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TITLE: REFRIGERATOR-COOLED CRYOSTATS FOR RESEARCH ON INERTIAL CONFINEMENT FUSION

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AUTHOR(S): James K. Hoffer and Robert J. Candler

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REFRIGERATOR-COOLED CRYOSTATS FOR RESEARCH
ON INERTIAL CONFINEMENT FUSION

J. K. Hoffer and R. J. Candler
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos, NM 87545

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-COOLLED CRYOSTATS FOR RESEARCH ON INERTIAL CONFINEMENT FUSION

By

James E. Hutton and Robert J. Canfield
Physics Division

Los Alamos National Laboratory
P. O. Box 1653
Los Alamos, New Mexico 87545

INTRODUCTION

It is becoming clear that cryogenics is a valuable tool for inertial confinement fusion research. Inertial confinement fusion (ICF) is a two-step process. The first step is heating the fuel to the ignition temperature by compression. The second step is to extract energy from the rapidly heated plasma. In order to achieve the required compression, it is necessary to have a relatively large quantity of matter contained in the target. To achieve a density which is equal to the liquid density at the triple point, a compression ratio of just over a thousand times is necessary.¹ However, pressuring the target will be accomplished near room temperature, and so one faces difficult engineering and number of symmetry problems. Many of these problems can be represented by a three-dimensional simulation of what the experiment is doing.

CRYOGENIC REQUIREMENTS

Before discussing the requirements, it will be useful to review the basic requirements of a laboratory cryostat in conjunction with the requirements of a three-dimensional simulation. The basic requirements of a laboratory cryostat are: (1) low temperatures, (2) low heat leak, (3) low pressure, (4) low vibration, (5) low noise, (6) low cost, and (7) low maintenance. The basic requirements of a three-dimensional simulation are: (1) low temperatures, (2) low heat leak, (3) low pressure, (4) low vibration, (5) low noise, (6) low cost, and (7) low maintenance.

heat sink at the top of the cryostat. The sample is placed in a vacuum can which sits on the bulk of the liquid 4 He bath. A concentric, thin-walled copper shield coated by AuB intercepts the laser beam from the 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 ^4He exchange gas to the nested cans. The can must then be evacuated if it is desired to change the sample temperature to levels significantly above (or below) the ^4He 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 EC target to near -20°K and to expose it to bursts of laser radiation. One must necessarily address the problem of the limited lifetime of the liquid ^4He bath, purchased transport and storage of the cryogen, 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.

REFLECTOR COOLED CRYOSTAT

Consider now the design shown in Fig. 3. This is a schematic drawing of a cryostat built by the authors for performing the temperature studies on support of the low-flame EC pump. It has been in continuous use over the past two years in a variety of tasks. The tuning studies of cooling procedures for prototypic hydrogen targets and direct observation of nuclear fusion initiation of cold targets added to the functionality of the liquid hydrogen cooling system. Instead of an elaborate technique of extrapolation of the data on the Gifford-Medwin cycle to predict extrapolation of the operating range, the fixed stage function of the cold head was used to determine the operating

stage temperature is typically about 60° F when the attached thermal shield is properly super-insulated. The second stage has a measured capacity of 5 W at 70° F and reaches 10° F under no load conditions. Here, however, about 25 lb of copper braid on the second stage, and the apparatus is limited to 110° K. Most of this mass is in the form of a "cold can" having external dimensions of 1.54 in diameter x 7.07 in. long. This space is filled with ^4He gas at a pressure of 200 torr at 70° F. The top of this can, known as the "cold plate", extends outwards to support a second thermal shield. Although this shield is not required to support the pressure of the gas, it is used in an attempt to make optimum use of the available insulation. The exchange gas can is intended to flow across the top of the cold can, 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° F at 70° F. A heater is wrapped around the second stage of the refrigerator to achieve closed-cycle temperature control of the cold can. Regulation to within 0.01° F is routinely achieved. After turning on the cooling water in the compression zone could opt for an uncooled compressor to and then switching on the compressor motor, the apparatus cools from room temperature to below 4° F in about 9 hours. Warm up is much slower - unless aided by heater power and/or pumping the vacuum space with exchange gas.

Closed-cycle helium refrigeration was developed to a high degree of reliability by the cryogenic industry. There are many companies both domestic and foreign and offering units of varying capacities, high reliability, low maintenance, prompt delivery and reasonable cost. The experience acquired in the development of these units can be used to advantage in the design of the refrigerator cold head or compressor. In addition, parts, tools, and supplies are available virtually anywhere in the world. It is recommended that one consult the catalogues of these companies for information on their products and services. It is also recommended that one consult the literature on the subject of helium refrigeration for additional information.

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 experiments¹ 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/target² assemblies for indirect drive studies.

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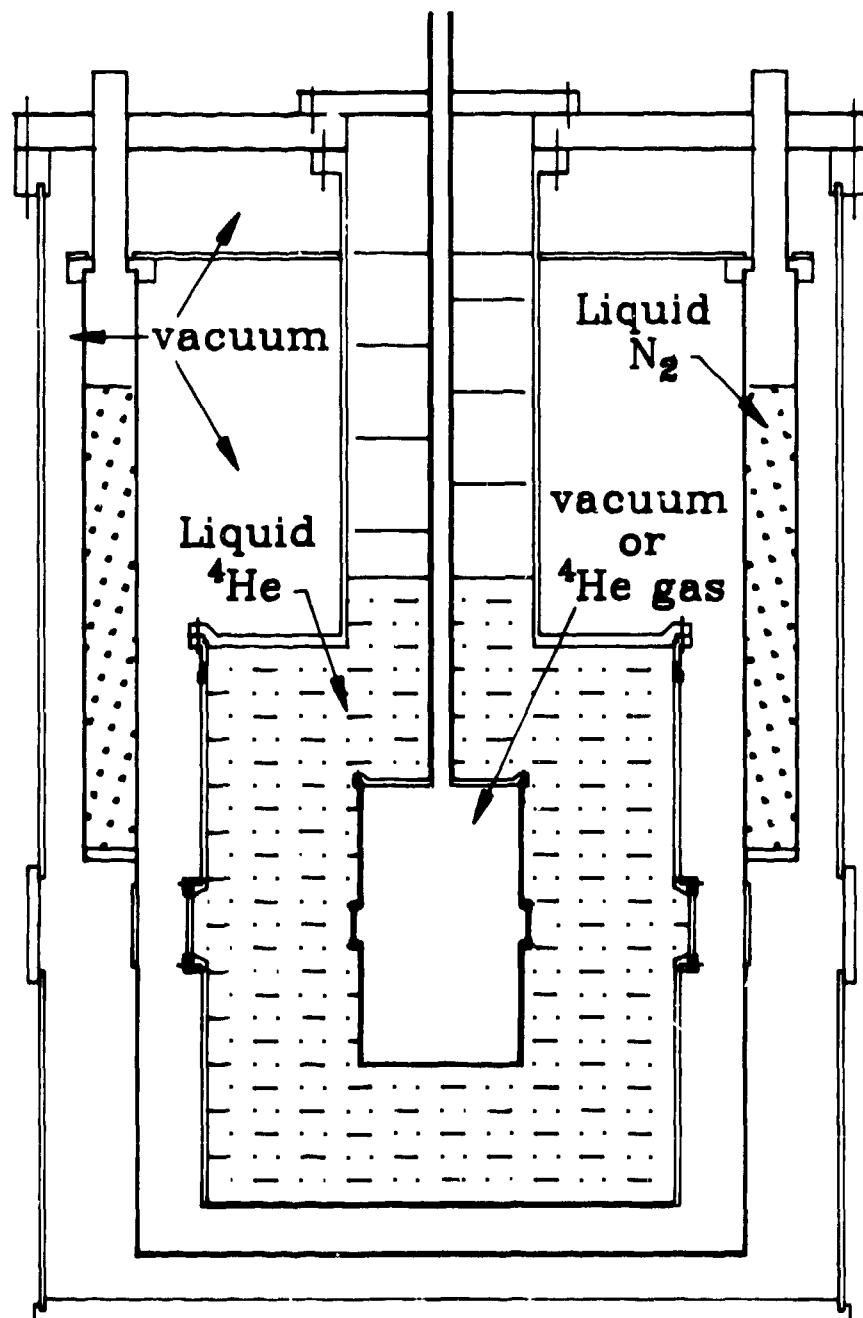


Figure 1. A conventional optical cryostat cooled with liquid cryogens.

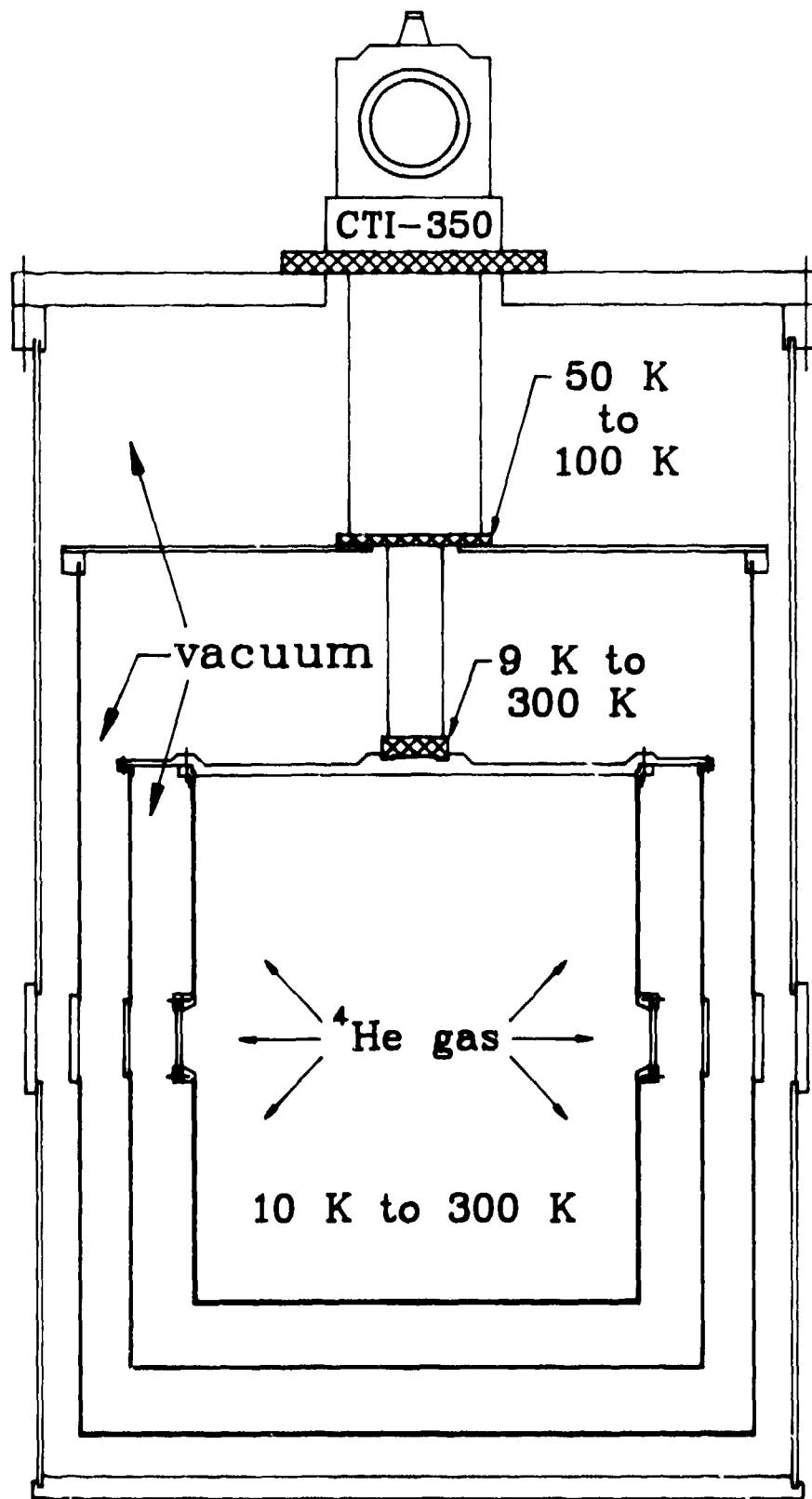


Figure 2. A refrigerator-cooled optical cryostat.

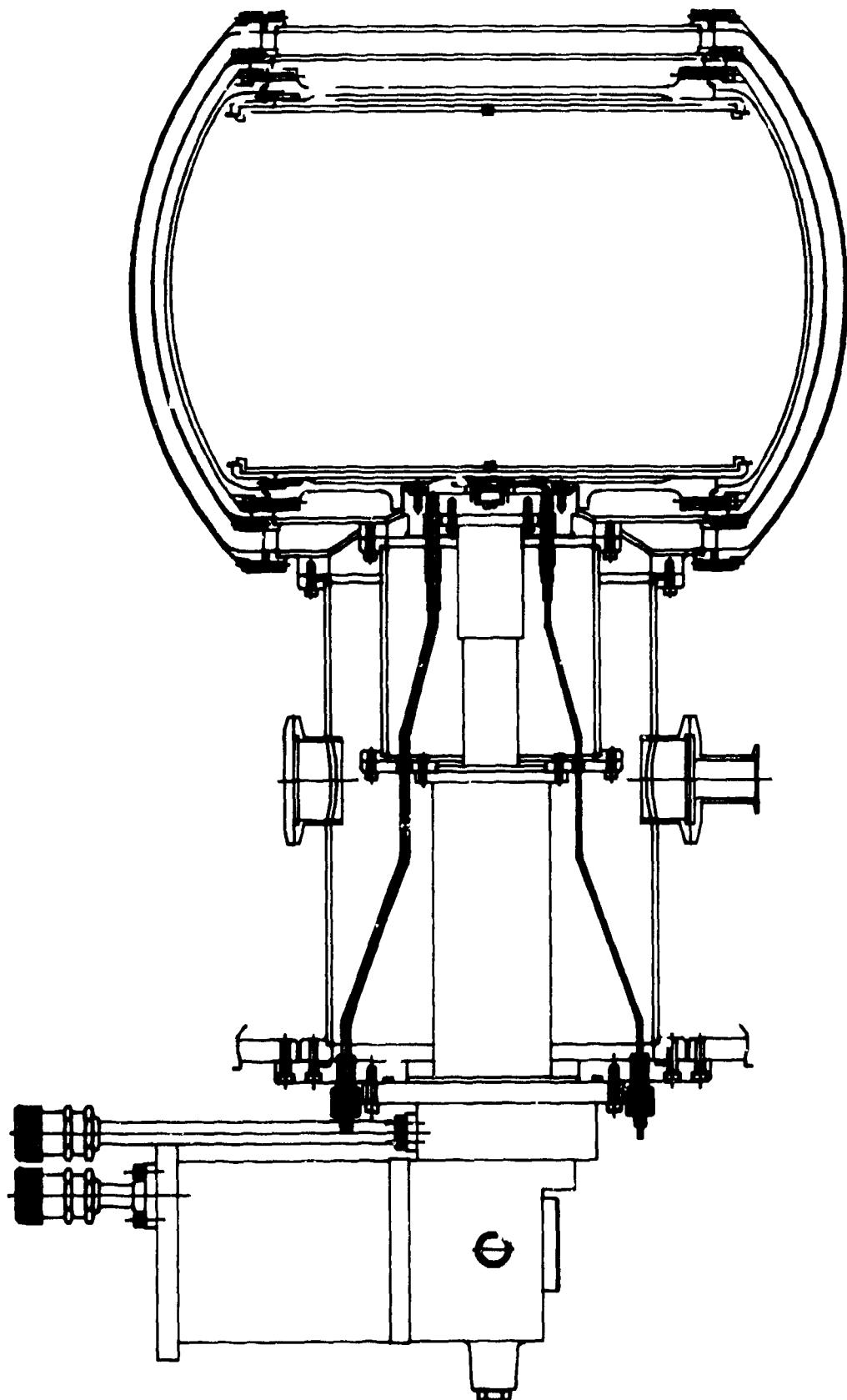


Figure 3. A refrigerator-cooled cryostat for inertial confinement fusion physics.

REFRIGERATOR-COOLED CRYOSTATS FOR RESEARCH ON INERTIAL CONFINEMENT FUSION

James C. Swift and Robert J. Landler, Jr.

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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 cannot 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 1 K and to expose it to bursts of laser radiation. One must necessarily address the problems of the limited lifetime of the liquid ^4He 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 reliability of the cycle in the laboratory environment. The low cost of the cycle and the ease of adapting it to different applications long term is a primary advantage of the system. It would not have been possible without this reliable technology.