Update On The Low Background IR Calibration Facility At The National Institute of Standards and Technology (Formerly NBS)

S.C. Ebner, A.C. Parr

Radiometric Physics Division
National Institute of Standards and Technology
(Formerly NBS)
Bldg. 221, Room A221
Gaithersburg, Maryland 20899

C.C. Hoyt

Cambridge Research And Instrumentation, Inc.
21 Erie Street
Cambridge, Massachusetts 02139

ABSTRACT

Details will be given about the recently completed facility for the calibration of infrared sources in a low background environment. The basic components of the facility are a large (60cm diameter by 152cm long) stainless steel vacuum chamber housed in a soft-wall cleanroom. A low background environment inside the chamber is achieved by cooling internal cryoshields to temperatures less than 20K using a closed cycle helium refrigerator. Sources of up to 30cm on a side can be inserted into the chamber for calibration. Total radiant power from the blackbodies is measured with an Absolute Cryogenic Radiometer. Plans will be discussed for future enhancement of the system allowing for measurement of spectral and angular distribution of the emitted radiation and possible experiments which could utilize the full capabilities of this system.

1. INTRODUCTION

We reviewed the design and development progress on the low background infrared (LBIR) facility at this meeting last year.[1] The system is now assembled and is undergoing vacuum and cryogenic systems testing. It is anticipated that calibration activity will start in the near future.

A meeting was held in November of 1988 which provided a forum for potential users to give their views on the projected use of the facility. It is expected that a users meeting will be held on a regular basis for user response and input on the LBIR program. A number of suggestions were offered at the meeting which will be useful in determining the direction of the research and development goals of the project. These suggestions included establishing a systematic error propagation methodology, developing the ability to give information on the spectral content of blackbody sources and to develop a calibration package which could circulate amongst users and serve as an intercomparison instrument. These suggestions, and the others given, will be given priority and serve as basis for developing the long term calibration and research strategy. A facility advisor group has been formed and will serve as a consultative body to give direct input to NIST on the priorities for the project. The group consists of representatives from industry, DOD and NIST.

The allied research activities for the project are proceeding according to expectations. The laser heterodyne densitometry project has made significant progress in determining the systematic errors involved in the technique and is developing new laser facilities for performing measurements in the infrared at 10 micrometers[2]. This technology will be made available to assist the technical staff at calibration facilities with the task of determining the attenuation of optical components in their calibration facilities. Plans are being made to start research and development activities to answer some of the other needs of the calibration community.

2. FACILITY

Fig. 1 shows the layout of the LBIR facility, which is located in the basement of the Physics Building at NIST. This location provides optimal isolation from vibration and also provides a high ceiling to permit adequate space for a clean room environment as well as affording clearance for cryogenic lines and connections. The room is 10m long, and 6.7m wide and is arranged as shown in fig. 1. The closed cycle helium refrigerator expansion unit (refrig.) is situated on the left side of the room. The compressor which drives the expansion unit is located in a special equipment room approximately 100 meters away and is not shown on the diagram. The central portion of the room which contains the apparatus is covered by a class 10,000 clean room. We expect to maintain ultrahigh vacuum conditions in the chamber and hence the surrounding workspace needs to be carefully controlled. The optical benches will allow for placement of lasers and other optical equipment in the calibration and research phases of the project. The calibration chamber has provisions for installing ports for optical input as well as other mechanical and electrical feed-throughs. The storage tank and bottle racks provide for helium reservoirs needed in various stages of the refrigerator's cooling cycle.

3. APPARATUS

The apparatus for accomplishing the calibration is shown in fig. 2. The vacuum shell housing the source and detector is constructed of type 304 stainless steel 152cm long and 60cm in diameter. All the flange connections associated with the chamber use all-metal seals. The absolute cryogenic radiometer (ACR) is shown mounted into the port closest to the blackbody (BB) source to be calibrated. Two additional ports are available for mounting the ACR farther from the source to allow for more intense sources. Initial pump-down of the chamber to approximately $1x10^{-8}$ torr is accomplished with the combination of a 170 l/sec turbopump and a 2000 l/sec cryopump (not shown). A 60 l/sec ion pump is available as a holding pump for occasions when the other pumps are offline. One such occasion occurs when the turbopump is used to pump down the auxiliary vacuum shell. When the front flange of the main chamber is rolled back on its linear bearing assemblies, the auxiliary vacuum chamber can be put into position with an overhead crane (not shown) and joined to the flange. With the blackbody mounted to an actively cooled plate cantilevered from the front flange, preconditioning of the blackbody can now be accomplished independent of the main chamber. The helium refrigerator is used to circulate cooled helium gas (15K) through a series of copper lines vacuum brazed to the outside of the inner and outer shields, also made of copper (shown in the cutaway portion of fig. 2). The shields are connected in series and separated by a 2.54cm gap with the inner shield operating at 20K and the outer one at 80K. The inner surface of the inner shield has a highly absorbing black coating of 3M's ECP 2200 paint[3] to cut down on scattered radiation. The refrigerator has a design cooling capacity of approximately 200 watts at 10K.

Not shown in fig. 2, but crucial to the apparatus, is a laser alignment device which attaches to a 7cm diameter flange on the front flange of the vacuum chamber. A HeNe laser produces a beam which passes through a vacuum window and is lined up with a pair of crosshairs mounted in a blackbody mounting plate similar to fig. 3. The plate is weighted to simulate the BB under test, cooled to 20K, and the optic axis is then established. The ACR is then adjusted to align with this optic axis. The dimensions of the plate allow for a blackbody to be mounted within a cubic area approximately 30.5cm on a side.

4. RADIOMETER

The photograph in fig. 4 shows the absolute cryogenic radiometer constructed for the LBIR chamber. The ACR is currently being installed and will undergo final stages of characterization once installation is complete.

The ACR is an electrical substitution radiometer (ESR) operated in "active cavity" mode where the temperature of the blackened cavity receiver is controlled continuously. The temperature is sensed with germanium resistance thermometers (GRTs) and heat is applied with resistive coils mounted on the receiver. With "non-equivalence" errors being negligible at the 1.0% level, absorbed radiation is equal in magnitude to the decrease in electrical power applied by the controller when the shutter is opened, and the same temperature is maintained at the receiver.

The overall design objective is to provide an accuracy of approximately 1.0% for flux levels as small as 20nW for wavelengths from the visible out to 30 micrometers. Table 1 lists the specific design objectives for the ACR.

Table 1. ACR CHARACTERISTICS

- Overall receiver absorptance from 300nm to 30 micrometers to be above 99.5%
- Responsivity of minimally 25 K/mW at 2.2 K
- Temperature stability of a few microkelvins, rms.
- Minimum sensitivity, or noise floor, at 0.2 nW
- Natural time constant between 20 and 30 sec
- Provision for accurate alignment of the receiver with the optical axis while the chamber is under vacuum and cooled down
- Aperture area known to within 0.1%

The ACR was designed so that aspects of the radiometer that affect overall accuracy, such as receiver absorptance, can be readily measured, or characterized. Much of the ACR characterization has been completed at the contracting company (CRI, Inc.)[4]. The receiver absorptance, responsivity, thermal time constant, temperature stability, and aperture area have been measured. Measurement of the minimum sensitivity will take place at NIST once the ACR has been installed. This step is left until after installation because the minimum sensitivity will depend on the background heat fluxes from the LBIR chamber.

The receiver was designed to yield an absorptance well above 99%. With such a high absorptance, ACR accuracy becomes less dependent on the receiver absorptance measurement. The receiver is an inverted copper cone with its inner surface coated with Chemglaze Z302[5], a specular (glossy) carbon black polyurethane. With an apex angle of 45 degrees and a specular finish, the light reflects four times before it can exit the receiver. The overall absorptance of the receiver was characterized by first measuring the absorptance of Chemglaze Z302 for a single reflection at an incidence angle of 45 degrees for wavelengths from 300nm to 40um (please refer to fig. 5). The absorptance was shown to be greater than 84% over the entire range. Four reflections should yield an overall absorptance over 99%. To verify the overall absorptance at one wavelength, an expanded HeNe laser beam and an integrating sphere were used. An absorptance of 99.87% was measured. Additional tests will be performed in the upcoming months to verify the absorptance at other laser wavelengths.

The receiver responsivity, natural time constant, and temperature stability under control were measured in a small test chamber. A responsivity of 30.2K/mW, a time constant of 18.4 sec, and a temperature stability of 3uK (rms) were observed. The responsivity and temperature stability suggest a minimum sensitivity of approximately 0.1nW. However, the actual minimum sensitivity will be determined in the LBIR chamber after installation.

A cross-sectional view of the ACR is shown in fig. 6. The radiometer is kinematically mounted to allow alignment of the receiver with the optical axis of the LBIR chamber while the chamber is evacuated and cooled down. Vertical and lateral adjustment with 0.025mm precision are made possible with a micrometer and a fine pitch collar wheel. The vacuum seal is made with a welded metal bellows.

An optical baffle minimizes scattered light incident upon the receiver and at the same time serves as a molecular trap, catching stray molecules before they can hit the receiver. The field of view of the radiometer is defined by a precision machined 3cm diameter invar aperture, whose area is known to within 0.1% at 4K and 2K. The liquid helium well holds 3 liters and provides more than 30 hours of operation at 4K and 20 hours at 2K (between refills) An operating temperature of 2K is maintained by a pressure regulator attached to the port on the liquid helium well.

The data acquisition electronics consist of two digital controllers that maintain constant temperatures at the receiver and the receiver mounting plate, which serves as the heat sink. In addition to controlling temperatures, the controllers provide accurate heater power readback which is used for the radiometric measurement. The electronics are interfaced to an IBM-AT[6] via an IEEE-488 bus. Each temperature controller uses an AC-bridge to sense the temperature. The output of the AC bridge is demodulated and sent to a microprocessor which applies appropriate electrical power to the heaters mounted on the receiver.

The data collection is performed through a menu-driven computer program. The program provides fully documented data files, data reduction functions, and plotting routines.

5. OPERATION

Calibration of a blackbody begins with either purchasing from NIST or building to NIST's specifications a blackbody mounting plate shown in fig. 3. The plate is made up of two precisely aligned and orthogonal copper plates with one plate containing an aperture and fiducial marks. It is the user's responsibility to mount his BB source to the plate normal to and precisely aligned with this same aperture and set of marks. In addition, the user is responsible for providing the distance from the origin of interest of BB radiation to a reference invar plate bolted to the front of the mounting plate. This dimension must be referenced to 20K. Once the plate with blackbody attached is bolted to the chamber's front flange, the distance from the reference plate to the ACR is measured with an internal Kaman[7] measuring device. The user will supply the electronics necessary to run their blackbody and all signal and control wiring from the user must be interfaced to two 35 pin Amphenol[8] model 36-15 connectors. Before inserting the blackbody into the main chamber, the auxiliary chamber is put in place and the entire assembly evacuated. Preconditioning begins by bringing the BB source up to operating temperature and monitoring for hydrocarbon contamination with a residual gas analyzer built into the auxiliary chamber. Hydrocarbon partial pressures will not be allowed to exceed $1x10^{-10}$ torr. Strict control of this standard is necessary to avoid contamination of the ACR receiver as well as future optical components envisioned for the calibration chamber.

Once preconditioning is complete, the auxiliary chamber is removed and the front flange rolled into position against the main chamber. After initial pump-down with the system's pumps, helium transfer takes place to complete the cycle. Turnaround time is anticipated to be several days. At least initially the calibration itself will be comprised of determination of irradiance of the source at temperature settings specified by the user.

Most of the operation of the facility is under automated control by a Compaq Deskpro 386 computer[9]. The Kaman proximity sensor as well as the Lake Shore[10] cryogenic controllers and its associated sensors are interfaced to it. An additional function is active control of the isothermal plate separating the blackbody and the ACR. By maintaining the temperature of this plate to within $\pm$ 5mK/min, a minimum of background fluctuations is seen by the ACR. Status of the entire system is displayed continuously and the ACR control function and calibration data are taken by the same computer.

6. ACKNOWLEDGEMENTS

The support of the U.S. Army Strategic Defense Command for this work is gratefully acknowledged. We also wish to thank the staff of Nichols Research in Huntsville, AL for advice and help over the course of this project. In addition, the following NIST staff members were instrumental in moving this project forward: Joel Fowler, Jim Proctor, and Pat Tobin.

REFERENCES

*References made in this paper to particular brand names or specific suppliers of a service are made for ease of understanding by the reader and do not constitute an endorsement of products or service by the National Institute of Standards and Technology over other competitive suppliers of similar products or service.

1. "Low Background Infrared Calibration Facility at the National Bureau of Standards", A.C. Parr, J. Fowler and S. Ebner, SPIE Vol 940 (1988).

2. "An Optical Heterodyne Densitometer", A.L. Migdall, Zheng Ying Cong, J. Hardis, J.J. Snyder, Second Workshop On Improvements To Photometry, Held at NBS, 1987.

3. 3M Company, 225-45-08 3M Center, St. Paul, MN 55144-1000.

4. Cambridge Research And Instrumentation Corporation, 21 Erie Street, Cambridge, MA 02139.

5. Lord Corporation, Industrial Coatings Division, 2000 W. Grandview Blvd., Erie, PA 16514-0038.

6. International Business Machines, P.O. Box 1328-C, Boca Ratan, FL 33432.

7. Kaman Instruments Corporation, 1500 Garden of the Gods Road, Colorado Springs, CO 80933-7463.

8. Amphenol Products, 4300 Commerce Court, Lisle, IL 60532.

9. Compaq Computer Corporation, Houston TX 77070.

10. Lake Shore Cryotronics, Incorporated, 64 East Walnut Street, Westerville, OH 43801.

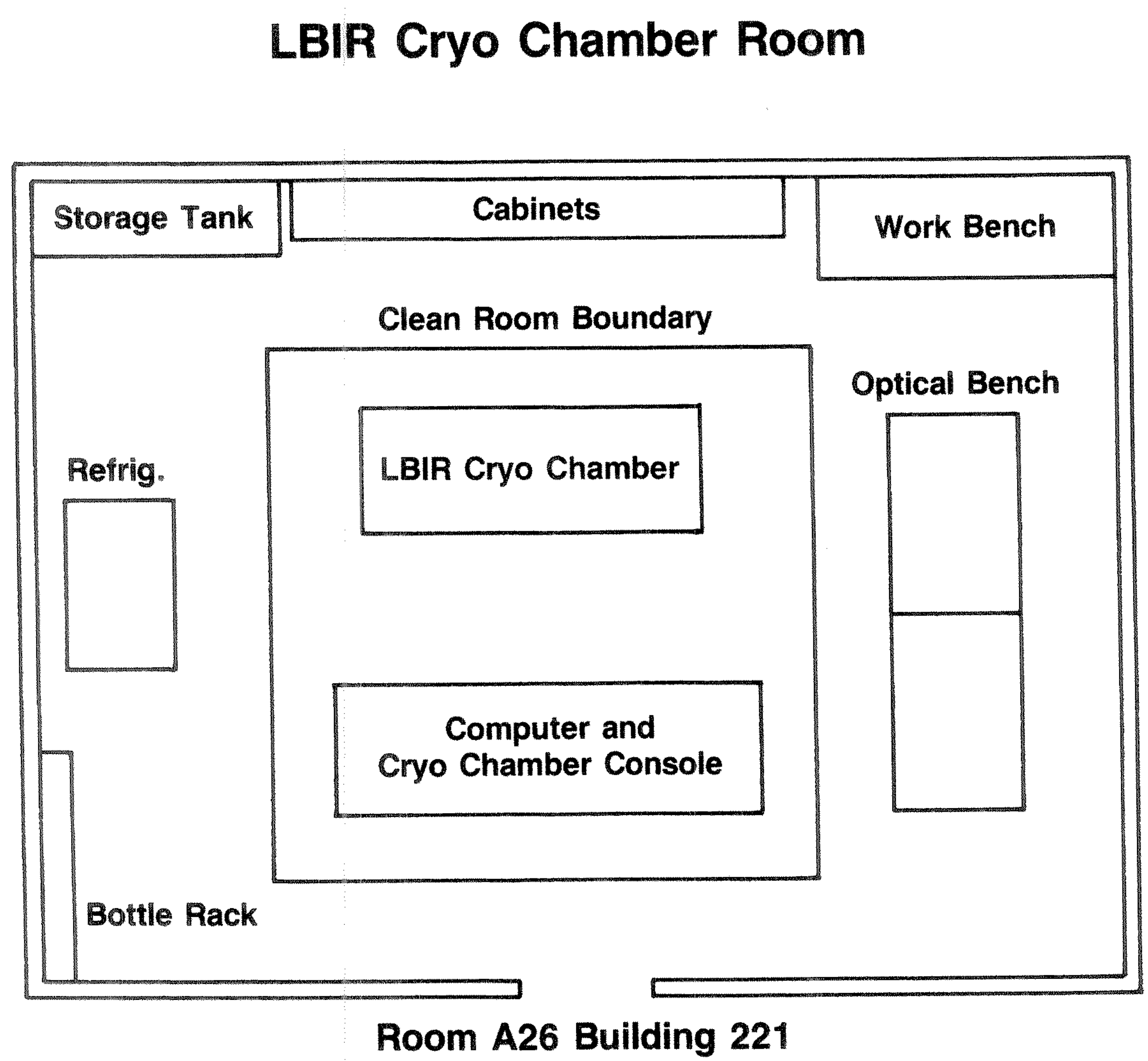


Figure 1. Layout of the LBIR Laboratory at NIST.

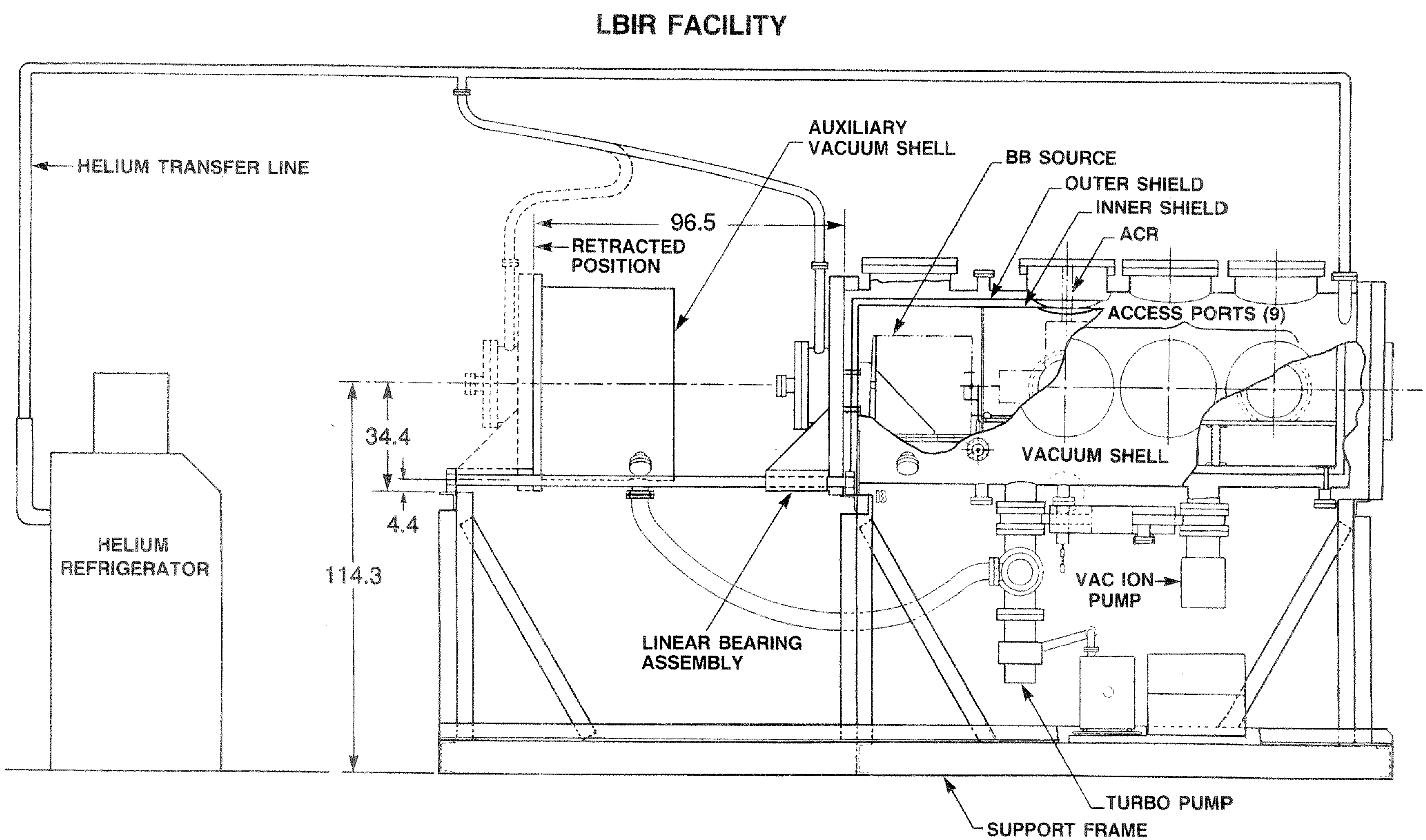


Figure 2. LBIR chamber with partial cutaway showing the major features of the apparatus. BB Source = Blackbody Source, ACR = Absolute Cryogenic Radiometer. (Dimensions in cm)

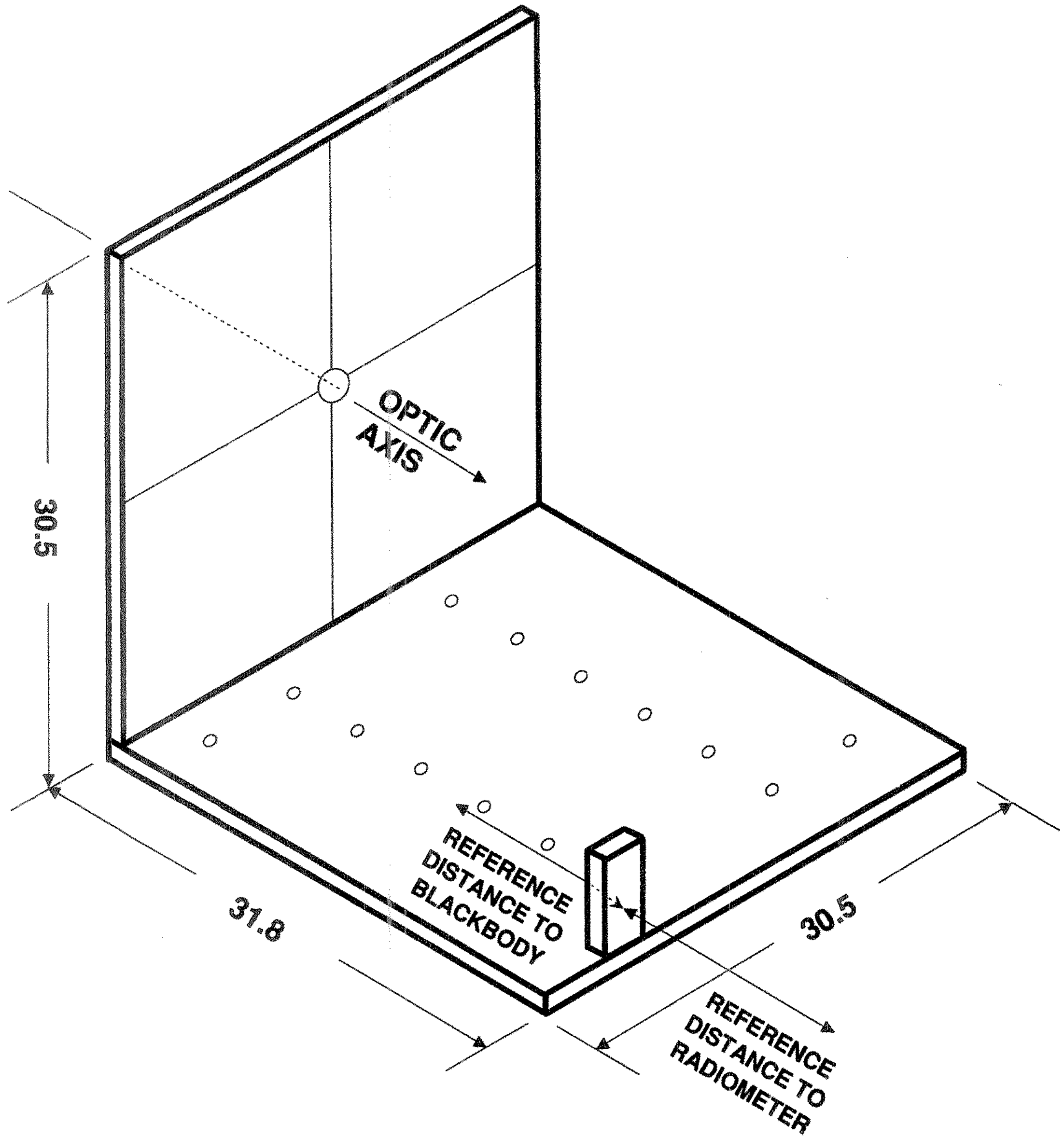


Figure 3. **BLACKBODY MOUNTING PLATE** (Dimensions in cm)

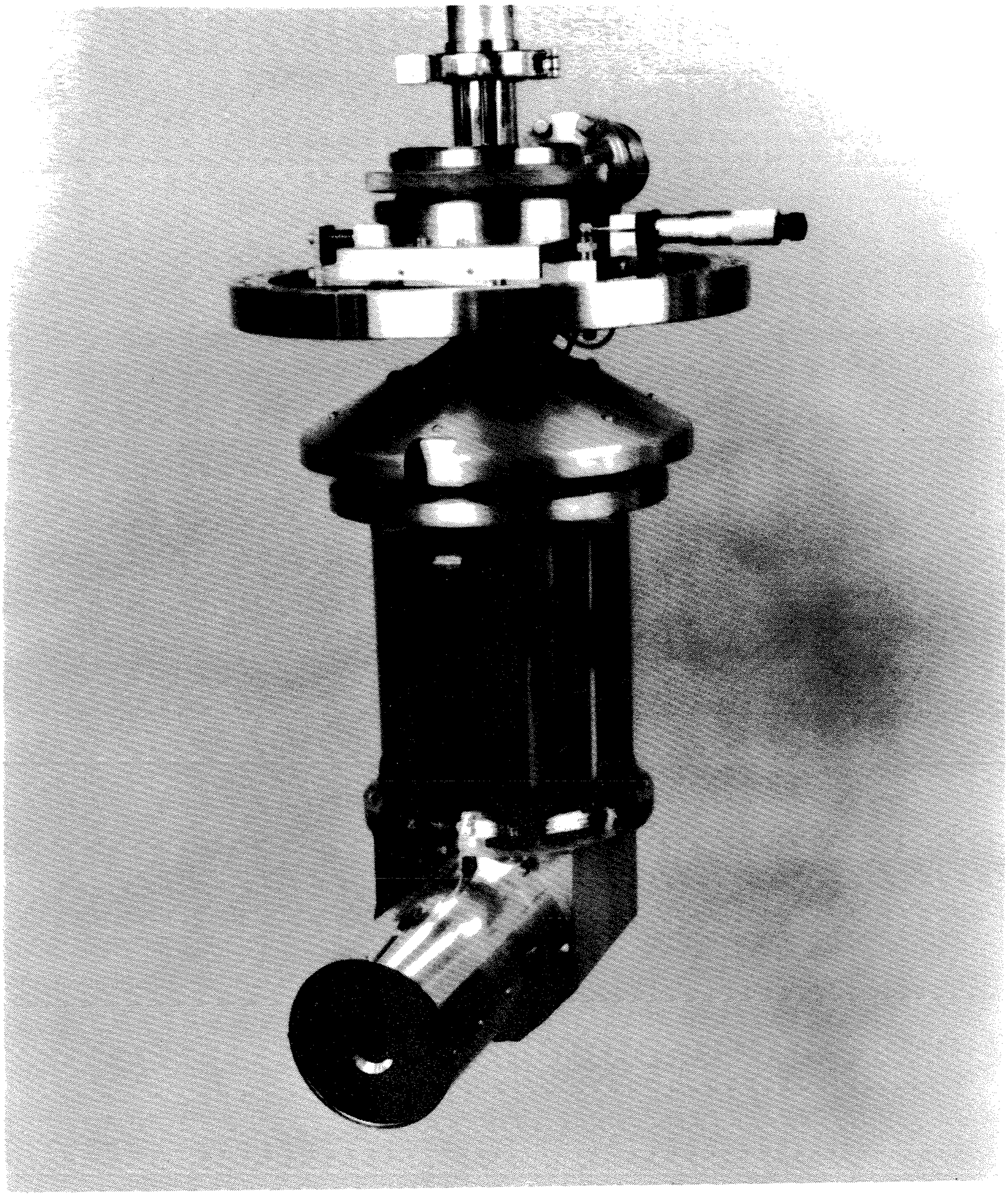
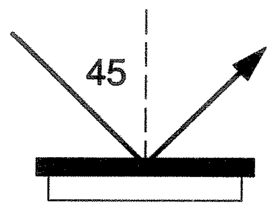


Figure 4. Absolute Cryogenic Radiometer

Receiver Absorptance Measurement

Objective: To determine absorptance between 300nm and 40μm

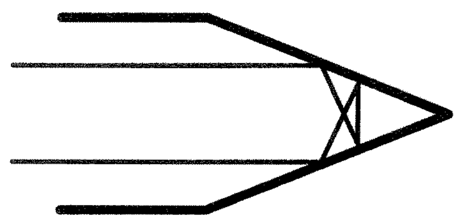
Step 1: Specular reflection measurement with a Beckman 4250 Spectrophotometer over wavelength range from 300nm to 40μm



Results:

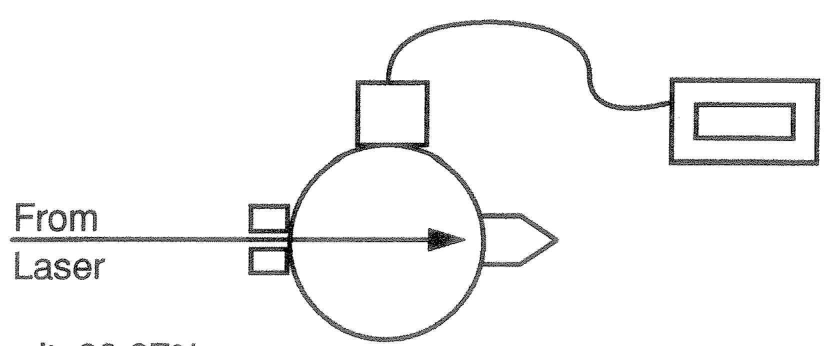
	300nm - 6.5μm	6.5 - 16μm	16 - 40μm
absorptance	>94%	>92%	>85%

Step Two: Overall Absorptance Calculation



We should get > 99.9% absorptance throughout wavelength range

Step Three: Verify at one wavelength: 632.8nm laser with integrating sphere



Result: 99.87%

Figure 5. Steps for arriving at the overall absorptance of the receiver.

The ACR Insert

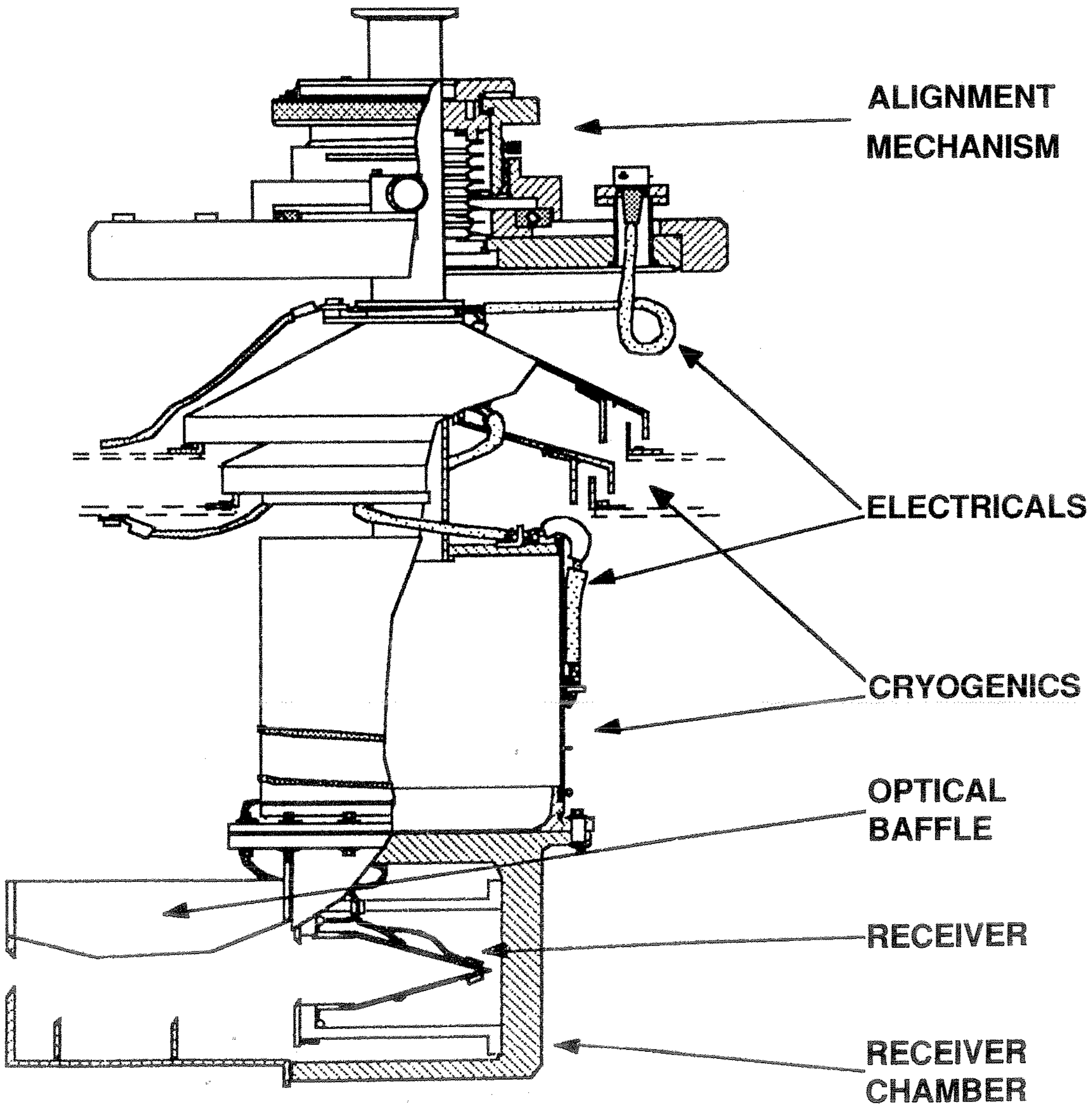


Figure 6. Cross-section view of the absolute cryogenic radiometer.