TITLE: # The 4KRL Cryo Facility

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1 SCOPE

1.1 Purpose

Purpose of the 4KRL is to provide a stable reference signal to the LFI radiometers. It is fully described in RD 1.
Purpose of the instrument described in this note is to provide a test facility for the 4KRL unit.
Purpose of this document is to describe the general characteristics and performance of this facility.

1.2 Document Overview

Requirement for the 4KRL cryo facility are reported in Section3. A general description of the instrument is reported in Section 4, including mechanical drawings and pictures. Analysis of performance are reported in Section 5.

1.3 TERMS and ACRONYMS

4K RL	4K Reference Load
CMB	Cosmic Microwave Background
EBB	Elegant Bread Board
FEM	Front End Module
FM	Flight Model
FPU	Focal Plane Unit
FS	Flight Spare
HFI	High Frequency Instrument
I/F	Interface
IL	Insertion Loss
LFI	Low Frequency Instrument
MS	Mounting Structure
N/A	Not Applicable
PD	Prototype Demonstrator
QM	Qualification Model
RH	Reference Horn
RL	Return Loss
RT	Reference Target
SS	Spin-Synchronous
TBC	To Be Confirmed
TBD	To Be Defined
TBR	To Be Refined
ThL	Thermal Link
WG	Waveguide

2 APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable documents

AD 1: FIRST/Planck Instrument Interface Document, Part A (SCI-PT-IIDA-04624, 2/0)
AD 2: FIRST/Planck Instrument Interface Document, Part B (SCI-PT-IIDB/LFI-04142, 2/0)
AD 3: LFI Interface Control Document (PL-LFI-PST-ID-010, 2.0)
AD 4: LFI/HFI Interface Document (PL-LFI-PST-ID-001, 1.0)
AD 5: LFI Specification (PL-LFI-PST-SP-001, 3.0)
AD 6: Planck LFI Instrument Design and Development Plan (PL-LFI-PST-PL-002, 2.0)
AD 7: Planck LFI Product Assurance Plan (PL-LFI-PST-PL-003, 3.0)
AD 8: Planck LFI Assembly Integration & Verification Plan (PL-LFI-PST-Pl-004, 3.0)
AD 9: FIRST/Planck Operations Interface Requirements Document (SCI-PT-RS-07360, 2/1)
AD 10: LFI Configuration and Data Management CADM Plan (PL-LFI-PST-PL-001, 3.0)
AD 11: LFI Instrument Deliverable Documentation List (DDL) (PL-LFI-PST-LI-007, 1.0)
AD 12: 4K Reference Load Requirement Specification (PL-LFI-TES-SP-001, 2.0)

2.2 Reference documents

RD 1: 4K Reference Load Design Report (PL-LFI-TES-RP-001, 2.0)
RD 2: HFI Temperature stability requirements (SR-PH211-990141-IAS, Issue 01)
RD 3: LFI signal oscillations induced by Sorption Cooler temperature variation (PL-LFI-PST-TN-010, Issue 1.0)
RD 4: Sumitomo Heavy Industries web page, www.shi.co.jp/english/

3 4KRL cryo facility requirement specification

3.1 Absolute temperature

The operating temperature of the 4KRL cryo facility must be below 8 K with 1.5 W (TBC) thermal load. This requirement ensures verification of the 4KRL unit thermal properties.

3.2 Temperature stability

Temperature fluctuations at the interface between the 4KRL cryo facility cold stage and the 4KRL unit shall be less than 20 mK (2σ, rms) (TBC) in the range 0.016-100 Hz.

3.3 Temperature measure accuracy

Some of the temperature sensors inside the 4KRL cryo facility shall be able to reach high accuracy and sensitivity.

3.3.1 Number of sensors

The 4KRL cryo facility shall be equipped with TBD high performance units and TBD *standard* level units.

3.3.2 Accuracy

The absolute temperature of the parts inside the 4KRL cryo facility shall be measured with an accuracy of 0.25 K (stat infos).

3.3.3 Sensitivity

A high-performance temperature sensors inside the 4KRL cryo facility shall have a sensitivity of 0.3 mK at 4.2 K and 0.65 mK at 20 K.

3.4 Volume

The volume of the 4KRL cryo facility shall allow mounting of the largest part of the 4KRL unit

3.5 Cleanliness

The 4KRL cryo facility shall meet the requirement of class 100000.

4 General description

The 4KRL cryo facility is based on a closed cycle cryocooler from the Sumitomo Industries, model SRDK-415. The cryocooler is mounted in a vacuum tight container designed to hold the 4KRL unit. An exploded view and assembly view of the system is reported in Figure 3 and Figure 4.

The cryo facility is composed by the following parts:

- Cryo-cooler
- Vacuum container
- Intermediate temperature plate and shield
- Cold plate and shield
- Vacuum pump and pressure sensor
- Temperature sensors wiring
- Temperature sensors

4.1 Cryo-cooler

Main characteristics of cold head are reported in Table 1.

Lowest temperature		3K
Cooling capacity (50Hz)	1st stage	1.5 W @ 4.2 K
	2nd stage	35 W @ 50K
Weight (cold head)		18 Kg
Dimension		180D x 294L x 557H (mm)

Table 1: main characteristics of the SHI RDK-415D cold head unit from RD 4

A load map for this unit is reported in Figure 1. A drawing of the cold head is reported in XX.

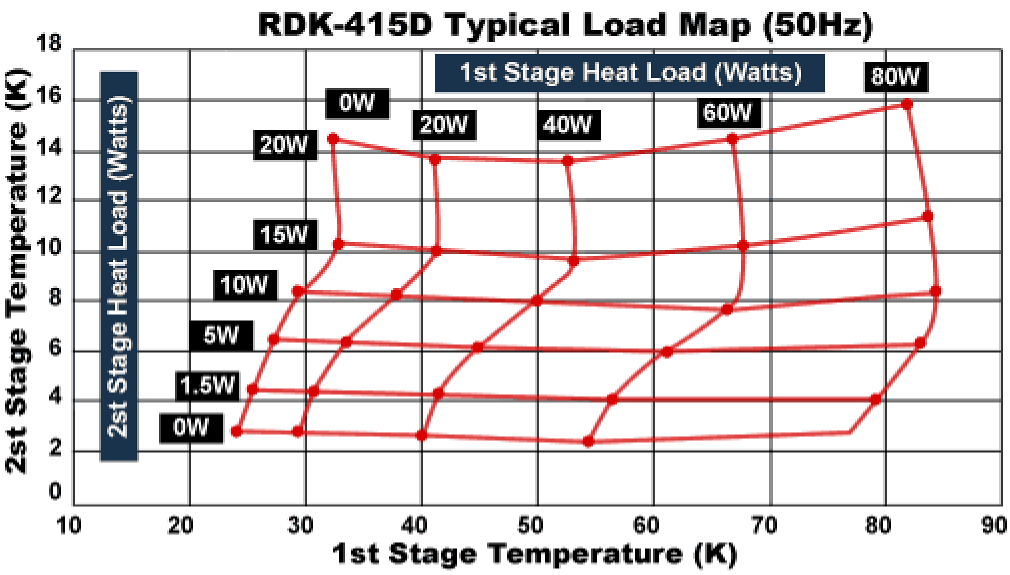

Figure 1: Load map for the SHI RD-415D cold head (from RD 4)

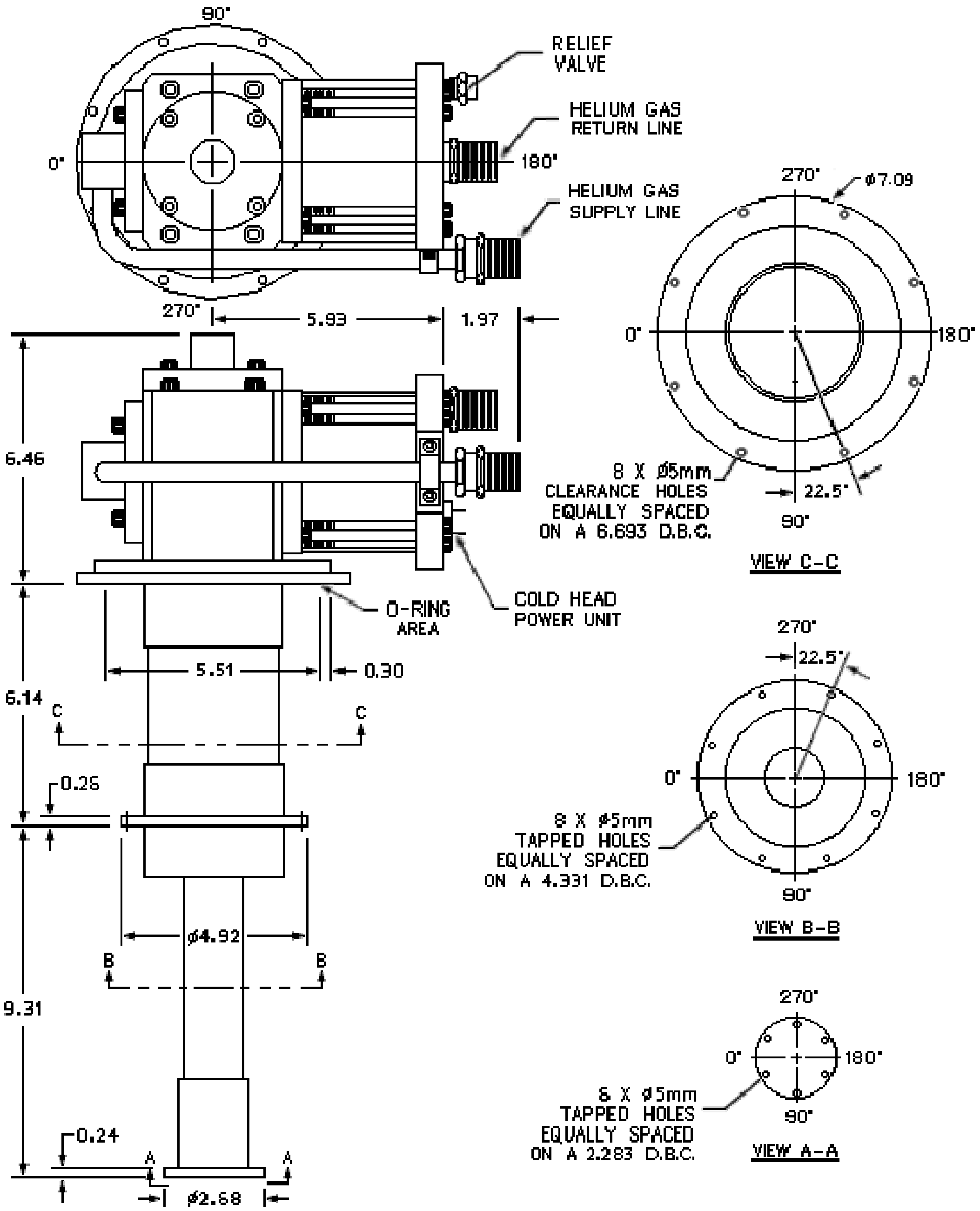

Figure 2: Cold head drawing from RD 4.

4.2 Vacuum container

A drawing of the vacuum container is reported in Figure 3 and Figure 4. It is composed by a cylindrical cover and a base plate (see Figure 5), both made of aluminum. Seven circular aperture, designed according to DN50 standard dimensions, are obtained on the base plate. These are used for vacuum pump connection, wiring connectors mounting and may allow vacuum interface for any device up to a diameter of 50 mm (i.e. WGs). A regular grid of female screw holes is machined in the inner surface to allow easy mounting of wire connectors. The inner surface of the vacuum container is covered with high reflectivity Al sheet.

4.3 Intermediate temperature plate and shield

An intermediate radiation shield is connected to the first stage of the cryo-cooler. The plate (see Figure 6 for a drawing) holds the radiation shield (Figure 8). They are made of aluminum 99.5%. A uniform grid of female screws allow for mounting of sensors and devices. Three circular aperture (diameter 50mm), aligned to three of the vacuum container apertures, are made on the plate. This may be used for thermal connection of WGs at an intermediate temperature. Aperture are covered when not in use. The shield and the plate are covered (inside and outside) with high reflectivity Al sheet to reduce radiative heat load.

4.4 Cold plate and shield

The cold plate (Figure 7) is connected to the cold stage of the cryocooler. It is made of OFHC copper for optimal thermal conduction. A radiation shield (Figure 9), made of Aluminum 99.5% is mounted on the cold plate. A uniform grid of female screws allow for mounting of the 4KRL parts under test, of sensors and devices. Three circular aperture (diameter 50mm), aligned to the intermediate plate and to three of the vacuum container apertures, are made on the plate. Aperture are covered when not in use. The shield and the plate are covered (inside and outside) with high reflectivity Al sheet to reduce radiative heat load.

4.5 Vacuum pump and pressure sensor

The 4KRL cryo facility is equipped with a dry pump by BOC Edwards, model XDS5. This unit is lubricant-free and ensures an ultimate vacuum of 0.057 mbar at the inlet. This ultimate pressure is sufficient to start the operation of the cryocooler.

4.6 Temperature sensors

Temperature sensors used are LakeShore DT670 silicon diodes. Read with a LakeShore temperature controller model 340, we are able to reach high-performance sensitivities, as shown in Section 3.3.3.

4.7 Temperature sensors wiring

The temperature sensors wiring is designed to minimize the EMC interference in the tests.
We have mounted a 24-pin Fischer vacuum connector. In the inner part of the cryostat there are two bridges consisting of 9-pin Cannon connectors, where sensors are cabled.
We report the connectors scheme in the table below.

Fischer pin Nr.	Cannon pin Nr.	Sensor 1	Sensor 2	Sensor3
1	1a	I+		
2	2a	V+		
3	3a	I-		
4	4a	V-		
5	5a			
6	6a			
7	7a			
8	8a			
9	9a			
10	1b		I+	
11	2b		V+	
12	3b		I-	
13	4b		V-	
14	5b			
15	6b			I+
16	7b			V+
17	8b			I-
18	9b			V-
19				
20				
21				
22				
23				
24				

We are going to cable another 24-pin and two 9-pin Fischer connectors, together with other Cannon inner bridges for final measurement configuration.

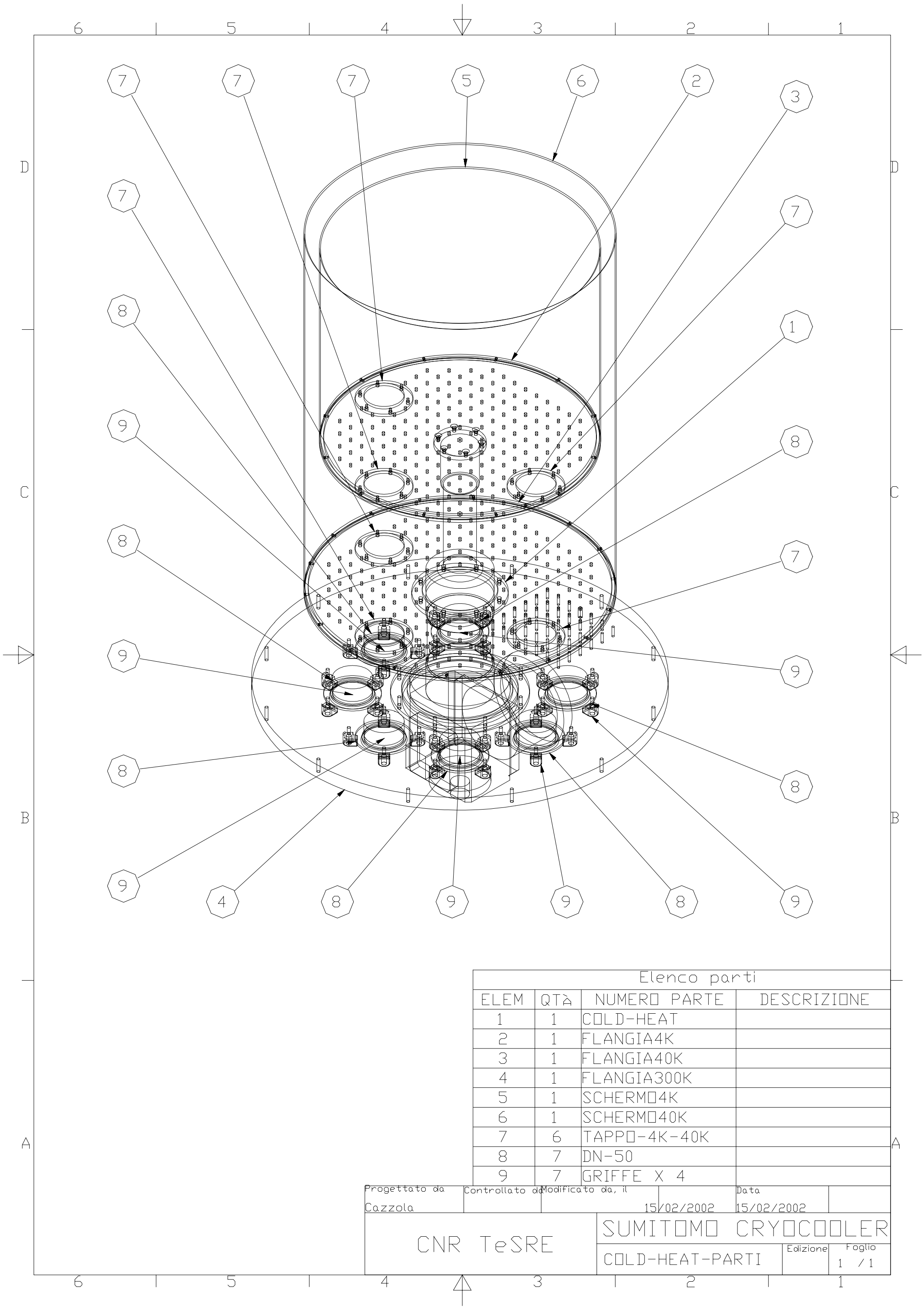

Figure 3: Exploded view of the 4KRL cryo facility

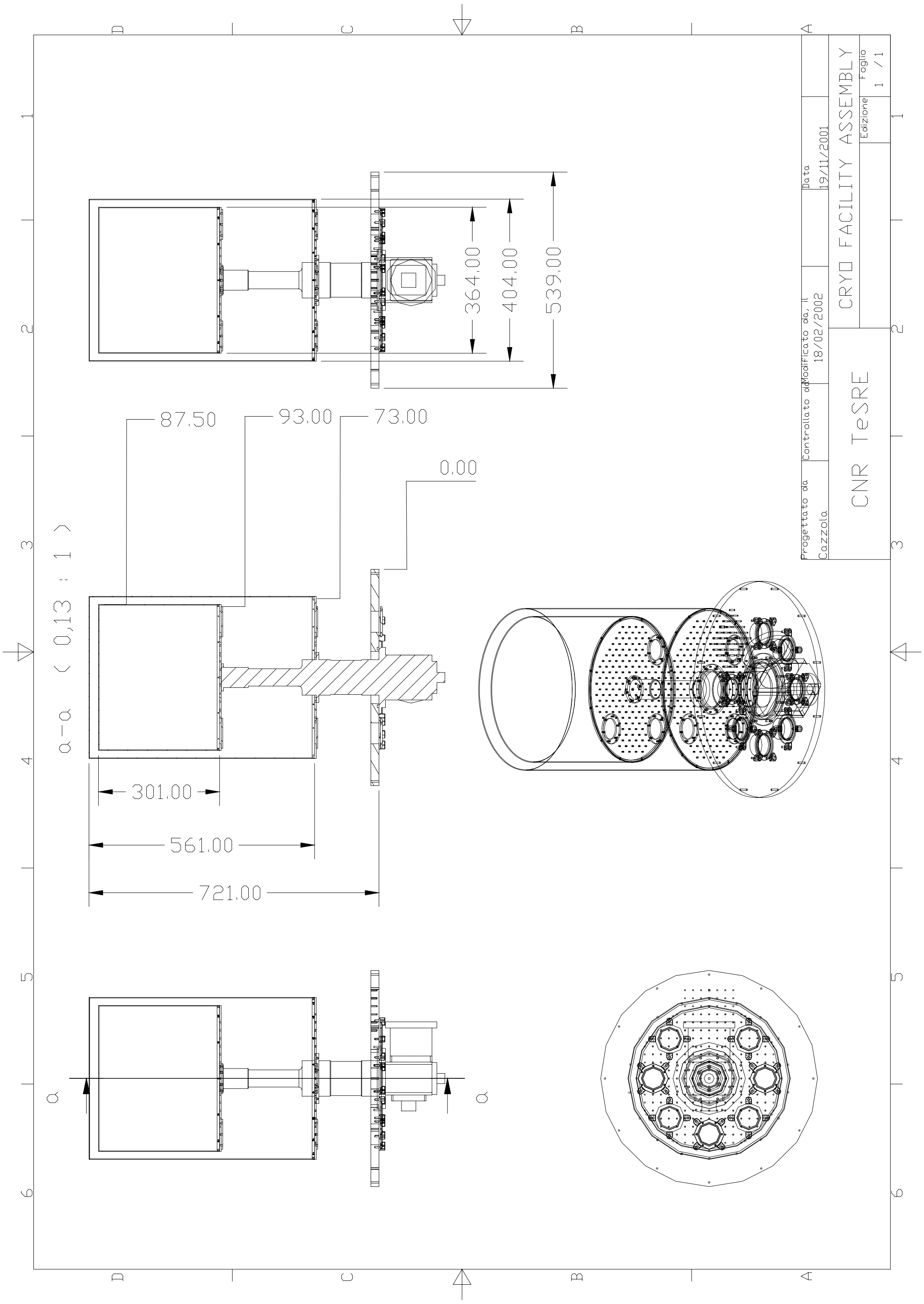

Figure 4: Assembly drawing of the 4KRL cryo facility.

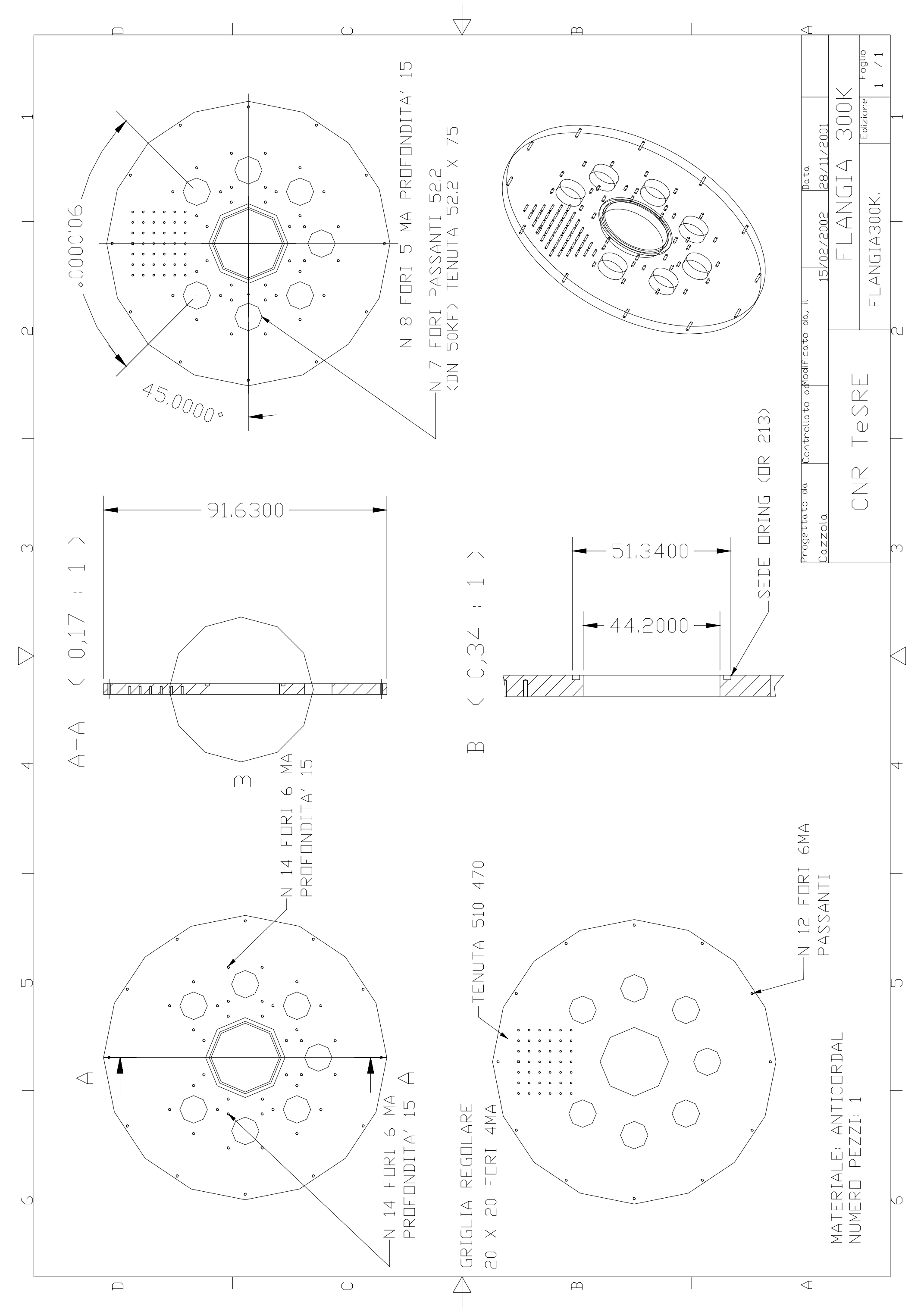

Figure 5: Drawing of the 300K flange, made of Anticorodal aluminum

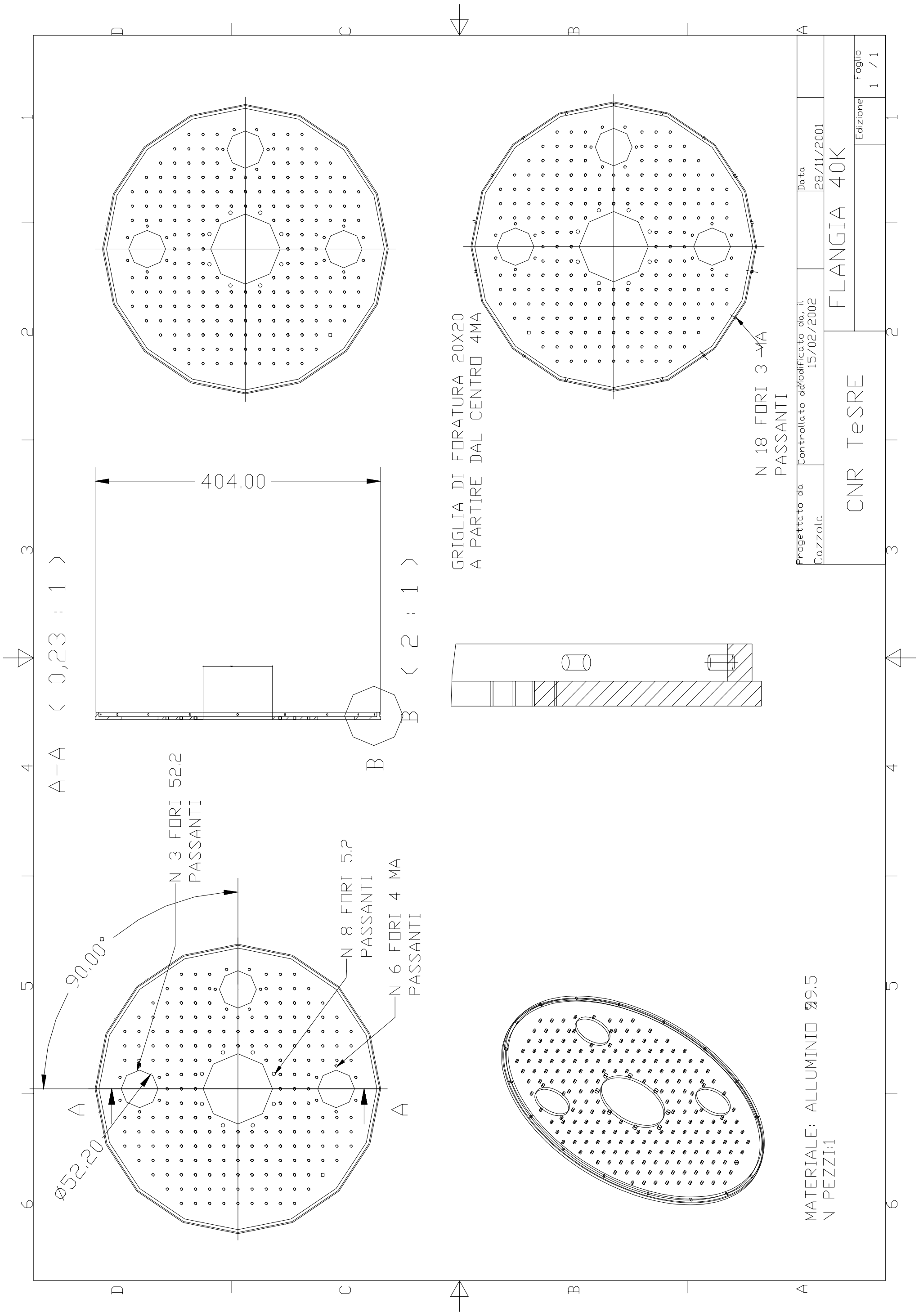

Figure 6: Drawing of the 40K flange made of aluminum 99.5%

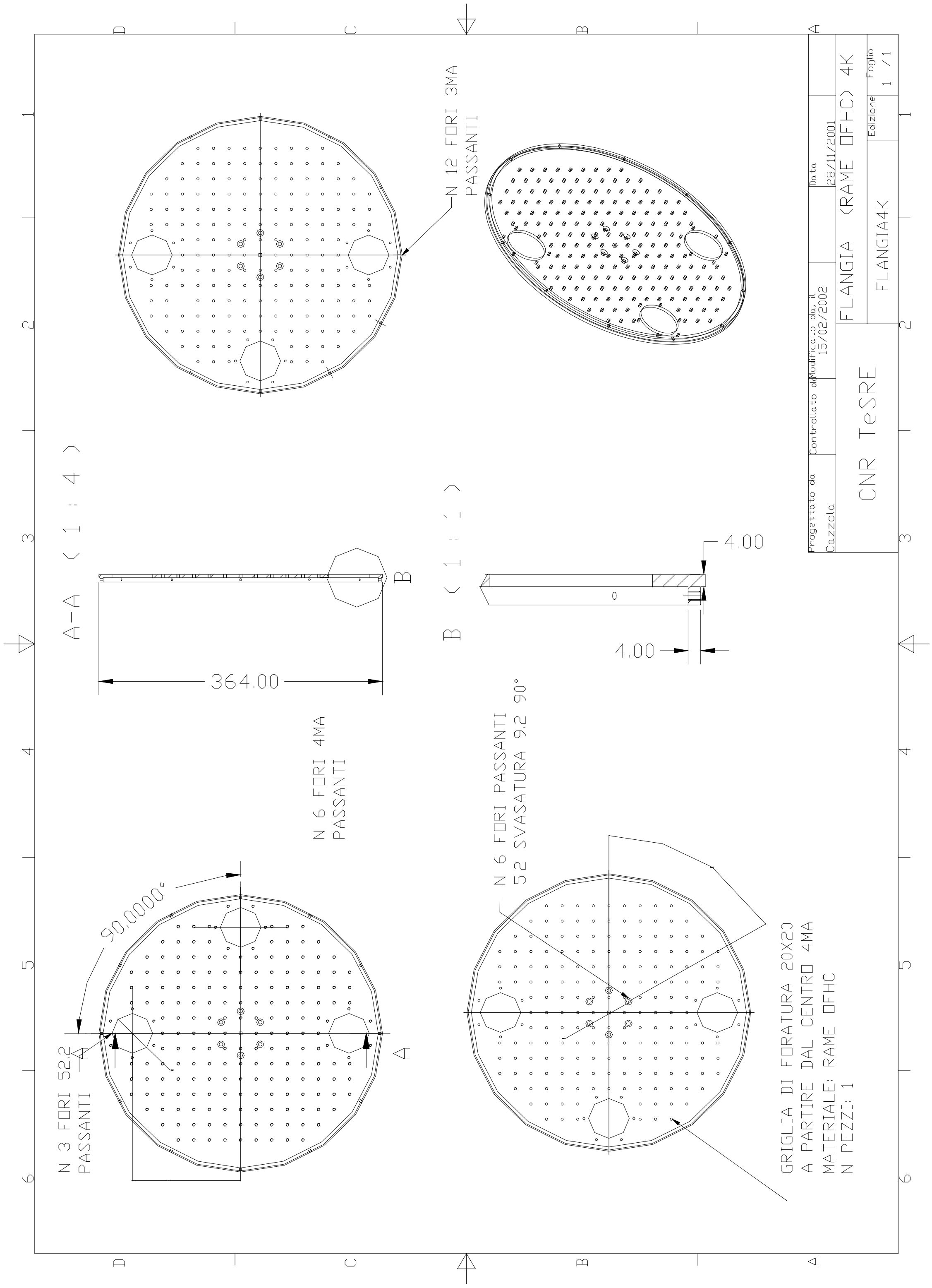

Figure 7: Drawing of the 4K flange made of OFHC copper

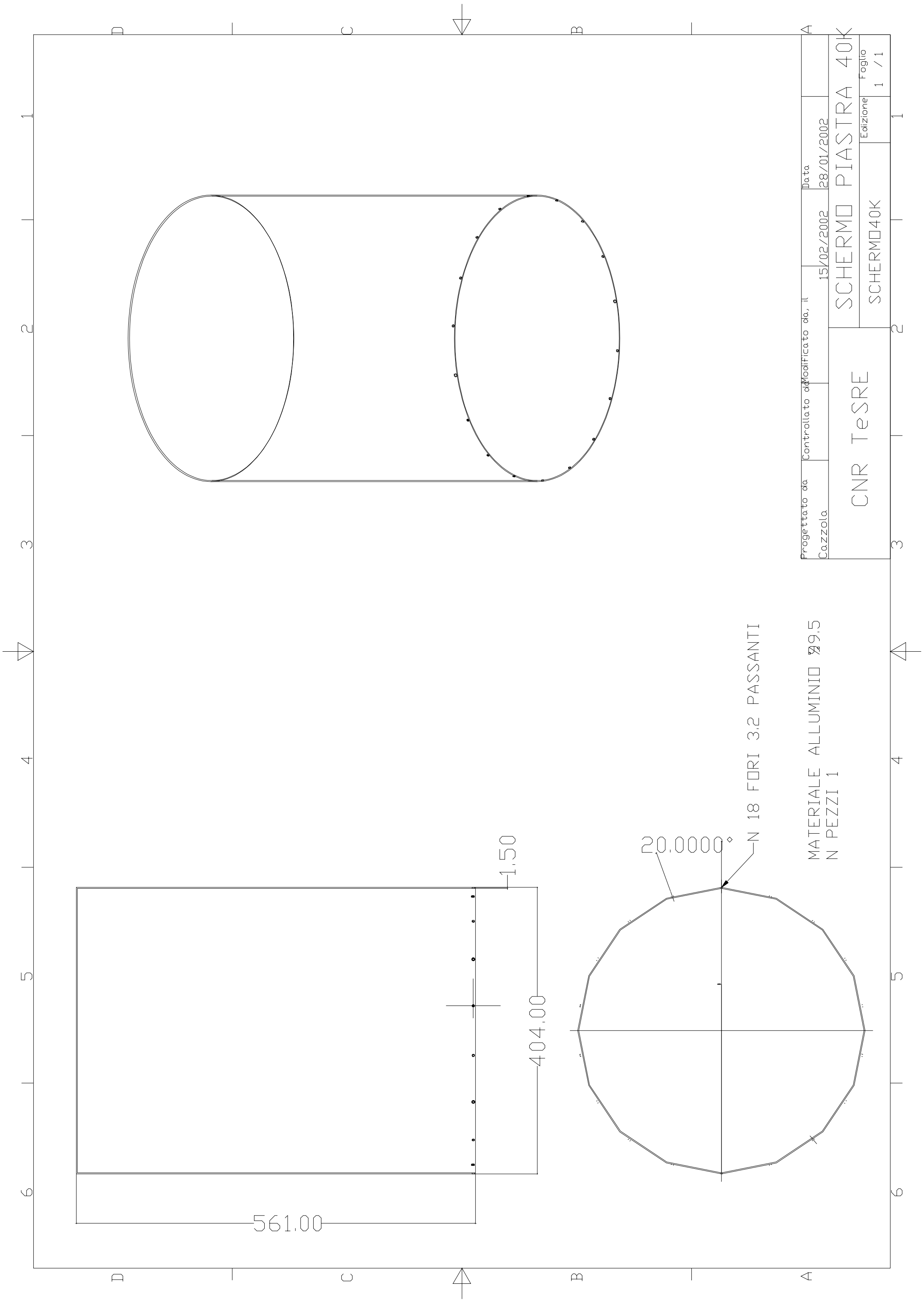

Figure 8: Drawing of the 40K radiation shield, made of aluminum 99.5%

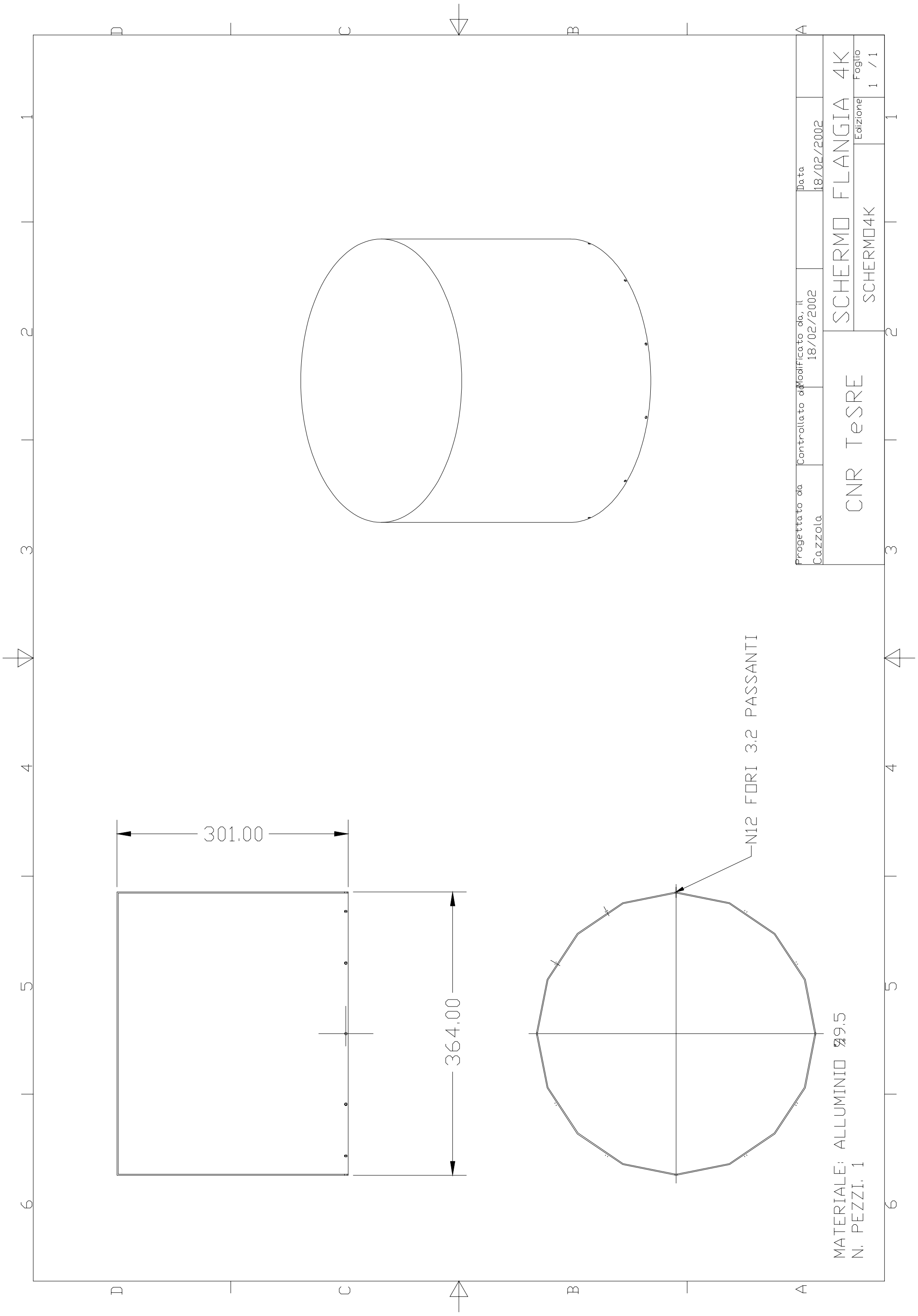

Figure 9: Drawing of the 4K radiation shield, made of aluminum 99.5%

5 4KRL Cryo Facility performance

The performance of the 4KRL cryo facility were measured during the first run. During these tests the intermediate stage flange was made of standard Al and not Al 99.5%. This results in a lower conductivity between the flange itself and the shield.

5.1 Temperature sensors setup

Three sensors were mounted for this test:

1. On top the warm shield (1st, external shield)
2. On top of the cold shield (2nd, internal shield)
3. On the cold plate, approximately at half radial distance

Sampling rate was set according to the kind of test performed:
Low rate (0.1 Hz) for long term stability
Intermediate and fast rate (5 and 10 Hz) for high detailed tests

5.2 Cool-down

A typical cool-down profile (without thermal load) is reported in Figure 10. Cold plate temperature is quickly stabilized, while a gradient is evident in the cold shield temperature. This effect may be related to a non-ideal thermal contact between the cold plate and the shield.

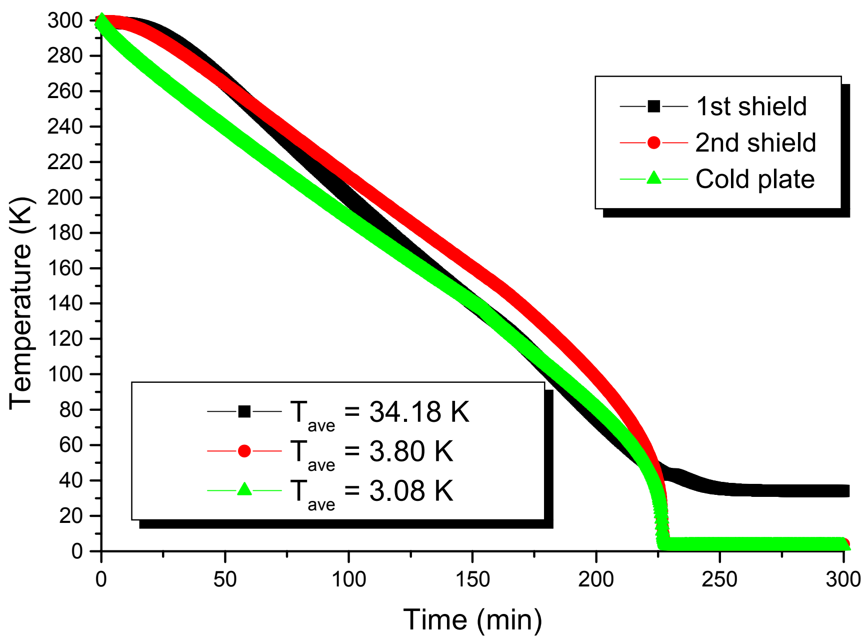

Figure 10: Cool-down profile. Sampling rate 0.1 Hz. T_{ave} refer to the stationary state (t>300 min).

5.3 Temperature stability

The long term temperature stability is reported in Figure 11 for the cold flange and the internal (cold) shield and in Figure 12 for the sensor on the cold shield.

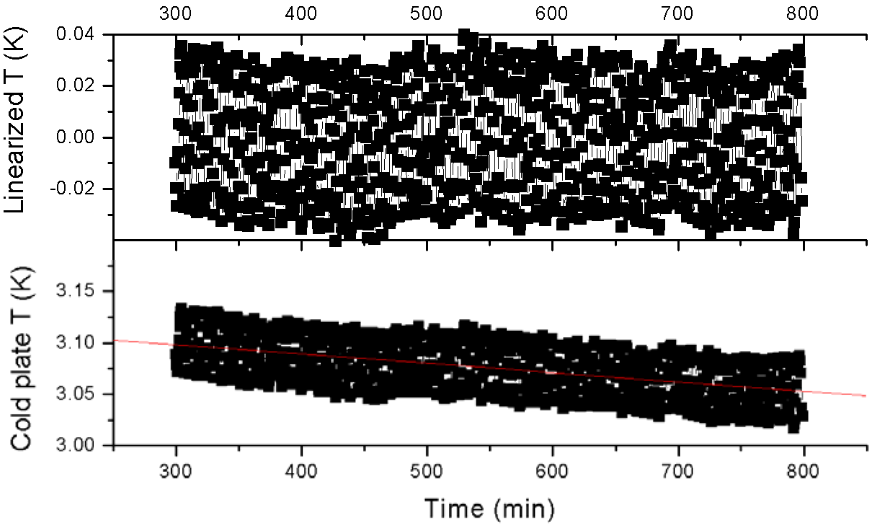

Figure 11: Fluctuations of the cold flange (lower panel). A linear drift is subtracted from the data to evaluate temperature fluctuations (upper panel)

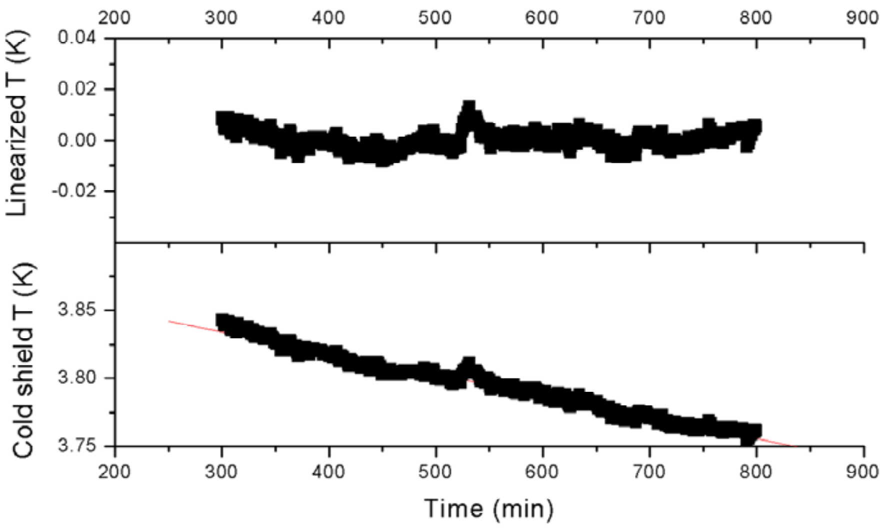

Figure 12: Fluctuation measured at the top of the cold shield. A linear drift is subtracted from the data to evaluate temperature fluctuations (upper panel)

As expected there is a temperature gradient between the flange and the top of the shield. As it is readily seen, there is a long-term temperature drift in both data sets.

The fluctuations on the shields are smaller than on the flange, as expected. RMS amplitude of these fluctuation 22.2 mK (1σ-level) and 3.4 mK (1σ-level) for the flange and the shield, respectively. This results of a peak-to-peak fluctuation of approximately 80 mK and 14 mK for the flange and the shield, respectively. These figures refer to about 8 hours of data.
A preliminary analysis of frequency behavior can be derived from Figure 13.

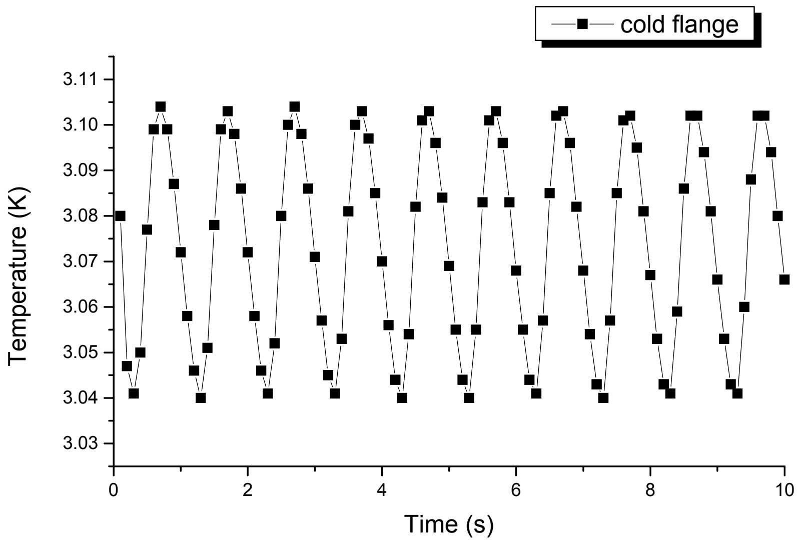

Figure 13: Temperature oscillations of the cold flange. Sampling rate: 10 Hz.

The main driver is the cooler frequency, that is 1 Hz. It is also evident the phase delay between the temperature on the shield and on the flange (Figure 14).

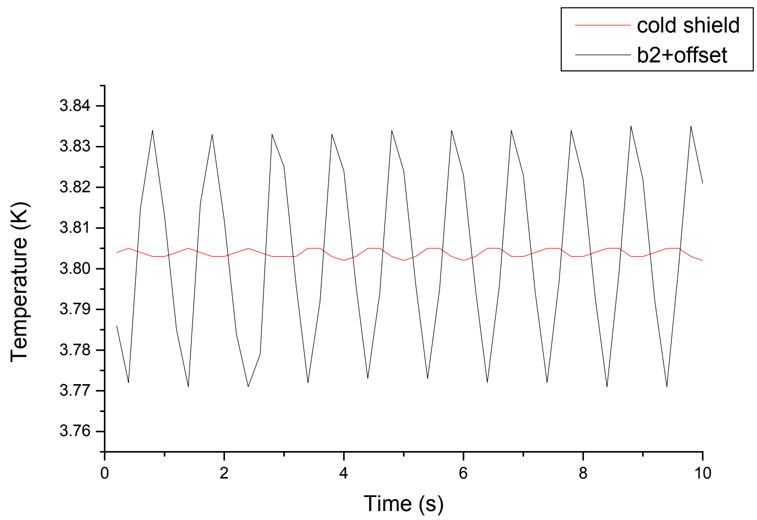

Figure 14: Plot showing the phase delay between the temperature oscillation. An offset is arbitrarily added to the cold flange temperature.