Document Title:	**Detailed Specification for a SIS100 Cryocatcher Unit**
Description:	This document represents the Detailed Specification for the manufacturing and testing of the cryocatcher unit for SIS100.
Division/ Organization:	SIS
Field of application:	Project FAIR@GSI

Document History:

Version	Date	Description	Author	Review / Approval
0.4	2013-01-07	Draft version	L. Bozyk	
1.1	2013-01-22	Final Version	L. Bozyk	
2.1	2013-08-28	Adjustable distance of cryocatcher distance to beam axis, new bellows	L. Bozyk	
2.2	2014-06-25	Notes from S.Wilfert included, galavic coating reworked, security note for FAT, spread for gHe-Flow rate included	L. Bozyk	
2.3	2014-06-30	Corrections from P.Spiller included, naming: module --> unit	L. Bozyk	
2.4	2014-07-03	Formal corrections	L. Bozyk	
3.0	2015-07-07	Correction of bakeout temperature	L. Bozyk	
3.1	2015-07-09	CID introduced	L. Bozyk	
4.0	2018-04-30	Modifications after production of first-of-series. See following table.	L. Bozyk	

Modifications compared to Version 3.1:

p. 4	Update of figure
p. 6	Aluminum covers for CF150 and every second CF100 flange
p. 6	UHV-gauges shall be installed at the CF40-flanges, will be provided by GSI, no plug at T-sensor cable
p. 8	Two different indium foils, vented screws for collimator blocks
p. 9	Hint onto thermal contact surfaces
p. 9	Ceramic spacers have been replaced by stainless steel. Only one
p. 9, p. 12	Protection structure for transportation removed
p. 10	2 mm copper instead of 1 mm
p. 11	Temperature sensor, has been changed, plug has been removed
p. 10	He-pipe has to be cut to final measures
p. 12	Transportation protection removed
p. 16	Bakeout temperature set to 250 °C, bakeout without indium foil, installation after successful vacuum properties acceptance test.
p. 18	Documentation has to be readable under Windows 7

EDMS **1261923 v.12** status **Released** access **Restricted**
F-DS-SIS-en-SI_0001_SIS100_Cryocatcher_Unit-V004a.pdf modified **2018-06-18 07:42**

Abstract

This document represents the Detailed Specification for the manufacturing and testing of the cryocatcher unit for SIS100. The unit consists of the actual cryocatcher, a support structure, and a cryogenic UHV chamber.
One pre series unit and 61 series units have to be manufactured.

Table of Contents

1. Purpose and classification of the document 4
2. Scope of the technical System 4
   - 2.1. System Overview 4
   - 2.2. Limits of the system and its environment 5
3. Technical Specifications 6
   - 3.1. Mandatory General Specifications, Common Specifications, and Technical Guidelines 6
   - 3.2. Detailed technical specifications for the cryocatcher unit components 8
     - 3.2.1. Cryocatcher block 8
     - 3.2.2. Cryocatcher Support 9
     - 3.2.3. Cryocatcher Chamber 10
     - 3.2.4. Temperature Sensor 11
     - 3.2.5. Flanges 11
     - 3.2.6. Fastener 12
     - 3.2.7. Labeling 12
     - 3.2.8. Packing and Transport 12
4. Manufacturing 12
   - 4.1. Cleanliness during manufacturing 12
   - 4.2. Welding 13
   - 4.3. Brazing 14
   - 4.4. Galvanic Coating 14
   - 4.5. Explosive Copper Plating 14
5. General cleaning procedure at GSI 15
6. Quality Assurance, Tests and Acceptance 15
   - 6.1. Factory Acceptance Test (FAT) 15
   - 6.2. Site Acceptance Test (SAT) 16
7. Documentation 17
   - 7.1. Engineering Documentation 17
     - 7.1.1. Material related Documentation and Certificates 18
     - 7.1.2. Process related Documentation 18
     - 7.1.3. Technical drawings and CAD – Data 18
     - 7.1.4. Structure of documentation 18
   - 7.2. FAT – Documentation 18
   - 7.3. SAT – Documentation 19

I. Related Documentation 20

1. Purpose and classification of the document

This document specifies the SIS100 Cryocatcher units. The cryocatchers are necessary to catch charge exchanged ions during heavy ion operation in SIS100. They are located between the superconducting quadrupole magnets in the cryogenic arcs inside the quadrupole cryostats.
Where ever requirements are specified in the General Specifications, technical Guidelines or detailed Specifications, they are only referenced in this document.
The tender contains the manufacturing of one First-of-series (FoS) cryocatcher-unit including packing and transport. After the successful delivery to GSI the tender contains 61 following units, each with packing and transport. Documentation of all steps is included in the delivered components.

2. Scope of the technical System

2.1. System Overview

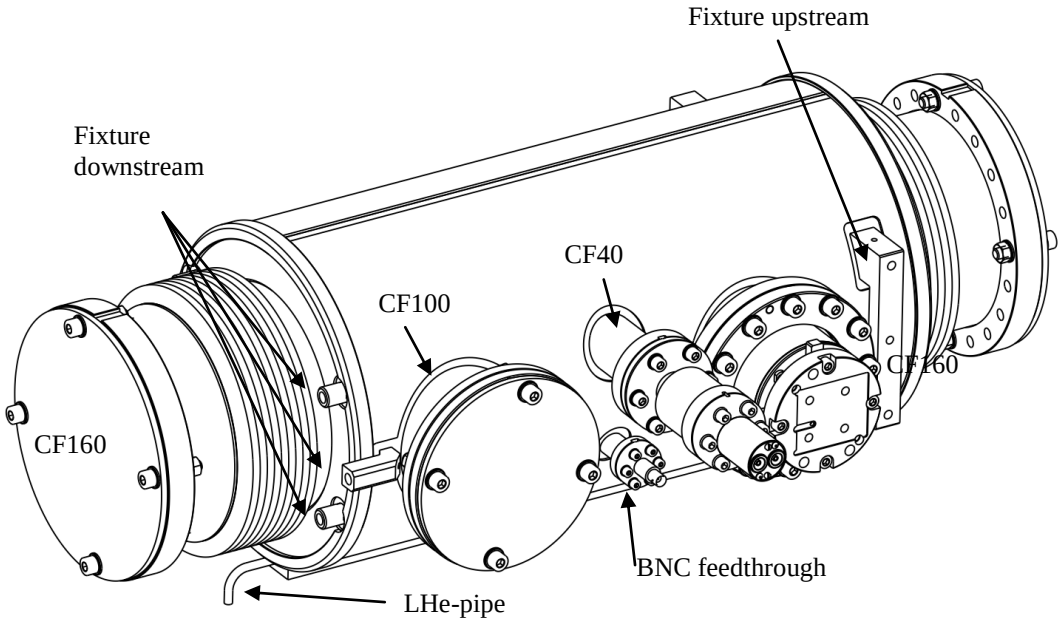


Figure 1: Overview drawing of the cryocatcher unit

For SIS100 a special synchrotron layout has been developed. It ensures, that charge exchanged ions are lost at well-defined positions, namely on the cryocatchers between the quadrupole magnets. Dynamic vacuum effects are suppressed effectively by means of special low desorbing surfaces, to ensure a reliable operation with high intensity heavy ion beams.
The cryocatcher unit consists of the actual cryocatcher, which is a copper block, a support structure, and a cryogenic UHV chamber. The vacuum chamber will act as a cryopump, therefore it has to be kept at a temperature below 10 K in order to freeze out gases on the inner surfaces. Freezing out of gases has to be avoided on the cryocatcher block, where lost ions are deposited, to keep desorption yield and pressure on beam axis low. Therefore, the cryocatcher block has to be kept at a higher temperature than the chamber.

This is realized by its special support structure, which allows connecting the cryocatcher thermally to the radiation shield of the cryostat.
A prototype cryocatcher has already been designed, manufactured, and tested at GSI. For details of the prototype, see [1]. This specification represents a refinement of this prototype.

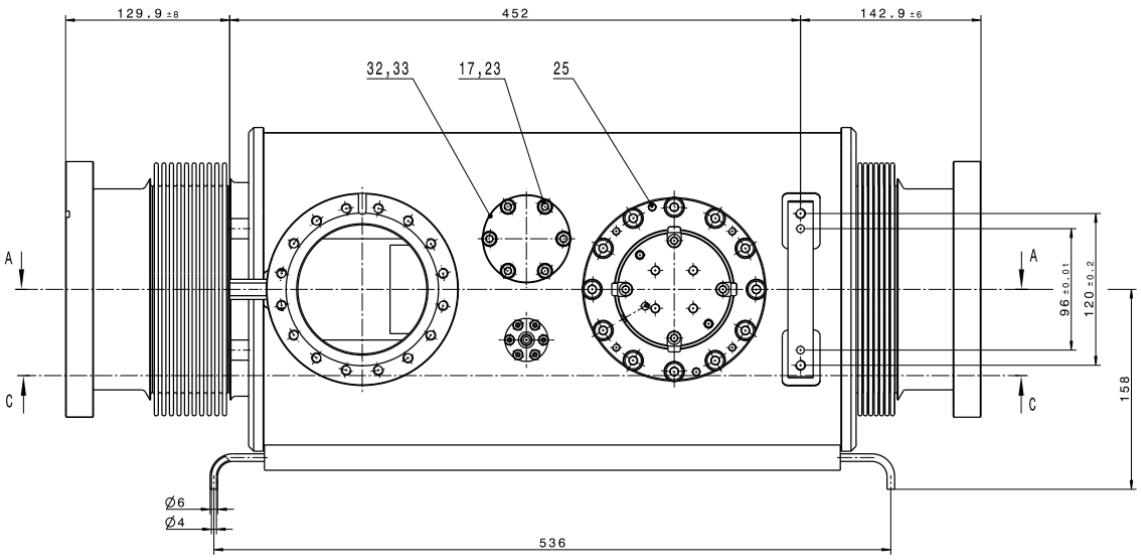


Figure 2: Side view of the cryocatcher unit.

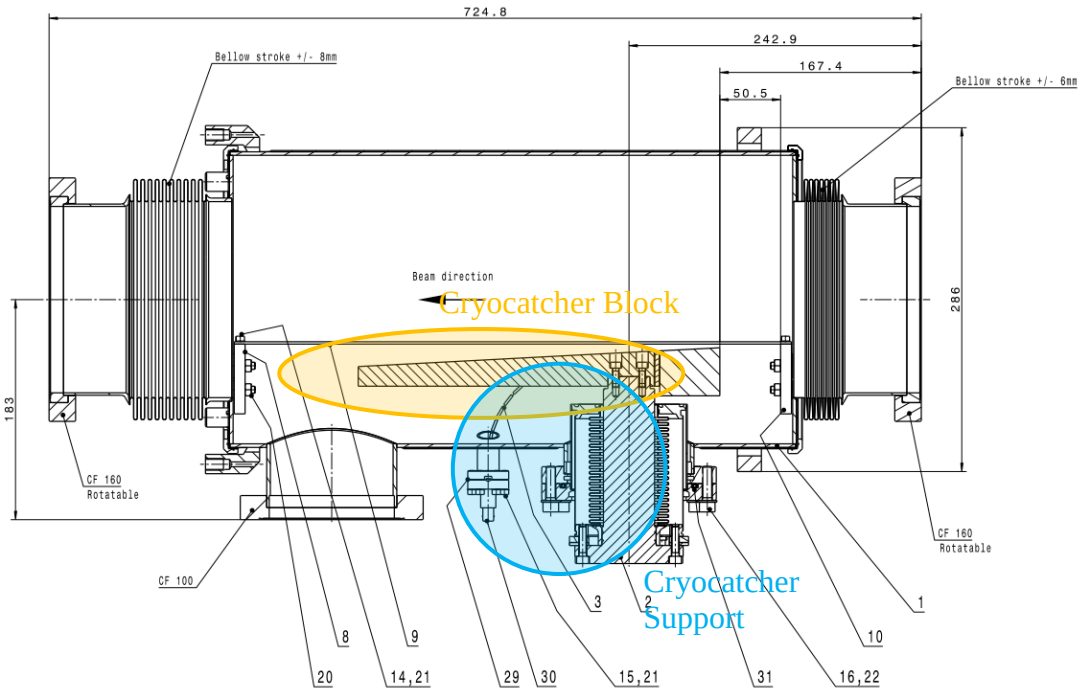


Figure 3: Horizontal cross section of the cryocatcher unit with dimensions

2.2. Limits of the system and its environment

The cryocatcher has the following interfaces to other systems:

- Support in the quadrupole cryostat to the common girder. The upstream side is a fixed bearing, the downstream side a loose bearing.

- CF160 flanges to the adjacent quadrupole vacuum chambers, thermal contraction compensation of the beam pipe on both sides. Both flanges shall be closed with aluminum covers for delivery.
- Connection of the cryocatcher support to the thermal radiation shield of the cryostat.
- CF100 flange for an arc roughing cold-warm-transition at every second cryocatcher-unit. These flanges shall be covered with aluminum covers for delivery. The CF100 flanges of the other cryocatcher units have to be sealed with a CF100 blank flange.
- A BNC cable and connectors for the electrical measurement of lost ions, connecting the cryocatcher with a feed-through in the service port of the cryostat. This cable will be connected to the CF16 BNC feedthrough at the chamber.
- A CF40 flange which shall be equipped with a measurement gauge. This gauge will be provided by GSI.
- Swagelok-connectors for the connection of the helium pipe on the bottom of the chamber to the liquid helium supply and return lines for the FoS-unit, open-ended pipes for the series units.
- A PT100 temperature sensor with cable

3. Technical Specifications

The cryocatcher unit has to be manufactured according to set of technical drawings MG-1004961-A-000 and subsequent, which will be provided to the contractor. The cryocatcher chamber has to enable a residual gas pressure in the range of 10^{-12} mbar and the cryocatcher unit will be operated in a cryogenic environment (i.e. 4.5 K). All manufacturing processes and materials have to be chosen accordingly.
Mandatory general and common specifications as well as mandatory technical guidelines for the production are listed in the following section. Detailed specifications for the different parts of the cryocatcher unit are also described in a following section.
In technical drawings the beam direction is usually from the right to the left. The right side is called the upstream (US) side, opposite to the beam direction, and the left side is called the downstream (DS) side, in beam direction.

3.1. Mandatory General Specifications, Common Specifications, and Technical Guidelines

The following general specifications are mandatory for the production of the cryocatcher units:

1. F-GS-F-01e-General_Specification_v1_2.pdf [2]

The following technical guidelines are mandatory for the production of the cryocatcher units:

1. FAIR Technical Guideline 2.1e: “Stainless steel for Beam Vacuum Chambers” [3]
2. FAIR Technical Guideline 2.3e: “Copper for vacuum applications” [4]
3. FAIR Technical Guideline 2.5e: “Vacuum Firing for Hydrogen Degassing of Materials and UHV Vacuum Chambers” [5]
4. FAIR Technical Guideline 2.6e: “Material for bakeable CF-flanges” [6]
5. FAIR Technical Guideline 2.7e: “Ceramics for Vacuum Applications” [7]
6. FAIR Technical Guideline 2.24e: “Materials in UHV” [8]

7. FAIR Technical Guideline 2.26e: “Forged blanks for Vacuum Applications 1.4429 /ESU” [9]
8. FAIR Technical Guideline 2.28e: “Stainless Steel for Beam Vacuum Chambers at Cryogenic Temperatures” [10]
9. FAIR Technical Guideline 2.35e: “Steel Materials for Pressurised Cryogenic Components” [11]
10. FAIR Technical Guideline 2.37e: “Specifications of Bolts, Studs, Nuts and Washers for cryogenic UHV components” [12]
11. FAIR Technical Guideline 3.1e: “Constructive Design of Weldings Seams for Vacuum Chambers” [13]
12. FAIR Technical Guideline 3.4e: “Manufacturing of CF-knife edge flanges” [14]
13. FAIR Technical Guideline 3.9e: “Welding of CF-Flanges on Tubes” [15]
14. FAIR Technical Guideline 3.17e: “Design of Thick-walled Vacuum Chambers” [16]
15. FAIR Technical Guideline 3.42e: “Copper Gaskets for ConFlat® flanges” [17]
16. FAIR Technical Guideline 3.56e: “Low Power Cabling for Cryogenic Purposes” [18]
17. FAIR Technical Guideline 5.1e: “Surface Conditions of Vacuum Chambers” [19]
18. FAIR Technical Guideline 6.1e: “Cleaning of UHV components /Stainless steel” [20]
19. FAIR Technical Guideline 6.2e: “Cleaning of Standard Vacuum Components” [21]
20. FAIR Technical Guideline 6.3e: “Cleaning Procedure for Bellows” [22]
21. FAIR Technical Guideline 6.4e: “Cleaning of Ceramics for use in UHV” [23]
22. FAIR Technical Guideline 6.8e: “Cleaning of Copper Components” [24]
23. FAIR Technical Guideline 6.10e: “Cleaning of Assemblies and Sub-assemblies in Vacuum” [25]
24. FAIR Technical Guideline 7.1e: “Mechanical Acceptance Tests for UHV Components” [26]
25. FAIR Technical Guideline 7.3e: “Vacuum Properties Acceptance Tests with Bakeout” [27]
26. FAIR Technical Guideline 7.15e: “Record for FAT Vacuum Components” [28]
27. FAIR Technical Guideline 7.23e: “He Leak Testing of Cryogenic Tubing” [29]
28. FAIR Technical Guideline 7.24e: “Pressurised Leak Testing of Cryogenic Tubing” [30]
29. FAIR Technical Guideline 7.25e: “Vacuum properties Acceptance Tests for Cryogenic Beam Vacuum components” [31]
30. FAIR Technical Guideline 7.26e: “Flow Rate Test for Cryogenic Processing Pipes” [32]
31. FAIR Technical Guideline 7.27e: “Residual Moisture Test for Cryogenic Processing Pipes” [33]
32. FAIR Technical Guideline 9.1e: “Transport and Packaging of Vacuum Components” [34]
33. FAIR Technical Guideline 13.1e: “Assembly Instructions for knife edge UHV flanges” [35]
34. FAIR Technical Guideline 13.5e: “Temperature Sensor Installation for Cryogenic Purposes” [36]
35. FAIR Technical Guideline 0.5e: “Permanent Tagging and Labelling of Components” [41]

Contradictions between the quoted technical guidelines and the specification at hand have to be clarified in written form.

3.2. Detailed technical specifications for the cryocatcher unit components

The cryocatcher unit consists of the actual cryocatcher block, its support structure and a UHV chamber. Figure 1 shows an overview drawing of the cryocatcher unit, Figure 3 shows a horizontal cross section with dimensions. Both drawings are taken from the set of blueprint drawings, which will be provided to the contractor. Detailed technical specifications are described in the following sections.

3.2.1. Cryocatcher block

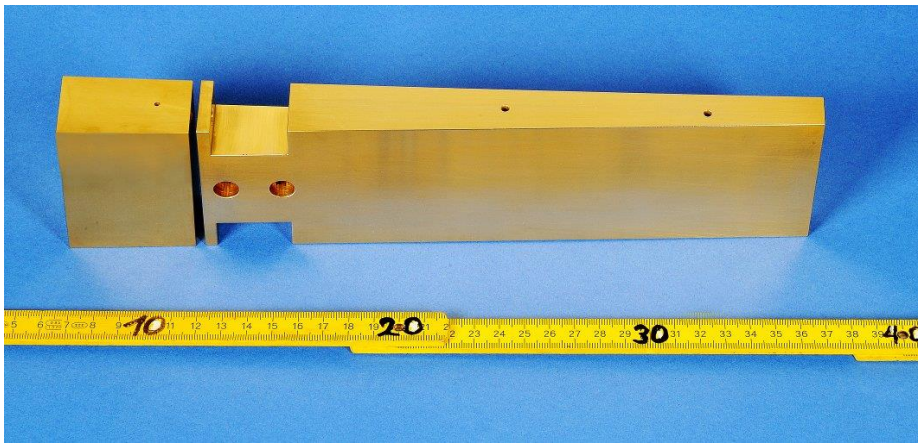


Figure 4: Photograph of the prototype cryocatcher block. The ceramic disk insulating both parts is missing. The folding rule represents the circulating beam. For the series cryocatcher, only the front part (left part) has to be coated with nickel and gold.

The cryocatcher blocks have to be made of OFHC copper, see also TG 2.3e [4]. They provide a perpendicular surface of incidence for lost ions. The position of this surface relative to the quadrupole upstream is crucial for the reliable functionality of the cryocatcher system. The precision of alignment of the cryocatcher has to be better than 0.5 mm. The angular alignment of the side of the cryocatcher facing the beam towards the beam axis has to be better than 0.1°. The front part has to be coated galvanically with 1 µm nickel and on top with 1 µm gold. Before coating the cryocatcher, the coating procedure has to be approved by GSI, see also section 4.4.
The front part is electrically insulated by a 4 mm thick ceramic disk from the back part, see also TG 2.7e [7]. This allows measuring the electrical current of the lost ions hitting the cryocatcher via a cable, which is attached to the front block. This stainless steel cable connects the cryocatcher front with the electrical feedthrough in the chamber body. It is surrounded by ceramic bushings to prevent an electrical short circuit.
In order to assure a good thermal contact, two different indium foils (250 µm thickness) are placed onto the two surfaces of the ceramic disk, before both blocks are screwed together. The screws are vented at their threads. During mounting, special care has to be taken, that no electrical short circuit between front and back part occurs. During FAT the electrical resistance between the block and the chamber body has to be measured in order to prove the sufficient electrical insulation, see also section 6.1.
To prevent grazing incidence, the surface of the cryocatcher facing the beam axis is tilted by 3°. The distance of the front edge of the cryocatcher to the beam axis is referred as distance of the cryocatcher to the beam axis, see section 3.2.2.

Further experiments on cold desorption that will be carried out at GSI will show, if another base material for the front part has to be chosen (e.g. stainless steel). GSI will inform the manufacturer in time about such a change.

3.2.2. Cryocatcher Support

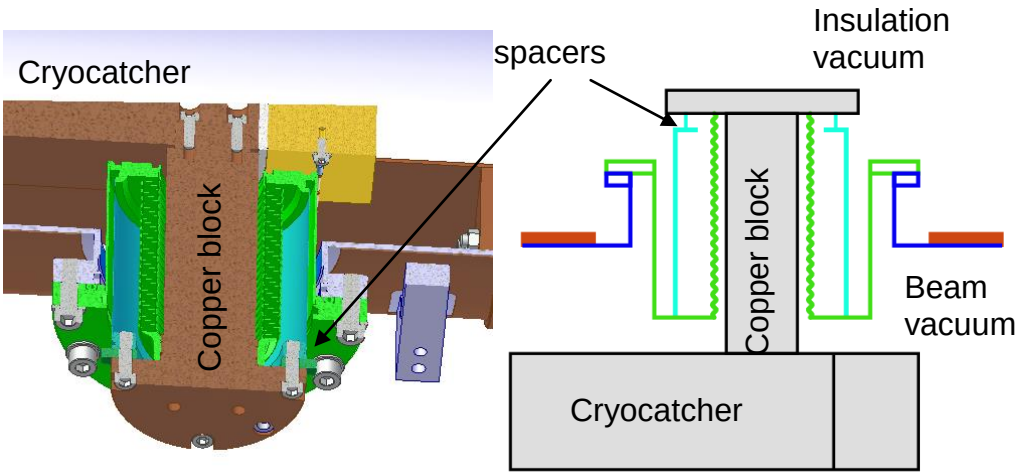


Figure 5: Model (left) and sketch (right) of the cryocatcher support.

The cryocatcher has to be kept at a higher temperature than the surrounding chamber. Therefore, its support has to act as a cold-warm-transition. It contains a bellow, which provides a high thermal resistance and a separation between beam vacuum and insulation vacuum. The actual support of the cryocatcher consists of a copper block inside the bellow. The block provides a good thermal contact to the warmer side of the bellow. In this way, a thermal contact to the cryocatcher from the insulation vacuum is established to connect it to the thermal shield. It has a temperature of 50 K – 80 K. The surface roughness of thermal contact surfaces has to be prepared according to the drawings. Special care has to be taken while handling the parts, in order not to damage these surfaces with scratches. To protect the contact surface during handling, it is put down.
Stainless steel spacers allow adjusting the distance of the cryocatcher to the beam axis. The distance is adjustable in the range of 35 mm and 45 mm by insertion of different spacers. The minimum distance of 35 mm is obtained by placing 2.5 mm spacers. The distance of each cryocatcher to the beam axis has to be set to 40 mm by the manufacturer, by inserting a 7.5 mm spacer.
The whole support structure is mounted inside a helicoflex sealed flange.

3.2.3. Cryocatcher Chamber

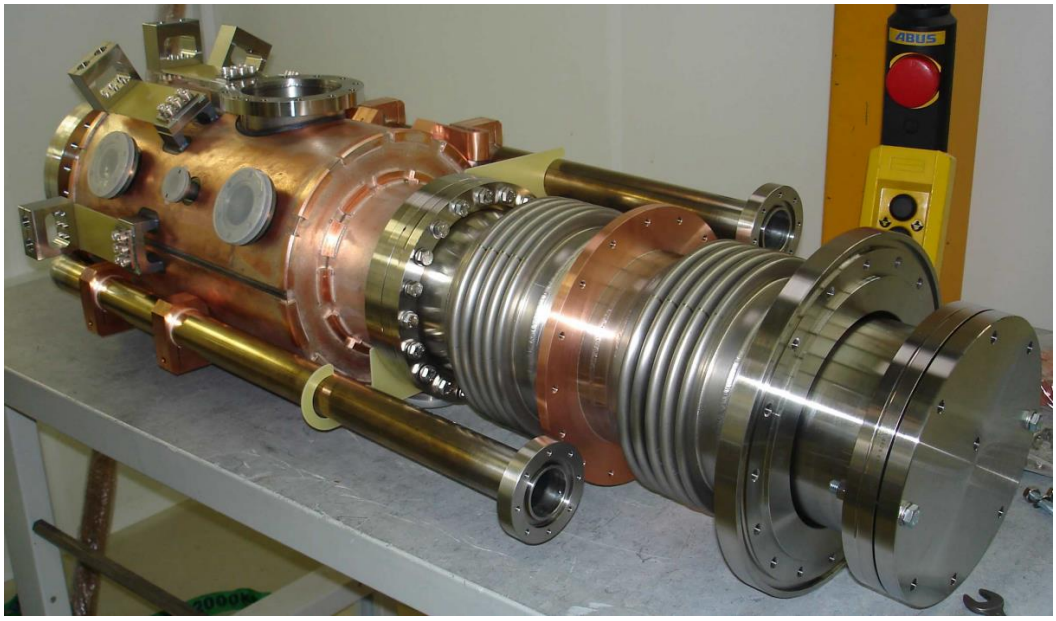
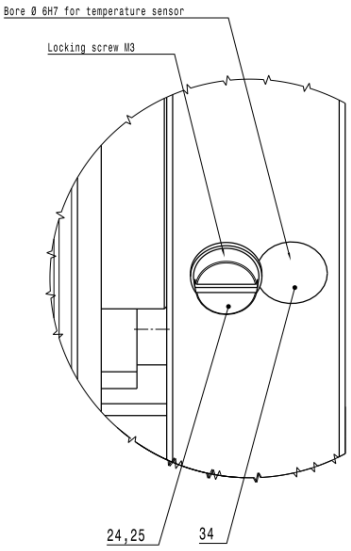


Figure 6: Photograph of the prototype cryocatcher chamber. No cold-warm-transition and a different He-pipe are necessary for the series chambers and the support structures looks different. This photography illustrates the copper plated chamber.

The chamber of the cryocatcher is part of the beam pipe in SIS100. It contains two CF160 flanges for the beam. They are connected to the adjacent quadrupole chambers. Furthermore the chamber contains a flange for the cryocatcher support, a CF16 flange for a feedthrough for the electrical measurement, a CF40 flange for an optional pressure measurement device, and a CF100 flange. Here a cold-warm-transition will be connected for arc roughing. Since such a roughing cwt is only foreseen on every second cryocatcher unit, the CF100 flange of the remaining units have to be sealed with a CF100 blank flange.
The chamber is plated with copper (Cw008A). The 2 mm thick copper layer ensures a homogeneous low temperature distribution over the whole inner surface of the chamber to obtain the required cryo-pumping speed. The copper is plated explosively onto the base material stainless steel (3 mm, 1.4404), before the chamber is manufactured. The plating procedure has to be approved by GSI, see section 4.5.
Cut-outs for weld seams, flanges, and support structures are also milled before the chamber is manufactured. In order to assure a good thermal contact over weld seams, they are bridged by thermal copper bridges, which are brazed onto the copper plating.
A pipe for liquid helium is brazed onto this coating for cooling. In operation, pressurized liquid helium (LHe, 2 bar) will be led through the cooling tube. From that point of view the cooling tubes and their machining have to be considered and handled according to PED 97/23/EC guidelines (Pressure Equipment Directive of the European Parliament and of the Council 97/23/EC) [37] or rather Druckgeräterichtline AD2000, see also TG 2.35e [11].The tubing material must be manufactured by a seamless process and should be cold finished and annealed. A LHe mass flow through the cooling pipes of minimum 0.2 g_{He}/s (at Lhe temperatures) has to be guaranteed. After testing the helium-tube, it has to be cut to final dimensions, rectangular and free of burr. The tube has to be sealed air-tight on both sides.
The chamber contains bellows on both sides in beam direction. These bellows have to compensate for the thermal contraction of the neighboring beam pipes in the quadrupole unit in longitudinal direction during every cool-down and warmup. Since the neighboring quadrupole magnets might be installed slightly tilted to compensate for fabrication

tolerances, the bellows at the cryocatcher unit also have to compensate a transversal offset. Since the neighboring quadrupole vacuum chambers are thin walled and therefore sensitive, the applied forces have to be minimized. To fulfill all these requirements, calculations have been performed and special bellows by Witzenmann GmbH have been chosen. The change of material properties due to cryogenic temperatures has been considered, as well as pressure differences and failure cases. The bellows can compensate all movements and displacements without applying impermissible forces to the thin-walled vacuum chambers. In order to verify the design calculation two special bellows are built and the reaction forces are measured by Witzenmann GmbH.
If the contractor chooses another supplier than Witzenmann GmbH for the manufacturing, the equivalence in construction, performance and quality has to be proven. The choice must be agreed with the contracting entity in written form.
Inside the cryocatcher chamber a secondary chamber around the cryocatcher is formed by copper plates. They reduce the vacuum conductance of desorbed gases to the beam axis and increase the cold pumping surface. The downstream side of these plates contains holes, to increase the vacuum conductance for arc roughing.

3.2.4. Temperature Sensor



A PT100 temperature sensor (Klasmeier, P100/3045 Class B, or equivalent in construction, performance, and quality) has to be installed into the copper of the cryocatcher support outside of the beam vacuum. The installation is described in the set of technical drawing and TG 13.5e [36]. The fitting has to be adapted such that the sensor can be pushed in by hand with slight pressure. If applicable a slight amount of Apiezon vacuum grease (or equivalent in performance and quality) to increase the thermal contact has to be applied to the sensor. If necessary the contracting entity has to be consulted.
The temperature sensor is secured inside the fitting by a lock screw with washer.
The pins of the temperature sensor have to be soldered to cable with a length of 2 m, fulfilling TG 3.56e [18] and TG 13.5e [36]. No plug is required.
For transportation of the cryocatcher unit, the excess cable has to be removable fixed to the chamber such that a damage-free transportation is guaranteed. The fixation must be fully removable without any residuals.
In case a temperature sensor equivalent to the PT100 Klasmeier P100/3045 is used, the choice of the dedicated sensor must be agreed with the contracting entity.

3.2.5. Flanges

Except for the flange holding the support structure, the chamber has to be equipped with UHV-tight ConFlat flanges. The flanges must be manufactured in such a way that:

1. The flange dimensions must conform to the standards according ISO/TS 3669-2 [38]. For details see also TG 3.4e [14].
2. The knife edge flanges are to be made from hot forged round blanks or forgings of austenitic stainless steel 1.4429 ESU (cf. [6], [9]).

3. Forgings shall have a Brinell hardness of 170 to 300 in the area of the sealing lip (cutting edge) of the ConFlat flange (cf. [6], [9]).
4. The flanges will be sealed with silver-plated OFC gaskets displaying a clamping pressure of $5…8.5 \cdot 10^8$ N/m² (cf. [17],[35]).
5. The flanges shall be vacuum-fired in a vacuum furnace at 950°C at pressures of about 10^{-5} mbar for two hours before being welded to the chamber ends, according to TG 2.5 [5].

3.2.6. Fastener

All bolts and screws in vacuum or used in ConFlat or helicoflex type vacuum flanges shall be silver plated and have the mechanical properties according to TG 2.37 [12]. All screws used in blind tapped holes have to be vented.

3.2.7. Labeling

Each vacuum chamber has to be marked with a Component ID number (CID) on the outer circumference of the CF100 flange, by chemical or electrical engraving, electrical etching or impact stamping. The nomenclature for the CIDs are in the responsibility of the Company and will be provided to the contractor according to [41].

3.2.8. Packing and Transport

After the vacuum chamber has been successfully passed the FAT (see section 6.1), it must be packed carefully and contained in such a way, that the chamber remains clean and free from damage (see TG 9.1e [34]). This requires a stable weather proved packaging. It is recommended to keep the chamber in a wooden box.
For shipping and storing all open flanges (two CF160 and one CF100 on every second unit) have to be covered such, that no dust or dirt can enter the vacuum chamber. GSI recommends matching aluminum covers with rubber sealing, fixed by screws to the flange. It has to be ensured, that the recipient remains free from contamination, even if the cryocatcher unit is stored or transported in a dusty environment.

4. Manufacturing

4.1. Cleanliness during manufacturing

The surface treatment and cleaning of all surfaces facing the vacuum is of crucial importance for attaining the in SIS100 required low ultimate pressures of ~10^{-12} mbar. During all stages of manufacturing a surface contamination has to be avoided. One has to pay carefully attention that the inner chamber surfaces remain totally free of greasy and oily substances. These surfaces must be absolutely free of contaminants, must not display any traces of corrosion, oxidation or temper colors. They have to be metallically glossy. Acidic or caustic liquids with subsequent neutralization treatment may not be used.
All mechanical cold working operations must exclude the use of heavy organic lubricants.

Strip and sheet material is to be cleaned before any cutting of forming operation commences. It is sufficient to swab with acetone or similar solvent. If a guillotine or press is to be used, the blades should also be cleaned with this solvent.
When the strip and sheet material or any other component forming part of or within the vacuum envelope has been cut, formed, finally machined and cleaned, the vacuum surfaces have never to be in contact with oily or greasy objects (including bare hands leaving finger prints) unless a thorough cleaning operation is scheduled to follow immediately afterwards.
Welding and assembling shall be done in a clean environment. Covers shall be provided to keep the room dust-free. The room shall be kept free from carbon steel contamination.
All machining coolants and cutting fluids shall be non-synthetic.

4.2. Welding

Welding of vacuum components requires specific guidelines, see TG 3.1e [13].
All parts to be welded must be cleaned prior to welding. All weld seams have to be vacuum tight down to temperatures of 4.5 K.
Whenever possible, single pass welds should be used.
TIG welding (commonly known as GTAW – gas tungsten arc welding) for round seams and electron beam welding (EB), laser welding (LW) or low current plasma arc (PAW, commonly known as microplasma welding) for lateral seams are regarded as suitable welding methods. The latter welding techniques shall be made without interruptions! TIG welding, EB, LW and PAW produce inherently good toughness even at cryogenic temperatures. All welds are to be homogeneous and free of inclusions. Grinding and filing is inadmissible.
In general, vacuum sealing welds shall be on the UHV side of the joint where feasible. Only if it is impossible to make sealing welds from the vacuum side welding from the outside is permitted. In this case, seams will be welded in such a way that there is a perfect root of the seam on the vacuum side. Externally made welds must have full penetration leaving a smooth surface on the vacuum inside. No porosity, cracks, inclusions, cold shuts, undercut, or underfill of the weld bead is permissible. Any later brushing or other finish work on the welds is prohibited generally. When it is necessary to weld both sides of a joint (only if required for structural reasons!!!), the vacuum side shall have a continuous weld to form the vacuum seal, and the opposite side shall have an intermittent or a drilled weld (stitch weld) to permit leak checking of the vacuum seal weld.
In general, welding has to comply with the standards DIN ISO 15607 and, depending on the specific welding technique with DIN ISO 15609-2, 15609-3 or 15609-4.
If, at any stage of manufacture, a weld seam is shown to be defective or loose, no rectification shall be done. It is non-permissible to rework the weld seam.
It is important to note that welding has to be done under optimal welding conditions in order to reduce the formation of delta ferrites to a minimum level in the welding seam. These delta ferrites lead to a weakly ferromagnetic behavior of the steel in the immediate vicinity of the welding joint which should be essentially avoided as far as possible.
Electron beam welding (EWB): Vacuum chamber for electron beam welding shall be evacuated to a vacuum of 10^{-5} mbar prior to welding. The welded parts must cool down for at least 30 minutes after welding prior to venting the welding chamber, or until the parts are sufficiently cool that no visible oxidation will occur. Venting has to be done using an inert gas like nitrogen. The parts must be properly fixed to keep the weld seam tight during welding. Tacking the part prior to the seal weld pass is advised.

4.3. Brazing

The brazing alloy must be composed of materials with saturation vapor pressure < 10^{-5} mbar at the brazing temperature; no organic content is allowed (see EN DIN 1044 and EN DIN 1045).
The vacuum brazing furnace should have a temperature control system with a precision better than ±25°C; it must have installations providing protection against sudden pressure surge or leaks; the brazing jig and associated fixture devices must be appropriate.
The brazing process must be performed according to the working temperature of the brazing alloy. The brazing cycle must be programmable. Brazing must be carried out under total pressures lower than 10^{-5} mbar. The residual gas content due to hydrocarbons or any other diffusion pump vapors should not exceed 10% of the total pressure.
The brazing temperature and the absolute residual gas pressure must be recorded during the complete brazing cycle. In addition, relevant comments have to be documented.
Each brazing seam has to be low temperature tight.
After brazing the vacuum chamber in the furnace has to be cooled down in such a way that no annealing colors or other surface contamination can occur. Venting has to be done using an inert gas like nitrogen.
If, at any stage of manufacture, a brazing seam is shown to be defective or loose, no rectification or filling shall be done. It is non-permissible to rework the brazing seam.

4.4. Galvanic Coating

The front part of the cryocatcher block has to be coated galvanically with nickel and gold. A coating thickness of each layer shall be 1 µm. The organic content (C,N,O) of the coating has to be lower than 5%. In order to reach the required cleanliness, a matt finish surface shall be produced.
Before coating the actual cryocatcher blocks, two small dedicated test samples (10 mm x 10 mm x 1 mm) have to be approved by GSI. The first test sample is a simple nickel coating onto copper; the second test sample has the gold coating on top. The approval is not necessary, if the galvanic coating takes place at the electroplating shop at GSI. Contract manufacturing at GSI may be possible, but responsibility, costs, finding an appointment, and negotiating is in the responsibility of the contractor.
The copper block has to be cleaned according to TG 6.8 [24] before galvanization.

4.5. Explosive Copper Plating

For the prototype, the plating was performed by “DMC Dynaplat Dynamic Materials” in Burbach[1]. Prior to manufacturing the prototype, different cryo-tests were performed with samples in order to assure the cryo-suitability of the plating technique. The copper plating must not detach from the stainless steel during cooldowns, at cryogenic temperatures, and during warmups. The test-samples were cooled in different shock-cycles in liquid nitrogen and liquid helium (cooling rate 150 K/min) and warmed up afterwards with 200 K/min. The binding zone was investigated with ultrasonic and SEM before and after these thermal cycles. No degradation could be observed. For the prototype the chamber material was satisfactory.
If another plating technology and/or company will be chosen, the manufacturer has to prove the cryo-suitability of the plating by comparable tests before the manufacturing

[1] Currently a delivery time of 6 months for the chamber material for all units has to be considered.

starts. A written approval by GSI is required. Explosively plated sheets eventually have to be reworked in order to reach the required flatness for the production.

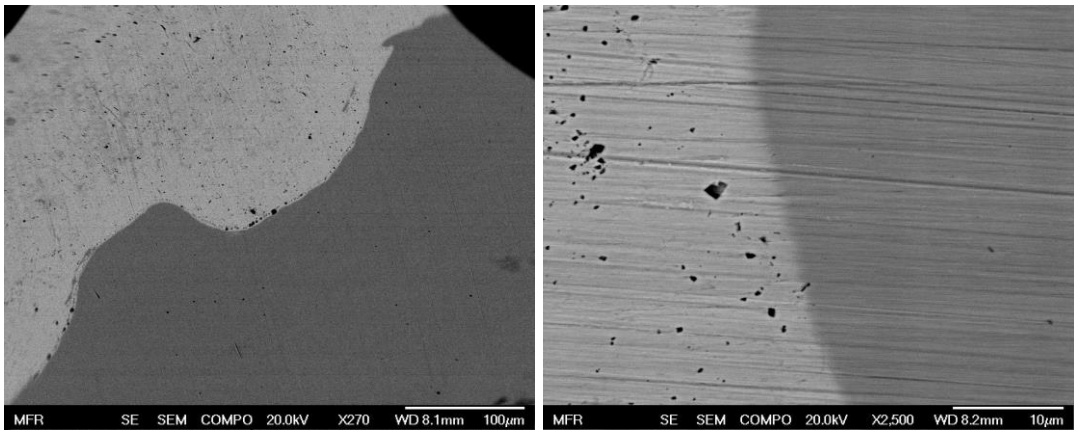


Figure 7: SEM pictures of the binding zone of a shock-cooled explosively plated test sample.

5. General cleaning procedure at GSI

The assembled vacuum chambers and their components are to be cleaned exclusively according to UHV standards procedure as described in TG 6.1e [20].
The outer copper surface of the UHV chamber has to be cleaned according to TG 6.8e [24].

6. Quality Assurance, Tests and Acceptance

6.1. Factory Acceptance Test (FAT)

The sequence of Factory Acceptance Tests shall be as follows:

I. Visual Inspection Test
   Upon completion of the chamber, the manufacturer shall inspect internally and externally the vacuum chamber to ensure that there are no defects which might render it unfit for UHV application. Particular attention shall be paid to the form and state of the inner surfaces of the vacuum chamber, the quality of welding and brazing seams on the sealing surfaces of flanges. All welding regions must be free from scale, voids, blow holes, etc, and there should be no visible evidence for inclusions. Each brazing seam has to be completely homogeneous without any trapped volume (see EN 13134). Any trace of colored oxide is not acceptable. All internal surfaces must be free from scratches and dents and there should be no visible evidence of inclusions. The sealing flanges must be inspected. Knife edges must be free from any scratches.

II. Mechanical Acceptance Tests
   The manufacturer is requested to carry out a Mechanical Acceptance Test according to TG 7.1e [26]. In addition, the manufacturer must demonstrate the leak-tightness and the flow rate test of the cooling tube system. In order to demonstrate the leak-tightness of the cooling tube circuit. The manufacturer has to use the pressure drop method described in TG 7.23e [29]. The cooling tubes have to

undergo a pressurized leak test, described in TG 7.24e [30]. The AD 2000 code [39] has to be applied for the cooling pipes. The design pressure is 19 bar(g). A pressure test according to the AD 2000-Technical Bulletin HP 30 [40] has to be performed.
Finally a residual moisture test according to TG 7.27e [33] has to be executed.
The proof of the required helium mass flow through the tubes has to be carried out at room temperature according to TG 7.26e [31]. The manufacturer has to demonstrate via a pressure drop (at room temperature) along the cooling circuit with an entrance pressure of 1.4 bar, that the spread of the measured flow rate from unit to unit is less than 10%.

III. Vacuum Properties Acceptance Tests
The manufacturer has to prove the vacuum properties of the fabricated vacuum chamber according to the Vacuum Acceptance Tests described in TG 7.3e [27]. Deviating from TG 7.3e the vacuum chamber has to be baked at only 250 °C. The indium foils must not be installed during bakeout, but only be mounted after successful vacuum properties acceptance tests. Eventual annealing colors on the outer copper surface have to be cleaned according to TG 6.8e [24]. Inspection and testing shall be performed using properly calibrated measuring and test equipment. For the vacuum inspection only the use of dry (oil free) pumping combinations is allowed.

IV. Electrical Properties Acceptance Tests
The manufacturer shall carry out a set of electrical measurements to verify that the insulation requirements between the front part of the cryocatcher block and the vacuum chamber are met completely. The contractor shall demonstrate that insulation resistance between the cryocatcher front and chamber wall is R_{ins} > 20MΩ.

V. All results of the Visual Inspection Test, Mechanical Acceptance Tests, Vacuum Properties Acceptance Tests, and Electrical Properties Acceptance Tests shall be summarized in a Record protocol for FAT Vacuum Components as given in TG 7.3e [27].

NOTE: Greatest caution is called for vacuum and leak tests using a leak detector. Due to the generation of high pressure differences during roughing, the integrated bellows of the cryocatcher may squeeze abruptly and can cause a considerable damage to the cryocatcher unit and/or to the person who is conducting the tests. Unless no special security measures have been taken, the vacuum properties acceptance tests of the cryocatcher unit may not be started. Before the vacuum chamber is roughed, each finally assembled cryocatcher unit has to be fixed in a suitable jig designed to prevent an axial, angular and lateral deformation of both bellows. In addition, the roughing of each catcher unit must be done very slowly using a manually adjustable throttle valve which reduces the effective pumping speed of the roughing pump. Both measures must be taken for a risk-free vacuum testing!

6.2. Site Acceptance Test (SAT)

One week prior to delivery of the cryocatcher units the manufacturer has to deliver the complete documentation to the ordering party (according to chapter 7). Otherwise the chambers will not be accepted and shipping may not start. The delivery has to be approved by the ordering party. Formal acceptance of the delivered vacuum chamber will

be take place only after successful completion of the Site Acceptance Tests (SAT) at GSI. The sequence of Site Acceptance Tests will be as follows:

I. Visual Inspection Test
After delivery, an internal and external visual inspection of the chamber will be carried out to ensure that there are no chamber defects. Particular attention will be paid to the form and condition of the inner surfaces of the vacuum chamber. All internal surfaces must be free from scratches and dents. The sealing flanges will be inspected intensively. All knife edges must be free from any scratches.

II. Mechanical Acceptance Tests
After the Visual Inspection Test each chamber has to undergo a second Mechanical Acceptance Test according to TG 7.1 [26]. In addition, the leak-tightness and the flow rate test of the cooling tube system will be carried out again. The pressure drop method and the proof of guaranteeing the required helium mass flow through the cooling tubes will be repeated.

III. Vacuum Properties Acceptance Tests at room temperature
Each chamber has to undergo a second Vacuum Properties Acceptance Test. The results of these tests will be compared with those provided by the manufacturers FAT.

IV. Electrical Properties Acceptance Tests
In addition, each chamber has to undergo a second Electrical Properties Acceptance Test. This is used to check the electrical insulation of the cryocatcher front part from the chamber. The insulation resistance has to be R_{ins} > 20MΩ.

V. Vacuum Properties Acceptance Tests at cryogenic temperatures
In order to check and examine the suitability and applicability of the chambers at cryogenic temperatures, their functionality will be tested in a cryostat at GSI. For this purpose each chamber is cooled down to LN_2 temperatures and warmed up again in multiple thermal cycles using the cooling tube. After warm up, a final leak test will be repeated to make sure that no leaks occurred due to the thermal cycle.

If the SAT fails it will be the responsibility of the manufacturer to arrange any necessary repair. In the case of return to the manufacturer premises the full set of Factory Acceptance Tests must be repeated before delivery.

7. Documentation

All documentation, either in electronic or in paper form, will become property of the ordering party, GSI. The documentation has to be according to Chapter 8 of the FAIR General Specification [2].

7.1. Engineering Documentation

The manufacturer has to submit the following documents.

7.1.1. Material related Documentation and Certificates

I. All relevant material certificates of construction materials used for the production of the vacuum chamber which confirm all relevant material properties have to be delivered. For further details see TG 3.1e [13].
II. Certificates for the used brazing material have to be delivered.
III. Certificates for the used galvanic coating materials have to be delivered.

7.1.2. Process related Documentation

I. The process description for each brazing process applied has to be delivered
II. The process description for each welding process applied has to be delivered as well as welder's certification.
III. The process description for each galvanic coating process applied has to be delivered.

7.1.3. Technical drawings and CAD – Data

I. A set of technical drawings of special tooling and equipment has to be delivered.

7.1.4. Structure of documentation

I. All documentation has to be delivered as printed versions (full scale) and as electronic copy on CD-ROM, readable under Microsoft Windows® 7.
II. All technical drawings have to be delivered as *.CATDrawing or *.dwg files.
III. In case of text, tables, diagrams and pictures the electronic version has to be in the PDF-format without any access restrictions.
IV. All documentation has to be delivered within compiled and structured files.
V. Any certificates have to be delivered as original versions compiled in files and shall be electronically scanned for electronic compilation.
VI. The documentation and certificates have to be compiled separately (printed and electronic version) for the content defined in
VII. All documentation has to be delivered in German or English.

7.2. FAT – Documentation

For FAT documentation the protocol given in TG 7.3e [27] has to be used. In addition all documents required by the TG 7.3 "Vacuum Properties Acceptance Tests with Bakeout" [27] have to be delivered.

7.3. SAT – Documentation

For SAT documentation a SAT protocol will be prepared according to TG 7.3 [27]. If the SAT fails, the SAT record will be delivered to chamber manufacturer with the demand of repair or rework.

I. Related Documentation

[1] "Entwicklung und Test eines Kryokollimator-Prototypen zur Kontrolle des dynamischen Vakuums im SIS100", L. Bozyk, Dissertation 2012, http://tuprints.ulb.tu-darmstadt.de/2968/

[2] F-GS-F-01e-General_Specification_v1_2.pdf: "General Specification for the FAIR Accelerator Facility Project"

[3] FAIR Technical Guideline F-TG-V-2.1e: "Stainless steel for Beam Vacuum Chambers"
[4] FAIR Technical Guideline F-TG-V-2.3e: "Copper for vacuum applications"
[5] FAIR Technical Guideline F-TG-V-2.5e: "Vacuum Firing for Hydrogen Degassing of Materials and UHV Vacuum Chambers"
[6] FAIR Technical Guideline F-TG-V-2.6e: "Material for bakeable CF-flanges"
[7] FAIR Technical Guideline F-TG-V-2.7e: "Ceramics for Vacuum Applications"
[8] FAIR Technical Guideline F-TG-V-2.24e: "Materials in UHV"
[9] FAIR Technical Guideline F-TG-V-2.26e: "Forged blanks for Vacuum Applications 1.4429 /ESU"
[10] FAIR Technical Guideline F-TG-V-2.28e: "Stainless Steel for Beam Vacuum Chambers at Cryogenic Temperatures"
[11] FAIR Technical Guideline F-TG-K-2.35e: "Steel Materials for Pressurised Cryogenic Components"
[12] FAIR Technical Guideline F-TG-V-2.37e: "Specifications of Bolts, Studs, Nuts and Washers for cryogenic UHV components"
[13] FAIR Technical Guideline F-TG-V-3.1e: "Constructive Design of Weldings Seams for Vacuum Chambers"
[14] FAIR Technical Guideline F-TG-V-3.4e: "Manufacturing of CF-knife edge flanges"
[15] FAIR Technical Guideline F-TG-V-3.9e: "Welding of CF-Flanges on Tubes"
[16] FAIR Technical Guideline F-TG-V-3.17e: "Design of Thick-walled Vacuum Chambers"
[17] FAIR Technical Guideline F-TG-V-3.42e: "Copper Gaskets for ConFlat® flanges"
[18] FAIR Technical Guideline F-TG-K-3.56e: "Low Power Cabling for Cryogenic Purposes"
[19] FAIR Technical Guideline F-TG-V-5.1e: "Surface Conditions of Vacuum Chambers"
[20] FAIR Technical Guideline F-TG-V-6.1e: "Cleaning of UHV components /Stainless steel"
[21] FAIR Technical Guideline F-TG-V-6.2e: "Cleaning of Standard Vacuum Components"
[22] FAIR Technical Guideline F-TG-V-6.3e: "Cleaning Procedure for Bellows"
[23] FAIR Technical Guideline F-TG-V-6.4e: "Cleaning of Ceramics for use in UHV"
[24] FAIR Technical Guideline F-TG-V-6.8e: "Cleaning of Copper Components"
[25] FAIR Technical Guideline F-TG-V-6.10e: "Cleaning of Assemblies and Sub-assemblies in Vacuum"
[26] FAIR Technical Guideline F-TG-V-7.1e: "Mechanical Acceptance Tests for UHV Components"
[27] FAIR Technical Guidelines F-TG-V-7.3e "Vacuum Properties Acceptance Tests with Bakeout"
[28] FAIR Technical Guideline F-TG-V-7.15e: "Record for FAT Vacuum Components"
[29] FAIR Technical Guideline F-TG-K-7.23e: "He Leak Testing of Cryogenic Tubing"

[30] FAIR Technical Guideline F-TG-K-7.24e: “Pressurised Leak Testing of Cryogenic tubing”
[31] FAIR Technical Guideline F-TG-V-7.25e: “Vacuum properties Acceptance Tests for Cryogenic Beam Vacuum components”
[32] FAIR Technical Guideline F-TG-K-7.26e: “Flow Rate Test for Cryogenic Processing Pipes”
[33] FAIR Technical Guideline F-TG-K-7.27e: “Residual Moisture Test for Cryogenic Processing Pipes”
[34] FAIR Technical Guideline F-TG-V-9.1e: “Transport and Packaging of Vacuum Components”
[35] FAIR Technical Guideline F-TG-V-13.1e: “Assembly Instructions for knife edge UHV flanges”
[36] FAIR Technical Guideline F-TG-K-13.5: “Temperature Sensor Installation for Cryogenic Purposes”
[37] Pressure Equipment Directive of the European Parliament and of the Council 97/23/EC (May, 29th 1997)
[38] Technical Specification ISO/TS 3669-2:2007€
[39] AD 2000-Code; Verband der TÜV e.V.:, Beuth Verlag GmbH; Berlin; Germany; 2009
[40] AD 2000-Technical Bulletin HP30, Durchführung von Druckprüfungen; Verband der TÜV e.V.; Beuth Verlag GmbH; Berlin; Germany; 2009
[41] FAIR Technical Guideline F-TG-B-0.5e: “Permanent Tagging and Labelling of Components“