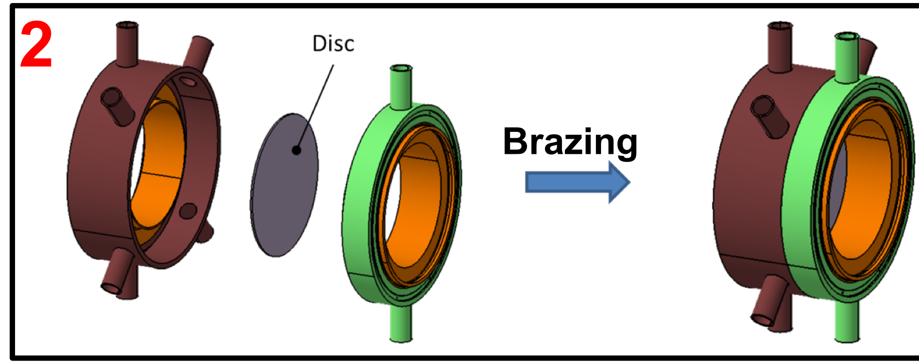


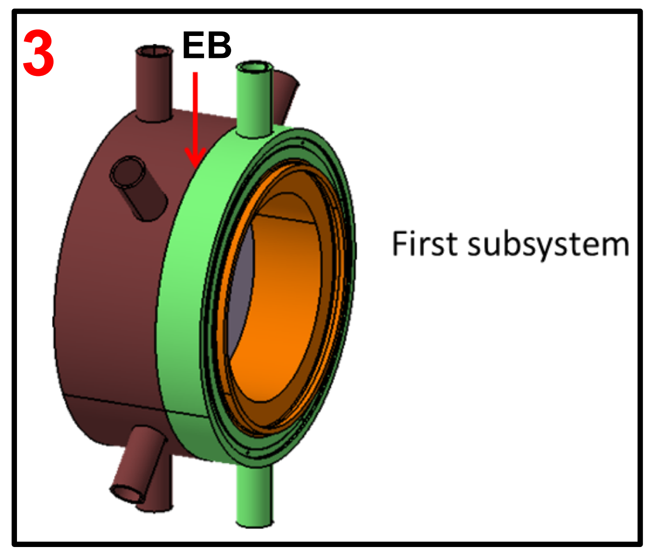
Exploded view of the window unit



Assembling sequence of the unit







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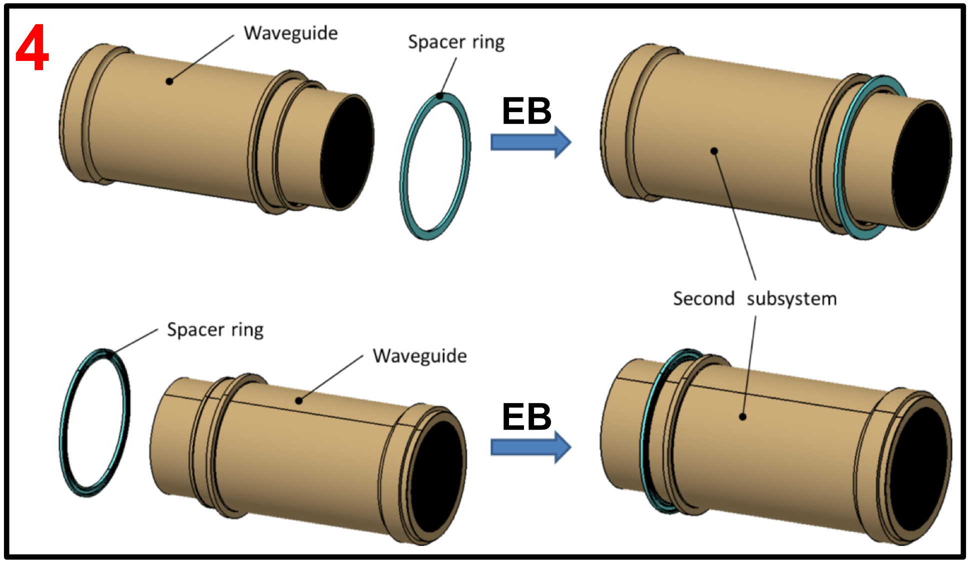
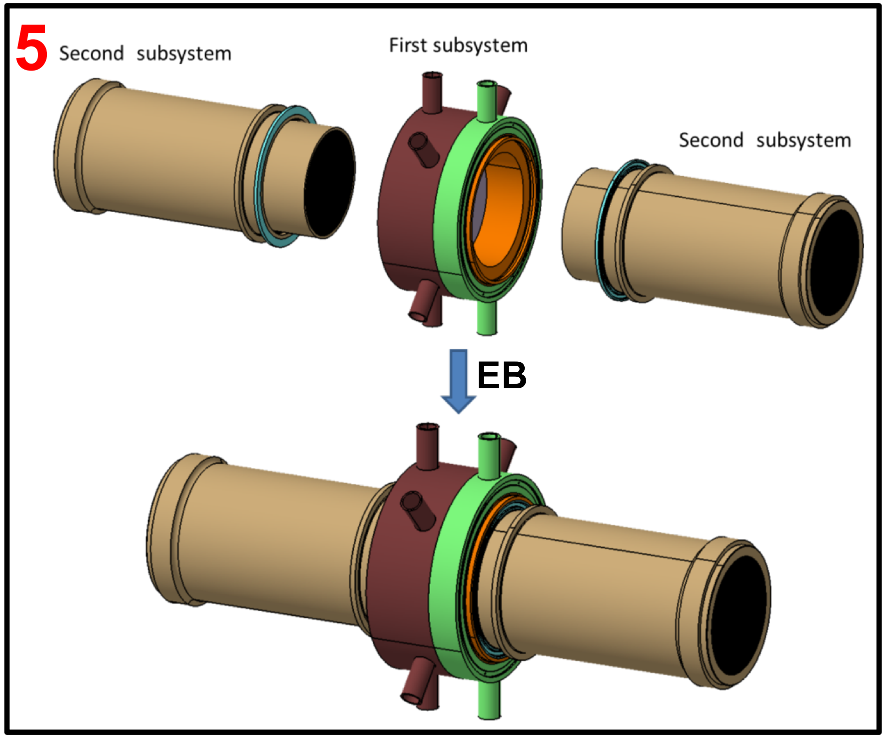
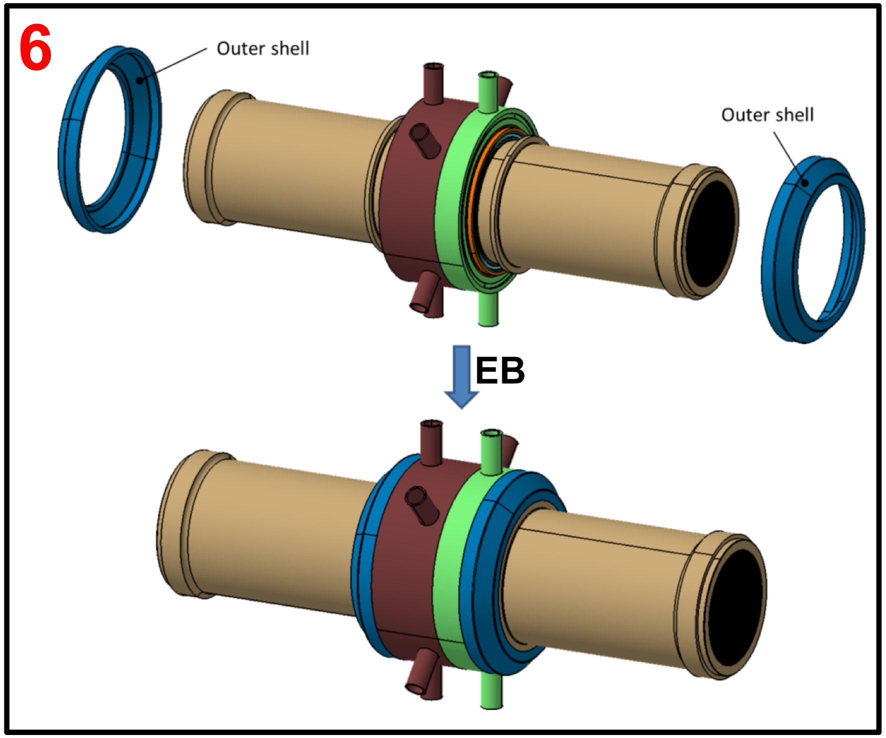
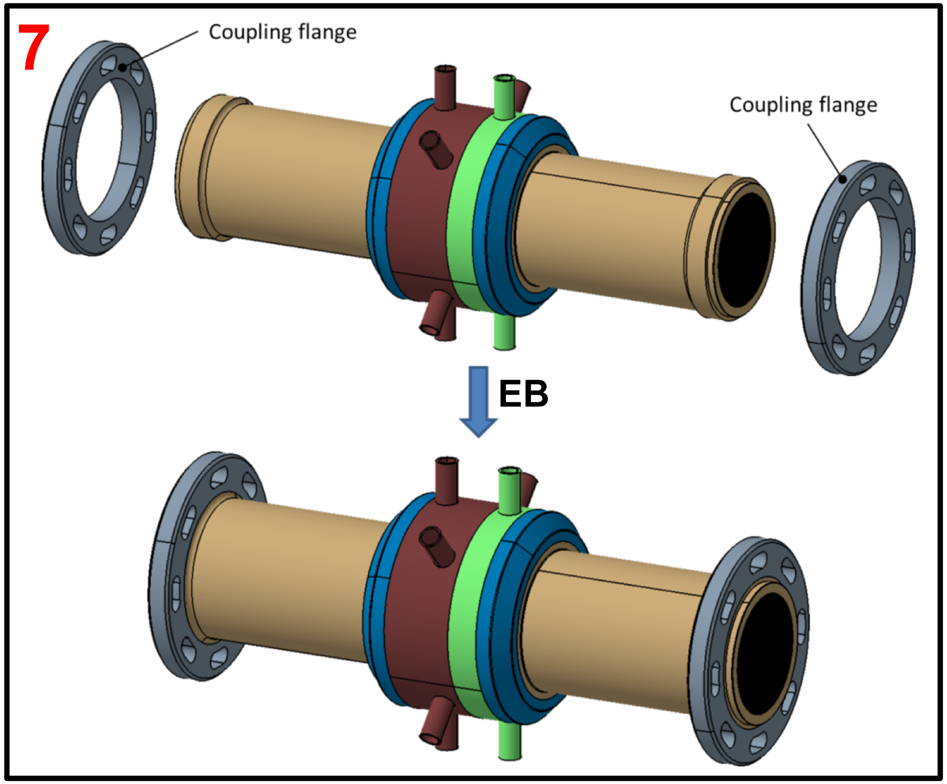




Assembling sequence of the unit





Window qualification program

- The window unit cannot be entirely covered by Codes & Standards.
- Functional, design, safety, operational, quality requirements (*Component Requirements Document*) and requirements related to the loading conditions (*Component Load Specification*) are being defined for the unit.

Window unit is qualified via

ASME code (III – NC, V, IX)

- Procedure and acceptance criteria for qualification of welded joints.
- Procedure and acceptance criteria for NDE of welded joints.
- Design criteria and allowable limits for the metallic parts.

Ad hoc program

- Dedicated testing program being developed in the context of F4E-OPE467.
- Design criterion based on the fracture mechanics method for the diamond disc.

Design criteria for metallic parts

Loading Category	Category I: Operational/Design Loading	Category II: Likely Loading	Category III: Unlikely Loading	Category IV: Extremely Unlikely Loading	Test Loading
Diamond window unit	Normal	Normal	Emergency	Faulted	Normal/test

Damage limits

Unit parts	Damage limits	Structural service criteria
Disc	Normal/Test	N/A
	Emergency	N/A
	Faulted	N/A
Cuffs	Normal/Test	ASME Level A
	Emergency	ASME Level A
	Faulted	ASME Level A
Cooling ring	Normal/Test	ASME Level A
	Emergency	ASME Level C

Correlation damage limits – ASME service levels

Structural service criteria	Stress intensity k factor
ASME Level A	1.0
ASME Level C	1.2
ASME Level D	2.0

ID	Design criteria
1	$P_m \leq kS_m$
2	$P_L \leq 1.5kS_m$
3	$P_L + P_b \leq 1.5kS_m$
4	$P_L + P_b + Q \leq 3S_m$
5	$P_L + P_b + Q + F \leq S_a$

- Mechanical load: criteria #1, #2 and #3.
- Mechanical + thermal load: criteria #1, #2, #3 and #4.
- Fatigue load: criterion #5.

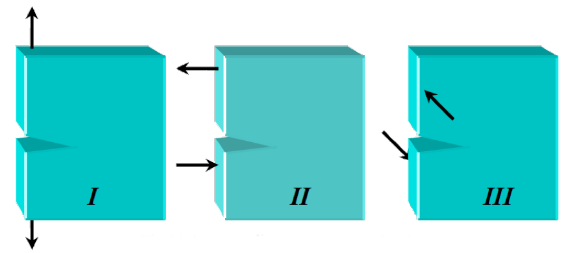
Design criterion for the diamond disc

<u>Failure to fracture</u> is the main failure mode to be considered for the diamond disc.

Stress intensity approach: $\mathbf{K_I \leq K_c}$

Stress intensity factor

Fracture toughness of diamond



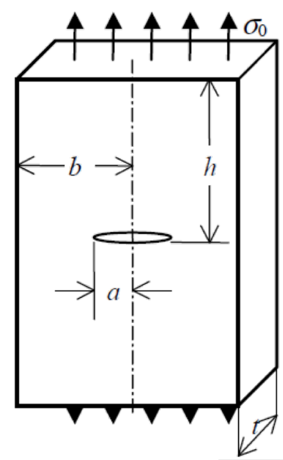
$K_c = 5.3 \pm 1.3$ MPa $m^{1/2}$

(M.D. Drory et al., J. Am. Ceram. Soc., Vol. 74, No. 12, December 1991)

$$K_I = \beta \ \sigma_0 \sqrt{\pi \ a}$$

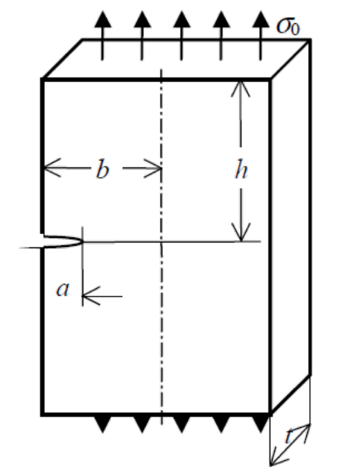
β = factor depending on geometry element – crack
σ_0 = reference stress in case of no crack
a = length of the crack

(G. Petrucci "Lezioni di Costruzione di Macchine")



$$K_I = \sigma_0 \sqrt{\pi a}$$

(For a/b ≤ 0.4)



$$K_I = 1.12 \ \sigma_0 \sqrt{\pi a}$$

(For a/b ≤ 0.13)

Testing program for the window prototype

BARE DISC

- Geometrical check (d, D, surface roughness)
- Optical check (cracks, impurities)
- Mechanical check (bow)
- Tanδ check (disc area mapping and at center)

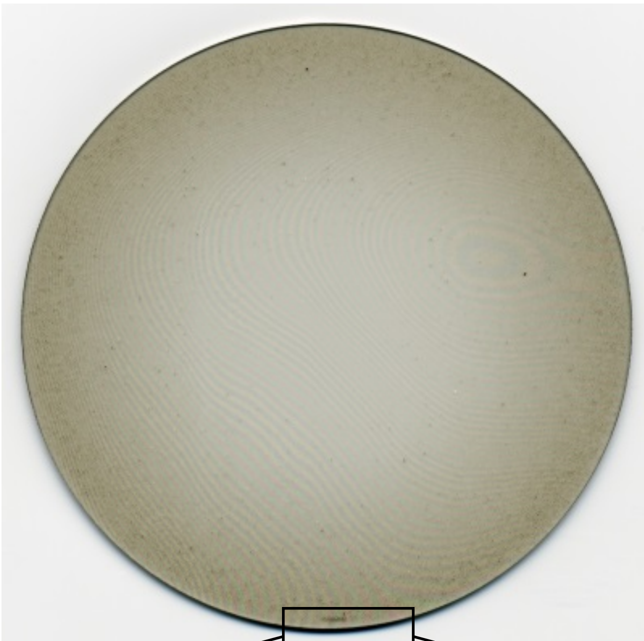
BRAZED DISC

- Geometrical check (e.g., cuffs centricity)
- Optical check
- Mechanical check (bow after brazing)
- Vacuum leakage check for braze
- Braze inspection (CT)
- Tanδ check at disc center

ASSEMBLY

- Geometrical check
- Tanδ check at disc center
- High power MW test (short and long pulse)
- Vacuum leakage check for all joints
- Cooling pressure testing
- Permeation test by Deuterium
- Seismic test
- Overpressure test

Qualification of the bare discs



Laser engraving
for identification

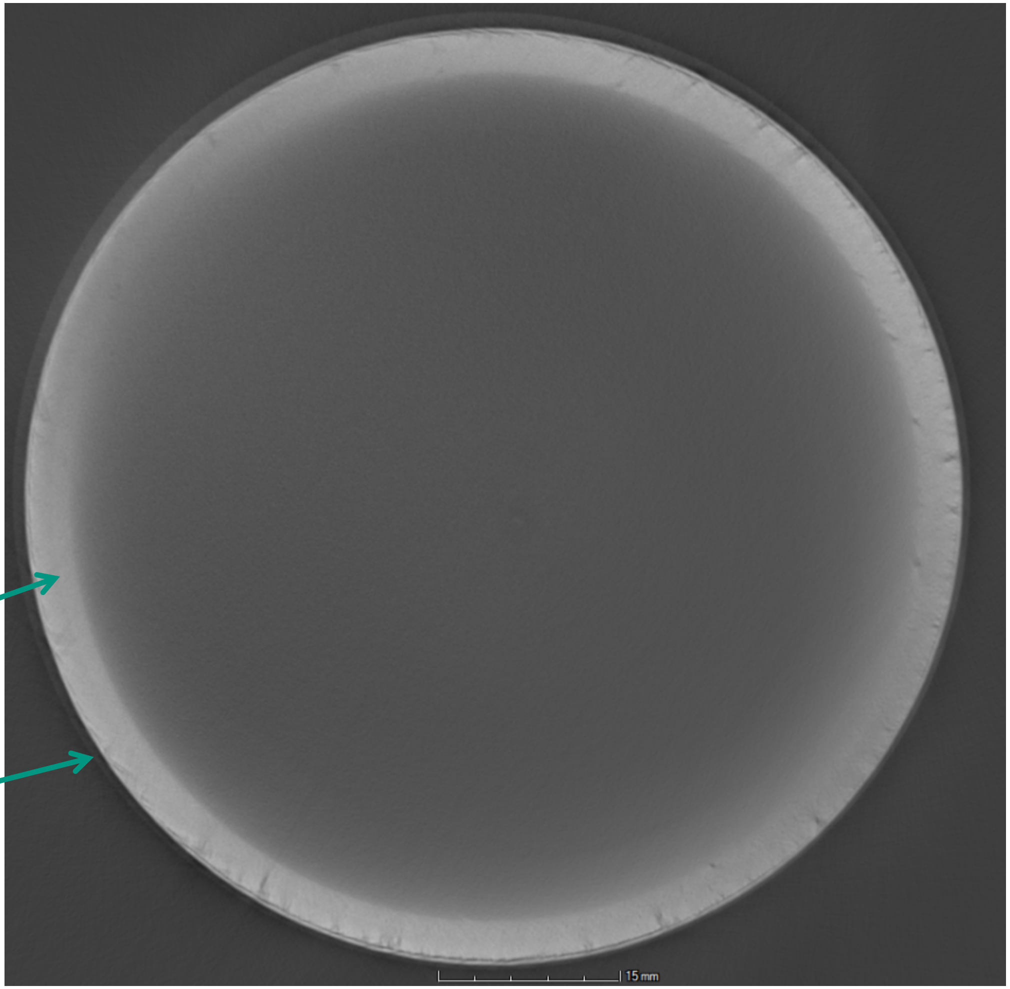
Parameter	T02-DM	T03-DM	Specification
diameter	79.95 mm	79.96 mm	80 mm (+0.2/−0.2 mm)
thickness (central)	1.1149 mm	1.1148 mm	1.11 mm (+0.005mm/ -0.000mm)
planarity *nucleation side* *growth side*	0.52 µm 0.66 µm	0.83 µm 1.43 µm	10 µm
Ra roughness *nucleation side* *growth side*	3.86 nm 2.11 nm	4.13 nm 3.91 nm	20 nm
permittivity ε_r	5.67	5.67	5.67
loss tanδ @ 170 GHz (mean D50)	$1.4 \cdot 10^{-5}$	$1.3 \cdot 10^{-5}$	$3.5 \cdot 10^{-5} \pm 5 \cdot 10^{-6}$
loss tanδ @ 170 GHz (mean D90)	$2.6 \cdot 10^{-5}$	$2.5 \cdot 10^{-5}$	$6 \cdot 10^{-5} \pm 1 \cdot 10^{-5}$
Central loss tanδ	$(3.6 \pm 0.9) \cdot 10^{-6}$ @169.57 GHz	$(4.2 \pm 1.1) \cdot 10^{-6}$ @169.58 GHz	

Brazed disc inspection at KIT by CT

Karlsruhe Institute of Technology

Brazing region

Disc edge



Top side of the diamond disc

Conclusions and outlook

- The design of the window unit was optimized by FEM analyses and in accordance with the ASME III - NC.
- The window unit shall be qualified by the ASME code and a specific program.
- Definition of the specific qualification program is on going and first results were obtained.
- Technical Specifications for the manufacturing of the window prototype are approaching the final phase in order to start the call for tender by F4E.

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