The ESS helium cooled rotating target

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

A. Aguilar, L. Mena, M. Mancisidor, I. Herranz,
R. Vivanco, M. Magán, G. Bakedano , T. Mora, J. Aguilar, P. Luna,
K. Sjogreen, U. Oden, F. Sordo, J.M. Perlado, J.L. Martínez

Oct. 30th - Nov. 4th, 2016

Table of contents

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.
- The collaboration between ESS-Bilbao and IFN started on 2009. ESS-bilbao Target division is working at IFN facilities in Madrid.
- On November 2014, ESS-Bilbao was chosen as ESS partner for Target Wheel, shaft and drive unit.
- On December 2014, ESS-Bilbao was chosen as ESS partner for TBD, Proton Beam Entrance Window and Monolith Vessel.
- On October 2015, and International Panel Chair by Matt Fletcher evaluate the Target Base Line with positive feedback.
- On Semtember 2016, Critical design review for the Spallation Material and the Cassettes.

ESS-Bilbao involvement on ESS target projec

ESS-Bilbao Workpackages

The total budget for ESS Target station is ∼ 150 M€. ESS-BILBAO Consortium has been chosen as ESS partner for ∼ 12-16 % of the Target Station project.

Work Package	KO meeting	Delivering date
Target Wheel & Shaft & Drive Unit	Jan-2015	Apr-2019
Proton beam entrance window	Apr-2015	Feb-2018
Tunning beam dump	Apr-2015	Feb-2018
Monolith vessel	Jun-2015	Feb-2018
Beam Instrumentation plug	—	Oct-2018
Neutron Beam Windows	–	Oct-2018
TOTAL	**17.9 M€**	

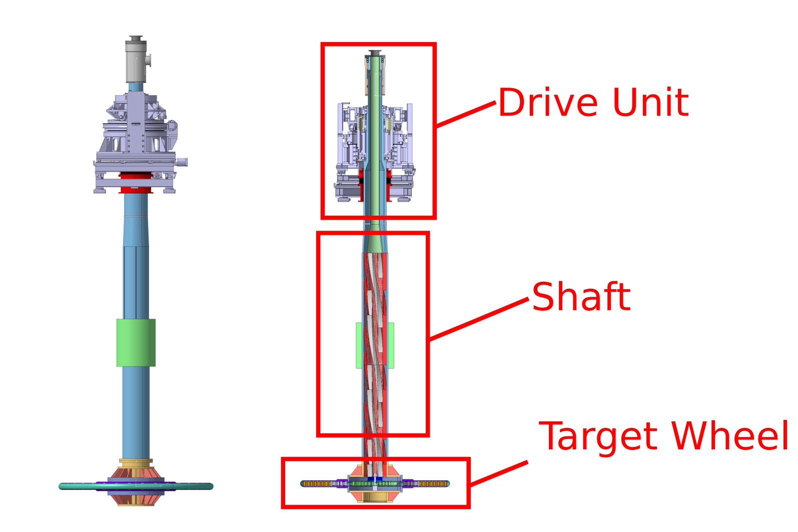
Introduction: ESS-Bilbao Target Workpackages

Target & Shaft & Drive Unit

- Spallation Material: Hot Rolled W
- Internal Structures and shielding: SS-316L
- Target Vessel and shaft: SS-316L
- Beam Power: 5 MW
- Max Proton Energy: 2 GeV
- Life Time: 5 years
- Coolant: helium
- Helium Pressure: 10 bar
- Helium flow mas: 3 kgs^{-1}
- RCC-MRx Class 2 Component
- Life time 5 years

Introduction: ESS-Bilbao Target Workpackages

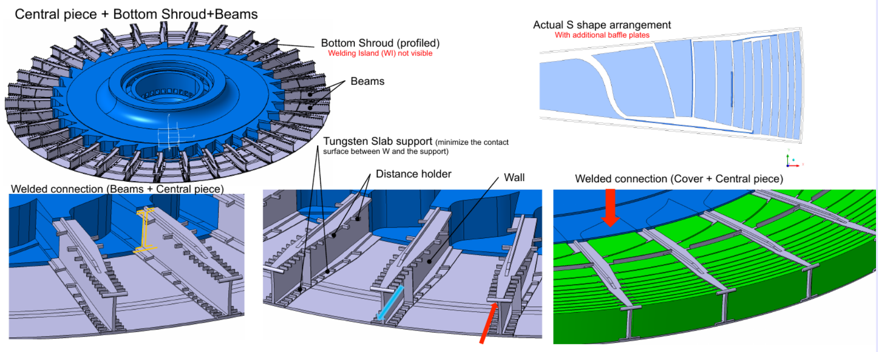
Target, shaft and Drive Unit



Target Wheel

Introduction:

TDR proposal (2013)

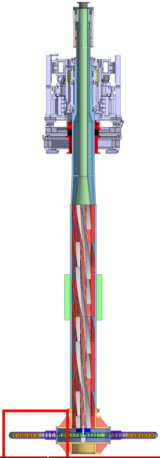


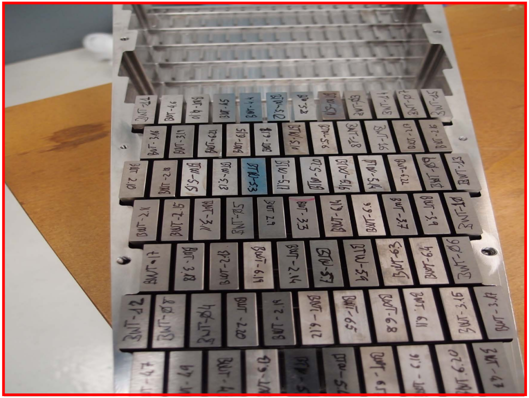
ESS-Bilbao target proposal

On January 2015, we propose a new configuration for the flow patron and the spallation material. It was accepted by ESS in the KO meeting.

Introduction: ESS-Bilbao Target Workpackages

The Spallation material is composed by $\sim$ 7000 80x30x10 mm^3 bricks on cross flow configuration

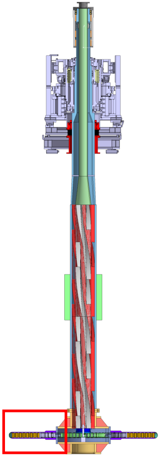


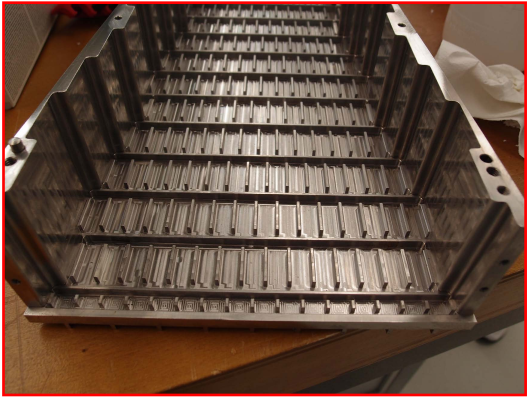


Spallation Material

Introduction: ESS-Bilbao Target Workpackages

The bricks are assembled in a SS-316L Cassette with groves drilled on it





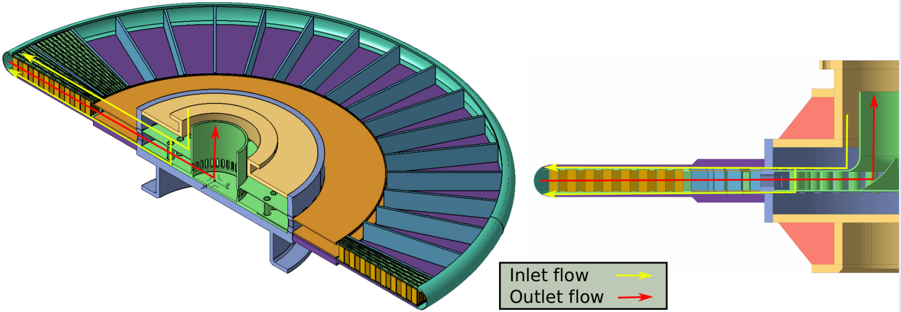
Internal structures (SS-316L)

Target Wheel base line

Target Vessel

The Target Wheel is composed by 36 “semi-targets” (cassette + spallation material) assembled in a wheel. Helium is introduced by a coaxial pipe and circulates through several open volumes to guaranty and homogeneous inlet pressure in from of the cassette.

Selection process

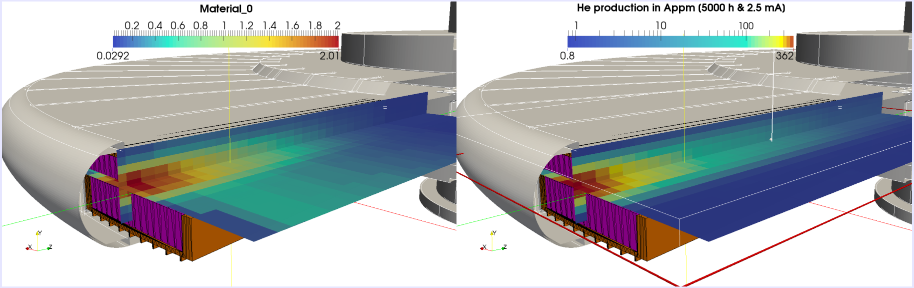


Spallation material: Irradiation Damage

Proton & neutron damage on W

Taking into account both types of particles, the maximum damage after 5 years of full power operation is $\sim$ 10 dpa with $\sim$ 360 appm of hellium and 1600 of hidrogen. Based on this values, the W will be brittle after $\sim$ 2 months of operation.

Neutron induced radiation damage [5000 h & 2.5 mA]

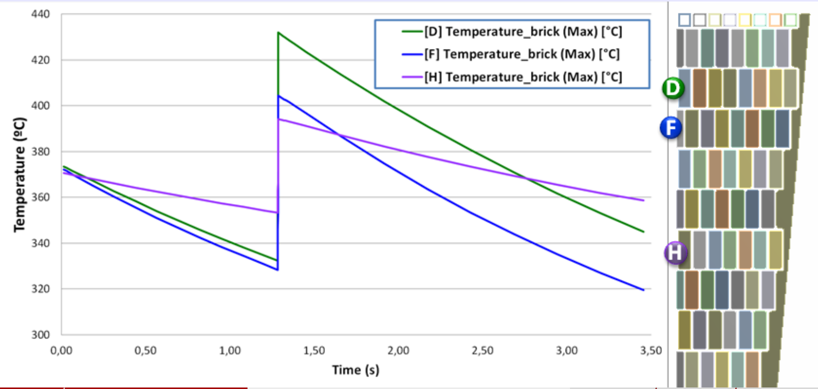


Spallation material: Thermomechanical analysis

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

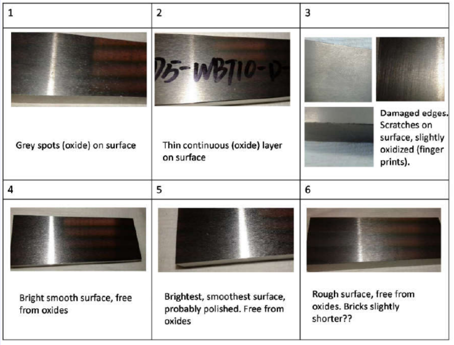


Spallation material: Quality evaluation

Evaluation of different suppliers

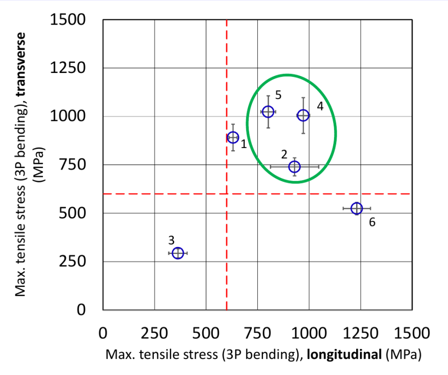
Taking into account the large differences on W grades, ESS-Bilbao is developing its own QA process to accept "W Suppliers" in the official "Call for tender process". Samples from 6 suppliers are under analysis at CEIT. This task will be completed in the next month and the data included in the CDR for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

QA analysis on going at CEIT



Spallation material: Quality evaluation

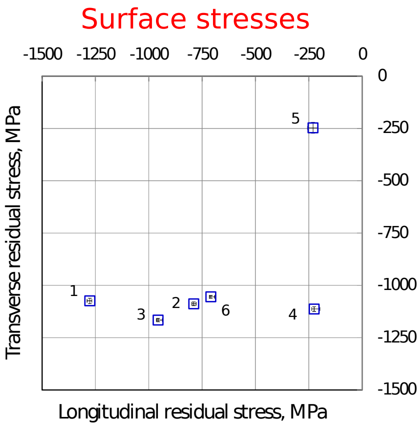
QA analysis on going at CEIT



W supplier	Visual inspection	Density, ρ (g cm^{-3}) Geom. ± assoc. error	Density, ρ (g cm^{-3}) Water displ. ± sd	E, Young modulus RPN (GPa) ± assoc. error	HV (1 kg) RP (kg mm^{-2}) ± 95% cl	Res. stresses, surface (MPa) ± sd σ_{11} (LD)	Res. stresses, surface (MPa) ± sd σ_{22} (TD)	Fractography	Chemical composition Impurities above threshold
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 stage 1

Surface stresses and diffraction peaks



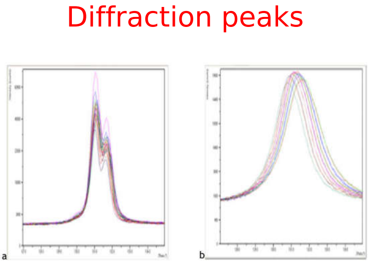


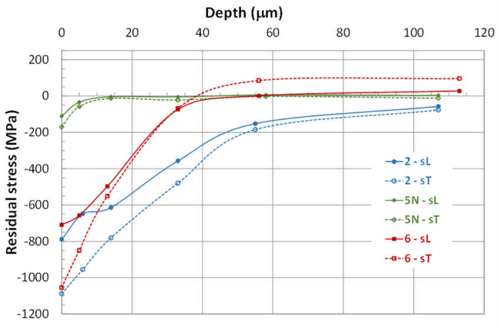
Figure 3. X-rays (321) diffraction peaks, samples 5 (a) and 2 (b).

Spallation material: Quality evaluation stage 2

In the second stage 2 suppliers shows optimal properties for our application

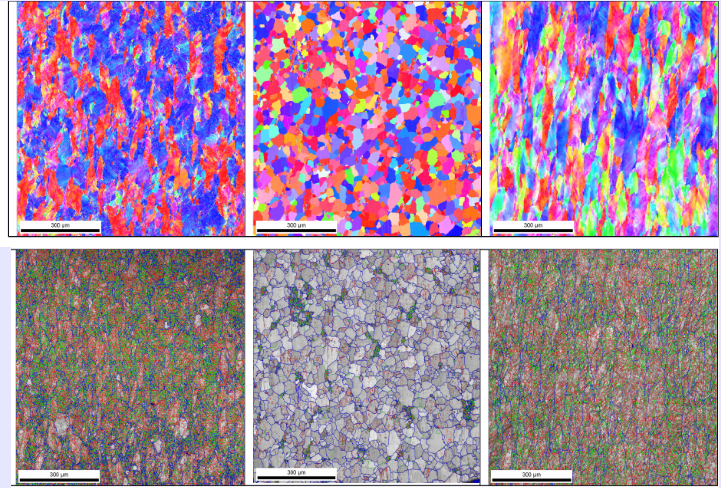
- Bricks 2 & 6: strong level of sub-surface biaxial compressive stresses up to resp. 30 and 50 mm
- Brick 5N: weak compressive surface stress up to less than 10 mm

Surface residual stresses



Spallation material: Quality evaluation

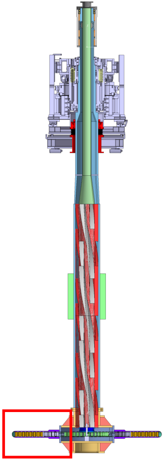
QA analysis on going at CEIT



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

Introduction: ESS-Bilbao Target Workpackages

Target, shaft and Drive Unit



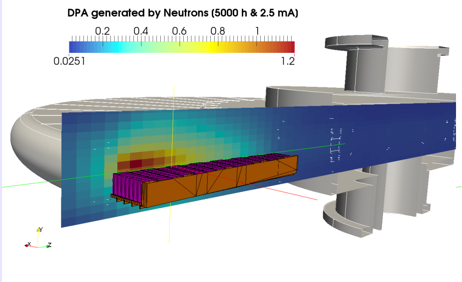
Target Wheel Vessel (SS-316L)

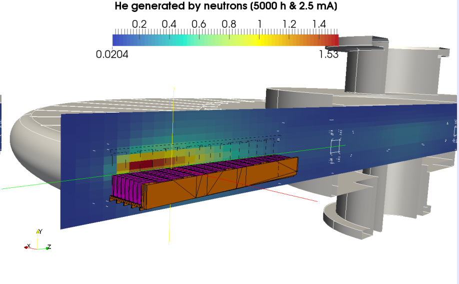
Target Vessel: Irradiation Damage

Neutron damage

Far from the proton beam window, the damage is mainly produced by neutrons. The maximum value, produced in the rib in between sectors the damage is $\sim$ 1.2 dpa and 1.6 appm of helium per year. After 5 years of operation the total damage is below 6 dpa with a gas accumulation below 9-10 appm of Helium.

Neutron induced radiation damage [5000 h & 2.5 mA]



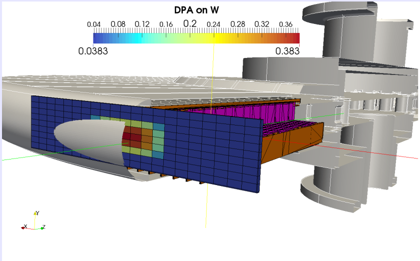


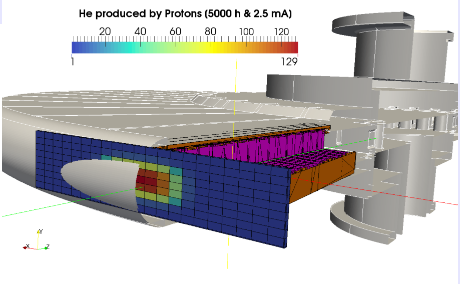
Proton beam window: Irradiation Damage

Neutron damage

On the proton beam window, the damage is mainly produced by protons. The maximum value, produced in the window is ∼ 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]



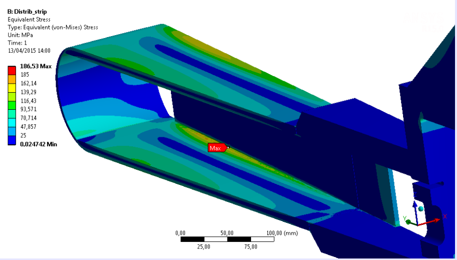


Target Vessel

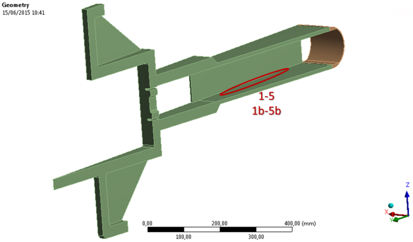
Mechanical analysis based on RCC-MRx

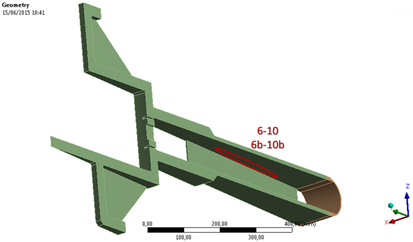
The Target vessel is considered as a Class 2 component (RCC-MRx). Based on that the mechanical analysis of the vessel has been completed including fatigue and welding analysis.

CFD analysis conditions



Target Vessel:Linearized analysis results





Rib zone results. Elastic analysis

- 20.5 MPa $(P_L) \leq$ 190.5 MPa $1.5 * S_m(100^o C)$
- 179 MPa $(P_L + P_b) \leq$ 190.5 MPa $(1.5 * S_m(100^o C))$
- 236.3 MPa $(P_L + Q) \leq$ 3711 MPa $(S^A_{em}(100^o C, 2.75 dpa))$
- 228.2 MPa $(P_L + P_b + Q + F) \leq$ 6371 MPa $(S^A_{et}(100^o C, 2.75 dpa))$

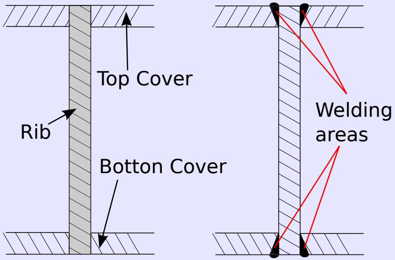
Target Vessel: Welding analysis

Welding analysis

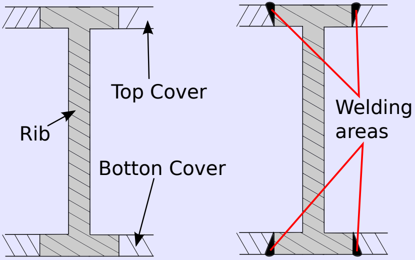
The welding regions has been agreed with manufactures and reviewed based on the RCC-Mrx criteria. Full penetration, volumetric inspections and one face surface inspections are need for the ribs. The stress values in the beam entrance window are much lower and only surface inspection will be needed.

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)

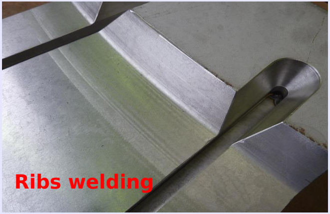


Target Vessel: Welding prototype

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

Alternative 1 prototype

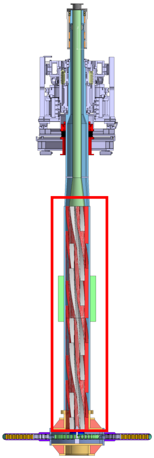
To evaluate the welding procedures and inspection a prototype based on Alternative 1 has been completed including all the inspection procedures considered on RCC-MRx system (RES and RAD) on the rib position and the window.

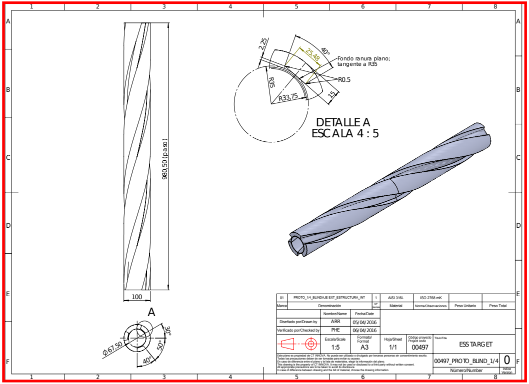
Manufacturing and inspections

Target Shaft

Target Shaft

Target, shaft and Drive Unit





Internal Shielding (SS-316L)

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

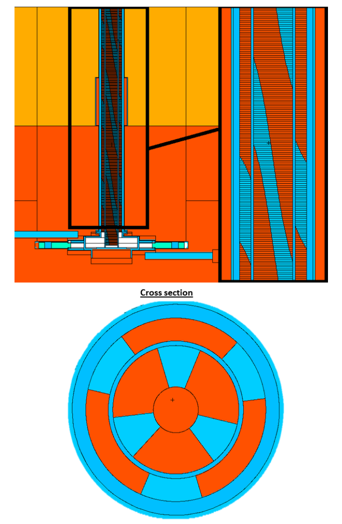
The configuration of the helium channels inside the shielding drives the pressure drop of the shaft. Several options are under evaluation in order to minimize the pressure drop and manufacturing requirements.

CFD-MCNPX optimization loop

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

Shaft shielding

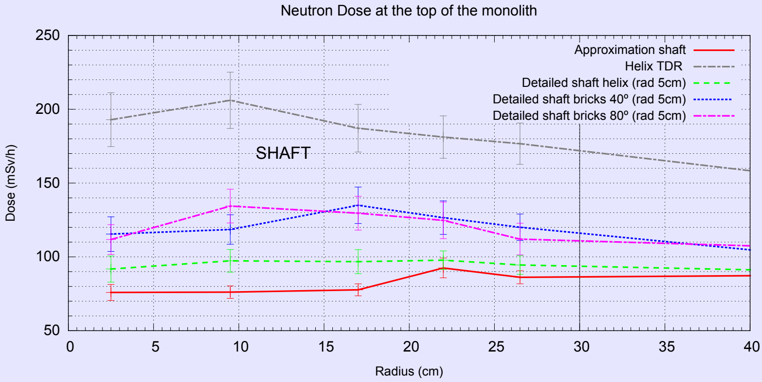
Shaft CFD-MCNPX analysis



- 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

Dose rate on top of the monolith for several shaft internal shielding configurations

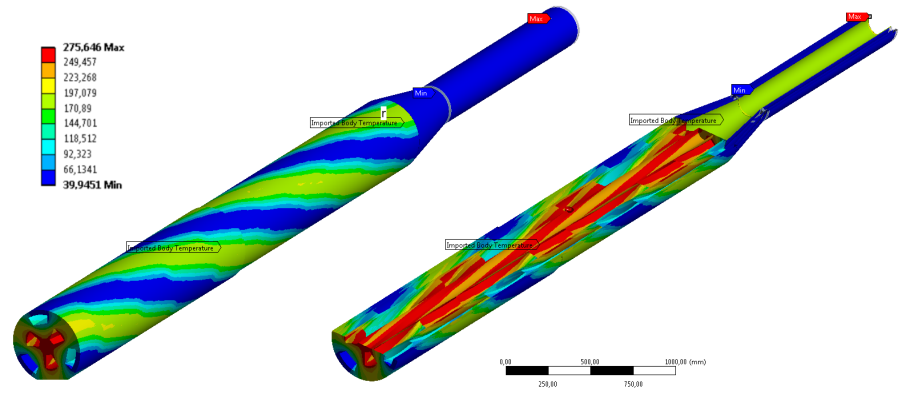


Shaft shielding

Thermomechanical analysis

Temperature distribution shows significant gradients associated to helium flow. However, primary and secondary loads are far below $RCC - MR_x$ mechanical limits.

Temperature distribution



Shaft shielding

Manufacturing prototype for Shaft internal shielding

- Manufacturing of the internal shielding "spiral channels" shows significant risk in the assembling process.
- 1:5 prototype has been completed to evaluate manufacturing tolerances. No significant deviation has been observed.

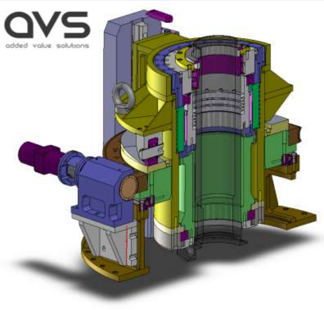
Drive Unit

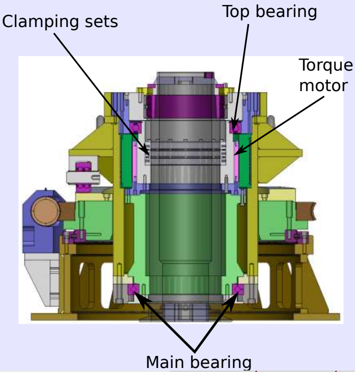
Drive Unit & Positioning system

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





Conclusions

Conclusions

Main remarks for lower and medium vessel

- KO meeting in January 2015.
- Iternational review pannel in October 2015.
- CDR for the spallation material and cassettes completed (September 28^{th})
- Full scale prototype for Target Vessel will be completed by January 2017.
- Manufacturing will start in November 2017 (Contact award for Cassette series)
- Up to November 2016, the target project is on schedule.