CUTE Project

Report

Detailed Design Report

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1 REFERENCE DOCUMENTS

1.1 REFERENCES

[REF1] **CUTE-CDR-REV1P0,** Conceptual Design Report, 2/2/2016,
[REF2] **CUTE-TN-005-REV1P0,** Suspension Modes Calculation

1.2 ANNEXES TO THE DDR

[AN1] **CUTE-TN-002-REV2P5,** Dilution Refrigerator Procurement Specifications
[AN2] **CUTE-TN-003-REV1P0,** CUTE Steel Platform Specifications
[AN3] **CUTE-TN-007-REV2P1,** Low radioactivity Management Plan
[AN4] **CUTE-TN-001-REV1P0,** Vibrations Specifications
[AN5] **CUTE-TN-005-REV1P0,** Suspension Design
[AN6] **CUTE-TN-009-REV1P0,** Instrumentation rack definition
[AN7] **CUTE-TN-011-REV1P2,** Clean Room specifications

1.3 ARCHIVED DRAWINGS

[AR1] **CUTE-DRW-001-REV1P1,** Results of the DR Design Study 6/7/2016 & update 31400-00-00
[AR2] **CUTE-DRW-002-REV1P5,** Platform Design
[AR3] **CUTE-DRW-003-REV1P3,** Crane Design
[AR4] **CUTE-DRW-004-REV1P4,** SNOLAB Implementation
[AR5] **CUTE-DRW-005-REV1P2,** Cooling Water Loop
[AR6] **CUTE-DRW-006-REV1P4,** Water tank and liner design
[AR7] **CUTE-DRW-007-REV1P1,** Overall experimental drawing
[AR8] **CUTE-DRW-009-REV1P0,** Clean Room
[AR9] **CUTE-DRW-011-REV0P3,** Dilution Refrigerator - fabrication
[AR10] **CUTE-DRW-012-REV0P2,** Electrical drawings
[AR11] **CUTE-DRW-013-REV0P2,** Surface & de-radonized air ventilation
[AR12] **CUTE-DRW-014-REV0P1,** External Lead Shield

1.4 SNOLAB CONTROLLED DRAWINGS LIST

[SNO1]	1210	QUDO	CRYOGENIC PIPING ARRANGEMENT
[SNO2]	1210	QUDO	CRYOSTAT SUSPENSION
[SNO3]	1211	QUDO	INSTRUMENTATION RACK
[SNO4]	2001	WSPO	CUTE PLATFORM STRUCTURAL DESIGN
[SNO5]	2002	QUDO	PLATFORM OPENNINGS AND CHECKER PLATE
[SNO6]	3001	ELSE	1000 KG MONORAIL GENERAL ARRANGEMENT
[SNO7]	3002	UNIO	LIFTING BEAM
[SNO8]	3003	QUDO	CRANE ARRANGEMENT WITH CRYOSTAT IN UPPER POSITION
[SNO9]	4100	QUDO	GENERAL ARRANGEMENT
[SNO10]	4210	SNCL	SNOLAB ELECTRICAL POWER DISTRIBUTION CUTE EXPERIMENT
[SNO11]	4300	QUDO	SURFACE & DE-RADONIZED AIR VENTILATION
[SNO12]	6101	QUDO	WATER TANK NOZZLE MODIFICATIONS
[SNO13]	6102	WSTO	WESTEEL WATER TANK DRAWINGS
[SNO14]	6103	WSTO	WESTEEL WATER TANK BILL OF MATERIAL
[SNO15]	6104	QUDO	TANK EDGE ANGLE
[SNO16]	6105	QUDO	TANK VERTICAL STIFFENER AND NOZZLE CLOCKING
[SNO17]	6201	QUDO	WATER TANK LINER MODIFICATIONS
[SNO18]	6202	QUDO	WATER TANK LID
[SNO19]	6300	SLDO	H2O SUPPLY/CIRCULATION SYSTEM FOR CUTE
[SNO20]	7001	QUDO	CLEAN ROOM CONCEPT
[SNO21]	8100	QUDO	EXPERIMENT ARRANGEMENT

2 ACRONYMS AND ABBREVIATIONS

ASD	Acceleration Spectral Density
CP	Cold Plate
DCRC	Readout Electronics
DR	Dilution Refrigerator
DSD	Displacement Spectral Density
DT	Detector Tower
HEMT	High Electron Mobility Transistor
I/F	Interface
IR	Infrared
LAN	Local Area Network
LF	Low frequency
LR	Low Radioactivity
LT	Low Temperature
LSM	Laboratoire Sous-terrain de Modane (France)
MC	Mixing Chamber
PT	Pulse Tube
SQUID	Superconducting Quantum Interference Device
S/STL	Stainless Steel
TBD	To be defined
VLT	Very Low Temperature

3 INTRODUCTION

This document summarizes the detailed design of the CUTE experiment and provides a link to other documents containing all the relevant information.

During the detailed design phase, some minor modifications have been made compared to the CDR document [REF1]:

- The vessel material has been changed from Acrylic to Stainless steel
- The 'phonic cabinet ' has been removed

The scientific requirements, defining the level of radioactivity background are unchanged. They are translated into a shield architecture and specifications on the activity level or the different critical materials surrounding the detector. A **Low Radioactivity Management Plan** [AN3] defines the requirements and the verification procedure implemented to achieve the final goal.

The CUTE experiment plans to have an upgraded shielding which is an external lead shield. The present design takes into account the added mass of lead into the stainless steel vessel (~4 Ton) of this upgraded version.

The DDR present an overview of the following sub-system design (Chap.5):

- The dilution refrigerator
- The platform design and the installation procedure
- The crane design and the installation procedure
- The water tank
- The Ultra Pure Water circulation loop
- The Clean Room
- The cooling water loop (designed by SLAC)
- The Low Radon Air Ventilation system

4 REQUIREMENTS

4.1 SHIELDING PERFORMANCES

SuperCDMS detectors have a relatively short characteristic pulse decay time, making it possible to operate them above ground; however, detailed studies of background discrimination (surface event and electron/nuclear recoil discrimination) are only possible if the neutron background is negligible. Given the characteristic pulse decay time, the maximum useful interaction rate in a SuperCDMS iZIP detector is of order of 10 Hz. In calibration measurements with radioactive sources one wants to ensure that the acquired data are dominated by events induced by the calibration source; this sets a limit on the overall background rate at about 1 Hz. SuperCDMS iZIP detectors need a discrimination power of better than 1 in 10^6 to achieve the goal sensitivity at WIMP masses above a few GeV/c^2. At 10 Hz it takes a bit more than one life day to acquire 10^6 events, so the neutron background must be considerably lower than 1/day per detector to make the demonstration of the required background discrimination power possible.

EDELWEISS detectors, which are also considered for testing within CUTE, have a considerably longer pulse duration, making it impossible to operate them above ground due to constant pile-up. Those detectors cannot be operated at more than about 1 Hz. If calibration measurements are to be attempted the required overall background rate must be considerably lower than 1 Hz.

These two conditions determine the minimum requirement for the shielding performance. Some of the other planned measurements may be possible at the above discussed rates, but would greatly benefit from lower background levels.

Monte Carlo simulations have been performed for a setup with similar geometry, studying the expected external background induced by radiation from the laboratory walls. Contamination within the water tank wall and the water itself was also studied (Liu, 2011). These early simulations do not include any background source within the cryostat or the drywell. Also the planned internal shielding, which blocks radiation from the dilution unit, but also external radiation from the ceiling of the laboratory, is not included. The simulations were performed for a stack of three SuperCDMS Soudan style Ge iZIP detectors with a mass of ~600 g each, while the SuperCDMS SNOLAB detectors will have a bit over twice the volume (~1.4 kg for Ge detectors and 600 g for Si detectors)

The table below shows a summary of the expected rates from different sources under different conditions. Be aware that the water shielding from below is somewhat reduced in the new geometry to accommodate for the limited height of the cavity and the expected size of the cryostat. To determine the gamma rates, any interaction in a detector is considered irrespective of the deposited energy. For nuclear recoils from neutrons only interactions between 10 and 100 keV are counted. This has traditionally been the range where CDMS analyses relied on full electron recoil discrimination to achieve the best background performance. The nuclear recoil rate between 1 and 10 keV is about 80 % higher than that in the 10-100 keV range. The statistical uncertainties on the quoted numbers are of order of 10 % for gammas and ~20 % for the neutron number. Systematic uncertainties from limited precision in the geometry as well as intrinsic uncertainties of the simulation are estimated to be of order of 50 %.

Source	Activity	Rate / 600 g (Ge)	Comment
Lab wall γs, no shielding	^{238}U, ^{232}Th, ^{40}K rate as expected at SNOLAB	10-15 Hz	For comparison
Lab wall γs		0.12 Hz	80 % from cavern ceiling
Lab wall γs, estimate with internal Pb shield		0.024 Hz	Assuming the internal Pb shielding effectively closes the gap from top
Water tank, steel: ^{60}Co	230 mBq/kg	0.0001 Hz (10/day)	High end of expected activity
Water, ^{238}U	0.02 ppm	0.1 Hz	Purified SNOLAB water is expected to be considerably cleaner
Water, ^{232}Th	0.1 ppm	0.1 Hz	
Water, ^{40}K	0.01 ppm	0.1 Hz	
Water, ^{222}Rn	10 Bq/m^3	0.005 Hz	Expected equilibrium activity
Lab wall neutrons	expected rate	0.08/day (10-100 keV)	50 % directly from cavern ceiling

Table 1: Estimated background contributions; uncertainties are dominated by systematic uncertainties in the simulation and are estimated to be of order of 50 %.

We find that ^{60}Co from the water tank is negligible; Rn in the water is subdominant in the initially planned shielding configuration, but does contribute at the 20 % level. Ionic contamination in the water does not appear to be important if water from the SNOLAB water purification plant is used. The typically reached purity is several orders of magnitude better than the numbers assumed in the table. The dominant background comes from gammas from the lab walls. When the internal lead shielding is included, the rate is only about a factor of 10 worse than what has e.g. been accomplished in the EDELWEISS II experiment.

The water shielding reduces the external background considerably, but it is not sufficient to completely block the high energy gammas from the rock. Therefore an upgrade is considered which will see an additional 10-15 cm of lead shielding inside the drywell, directly surrounding the cryostat. In order to take full advantage of the improved shielding the internal background from the cryostat must also be minimized: The components of the cryostat that are in direct line of sight to the detectors are required to be made of low-activity copper, so that their contributions to the overall rate stay subdominant. Similarly the lead used for the internal shielding needs to be sufficiently low activity so its contributions are negligible. More detailed simulations including internal contamination and the updated geometry are being performed. First results indicate that to goal of subdominant internal background can be achieved by building the inner cans of the cryostat out of copper of high but readily available quality (U/Th contamination of order of 1 mBq/kg or better). On the effect of Rn in the water, the old and new simulations give similar results for a geometry without the external shielding; if the external shielding is added the expected Rn induced rate in the detector drops to considerably less than 1 event /keV/kg/day (in the 1-10 keV range). Similarly, the expected background from external sources drops to about 1 event/keV/kg/day if the external lead is added. Considering these new results (which are consistent with extrapolations from the old simulations) we estimate that the total gamma background in CUTE as measured with a Ge detector will be of order of 20-30 events/keV/kg/day without the external lead and of order of 1 event/keV/kg/day if the external lead is installed. This residual background will be dominated by gammas coming in from the top through the gap between the internal and external shielding. Further improvements of the background are conceivable by improving the internal shielding geometry. Such moderate modifications may be considered in the future if a demand for even lower background comes up.

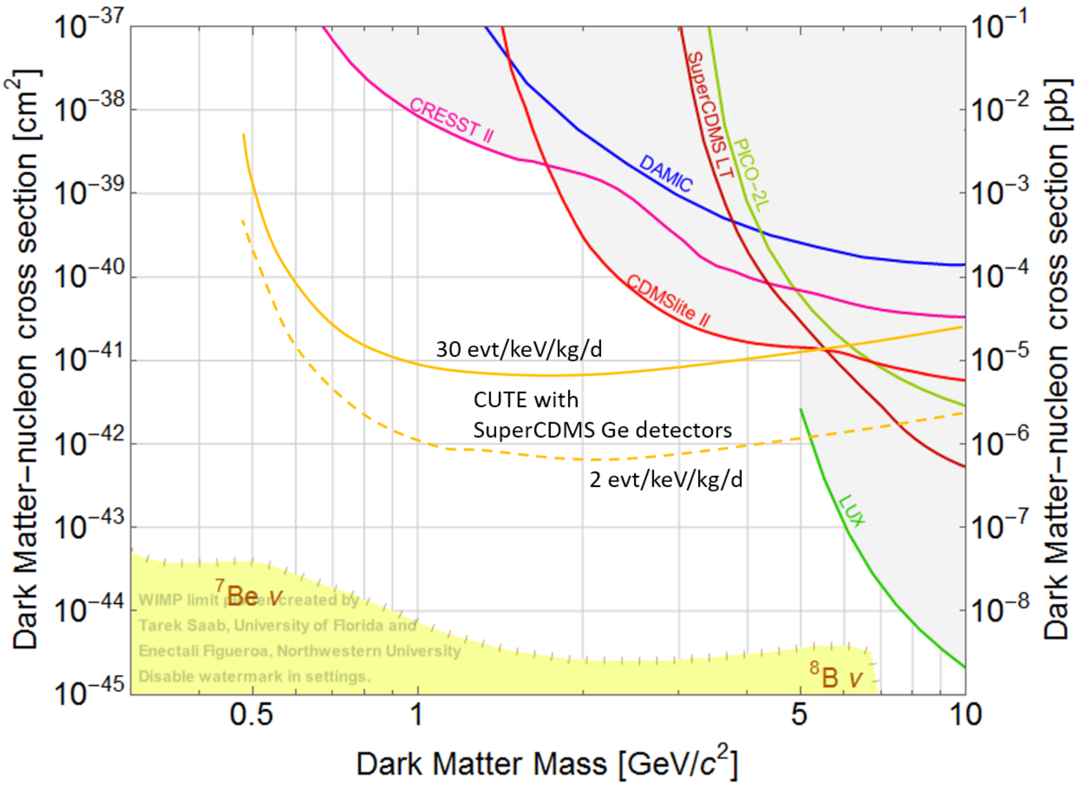

Figure 1: Estimated sensitivity to low-mass WIMPs for SuperCDMS Ge HV detectors operated in CUTE for two different background scenarios expected to be achievable with (2 events/keV/kg/day) and without the external lead respectively (30 events/keV/kg/day).

4.1.1 Nominal shielding

For the nominal shielding, the neutron flux is attenuated by the water, excepted from the top where only a lead shield is installed close to the top of the detector tower. Low radioactivity materials are selected in the field of view of the detector (mainly pure copper). For mechanical constraint and cost, the external can of the cryostat is made of selected stainless steel. A magnetic shield (1 mm-thick mu-metal cylinder) will be mounted around the cryostat external can.

4.1.2 Upgraded shielding

In order to lower the gamma flux and have a better closure of the top field-of-view, we plan to add an external lead shield (100 mm on the side walls and 150 mm on the bottom). This improvement lowers the experimental background by about an order of magnitude. The CUTE facility is designed to accommodate this improvement in a future upgrade.

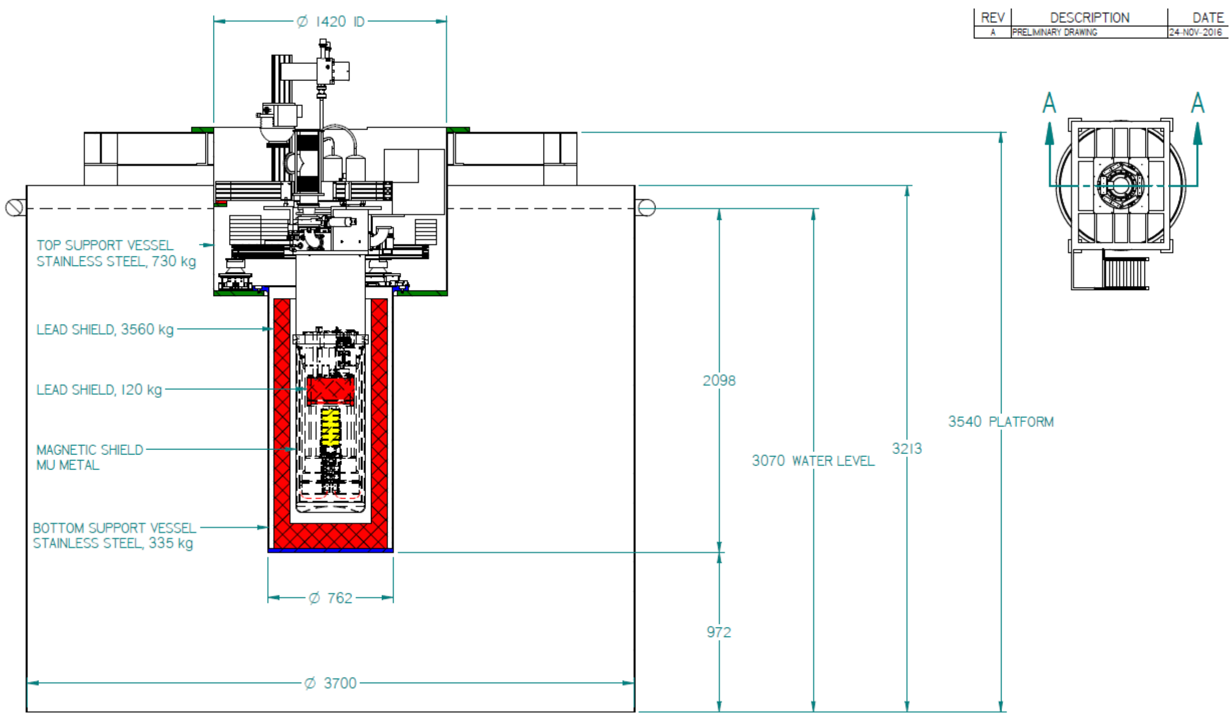

Figure 2: CUTE view with the upgraded shielding - pure water (D=3600mm) + Internal Lead shield (150mm thick) and the external lead (100 mm) [SNO21]

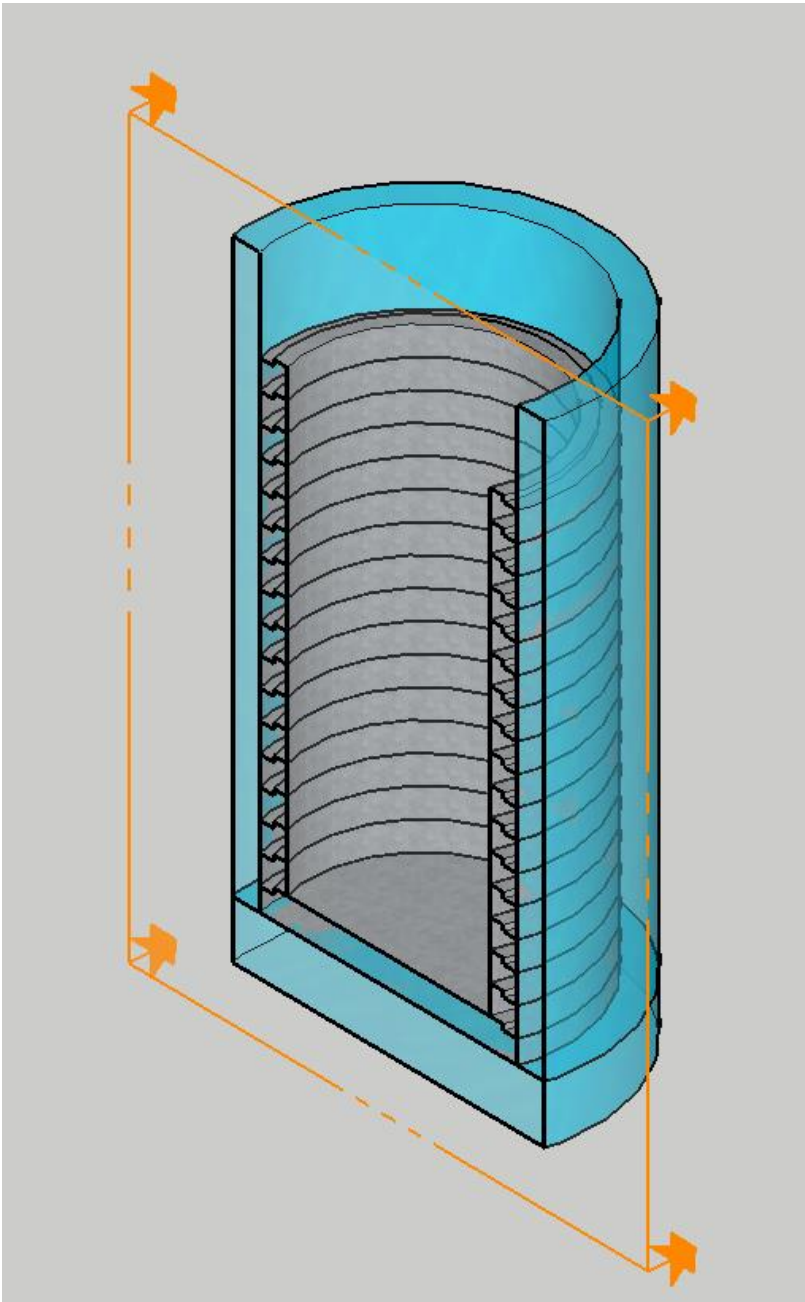

Figure 3: External lead shield (conceptual drawing for stacked lead pieces of ~200 kg)

4.2 Detectors requirements

The primary goal of the facility is to test and qualify SuperCDMS and EURECA detectors for the operation in the SuperCDMS SNOLAB experimental setup. The requirements on the detectors are thus given by goals for this experiment. The CUTE facility must provide the connectivity (mechanically, thermally and electrically) to operate the detectors without compromising their performance.

4.2.1 Mechanical Connectivity

SuperCDMS detectors will be mounted in stacks of six onto a mechanical structure, called “tower”. The tower provides the mechanical support and electrical connectivity between the 4K stage and the base temperature stage where the detectors are operated while minimizing the thermal load onto the detector stage. At the same time the tower includes the first stage amplifier circuits.

EURECA is working on adapting the SuperCDMS tower design so it can hold the CRESST or EDELWEISS detectors. This design is not completed yet, but the mechanical, thermal and electrical interface to the facility will be identical. The EDELWEISS detector stack will be slightly longer since the height of the individual EDELWEISS detectors is slightly more than this of the SuperCDMS detectors.

The CRESST tower design is less advanced, but will likely not exceed the EDELWEISS tower length since it will also have to fit into the SuperCDMS experimental setup. The sample chamber of the dilution refrigerator for CUTE will be designed large enough to hold a full SuperCDMS or EDELWEISS tower. The mechanical and thermal connections are being designed to fit the existing SuperCDMS tower design.

4.2.2 Thermal Requirements

SuperCDMS iZIP detectors were operated at the Soudan Underground Laboratory at temperatures of ~50 mK. However, if designed for a lower operational temperature the performance of the thermal readout will significantly improve. EDELWEISS and CRESST detectors are operated at considerably lower temperatures (15-20 mK). The goal for SuperCDMS SNOLAB is to provide enough cooling power so that the detectors can be operated at 15 mK. We aim for the same thermal performance for CUTE. While it is a challenge to design the cryostat system for achieving this goal for SuperCDMS where up to 31 towers can be operated simultaneously, it is easily achievable for CUTE where only one tower will be operated and the thermal connection to the refrigeration unit is much shorter. Also the thermal load on the intermediate thermal stages is of no concern in CUTE with a standard dilution refrigeration unit.

4.2.3 Electrical Connectivity and Detector Readout

The SuperCDMS tower design provides a well-defined electrical interface for the detector operation. SuperCDMS also has defined the type of feed-through connectors to be used to bring the signals out of the vacuum space. CUTE will provide interfaces at the 4K stage as well as at room temperature outside the vacuum that are compatible with the SuperCDMS design. We are also planning on using the same type of wiring option inside the cryostat as will be used by SuperCDMS (flat bundles of twisted pair wires with 50 pairs per bundle, enough to serve one detector). Eventually the facility will be equipped with six cables so a whole tower can be read out simultaneously, but depending on cost and availability we expect to start with a smaller number of wire bundles. We also plan to use the same type of vacuum feed-through; however, as an alternative we may consider using standard 50-pin sub-D connectors instead, using adaptors inside for the cable and outside to connect to the readout electronics. The present default design for the cable bundles for SuperCDMS does not foresee shielding; however, if shielding should be required for either SuperCDMS or EDELWEISS, it is an easy adaptation to shield the wires.

The design of the cabling and electronics within the tower as well as the complete readout chain outside the vacuum space is under the control and responsibility of SuperCDMS and EURECA. However, CUTE will provide a computer for data acquisition and storage.

4.2.4 Microphonics

Both SuperCDMS and EDELWEISS detectors and their readout electronics show some sensitivity to micro-vibrations. The dilution refrigerator for CUTE will be cooled down to about 4 K using pulse-tube coolers rather than liquid cryogenics. This bears the danger of introducing excess vibrations.

We are planning a dedicated measurement campaign at Queen's to quantify the sensitivity of the new SuperCDMS detectors to vibrations over a wide frequency range; however, the information from this campaign will not be available in time before ordering the refrigerator. We therefore defined very strict requirements that have to be met by the manufacturer so we can ensure that our measurements will not be compromised by residual vibrations from the pulse tube cooler.

The estimated level of microvibrations required for the detectors is ~1 $\mu g/Hz^{1/2}$ in the detector bandwith (1-1000 Hz). This is challenging for the state-of-the art dilution refrigerators and will require a careful validation plan.

4.2.5 Magnetic Shielding

The thermal readout of SuperCDMS detectors is based on SQUID amplifiers which are very sensitive magnetometers. As such, their performance as amplifiers (in particular their noise performance) can be impacted by external magnetic fields. Therefore, to guarantee optimal performance, an external magnetic shield is required that reduces any external magnetic fields to a level at least a factor of 50 less than the earth magnetic field, i.e. ~1 μT. This value can be achieved with a mu-metal cyclinder of ~1 mm thickness around the external can of the cryostat.

4.3 OPERATION REQUIREMENTS

The foreseen cycle of a **Detector Tower** characterization is the following:

STEP	DURATION	DESCRIPTION
DT mounting	1 day	• Remove the cryostat • open the cans • mount the tower • electrical checks • cryostat mounting/alignement • vaccum & leak checks
Cooldown	5-10 days	• Automated operation • Preliminary tests on DT to be done • 50L liquid N2 for the charcoal filter
Operation	2 weeks to 3 months	• Depends on the objectives, low-mass WIMPS search could take longer time • Most measurements could be done remotely • Current cyrostat operation concerns the charcoal filter LN2 filling (25L/week)
Warm-up	3 days	• Fully automated & remotely controlled
DT removing	1 day	• DT should be placed in a special container (Radon protection) and/or into the SuperCDMS clean room

Table 2: CUTE Measurement cycle

5 Design

5.1 Overall system & implementation at SNOLAB

The CUTE experiment surface allocation has been defined considering: 1) the surface and height needed for CUTE; 2) the access required for SuperCDMS; and 3) the access and surface limitation for the other experiments in the drift. An accurate model of the cavern (LIDAR scan) has been used to optimize the exact position of CUTE.

The overall system to be considered for the implementation is divided in sub-systems:

- The platform
- The crane
- The Clean Room
- The GHS (dilution gas handling system)
- The PT compressor
- The acquisition system (DAQ)
- The UPW sterilizer and water circulation pump
- The cooling loop system

The implementation is shown in Figure 4 and Figure 5.

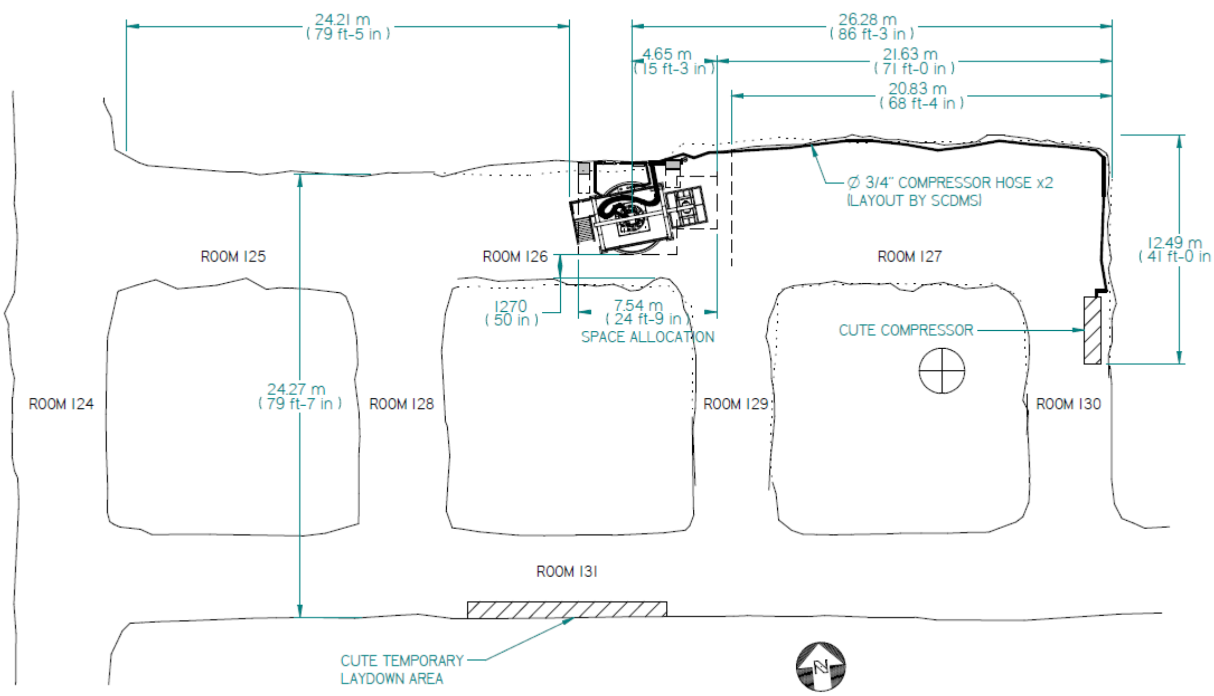

Figure 4: Top view of the CUTE experiment in SNOLAB [SNO9]

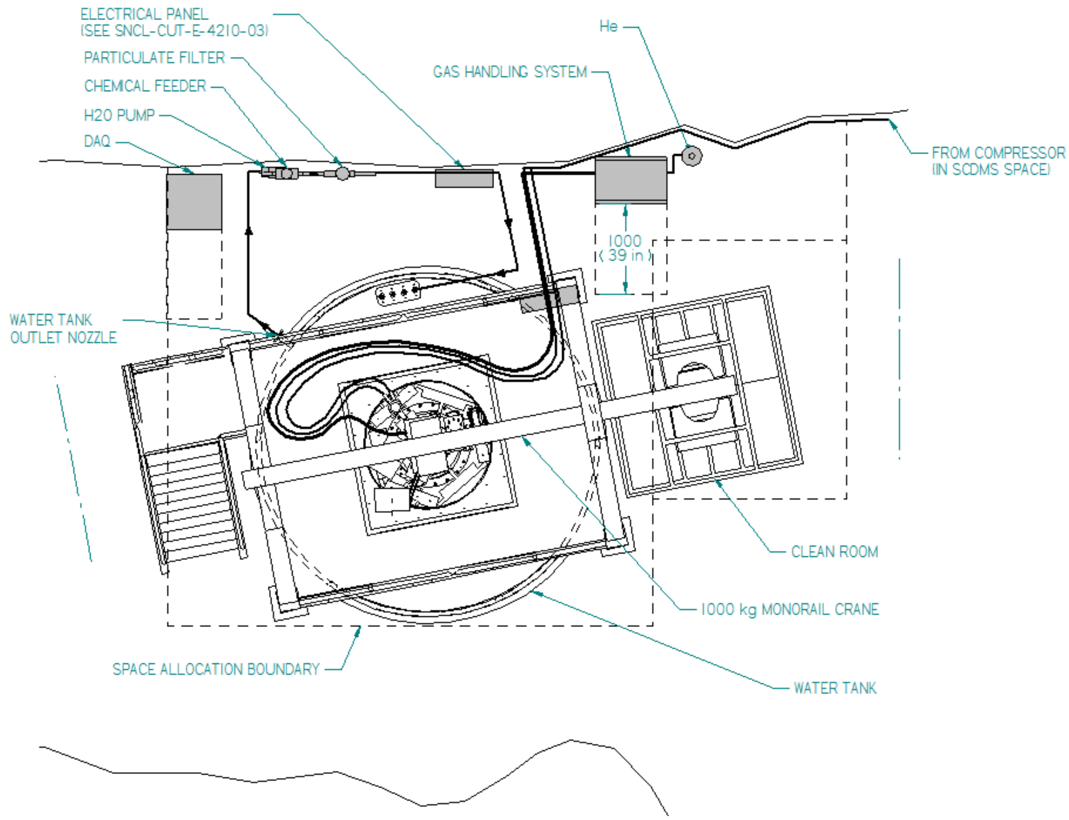

Figure 5: General arrangement of CUTE.

5.2 DILUTION REFRIGERATOR

5.2.1 Design Principles

- The base temperature of the DR is driven by the detectors requirements; the EDELWEISS detectors are the more demanding (15 mK). Some margins are taken for the thermal resistance between the fridge and the Detectors Tower Interfaces.
- The cooling power on the coldest stages (1K, 0.1K and 13mK) are driven by the cooldown time, more than the stationary thermal loads during operation
- Due to the large mass of lead (~100 kg) added to provide a low radioactivity background, and to the mass of the Detector Tower (~20 kg), special cares have been taken to provide some thermal links acting as heat switches between the 4K & 1K stages needed to keep the cooldown time below 1 week [AN1]
- The microvibrations transmission between the Pulse Tube Head and the detectors is a major issue in such kind of cryostat. A careful analysis has been done to drive the main choices of the design; i.e. the type of supports, the impact of the various bellows stiffness and the global arrangement of the perturbative elements mounted at the top of the cryostat [REF2][AN4]
- Finally, the place constraints at SNOLAB which is a severe limitation was driver for the architecture of the top of the cryostat and the operations on the Detector Tower.

The design has been done during the design phase with the manufacturer in order to define the needed customizations of the standard fridge model. The main points were:

- The overall size of the cryostat
- The optimization of the top flange to control the vibrations transmission
- The addition of an internal lead shield (~100 kg at 1K)
- The mounting and interfaces with the Detector Tower

The [AN1] contents of the definitions of the cryostat and needed piping. The [AN1] summarizes the requirements for the cryostat procurement and the test plan.

5.2.2 Interfaces

The DR has interfaces with:

- The *platform*: mechanical fixations, piping and electrical cables
- The crane: attachment of the lifting beam

5.3 Platform

5.3.1 Description

The platform is an elevated steel support structure, centered over the water shield tank. The platform supports the mass of the experiment, and allows access for staff during during installation, and for transfer of the cryostat to the clean room. Due to space constraints, and infrequent access requirements during detector operation, access to the platform is from a high-incline “ships ladder” type stairway.

Structural engineering of the platform has been completed by WSP Canada. SCR Mining is responsible for fabrication of the steel (subcontracted to a local Sudbury fabricator), and installation of the platform underground.

The platform is serviced by a 1000 kg crane. A central cylindrical structure, consisting of two stainless steel vessels, provides the support interface for the cryostat, and acts as a watertight barrier between the cryostat and the water tank.

General specifications for the platform are summarized below:

- Nominal platform elevation 3540 mm
- Platform column centres on a rectangle of size 3700 x 2800 mm
- Central rectangular square opening of size 1500 x 1500 mm
- Man access opening (762 x 762 mm) beside the central opening
- Nominal 73 mm radial clearance from water tank wind ring to columns
- Nominal 197 mm radial clearance from water tank to column base plates
- Nominal 121 mm vertical clearance from top of water tank to platform steel members
- Handrail with kick plate all around platform
- Saloon-style gate on east side for moving materials on to platform from floor
- Platform ladder (compact stair) for access to platform
- Removable checker-style deck plating
- Mass of steel ~4150 kg

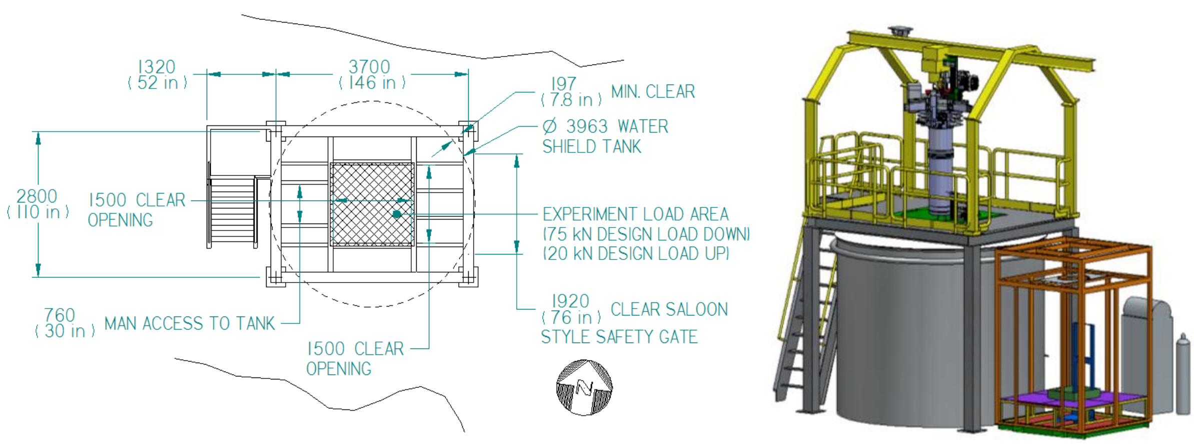

Figure 6: (Left) Platform plan view. (Right) Platform shown with cryostat raised.

5.3.2 Reference Documents

Relevant documents for the platform and central support vessels are summarized below:

WSPO-CUT-AR-2001-01 thru -04	Platform structural specifications and framing plan
QUDO-CUT-AR-2002-01 thru -03	Platform openings, central support vessel connection details, and checker plate arrangement
QUDO-CUT-AR-2101-01 thru -07	Support vessel (dry well)
CUTE-TN-008	Technical Note – CUTE Platform Stair Design

5.3.3 Platform Design Loads

Platform design loads are summarized in the table below. In addition, the platform has been designed by WSP Canada to withstand the SNOLAB design seismic event, as specified in the following documents:

1. ICCI-SNO+ForcingFunctionsMemoOct2009-6.pdf *"Proposed Dynamic Loading Design Parameters for SNOLab Site"*
2. ForcingFunction.xls *The supplied forcing function (referenced in document 1)*
3. QUDO-DEC-TR-0010-B.pdf *"SNOLAB Seismic Spectral Response Acceleration Functions"*
4. UADO-DEC-TR-0022-00_Rev_A.pdf *"The SNOLAB Seismic Design Response Spectrum and Accelerations"*

5. Location	Load Description	Design Load (down unless otherwise specified)
Uniformly distributed across the deck platform (live load)	Live load (for personnel and tools, small temporary equipment)	6 kN/m^2 (125 lbf/ft^2)
Crane area (live load)	Any equipment lowered by the top support structure onto the deck	21 kN/m^2 (438 lbf/ft^2)
Crane load (live load)	Loads due to crane (east/west movement only)	10 kN
Concentrated load on rectangular opening at centre of platform (dead load)	Mass of cryostat + support vessels + lead shield upgrade; water tank empty	75 kN
	OR, Mass of support vessels; buoyancy from full water tank	20 kN (up)

Perimeter of platform (dead load)	Cleanroom (mass of Unistrut framing + HEPA/fan modules + lighting)	6.7 kN

Table 3: Platform design loads

5.3.4 Installation

SCR Mining will install the platform. Mobilization details are summarized below:

- SNOLAB will deliver and clean materials and equipment from surface to work site in the lab underground.
- Laydown area will be in the LAD (see Figure 7 below), and job boxes may be kept in the work space.
- Erection equipment will include the RBK and existing 12 ton hitch above the CUTE experiment.
- The water tank will be assembled before the platform is erected, and scaffolding may be installed inside the water tank during platform erection.
- Assembly of the platform will not require installation of dust walls. The platform is entirely bolt together, and platform anchors require short drills (125 mm minimum embedment), using an electric drill and vacuum.
- SNOLAB will provide vacuum cleaning equipment for use by SCR when drilling.
- WSP will conduct a site visit to confirm that the Work is in general conformance with the Contract Documents prepared by their firm.

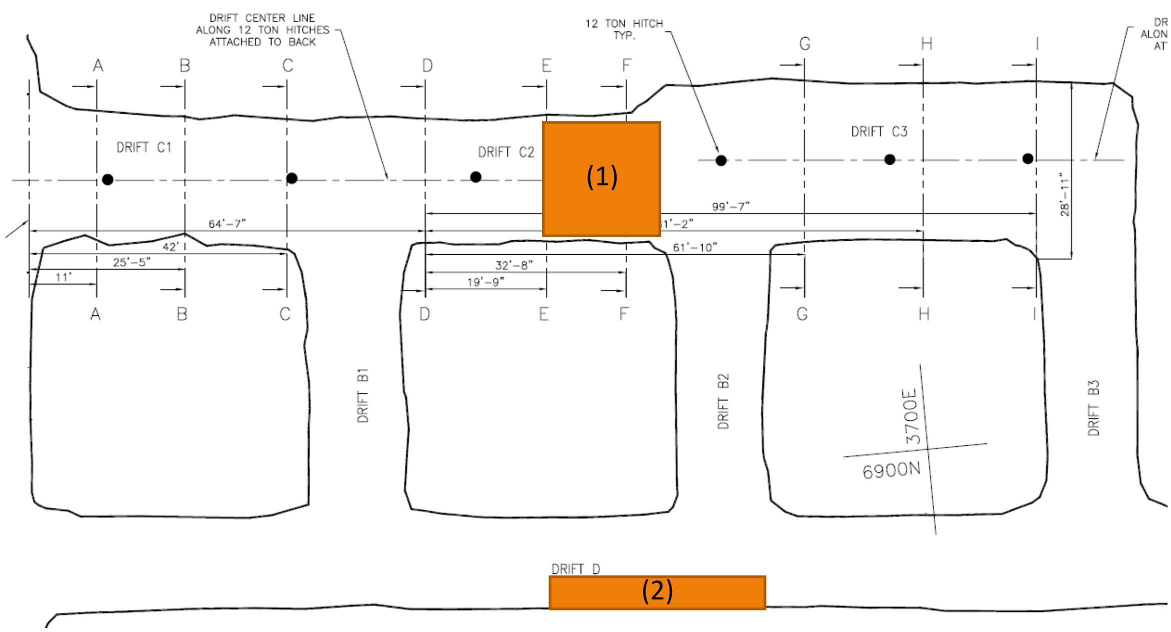

Figure 7: (1) CUTE construction area. (2) Laydown area.

5.3.5 Cryostat Support

The cryostat support vessels are shown in Figure 8 below. The vessels are fabricated from 316L stainless steel. Design conditions are detailed in QUDO-CUT-AR-2101-01 and -03. Mounting of the top support vessel to the platform is detailed in QUDO-CUT-AR-2002-01 and -02.

The cryostat mounts to the inside of the top support vessel. Tapped holes in both vessels are provided for attachment of lifting hardware during installation, and an O-ring between the top and bottom vessels provided a watertight seal during operation.

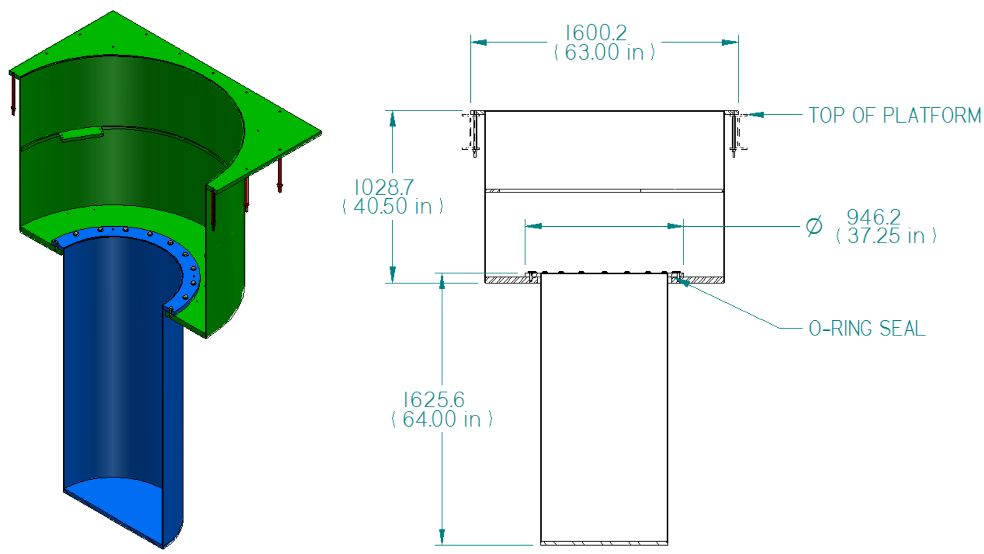

Figure 8: (Left) Support vessel 3D arrangement, showing top (green) and bottom (blue) support vessels. (Right) Support vessel cross-section, showing outside dimensions.

The pulse tube head is rigidly connected to the top support vessel with three aluminum beams. In order to isolate the detectors from vibrations (primarily induced to the platform by the Pulse Tube Head), the lower cryostat is coupled to the Pulse Tube Head through a soft bellows, and supported from below by three elastomer dampers. Each damper is coupled to a stepper-motor-driven lab jack, in order to maintain the cryostat in a constant position through a range of operating conditions. Counterweight masses are added to load each damper within a desired range.

A schematic of the cryostat support arrangement is shown in Figure 9 below, beginning with the assembly sequence.

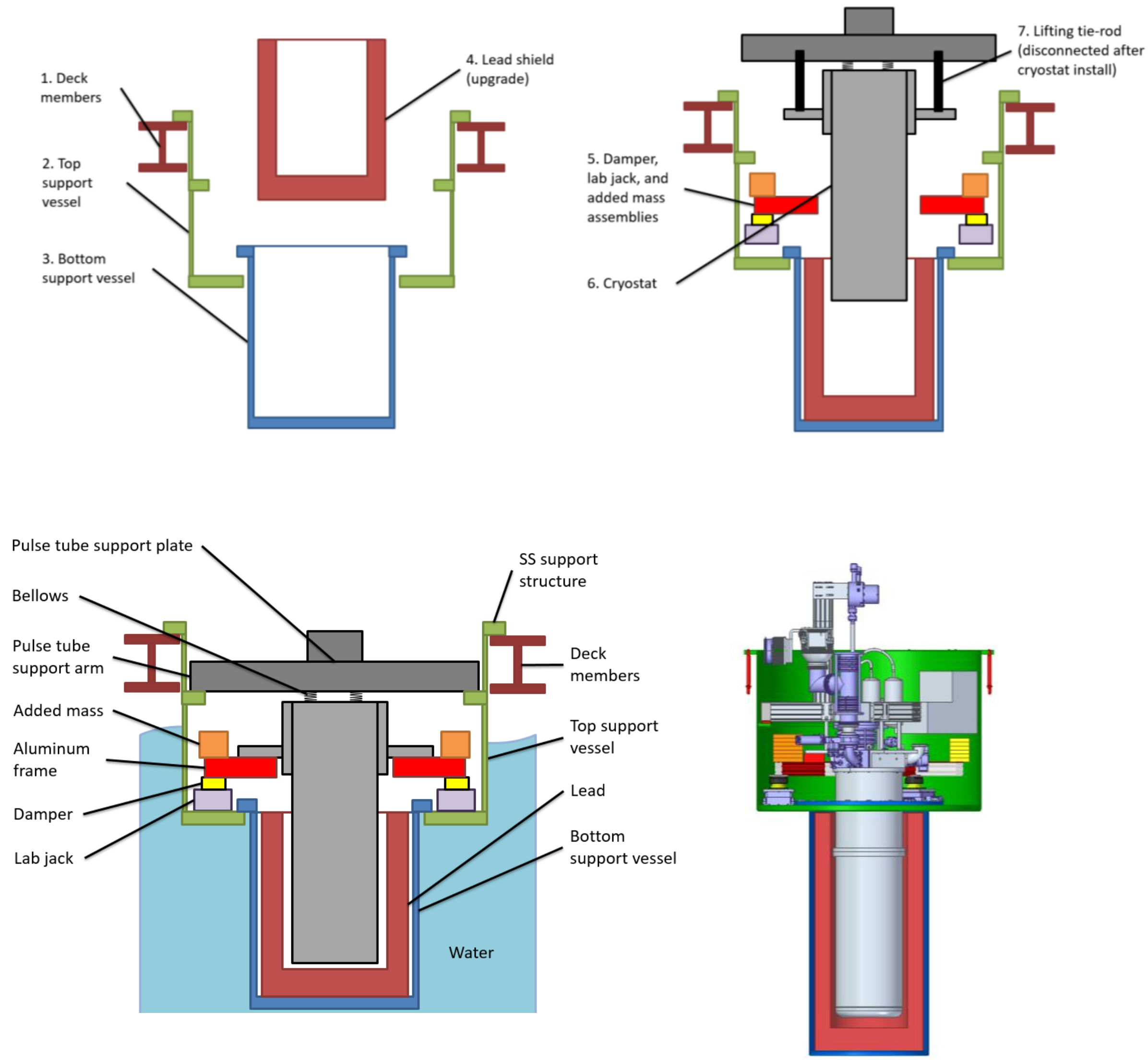

Figure 9: Cryostat support arrangement.

(Top-left) 1. The platform is installed; 2. The top vessel is lowered and connected to the top of the platform; 3. The bottom vessel is lowered and sealed to the support structure; 4. The lead shield (upgrade) is assembled inside the vessel by lowering and stacking thin lead rings.

(Top-right) 5. The lab jacks, dampers, and added masses are lowered and mounted inside the support structure; 6. The cryostat is lowered and mounted to the dampers with added masses, and the pulse tube plate is rigidly connected to the top support vessel; 7. The lifting tie-rods are disconnected, allowing the lower cryostat to rest on the damper assembly.

(Bottom-left) Conceptual arrangement of the cryostat support assembly. The lower cryostat rests on three damper assemblies that are equally distributed around the base plate of the top support vessel.

(Bottom-right) CAD view of support arrangement.

5.4 CRANE

5.4.1 Description

The crane is a 1 tonne (1000 kg) freestanding monorail, coupled directly to the top of the steel platform. The monorail runs along the east/west center line of the platform, and includes a 5 ft. cantilever off the east side. Additional specifications are summarized below:

- VFD trolley and hoist for smooth starts and stops
- Food grade hoist with stainless steel hook
- Drawings signed and sealed by Ontario P.Eng.
- Assembled, load tested, and ESA inspected at fabrication shop before delivery to SNOLAB

5.4.2 Design Criteria

The main function of the crane is to move the cryostat between the platform and the clean room, for mounting and dismounting of the Detector Tower. The rated lifting capacity of 1 tonne is chosen to provide a large margin of safety compared to the mass of the suspended system (< 500 kg). The crane will also be used for assembly phases (e.g. installation of the support vessels, and mounting the external lead shield upgrade).

Of particular importance in the crane design is the requirement for a low-headroom design. To ensure fit and function of the crane, the following strategies have been used:

- Use of the LIDAR (3D scan) survey of the ladder lab, for accurate mapping of the rock back above the crane
- Use of a low-headroom hoist
- Custom designed crane structure, to maximize clearance to the rock back
- Custom designed 3-point lifting beam when lifting the cryostat, to minimize required height of rigging

5.4.3 Lifting Beam

The lifting beam is used to couple the cryostat to the hoist, and has the following specifications:

- 1000 kg capacity 3-point stainless steel lifting beam (1 central lifting point to hoist, with three 333 kg radial lifting points to attach to the cryostat).
- Designed according to ASME B30.20 BTH-1 standards.
- Includes 125% proof load test report.
- Drawings signed and sealed by Ontario P.Eng.

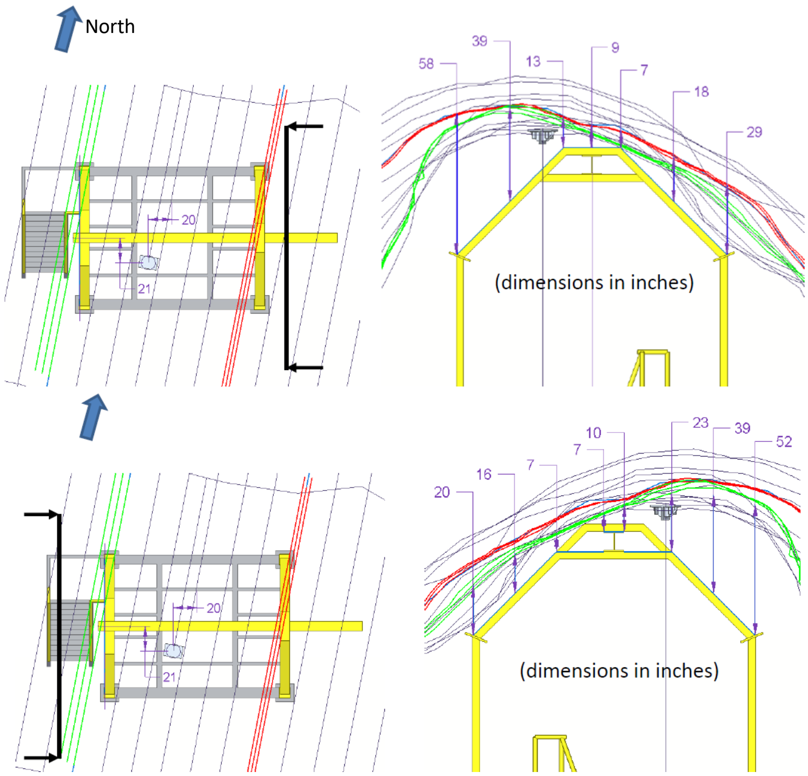

Figure 10: Crane clearances to rock.

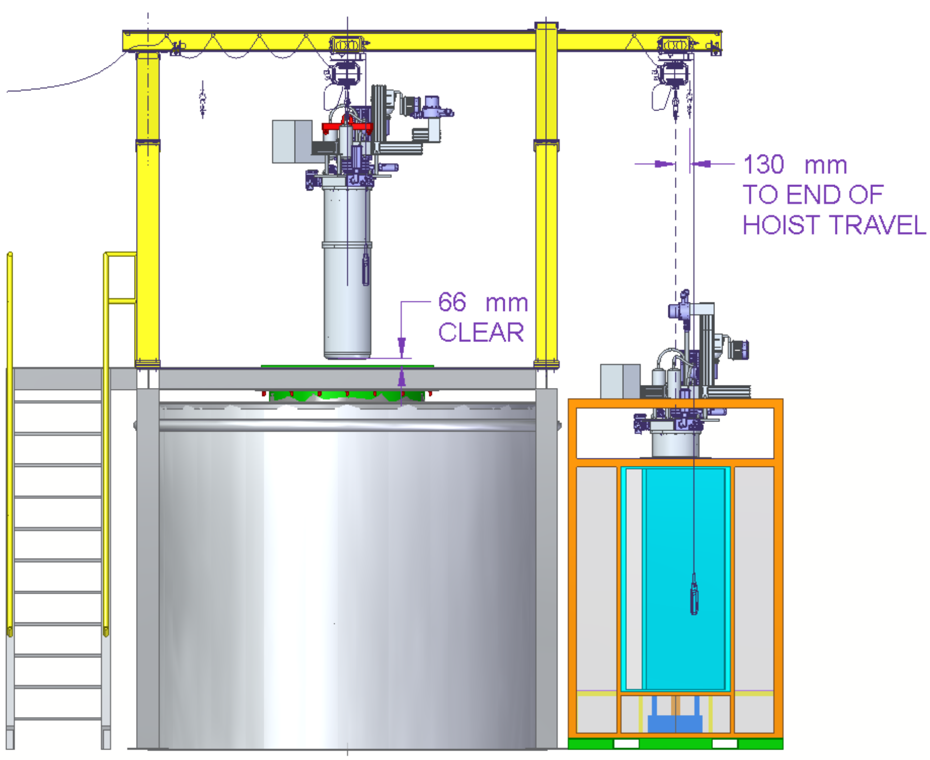

Figure 11: Crane arrangement.

5.4.4 Interfaces

- Platform
- Dilution refrigerator

5.5 Water Tank

5.5.1 Description

The water tank is manufactured by is Westeel, and is already available at SNOLAB. The tank consists of a cylindrical "grain bin" style stainless steel tank, assembled from corrugated sheets. A backing PVC layer, covering the floors and wall, is installed first. Inside the backing layer, the watertight PVC liner is installed. A flexible PVC lid is clamped around the top support vessel, and covers the top of the water tank. Four bulkhead fittings for tank services are fastened to a stainless steel plate at the perimeter of the lid. Six vertical stiffeners distributed around the tank are used to support a stiffening ring near the floor, used to tie off and support the liners and lid.

Anchor brackets at the base of each vertical stiffener are used to anchor the tank to the ground. Anchors provide vertical restraint only; Oversized holes in the anchor brackets allow horizontal motion of the tank, in the event of a large seismic event. This is the same approach that has been adopted for the DEAP and MiniClean water tanks.

Access to the tank during construction is either through a removable set of "door" panels, or with a Bosun's chair through an opening in the platform.

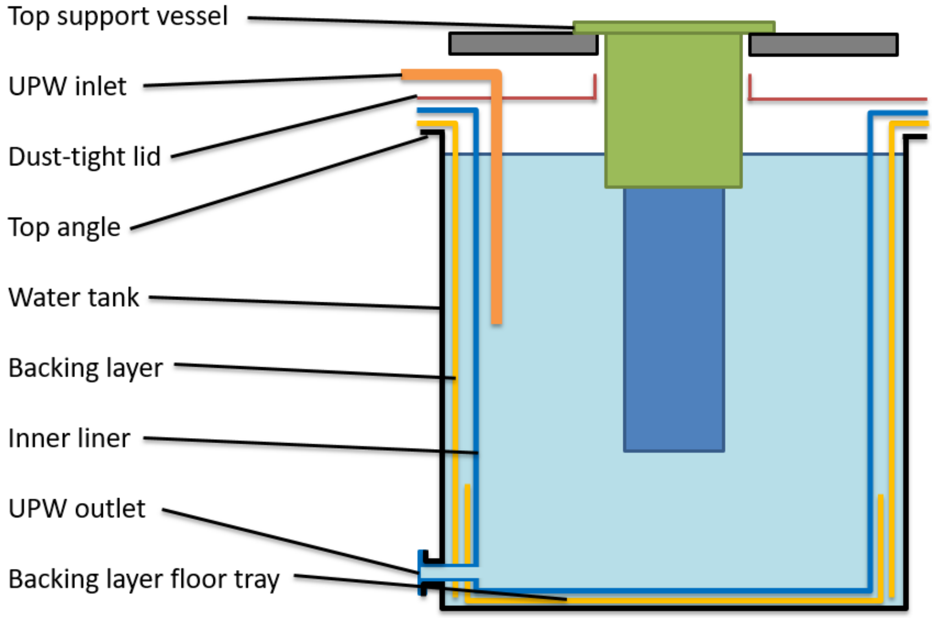

Figure 12: Water tank arrangement cross-section.

5.5.2 Reference Documents

Relevant documents for the water tank are summarized below:

CUTE-TN-004	Water tank, liner, and lid specification
QUDO-CUT-D-6101-01 thru -02	Water tank nozzle modification
WSTO-CUT-D-6102-01 thru -10	Water tank top row sheet modifications

WSTO-CUT-D-6102-11	Water tank general arrangement
WSTO-CUT-L-6103-01	Water tank parts list (Westeel parts)
QUDO-CUT-D-6104-01 thru -02	Water tank edge angle
QUDO-CUT-AR-6105-01 thru -02	Water tank orientation, vertical stiffener, and wind ring attachment
QUDO-CUT-L-6106-01	Water tank bill of materials
QUDO-CUT-AR-6201-01	Tank liner modifications
QUDO-CUT-AR-6202-01 thru-03	Tank lid arrangement
QUDO-CUT-D-6202-04 thru -05	Tank lid part details

5.5.3 Water Tank Specifications

Details for the water tank and liner are outlined in the specification document (CUTE-TN-004), and a summary of specifications is provided below:

- Diameter at tank corrugation centreline= 12’-2.2” (without stiffening ring)
- Diameter at outside of wind ring = 13’
- Original height = 12’-2.5” (as originally purchased)
- Final height = 10’-6.5” (after modifications to reduce height)
- Tank volume (final height) = 35 m^3
- The water tank is not required to be light tight
- The lid is not required to be gas tight, nor is it load bearing
- Top angle for mounting of the liner and backing layer
- Six vertical stiffeners for anchoring to the floor, and supporting the wind ring
- Bottom angle for additional support of shims for leveling

5.5.4 Interfaces

- Ground
- External stainless steel vessel
- Water circulation system

5.6 ULTRA PURE WATER CIRCULATION SYSTEM

5.6.1 Design Criteria

Keep the water clean, limits the biological growth. The system combines a particle filter with a UV sterilizer. A pump is required to circulate the water into the filtering system. The recirculation rate is compatible with a complete tank content circulation within one day.

The following figure shows the principle of the system with the connections to the pure water supply and the exhaust. The pipes enter into the water tank through a modified panel. The return pipe will be designed in order to evacuate completely the water from the tank.

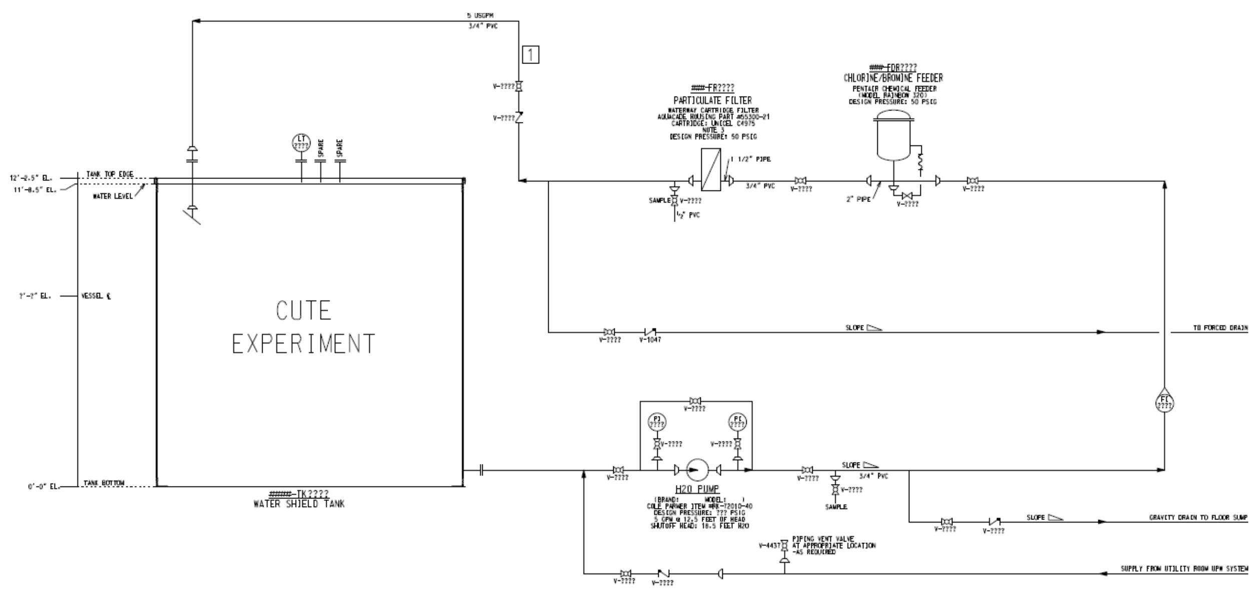

Figure 13: Water tank circulation system [AR6]

5.6.2 Interfaces

- Water tank (modified panel and nozzle installation)
- UPW Pure water supply from SNOLAB
- Exhaust water system
- Electrical power supply
- Ground installation

5.7 CLEAN ROOM

5.7.1 Design Criteria

The clean room is mounted on the platform. It provides a low Radon ambient to limit the Radon exposition on the Detector Tower during the mounting or dismounting operation.

SNOLAB air has a Radon content of ~130 Bq/ m^3, which is considered too high. The solution is to use surface air (~3 Bq/ m^3). The air must be filtered (particulate, oil and coalescing, carbon adsorption), and will be tested according to limits set out by CSA Z180.1 – 00 in order to certify it as human breathing air. The typical ventilation rate of 1 volume/hour is ~50 m^3/h (~30 CFM) with de-radonized air (< 0.1 Bq/m^3). Both the filter and the fan will be included within the clean room structure.

When the de-radonized air facility will be available from SuperCDMS, we could use it for our clean room air supply.

The total expected Radon for a complete mounting/dismounting cycle is 10 Bq/m^3.h for a maximum accepted exposition of 80 Bq/m^3.h. The Specifications of the Clean Room are described in [AN7].

5.7.2 Interfaces

- Deck
- Surface air from SNOLAB (Low Radon air supply from SuperCDMS when available)
- Electrical power supply

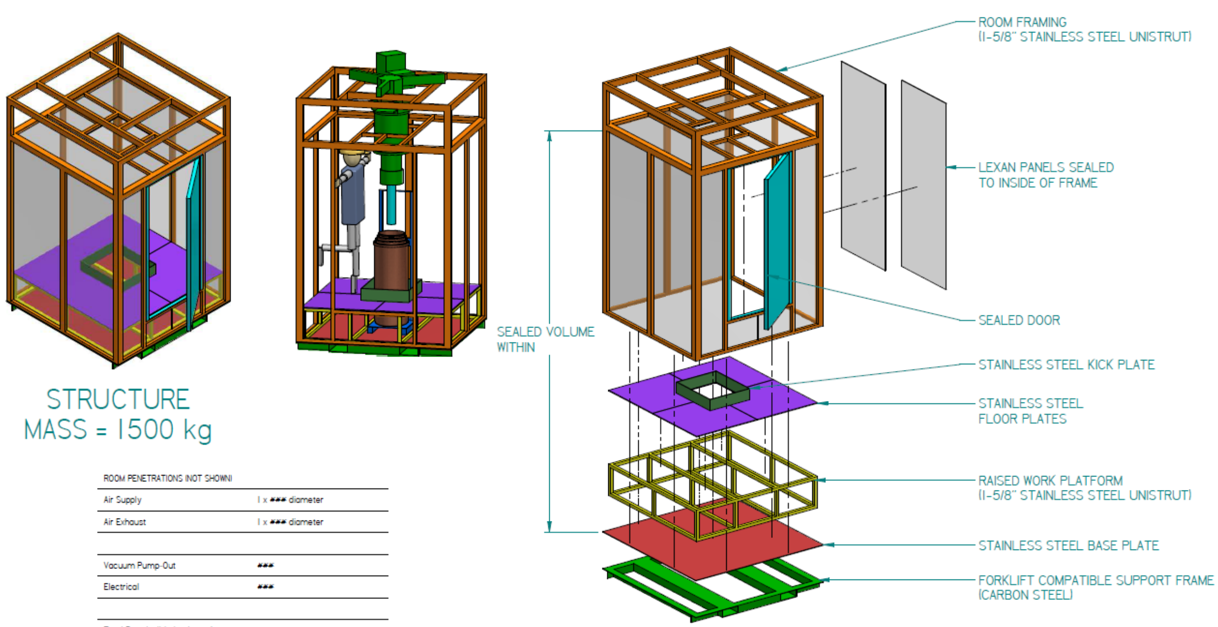

Figure 14: Clean Room conceptual design [AN7][SNO20]

5.8 COOLING WATER LOOP

5.8.1 Design Criteria

The cooling water loop is required to remove heat from the pulse tube compressor (Cryomech CP1100, nominal 10.7 kW). Heat will be rejected to the mine supply water using a plate frame heat exchanger. The system will be shared between SuperCDMS and CUTE, with the CUTE side of the system coming online before SuperCDMS. A P&ID of the system is shown below. Cooling water requirements for the CUTE compressor are the following:

- Qmax = 11.5 kW * 1.2 = 13.8 kW (20% safety margin)
- Max flow = 11.5 L/min (3 GPM)
- Min flow = 4.5 L/min (1.2 GPM)
- Maximum water inlet temperature = 27°C
- Maximum pressure = 110 psig

5.8.2 SuperCDMS Responsibilities

SuperCDMS has taken responsibility for the following aspects of the design:

- Cooling loop P&ID (See F10058729)
- Heat exchanger specification (this heat exchanger will service both CUTE and SuperCDMS head loads)
- Piping size, type and schedule
- Installation specifications
- Recommended pump size for CUTE side of the system (to be taken offline when the SuperCDMS system comes online
- Water specification, cleanliness and treatment
- 3-way control valve specifications (for partial flow bypass to prevent excess heat removal from the compressor)
- Expansion tank specification (open-top tank is preferred)

5.8.3 CUTE Responsibilities

CUTE is responsible for the following:

- Layout of equipment (heat exchanger, CUTE-side pump, expansion tank) and piping
- Review component list and purchase CUTE components
- Review pressure drop calculations

5.8.4 CUTE Responsibilities

Specifications for the heat exchanger are summarized below:

- CUTE/SuperCDMS minimum flowrate = 11.44 GPM
- SNOLAB chilled water flow rate = 25 GPM (50% of the maximum permissible from SLDO-UGL-FL-3003-01 Rev 0)
- Chilled water supply pressure = 250 psig (SNOLAB chilled water design pressure)
- Chilled water supply temperature = 4.4°C
- CUTE/SuperCDMS inlet temperature = 48.8°C

- CUTE/SuperCDMS outlet temperature = 7.2°C

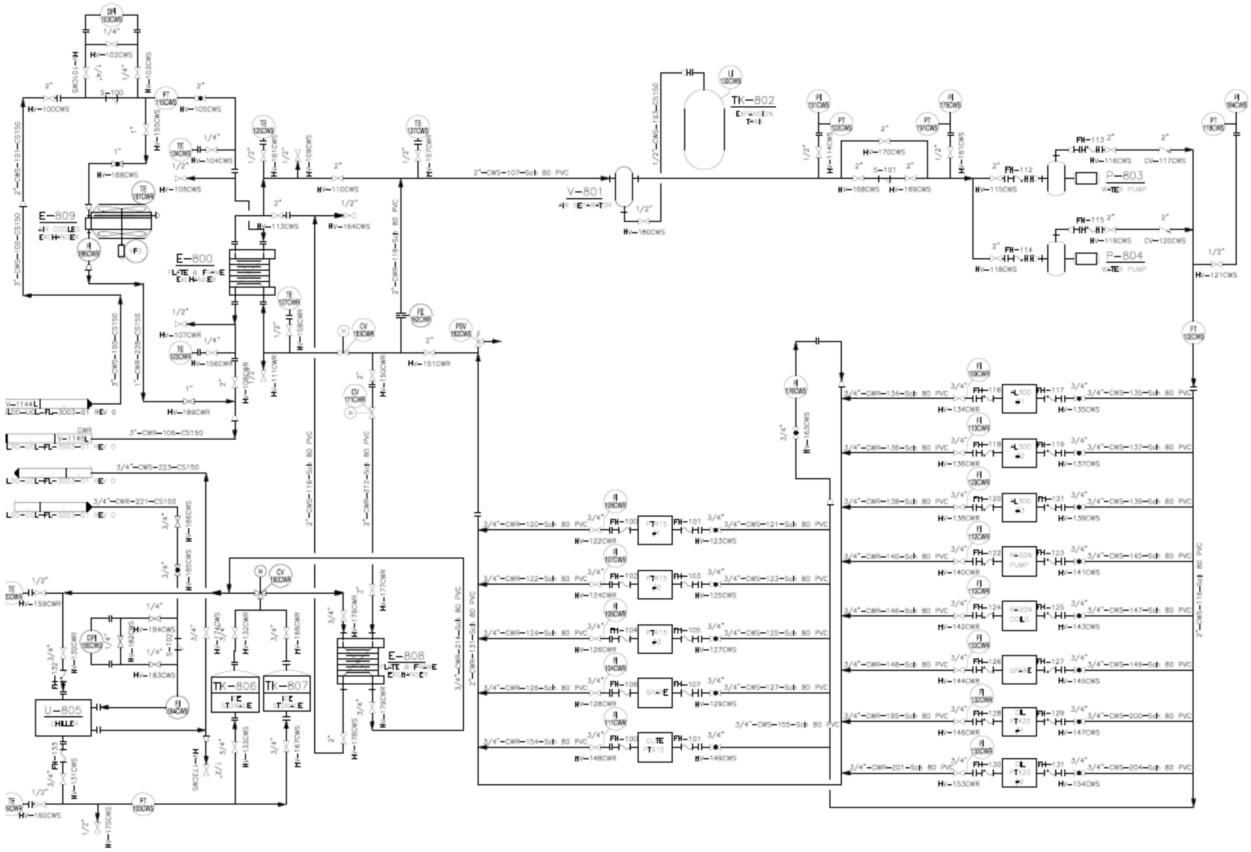

Figure 15: Cooling water loop PID [AR5]

5.8.5 Interfaces

- Cooling water system from SuperCDMS
- Cooling water from SNOLAB
- Pulse Tube compressor

5.9 Low Radon Air Ventilation system

Radon concentration in SNOLAB (~130 Bq/m^3) is a contribution to the CUTE background. There are two ventilation circulation of surface air (<10 Bq/m^3) from the surface:

- Around the cryostat to limit the background within the air volume between the outter crystat can and the external lead shield
- To the Clean Room in order to limit the exposition during the mounting and dismounting operation

SuperCDMS plans to install a de-radonized air ventilation system (< 1 Bq/m3) which could be used when available.

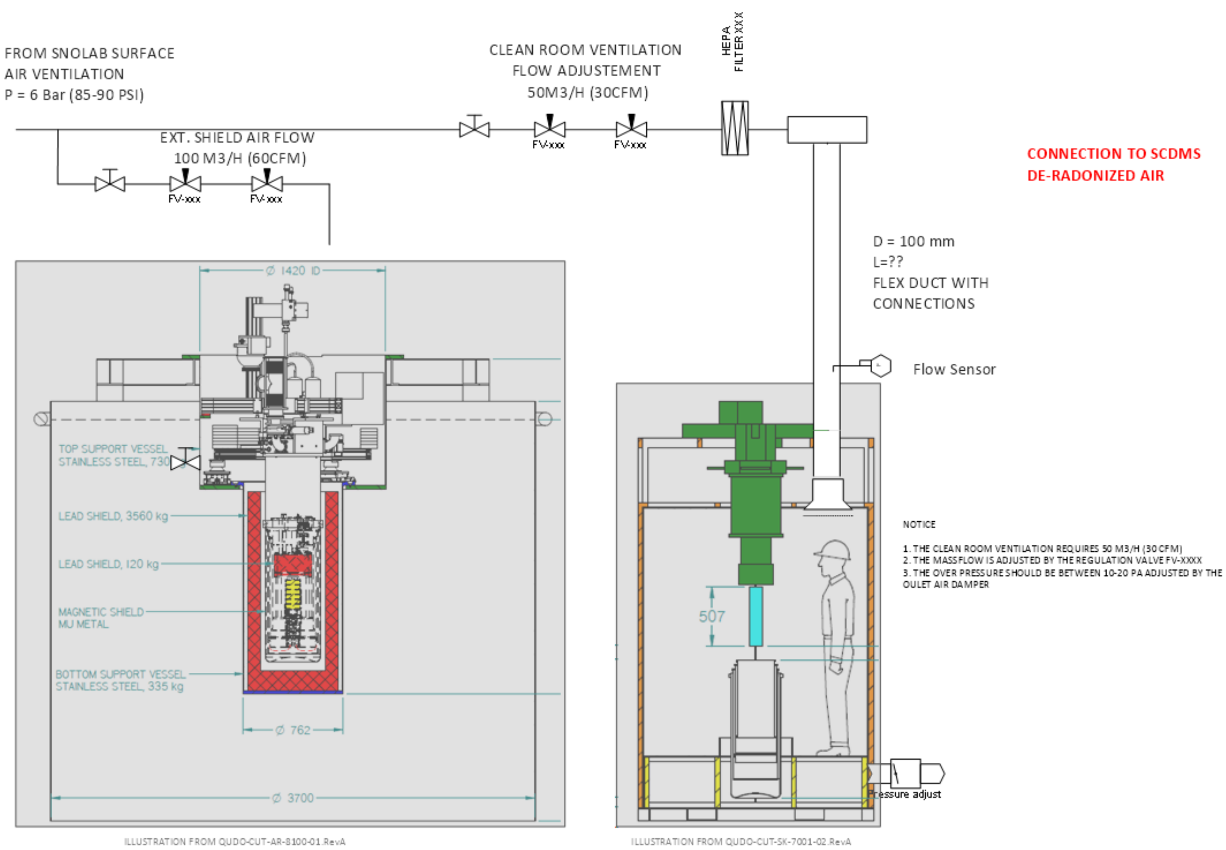

Figure 16: Low-Radon ventilation system [AR12]

5.10 LIFE SAFETY DESIGN

Various features are incorporated into the design of CUTE in order to ensure life safety. These include:

- Standard hand rails with kick plate around the platform to prevent falls and knocking tools to the ground.
- Stair access for increased safety when traveling to the top of the platform.
- Filtration and CSA-approved analysis of compressed breathing air for the cleanroom.
- Design of the platform to survive seismic-induced forces.
- Incorporation of travel restraint to prevent falls when workers are on deck, and transporting a load onto the platform.
- Incorporation of a vented lid over the water tank to remove an open-water hazard, and minimize biological growth.
- Open-top stainless steel support vessel, providing inherent safety against accidental over pressure.

5.11 WASTE MANAGEMENT

CUTE will generate minimal waste. Sources of waste are detailed below:

Waste Source	**Quantity / Frequency**
Shield tank UPW	35 tonnes discharged to drain once during decommissioning
Empty helium bottle	1 empty bottle per year
Liquid nitrogen boil-off	Vented to lab @ 100 L N2/week
Clean room clothing, gloves	A few pairs of gloves per day

6 SNOLAB RESOURCE REQUIREMENTS

6.1 SPACE REQUIREMENTS

Requested space for during the experiment run time is shown in Section 5.1. During construction, additional lay down area is requested along the south wall of drift D, and the west wall of drift B2 (see Section 5.3.3).

6.2 ELECTRICAL

Peak electrical load is expected to be 18 kW. Major electrical loads are summarized in the table below. There is not currently a plan to incorporate UPS or generator backup for any electrical.

The electrical drawings are available in [AR10] and [SNO10].

		Electrical						
Component Name	**Component Description**	**V**	**# phases**	**FLA**	**Average Current**	**Fuse**	**Power**	**Duty Cycle**
		(V)	**(1 or 3)**	**(A)**	**(A)**	**(A)**	**(W)**	**(%)**
Crane hoist/trolley	Electrified chain hoist and trolley (qty 2 refers to 1 box for hoist and 1 box for trolley)	575	3	?	?	?	900	<1%
H2O Circulation system	Unistrut frame with circulation pump micron filter, UV sterilizer	120	1	1.3			156	100%
Pulse tube compressor	Compressor + heads	208?	3				11500	100%
Gas handling system	Gas handling system for the cryostat	120	1				2000	100%
Instrumentation Rack	Electrical pannel with R/O electronics and control	120					500	100%
Network	Switches (Nb TBD)	120	1				500	100%
Computer workstation	(connected to UPS 4kW)	120	1				2000	100%
RGA		120	1				300	100%
					Total Power		**17.856**	**kW**

Table 4: Electrical summary systems [CUTE-MatsterEquipementList-REV1P1]

6.3 NETWORK COMMUNICATIONS

CUTE is expected to take data at a rate of 300 GByte/day or 1 TByte/week.

6.4 VENTILATION

The CUTE cleanroom will recirculate lab air. Make-up surface air is requested at a rate of 30 CFM (50 m^3/hr) to provide a radon-reduced environment during mounting/dismounting of detectors. This would be used until a point at which the SuperCDMS RRA system comes online and is made available to CUTE.

6.5 CHILLED WATER

The CUTE pulse tube compressor requires chilled water at a nominal rate of 10.7 kW, and a maximum of 11.5 kW. A maximum flow rate of 25 GPM from the SNOLAB chilled water system is requested, in order to meet the required cooling for both CUTE and SuperCDMS. Additional details are provided in the Cooling Loop section of this report; Section 5.8.

6.6 Ultra pure water (UPW)

Filling of the CUTE water tank will require 35 tonnes of water from the UPW system. Under normal operating conditions, there are no plans to drain the water tank.

6.7 Forced drain

In the event that the water tank needs to be emptied, water will be sent to drain.

6.8 Compressed air

Compressed air will be required to actuate several pneumatic valves, at the typical supply pressure of ~6 bar (~90 psi).

6.9 Consumables

An auxillary helium supply is required to purge pipes during connection, to fill the pulse tube, and to optimize the cooling performance. This consists of a standard helium bottle. In addition, a small liquid nitrogen inventory is required for filtering the DR helium to 25L/week. The required inventory of consumable gases and liquids is summarized below:

- Grade 5 helium: 1 bottle per year
- Liquid nitrogen: 400 L per year (30% duty cycle)

6.10 Rail cars

All equipment for CUTE is designed to be cageable. With the exception of the crane monorail, all items will fit within the standard limits for a rail car [SLDO-DEC-SP-1506-01]. The monorail is an 18 ft. long, 8 in. deep steel beam, and will require the use of both decks.

The estimation of rail cars is given in [CUTE-MatsterEquipementList-REV1P1].

6.11 Installation support

Support is requested from the SNOLAB installation group for several installation tasks.

7 DECOMMISSIONING

At the end of the experiment, it is proposed that the following equipment be left in place, with ownership transferred to or maintained by SNOLAB:

- Platform and 1-tonne crane
- Water tank and liner
- Electrical distribution
- Water circulation system
- Clean room

Removal of the remaining equipment would follow the following steps:

1. Warm up and dismount detector tower from cryostat.
2. Drain shield tank.
3. Take the pulse tube compressor cooling water system offline.
4. Pack up detector tower(s) and ship away from site.
5. Disassemble cryostat, compressor, and gas handling system.
6. Pack cryostat, compressor, and gas handling system in shipping containers, and ship away from site.
7. Cut up stainless steel support structure and dispose of materials.
8. Remove the CUTE-side cooling water piping system.

8 SUMMARY

The detailed design of the CUTE facility is completed for the main items of the infrastructure at SNOLAB:

- Platform
- Crane
- Water tank modifications
- Ultra Pure Water Circulation system
- Electrical power installation
- Cyrogenic piping routing

The cooling water loop needed for the Pulse Tube compressor is made by SLAC.

The detailed design of the instrument is complete for the following items:

- Dilution refrigerator (sub-contracted to Cryoconcept)

The detailed design of the following parts is closed to finalization:

- Suspension system
- Clean Room
- Instrumentation rack (control electronics for the suspension)