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# REFRIGERATOR-COOLED CRYOSTATS FOR RESEARCH ON INERTIAL CONFINEMENT FUSION

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## Abstract

In order to utilize the increased density of liquified or solidified DT fuel, one must provide means for cooling fusion targets to the range 15 K to 25 K. The heat loads at these low temperatures can be kept modest by providing adequate thermal shielding maintained near 75 K. Modern closed-cycle-helium refrigerators, operating on the Gifford-McMahon cycle, provide for both thermal loads reliably and inexpensively, thanks to the increasing implementation of the commercial cryopump. By adding a large sealed can containing helium exchange gas to the second stage of the refrigerator, we create a nearly ideal environment for cryogenic fusion targets. We discuss the design and operation of two separate apparatus. One has been used almost continuously over the past two years for various inertial confinement fusion studies.

# REFRIGERATOR-COOLED CRYOSTATS FOR RESEARCH ON INERTIAL CONFINEMENT FUSION

by

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## INTRODUCTION

It is becoming clear that cryogenics is a valuable tool for [illegible] confinement fusion (ICF) [illegible] pellet targets. [illegible] density [illegible] temperature [illegible] not be easily matched in room temperature [illegible] by utilizing relatively thick walls to safely contain the high pressures needed. To achieve a density in DT equal to the liquid density at the triple point, a room-temperature pressure of just over 5 kbar (~75,000 psi) is necessary.[1] However, providing the target with an environment near 20 K is generally not accomplished without overcoming a number of cryogenic problems. Many of these problems can be circumvented by utilizing a closed cycle helium refrigerator as the cryogenic cooling agent.

## CONVENTIONAL CRYOSTATS

Before discussing these advantages, it will be instructive to review briefly conventional cryostats, i.e., one cooled with [illegible] liquid helium [illegible]

[illegible] gradients in the bulk of the liquid are negligible. [illegible] shield cooled by $LN_2$ intercepts the room temperature thermal radiation and hence significantly reduces the heat leak to the $^4$He bath. The experimental sample is cooled by either closing a heat switch or by admitting $^4$He exchange gas to the sealed can. The can must then be evacuated if it is desired to change the sample temperature to levels significantly above (or below) the $^4$He bath temperature. Optical access is accomplished by sealing fused quartz or sapphire windows into all the nested cans. Likewise, optical access from above or below could be achieved. Thus such a cryostat, in principle, could be used to cool an ICF target to near 20 K and to expose it to bursts of laser radiation. One must necessarily address the problems of the limited lifetime of the liquid $^4$He bath; purchase, transport and storage of the cryogens; and the transfer of the cryogens into the cryostat. However, a more significant problem is that the target generally cannot be heated directly with a contact heater because that would affect the target symmetry. The target would have to be heated indirectly or be enclosed in yet another exchange gas can.

## REFRIGERATOR COOLED CRYOSTATS

Consider now the design shown in Fig. 2. This is a scale drawing of a cryostat built by the authors for performing low temperature studies in support of the Los Alamos ICF program. It has been in continuous use over the past two years in a variety of tasks, including studies of filling procedures for prototype cryogenic targets and direct observations[1] of uniform [illegible] distribution of solid $D_2$ and solid DT in [illegible]. No liquid cryogens are needed. Instead, a closed-cycle helium refrigerator [illegible] on the Gifford McMahon cycle supplies refrigeration at two separate stages. The first stage [illegible] stage temperature is typically about 80 K when the attached thermal shield is properly super insulated. The second stage has a measured capacity of 5 W at 20 K and reaches 10 K under no-load conditions. Here, however, about 25 kg of copper hangs on the second stage and the apparatus is limited to 11.4 K. Most of this mass is in the form of a "cold can" having internal dimensions of 25.4 cm diameter x 30.5 cm long. This space is filled with $^4$He gas at a pressure of 200 torr at 20 K. The top of this can, known as the "cold plate", extends outwards to [illegible] second thermal shield. Although this shield is not [illegible] [illegible] attempt to [illegible] the exchange gas [illegible] it to the [illegible] rendering the interior more isothermal. This has apparently been successful - separate interior thermometers at the top, bottom, and sides of the cold can all agree within 0.05 K at 20 K. A heater is wrapped around the second stage of the refrigerator to achieve closed-cycle temperature control of the cold can. Regulation to within 0.1 K is routinely achieved. After turning on the cooling water for the compressor (one could opt for an air cooled compressor), and then switching on the compressor motor, the apparatus cools from room temperature to below 20 K in about 9 hours. Warm up is much slower unless aided by heater power and/or spoiling the vacuum space with exchange gas.

Closed cycle helium refrigerators were developed to a high degree of reliability by the cryopump industry. There are many suppliers, both domestic and foreign, all offering units of varying capacity, high reliability, low maintenance, prompt service and reasonable cost. Our experience supports the excellent service record of these units as we have had no [illegible] with either the refrigerator cold head or compressor. [illegible] of third party vendors will supply [illegible] similar [illegible] can such as used here. It is precisely the large working volume of the helium-filled cold can which makes this type of cryostat uniquely suited to ICF studies.

Unattended operation for long periods of time is one of the major advantages of a cryostat of this type. Our long-term experiments[3] in liquid and solid $T_2$ and DT would not have been possible without this valuable feature. In one experiment, we followed the crystalline growth patterns in a sample of frozen $T_2$ for over a two week period.

Although our cryostat incorporates optical access via four sets of fused silica windows at 90° angles, in its present form it is not suitable for multiple-beam implosion studies on actual ICF targets. To do so, the beams or beam pipes would have to be integrated into the design of the cryostat. Nonetheless, the cryogenic concepts utilized here would be applicable to such an integrated design. Fig. 3 shows such a design, where hemispherical windows would allow converging beams from a wide solid angle to impinge on the target. The large working volume of approximately 13 L would permit the installation of optics necessary for direct-drive targets, as well as hohlraum/target[5] assemblies for indirect drive studies.

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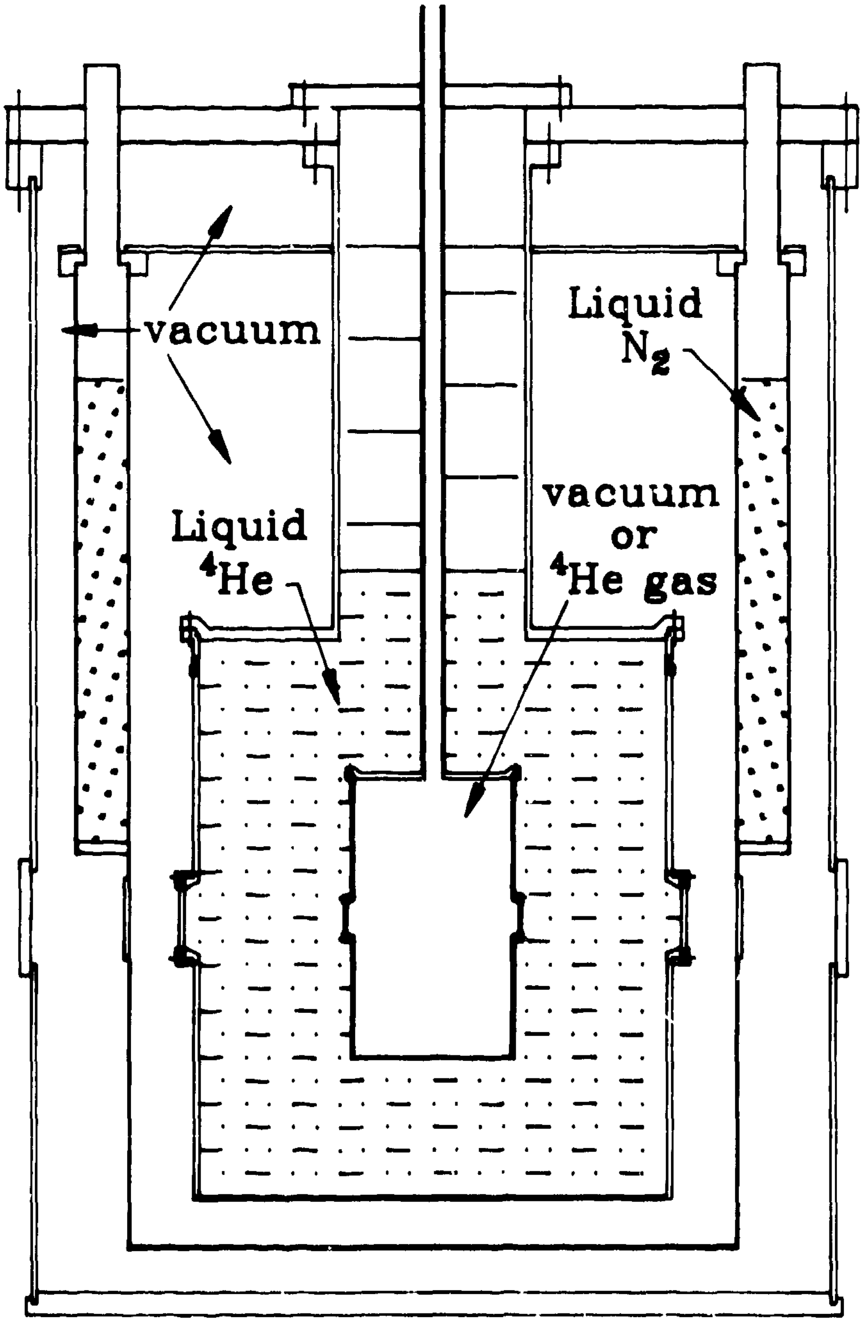

Figure 1. A conventional optical cryostat cooled with liquid cryogens.

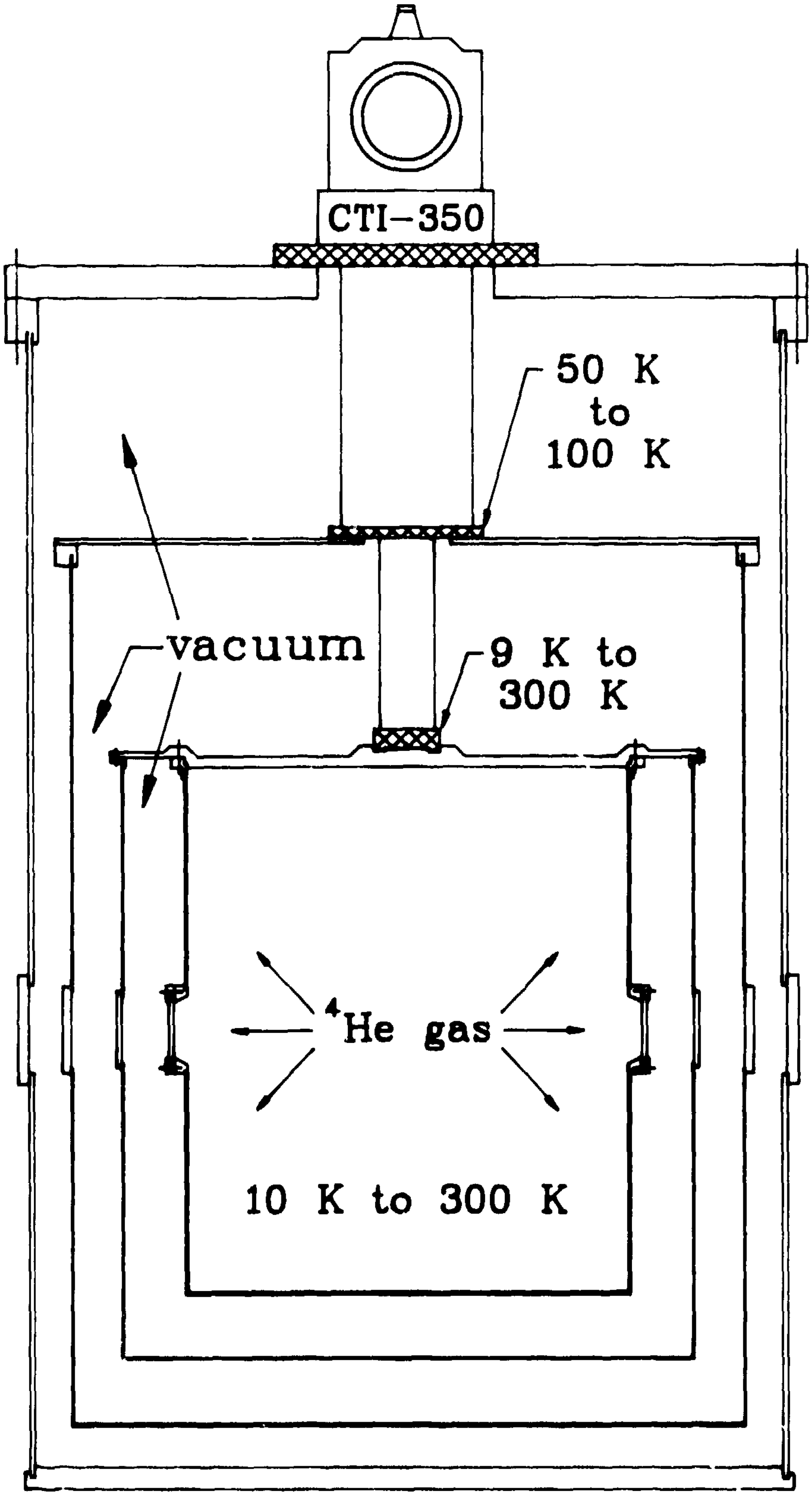

Figure 2. A refrigerator-cooled optical cryostat.

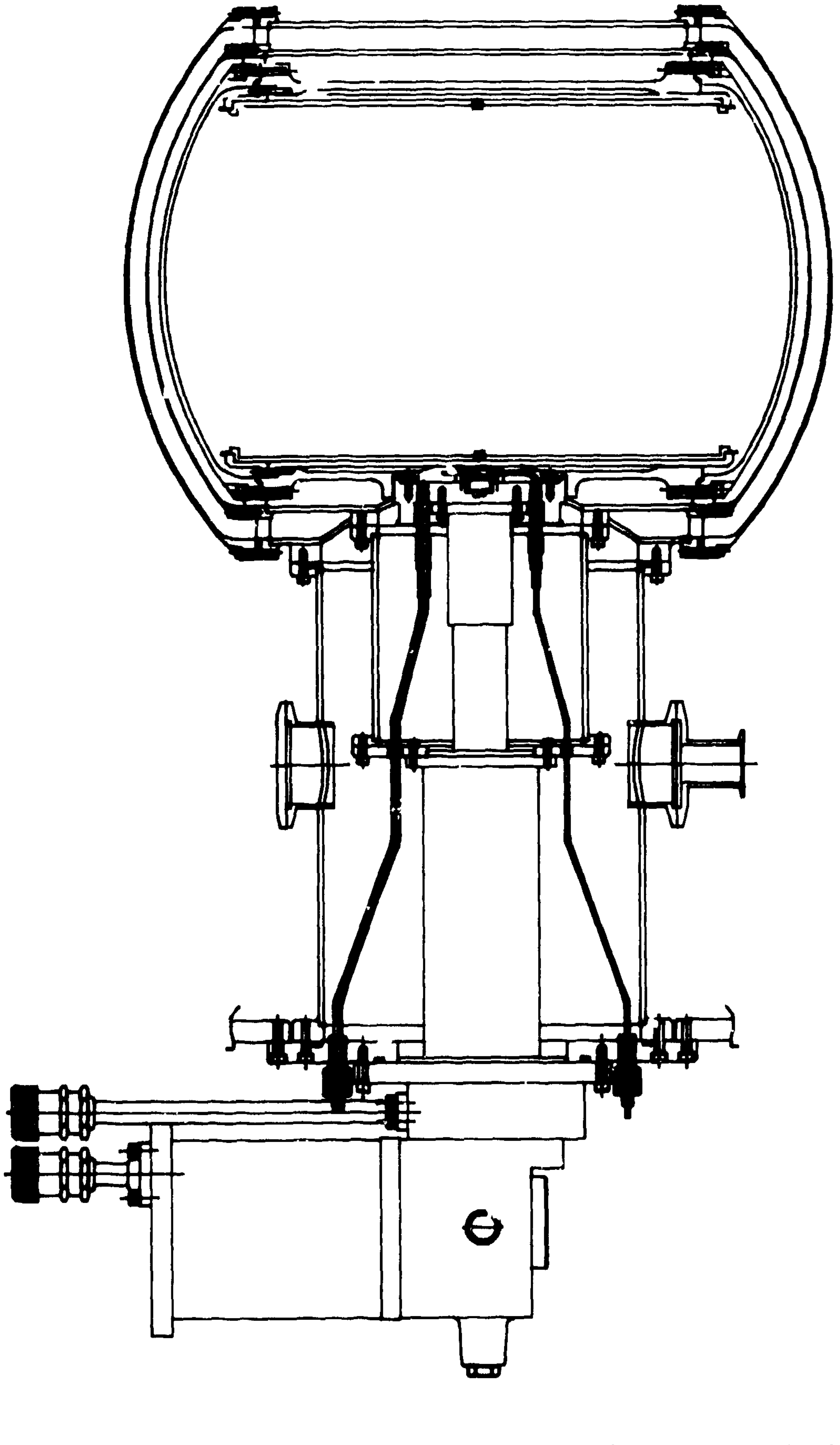

Figure 3. A refrigerator–cooled cryostat for inertial confinement fusion physics.

# REFRIGERATOR-COOLED CRYOSTATS FOR RESEARCH ON INERTIAL CONFINEMENT FUSION

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## SUMMARY

Cryogenics is a valuable tool for conducting research on inertial confinement fusion prototype targets. The increased density in the DT fuel afforded by cryogenic temperatures can not be easily matched in room-temperature designs. To achieve a density in DT equal to the liquid density at the triple point, a room-temperature pressure of just over 3 kbar (44,550 psi) is necessary. Many cryogenic problems can be circumvented by utilizing a closed-cycle-helium refrigerator as the cooling agent.

A conventional cryostat cooled by liquid cryogens could be used to cool an ICF target to near 20 K and to expose it to bursts of laser radiation. One must necessarily address the problems of the limited lifetime of the liquid $^4$He bath; purchase, transport and storage of the cryogens; as well as the hazards of transfer of the cryogens into the cryostat. However, a significant problem is that the target generally cannot be heated directly with a contact heater because that would affect the target symmetry.

We have built two separate cryostats each cooled by a closed-cycle-helium refrigerator operating on the Gifford-McMahon cycle. The design of both cryostats is presented, and the operation of one of them is discussed thoroughly. No liquid cryogens are needed. This type of refrigerator has been developed to a high degree of reliability in the cryopump industry. Our experience supports the [illegible] unattended operation [illegible] for long periods of time [illegible] days. Our long-term experiments [illegible] would not have been possible without this valuable feature.