Trip Report
Prepared by Tom Stoffel for the
Atmospheric Radiation Measurement (ARM) Program
October 17, 2001

Purpose of Travel
Participate in the Second International Pyrgeometer and Absolute Sky-scanning Radiometer Comparisons (IPASRC-II) conducted at the North Slope of Alaska (NSA) site in Barrow as an Intensive Observation Period (IOP).

Dates of Travel
March 9 – 17, 2001

Summary
The Second International Pyrgeometer and Absolute Sky-scanning Radiometer Comparison (PASRC-II) was conducted in Barrow, Alaska from March 2 -17, 2001 as an Intensive Operational Period (IOP). Organized by the ARM Program as an IOP, the results were from the combined efforts of NOAA, SUNYA, WRC/PMOD, and NREL. Measured data from 12 pyrgeometers and the Absolute Sky-scanning Radiometer (ASR) were collected over four nights. The commercially available radiometers were mounted on automatic solar trackers with heated ventilation and shading from shortwave irradiance during limited daytime experiments. Downwelling hemispheric longwave irradiance levels ranged from 120 to 150 Wm^{-2} representative of the very clear and cold sky conditions during the IOP. Preliminary data analyses suggest good agreement among the instruments (+/- 3 to 6 Wm^{-2}) and the need for pyrgeometer calibration/characterization for polar climates. This is consistent with the protocol established by the World Meteorological Organization's Baseline Surface Radiation Network (BSRN). The final report of the IPASRC-II will be submitted for journal publication in 2002.

Background
Accurate measurements of longwave irradiance are important to understanding the total energy balance of the earth-ocean-atmosphere system. Presently, there is no recognized standard procedure or reference instrument for calibrating pyrgeometers used to measure broadband longwave irradiance. Commercially available pyrgeometers are generally calibrated using temperature-controlled blackbody sources [Eppley, Kipp & Zonen]. For the past decade, scientists at the World Radiation Center (WRC), Physikalisch-Meteorologisches Observatorium Davos (PMOD) in Switzerland have been working to improve blackbody system design and develop an absolute radiometer as a possible reference standard [Philipona and Fröhlich, 1994; Philipona and Fröhlich, 1995]. The new Absolute Sky-scanning Radiometer (ASR) uses a blackbody calibration reference as an integral part of its operation.

Recognizing the importance of pyrgeometer calibration and measurement performance to climate change research, the ARM Program conducted the First International Pyrgeometer and Absolute Sky-scanning Radiometer Comparison (IPASRC-I). Longwave irradiance measurements from 15 pyrgeometers and the ASR prototype were collected at the Radiometer Calibration Facility at the Southern Great Plains (SGP) site in Oklahoma

during September 1999. Results from this Intensive Observation Period (IOP) suggested good agreement (less than 2 Wm^{-2}) among the radiometer measurements, the Atmospheric Emitted Radiance Interferometer (AERI), and radiative transfer models (LBLRTM and MODTRAN). The results were valid only in the range of 260 Wm^{-2} and 420 Wm^{-2} experienced during nighttime conditions at the SGP (Philipona, et al, 2001)

A second comparison was conducted at the NSA site in order to learn more about the accuracy of longwave measurements and calculations at lower irradiance levels.

As the SIRS and RCF Instrument Mentor, I was able to contribute to the IPASRC-II IOP along with my colleagues at NOAA/CMDL, WRC/PMOD, ASCR/SUNYA, and, of course, the NSA operations staff.

Accomplishments

Consistent with the approved Statement of Work, NREL performed the following technical services for the IPASRC-II IOP (See Appendix A).

Task 1: Planning and Preparations

NREL provided technical support for the development of the measurement systems and pre-IOP radiometer calibrations. Stoffel collaborated with other IOP participants (Rolf Philipona, Ellsworth Dutton, Joe Michalsky, and Jeff Zirzow) to provide information, hardware, software, and procedures for executing the IOP. Reda provided blackbody calibrations and outdoor characterizations of selected pyrgeometers prior to delivery to NOAA/CMDL for establishing reference standard instrument performance [Reda, et al, 1999].

Key NREL staff: Tom Stoffel and Ibrahim Reda

Task 2: Measurement Campaign

NREL assisted with the collection of longwave radiation measurements at the IOP site in Barrow Alaska and helped with instrument removal at conclusion of measurements. (See Figure 1). Table 1 has a summary of the instruments used for the IOP. NREL provided the NESLAB temperature-controlled circulating bath for operating the ASR.

Key NREL staff: Tom Stoffel

Task 3: Analyses and Reporting

NREL assisted the IOP Team with the analysis and reporting of the IPASRC-II measurements. In particular, NREL produced the results of selected pyrgeometer calibrations using the new ARM Pyrgeometer Blackbody Calibration System at NREL's Solar Radiation Research Laboratory. Results were summarized in a technical poster at the ARM Science Team Meeting, March 2001.

Key NREL staff: Ibrahim Reda

Results

Measured downwelling longwave irradiance from 12 pyrgeometers and abbreviated scans from the ASR were collected during the nights of March 11 – 14, 2001 at the Barrow facility. Sky conditions were excellent, providing the cold, cloudless measurements needed for the IOP. Preliminary data analyses indicate good agreement among the commercially available pyrgeometers (See Figure 1). For the most part, longwave irradiance measurements differed by less than ± 3 to ± 6 Wm^{-2} over the range of 120 to 160 Wm^{-2}. Blackbody calibrations performed by NOAA/CMDL prior to deployment in Barrow, were used to compute the measured longwave irradiances for the IOP.

Early reviews of the data suggest the need for calibrating pyrgeometers according to the intended climate regime. This is consistent with the protocols developed by the World Meteorological Organization's Baseline Surface Radiation Network (BSRN). Additionally, the value of combining controlled blackbody characterizations and "field calibrations" under atmospheric conditions for pyrgeometer calibrations is consistent with the proposed strategy for the ARM Program (See Appendix B).

Expense Summary

Transportation	$ 1424.51
Lodging	150.00
Miscellaneous & Incidental Expenses	691.36
Total Expenses	$2,265.87

References

Eppley: Precision Infrared Radiometer Specifications. **http://www.eppleylab.com**

Hickey, J., 2000: Instrument Manual, Pyrgeometer Blackbody Calibration System Version 2.0. The Eppley Laboratory, Inc., Newport, RI. 15 pp.

Kipp & Zonen: Pyrgeometer Model CG-4 manual.
http://www.kippzonen.com/product/cg4.html

Philipona, R., Fröhlich, C., 1994: A new Approach to Calibrate Eppley PIR Pyrgeometer, TECO-94, WMO/TD-No. 588. World Meteorological Organization, Geneva, Switzerland.

Philipona R., Fröhlich, C., and Betz Ch., 1995: Characterization of Pyrgeometers and the Accuracy of Atmospheric Longwave Radiation Measurements, Applied Optics Vol 34, 1598-1605.

Philipona, R., E.G. Dutton, T. Stoffel, J. Michalsky, I. Reda, A. Stifter, P. Wendling, S.A. Clough, E.J. Mlawer, G. Anderson, H.E. Revercomb, and T. R. Shippert, 2001: Atmospheric Longwave Irradiance Uncertainty: Pyrgeometers Compared to an Absolute

Sky-scanning Radiometer, AERI, and Radiative Transfer Model Calculations. Journal of Geophysical Research – Atmospheres (In Press).

Reda, I., T.L. Stoffel and J.A. Treadwell, 1999: Pyrgeometer Calibrations for the ARM Program. Proc. Ninth ARM Science Team Meeting. San Antonio, Texas, March 22-26, 1999.

Figures and Tables

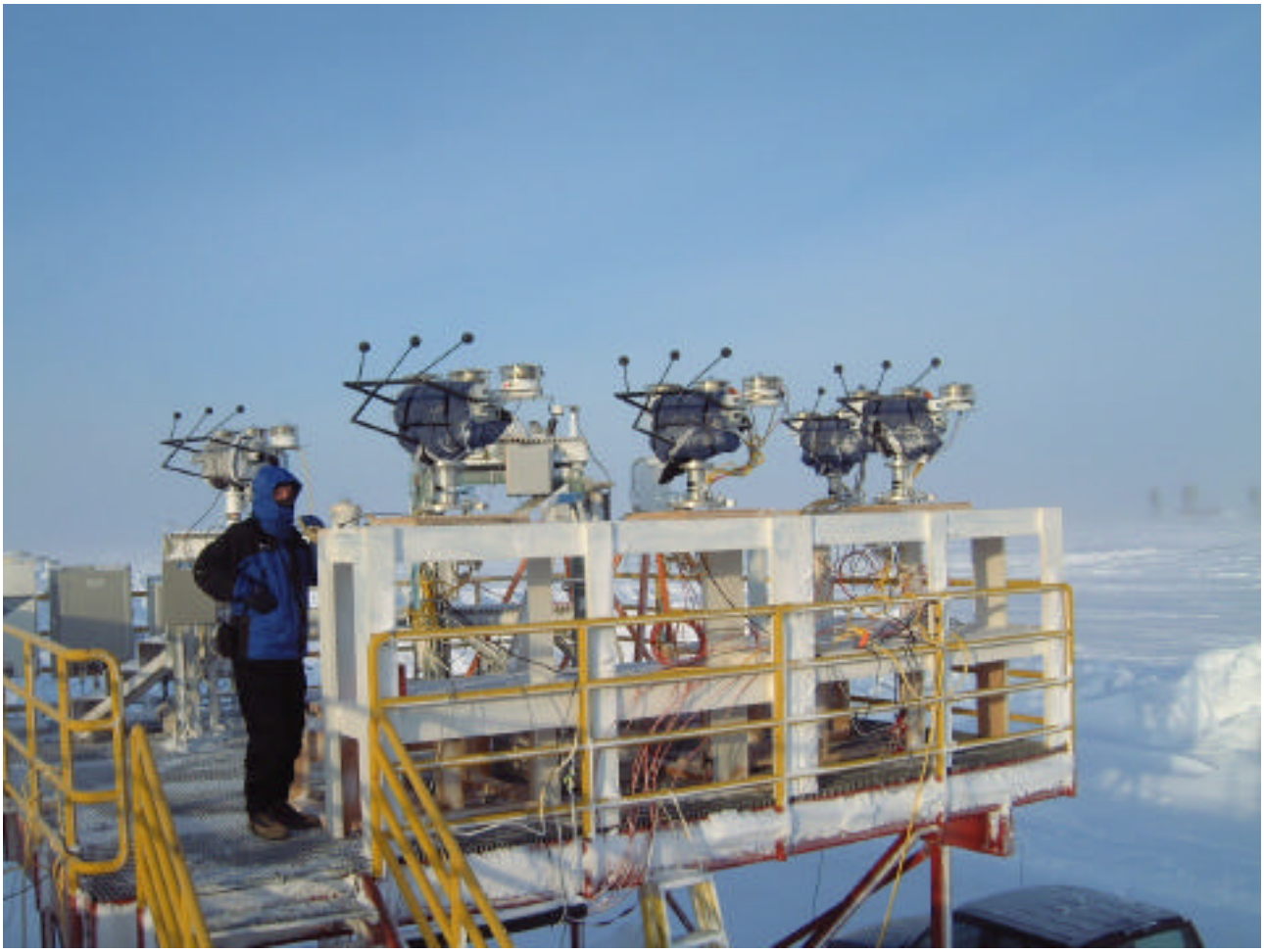

Figure 1. IPASRC-II Instruments Deployed at ARM's Barrow Station

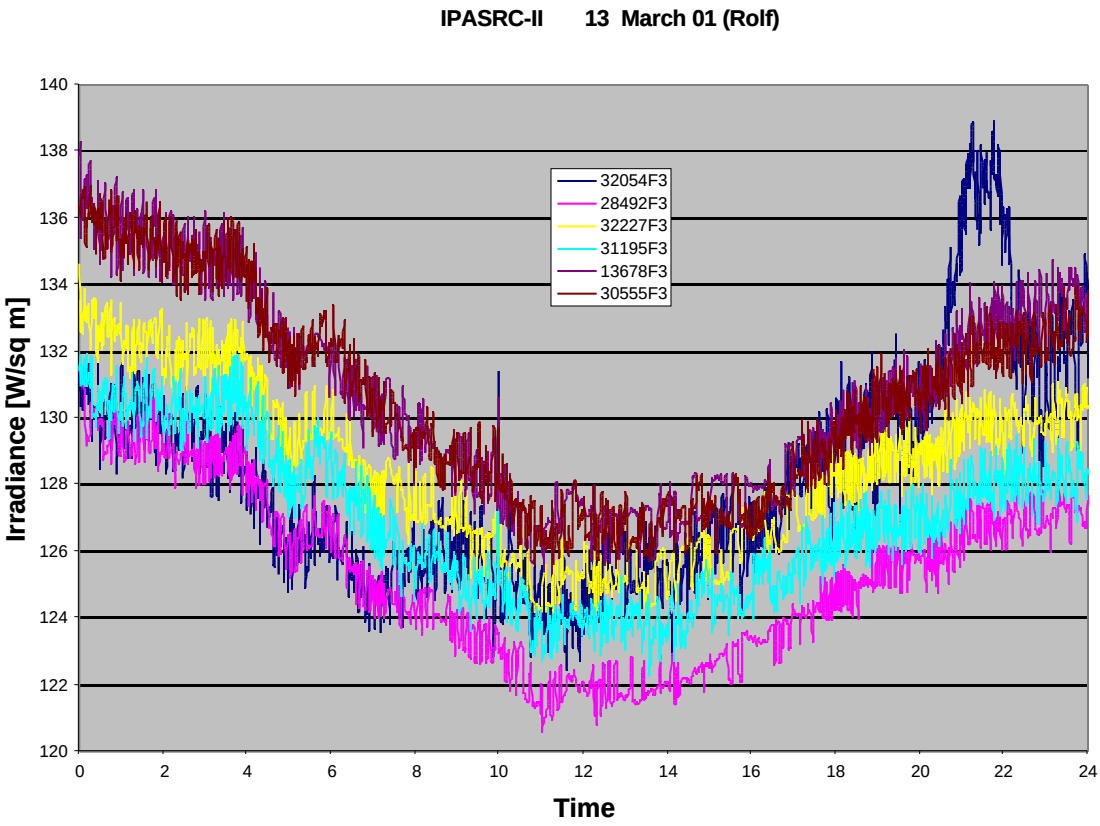

Figure 2. Measurement Sample from Six Pyrgeometers Based on NOAA/CMDL Blackbody Calibrations.

Table 1. List of Pyrgeometers and Pyranometers Used in IPASRC-II

No.	Serial Number	Owner / Model
1	31463F3	Physikalisch-Meteorologisches Observatorium Davos (PMOD) / PIR
2	FT005	PMOD / CG-4
3	FT004	PMOD / CG-4
4	32205F3 mod	Japan Meteorological Association / PIR
5	32054F3	NASA / PIR
6	31195F3	NREL / PIR
7	13678F3	Australian Bureau of Meteorology / PIR
8	26036F3 mod	NASA / PIR
9	30555F3	NOAA – Climate Monitoring & Diagnostics Laboratory / PIR
10	30475F3 mod	Deutcher Vetter Deinst / PIR
11	32227F3	The Eppley Laboratory, Inc. / PIR
12	28146F3 mod	Canadian Atmospheric Environment Service / PIR
13	32046F3	NASA / PSP (Diffuse Shortwave)
14	29255F3	NOAA – Surface Radiation Research Branch / PSP
15	32041F3	ARM-North Slope of Alaska / PSP (Global)

Appendix A.

STATEMENT OF WORK
National Renewable Energy Laboratory
Amendment to FY 2001 Tasks

BACKGROUND

The Atmospheric Radiation Measurement (ARM) Program has scheduled an Intensive Operational Period (IOP) at the North Slope of Alaska for the Second International Pyrgeometer & Absolute Sky-scanning Radiometer Comparisons (IPASRC-II). The purpose for the IOP is to better understand the measurement of longwave irradiance at the surface and to improve the calibration of pyrgeometers.

In support of the IOP, the National Renewable Energy Laboratory (NREL) shall provide technical services as described below.

SCOPE

The National Renewable Energy Laboratory (NREL) participation in the ARM Program's IPASRC-II IOP consists of the following tasks:

Task 1: Planning and Preparations

Provide technical support for the development of the measurement systems and pre-IOP radiometer calibrations. Collaborate with other IOP participants (Rolf Philipona, Ellsworth Dutton, Joe Michalsky, and Jeff Zirzow) to provide information, hardware, software, and procedures for executing the IOP. Provide blackbody calibrations and outdoor characterizations of selected pyrgeometers prior to delivery to NOAA/CMDL for establishing reference standard instrument performance.

Key NREL staff: Tom Stoffel and Ibrahim Reda

Task 2: Measurement Campaign

Assist with the collection of longwave radiation measurements at the IOP site in Barrow Alaska. Help with instrument removal at conclusion of measurements.

Key NREL staff: Tom Stoffel

Task 3: Analyses and Reporting

Assist the IOP Team with the analysis and reporting of the IPASRC-II measurements.

Key NREL staff: Ibrahim Reda

MAJOR MILESTONES

1. IOP Preparations – Logistical support for installation of pyrgeometers and the Absolute Skyscanning Radiometer at the NSA site in Barrow, Alaska. [March 2, 2001]
2. IOP Operations – Technical support for the operation and maintenance of the radiometer systems during the IOP. [March 5-17, 2001]
3. IOP Pyrgeometer Calibrations – Perform pre- and/or post-IOP calibrations of selected pyrgeometers using the Pyrgeometer Blackbody Calibration System at NREL. [April 30, 2001]
4. IOP Analyses and Reporting – Collaborations with IOP scientists [September 30, 2001]

DELIVERABLES

1. Ship NESLAB Circulator and supporting equipment to NSA [March 2, 2001]
2. Assist IOP scientists with data collection and radiometer operations [March 17, 2001]
3. Report of NREL participation through post-calibrations of pyrgeometers [September 30, 2001]

FY2001 FUNDING

IOP participation $30,260 [see attached *Cost Development Worksheet* for details]

Appendix B.

Pyrgeometer Calibration Strategy For the ARM Program

Tom Stoffel

September 21, 2001 (Revised 10-17-01)

SUMMARY

In the absence of an internationally recognized calibration standard for pyrgeometers, the ARM Program has developed a calibration method based on a new blackbody system and outdoor comparisons with transfer standards. The measurement uncertainty goal for broadband longwave irradiance data from all pyrgeometers deployed in the SIRS and ARCS platforms is ± 1 Wm^{-2}. Preliminary analyses of our present capabilities suggest the calibration process approaches this limit. Routine pyrgeometer calibrations are planned to begin in 2002. Measurement research will continue to improve the calibration processes, pyrgeometer characterizations, and overall quality of field data.

BACKGROUND

Atmospheric longwave radiation is one of the most fundamental elements for understanding climate change. The ARM Program has deployed dozens of pyrgeometers to collect the downwelling and upwelling components of longwave irradiance. The quality of these measurements is greatly dependent on accurate, traceable, and routine calibration.

Presently, there is no internationally recognized standard for the calibration of pyrgeometers. Historically, the radiometer community has relied on well-characterized blackbody calibration chambers for pyrgeometer calibrations. In the past few years, the development of an Absolute Sky-scanning Radiometer (ASR) by the Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center (PMOD/WRC) has provided a completely different design and measurement principle for calibrating pyrgeometers out of doors. To date, two international comparisons of pyrgeometers, calibrated by a variety of blackbody designs and methods, and the ASR have provided measurement results for establishing the relative accuracies of longwave irradiance data from commercially available pyrgeometers.

APPROACH

The ARM Program will use a combination of indoor blackbody characterizations of reference standard pyrgeometers and outdoor comparisons to calibrate pyrgeometers for continuous field measurements. Working with The Eppley Laboratory, Inc. and

the National Renewable Energy Laboratory (NREL), the ARM Program has developed an improved Pyrgeometer Blackbody Calibration System that can achieve the calibration protocols developed by the World Meteorological Organization's Baseline Surface Radiation Network (BSRN). Several pyrgeometers have been calibrated and characterized using the new calibration system. Some of these instruments have participated in both of the International Pyrgeometer and Absolute Sky-scanning Radiometer Comparisons (IPASRC-I and IPASRC-II). The results of these comparisons indicate good agreement between indoor blackbody calibrations and outdoor comparisons, approaching ± 1 Wm^{-2} precision for some instruments and up to ± 6 Wm^{-2} for some conditions.

A Pyrgeometer Blackbody Calibration System will be installed at the Radiometer Calibration Facility at the Southern Great Plains site (SGP/RCF) and at the Solar Radiation Research Laboratory at NREL (See Fig. 1). These two blackbody systems will be used to calibrate and characterize eight existing pyrgeometers, six Eppley Model PIR and two Kipp & Zonen Model CG-4, forming two Pyrgeometer Transfer Reference Groups (PTRG). Each PTRG will be calibrated and characterized at least annually at NREL and the SGP/RCF.

Standard metrology practices require a traceable, stable, and fully characterized measurement reference (e.g., the World Radiometric Reference for broadband shortwave irradiance developed and maintained by the PMOD/WRC). The Pyrgeometer Transfer Reference (PTR) for the ARM Program has been established as the average of the PTRG instruments when deployed for outdoor, downwelling, irradiance measurements (See Fig. 2). The PTR will be maintained by inter-comparisons of the PTRGs at NREL and SGP/RCF. The calibrations of all of the pyrgeometers deployed for operation at all ARM field sites will be calibrated and characterized annually using the PTR at the SGP/RCF (See Fig. 3).

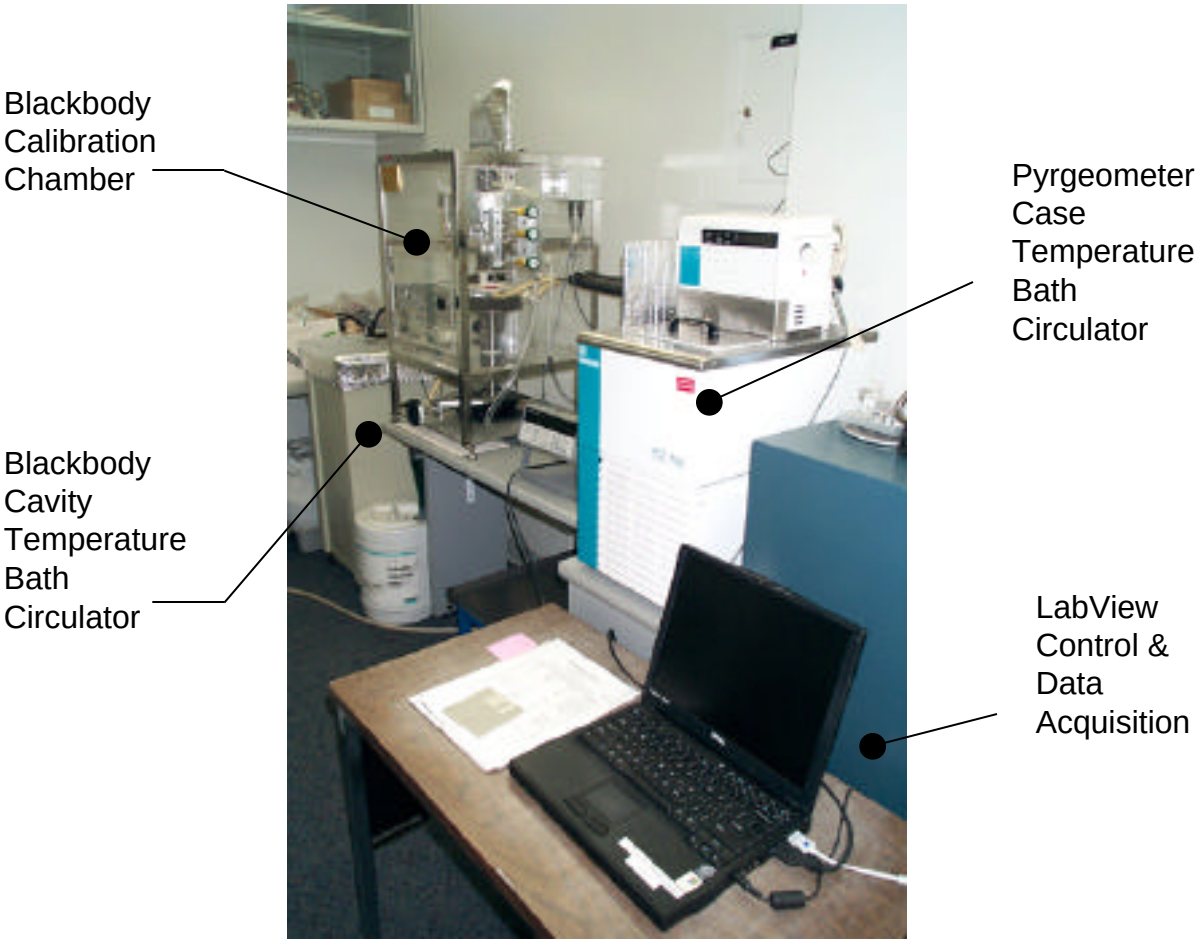

Figure 1. ARM Pyrgeometer Blackbody Calibration System

Figure 2-a. PIR mounted on thermal controller

Figure 2-b. CG-4 with adapter below blackbody

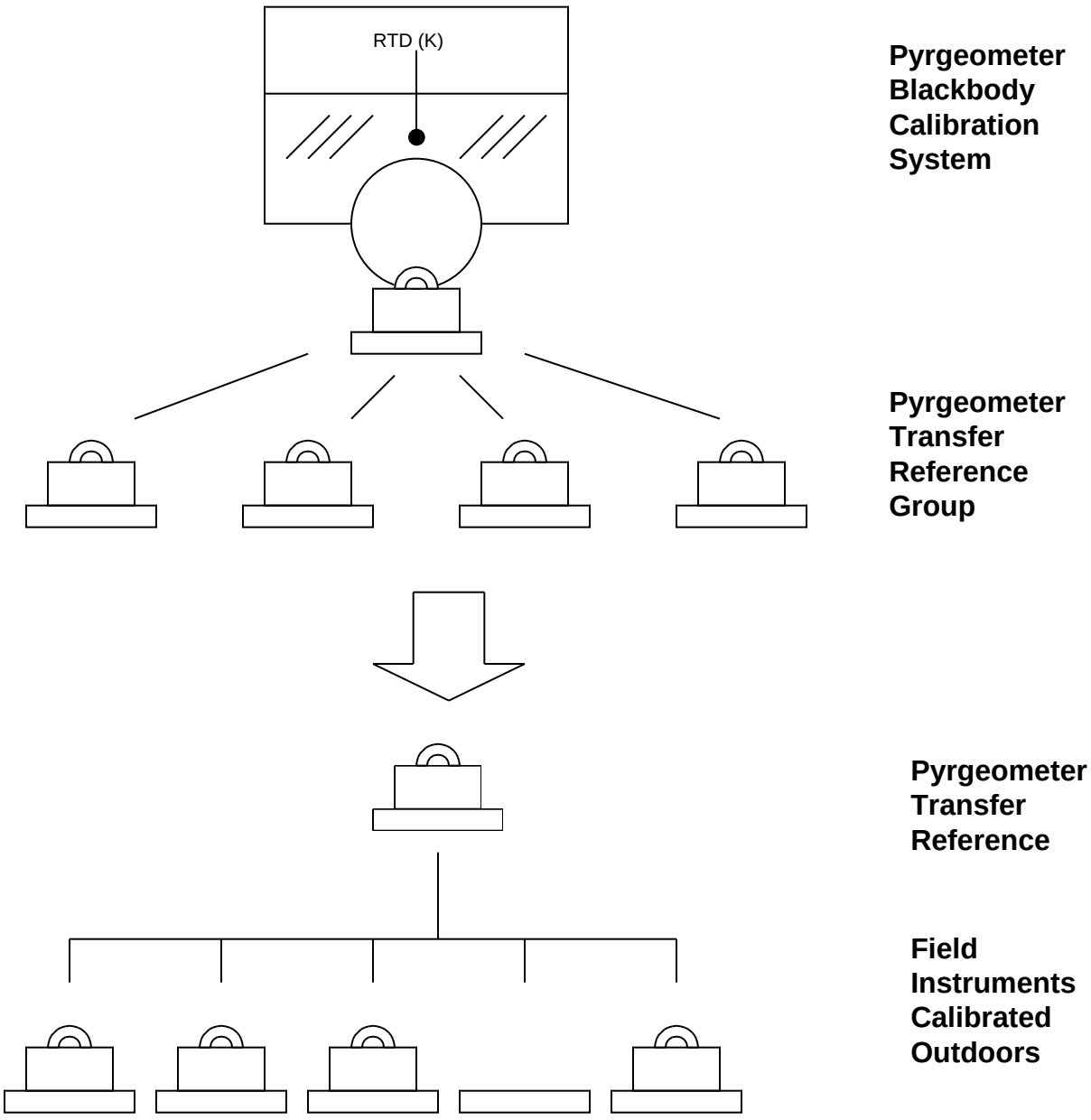

Figure 3. Pyrgeometer Calibration Concept Diagram