TECHNICAL SPECIFICATION

# ISO/TS 14934-4

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# Fire tests — Calibration of heat flux meters —

## Part 4: Guidance on the use of heat flux meters in fire tests

*Essais au feu — Étalonnage et utilisation des appareils de mesure du flux thermique —*

*Partie 4: Lignes directrices pour l'utilisation des fluxmètres thermiques dans les essais au feu*

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# Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 14934-4 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 1, *Fire initiation and growth*.

ISO/TS 14934 consists of the following parts, under the general title *Fire tests — Calibration of heat flux meters*:

— *Part 1: General principles* (Technical Specification)

— *Part 2: Primary calibration methods*

— *Part 3: Secondary calibration method*

— *Part 4: Guidance on the use of heat flux meters in fire tests* (Technical Specification)

# Introduction

In practice, radiant heat flux is usually measured with so-called total heat flux meters of the Schmidt-Boelter (thermopile) or Gardon (foil) type. Such meters register the combined heat flux by radiation and convection to a cooled surface. The contribution to the heat transfer by convection depends mainly on the temperature difference between the surrounding gases and the sensing surface, and on the velocity of the surrounding gases. It will, however, also depend on the size and shape of the heat flux meter, its orientation and on its temperature level, which is near the cooling-water temperature. In many practical situations in fire testing, the contribution due to convection to the sensing surface of the instrument can amount to 25 % of the radiant heat flux. Therefore, it is always necessary to determine and control this part.

To determine the fraction of total heat flux due to radiation, a calibration scheme has been developed where primary calibration is performed on two different types of heat flux meters:

— a total hemispherical radiometer sensitive to radiation only;

— a total heat flux meter (most frequently used) sensitive to both radiant heat transfer and to convective heat transfer.

When using heat flux meters, it is important to realize that only incident radiant heat flux can be measured directly. The net radiant heat flux, as well as the heat transfer by convection to a body, depend on, among other things, the temperature of the receiving surface, while the instrument responds to heat transfer to a cooled surface.

This Technical Specification provides guidance on how this type of instrument is used and how the results are interpreted.

# Fire tests — Calibration of heat flux meters —

# Part 4:
# Guidance on the use of heat flux meters in fire tests

## 1 Scope

This Technical Specification provides guidance on the use of heat flux meters in fire testing applications, including the description and working principles of common heat flux meters and methods for their selection and maintenance. The guidance can also be applied to measuring heat flux from radiant panels and other large heat sources used to simulate the heat flux from a fire. It is applicable for all common testing purposes when measuring heat flux from radiant sources.

This Technical Specification also provides basic theory and working principles of heat flux meters and methods for selection, use and maintenance of heat flux meters. Although it is particularly aimed at the application of heat flux meters in fire tests and experimental works concerning fire research, it can also serve as a guide for other research applications, for example, research on boilers, combustion processes, etc.

Instruments, which measure the transient temperature of a solid body of known mass and heat capacity to infer the heat flux (slug calorimeter type), are not covered by this Technical Specification.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13943:2000, *Fire safety — Vocabulary*

ISO 14934-2:2006, *Fire tests — Calibration and use of heat flux meters — Primary calibration methods*

ISO 14934-3, *Fire tests — Calibration and use of heat flux meters — Secondary calibration method*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943:2000 and ISO 14934-2 apply.

## 4 General information on heat flux meters

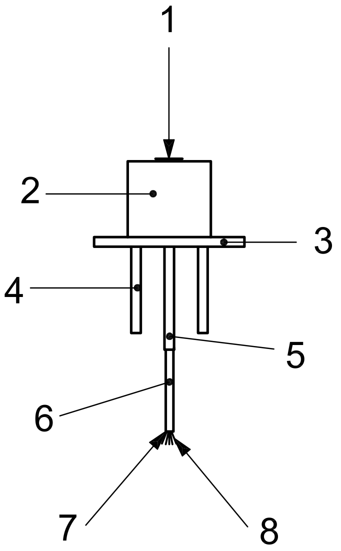
### 4.1 General

A heat flux meter is an instrument which measures the radiant and convective heat that is transferred from the fire environment to a sensing element. In practice, heat flux is most commonly measured with total heat flux meters of the Schmidt-Boelter (thermopile) or Gardon (foil) type. Although there is a wide variety of designs of heat flux meters, a typical design consists of a thermopile sensor, mounted on a metal body that is cooled by water. The body acts as a constant-temperature heat sink. The thermopile sensor typically has a nearly black surface which is assumed to absorb all incident radiation, or of which the which emissivity is given.

It is assumed that sensitivity does not depend on wavelength over the spectral range of the radiating sources. Deviations from the ideal directional response characteristics can normally also be disregarded.

In a normal situation, the field of view is assumed to be 180° and the surface is assumed to be a perfect black body, both regarding the spectral characteristics and the directional response.

In general, heat flux meters consist of an absorber of heat flux, body, water-cooling system and wiring as shown in Figure 1. They often also have a flange for mounting purposes.




**Key**

| | | | |
|---|---|---|---|
| 1 | Absorber | 5 | Tube for wiring |
| 2 | Body | 6 | Cable |
| 3 | Flange | 7 | Heat-flux-meter signal |
| 4 | Tube for water supply | 8 | Temperature-sensor signal |

**Figure 1 — General features of heat flux meters**

The sensing surface shall remain free of deposition of soot or other particulates. It should be noted that soot may collect on the cool gauge surface and can affect the gauge output.

## 4.2 Principle of measurement

The incident heat flux onto the absorber creates a local temperature difference. This difference is measured, resulting in an output signal (voltage). As a first approximation, this voltage is linear with the heat flux received by the sensor. In most heat flux meters, the measurement of the temperature difference is based on thermocouples or thermopiles, which are passive and do not require any external power.

Within a limited working range, the relationship between the heat flux received by the sensor and the output signal can be assumed to be linear. However, it should be noted that the output signal is not always linear to the incident heat flux (see 3.4.3).



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## 4.3 Design of heat flux meter

### 4.3.1 General

There are two types of heat flux meters that are widely used in fire tests: so-called Gardon (foil) type and Schmidt-Boelter (thermopile) type.

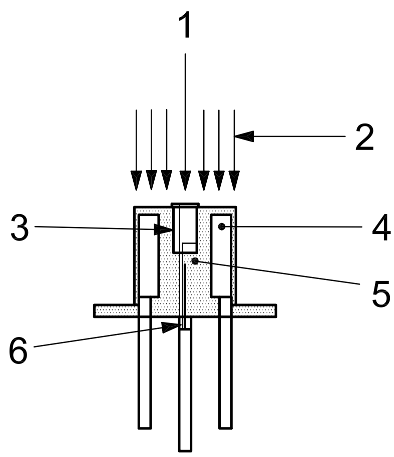
The Gardon-type heat flux meter has a very wide working range and a very fast response time. However, it has a low sensitivity and therefore does not work with low heat fluxes.

The Schmidt-Boelter-type heat flux meter generally has a much higher sensitivity than Gardon gauges.

Another type of heat flux meter is a hemispherical radiometer, sensitive to irradiance only, i.e. it is not sensitive to the surrounding gas temperature and velocity, and is used for estimating the convective part of the heat transfer measured with total heat flux meters.

### 4.3.2 Gardon-type heat flux meter

The Gardon-type heat flux meters have an absorber, which is deposited on a thin foil. The absorbed heat is conducted radially along the foil into the body, which is water-cooled. The absorber has an approximately parabolic temperature distribution. The temperature at the centre is high, varying with heat flux to the sensor, while the temperature at the edge is relatively low, remaining at the constant body temperature, i.e. the temperature of the cooling water. The temperature profile is no longer parabolic when a significant convective cross-flow is present. The temperature difference between the centre and the edge is measured by a thermocouple. A schematic view of the Gardon-type heat flux meter is shown in Figure 2.




**Key**

1 Foil with black absorber (usually constantan)

2 Incident heat flux

3 Wire connected to the centre of the foil

4 Cooling water

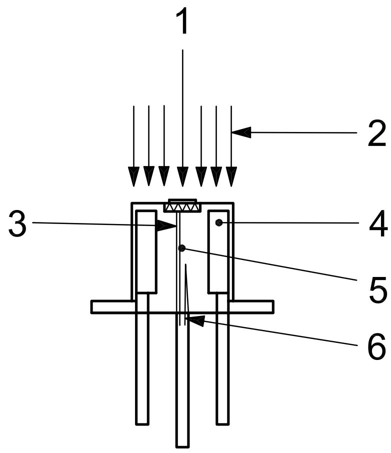
5 Wire connected to the body (or edge of the foil)

6 Thermocouple for body temperature measurement

**Figure 2 — Gardon-type heat flux meter**

### 4.3.3 Schmidt-Boelter-type heat flux meter

A Schmidt-Boelter-type heat flux meter has a relatively thick thermopile mounted on a heat sink, the water-cooled body of the gauge. The absorbed heat is conducted perpendicular to the absorber surface through the sensor into the heat sink. The absorber has a relatively uniform temperature distribution. The temperature difference between the sensor and the body is measured by the multiple thermocouples connected in series in the thermopile. A schematic view of the Schmidt-Boelter-type heat flux meter is shown in Figure 3.




**Key**

1 Foil with black absorber (usually constantan)

2 Incident heat flux

3 Wire connected to the centre of the thermopile

4 Cooling water

5 Wire connected to the centre of the thermopile

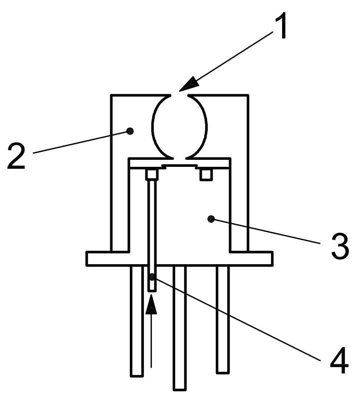
6 Thermocouple for body temperature measurement

**Figure 3 — Schmidt-Boelter-type heat flux meter**

### 4.3.4 Hemispherical radiometer

A hemispherical radiometer is used for measuring irradiance. It is not sensitive to convective heat transfer conditions, i.e. surrounding gas temperature and velocity.

Hemispherical radiometers, as shown in Figure 4, have a reflecting interior (usually gold plated), which reflects the irradiance to the absorber, which is thus kept free of the influence of convection. Hemispherical radiometers are often used in flame research and are often equipped with air purging to keep the reflector free of soot.




**Key**

1 Aperture

2 Body with reflecting interior

3 Heat sink

4 Output wire

**Figure 4 — Hemispherical radiometer**

## 4.4 Measurement characteristics

### 4.4.1 Response time

Because the duration of many standardized tests is limited, a quick response is required from heat flux meters. In many cases, a full-scale response (99 %) of less than 10 s is required.

In general, in the application of the response time when a heat flux meter with a constant body temperature is exposed to an irradiance level starting from $t = 0$, the behaviour of signal output can be described by Equation (1):

$$U_{\text{out}} = I \cdot S_1 \left(1 - \mathrm{e}^{-t/t_{\text{sen}}}\right) \tag{1}$$

where

$U_{\text{out}}$ is the output signal, in V;

$S_1$ is the primary sensitivity, in mV/W·m$^{-2}$;

$I$ is the heat flux, in W/m$^2$;

$t$ is the time, in s;

$t_{\text{sen}}$ is the sensor time constant, in s.

The response time of a particular sensor is therefore usually indicated by its time constant. The time constant of a heat flux meter can also be seen as the time in which 63 % of the full scale (100 %) response is reached.

As a rule, the full-scale response (99 %) is reached within a timeframe of 5 times the time constant. In practice, this means that after 5 times the time constant, the response time no longer is a significant source of error.

For Gardon gauges, based on a foil, the response time can be approximated by Equation (2):

$$t_{\text{sen}} = \rho \cdot c_{\text{p}} \cdot D^2 / 16\lambda \tag{2}$$

where

$t_{\text{sen}}$ is the sensor time constant, in s;

$\rho$ is the foil density, in kg/m$^3$;

$c_{\text{p}}$ is the foil specific heat capacity, in J/kg·K;

$D$ is the foil diameter, in m;

$\lambda$ is the foil thermal conductivity, in W/m·K.

For Schmidt-Boelter Gauges, based on a thermopile, the response time can be approximated according to Reference [7] by Equation (3):

$$t_{\text{sen}} = \left(4/\pi^2\right)\left(\rho \cdot c_{\text{p}} \cdot D^2 / \lambda\right) \tag{3}$$

where

$t_{\text{sen}}$ is the sensor time constant, in s;

$\rho$ is the sensor density, in kg/m$^3$

$c_p$ is the sensor specific heat capacity, in J/kg·K;

$D$ is the sensor thickness, in m;

$\lambda$ is the sensor thermal conductivity, in W/m·K.

Most heat flux meters currently used for fire tests have a time constant of about 1 s or less. Therefore, measured results of heat flux in nearly steady-state conditions in fire tests can be deemed as instantaneous.

If heat flux is measured during a very fast phenomenon, such as a flashover stage or explosion, it may be necessary to correct the measured results of heat flux using the time constant.

### 4.4.2 Working range

In general, a heat flux meter of a particular type is designed to measure within a certain heat flux range (its working range). Also, the sensor has a certain sensitivity and a certain response time to reach a certain output signal level. The main restriction is that the absorber temperature is kept within acceptable limits, in which the paint and sensor will not be destroyed.

The absorber temperature rise is a result of the incident heat flux, sensor construction and cooling system.

### 4.4.3 Sensitivity of heat flux meters

The sensitivity of heat flux meters is primarily determined by the physical composition of the sensor itself. The combined properties of the absorber, surrounding geometry (limiting the field of view), window and thermopile will result in a certain output at a certain level of incident radiation.

The incident radiation level, as a function of the output voltage signal, is assumed to be a second-degree polynomial:

$$I = A_0 + A_1 \cdot U_{out} + A_2 \cdot U_{out}^2 \tag{4}$$

where

$I$ is the incident radiation as defined by the calibration method (Clauses 7, 8 and 9 and ISO 14934-2);

NOTE The calculation procedure for this method takes into account. the view-angle dependence.

$A_0$, $A_1$ and $A_2$ are constants to be determined by the calibration procedure;

$U_{out}$ is the output voltage signal, in V;

$A_0$ can be identified as:

$$A_0 = \eta \cdot \sigma \cdot T_{wc}^4 \tag{5}$$

where

$\eta$ is a coefficient expressing the influence of convection in the calibration situation;

$T_{wc}$ is the absolute temperature of the cooling water during calibration, in K.

When the heat transfer by convection during calibration can be neglected, the coefficient $\eta$ is equal to 1,0 and $A_0$ can be calculated directly. Otherwise $A_0$ has to be determined together with $A_1$ and $A_2$ in a best-fit procedure as described in Clause 10 and ISO 14934-2. The coefficient $\eta$ can then be calculated as:

$$\eta = A_0 / \sigma \cdot T_{wc}^4 \qquad (6)$$

When used in practice, the incident radiation $I$ is calculated for various water temperatures, $T_w$, as:

$$I = I_w + A_1 \cdot U_{out} + A_2 \cdot U_{out}^2$$

where

$$I_w = \eta \cdot \sigma \cdot T_w^4 \qquad (7)$$

and

$T_w$ is the in use temperature of the cooling water. The first and third terms are, in most cases, small in comparison to the second term.

In many cases, manufacturers only provide a linearized sensitivity coefficient ($A_0$ and $A_1$ in Équation (4)), In such cases, they assume that $A_0$ and $A_2$ are zero.

#### 4.4.4 Spectral and directional response

The values measured by the heat flux meters described in this Technical Specification, i.e. the Gardon type, the Schmidt-Boelter type and the hemispherical radiometers, can be affected by their distance from the fire and the orientation of the sensing surface in relation to the fire. These meters also respond differently to radiation in different spectral ranges. However, they are designed to have a close to hemispherical view angle and the sensing elements are coated to achieve spectral absorptivities in excess of 0,9. Therefore, for many common fire tests for which they are used, the uncertainty caused by directional and spectral variations in the fires themselves can be assumed to be small.

There are two situations that need particular care when using these heat flux meters that could cause them to deviate significantly from the ideal. First, if a window is fitted to the heat flux meter to eliminate convection, both the view angle and the spectral response of the heat flux meter can be significantly affected. Second, if the coating on the sensing element becomes contaminated, the spectral response of the heat flux meter may change. The manufacturer's recommendations should be followed for recoating the sensing element to minimize uncertainties due to spectral response.

#### 4.4.5 Sensitivity to convective heat transfer

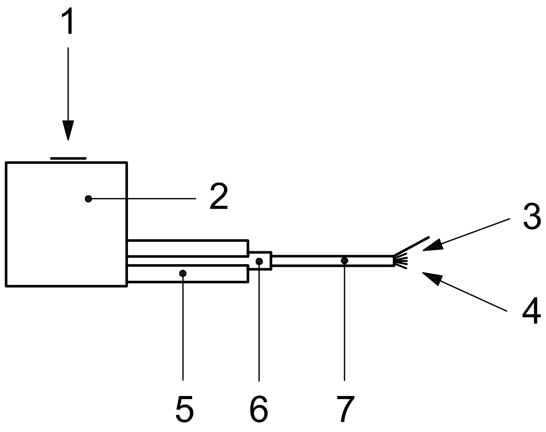
The Gardon and Schmidt-Boelter-type heat flux meters described in 4.3.2 and 4.3.3 are sensitive to both incident radiant heat flux and convective heat transfer. The convective heat transfer is normally reduced to a minimum during calibration in a calibration furnace, while in a fire test situation the convective heat transfer can be significant. Furthermore, it should be noted that the convective heat transfer in an arbitrary situation could give either a positive contribution (heating the sensor) or a negative (cooling the sensor) depending on the gas temperature adjacent to the sensor in comparison to the sensor surface temperature.

### 4.5 Physical shape of heat flux meter

The shape of a heat flux meter is usually cylindrical. The absorber is usually directly attached to the body: a water-cooled heat sink. There is a wide variety of sizes (diameter as well as height) of the cylindrical body.

Tubes for water inlet and outlet, as well as lead wires from the thermocouple or thermopile, are attached to the body. Heat flux meters can be categorized by the type of tube attachment: the horizontal type as shown in Figure 5 with tubes and wiring attached to the side wall of the body, and the vertical type as shown in Figure 1 with tubes and wiring attached to the bottom of the body.

In order to facilitate installation, a flange may be attached to the body of the heat flux meter (see Figure 6). The side of the body may have a threaded hole or female thread for installation (see Figure 6).




**Key**

1 Absorber

2 Body

3 Temperature-sensor signal

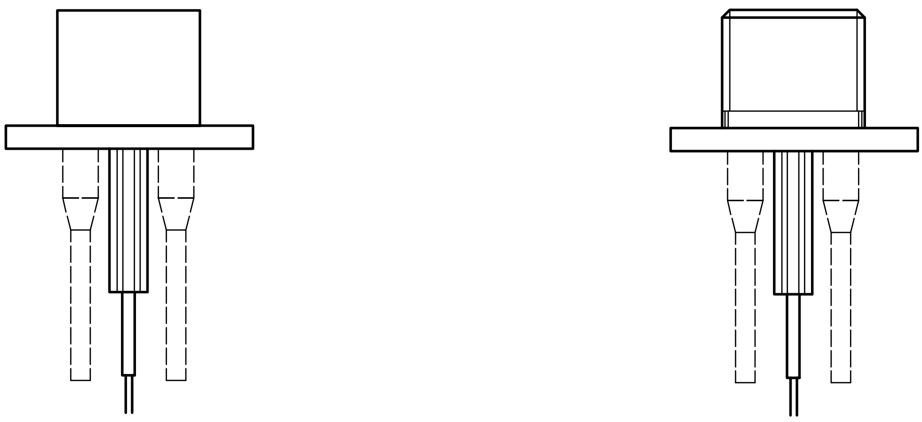
4 Heat-flux-meter signal

5 Tube for water supply

6 Tube for wiring

7 Cable

**Figure 5 — Horizontal-type heat flux meter**



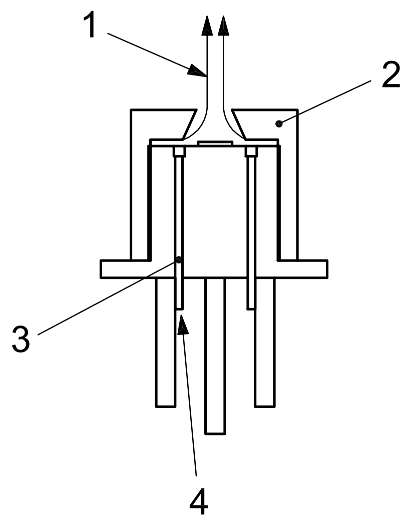
**a) Flanged heat flux meter** **b) Flanged and threaded heat flux meter**

**Figure 6 — Heat flux meters**

## 5 Attachments to heat flux meters

### 5.1 Air purging

Air purging (see Figure 7) may be used in combination with a heat flux meter. This is particularly useful when an extensive amount of smoke or soot is expected during the experiment. Air-purge systems are used to prevent the smoke particles from accumulating onto the absorber of the heat flux meter. It should be noted that purged air can affect the combustion and heat transfer, in particular convection, around the heat flux meter. Air-purged sensors will require dedicated calibration. (See also Clause 6.)




**Key**

1 Air outflow

2 Cover for guiding air flow

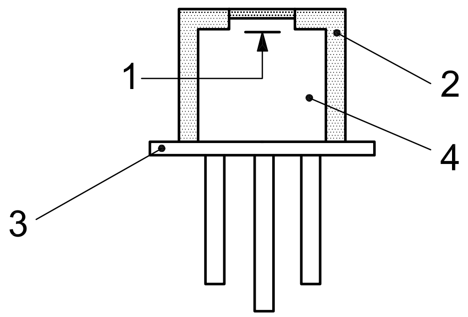
3 Air pipe

4 Purging air

**Figure 7 — Heat flux meter with an air-purge system**

## 5.2 Windows

In order to measure radiation only, and thus avoid the contribution of convection, a window may be attached in front of the absorber of a heat flux meter (see Figure 8). It should be noted that the window may absorb a significant part of the radiation, and also that the mounting of a window will change the field of view. Therefore, the choice of window material, as well as mechanical mounting, will affect the measurement. This will require dedicated calibration (see also Clause 6). Figure 9 shows examples of transmission of some types of window materials.




**Key**

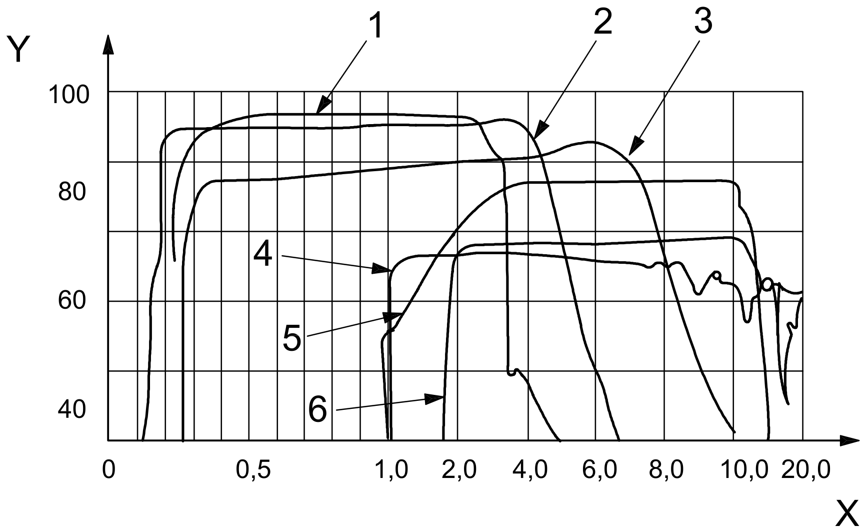
1 Sensing surface of the heat flux meter

2 Holder for window with a window facing 1

3 Base

4 Heat-flux-meter body

**Figure 8 — Heat flux meter with a window**




**Key**

X Wave length (nm)

Y Transmittance (%)

1 Crystal, quartz

2 Sapphire

3 YTTRALOX

4 Silicon

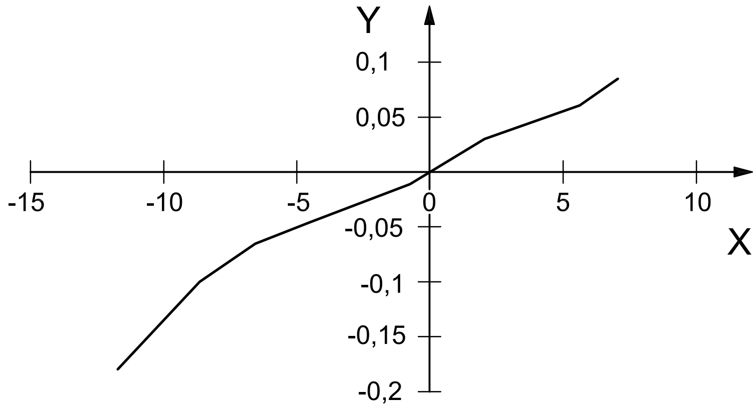
5 IRTRAN2

6 Germanium

**Figure 9 — Transmittance curve of each window material**

## 5.3 Cooling system

For both the Gardon-type and the Schmidt-Boelter-type heat flux meters, the body is usually cooled and stabilized by circulating water. Care should be taken that the water temperature remains as constant as possible, and that it remains above the local dew-point temperature. If the cooling water temperature is below the dew point of ambient air, water condenses on the exposed surface of the heat flux meter and gives an incorrect measurement. In the case of measurement of a very low level of heat flux, the temperature change of cooling water may affect the measurement considerably. Figure 10 shows the signal output of a heat flux meter, which is exposed to no irradiance when the cooling water temperature is different from ambient temperature. Use of a cooling water circulation system, as shown in Figure 11, is recommended. The cooling capacity of the water should be large enough to avoid temperature change due to the heat received by the heat flux meter. Less than a litre per minute is usually sufficient for this purpose.

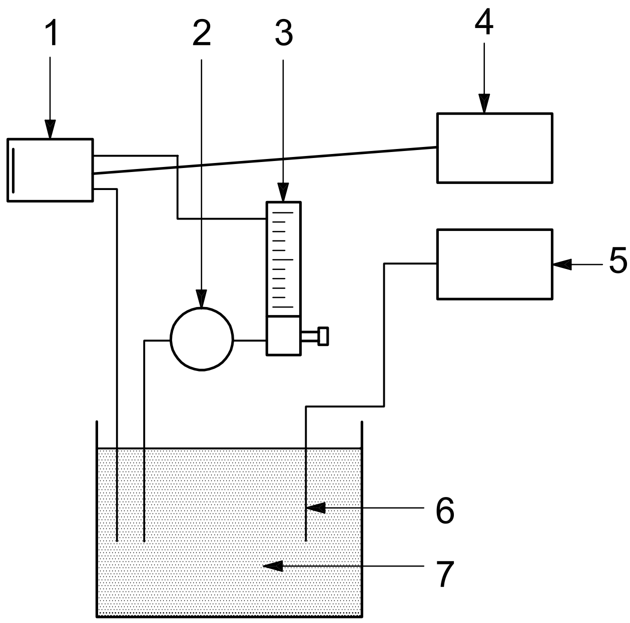



**Key**

X Temperature difference (°C)

Y Output (kW/m$^2$)

**Figure 10 — Output of heat flux meter against difference between cooling water temperature and ambient temperature (when no irradiance is given)**




**Key**

| | | | |
|---|---|---|---|
| 1 | Heat flux meter | 4 | Signal analyser (voltmeter) |
| 2 | Pump | 5 and 6 | Water temperature controller |
| 3 | Flow meter | 7 | Cooling water |

**Figure 11 — Cooling water circulation system**

# 6 Selection of a suitable heat flux meter

## 6.1 General

There are several criteria for the selection of a suitable heat flux meter for use in a fire test, such as:

— range of measurement;

— dimensions and weight;

— orientation of sensor surface against wiring and piping system;

— view angle; and

— assessment of level of convection heat transfer [8].

## 6.2 Range of measurement

### 6.2.1 Evaluating the working and calibration range

Excessive incident heat flux to a heat flux meter beyond its working range may cause destruction of the heat flux meter. On the other hand, the use of heat flux meters to measure at very low levels of heat flux (in relation to the working/calibration range of a heat flux meter) may cause large inaccuracies and errors. Therefore, the working range, as well as the calibration range of the heat flux meter, should match the conditions of the intended measurement.

### 6.2.2 Looking at the required test method

When selecting a heat flux meter, it is important to estimate the heat flux level to be measured. In the case of standardized tests, the heat flux level is defined in the standards covering these tests.

### 6.2.3 Estimation of the expected heat flux

When a heat flux meter is used in a real-scale fire test or in a test where combustion cannot be controlled, the following assumption may help to choose a suitable heat flux meter. Table 1 gives typical levels of heat flux at various fire conditions.

**Table 1 — Typical levels of heat flux**

| Typical range of heat flux<br>$kW/m^2$ | Phenomenon |
|---|---|
| 200 to 100 | Incident heat flux on the wall in a developed fire enclosure |
| about 100 | Radiation from burning house |
| about 30 | Causing ignition of tree |
| 20 to 10 | Causing ignition of timber |
| about 7 or 8 | Lowest level for causing ignition of a timber wall under a pilot flame |
| about 4 | Lowest level for causing a burn |
| about 2,5 | Highest level for people to endure |
| 1,5 | Solar constant |

**6.2.3.1** When heat flux is measured in a developing stage of fire with a single flame, the heat flux from the flame can be up to 100 kW/m$^2$, even if the measurement is made in contact with the flame.

**6.2.3.2** When heat flux is measured in a fully developed fire or in a fire resistance test for structural members, a maximum level of 300 kW/m$^2$ can be reached.

**6.2.3.3** When heat flux from a fire plume is measured, the level depends upon the size of the fire plume and the distance from it.

**6.2.3.4** When measuring heat flux along an escape route, a low level of heat flux, such as below 5 kW/m$^2$, should be measurable.

## 6.3 Type, dimensions and orientation

The type, dimensions and orientation (horizontal or vertical) of the heat flux meter used in a fire test should be specified in the test method. If such a specification is not given by the standard, the manufacturer of the test equipment might recommend the type, dimensions and orientation of the heat flux meter to be used in the test equipment.

When a heat flux meter is installed in a specimen, the water cooling system of the heat flux meter may have a cooling effect on the specimen. This may cause a drop in the temperature of the specimen around the heat flux meter and result in a delay or failure of ignition and/or flame spread. In this case, use of a small-size heat flux meter is recommended.

Where a heat flux meter is installed in a large-scale test specimen, care should be taken that the heat flux meter, as well as the wiring and piping system, are robust enough for the purpose.

NOTE It is suggested that a piece of insulation material, such as ceramic fibre, can be inserted between the heat flux meter and the test rig or the specimen, and that the wires and pipes of the gauge should be also protected with a piece of insulation material.

## 6.4 View angle

If a window or air-purge system is installed in a heat flux meter, the view angle will be limited, and care should be taken to ensure that the targeted heat source is within the view angle. Where the size of the heat source cannot be defined, heat flux meters which have a limited view angle should not be used [9].

## 6.5 Response time

Most of the Gardon-type and Schmidt-Boelter-type heat flux meters have a short time constant of less than one second. Therefore, there is no need to consider the response time for the application to standardized fire tests, where the heat conditions are relatively constant. However, if the heat flux is measured in a very fast phenomenon, such as a flashover or explosion, the response time should be taken into account for the selection of the heat flux meter.

## 6.6 Sensitivity to convective heat transfer

The Gardon- and Schmidt-Boelter-type heat flux meters are not equally sensitive to convective heat transfer. The surface temperature is lower on the Schmidt-Boelter type, which should be taken into account.

# 7 Performing a measurement

## 7.1 Installation

### 7.1.1 Installation of heat flux meter on test equipment

The method of installing a heat flux meter on test equipment is usually specified in the test standard.

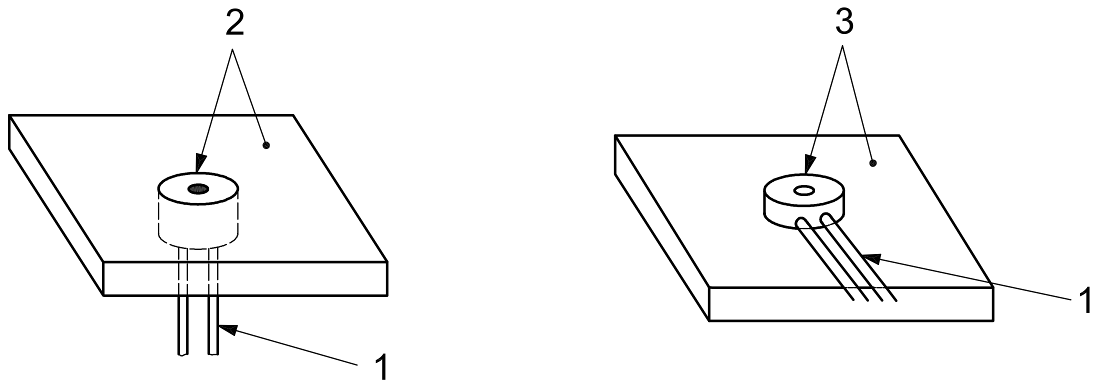
### 7.1.2 Installation of heat flux meter in specimen

When a heat flux meter is installed in a specimen or a dummy specimen, holes are drilled in the specimen to accommodate the body of the heat flux meter. In general, it is recommended to have the surface of the heat flux meter at the same height as the surface of the specimen.

When the surface of a heat flux meter is on a same level as the surface of the specimen, both convective and irradiative heat transfer to the cooled absorber are measured. It should be noted that the heat flux meter measures heat transfer to the cooled surface of the absorber and is dependent on its temperature. The heat transfer from the environment to the specimen surface is in general much smaller as the specimen surface temperature rises. When the surface of the heat flux meter protrudes from the surface of the specimen, in particular when orientated vertically, the convective heat is altered. If the heat flux meter recesses from the surface of the specimen, the edge and side wall of the hole of the specimen limit the field of view to the heat source. Recessed as well as protruded mounting should be used in exceptional cases only, and should be well documented.

In a large-scale fire test, the heat flux to a heat flux meter mounted in the specimen is sometimes measured. In order to install a vertical type heat flux meter in a specimen, a hole may be made in the specimen through which the heat flux meter is inserted (see Figure 13). In this case, the tubes for water supply and lead wires may be protected by the specimen. However, care should be taken to avoid damage or mechanical stress to the sensor by collapse or deformation of the specimen. It is recommended to insert an insulation material, such as ceramic wool, between the side of the heat flux meter and the wall of the hole of the specimen. This insulation material may protect the heat flux meter from any deformation of the specimen, and also reduce the cooling effect of the water-cooling system of the heat flux meter to the specimen.

Horizontal-type heat flux meters can be mounted on the surface of the specimen in large-scale tests, without any treatment of the specimen (see Figure 12). In this case, the heat flux meter protrudes from the surface of the specimen. The tubes for water supply and lead wires are now exposed to the heat source, and should be protected by appropriate means.




**a) Heat flux meter installed in the specimen through a hole**

**b) Heat flux meter installed on the surface of the specimen**

**Key**

1 Tube for cooling water

2 Surface of the heat flux meter is on the same level as the surface of the specimen

3 The heat flux meter protrudes from the surface of the specimen

**Figure 12 — Installation of heat flux meter to specimen**


PROOF/ÉPREUVE

## 7.2 Target surface

Heat flux meters are usually supplied with a plastic cover to protect the sensing surface. This cover shall be removed before testing. The plastic cover easily melts at high temperatures and adheres to the target, and it is difficult to remove.

## 7.3 Electronics

The electronic device connecting to the output of the heat flux meter should have an input impedance of at least 1 000 times the impedance of the sensor of the heat flux meter.

After installation, a check of the electronic circuit should be carried out. The check consists of replacement of the sensors by

— a resistor of similar resistance value to the sensor, to verify that there are no significant offsets, and

— a voltage source to verify the voltage measurements.

## 7.4 Relationship between output voltage and total heat flux

The sensitivity of heat flux meters is primarily determined by the physical composition of the sensor itself. The combined properties of the absorber, surrounding geometry (limiting the field of view), window, and thermopile will result in a certain output at a certain level of incident radiation.

The total heat flux to the sensor, $q_{\text{tot}}$, may be written as

$$q_{\text{tot}} = q_{\text{rad}} - q_{\text{emi}} + q_{\text{con}} \tag{8}$$

where

$q_{\text{tot}}$ is the total heat flux to the sensor;

$q_{\text{rad}}$ is the heat radiation absorbed by the sensor;

$q_{\text{emi}}$ is the emitted heat radiation from the sensor;

$q_{\text{con}}$ is the convective heat transfer to the sensor.

The heat radiation that is absorbed by the sensor depends on the absorptivity of the sensor surface as

$$q_{\text{rad}} = \varepsilon \cdot I_{\text{rad}} \tag{9}$$

where

$\varepsilon$ is the absorptivity of the sensor; the absorptivity and the emissivity of the sensor are assumed to be equal;

$I_{\text{rad}}$ is the incident heat radiation as defined by the calibration method; the view angle dependence for the method is included in the value.

The emitted heat radiation from the sensor, $q_{emi}$, is

$$q_{emi} = \varepsilon \cdot \sigma \cdot T_w^4 \quad (10)$$

where

$T_w$ is the absolute temperature of the cooling water, which is assumed to also represent the temperature of the sensor.

The convective heat transfer, $q_{con}$, is specific for the calibration method. It depends on the calibration configuration and on the temperature of the cooling water and the ambient air.

The total heat flux to the sensor, $q_{tot}$, is assumed to be a second-degree polynomial of the output voltage signal:

$$q_{tot} = A_0 + A_1 \cdot U_{out} + A_2 \cdot U_{out}^2 \quad (11)$$

where

$A_0$, $A_1$, $A_2$ are constants to be determined by the calibration procedure in a best-fit procedure as described in Clause 10 of ISO 14934-2:2006;

$U_{out}$ is the output voltage signal.

Heat flux meters in special applications; e.g. used with view-limiting devices, air-purging systems, conical receivers, should be calibrated including these additional features. When making calibrations of such sensors against traceable standards, the measurement conditions and the corrections that are applied when calculating the sensitivity should be carefully documented.

# 8 Calibration

## 8.1 Secondary standard heat flux meter

A secondary standard heat flux meter, which has been calibrated in a laboratory that is designated to perform this secondary calibration in accordance with ISO 14934-3, shall be obtained in order to calibrate heat flux meters to be used in a laboratory.

It is recommended to prepare at least three secondary standard heat flux meters, which are calibrated in accordance with ISO 14934-3. It is useful to conduct comparison calibration between these secondary standard heat flux meters, so that a secondary standard heat flux meter which gives wrong measurements can be found, assuming that the other two are in order.

## 8.2 Working standard heat flux meters

Working heat flux meters to be used in fire tests should be calibrated by comparison with the secondary standard heat flux meters following the method specified in ISO 14934-3.

## 8.3 Frequency of calibration

Fire test standards may specify the interval of calibration of the working heat flux meter. If there is no specification in the intended fire test standard, it is recommended to use ISO 5660-1:2002, 10.3.1 for this purpose.

# 9 Maintenance

## 9.1 Absorber

During the use of heat flux meters, the colour of the absorber surface may change. This may be caused by overheating, deposition of soot, ash and/or other particles, reaction of the coating with gasses, etc. In the case of minor colour change, the heat flux meter may be used after cleaning the surface and recalibration. If the extent of colour change is large, or in the case of the coating letting loose, the surface shall be repainted in accordance with manufacturer's recommendations. When the absorber of a heat flux meter is repainted or substantially cleaned, the heat flux meter shall be calibrated.

## 9.2 Wiring

The output lead wire shall be examined. Large noise in the output suggests a defect or snapping in the wiring. No signal change when facing the sensor to a heat source may mean a short in the wiring or an open circuit.

## 9.3 Water supply

The water supply system for cooling the heat flux meter shall be checked and it is important to make sure that there is no leakage of water, and that water flow is sufficient and constant. Filtering the water supply may be appropriate to keep particulates from blocking the water passages inside the gauge.

# 10 Use of heat flux meters in fire tests

## 10.1 General

This clause gives examples of the application of heat flux meters in standardized fire tests. The text serves as an illustration only and for detailed test procedures the individual standards shall be used.

## 10.2 Ignitability test (see ISO 5657)

The specimen is exposed to 5 levels of incident heat flux (10, 20, 30, 40, 50 kW $m^{-2}$) and the ignition time under each incident heat flux level is measured. A heat flux meter is attached to a non-combustible board which is placed in the specimen position. The temperature of the cone heater is adjusted in order to obtain the required incident heat flux to the specimen position. Gardon- or Schmidt-Boelter-type heat flux meters can both be used for the purpose. A heat flux meter with a working range of up to 100 kW $m^{-2}$ should be used. Its absorber should be 10 mm in diameter.

## 10.3 Spread of flame test (see ISO 5658, all parts)

The distribution of incident heat flux in the plane of the specimen is specified in the standards.

In order to achieve repeatability with earlier testing, prior to the test itself, the complete system is adjusted. This is done by measurement of the heat flux at the fixed locations using a heat flux meter inserted into holes in a non-combustible board (for example, silica-acid-calcium board with a density of about 800 kg $m^{-3}$). The board is temporarily put in place of the specimen, and the gas supply to the heat source is adjusted in order to obtain the prescribed distribution of heat flux. The area of the non-combustible board, within 300 mm from the edge receiving a lower heat flux, is lowered by 10 mm in order to prevent convective heat flux around the area. This is necessary because, in that area, the convective flux is relatively high in comparison with the radiant heat flux. When no measurement is done in a hole, it should be closed by plugs made of the specimen material and with a minimum discontinuity of the surface area. Incident heat flux at a location closest to the heat source is about 50 kW $m^{-2}$, enough to ignite clothes and to burn, so care should be taken when conducting the experiment.

### 10.4 Heat release, smoke production and mass loss (see ISO 5660, all parts, and ISO 17554)

In this test the heat flux meter is used to verify the heat flux level at the location of the specimen. A Schmidt-Boelter-type heat flux meter with a working range of 0 to 100kW/$m^2$ should be used for adjusting the heat flux level. The diameter of the black paint on the absorber is about 12,5 mm. It is important to ensure that the cooling water is flowing and that the vulnerable black coating on the absorber is handled with care. In order to maintain a stable reference, calibration of the heat flux meter should be done on a daily basis. The absorber should be positioned at the location of the central part of the specimen. If necessary, the specimen holder should be removed in order to be able to place the sensor at that particular location.

### 10.5 Full-scale room test for surface products (see ISO 9705)

In this test, a heat flux meter is mounted at the geometric centre of the floor of the test room. The target surface protrudes from the floor surface by 5 mm to 30 mm. Use of any window is prohibited. An optional heat flux meter can be mounted at the geometric centre of the opening of the test room.

### 10.6 Façade tests (see ISO 13785-2)

Heat flux meters are installed on the specimen to measure the heat output condition of the fire room attached to the test assembly.

### 10.7 Spread of flame test for floor coverings (see ISO 9239, all parts)

In ISO 9239, the specimen is exposed to a specified distribution of heat flux along the longitudinal surface. The maximum heat flux to the specimen is 11 kW/$m^2$ in ISO 9239-1 and 25 kW/$m^2$ in ISO 9239-2. Adjustment of the radiant-panel heat source is carried out with a dummy specimen with holes in which a heat flux meter is inserted.

### 10.8 Intermediate-scale heat-release calorimeter (ICAL) (see ISO/TR 14696)

The irradiance level to the specimen is adjusted using a heat flux calibration panel of 1 000 mm × 1 000 mm made of 12 mm to 13 mm thick calcium silicate board of nominal density 600 kg/$m^3$ to 850 kg/$m^3$. Five rows and columns of holes (25 holes in total) are drilled with their centres 224 mm apart, and 52 mm from the edges on all sides of the panel. The heat flux meter is inserted in the holes and extends 15 mm toward the radiant panel from the exposed surface of the calibration panel, to minimize the convective-heat-transfer contribution during the measurement. Heat flux is measured in several distances between the calibration panel and the radiant panel, i.e. 300, 400, 600, 800, 1 000, 2 000, 3 000, 4 000, 5 000 and 6 000 mm.

# Bibliography


[1] ISO 5657:1997, *Reaction to fire tests — Ignitability of building products using a radiant heat source*

[2] ISO 5658-2:1996, *Reaction to fire tests — Spread of flame — Part 2: Lateral spread on building and transport products in vertical configuration*

[3] ISO 5658-4:2001, *Reaction to fire tests — Spread of flame — Part 4: Intermediate-scale test of vertical spread of flame with vertically oriented specimen*

[4] ISO 5660-1:2002, *Reaction to fire tests — Heat release, smoke production and mass loss rate — Part 1: Heat release rate* (cone calorimeter method)

[5] ISO 5660-2:2002, *Reaction to fire tests — Heat release, smoke production and mass loss rate — Part 2: Smoke production rate* (dynamic measurement)

[6] ISO/TR 5660-3:2003, *Reaction-to-fire tests — Heat release, smoke production and mass loss rate — Part 3: Guidance on measurement*

[7] ISO 9060, *Solar Energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation*

[8] ISO 9239-1:2002, *Reaction to fire tests for floorings —- Part 1: Determination of the burning behaviour using a radiant heat source*

[9] ISO 9239-2:2002, *Reaction to fire tests for floorings — Part 2: Determination of flame spread at a heat flux level of 25 kW/m*$^2$

[10] ISO 9705:1993, *Fire tests — Full-scale room test for surface products*

[11] ISO 13785-2:2002, *Reaction to fire tests for facades — Part 2: Large-scale test*

[12] ISO/TR 14696:1999, *Reaction to fire tests — Determination of fire parameters of materials, products and assemblies using an intermediate-scale heat release calorimeter (ICAL)*

[13] ISO/TS 14934-1, *Fire tests — Calibration and use of heat flux meters — General principles*

[14] ISO 17554, *Reaction to fire tests — Mass loss measurement*

[15] ORTOLANO, D.J., HINES, F.F. *A simplified Approach to Heat Flow Measurement, Advances in Instrumentation,* Volume 38, Part 2. Proceedings of the International Conference and Exhibit, Houston Texas, October 10-13, 1983. Instrument Society of America, 1983

[16] HOLMAN, J.P., *Heat Transfer*; McGraw-Hill, 1990

[17] Hukseflux Thermal Sensors, *Application and Specification of Heat flux meters*, Version 9904, Hukseflux Thermal Sensors, Delft, The Netherlands

[18] ASTM C1130, *Standard Practice for Calibrating Thin Heat Flux Transducers*, ASTM, West Conshohocken, USA

[19] ASTM E 511-01, *Standard Test Method for Measuring Heat Flux Using a Copper-Constantan Circular Foil, Heat Flux Transducer*, ASTM, West Conshohocken, USA

[20] ROBERTSON, A.F. and Ohlemiller, T.J., *Low Heat Flux Measurements: Some Precautions*, Fire Safety J. Vol. 25, No.2, pp.109-124 (1995)

[21] KIDD, C.T., *Dynamic Characteristics of Direct-Reading Heat Flux Sensors*, International Instrumentation Symposium, Albuquerque, NM May 2-6, 1999, page 9

[22] KUO, C.H. and KULKARNI, A.K., *Analysis of Heat Flux Measurement by Circular Foil Gages in a Mixed Convection/Radiation Environment*, ASME/JSME Thermal Engineering Proceedings, Volume 5, ASME 1991, pp 44-45

[23] APLERT, R.L., ORLOFF, L., and de RIS, J.L., *Angular Sensitivity of Heat Flux Gages*, Thermal Measurements: The Foundation of Fire Standards, ASTM STP 1427, L.A. Gritzo and N.J, Alvares, Eds., ASTM, West Conshohocken, USA, 2002

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