Cryogenic Upgrade of the Helium Central Liquefier and Superconducting Cable & Wire Test Facilities at CERN

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Abstract. The demand for liquid helium (LHe) for users at CERN without dedicated cryogenic infrastructure is set to increase due to future projects and experiments in the Antiproton Decelerator. LHe is supplied to the users by means of 500 liter dewars filled by the central liquefier (B165) that comprises a cryogenic plant of 400 W @ 4.5 K. In addition, the Superconducting Cable & Wire Test Facility (B163) located nearby will be upgraded to incorporate the forthcoming installation of the new test station FRESCA 2. B163 includes a second cryogenic plant of 400 W @ 4.5 K and a dedicated cryogenic distribution system. To maximize the production of the two cryogenic plants and their ancillary infrastructure, thus improving the subsequent distribution of LHe, a combined cryogenic distribution system has been developed. This system will increase the LHe storage capacity; allow the direct transfer of helium inventory between both facilities and the gravity filling of large capacity trailer dewars in addition to the 500 liter dewar fleet. This paper details the architecture of the new cryogenic distribution system, the analysis undertaken to define it, the design and specifications of the various components and the schedule of the realization of the project.

1. Introduction
The central cryogenic infrastructure on the CERN Meyrin site comprises the central liquefier and the central cryogenic laboratory (Cryolab) situated in Building 165 (B165), the central purifier situated in Building 253 (B253) and the superconducting (SC) wire & cable test facility situated in Building 163 (B163).

1.1. The cryogenic infrastructure of B165, B163 and B253
The central liquefier is a 70 l/h (2.5 g/s) Sulzer CNA 47/90 helium liquefier (equivalent to a TCF50) [1] manufactured in 1990, which supplies liquid helium (LHe) to experiments and laboratories hosted at CERN without their own cryogenic infrastructure. LHe is transported to clients in mobile dewar with capacities from 100 liters to 500 liters. A 3 kPa low pressure recuperation network (gazometer) returns the impure gaseous helium (GHe) to the Central Purifier [2] where 24 m$^3$ of impure and 78 m$^3$ of pure GHe at 300 K can be stored at 160 bar in either 1,000 liter jumbo cylinders or 50 liter batteries before it is re-liquefied.

From 1998 to 2006, up to 30 clients were supplied an average annual LHe volume of 250,000 liters [2][3]. Since this time the average annual demand has increased, peaking at more than 400,000 liters during 2010, due to the LHe requirement of the ALPHA, ASACUSA, ATRAP and AEgIS experiments in the Antiproton Decelerator (AD) [4]. Future demand is set to increase further due to upgrade of the present experiments and the additional BASE and GBAR experiments [5]. To meet this increased demand the production capacity of the central liquefier was increased to 160 l/h (5.2 g/s) by boosting
with liquid nitrogen (LN2). Unfortunately, production became limited by the present LHe storage of 5,000 liters.

At the end of the 1990s B163 was built to meet the demand to test SC wires and cables for the LHC magnets [6]. Situated next to B165, the cryogenic facility is also based on a Sulzer TCF50 helium liquefier boosted with LN2, supplying LHe at 160 l/h. The test facility [7] comprises seven small test cryostats (STC) supplied directly from the liquefier, and the FRESCA double test cryostat (F1) [8], which is fed from a 6,000 liter dewar supplied from the LHe not used by the STC. To operate at 1.9 K, each STC has a dedicated warm pumping unit (WPU) with a capacity of 0.16 g/s at 15 mbar and 300 K. The WPU for F1 is situated in B165 and connected to the cryostat by the pumping line which passes under route Veksler. This WPU has a maximum pumping capacity of 1.33 g/s at 10 mbar and 300 K.

The performance of the cryogenic infrastructure in B163 has enabled much research however, in the framework of the high luminosity large hadron collider project (HL-LHC), during 2020 the facility will be upgraded with the installation of the FRESCA 2 test cryostat (F2) [9]. Similar to F1 but larger to accommodate the high field FRESCA 2 magnet, the test station will test SC cables for next generation accelerator magnets [10] and will increase the LHe and 1.9 K pumping requirement in B163.

1.2. The cryogenic upgrade of B165 and B163

To meet the future LHe requirement in B165 and B163 by harnessing the full LHe production capacity of the two existing liquefiers, a new combined cryogenic distribution system (CDS) is being installed.

To maximise LHe production, storage capacity is increased with the installation of a 20,000 liter LHe dewar. To improve the efficiency of deliveries to the AD the cryogenic infrastructure is upgraded to allow the gravity filling of 10,000 liter trailer dewars transportable by road in addition to the 100 liter to 500 liter mobile dewars.

The cryogenic infrastructure of B163 will be upgraded to enable the transfer of surplus LHe from B165, connect the existing 6,000 liter dewar directly to the liquefier and prepare for the future connection of F2. The WPU for F1 will be upgraded to meet the 2 g/s @ 10 mbar pumping requirement of F2.

In addition in order to save requalification costs, the GHe storage in B253 will be consolidated with the replacement of all 50 liter batteries by 24 jumbo cylinders with a total volume of 72 m³ at 200 bar.
Figure 2 presents the global process flow diagram showing the existing and new infrastructure.

2. Definition of upgrade

2.1. LHe demand from B165 clients
The cryogenic group at CERN ensures the delivery of 10,000 liters of LHe to the experiments of the AD each week, however a greater quantity is regularly delivered. To predict the quantity of LHe required in the coming years, the historic deliveries to all clients during 2015, 2016 and 2017 were studied, see table 1. The LHe requirement varies throughout the year depending on the operational cycle of each client. With the demand from the AD experiments predicted increase by 20% in the coming years, figure 3 shows the current and likely future variation in deliveries.

To improve the efficiency of deliveries to the AD it is proposed to use a 10,000 liter trailer dewar. Meaning that during periods of high requirement 1 to 2 deliveries will be required each week.

Figure 3. LHe deliveries from B165 - Years 2015 & 2016 & 2017
2.2. **LHe demand from B163 clients**

The historic LHe requirements of the STC and F1 are known, while the LHe requirement of F2 was scaled from F1. Table 2 details the LHe requirement throughout the operation of each test cryostat. During peak operation of B163 the STC are operated on an automated schedule, allowing time to change the test sample before cooling down. F1 and F2 will share the WPU, so it is not possible to simultaneously test at 1.9 K in both cryostats. However it is envisaged that the external cryostat of one cryostat could be at 4.5 K while testing is undertaken in the other. Bi-weekly testing is planned in the internal cryostats of F1 and F2.

Table 2. Individual LHe requirement of test cryostats in B163

| Cryostat | Operation from 300 K to 4 K | Operation from 4 K to 1.9 K |
|----------|----------------------------|-----------------------------|
|          | Freq’y | Cool down | 4 K Testing | Freq’y | Cool down | 1.9 K Testing |
| STC      |        | g/s       | hr           |        | g/s       | hr           |
| 1 new    | 100    | Constant  | 2.0          | 0.5    | Rare      | 1.5          |
| 2        | 50     | Daily     | 2.0          | 0.5    | Daily     | 1.5          |
| 3        | 50     | Daily     | 2.0          | 0.5    | Daily     | 1.5          |
| F1       | 1000   | 4 months  | 3.2          | 1.8    | 24        | 4 months     |
|          | 260    | Weekly    | 3.1          | 5.5    | 4.0       | 8            |
| F2       | 1400   | Constant  | 3.5          | 80     | 2.0       | Constant     |
|          | 50     | Bi-weekly | 3.5          | 6      | 4.0       | 8            |

To define the combined requirement of the test stations in B163, a worst case test schedule was defined. From this the worst case weekly LHe requirement was defined for three different operational configurations; F1+F2+STC which incorporated all stations in table 2, F2+STC where F1 does not operate, STC where only the STC operate. The resulting LHe requirements are shown in table 3.

Table 3. Worst case weekly LHe requirement in B163

| Configuration | Load Case | Total average requirement (l/week) | Weekly flow rate (g/s) |
|---------------|-----------|-----------------------------------|------------------------|
| 1             | F1+F2+STC | 47,700                            | 8.5                    |
| 2             | F2+STC    | 33,700                            | 6.7                    |
| 3             | STC       | 12,800                            | 2.60                   |

Outside normal operation, the highest individual demand for LHe occurs during the cool down of either F1 or F2 external cryostat. This event should not occur more than two times during one year and it is accepted that the operation of the other test stations may be affected.

2.3. **Combined LHe demand from B165 and B163 client**

The maximum combined LHe production of B165 and B163 is conservatively 10 g/s. From Monday to Friday LHe requirement is high and the level of LHe stored reduces, recuperating by up to 7,100 liters during the weekend. In times of high requirement in B165 and B163, the amount of LHe stored cannot be fully recuperated and will reduce each week. If the high LHe requirement continues the decreasing level of LHe stored will cause a shortage.
A study was undertaken to understand the changing LHe level in the LHe dewars of B165 and B163. The worst case operational configurations in B163 were combined with the future delivery schedule from B165 shown in figure 3. It was found that a shortage would occur if configuration 1 (F1+F2+STC) was combined with peak delivery periods in B165 from May to December. With both LHe Dewar full at the start of the week and a total useable storage volume of 22,400 liters, a shortage occurs after 1 week and 2.7 days of operation. To avoid such a shortage, the operation of B163 must be managed to only operate in configuration 1 during from January to April when demand in B165 is low. Configuration 2 (F2+STC) is considered to be a more realistic representation of the likely operation in B163. The result of the study is summarised in figure 4 and shows that this demand can be met throughout the year.

Figure 4. Combined weekly requirement and supply of LHe

2.4. GHe infrastructure
Pure GHe returns to the compressor (CP) low pressure circuit, where it is stored at up to 12 bar in four 80 m³ GHe Buffers (MP storage, cf. figure 2). Configuration 1 in B163 is expected to produce pure GHe at an average flow of 5.6 g/s and peak flow of 9.3 g/s. As the maximum liquefaction rate of 10 g/s is greater than the peak pure GHe flow no increase in MP storage volume was planned.

Impure GHe returns to the central purifier via the gazometer where it is compressed to 200 bar, purified and stored in high pressure storage (HP storage). The recuperation compressors have a maximum capacity of 26 g/s. Configuration 1 in B163 is expected to produce impure GHe at an average flow of 2.9 g/s and peak flow of 7.9 g/s. This quantity may be higher during the cool down of F1 or F2 external cryostats, however due to its infrequency an effect on normal operation is accepted. The clients of B165 are expected to produce impure GHe at an average flow of 2.9 g/s and peak flow of 4.1 g/s. Combining configuration 1 in B163 and the worst-case deliveries to the clients of B165, the estimated combined average flow rate of pure and impure GHe return is 11.4 g/s. During one week of operation with full liquefaction of 10 g/s, there will be a margin of 33 % with regard to the current GHe storage available. Assuming that LHe storage is full at the start of the week, the system could operate for 1 week and 5 days before running out of GHe storage, meaning that LHe storage capacity limits operation before GHe storage. If configuration 2 is considered the average weekly flow rate of GHe return drops to 9.6 g/s and the margin increases to 75 %.

2.5. The new cryogenic distribution system of B165 and B163
A process flow diagram of the combined CDS of B165 and B163 is shown in figure 5. It has been designed to meet the essential functional modes with other combinations also possible to allow operation as flexible as reasonable. The main functional modes of the CDS are listed in table 4.

| No. | From To | Frequency | No. | From To | Frequency |
|-----|---------|-----------|-----|---------|-----------|
| 1   | B165 Liquefier B165 Dewar | Continuous | 6   | Trailer Dewar B165 Filling Station | Possible |
| 2   | B165 Dewar Trailer Dewar | 2 per week | 7   | B163 Liquefier B163 Dewar | Continuous |
| 3   | B165 Dewar B165 Filling Station | 30 per week | 8   | B163 Dewar B163 client | Continuous |
| 4   | B165 Dewar B163 Dewar | 1-3 per week | 9   | B163 Dewar B165 Dewar | Rare |
| 5   | Trailer Dewar B165 Dewar | Monthly |
As shown in figure 6, the 20,000 liter LHe dewar of B165 is located behind B165 and supported on a 3 m high support tower to enable gravity filling to the 10,000 liter trailer Dewar. The CDS of B165 comprises a cryogenic valve box (VB) and three cryogenic transfer lines (TL) for LHe, all equipped with thermal shields actively cooled by LN2. LN2 is supplied from the existing 40,000 liter dewar via a new cryogenic valve box designed to supply all LN2 clients in the vicinity of B165, including the CDS of B165 and B163, the central purifier and the Cryolab. The CDS connects to the existing infrastructure, including the liquefier (CB), filling station and 10,000 liter trailer dewar using flexible lines with cryogenic bayonet connections.

In B163 the 6,000 liter dewar is installed at one end of a 4.3 m deep pit next to F1, F2 will be installed in the pit on the far side of F1. The main cryogenic valve box of B163 will be positioned above the dewar with cryogenic transfer lines linking to the liquefier, the CDS of B165, the STC and the satellite valve boxes (SVB) of F1 and F2. The valve box, satellite valve boxes and transfer lines will be equipped with thermal shields actively cooled with LN2 which is supplied from B165 through the thermal shield circuit of the interconnecting transfer line TL3. The CDS connects to the existing infrastructure, including the liquefier, F1 and the transfer line to the STC using flexible lines with cryogenic bayonet connections. The F2 cryostat will be connected using two thermally shielded welded connections.

A significant amount of warm infrastructure is required to manage the GHe leaving the combined CDS. In B165 one gas management panel (GMP) is dedicated to the GHe leaving the CDS, while two panels manage the CP and MP storage respectively. In B163 the CDS, F1 and F2 will each be assigned a dedicated GMP. Figures 6 and Figure 7 show the layout of the cryogenic components of B165 and B163 respectively.

2.6. Electricity and process control
The existing hardware and software of the cryogenic infrastructure in B165 was obsolete and not adapted to deal with the new equipment. Consequently a new process control system was designed and manufactured to the latest CERN standards. The new system features three PLCs with over 400 inputs/outputs and uses the same control architecture as the CERN LHC cryogenic system [11].
Individual PLC’s are dedicated to the management of the compressor and liquefier, the CDS for LHe including the filling station and the trailer dewar, the CDS for LN2 and MP storage.

Using operational experience and availability studies [12] made on other cryogenic plants at CERN, the control architecture was designed to improve plant availability, reduce the number of components, optimise maintenance and improve flexibility during operation [13]. This was achieved with the introduction of a redundant 24VDC power supply, redundant Profibus PA architecture and the latest release of the CERN standard control framework CERN CPCP-UNICOS [14]. The control system ensures fully automated operation of the cryoplant and the functional modes listed in table 4.

3. Upgrade of B165 and B163
The contract for the new CDS was placed with AS Scientific© in 2018 and the 20,000 liter dewar was previously ordered from Cryo Diffusion©. The cryogenic adaptor between the 20,000 liter dewar and the B165 CDS was built by CERN as well as the GMP’s and warm infrastructure.

Due to the continuous use by the clients, the operation of the LN2 distribution system and the central purifier can not be interrupted for more than one day. In order to limit the shutdown time of the installations the upgrade works were planned in several phases, starting with B165 then B163.

In B165, preparation began with the civil works for the 20,000 liter dewar and MP storage. Once installed, the neck of the 20,000 liter dewar was found to be damaged so was removed for repair. Several element of the LN2 system were also installed.

Operation of B165 stopped on the first of April 2019 and the cryogenic infrastructure isolated from the gazometer circuit. Work began with the removal of the existing 5,000 liter dewar, CP piping and related infrastructure, then progressed with the installation of the new GMP’s and electrical control cabinets. Finally the new LHe CDS and repaired 20,000 liter dewar were installed followed by the LN2 transfer lines, electrical cabling and the connection of the flexible transfer lines.

Partial commissioning of the LN2 CDS occurred during the third week of May and the system began operation during the first week of June without issue.

Commissioning of the LHe CDS began during the second week of June, the start-up of the CP and liquefier occurring without problem. The 20,000 liter dewar was not cold in time for the first planned delivery of LHe, so to ensure delivery the CDS was successfully used to transfer LHe from a 10,000 liter trailer dewar to 500 liter dewars, verifying functional mode six (table 4).

In parallel the CP and liquefier were put into operation to cool down the 20,000 liter dewar. The rate of the cool down was limited to control the temperature difference across the heat exchangers in the liquefier. Transfer of the full LHe production of the liquefier to the 20,000 liter dewar without excessive flash was achieved with and without active cooling of the thermal shields, verifying functional mode 1. Once the level in the 20,000 liter dewar was acceptable, direct filling of 500 liter dewars was undertaken, verifying functional mode 3. Functional mode 5 was also verified with the transfer of LHe from the 10,000 liter trailer dewar to help fill the 20,000 liter dewar.
B165 is now under operation to deliver LHe to clients, commissioning of the final untested functional modes will be undertaken when possible. The upgrade of B163 is planned to start in mid-September 2019 and finish early in 2020.

4. Conclusion
Rather than purchase a new cryogenic plant to supply the increased LHe requirement in B165 and B163, a new CDS has been designed and procured to maximize and share the production of the liquefiers in the two adjacent buildings. This CDS will enable the cryogenic group at CERN to meet the increased requirement of LHe in B165 and B163.

The CDS of B165 was successfully installed and commissioned during 2019, increasing LHe storage capacity to 20,000 liter and enabling the gravity filling of 10,000 liter trailer dewars. The installation of CDS for B163 is scheduled to finish early in 2020. Once complete the CDS will supply all of the cryogenic test stations in B163 include F2 and make it possible to transfer surplus LHe from B165.

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