Simulation process for ESS Helium Cooled rotating Target

Consorcio ESS-BILBAO & European Spallation Source ERIC

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06 April 2021

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Introduction

Introduction

ESS project

ESS is an going project to build a 5 MW spallation soure in Lund (Sweden) with a total budget $\sim 1800 M e$. There is 17 Eu countries that take part in the project. Spain contributes with 3% of the total construction cost total construction cost.

ESS construction site (View in January 2021)

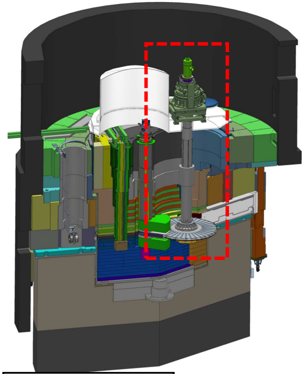
ESS-BILBAO Consortium

Role and functions

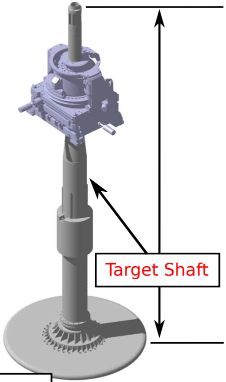
- ESS-Bilbao is public consortium between Spanish Central Government and regional goverment of Vase Country region.
- ESS-BILBAO has been nominated as Spanish representing entity for ESS operational phase.
- Staff of 50 scientists & engineers.
- The collaboration between ESS-Bilbao and IFN started on 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 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.
- Target Vessel prototyping activities were completed between 2017 and 2018.
- Target Vessel CDR completed on July 2019.
- Manufacturing of Target Vessel and shaft is on going. We expect to deliver the Target in Summer 2021.

Introduction

ESS Target system on ESS target station



ESS Target Station



Target system

Challenges for ESS Target

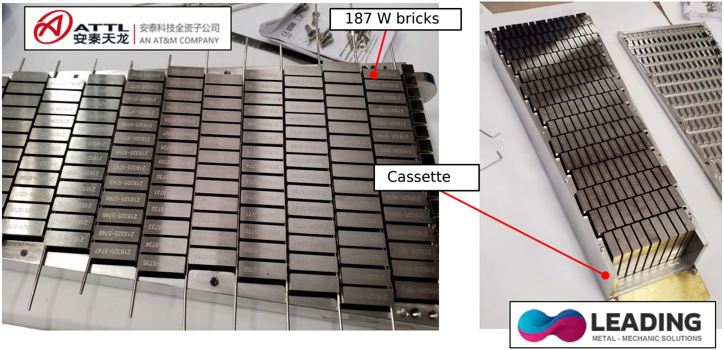
- 5 MW target
- Helium cooled
- Rotating device
- 125 000 h.MW life time
- Safety related equipment
- RCC-MR_x N2Rx
- 8 m hight
- 17000 kg mass

Introduction

Spallation material

The spallation material is composed by 10x30x80 mm tungsten bricks (manufacturer by ATTL). The bricks are assembled in an stainless steel structure (Cassette, manufactured by Leading) in cross flow configuration. The cooling channels are configured by the apace in between bricks.

Cassette Assembling

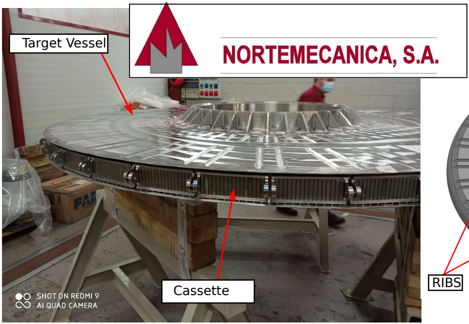


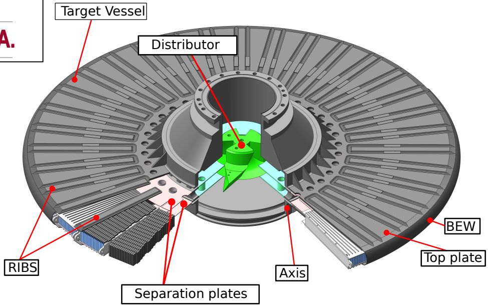
Introduction

Target Vessel

The 36 cassettes are assembled in stainless steel vessel (manufactured by Nortemecanica). The Target Vessel includes the internal structures that distribute the helium flow from the target shafts to the cassettes.

Target Vessel



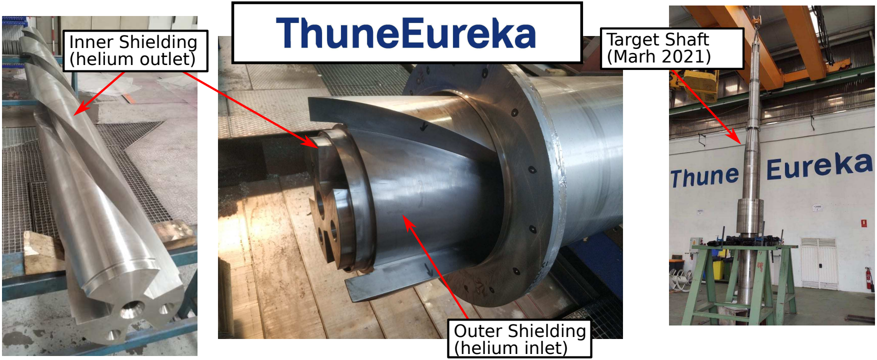


Introduction

Target Shaft

The Target Shaft is a coaxial pipe that guides the helium flow to the Target Vessel (manufactured by Thuneureka). It includes helical shielding to stop neutrons optimizing the helium pressure drop.

Target Shaft



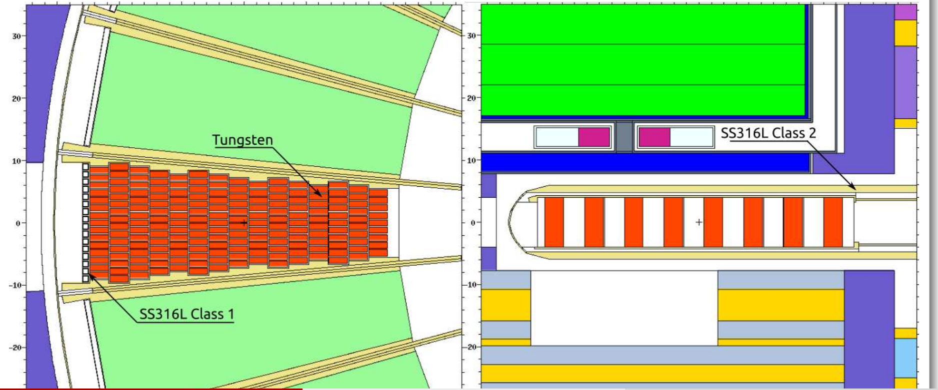
Particle transport model

Particle transport model

Geometrical model for particle transport analysis

The MCNP6 model has been created with SuperMC in order to reproduce complete the Target CAD geometry. Only the Cassette in from of the beam is complete detailed (“active cassette”). The other 35 are approximated by a homogeneous media.

MCNP6 model

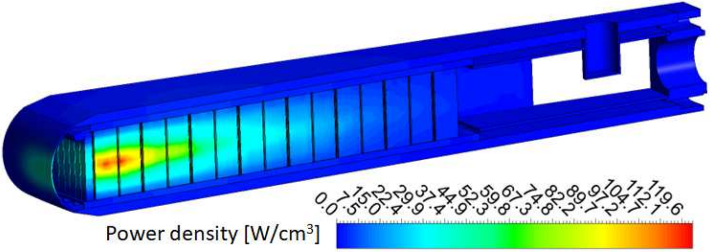


Particle transport model

Heat load

Two heat sources has been introduced in the thermal model: active source and passive source. The active source is given when the cassette is facing the beam and the passive source is the average of the remaining 35 positions.

Time averaged power density load profile



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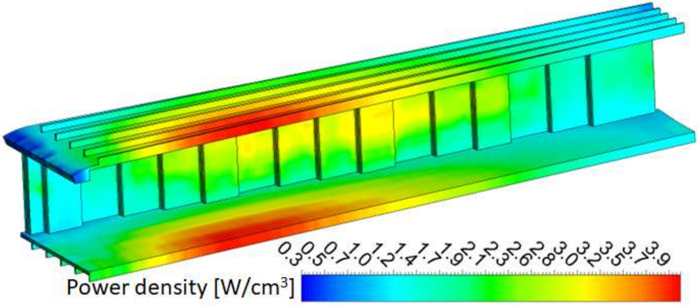


Particle transport model

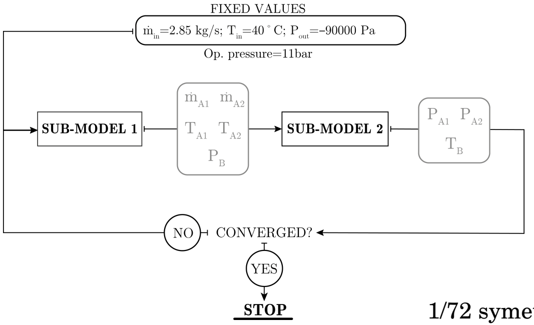
Heat deposition exchange form MCNP to CFD model

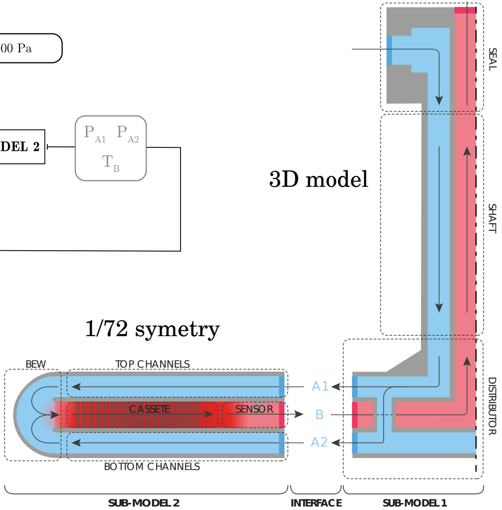
		Max Power Density (t-aver) (W/cm3)		Power deposition (t-aver) (kW)	
Id	**Zones**	MCNP	CFD	MCNP	CFD
A	Tungsten	128.4	126.0	2704.0	2678.3
B	BEW	36.8	39.5	12.9	12.7
C	Cassette_down	3.2	4.0	24.1	24.1
D	Cassette_side	2.5	3.4	48.3	48.6
E	Cassette_up	3.0	4.0	25.1	25.2
G	Shroud_up	3.6	2.8	68.5	67.7
H	Shroud_down	2.5	2.4	58.1	58.3
F	Ribs	3.4	2.9	34.0	33.8
I1	Cylinder	0.9	0.9	-	5.5
K	Separators	1.0	0.9	4.7	4.7
R	Dummies	42.1	38.4	-	17.4
			TOTAL	2975	2976

Thermal analysis

Thermal analysis

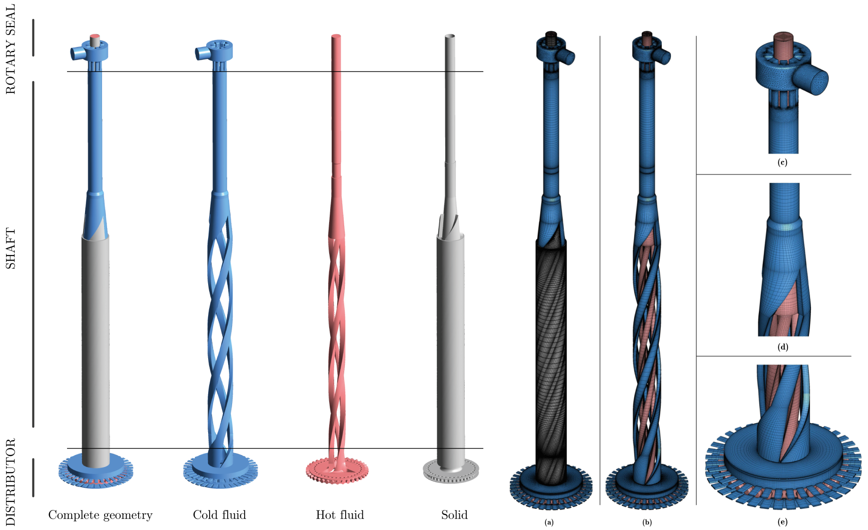
Target CFD submodeling scheme





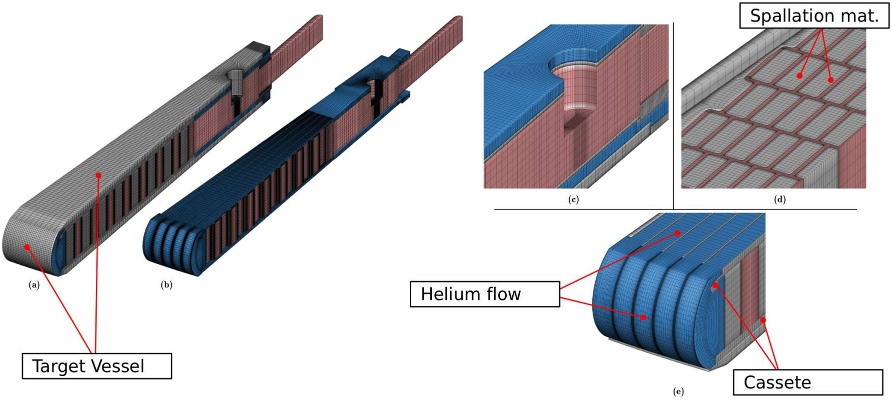
Thermal analysis

Submodel 1: Target Shaft, complete 3D model of Shaft and distributor area



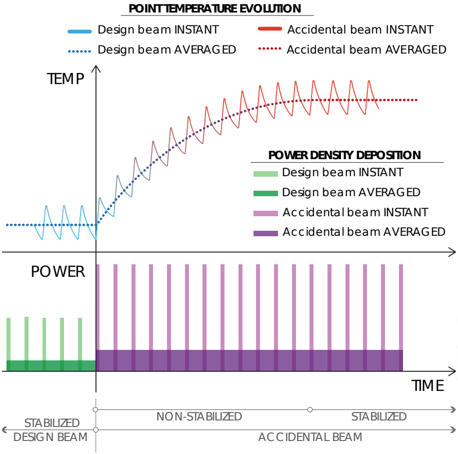
Thermal analysis

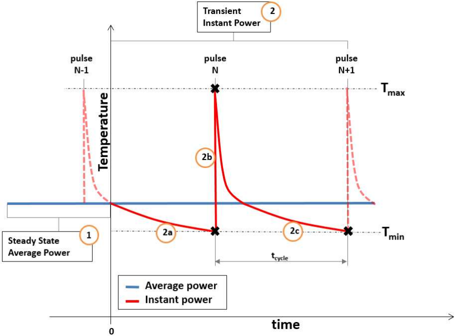
Submodel 2: Spallation material, Cassette and vessel. Symmetry 1/72



Thermal analysis

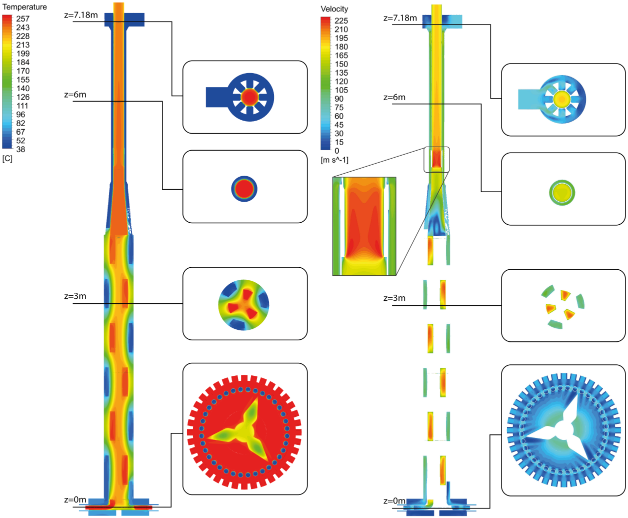
Target Transients, pulses and time average heat loads on submodel 2





Thermal analysis

Submodel 1: Target Shaft temperature and helium velocity

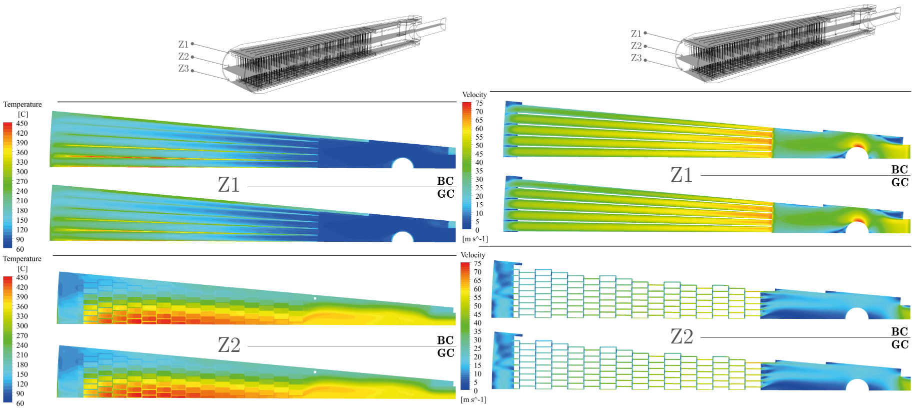


Thermal analysis

Submodel 2: Target vessel

Time average temperature for normal operational conditions shows maximum T in the W lower than 500^{o}C. Velocity of the helium between the bricks will be lower than 100 m/s.

Time average Temperature and velocity



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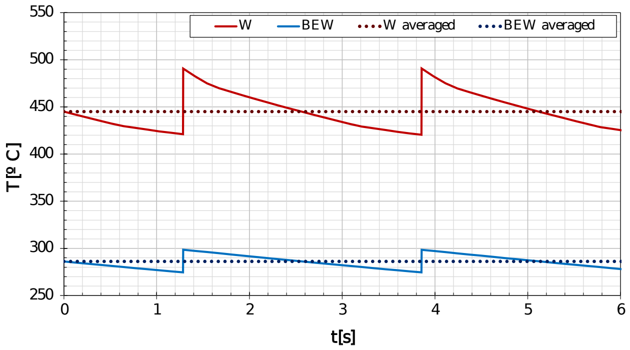


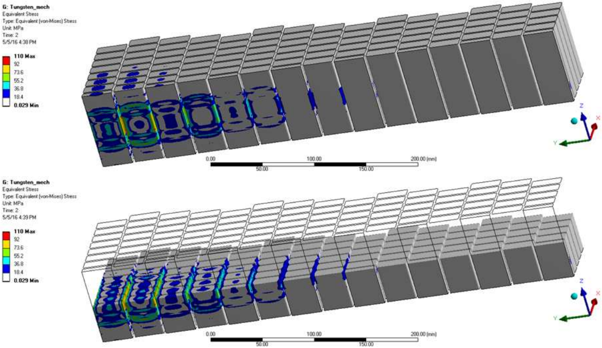
Mechanical analysis

Mechanical analysis

Submodel 1: Spallation material

Spallation material temperature is evaluated as not constrained blocks. Thermal stress levels are far below 100 MPa.

Spallation Material and Vessel

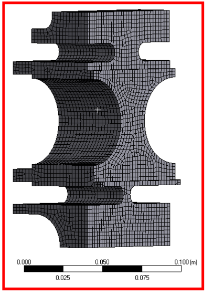


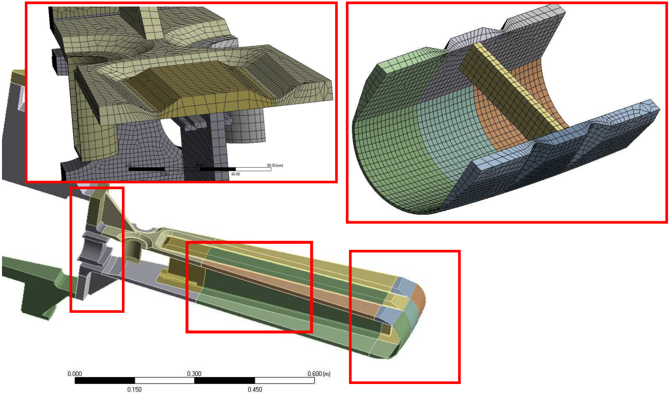
Mechanical analysis

Submodel 1: Vessel

Target Vessel is evaluated according to RCC-MRx nuclear equipment design code. Standard safety factors for weldings according to the possible inspection techniques has been applied.

Vessel





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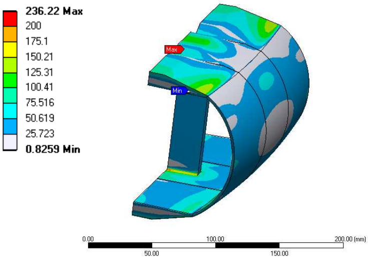

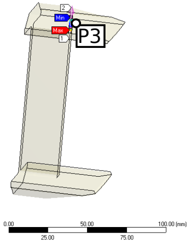

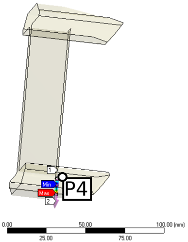

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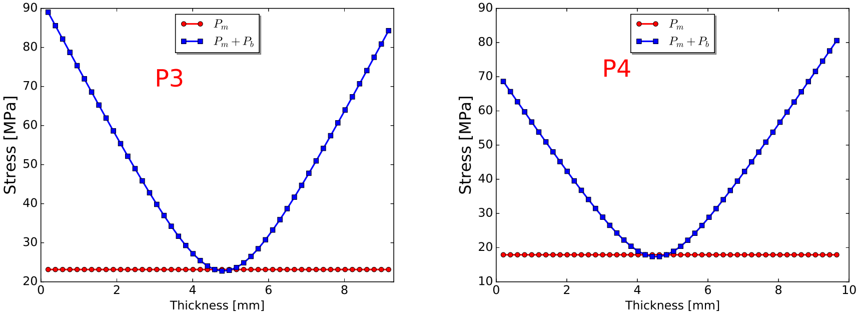

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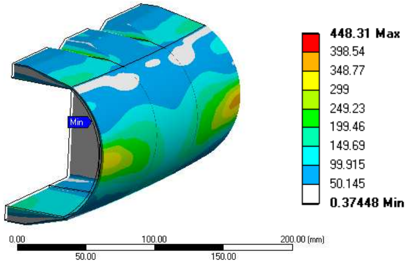

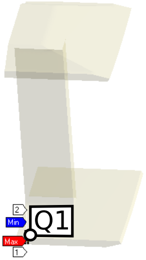

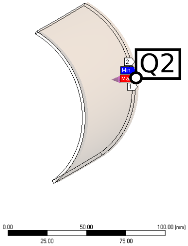

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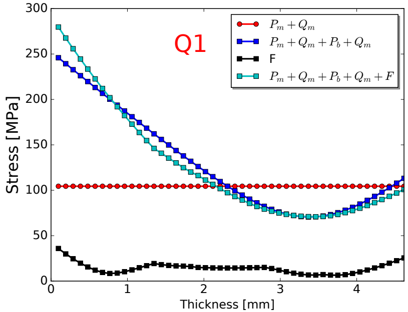

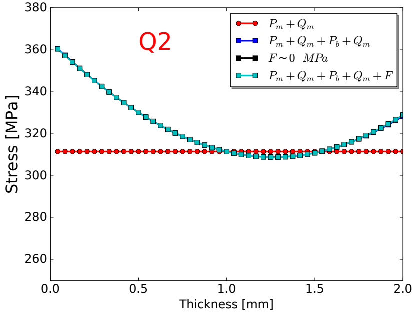

Conclusions

Target: Conclusions

Main remarks

- Target Design process is completed. CDR was held on June 2019.
- ESS BILBAO has developed thermomechanical models to predict ESS Target behaviour.
- Target design is completed
- Manufacturing process on going.

Support slides

Materials specification

Example of marterial limits based on $RCC - MR_x$ (Primary loads)

The material CuCr1Zr is not included in the A3 specifications, however, mechanical limits can be generated according to A.3.GEN section. According to A.3.GEN.22 S_m is defined as the minimum of:

- 2/3 for yield strength
- 1/3 for tensile strength

CuCr1Zr limits based on $RCC - MR_x$

Temperature (^oC)	YS (MPa)	UYS (MPa)	2/3 YS (MPa)	1/3 UYS (MPa)	S_m (MPa)
20	270**	360	180	120	120
200	254	350	169	116	116
300	234	310	156	103	103
400	207	260	138	86	86

S_m evaluation for Cu1CrZr alloy. Mechanical test shows YS $\sim$ 243 MPa

Materials specification

Example of marterial limits based on $RCC - MR_x$ (Secondary loads)

The evaluation of the radiation level will be done according to displacements per atoms (DPA) NRT as defined by Norgett & Robinson. References available shows significant radiation damage effects for 2 DPA and according to A3.GEN.42 the evaluation of the S^A_{em} for protection level A:

$$S^A_{em}(\Theta, G) = (\frac{r}{r+1} \cdot R_m(\Theta, G) + \frac{E}{r+1} \cdot \frac{1}{100} \cdot A_{gt}(\Theta, G))/2.5 \quad (1)$$

$$S^A_{et}(\Theta, G) = k_b \cdot (\frac{r}{r+1} \cdot R_m(\Theta, G) + \frac{E}{r+1} \cdot \frac{1}{100} \cdot \frac{1}{2} \cdot (A_{gt}(\Theta, G) + A_t(\Theta, G)))/2.5 \quad (2)$$

Where R_m is the minimum tensile strength (UYS), A_{gt} is the total elongation percentage at maximum force, A_t is the total elongation percentage at fracture and E is the Young Modulus and r is the elastic follow-up factor (r = 3).