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# 900-L liquid xenon cryogenic system operation for the MEG experiment

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A cryogenic system for the MEG (muon rare decay) experiment has started operation at the Paul Sherrer Institute in Zurich. The main part of the MEG detector is the 900-L liquid xenon calorimeter for gamma ray detection, equipped with 850 photo multipliers directly immersed in liquid xenon. A 200 W pulse tube cryocooler enabled $LN_2$-free operation of this calorimeter. A liquid purification system; using a liquid pump and a zero boil-off 1000-L cryogenic buffer dewar is also included in the system. The first entire engineering run was carried out in November-December 2007 and satisfactory cryogenic performances were confirmed.

## INTRODUCTION

A physics experiment on μ–particle rare decay events to gamma ray and positron, the so-called MU-E-GAMMA (MEG) experiment [1], has started its first engineering run at the Paul Scherrer Institute in Zurich from November to December 2007. And now, the MEG detectors are almost ready to detect gamma rays and positrons with extremely high sensitivity. In this experiment, liquid xenon (LXe) is used in scintillation calorimeters because of its:- fast response, large atomic number, and high density. 900 L of liquid xenon is used as the medium in the calorimeter, and is viewed by 850 photomultiplier tubes (PMTs) immersed in it. The required liquid xenon purity is of the order of ppb of water, and is obtained by using a cryogenic centrifugal pump and cooled molecular sieves. The heat load of the calorimeter at temperature around 165-170 K is expected to be approximately 120-160 W, which can be compensated by a 200 W pulse-tube cryocooler developed at KEK and manufactured by Iwatani Industrial Gas Corp [2]. Also, a cryocooler-mounted zero boil-off 1000-L dewar works as a cryogenic buffer tank in the system. This paper describes the performance results obtained, mainly during operation in the first engineering run.

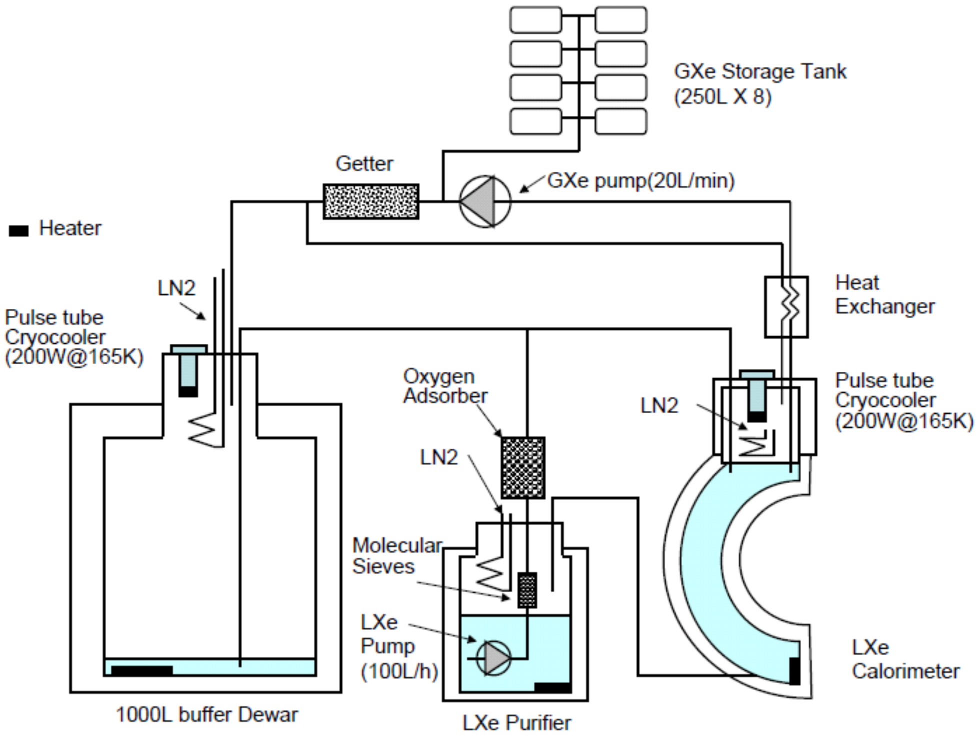

Figure 1 Simplified layout of the MEG liquid xenon cryogenic system

CRYOGENIC COMPONENTS AND LAYOUT

Figure 1 shows a schematic drawing of the MEG LXe cryogenic system. The main components are:-
a 900-L LXe calorimeter, a 1000-L cryogenic buffer dewar, a liquid phase purifier with a liquid xenon pump and the related equipment. Both calorimeter and dewar are equipped with pulse tube cryocoolers to maintain the cryogenic condition without consumption of $LN_2$. The purpose and features of each of components are briefly summarized as follows:-

<u>LXe calorimeter</u>

This is the key detector for precise measurement of gummer ray emission when the rare muon particle decay event occurs. Scintillation light with a wavelength of 178 nm is captured by 850 PMTs directly immersed in liquid xenon. To ensure physics experiment with long term stability, a pulse tube cryocooler is mounted on the top-flange to cancel heat loads conducted into the calorimeter. These loads are caused by:-
dissipation in the large number of PMTs, heat conduction through approximately a few 1000 of cables, and other parasitic heat from the environment. The cooling capacity of the pulse tube cryocooler is 200 W at 165-170 K; around boiling point of liquid xenon at 1 atmospheric pressure, which is enough to keep the calorimeter cold without any liquid cryogen.

<u>LXe purifier with liquid pump [3]</u>

Liquid xenon of high purity is essential for the MEG experiment, because water contamination of a few tens of ppb in the liquid xenon effectively adsorbs scintillation light. Low temperature molecular sieves act

Table 1 Summary of cryogenic components in the MEG system

| **Component** | Liquid Volumes- (L) | Features |
|---|---|---|
| **Liquid xenon calorimeter** | 900 | 850 Photomultipliers immersed in liquid |
| **Liquid xenon purifier** | 30 | 100L/h liquid pump, molecular sieves, oxygen adsorption |
| **1000 L storage dewar** | 1000 | Zero boil-off performance by pulse tube cryocooler |
| **Pulse tube cryocooler** | -- | 200 W at 165-170 K (6 kW compressor) |

as a good absorbers for water, and also, reduced metal pellets work as good absorbers to get rid of oxygen contamination. In order to get a realistic purification speed, a liquid pump with nominal 100 L/h circulation speed is installed. The actually obtained circulation speed is around 50 L/h, due to flow impedance of the molecular sieves and pellets in the purifier, but this is enough performance to purify all the liquid (once through) within about 18 hours. If we use a gas diaphragm pump with liquid equivalent speed around 1L/h, it will take over 1 month to purify 900-L of the liquid xenon.

1000L cryogenic buffer dewar [4]

Initially, 900 L of liquid xenon was liquefied in this dewar, independently from the calorimeter. With the high cooling power pulse tube cryocooler mounted in the dewar, the dewar acts as a zero boil-off dewar and the liquid xenon could be kept inside without loss. This dewar also acts as a cryogenic buffer tank during the experiment. In case of emergency, all the liquid in the calorimeter can be evacuated to this dewar by using the liquid pump.

High power pulse tube cryocooler for liquid xenon

Two sets of pulse tube cryocooler are installed in the system for $LN_2$ free operation: one for the calorimeter, and another one for the 1000-L dewar. Each cryocooler has a cooling power of 200 W at 165-170 K by operating a 6 kW G-M type compressor. This cryocooler was originally developed in KEK and manufactured by Iwatani after technology transfer.

Table 1 summarizes the liquid xenon volume capacities and the featuring performance of each component.

## OVERALL OPERATION

Liquid xenon transfer from 1000L dewar to calorimeter

After completion of the calorimeter as a detector including all the PMTs set up, 900-L of liquid xenon was transferred from the 1000-L dewar to the calorimeter by pressurizing dewar using 400 W heaters inside. It took about 85 hours to transfer almost 900-L of liquid xenon, under the pressure condition of 0.26 MPa for the dewar and 0.12 MPa for the calorimeter.

Liquid phase purification

Based on the experimental result obtained by the large proto calorimeter experiments prior to the MEG experiment [3], it is known that water contaminant comes out from the surface of materials used inside the calorimeter, and diffuse into the liquid after immersed in the liquid xenon. So the liquid phase purification is essential to obtain liquid xenon with water contamination less than a few ppb. The liquid pump was started soon after liquid transfer completed and kept running as long as possible. The purity of liquid was monitored by measuring the amount of light captured by several PMTs positioned at the different distances from the radiation source.

<u>Heat load estimation at steady state</u>

After some hundreds of hour's purification, the calorimeter becomes ready for the physics experiment. Figure 2 shows a typical view graph of the control panel. It indicates temperature and pressure profiles of the calorimeter under control only by the pulse tube cryocooler mounted at the top-flange. The calorimeter was maintained steady from 18:30 to 22:20 for measuring the heat balance of the calorimeter. The heater power activated during this period was about 25-30 W. All the PMTs inside the calorimeter were turned on and the total heat dissipation was calculated as about 40 W. The original cooling power of the pulse tube cryocooler under vacuum condition was already confirmed as about 200 W at 168-170 K [5]. So that the total heat input to the calorimeter could be estimated as around 130 W at this temperature. The amount of

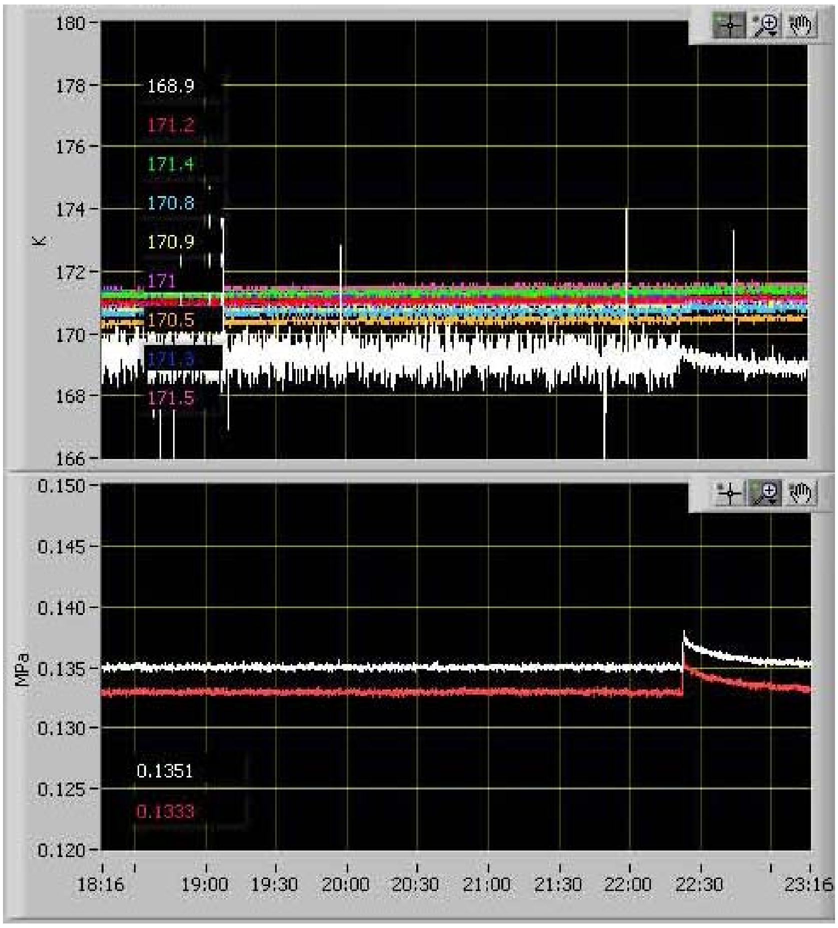


Figure 2 Typical pressure (lower part) and temperature (upper part) profiles during a steady state of calorimeter maintained only by a pulse tube cryocooler operation

this heat comes through the cryostat support structure, radiation, and also comes through a few thousands of cables for signals and high voltage supply. In general, it will take a long time for 900-L of liquid xenon to reach a thermally stable condition, because of the huge heat capacity of the liquid. These are preliminary measurements, and we will measure the heater power at different pressures and temperatures to evaluate the thermal budget and operating margin of the pulse tube cryocooler performance more precisely.

## SUMMARY

The cryogenic system of the μ–particle rare decay physics experiment, the MU-E-GAMMA (MEG) experiment, including 900-L liquid xenon calorimeter, liquid purifier and a 1000-L cryogenic buffer dewar has been operated successfully. By using the pulse tube cryocooler with 200 W of cooling power at 170 K, the $LN_2$ free operation has been confirmed for steady state operation.

## ACKNOWLEDGEMENTS

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