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APPLICATION OF CRYOCOOLERS TO A VINTAGE DILUTION REFRIGERATOR

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ABSTRACT

A dilution refrigerator is required for 50mK detector operation of CDMS (Cryogenic Dark Matter Search). Besides shielding the dilution refrigerator itself, the liquid nitrogen shield and liquid helium bath in the refrigerator cool the detector cryostat heat shields and cool electronics, resulting in significant external heat loads at 80K and at 4K.

An Oxford Instruments Kelvinox 400 has served this role for ten years but required daily transfers of liquid nitrogen and liquid helium. Complicating the cryogen supply is the location 800 meters below ground in an RF shielded, class 10000 clean room at Soudan, MN.

Nitrogen and helium re-liquefiers using cryocoolers were installed outside the clean room and continuously condense room temperature gas and return the liquids to the dilution refrigerator through a transfer line. This paper will describe the design, installation, controls and performance of liquefaction systems.

KEYWORDS: dilution refrigerator pulse tube cryocooler re-liquefier Soudan cryogenic dark matter search

INTRODUCTION

A dilution refrigerator is required for 50mK detector operation of CDMS (Cryogenic Dark Matter Search). Besides shielding the dilution refrigerator itself, the liquid nitrogen shield and liquid helium bath in the refrigerator cool the detector cryostat heat shields and cool electronics, resulting in significant external heat loads at 78K and at 4.3K.

An Oxford Instruments Kelvinox 400 has served this role for ten years but required daily transfers of liquid nitrogen and liquid helium. Complicating the cryogen supply is the location 714 meters below ground in an RF shielded, class 10000 clean room at Soudan, MN.

Nitrogen and helium re-liquefiers using pulse tube and GM cryocoolers were installed outside the clean room and continuously condense room temperature gas and return the liquids to the dilution refrigerator through a transfer line. This paper will describe the design, installation, controls and performance of liquefaction systems.

CRYOGENIC SYSTEM OVERALL DESCRIPTION

Cryocoolers were added for three portions of the CDMS cryogenic system. A Cryomech AL300 was used to re-liquefy nitrogen for the dilution refrigerator shield. A Cryomech PT 415 re-liquefier was used for the external cold trap helium and two, PT 415's were used for the dilution refrigerator bath. This paper will describe the design, installation and performance of these three cryogenic sub-systems.

Location

The project location imposed a number of constraints on the re-liquefier installation. The dilution refrigerator is inside an RF shielded, class 10000 clean room, located 714m below the ground surface at Soudan, MN. All vacuum pumps, electric valves, and support equipment for the dilution refrigerator are outside the RF room. All tubing through the RF room wall is equipped with dielectric breaks. Space in and around the RF room is congested making additional equipment difficult to accommodate. There is no regular weekend or holiday access to the facility. The last operating run was cut short by a fire at the laboratory.

Dilution Refrigerator

The Oxford Kelvinox 400 has been in service for ten years at Soudan, providing detector cooling, electronics cooling and heat shielding at five stages including the detectors at 50mK. This paper describes the cooling loads at 80K and 4K. It also describes refrigeration for a 4K cold trap in the He3-He4 mixture circulation system.

Prior to cryocooler installation both the dilution refrigerator shield and the bath required daily filling. The filling was done with an automated system which was monitored closely. Liquid nitrogen and liquid helium supply dewars were delivered weekly and hauled underground, a significant regular task. The external cold trap was manually filled with liquid helium weekly. Re-liquefier installation has dramatically reduced the number of transfers, reducing handling effort and the cost of the cryogenic liquids as well as reducing the use of non-renewable helium resources.

EXTERNAL COLD TRAP

Description

In addition to an activated carbon cold trap at 80K, long term operation of a dilution refrigerator is improved with a cold trap operating at 4.2K. This trap is housed in a 120 liter helium cryostat. The cold trap can function over a range of cryostat levels from 0.5m to 1.0m. A Cryomech PT415 re-liquefier was installed on the cryostat.

Installation

A custom lifting stand was built to fit the crowded location adjacent to the cryostat. An opening on the cryostat was modified to fit the 12.7 mm re-liquefier drain leg. Pressure control was used to operate the re-liquefier heater, and also to operate vent and supply valves. This provided more precise control than temperature control, and allowed the system to vent during power outages, or to liquefy gas from a high pressure cylinder to fill the cryostat.

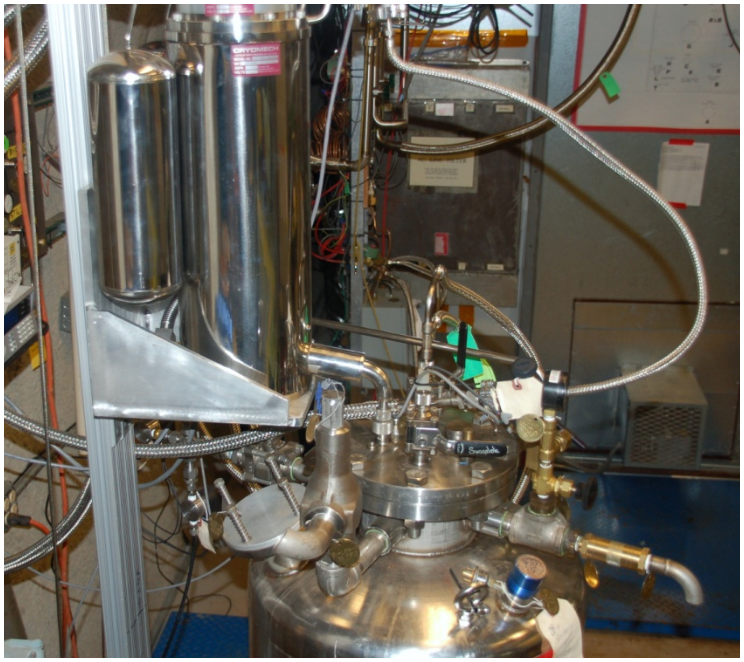

FIGURE 1. Cryomech PT15 re-liquefier installed in 120 liter external cold trap cryostat. Lifting bracket on left, cryocooler drain line in middle, cryostat lower center

External Cold Trap Performance

Prior to the re-liquefier installation, the boiloff was 3.25 SL/M and the cryostat was filled weekly. The cryostat was initially filled with liquid helium and the re-liquefier was started. Commissioning involved re-liquefier gas valve adjustment and heater control tuning. No additional transfers were required during the initial five month run. During that time some helium losses occurred during power outages and small leaks. The cryostat was refilled by condensing helium gas from high pressure cylinders. The cryostat was refilled from high pressure gas cylinders at about 4 SL/M. Following the initial run the insulating vacuum was spoiled in the re-liquefier, but no detrimental performance was observed during the run. The pumpout port seal was cleaned and no further vacuum problems have occurred.

DILUTION REFRIGERATOR SHIELD

Description

The dilution refrigerator shield uses liquid nitrogen to shield the colder portions of the refrigerator and the detector cryostat. A Cryomech AL300 was adapted for re-liquefier use. The system operates as a thermo-siphon, and cools both the dilution refrigerator shield and the helium transfer line feeding it. See figure 3. The cryocooler is located outside the experiment RF room with a 3.8 meter transfer line length.

Installation

The Cryocooler was equipped with a heat exchanger to desuperheat and condense nitrogen. The heat exchanger also provided mounting for temperature sensors and 350 watt cartridge heaters. A vacuum insulated vessel manufactured by Ability Engineering housed the cryocooler and heat exchanger assembly. The assembly was elevated to allow operation as a thermo-siphon. An automatic control valve limits the thermo siphon flow and heaters are used to maintain pressure control. Nitrogen gas makeup was not connected during the initial run but will be operational in the future.

FIGURE 2. Nitrogen Re-liquefier. Note gas feed line on the left and liquid drain line from the bottom of the vessel.

Nitrogen Re-liquefier Performance

Prior to the re-liquefier installation, the dilution refrigerator required daily filling. Nitrogen consumption was 15.6 SL/M. The re-liquefier carried this condensation load plus heat load from the new transfer line. Commissioning involved tuning the heater controls. The average heater power was 150 watts.

With the re-liquefaction system running there were still losses at 0.9 SL/M. This was determined to be due to leaks. The leaks will be reduced, but probably not eliminated. A gas makeup system from nitrogen supply dewars was installed to make up the losses.

DILIUTION REFRIGERATOR BATH

Description

The dilution refrigerator bath poses the most challenging circumstances of the three re-liquefier systems. This is primarily due to the layout of the existing facility and the need to keep electrical noise and vibration away from the CDMS detectors. Therefore a transfer line was required between the re-liquefiers and the bath. This transfer line must have very low heat load at 4K or the re-liquefaction system would not work. Outside the RF room space was limited as well. To minimize transfer line length the re-liquefiers were mounted just outside the RF room between existing equipment and the RF room wall. Helium consumption has been substantially decreased but not stopped.

Transfer Line

The 3.8 meter length transfer line was designed with a heat load goal of 100 mW. It is fully heat shielded with liquid nitrogen. Inner tube supports are made with very thin G10 cylinders. Other requirements included dielectric break, flexibility for thermal contraction, installation in two parts, fitting with existing equipment, nitrogen storage for at least four days operation, connections for liquid nitrogen, two helium re-liquefiers, the dilution refrigerator helium bath and the dilution refrigerator liquid nitrogen shield.

Figure 3 shows the transfer line assembly and the details around the connection point. The left side includes the eleven liter nitrogen storage, liquid nitrogen supply and vent lines, and bayonet connections to receive the re-liquefier drain legs and the vacuum jacket bellows. The connection between the two portions is just to the right of the RF room wall. The right side of figure 3 shows the portion of the transfer line inside the RF room. It includes the VCR connections, ceramic seals and bellows at the connection point, as well as the bayonet to feed the dilution refrigerator. Liquid nitrogen is drawn off the right end of the transfer line to feed the dilution refrigerator shield. Details of the connection area are shown above the transfer line assembly. Figures 4, 5 and 6 show the transfer line as installed in the congested location.

Installation

Due to space limitations the installation sequence was difficult. Custom stingers were made to fit ports on the dilution refrigerator for helium and nitrogen. The stinger for the dilution refrigerator insertion is actively shielded through most of its length. It is connected to the nitrogen supply with flexible hoses. The outside portion of the transfer line was mounted in a narrow space just outside the RF room. After alignment the two sections were joined with VCR connections. Dielectric break was made with Ceramtec fittings on the cryogenic lines and non-metallic fasteners and supports on the ISO vacuum flange.

To evaluate the relative performance of two parallel re-liquefiers each was equipped with a mass flowmeter. Pressure drop through the flow meters as well as height limitation due to outside constraints prevented the proper thermo-siphon from being achieved, so small, dry compressors were added to the gas side of each re-liquefier. The flow then was easily adjustable to optimize the re-liquefier performance. The heaters for the liquefiers were connected to a PLC for pressure control.

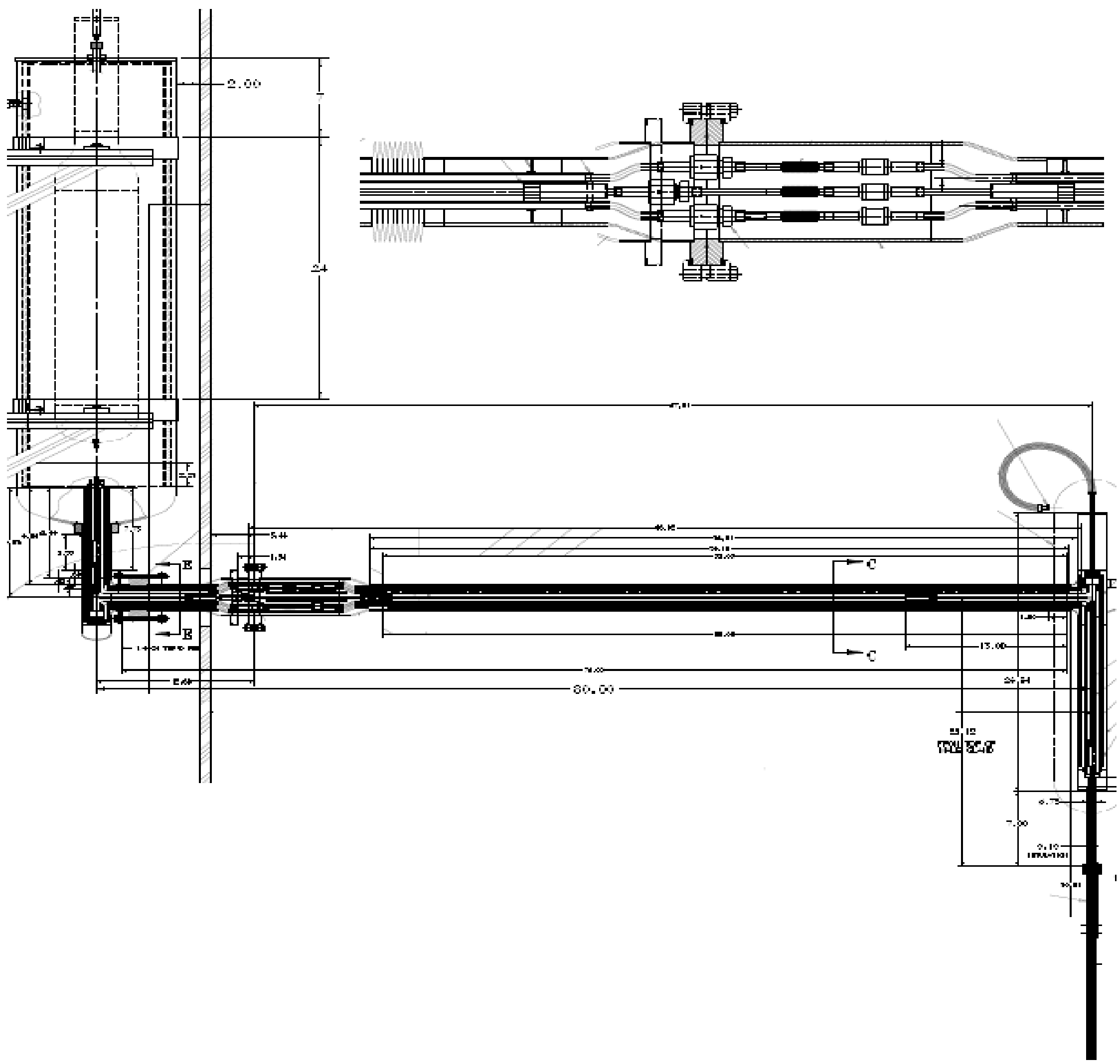

FIGURE 3. Low heat load transfer line between re-liquefiers and dilution refrigerator. The Nitrogen and Helium re-liquefier liquid inlet connections are at the upper left. The liquid nitrogen reservoir is on the left side. The RF room wall is just to the right of the reservoir. The dilution refrigerator nitrogen supply is at the upper right and the helium supply is at the lower right. The connection detail with VCR connections, dielectric breaks and flexible connections is shown above.

Bath Re-liquefier and Transfer Line Performance

This dilution refrigerator liquid helium bath provides heat shielding for the refrigerator itself, provides cooling for the detector cryostat, and electronics cooling.

Prior to cryocooler installation the dilution refrigerator bath was filled daily, with a loss rate of 10.0 SL/M. This rate includes boiloff and the amount consumed by feeding the 1K pot. After re-liquefier installation the bath losses were reduced to 2.4 SL/M, which led to bath refilling every five days. Evaluation of the re-liquefier flow rates and conditions determined a transfer line heat load of 220mW.

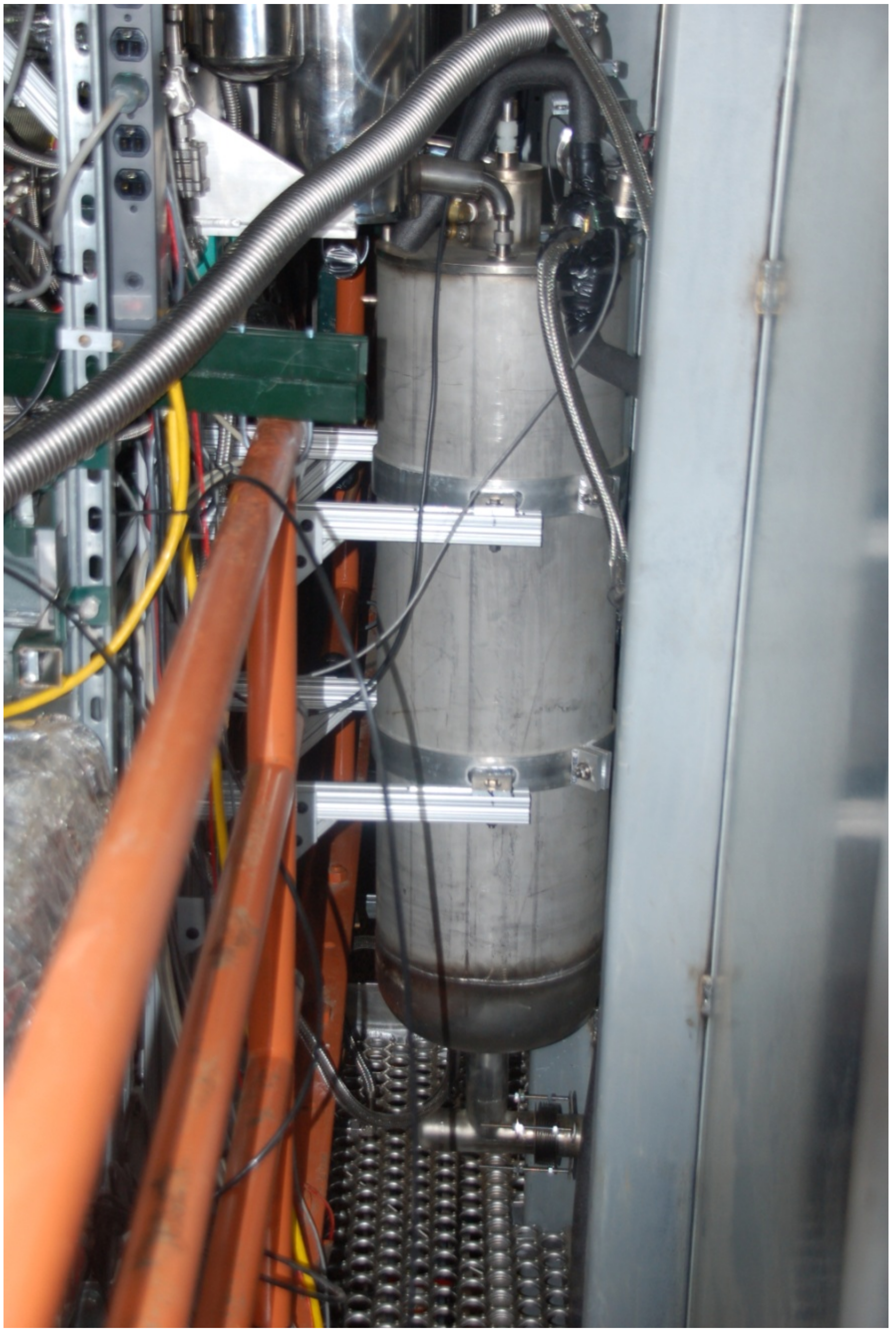

FIGURE 4. Transfer line outside the RF room showing re-liquefier drain leg, nitrogen connections and bottom connection through the RF room wall on the right

During the design phase it was apparent that two PT-415 re-liquefiers would be marginal, but space limitations and cost were both considerations against installing three. Some insulating vacuum problems with the re-liquefier pumpout ports may have reduced their performance slightly. The connection are of the transfer line was not actively shielded. An actively cooled shield was added in this area and all insulating vacuums will be thoroughly pumped out before the next run.

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