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# The Liquid Krypton Calorimeter Cryogenics for the NA48 Experiment

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## Abstract

The NA48 cryogenic system has to provide stable thermal conditions (120 K) in a 9000 liter liquid krypton calorimeter, and has to ensure safe and loss free storage of the liquid during idle periods.
Direct cooling of the krypton by nitrogen is used in emergency cases, while an intermediate cooler, containing saturated liquid argon at around 10 bar (117 K) is used under normal operation conditions when high thermal stability is needed.
The krypton pressure is, during data taking, regulated to a value of (1.05 ± 0.01) bar for a period of about 8 months of continuous operation of the calorimeter.

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## 1 INTRODUCTION

The NA48 experiment aims to measure the direct CP violation in the $K^0$-$\overline{K}^0$ system with a precision better than 0.02% [1]. Part of the experiment is an electromagnetic calorimeter filled with 9000 liter of liquid krypton. The purpose of the cryogenic system is to provide stable thermal conditions in the liquid krypton when the calorimeter is in operation, and to assure safe and loss-free storage of the liquid during long idle periods.

## 2 THE CRYOGENIC SYSTEM

The cryogenic system consists basically of the calorimeter cryostat, a krypton storage dewar and two nitrogen dewars. The calorimeter is further equipped with a cool down/warm up unit. Liquid transfer is generally achieved with a centrifugal pump and there are several purifiers for purification of the krypton either in the liquid or in the gas phase.

### 2.1 The calorimeter cryostat

The vacuum insulated cryostat has a liquid volume of about 9000 liter. The main static heat source is the solid conduction through the suspension of the inner vessel and through the signal and power cables, altogether 2 kW. The calorimeter is equipped with nearly 14000 preamplifiers located in the liquid, which are producing another 1.3 kW. Hence, the total heat input amounts to about 3.3 kW.
Direct cooling of the krypton with liquid nitrogen is possible, but not advisable if high stability is required, because of the large temperature difference between the two liquids, making the precise temperature control difficult. To overcome this problem, we have developed a krypton condenser using liquid argon as intermediate coolant (see next paragraph). Simple nitrogen cooled emergency coolers are however activated in case of unforeseen pressure rises, using heat exchangers situated in the gas space of the calorimeter and of the storage dewar.

### 2.2 The krypton condenser

The krypton condenser, schematically shown in figure 1, forms a separate unit outside the cryostat and is used to re-liquefy the gas evaporating from the calorimeter. The krypton gas is brought in thermal contact with the heat exchanger cooled from the bath of saturated liquid argon at 10 bar. The corresponding argon bath temperature is 117 K, slightly above the triple point of krypton (115.95 K). The argon is, in turn, cooled by liquid nitrogen flowing through a heat exchanger in the gas space of the vessel. The nitrogen flow is controlled such as to maintain the argon bath pressure constant.

The characteristics of the condenser are explained in figure 2 showing the vapor pressure curves of argon and krypton. To a given pressure $P_{Ar}$ in the argon vessel corresponds an argon bath temperature $T_{Ar}$. The liquefaction process requires a temperature difference $\Delta T$ between the krypton and the argon bath, and consequently the liquefied krypton leaves the condenser at a temperature $T_{Kr}$, which will result in a cryostat pressure $P_{Kr}$. From figure 2 follows, that if $T_{Kr}$ and hence $P_{Kr}$ have the tendency to increase [decrease], $\Delta T$ will change accordingly. The krypton liquefaction rate will become larger [smaller] and this will, in turn, result in a decrease [increase] of $P_{Kr}$. In this way the system tends to a stable equilibrium under a constant heat input.

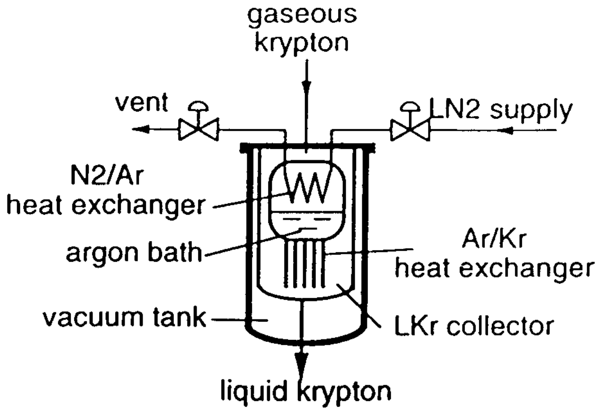


Figure 1, the krypton condenser

To obtain a stable krypton pressure, even under varying dynamic heat-loads, a regulation on the argon set-pressure is made as function of the krypton pressure. A larger heat load into the cryostat will create a higher krypton pressure and will thus require a lower set-pressure of the argon bath to re-establish the desired krypton pressure.

The evaporating krypton gas (typically around 450 l/min NTP) is sent through a purifier before being re-liquefied (see figure 3). The cold surface of the condenser, around 3 $m^2$ for a nominal cooling power of 4.5 kW, is made of 230 vertical pipes, which are at the top connected to the argon reservoir. The krypton condensing on the outer surface of the pipes (around 0.7 $l_{liquid}$/min) drops down into a collector and flows back to the calorimeter via a vacuum insulated transfer line.

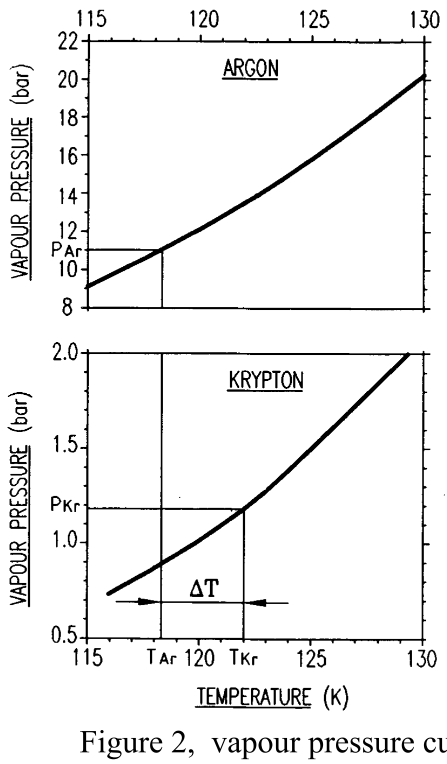


Figure 2, vapour pressure curves of argon and krypton

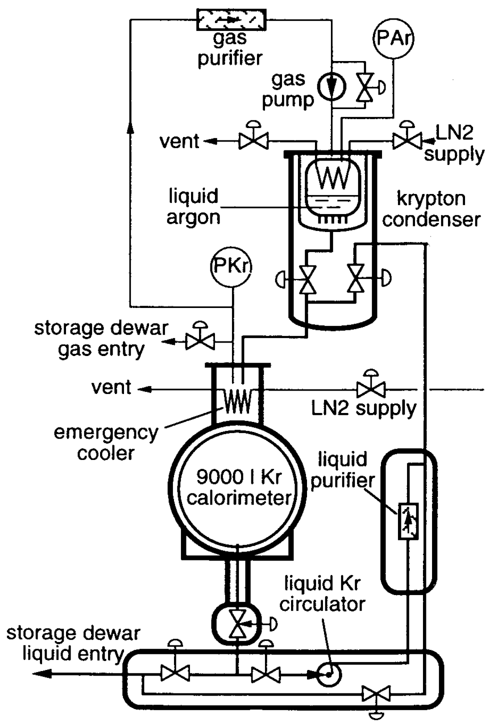


Figure 3, krypton flow scheme

2.3 The purifiers

The signal generation process in the calorimeter can be altered by the presence of electronegative impurities ($O_2$, $CO_2$, halogens, unsaturated hydrocarbons etc.). Commercial Oxisorb [2] purifiers are used to purify the krypton either in gas phase, during normal operation, or in liquid phase when a fast purification cycle is needed. Purification in liquid phase is however avoided during data-taking periods as it may disturb the thermal conditions in the calorimeter.

2.4 The liquid krypton circulator

The krypton can be circulated in liquid phase through a purifier by means of a centrifugal liquid krypton pump [3] (1000 liter/hour, $\Delta p = 2$ bar). In this case the liquid is taken from the bottom of the cryostat and passed through the purifier which is located in an independent vacuum insulated box. The cold part of the pump is hermetically sealed from the electric motor by means of a magnetic coupling. In this way the risk of contamination of the liquid by impurities emanating from the driving system is avoided.

2.5 The pre-cooling unit

Temperature differences within the calorimeter, having a cold mass with an integral heat capacity of around 600 MJ, must be well controlled to avoid excessive distortions. Before the run, the calorimeter is pumped and filled with krypton gas, which is then circulated by means of a room temperature contamination-free pump [4] through an external gas purifier. In parallel, the calorimeter is gradually cooled at a speed of typically 0.5 K/hr by means of a nitrogen gas flow (kept constant at 0.4 kg/s) through cooling channels welded to the outer surface of the krypton vessel. The temperature of the nitrogen gas is adjusted by a controlled injection of liquid nitrogen. Krypton gas is added to the inner volume such as to maintain a small over-pressure to atmosphere. The calorimeter is thus cooled by heat contact to the nitrogen flow and by krypton gas convection in the inner vessel, under careful monitoring of the temperature gradients.
Warm up of the cryostat is achieved with the same system, which is equipped with electric heaters for a controlled temperature increase of the circulating nitrogen.

2.6 The 10000 liter storage dewar

During the shut down, a period of typically several months per year, the krypton is stored in a 10000 liter low loss storage dewar. This dewar is equipped with its own external krypton condenser and an internal emergency cooler. With the krypton condenser in operation, the external gas flow is continuously purified. If desired, the gas flow can be increased by means of electric heaters sitting at the bottom of the storage dewar.

2.7 The nitrogen storage dewars

As nitrogen is the only cold source for the system, its permanent availability is of vital importance. We are using two commercial 15000 liter dewars, one which is permanently kept full, while the other is in operation. The nitrogen consumption is around 2100 liter/day during data-taking periods.

## 3 THE SLOW CONTROL

Access to the underground experimental area is prohibited when the beam is on, and restricted at other times. These circumstances, together with the large geographic extension of the cryogenic installation, call for a remotely controlled system and a high level of automatisation.
The cryogenic installation is controlled by a PLC set up divided in four systems: the cryostat control, the krypton storage control, the nitrogen storage control and a system devoted to temperature measurements. We have adopted this division to allow fully independent operation, that is to say, during the shut-down the cryostat control can be switched off, while the krypton storage and the nitrogen storage control must continue to function. The PLC's are connected to an UPS system giving an autonomy of six hours in case of a power failure.

## 4 RESULTS

After 19 months of operational experience, we can resume the results as follows:

- Cool down and warm up can be perfectly controlled such that the internal temperature gradients remain within tolerable limits;
- The system allows for uninterrupted operation over periods of many months with no supervision;
- Krypton impurity level stays within 10 to 100 ppb $O_2$ equivalent;
- During data taking, the pressure in the calorimeter remains within ±10 mbar over periods of months (see for example figure 4);
- Power failures have never lead to difficult situations;
- No beam time has been lost due to problems with the cryogenic system.

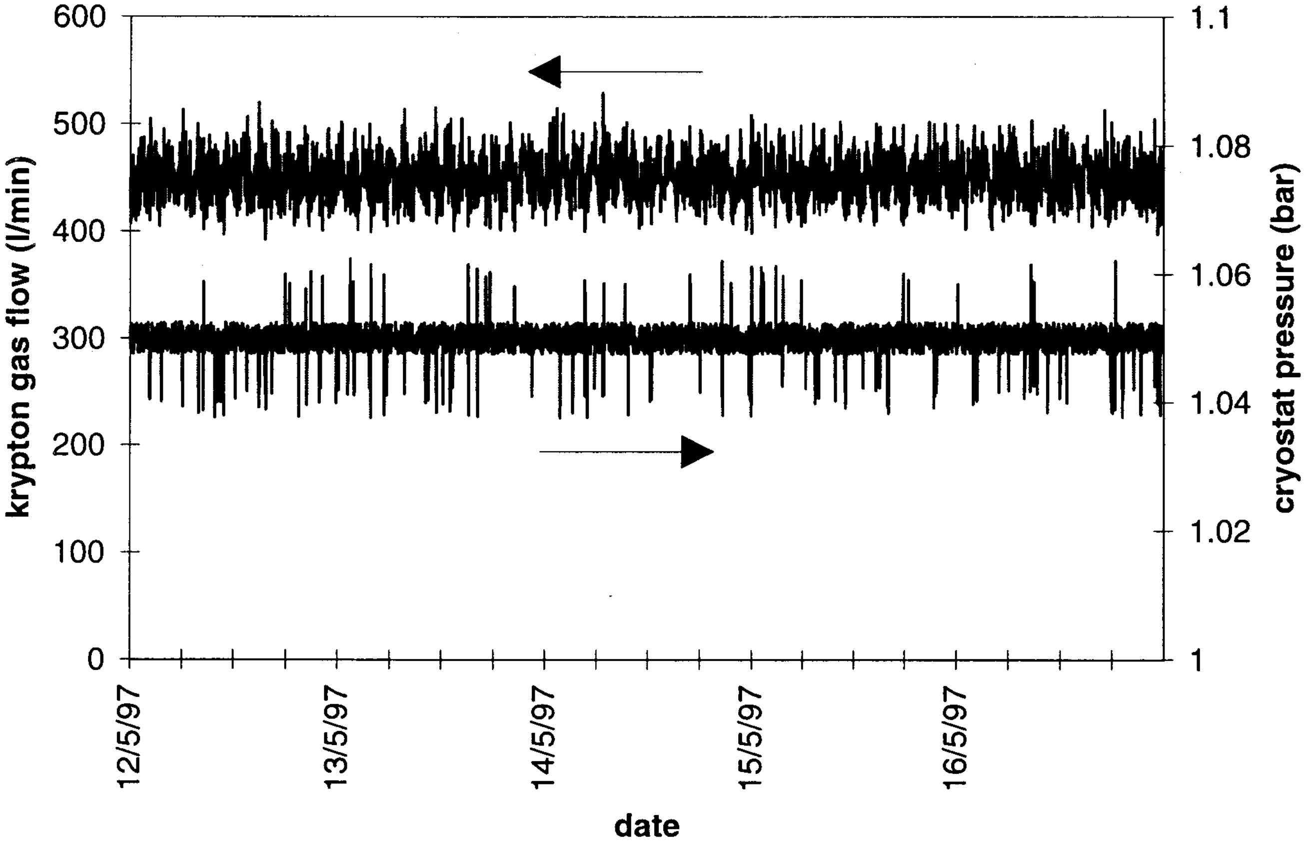


Figure 4, krypton pressure and krypton gas flow over a period of five days

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