DESIGN AND TESTING OF CRYOGENIC SYSTEMS DEDICATED TO NEUTRON SOURCES

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Abstract

Thanks to its experience in past projects in the field of neutron sources, Air Liquide DTA was involved in recent years in two major projects : a new Cold Neutron Source (OPAL) at ANSTO, Australia and a Spallation Neutron Source at ISIS, United Kingdom. The OPAL CNS is a liquid deuterium moderated source operating with a cold box with a refrigeration capacity of 5 kW at 20K designed and manufactured by Air Liquide DTA. ISIS Target Station 2 is a liquid hydrogen and solid methane moderated source for which Air Liquide DTA provided two Helium cold boxes (about 600W) operating at 20K derived from the standard *Helial* product, one customised cryogenic hydrogen loop, and very specific remote dismountable cryogenic transfer lines.

These two cryogenic systems were fully commissioned on Air Liquide DTA dedicated test area before delivery to the customers.

The purpose of this paper is to give a compared overview of the design and testing of the proposed cryogenic systems for these two projects.

INTRODUCTION

From 70's, AIR LIQUIDE DTA is continuously involved in Helium refrigeration systems thanks, in particular, to its own very reliable turbo-expander technology. The capacity and application range of the designed systems is very large: from small standard liquefiers, (*Helial* frame), (10 L/h) which supplies laboratories with liquid helium for experiments to very large refrigerators for International scientific programs (18 kW@4.5K for LHC).

Among these various projects, AIR LIQUIDE DTA has also been always present in the specific field of cooling systems for neutron sources. The first reference (oldest turbo-expander in activity without interruption) was ILL (Institut Laue Langevin) in Grenoble started-up in 1972. Recently, after continuous activity in this domain, AIR LIQUIDE DTA proposed fully support on all the cryogenic systems to two major neutrons sources projects : ANSTO in Australia and ISIS Target station 2 in United Kingdom.

INVAP : A 5000W REFRIGERATOR FOR AUSTRALIAN NEUTRON SOURCE

In 2001, INVAP selected AIR LIQUIDE DTA to design the cryogenic system to cool-down the moderator of the Australian neutron source. The equipment should provide 5000W of cooling power at 18.9K to liquefy and keep cold the deuterium material (see Figure 1). This fluid circulating in a thermosiphon aims to slow-down the neutrons produced continuously by the reactor.

Figure 1: In-pile assembly.

The technical solution was a customised Brayton cycle based on one AIR LIQUIDE gas bearings turbo-expander (range TC4) supplied by two oil-lubricated screw compressors (160 g/s, 500 kW) and a dedicated oil removal and gas management system.

In addition, the Helium Refrigeration system shall comply with very specific requirements linked to the customer application:

- **Very narrow pressure range for operation**

Table 1: Pressure range (bar abs)

Service	Alarm	Trip	Set for PSV	Ultimate
2.8	2.9	2.95	3	4

A very reliable control program should be designed to be able to operate the system in this range of pressure. In addition, to mitigate pressure variations, a warm relief tank is connected to cold end of the refrigerator.

- **Precise temperature control**

During transient phases (for example refer to Figure 2), temperature evolutions had to be smooth (in particular to avoid deuterium freezing at 18K). This could be done using heater and attenuator on turbine speed control.

- **Very reliable Control Program**

Many failure scenario imagined by the customer linked to the application can be handled as safely as possible by HRS system.

- **Requirement of SO mode (Stand-by)**

In order to remove constantly heat load in moderator, in any situation and any temperature, the HRS system has to run safely.

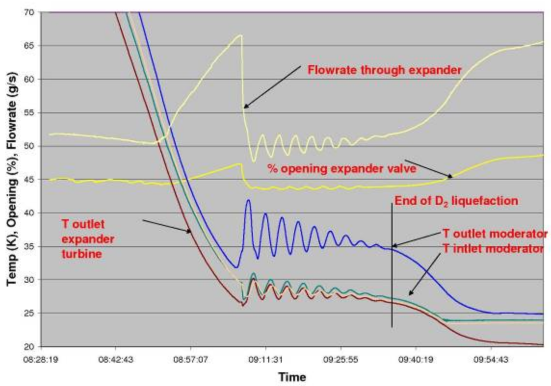


Figure 2: Cool-down of the moderator

The full refrigeration equipment (excepted moderator) was then tested and commissioned on AIR LIQUIDE DTA Test Area at the beginning of 2004.

Finally, in 2005, the system was connected to the in-pile device through cryogenic lines supplied by AIR LIQUIDE and was definitively transferred to the customer.

The figure 1 demonstrates typical transient sequences during Deuterium Liquefaction. The reliable system, in particular the turbo-expander, is able to handle these transitions without any problem.

A CRYOGENIC SYSTEM FOR THE NEW TARGET STATION 2 AT ISIS SNS: A COMPLETE STORY

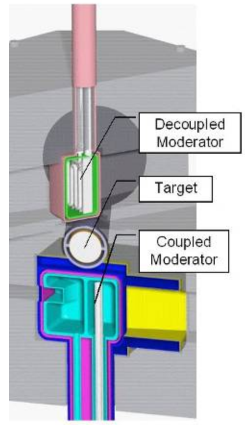
The ISIS pulsed neutron and muon source at RAL in Oxfordshire is a world-leading centre for research in the physical and life sciences. ISIS Target Station 2 is a **major upgrade** of the ISIS spallation neutron source

⇨ Opens up new areas of research in soft matter, advanced materials and bio-science

To optimize the performance of this new installation, a new concept of moderators was conceived, in particular a **combined moderator Liquid Hydrogen / Solid Methane**.

This device aims to slow-down neutrons produced in the target by a process called spallation. The tungsten target is bombarded with pulses of high energy protons which drives neutrons from the nuclei of the target atoms.

Specification



	Decoupled	Coupled
Moderating material	S-CH_4	S-CH_4 L-H_2
Operating Temp.	26 K	26 K (CH_4) 20 K (LH_2)
Cooling fluid	He	H_2
Heat Load (at base temperature)	300 W	290 W
Temp. stability	±0.25 K in any 24hrs	±0.75 K in any 24hrs
Ortho-para stability	N/A	±0.5% in any 24hrs
"Anneal" time*	<1hr in any 24hrs	
CH_4 change time*	<3hr in any 72hrs	

* Due to radiation damage to the CH_4

Figure 3: ISIS Specification

From summer 2004 to August 2008, Air Liquide DTA accompanied ISIS along all the steps of this project :

Step 1 : Support for concept validation

After thermo-hydraulics numerical simulation of new combined moderator, ISIS performed real tests on AIR LIQUIDE Facility area (See Figure 4). The thermal transfer capacity from LH_2 cell to SCH_4 cell (filled with alumina foam) and operation with subcooled LH_2 without vaporization could have been validated.

Figure 4: DTA Facility area

Step 2 : Design of the cryogenic system

In addition to satisfy the customer main specifications (Table 2), the complete cryogenic system should comply with the following specific features :

- ATEX areas around CH_4 and H_2 equipments
- Electronic equipments : Radiation resistant (Level ~ 60 mGy/hr)
- Cryogenic lines : Remote dismountable and equipped with a tertiary containment

- Control system: Complete management of cryogenic system (CH_4, H_2, He) and its specific transient sequences
  - ➪ Anneal phase: Removal of CH_4 residuals by increasing to 60K
  - ➪ Charge change phase: Removal of degraded CH_4 charge by vaporisation at 120K

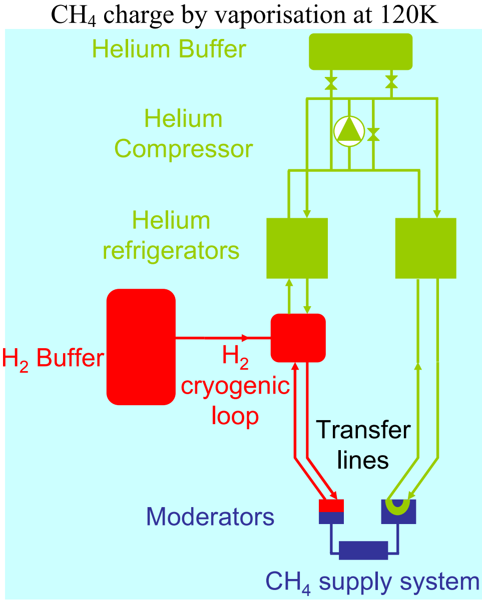


Figure 5: Cryogenic system principle

A customized management of liquid hydrogen loop: the cold buffer

In order to get a smooth pressure control in H_2 loop which is critical to guarantee subcooled conditions (Pressure Loop ~ 4 bara where $T_{saturation}$ = 26K), a cold buffer (refer Figure 5) is included with a double regulation inside (heater to increase the pressure & liquid injection to decrease the pressure).

In addition, this cold buffer acts also as a buffer during frequent transient phases (anneal and charge change) avoiding to vaporise liquid hydrogen inventory.

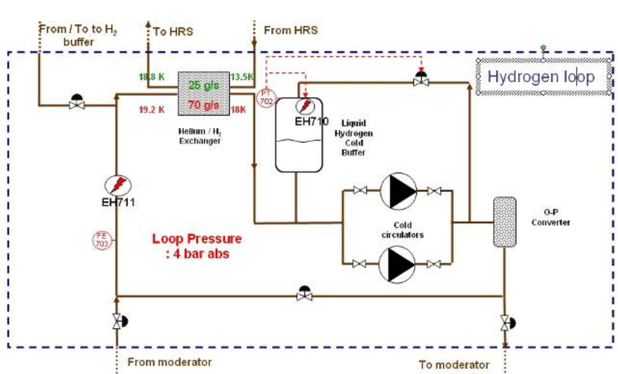


Figure 6: H_2 Loop PFD

Step 3 : Test of the cryogenic system

A complete test of the Cryogenic System (Helium Refrigeration System & H_2 loop & Moderator & CH_4 distribution system) has been carried out successfully on Air Liquide Test Facility in March 2007.

A margin of 80 W in nominal conditions has been demonstrated for H_2 loop and transient phases were shorter than specified :

- Anneal: 20 mn instead of 1 hr
- Charge Change: 2 hr instead of 3 hr

Finally, the Pressure stability of the H_2 loop remained in any case lower than +/-50 mbar.

Step 4 : Final commissioning

After a successful and fast commissioning at ISIS site in August 2008, Air Liquide accompanied ISIS in the continuous improvement of the control system. Moreover, Air Liquide ensures regular maintenance, in particular during last shut-down in May 2010.

REFERENCES AND PROJECTS IN PROGRESS

On figure 7, are presented major recent references of Helium Refrigeration systems of AIR LIQUIDE DTA.

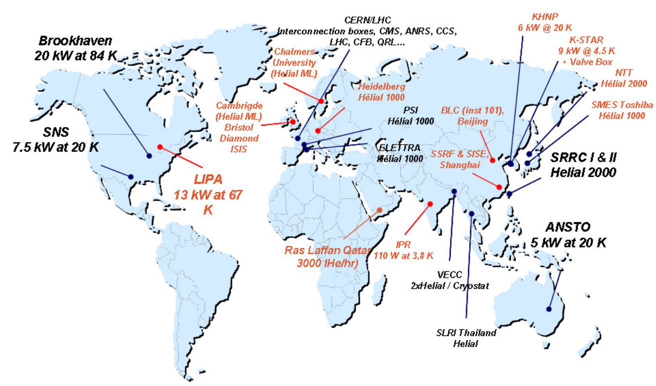


Figure 7: AIR LIQUIDE DTA References

The recent references for superconducting cavities are NSRRC and NSRRC II (Taïwan), DIAMOND (U.K.), SOLEIL (France), SSRF (China).

At present, other projects are in progress to propose customised solutions. In several cases, these systems will be fully tested at DTA.

- **UCNS Garching**: Ultra Cold Neutron Source for Reactor FRMII (TU Munich) ➪ 2 x 650 W@4.5K & 1 supercritical helium loop
- **SPIRAL II**: Helium refrigerator for GANIL (Caen, France) => 1100 W @ 4.5 K & 3000 W @ 60 K & 10 l/hr
- **HMFL**: Helium Refrigerator for Hybrid Magnet for CAS (Hefei, China) ➪ 360W@4,5K
- **Neurospin**: Helium Refrigerator for 1.8K RMN experimental installation for CEA (Saclay, France) ➪ 40W@4,5K & 900W@50K & 70 L/hr
- **PAL**: Helium Refrigerator and Transfer lines for Synchrotron at Pohang Accelerator Laboratory (Korea) ➪ 700 W@4.5K & 28 l/hr