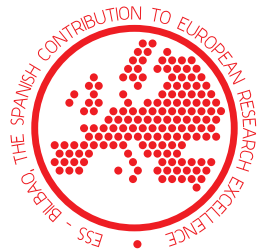

ESS bilbao

EUROPEAN SPALLATION SOURCE

ESS Target Design progress

Consorcio ESS-BILBAO & Instituto de Fusión Nuclear & ESS-AB

A. Aguilar, L. Mena, M. Mancisidor, I. Herranz,
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F. Sordo, J.M. Perlado, J.L. Martínez

July 6, 2016

Table of contents

1. Introduction
2. Spallation Material
3. Internal Structures and vessel
4. Target vessel
5. Shaft and shielding
6. Drive Unit
7. Rotating Seal
8. Conclusions

Introduction

ESS-BILBAO Consortium

Role and functions

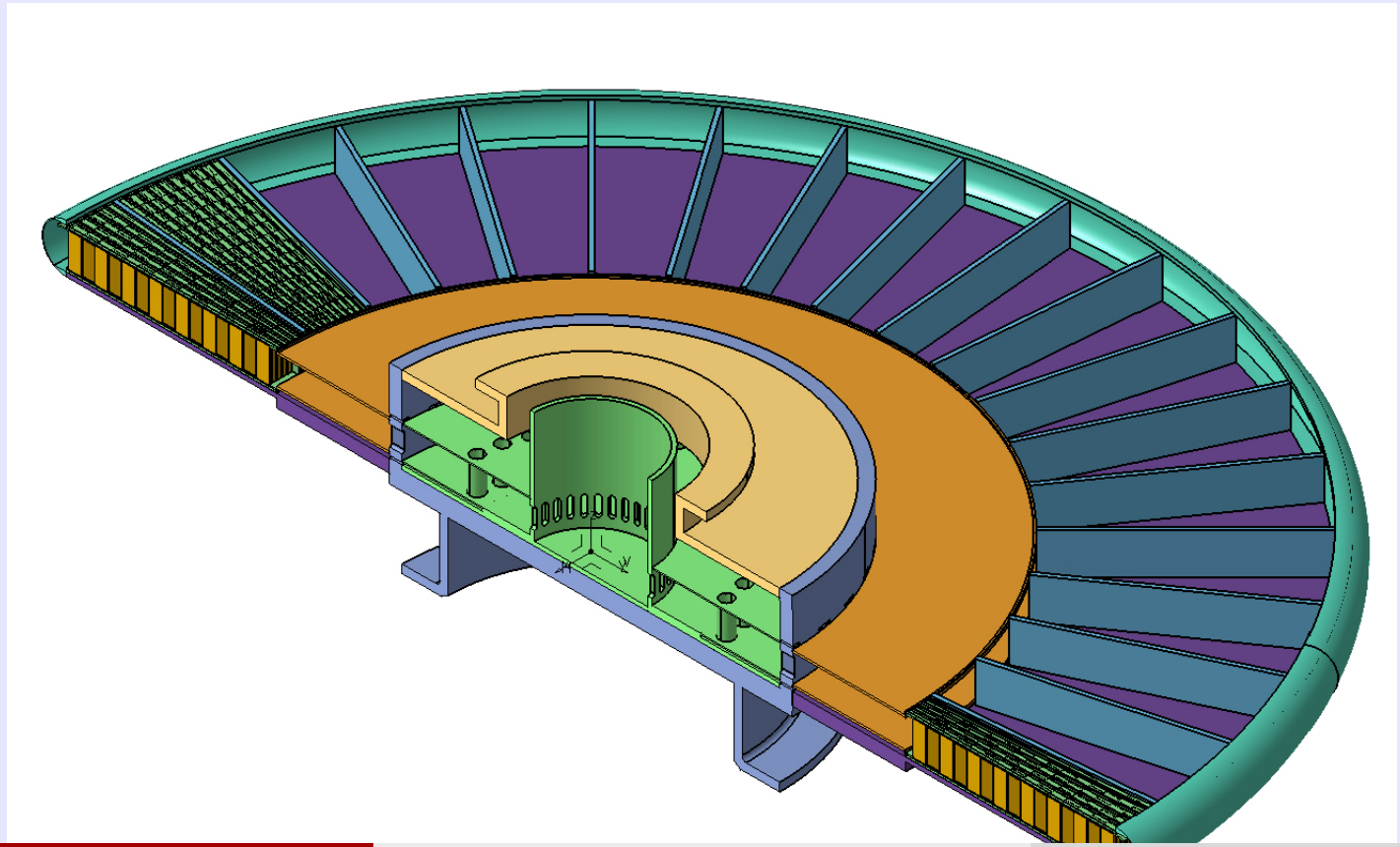
- The Spanish Government has taken the decision to make ESS-BILBAO the only contractor from Spain to ESS project.
- Staff of 65 scientists & engineers and the possibility to hire extra staff.
- ESS-BILBAO has been nominated as Spanish representing entity for ESS operational phase.
- ESS-BILBAO has already received the money for the following years activities ($>$ 20 M€) and additional grants will be provided in due time.
- ESS-BILBAO is a private entity, so we have a large flexibility to employ and subcontract.
- On November 2014, ESS-Bilbao was chosen as ESS partner for Target Wheel, shaft and drive unit.
- On October 2015, and International Panel Chair by Matt Fletcher evaluate the Target Base Line with positive feedback.
- On July 2016, Critical design review for the Spallation Material and the Cassettes. Delayed to September 28^{th} due to licensing analysis required by ESS.

Target Wheel base line

Target Vessel

On the basis of the base line helium flow path, an alternative configuration for the vessel is proposed.

Selection process



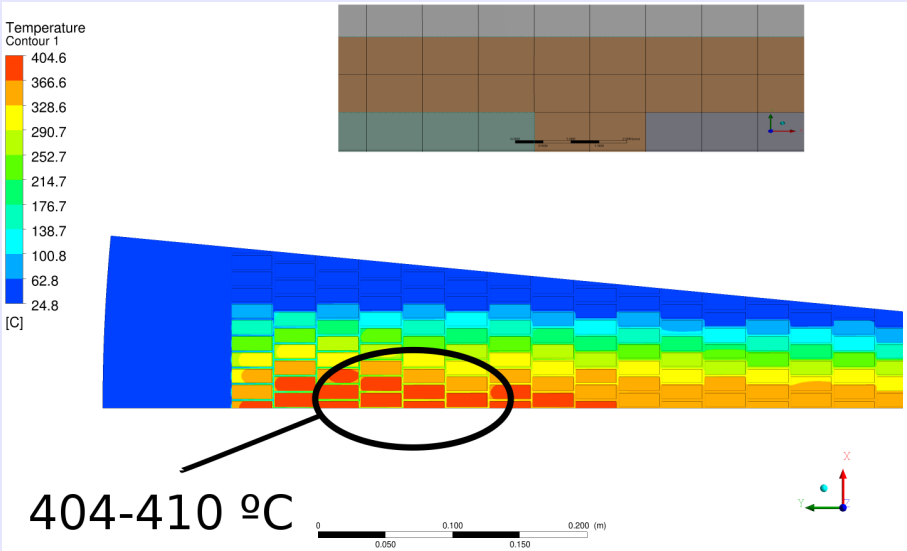
Spallation Material

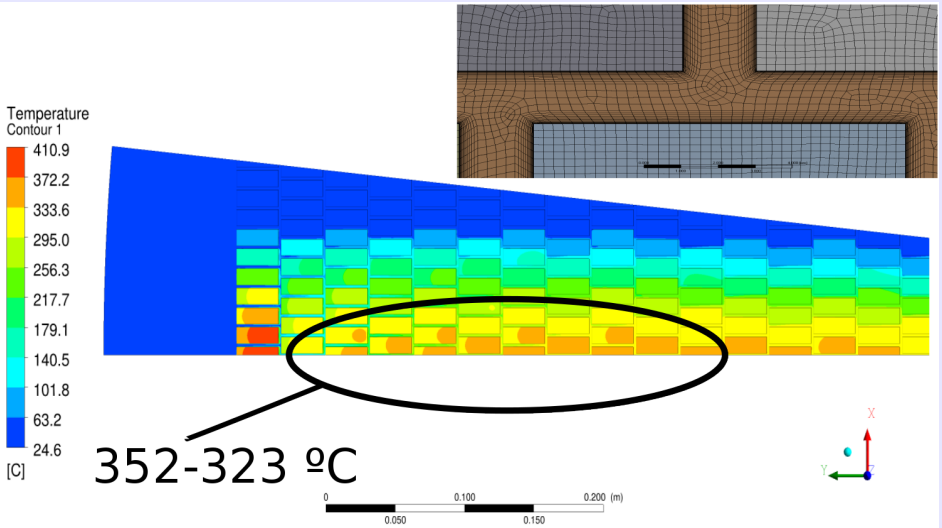
Spallation material: Final Thermomechanical analysis

Thermal analysis

The turbulence distribution plays a significant role in the heat exchange distribution in the proposed geometry for the Spalation material. Taking into account the transient effect, the boundary layer, the compressible flow and the 3D geometry produces a problem close to impossible to solve.

CFD analysis conditions





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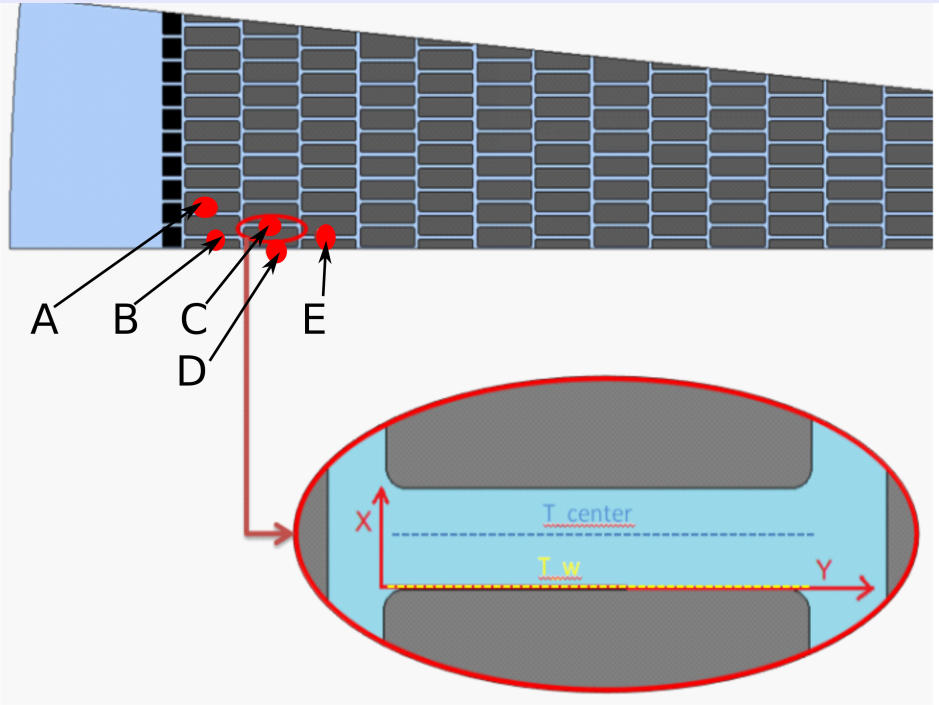
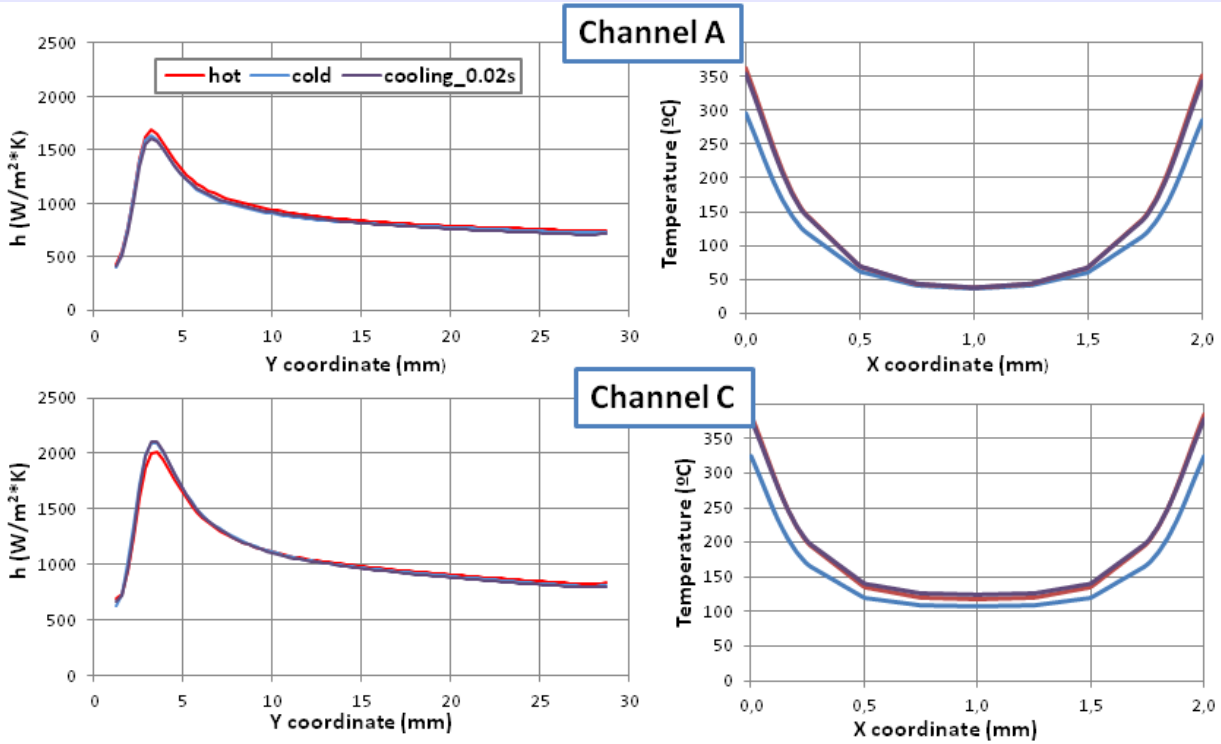


Spallation material: Final Thermomechanical analysis

Fluid-solid uncoupling

Bulk temperature and heat transfer coefficient (h) are no time-dependent variables. We could obtain both variables from a CFD steady state simulation at average power and using them as boundary condition in a transient thermal analysis (FEM) for the spallation material and the cassette.

Steady state solution



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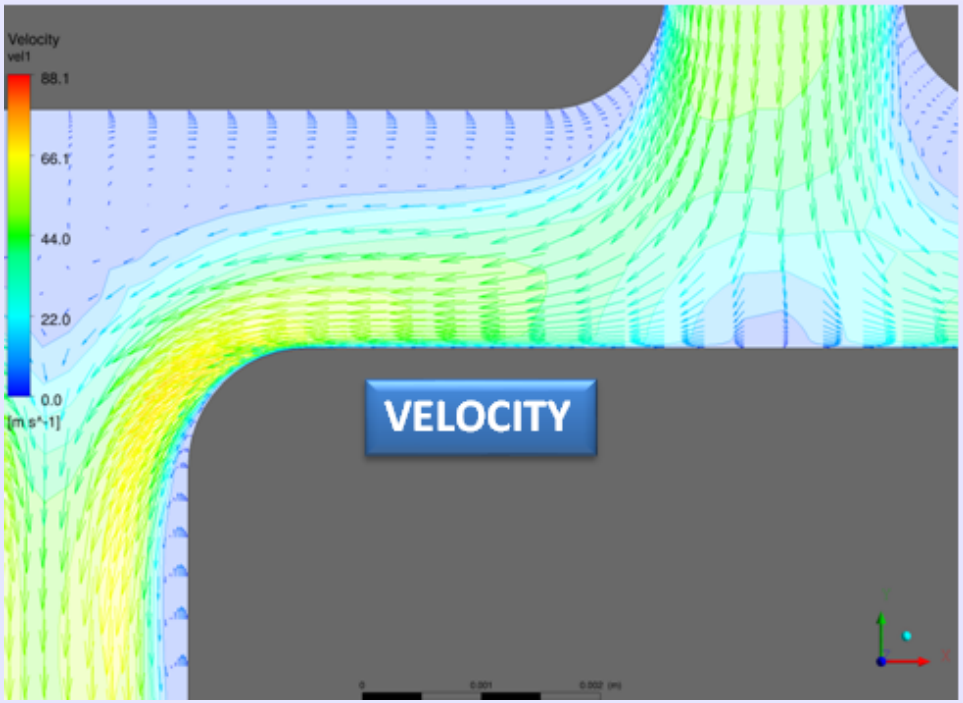

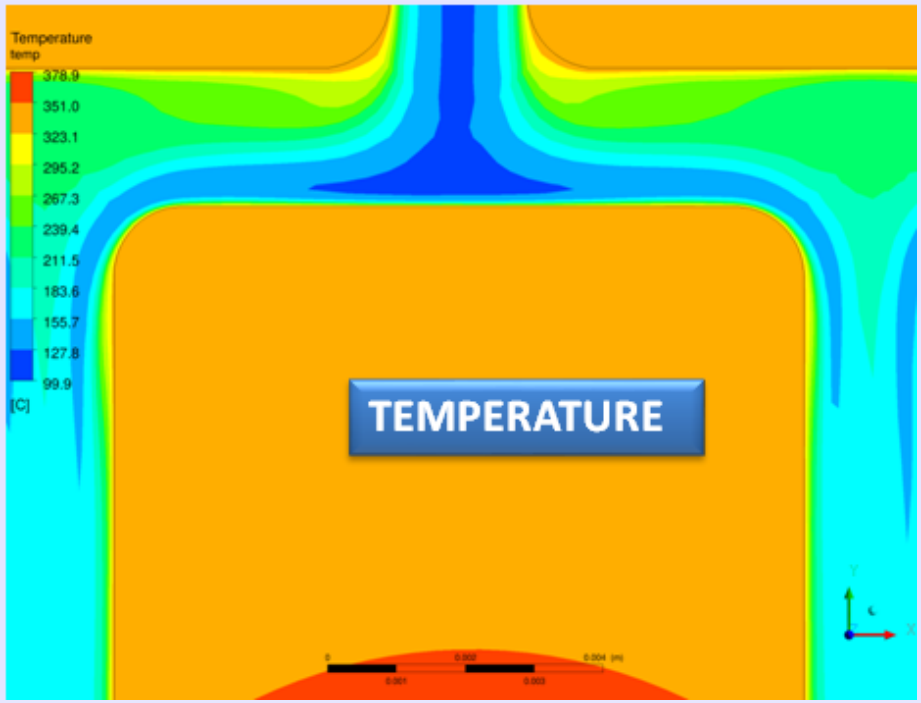

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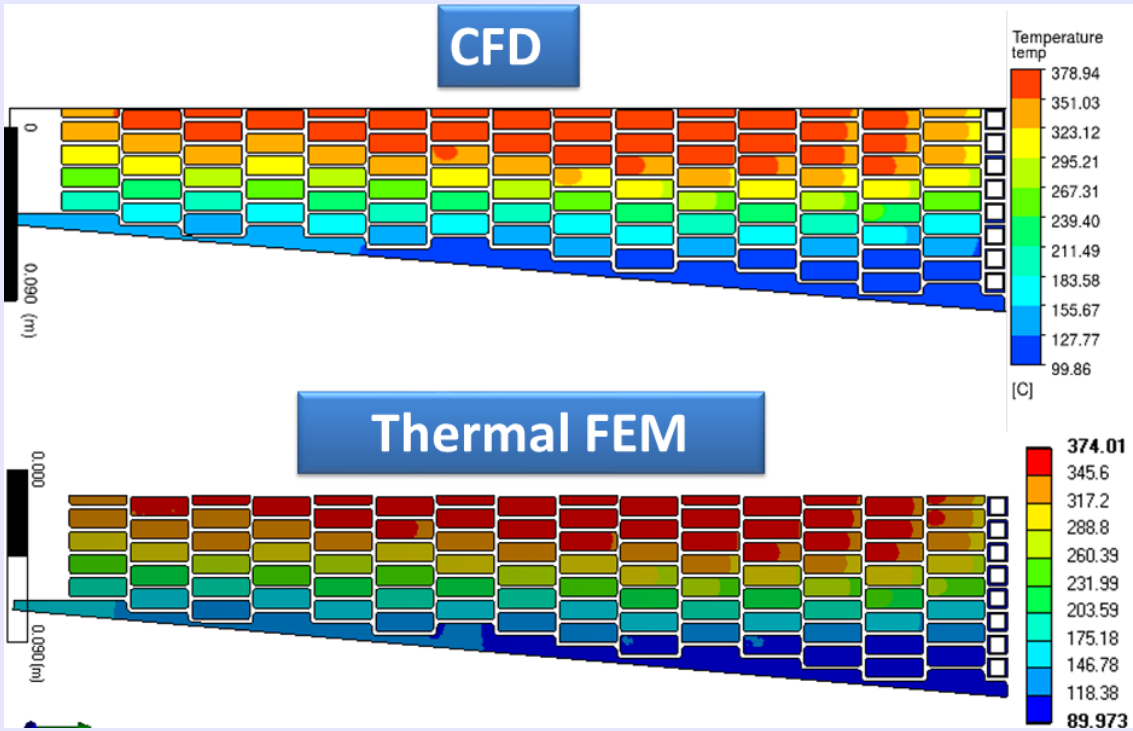

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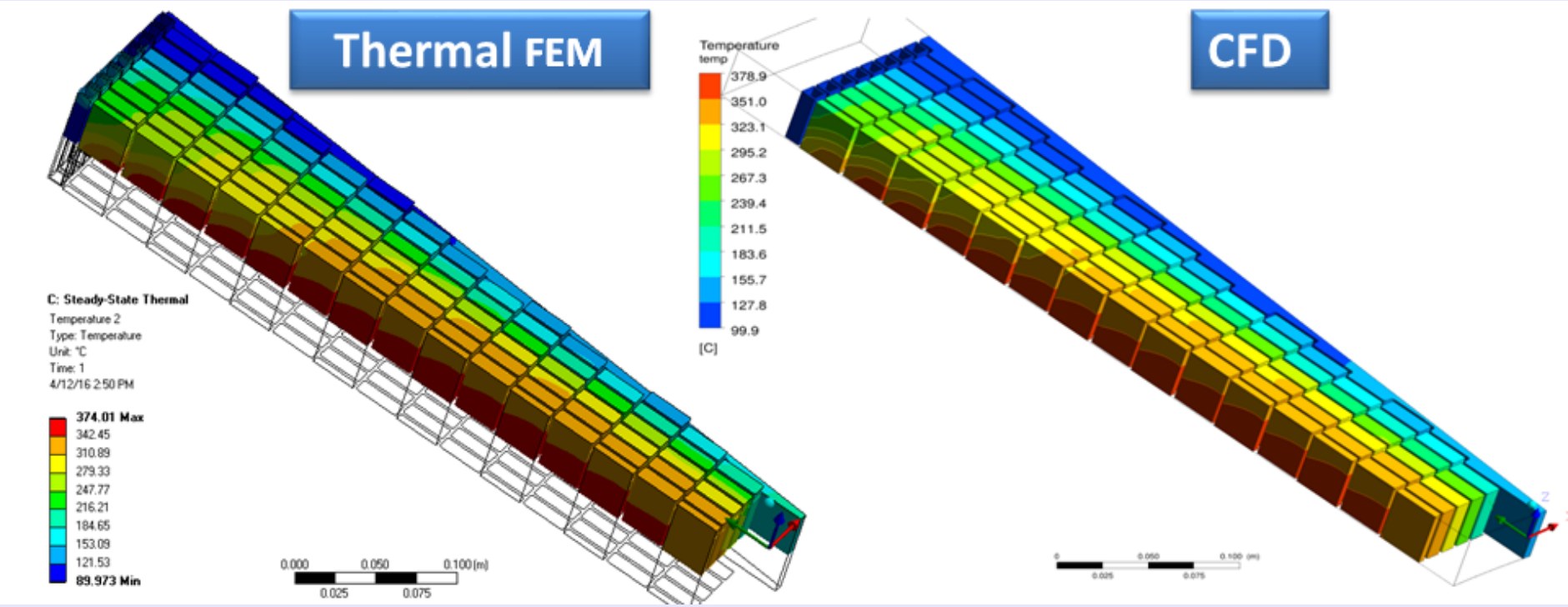
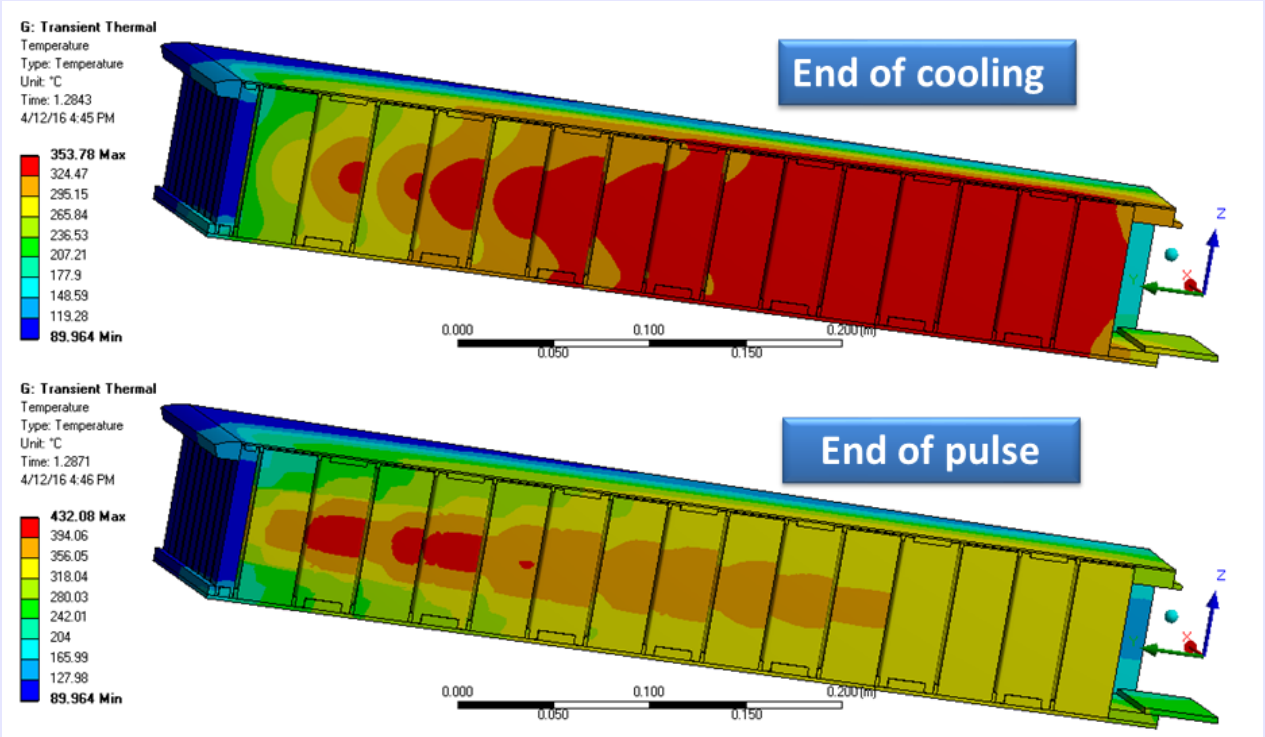


Spallation material: Final Thermomechanical analysis

Thermal transient analysis

Setting the heat transfer coefficient (h) obtained from CFD and the thermal source obtained from MCNP accurate thermal profiles of the cassette and tungsten are obtained, reducing the computational resources and times to something achievable.

Transient solution



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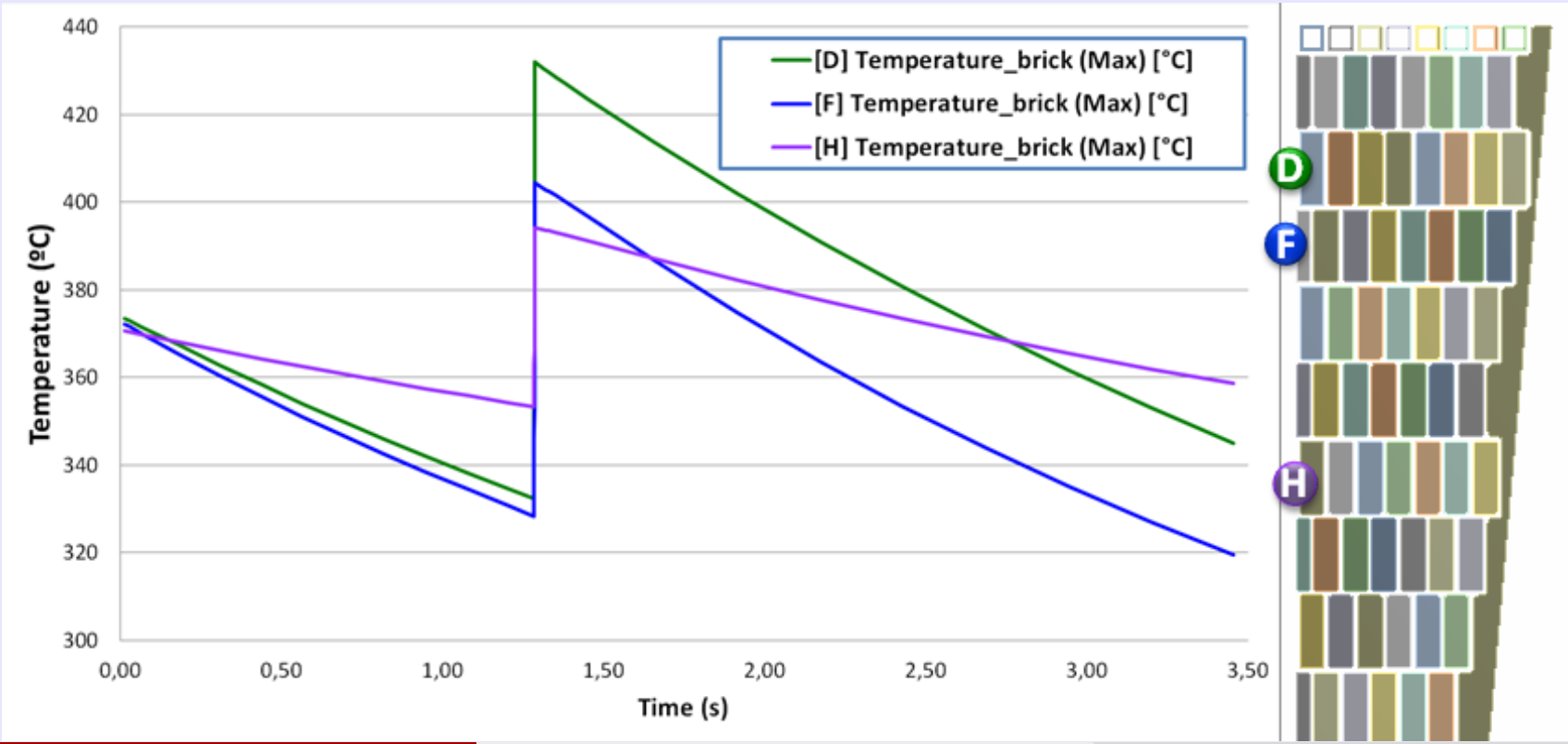

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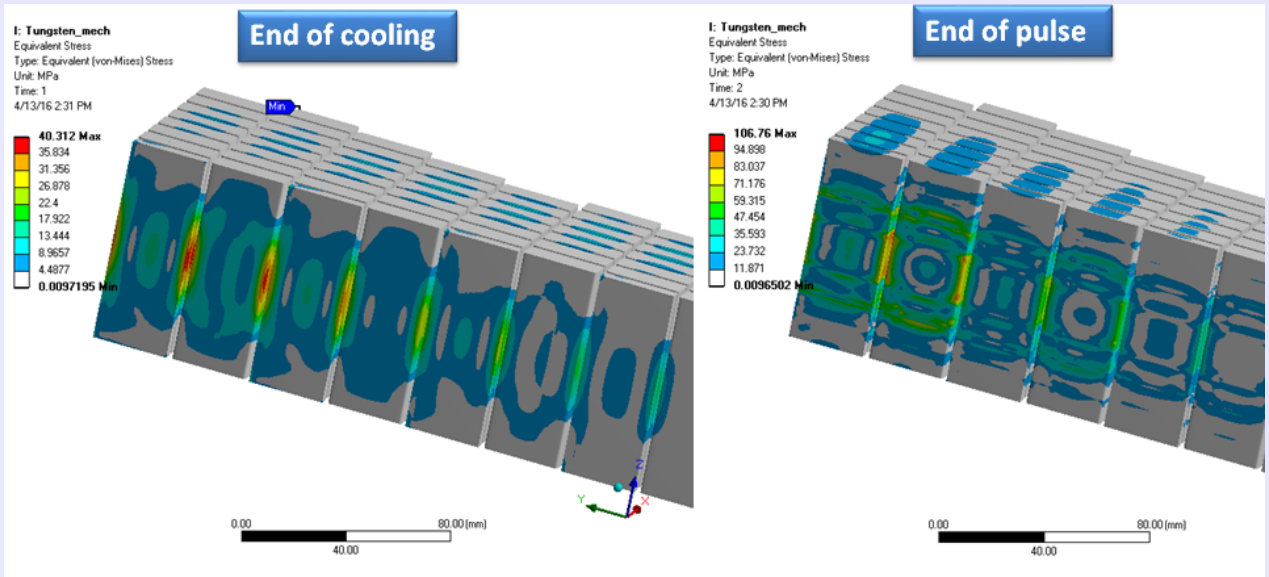
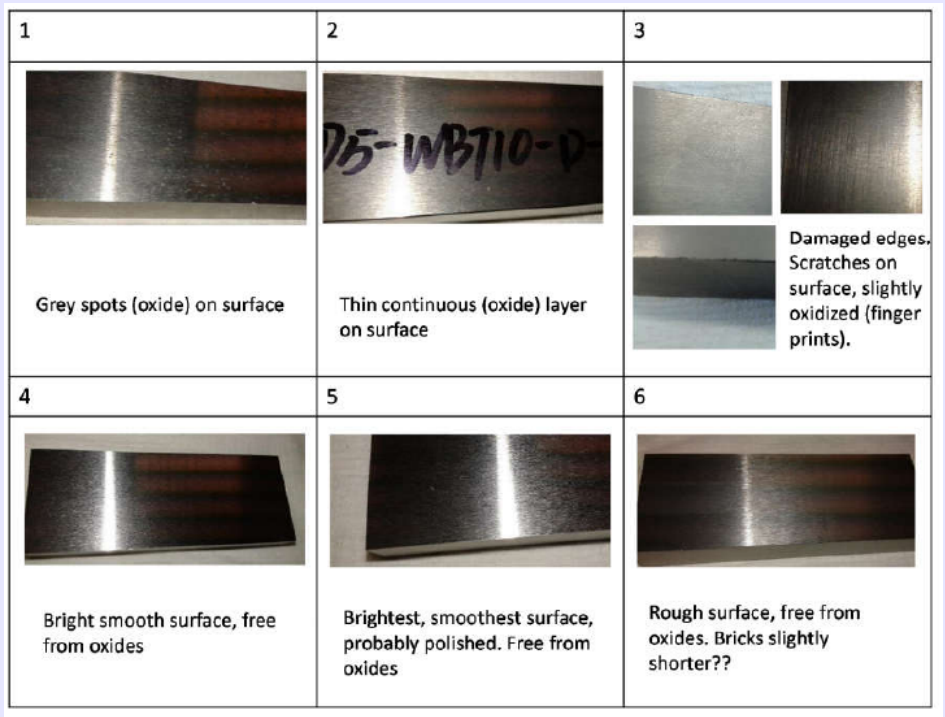


Spallation material: Quality evaluation

Evaluation of different suppliers

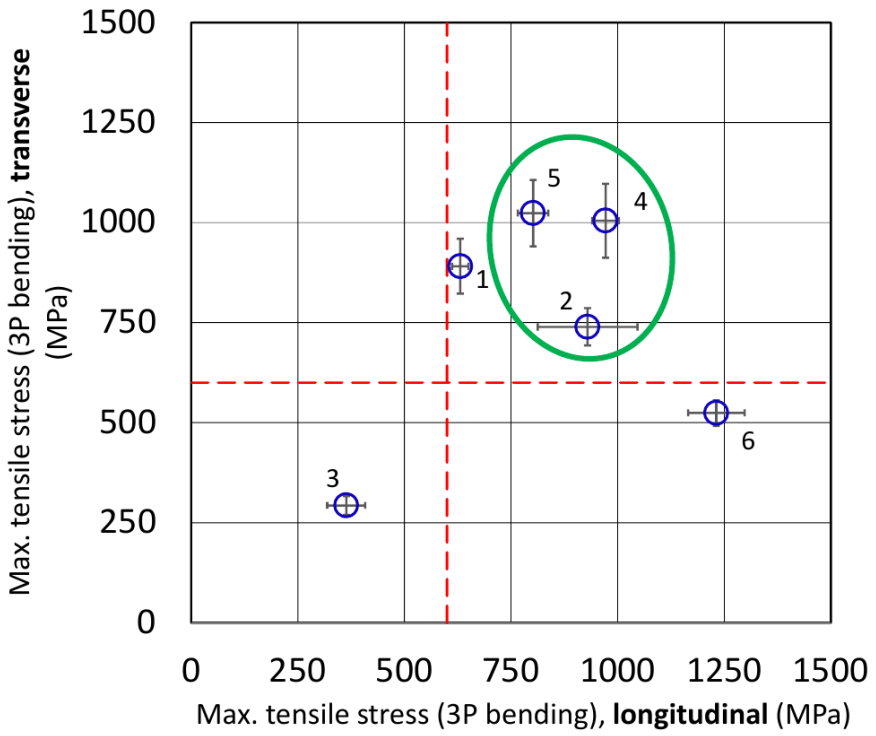
Taking into account the large differences on W grades, ESS-Bilbao is developing its own QA process to accept "W Suppliers" in the official "Call for tender process". Samples from 6 suppliers are under analysis at CEIT. This task will be completed in the next month and the data included in the CDR for Spallation material .

QA analysis on going at CEIT



Spallation material: Quality evaluation

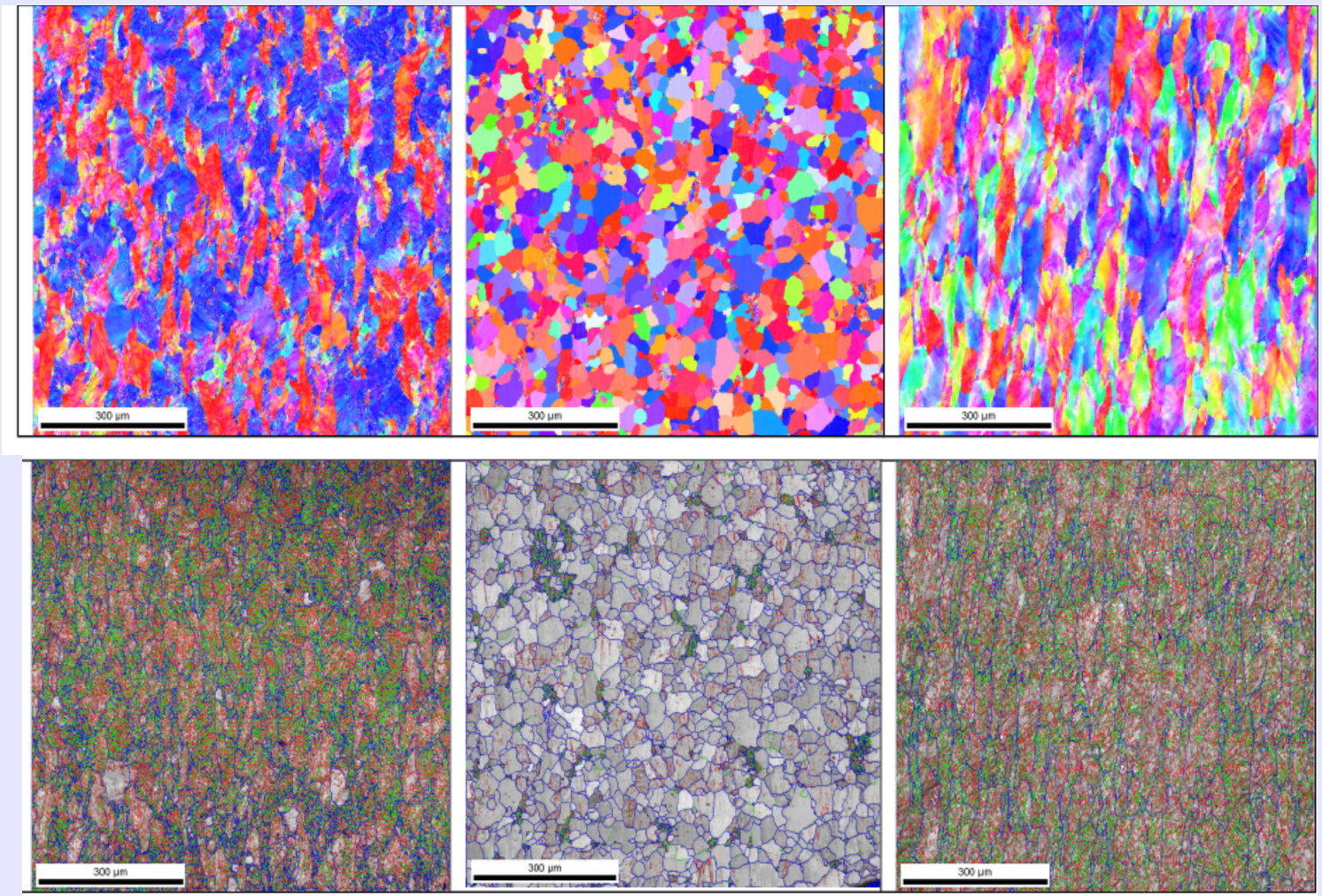
QA analysis on going at CEIT



W supplier	Visual inspection	Density, ρ (g cm^{-3})		E, Young modulus sRPN (GPa) ± assoc. error	HV (1 kg) RP (kg mm^{-2}) ± 95% cl	Res. stresses, surface (MPa) ± sd		Fractography	Chemical composition Impurities above threshold
		Geom. ± assoc. error	Water displ. ± sd			σ_{11} (LD)	σ_{22} (TD)		
1	Grey spots (oxide) on	19.22 ±0.03	18.95 ±0.22	403.9 ±0.7	423.7 ±25.7	-1276 ±9	-1074 ±13	Brittle, transgranular, distorted cleavage ,	-
2	Thin continuous (oxide)	19.16 ±0.03	19.21 ±0.03	405.9 ±0.8	496.5 ±9.5	-789 ± 11	-1088 ± 9	Brittle, transgranular, distorted cleavage , oriented facets Minor	-
3	Damaged edges.	18.27 ±0.03	17.69 ±0.03	364.9 ±0.7	355 ±6	-956 ± 20	-1166 ± 8	Brittle, intergranular fracture, equiaxed grains, high porosity	-
4	Bright smooth surface,	19.24 ±0.03	19.20 ±0.03	408.1 ±0.8	496 ±6.0	-225 ± 27	-1113 ± 11	Brittle, transgranular, distorted cleavage , oriented facets	-
5	Brightest, smoothest surface.	19.22 ±0.03	19.23 ±0.01	406.4 ±0.8	412 ±16	-230 ±24	-247 ±26	Brittle, transgranular, distorted cleavage , oriented facets	>30 ppm O (44 ppm)
6	Rough surface, free from oxides.	19.26 ±0.03	19.15 ±0.05	391.4 ±0.7	470 ±5.0	-709 ± 18	-1055 ± 7	Brittle, transgranular, distorted cleavage , oriented facets	-

Spallation material: Quality evaluation

QA analysis on going at CEIT



Supplierts 2, 5 and 6. Gran structure in the middle plane.

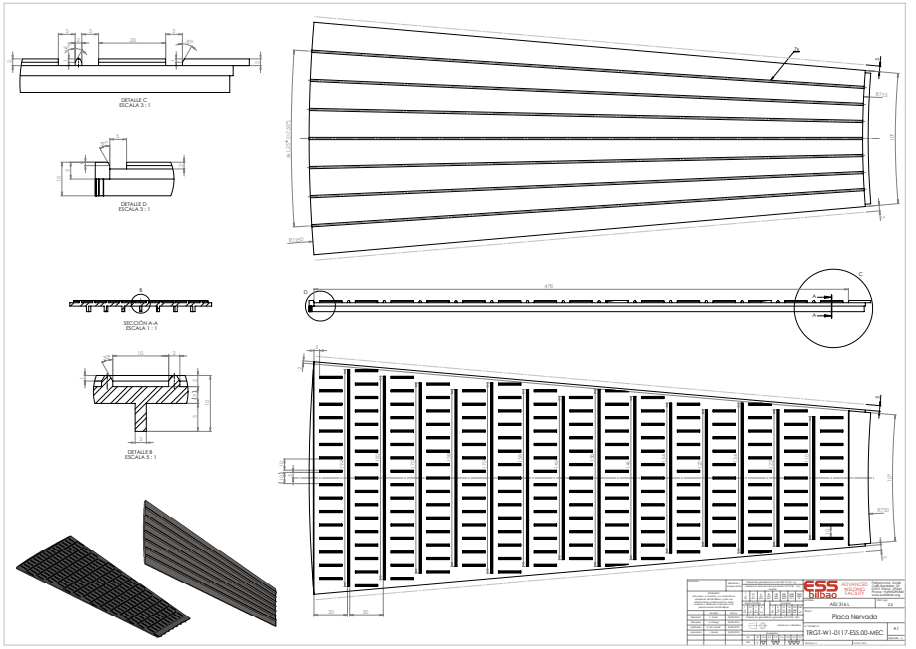
Internal Structures

Internal Structures: Cassette Manufacturing Test v2.0

Cassette Manufacturing Test

The Cassettes are critical elements for the configuration of the He channels in between W bricks. Despite of the fact that cassettes are not part of the nuclear credited elements of the target, the geometry and the tolerances produces a complex manufacturing problem.

Contract award to Leading Enterprises (v2.0)



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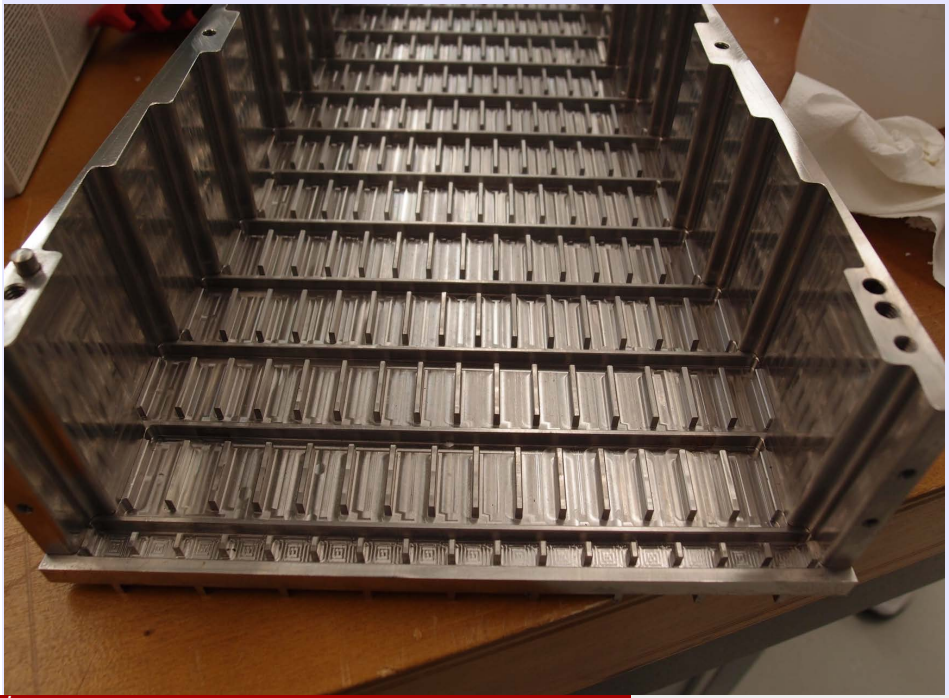
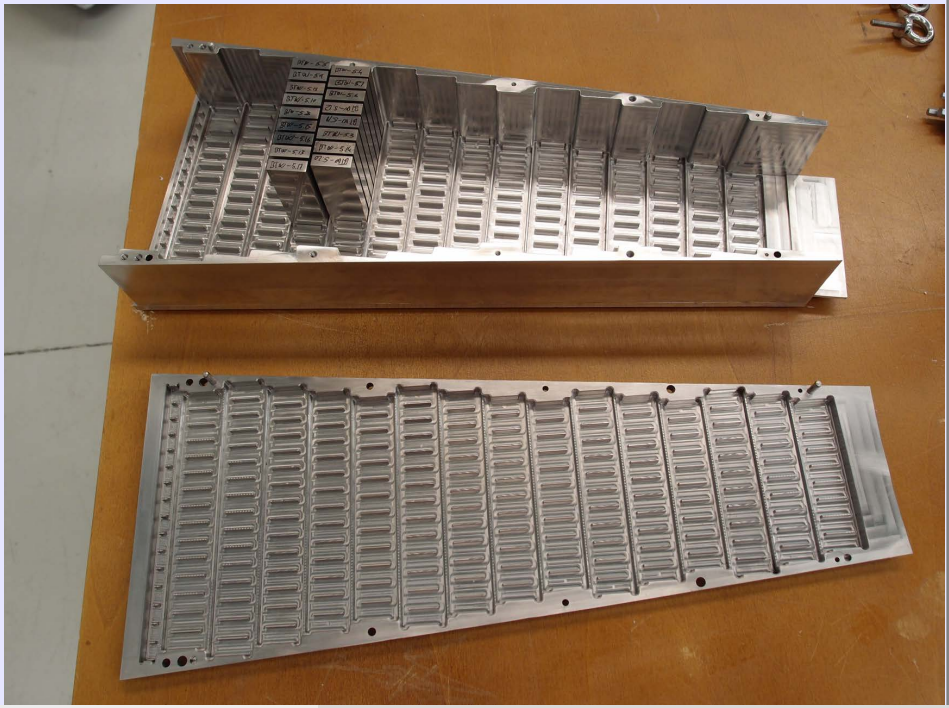
Internal Structures: Cassette Manufacturing Test

Cassette Manufacturing Test: Lessons learned

- The introduction of self aligning elements and chamfers simplifies assembling process.
- Bolted union is between all the elements.
- Lid and plate machined from the same plate.
- 120 bricks assembled in $\sim$ 10 minutes.

EDD v2.0 completed





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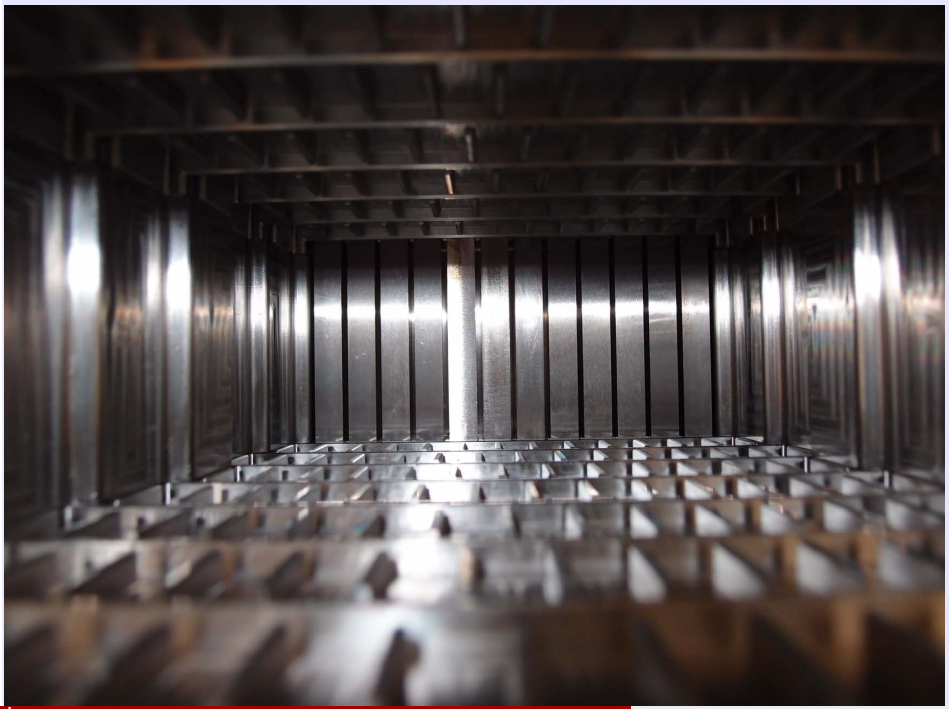
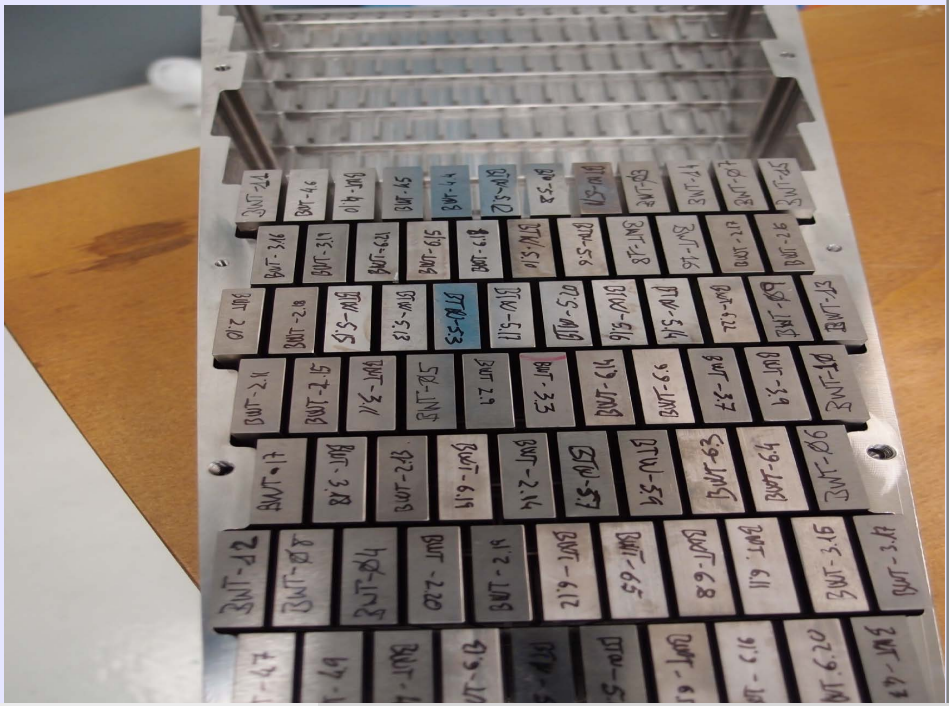


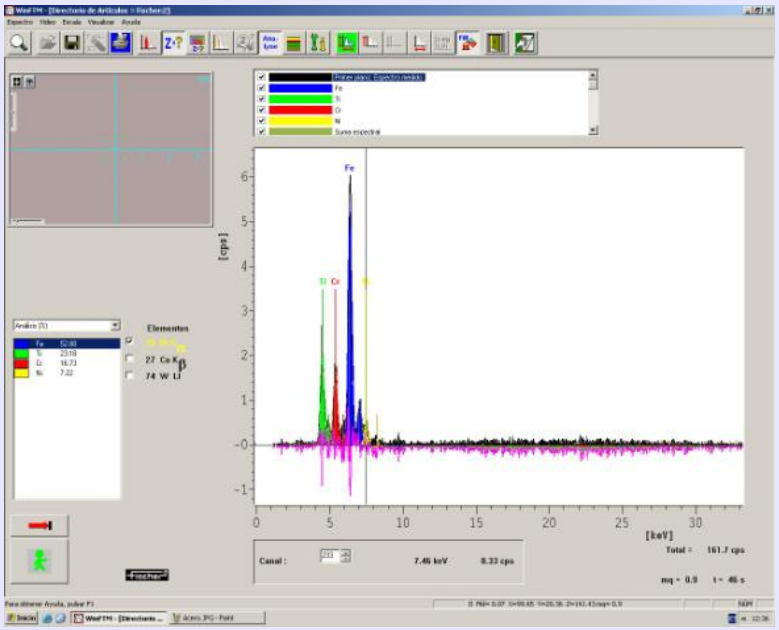


Internal Structures: Vibration experiment

Vibration experiment

The assembling process has been tested on a vibration experiment to evaluate the powder production. The vibration conditions reproduced 10^7 cycles with 1-10 g acceleration in two directions with a 11 bricks prototype. The production of powder was 36.4-355 μg which means $\sim$ 250-2500 $mg \cdot year^{-1}$ in the full target wheel. The RMS analysis shows that only steel powder is produced.

Vibration experiment



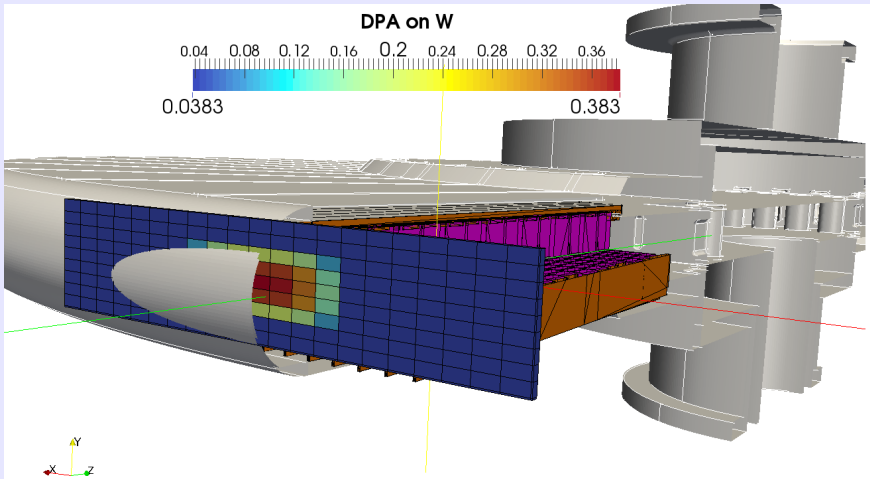
Target Vessel

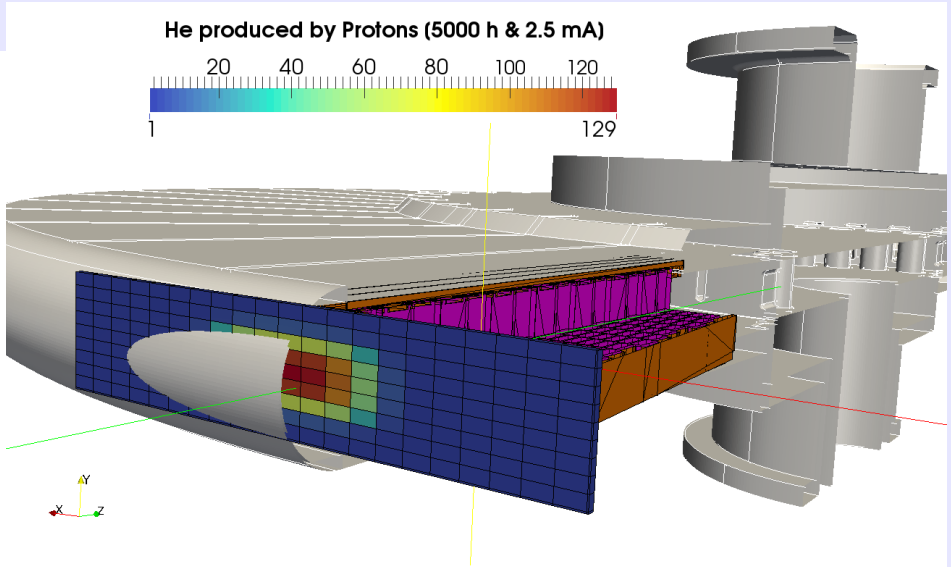
Proton beam window: Irradiation Damage

Neutron damage

On the proton beam window, the damage is mainly produced by protons. The maximum value, produced in the window is $\sim$ 0.7 dpa and 130 appm of helium per year. After 5 years of operation the total damage is below 3.5 dpa with a gas accumulation below 700 appm.

Proton induced radiation damage [5000 h & 2.5 mA]



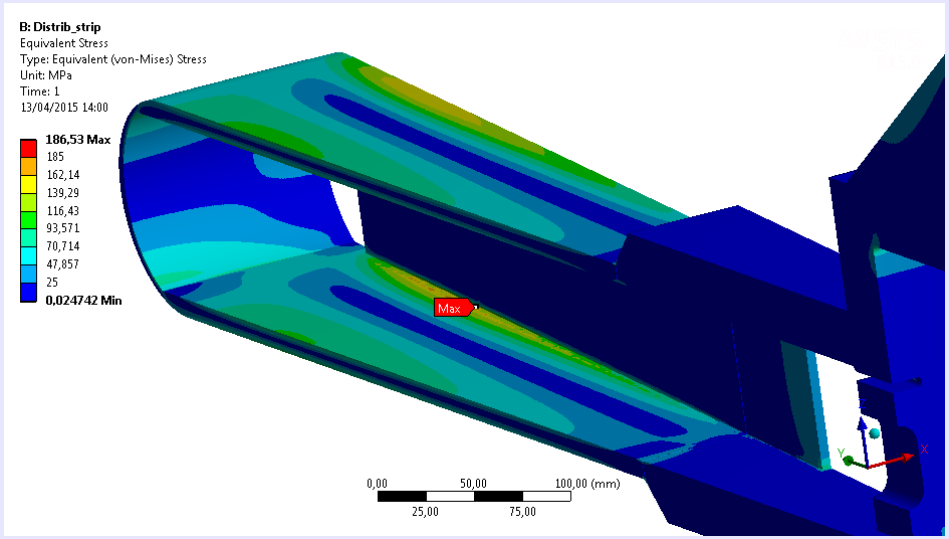


Target Vessel

Mechanical analysis based on RCC-MRx

The Target vessel is considered as a Class 2 component (RCC-MRx). Based on that the mechanical analysis of the vessel has been completed including fatigue and welding analysis.

CFD analysis conditions



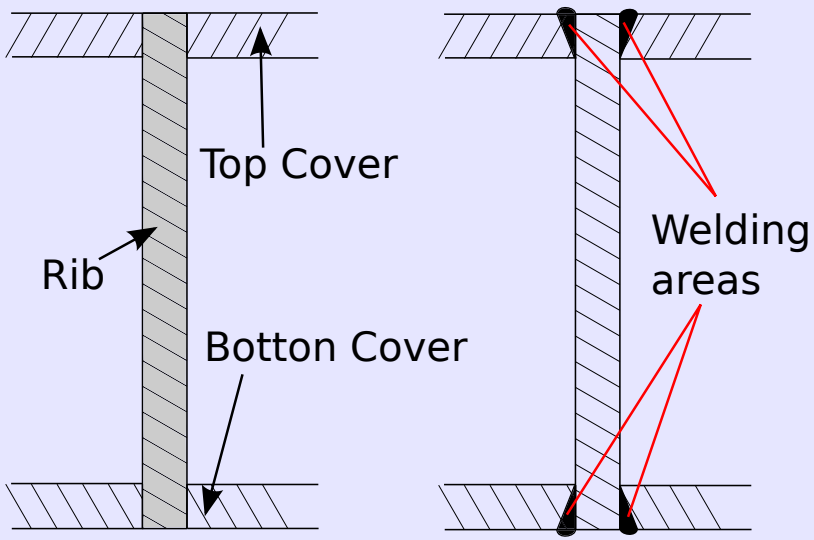
Target Vessel: Welding analysis

Welding analysis

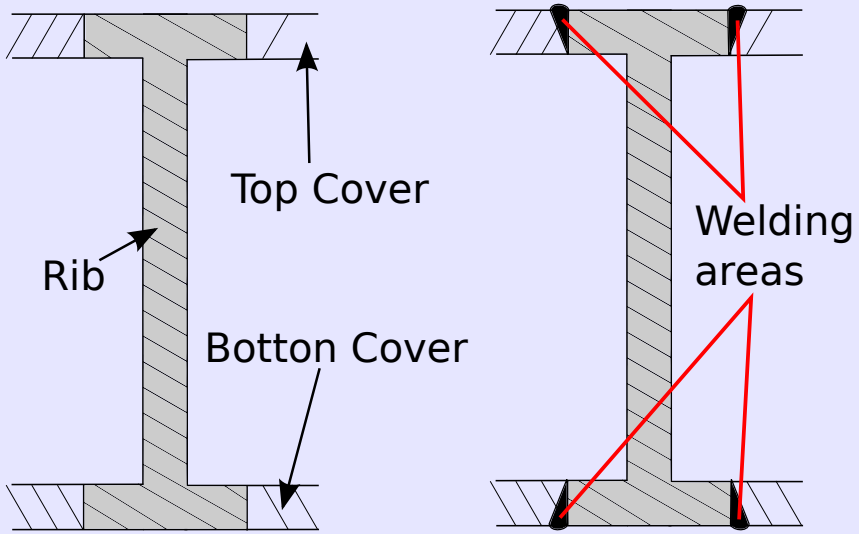
The welding regions has been agreed with manufactures and reviewed based on the RCC-Mrx criteria. Full penetration, volumetric inspections and one face surface inspections are need for the ribs. The stress values in the beam entrance window are much lower and only surface inspection will be needed.

Full penetration weldings in the ribs

Alternative 1 ($P_L = 179$ MPa in welding area, Based on interpretation)



Alternative 2 ($P_L = 125$ MPa at 2 cm, Welding Type II.1)



Target Vessel: Welding definition for Target Wheel

Inspections before welding

Table RS 7720 — *c : class $N2_{Rx}$ box structure welds*
1 : examination of surface to be welded (before welding)

Type	Austenitic	Ferritic	Aluminium (not coverd)	Zirconium (not coverd)	X	Non destructive examination	Criteria
1.2 Butt welded joint (Type II.1)  Gas shielding	ROLLED FORGED (e ≥ 10 mm)			X		RES or MAG	**RS 7363**
					X	RES	**RS 7363**
	CAST (e ≥ 10 mm)			X		RES or MAG	**RS 7363**
					X	RES	**RS 7363**
2. Butt weld on permanent backing strip (Type II.2) 	ROLLED FORGED (e ≥ 10 mm)			X		RES or MAG	**RS 7363**
					X	RES	**RS 7363**
	CAST (all thicknesses)			X		RES or MAG	**RS 7363**
					X	RES	**RS 7363**

RES= Liquid penetrant examination

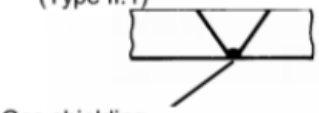
Remarks

The RCC-MRx system only covers RES (liquid penetrant inspections) analysis for the surfaces before welding.

Target Vessel: Welding definition for Target Wheel

Inspections during welding

Table RS 7720 — *c : class $N2_{Rx}$ box structure welds*; *2 : examination during weld operation*

Type	Austenitic	Ferritic	Aluminium (not coverd)	Zirconium (not coverd)	X	Non destructive examination	Criteria
1.2 Butt welded joint (Type II.1)  Gas shielding	If neither RAD nor US can be performed on completed weld, examination of root pass (RS 7722.11) and examination every 3 layers during filling up of the weld (RS 7723.1)			X	X X	RES or MAG (1) RES	**RS 7724.1** **RS 7724.2** **RS 7724.1**
2. Butt weld on permanent backing strip (Type II.2) 	If neither RAD nor US can be performed on completed weld, examination of root pass (RS 7722.11) and examination every 3 layers during filling up of the weld (RS 7723.1)			X	X X	RES or MAG (1) RES	**RS 7724.1** **RS 7724.2** **RS 7724.1**

Remarks

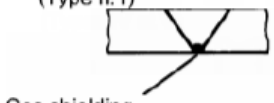
The RCC-MRx system only covers RES analysis during welding. These means one inspection on the root and one inspection each three layers of welding ($\sim$ 4-5 layers).

Target Vessel: Welding definition for Target Wheel

Inspections after welding

After weld eexamination: RAD on 100% of the welding area

Table RS 7720 — *c : class $N2_{Rx}$ box structure welds*; *3 : examination after weld operation*

Type	Austenitic	Ferritic	Aluminium (not coverd)	Zirconium (not coverd)	X	Non destructive examination	Criteria
1.2 Butt welded joint (Type II.1)  Gas shielding	All thicknesses : (outer face accessible)			X		RES	RS 7724.1
		X				RES or MAG	RS 7724.1 RS 7724.2
	Reference examination	X		X	X	RAD(*)(**)	RS 7724.3
	Aternative examination	X		X	X	US(*)(**)	RS 7724.4
	(*) If neither RAD nor US can be performed see examination during weld operation (**) 100% for categories a and b, 10% for category c, none for category d (RC 3834.3)						
2. Butt weld on permanent backing strip (Type II.2) 	All thicknesses : (outer face accessible)			X		RES	RS 7724.1
		X				RES or MAG	RS 7724.1 RS 7724.2
				X	X	RAD(*)(***)	RS 7724.3
	(*) If RAD cannot be performed see examination during weld operation (***) 10% for category c, none for category d (RC 3834.3)						

Remarks

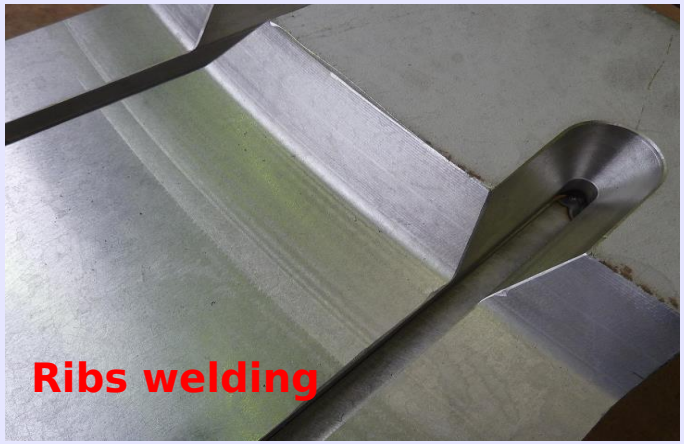
The RCC-MRx system requires RES inspection for the external surface of the welding. Even if it is not needed for the welding qualification, our manufacturer recommends to include 70% RAD inspection without increasing the N coefficient on the design process.

Target Vessel: Welding prototype

Alternative 1 prototype

To evaluate the welding procedures and inspection a prototype based on Alternative 1 has been completed including all the inspection procedures considered on RCC-MRx system (RES and RAD) on the rib position and the window.

Manufacturing and inspections



Target Vessel: Welding prototype

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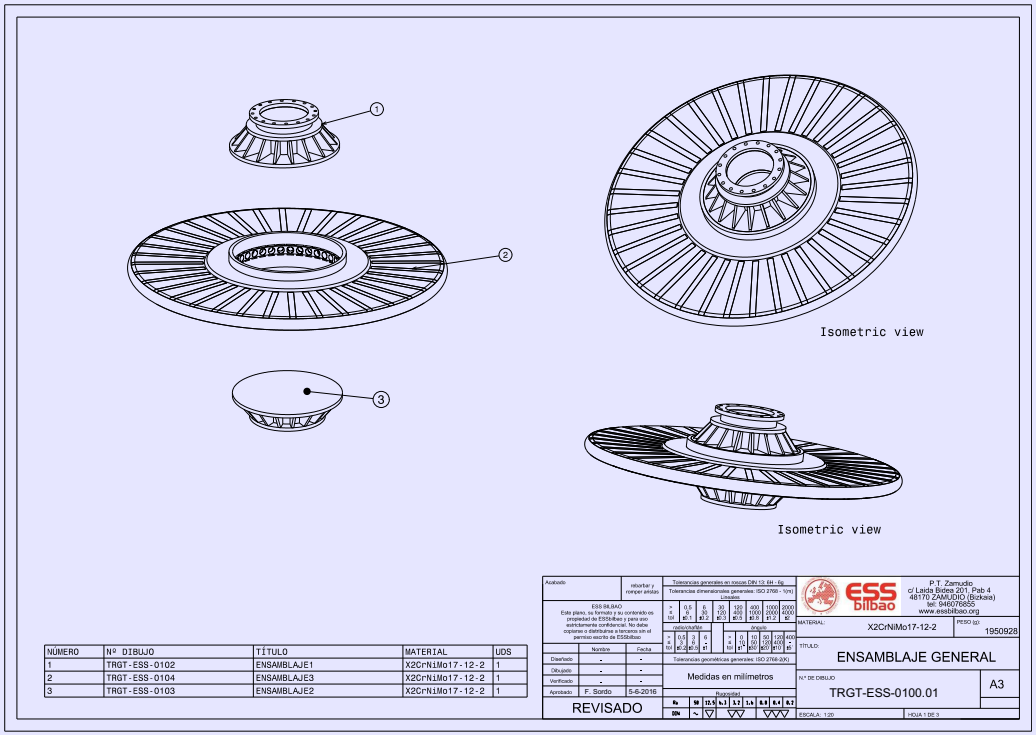
Manufacturing and inspections

Target Vessel: Welding prototype

Full Scale Target Vessel prototype

A full scale prototype of the Target Vessel is on going. Call for Tender documentation has been submitted to ESS-Bilbao council for approval ($\sim 15^{th}$ July). We plan to complete the prototype in by the end of the year.

Target Vessel prototype



Shaft and shielding

Shaft shielding

Shielding requirements

The internal shielding of the shaft is a critical requirement to reduce the dose rate values on top of the target monolith. Along the last months the average shielding requirement has been estimated ($\sim$ 60 % of steel density) but the shape of the shielding was not taken in to account so the neutron streaming was not properly evaluated.

Pressure drop & manufacturing

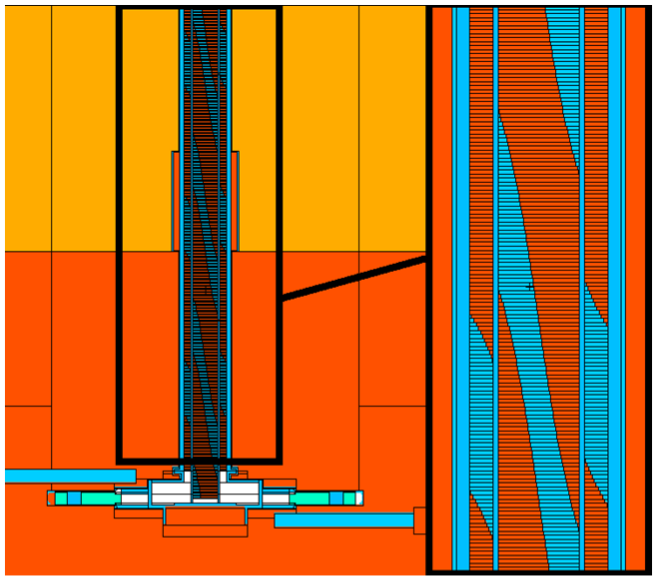
The configuration of the helium channels inside the shielding drives the pressure drop of the shaft. Several options are under evaluation in order to minimize the pressure drop and manufacturing requirements.

CFD-MCNPX optimization loop

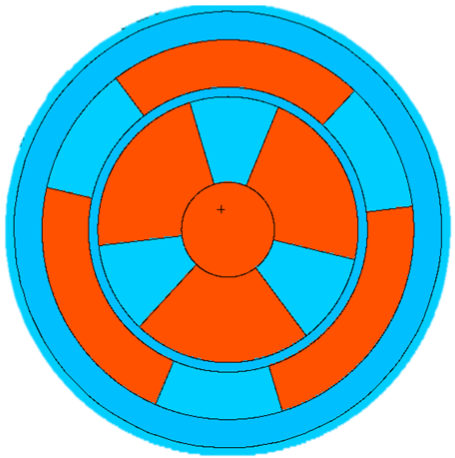
Based on previous requirements, a neutronic-fluid dynamic optimization loop is on going to evaluate several shielding solutions.

Shaft shielding

Shaft CFD-MCNPX analysis



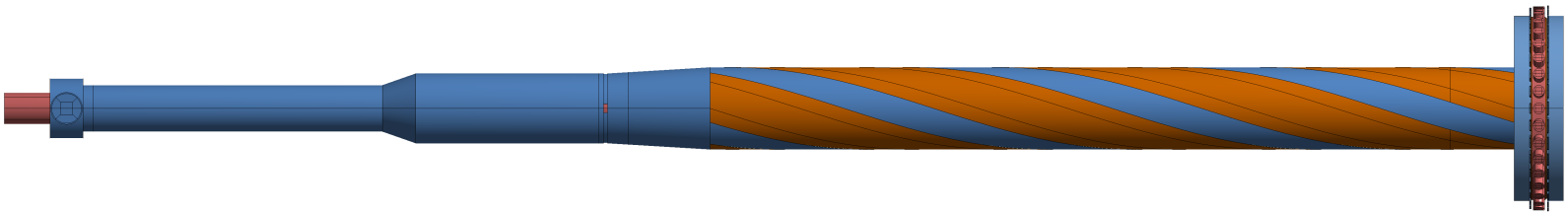
Cross section



- Comparison between two shaft shielding options has been completed considering CFD and shielding analysis.
- After discussion with manufacturer Helical shileding has been choosen (three helical channels for inner and outer shielding)

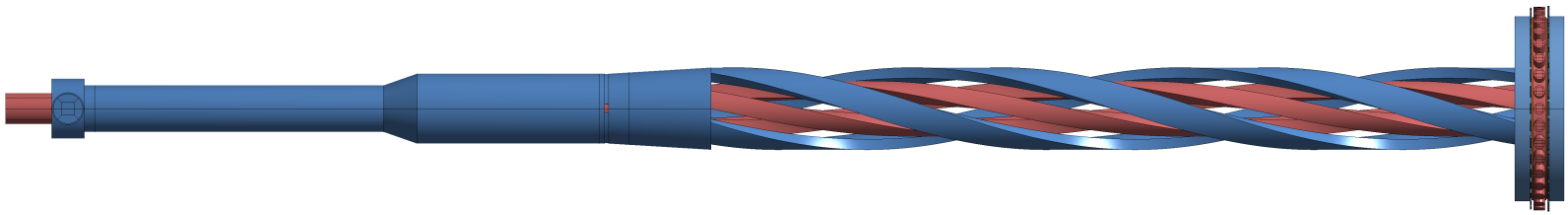
Shaft shielding

CFD and FEM complete model from Rotating Seal to wheel distributor



Shaft shielding

CFD and FEM complete model from Rotating Seal to wheel distributor



Shaft shielding

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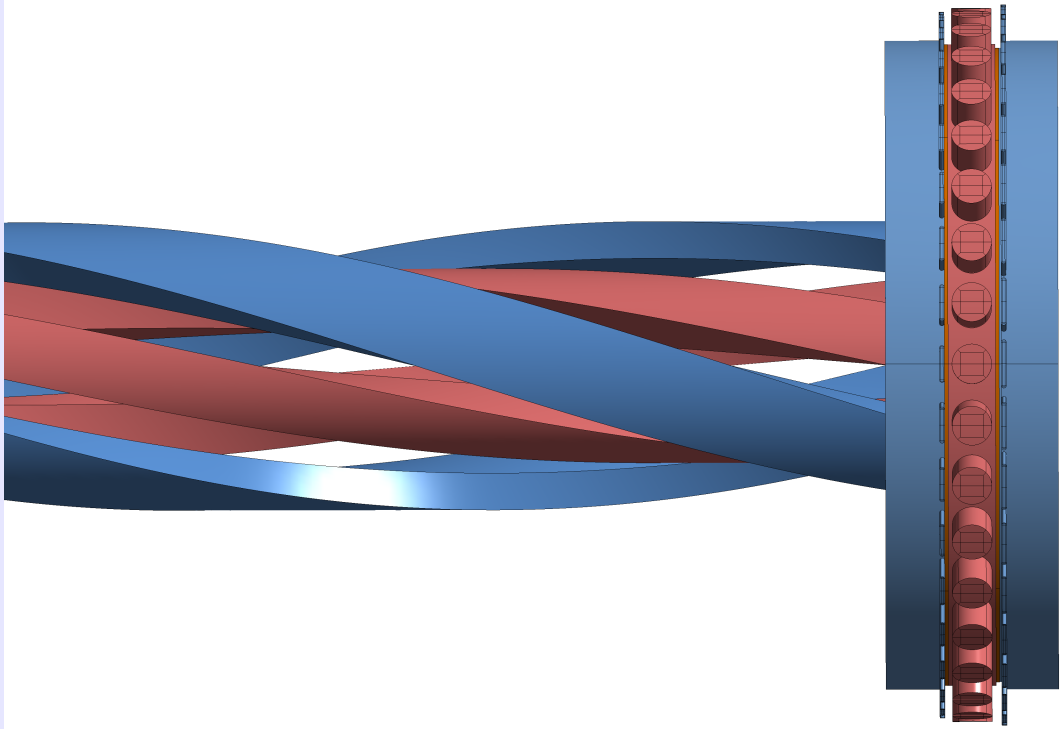
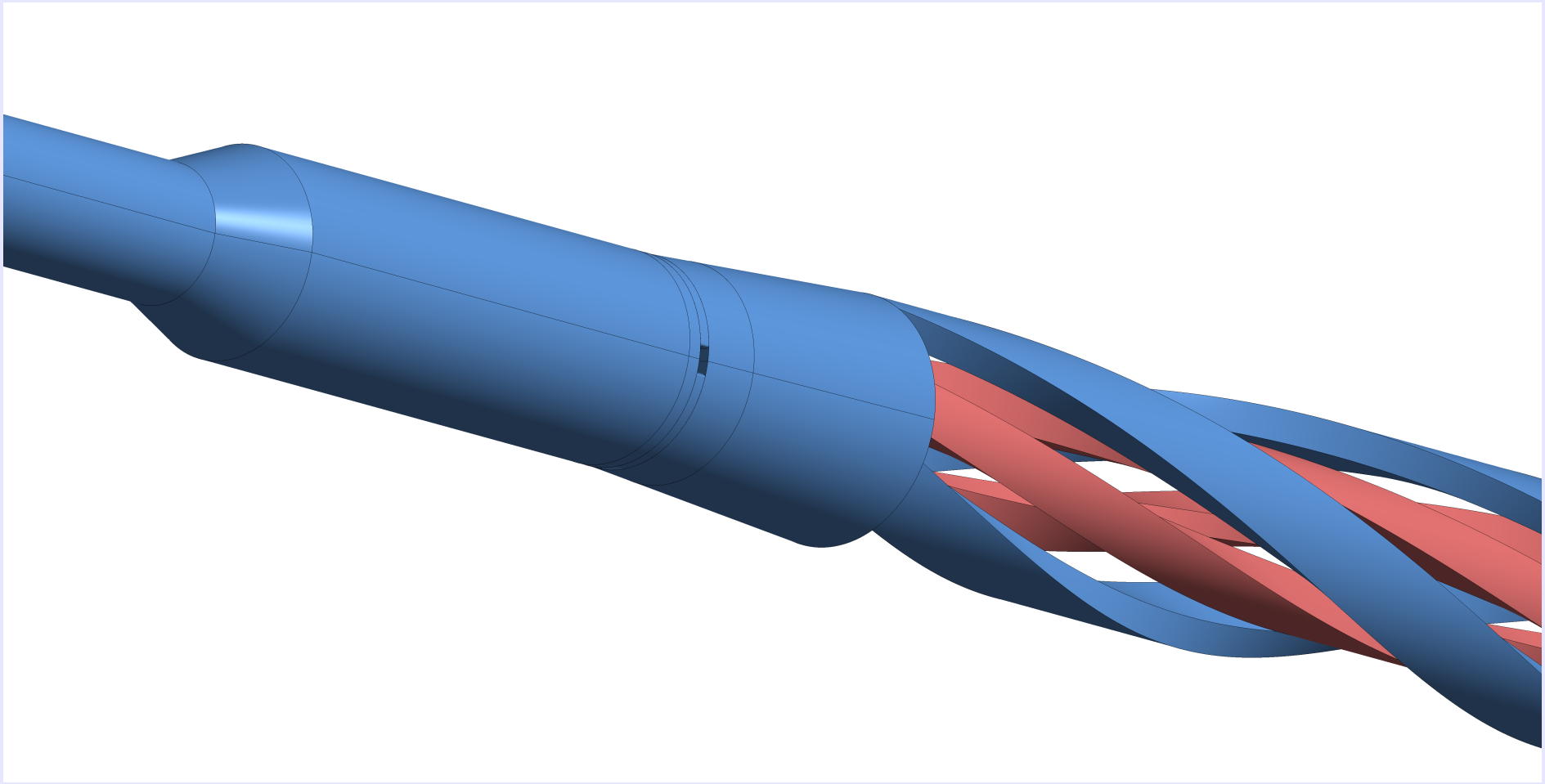


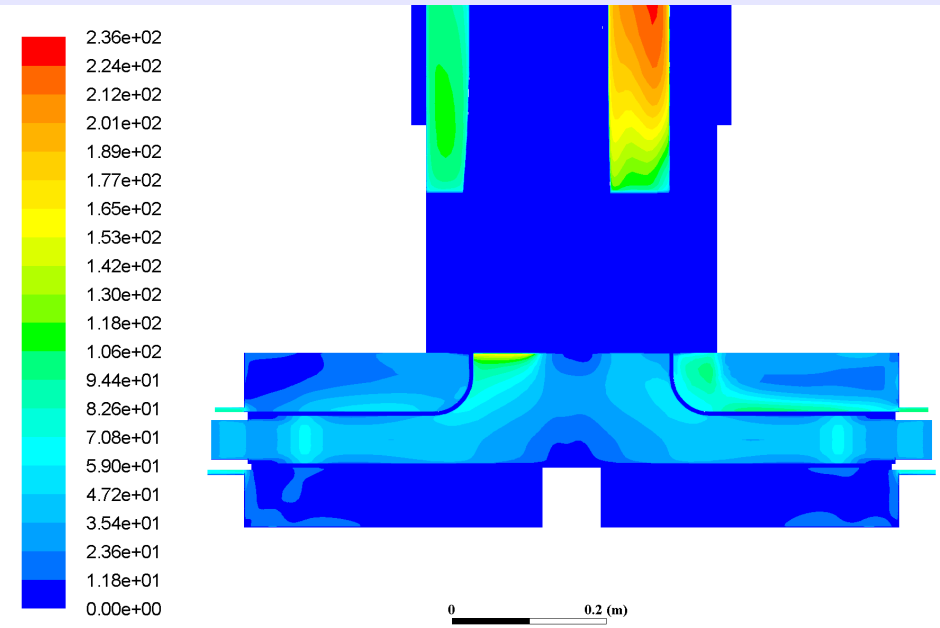
Shaft shielding

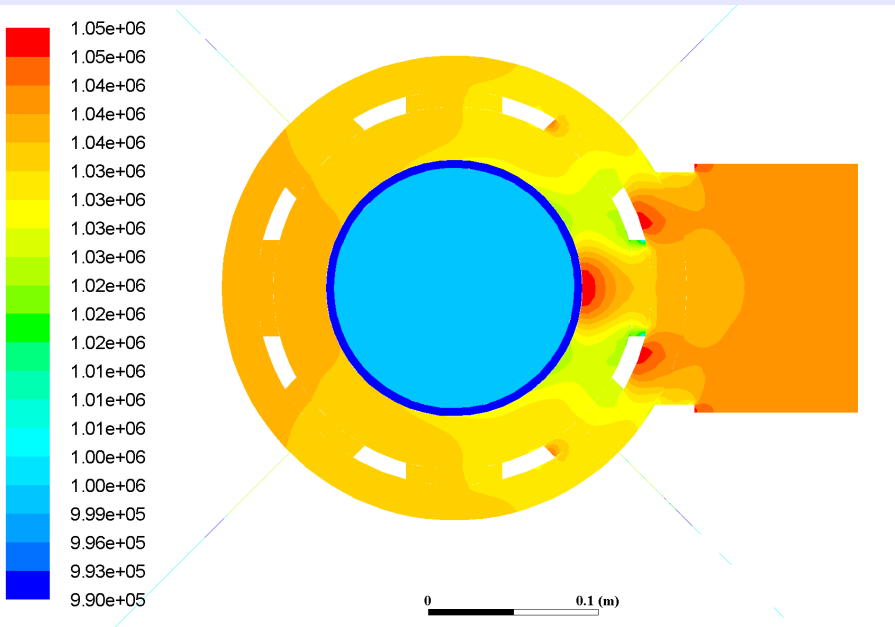
CFD and FEM complete model from Rotating Seal to wheel distributor



Shaft shielding

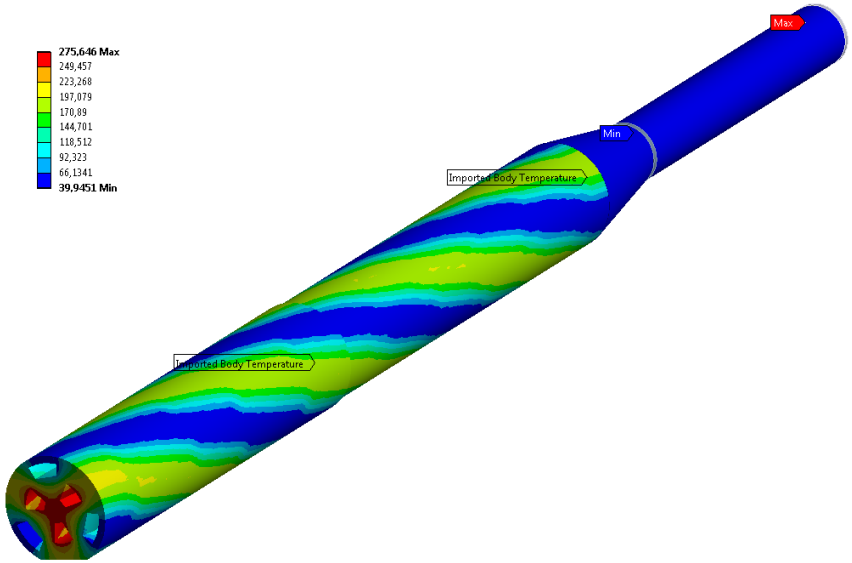
CFD and FEM complete model from Rotating Seal to wheel distributor

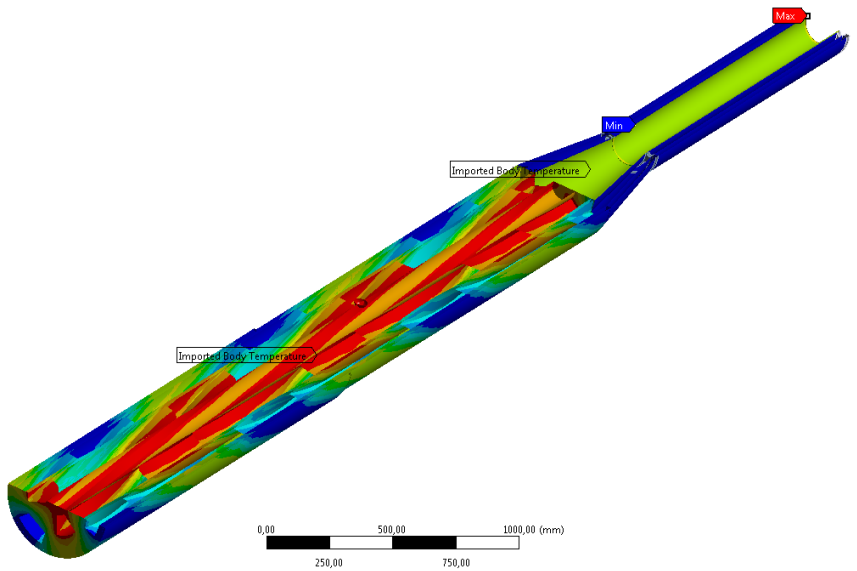




Shaft shielding

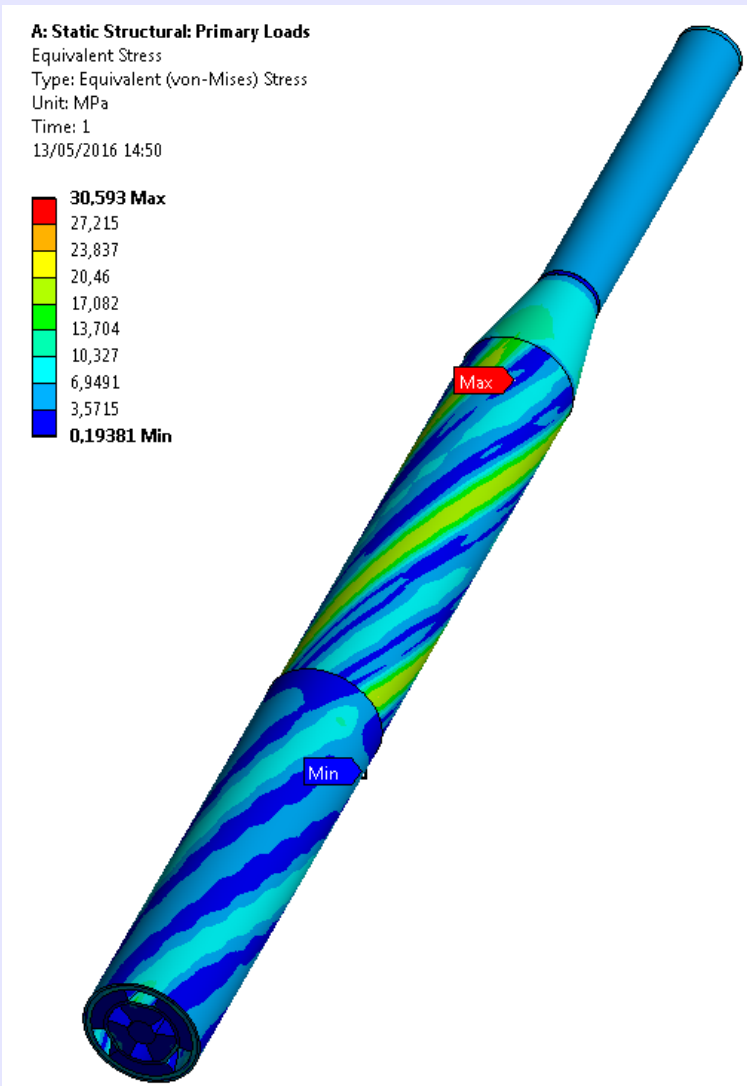
CFD and FEM complete model from Rotating Seal to wheel distributor

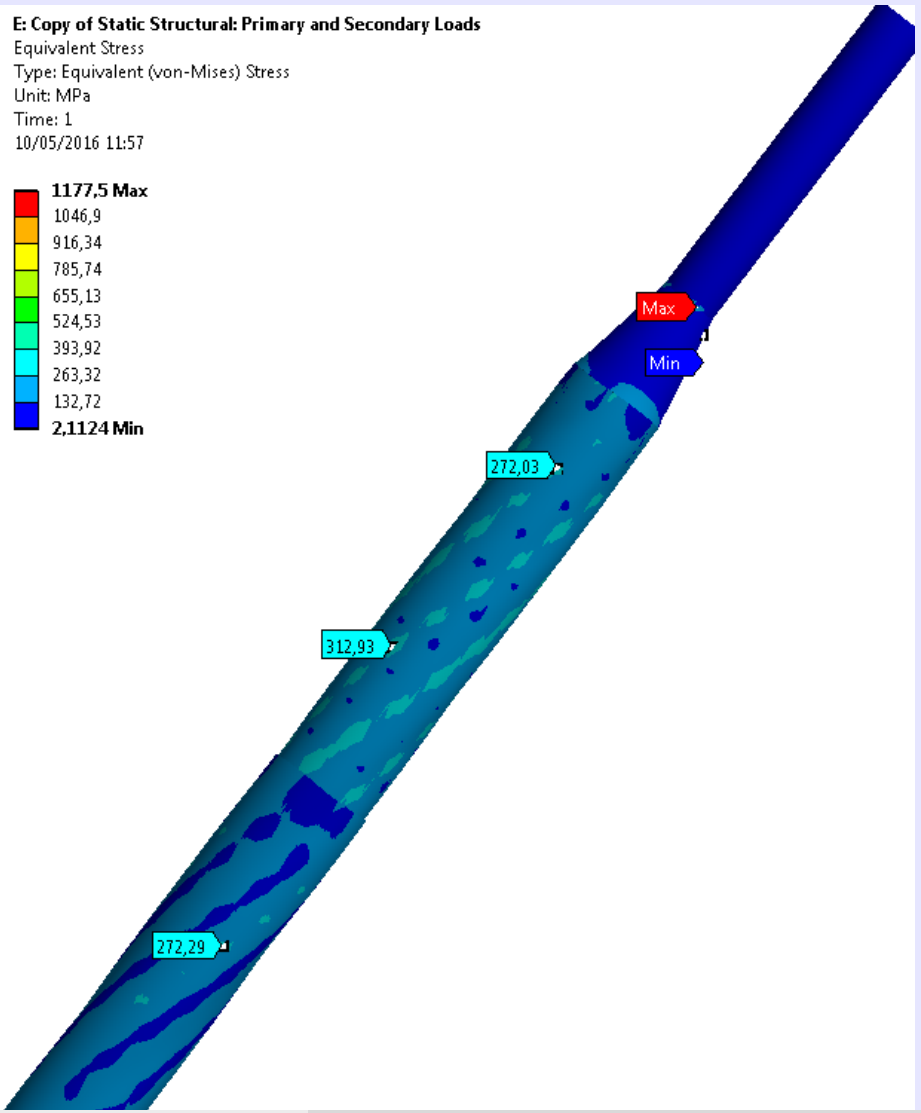




Shaft shielding

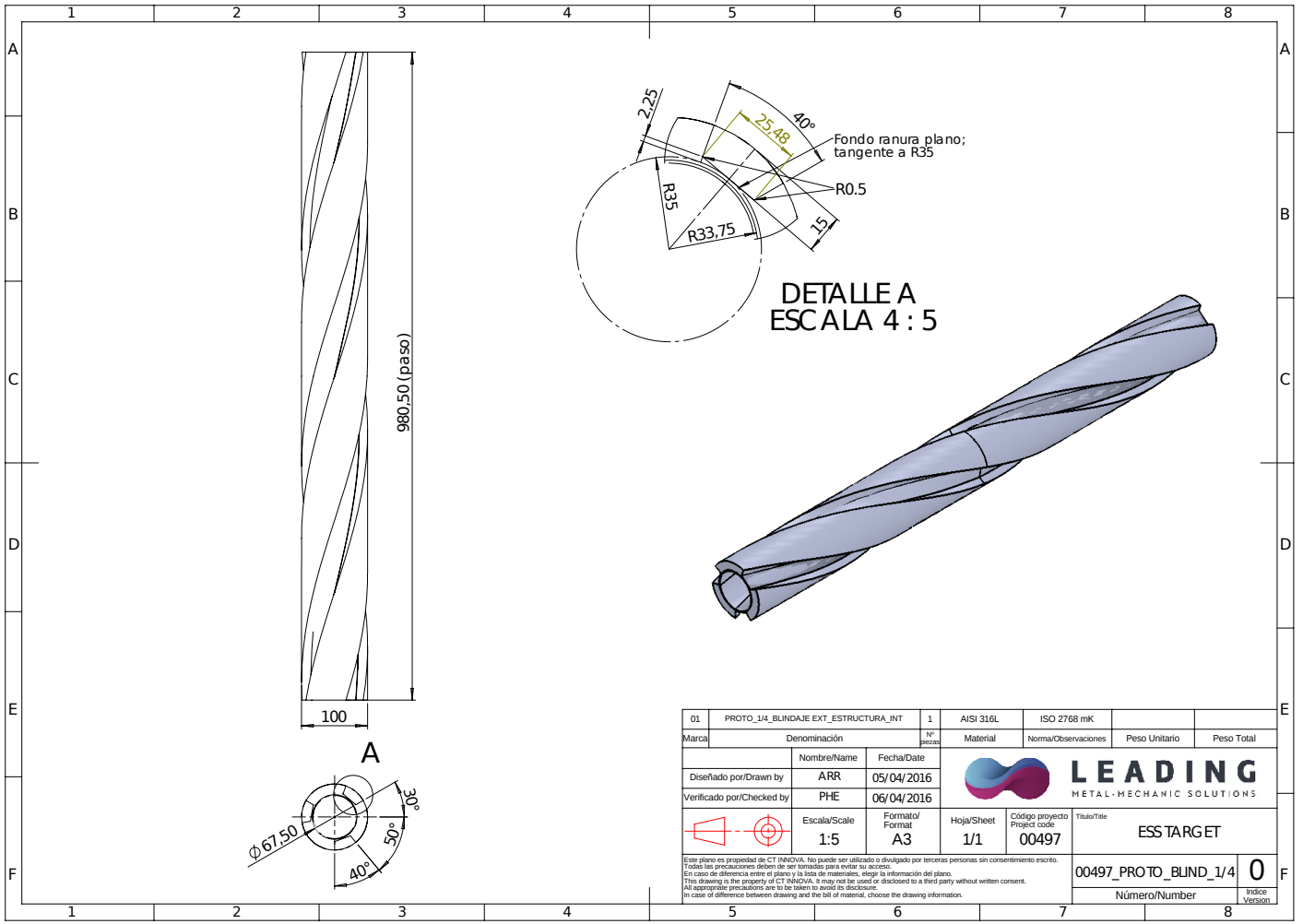
CFD and FEM complete model from Rotating Seal to wheel distributor





Shaft shielding

On going manufacturing prototype



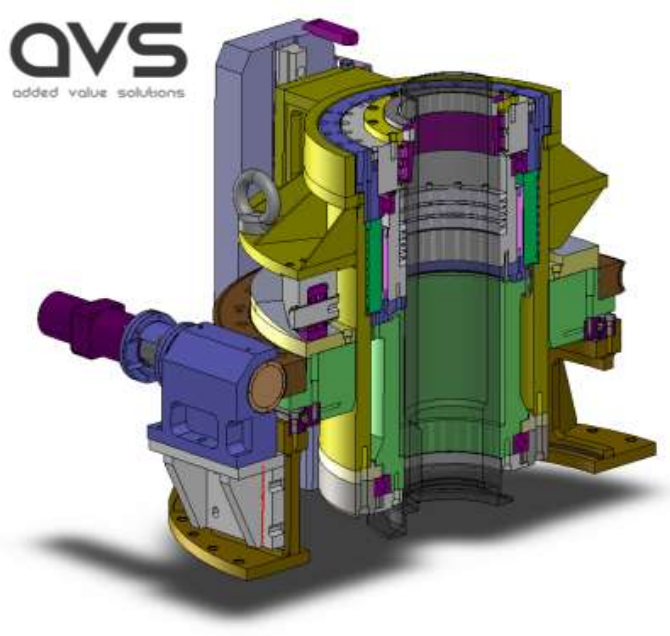
Drive Unit

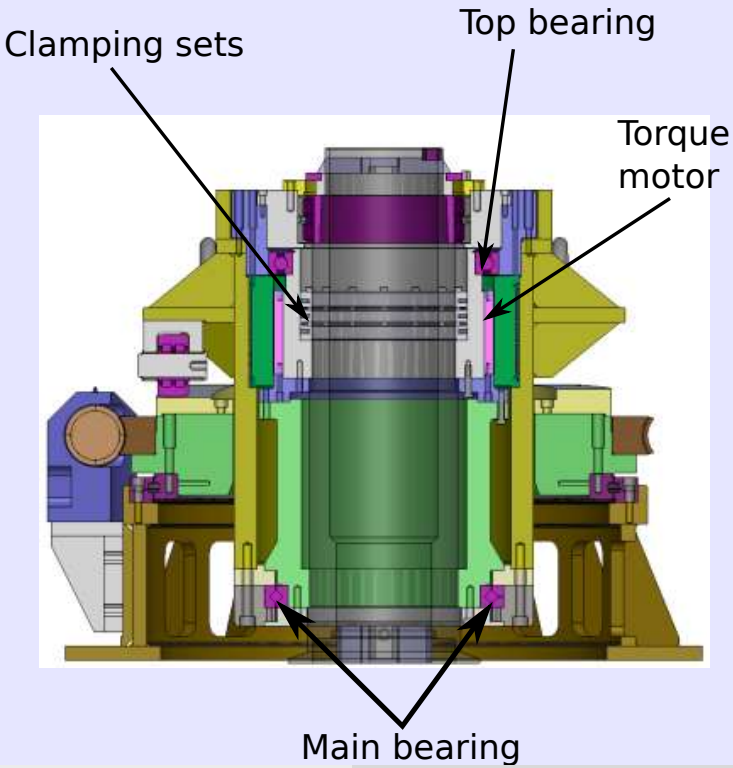
Drive Unit & Positioning system

Preliminary design

ESS-Bilbao awarded a contract to A.V.S. for the design of the drive unit. The main components definition has been completed, including definition of the main bearing system, clamping system and motor.

Drive Unit





Drive Unit & Positioning system

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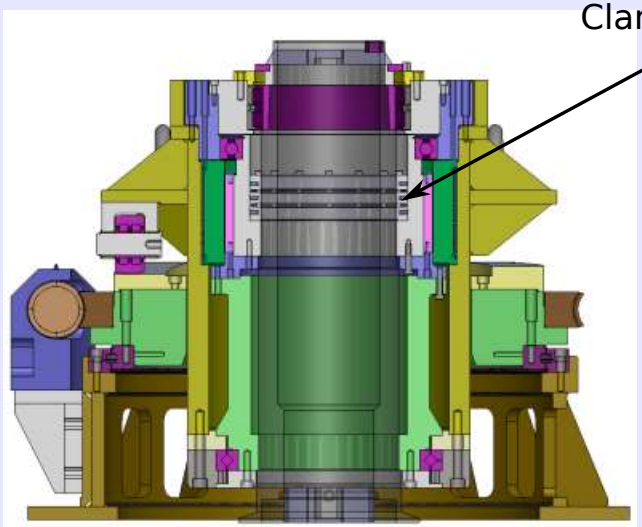
ESS-Bilbao awarded a contract to A.V.S. for the design of the drive unit. The main components definition has been completed, including definition of the main bearing system, clamping system and motor.

Drive Unit



Order No.	Dimensions in mm			Clamping screws				Transmittable forces		Moment of inertia J
	d_1	d_2	L	ISO	h	M_A	No.	M or F_a		
	H6	h5		4762	mm	Nm		Nm	N	kg cm²
DSL 300.350	300	350	102	M10	10	60	15	53500	356700	3360.000

Drive Unit & Positioning system

Preliminary design

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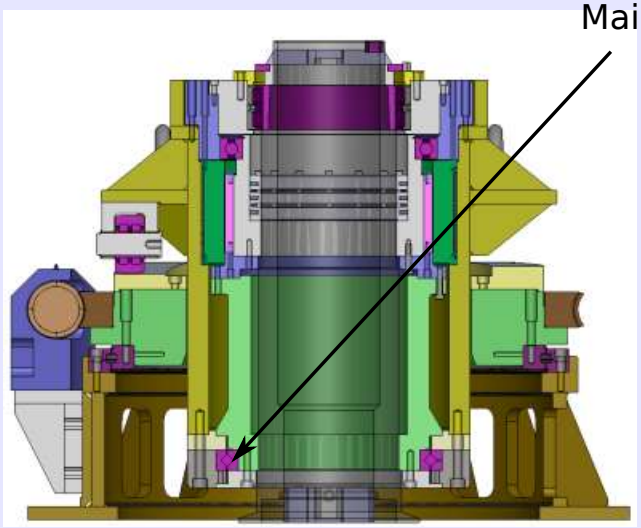
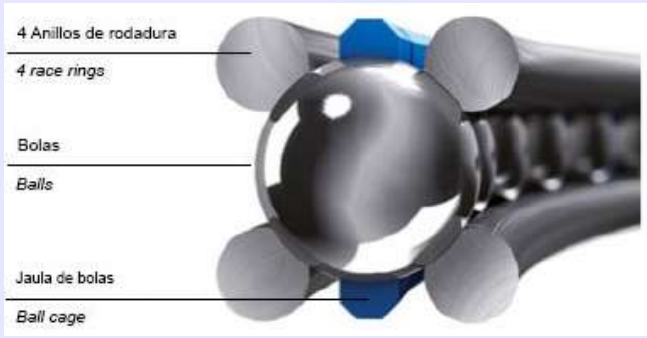
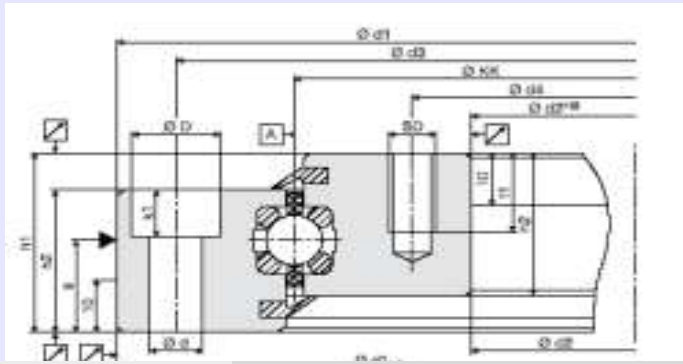
Drive Unit

Main Baring: Franke Bearing







Materials

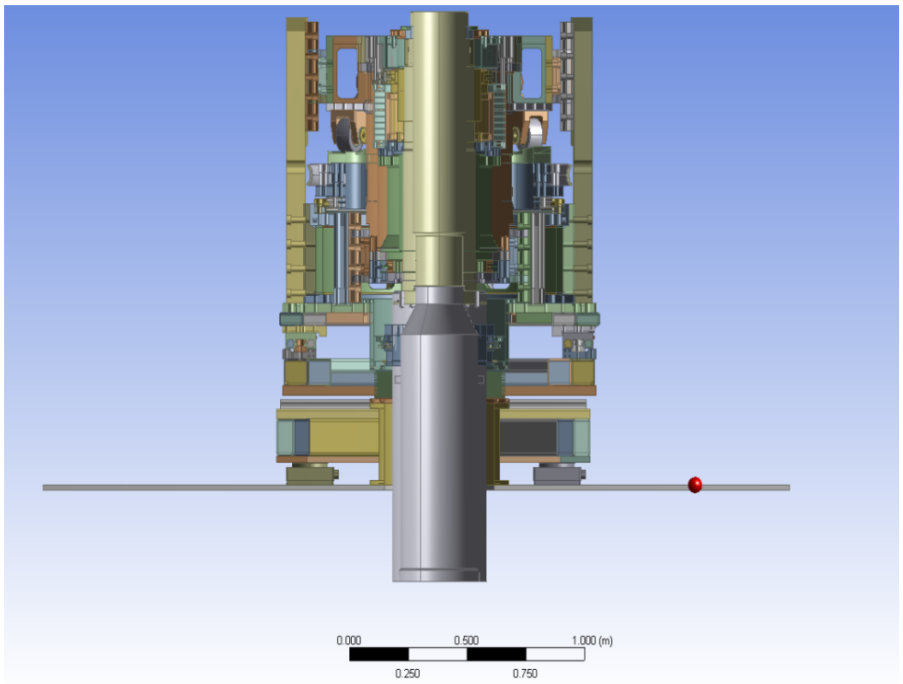
	Inner / Outer ring	Race ring	Balls	Cage	Seals
Standard	C45N	54SiCr6	100Cr6	PA12	NBR
Special	Niro X5CrNi18.10 Brass CuSn12 Plastic Magnesium Coatings	Niro X12CrNi177 Niro X7CrNi177 Duratherm Coating: Corrotect ATC	Niro X45Cr13 POM Ceramic Al_2O_3 Ceramic Si_3N_4	Non-corrosive Bronze Laminate Brass Teflon	Viton Teflon Labyrinth Metal seal

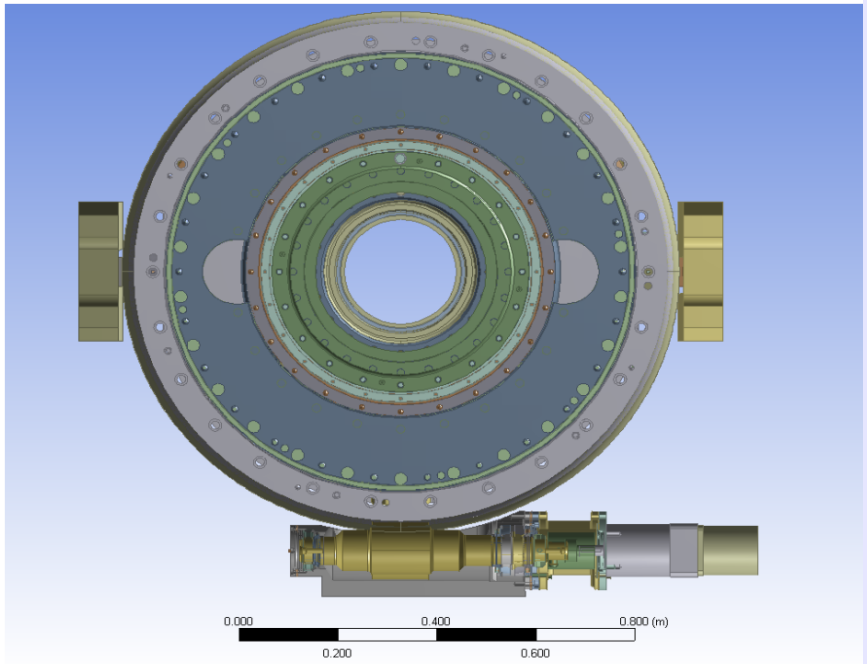
Drive Unit & Positioning system

Activation analysis

A complete damage and activation analysis has been performed to evaluate the life time and the handling operation of the drive unit.

Drive Unit mcnpx model





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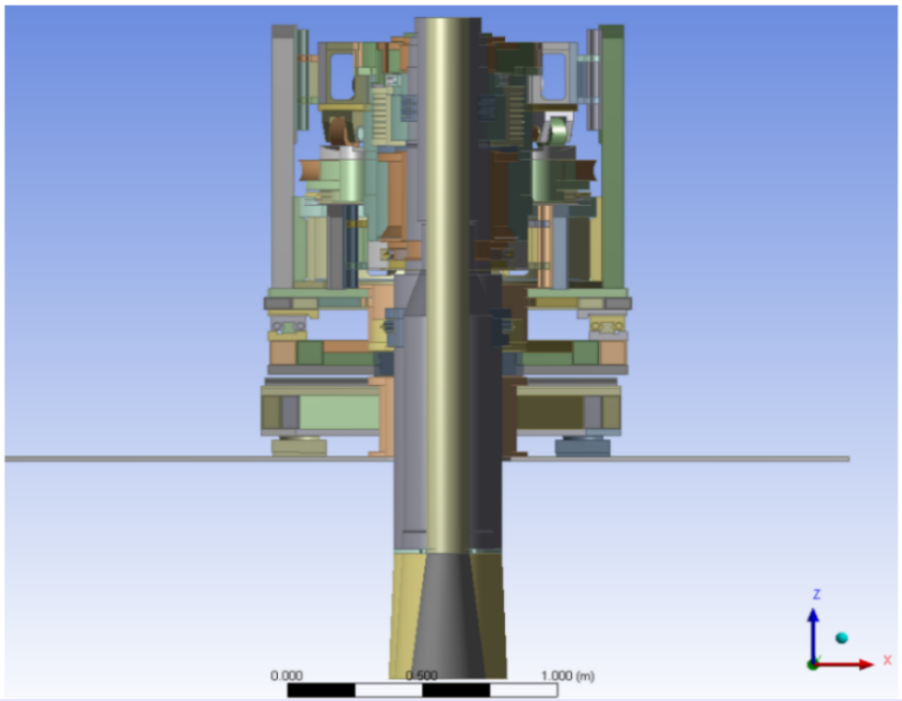
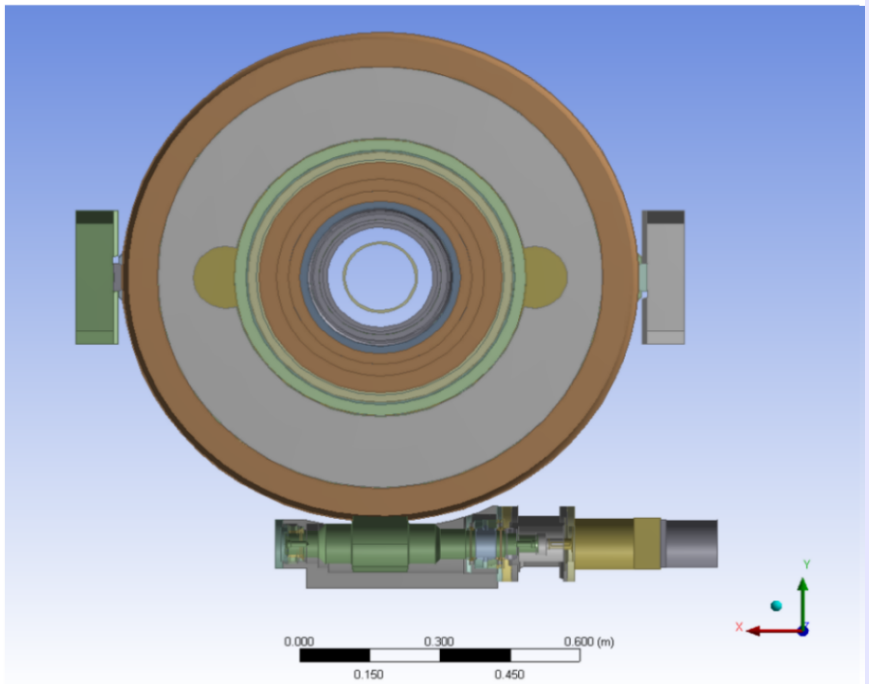


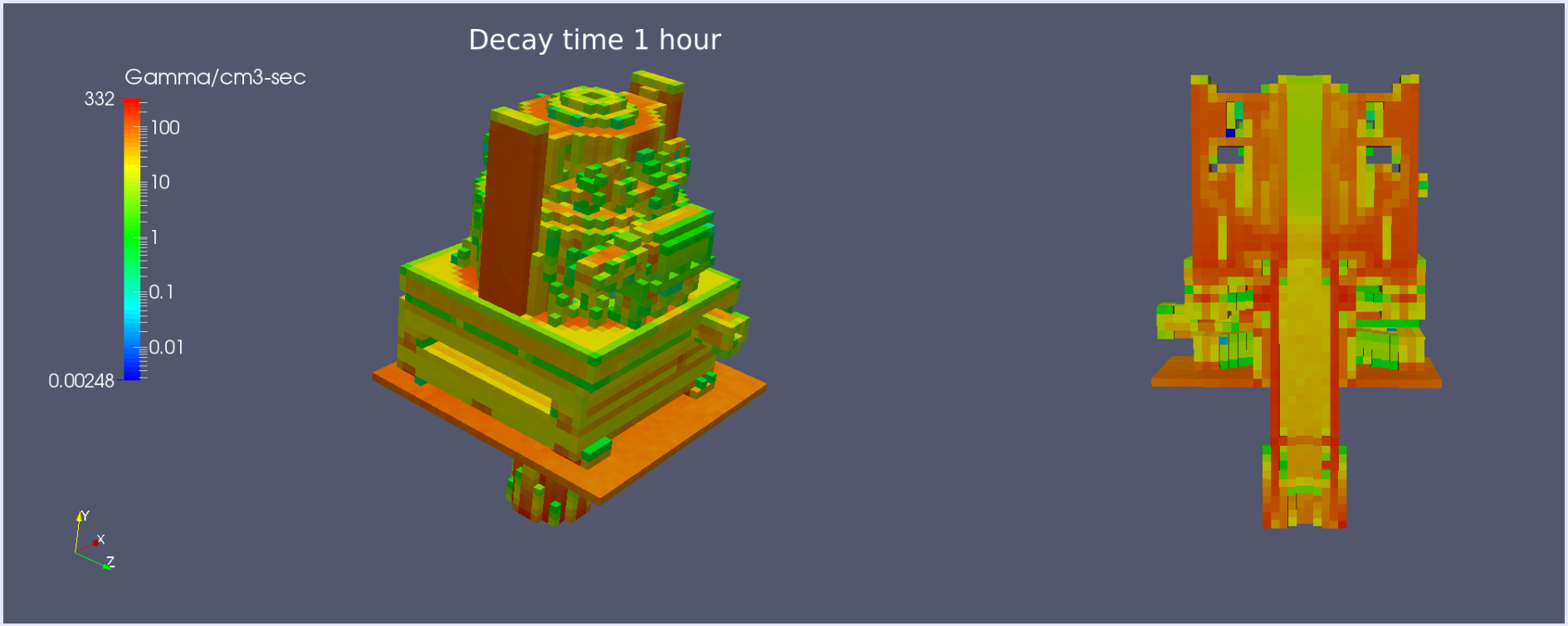


Drive Unit & Positioning system

Activation analysis

A complete damage and activation analysis has been performed to evaluate the life time and the handling operation of the drive unit.

Drive Unit decay radiation 1 hour after the shutdown



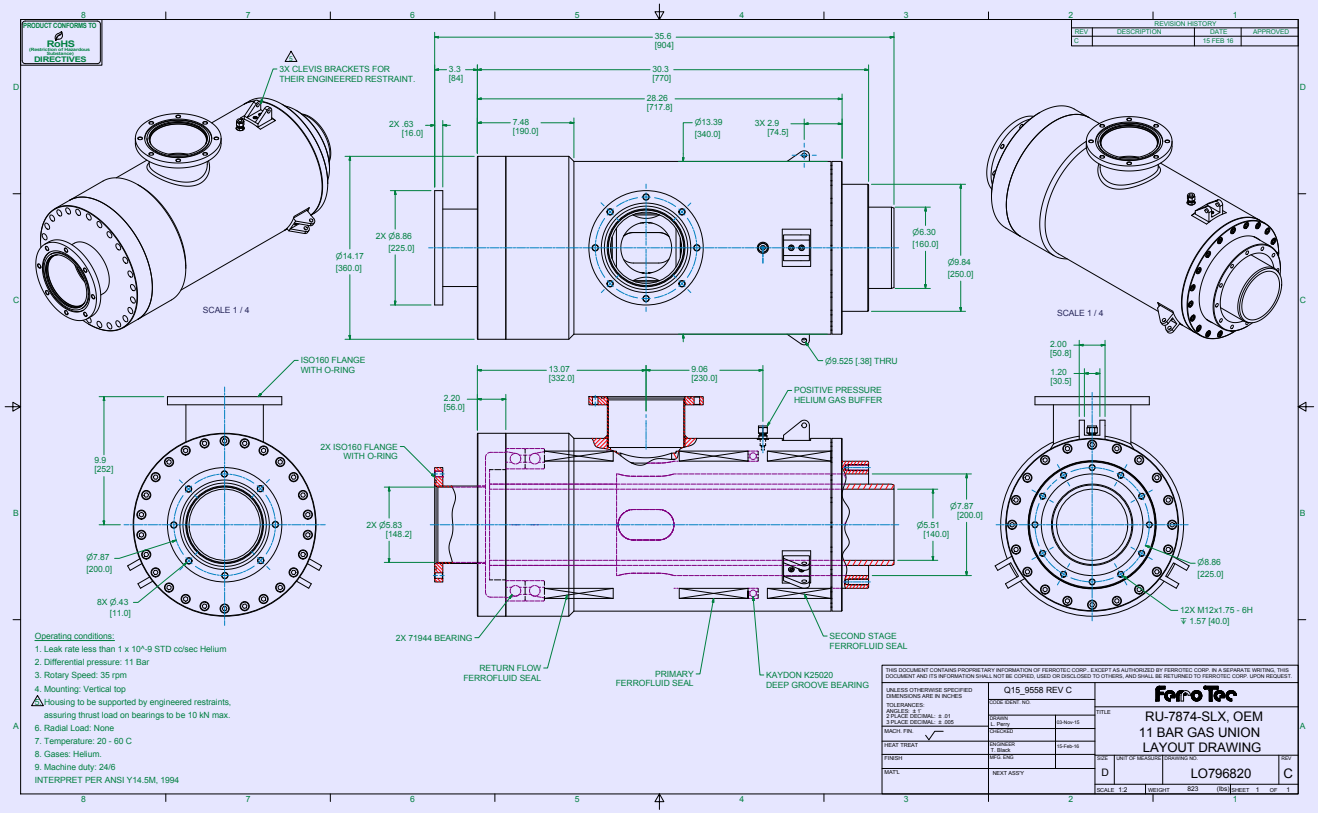
Rotating Seal

Rotating seal

Commercial product: Ferrofluid seal

The proposed seal is a commercial component which includes a double ferro-fluid seal. The manufacturer has measured helium leaks below $10^9 ccs^{-1}$

Positioning system



Conclusions

On going works

- The analysis of the Spalation Material is almost completed. The CDR is schedule by September.
- Internal structures are ready for the CDR, including full scale prototype.
- The manufacturing process for the target vessel is well advanced including the inspection process for the critical areas.
- Full scale prototype of the Target Vessel is on going.
- Conceptual designs has been completed for the drive unit and the rotating seal.