U.S. Department
of Transportation
**Federal Aviation
Administration**

Technical Center

Atlantic City Int'l Airport
New Jersey 08405

June 11, 1993

Dear Group Member:

Enclosed please find the Minutes from the recent International Aircraft Materials Fire Test Working Group Meeting held at Boeing Commercial Airplane Group in Renton, Washington, U.S.A., on May 25 and May 26, 1993.

Also enclosed is a ***Mailing List Request Form***. If you would like to remain on the Working Group mailing list, you must return this form to April Horner by ***Friday, July 9, 1993***, via fax at 609-485-5796. All organizations with two or more individuals involved in the Working Group will receive one package from us beginning with this mailing. If you receive the package, please be sure to forward copies to other members of your organization who are involved in the group. This is part of our effort to reduce mailing costs and multiple mailings to the same organization.

The next meeting will be hosted by Schneller S.A., Paris, France, on October 4-5, 1993. Everyone planning to attend should have returned their *Hotel Preference and Registration Form* to Schneller by *June 15, 1993*.

I look forward to seeing you in Paris.

Sincerely,

Richard Hill

Richard Hill
Program Manager

Enclosures

MAILING LIST REQUEST FORM

I WOULD LIKE TO REMAIN ON THE MAILING LIST FOR THE INTERNATIONAL AIRCRAFT MATERIALS FIRE TEST WORKING GROUP MEETINGS AND GROUP MEMBER INFORMATION AND CORRESPONDENCE.

MY CORRECT MAILING ADDRESS AND TELEPHONE AND FAX NUMBERS ARE LISTED BELOW:

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FAX: ______________________________

ALL FORMS MUST BE RETURNED BY *FRIDAY, JULY 9, 1993* TO:

APRIL HORNER
ACD-240/BLDG. 287
FAX #: 609-485-5796

INTERNATIONAL AIRCRAFT MATERIALS FIRE TEST WORKING GROUP MEETING MINUTES

HOSTED BY BOEING COMMERCIAL AIRPLANE GROUP
RENTON, WASHINGTON, USA

TUESDAY, MAY 25, 1993

HEAT FLUX TRANSDUCER PRESENTATIONS

D. HILL gave background on transducer problems.

BILL CLAYTON of HY-CAL ENGINEERING and LARRY JONES OF MEDTHERM gave presentations on their respective organization's transducers and calibration methods.

Some discussion occurred regarding Incident versus Absorbed heat flux.

H. BARRETT (Polyplastex): Shouldn't we be using radiometer instead of calorimeter?

B. CLAYTON (HY-CAL): I think you are using the right instrument in the calorimeter. How you use it may need to be adjusted.

A copy of the Technical Report entitled: ***Heat-Flow Transducers*** written by Wilson A. Clayton of Hy-Cal Engineering is included in this package.

NIST PRESENTATION

KEN STECKLER of the National Institute of Standards and Technology (NIST) gave update on standard. He discussed NIST's reasons for providing NIST certified calibration. He also cited an independent study done at NIST which concluded it would cost $30,000 a year to maintain a calibration program at NIST.

USERS' PROBLEMS

JIM PETERSON of Boeing discussed Users' Problems concerning OSU (Heat Release) Test.

SUMMARY OF CONCLUSIONS FROM PRESENTATIONS AND PROBLEMS

D. HILL noted that there are two (2) measurements for heat flux: Absorbed and Incident and calibration chart should be the Incident flux.

J. PETERSON (Boeing): Because of the geometry of the globars in the OSU, can you get different results with calorimeters inside the OSU?

B. CLAYTON (Hy-Cal): Yes, you can, probably less than 3% difference.

D. HILL: Would it be useful if we were to purchase a transducer from each manufacturer and ask each manufacturer to calibrate the three (3) transducers and then get a transducer from NIST to serve as the FAA standard and get the manufacturers to use the NIST transducer as the standard to calibrate their units. This will determine whether it is a procedural problem or another type of problem.

S. CAMPBELL (Douglas): Should we expect calibration within 2 to 3% from different manufacturers?

L. JONES (Medtherm): Yes, within 2 to 3%.

D. HILL: Reviewed development of standard method of calibration as discussed by K. Steckler of NIST. He asked Larry Jones of Medtherm his thoughts on this standard and if it would be something the manufacturers would accept.

L. JONES: As far as Medtherm is concerned, this is something we have thought would be beneficial for a long time.
D. HILL: We could solve a lot of these problems if the manufacturers had a standard. This will help determine if there is a problem dealing directly with the calorimeter itself or the way it is calibrated at the labs.

D. HILL - SUMMARY - There is no need to specify a specific type of paint for resurfacing the transducer face, but make it clear that the transducer may have to be recalibrated if it is resurfaced unless you know you are putting a coating with the same emissivity on the plate. The group not interested in a standard black paint. The FAA Tech Center will work with Ken Steckler of NIST to set up a round robin with calorimeter manufacturers.

WEDNESDAY, MAY 26, 1993

ROUND ROBIN REVIEW ON REPLACEMENT HEATING ELEMENT FOR NBS SMOKE CHAMBER

D. JOHNSON: Reviewed data collected using the heating element developed by NIST as replacement element for NBS Smoke Chamber. Reason for new furnace: To reduce calibration time of NBS (currently 45 minutes to 1 hour). He reviewed the results he received back from 6 out of 7 of the labs participating in the round robin *(copies of data from labs involved in round robin are included in this package)*. He had labs use an FAA standard panel he supplied with heating element and their own second panel with known repeatability. He asked if any other labs were interested in participating.

H. CURRY (GE Plastics): How do we get these furnaces fabricated?

D. JOHNSON: The heating element can be bought right now, and you can build your own.

MEMBER QUESTION: Are you going to add a drawing to the handbook that details how the element is built?

D. JOHNSON: Not at this time. We have to wait for the results of the round robin after the elements are sent out with the calorimeter. In the next round robin I will ask more about the samples used at the labs.

HUGH BARRETT'S PRESENTATION ON OSU HEAT RELEASE RATE REFERENCE SYSTEM

The kit he sent to round robin members included: A mounting plate, Polycot paper, and water. He reviewed the test plan--each lab ran 18 reference specimens. He reviewed the list of reference requirements. He reviewed results he got when he ran reference specimen. Anyone who would like results of this round robin should contact Hugh Barrett (see attendance sheet for his telephone number).

D. HILL: Regarding the list of Reference Requirements--The only thing you varied was heat flux are you planning to vary anything else, airflow--for example?

H. BARRETT: The best way to handle this would be to run another round robin keeping heat flux constant and varying airflow rate (for example; keep the heat flux and 3.5 watts and vary the airflow).

MEMBER QUESTION: Where are you going with this?

H. BARRETT: Originally, people who ran OSU everyday were looking for a standard panel to check unit.

D. HILL: Gave background on this round robin project: FAA does not have a standard panel-- we have some material we purchase from Schneller that we send to new labs to check their machines. This will not become a requirement. Industry felt that development of a standard panel would be beneficial and Hugh Barrett took on this project.

SCHNELLER ROUND ROBIN
RESULTS PRESENTED BY REINHARD FELDER

R. FELDER: Reviewed plans to establish a mini round robin and eventually a 10-lab round robin. He asked those interested in participating to let him know. 8 of the 9 labs participating in the thermocouples testing sent in their results. This data was reviewed. He will provide the results to anyone interested.

GROUP OSU PROBLEMS

L. WALKER (Los Angeles-ACO): Has there been a resolution on orientation of specimen?

D. JOHNSON: There is something in the Handbook.

D. HILL: First you have to believe there may be a difference and if so, you have to test the material in both directions. If you have a material that you know does not matter then it does not have to be tested in two (2) different directions.

J. PETERSON: What about the statement in Handbook on carpet?

D. HILL: Variations within 10% covers all materials. It is only for those materials where you know or believe there may be a difference.

D. JOHNSON: I have not received any comments on 15-hole upper pilot burner.

H. LUTZ (Boeing): We have a problem with upper pilot extinguishing.

D. HILL: Would a questionnaire to all group members be useful to ask all group members how they adjust the upper pilot burner, etc.? Give Dick Johnson your input on what types of questions should appear on this questionnaire.

H. LUTZ (Boeing): Would there be any interest in looking at the air splits?

D. HILL: We have worked on something similar in the past.

PAT RYAN (Douglas): Reviewed viewgraphs of calorimeter measurements he received from FAA Tech Center, Hy-Cal Engineering, and Medtherm and how they differed.

NBS SMOKE CHAMBER

D. HILL: Are there any problems on NBS Smoke Chamber that need to be addressed?

MEMBER QUESTION: Does it make a difference on how timely you control conditioning of samples?

MEMBER COMMENT: Yes, it does on thermoplastics.

D. HILL: Is conditioning materials a big problem? Is it too difficult or expensive to get a conditioning chamber? It may not matter on some materials, but it is just as easy to condition all materials than to make a case on specific materials individually.

BUNSEN BURNER TESTS

D. HILL: Are there any problems or concerns on Bunsen Burner tests?

There were no comments from the group.

OIL BURNER FOR SEATS AND CARGO LINERS

D. HILL: Are there any problems or concerns on either of the Oil Burner tests?

S. CAMPBELL (Douglas): Expressed some concern on airflow (in test room).

P. RYAN (Douglas): Questioned airflow as far as pass/fail--what should airflow be?

TOXICITY DISCUSSION
GIUSEPPE BIAMONTE OF AVIOINTERIORS

He posed question to group concerning what types of toxicity tests they are required to run by different aircraft manufacturers.

J. PETERSON: Gave history of toxicity testing.

D. HILL: Gave FAA Tech Center's view (Not an FAA-wide view): The FAA does not require toxicity testing. We are not going to create a standardized toxicity test. Any manufacturer interested can submit their toxicity requirements to us, and we will distribute them to the group.

CABIN WATER SPRAY PROGRAM UPDATE

D. HILL gave presentation and update on Cabin Water Spray Program.

NEW TEST METHOD

D. HILL: It may be possible to devise a new test method or modifications to the OSU to achieve the same results as the OSU. It must be equivalent with the same numbers. This idea was presented to group at last meeting, and to date we have not received any response from anyone showing any interest in working on this project with us. The goal would be a test that is easier to conduct and achieve the same results. Are there any comments on this?

H. BARRETT: Are you (FAA Tech Center) working on anything on this now?

D. HILL: Not at this point. We have some ideas, but we have not worked on anything so far. If you are interested, we will work with industry to try to develop a new test, but we are not going to develop it on our own.

NEXT MEETING

The next meeting will be hosted by Schneller, Paris, France, on October 4-5, 1993. Registration forms are due to Marion Coram at Schneller, Paris, by June 15, 1993.

Technical Report 438

Heat-Flow Transducers

Wilson A. Clayton
Hy-Cal Engineering

Used with permision from ***HANDBOOK OF APPLIED THERMAL DESIGN,*** pages 12-78 through 12-84
McGraw-Hill Inc., New York, © 1989, Eric C. Guyer, Editor in Chief

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Heat-flow transducers measure net heat-transfer rate at the transducer sensing surface. They are generally called "calorimeters," which should not be confused with apparatus also called calorimeters used to measure heat content.

11.1 CONTINUOUS TOTAL HEAT-FLOW MEASUREMENT

Total heat flow rate calorimeters are designed to measure net heat exchange by both convection and radiation in any combination present. Special design constraints must be met to measure conduction heat flow. Transducers are not able to distinguish convection or conduction from radiation heat transfer without special application considerations or modification to suppress one of the heat-transfer mechanisms. The most common modification is the installation of an infrared window over the active sensor, which blocks convection or conduction and changes the transducer into a broad wavelength band radiometer. A highly reflective sensing surface can be used to suppress, but not completely eliminate, sensitivity to radiation heat exchange. Compared to radiometers and pyrometers, sensor technology suitable for measurement of convection or conduction heat transfer is limited, particularly by the requirement for smooth surfaces that avoid disturbances in convection boundary layers.

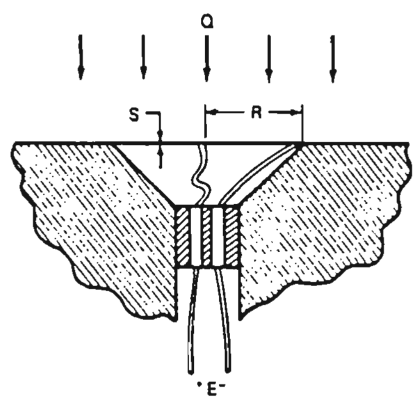
General purpose heat-flow transducers are suitable for continuous use. Transient calorimeters providing output that must be analyzed in terms of transient response to a heat pulse are not included in this discussion. General purpose total calorimeters are characterized in terms of steady net heat transfer, with transducer time constant being a factor in selection and application. Useful calorimeters are largely independent of mounting boundary conditions except at low heat source temperatures, requiring only a heat sink provided by fluid cooling or heat sink mass sufficient for the period of heat application. A special case, wide area blanket type heat-flow meters, is discussed separately in Sec. 11.5.

11.2 DIFFERENTIAL THERMOELECTRIC TRANSDUCERS

Total heat-flow rate calorimeters are generally constructed using one of two types of differential thermoelectric sensors. The broadest range of applicability is provided by the circular foil calorimeter and the greatest sensitivity for heat transfer below 60 Btu/ft^2-s (68 W/cm^2) is provided by the in-depth thermopile calorimeter. Both provide millivolt level outputs driven by temperature gradients between differential thermocouple junctions. Copper-Constantan thermoelectric elements are used except in specialized applications. The depth of the sensing element in the heat-flow direction is kept small so that heat flow is always one dimensional overall through the sensing area into the heat sink body of the transducer. This is a design requirement for independence from mounting boundary conditions that may involve heat loss or gain at the edges of the calorimeter body. Designs that generate output from a temperature difference over a significant depth, greater than 0.02 in (0.5 mm), require a relatively large guard area or installation-dependent calibration that included effects of usually unstable multidimensional heat flow.

Circular Foil Calorimeters

The circular foil calorimeter is elegant in its simplicity and performance. It was first conceived and demonstrated by Robert Gardon for Corning Glass, and is widely known as the *Gardon gage*[2]. Methods for practical manufacture and calibration were developed by R. A. Whitmore at Hy-Cal Engineering[3] and E. W. Malone at Boeing Co.[4] Figure 11.1 illustrates the thermal and physical cross section of this sensor. Net absorbed heat flow on the foil surface drives a parabolic temperature gradient between the center and the edges of the foil as the heat absorbed in the foil conducts radially to the edge. Direction of heat flow in the heat sink has no effect on this transducer making it independent of its mounting.



$$E = \frac{QR\epsilon}{4SK}\left[\frac{1}{1 + C\frac{k_w}{k}}\right] = \frac{QR\epsilon}{4S(k + Ck_w)}$$

Fig. 11.1 Circular foil calorimeter. [E = output signal, Q = heat flux, R = radius of foil, S = thickness of foil, ϵ = thermoelectric potential of foil-wire combination, k = thermal conductivity of foil, k_w = thermal conductivity of wire, C = geometry dependent constant (0.025 is typical), $1/[1 + C(k_w/k)]$ = center-wire correction term (often neglected).]

Output is generated by the differential thermocouple formed through the foil between junctions at the butt welded center wire and edge wire. The preferred construction uses Constantan foil, copper center wire, and copper body, so a copper lead connection anywhere on the copper body replaces the requirement for an edge wire. These materials provide a linear output to 10 mV full scale versus heat flow over a useful operating temperature range to 400°F (200°C) at the foil edge.

All welded construction provides reproducible, stable transducers. Brazing or soldering is not suitable due to imprecise and unstable location of the effective thermoelectric junctions. Foil thicknesses range from 0.0004 to 0.008 in (0.01 to 0.2 mm) and foil diameters range from 0.04 to 0.2 in (1 to 5 mm) for measurement of heat-flow rates between 3000 and 3 Btu/ft^2·s (3400 and 3.4 W/cm^2) at 10 mV full-scale output from the smallest, thinnest to the largest, thickest foils. Copper center wire, usually 0.003 in (0.076 mm) diameter, depresses theoretical output by heat conduction down the wire that is proportional to the ratio of the copper wire and Constantan foil conductivities and a coefficient derived from the heat flow geometry within the transducer.[6] The center wire effect is negligible for other foil-wire combinations since copper is the only high-conductivity wire considered.

Circular foil calorimeter output at steady heat-flow rate is driven by ΔT from the relationship in Fig. 11.1, the differential thermoelectric potential ε of the foil disk-wire combination and a geometry dependent correction Ck_w for center wire conduction.[7]

The constant C can range from 0.005 for minimum center wire effect to 0.05 for maximum center wire effect, but is fixed for a given design and experimentally averages 0.025 in typical transducers. The nominal center wire correction never exceeded 6 percent for lower conductivity center wires but ranged as high as 28 percent for copper center wires in

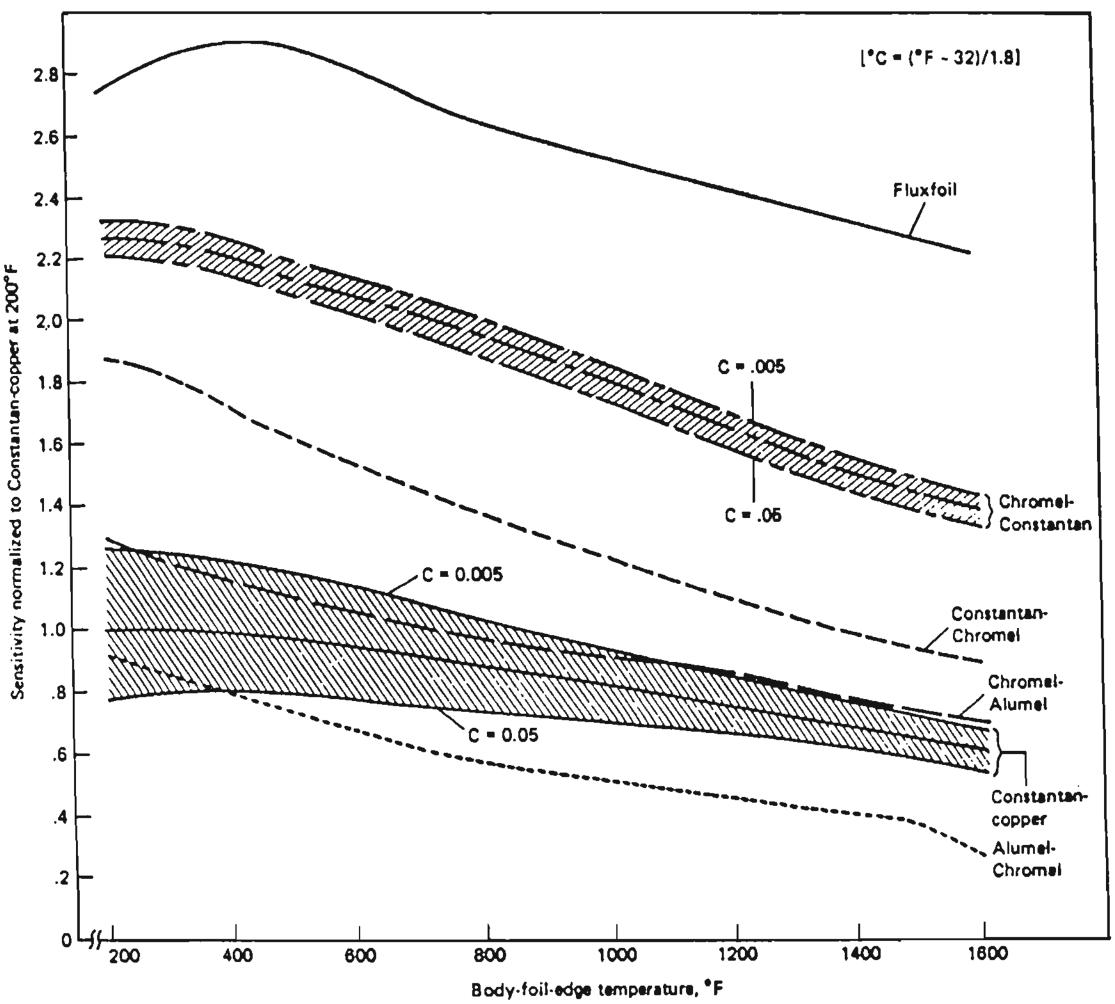


Fig. 11.2 Relative circular foil calorimeter sensitivity. [Base sensitivity, ε/k = 1.4094 μV · h · ft/Btu (1.4664 μV · m/W), where ε = 28.9 μV/°F (52 μV/°C). Average center-wire effect: C = 0.025, except as noted.]

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experiments that compared predicted and measured behavior of circular foil calorimeters constructed from every practical combination of standard thermocouple material used for the foil and wire.[7] Figure 11.2 shows the relative outputs of all the foil-wire combinations evaluated for a median foil temperature 200°F (111°C) above the foil-edge heat sink temperature. Easier comparison of the effects of operating temperature is given by normalizing the results to the lowest body-foil edge temperature and comparing these as plotted in Fig. 11.3.

The Constantan-copper construction (Figs. 11.2 and 11.3) has nominally perfect performance, defined as constant sensitivity ε/k, up to 400°F (200°C). Chromel-Constantan provides high sensitivity and good (linear) performance if not heated. The highest sensitivity and best sensitivity stability to the highest operating temperatures is found in a nontraditional foil-wire combination[7] named Fluxfoil. Figure 11.4 shows Fluxfoil experimental data with a superimposed scale of minimum calorimeter full-scale flux levels versus temperature. The minimum flux levels are required for the internal radiation transfer from the back of the foil to the body cavity to remain negligible, otherwise a rapid loss in sensitivity occurs. This radiation transfer effect of high-temperature operation is not included in the relationship in Fig. 11.1, and is a fundamental limitation on minimum net heat-transfer rates that can be measured at high temperatures.

In-Depth Thermopile Calorimeters

In-depth thermopile calorimeters use the thermopile concept for a high-sensitivity measurement of the temperature gradient proportional to heat flow through a small thickness of thermal insulator. Figure 11.5 shows the most common configuration and insulator size. Dense thermopiles are made by winding 0.001 in (0.025 mm) diameter Constantan at a 0.003 in (0.075 mm) pitch. The length of the winding is as required for the number of thermopile junctions desired, but typically less than 0.5 in (12.7 mm). Copper is plated over slightly more than one-half of the Constantan winding width, electrically shorting the high electrical resistance Constantan and forming copper-Constantan junctions on both surfaces where the copper plating is stopped. Hot and cold junctions are automatically formed in series for the thermopiles using this method. Copper-Constantan is the only industrial thermoelectric pair with enough difference in electrical conductivity for application in this method.

Conceptually the output from the configuration in Fig. 11.5 is easily predicted from the expected temperature gradient and the number of thermopile junctions. This is not true in practice due to the actual complexity of heat flow in the composite material formed during assembly of the in-depth thermopile by potting in the calorimeter body with high temperature epoxies. The thermopile must be submerged just below the heat receiving surface of the calorimeter assembly. For all but the lowest heat-flow rates the

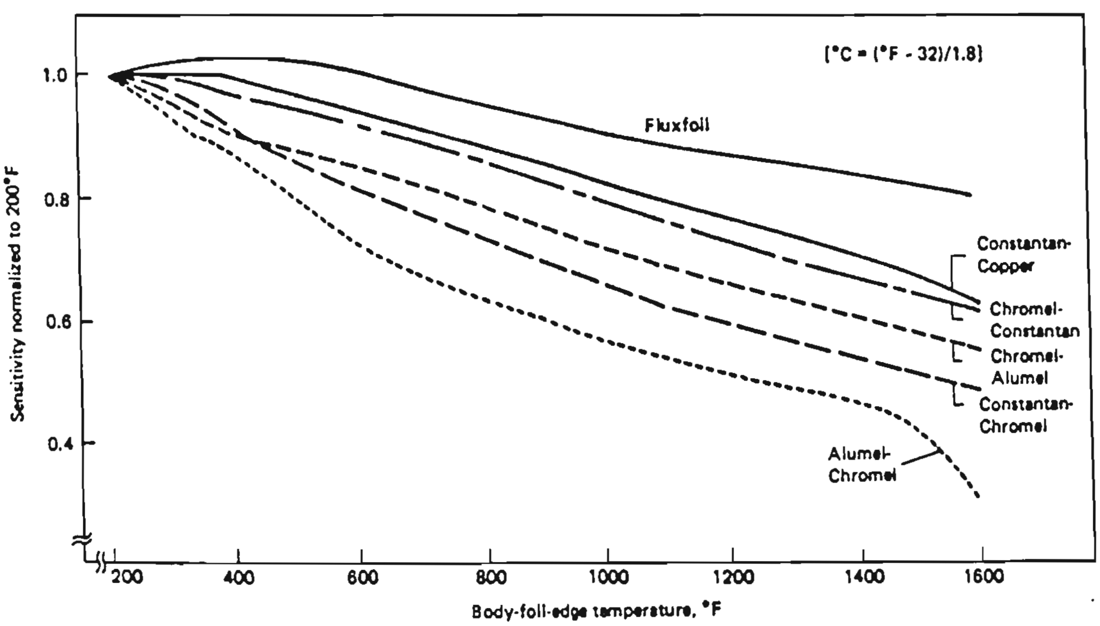

Fig. 11.3 Normalized circular foil calorimeter sensitivity versus temperature. (Average center-wire effect: $C = 0.025$. Foil average temperature 200°F above body.)

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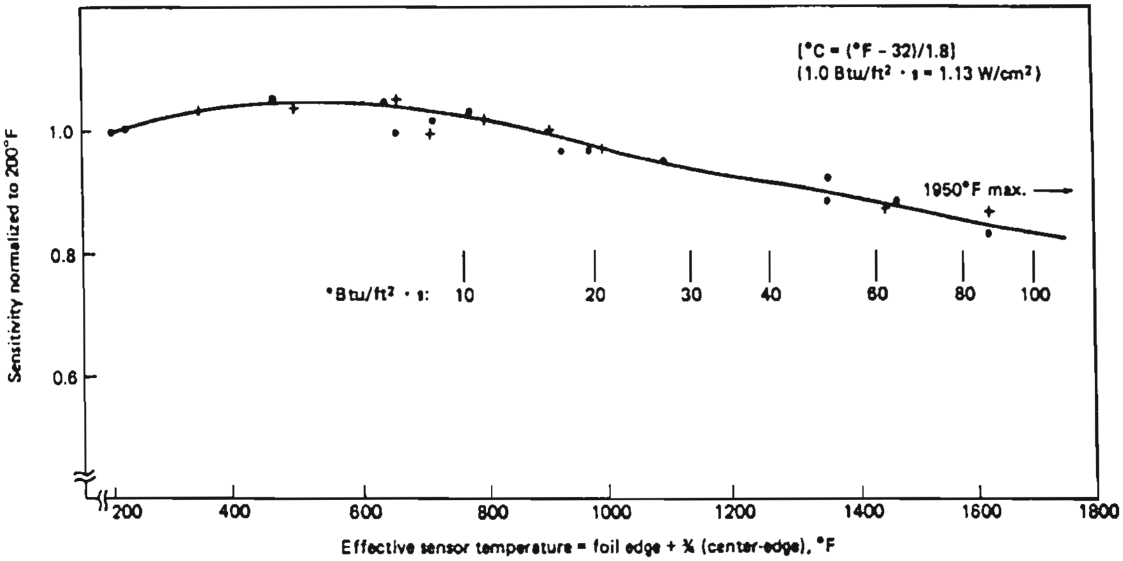

Fig. 11.4 Normalized Fluxfoil calorimeter sensitivity versus temperature. [Base sensitivity, ϵ/k = 2.75 μV · h · ft/Btu (2.86 μV · m/W). Thermoelectric potential, ϵ = 30 μV/°F (54 μV/°C) nominal. (*Gage 10-mV full-scale limit for negligible internal radiation loss.) (Data for two samples shown.)]

thermopile must be seated in a cavity in the calorimeter body. Heat flow is no longer one-dimensional through the thermopile but all boundary conditions are fixed by the assembly to produce a stable transducer.

All successful combinations of insulating spacer, winding wire, plating, potting materials, and final mounting configurations have been empirically derived to produce calorimeters that have excellent independence of operating temperatures above 32°F (0°C). Temperature correction is required for satisfactory measurements below - 58°F(-50°C) for any available in-depth thermopile calorimeter. Low temperature operation is a special concern because only in-depth thermopile calorimeters are sufficiently sensitive for measurement of the low heat-transfer rates associated with low temperatures. Operation down to -328°F (-200°C) is possible. Maximum operating temperature is limited to 500°F (260°C) by the epoxies used in assembly, and then only at less than full rated heat flux level. In-depth thermopiles used for the highest fluxes typically may be only 0.005 in (0.125 mm) in total thickness but will typically experience 9°F (5°C) temperature gradient per Btu/ft • s (W/cm²) unit of heat transfer. At the maximum available transducer rating of 60 Btu/ft² • s (60 W/cm²), this corresponds to 540°F (300°C) nominal temperature elevation at the hot junctions, hence the cold junction-body temperature may not be allowed to rise more than 50°F (28°C) or the potting materials will be pyrolized.

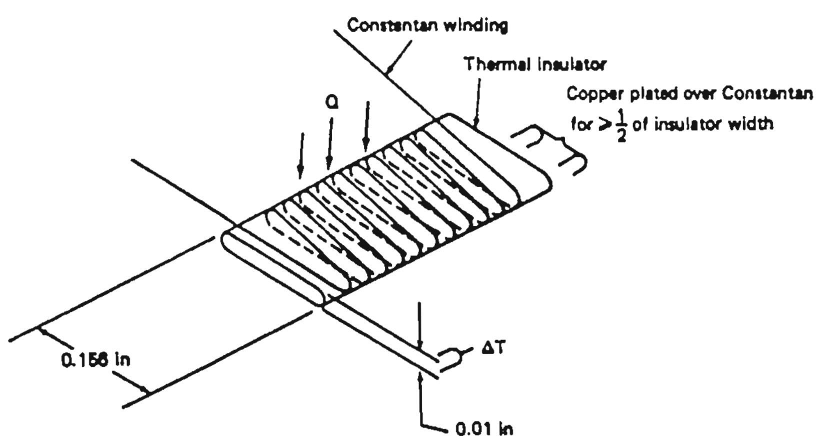

Fig. 11.5 In-depth thermopile with hot junction on top and cold junction on bottom.

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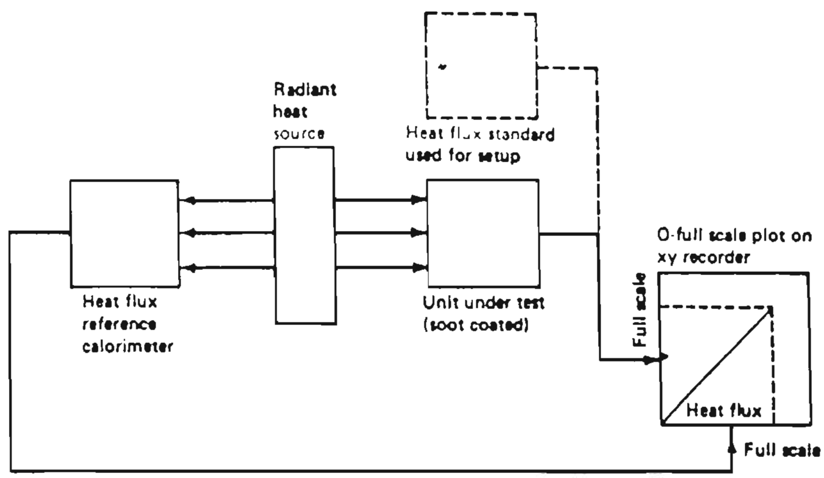

Fig. 11.6 Heat flux calibration schematic.

11.3 Heat-Flow Transducer Calibration

No international standard exists for heat-transfer rate calibration. Practical methods traceable through other measurements have been developed and proven using radiation heat transfer. The universally accepted calibration method was originally patented by Hy-Cal Engineering. Traceability is through traceable optical pyrometer temperature measurement to establish the level of narrow-angle black-body radiation incident on a transfer standard calorimeter. The transfer standard, calibrated with narrow-angle blackbody radiation, is used with a wide-angle radiation source to establish wide-angle calibrations of a group of working standards covering all levels of heat-transfer rate up to about 300 Btu/ft²•s (300 W/cm²).

Figure 11.6 illustrates the routine applications of the wide-angle radiation method of heat-flux calibration. The radiant heat source is a resistively heated graphite plate bathed in inert gas under a water-cooled cover. Viewports are provided to both sides of the plate. Initially a working standard and a "reference" calorimeter are affixed on opposite sides of the source. Outputs are connected to an xy recorder as shown. As power is applied to the source, the sensitivity of the heat-flux scale on the xy recorder is adjusted to position the output of the working standard on its known slope. The system is then said to be "standardized." Any number of units under test can then be sequentially substituted in the exact position of the working standard and calibrated continuously over the full range by increasing the power through the source starting at zero. The method requires no assumptions providing the calibrations are performed with exact reproduction of the positioning of the working standard when the setup is "standardized." In addition, all exposed surfaces must be uniformly blacked to prevent internal reflection variations.

Most of the uncertainly in this calibration method comes directly from the accuracy with which the original blackbody reference temperature can be determined. A good optical pyrometer may be certified to ½ percent of temperature reading. Radiation level is dependent on temperature to the fourth power, so an initial 2 percent uncertainly results from $\pm ½ \times 4 = \pm 2$ percent. All other instrumentation transfer errors are relatively minor. The typical rated accuracy of this calibration method is better than ±3 percent of reading. Short-term method repeatability is better than ±½ percent.

Calorimeters for measurements in multiple mechanisms of convection and radiation are always soot blacked and calibrated in terms of absorbed radiation. The permanent coating is applied after calibration and does not impact the calibration sensitivity. Radiometer configurations are not soot coated and are calibrated for incident radiation. This calibration automatically includes the instrument absorbtivity. The standards are always reproducibly sooted.

For the special case of solar instruments, the above source is used with a water filter to obtain very precise and practical calibrations up to solar radiation levels of 100 solar constants (13.6 W/cm²).

Calibrations beyond levels obtainable with the above method are always extrapolated, which places great importance on well-understood designs and reliable production of linear output transducers.

11.4 Transducer Application Limitations

The descriptions of the operating principles of differential thermoelectric transducers in Sec. 11.2

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emphasized behavior over a broad range of operating temperatures. Operating temperature is the second most important application consideration after estimation of the level of heat transfer rate to be measured. In-depth thermopile calorimeters are limited to below 60 Btu/ft^2 • s (68 W/cm^2) and circular foil calorimeters are used only above 3 Btu/ft^2 • s (3.4 W/cm^2) unless low temperature gradient (and low output) is desirable. Normal instruments of both types are limited to about 400°F (200°C) by epoxies and other materials used. In-depth thermopiles can be calibrated for lower-temperature use and circular foils for higher-temperature use within limitations indicated in Fig. 11.4.

After temperature, application constraints are primarily geometric. For convection measurements the sensing surface must be smooth relative to the boundary-layer thickness, and the shape presented must meet measurement parameters. Often these considerations will run into constraints of minimum size, which are about 0.06 in (1.5 mm) thickness on all types *or* exposed diameter on circular foil types. Shape has little constraint otherwise as long as there is some volume to hook-up lead wire. Figure 11.7 suggests widely used practical shapes of circular foil calorimeters. When these transducer types are configured with windows as radiometers (Fig. 11.8) then view factor will be an overriding geometric consideration.

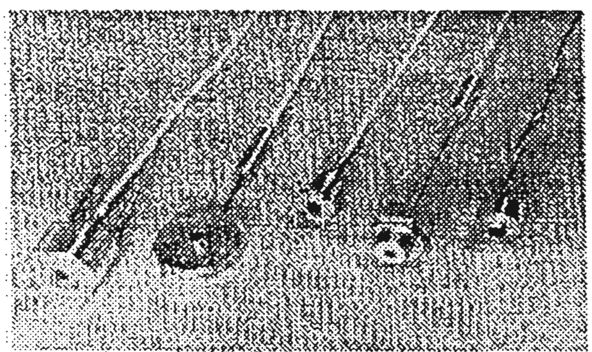

Fig. 11.7 Circular foil calorimeters. Unit at left is water cooled with 1.0-in diameter, a standard in many tests.

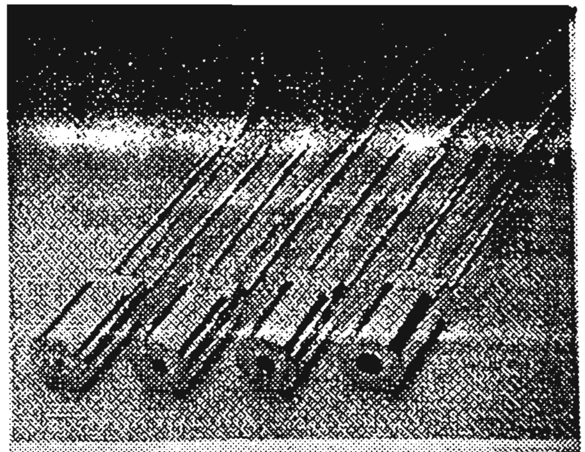

Fig. 11.8 Narrow-angle radiometers. Total view angles 5.5, 11.2, 15, and 30 degrees. In this application only, a thin film thermopile[14] provides fast 10 ms time constant. Water cooled. Gas purge prevents window fouling.

None of the calorimeters described here are suitable for transient measurements, so time response may be a limiting consideration. In-depth thermopile or circular-foil calorimeters can generally not be specified faster than 120- or 15- ms time constants, respectively, with longer time constants required below 5 or 120 Btu/ft^2 • s (54.6 or 136 W/cm^2) heat-flux levels, respectively. Finally, all of these transducers are designed to generate their rated output at a significant surface temperature rise on the order of 300°F (166°C). This renders these devices generally unsuitable for measurements of transfer coefficients unless they are operated at the low end of their design range to limit temperature gradients. Circular foil calorimeters do offer the advantage that the output is a direct measure of the foil edge to center temperature gradient. The effective temperature is then a mean foil temperature, usually three-fourths of the edge to center gradient, plus the foil edge or body temperature measured separately. It is generally accepted and experimentally verified that the foil temperature gradient does not cause a significant distortion of the thermal boundary layer.[8]

11.5 Heat-Flow Meters

Heat-flow meters are a special case of in-depth thermopile instrument distinguished by the fact that the thermopile is not built into a heat sink to form a complete instrument with fixed internal heat flow. Rather, the thermopile is contained in surrounding material to facilitate its mounting on the heat sink included in the measurement. Analysis of this application is extremely difficult due to great dependence on the wide range of boundary conditions encountered. A significant consideration is that these devices cannot always be calibrated by the radiation method described previously, and require a heat-flow stack measurement for calibration. See Refs. 9-13 for recent attempts to understand heat-flow meter measurements.

A typical application of heat-flow meters is in the measurement of heat transfer in various types of building construction. These measurements, of considerable interest worldwide (see References), have proven extremely difficult within demonstrable

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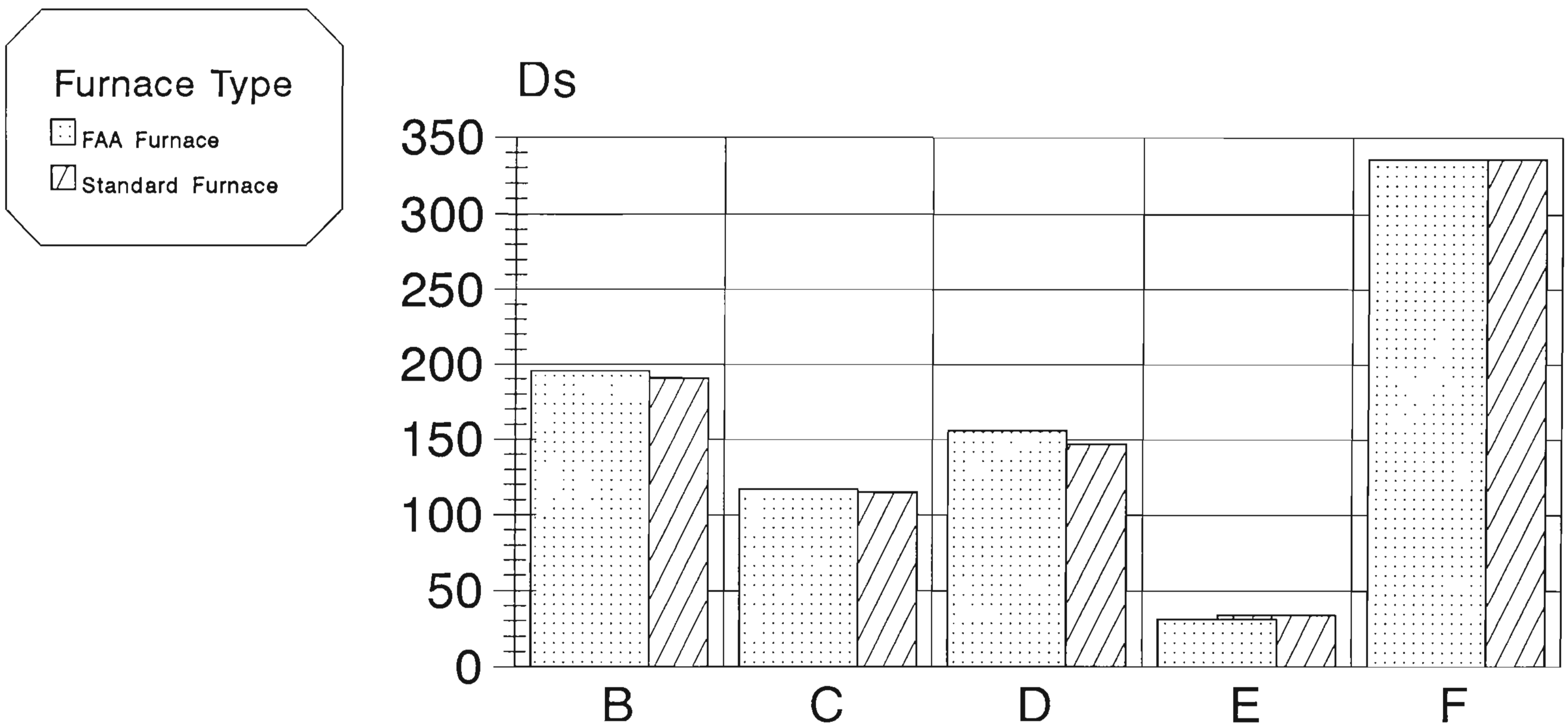
error lower than about ±15 percent. The measured heat flow is normally lower than undisturbed heat flow without the effects of adding the heat-flow meter. The only predictable exceptions are in cases where the meter is fit into a cavity on the surface which generally reduces and may yield positive errors or where the undisturbed test surface thermal resistance is much lower than the sum of the meter and its contact thermal resistance. The latter case is typical of high surface heat-transfer coefficients where lateral heat flow is relatively unimpeded and the heat-flow direction is from the mounted side. §

REFERENCES

1. R.J. Goldstein and H.P. Chiang, "Measurement of Temperature and Heat Transfer," in W.M. Rohsenow, J.P. Hartnett, E.N. Ganić (eds.), *Handbook of Heat Transfer Appliications*, 2nd ed., McGraw-Hill, New York, 1985.
2. R. Gardon, "An Instrument For The Direct Measurement of Intense Thermal Radiation," *Rev. Sci. Instrum.* **24**(5), 366 (1953).
3. "A Discussion of the Standardized Procedure For Calibrating Heat Flux Transducers," *19th Annu. ISA Conf. Exhib.* (Hy-Cal Engineering Publication TR-209, October 1964).
4. E.W. Malone, "Design and Calibration of Thin-Foil Heat Flux Sensors," *ISA Trans,* **7**, 175-179 (1968).
5. L.W. Woodruff, L.F. Hearne, and T.J. Keliher, "Interpretation of Asymptotic Calorimeter Measurements," *AIAA Journal,* **5**(4), 795-797 (1967).
6. N.R. Keltner and M.W. Wildin, "Transient Response of Circular Foil Heat-Flux Gauges to Radiative Fluxes," *Rev. Sci. Instrum.* **46**(9), 1161-1166 (1975).
7. W.A. Clayton, "High Temperature Circular Foil Heat Flux Gauge," *ISA International Instrum. Conf.* (Hy-Cal Engineering Publication TR-417, May 1980).
8. S.A. Striegl and T.E. Diller "The Effect of Entrainment Temperature on Jet Impingement Heat Transfer," *J. Heat Transfer,* Trans. ASME, **106**, 27-33 (1984).
9. G.J. Borell and T.E. Diller, "A Convection Calibration Method for Local Heat Flux Gages," *Natl. Heat Transfer Conf.* (August 1984).
10. Hauser, R.L., "Principles and Performance of In Situ Heat Flux Transducer," *ASTM Workshop on Applications of Heat Flow Sensors* (Hauser Laboratories, September 1983).
11. S.N. Flanders, "Confidence in Heat Flux Transducer Measurements," *ASHRAE Trans.* **91**, part 1 (January 1985).
12. H.A. Trethowen, "Measurement Errors With Surface-Mounted Heat Flux Sensors," Building Research Association of New Zealand, 1986.
13. *Heat Flux Measurement-Proc. 2d Workshop IMEKO* (International Measurement Confederation, Budapest, Hungary, 1986; ITC series no. 9, OMIKK-Technoinform, Budapest).
14. R.D. Baxter, Small Size, High-Performance Radiation Thermopile, U.S. Patent 4,111,717 (1978).

FAA Furnace vs. Standard Furnace

Lab Selected Panel

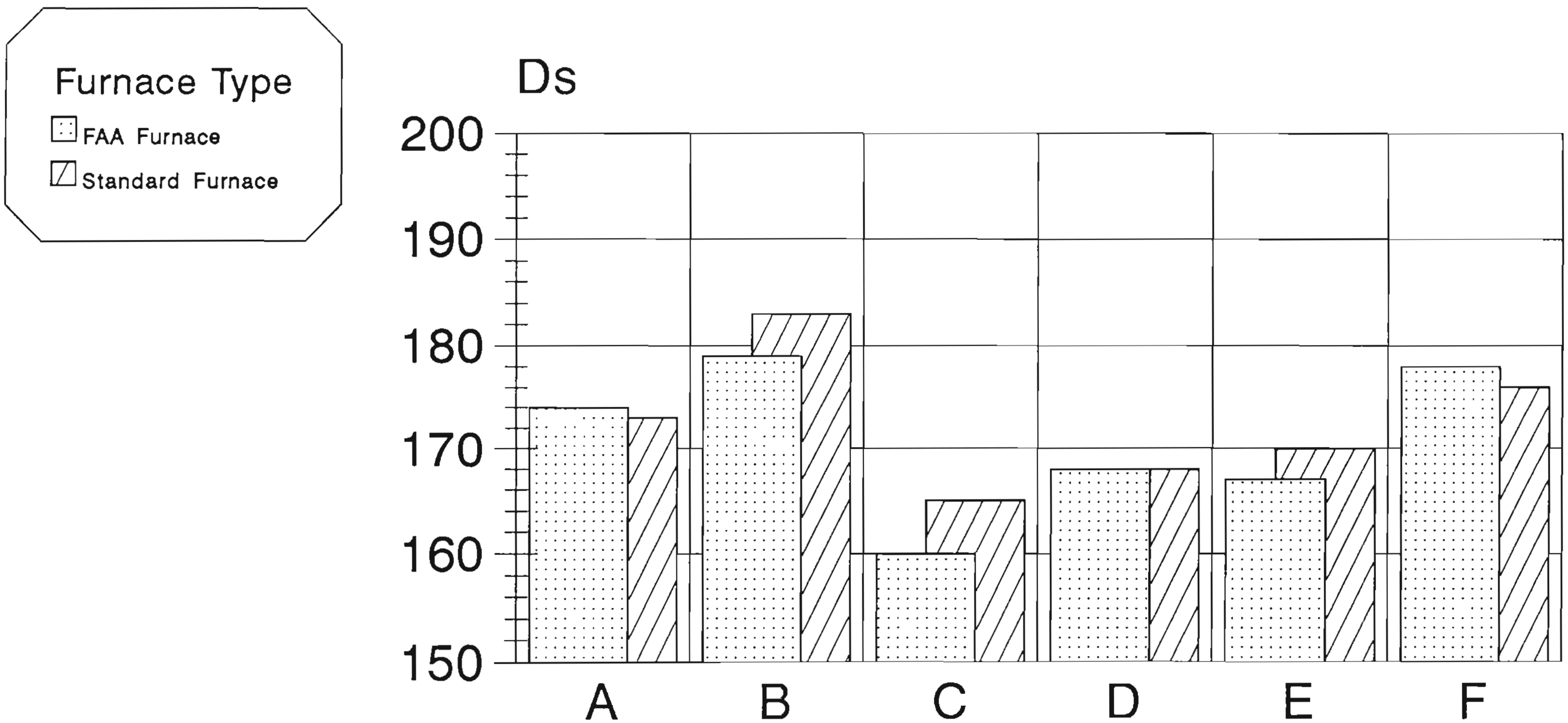


	B	C	D	E	F
FAA Furnace	196	117	156	31	336
Standard Furnace	191	115	147	34	336

Company Code

FAA Furnace vs. Standard Furnace

FAA Standard Panel



	A	B	C	D	E	F
FAA Furnace	174	179	160	168	167	178
Standard Furnace	173	183	165	168	170	176

Company Code

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