NISTIR 7199

NIST / LBIR Facility Five Year Plan (FY05-FY09)

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TECHNOLOGY ADMINISTRATION
Phillip J. Bond, Under Secretary of Commerce for Technology
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
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NIST / LBIR Facility Five Year Plan (FY05 – FY09)

Executive Summary

The NIST Low Background Infrared (LBIR) Calibration facility has become a national center for the development and dissemination of absolute standards and their traceability for the measurement of low level infrared radiation. The five year (FY 05 to FY 09) plan for this facility, described in this report, addresses the maintenance of LBIR core competencies and further improvements to meet current and future customer requirements.

The customers of the LBIR facility are contractors of the Missile Defense Agency (MDA), Department of Defense (DoD). The main focus in recent years has been the Exo-Atmospheric Kill Vehicle (EKV) Program of the Army and the Standard Missile (SM3) Program of the Navy. The prime contractors for these programs are Boeing and Raytheon. Test chambers used in these programs which are supported by the LBIR facility include the Raytheon Low-background Scanning Point Source test chambers, known by the acronyms LSPS 10a, LSPS 11a, and LSPS 16a, and the Army Portable Optical Sensor Testbed (POST) chamber. The LBIR facility also supports the 7V and 10V test chambers at the Air Force Arnold Engineering Development Center, Tennessee, the MIC chambers at the Space Dynamics Laboratory, Utah, and the chambers operated by Northrop Grumman for the Space Based Infrared System-High (SBIRS High) program, California, all of which have requirements to establish NIST traceability for their infrared calibrations. Future customers include the LSPS type chamber being built at the Johns Hopkins Applied Physics Laboratory in Maryland for the Navy and the space simulator chamber at the Kinetic Kill Vehicle Hardware in the Loop Simulator (KHILS) facility at Eglin Air Force Base, Florida.

In the following table, we briefly describe the tasks necessary to meet our customer needs and provide associated timelines. Current projects are funded through different organizations within MDA. Funding for future projects is pending.

Project Under Development = XX
Program in Operation = X

Current Projects

Projects & Brief description	FY 05	FY 06	FY 07	FY 08	FY 09
<u>Cryogenic Blackbody Calibrations:</u> Customer blackbodies are calibrated for effective radiometric temperature as a function of core contact temperature sensor setting and effective aperture area for small apertures. This ongoing service to customers has several broadband calibrations scheduled in advance each year.	X	X	X	X	X

Projects & Brief description	FY 05	FY 06	FY 07	FY 08	FY 09
Aperture Area Measurement: Verify effective aperture area measurements used in blackbody calibrations and develop capability to measure tiny apertures of sizes less than 0.4 mm in diameter to better than 1% area uncertainty.	XX	X	X	X	X
Diffraction Modeling: Theoretical calculations to accurately model the diffraction effects in optical configurations used in calibration efforts (blackbody calibrations, the BXR I, the 10 cm Collimator, the LSPS chambers, POST, MIC chamber, etc.)	X	X	X	X	X
BXR I: The NIST transfer standard radiometer is used at customer sites for measuring the collimated output of cryogenic chambers being used for missile defense sensor calibrations.	X	X	X	X	X
10 cm Collimator (10CC) and Broadband Calibration Chamber Upgrade (BCC): The BCC is being upgraded for the calibration of the 10CC. This effort will improve the calibration of the BXR series radiometers from the current 12 % to an estimated 3 % standard uncertainty.	X	X	X	X	X
High Quality Filter Procurement: The goal of this task is to define specifications and purchase high quality filters for the BXR radiometers and the 10 cm Collimator. The filters will reduce uncertainty by improving in-band throughput and reducing out of band leakage.	XX	X	X	X	X
BXR II: This next generation BXR radiometer will be capable of calibrating monochromatic sources using an on-board Absolute Cryogenic Radiometer (ACR) and provide 2 wavenumber spectral resolution of broadband sources using a cryogenic Fourier Transform Spectrometer (FTS). It will also have all the functionality of the BXR I so that it can fill the present BXR I role in the event of catastrophic failure. According to the current plan BXR II will be fully operational in FY 07.	XX	X	X	X	X

Projects & Brief description	FY 05	FY 06	FY 07	FY 08	FY 09
Spectral Calibration of Detectors: The capability to for spectral calibration of detectors will be re-established in the Spectral Calibration Chamber (SCC). Currently the SCC is being used for the broadband calibration of blackbodies.	XX	XX	X	X	X
Absolute Cryogenic Radiometer (ACR) Improvements: The core component of the LBIR facility is the ACR. Continuous improvement of radiometer design and construction to achieve a 10 fW noise floor is being pursued to meet calibration needs at the customers operational flux levels by FY 06.	XX	XX	X	X	X

Proposed Future Projects

Projects & Brief description	FY 05	FY 06	FY 07	FY 08	FY 09
Spatial Mapping Instrument: The proposed instrument would be capable of producing a spatial map of the output beam of the customer test chambers. Currently there is no capability at the test chambers to verify the assumption that the collimated output of the test chambers is uniform.					
Multipurpose Calibration Chamber (MCC): A new cryogenic chamber with the required volume and working surface area to accommodate spectral calibration of blackbodies will be pursued. When this chamber becomes available it will support the spectral calibration of blackbodies as well as all the functions of the other chambers to help relieve work backlog.					
Liquid Nitrogen Supply for the LBIR Facility: Current He-refrigerator capacity at the LBIR facility is just enough to run two chambers in parallel. When the 10CC is operated with the BCC, the refrigerators will be at or close to maximum capacity with no capacity for operations in the MCC or SCC. We propose installing a Liquid Nitrogen tank of sufficient capacity at the LBIR facility so that pre-cooling of the He gas would double the refrigerator capacity. In addition to providing full refrigeration capacity, it would reduce background noise when fewer chambers are used and wear and tear on the refrigerators.					

NIST / LBIR Facility Five Year Plan (FY05 – FY09)

Introduction

Much progress has been made during the last decade in building the infrared capabilities at NIST to meet the calibration needs of the Missile Defense Agency (MDA), of the Department of Defense (DoD). Specifically, the absolute cryogenic radiometers (ACR I, ACR II, ACR IIb) at the Low Background Infrared (LBIR) Calibration Facility have been serving as national standards for measuring low levels of infrared radiation for space borne sensor calibrations (Ref. 1,2,3). Two cryogenic vacuum chambers, both 150 cm long and 60 cm in diameter, have been operating at the LBIR facility providing the required background temperatures below 20 K for calibration of low power IR sources that simulate missile signatures in space. Much of the funding for the operation and upgrading of the LBIR facility has been received from the Ground Test Facilities office of MDA, formerly the Ballistic Missile Defense Organization (BMDO). Also, the Ground-based Midcourse Defense (GMD) program office has recently been funding the facility to provide not only cryogenic blackbody calibrations for their contractor test chambers but also to develop transfer standard radiometers to help characterize the output of those test chambers. We also used funding from the DoD Calibration Coordination Group to assist the development of the Infrared Fourier Transform (FT-IR) Spectrophotometry Laboratory (see Appendix A), which has provided vital service to the LBIR Calibration Facility.

As recent test flights have proven the basic capability of the Exo-atmospheric Kill Vehicle (EKV) for missile defense, there is a growing need to improve the accuracy of its IR sensor calibration to meet advanced threats requiring accurate discrimination to select the hard body from among many decoys. To meet these requirements, the GMD Program Office has been funding the LBIR facility to provide improved accuracy and traceability for radiometric calibrations for their contractors. In addition to GMD, the Navy Standard Missile Program Office has also been working with the LBIR facility to build NIST capabilities to meet the needs of their contractors. Based on these and other projected requirements, we have developed this five year plan for maintenance, operation and expansion of the LBIR facility. The following sections describe the individual tasks in the five year plan. They are discussed under the subheadings of Current Projects and Proposed Future Projects. Current Projects are ongoing and designed to meet the largest, currently known customer needs, whereas Future Projects are planned efforts to meet longer term, but still important requirements.

Customers

Customers of the LBIR facility are the MDA contractors. The main focus in recent years has been the EKV Program of the Army and the Standard Missile Program of the Navy. The contractors for these programs are Boeing and Raytheon. Test chambers used in these programs supported by the LBIR facility include the Raytheon Low-background Scanning Point Source chambers known as LSPS 10a, LSPS 11a and LSPS 16a, and the Army test chamber, POST. The LBIR facility also supports the 7V and 10V test chambers at the Arnold Engineering Development Center, the MIC chambers at the Space Dynamics Laboratory, and the chambers operated by Northrop Grumman for the Space Based Infrared System-High (SBIRS High) program, all of which have requirements to establish NIST traceability for their infrared calibrations. Future customers include the LSPS type chamber being built at the Johns Hopkins Applied Physics Laboratory and the space simulator chamber at the Kinetic Kill Vehicle Hardware in the Loop Simulator (KHILS) facility at Eglin Air Force Base, Florida.

Current Projects

Cryogenic Blackbody Calibrations

Cryogenic blackbody calibrations have traditionally been the main thrust of LBIR calibration efforts (Figure 1). Previously, we calibrated blackbodies for effective radiometric temperature as a function of core set point temperature and chosen defining aperture. Blackbody calibration reports were provided in this manner until 2001, when we calibrated a blackbody with large aperture area measurement errors for its smaller apertures. If the traditional method of calibration report generation would have been followed, blackbody core temperature corrections would have varied significantly in an inconsistent manner as a function of blackbody aperture area. This is an unphysical result, but had been accepted in previous reports because aperture measurement errors had been small. However, since 2001 some of the blackbodies that we calibrated had significantly smaller apertures and thus greater relative aperture area uncertainty.

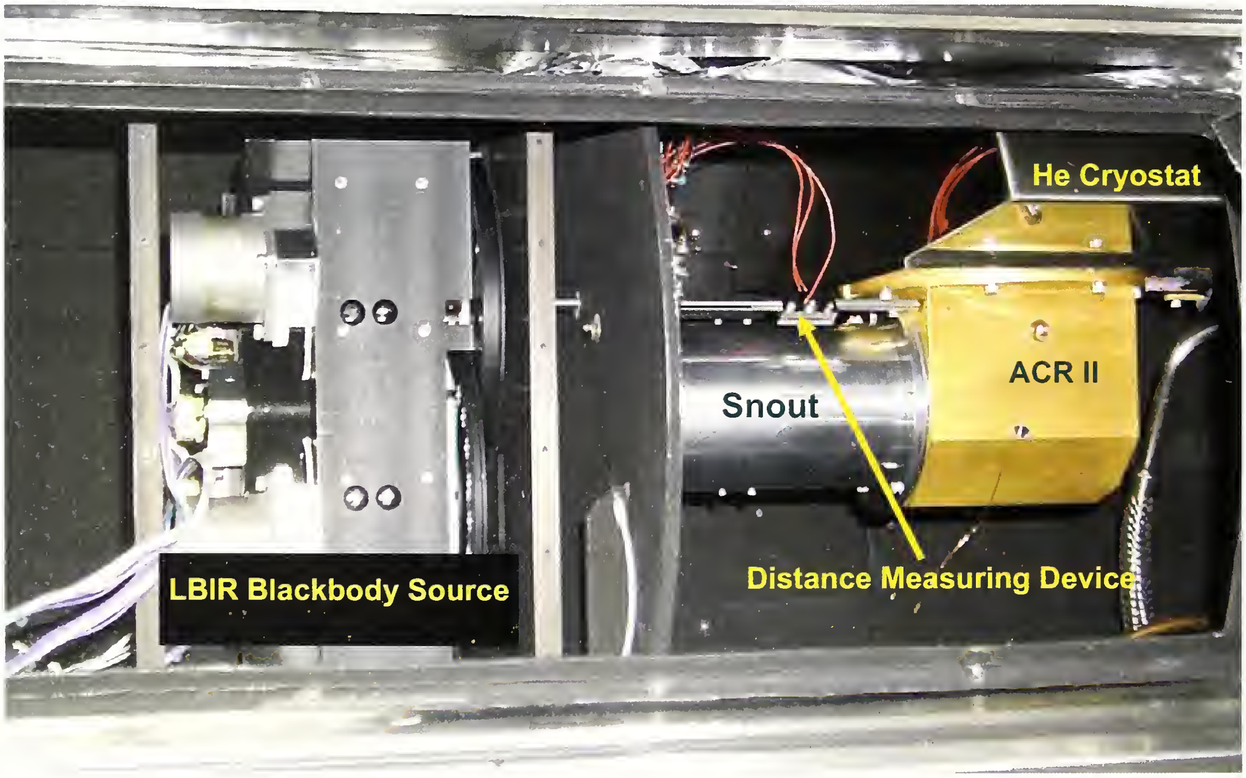


Figure 1. Typical experimental arrangement showing the placement of a blackbody in front of the ACR II. The ACR II is operated at 2.0 K, and the distance measuring device is used to reduce uncertainties in the configuration factor when computing radiance.

As a result of this growing inconsistency, we adopted a method of blackbody calibration that is less sensitive to aperture area uncertainty. Radiometric core temperatures are now measured through the larger apertures, where aperture area uncertainty is relatively small. These radiometric core temperatures are then averaged together, weighting the more accurate measurements most heavily. This averaged radiometric core temperature calibration is then used as a temperature set point correction for all apertures. Subsequently, we use the radiometric core temperature to calculate the effective aperture area for all the smaller apertures not used in determining the radiometric core temperature, based on the power measured through these smaller apertures. The LBIR blackbody calibration reports currently provide the following key information:

1. The radiometric blackbody temperature for the individual larger apertures where aperture area uncertainty is small.
2. The averaged radiometric temperature for these larger apertures.
3. The effective aperture radii for the smaller apertures not used in the averaged radiometric temperature determination.

Either the averaged radiometric temperature or the individual radiometric temperatures may be used with the larger apertures. However, the averaged radiometric temperature must be used with the smaller apertures.

There are complications that may result in inaccuracies in the above calibration method. First, we assume the blackbody core emission follows Planck's law with emissivity of 1. Any deviation from being a perfect blackbody would result in a radiometric temperature calibration lower than actual. This deviation can not be detected by the contact temperature sensors in the core as they are usually not calibrated for the radiometric temperature of the blackbody. The uncertainty of diffraction calculations is the second source of inaccuracy. We use diffraction calculations to correct power measurements made by the ACR as a function of blackbody core temperature and aperture size. The corrections have traditionally been accepted, "as is," because the uncertainty has been only a small contributor to the total uncertainty presented in the calibration report. However this is no longer true when blackbody sources with smaller apertures need to be calibrated at lower temperatures. Both of these conditions lead to larger diffraction corrections, and thus larger diffraction correction uncertainties. Unfortunately, these issues are entangled such that non-blackness of the core, temperature sensor uncertainty, aperture area uncertainty, and diffraction uncertainty can not be easily separated.

We have envisioned methods to untangle these uncertainties and propose solutions in this paragraph and in other sections of this 5 year plan. The blackbody core contact temperature sensor uncertainty can be reduced by recalibrating the temperature sensors as they are mounted in the core. This can be accomplished by immersing the core with the temperature sensors and wiring in a NIST temperature sensor calibration bath. This procedure may or may not be possible for all blackbody sources depending on how modular the design is and how easily the core can be removed from the blackbody housing assembly. We used this temperature bath sensor calibration procedure for one of the LBIR blackbody cores as a proof of principle. In this effort, we enclosed the core in a water proof container and immersed it in a precision temperature controlled water bath. The electrical leads from the temperature sensors were accessed through wiring brought through a conduit that gave water tight access to the vessel containing the core. In this way, the water bath controlled the core temperature while the temperature sensor resistance could be measured, providing a new calibration curve for the temperature sensors. This type of temperature bath sensor calibration service is scheduled to be available in FY 05. The aperture area uncertainty and diffraction uncertainty are addressed in other sections of this report.

Currently there is a long queue for blackbody calibrations and we expect this to continue considering the current set of blackbodies in the field will need periodic recalibration. In addition, as the performance requirements from the blackbodies increase, the amount of time necessary for a complete calibration will likewise increase. For example, the bath calibration of the temperature sensors proposed above will add time, as will the spectral calibration of the emission. We anticipate the demand for blackbody calibrations to continue growing for the foreseeable future.

Aperture Area Measurement

The importance of aperture area measurement is well understood. It is clear that uncertainty in aperture area directly translates into uncertainty in the power transmitted through the aperture. In a simplistic, purely geometric optical analysis, with an ideal, sharp aperture edge, dimensional measurement uncertainty would be the only source of aperture throughput uncertainty. However, the assumed simplicity of how apertures are applied in optical models breaks down as the apertures become small, especially as the size approaches the wavelength of transmitted light. From a purely mechanical standpoint, smaller apertures have issues with edge roughness, non-roundness, and defining edge thickness that make the apertures depart from the ideal way they are applied in models. If a more complete electromagnetic wave propagation model is considered, as aperture sizes approach the wavelength of transmitted light, variations in attenuation occur in addition to the geometric beam size reduction that the aperture provides. At the LBIR facility, it is now common to make power measurements from a 300 K blackbody through apertures as small as 50 μm in diameter. In this case, the aperture is only 5 times larger than the 10 μm wavelength radiation which represents the peak emission of a 300 K blackbody. Apertures that are between 1 to 10 wavelengths in diameter have transmission values modulated significantly due to diffraction compared to that expected from purely geometric considerations. For example, when the diameter is 7 wavelengths, transmission is enhanced by about 5 %; when that diameter is 4.5 wavelengths, transmission is reduced by 15 %; and when that diameter is 2.5 wavelengths, transmission is enhanced by about 25 %. When the wavelength of light is about the same as the aperture diameter, there is almost zero transmission. We estimate for a 300 K blackbody, about 1 % less power is transmitted through a 50 μm aperture than is expected based on a geometric model. This situation becomes significantly worse for lower blackbody temperatures.

The need to characterize small apertures and understand their effects well is growing as lower irradiances from infrared test chambers are in demand. The IR community is using blackbody sources with smaller apertures and lower temperatures which both increase the need for this knowledge. This understanding has to first start with the ability to accurately determine the physical dimensions of the apertures in question. The current aperture measurement capability at NIST consists of the Absolute Aperture Area Facility (AAAF) (Ref. 4). This facility is capable of measuring apertures larger than 350 μm, but for apertures smaller than 350 μm there is no NIST certified measurement capability. The aperture manufacturers often have some measurement capability and will provide a measurement report. For larger apertures, with diameters greater than 500 μm, these measurements can usually be trusted to about 0.1 %, although their claimed measurement uncertainty may not be reliable. For apertures smaller than 500 μm, the manufacturer's measurements are not at all reliable based on our evaluations at the LBIR facility.

Plans to evaluate the small aperture measurement capabilities at NIST and elsewhere, and investigate the effects of small apertures on optical power transmission are underway at the LBIR facility. We have purchased apertures spanning from 50 μm to 5 mm. Both the manufacturer and the AAAF at NIST have measured the apertures. The diameter measurements agree to within 0.03 % for the largest, 5 mm aperture. However, for the smallest aperture of 350 μm that NIST could measure, they agree to only about 0.9 %.

We made relative optical power measurements on the apertures at visible wavelengths. In this first effort, we compared power measurements through the larger apertures, where aperture area is known well, to similar measurements made through the smaller apertures, where aperture area measurements become more dubious. At 532 nm, even the smallest apertures under consideration should be relatively large as compared to the wavelength. We measured signals as a function of detector distance to determine if the apertures were behaving like a Lambertian source. However, non-uniformities in the integrating sphere illumination prevented agreement between the physical dimensions and the relative power measurements to better than 1 %. We then implemented an improved illumination method for the sphere and further testing will be performed in the near future.

We will perform these measurements again using 10 μm output from a CO_2 laser to determine the effects of longer wavelengths on the power transmission through the apertures. Finally, we will mount these apertures on the aperture wheel of a cryogenic blackbody and perform a typical blackbody calibration. Once again, power measured through the relatively well known large apertures will be compared to power measured through the smaller apertures to look for the effects of aperture size on long wavelength transmission. Due to the broadband nature of the blackbody emission according to Planck's law, the effect should be more pronounced than for the monochromatic 10 μm radiation. In addition, blackbody temperature can be lowered to favor longer wavelength emission increasing the magnitude of diffraction effects of long wavelength light passing through small apertures. Based on the analysis from the above experiments, which are expected to be finished by late FY 05, we will develop plans for a better aperture measurement capability at NIST.

Diffraction Modeling

The importance of diffraction modeling for the wavelengths of interest at the LBIR facility has always been high. It is easy to become complacent when the wavelengths that are most easy to work with, the visible, do not require much consideration to diffraction for most typical optical applications. However, for the 2 μm to 50 μm portion of the spectrum this is no longer true. For example, if a 7 cm mirror is used to focus a 25 μm wavelength beam through a 1 mm aperture, nearly 5 % of the radiation will not pass through the aperture because of diffraction. As another example, if a blackbody is calibrated at 180 K through a 50 μm aperture, the measured power through a 2 cm aperture 30 cm away will be 40 % lower due to diffraction losses than anticipated from strictly geometric considerations.

Diffraction corrections have been applied to blackbody calibrations since the beginning of the LBIR facility. Until recently, the optical systems have been simple and the corrections have been relatively small, however, the need to improve the correction calculation capability has grown in two ways. We mentioned the first way in the above section on Cryogenic Blackbody Calibrations. Until recently, blackbody diffraction corrections have been 10 % of the power or less because blackbodies were operated at higher temperatures and used larger apertures. We conservatively assigned the uncertainty given to the diffraction corrections at 10 % of the overall correction, so uncertainties mostly remained below 1 %. However, as the IR community strived for lower powers, they are using blackbody sources at lower temperatures and with smaller apertures. It is now common to see diffraction corrections as large as 50 %. Our current conservative method of determining uncertainty would then give us a 5 % uncertainty. This is unacceptable for some customers. To address this issue, we need to reduce the uncertainty assigned to the correction through verification with well controlled experiments. The other improvement in diffraction modeling capability is being driven by the need to model optical systems that are not in the paraxial limit (axial in symmetry). Most high performance optical systems use mirrors to avoid chromatic distortion effects and maximize spectral band transmittance. As a result, if central obscurations need to be avoided, any optical design needs to be non-paraxial. Indeed, nearly all customer infrared test chambers are off axis in design as are all the in house or developmental assets in the LBIR facility.

We will pursue the diffraction correction modeling improvements with a two pronged effort. First, to reduce diffraction uncertainty from blackbodies modeled in the paraxial limit, we will perform experiments to verify the accuracy of the diffraction model. This will either verify the diffraction model and computational method being used, or lead to further development and improvements in both of those areas. In both cases, uncertainty would be reduced. An example of an experiment that would address this diffraction issue would be to use the LBIR blackbody in some well defined limiting and non-limiting aperture configurations and use a BIB detector mounted at a distance behind a filter wheel on the recently developed X-Y translation stage to map out diffraction patterns as a function of wavelength. These measurements could then be compared to theory for accuracy. Second, for improvements in the diffraction modeling of more sophisticated optical systems that have mirrors in non-paraxial configurations, more work is needed. The code for this modeling is still being improved; however we have achieved several useful results. We have also performed measurements for the non-paraxial case of radiation directly from a blackbody and are comparing them to theory. Verification of more complex optical arrangements will have to wait until the LBIR facility obtains the new Multipurpose Calibration Chamber (MCC) mentioned below.

The demand for accurate diffraction modeling is considerable. The internal NIST demand is driven by the routine need for diffraction modeling for blackbodies undergoing calibration, to the more complex modeling of the 10 cm Collimator (10CC), to the very complex modeling of the BXR I and BXR II radiometers. External demand for diffraction modeling is driven by the need to fully understand test chambers like the MIC chambers at Space Dynamics Lab, the LSPS 10a, 11a and 16a chambers at Raytheon, the Boeing POST chamber, and the 7V and 10 V chambers at AEDC. Although some of these chambers have already been modeled, most need further study. Fortunately the chambers only need to be modeled once, but there is currently a backlog of modeling to be done.

BXR I

The BXR I is an instrument designed as a transfer standard for low background test chambers that generate a highly collimated infrared beam (Figure 2). With minimal effort, we can pack the BXR I with its control electronics and send it to a user's site for

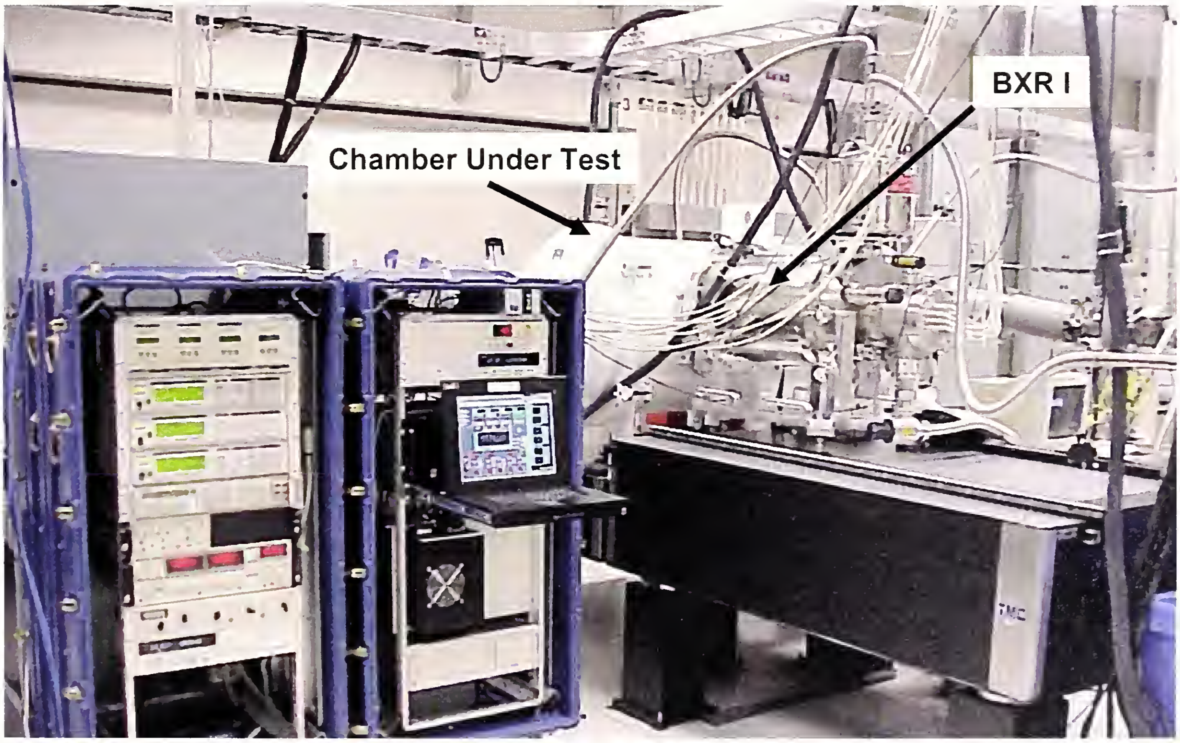


Figure 2. The BXR I (stainless steel) shown evaluating a collimated infrared source test chamber (white). The two blue electronics control racks travel with the BXR I on deployments.

test chamber evaluation. It has a ± 2 mrad angle of acceptance, a 7 cm entrance aperture, and can measure irradiances down to 1 fW/cm^2 within its 2 μm to 30 μm spectral sensitivity. Spectral capability is generated by a set of narrow band pass filters that span wavelengths from 2 μm to 14 μm. The filters can be changed to suit the spectral needs of the end user. A measurement capability also exists so a user's beam can be characterized for its linear polarization. The BXR I has been in service since May 2001, has evaluated 4 chambers and has shown excellent stability.

The BXR has a few remaining drawbacks that we should resolve in the near future. The largest problem has been the difficulty of developing a source to calibrate the BXR I. As a stop gap measure, we developed a 1 cm collimator to provide some level of calibration. Due to several issues with the 1 cm collimator, the calibration is limited to about ± 11 %. To address this limitation, a new 10 cm collimated source has been delivered and is operational. We expect it to reduce the calibration uncertainty to about ± 3 % for signals that are not noise limited. The 10 cm Collimator (10CC) and other LBIR improvements for calibrating the BXR I are discussed in more detail below. Another, but less significant, problem is out-of-band leakage through the filters in the BXR I. We selected the band pass filters to be very narrow in order to simplify the spectral analysis of the data. However the effect of this is that the out-of-band leakage becomes a significant fraction of the signal and results in undesirable uncertainty. We are addressing this uncertainty by attempting to accurately characterize the out-of-band transmission through the filters. By using the BXR I at the exit port of an FTIR instrument, we will obtain measurements through its filters using the highly sensitive BIB detector. The low level out-of-band leakage of the filters should then be characterized well enough to remove it as a significant contributor to uncertainty.

The BXR I workload is expected to remain high for the foreseeable future. This past year, the BXR I evaluated the other Raytheon 11a Chamber (Floyd). New chambers coming on-line that require BXR I calibrations are the AEDC 10V chamber and the Raytheon 16a chambers. These chambers are expected to start service in the next 1 to 2 years. We expect calibration support for these chambers to be continuous as the chambers will probably require annual or biannual recertification. Although the BXR II will have BXR I like capability, it will probably not alleviate the demand on the BXR I because the BXR II will have a different set of chambers to service, mainly the Raytheon VOB and KVITS chambers. The demand for the BXR I is expected to continue for many years to come and could grow if other test chambers, like those of Space Dynamics Labs and Northrop Grumman, are determined to require calibration as well.

10 cm Collimator (10CC) and Broadband Calibration Chamber (BCC) Upgrade

We initiated the 10CC (Figure 3) and the BCC upgrade (Figure 4) to calibrate the BXR I, although the BCC was in need of an upgrade well before the existence of the BXR I. As mentioned above, the 10CC is designed to be a calibration source for the BXR I, as well as for any similar instruments. We designed its optical system to be easily modeled, with diffraction concerns kept to a minimum. This was done to maximize the agreement between its actual and theoretical performance, which is a necessary step in maximizing confidence in its calibration. The BCC upgrade was, in part, designed around the ability to calibrate the 10CC with one of the absolute cryogenic radiometers used in the LBIR facility. To do this, two significant changes were made. First, we developed a new shroud to take advantage of the new refrigeration capacity at LBIR. Second, we designed and built new end caps with greater electrical feed through capacity and optical plates for mounting the hardware necessary to collect a 10 cm beam and direct it into an ACR. We expect the BCC improvements to help the broadband blackbody calibrations as well, in terms of lower background noise and longer liquid He cryostat hold time. The BCC upgrade is complete with only minor modifications still to be made. The 10CC was tested and made operational in the first quarter of FY 05.

Filter Procurement

A high quality custom filter procurement effort is being driven by the need for greater spectral calibration capability and the lack of high quality off-the-shelf filters that suit our needs. We developed the BXR I using off the-shelf-filters, with mixed results. Although the filters did perform their basic function, they were not designed for long wavelength

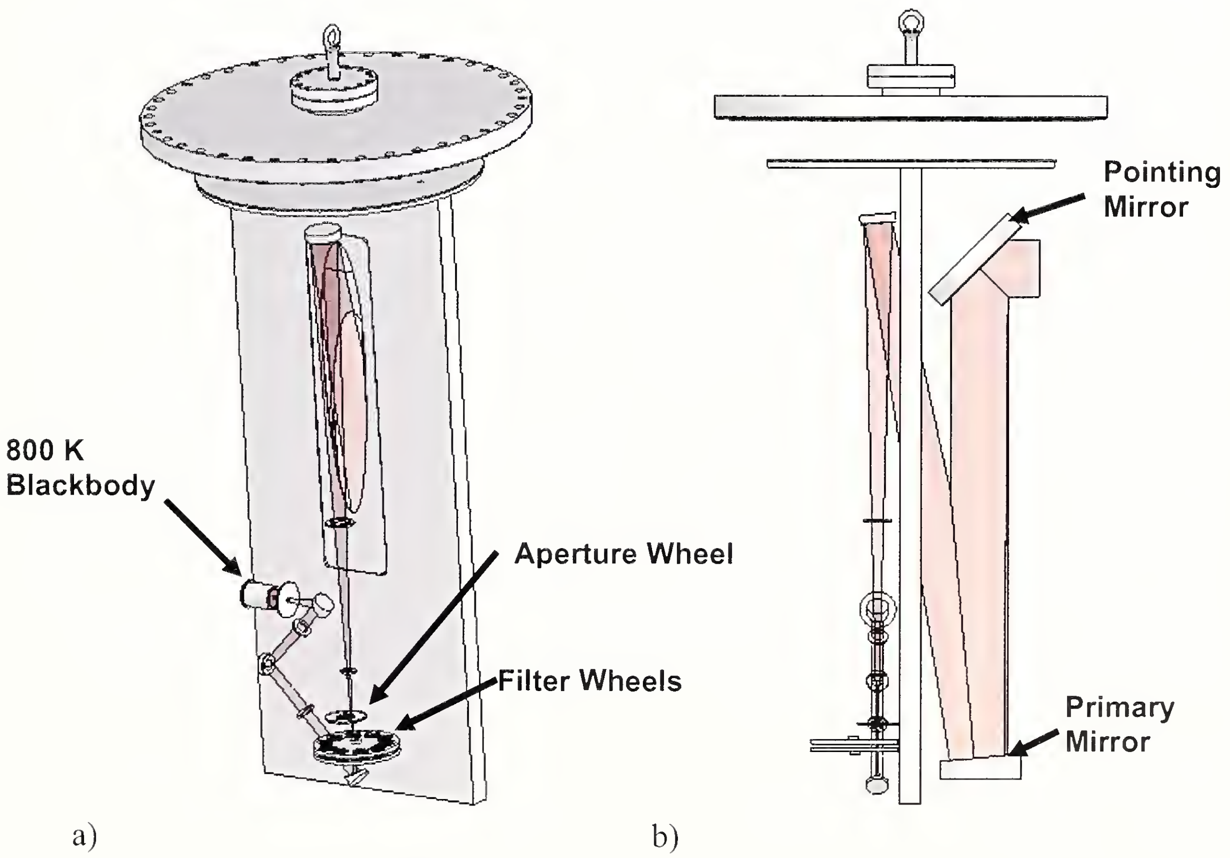


Figure 3. a) The source side of the 10 cm Collimator contains the blackbody source and some relay optics to focus radiation onto the defining aperture of the primary mirror. Between the blackbody source and the defining aperture there are two filter wheels and a collimated portion that could be used for future optical features such as a monochromator, a Fourier transform spectrometer, or additional filter wheels. b) The side profile view shows the opposite side of the optics plate and the location and orientation of the primary collimating mirror and pointing mirror.

blocking. We have also discovered that all the filters redirect the beam from its original trajectory, some by as much as 4 mrad. This redirection of the beam has caused great difficulties in the 1 cm collimator used to calibrate the BXR I and significant difficulties within the BXR I during regular operation. We have implemented partial work-around solutions to the out-of-band leakage and beam redirection issues but they still contribute significantly to final calibration uncertainty. Both of these problems can be entirely alleviated by appropriately specified custom filters.

An additional benefit that could be attained through custom filters is improvement in the spectral power sensitivity of the BXR I. Most of the filters currently in the BXR I have a narrower bandwidth than 230 nm. The custom filters can be chosen to be 1 μm in bandwidth while still maintaining significant spectral capability, and improving the noise floor of the instrument by more than a factor of 4 for most filter wavelengths. This improvement would put the BXR I sensitivity at 1 % Type A uncertainty for signals below 10 fW/(cm^2)/(μm) for most of the filter wavelengths.

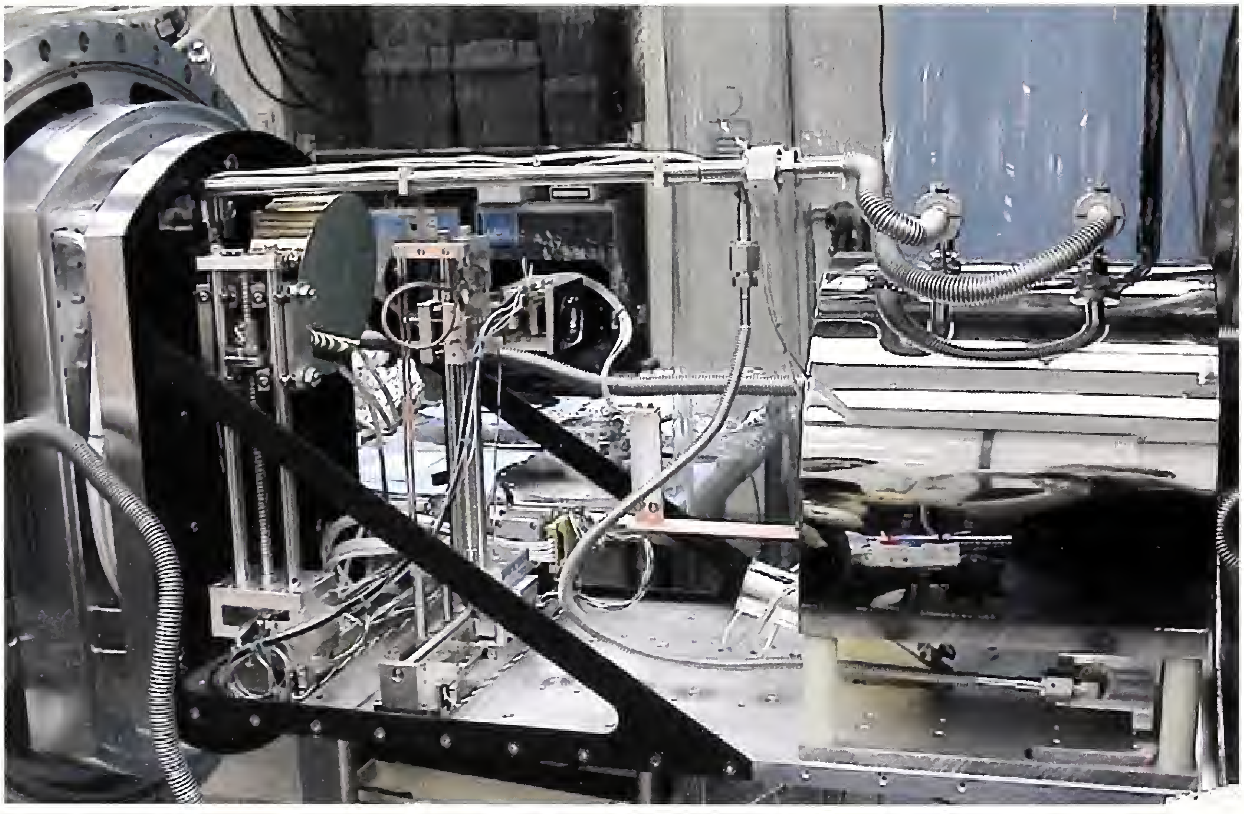


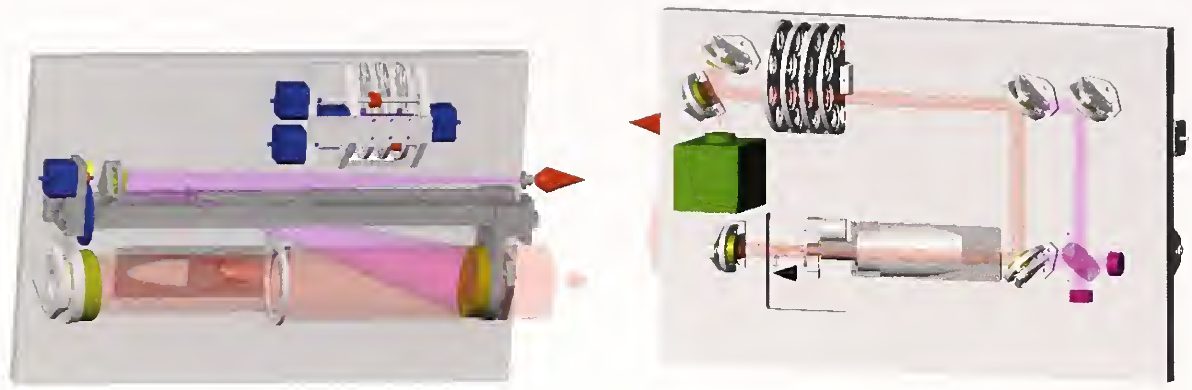
Figure 4) The Broadband calibration chamber back-end where the collection mirror is located for the calibration of the 10 cm Collimator output beam. The mirror focuses the collimated beam into the ACR for calibration. The mirror is then moved above the beam to allow it to pass to the BXR I. In front of the mirror is a detector on an X-Y translation stage that is used to map out the uniformity of the collimated beam.

We procured and characterized two sets of ten sample filters of 1 μm band width centered at 6.5 μm and 11.5 μm. The filters demonstrated a good in-band square shape and excellent out-of-band blocking. All ten filters of each band pass survived multiple cryocycles to below 80 K and at least two cryocycles to 20 K. Based on the successful fabrication and testing of the sample filters, we ordered the remaining filter set. However, we changed the filter set specifications to accommodate a new testing methodology. Instead of specific band passes, we ordered a series of short and long wave passes. All of the short wave passes will be mounted on one filter wheel, while all of the long wave passes will be used on another filter wheel. In this way, the filters can be mixed and matched so that variable band passes can be generated. The most narrow band pass selectable is 0.3 μm, and the widest band pass is about 4.3 μm. In this way, the narrower band pass can be selected for higher spectral resolution when there is ample signal, and a wider band pass can be selected when power sensitivity is needed for detection of weak signals. We expect the first filters in early FY 05, and the order should be completed some time in mid FY 05.

Before these filters can be used in their most optimal way, we need to more accurately determine the BXR I spectral sensitivity. This consists primarily of determining the spectral sensitivity of the Si:As Blocked Impurity Band detectors used in the BXR I. The laborious part of this task involves bringing the Spectral Calibration of Detectors Program back on-line. This is explained in more detail below.

BXR II

The next generation transfer standard radiometer, the BXR II (Figure 5), has been funded and is currently in the design and build phase. The BXR II is the natural progression of the BXR I and we are designing it to overcome the limitations of the BXR I and have more functionality. The BXR II will have all the capability of the BXR I with increased functionality added in two stages. The first stage will be to incorporate an ACR within the portable radiometer which will allow the BXR II to make spectral calibrations of user chambers having monochromatic sources. This is a capability that the BXR I can not fulfill and yet is needed for the Raytheon VOB and KVITS chambers, the Boeing POST chamber, the AEDC 7V chamber, and other chambers likely to have this need as well. The second BXR II enhancement will be the addition of an internal Fourier Transform Spectrometer (FTS). The BXR II will initially have limited spectral resolution, like the BXR I, then the FTS will be added in about two years to broaden the spectral range of the BXR II. This will greatly increase the spectral performance from a resolution around 0.3 μm at selected wavelengths to about 1 wavenumber (10 nm at 10 μm) from 4 μm to 15 μm. This measurement capability will remove the assumption from the current method of analysis that the output of the test chambers is spectrally smooth and relatively constant in slope within the spectral width of the band-pass filters. The current plan is to have the BXR I and ACR phase of the BXR II implemented and providing service to the user community in FY 06. The FTS component of the BXR II will then be incorporated in FY 07. The BXR II will also serve as backup in case of a catastrophic problem with the BXR I.



a) b)

Figure 5. a) A reference source and the optics associated with it that can be placed into the measured beam path are traced through by the magenta beam. The pink beam is the trace of the beam being calibrated. The entrance optics of the BXR II consists primarily of a pupil (defining entrance aperture), an off-axis parabola, and a field stop. Baffling to reduce scatter is not shown. b) On the opposite side of the vertical optics plate from the entrance optics are the active optics. There is an Absolute Cryogenic Radiometer that can be moved into the beam, a cryogenic Fourier transform spectrometer through which the beam can be optionally routed (shown in magenta), a filter wheel, and an As doped Si infrared detector (green).

Spectral Calibration of Detectors

There is a continuing need for spectral calibration of detectors. A program to provide spectrally calibrated detectors existed in the past and was put on hold because chamber space at LBIR needed to be dedicated to higher priority programs like calibrations of customer blackbodies and the BXR I. Currently, the BXR I relies nearly entirely on an end-to-end system level calibration because the spectral response of its detector is not known well enough to produce an accurate model based on component level characterizations. Typically, NIST practice is to show agreement between modeling and measurement to support estimated calibration uncertainties. Fortunately, for practical purposes, the end-to-end method of calibrating the BXR I has been sufficient because most of the spectral filters are narrow enough that the spectral response of the BXR I can safely be considered to be linear in slope within the band-pass of the filter. This will no longer be true when the BXR I filters are widened to allow increased signal sensitivity in order to meet the user's requirements at low irradiance levels. Therefore, spectral characterization of the detector responsivity becomes important for modeling and estimating the uncertainties in BXR I responsivity using broad band filters.

The Spectral Calibration of Detectors Program can be made completely operational again without the sole dedication of the SCC to the program, by developing the optical arrangement on a separate breadboard. Then, when chamber space is available, the entire breadboard could be bolted on the actively cooled plate of whichever chamber is available. This would allow for the continued development of a needed program before any dedicated chamber space is made available in mid FY 06. To a limited extent, this work is actually continuing in that the LBIR cryogenic monochromator, the Spectral Instrument (SI), is in the process of being. Its performance had been one of the developmental issues in the previous program. The other major issue from the previous program would be solved by using some additional refocusing mirrors. The spectral calibration of detectors is needed much sooner than dedicated chamber space can be made available. This will be most easily achieved by building up the optical arrangement on a separate breadboard.

Absolute Cryogenic Radiometer (ACR) Improvements

The core component of the calibration capability at the LBIR facility is the ACR. The original ACR, which is still in service, has a peak to peak noise floor of about 50 pW. A newer radiometer, called the ACR II, has a peak to peak noise floor below 10 pW. As good as this may be, we still need further improvements in power measurement capability. To measure low irradiances currently generated by test chambers to calibrate remote sensors, the BXR instruments will need to be calibrated with an ACR having a noise floor of 10 fW just to catch up with current capability. At this time, BXR I calibrations are performed at higher powers, and extrapolations based on models and assumptions about detector linearity are used to extend the calibration to low irradiances put out by these chambers.

For these reasons, it is imperative that the LBIR facility make ACR improvements an ongoing process. Developing an ACR with a 10 fW noise floor is a goal that should be reached incrementally in a continuous development effort. Plans are currently in place to make the next incremental step from our current noise floor of less than 10 pW to possibly 100 fW by the end of FY 06. We will apply any lessons learned from this development toward further reductions in noise floor, possibly reaching 10 fW by FY 07.

Proposed Future Projects

Spatial Mapping Instrument

Spatial uniformity of the infrared test chamber output is still largely unknown and the only claims to uniformity are almost always through theoretical modeling. Although the BXR I can measure the irradiance from these chambers, it only samples a 7 cm diameter portion of beams that can be as large as 50 cm in diameter. Moving the BXR I around within the beam would be mechanically impractical and slow. A much more practical solution is to develop a small, simple and portable instrument specifically for testing infrared test chambers on location. Such an instrument would only need a detector on an X-Y translation stage and possibly one collection optic. There would be no calibration effort needed since it would only be designed to make relative spatial signal measurements within a beam. Such an instrument could be available in FY 06.

Multipurpose Calibration Chamber (MCC)

The conception of a new cryogenic chamber, the Multipurpose Calibration Chamber, is the result of two driving factors. First, the current chamber capacity is causing a backlog in calibration efforts. Significant delays have resulted due to the volume of work and because we have been forced to reconfigure chambers for various user requirements. We created the current chamber space by suspending the spectral calibration of detectors program. This program was on the verge of producing spectrally calibrated transfer standard detectors and is currently needed to support the BXR I and BXR II work. We expect the chamber space shortage to get worse. The arrival of the 10CC will add to the chamber workload and reduce overall chamber space flexibility because it can only interface with the BCC. Then, in the near future, the BXR II will be finished and the Spectral Calibration of Detectors Program will need to be activated again, both creating more demand on chamber capacity. The second driving factor for a new cryogenic chamber is that the two chambers now in operation are very limited in contiguous, usable, flat working space inside the chamber required for complicated and precise optical arrangements. Potential future programs like the spectral calibration of blackbodies can not be executed in either the BCC or SCC due to space constraints. A large working flat space would allow for the easy reconfiguration of different optical arrangements ranging from as simple as routine radiance temperature blackbody calibrations, to calibrating the BXR instruments, to the spectral calibrations of blackbodies.

The proposed chamber will address a broad range of anticipated uses, and will thus be called the Multipurpose Calibration Chamber, or MCC. It will contain a cryogenic optical bench approximately 1 m x 1.5 m in size which will be enclosed in a cryogenic shroud. The vacuum vessel and shroud will have appropriately sized and placed ports for the use of the 10 cm collimator, the BXR instruments, and other yet to be determined requirements. Such a chamber could be available from surplus property of a DoD facility and this possibility will be fully explored before seeking funds to fabricate a new one.

LN_2 Supply

Refrigeration capacity is satisfactory for our current needs; however this may change in the near future. The arrival of the 10CC will add about 60 % more heat load when operating the BCC to calibrate the BXR instruments. This is well beyond the capacity of the old 1430 Refrigerator and will bring the new 1620 Refrigerator to its limit. The new MCC would also be beyond the limit of the old 1430 refrigerator and challenge the capacity of the 1620 refrigerator as well. There are two good reasons to stay within the operational limit of the 1430 refrigerator. First, a backup is needed in case the 1620 refrigerator fails catastrophically. This has happened in the past, and having the spare refrigerator has allowed for continued chamber operations with a relatively minor degradation in background noise performance. Second, we have long been striving to operate two chambers simultaneously to ease the backlog of work but, until now, it has not been possible due to compressor limitations. Since we installed a second compressor this is no longer a constraint. The ability to run two chambers simultaneously will be a great benefit in the near future as activities increase as BXR I calibrations become more routine and as the BXR II is brought into service.

The most efficient way to increase refrigeration capacity to meet anticipated need is to implement liquid nitrogen pre-cooling of Helium gas. In this mode of operation, incoming Helium gas to the refrigerators is pre-cooled by liquid nitrogen. This has the effect of doubling the refrigeration capacity of both refrigerators and reducing the ice buildup on the exit valves of the refrigerator expansion pistons, which improves temperature stability. In addition, even when the added capacity is not needed to handle the new chamber loads, the capacity could be used for two other beneficial effects: 1) to generate lower background operating temperatures, which may very well be needed to meet the ultimate goal of effectively using an ACR with a 10 fW noise floor, and/or 2) to allow the refrigerators to operate at slower speeds which greatly reduces maintenance costs and down time. The liquid nitrogen pre-cooling system could be in place by FY 07.

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Appendix A: Infrared Fourier Transform Spectrophotometry Laboratory

The Infrared Fourier Transform (FT-IR) Spectrophotometry Laboratory serves as the measurement facility for characterization of the optical properties of materials in the infrared spectral range of 1 μm to 100 μm, with particular emphasis on the 2 μm to 20 μm region. The facility is built around several commercial FT-IR Instruments. Custom specialized accessories have been developed to enable transmittance, reflectance and emittance measurements of a wide variety of sample types and under the variable control of measurement geometry, beam polarization and sample temperature. Methodologies and new techniques have been developed for high accuracy measurements. In addition to the directly measured quantities, characterization of other properties such as refractive index and Mueller matrix elements has been implemented.

The laboratory serves a wide variety of industries and agencies that (a) require infrared optical property information, including manufacturers of optical components, infrared detectors, and spectrophotometers, materials processing, aerospace, and defense industries, or (b) use optical measurement instrumentation, such as the chemical, pharmaceutical, food, agriculture, and remote sensing industries.

Measurement services currently available as special tests include regular reflectance and transmittance over a range of incidence angles and over a range of temperatures from 10 K to 300 K, for the wavelength range of 1 μm to 100 μm. In addition, 8 degree-hemispherical (diffuse) reflectance and transmittance can be measured from 2 μm to 19 μm. The polarimetric dependence of these properties (ellipsometry and polarimetry) can also be measured over the 2 μm to 50 μm range, with complete Mueller matrix information over the 2 μm to 6 μm range.