# SYSTEM 1000 TARGET WHEEL, DRIVE AND SHAFT DESIGN SPECIFICATION MECHANICAL

| | Name | Role/Title |
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# 1. INTRODUCTION

In order to begin the detailed design, it is necessary to establish the DS, Design Specification Mechanical (KSmek). The Design Specifications shall contain relevant information that the design team needs in order to perform the detailed design.

# 2. DESCRIPTION OF THE ACTION

New Construction.

# 3. FUNCTIONAL REQUIREMENTS

## 3.1. General description

The Target wheel is essential to the fundamental purpose of the ESS facility in that it is the source of the neutrons produced during the spallation process as a result of the interaction with the 2 GeV 5 MW proton beam generated by the ESS linear accelerator.

The wheel and shaft systems are contained within the target monolith, which is located in the Target building at the end of the accelerator-to-target (A2T) area (see Figure 1). The wheel is a disk composed of 36 sectors of tungsten blocks contained within a steel shroud and cooled by flowing helium (see Figure 2). It is located deep within the target monolith (see Figure 3) at the base of a 5 m long shaft that positions the wheel at the level of the incoming proton beam.

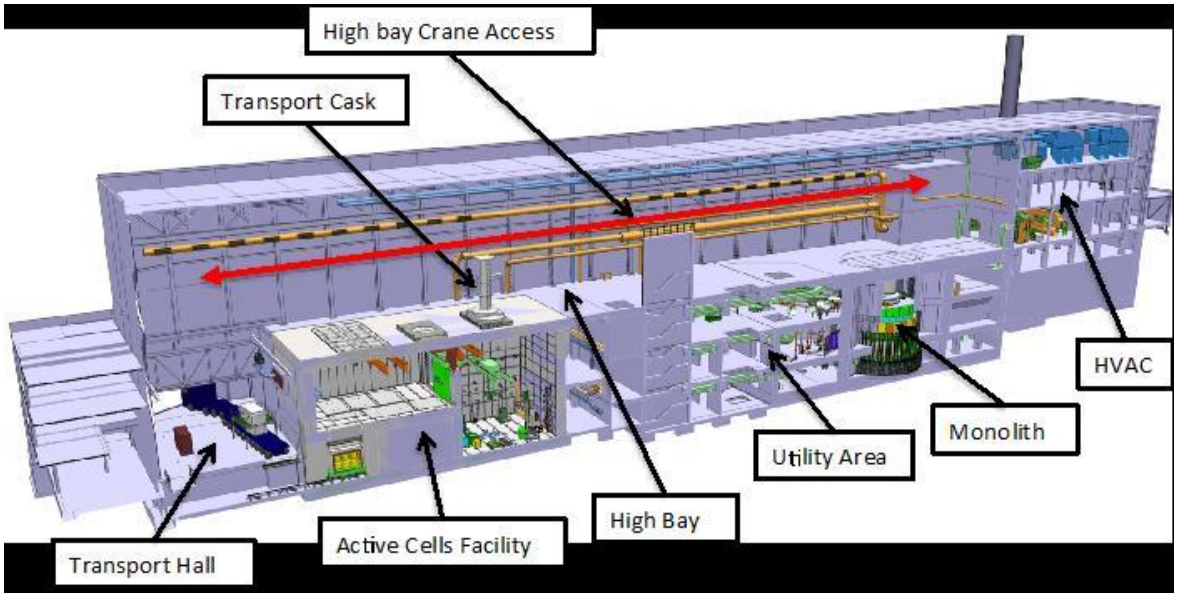



**Figure 1 – Target building - Monolith area containing target wheel shown on right**

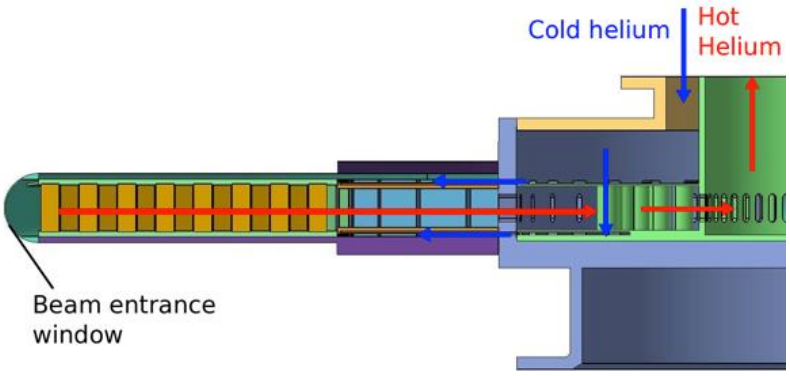



**Figure 2 – Principal helium gas coolant flow path through target wheel**

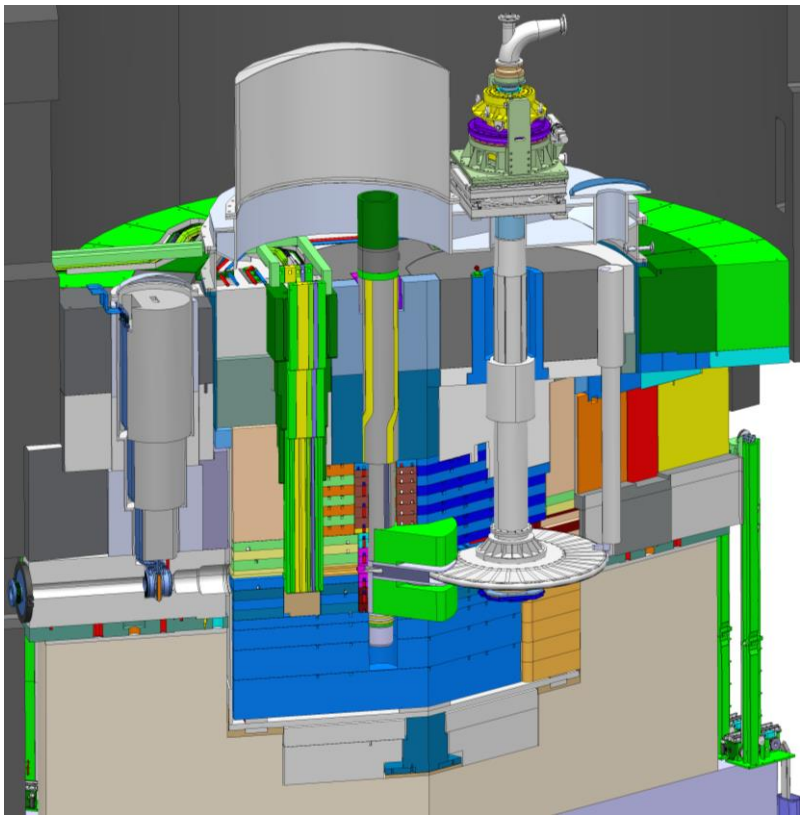


**Figure 3 – Cross section of the Target Monolith**

During normal operations, the wheel rotates around a vertical axis at a rate of 23 rpm to bring consecutive sectors into alignment with the impact of the proton beam to optimize neutron production. The flowing helium cools the spallation material. The rotation of the wheel is timed with the arrival of the proton beam such that the beam interacts with each sector once every 2.6 seconds.

### 3.2. System parts

The system is divided into four parts.

| System part | Description | Interfaces |
|---|---|---|
| A | Target wheel vessel, including internal parts and spallation material. | Target wheel vessel up to lower shaft flange. |
| B | Target shaft | Shaft lower flange, interface to helium feedthrough and shaft vacuum seal |
| C | Drive unit. | From clamp where drive unit is connected to shaft to bolt connection to monolith vessel lid. |
| D | Helium feedthrough and shaft vacuum seal | Flange connection to helium cooling system, (system 1010), ferrofluidic seal buffer gas connection to pristine helium (system 1011). |

**Table 1 System parts**

### 3.3. Function and requirements related to operation and performance

All requirements specified in [1] and [2] are relevant because the whole system is being built.

## 4. QUALITY ASSURANCE AND ACCREDITATION

Requirements on quality assurance and accreditation are specified in [4]. Specifically, rules related to review and approval procedure are defined in [5].

## 5. INTERFACE TO OTHER SYSTEMS, STRUCTURES AND COMPONENTS

Physical interface to helium cooling system is specified in [6]. Physical interface to inner shielding is specified in [7]. Physical interface to monolith vessel is specified in [8].

## 6. STRUCTURAL VERIFICATION

Requirements on structural verification are specified in Design basis [3].

# 7. PRESSURE RELIEF ANALYSIS

The pressure relief of the system is done through the helium cooling system. It is specified in [9].

# 8. INNER AND OUTER ENVIRONMENT

Requirements on inner environment are specified in [6]. Requirements on outer environment are specified in [10] for parts in connection cell. For parts in monolith requirements on outer environment are specified in [11].

# 9. CLASSIFICATION

According to Swedish Radiation Safety Authority (SSM) 15-36, Permit from SSM including updated conditions for physical protection [13], each mechanical component shall have a specific safety and quality classification. This gives the design requirements and quality assurance measures for the design, manufacture and installation as well as repair of components intended for use in the facility.

Classification is specified in [29].

## 9.1. Safety Classes

| System part | Description | Safety class |
|---|---|---|
| A | Target vessel, including internal parts and spallation material. | Safety-related SSC |
| B | Target shaft | Safety SSC |
| C | Drive unit. | Safety SSC |
| D | Helium feedthrough and shaft vacuum seal | Safety SSC |

**Table 2 Safety classification**

## 9.2. Mechanical Quality Class

| System part | Description | Mechanical quality class |
|---|---|---|
| A | Target vessel, including internal parts and spallation material. | MQC4A with additional requirements corresponding to MQC2. |
| B | Target shaft, including seal between shaft and monolith and seal between helium connection and shaft, and suspension where the shaft penetrates monolith cover. | MQC3 |
| C | Drive unit. | MQC3 |
| D | Helium feedthrough and shaft vacuum seal | MQC3 |

**Table 3 Quality classification**

## 9.3. Entrance Keys to RCC-MRx

| System part | Description | Structure | Cobalt purity class | Cleanliness class | Level of irradiation | Creep |
|---|---|---|---|---|---|---|
| Reference RCC/MRx | | RC 3000 | RB 2400 | RF 6000 | Appendix A3.S | Appendix A3.S |
| A | Target vessel, including internal parts and spallation material. | Box structure | 2 | B | Not negligible | Negligible |
| B | Target shaft | Vessel | 2 | B | Negligible | Negligible |
| C | Drive unit. | Support to C. | N/A | N/A | Negligible | Negligible |
| D | Helium feedthrough and shaft vacuum seal | Vessel | N/A | B | Negligible | Negligible |

**Table 4 Other classification**

# 10. APPLICABLE CODE

| System part | Description | Code framework for structural verification, manufacturing and testing | Remark |
|---|---|---|---|
| A | Target vessel, including internal parts and spallation material. | RCC-MRx N2Rx | Must also fulfill requirements according to EN 13445. RCC-MRx fulfills EN 13445 if additional requirements in RCC-MRx REC 3000 are fulfilled. |
| B | Target shaft | RCC-MRx N3Rx /EN 13445 | Can be evaluated, designed and tested according to EN 13445 if requirements according to RCC-MRx REC 2000 are fulfilled. |
| C | Drive unit. | RCC-MRx N3Rx /EN 13445 | Can be evaluated, designed and tested according to EN 13445 if requirements according to RCC-MRx REC 2000 are fulfilled. |
| D | Helium feedthrough and shaft vacuum seal | RCC-MRx N3Rx /EN 13445 | Can be evaluated, designed and tested according to EN 13445 if requirements according to RCC-MRx REC 2000 are fulfilled.<br><br>Note: REC 2000 does not apply to bellows. See [31]. |

**Table 5 Applicable code**

# 11. MATERIAL REQUIREMENTS

Requirements on review and documentation according to [4] and specified in [5].

| System part | Specification | ESS Eric additional requirements |
|---|---|---|
| A | Mandatory inspection according to general inspection plan see [24] | Cobalt purity class 2 according to Article RB 2400 .<br><br>Required surface condition for vacuum specified in [12]. |
| B | Mandatory inspection according to general inspection plan see [26]. | Cobalt purity class 2 according to Article RB 2400 .<br><br>For part of shaft in monolith, additional requirements specified in [12] |
| C | Mandatory inspection according to general inspection plan see [27]. | Harmonized European standards |
| D | Mandatory inspection according to general inspection plan see [31][32]. | Harmonized European standards |

**Table 6 Material requirements**

## 11.1. Steel material selection

| System part | Description | Material |
|---|---|---|
| A, B, D | Target vessel, shaft | X2CrNiMo17-12-2 in solution annealed condition |
| C | Drive unit, feedthrough and vacuum seals | Harmonized European standards |

**Table 7 Steel material selection**

# 12.MANUFACTURING

## 12.1. Welding requirements

The manufacturer shall be qualified acc. to SS-EN ISO 3834-2: Comprehensive Quality Requirements.

-Acceptance of filler materials

-Welding procedure qualification

-Qualification of welders and weld operators

-Technical qualification of production workshop

| System part | Specification | ESS Eric additional requirements |
|---|---|---|
| A | Mandatory inspection according to general inspection plan see [24] | See [5] Chapter 4.3. In relation to the vacuum requirements, one test piece including weld in final condition for each weld operator shall be welded, machined to final expected condition and submitted to ESS vacuum group for qualification according to vacuum group quality standards. |
| B | Mandatory inspection according to general inspection plan see [26]. | For parts within monolith- also see [5] |
| C | N/A | N/A |
| D | Mandatory inspection according to general inspection plan see [31][32]. | For parts within monolith- also see [5] |

**Table 8 Welding requirements**

## 12.2. **Forming**

| System part | Specification | ESS Eric additional requirements |
|---|---|---|
| A | Mandatory inspection according to general inspection plan see [24] | See reference [21]. |
| B | Mandatory inspection according to general inspection plan see [26]. | - |
| C | Mandatory inspection according to general inspection plan see [27] | - |
| D | Mandatory inspection according to general inspection plan see [31][32]. | |

**Table 9 Forming**

## 12.3. **Heat treatment**

| System part | Relevant section | ESS Eric additional requirements |
|---|---|---|
| A | Mandatory inspection according to general inspection plan see [24] | - |
| B | Mandatory inspection according to general inspection plan see [26]. | - |
| C | Mandatory inspection according to general inspection plan see [27] | Hardening method and hardness (HRC) specified. |
| D | Mandatory inspection according to general inspection plan see [31][32]. | - |

**Table 10 Heat treatment**

## 12.4. Surface finish, roughness, machining

| System part | Relevant section | ESS Eric additional requirements |
|---|---|---|
| A,B,C,D | N/A | For parts in monolith, [12] |

**Table 11 Roughness**

## 12.5. Painting

| System part | Relevant section | ESS Eric additional requirements |
|---|---|---|
| C | N/A | Painted surfaces shall be possible to decontaminate. This shall be documented in accordance with ISO 8690 or equivalent. Supplier shall provide specification of painting system for review. |

**Table 12 Painting**

## 12.6. Hard coating of wear surfaces

| System part | Relevant section | ESS Eric additional requirements |
|---|---|---|
| C | N/A | Coating method and microhardness specified. |

**Table 13 Hard coating**

## 12.7. **Cleaning**

| System part | Specification | ESS Eric additional requirements |
|---|---|---|
| A | Mandatory inspection according to general inspection plan see [24] | [12]. Parts not possible to clean after welding must be cleaned before welding.<br><br>Suppliers cleaning instruction shall comprise cleanliness including final assembly, packing and Factory Acceptance Test.<br><br>Cleanliness class B (See 9.3). |
| B | Mandatory inspection according to general inspection plan see [26]. | [12] applies to part of shaft in monolith. Parts not possible to clean after welding must be cleaned before welding.<br><br>Suppliers cleaning instruction shall comprise cleanliness including final assembly, packing and Factory Acceptance Test.<br><br>Cleanliness class B (See 9.3) |
| C | Mandatory inspection according to general inspection plan see [27] | Suppliers cleaning instruction shall comprise cleanliness including final assembly, packing and Factory Acceptance Test. |
| D | Mandatory inspection according to general inspection plan see [31][32]. | Suppliers cleaning instruction shall comprise cleanliness including final assembly, packing and Factory Acceptance Test. |

**Table 14 Cleaning**

## 12.8. Identification and marking

| System part | Specification |
|---|---|
| A | Mandatory inspection according to general inspection plan see [24] |
| B | Mandatory inspection according to general inspection plan see [26]. |
| C | Mandatory inspection according to general inspection plan see [27] |
| D | Mandatory inspection according to general inspection plan see [31][32]. |

**Table 15 Identification and marking**

## 12.9. Packing, transportation and storage

| System part | Specification | ESS Eric additional requirements |
|---|---|---|
| A | Mandatory inspection according to general inspection plan see [24] | Packing shall be seaworthy. Components shall me protected against corrosion. Bearings shall be fixed with transport- protection devices to protect from transport damage. |
| B | Mandatory inspection according to general inspection plan see [26]. | Packing shall be seaworthy. Components shall me protected against corrosion. Bearings shall be fixed with transport- protection devices to protect from transport damage. |
| C | Mandatory inspection according to general inspection plan see [27] | Packing shall be seaworthy. Components shall me protected against corrosion. Bearings shall be fixed with transport- protection devices to protect from transport damage. |
| D | Mandatory inspection according to general inspection plan see [31][32]. | Packing shall be seaworthy. Components shall me protected against corrosion. Bearings shall be fixed with transport- protection devices to protect from transport damage. |

**Table 16 Packing**

# 13.INSPECTIONS AND FUTURE IN-SERVICE INSPECTIONS

## 13.1. Inspections during manufacturing

Mechanical components must be designed in such a way that it should be easy to perform maintenance, inspection and decontamination.

-Ultrasonic examination

-Radiographic examination

-Liquid penetrant examination

-Visual examination and metrology

| System part | Specification |
|---|---|
| A | Mandatory inspection according to general inspection plan see [24] |
| B | Mandatory inspection according to general inspection plan see [26]. |
| C | Mandatory inspection according to general inspection plan see [27] |
| D | Mandatory inspection according to general inspection plan see [31][32]. |

**Table 17 Non- Destructive Testing**

## 13.2. **In service inspections**

The following geometrical limitations apply to ensure that the design is possible to inspect during operation. Note that these requirements only apply to parts accessible during operation, ie accessible welds in system part B, C and D.

In figures below, F shall be assumed to be 13 mm.

Tapering for in-service inspection:

If machining is required (see Figures 4-3 – 4-7) the items that are subjected to in-service inspection shall be capable to examination with either Pulse Echo (UT) or Phase Array (PAUT) according to the qualified ultrasonic procedures. The method to be applied depends on types of possible damage mechanisms and material. The selection of method impacts the distance F in below form, due to this reason the geometrical shape has to be determined on a case by case basis.

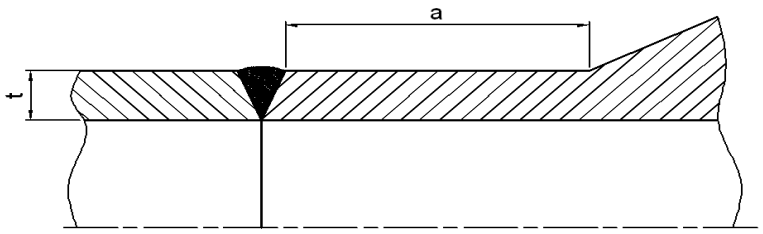
At tapering adjacent to butt weld joints the design rules for external and internal taper to be satisfied (Figure 4-3 and 4-5) unless otherwise agreed.

The following units are utilised in the Figures 4-3 – 4-7:

r = radius between taper and a-measure or b-measure in mm
a- and b-measure = necessary distance for in-service inspection in mm
t, $t_1$ and $t_2$ = wall thickness
F = distance between the point for the out-signal and the backside of the transducer (in general the value of 13 mm is used)

When Phase Array is used for ultrasonic test shall F=52 mm be applied when 6.0<t<11 and F=70 be applied when 11<t<40.

k = half the joint width




| | |
|---|---|
| $3{,}9 \leq t \leq 6{,}0$ | $a = 3 \cdot t + 25 + F$ |
| $6{,}0 < t \leq 11$ | $a = 3 \cdot t + 15 + F$ |
| $11 < t \leq 40$ | $a = 3 \cdot t + 10 + F$ |

Figure 4-3. Minimum external straight distance from weld joint

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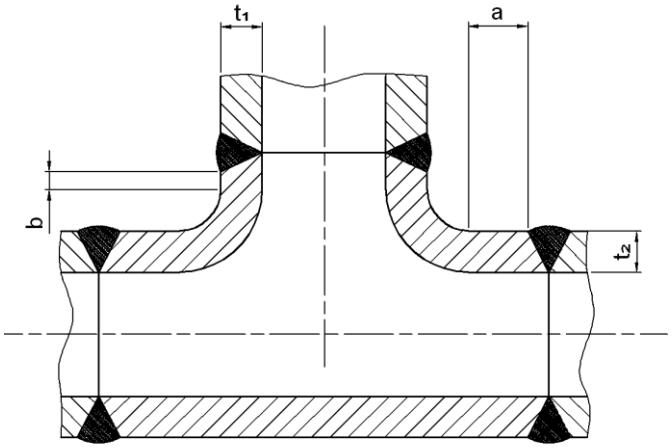
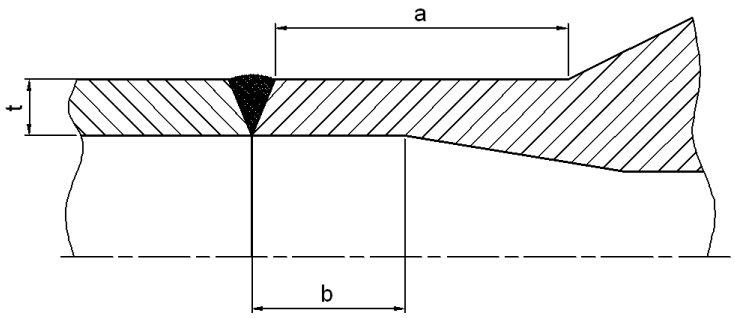
**Figure 4 Requirements for in-service inspection of welds, part 1 [30]**




Requirement: ΔT < 100 ºC

| | | |
|---|---|---|
| $3{,}9 \leq t \leq 6{,}0$ | $a = 3 \cdot t_2 + 25 + F$ | $b = 3 \cdot t_1 + 25 + F$ |
| $6{,}0 < t \leq 11$ | $a = 3 \cdot t_2 + 15 + F$ | $b = 3 \cdot t_1 + 15 + F$ |
| $11 < t \leq 40$ | $a = 3 \cdot t_2 + 10 + F$ | $b = 3 \cdot t_1 + 10 + F$ |

Figure 4-4. Minimum straight distance at welding of T-piece




| | | |
|---|---|---|
| $3{,}9 \leq t \leq 6{,}0$ | $a = 3 \cdot t + 25 + F$ | $b = 25 + F$ |
| $6{,}0 < t \leq 11$ | $a = 3 \cdot t + 15 + F$ | $b = 15 + F$ |
| $11 < t \leq 40$ | $a = 3 \cdot t + 10 + F$ | $b = 10 + F$ |

Figure 4-5. Minimum straight distance from weld joint

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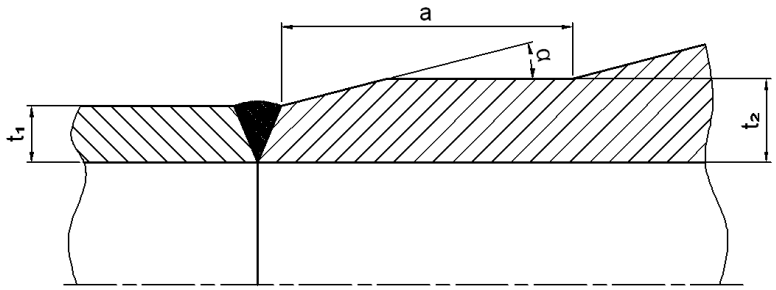
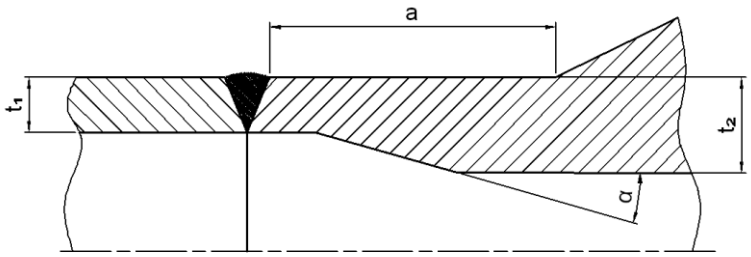
**Figure 5- Requirements for in-service inspection of welds, part 2[30]**




Requirement: $\alpha = \leq 18°$

$3{,}9 \leq t_1 \leq 6{,}0$ $\quad a = 3 \cdot t_2 + 25 + F$
$6{,}0 < t_1 \leq 11$ $\quad a = 3 \cdot t_2 + 15 + F$
$11 < t_1 \leq 40$ $\quad a = 3 \cdot t_2 + 10 + F$

Figure 4-6. Maximum external angle of taper at weld joint




Requirement: $\alpha \leq 14°$

$3{,}9 \leq t_1 \leq 6{,}0$ $\quad a = 3 \cdot t_2 + 25 + F$
$6{,}0 < t_1 \leq 11$ $\quad a = 3 \cdot t_2 + 15 + F$
$11 < t_1 \leq 40$ $\quad a = 3 \cdot t_2 + 10 + F$

Figure 4-7. Maximum internal angle of taper at weld joint

In addition to this the following general recommendations can be made:

1. These design rules are general and optimisation of a- and b-measures may be done by variation of the angle and transducer design according to the requirements in the procedure. When required the respectively quality department to be contacted to obtain information.
2. When designing tee pieces, which will be inspected, concerning thermal fatigue contact should be taken with the quality department/test laboratory for discussions about the geometric design.
3. Full volumetric inspection may be required at risk of mechanical fatigue. Therefore inside and outside taper should be avoided at immediate connection to the weld joint since this will complicate the inspection.

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**Figure 6 Requirements for in-service inspection of welds, part 3[30]**

4. At new installation the weld crown on the outside of the item should be ground flush with the center of the weld clearly marked.

**Figure 7 Requirements for in-service inspections of welds, part 4[30]**

## 13.3. Helium Leak testing

| System part | Relevant section | ESS Eric additional requirements |
|---|---|---|
| A | RCC-MRx RMC 7000 | See reference [12].<br><br>Leak testing of both prototype and final vessel shall be done by ESS Vacuum group. Leak testing shall be performed with vacuum inside vessel in a helium atmosphere.<br><br>Leak test shall be done on prototype before pressure testing, on prototype after pressure testing, on final vessel before pressure testing and on final vessel after pressure testing. |
| B, D | EN13445-5 | See reference [12] |

**Table 18 Leak testing**

## 13.4. **Hydrostatic testing**

| System part | Specification | ESS Eric additional requirements |
|---|---|---|
| A | Mandatory inspection according to general inspection plan see [24] | See reference [12]<br><br>After hydrostatic testing component must be baked to get rid of all water before helium test. |
| B | Mandatory inspection according to general inspection plan see [26]. | See reference [12].<br><br>After hydrostatic testing component must be baked to get rid of all water before helium test. |
| D | Mandatory inspection according to general inspection plan see [31][32]. | See reference [12].<br><br>After hydrostatic testing component must be baked to get rid of all water before helium test. |

**Table 19 Pressure test**

## 13.5. **Factory Acceptance Test**

| System part | Specification |
|---|---|
| A,B,C,D | [12], [17], [18] |

**Table 20 FAT**

### 13.6. **Final control documentation**

| System part | Specification |
|---|---|
| A | Mandatory inspection according to general inspection plan see [24] |
| B | Mandatory inspection according to general inspection plan see [26]. |
| C | Mandatory inspection according to general inspection plan see [27] |
| D | Mandatory inspection according to general inspection plan see [31][32]. |

**Table 21 Final control documentation**

## 14.VALVES AND INTERLOCKS

No hardware interlocks. Software interlocks are specified in [22].

## 15.CRITERIA FOR OPERATIONAL READINESS

| System part | Specification |
|---|---|
| A,B,C,D | Before the system is accepted for operation, test and commissioning as specified in [13], [17], [18] must be performed and approved.<br><br>As part of the system validation, an operational test at defined beam power shall be done to verify that the operational temperature is within limits specified in [28]. |

**Table 22 Operational readiness**

## 16.P&ID

See [23]

# 17.GLOSSARY

| Term | Definition |
|---|---|
| SSM | Swedish Radiation Safety Authority |
| SSC | Systems, Structures and Components |

# 18.REFERENCES

[1] ESS-0020435 System Description Requirements- target wheel, drive and shaft
[2] ESS-0026412 System Description Solution- target wheel, drive and shaft
[3] ESS-0060792 WP2 Target wheel, drive and shaft- design basis
[4] ESS-0047989 ESS Rules for quality regulation- mechanical equipment
[5] ESS-0102039 WP2 Target systems routine for review and approval of manufacturing and control documentation
[6] ESS-0019346 ICD Helium cooling systems- target wheel, drive and shaft
[7] ESS-0096589 ICD-R Inner shielding- Target wheel, drive and shaft
[8] ESS-0079166 ICD-R Covers, penetrations and monolith vessel- target wheel, drive and shaft
[9] ESS-0089520 Design Specification mechanical (KSMek) Target cooling systems
[10] ESS-0034721 ICD-R: Target system heating ventilation air conditioning vs target wheel drive
[11] ESS-0059764 ICD-R system 1020 Monolith atmosphere system- Target wheel, drive and shaft
[12] ESS-0057844 ESS Monolith vessel vacuum rules
[13] Swedish Radiation Safety Authority (SSM) 15-36, Permit from SSM including updated conditions for physical protection. Swedish original (ESS-0015358), English translation (ESS-0018828)
[14] ESS rule for identification and classification of safety important components: (ESS-0016468)
[15] ESS Rule for Radiological Safety Classification for Mechanical Equipment: (ESS-0033258)
[16] ESS-0015573 RCC-MRx 2012 Addendum 2013
[17] ESS-0027392 Validation plan target systems
[18] ESS-0104958 Target wheel, drive and shaft summary and planning of testing activities
[19] ESS Rules for Principles In-Service Inspection: (ESS-0053218)
[20] Standards & Norms applicable for ESS: (ESS-0001515)
[21] ESS-0111453 WP2 target systems requirements on forming of beam entrance window
[22] ESS-0038137 Specification for control system for target wheel, drive and shaft
[23] ESS-0023965 P&ID system 1000

[24] ESS-0124054 General inspection plan target vessel
[25] ESS-0124284 General Inspection plan pedestal
[26] ESS-0124290 General inspection plan target shaft
[27] ESS-0136231 General inspection plan target drive unit
[28] ESS-0003310 Beam on target requirements
[29] ESS-0218036 Specification of safety-and quality classification for Target wheel, drive and shaft
[30] Technical Requirements for Mechanical equipment (TBM) Swedish nuclear power industry, edition 2015
[31] ESS-0236106 General inspection plan bellow
[32] ESS-0242705 General inspection plan ferrofluidic seals

## 19.DOCUMENT REVISION HISTORY

| Revision | Reason for and description of change | Author | Date |
|---|---|---|---|
| 1 | First issue | Kristoffer Sjögreen | 2017-07-24 |
| 2 | Changed to cobalt class 1 | Kristoffer Sjögreen | 2017-10-02 |
| 3 | Changed to cobalt class 2 and put requirement on fulfilling hot commissioning test to verify accelerator heat load.<br>Removed pedestal. | Kristoffer Sjögreen | 2017-10-09 |
| 4 | Refer to classification document. Requirements on in-service inspection. Examples of inspection procedures removed. Separate system part for seals added. | Kristoffer Sjögreen | 2018-01-08 |