CAHIER DES CLAUSES TECHNIQUES PARTICULIERES (CCTP)

Pulse-tube dilution refrigerator for the TES4DM project

Centre National de la Recherche Scientifique
CNRS-LPSC | 53, avenue des Martyrs 38026 Grenoble Cedex 9

Établissement Public à caractère scientifique et technologique

Table of Contents

1. The Neutrino Group of CNRS-LPSC

1.1. The organization

The *Laboratoire de Physique Subatomique et de Cosmologie* (LPSC) is a « *Unité Mixte* » of research supported by CNRS(IN2P3), the University of Grenoble Alpes (UGA) and the institute of technology Grenoble INP. The mission of the laboratory is focused on fundamental physics research: particle physics, nuclear physics, astro-particle physics, cosmology and applications to energy and health, accelerators and ion sources, and plasma.
The neutrino group is one of the fundamental physics research groups at LPSC. The mission of the neutrino group is the study of physics beyond the Standard Model through the research of dark matter through direct interaction and the study of neutrino properties.

1.2. Activities of the Neutrino group

While the team research programme focuses on the neutrino properties working on experiments like DUNE and RICOCHET, a strong core composed by 1 DR, 1 CR, 1 Professor, 1 postdoc and a PhD student center its research activities in the TESSERACT experiment, optimizing the germanium cryogenic detectors in use at RICOCHET for direct dark matter searches.

2. Context

The TES4DM project, in the framework of the TESSERACT collaboration, aims at the direct detection of dark matter with cryogenic calorimeters.
The TES4DM project will employ germanium and silicon targets to detect dark matter interactions with the detector targets. The cryogenic calorimeters are operated at ~10 mK and a dilution refrigerator is required to reach these temperatures. Two identical dilution refrigerators will be purchased within the TESSERACT collaboration. This tender focuses on the purchase of one dilution refrigerator for the TES4DM project.

The final location of the dilution refrigerator will be underground at the Modane underground laboratory (LSM). The LSM is the deepest DUL in Europe. It is supported by CNRS/IN2P3 and the Université Grenoble-Alpes. LSM is an IN2P3 French national platform attached to the Laboratoire de Physique Subatomique et Cosmologie (LPSC) in Grenoble since 2019. It is dedicated to the development of the astroparticle and nuclear physics programs.
The dilution refrigerator will be first commissioned at the surface at LPSC in a brand new ISO8 clean room to check its cryogenic performance and finalize the customization for the detector payload such as cabling, heat sink and vibration. Once the commissioning at the surface is validated, the dilution refrigerator will be packed and transported to the Modane underground laboratory. Special care will be needed in the original packaging to be reused for the second transportation.

3. Tender offer (Objet du marche)

The neutrino group at LPSC is enquiring for **one** dilution refrigerator to search for dark matter at the Laboratoire Souterrain de Modane with cryogenic calorimeters.

The background minimization is one of the key characteristics of the TESSERACT experiment. In its final configuration, the TESSERACT dilution refrigerator canister layout will have to enclose the detector payloads with warm external shielding to the greatest extent possible. This is achieved by a section of reduced diameter between the main body of the dilution refrigerator (coming as a standard dilution unit) and the payload containing lower canister. This customization, corresponding to these reduced diameter sections, is referred to as the "neck". Figure 1 (left) shows the dilution refrigerator neck structure and the shielding surrounding it. Figure 1 (right) shows a sketch of the "standard" portion of the dilution refrigerator (top), the neck structure, followed by the detector box (bottom). Figure 2 offers a 3D view of the neck section together with the requested thermometry layout.

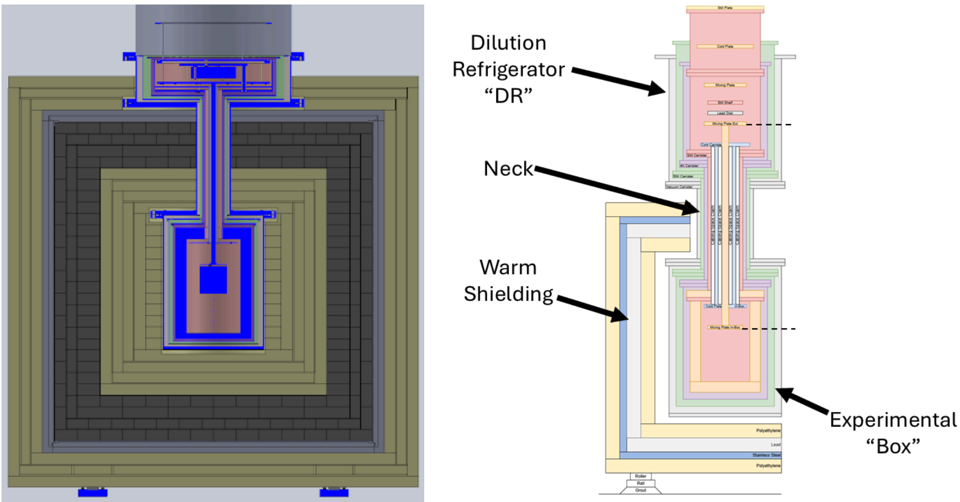

Figure 1: Left: TESSERACT warm shielding with dimensions surrounding the central cryostat. From outside to inside: a layer of PE, a stainless-steel enclosure, lead bricks, another layer of PE, and then the cryostat. The grey portion of the cylinder at the top of the image is the "standard" portion of the fridge from the commercial vendor. Right: a cartoon diagram of the cryostat with layers (not to scale).

The technical requirements for this apparatus are listed in the next sections of the document. A summary of these requirements in the form of a compliance matrix can be found in the *Dossier de Consultation des Entreprise*. This Compliance Matrix (CM) is an annex of the *Règlement de la Consultation*. The CM contains all the elements that will be evaluated to determine the overall technical value score. Each "element" can obtain a maximum of 10 points, which will be multiplied by a weighting factor. The technical value score will be calculated using the number of points obtained in relation to the maximum number of points possible.

Note: In the following sections and in the CM we give, for each requirement:

- The reference number (**Ref.**)
- The **designation**
- The **required value**, which corresponds to the value the system shall provide at minimum. Deviations can be accepted but, combined with the flexibility criterion (see below) it will have an impact on the evaluation of the associated requirement.
- A flexibility criterion (**Flex.**) applicable on the required value only:
    0. No flexibility
    1. Low flexibility
    2. Flexible requirement

The flexibility parameter is given (Flex.) for all requirements. It will be used in the evaluation of the proposals: “0” means “elimination factor” (i.e., if the proposal does not meet this criterion, no points will be awarded) and “2” will be associated with a low weighing factor.

- The **goal value**, which corresponds to the value we would like the system to reach.
- Each point is evaluated with a maximal score of 10 multiplied by the weighting.

3.1. Expected technical characteristics: cryogenic performance

Table 1 reports the required cryogenic performance for dilution refrigerator.

Table 1: Expected cryogenics performance

Ref.	Designation	Required value	Flex.	Goal value	Comment
3.1.1	Minimum temperature	<10 mK	0	8 mK	As measured on the mixing chamber temperature thermometer mounted on the mixing chamber plate
3.1.2	Cooling power at the cold plate stage with the mixing chamber temperature lower than 14 mK.	320 µW	0		Alternative methods to improve the cooling power include: • Addition of 3He to the mixture (3-5 L); • Addition of a second turbo pump in parallel to the first on the still line; • Increase the number of heat exchangers
3.1.3	Cooling power at the mixing chamber stage with the temperature stabilized at 20 mK	12 µW	0		
3.1.4	Cooling power at the mixing chamber stage with the temperature stabilized at 100 mK	450 µW	0		
3.1.5	Temperature stages	Cold plate < 100mK Still plate < 1K 4K plate < 4.2 K 60K plate < 70 K	0		Effective temperatures in nominal operation to be provided
3.1.6	Controlling the temperature of the mixing chamber plate up to 30 K while maintaining a pulse tube temperature at 4.2 K		0		Adds flexibilities to detector studies at different temperatures.
3.1.7	Galvanic isolation from the gas-handling system and the pulse tube compressor	Complete ground isolation between the dilution refrigerator and the gas-handling system, and between the dilution refrigerator and the pulse-tube compressor (isolation resistance > 1G Ω)	0		Use Swagelok or equivalent electrical isolator for the condensing lines and standard Teflon/plastic centering rings for the clamps for the still line.
3.1.8	The detector box temperature with 500 nW heat load in nominal fridge operation. See **Sec. 3.10**.	<= 12 mK	0		The vendor will document with a report that this performance is achieved in house before shipping the dilution refrigerator.

3.2. Expected technical characteristics: Pulse-Tube cooler/vibration dampening

Table 2: Expected technical characteristics for the pulse-tube cryocooler.

Ref.	Designation	Required value	Flex.	Goal value	Comment
3.2.1	The pulse tube cooler should have a cooling power ≥ 1.3W at 4.2K.	≥ 1.3W at 4.2K	0		There is no need for a large cooling power at 4K and 50K, only vibration should drive the choice of the pulse tube cryocooler.
3.2.2	The cryocooler shall be equipped with a remote valve option.		0		Offering the possibility to the customer to mount the valve on an independent mechanical support

3.3. Expected technical characteristics: Gas-Handling System

Table 3: Expected technical characteristics for the gas handling system.

Ref.	Designation	Required value	Flex.	Goal value	Comment
3.3.1	The compressor used for condensing the mixture must be able to operate with an outlet pressure of up to 3 bar without risk of failure		0		Two membranes are required to limit the risk of mix loss in case of failure
3.3.2	Scroll pumps are not allowed in the dilution circuit.		0		Mitigation in place to reduce the risk of blockages from dust contamination.
3.3.3	Two separate vacuum circuits for the OVC and the dilution are required, with therefore two different turbo pumps and two different primary pumps.		0		Mitigation to avoid air contamination
3.3.4	Safety	The gas-handling system, together with monitoring system, shall ensure automatic recovery of the mixture in case of trouble	0		List of potential issues to how they are handled: - Power shut down - Inlet line clog - air leak into OVC - cooling water shut down - etc.

3.4. Expected technical characteristics: ^{3}He-^{4}He mixture

Table 4: Expected technical characteristics for the He-3 mixture

Ref.	Designation	Required value	Flex.	Goal value	Comment
3.4.1	The dilution refrigerator must be delivered with the correct amount of ^{3}He-^{4}He mixture to achieve the specifications listed in this document		0		

3.5. Expected technical characteristics: Monitoring system and operations

Table 5: Expected technical characteristics for the monitoring system

Ref.	Designation	Required value	Flex.	Goal value	Comment
3.5.1	Elapsed time for each of the components requiring maintenance (pulse tube cryocooler, pumps, compressor, etc.) shall be recorded and easily accessible.		0		
3.5.2	The system shall provide an automatic cool down procedure of the dilution refrigerator from room temperature to base temperature		0		
3.5.3	The system shall provide an automatic warm up procedure of the dilution refrigerator, including mixture recovery		0		
3.5.4	The dilution refrigerator shall be equipped with a pressure gauge to control the outer vacuum chamber.		0		The type of gauge shall be indicated
3.5.5	It is required that we can extract any of the relevant fridge data (pressures, flow rate, temperatures) from the fridge computer to be stored in a database owned and managed by the customer		0		

3.6. Expected technical characteristics: Temperature measurement

Table 6: Expected technical characteristics for the measurement of the temperatures

Ref.	Designation	Required value	Flex.	Goal value	Comment
3.6.1	The system shall comprise at least the following calibrated thermometers: - 1 full range thermometer at the MC level - 1 RuO2 thermometer at the cold plate level - 1 CERNOX thermometer at the still plate level - 1 CERNOX thermometer at the 4 K plate level - 1 CERNOX thermometer at the 50 K plate level - 2 RuO2 thermometer at the end of the 10mK cold finger - 1 RuO2 thermometer at the payload cold flange - 1 CERNOX thermometer at the bottom of the payload still canister		0		See Figure 2 for the position of the last four thermometers
3.6.2	The temperature controller must be able to monitor a temperature as low as 8 mK		0		
3.6.3	The system shall comprise at least 3 heaters: - 1 heater at the mixing chamber level - 1 heater at the still plate level - 1 heater at the detector plate		0		

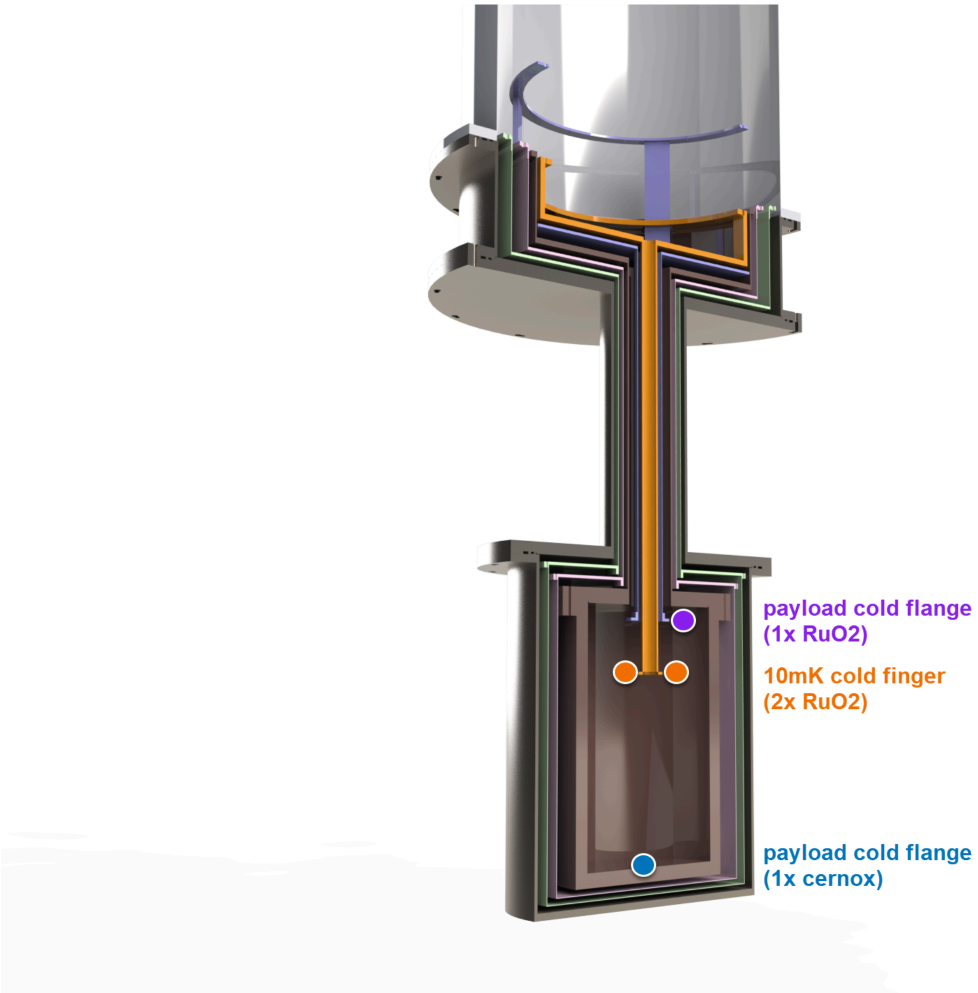

Figure 2 : Sketch of the position of: (1) the payload still cernox, (2) the payload cold flange RuO2 and, (3) the two RuO2 sensors on the 10mK cold finger.

3.7. Expected technical characteristics: Weight loading

Each dilution refrigerator thermal plate needs to be able to support the following weights in order to allow for the installation of the inner shielding and detectors.

Table 7 : Expected technical characteristics for the weight that each stage of the dilution refrigerator need to be able to support.

Ref.	Designation	Required value	Flex.	Goal value	Comment
3.7.1	Weight that the 300 K thermal stage shall be able to support	**550 kg**	0		
3.7.2	Weight that the 50 K thermal stage shall be able to support	**390 kg**	0		
3.7.3	Weight that the 4K thermal stage shall be able to support	**355 kg**	0		
3.7.4	Weight that the still thermal stage shall be able to support	**325 kg**	0		
3.7.5	Weight that the cold plate thermal stage shall be able to support	**110 kg**	0		

3.7.6	Weight that the mixing chamber thermal stage shall be able to support	**60 kg**	0		

3.8. Vibrations

Achievement of lowest possible vibration is of highest importance. Vibrations are measured utilizing accelerometers mounted at various points in the fridge. Vibration measurement results are described in a power spectral density (PSD) and can be expressed either as displacement per root-Hz (m/√Hz) or as acceleration per root-Hz (g/√Hz). The two units can be compared via the following equation:

$$PSD_d(f_i) = \frac{(9.8\, m/s^2)}{(2\pi f_i)^2} \cdot PSD_a(f_i)$$

f_i refers to the frequency bin, $PSD_d(f_i)$ refers to the displacement power spectral density in the f_i-th frequency bin, and $PSD_a(f_i)$ refers to the acceleration power spectral density in the f_i-th frequency bin. Due to the $1/f^2$ dependence, low frequencies can dominate displacement measurements. The RMS displacement is used to compare different regions within a PSD or different PSD measurements. The RMS displacement is calculated as:

$$RMS\Big|_{f_l}^{f_u} = \sqrt{\sum_{f=f_l}^{f_u} \left(PSD_d\right)^2 \Delta f}$$

In this equation, f_l and f_u are the lower and upper frequency bounds respectively of the frequency range being compared. Δf is the discrete frequency step, Δf = 1/tw where tw is the time domain window for acquisition of the vibrational data. i.e. if tw = 5 s, then Δf = (1/5) Hz.

Req. 3.8.1 (Flex. 0): The vendor should provide documentation about the vibration minimization and associated data that the customer can use in a comparative review of the offers. The vibration data – measured with an accelerometer on the mixing chamber plate – should come from a standard system without the customizations discussed in Sections 3.9 and 3.10.

Req. 3.8.2 (Flex. 0): The cold head should be mechanically decoupled from the cryostat frame at room temperature with the use of an edge-welded bellows and a dedicated frame for maximum decoupling.

3.9. Expected technical characteristics: Interface requirements

3.9.1. Implementation in the experimental room

The LPSC clean room is already built. CAD file of the cleanroom at LPSC will be made available upon request of the candidate. Upon request, it is also possible to organize a visit to the clean room at LPSC.

Req. 3.9.1.1 (Flex. 0): The pulse tube compressor will be located outside of the clean room. The distance between the pulse tube remote valve and the compressor is estimated to be 17m. The tubing must be compatible with 20m. Final tubing length will have to be defined precisely during the engineering study between customer and vendor.

__Req. 3.9.1.2__ (Flex. 0): The gas-handling system will be located outside of the clean room. The distance between the gas-handling system and top of the dilution refrigerator is estimated to be 17m. The tubing must be compatible with 20m. Final tubing length will have to be defined precisely during the engineering study between customer and vendor.

__Req. 3.9.1.3__ (Flex. 0): The clearance height of the experimental room at LPSC is 3.6 m on top of a 30 cm high platform for load bearing. The dilution refrigerator system should be able to fit within 3.5 m from the platform flooring with enough clearance to open and close the cryostat canisters. However, the cryostat frame will need to be bolted to the clean room floor laying below the platform. During the mounting of the fridge, there is a trap door above the anticipated position of the cryostat that can be opened and allows for more vertical space during the installation. Figure 3 shows a photograph of the trap door on the clean room roof at LPSC (left) and the clearance height of the clean room (right).

__Req. 3.9.1.4__ (Flex. 0): The dilution refrigerator will be lowered inside the clean room through the trap door and using the crane in the experimental area where the clean room is located. The dilution refrigerator needs to be equipped with lifting rings or an equivalent mechanism to allow its handling with the crane. Authorized and trained LPSC staff will be in charge of the operation of the crane under the supervision of the vendor.

Figure 3 : Left: Photograph of the trap on top of the clean room. The size of the trap door is 2 m x 2 m. The maximum height of the parts that can be lifted by the crane from outside the clean room to inside, via this trap door, is about 1.5 - 1.6 m. Alternatively, parts can be brought inside the experimental area via its direct access door of 1.8 m width and 2 m height. Right: sketch showing the room and platform dimensions.

3.9.2. Mechanical support of the Dilution Refrigerator

__Req. 3.9.2.1__ (Flex. 0): The dilution refrigerator should come with a support frame, which must be non-magnetic.

__Req. 3.9.2.2__ (Flex. 0): The fridge frame must accommodate below it a 1700 mm wide by 2225 mm tall (includes the height of shielding and platform) box which will be the warm shield. The frame must be open on all four sides: two sides to allow shielding movement, the other two sides to allow access to the cryostat when the shield is open. An open shield around the lower dilution refrigerator vessel can be seen in Figure 4.

Req. 3.9.2.3 (Flex. 0): Any additional frame to hold parts, e.g. rotary valve motor, needs to be built around the shield and allow the shield to close around the dilution refrigerator.

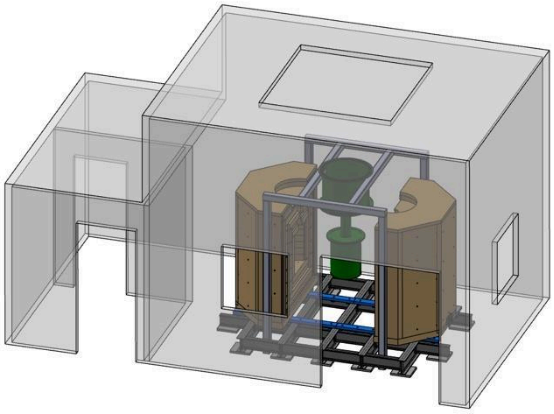

Figure 4: Preliminary layout of the TES4DM setup at the Laboratoire de Physique Subatomique et de Cosmologie (Grenoble). The open warm shield is mounted on rails on top of a load-bearing platform.

3.9.3. Fluid interfaces

Req. 3.9.3.1 (Flex. 0): The gas-handling system shall include one port of NW/KF type (e.g. NW/KF25) for mixture filling

Req. 3.9.3.2 (Flex. 0): The gas-handling system shall include one separate port of NW/KF type (e.g. NW/KF25) for leak testing.

Req. 3.9.3.3 (Flex. 0): In case the gas-handling system would not include the auxiliary pumping unit, the gas-handling system shall include one separate port of NW/KF type (e.g. NW/KF25) to connect the auxiliary unit (to allow pumping of the dilution refrigerator inlet and pumping lines for instance).

Note: ports required in **Req. 3.9.3.1** to **Req. 3.9.3.3** could be coupled in 2 or maybe even 1 single port fulfilling the three functions.

3.9.4. Readout ports

Req. 3.9.4.1 (Flex. 0): At the minimum, qty. nine (9) feedthrough ports with diameters ranging from 25 to 100 mm with at least qty. one (1) of 25 mm diameter, qty. two (2) of diameter 40 mm, qty. four (4) of diameter 50 mm, and qty. two (2) of 100 mm diameter - are required for detector readout cables, laser integration as well as additional tubing for our He-based detector technology, and warm electronics integration.

3.10. Mechanical structure

The TESSERACT collaboration performed an initial study of the design for the neck structure. The Solidworks and STEP files will be made available upon request of the candidate. If design elements suggested here would not be possible within cryogenic or weight restrictions then we are

open to re-design and we defer to the manufacturer's discretion. If design elements suggested here would incur considerable delay or increase in cost, then we are similarly open to re-design at the manufacturer's discretion. However, the design constraints in the following requirements should not be changed as they are necessary for the detector payload integration.
Figure 5 shows an example of the assembly of the neck and lower section of the dilution refrigerator from our initial study.

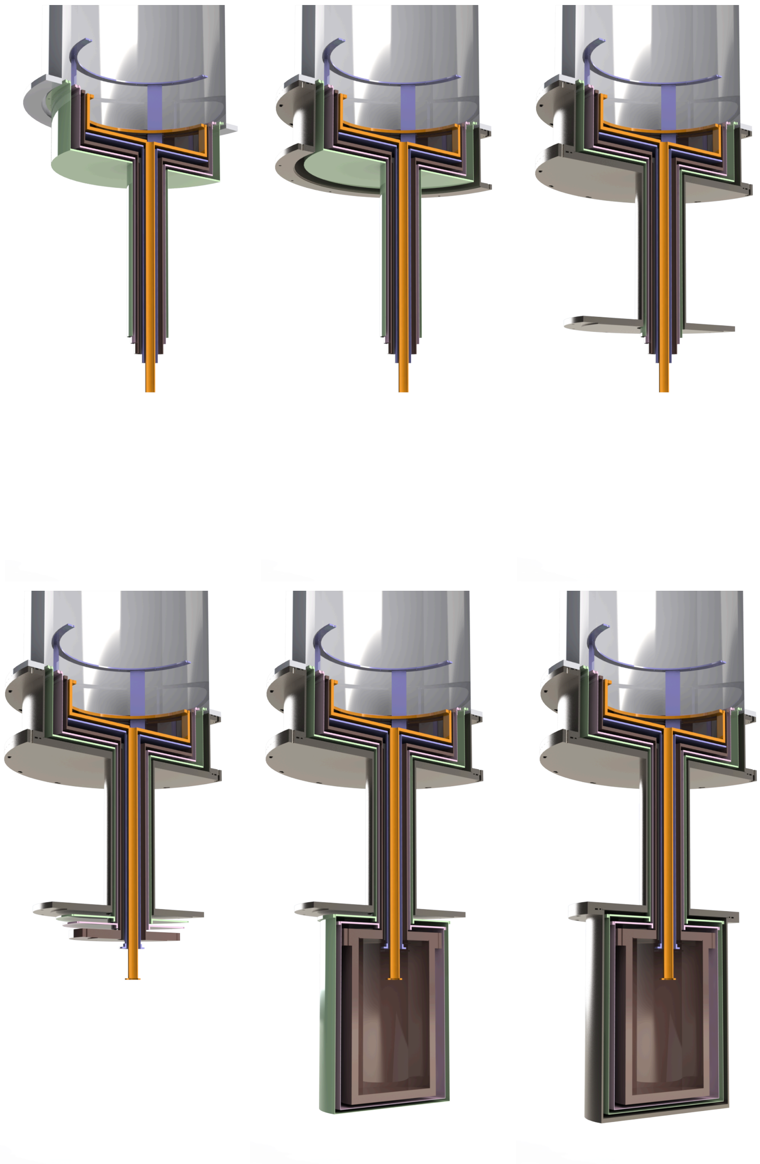

Figure 5 : assembly of the lower section of the dilution refrigerator.

The following elements will be referred in the **Req. 3.10.3, Req. 3.10.5, Req. 3.10.9** and **Req. 3.10.10** and can be seen in Figure 6 (left):

- "*extended mixing chamber plate*": plate connected to the mixing chamber where the cold finger is connected;
- "*extended cold plate*": plate below the extended mixing chamber plate where the cold neck is attached;
- *"still canister flange above the neck"*: still canister flange where the still neck is attached.

- "*support flange for payload still canister*": thick flange below the neck supporting the bottom still thermal canister;
- "*payload cold flange*": 100mK flange below the neck.

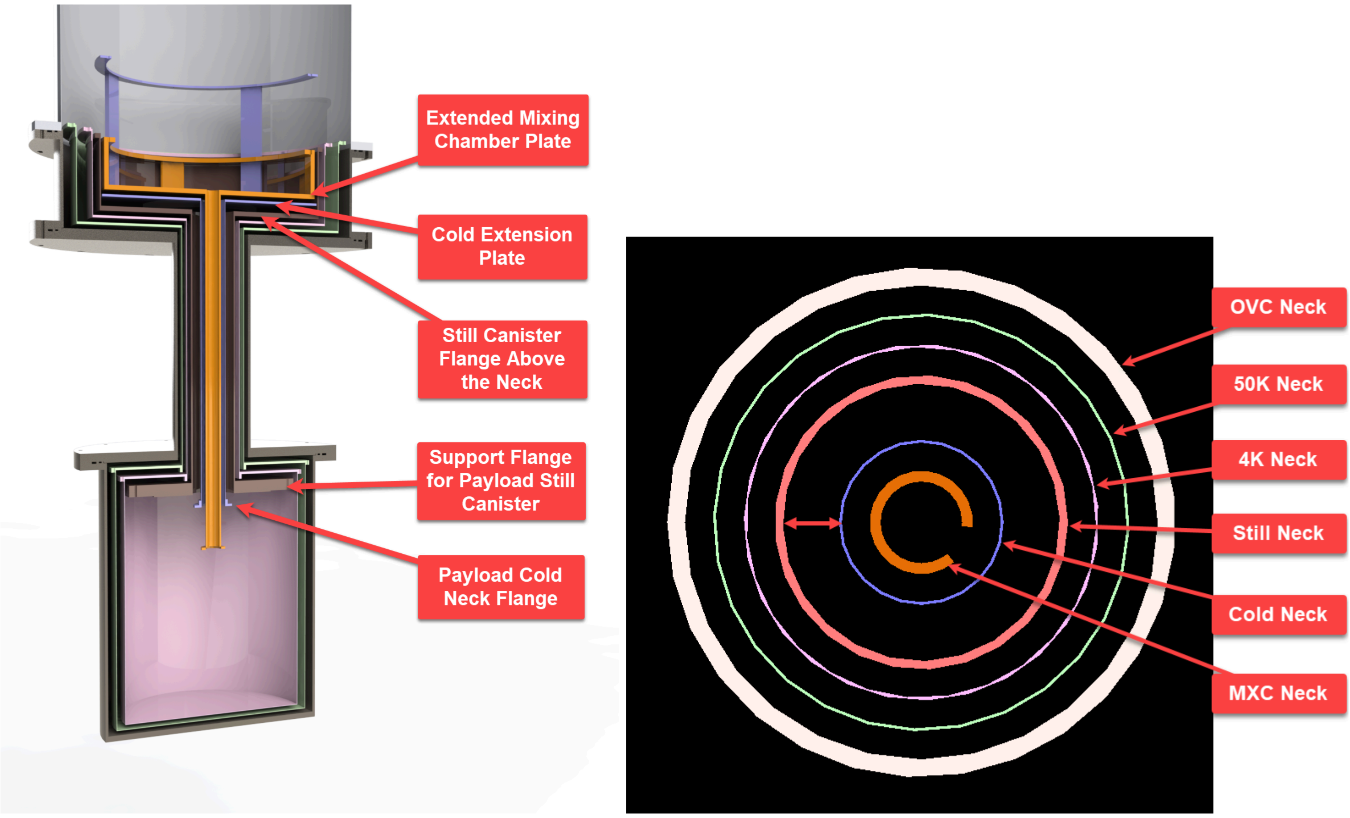

Figure 6: Left: Description of the definition used in ***Req. 3.10.3, Req. 3.10.5, Req. 3.10.9*** *and* ***Req. 3.10.10.*** *Right: distance between the inner diameter of the still neck and the outer diameter of the cold neck from* ***Req. 3.10.5****.*

Req. 3.10.1 (Flex. 0): The vendor should provide a payload still canister and a 10 mK cold finger, even if these items might be replaced by the customer after purchase with a thicker customized payload still canister and a hollow 10 mK cold finger. The requirements listed below are defined such that the customer can later replace these two parts. This later customer replacement will not void the warranty. The 10mK cold finger shall be removable, ideally mounted to the bolt pattern described in Req. 3.10.9-C.

Req. 3.10.2 (Flex. 0): The inner diameter of the payload still canister needs to be at least **285 mm** in diameter and at least **458 mm** high to ensure sufficient experimental volume.

Req. 3.10.3 (Flex. 0): The *support flange of the payload still canister* (see Figure 6, left) should be at least **25 mm** thick, have a **395 mm** diameter, and have a bolt circle diameter of **365 mm** to mate to the canister below. It needs to support a **130-kg** load with less than **1.0 mm** of deformation.

Req. 3.10.4 (Flex. 0): The inner dimensions of the payload 4K canister need to be at least **415 mm** in diameter and **535 mm** in height to allow the space for a customer-provided thicker still canister.

Req. 3.10.5 (Flex. 0): The following clearances are required for routing of readout cables and tubing for the detectors:

A. The distance between the bottom of the mixing chamber plate and the top of the *extended mixing chamber plate* (see Figure 6, left) is at least **100 mm**.
B. The distance between the top surface of the *still canister flange above the neck* (see Figure 6, left) and bottom of the *extended cold plate* (see Figure 6, left) is at least **20 mm**.
C. The inner diameter of the *cold neck* needs to be at least **57 mm.**
D. The radial distance between the inner diameter of the still neck and the outer diameter of the cold neck needs to be at least **20 mm, see Figure 6 (right). To state this a different way, the still neck inner diameter must be 40 mm larger than the cold neck outer diameter.**

Req. 3.10.6 (Flex. 1): The dimensions of the payload section of the outer vacuum chamber should be in the following range:
A. Outer diameter of the canister (not including flange diameter) between **490 mm and 530 mm,**
B. Outer height (from bottom to flange mating surface) between **590 mm and 630 mm**.

Req. 3.10.7 (Flex. 1): The outer vacuum neck should have the dimensions in the ranges below:
A. Outer diameter of the neck region between **162 mm and 202 mm.**
B. Height (from upper to lower flange mating surfaces) between **470 mm and 510 mm.**

Req. 3.10.8 (Flex. 0): The bottom of the outer vacuum chamber shall be a distance from the *support platform* either **680 mm** or equal to the height of the outer vacuum chamber **Req. 3.10.6** plus **2.5 cm**, whichever is greater. The platform flooring is 30 cm above the floor so the distance from the floor is either of the two values plus 30 cm.

Req. 3.10.9 (Flex. 0): We will need holes in the following positions. The final dimensions and specifications of these holes will be provided by the customer when the contract is signed.
A. A set of mounting holes in the *extended cold plate* (see Figure 6, left) to mount the vibration decoupler
B. A set of mounting holes on the *payload cold flange* (see Figure 6, left) to mount the thermal straps.
C. A set of mounting holes on the *extended mixing chamber plate* (see Figure 6, left) to mount a later customer-supplied cold finger.
D. A set of feedthroughs in the *extended cold plate* and *extended mixing chamber plate* for readout cables.

Req. 3.10.10 (Flex. 0): The *10 mK cold finger* and 100 mK neck provided by the vendor will each extend **a prescribed distance** into the *payload still canister* as described below:

A. Distance from bottom of 10 mK flange to payload still plate mating surface: 125 mm
B. Distance from bottom of 100 mK flange to payload still plate mating surface: 30 mm

No other geometrical constraints on the 10 mK cold finger design should be implied or understood from customer-provided renderings and CAD. (The vendor-supplied 10 mK cold finger can be a simple solid cylindrical geometry.)

Req. 3.10.11 (Flex. 0): The thickness of the 100 mK cold neck needs to be at least **2 mm** (for thermal reasons to support later customer heatloads). Greater thicknesses would be much appreciated if practical.

Req. 3.10.12 (Flex. 0): After the vendor has finalized the engineering plan for the cryostat, the vendor will produce a report with the dimensions and technical designs for the client to review and, after 10 business days for review, a meeting will be organized for final approval.

3.11. Reliability

Reliability / maintenance issues are of utmost importance.

Req. 3.11.1 (Flex. 0): The vendor shall provide, within the technical proposal, the list of elements requiring maintenance and provide technical details on the maintenance to be performed.

3.12. Expected documentation and samples

The system will need power supply as well as compressed air or water and other potential resources.

Req. 3.12.1 (Flex. 0): The vendor shall indicate, within the technical proposal, the necessary resources: number and type of power supplies (mono-phase, 3-phase, type of plug), number of lines for compressed air and associated technical specifications (e.g. nominal pressure), number and type of water lines and associated technical specifications (e.g. flow rate), any other resources needed to operate the system: LN2 for nitrogen trap, etc.

Req. 3.12.2 (Flex. 0): The vendor shall provide upon the successful completion of performance tests conducted at the vendor's premises:

- A factory test report

Req. 3.12.3 (Flex. 0): the vendor shall provide at the latest at the delivery, all the documentation needed to operate and maintain the system along with the samples of materials used in the dilution refrigerator production. This documentation in English includes at least:

- User Manual with detailed operation instructions, troubleshooting, software description
- Maintenance plan, list of elements requiring maintenance and maintenance procedures in **Req. 3.11.1**.
- Calibration data for thermometers, flowmeter, etc
- Interface drawings updated according to the "as built" system
- Written procedure and photographic report on how to package the dilution refrigerator
- STEP files of the dilution refrigerator
- Test protocol (for the test at customer's premises)
- Acceptance test report (after successful tests at customer's premises)
- Certificates of conformity for the CE, calibration certificates, etc.
- The samples from the same batch of the materials of thermal canisters and plates used in the dilution refrigerator construction process have to be provided to allow screening tests (LPSC responsibility)
- Report detailed in **Req. 3.1.8.**

3.13. Packaging for the shipping

Req. 3.13.1 (Flex. 0): the original packaging will be left at the LPSC and need to be reused for the second transportation to LSM.

Req. 3.13.2 (Flex. 1): the original packaging should be made with recyclable material whenever possible.

3.14. Installation and commissioning at LPSC

Req. 3.14.1 (Flex. 0): the vendor will install the dilution refrigerator at LPSC and will perform the first cool down to demonstrate the performance of the dilution refrigerator.

Req. 3.14.2 (Flex. 0): the vendor will perform a user training to use the system during the first cool down or during a dedicated meeting following it. A team of roughly 5 persons will need to be trained.

3.15. Radiopurity

Req. 3.15.1 (Flex. 0): we ask the vendor to use gloves when handling the copper screens and plates in the neck and payload canister region of the dilution refrigerator for radiopurity reasons.

4. *Prestation Supplementaire Eventuelle* (PSE)

4.1. Relocation to Laboratoire Souterrain de Modane

PSE 1: As a potential supplementary service, provision of relocation (packaging, shipment, integration at the LSM underground lab and onsite cryogenic performance validation) of the system from the LPSC (Grenoble, France) to Laboratoire Souterrain de Modane (Modane, France).

Standard shift times are from Monday to Friday. Week-end shifts are not usually foreseen.

- 8:30 leaving LSM surface building
- 12:00 arriving LSM surface building
- 13:30 leaving LSM surface building
- 17:00 arriving LSM surface building

The access to the LSM underground facility is done in accordance with LSM regulations and current safety rules governing access to the tunnel. Users cannot drive themselves through the tunnel to access the underground laboratory. An authorized LSM driver will escort people to the underground laboratory.

4.2. Electromagnetic interference (EMI) mitigation

PSE 2: Whenever possible, we ask for EMI mitigations at each vacuum joint using either metallic o-ring, dual grooves to insert spira-shields, or aluminium seals ISO-KF. Those include user ports, cold head mounting and outer vacuum chamber joints. Note that no EMI mitigation is required on the dilution unit seals.