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Calibration at 24 °C of a Heat-Flow-Meter Apparatus Having 610 mm Square Plates

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, MD 20899

Prepared for:
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of a Heat-Flow-Meter Apparatus

Having 610 mm Square Plates

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ABSTRACT: Results are summarized for 38 individual calibration measurements conducted at 24°C and atmospheric conditions for a heat-flow-meter apparatus having 610 mm square plates. The apparatus was calibrated using a 26.2-mm-thick specimen of fibrous-glass board having a density of 139 kg/m^3. The specimen was selected from an internal lot (Lot 1970) of Standard Reference Material (SRM) similar to SRMs 1450, 1450a, and 1450b. Values of apparent thermal conductivity were predicted using a regression equation developed for this lot of fibrous-glass insulation. Calibration measurements varied ±0.4% with a small drift of 0.4% over 250 days. The apparent thermal conductivity of the calibration specimen was also measured using the National Institute of Standards and Technology's one-metre Line-Heat-Source Guarded Hot Plate. Agreement between measurements of thermal conductivity of the guarded hot plate and predicted values were within +0.2 to -0.3% at 24°C. The report describes the heat-flow-meter apparatus and the computer data-acquisition-system used to collect data from the apparatus.

Key words: calibration, computer, data-acquisition-system, guarded hot plate, heat-flow-meter, heat-flux-transducer, Standard Reference Material

1. INTRODUCTION

Two time-proven methods to determine the thermal conductivity of flat specimens are the guarded hot plate and the heat-flow-meter apparatus (ASTM[1] Test Methods C 177 and C 518 [1], respectively). Both methods use parallel plates to induce a steady temperature gradient across the thickness of the specimen. However, whereas the guarded hot plate method is considered absolute in the determination of thermal conductivity, the heat-flow-meter apparatus requires calibration. To calibrate a heat-flow-meter apparatus, a specimen having a known thermal conductivity is used to determine the sensitivity of the apparatus. For this purpose, Standard Reference Materials and Transfer Standards are available from the National Institute of Standards and Technology (NIST).

As part of a project with the Department of Energy, NIST conducted 38 individual calibration measurements of a commercial heat-flow-meter apparatus over a period of 250 days. The apparatus utilizes a single heat-flux-transducer, 254 by 254 mm, embedded at the center of an electrically heated plate, 610 by 610 mm (see Configuration A of ASTM C 518 [1]). The heat-flow-meter apparatus was calibrated using a specimen of high-density fibrous-glass board selected from an internal lot of Standard Reference Material (SRM). The lot was the same material supplied as NIST's SRMs 1450, 1450a, and the most recent, 1450b. Calibration measurements were conducted under atmospheric conditions at room-temperature (24°C, 40% relative humidity) and a temperature difference of 22°C.

Prior to calibration measurements, the apparent thermal conductivity of the specimen was measured using NIST's one-metre Line-Heat-Source Guarded Hot Plate [2]. Measurements were conducted over a temperature range of 10 to 50°C and compared to values computed from an equation describing the apparent thermal conductivity [3] of the SRM lot of fibrous-glass insulation as a function of density and temperature. This report details the measurements of the guarded hot plate and the calibration of the heat-flow-meter apparatus. A description of the heat-flow-meter apparatus and computer data-acquisition-system is presented.

2. DESCRIPTION OF HEAT-FLOW-METER APPARATUS

2.1 History

The heat-flow-meter (HFM) apparatus was originally purchased by NIST in November of 1978. During the years 1981 to 1985, NIST re-designed several control circuits to extend the temperature-range capability of the original apparatus. While most of the field changes were documented, some were not. The departure of key personnel from 1985 to 1987 hastened inactivity of the apparatus. Eventually, extensive re-work by the manufacturer was necessary to continue operating the apparatus. In August of 1988, the apparatus was returned to the manufacturer to upgrade several components. The upgraded HFM apparatus was delivered to NIST in August of 1989.

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[1]American Society For Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187.

2.2 Design Characteristics

The first objective of the upgrade was to improve the response-time of the heat-flow-meter apparatus. To achieve a quicker response of the apparatus, two components were replaced. The heat-flux-transducer assembly was rebuilt using a thin, light-weight, heat-flux-transducer and the original temperature sensors (RTDs - resistive temperature devices) in the hot and cold plates were replaced with Type K thermocouples[2]. The second objective of upgrading the apparatus was to facilitate computer control and data acquisition. For automatic temperature control, the analog controllers for the hot and cold plates were replaced with digital, computer-addressable controllers. Additionally, an output connector for the sensors and temperature controllers was installed to facilitate data acquisition by a computer. A computer data-acquisition-system installed by NIST is discussed in Section 3.

Significant features of the heat-flow-meter apparatus are summarized in Table 1. Additional information for this type of apparatus is available in ASTM Standard Test Method C 518 [1].

TABLE 1

Characteristic Features of Heat-Flow-Meter Apparatus.

1. Configuration:	Single transducer - hot face, lower plate
2. Plate geometry[1]:	Square, nominal 610 x 610 mm
3. Meter-area:	Square, nominal 254 x 254 mm
4. Hot-face surface	
a. Range[2]:	20 to 50°C, Resolution 1°C
b. Emittance[3]:	0.80
5. Cold-face surface	
a. Range[2]:	0 to 30°C, Resolution 1°C
b. Emittance[3]:	0.82
6. Ambient-air range[2]:	10 to 40°C, Resolution 1°C
7. Thermocouple limit of error[2]:	Type K, ±1.1°C or 0.4% (special limits)

[1] Note, that the apparatus can accommodate specimens up to 615 by 615 mm, and up to 200 mm in thickness.
[2] Manufacturer's specification.
[3] Manufacturer's measurement, ASTM E 408.

The heat-flow-meter apparatus utilized a single heat-flux-transducer (254 by 254 mm) embedded in the center of the hot-face surface (Figure 1a). Encompassing the main heater for the heat-flux-transducer was a guard heater controlled by a 64-junction differential thermopile (Figure 1b). The temperature difference (Δ_{TP}) across the interface was controlled manually using a

[2]Nickel and 10 percent chromium (+) versus nickel and 5 percent aluminum and silicon (-)

potentiometer. The heat-flux-transducer consists of multiple copper-constantan (Type T) junctions deposited using a photoetching technique and located in parallel planes [4] (Figure 2).

Heat losses from the outer edges of the specimen were minimized by an air-conditioning system controlling the ambient air. Cooling for the apparatus was provided by two separate Refrigerant-12 systems. A small compressor circulated refrigerant to an expansion device in the upper cold plate while a larger compressor provided cooling and dehumidification for ambient air circulated around the plates. The evaporator coil for the ambient air was limited (by NIST) to 16°C by adjusting its pressure regulating valve. An electric resistance heater provided the heating power to raise the ambient air to 24°C for the calibration tests.

3. DESCRIPTION OF COMPUTER DATA-ACQUISITION-SYSTEM

3.1 Hardware

A schematic of the hardware for the computer data-acquisition-system is shown in Figure 3. The hardware for the computer data-acquisition-system consisted of three components; a personal-computer (PC) functioning as a controller, a data-acquisition-system (DAS), and an RS-232/422 serial interface. A stripchart recorder was also installed to monitor the apparatus independently. Sensor signals from the HFM were available at two locations: 1) an output connector for the DAS and 2) a connector for the stripchart indicator (see Figure 3). An RS-232/422 interface to address the temperature controllers was installed, but not used. Instead, temperature settings for the hot plate, cold plate, and ambient air were set manually.

The PC controller utilized an 8088 processor and two input/output (IO) cards for communication with external devices (via RS-232 and IEEE-488 protocols). For the RS-232 interface, an RS-232 serial port of the PC's random-access-memory card was configured as communication port #1. An RS-232/RS-422 serial interface was purchased to convert the RS-232 carrier signal to RS-422 (see Figure 3). To interface the PC and the DAS, a language-processor card for IEEE-488 protocol was installed. Software for IEEE-488 protocol was purchased from a vendor. To store data, the PC used a high-density disk drive capable of storing 1.44 megabytes per floppy disk.

All seven sensor signals of the HFM were scanned at minutely intervals using the DAS (controlled by the PC). Low-level DC voltage signals from the HFM sensors were measured in the DAS using an analog-to-digital, 5½-digit voltmeter having a resolution of 1 microvolt. A list of channels allocated for each sensor is shown in Table 2.

TABLE 2

Channel allocation for the HFM sensors.

Channel	Sensor
00	Thermocouple, Type K, Hot Plate (T_H)
01	Thermocouple, Type K, Cold Plate (T_C)
02	Thermocouple, Type K, not used
03	Thermocouple, Type K, Ambient (T_A)
04	Voltage, Thermocouple Reference
05	Voltage, Plate Separation (Δx)
06	Voltage, Heat Flux Transducer (E)
07	Voltage, Differential Thermopile (Δ_{TP}) between main & guard heaters

To communicate with the temperature controllers of the HFM, an RS-232/422 serial interface was used to convert the RS-232 carrier signal to RS-422. Unlike RS-232, RS-422 can handle multiple devices on the bus. However, each device must have its own unique address. In our case, the temperature controller for the ambient air, the hot plate, and the cold plate was assigned the addresses of 01, 02, and 03, respectively. The wiring diagram for the interface is shown in Appendix A.

3.2 Software for Collecting Data

A short program called HFM.BAS was developed at NIST to collect, reduce, and store data retrieved from the HFM. HFM.BAS was written in the BASIC programming language. To handle IEEE-488 protocol, additional BASIC software was purchased from a vendor. A listing of the program developed at NIST (lines 1100 to END) is provided in Appendix B.

HFM.BAS runs in one of two modes - calibrate or measurement - depending on the type of test required. The time interval of a scan is set to 1 minute, or multiples thereof (see line 2230 in Appendix B). For each scan, the program requests the DAS to monitor 7 channels (specified in Table 2), and then retrieves the raw-voltage values over the IEEE-488 interface. HFM.BAS reduces the raw-voltages to engineering data and displays the data for about 30 seconds on the monitor. For the remainder of the scan interval, the program displays a time-history of the last 15 scans of output of the heat-flux-transducer (HFT).

At the operator's discretion, a file is opened to store engineering data. The following parameters - T_H, T_C, T_A, E, Δx, Δ_{TP} (see Table 2), as well as the temperature difference (ΔT) and mean specimen temperature (T_M) - are stored at each scan interval. For a calibration test, HFM.BAS computes and stores values of the calibration coefficient (S). In the measurement mode, HFM.BAS computes and stores values of thermal resistance (R-value) and apparent thermal conductivity[3] (λ).

[3]For brevity, the term "thermal conductivity" shall be used in the remaining text of this report.

3.3 Software for Analyzing Data

At the conclusion of a test, the engineering data are imported into a spreadsheet and plotted to determine steady-state conditions. Generally, the output of the HFT is the key parameter in determining the steady-state portion of the test. The HFT output (in millivolts) for a four-hour calibration test using a 26.2 mm thick specimen of fibrous-glass board having a bulk density of 139 kg/m^3 is illustrated in Figures 2a, 2b, and 2c. Note, the ΔT for this test was maintained at 27.8°C. The transient portion of the test was less than 30 minutes (see Figure 4b). The steady-state portion for the HFT output is illustrated in Figure 4c ($\bar{E}$ = 3.675 ± 0.018 mV). The variation of 0.018 mV was derived from 2 times the standard deviation. A summary sheet of data for the steady-state portion of the test is illustrated in Appendix C.

3.4 Software for Temperature Controllers

As mentioned in section 3.1, the settings for the temperature controllers for the HFM are set manually. At present, HFM.BAS does not communicate with the temperature controllers of the HFM. However, a program is available from the manufacturer of the temperature controllers to monitor the controllers using the PC. This program is executed from the operating system environment (DOS) prior to loading BASIC.

4. CALIBRATION OF HEAT-FLOW-METER APPARATUS

4.1 Calibration Coefficient (S)

A calibration coefficient (S) for the HFM apparatus is determined from the following equation:

$$S = (T_H - T_C)/(E \cdot R) \tag{1}$$

where:

- S = calibration coefficient at the specimen thickness and mean temperature of the transducer $((W/(m^2 \cdot mV))$,
- T_H = hot plate temperature (°C),
- T_C = cold plate temperature (°C),
- E = output of the heat flux transducer (mV), and,
- R = specimen thermal resistance $(m^2 \cdot K/W)$.

Generally, S is determined as a function of temperature, and a calibration curve of $S=S[T_M]$ is generated over a range of mean specimen temperatures. Calibration curves may also be determined as a function of specimen thickness, $S=S[\Delta x]$. In this report, however, all calibration measurements of the HFM were conducted at T_M = 24°C with a single specimen having a thickness of 26.2 mm. Further details for calibrating the heat-flow-meter apparatus are available in ASTM Test Method C 518 [1].

4.2 Calibration Specimen

For calibrating NIST's HFM apparatus, a specimen of insulation was selected from an in-house lot of high-density fibrous-glass boards previously described by Siu [3]. Siu identified this lot of insulation as Lot 1970. Lot 1970 was the same material supplied later [5] to the Standard Reference Materials Program (Standard Reference Materials 1450, 1450a, and the most recent, 1450b). The specimen was identified by the letter "J" and the nominal size was 1220 by 1220 by 26 mm. Two specimens, one for NIST's one-metre Guarded Hot Plate and one for the HFM apparatus, were cut from the central area of "J". The relative sizes of the two specimens and the meter-areas of each apparatus are illustrated in Figure 5.

The thermal conductivity of Lot 1970 was predicted using a regression equation developed by Siu [3]:

$$\lambda = 0.02052 + 1.303\times10^{-5}\cdot\rho + 4.015\times10^{-10}\cdot T_M^3 \tag{2}$$

where:

ρ = bulk density of sample (kg/m^3), and
T_M = mean specimen temperature (K).

Regression coefficients were determined from a fit of 37 measurements of thermal conductivity of Lot 1970 using NIST's 200 mm square Guarded Hot Plate [3]. The bulk density for the 37 specimens ranged from 117 to 129 kg/m^3. The mean specimen temperature (T_M) of Equation 2 was defined as the average temperature of the hot and cold plates.

5. GUARDED-HOT-PLATE MEASUREMENTS

To check the value of λ predicted by Equation 2, the thermal conductivity of specimen "J" was determined using NIST's one-metre Line-Heat-Source Guarded Hot Plate (GHP) [2]. In 1989, nineteen (19) measurements of thermal conductivity for specimen "J" were conducted over the temperature range of 10 to 50°C. Measurements progressed in sequence starting at 10°C, proceeding to 50°C, and then returning again to 24°C. The sequence of measurements required 35 days. After the HFM tests, a single measurement was conducted again at 24°C for 24 hours in 1990. All measurements were conducted with heat flow in the upward direction.

Measurements of thickness of specimen "J" were determined independently prior to thermal measurements. The disk was placed on a black-granite plate (1200 by 1800 by 200 mm) having a flatness specification of 0.0152 mm (unilateral tolerance). Individual measurements of thickness were made using a caliper having a resolution of 0.1 mm. Eight individual measurements located around the perimeter of a 406 mm diameter circle and the center point were averaged to determine a thickness of 26.2 mm for the specimen. The diameter of the specimen was determined to be 1017 mm, and the bulk density for this diameter was 141 kg/m^3.

Measured values of thermal conductivity (λ_{meas}), values of λ predicted by Equation 2, and deviations ($\Delta\lambda$) for all guarded-hot-plate tests are summarized in Table 3. Thermal conductivity as a function of mean specimen temperature T_M is illustrated in Figure 6a. Measurements are shown as individual data points and λ is shown as a solid line. Deviations ($\Delta\lambda$) are presented in Figure 6b. Agreement between measurements and predicted values of λ is better than 1% at T_M from 24 to 50°C. At 24°C (room-temperature), the deviation ranged from +0.2 to -0.3%. The lower value of λ at 24°C obtained at the end of 1989 testing is attributed to moisture migrating from the specimen during measurements at T_M above 40°C. Note the bias in the data at T_M below 24°C, indicating some systematic difference between NIST's one-metre and 200 mm GHPs at temperatures below 24°C.

TABLE 3

NIST 1-metre Guarded Hot Plate measurements (1989 and 1990)
Specimen: high-density fibrous-glass board (Lot 1970), 26.2 mm thick
ρ = 141 kilograms/cubic metre (1017 mm diameter)

Test #		T_H (°C)	T_C (°C)	T_A (°C)	T_M (°C)	ΔT (°C)	λ_{meas} (W/m•K)	λ (W/m•K)	$\Delta\lambda$ (%)
1A	89-071A	23.89	-3.88	10.4	10.00	27.77	0.0311	0.0315	-1.2
1B	89-071B	23.89	-3.88	10.4	10.00	27.77	0.0311	0.0315	-1.2
1C	89-071C	23.89	-3.88	10.4	10.00	27.77	0.0311	0.0315	-1.2
2A	89-071D	28.89	1.08	15.1	14.99	27.81	0.0318	0.0320	-0.6
2B	89-071E	28.89	1.08	15.1	14.98	27.81	0.0318	0.0320	-0.6
2C	89-071F	28.89	1.08	15.1	14.98	27.81	0.0318	0.0320	-0.6
3A	89-071G	37.78	10.02	23.5	23.90	27.76	0.0329	0.0329	0.1
3B	89-071H	37.78	10.01	23.5	23.89	27.77	0.0329	0.0329	0.2
3C	89-071I	37.78	10.01	23.5	23.89	27.77	0.0330	0.0329	0.2
4A	89-071J	43.89	16.12	30.2	30.01	27.77	0.0338	0.0335	0.7
4B	89-071K	43.89	16.12	30.2	30.01	27.77	0.0338	0.0335	0.7
4C	89-071L	43.89	16.12	30.1	30.01	27.77	0.0338	0.0335	0.7
5A	89-071M	53.89	26.11	39.3	40.00	27.78	0.0349	0.0347	0.7
5B	89-071N	53.89	26.11	39.2	40.00	27.78	0.0349	0.0347	0.6
6A	89-071P	63.89	36.09	50.1	49.99	27.80	0.0360	0.0359	0.2
6B	89-071Q	63.89	36.09	50.1	49.99	27.80	0.0360	0.0359	0.2
7A	89-071R	37.79	9.99	23.5	23.89	27.80	0.0328	0.0329	-0.3
7B	89-071S	37.79	9.97	23.4	23.88	27.82	0.0328	0.0329	-0.3
7C	89-071T	37.79	9.98	23.3	23.88	27.81	0.0328	0.0329	-0.3
8	90-099A	35.00	12.79	23.4	23.90	22.21	0.0328	0.0329	-0.3

6. HEAT-FLOW-METER CALIBRATION MEASUREMENTS

Thirty-eight (38) calibration measurements were conducted at T_M = 24°C, ΔT = 22°C, and atmospheric conditions over a period of 250 days. All measurements were conducted with heat flow in the upward direction. Measurements began 11 Dec. 1989 and finished 20 Aug. 1990. To calibrate the HFM (Heat Flow Meter) apparatus, a square specimen, (nominally 614 by 614 mm), was cut (see

Figure 5) from the central area of the 1017-mm-diameter disk. Prior to each calibration measurement, the specimen was conditioned at 90°C for about 24 hours. The density of the square specimen was determined to be 139 kg/m^3, about 1% less than the density of the disk.

Values of the calibration coefficient (S) for each test were computed using Equation 1 and are summarized in Table 4. Also summarized are values of λ calculated from Equation 2, as well as thermal and engineering test data - T_H, T_C, T_A, T_M, ΔT, E, Δ_{TP}, ρ, initial specimen mass (M_i), final specimen mass (M_f), and mass change (ΔM). Calibration tests were completed in 4 to 6 hours and the mass gain of the specimen during the test was about 0.3%. For the 38 tests, S ranged from 9.21 to 9.28 W/(m^2•mV) (±0.4%).

Values of S are plotted as a function of mean specimen temperature in Figure 7. Note that the data include one point at a mean specimen temperature of about 24.3°C. During this test, the circulation fans for the laboratory were disrupted causing the temperature of the air to rise. The value of S for this test, however, is still within the variation of the data and therefore is included.

An examination of Figure 7 indicates two groups of data. Plotting S over the 250-day testing period reveals a small monotonic decrease in S as shown in Figure 8. The average of the first 50 days was 9.27 ± 0.01 W/(m^2•mV) and the average of the data for days 50 to 250 was 9.23 ± 0.02 W/(m^2•mV), a decrease of 0.4% in S. The variations provided are derived from 2 times the standard deviation of the average.

Since no change was observed in the thermal conductivity of the specimen when checked again in the GHP in 1990, the authors believe the trend in S to be caused by a small drift in the apparatus. The reason for the drift is not known at present. Checking Table 4, reveals a similar decline in the ambient temperature of 3% over 250 days. However, plotting S as a function of T_A shows only a weak correlation between the ambient air temperature and the calibration coefficient as illustrated in Figure 9. Additional calibration measurements are in process to track the drift.

7. SUMMARY

Recent modifications by the manufacturer to upgrade NIST's heat-flow-meter apparatus have improved the response time and computer accessibility of the apparatus. NIST has installed a computer data-acquisition-system and developed software to collect, reduce, and store data taken from the apparatus. A listing of NIST's software is provided in Appendix B. Spreadsheets based on commercially available software have been developed to analyze and plot the reduced data.

Over a period of 250 days, 38 individual calibration measurements of the apparatus were conducted at T_M = 24°C, ΔT = 22°C, and atmospheric conditions. The apparatus was calibrated using a specimen of fibrous-glass board having a thickness of 26.2 mm and a density of 139 kg/m^3. The specimen was selected from an internal SRM lot (Lot 1970) similar to Standard Reference Materials 1450, 1450a, and 1450b. The thermal conductivity of the specimen was computed using a regression equation developed for Lot 1970 by Siu [3]. The thermal

TABLE 4

Calibration measurements of Heat-Flow-Meter Apparatus
Specimen: high-density fibrous-glass board (Lot 1970), 26.2 mm thick

	Test #	Day	T_H (°C)	T_C (°C)	T_A (°C)	T_M (°C)	ΔT (°C)	E (mV)	Δ_{TP} (mV)	ρ (kg/m^3)	M_i (g)	M_f (g)	ΔM (%)	λ W/(m·K)	S W/(m^2·mV)
1	H891211A	0	34.9	13.3	24.2	24.1	21.6	2.918	0.007	138.8	1365.6	1369.9	0.3	0.0329	9.27
2	H891212A	1	34.9	13.3	24.1	24.1	21.6	2.915	0.006	138.8	1365.8	1369.9	0.3	0.0329	9.28
3	H891213A	2	34.9	13.3	24.2	24.1	21.6	2.920	0.008	138.8	1365.7	1369.7	0.3	0.0329	9.27
4	H891214A	3	34.8	13.3	24.1	24.1	21.6	2.919	0.006	138.8	1365.7	1370.0	0.3	0.0329	9.26
5	H891215A	4	34.9	13.3	24.1	24.1	21.6	2.920	0.007	138.8	1365.6	1369.9	0.3	0.0329	9.26
6	H891216A	5	34.9	13.3	24.2	24.1	21.6	2.923	0.008	138.8	1365.8	1369.7	0.3	0.0329	9.26
7	H891217A	6	34.9	13.3	24.1	24.1	21.6	2.925	0.006	138.8	1365.6	1369.6	0.3	0.0329	9.26
8	H891218A	7	35.1	13.5	24.4	24.3	21.6	2.929	0.005	138.8	1365.6	1369.5	0.3	0.0329	9.27
9	H891219A	8	34.9	13.3	24.1	24.1	21.6	2.922	0.006	138.8	1365.6	1369.4	0.3	0.0329	9.27
10	H891220A	9	34.9	13.3	24.2	24.1	21.6	2.921	0.006	138.8	1365.5	1369.8	0.3	0.0329	9.26
11	H900115A	35	34.8	13.3	23.9	24.1	21.6	2.916	-0.001	138.8	1365.7	1370.0	0.3	0.0329	9.28
12	H900116A	36	34.9	13.3	23.9	24.1	21.6	2.918	-0.002	138.8	1365.5	1369.8	0.3	0.0329	9.28
13	H900117A	37	34.9	13.3	23.8	24.1	21.6	2.917	-0.003	138.8	1365.7	1370.1	0.3	0.0329	9.27
14	H900118A	38	34.9	13.3	23.8	24.1	21.6	2.917	-0.002	138.8	1365.7	1370.2	0.3	0.0329	9.27
15	H900119A	39	34.8	13.3	23.8	24.1	21.6	2.922	-0.003	138.8	1365.5	1369.8	0.3	0.0329	9.26
16	H900122A	42	34.8	13.3	23.8	24.1	21.5	2.916	-0.002	138.8	1365.5	1369.5	0.3	0.0329	9.27
17	H900123A	43	34.9	13.3	23.8	24.1	21.6	2.917	-0.001	138.8	1365.5	1369.8	0.3	0.0329	9.27
18	H900124A	44	34.8	13.3	23.8	24.1	21.6	2.919	-0.002	138.8	1365.5	1370.0	0.3	0.0329	9.26
19	H900125A	45	34.9	13.3	23.8	24.1	21.6	2.920	-0.001	138.8	1365.7	1370.3	0.3	0.0329	9.26
20	H900126A	46	34.9	13.3	23.8	24.1	21.6	2.922	-0.001	138.8	1365.5	1369.7	0.3	0.0329	9.25
21	R900212B	63	34.9	13.3	23.7	24.1	21.5	2.926	-0.001	138.8	1365.2	1369.4	0.3	0.0329	9.24
22	R900306A	85	34.8	13.3	23.7	24.1	21.5	2.925	-0.003	138.8	1365.5	1369.7	0.3	0.0329	9.24
23	R900307A	86	34.8	13.3	23.7	24.1	21.5	2.926	-0.004	138.8	1365.2	1369.5	0.3	0.0329	9.23
24	R900308A	87	34.8	13.3	23.7	24.1	21.5	2.920	-0.004	138.7	1364.8	1369.5	0.3	0.0329	9.26
25	R900309A	88	34.8	13.3	23.7	24.1	21.5	2.928	-0.003	138.8	1365.4	1369.5	0.3	0.0329	9.24
26	R900312A	91	34.8	13.3	23.7	24.1	21.5	2.925	-0.003	138.8	1365.8	1370.1	0.3	0.0329	9.24
27	R900326A	105	34.8	13.3	23.7	24.1	21.5	2.924	-0.004	138.8	1365.5	1368.8	0.2	0.0329	9.23
28	R900327A	106	34.9	13.3	23.7	24.1	21.5	2.926	-0.003	138.8	1365.3	1369.2	0.3	0.0329	9.24
29	R900328A	107	34.8	13.3	23.7	24.1	21.5	2.925	-0.004	138.8	1365.1	1368.9	0.3	0.0329	9.24
30	R900329A	108	34.9	13.4	23.8	24.1	21.5	2.930	-0.003	138.8	1365.2	1369.1	0.3	0.0329	9.23
31	R900330A	109	34.8	13.3	23.7	24.1	21.5	2.931	-0.005	138.8	1365.2	1368.9	0.3	0.0329	9.21
32	R900418A	128	34.8	13.3	23.7	24.1	21.5	2.927	-0.004	138.9	1366.3	1370.0	0.3	0.0329	9.24
33	R900425A	135	34.8	13.3	23.7	24.1	21.5	2.927	-0.004	138.9	1366.4	1370.5	0.3	0.0329	9.23
34	R900502A	142	34.8	13.3	23.7	24.1	21.5	2.928	-0.004	138.9	1366.4	1370.5	0.3	0.0329	9.23
35	R900706A	207	34.8	13.3	23.6	24.1	21.5	2.922	-0.002	139.0	1367.2	1372.0	0.4	0.0329	9.23
36	R900730A	231	34.8	13.3	23.6	24.1	21.5	2.927	-0.001	139.1	1368.0	1372.0	0.3	0.0329	9.23
37	R900802A	234	34.8	13.3	23.6	24.1	21.5	2.925	-0.001	138.9	1366.7	1371.3	0.3	0.0329	9.23
38	R900820A	252	34.8	13.3	23.6	24.1	21.5	2.929	-0.003	138.9	1366.5	1371.2	0.3	0.0329	9.22

Note: Test # provides date of test (e.g. H891211A = 89/12/11 [December 11, 1989]) conductivity at 24°C of the specimen was also determined using NIST's one-metre Line-Heat-Source Guarded Hot Plate. Measurements at 24°C and predictions of thermal conductivity agreed within +0.2 to -0.3%.

The calibration coefficient at 24°C of the HFM varied from 9.21 to 9.28 W/(m^2•mV), or ±0.4%. After 50 days, a slight drift of 0.4% was observed in the calibration coefficient of the apparatus. The reason for the drift is not understood at present. However, calibration measurements are continuing to examine the magnitude of the drift.

8. ACKNOWLEDGMENTS

The calibration of NIST's HFM apparatus was part of a project with the Department of Energy to examine the uncertainty of heat-flow-meter apparatus for materials having different thermal conductivities and thicknesses than available NIST reference materials. Funds to upgrade the HFM apparatus were appropriated by the Department of Commerce.

9. REFERENCES

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2. Powell, F.J. and Rennex, B.G. "The NBS Line-Heat-Source Guarded Hot Plate For Thick Materials," Proceedings ASHRAE/DOE Conference - II, Atlanta:ASHRAE, 657-672 (1983).

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5. Hust, J.G. "*Standard Reference Materials:* Glass Fiberblanket SRM for Thermal Resistance," NBS Special Publication 260-98, Washington D.C. (1985).

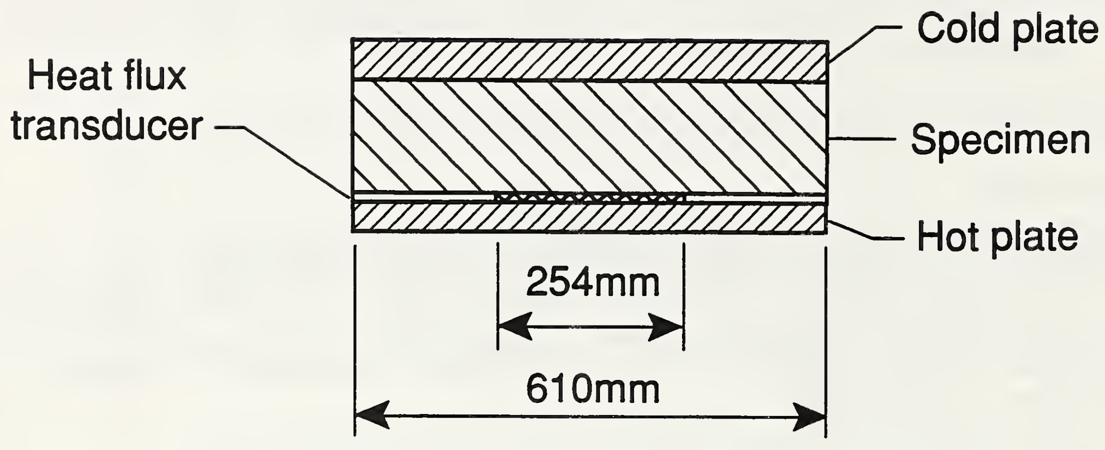


Figure 1a. Configuration of Heat-Flow-Meter Apparatus

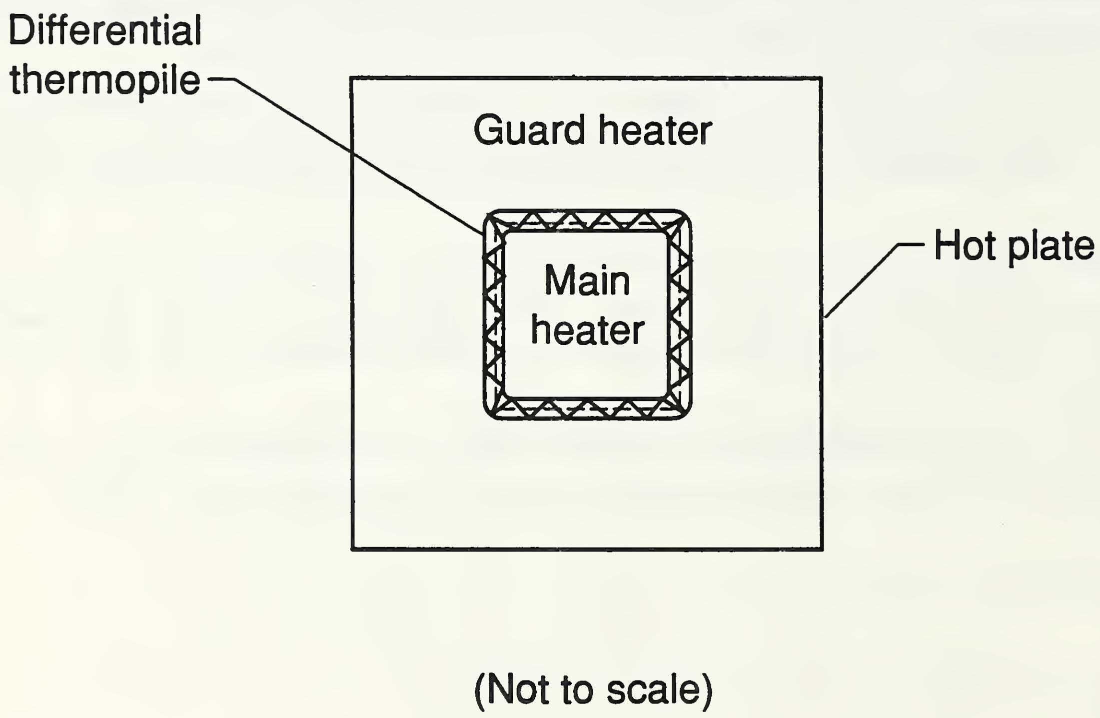


Figure 1b. Location of differential thermopile for guard heater

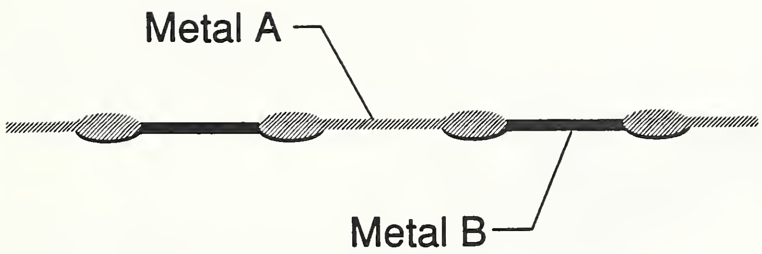


Figure 2a. Principle behind the coplanar-junction flowmeter (Degenne and Klarsfeld [1985], Used by permission from ASTM)

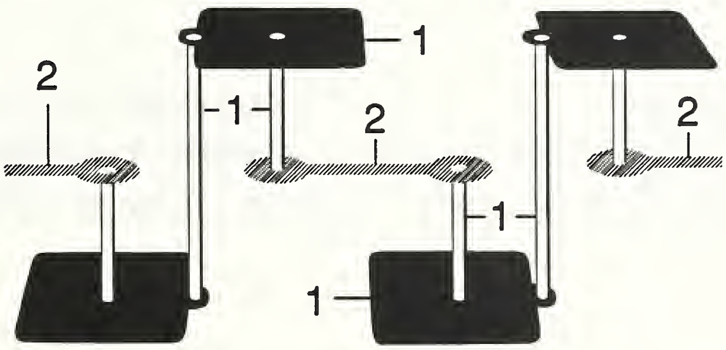


Figure 2b. Principle for constructing the flowmeter junction (Degenne and Klarsfeld [1985], Used by permission from ASTM)

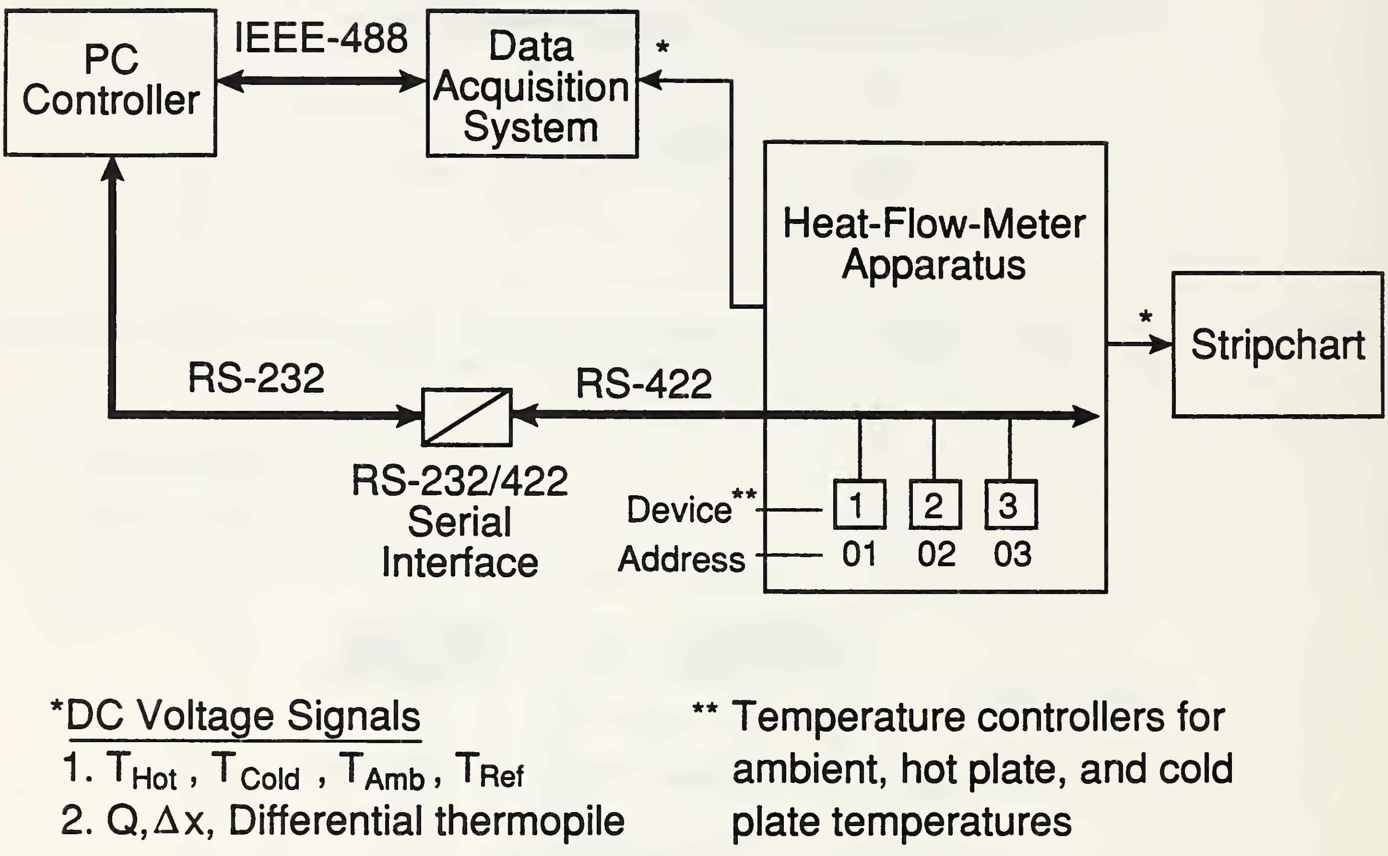


Figure 3. Schematic of hardware for the computer data-acquisition-system.

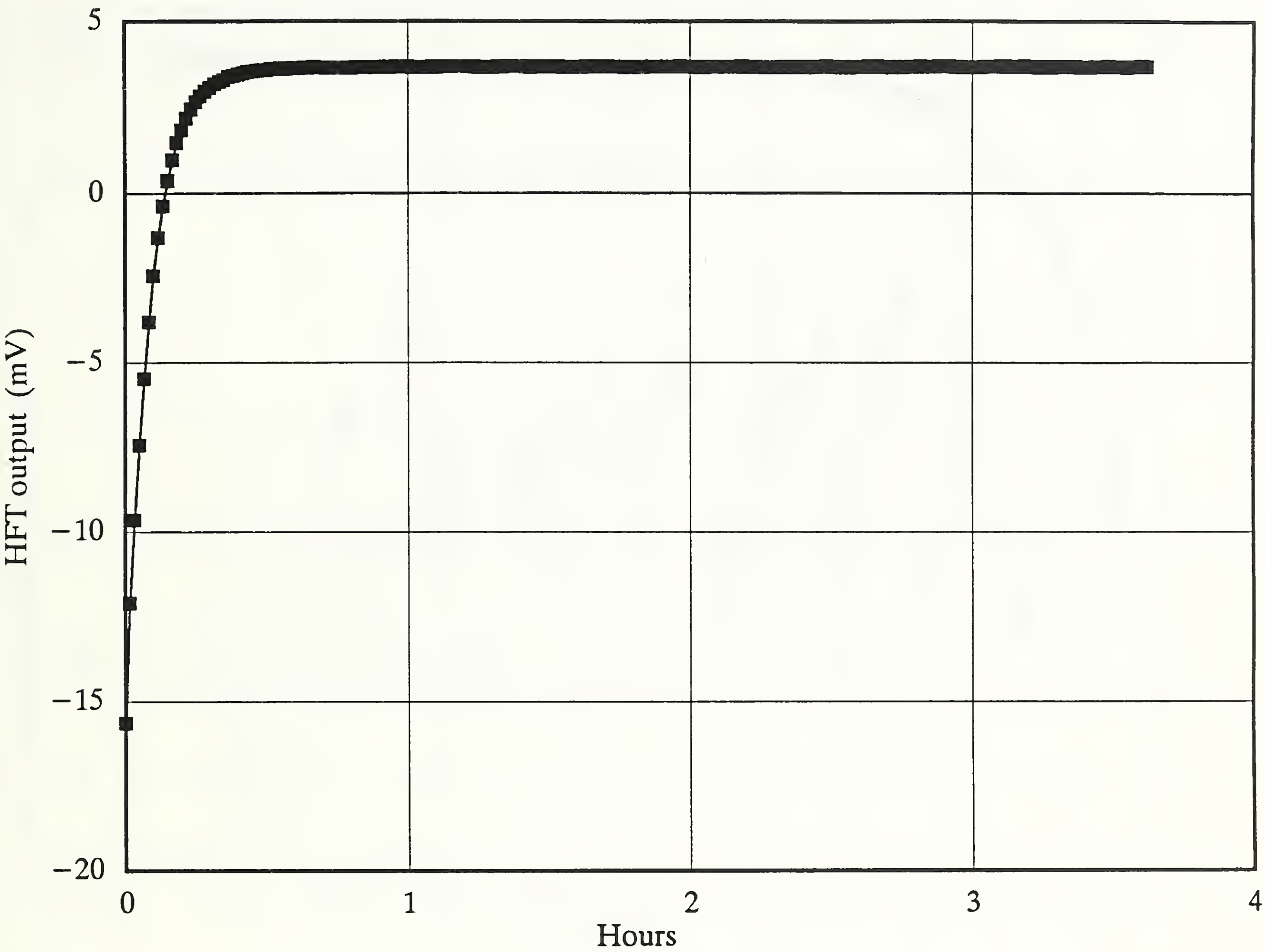


Figure 4a. Output of the heat-flux-transducer for a four-hour calibration test using a specimen of fibrous-glass insulation 26.2 mm thick and a density of 139 kg/m^3. Note, the ΔT for this test was maintained at 27.8°C.

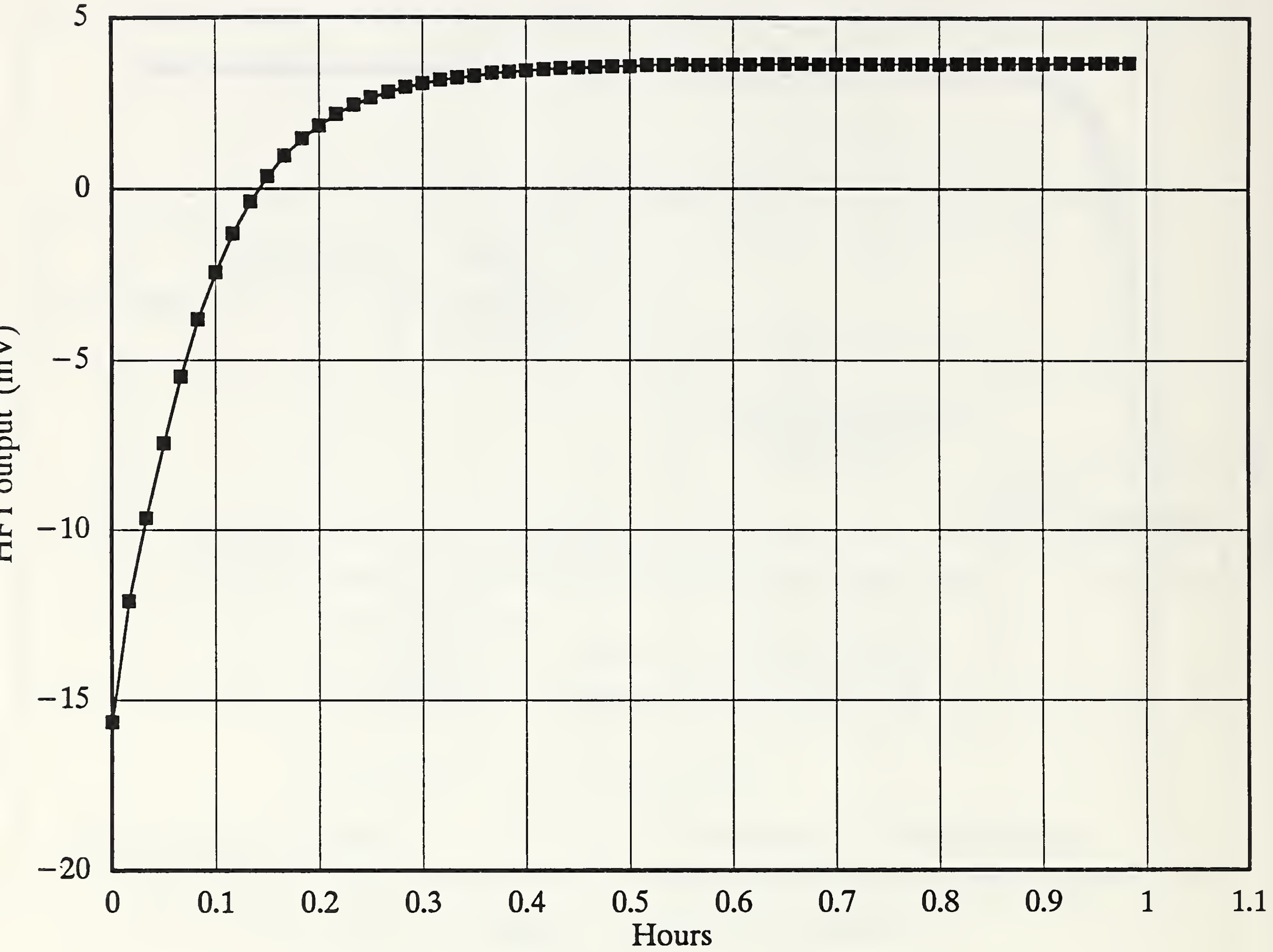


Figure 4b. Output of the heat-flux-transducer for the first hour of the calibration test.

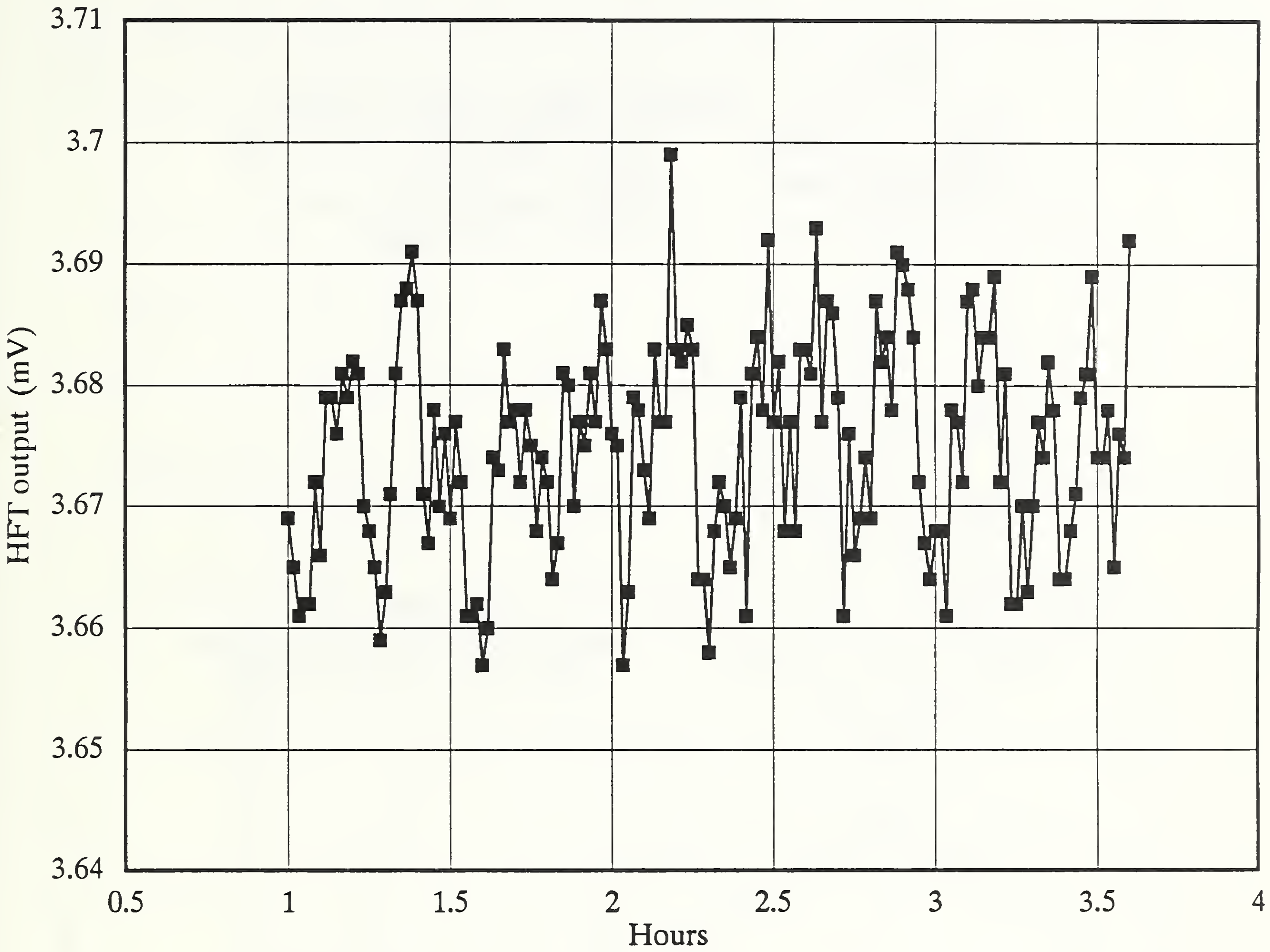


Figure 4c. Output of the heat-flux-transducer for the steady-state portion of the calibration test.

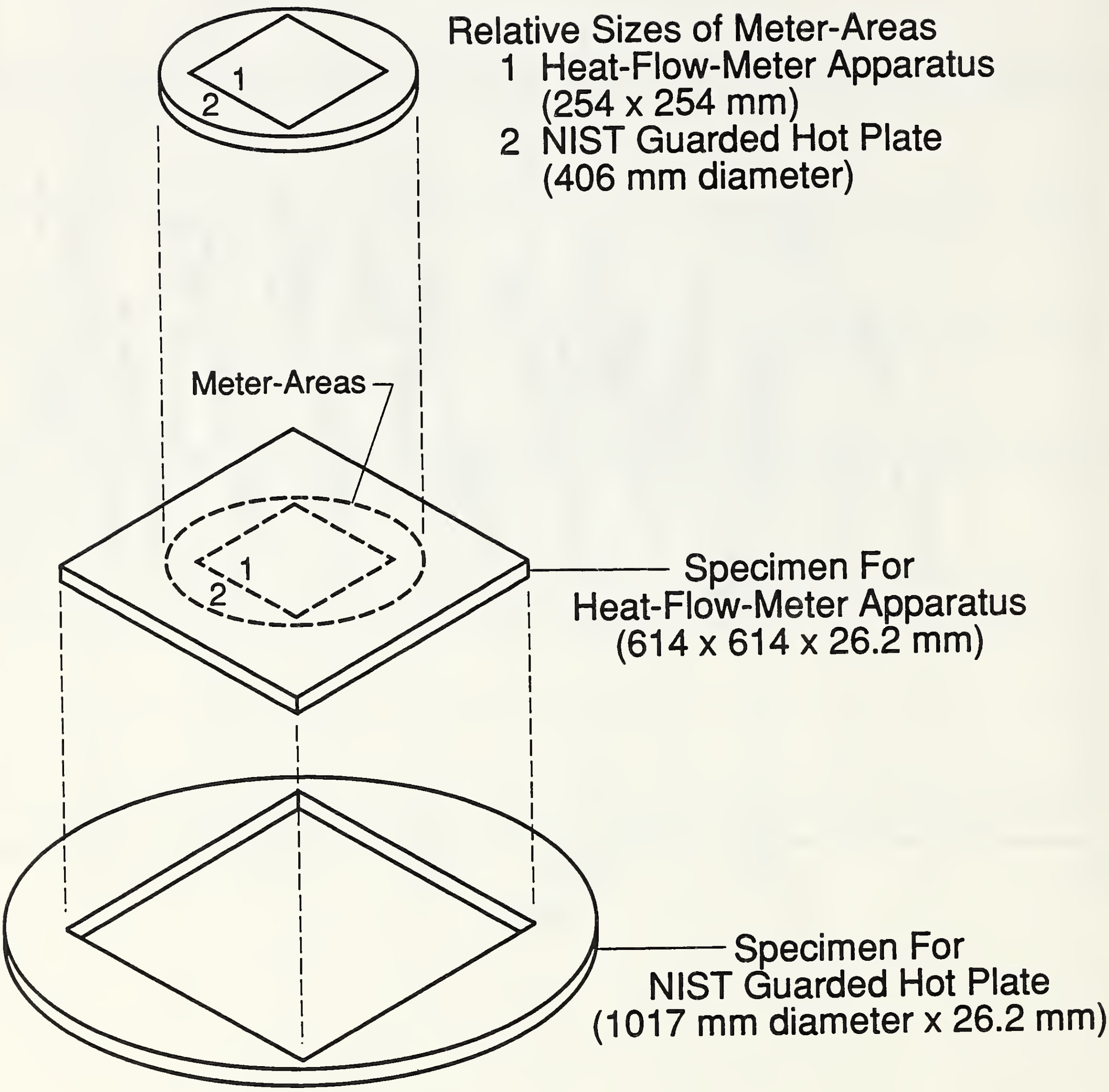


Figure 5. Relative sizes of the specimens used in the guarded hot plate and heat-flow-meter apparatus.

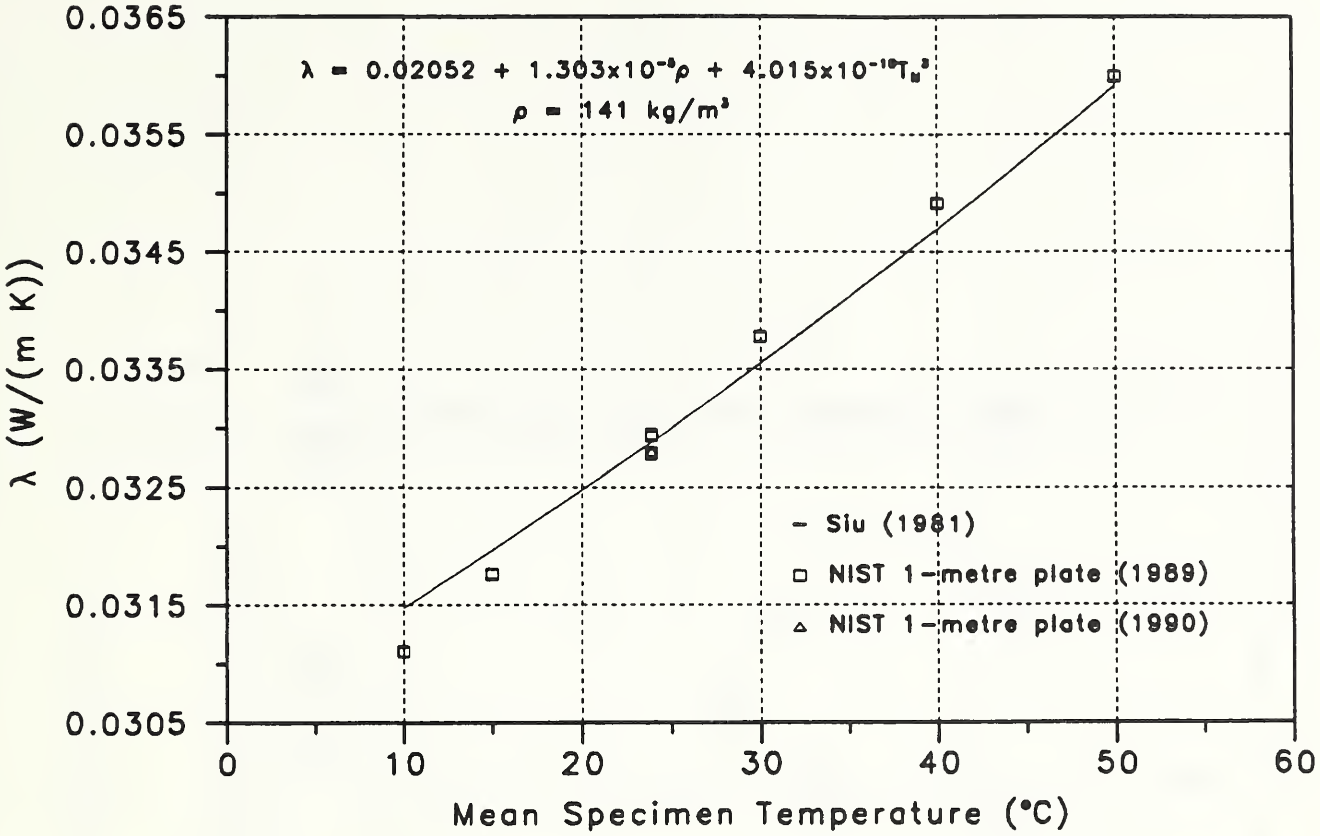


Figure 6a. Thermal conductivity from 10 to 50°C of fibrous-glass insulation (Lot 1970). Specimen was 26.2 mm thick having a bulk density of 141 kg/m^3.

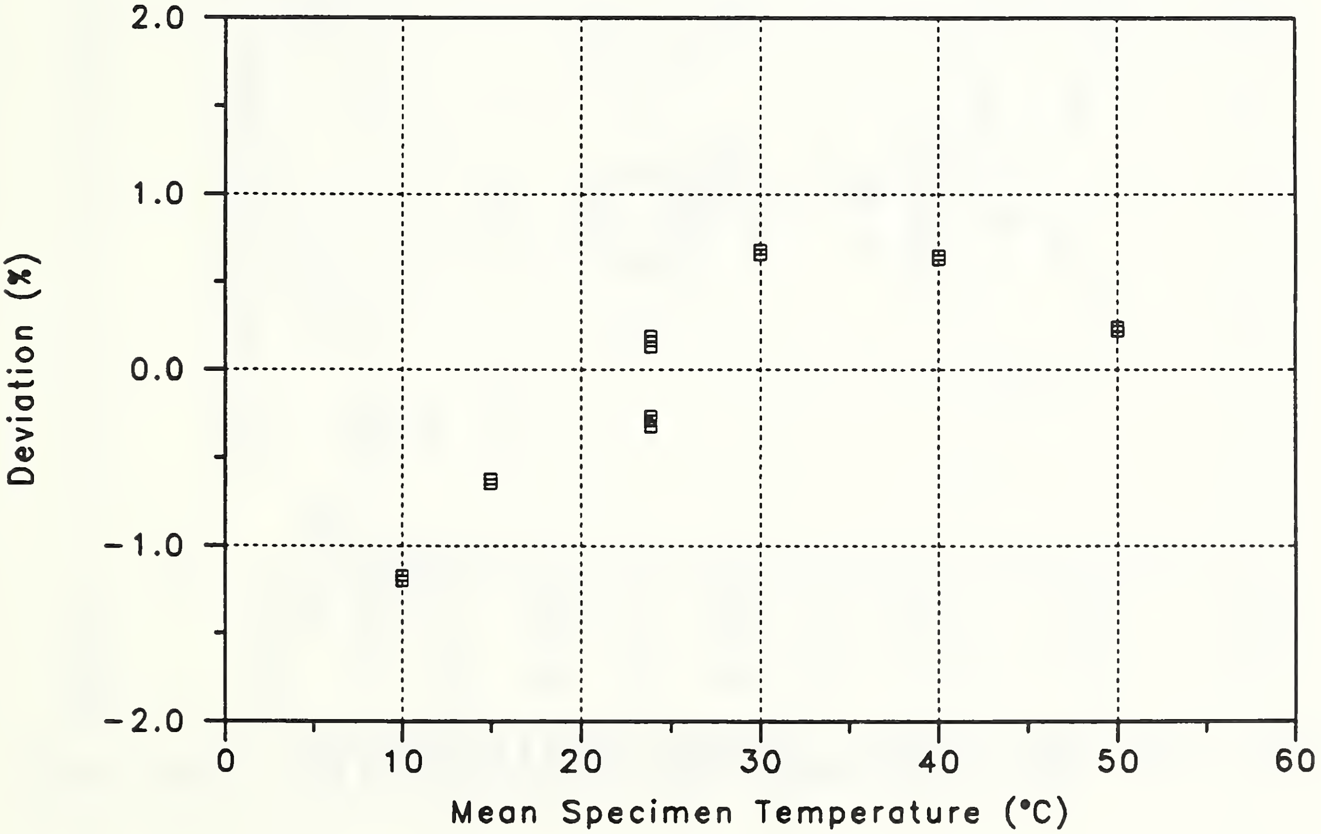


Figure 6b. Percent deviation of measurements from predicted values of thermal conductivity for fibrous-glass insulation (Lot 1970).

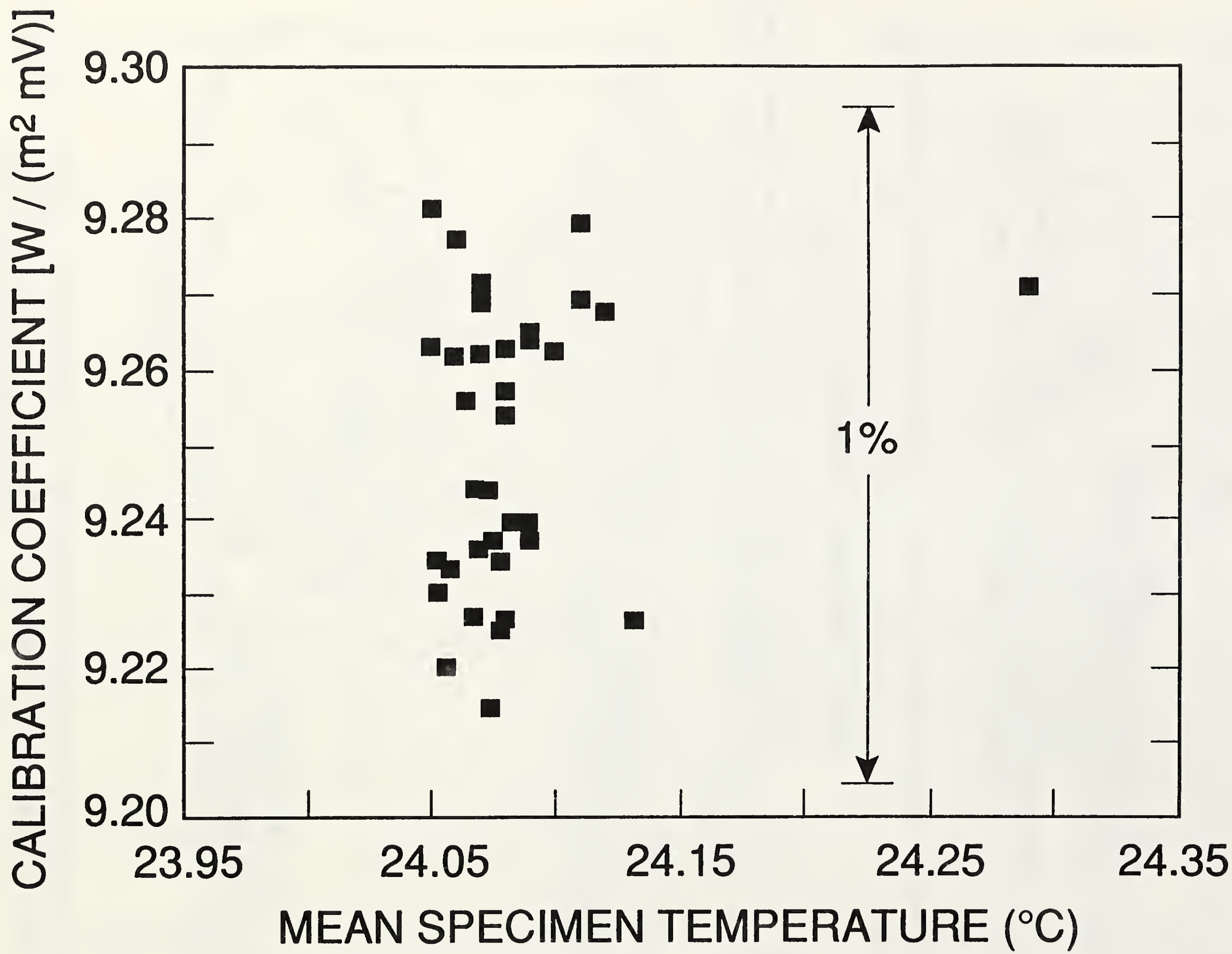


Figure 7. Calibration coefficient as a function of mean specimen temperature.

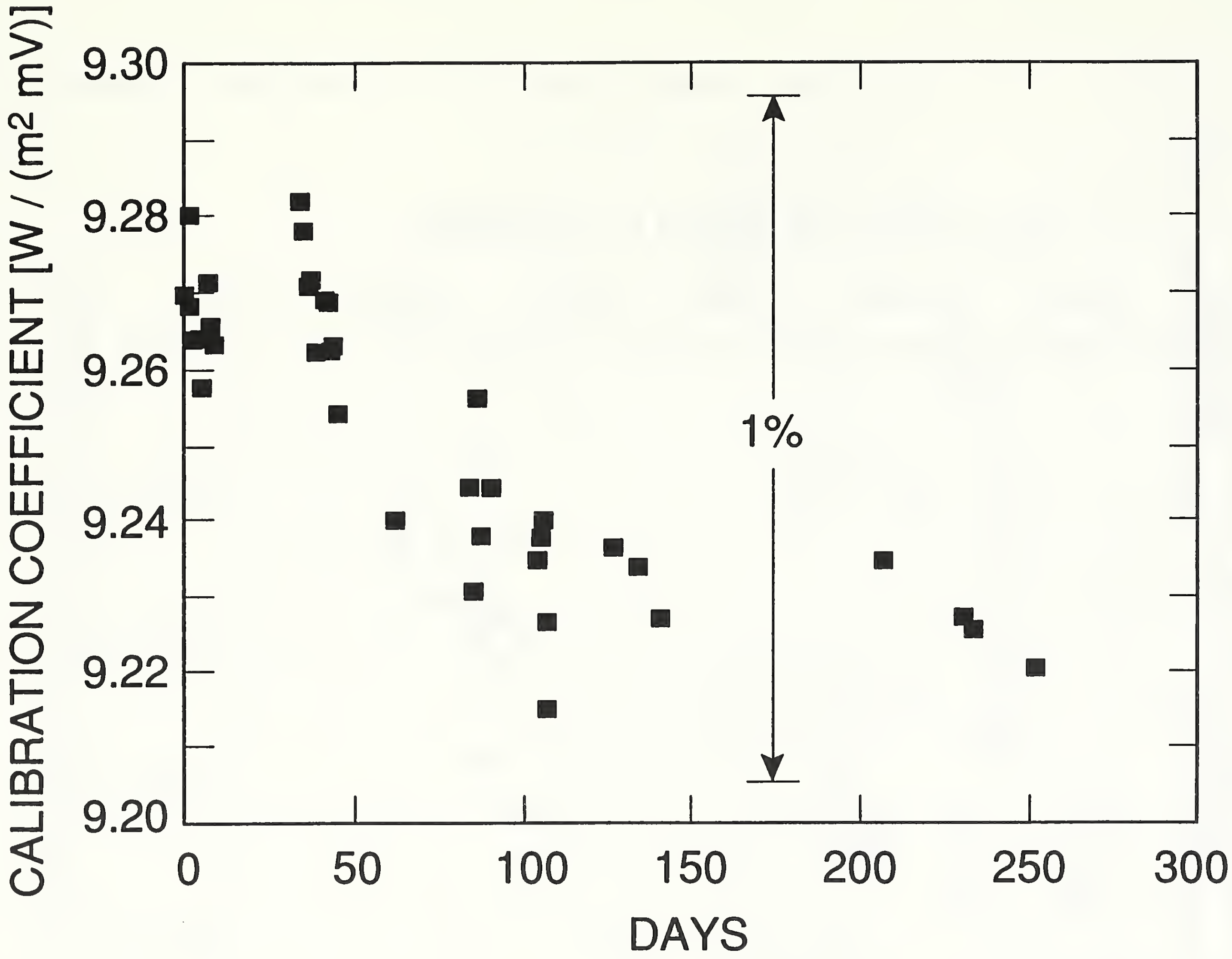


Figure 8. Calibration coefficient plotted over 250 days.

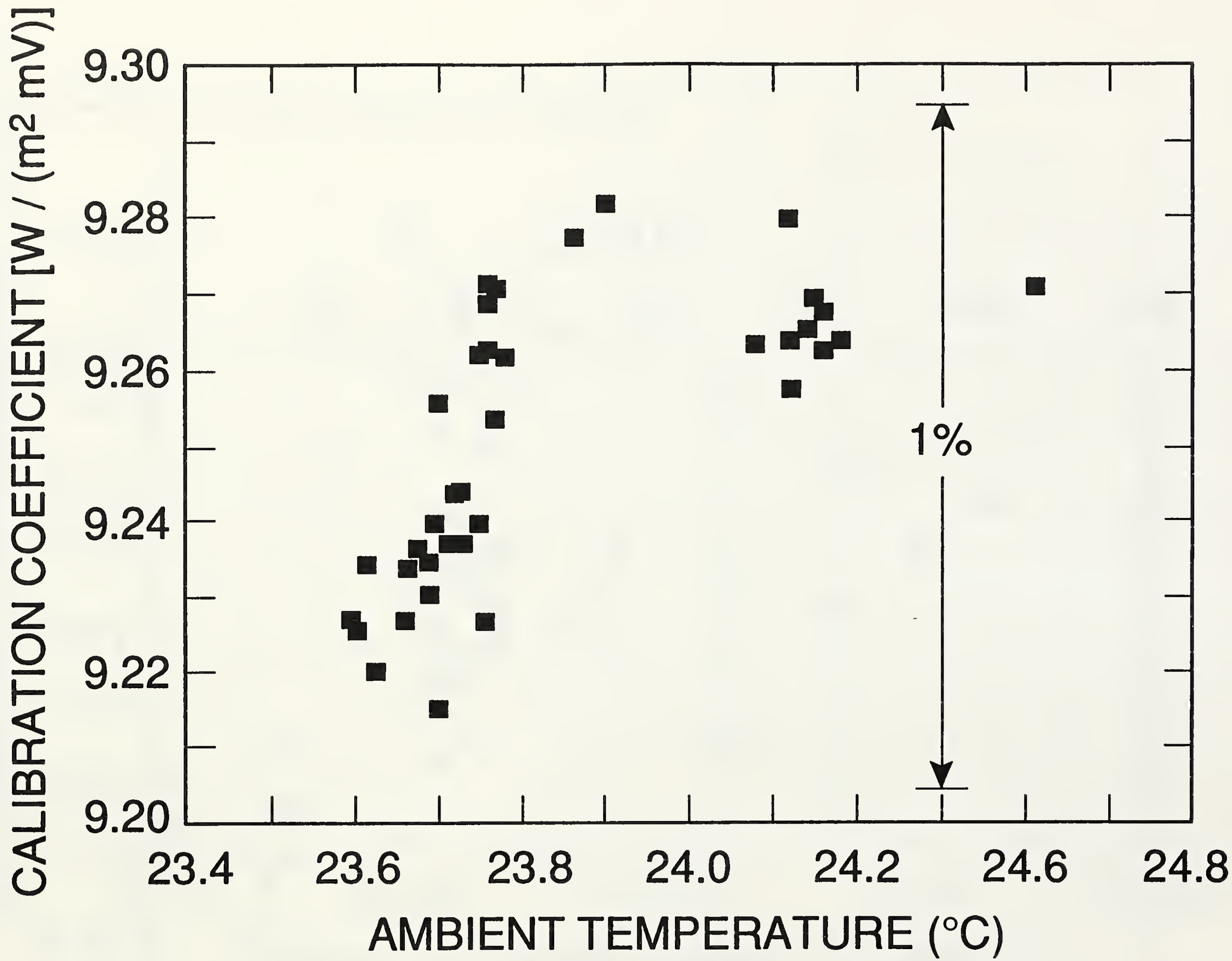
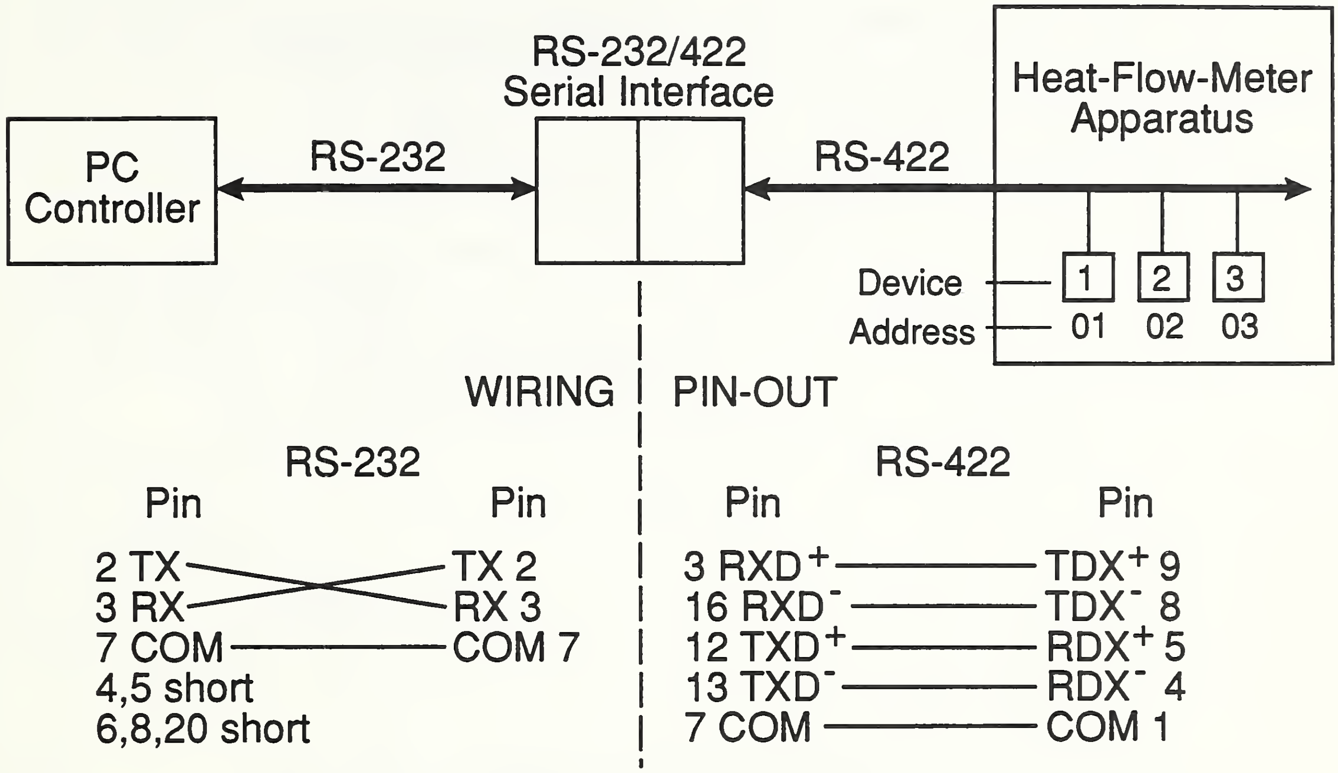


Figure 9. Calibration coefficient as a function of ambient temperature.

10. APPENDIX - A: Wiring Diagram for the RS-232/RS-422 Interface



11. APPENDIX - B: Listing of BASIC program HFM.BAS

```
1100  ' User program can begin anywhere past this point
1110  ' Time interval set in line 2230
1120 '
1130 ' ****************************************************************************
1140 ' *                   PROGRAM TO SCAN THE SENSORS OF A                       *
1150 ' *                       HEAT-FLOW-METER APPARATUS                          *
1160 ' *                                                                          *
1170 ' *                                HFM.BAS                                   *
1180 ' *                         BY B.L.  NOV. 1989                               *
1190 ' *                         REVISED  JAN. 1991
1200 ' ****************************************************************************
1210 '
1220 ' DIMENSION ARRAYS FOR VOLTAGES, TEMPERATURES, AND TIME HISTORY
1230 DIM TEMP(10),EMF(10),EMF.REF(10)
1240 DIM QTH(16),HOURTH(16),MINTH(16)
1250 SCAN=0:FLAG.MIN=1        ' USE FLAG.MIN TO STORE LAST MINUTE
1260 CALIBRATE=0:MEASURE=0    ' INITIALIZE MODE OF OPERATION
1270 ANS$="N"        ' FLAG TO WRITE DATA TO THE DISK
1280 DAS=709         ' SET DATA ACQUISITION SYSTEM ADDRESS TO 709
1290 '
1300 ' SET-UP FUNCTION KEYS
1310 KEY 1, " ":KEY 2, " ":KEY 3," ":KEY 4," ":KEY 5," ":KEY 7," "
1320 KEY 8, " ":KEY 9, " "
1330 KEY 10, "TERMINATE"+CHR$(13)
1340 KEY 6, "WRITE"+CHR$(13)
1350 KEY(10) ON      ' TO TERMINATE THE PROGRAM
1360 KEY(6) ON       ' TO WRITE(SAVE) DATA TO DISK
1370 ON KEY(10) GOSUB 4100
1380 ON KEY(6) GOSUB 3860
1390 '
1400 ' PRINT 1ST MENU
1410 CLS
1420 PRINT "              DISPLAY HEAT FLOW METER MEASUREMENTS":PRINT:PRINT
1430 PRINT:PRINT"          -------------------------------------------":PRINT
1440 PRINT:PRINT"            1.   DO YOU WANT TO CALIBRATE?          ":PRINT
1450 PRINT:PRINT"            2.   DO YOU WANT TO MEASURE A SAMPLE?   ":PRINT
1460 PRINT:PRINT"          -------------------------------------------":PRINT
1470 PRINT:INPUT"                 ENTER   1   OR    2                ";CHOICE$
1480 IF CHOICE$="1" THEN CALIBRATE=1
1490 IF CHOICE$="2" THEN MEASURE=1
1500 IF CHOICE$<>"1" AND CHOICE$<>"2" THEN GOTO 1420
1510 CLS
1520 FOR I=1 TO 5 STEP 1
1530 PRINT " "
1540 NEXT I
1550 PRINT "        AT THIS TIME, PLACE A NEW FORMATTED DISC IN DISC DRIVE B"
1560 PRINT " "
1570 INPUT "              PRESS 'ENTER' WHEN YOU ARE READY TO CONTINUE";AA$:CLS
1580 '
1590 ' SET CLOCK FOR 3497A DATA ACQUISITION SYSTEM
1600 PRINT " "
1610 INPUT "                    CURRENT TIME MMDDHHMMSS"; CURRENT.TIME$
1620 GOSUB 2270        ' SET 3497A REAL TIME CLOCK
1630 PRINT
1640 '
1650 ' INPUT NAME OF MATERIAL TO BE CALIBRATED AND THERMAL CONDUCTIVITY
1660 IF CALIBRATE= 1 THEN PRINT:INPUT "        NAME OF MATERIAL USED FOR CALIBRATION IS (LIMIT 9 CHAR)";K$
1670 IF CALIBRATE = 1 THEN PRINT:INPUT "         CONDUCTIVITY IN WATTS PER METER PER DEGREE KELVIN IS ";K
1680 '
1690 '
1700 ' PROMPT USER FOR TEST INFORMATION
1710 IF MEASURE=1 THEN PRINT:INPUT "          THE SAMPLE TO BE MEASURED IS(LIMIT 9 CHAR)";K$
1720 IF MEASURE=1 THEN PRINT:INPUT "CALIBRATION COEFFICIENT IN WATTS PER METER SQUARED PER MILLIVOLT  ";S
1730 PRINT:PRINT"                 DENSITY OF SAMPLE IN KG PER METER CUBED"
1740 PRINT:INPUT"                     IF UNKNOWN PLEASE ENTER 0";DEN
```

```
1750 PRINT:INPUT"                    ENTER TEST DESIGNATOR [A,B,C....]";TEST$
1760 '
1770 ' INPUT START AND FINISH TIMES FOR COLLECTING DATA
1780 PRINT:INPUT "         DATA SCANNING START TIME MM:DD:HH:MM:SS"; START.TIME$
1790 START.SEC$=MID$(START.TIME$,13,2) : START.SEC=VAL(START.SEC$)
1800 PRINT:INPUT "         DATA SCANNING FINISH TIME MM:DD:HH:MM:SS";FINISH.TIME$
1810 '
1820 LOCATE 23,20:PRINT "WAITING FOR SCANNING TO BEGIN"
1830 '
1840 '
1850 GOSUB 2380 :      ' CHECK CLOCK TO SEE IF DATA COLLECTION SHOULD BEGIN
1860 ' DATA COLLECTION SCANS ARE READINGS TAKEN AT SET INTERVALS (LINE 2210)
1870 LET A$=CURRENT.TIME$
1880 MON$=LEFT$(A$,2)
1890 MON=VAL(MON$)
1900 DAY$=MID$(A$,4,2)
1910 DAY=VAL(DAY$)
1920 HHMMSS$=RIGHT$(A$,10)
1930 ' OBTAIN THE HOUR FROM A$ STRING
1940 HOUR$=LEFT$(HHMMSS$,2)
1950 HOUR =VAL(HOUR$)
1960 ' OBTAIN THE MINUTE
1970 MINUTE$=MID$(HHMMSS$,4,2)
1980 MINUTE=VAL(MINUTE$)
1990 IF FLAG.MIN=1 THEN LAST.MIN=MINUTE:FLAG.MIN=0     ' USE FOR TIMER
2000 ' OBTAIN THE SECONDS
2010 SEC$=MID$(A$,13,2)
2020 SEC=VAL(SEC$)
2030 '
2040 '  THE FOLLOWING DETERMINES THE PRESENT MONTH
2050 YEAR$="91"
2060 IF MON=1 THEN MONTH$="JANUARY"  : GOTO 2190
2070 IF MON=2 THEN MONTH$="FEBRUARY" : GOTO 2190
2080 IF MON=3 THEN MONTH$="MARCH"    : GOTO 2190
2090 IF MON=4 THEN MONTH$="APRIL"    : GOTO 2190
2100 IF MON=5 THEN MONTH$="MAY"      : GOTO 2190
2110 IF MON=6 THEN MONTH$="JUNE"     : GOTO 2190
2120 IF MON=7 THEN MONTH$="JULY"     : GOTO 2190
2130 IF MON=8 THEN MONTH$="AUGUST"   : GOTO 2190
2140 IF MON=9 THEN MONTH$="SEPTEMBER": GOTO 2190
2150 IF MON=10 THEN MONTH$="OCTOBER" : GOTO 2190
2160 IF MON=11 THEN MONTH$="NOVEMBER": GOTO 2190
2170 IF MON=12 THEN MONTH$="DECEMBER": GOTO 2190
2180 '
2190 '  SCAN CHANNELS WHEN MULTIPLES OF 60 SECONDS HAVE ELAPSED
2200 IF SEC=START.SEC AND LAST.MIN<>MINUTE THEN SCAN = SCAN + 1
2210 IF SEC=START.SEC AND LAST.MIN<>MINUTE THEN FLAG.MIN=1  ' STORE TO COMPARE
2220 LOCATE 23,20:IF SEC=START.SEC AND LAST.MIN<>MINUTE THEN PRINT "CURRENT TIME IS ";CURRENT.TIME$;
2230 IF SCAN = 1 THEN GOSUB 2610      ' SCAN = INTERVAL OF SCAN IN minutes
2240 GOTO 1850                        ' CHECK CLOCK
2250 '
2260 ' ************************************************************************
2270 ' THIS SUBROUTINE SETS THE REAL TIME CLOCK IN THE HP3497A
2280 '               DATA ACQUISITION SYSTEM
2290 ' ADD THE COMMAND LETTERS "TD" TO THE DESIRED SET TIME
2300 CODES$="TD"+CURRENT.TIME$
2310 LENGTH=LEN(CODES$)
2320 '
2330 ' SEND CLOCK SET COMMAND OVER IEEE-488 BUS
2340 CALL IOOUTPUTS (DAS,CODES$,LENGTH)
2350 RETURN
2360 '
2370 ' ************************************************************************
2380 ' THIS SUBROUTINE READS THE CLOCK IN THE HP3497A AND CHECKS
2390 '  IS IT TIME TO START TAKING DATA?
2400 '  IS IT TIME TO STOP  TAKING DATA?
2410 '
2420 CODES$="TD"
2430 LENGTH=LEN(CODES$)
```

```
2440 CALL IOOUTPUTS(DAS,CODES$,LENGTH)
2450 '
2460 ' BRING BACK THE CURRENT TIME OVER THE IEEE-488 BUS
2470 MAX.LENGTH=16 : ACTUAL.LENGTH=0
2480 CURRENT.TIME$=SPACE$(MAX.LENGTH)
2490 CALL IOENTERS (DAS,CURRENT.TIME$,MAX.LENGTH,ACTUAL.LENGTH)
2500 ' COMPARE THE CURRENT TIME TO THE DESIRED START TIME
2510 ' IF THE CURRENT TIME IS GREATER THAN OR EQUAL TO THE
2520 ' DESIRED START TIME THEN RETURN AND BEGIN DATA COLLECTION
2530 ' IF NOT CONTINUE TO READ CLOCK AND DISPLAY CURRENT TIME
2540 '
2550 IF CURRENT.TIME$ >= FINISH.TIME$ THEN GOTO 4100 ' THIS CLOSES THE FILE
2560 IF CURRENT.TIME$>=START.TIME$ THEN GOTO 2580
2570 IF CURRENT.TIME$ <  START.TIME$ THEN GOTO 2410
2580 RETURN
2590 '
2600 ' ***********************************************************************
2610 ' THIS SUBROUTINE PREPARES HP3497A FOR A SCAN,
2620 '  SCANS 7 CHANNELS, REDUCES RAW VOLTAGES
2630 '  TO ENGINEERING UNITS, AND UPDATES SCREEN
2640 '
2650 SCAN = 0       ' RESET MINUTE COUNTER
2660 CODES$="VA1"  ' VOLTMETER AUTO-ZERO ON (MAY BE REMOVED FOR SPEED)
2670 LENGTH=LEN(CODES$)
2680 CALL IOOUTPUTS (DAS,CODES$,LENGTH)
2690 '
2700 CODES$="VD5"  ' VOLTMETER 5-1/2 DIGIT RESOLUTION, HIGHEST NOISE REJECTION
2710 LENGTH=LEN(CODES$)
2720 CALL IOOUTPUTS (DAS,CODES$,LENGTH)
2730 '
2740 '  SLOT    EMF     VAR     DESCRIPTION                       UNITS
2750 '    0       0      TH      HEAT FLOW METER (TH #6)           VOLTS
2760 '    0       1      TC      UPPER HEATER (T5)                   |
2770 '    0       2      T2      HEAT SINK (TT)                      |
2780 '    0       3      TA      UPPER LEFT SIDE OF AIR CHAMBER      |
2790 '    0       4      REF     THERMOCOUPLE REFERENCE VOLTAGE      |
2800 '    0       5      DX      DELTA-X, PLATE SEPARATION           |
2810 '    0       6      Q       HEAT FLUX TRANSDUCER                |
2820 '    0       7      DIFF    GAP THERMOPILE (64 JUNCTION)       \|/
2830 '
2840 FOR I=0 TO 7
2850 CODES$="AI"+STR$(I)    ' ANALOG INCREMENT
2860 LENGTH=LEN(CODES$)
2870 CALL IOOUTPUTS(DAS,CODES$,LENGTH)
2880 CALL IOENTER (DAS,VOLT)
2890 EMF(I)=VOLT
2900 NEXT I
2910 '
2920 REF=EMF(4)   ' REFERENCE VOLTAGE FOR TYPE K THERMOCOUPLES
2930 ' ADD REF VOLTAGE TO EMF CHANNEL 0 TO 3 USED FOR TEMP
2940 FOR I = 0 TO 3:EMF.REF(I)=EMF(I)+REF:NEXT I
2950 ' CONVERT volts TO microvolts
2960 FOR I = O TO 3:EMF.REF(I)=EMF.REF(I) * 1000000!:NEXT I
2970 ' CONVERT microvolts TO deg. C (NBS MONOGRAPH #125, p. 384)
2980     A1=.024363851#
2990     A2=.000000056206931#
3000     A3=-3.882562E-12
3010     A4=3.9120208D-17
3020 FOR L=0 TO 3
3030 TEMP(L)=A1*EMF.REF(L) + A2*EMF.REF(L)^2 + A3*EMF.REF(L)^3 + A4*EMF.REF(L)^4
3040 NEXT L
3050 '
3060 ' COMPUTE MEAN TEMPERATURE (MT), degree C
3070 TH=TEMP(0):   TC=TEMP(1)
3080 MT = .5 * (TH+TC)
3090 ' TEMPERATURE DIFF, DELTA.T (PLATE TO PLATE)
3100 DELTA.T = TH - TC
3110 ' CALIBRATION COEFFICIENT, S, W/m^2 per mV
3120 '                 S = DELTA.T / (Q * R)
```

```
3130 '     WHERE
3140 '          DELTA.T = TEMPERATURE DIFF, PLATE TO PLATE      deg. C
3150 '                Q = HEAT-FLUX-TRANSDUCER OUTPUT, EMF(6)  V * 1000
3160 '                R = THERMAL RESISTANCE OF REFERENCE MATERIAL
3170 '                  =  DX/K WHERE
3180 '                         DX = EMF(5)
3190 '                          K = K(MT) INPUT
3200 Q=EMF(6) * 1000    ' HEAT FLUX: CONVERT volts TO millivolts
3210 '
3220 QTH(16)=Q:HOURTH(16)=HOUR:MINTH(16)=MINUTE   ' USE FOR TIME HISTORY
3230 '
3240 DX=EMF(5) * 10     ' PLATE SEPARATION: CONVERT volts TO metres
3250 '
3260 IF CALIBRATE=1 THEN R = DX/K                            ' REFERENCE MATERIAL
3270 IF R = 0 THEN R = .0001      ' USE IF HFM IS NOT RUNNING.........
3280 IF CALIBRATE=1 THEN S = DELTA.T / (Q * R)          ' REFERENCE MATERIAL
3290 '
3300 ' COMPUTE SAMPLE CONDUCTIVITY, K (W / m . K)
3310 IF MEASURE=1 THEN R = DELTA.T / (Q * S)            ' SAMPLE MATERIAL
3320 IF MEASURE=1 THEN K = DX / R                       ' SAMPLE MATERIAL
3330 '
3340 DIFF=EMF(7) * 1000  ' GAP THERMOPILE: CONVERT volts TO millivolts
3350 '
3360 '  - - -  DISPLAY TEMPERATURES AND FLUX TO SCREEN AT EVERY INTERVAL
3370 IF CALIBRATE = 1 THEN CLS:PRINT"              MATERIAL USED FOR CALIBRATION IS ";K$
3380 IF  MEASURE =  1 THEN CLS:PRINT"                  SAMPLE TO BE MEASURED IS ";K$
3390 PRINT:PRINT"                CURRENT TIME IS ";MONTH$;" ";DAYS$;" ";HHMMSS$
3400 PRINT
3410 PRINT "            1.       T HOT      (deg. C)     ";TH
3420 PRINT "            2.       T COLD                  ";TC
3430 PRINT "            3.       T AMBIENT               ";TEMP(3)
3440 PRINT "            4.       MEAN T                  ";MT
3450 PRINT "            5.       DELTA T                 ";DELTA.T
3460 PRINT "            6.       DELTA X    (metre)      ";DX
3470 PRINT "            7.       FLUX, Q    (mV)         ";Q
3480 PRINT "            8.       DIFF       (mV)         ";DIFF
3490 PRINT "            9.       CAL. COEF. (W/m^2/mV)   ";S
3500 IF CALIBRATE=1 THEN PRINT "           10.      K INPUT    (W/(m . K)   ";K
3510 IF  MEASURE =1 THEN PRINT "           10.      SAMPLE R   (m^2 . K/W)  ";R
3520 IF  MEASURE =1 THEN PRINT "           11.      SAMPLE K   (W/(m . K)   ";K
3530 PRINT
3540 '
3550 IF ANS$= "Y" THEN PRINT:PRINT:PRINT "                 WRITING DATA TO DISK ";HFN$
3560 IF ANS$= "Y" AND FIRST.LINE = 1 AND CALIBRATE=1 THEN GOSUB 3950
3570 IF ANS$= "Y" AND FIRST.LINE = 1 AND MEASURE=1 THEN GOSUB 4020
3580 IF ANS$ = "Y" AND CALIBRATE=1 THEN WRITE#1,MON,DAY,HOUR,MINUTE,TH,TC,TEMP(3),MT,DELTA.T,DX,Q,DIFF,S
3590 IF ANS$ = "Y" AND MEASURE=1   THEN WRITE#1,MON,DAY,HOUR,MINUTE,TH,TC,TEMP(3),MT,DELTA.T,DX,Q,DIFF,R,K
3600 '
3610 ' TIMING LOOP FOR DISPLAY (CHANGE UPPER LIMIT AS NECESSARY)
3620 IMSEC=0
3630 FOR DISPLAY = 1 TO 1800:IMSEC=IMSEC+1:NEXT DISPLAY
3640 '
3650 ' ROUTINE TO LOAD 15-INTERVAL PAST HISTORY ARRAY
3660 FOR DISP = 1 TO 15
3670    HOURTH(DISP) = HOURTH(DISP+1)
3680     MINTH(DISP) = MINTH(DISP+1)
3690       QTH(DISP) = QTH(DISP+1)
3700 NEXT DISP
3710 '
3720 CLS
3730 PRINT"          PAST HISTORY OF Q,FLUX FOR THE LAST 15 INTERVALS":PRINT
3740 PRINT"              HOUR      MINUTES      FLUX, Q (mV)":PRINT
3750 '
3760 FOR TH.DIS = 1 TO 15
3770 PRINT " ",HOURTH(TH.DIS),MINTH(TH.DIS),QTH(TH.DIS)
3780 NEXT TH.DIS
3790 '
3800 PRINT
3810 IF ANS$ = "N" THEN PRINT "         USE FUNCTION KEY #6 TO BEGIN WRITING DATA TO DISK"
```

```
3820 RETURN
3830 '
3840 ' ***********************************************************************
3850 ' SUBROUTINE:       FUNCTION KEY #6............
3860 ANS$ = "Y"          ' FLAG TO BEGIN SAVING DATA
3870 HFN$="B:R"+YEAR$+MON$+DAY$+TEST$+".DAT":HFN123$="R"+YEAR$+MON$+DAY$+TEST$
3880 PRINT:PRINT "                          WRITE DATA TO ";HFN$
3890 OPEN HFN$ FOR OUTPUT AS #1
3900 FIRST.LINE = 1      ' USE TO WRITE NAME OF MATERIAL AND VALUE OF K
3910 RETURN
3920 '
3930 ' ***********************************************************************
3940 ' SUBROUTINE: CALIBRATION - FILE, MATERIAL, CONDUCTIVITY, HEADINGS
3950 WRITE#1,HFN123$,K$,"   Ki = ",K,"  DEN = ",DEN:FIRST.LINE=0
3960 WRITE#1," "
3970 WRITE#1,"  MONTH      DAY     HOUR   MINUTE    TH       TC       TA       MT     DELTA.T    DX
Q      DIFF       S"
3980 WRITE#1," "
3990 RETURN
4000 '
4010 ' ***********************************************************************
4020 ' SUBROUTINE: MEASUREMENT - FILE, MATERIAL, CALIB. COEF., DENSITY, HEADINGS
4030 WRITE#1,HFN123$,K$,"    S = ",S,"  DEN = ",DEN:FIRST.LINE=0
4040 WRITE#1," "
4050 WRITE#1,"  MONTH      DAY     HOUR   MINUTE    TH       TC       TA       MT     DELTA.T    DX
Q      DIFF       R       K"
4060 WRITE#1," "
4070 RETURN
4080 '
4090 ' ***********************************************************************
4100 PRINT:PRINT "         TEST HAS BEEN TERMINATED..................."
4110 CLOSE   ' closing data file
4120 BEEP
4130 END     ' end program
```

12. APPENDIX - C: Summary of data of typical calibration test

TEST #: H891127a
Object: Calibrate K = 0.032846
Matl: fibrboard
Den: 138.862

DATA SUMMARY
Start: 11/27 14:31
End: 11/27 17:07
Rdgs: 157

Variable	Average	Std	Min	Max	
Hot:	37.55	0.03	37.47	37.66	deg C
Cold:	10.30	0.03	10.22	10.44	deg C
Amb:	23.23	0.04	23.14	23.36	deg C
Mean:	23.93	0.03	23.86	24.05	deg C
Delta T:	27.24	0.02	27.15	27.30	deg C
Delta X:	0.02620	0.00001	0.02618	0.02622	metre
E:	3.675	0.009	3.657	3.699	mV
Diff:	-0.022	0.006	-0.045	-0.002	mV
S init:	9.2951	0.0220	9.2227	9.3483	$W/(m^2 \cdot mV)$

TEST RESULTS
a: 0.02052
b: 1.30E-05
c: 4.015E-10

k final: 32.86 $mW/(m \cdot K)$
S final: 9.2979 $W/(m^2 \cdot mV)$

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Robert R. Zarr and Betty A. Licitra

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10. SUPPLEMENTARY NOTES

☐ DOCUMENT DESCRIBES A COMPUTER PROGRAM; SF-185, FIPS SOFTWARE SUMMARY, IS ATTACHED.

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.)

Results are summarized for 38 individual calibration measurements conducted at 24°C and atmospheric conditions for a heat-flow-meter apparatus having 610 mm square plates. The apparatus was calibrated using a 26.2-mm-thick specimen of fibrous-glass board having a density of 139 kg/m^3. The specimen was selected from an internal lot (Lot 1970) of Standard Reference Material (SRM) similar to SRMs 1450, 1450a, and 1450b. Values of apparent thermal conductivity were predicted using a regression equation developed for this lot of fibrous-glass insulation. Calibration measurements varied ±0.4% with a small drift of 0.4% over 250 days. The apparent thermal conductivity of the calibration specimen was also measured using the National Institute of Standards and Technology's one-metre Line-Heat-Source Guarded Hot Plate. Agreement between measurements of thermal conductivity of the guarded hot plate and predicted values were within +0.2 to -0.3% at 24°C. The report describes the heat-flow-meter apparatus and the computer data-acquisition-system used to collect data from the apparatus.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)
calibration, computer, data-acquisition-system, guarded hot plate, heat-flow-meter, heat-flux-transducer, Standard Reference Material

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