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NIST/BFRL CALIBRATION SYSTEM FOR HEAT-FLUX GAGES

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ABSTRACT

This report of test describes a heat-flux gage calibration system that was developed at the National Bureau of Standards during the 1970s. It is based on a commercial radiant heater incorporating a tungsten lamp and elliptical mirror. A kaleidoscope flux redistributor is used to improve the uniformity of the heat flux distribution at the gage surface. The results of recent calibrations for ten heat flux gages are compared with calibrations supplied by the gage manufacturer.

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Fire researchers in the Building and Fire Research Laboratory of the National Institute of Standards and Technology and their predecessor institutions have used an in-house facility for calibrating heat-flux gages for at least twenty-five years. Despite the long term use of and general satisfaction with the facility, there appears to be no existing written record of the calibration system. This Report of Test is designed to capture existing knowledge of this facility as of August, 2001.

The facility was designed and constructed by Dr. James Quintiere working with William Rinkinen.

1. Calibration Facility

The heat source consists of a commercial radiant heater (Model RH-2, Part No. 122-001, Serial Number 003, NBS #182887, no updated NIST number) from Tamarack Science Co., Inc. of 281 E. Emerson Ave., Orange, CA 92665.* Apparently, this company is no longer in existence. A search identified an existing company in Orange, CA named Tamarack US Corporation, but when contacted, they professed no knowledge of Tamarack Science Co. The NBS serial number indicates this lamp was purchased in 1974.

The radiant heater incorporates a 2000 W tungsten-halogen filament lamp (Model CYX) from Sylvania. A spare lamp is available. The lamp is located in a large ellipsoidal reflector, with the lamp placed at one of the foci and the entrance to the kaleidoscope flux redistributor (see below) at the other. The distance between the foci is roughly 30.5 cm. The lamp is placed inside the ellipsoidal mirror through a hole in the lower rear of one side. A metal housing surrounds the half of the ellipsoidal mirror containing the lamp. The mirror passes through the wall of the housing and extends 10 cm before being cut off short of the second focus of ellipse. The lamp housing with extended mirror can be seen in the photograph included as Figure 1.

A 25.4 cm wide × 26.4 cm high blackened radiation shield with a 6.4 cm wide × 6.4 cm high square cut out centered on the mirror axis is positioned 2.5 cm from the mirror. A small box open at both ends is attached over the radiation shield cut out on the side opposite to the lamp. (see Fig. 1) Its length is roughly 7.6 cm. Dr. Quintiere indicated that this box was designed

*Certain commercial equipment, instruments, or material are identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment are necessarily the best available for the purpose.

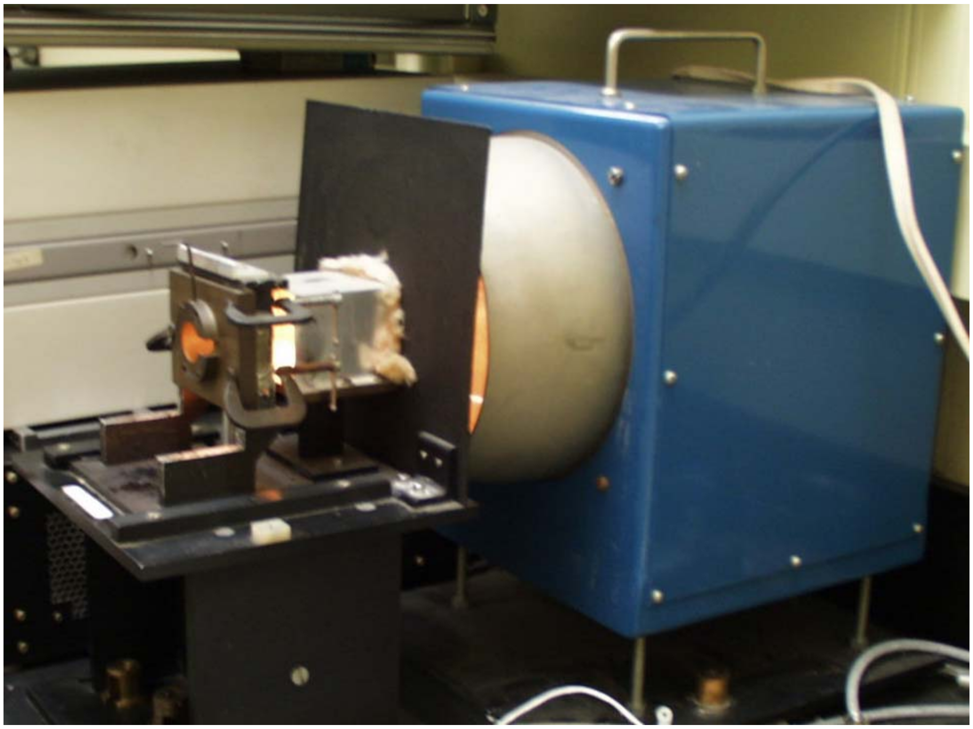

Figure 1. A photograph of the NIST/BFRL Calibration System for Heat-Flux Gages is shown. The blue box is the housing for the 2 kW tungsten lamp, and a portion of the ellipsoidal mirror can be seen extending from the housing. Other components include the heat shield, kaleidoscope flux redistributor, and the mount for the heat flux gages.

to improve the uniformity of the heat flux spatial distribution reaching the gage.[1] This type of devices has been described in the literature by Chen et al.[2] and Glaser et al.[3] They refer to it as a "kaleidoscope" or "flux redistributor." When its entrance is placed at the focal point of an optical system, internal reflections of light within the box redistribute the energy flux by forming and superimposing multiple images such that the flux distribution becomes more uniform at the exit.

The heat flux gage to be exposed is placed in a specially machined metal holder measuring 11.4 cm wide × 8.3 cm high with a centered 2.5 cm diameter hole (see Fig. 2). Either the gage itself (for 2.5 cm gages) or a machined 2.5-cm-diameter holder with inserted heat flux gage (for gages smaller than 2.5 cm) is placed in this holder such that the heat flux gage surface is flush with the mount side facing the lamp. A set-screw is used to lock the gage or mount in place.

The gage holder is clamped to a mount measuring 11 cm wide × 13.7 cm high with a 15.2 cm wide × 10.4 cm long base with two slots on either side of the lamp axis. The mount and gage holder are secured with bolts to a 25.4 cm wide × 23.9 cm wide × 18.8 cm high pedestal equipped with two slotted bars attached to its top surface such that they form a slide for the gage mount. This arrangement allows the distance between the gage surface and the kaleidoscope flux redistributor to be adjusted along the system's horizontal axis.

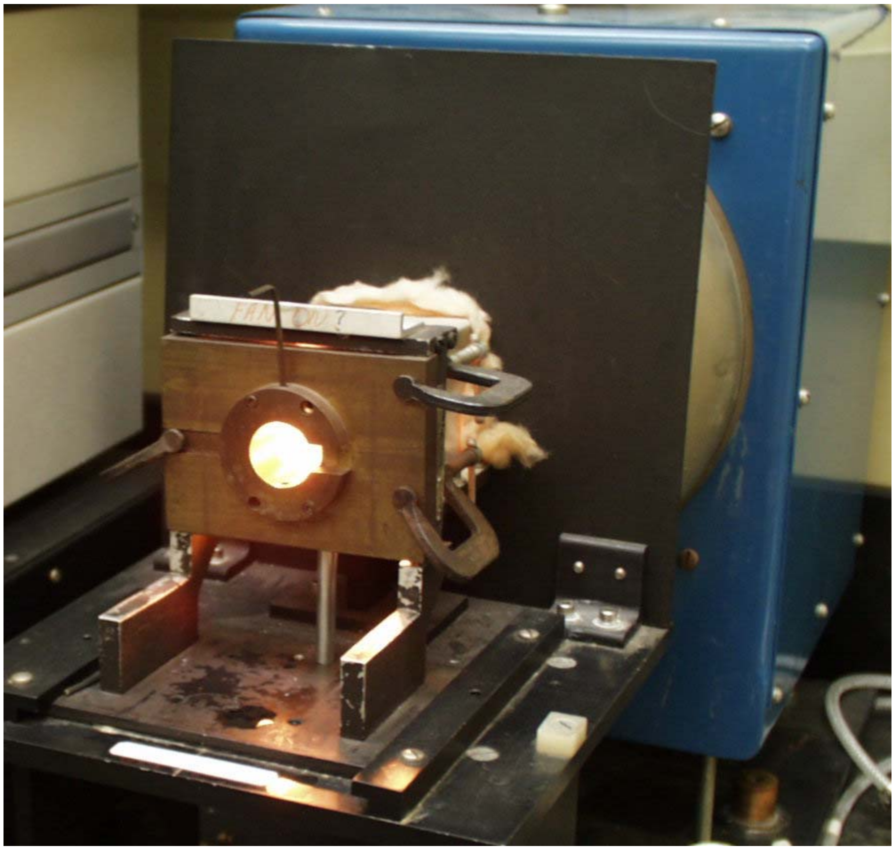

Figure 2. Close-up photograph showing the heat-flux gage holder and mount attached to the pedestal.

In addition to the heat flux gage mount, the kaleidoscope flux redistributor and radiation shield are attached to the pedestal. Brackets are used for the shield that is placed 1.3 cm from the edge of the pedestal facing the lamp. A specially constructed mount is attached to the pedestal to hold the kaleidoscope flux redistributor in place. The open distance between the read end of the kaleidoscope flux redistributor and the surface of the heat flux gage mount is roughly 3.3 cm.

Both the radiant heat source and the pedestal are attached to a 34.9 cm wide × 71.1 cm long × 0.6 cm thick metal base. The base is equipped with 2.2 cm high legs. The lamp housing is mounted with threaded rods that allow the height of the lamp to be varied relative to the base. The lower side of the pedestal is slotted along the lamp-axis direction so that the pedestal can be positioned before being bolted securely to the base.

To our knowledge, no adjustments to the apparatus have been made since it was originally configured. No records of initial testing have been found, but conversations with Dr. James Quintiere indicated that adjustments and measurements were made to ensure that the radiant flux level over the 2.5 cm diameter circular area corresponding to the location of the heat flux gage was uniform.[1]

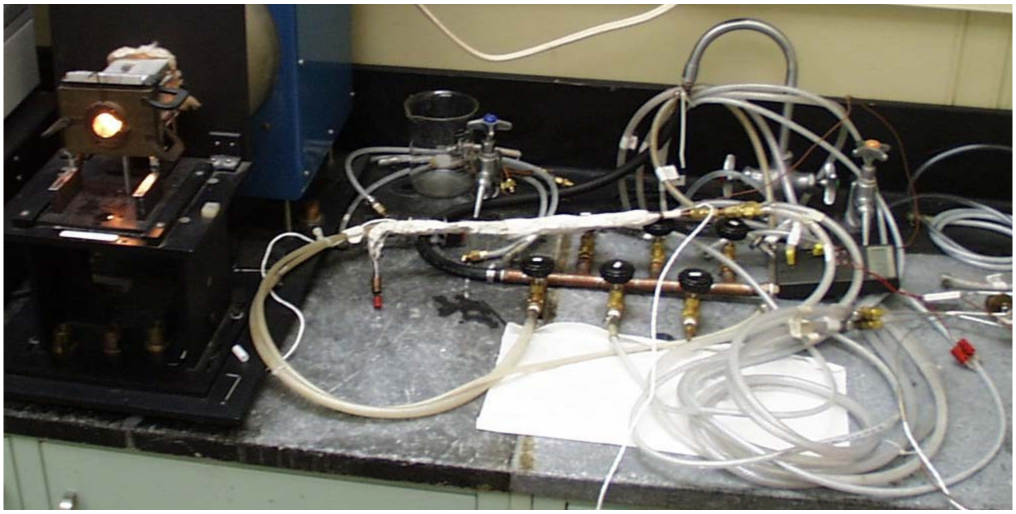

Figure 3. This photograph shows the water manifold used to provide water flows for up to six heat-flux gages.

Heat flux calibrations are performed using secondary-standard heat flux gages. Two Gardon gages, originally calibrated by the Radiometric Physics Division of the National Bureau of Standards in 1974, have been used. One of the standard gages was inadvertently used during actual fire testing, and was subsequently removed from service as a secondary standard. A brief description of the two gages and their calibrations is included in Appendix A.

The lamp is powered by a Sorenson DCR 150-18A DC power supply, which allows the voltage and current to be varied from 0 V to 200 V and 0 A to 20 A, respectively. The voltage outputs of the heat flux gages are recorded with a HP 3456A digital voltmeter using a 60 s averaging period with two readings per second.

A system of water lines (shown in Fig. 3) has been assembled with valves such that controlled volume flow rates of tap cooling water can be provided to up to six heat flux gages simultaneously. The water temperature is generally recorded during a test.

2. Calibration Procedure

A written procedure prepared in 1985 is used for heat flux gage calibrations with the current system. It is reproduced in Appendix B.

In order to perform a heat-flux gage calibration an arbitrary heat flux level is initially set by adjusting the lamp power supply voltage and current. A sufficient period (generally 20 min) is allowed for the lamp intensity to stabilize. After the lamp intensity is stabilized, the secondary-standard heat flux gage is positioned in the holder (see Fig. 4) and connected to the digital voltmeter (see Fig. 5). The voltage generated by the gage is then recorded. Generally, five or more 30 s readings are recorded to ensure that the radiant flux is not changing. At this point a 60 s average is recorded that is taken as the gage response to the imposed heat flux. The

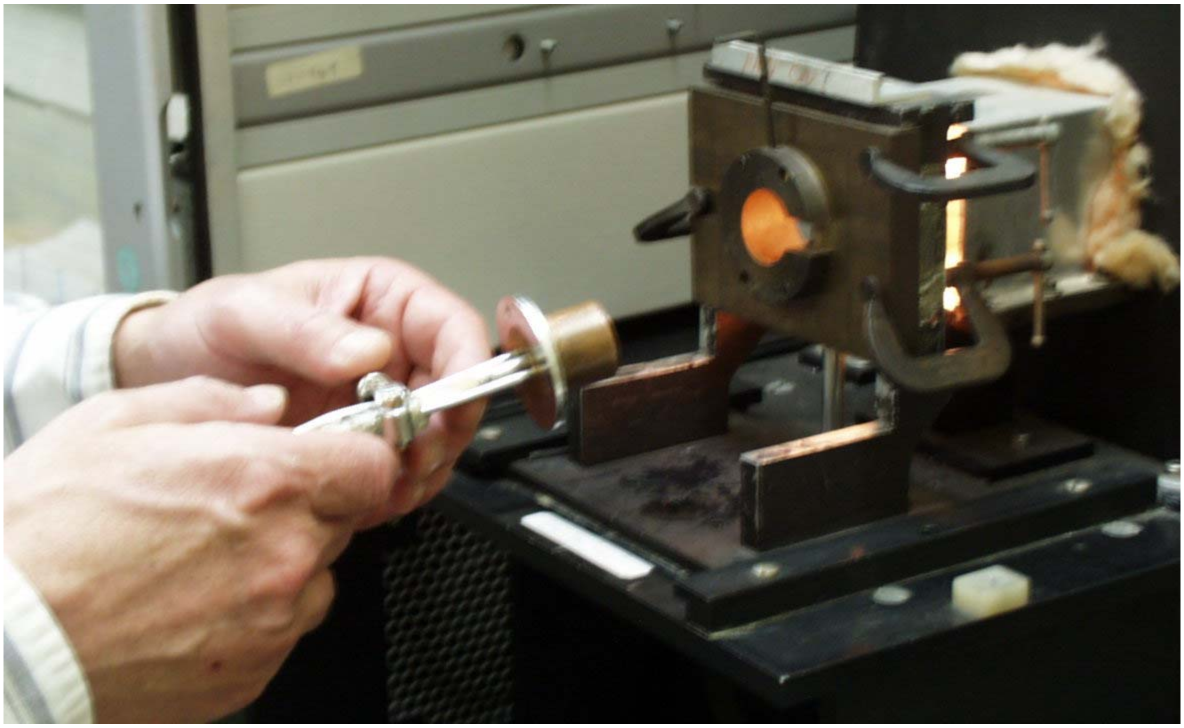

Figure 4. Photograph showing a heat flux gage being placed in the calibration facility.

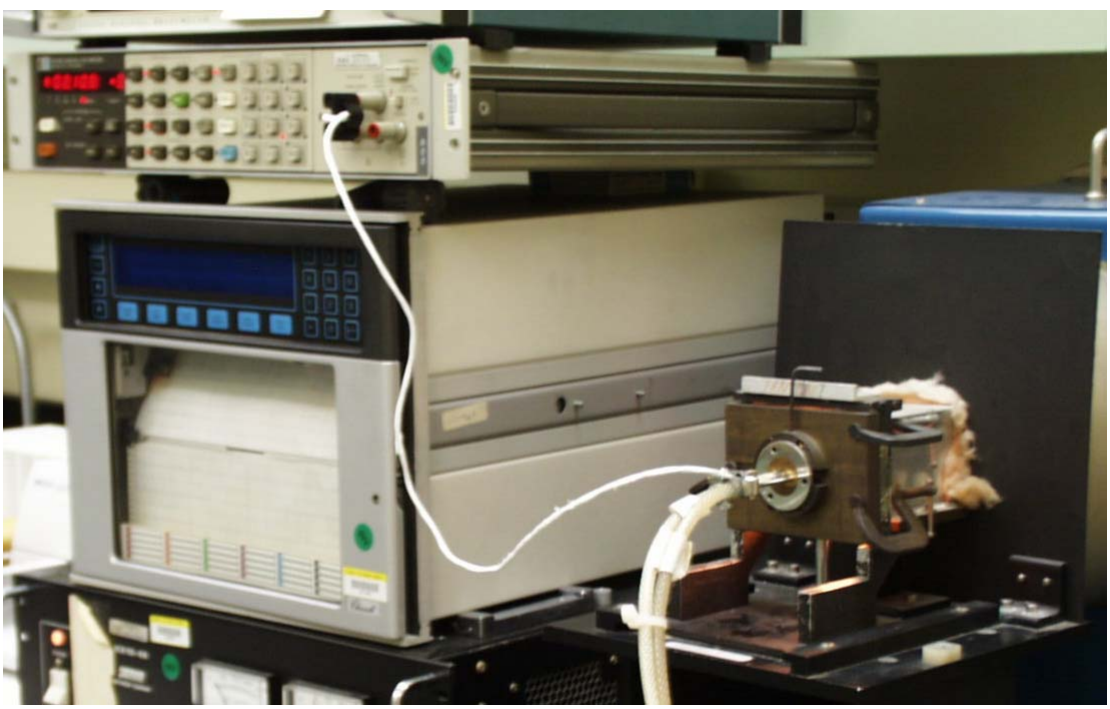

Figure 5. Photograph of a heat flux gage in place in the calibration facility and connected to the voltmeter and water lines.

corresponding heat flux at the gage location is determined using the calibration value from the secondary standard.

Following the characterization of the heat flux, the standard gage is immediately replaced with the gage to be calibrated, and a 60 s average voltage is recorded, taken to be the response of the gage to the imposed heat flux. If more than one gage is to be calibrated, the measurement is repeated until the response of each gage to be calibrated has been recorded for the current applied heat flux.

Generally, gage response is characterized at three or more flux levels. Once a calibration cycle is completed, the lamp output is readjusted to another flux level, and, following a stabilization period, the entire measurement procedure is repeated. As an example, during a recent test, lamp currents of approximately 4 A, 5 A, 6 A, and 6.8 A were used to generate heat flux levels at the gage on the order of 1.8 kW/m^2, 4 kW/m^2, 10 kW/m^2, and 15 kW/m^2, respectively. Current practice is to limit maximum heat flux values to no more than 15 kW/m^2 in order to protect the secondary-standard gage and the lamp.

Following the completion of a calibration the results are plotted as imposed heat flux (kW/m^2) versus the corresponding gage output readings in mV. Generally a linear least squares curve is employed to fit the experimental data points, and the result is reported in terms of kW/m^2 per millivolt.

3. Comparison of NIST/BFRL Calibration with Values Provided by a Heat Flux Gage Vendor

It is not possible without a full and careful study to assess the absolute accuracy of calibrations using the NIST/BFRL calibration facility. Some insights can be obtained by comparing the results with calibrations supplied by a commercial supplier of heat flux gages. Recently ten heat flux gages were purchased by BFRL researchers and calibrated using the approach described in this report at various values of heat flux up to 15 kW/m^2. The results were fit to a straight line. The heat-flux gage manufacturer provided gage output voltages for a 100 kW/m^2 imposed flux. In order to compare the two results, the NIST/BFRL calibrations were extrapolated to 100 kW/m^2. Table 1 lists the output voltages supplied by the manufacturer for the ten gages and compares them with values extrapolated from the internal NIST/BFRL calibrations. The results are plotted graphically in Fig. 6.

It is evident that the predicted voltage outputs based on the NIST/BFRL calibrations all fall below the values based on the manufacturer’s calibrations. The average difference for the ten gages is 2.3 %. The data also indicate that the two sets of calibrations are highly correlated with both yielding very similar slopes. Based on this result, as well as the slight variations in data around a line evident in Fig. 6, it is concluded that the repeatability of heat flux calibrations using this facility is better than 2 %.

Table 1. Comparison of Output Voltages for 100 kW/m^2 Provided by Manufacturer and Values Extrapolated From NIST/BFRL Calibrations

Gage #	Manuf. Calibration	NIST Extrapolation	% Difference
1	13.08 mV	12.77 mV	-2.4
2	13.23 mV	12.94 mV	-2.2
3	13.90 mV	13.56 mV	-2.4
4	13.64 mV	13.36 mV	-2.1
5	13.22 mV	12.85 mV	-2.8
6	12.39 mV	12.05 mV	-2.7
7	13.33 mV	13.12 mV	-1.6
8	13.22 mV	12.98 mV	-1.8
9	13.21 mV	12.94 mV	-2.0
10	13.69 mV	13.33 mV	-2.6

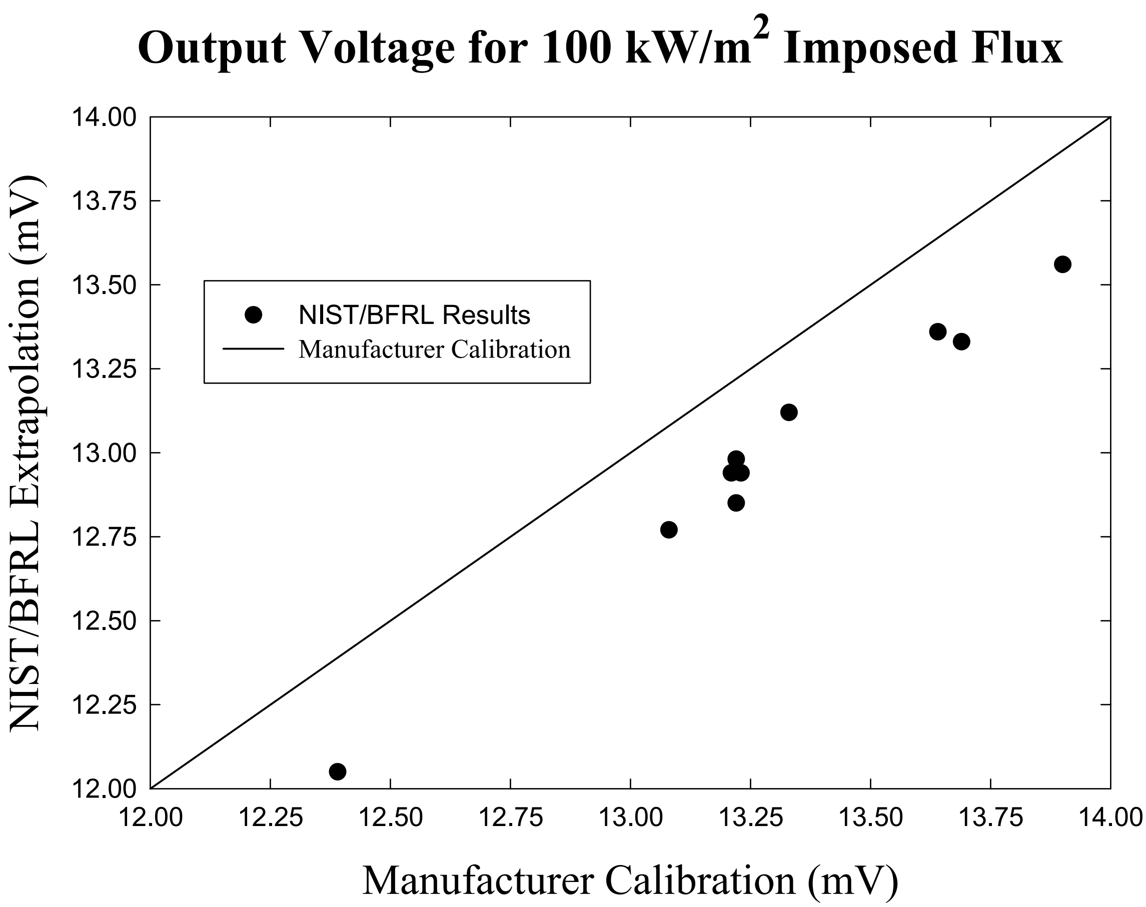

Figure 6. Comparison of manufacturer and NIST/BFRL calibration results for ten commercial heat flux gages in terms of the output voltage for a 100 kW/m^2 input. The manufacturer imposed a 100 kW/m^2 flux, and the NIST value has been extrapolated to this value using a calibration curve determined using lower heat flux values.

4. Acknowledgements

The authors thank Dr. Jim Quintiere, (University of Maryland) Ken Steckler, (ATF) Dr. Tom Ohlemiller, (NIST) Dr. Bill Grosshandler (NIST), Dr. Rodney Bryant (NIST) and Dr. Ben Tsai (NIST) for many helpful discussions and suggestions.

5. References

1. J. G. Quintiere, University of Maryland, College Park, MD, personal communication (July, 2001)
2. M. M. Chen, J. B. Berkowitz-Mattuck, and P. E. Glaser, "The Use of a Kaleidoscope to Obtain Uniform Flux Over a Large Area in a Solar or Arc Imaging Furnace," Applied Optics 2, 265-271 (1963).
3. P. E. Glaser, M. M. Chen, J. Berkowitz-Mattuck, "The Flux Redistributor," *Solar Energy* **7**, 12-17 (1967).

Appendix A: Secondary-Standard Heat Flux Gages

Two commercial Gardon gages, purchased from Medtherm Corporation in 1974, have been used as secondary heat flux standards in the NIST/BFRL heat flux gage calibration facility. Both were calibrated by William Waters of the Radiometric Physics Division.

The first gage is a Model 64-2-20 (serial # 124421) equipped with a flange and having a nominal full-scale range of 23 kW/m^2. Its calibration constant was measured to be 2.69 (kW/cm^2)/mV. This is the sole secondary heat flux gage standard currently used with the facility.

The second gage was a Model 64-1-20 (serial #11971) equipped with a flange and having a nominal full-scale range of 11 kW/m^2. Its calibration constant was measured to be 1.335 (kW/cm^2)/mV. This gage is the one inadvertently used in a fire test, and it has been retired as a secondary standard, even though it is still maintained within the lab.

The second gage was the one used for the calibration example included in Appendix B. The sample date indicated the data was recorded on Oct. 1, 1985. It is clear from this example, as well as Instruction #8 in Appendix B, that it was common to use this heat flux standard gage at levels well above its nominal full-scale range.

Appendix B: PROCEDURE FOR CALIBRATING FLUX SENSORS

1. Plug in fan

2. Plug in voltmeter

3. Place Standard Sensor in holder

4. Connect H_2O line to Standard Sensor

5. Connect H_2O line to sensor to be calibrated

6. Turn on H_2O – small flow – note whether using hot or cold H_2O
(normal procedure uses cold water)

7. Turn on Power Supply (some nominal setting – 5 Amps, 25 Volts)
Allow to come to equilibrium (reading at sensor voltmeter)

8. Record output of Standard Sensor and reference sensor at varying irradiances. Do not exceed 30 kW/m^2 for Standard Sensor.

Example:

Standard # 11971 Calibration Factor 0.1335 $(W/cm^2)/mV$
Reference # 331821

Standard (mV)		Calibration Factor $(W/cm^2)/mV$		(W/cm^2)	Reference (mV)	Reference Slope $(W/cm^2)/mV$
4.32	*	0.1335	=	0.5767	1.04	0.5545
7.21	*	0.1335	=	0.963	1.74	0.5534
11.68	*	0.1335	=	1.559	2.79	0.5588
13.58	*	0.1335	=	1.813	3.28	0.5527
					Average slope	0.5547

9. Plot data (see sample)

10. Determine reference sensor calibration factor from curve slope

11. Turn off Power Supply

12. Turn off H_2O

13. Disconnect H_2O line to reference sensor

14. Disconnect H_2O line to Standard Sensor

15. Remove Standard Sensor and replace in box

16. Unplug voltmeter

17. Unplug fan