The management of cryogens at CERN

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CERN is a large user of industrially procured cryogens essentially liquid helium and nitrogen. Recent contracts have been placed by the Organization for the delivery of quantities up to 280 tons of liquid helium over four years and up to 50000 tons of liquid nitrogen over three years. Main users are the very large cryogenic system of the LHC accelerator complex, the physics experiments using superconducting magnets and liquefied gases and all the related test facilities whether industrial or laboratory scale. With the commissioning of LHC, the need of cryogens at CERN will considerably increase and the procurement policy must be adapted accordingly. In this paper, we discuss procurement strategy for liquid helium and nitrogen, including delivery rates, distribution methods and adopted safety standards. Global turnover, on site re-liquefaction capacity, operational consumption, accidental losses, purification means and storage capacity will be described. Finally, the short to medium term evolution of the Organization's requirements will be reviewed.

INTRODUCTION

The European Organization for Nuclear Research (CERN) is an international organization, seated in Geneva, Switzerland, with 20 Member States. Its objective is to provide for collaboration among European States in the field of high energy physics research and to this end it designs, constructs and runs the necessary particle accelerators and the associated experiments.

To perform its scientific program, CERN has to operate several helium cryogenic plants and their ancillary equipment. Liquid helium plants are used for superconducting components of accelerators, physics experiments and tests bench facilities. Liquid nitrogen is used for pre cooling of super conducting magnets for accelerator and experiments, boosting the plant liquefaction capacity, purification systems and cooling of liquid argon and krypton calorimeters.

The procurement of these cryogens is achieved via industrial contracts placed by CERN with several companies.

INVENTORY OF CRYOGENIC PLANTS & ANCILLARY EQUIPMENT

With the implementation of the LHC helium refrigeration system, Lebrun [1] for the cooling at 1.9 K of superconducting magnets distributed over the 26.7 km of the underground accelerator, CERN has reached an unprecedented level of overall helium refrigeration capacity in research facilities. The refrigeration system consists of eight plants each providing a capacity of 18 kW @ 4.5 K. In order to achieve operation at 1.9 K, eight additional 2.4 kW @ 1.8 K refrigeration units, Tavian [2] are implemented in the accelerator complex infrastructure.

In the framework of the LHC collider physics program, the two main experiments ATLAS and CMS have decided to use superconducting magnets as particle spectrometers and three independent refrigeration units are in the installation process, Passardi [3]. A new refrigeration system of a capacity of 1.5 kW @ 4.5 K is implemented for the operation of the superconducting solenoid of CMS. Two helium independent refrigeration systems are installed for the operation of the ATLAS toroidal magnetic system including a thin central solenoid: the main unit with a capacity of 6 kW @ 4.5 K and the thermal shields unit with a capacity of 20 kW @ 40-80 K. In addition to fulfill the ATLAS liquid argon calorimeter cooling requirements, a nitrogen refrigeration unit with a capacity of 20 kW @ 84 K will be used.

Several other helium cryogenic systems are in continuous operation supplying refrigeration capacity for the cryogenic test benches of the LHC superconducting wires, cables and magnets, the spectrometers of fixed target physics experiments, the LHC detector components and various cryogenic laboratory test facilities. Table 1 summarizes the number of helium refrigeration units actually installed at CERN either in operation or in installation and commissioning phases. Refrigeration power is provided at several temperature stages but for homogeneity reasons equivalent capacity @ 4.5 K is shown.

Table 1 Number and capacity of helium refrigeration units at CERN

Helium refrigeration capacity @ 4.5 K [kW]	Number of units	Total helium refrigeration capacity@ 4.5 K [kW]
18	8	144
6	2	12
1.5	1	1.5
1.2	1	1.2
0.8	2	1.6
0.4	9	3.6
0.1	1	0.1
Total	**24**	**164**

Helium refrigeration capacity@ 1.8 K [kW]	Number of units	Total helium refrigeration capacity@ 1.8 K [kW]
2.4	**8**	**19.2**

With the increase of the installed helium refrigeration capacity and ancillary infrastructure, the needs for helium and nitrogen storage have been upgraded. New 250 Nm^3 (2.1 MPa maximum operating pressure) horizontal gas tanks are installed for the LHC cryogenic project including the experiments. The existing helium storage capacity in using gas tanks of 80 Nm^3 (1.5 & 2.1 MPa maximum operating pressure), recovered for the former LEP project, are maintained in operation. Table 2 summarizes the helium gas storage capacity presently at CERN.

Table 2 Helium gas storage capacity at CERN

Tank capacity [Nm^3]	250 (2.1 MPa)	80 (1.5 & 2.1 MPa)
Number of units	60	65
Total capacity [Nm^3]	**393000**	

The storage of helium in liquid phase is used for supplying local refrigeration capacity to large and medium test bench areas. Four fixed units are operational, including one large container of 25000 liter capacity and three smaller of respectively 6000, 5000 and 2000 liter capacities. In addition two 11000 liter transportable liquid helium containers allow operational flexibility following specific requirements. At laboratory scale and for small applications, liquid helium is stored and distributed CERN-wide by means of a fleet of transportable containers. The fleet includes containers of a wide range capacity, starting at 100 liter (10 units), 450 liter (3 units), 500 liter (14 units), 1000 liter (2 units) and 2000 liter (1 unit).

For liquid nitrogen the storage capacity has been increased by installing 13 additional vertical containers of 50000 liter capacity, distributed around the LHC accelerator and experiment facilities. Table 3 summarizes the present liquid nitrogen storage capacity at CERN, including all existing infrastructures.

Table 3 Liquid nitrogen storage capacity at CERN

Container capacity [l]	50000	40000	27000	20000	15000	7000	6000
Number of units	16	1	2	2	2	1	9
Total capacity [l]	**1025000**						

The LHC helium cryogenics, for both accelerator and experiments, following an accidental or scheduled plant shutdown, foresees helium recovery to the 250 Nm^3 (2.1 MPa maximum operating pressure) horizontal gas tanks, thus avoiding investment on capital and maintenance expensive low-pressure recovery with associated purification systems.

For the existing cryogenic test facilities and physics experiments with wide geographical distribution, CERN uses a low and high-pressure helium recovery network interconnecting several sites over long distances. A 5 km long, 20 MPa maximum operating pressure, high-grade helium distribution line has been implemented as well two independent low-grade helium recovery lines (3 kPa and 20 MPa maximum operating relative pressure) each about 3 km long. The actual overall capacity of helium low-pressure recovery and purification at CERN totals: 2020 m^3 storage volume (21 units ranging from 20, 80 and 600 m^3 gas bags, 2 kPa maximum operating pressure), 1350 Nm^3/h recovery flow (ten helium reciprocating compressor units ranging from 50 to 400 Nm^3/h, 20 MPa maximum operating pressure) with five associated purification units ranging from 100 to 200 m^3/h, 20 MPa maximum operating pressure.

To procure the cryogens to the above facilities, CERN places renewable contracts with highly qualified industrial partners complying with the Organizations' selection criteria and purchasing rules as well with the International Standards for the management of helium or nitrogen facilities including production, trading, transport and delivery. As a general rule, CERN has always promoted the selection of several contractual suppliers (from two to three at the present time) in order to secure the deliveries.

Procurement of High-Grade Helium

Liquid helium (in 11000 US gallons transportable containers) is delivered to CERN technical sites. The minimum quantity to be delivered, at CERN, at one time is 1250 kg of liquid helium. Helium is stored indoors in liquid phase in the 25000 liters fixed container or in the two 11000 liters transportable units. Transfer of liquid helium directly into the suction side of the cryogenic plant compressors is performed by means of special charging devices provided by CERN. In addition to liquid helium procurement, CERN has the contractual possibility of specific deliveries for high-grade gaseous helium (quality 4.6) or low-grade gaseous helium (2% max. impurities) in high-pressure tube trailers with a minimum delivery at one time of 3000 Nm^3. The contractors assume the full responsibility for helium delivery. The normal minimum delay for contractual delivery time is one working week. CERN also implemented a contractual option allowing short-notice delay (48 hours) for delivery of up to 3000 kg of liquid helium in case of major accidental loss. The normal average unloading time is 24 hours per container (11000 US gallons).

In the last six years CERN has placed six contracts in two independent contractual periods of 3 years. Three contracts were placed for the 1998 to 2000 period with Air Liquide (FR), Carbagas (CH) and Messer Griesheim (DE). After renewal of the tender procedure three new contracts have been placed for the 2001 to 2003 period with BOC (UK), Carbagas (CH) and Messer Griesheim (DE). In total, 157422 kg of liquid helium have been delivered. Table 4 summarizes the yearly helium deliveries to CERN for the 1998-2003 period.

With the commissioning of LHC, the need for helium deliveries at CERN is considerably increasing and the procurement adapted accordingly. New contracts have been placed with Air Products (FR) and Carbagas (CH) covering the operational period 2004 to 2007 for an estimated quantity to be delivered of 280000 kg including an option for an additional quantity of 50000 kg. The first full load of the LHC collider (about 96000 kg of liquid helium) is included in the above mentioned quantities as well the delivery requirements for completing the tests and commissioning of the LHC accelerator and experiment superconducting devices with associated cryogenic plants.

Procurement of liquid nitrogen

Liquid nitrogen in transportable containers is delivered to the various CERN technical sites. The minimum quantity to be delivered, at CERN, at one time is 20 ton of liquid nitrogen. Liquid nitrogen is stored outdoors in several (33 units at present time) vertical containers with a capacity range from to 6000 to 50000 liter (Table 3). CERN requires liquid nitrogen of cryogenic grade quality corresponding to a maximum impurity level of 1 ppm for H_2, CO_2, C_xH_y, 10 ppm for H_2O, O_2 and 150 ppm for Ar. The contractors assume the full responsibility for nitrogen delivery. The normal minimum delay for contractual delivery time is fixed to 24 hours. The normal average unloading time is 3 hours per 20 ton delivery of liquid nitrogen.

Since 1998, CERN has strengthened the safety requirements of its liquid nitrogen storage containers improving both the installations on its premises and the unloading procedures. The implementation of high-pressure liquid nitrogen storage containers (maximum operating pressure 1.8 MPa) equipped with an additional inlet safety filling valve provide protection of the storage container from over pressurization during transfer. The installation of two identical circuits constituted by safety valves and bursting discs working on switchable mode by means of a diverter valve allow periodic inspection and test of the relief system without interruption of operation.

For the period from 1999 to 2001, CERN has placed three contracts with Air Products (FR), Messer Griesheim (FR) and Praxair (FR) with a total delivered quantity of 12617 ton of liquid nitrogen. For the commissioning of the LHC refrigeration systems and cryogenic tests of LHC components, the procurement was adapted accordingly by placing contracts for the period 2002 to 2005 for an estimated quantity to be delivered of up to 50000 ton of liquid nitrogen. Table 4 summarizes the liquid nitrogen delivery distribution at CERN for the 1998 to 2003 operational period.

Table 4 Helium & Nitrogen deliveries at CERN (1998-2003)

Year	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Total**
Helium deliveries [kg]	21980	26874	29682	21598	21613	35675	**157422**
Nitrogen deliveries [t]	3982	3046	5388	4183	4344	5147	**26090**

In situ helium liquefaction and management

Liquid helium deliveries to small applications in the range of 100 to 2000 liter are performed internally at CERN by means of the transportable containers. For this purpose, CERN is operating a central helium liquefier allowing local liquid helium distribution at the level of about 250000 liter per year (mean value over the last four years) to more than 30 users. Helium gas is recovered via a dedicated network with an on-line purification and quality control allowing a continuous re-liquefaction. Including all CERN cryogenic activities the helium management in terms of total inventory, deliveries, operational losses and purification load as observed for the 2003 year is summarized in Figure 1. Operational losses reached the level of about 24000 kg for a final inventory of 12500 kg while the annual purification load, based on recovery compressors' running, was evaluated to 194000 Kg. No major accidental losses have been observed. However, many uses concern component tests, with frequently opened cryostats.

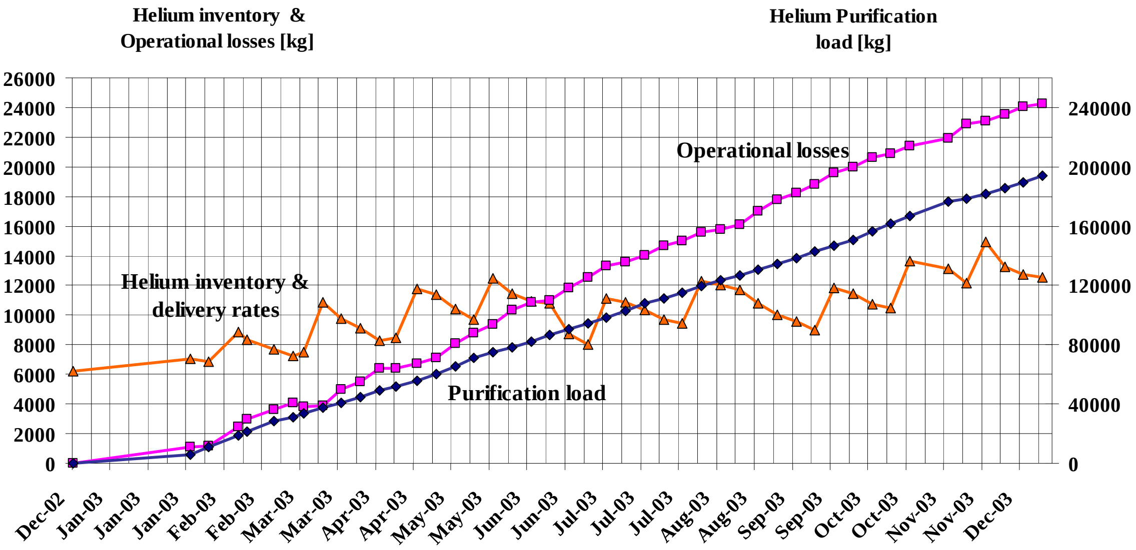

Figure 1 Helium management at CERN in 2003

OUTLOOK

With respect to the test and commissioning program of the LHC cryogenics, CERN implemented new contracts for helium deliveries for an estimated quantity of up to 280000 kg over the 2004-2007 periods, including the first full load of the LHC. For the liquid nitrogen deliveries the present contracts placed for an estimated quantity of up to 50000 ton covers the needs for all commissioning activities over the 2002-2005 periods. New contracts have to be placed at later stage covering also the need of the cool down of the full LHC magnetic system requiring about 10000 ton of liquid nitrogen for each complete thermal cycle.

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REFERENCES

1. Lebrun, Ph., Large Cryogenic Helium Refrigeration System for the LHC, 3rd International Conference on Cryogenics & Refrigeration (ICCR'2003)
2. Tavian, L., Large Cryogenics systems at 1.8 K, 7th European Particle Accelerator Conference (EPAC'2000)
3. Passardi, G. and Tavian L., Cryogenics at CERN, 19th International Cryogenic Engineering Conference (ICEC'2002)