NIST HANDBOOK 147

LBIR Facility User Handbook

L · B · I · R

CALIBRATION · FACILITY

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National Institute of Standards and Technology

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LBIR Facility User Handbook

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June 1991

U.S. Department of Commerce
Robert A. Mosbacher, Secretary

National Institute of Standards and Technology
John W. Lyons, Director

National Institute of Standards and Technology Handbook 147
Natl. Inst. Stand. Technol. Handb. 147, 26 pages (June 1991)
CODEN: NIHAE2

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1991

CONTENTS

1. INTRODUCTION

The Low Background Infrared Calibration Facility (LBIR) at NIST is a rebirth of a facility that operated at NBS until early 1985. The earlier facility had served a user community providing total power measurements from blackbodies in a cryogenic environment. Due to age and maintenance costs, NIST management decided that support of the facility was no longer feasible and calibration services ceased. A survey, requested by Department of Defense (DOD) through the Calibration Coordination Group (CCG), was conducted with the help of outside experts which considered the Nation's long term needs for calibration activity in the low background infrared. It was a conclusion of this survey that there was a heightened national need for calibration and research activity in the low background infrared and that NIST should serve as the lead calibration laboratory. With funding from the Department of Defense through the Strategic Defense Command, a new facility was designed and constructed and came on line and performed its first calibration in December 1989.

Using experience gained from the previous facility and the input from a blackbody workshop held in Huntsville, the new LBIR Facility was constructed with several improvements over the old facility. For example, a closed cycle helium refrigerator is used for chamber cooling operations, cutting down significantly on liquid helium costs associated with the previous open-cycle operation. A state-of-the-art Absolute Cryogenic Radiometer (ACR) is used as the primary detector, resulting in improved accuracy of the flux measurement from 5% to 1%. In addition, the complete apparatus is enclosed in a class 10,000 cleanroom to insure the cleanliness of the user's source and to maintain cleanliness for optical measurements.

The staff of the new facility is committed to making the operation user friendly. Along these lines a committee was formed from a cross-section of the user community and other experts in low background technology. It serves as a consultative body to give direct input to NIST on the priorities and direction of the project. In addition, regularly scheduled workshops are held with users and NIST staff interacting to discuss progress on calibration activity.

It was in the spirit of "user friendliness" that this handbook was written. We hope it will serve you, the user, as a worthwhile tool.

We welcome you to visit our facility during any working day. Appendix A gives details of directions to get to NIST. A list of hotels and restaurants in the area is given in Appendix B.

2. LBIR CALIBRATION FACILITY

2.1 Overview and Physical Layout

Figure 1 shows the layout of the LBIR facility located in the basement of the Physics building at NIST (Bldg. 221/Room A26). The location was chosen to provide optimal isolation from vibration as well as a high ceiling for installation of a soft-wall cleanroom. The room is 1000 cm long and 670 cm wide with the cleanroom occupying 430 × 520 × 320 cm high in the middle of the room. The cleanroom is of the vertical random flow type and, at class 10,000, does require the use of cleanroom apparel while working inside. The clear plastic walls of the cleanroom allow visibility to other parts of the lab. On the left side of the room is situated the closed cycle helium refrigerator expansion unit (Refrig.). Two compressors drive the refrigerator and are located in a special equipment room approximately 100 meters away and not shown in figure 1. The large storage tank and bottle racks provide ultra pure helium reservoirs needed in various stages of the refrigerator's cooling cycle. The optical bench allows for the placement of lasers and other optical equipment to be used in the calibration and research phases of the project. Also not shown in figure 1 is a partial laboratory module used for temporarily storing the user's shipping containers. Located on the second floor of the Physics building, it also houses the facility's test chamber used primarily for residual gas analysis of vacuum components.

The apparatus for accomplishing the calibration is shown in figure 2. The vacuum tank housing the source and detector is constructed of type 304 stainless steel 152 cm long and 60 cm in diameter. All the flange connections associated with the chamber use 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 accommodate more intense sources. The distance between the center-lines of the ports is 33 cm. Initial pumpdown of the chamber to 1.33×10^{-6} Pa is accomplished with the combination of a 500 L/s turbopump and two 2000 L/s cryopumps (not shown). The auxiliary chamber is pumped by a 170 L/s turbopump and 2000 L/s cryopump. When the front

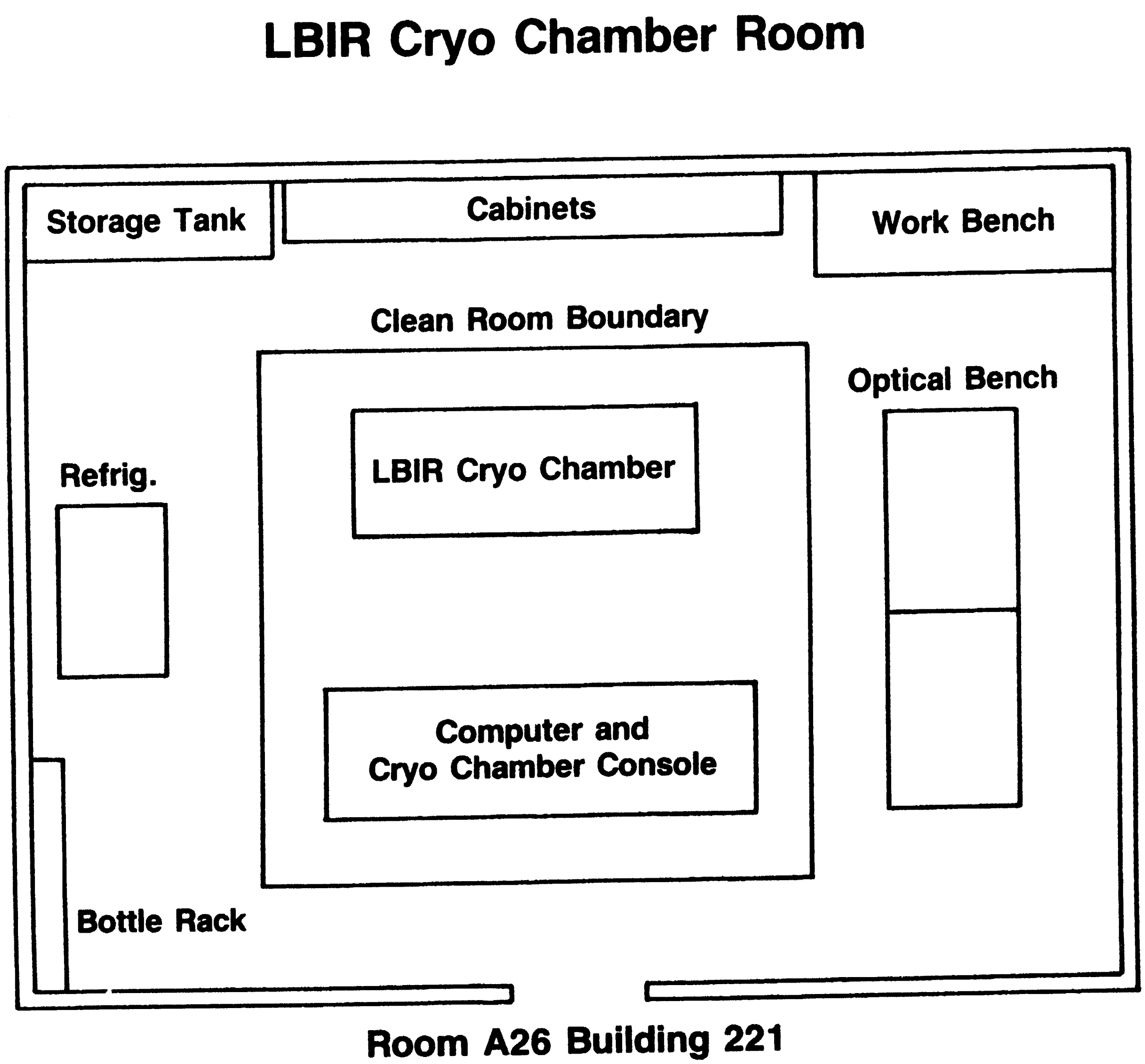

Figure 1. Layout of the LBIR Laboratory at NIST.

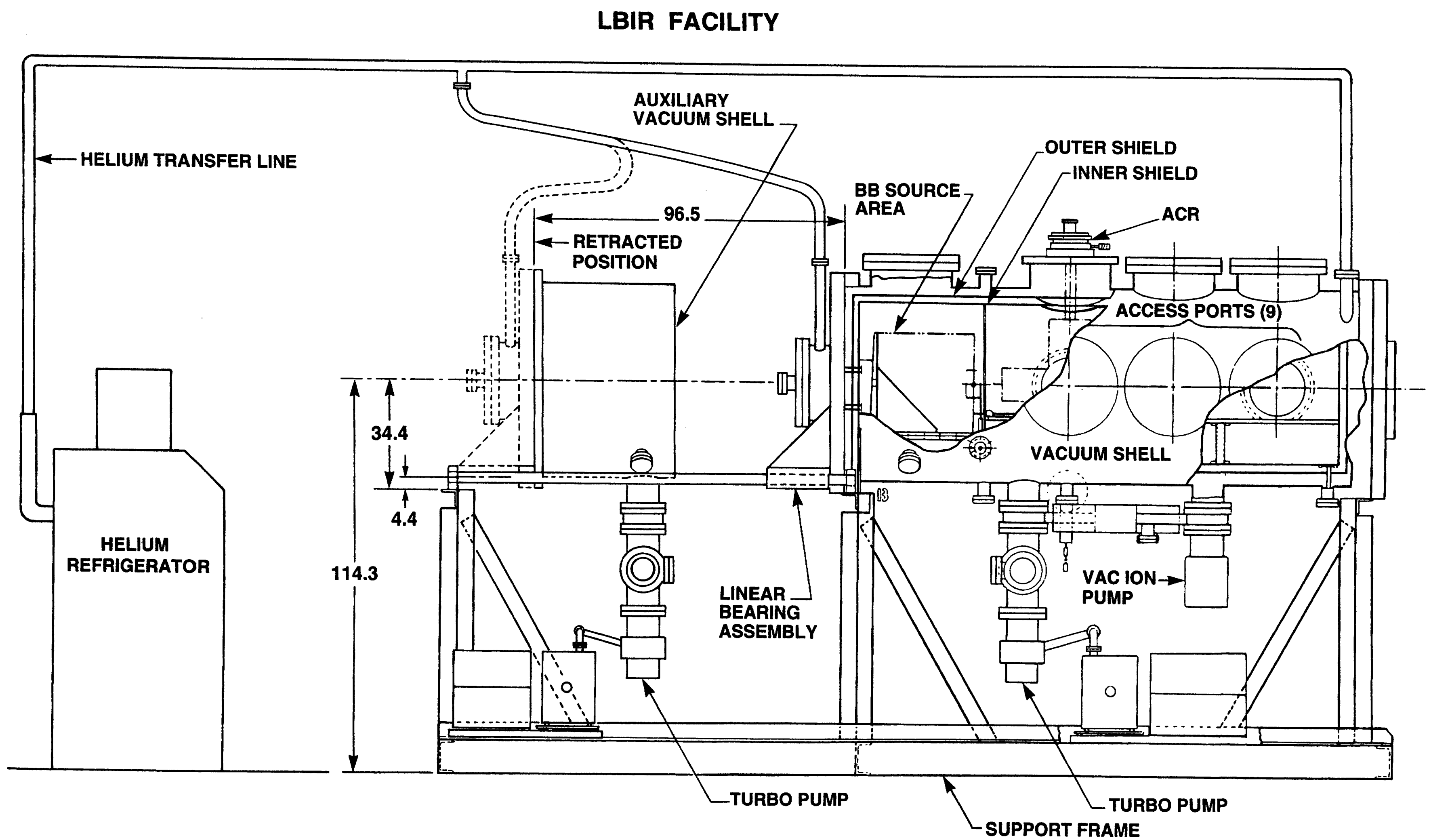

Figure 2. LBIR chamber with partial cutaway showing the major feature of the apparatus.
BB Source = Blackbody Source, ACR = Absolute Cryogenic Radiometer. (dim. in cm)

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 bolted 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 (15 K) 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 two shields are connected in series and separated by a 2.54 cm gap with the inner shield operating at 20 K and the outer one at 40 K. The inner surface of the inner shield has a highly absorbing black coating of 3M's[1] ECP 2200 [1] paint to cut down on scattered radiation. The refrigerator has a design cooling capacity of approximately 200 watts at 10 K.

Not shown in figure 2, but crucial to the apparatus, is a laser alignment device which attaches to a 7 cm 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 figure 3. The plate is weighted to simulate the BB under test, cooled to 20 K, 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 30.5 cm on a side.

2.2 Absolute Cryogenic Radiometer (ACR)

The standard detector at the LBIR facility is the Absolute Cryogenic Radiometer (ACR). The ACR is an electrical substitution radiometer (ESR) operated at cryogenic temperatures (2-4 K). It was built for the facility by Cambridge Research and Instrumentation, Inc. [2] The complete description of the ACR and its characterization as an absolute detector for infrared calibrations at NIST can be found in reference [3], parts of which are reproduced below.

2.2.1 Basics of ESR Operation

Figure 4 gives a schematic representation of electrical substitution radiometer (ESR) operation. The radiative flux, F, to be measured is absorbed by blackened surfaces (a) on the receiver. This radiation heats the receiver (b) to an equilibrium temperature determined by the radiative flux and by the thermal resistance of the heat link (c) connecting the receiver to the heat sink (d). This temperature is sensed by a thermometer (e). The radiative heating is stopped by shuttering the flux and then replaced with electrical heating to the same temperature by passing an accurately measured electrical power through a resistive coil (f) on the receiver. To within nonequivalence errors due to small differences in isotherms set up by radiant and electrical heating, the radiative flux to be measured is equal to the absolute electrical power dissipated in the heater circuit.

2.2.2 Advantages of Cryogenic Operation

Characterization of the radiometer is greatly simplified by its operating point at liquid helium temperatures. The full equation describing the energy balance of a conventional ESR receiver operated at room temperature contains terms describing radiative and convective energy flow between the receiver and its enclosure that are difficult to evaluate accurately. Additional implicit terms associated with Joule losses in the heater connections and with the different isotherms established throughout the radiometer under electrical and radiant heating, are lumped together as "nonequivalence" errors.

The design of the radiometer, and its operation in high vacuum at liquid helium temperatures, makes it easy to show that the radiative and convective couplings between the receiver and its enclosure can be neglected if the vacuum pressure is at the 10^{-7} Pa level and the surrounding temperatures are less than 10 K.

Several important properties of materials are affected by liquid helium cooling. The high thermal conductivity and extremely low heat capacity of pure copper at 2-4 K dramatically increase the thermal diffusivity of the receiver. The use of superconducting wire effectively eliminates Joule heating losses in the heating leads. Both reduce the limiting non-equivalence errors permitting characterization to an absolute accuracy of well below 1%.

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[1] 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.

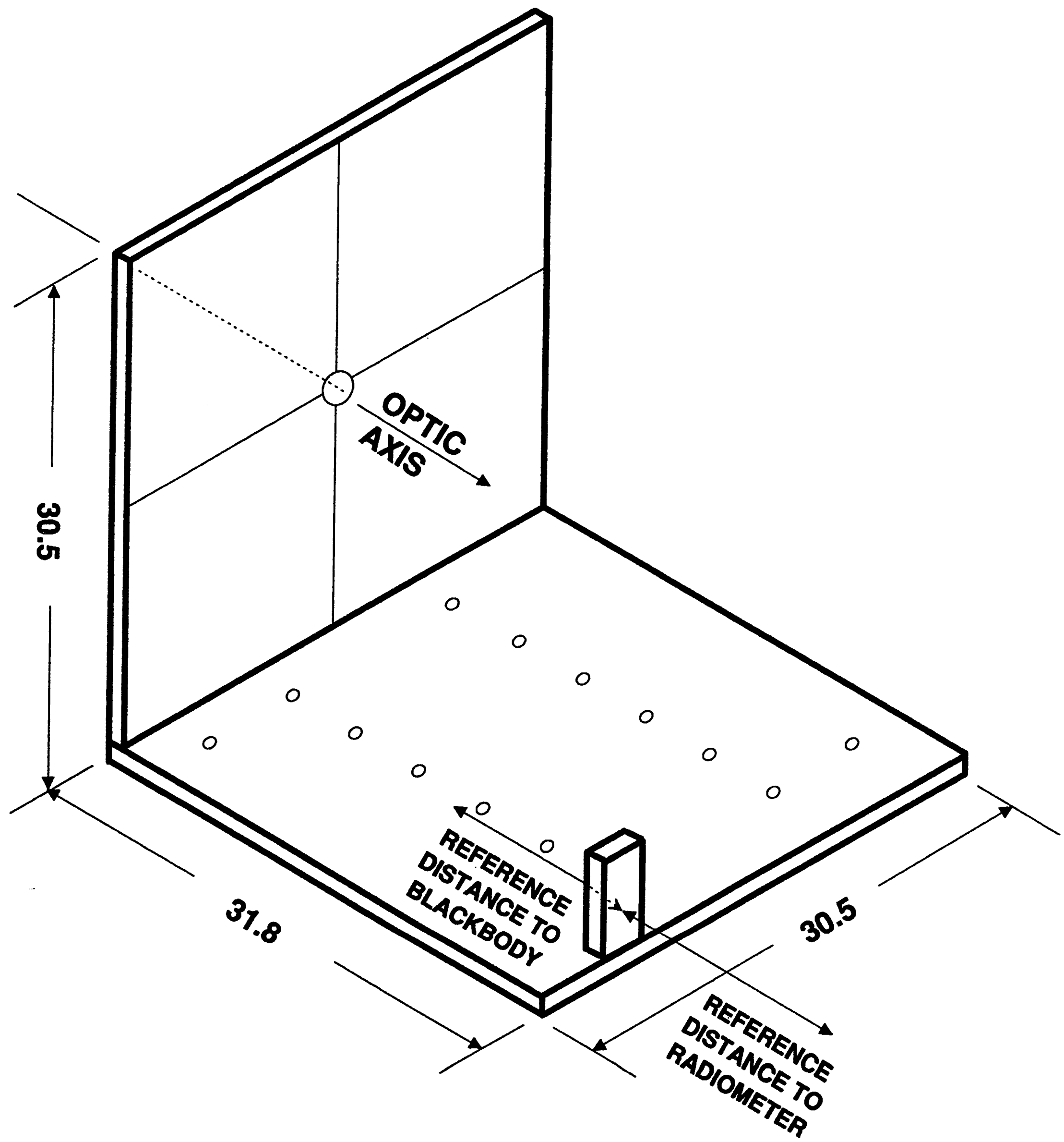

Figure 3. Blackbody Mounting Plate (Dimensions in cm).

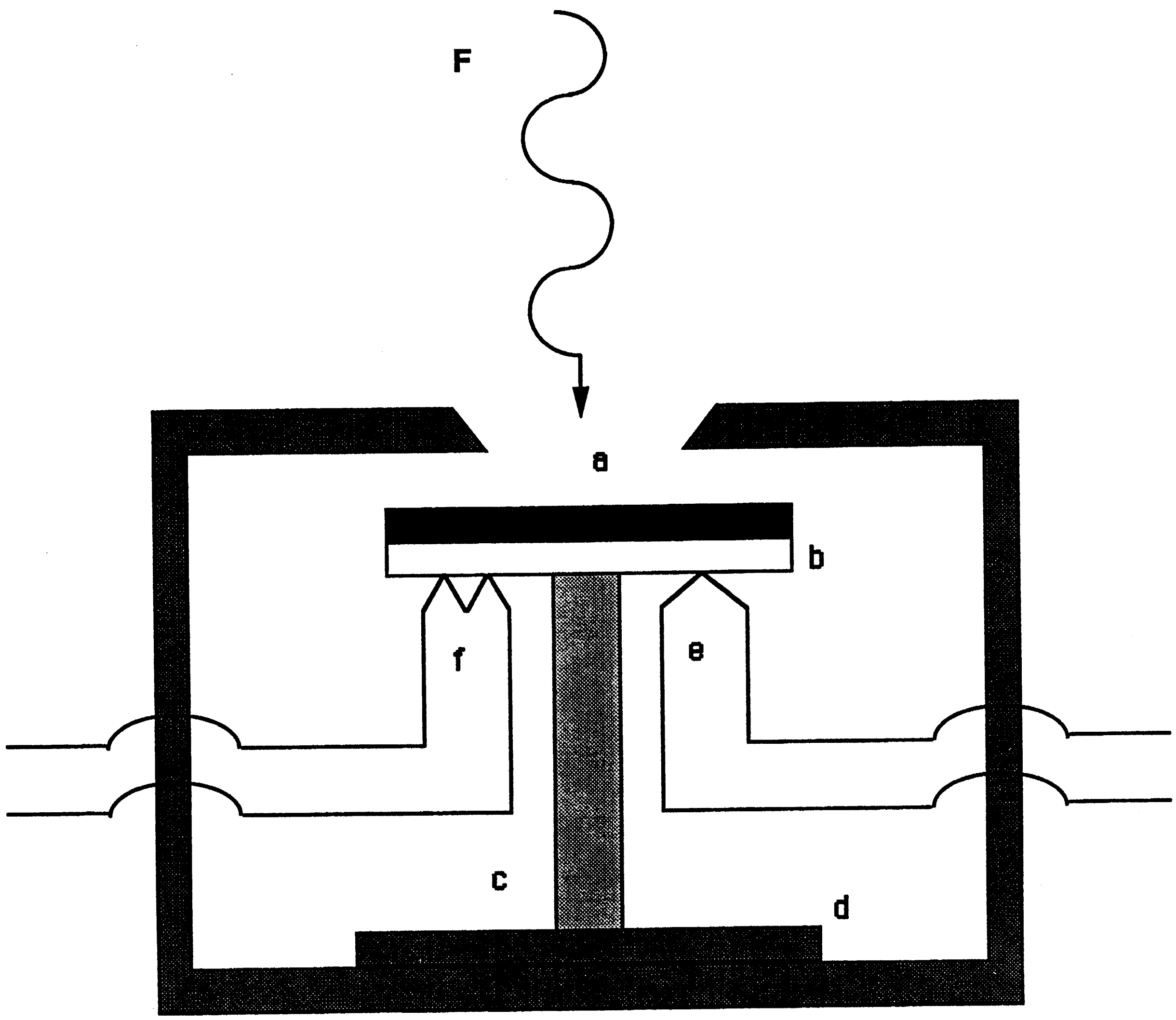

Figure 4. Basics of ESR operation.

2.2.3 The Radiometer Design

The ACR dewar is shown in figure 5. The ACR is 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, the absorbed radiation is equal in magnitude to the decrease in electrical power applied by the controller when the shutter in front of the ACR is opened, and the same temperature is maintained at the receiver.

The receiver is an inverted copper cone with its inner surface coated with Chemglaze Z302, a specular (glossy) carbon black polyurethane [4]. With an apex angle of 45 degrees and specular finish, the light reflects at least four times before it can exit the receiver. Electrical connections to the cavity heater and sensor are made with superconducting NbTi wire to avoid lead resistance losses. All connections are made with small diameter wire thermally anchored to minimize unwanted heat fluxes to the receiver.

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 adjustments for optical alignment with 0.025 mm precision are made possible with a micrometer and a fine pitch collar wheel. The vacuum seal is made with 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 3 cm diameter invar aperture, whose area is known to within 0.1% at 4 K and 2 K. An operating temperature of 2 K is maintained by evacuation after the dewar is filled with liquid helium, using a pressure regulator attached to the port of the liquid helium well. The dewar has a capacity of 3 L and a hold time of greater than 30 h at 4 K.

The data acquisition electronics consist of two digital controllers that maintain constant temperatures at the receiver and the receiver mounting plate, which serves as a heat sink. In addition to controlling temperatures, the controllers provide accurate heater power output which is used for the radiometric measurement. The electronics unit has a GPIB (IEEE-488) interface for control of the data collection process through the IBM-AT [5]. 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 heater and the heat sink.

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

2.2.4 ACR Characteristics

Radiometric:		
Spectral Range of Receiver above 99.5% absorptance		0.3–30.0 μm
Aperture Diameter		30 mm
Receiver Response Time (1/e)		33 s @ 4.2 K 18 s @ 2.0 K
Receiver Responsivity		23 K/mW @ 4.2 K 30 K/mW @ 2.0 K
Maximum Power		100 μW
Resolution		0.2 nW
Absolute Uncertainty in Radiometric Power Measurement (95% confidence level)		1%
Radiometer Duty Cycle		10 min.
Physical:	Dimensions	Weight
Control Electronics Console	48 cm × 28 cm × 28 cm	approx. 9 kg
Cryogenic:		
Liquid Helium Capacity		3 L
Helium Hold Time		30 h at 4.2 K 20 h at 2.0 K
Electrical:		110 V AC 60 Hz

The ACR Insert

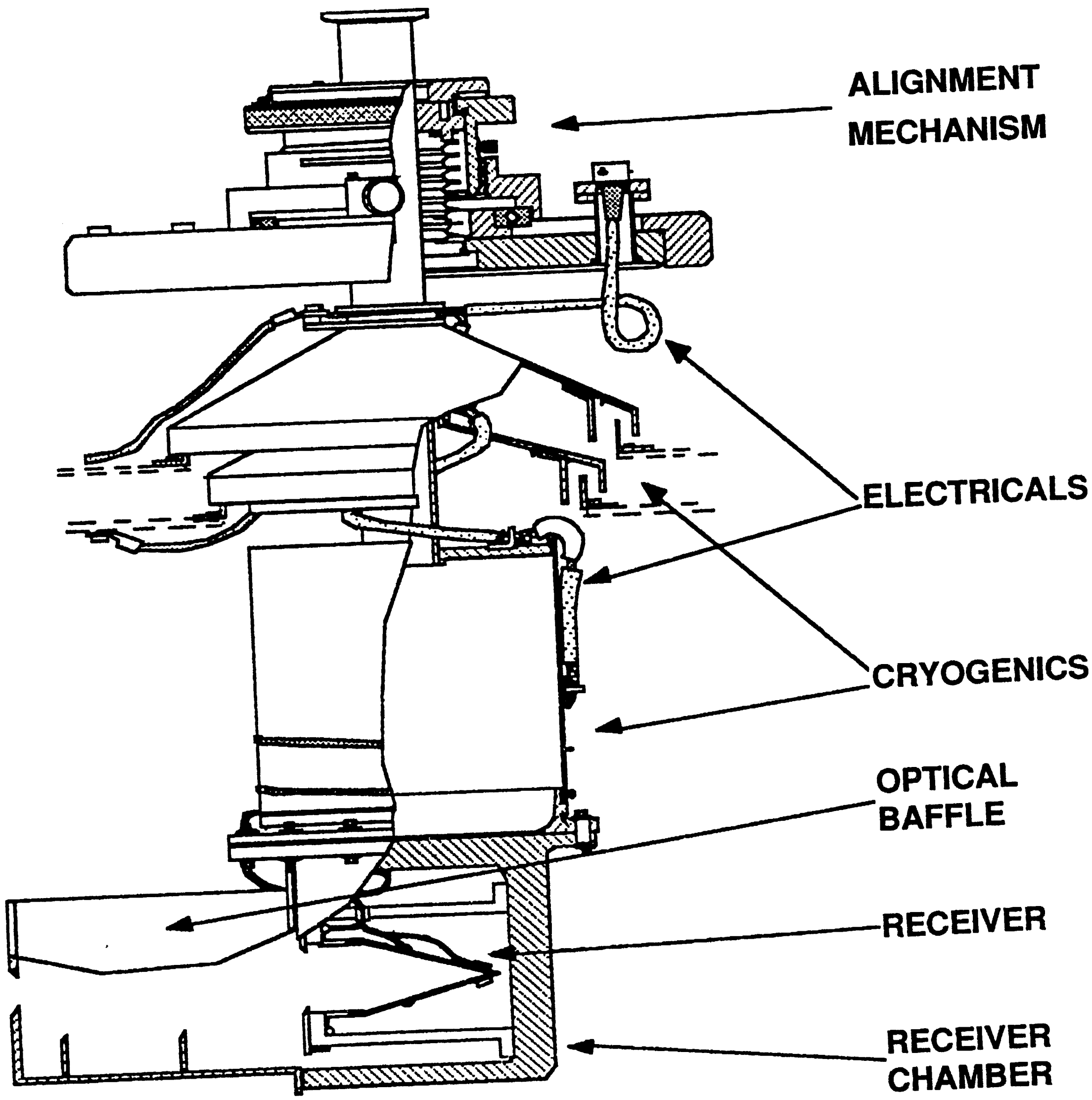

Figure 5. Cross-section view of the absolute cryogenic radiometer.

2.2.5 Radiometer Characterization

The main objective of the characterization is to evaluate the aspects of the radiometer that affect the overall accuracy, such as receiver absorptance, aperture area and non-equivalence effects. The characterization procedure consisted of measuring these effects, using the results to produce an "error budget" which gives the uncertainty of the radiometric measurement. This procedure will be repeated periodically to check for changes in the radiometer's characteristics. For this purpose, two identical receivers have been built and both were characterized initially and identified to be identical. One receiver is stored as a reference standard and the other is used as a working standard. Intercomparison of these receivers and comparison with other primary standards will be performed year to year.

The spare receiver is stored in a dessicator to protect it from contamination. The geometry of the receiver is such that a small degradation in coating absorptivity will not effect significantly the overall absorptance of the receiver. However, an accidental leak while at helium temperatures, or some other larger scale contamination will probably necessitate a remeasurement of the receiver overall absorptivity. In any event, the overall absorptivity of the receivers will be remeasured every year or so to ensure absolute accuracy.

2.2.5.1 The Radiometer Equation

The equation used to calculate the radiometric power is
electrical power = radiative power

$$V_1 \cdot (V_2/R) = F \cdot A \cdot N$$

where

V_1 = voltage across the heater

V_2 = voltage across the current sense resistor

R = current sense resistance

F = radiant flux

A = receiver absorptance

N = non-equivalance

Solving for the power, F, we get

$$F = V_1 \cdot (V_2/R) \cdot (1/A) \cdot (1/N).$$

The irradiance is the flux divided by the aperture area.

2.2.5.2 Receiver Absorptance

The absorptance of the receiver is designed to be more than 99.5% and extremely uniform over the wavelength range from 0.3 μm to 30 μm. This is made possible by giving the receiver an inverted cone geometry and coating the inner surface with a glossy black paint. Collimated light must reflect at least four times before it can exit the receiver. With high absorption with each reflection, the overall receiver absorptance is extremely high.

The absorptance has been measured at 632.8 nm to be 99.87%. It has been extrapolated out into the infrared to be greater than 99.5%. The extrapolation is based on single reflection data taken with a Beckman 4250 photospectrometer, which has a spectral range from 0.3 μm to 40 μm.

2.2.5.3 The Uncertainty Budget for the Radiometer

The total uncertainty of the radiometer characterization is determined by taking into account the uncertainties of individual measurements for each term of the radiometer equation given in section 2.2.5.1. It is calculated as the quadrature sum of the individual uncertainties. This uncertainty will be used later to calculate the overall uncertainty for measurements of radiant power and radiance temperature. The uncertainty budget is shown below in Table 1. The uncertainties listed in Table 1 under the columns of "hardware" and "with software calibration" are different only for the current sense resistance and voltage measurement electronics for the following reason: the ACR software computes the electrical power supplied to the receiver heater by using the voltage and current values measured by the internal electronics of the receiver controller. The hardware uncertainty column lists the uncertainties in these measurements because of the uncertainties in the characterization of the individual hardware components. However, a software calibration involves measuring the voltage and current by using external electronics with precision components and the gains in internal electronics are adjusted to measure identical values, which are read and displayed by the receiver controller software. Therefore, the software calibration reduces the uncertainties in these measurements and for this reason it is advisable to repeat it each year. Uncertainties are given here in terms of one standard deviation of the mean. When used on page 17 to calculate the overall uncertainty, they will be multiplied by two for combination with other uncertainty components at an approximate 95% confidence level.

Table 1. Uncertainty budget for the radiometer characterization

Measurement	Method	Magnitude	Uncertainty (1 std. dev. of the mean) Hardware	w/Software Calibration
a. current sense resistance	NIST-traceable ohmmeter	depends on range	0.1%	0.01%/yr
b. voltage measurement electronics	NIST-traceable voltmeter	depends on range	0.5%	0.05%/yr
c. receiver absorptance	integrating sphere at 632.8 nm	receiv. no. 1 (0.9987) receiv. no. 2 (0.9989)	0.1%	0.1%
d. non-equivalence	dual heaters	0.03%	0.03%	0.03%
Calculated Uncertainty:	(square root of the sum of squares)		0.52%	0.12%

2.3 Integrating a Blackbody Source into the Facility

An integral part of the calibration process at the LBIR facility is the integration of the blackbody source to the mounting table. Shown in detail in figure 3, the table consists of two right angle mounted plates made from OFHC copper. They have been ground for flatness and gold coated to prevent oxidation. The 30.48 × 30.48 × 30.48 cm cubed area defines the dimension within which the user must keep his blackbody source. The important points to note for mounting a blackbody source to this mounting table are described below.

The plate tapped with twelve 10-32 holes bolts flush to the actively cooled plate cantilevered from the removable front flange of the chamber. These mounting screws come in from the bottom side and do not protrude above the top surface. The user should not consider using these tapped holes as any part of his mounting arrangement. Since the mounting plate becomes the property of the user as part of the calibration fee, the user is free to drill whatever other holes are necessary for mounting his blackbody. The only restrictions are that they not interfere with our tapped mounting holes and the fasteners used should not protrude beyond flush with any surface. The plates are 1.27 cm thick. It is important to take care not to scratch or nick any mounting surface to the extent that it impedes the ability of the plate to mount flush to the cooling plate for maximum thermal transfer.

There is a 2.54 cm wide × 5.715 cm high × 1.27 cm thick invar plate mounted vertically in one corner of the bottom mounting plate. The purpose of this plate, or tab, is to contact a spring-loaded invar rod on which is mounted a non-contact sensor. As the front flange is rolled into position and bolted to the main

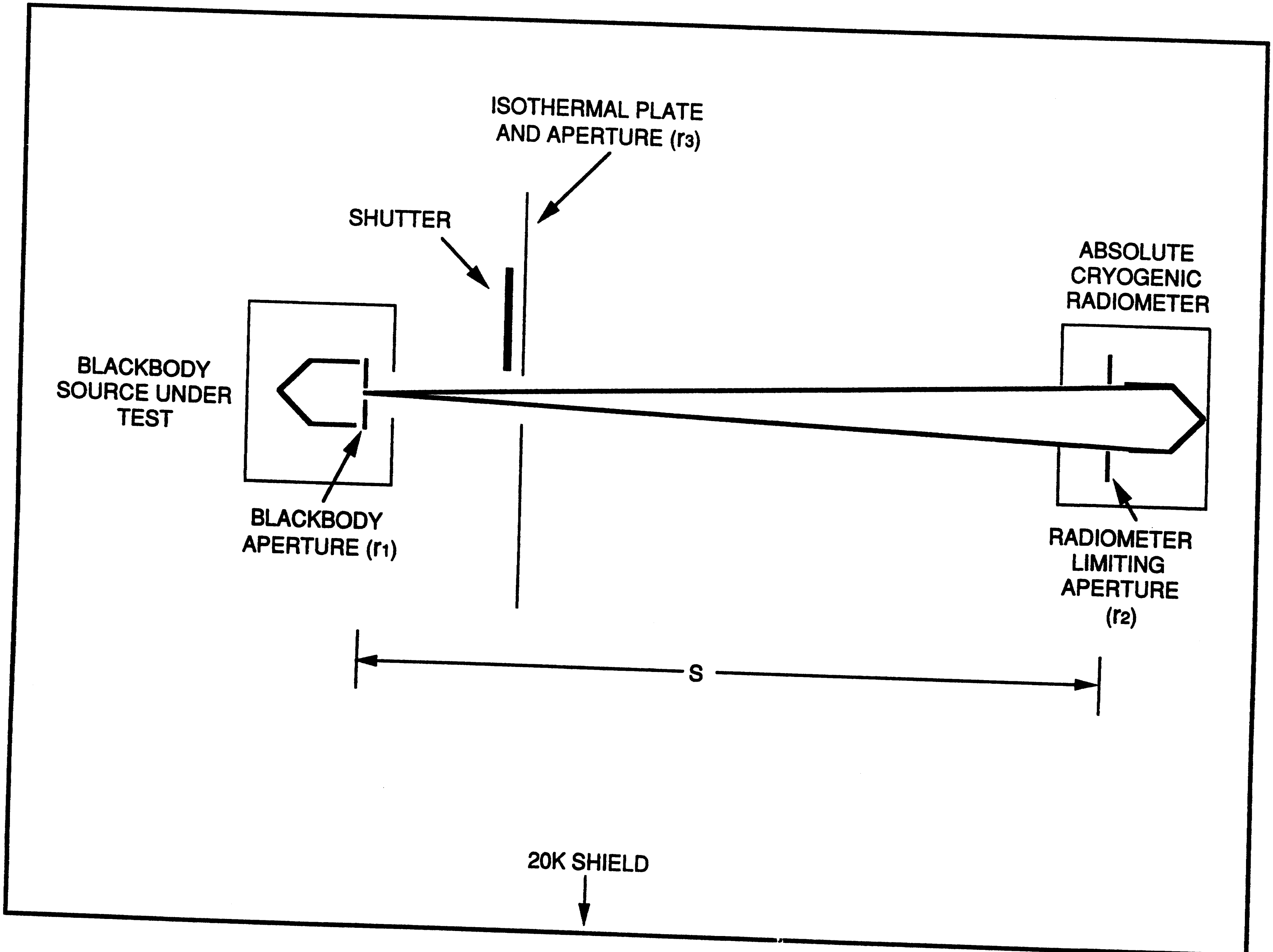

Figure 6. Blackbody calibration setup inside the LBIR chamber.

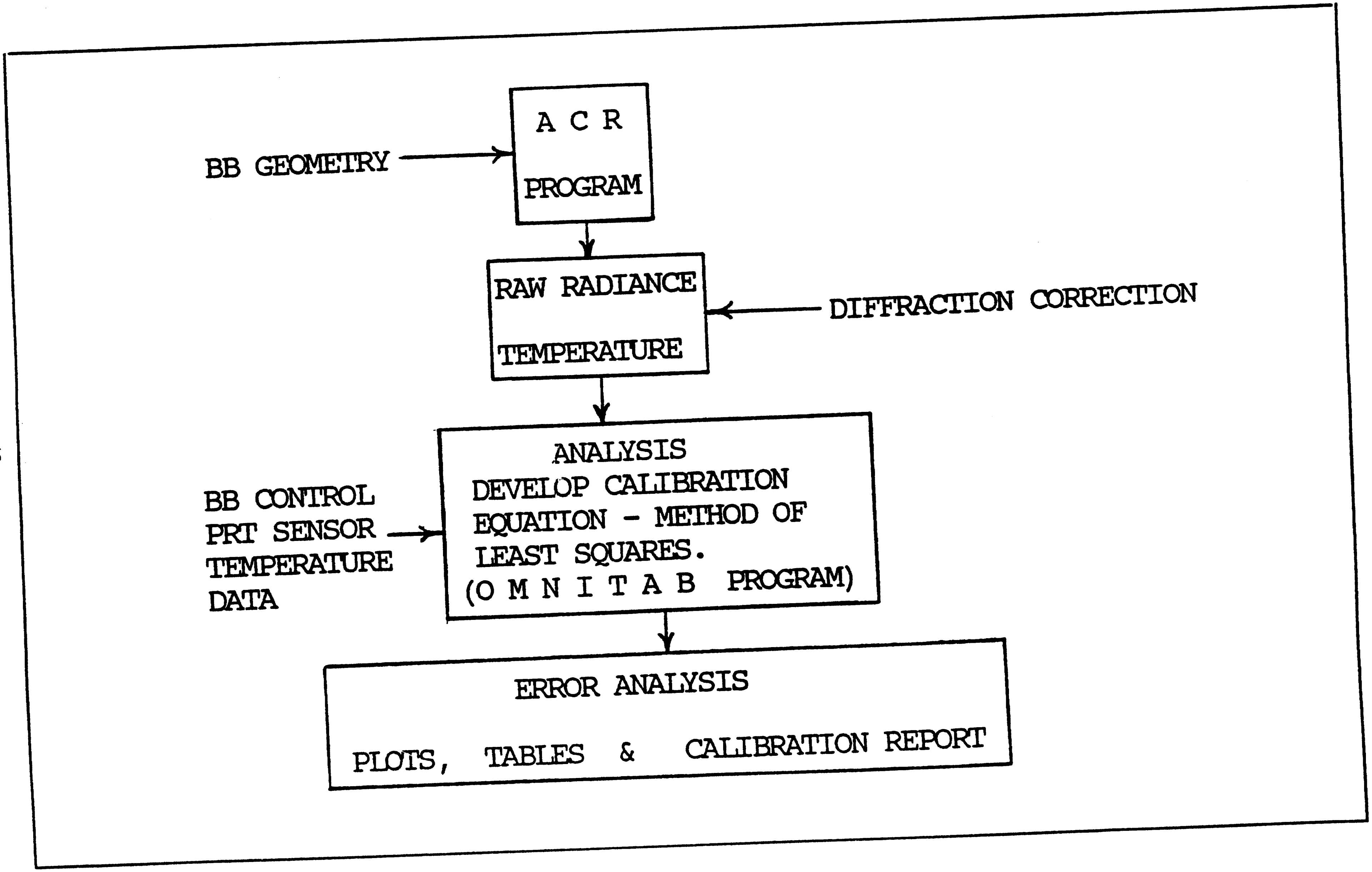

Figure 7. Flow chart of data analysis for blackbody calibration.

chamber, the tab pushes the rod, and therefore the sensor, up to but not touching a reference tab, or target, mounted to the absolute cryogenic radiometer (ACR) heat sink. The dimension of the gap between sensor and target is read out by the sensor electronics. When this dimension is added to a series of fixed dimensions, the distance from the blackbody source aperture to the ACR aperture can be determined. It is the user's responsiblity to supply the distance from their blackbody aperture to the front surface (surface contacting rod) of the vertical invar tab. This distance must also be computed for 20 K and be as precise as possible. We are trying to achieve an overall accuracy of 0.076 to 0.127 mm for the total distance from source to radiometer. The vertical copper plate, which forms the other half of the blackbody mounting plate fixture, has a 1.905 cm diameter hole bored on center. The hole is divided by a pair of fiducial marks machined into the copper. An imaginary straight line normal to the hole and passing through the intersection of the two fiducial marks, forms the optic axis. It is the user's responsibility to mount his blackbody with its optic axis coincident with the imaginary one. This same optic axis has been simulated by the LBIR staff prior to the arrival of the user's table and blackbody assembly. Apertures and the ACR will have already been aligned using an identical mounting plate with one difference. Instead of an L-shaped mounting plate, we have added an additional vertical plate with matching hole and fiducial marks to form a U-shaped fixture. The 1.905 cm diameter holes are fitted with two precision machined sets of crosshairs, extending the already existing fiducial marks. A HeNe laser is then passed through an external vacuum window on the chamber and aligned with the pair of crosshairs forming a visible optic axis.

One final point that should be mentioned is the present lack of scanning capability. The blackbody mounting table is fixed rigidly to the actively cooled plate and the ACR has only limited motion for alignment purposes. Therefore, the user should align his instrument in a manner which will maximize the information desired. Users requiring additional information or assistance in interfacing to the mounting table are invited to contact LBIR staff. It's our intent to make the LBIR facility as user-friendly as possible and we encourage input to that end.

2.4 Vacuum Integrity Procedure

The need to detect lower and lower radiant flux levels has resulted in the need for improved vacuum integrity. It is essential for the operation of the Absolute Cryogenic Radiometer (ACR) that ultra high vacuum levels be achieved in our calibration chamber. This means a total pressure in the chamber of approximately 1.33×10^{-6} Pa before cooling with 15 K gas. The partial pressures of hydrocarbons (beyond approximately 45 AMU) should not exceed 1.33×10^{-8} Pa. Not only will hydrocarbons degrade the performance of the ACR, but they can seriously affect optical elements planned for future installation in the calibration chamber. A residual gas analyzer (RGA) mounted on the chamber is used for partial pressure analysis. Before a user's blackbody is exposed to the calibration chamber, it must undergo pre-conditioning in the auxiliary chamber, which is also equipped with a RGA. Here, the instrument can be cycled and monitored for outgassing. If necessary, baking can be performed to hasten clean up.

The required level of cleanliness is easily attainable if reasonable care is used. This begins with the selection of materials used to construct an instrument. Excellent references [6] exist which can help one choose materials based on outgassing properties. If in doubt about a particular material, contact NIST staff. A sample of the material can be tested in the NIST test chamber. Once the materials have been chosen, they need to be cleaned.

Our cleaning is basically three steps—acetone, alcohol (ethyl or methyl) and freon (Precision Cleaning Agent) in that order. Care should be taken to wear gloves during the cleaning process, not only to protect your hands, but also to keep oily fingerprints and smudges off the object being cleaned. It should be noted here that parts being fabricated out of copper should be machined using a non-hydrocarbon based cutting oil to facilitate cleaning later and to minimize outgassing. Small parts can be immersed in a beaker of the appropriate solvent and placed in an ultrasonic cleaner for a period of 10-15 min for each cleaning. Larger parts need to be washed off using squirt bottles of the appropriate solvents. Freon used for cleaning should be kept in Teflon squirt bottles only. O-rings, where present, should be made from Viton and cleaned only with isopropyl alcohol. Never clean an O-ring with acetone or freon as these solvents are absorbed by the Viton. The final test for cleanliness is made by washing the object down with freon and watching the resulting evaporation pattern of the liquid. It should run down the object in a tree-like pattern, a variation of the standard "water break" test [7]. The last bit of liquid to evaporate should not leave any trace of residue. A stain means the object is not thoroughly clean, or the freon is contaminated (reason for the Teflon bottles).

As mentioned previously, baking is often an effective means of "cleaning" an instrument in vacuum. If conditions require it, a high temperature bake up to 350 °C can be performed in the facility's test stand. Equipped with its own turbomolecular pump and RGA, the system serves as a test station to evaluate the cleanliness of user supplied devices. Various size ports up to 51 cm diameter will accommodate several sizes of objects. Instruments with a known vacuum history will be placed immediately in the auxiliary chamber inside the clean room. Here, the instrument (attached to its mounting plate) is bolted to the actively cooled plate cantilevered from the front flange of the main chamber. All the necessary electrical connections should be made at this time. The auxiliary chamber is then lowered into position with the overhead crane. Pumpdown is achieved with a dedicated 170 L/s turbomolecular pump and 2000 L/s cryopump. A residual gas analysis is performed to determine if the cleanliness level is satisfactory. Temperature cycling of the instrument may also take place, and another residual gas analysis done. Clean up, if necessary, may be accomplished by baking the system not to exceed 100 °C. Upon meeting the accepted level of cleanliness, the system is vented with nitrogen, the auxiliary chamber is removed, and the front flange with the instrument still attached is rolled into position and bolted to the main chamber. Pumpdown is accomplished with a 500 L/s turbomolecular pump and 2000 L/s cryopump combination. A final residual gas analysis is performed and if necessary a mild 75 °C bake is possible.

Once all the previous steps have been satisfied, cool down to 20 K is begun using the facility's helium process refrigerator.

2.5 Clean Room Procedures

The clean room that is utilized for the facility is a class 10,000 soft-wall room. It measures 430 × 520 cm with a ceiling height (inside dimension) of 320 cm. With 10 High Efficiency Particulate Air (HEPA) filter units providing the vertical downflow, we anticipate the room is probably a good deal cleaner than class 10,000. For that reason, we try to adhere to class 1,000 requirements. This means anyone entering the clean room to access the calibration chamber will be required to wear clean room attire consisting of coat, booties and hood. Paper products will be held to an absolute minimum inside the room. Only lint free wiping cloths are allowed. Nylon gloves are permitted inside the clean room, but only lint free gloves are permitted to be worn while working inside the vacuum chamber. The clean room exists to minimize the amount of airborne contaminants inside the chamber. This is necessary in order not to affect the small aperture of some sources or the sensitivity of the radiometer. Therefore, items which have been pre-cleaned for insertion in the chamber, but allowed to sit around in the clean room for any appreciable time, should be sprayed with an aerosol duster for the purpose of removing dust. While small quantities of cleaning solvents are kept in the clean room, the majority of pre-cleaning should be done outside the room. A 26.5 liter capacity ultrasonic cleaner is available to aid in this process. More will be said about solvent cleaning while discussing vacuum integrity. Pre-cleaning also pertains to virtually any piece of equipment brought inside the clean area. Items such as computers, electronic equipment, gas bottles, etc., should be wiped down with tacky-wipes first. No operation resulting in the creation of smoke or fire is allowed in the clean room.

2.6 Cryogenics and Electrical Layout

2.6.1 Cryogenics

The LBIR chamber contains two coaxial copper cylinders with endplates which are cooled by the helium refrigerator. The inner shield is cooled to approximately 20 K, the outer shield to approximately 40 K. The blackbody mounting shelf and the main chamber have separate cold helium feeds with flow control valves to allow diverting additional cooling to the blackbody, if needed. The cryoshields have several silicon diode thermometers attached at various points (fig. 8). These thermometers are monitored during calibration to ensure stability of the IR environment. The inner shield supports a copper disk which separates the blackbody chamber from the ACR chamber. This disk, called the isothermal plate, is moderately thermally insulated from the inner shield. The temperature of the isothermal plate and its aperture and shutter are monitored by three precision silicon diode thermometers and controlled using an integral heating element. The isothermal plate can be controlled to 0.005 K if necessary.

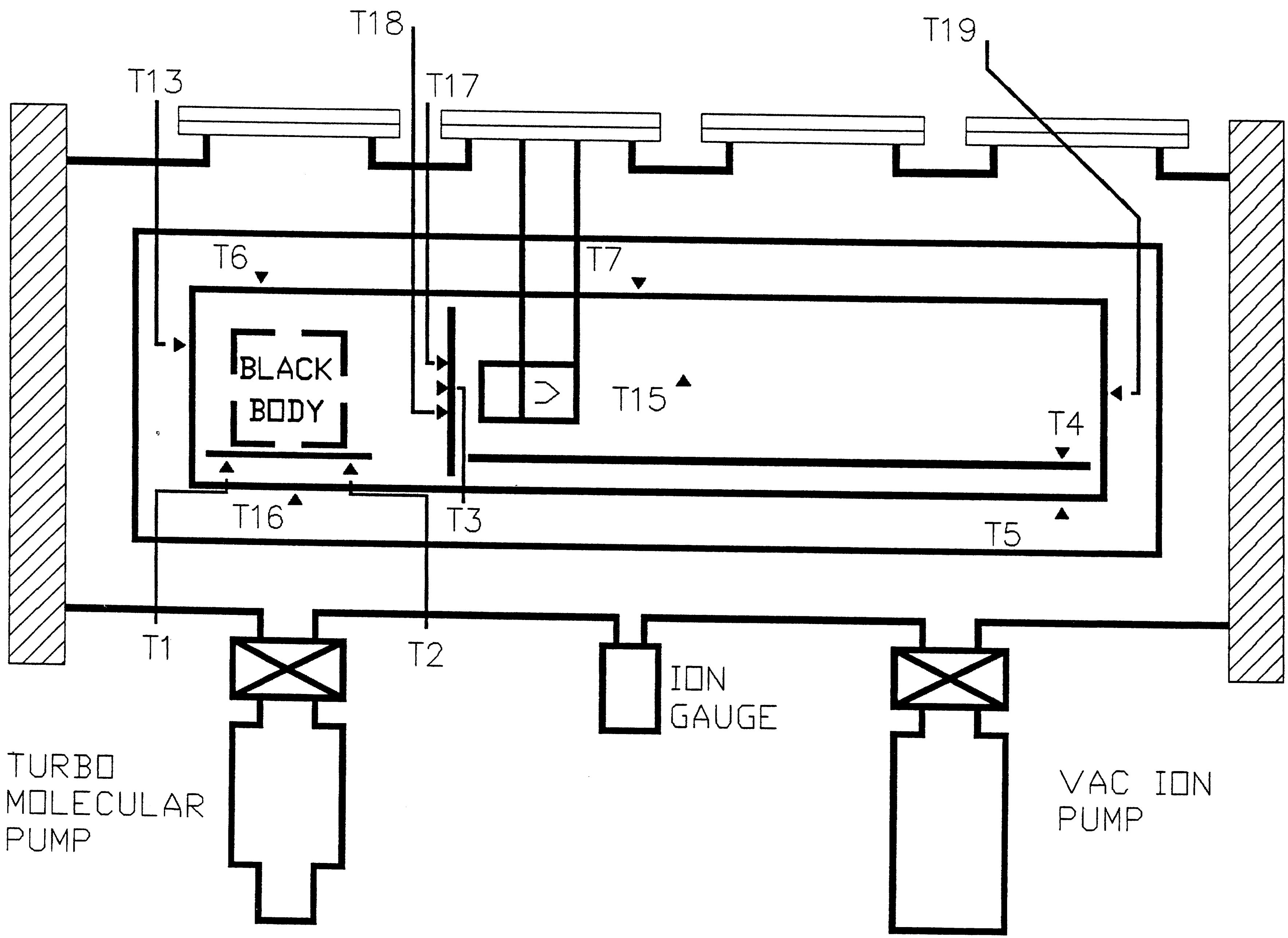

Figure 8. Location of cryoshield silicon diode thermometers.

2.6.2 Electrical Layout

The LBIR chamber has two 35 pin vacuum feedthroughs terminated internally with two similar connectors, one on each side of the blackbody mounting shelf. These connectors have 12 conductors of #26AWG stranded copper wire, 10 conductors of #30AWG solid copper wire, and 48 conductors (12 sets of 4 conductor ribbon cable) of #36AWG phosphor-bronze wire. The #36AWG wire, used for 4-wire measurement of temperature sensors, has a resistance of about 25 Ω from the vacuum feedthrough to the internal connector. Therefore, your current source should have sufficient compliance to supply your sensors with about 50 Ω in series with the sensor.

Blackbody parameters to be monitored during calibration should be available as a voltage signal to be measured by our HP 3457A multimeter. The multimeter has an input scanner with eight channels available for your use. The inputs to the scanner have shielded twisted pair cables, each terminated in a male BNC connector with a separate drain wire. The drain wire can be used to ground floating sensor readout circuits if needed. All eight inputs are floating. Any special wiring requirements (grounding, floating, isolation, etc.) should be specified in advance. You are responsible for providing all instrumentation and equipment needed for the operation of your blackbody. If you have your own data gathering system and want it to be used during the calibration, we will make every effort to accommodate you, if possible. Your external equipment should be mounted in a single rack unit with approximately 5 to 6 m of cable to the chamber connectors. If shorter cable lengths are needed, they should not be less than 2.5 m.

2.7 Scenario for Customer Blackbody Calibration

Calibration requirements for the customer blackbodies are broadly of two kinds: 1) Measurement of the radiant power at the ACR aperture. 2) Calibration of the Platinum Resistance Thermometer (PTR) of the blackbody in terms of the radiance temperature measured by the ACR for different blackbody aperture settings. In both cases, the quantity to be measured absolutely is the radiant power at the ACR aperture. This quantity is measured by the ACR as follows. The radiation from the blackbody is blocked from the ACR receiver by using the shutoff position in the blackbody aperture wheel (if available). The electrical heater power to the ACR receiver is set to a value higher (preferably 20 - 30%) than the expected radiant power from the blackbody. This is to ensure that the temperature controller servo (AC bridge) can maintain the receiver temperature constant by varying the remaining amount of electrical power required, once the radiant power is allowed to fall on the receiver. After the AC bridge is balanced, the blackbody radiation is allowed to enter the ACR by turning the aperture wheel to a chosen aperture position. If the customer blackbody is equipped with a fixed slit with no aperture wheel, the shutter at the isothermal plate is used for blocking or letting the radiation through. The difference between the initial electrical power setting and the final electrical power after radiant power falls on the receiver is the irradiance at the ACR aperture. It is displayed on the monitor, updated and recorded every second by the ACR program. The recorded data are available as a data file for the calibration report. Preliminary estimates of radiant power at the ACR aperture can be made by using the Stefan-Boltzmann law and using the distance between the ACR aperture and the blackbody aperture. This distance is approximately 33 cm if the ACR is located in the vertical port nearest to the blackbody. The noise floor in the chamber has been measured to be ± 2 nW and measurements of power levels below 20 nW have larger uncertainty. The maximum power that the ACR is designed to measure is 100 μW. The other two vertical ports could be used for locating the ACR to reduce the power load on the ACR receiver, if intense sources are to be calibrated. The ACR ports are located 33 cm apart from each other (fig. 2).

Figure 6 shows the arrangement inside the chamber for the blackbody calibration. The user supplies the measurement of the radius of the blackbody aperture, r_1, corrected for thermal contraction at 20 K. The radius of the ACR aperture, r_2, is determined by the precision metrology group at NIST by measuring its diameter at room temperature in three different orientations. It is corrected for thermal contraction by using the data given in reference [8]. The distance, s, between the blackbody aperture and the ACR limiting aperture is measured in two parts. One part is the user supplied measurement of the distance between the blackbody aperture and the front surface of the tab on the blackbody mounting plate (fig. 3). The other part is the distance from the front surface of the tab to the ACR aperture measured by NIST personnel. In the later part, a Kaman proximity sensor [9] located internally is used for the measurement of the final location of the tab in reference to the ACR aperture before the chamber is evacuated. The measurements are done at ambient temperature and are corrected for thermal contraction due to cooling of the chamber and the ACR to 20 K and 4 K respectively. The radius of the aperture in the isothermal plate, r_3, is chosen to limit the background flux from the blackbody front surface. However, it will allow the full cone of light from the blackbody aperture to reach the ACR aperture.

The following equation deduced from the Stefan-Boltzman law was used to convert radiant power data into radiance temperatures.

$$T = \left[\frac{E}{F_1 A_1 \sigma_M} \right]^{1/4} \quad \ldots\ldots\ldots\ldots \qquad (1)$$

where

$$F_1 = 1/2\,[z - [z^2 - 4\,x^2 y^2]^{1/2}\,]$$

and where

$$x = \frac{r_2}{s},\ y = \frac{s}{r_1},\ z = 1 + (1 + x^2)\,y^2$$

A_1 is the area of the blackbody aperture; E is the power in watts, and $\sigma_M = 5.67051 \times 10^{-12}$ W cm^{-2} K^{-4}.

The ACR data of radiometric power and the corresponding radiometric temperature are analyzed to produce a report of the calibration to the user. The procedure is illustrated in figure 7. Diffraction losses in the beam path are estimated by using the procedures published in references [10] and [11]. The measured data are corrected for the total diffraction loss. The procedures adopted for calculating the diffraction loss are described in detail in reference [12]. A calibration equation in the form of a polynomial is developed by using least squares fitting of the data of radiometric temperatures as a function of the corresponding blackbody control sensor temperatures. The calibration equation will be useful to predict the radiance temperature for any given control sensor temperature within the temperature range of calibration. There are no additional uncertainties from the least square fitting.

The uncertainties in the measurements are classified as systematic or random. Systematic uncertainties do not change during the radiometric power measurements. They are the uncertainties in the measurements of the following quantities:

Radius of the BB aperture (r_1)
Distance between the BB aperture and the ACR aperture (s)
Radius of the ACR aperture (r_2)

The uncertainty in the diffraction calculations is also a systematic uncertainty. It is considered to be ± 20% of the calculated correction [12] at an approximate confidence level of 95%. The uncertainty in the characterization of the radiometer given in Table 1, i.e., 0.12% of the measured radiant power, is another systematic uncertainty component. The total systematic uncertainty is the square root of the sum of squares of the individual components, all taken as two standard deviations of the mean or an approximate confidence level of 95%. The random uncertainty is the statistical uncertainty in the ACR measurement of the radiant power. The data is collected every second for approximately three minutes. The data is averaged and the standard deviation is calculated. The measurement process is repeated at least three times on different days to test for reproducibility. The inverse of the square of the standard deviation is used as the weight factor for each data point of the three repeated measurements in the least square fitting analysis to obtain the calibration equation. The uncertainty based on the 95% confidence band for the calibration equation is the total random component. The systematic and random uncertainties are separately listed in the calibration report. The total uncertainty is reported as the sum of the systematic and random components following the recommendations of the chairman of the LBIR User Board and a member of the Statistical Engineering Division at NIST who provides guidance for the development and implementation of measurement assurance programs. However, many radiometric experimenters calculate the total uncertainty by the square root of the sum of squares of systematic (2σ) and random (95% confidence band) components. The user can also calculate his total uncertainty accordingly because the systematic (1σ) and random (95% confidence band) components are listed separately in the report.

The systematic and random uncertainties in the reported values of radiance temperatures are obtained by using eq (1) and the theory of error propagation. A more thorough description of these procedures is given in reference [13].

Typical uncertainties of the measured quantities encountered in cryogenic blackbody calibrations are listed in the following overall uncertainty budget:

OVERALL UNCERTAINTY BUDGET

Systematic Uncertainty (2σ)	*Measured Radiant Power*	*Deduced Radiance Temperature*
1. Distance between apertures (s)	–	0.12%
2. Radius of BB aperture (r_1)	–	0.4%
3. Radius of ACR aperture (r_2)	–	0.004%
4. Uncertainty in diffraction correction	–	0.1%
5. Uncertainty in characterization of the ACR	0.24%	0.06%
Total Systematic Uncertainty (2σ)	0.24%	0.43%
Random Uncertainty (2σ)	0.6%	0.7%
Add:	0.9%	1.2%
[Note: Rounded up.]		

3. FUTURE DIRECTIONS

The LBIR facility is in the process of being equipped with a spectral instrument that will be capable of performing the following tasks.

1. Spectrally resolve and calibrate the radiation from blackbodies.
2. Spectrally calibrate detectors such as Blocked Impurity Band (BIB) devices and Solid State Photomultipliers (SSPM).
3. Characterize and calibrate optical components such as filters and other attenuators for LBIR applications.

A cryogenic blackbody is being built for this purpose. Also, Lead Salt Diode Lasers in the range of 2 to 30 μm are being investigated as radiation sources for these tasks. The technical approach in all these applications is to use the Absolute Cryogenic Radiometer (ACR) as the standard detector. A bolometer that uses a Superconducting Kinetic Inductance Thermometer is under development at NIST Boulder Laboratories which could also be used as a standard detector, especially for applications that require higher sensitivity than the present ACR.

4. REFERENCES

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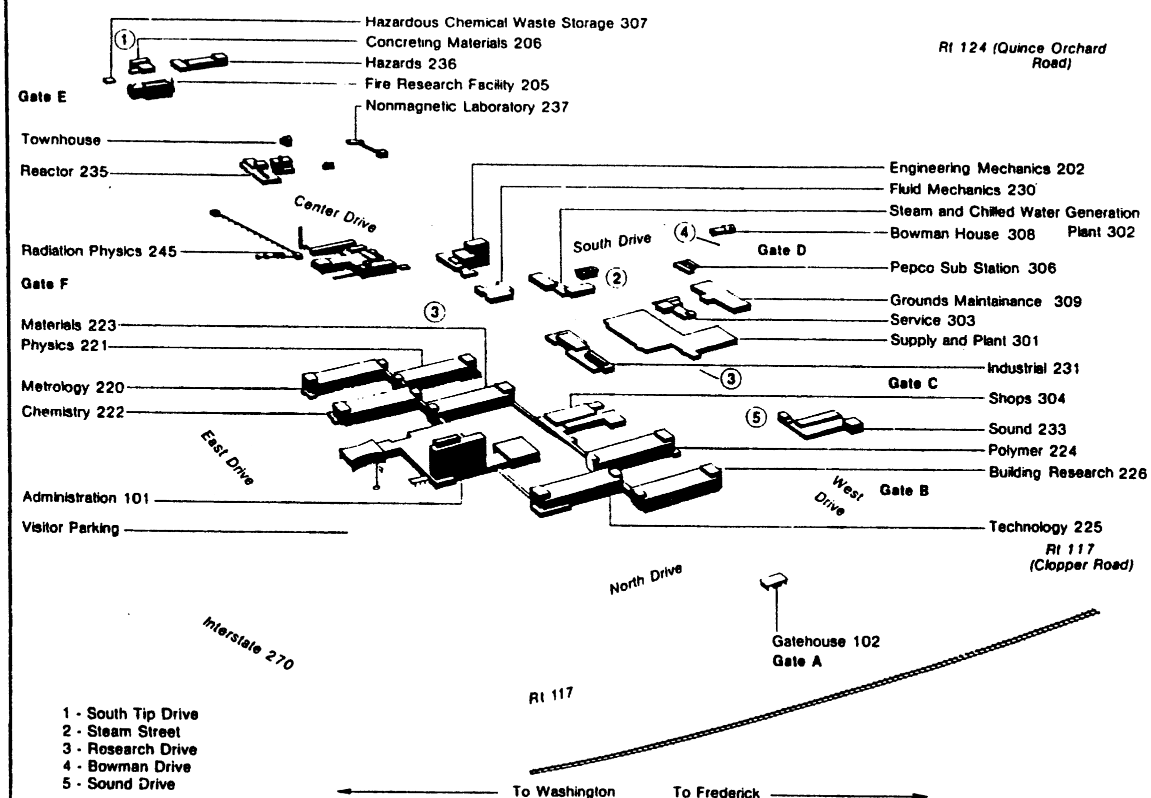
[12] Datla, R. U.; Diffraction Corrections for Cryogenic Blackbody Calibrations at NIST LBIR facility. (in preparation).
[13] Datla, R. U.; Parr, A. C.; Cryogenic Blackbody Calibrations at NIST LBIR facility. (in preparation).

NIST GROUNDS



U.S. Department of Commerce
National Institute of Standards and Technology
Gaithersburg, Maryland

NIST SHUTTLE SCHEDULE

Leave NIST	Arrive Commerce	Leave Commerce	Arrive NIST
9:10	9:50	3:10	3:50
11:10	11:50	4:10	4:50

All shuttles leave from the front of the NIST Administration Building.

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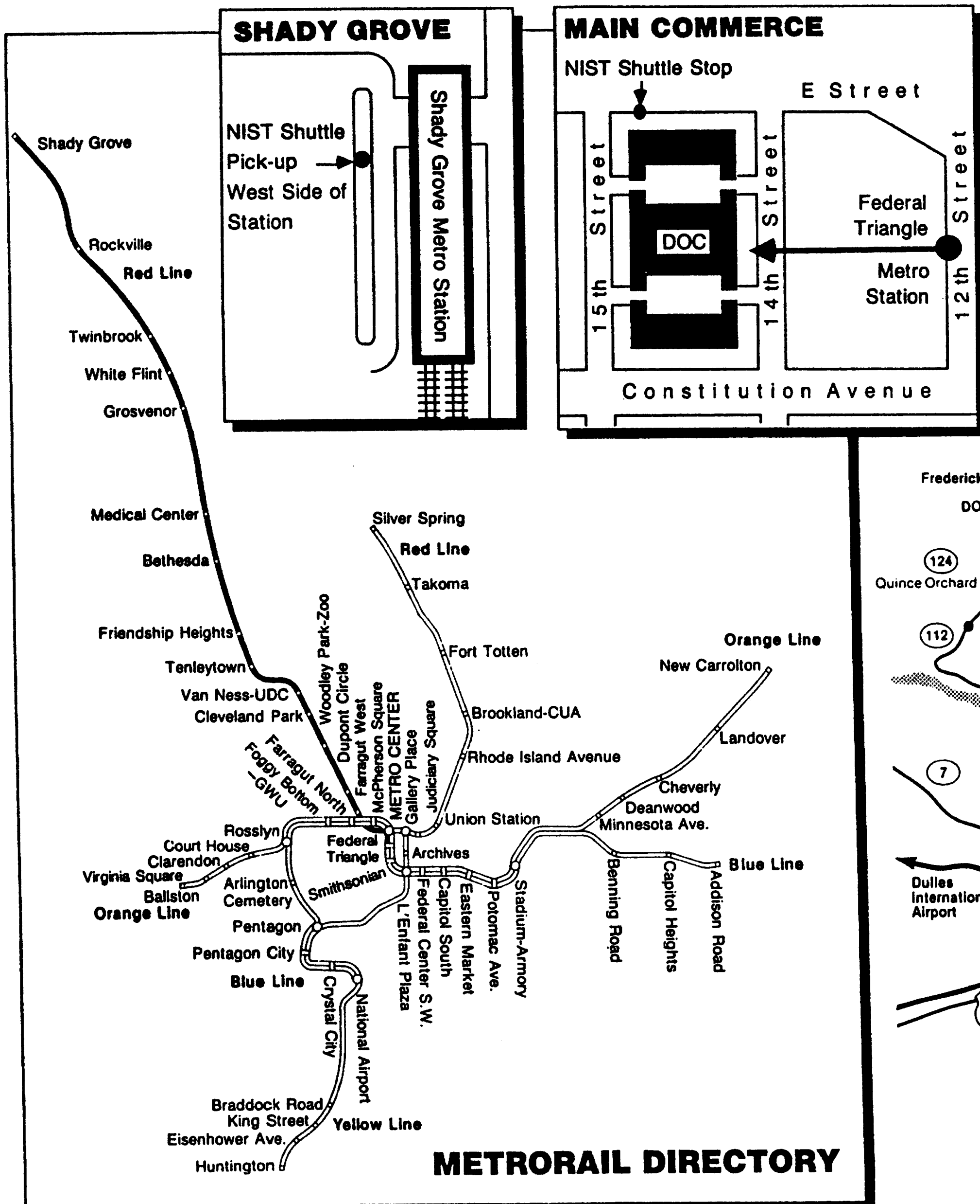
The National Institute of Standards and Technology is located near Gaithersburg, Maryland, just off interstate Route 270, 20 air miles (32 kilometers) from the zero milestone in Washington. Exit at Route 117 West. Turn left at first stop light.

Visitors should go to the receptionist in the main lobby of the Administration Building for directions or for shuttle service to other buildings on the site.

There are two methods of transportation from the Washington area to the Institute at Gaithersburg. 1) The Institute provides a shuttle service for official visitors and staff leaving the Department of Commerce (15th St. and Pennsylvania Ave.). Call 975-5922 for reservations. 2) The Institute provides shuttle service for official visitors and staff from the Shady Grove Metrorail Station to NIST. The Shuttle leaves on the quarter and three-quarter hour (e.g., 8:15, 8:45 ... 5:15, 6:00) from the West side Kiss and Ride Parking Lot. Shuttle is not to be used for commuting between home and work.



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or
River Road (Route 190) to I 495, or
Geo. Washington Memorial Pkwy. (Va. side) to I 495
I 495, follow signs to I 270 North.

From Dulles Airport --
Dulles Access Road to I 495
I 495 to I 270 North.

From National Airport --
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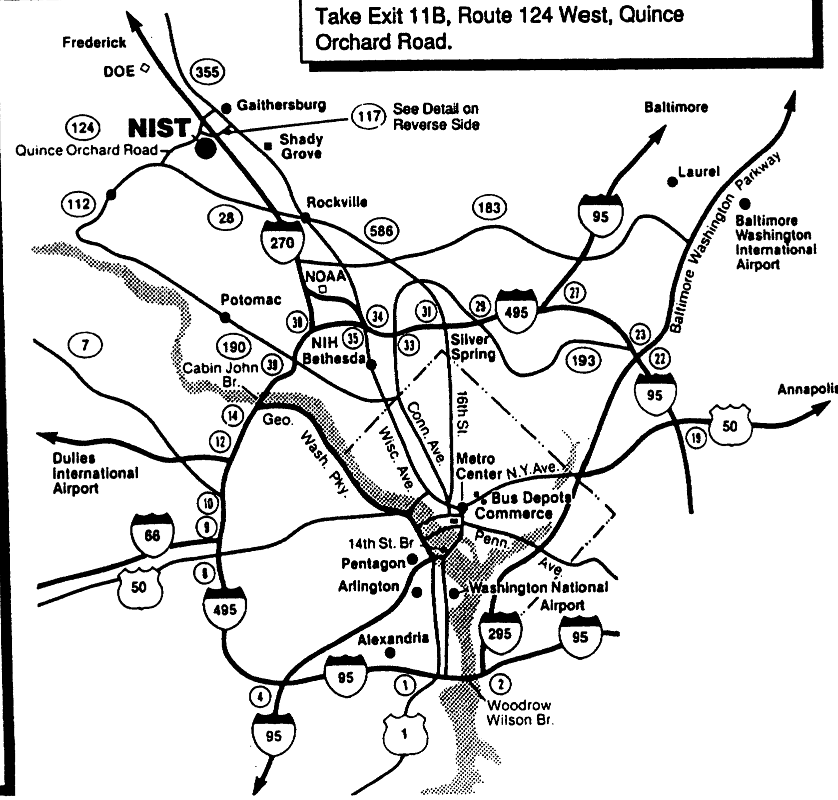

APPENDIX B

HOTELS AND MOTELS
(Rates 1991)

Gaithersburg/Rockville	Gov't Rate	Single	Double	Features
Comfort Inn-Shady Grove 16216 Frederick Road 330-0023	X	$58.00 $49.00	$68.00 $59.00	P, CB
Compri Hotel 805 Russell Ave. 670-0008	X	$94.00 $54.00 $79.00	$104.00 (S-Th) $ 54.00 (F-Sat) $ 89.00	S, L, J, S
Days Inn 16001 Shady Grove Rd. 948-4300	X	$55.00 $49.00 (wkend)		P, R
Holiday Inn 2 Montgomery Village Ave. 948-8900	X	$69.00 $72.00	$ 87.00	P, R, L
Marriott-Gaithersburg 620 Lakeforest Blvd. 977-8900	X	$99.00 $84.00	$115.00 $ 92.00	P, R, L, Hlth Club
Courtyard By Marriott 2500 Research Blvd. Rockville, MD 670-6700		$79.00 $76.00	$ 89.00 (M-Th) $ 76.00 (F-S)	P, R, L
Ramada Inn-Rockville 1251 West Montgomery Ave. Rockville, MD 424-4940		$73.00 Full Breakfast (incl for NIST)	$73.00	P, R, L
Red Roof Inn 497 Quince Orchard Rd. 977-3311	X	$46.95 $44.95	$ 48.95 $ 46.95	
Sheraton-Potomac Inn 3 Research Court Rockville, MD 840-0200	X	$70.00 $59.00	$ 80.00 $ 69.00	P, R, L Hlth Club
Woodfin Suites 1380 Piccard Drive Rockville, MD 590-9880	X	$95.00* $84.00*		

<u>Legend</u>

P = Pool
R = Restaurant
L = Lounge
CB = Continental Breakfast
S = Sauna
J = Jacuzzi
SN = Snack Bar
* This hotel offers a wide variety of Amenities

NIST-114A
(REV. 3-90)

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NUMBER
NIST Handbook 147

2. PERFORMING ORGANIZATION REPORT NUMBER

3. PUBLICATION DATE
June 1991

4. TITLE AND SUBTITLE

NIST- LBIR Facility User Handbook

5. AUTHOR(S)

R.U. Datla, S.C. Ebner, J. Proctor, A.C. Parr

6. PERFORMING ORGANIZATION (IF JOINT OR OTHER THAN NIST, SEE INSTRUCTIONS)

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
GAITHERSBURG, MD 20899

7. CONTRACT/GRANT NUMBER

8. TYPE OF REPORT AND PERIOD COVERED
Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)

Stuart Horn
US Army Strategic Defense Command
CSSD-SD-P
P.O. Box 1500 Huntsville, AL 35807-3801

10. SUPPLEMENTARY NOTES

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

A handbook has been prepared to aid prospective users of NIST's Low Background Infrared Calibration Facility. A detailed overview of the facility is given, including directions to the NIST site and places to stay. The sponsorship of the facility by the Strategic Defense Command to serve the community using blackbody sources in a cryogenic environment is stated in the introduction. The vacuum and cryogenic hardware associated with the facility is discussed in detail as well as procedures the user must follow regarding clean room practice, vacuum compatibility and electrical hookup. Much discussion is also given to Absolute Cryogenic Radiometer (ACR) which serves as the standard detector for the system. An electrical substitution radiometer, the ACR measures the total flux emitted from a blackbody.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

ACR (Absolute Cryogenic Radiometer); blackbody; cleanroom; cryogenic; electrical substitution; LBIR (Low Background Infrared)

13. AVAILABILITY

- [ ] UNLIMITED
- [X] FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NATIONAL TECHNICAL INFORMATION SERVICE (NTIS).
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14. NUMBER OF PRINTED PAGES
27

15. PRICE

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