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Points of View in Testing Flame Detectors

M. Schnell

Verband der Sachversicherer, e. V.
Cologne, West Germany

Translated for:

Center for Fire Research
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

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Final Report

U. S. DEPARTMENT OF COMMERCE
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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, ***Secretary***
Dr. Betsy Ancker-Johnson, ***Assistant Secretary for Science and Technology***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Acting Director***

PREFACE

This report is a translation of a paper prepared by M. Schnell and presented by him at the Seventh International Seminar on Problems in Automatic Fire Detection held in Aachen, Germany, on March 5-6, 1975. The Seminar was sponsored by the Institute for Electrical Communications Engineering in Aachen in conjunction with the Gesamthochschule in Duisburg.

This translation has been prepared to disseminate useful information on a need-to-know basis and is not an original work of the Center for Fire Research.

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Richard G. Bright
Program for Fire Detection
and Control Systems
Center for Fire Research

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POINTS OF VIEW IN TESTING FLAME DETECTORS

M. Schnell[1]

Abstract

The general principles for type testing the fire detectors which are already in use in the assessment of heat and smoke detectors are summarized. These include the so-called basic tests and the trial tests. The trial tests were intended to include all test fires in order to ensure comparability of tested fire detectors. Additional test fires are proposed which are intended to permit differentiated comparison of flame detectors between one another. The main problem in assessing the performance of flame detectors during environmental influences is the selection of a suitable radiation source for reproducibly simulating the characteristic "flame." The requirements that this radiation source must fulfill are dealt with and various realizations involved are discussed. The practical testing of infrared flame detectors to the basic tests is described. In addition, a suggested test apparatus for ultraviolet flame detectors is dealt with.

Key words: Detection; fire detectors; flame detectors; heat detectors; infrared detectors; smoke detectors; testing; ultraviolet detectors.

1. INTRODUCTION

In various national and international panels, suggestions for suitable testing of automatic fire detectors have been discussed for many years. In practice, only heat detectors and smoke detectors have hitherto been considered. This work has in the meantime more or less reached its terminus.

For many years, however, automatic fire detectors have also been utilized in practice, which address other fire characteristics, such as, for example, changes in air humidity, air turbulence, or flame radiation. Among these types of fire detectors, the most important group is represented by flame radiation detectors. Their utilization has proven

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[1] At the time this paper was presented, Mr. Schnell was at the Gesamthochschule, Duisburg, Germany.

suitable in various applications. The need soon arose to set requirements for radiation detectors, similar to those for smoke and heat detectors — requirements which can be checked in the laboratory as easily as possible.

To improve understanding, the essential viewpoints in testing heat and smoke detectors shall here be reviewed.

2. BASIC TESTING

The requirements and the associated test methods can be divided into two groups. In one group, the influence of deleterious environmental influences, occurring in practice on the detector, are checked. This first group is called basic test. Here, in most cases, the procedure is as follows:

> The automatic fire detector to be tested is exposed to a simulated increasing fire characteristic. A measurable physical quantity which characterizes this fire characteristic is recorded. The measured value at the time the detector is triggered, the so-called threshold value, is recorded; then the automatic fire detector to be tested is subjected to a certain environmental stress. Next, the threshold value is again measured and tested according to the above method, to see whether, and to what extent, it has changed.

Very high requirements must be made with respect to the reproducibility of the simulated fire characteristic and with respect to the reliability of the measurement devices used. Only thus can it be reliably determined that differing measured values are based on changes in the test sample and not on changes of the measuring devices. To meet these requirements, which are obvious in themselves, is often quite difficult. The importance of this problem becomes clear, for example, in measuring the "smoke density" in testing smoke detectors. Here, the concept "smoke density" is deliberately not specified more closely. Smoke can only be completely described by measuring many (at least 6) parameters. But at this time, it is not yet possible to measure all these parameters continuously and simultaneously. As a rule, only two measuring processes are simultaneously utilized.

It is improbable that the same results are attained for different experiments, when simultaneous measurements, using two different methods, are made on practically occurring smokes, even though essential smoke parameters are different.

Of course, the assumption that this is improbable is justified when the measuring range, in which the used measurement devices operate reliably, and their behavior under temperature changes and higher flow velocities are known.

In the second group, four of the fire detectors to be tested are exposed to real test fires, and their behavior is checked. This group of tests is called trial test.

3. TRIAL TESTING

In principle, all types of fire detectors are exposed to the same test fires, to make possible comparison of the sensitivity to different types of fires between different types of detection.

The following five types of fires are under discussion and have already been used for several years — at least in Germany, and according to my knowledge also in Switzerland:

1. Open wood-burning fire (loosely stacked, dried small beechwood sticks)
2. Smoldering fire (smoldering of several small, dried beechwood sticks on a heating plate — no flames)
3. Synthetics fire (polyurethane — soft foam mats without fire inhibiting additives)
4. Diesel fuel fire
5. Alcohol fuel fire

Each fire is carried out in three steps, i.e. with different amounts of fuel material, which increases with the step number.

Type of Test Fire	Amount of Fuel Material				Fuel Material
1. Open wood-burning fire	0.75	1.5	3.0	kg	Beechwood $10 \times 20 \times 250$ mm^3
2. Smoldering fire	3	6	12	pieces	$10 \times 20 \times 50$ mm^3
3. Synthetics fire	1	2	3	mats	Polyurethane-soft foam mats $20 \times 400 \times 500$ mm^3
4. Diesel fuel fire	15 25	25 50	40 100	g cm^2	Diesel fuel (surface)
5. Alcohol fuel fire	1.2 1100	1.6 1500	2.0 1900	kg cm^2	Alcohol fuel C_2H_5OH (surface)

The result of the trial test is recorded in a calibration table. That means whether, and at what step, and at which type of fire a detection ensemble has been triggered is shown in tabular form.

Such calibration tables can, for example, look like this:

Type of Fire	Classification		
	I	II	III
1. Open wood-burning fire	-	-	X
2. Smoldering fire	X	-	-
3. Synthetics fire	-	X	-
4. Diesel oil fire	-	X	-
5. Fuel alcohol fire	-	-	-

(Typical result for a smoke detector)

Type of Fire	Classification		
	I	II	III
1. Open wood-burning fire	X	-	-
2. Smoldering fire	-	-	-
3. Synthetics fire	X	-	-
4. Diesel oil fire	-	X	-
5. Fuel alcohol fire	X	-	-

(Typical result for an infrared radiation detector)

A cross at test fire No. 1, Step I, means that all four samples of a certain detector type triggered for the smallest amounts of fuel material. The suitability table which is to be prepared for all types of automatic fire detectors is an important aid in choosing the correct type of fire detector in projecting automatic fire detection systems.

To conclude this general survey, all tests will once again be summarized in tabular form:

1. Switch-on
2. Reproducibility
3. Directional Dependence
4. Sample Scatter
5. Electric Energy Supply
    a) Long-term fluctuations
    b) Noise Voltages
6. Wind Dependence (only smoke detectors)
7. Temperature Dependence
    a) High Temperatures
    b) Low Temperatures
8. Glare (only optical smoke detectors and radiation detectors)
9. Moisture Requirement
10. Vibration
11. Mechanical Shock
12. Mechanical Impact
13. Corrosion (SO_2 and H_2S — atmosphere)
14. Dust (only smoke detectors)
15. Trial Test (5 test fires)

In the first 4 tests, the fire detectors are examined for direct deficiencies in mechanical construction and electrical circuitry. In tests 5 through 14, the influence of disruptive environmental influences are investigated. Finally, with test 15, sensitivity is tested and the suitability table is produced.

After this general survey concerning testing methodology in general, the special testing technology for radiation detectors will now be addressed more closely.

First of all, the most important types of radiation detectors will be mentioned:

1. The radiation itself and the time behavior of the radiation is monitored in one definite wavelength band in the infrared region. The detector triggers when infrared radiation occurs for a definite time, and if it fluctuates with a characteristic frequency ("flicker").

2. Radiation is monitored in two wavelength ranges (one range in the visible and one in the infrared, or both in the infrared). The detector triggers when the radiation intensities in the two ranges have a ratio typical for flames.

3. Like 2, but the time behavior is additionally evaluated.

4. The light-sensitive element of the radiation detector is a switching tube, to which electric voltage is applied, and which triggers when ultraviolet radiation occurs in the range of about 0.22 μm to about 0.28 μm. To increase reliability against mis-triggering, the tubes are generally connected to an impulse voltage, so that, when the tube is triggered, it immediately turns off again at the end of a voltage impulse.

   Only when a certain number of triggers per unit time is reached, does the radiation detector itself trigger.

4. TESTING TECHNOLOGY

The problem now is to find a suitable measuring and test apparatus with which the triggering threshold of the detectors can be measured in the basic test, for example, before and after an environmental stress. It was originally planned to test all types of radiation detectors, that is ultraviolet and infrared radiation detectors, with one apparatus. However, this idea again, had to be abandoned for the following reasons:

1. The basic difference in the mode of action between ultraviolet and infrared radiation detectors.

2. Constancy of the radiation must be able to be continuously monitored during the experiments. This presents great difficulties because, in the ultraviolet region of interest (0.2...0.3 µm), the radiative powers differ by orders of magnitude from those in the infrared region of interest (0.8...10 µm). No receiver exists which is capable of measuring with sufficient accuracy in both regions simultaneously.

3. Finding a reproducible laboratory flame, which emits constant radiative power in both regions at the same time, poses difficulties.

Because of the wider distribution of infrared radiation detectors, the principal endeavor has first of all been concerned with the development of testing technology for such detectors.

Let us consider the emission spectra of flames where hydrocarbons are principally burned (figures 1 and 2). The similarity of the spectra is very conspicuous. The emphatic peak at 4.4 µm which belongs to a CO_2 — resonance line, is especially characteristic.

If emission spectra of artificial radiation sources are considered, such as incandescent lamps, heating bodies, etc., an entirely different course results. The emission spectrum of a black body is here shown (figure 3) as representative for such radiation sources.

It is just these characteristic differences that are utilized by many infrared radiation detectors to improve reliability against false alarms. Therefore, it is immediately clear that, for example, a black body simulator cannot cause such detectors to trigger, and is therefore not suitable to simulate the fire characteristic "flame radiation."

According to this insight, the problem is to develop a suitable laboratory flame based on hydrocarbons. This flame should be reproducible with sufficient accuracy relative to constancy of emission and time behavior. The radiative power of a flame can in principle be controlled by controlling the supply of fuel. But not so its time behavior. Flickering is co-determined by external influences, such as, for example, air motion in the laboratory.

The problem can be solved by using a laboratory flame whose radiation is constant in time: a flame, therefore, which does not flicker. The "flicker," which is required for triggering most detectors, is generated by a chopper disk in the ray path between flame and detector.

Here in the Institute, a device has been used for several years, which operates with a non-flickering methane flame (figures 4 through 6).

An aperture system, a chopper disk, and several control devices are built into a stable metal chassis. The burner system is solidly connected with the chassis. The entire device is mounted on an optic bench. Since the flame is to burn very quietly, two tubes are fastened to the burning chamber, which result in laminar gas flow. The vertical pressure tube in front of the combustion chamber generally prevents flickering caused by turbulent environmental air, and gives an even flow of surrounding air through the two apertures in the combustion chamber. The fuel gas is brought in through a tube which lies concentrically in the air supply tube. By moving the gas supply tube and by changing the through-flow of gas, the flicker of the flame can be minimized. The combustion chamber block is water-cooled through drilled channels, so that any heat radiation from hot metal worth speaking of is generally prevented.

Originally, the device was operated with natural gas from the city supply. But it turned out that pressure pulses, which are unavoidable in the gas line, produced too strong a flicker of the flame. It was further determined that the composition of natural gas is not always the same, so that the reproducibility of the flame emission spectrum could not always be guaranteed.

For this reason, methane from a pressurized bottle was chosen as fuel gas. The gas is brought to the burner through a pressure reduction valve, a pneumatic flow control, and a flow metering device.

Immediately in front of the combustion chamber, there is an adjustable hole aperture, through which part of the flame radiation can exit. Before the aperture there is a perforated disk, driven by an electric motor, by means of which chopping frequencies of about 1 Hz to 30 Hz can be set. The chopper frequency is sensed by a photocell and is indicated digitally.

Since the sensitivity of radiation detectors is not to be measured with the device, but only relative changes in trigger threshold, precise knowledge of the spectral distribution of the emission spectrum is not required. It is sufficient when all infrared radiation detectors under test can reliably be made to trigger.

The dependence of the radiation density on the distance between radiation source and receiver is measured with a silicon photodiode, a PbS photoresistor, and a radiation thermoelement. This dependence can be described by the following formula:

$$\phi = \frac{(r_o)^2}{r} \cdot \phi_o \quad .$$

Here symbols have the following meaning:

ϕ	Radiation flow recorded by the receiver
ϕ_o	Radiation flow measured in a reference plane in front of the device
r	Distance between receiver and radiation source
r_o	Distance of the reference plane from the radiation source.

Through this relation, relative changes in the triggering threshold of detectors can be determined by determining the distance differences. By slightly changing the gas flow, the residual flicker of the flame can be minimized to about 1% of the mean value of the radiation intensity. Experiments have shown that, with this residual flicker, commercial radiation detectors are not brought to trigger.

The constancy of the radiation source is checked with the PbS photoresistor. Within a time interval of 4 hours, the maximum deviations that occurred were 2.5%.

With a heat-up time of at least 20 minutes each time, the radiation intensity can be reproduced without new corrections with an accuracy of 2.5%.

Naturally, the radiation intensity can at any time be monitored during the experiment by means of the PbS photoresistance and, should circumstances so require, can be readjusted by small changes in the gas flow. The device was tested with various commercial radiation detectors. The maximum distances between the detectors and the flame were determined, where triggering just barely occurred. After several hours and days, these distances were determined anew, whereby the detectors were exposed to no special stresses in the meantime.

The maximum distances for which triggering just barely occurred then corresponded to a sensitivity change of about 0.5%, which lies within the accuracy of measurement.

For practical tests from the "basic test" group, the detector under test is mounted on a stand so that the light-sensitive part is at the height of the aperture opening of the measuring apparatus. In addition, the detector can be rotated about the stand axis. The angle of rotation and the distance to the burner flame can be read.

The chopper frequency for which the radiation detector under test has maximum sensitivity is set at the measuring apparatus. The detector is first pushed so near the aperture opening that it certainly triggers. The triggering time required for this is noted. Then the detector is pushed so far away from the aperture opening that it no longer triggers. Then the radiation detector is pushed closer to the aperture opening step-by-step. At each step, one waits for three times the previously measured triggering time. The point is determined at which the detector triggers three times, one after the other. As a control, a position is sought, which lies as close as possible behind this "triggering point," at which the detector does not trigger. The step sizes should amount to 1/2 cm to 2 cm, depending on the distance from the radiation source.

The entire procedure should be begun at the earliest 15 minutes after connection to the supply voltage and should be concluded at the latest after another 15 minutes, since the sensitivity of some light detectors can still change even after several hours.

Special requirements hold for the following tests, because of the physical peculiarities of radiation detectors.

4.1. Directional Dependence

The triggering thresholds are determined in a range of angular openings of 120°; i.e., a radiation detector should meet the still-to-be-formulated requirement for the triggering threshold within a range of opening angles of 120°.

4.2. Glare

Glare from foreign radiation can shift the operating point of photoelectric construction elements into a non-linear region, which would entail reduction of sensitivity. The following types of glare are proposed:

1. One-hour irradiation with a circular fluorescent lamp (32 watts) at a distance of 30 cm
2. One-hour irradiation with two incandescent lamps (25 watts each) at a distance of 30 cm.

Both interfering radiation sources are connected to alternating voltage. During the glare exposure, the detectors should not trigger. During and after each glare exposure, the triggering threshold of the detector is again measured.

The remaining tests of the "basic tests" do not differ essentially from those for smoke and heat detectors. The triggering threshold of the detectors is measured before and during or after each stress. The change in the value of the triggering threshold may not exceed a certain value. The permissible value for the relative change must be set when more test experience has been accumulated. We consider a factor of two suitable as the maximum permissible change for the present time.

4.3. Trial Test

In addition to the five proposed test fires, a fire is also to be introduced which is specific to the radiation detector. The purpose of this additional fire is to see whether fires can still be detected at great distances. A methyl alcohol test fire (burning surface 2000 to 3000 cm^2) is proposed, to be detected at a horizontal distance of 15 m.

5. CONCLUSIONS

The proposed requirements and tests for infrared radiation detectors in our opinion allow the opportunity of objective evaluation of a type of fire detector which is in many cases a good supplement for a classical fire detection system. In some applications, radiation detectors are the only usable type of fire detector because of special circumstances.

Because of the completely different functional principle of ultraviolet radiation detectors (no consideration of the temporal behavior of flames, no evaluation of certain peculiarities in the flame emission spectrum), the use of laboratory flames can be dispensed within simulating the ultraviolet flame radiation as a fire characteristic.

Experiments which promise success were performed by us. Here, mercury vapor lamps were used as radiation sources. The 0.2537 μm emission line is filtered out through an optical interference filter and is attenuated. The radiation is measured with a photomultiplier that is sensitive only in the ultraviolet.

The current through the mercury vapor lamp is adjustable. A linear increase of the radiative power of the 0.2537 μm emission line is achieved through a function generator, which prescribes a long linear rise of the should-value. The photomultiplier serves as an is-value sensor. Radiative power is increased until the detector under test triggers. With this method it is possible to measure triggering thresholds for ultraviolet radiation detectors. For the rest, the same procedure can be used as for infrared radiation detectors. The entire procedure is still in the experimental stage and is not yet suitable for running-type tests for ultraviolet radiation detectors.

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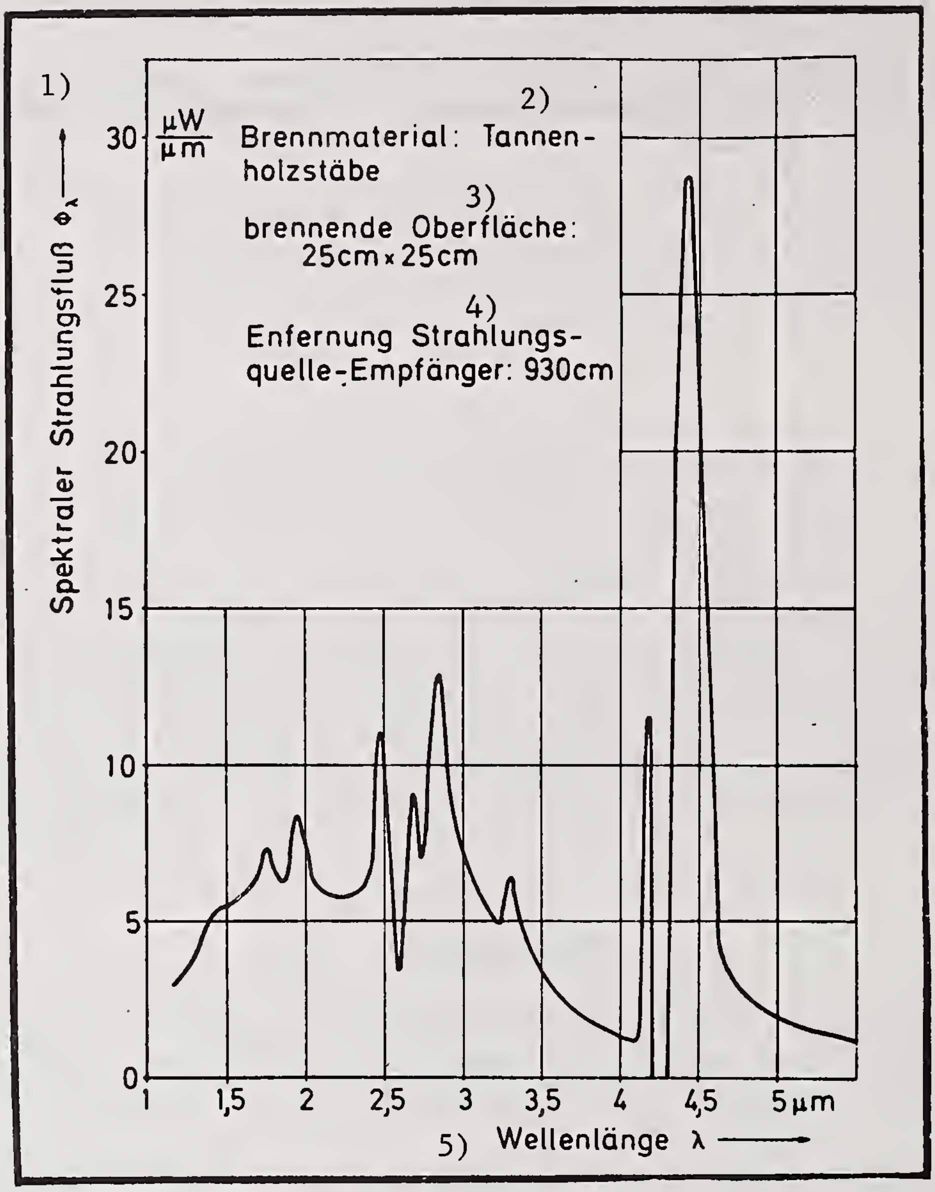

Figure 1. Emission Spectrum of a Wood Fire, (According to Kirsch)

1. Spectral Radiation Flow
2. Fuel Material: Fir Wood Sticks
3. Burning Surface: 25 cm x 25 cm
4. Radiation Source — Detector Distance: 930 cm
5. Wavelength

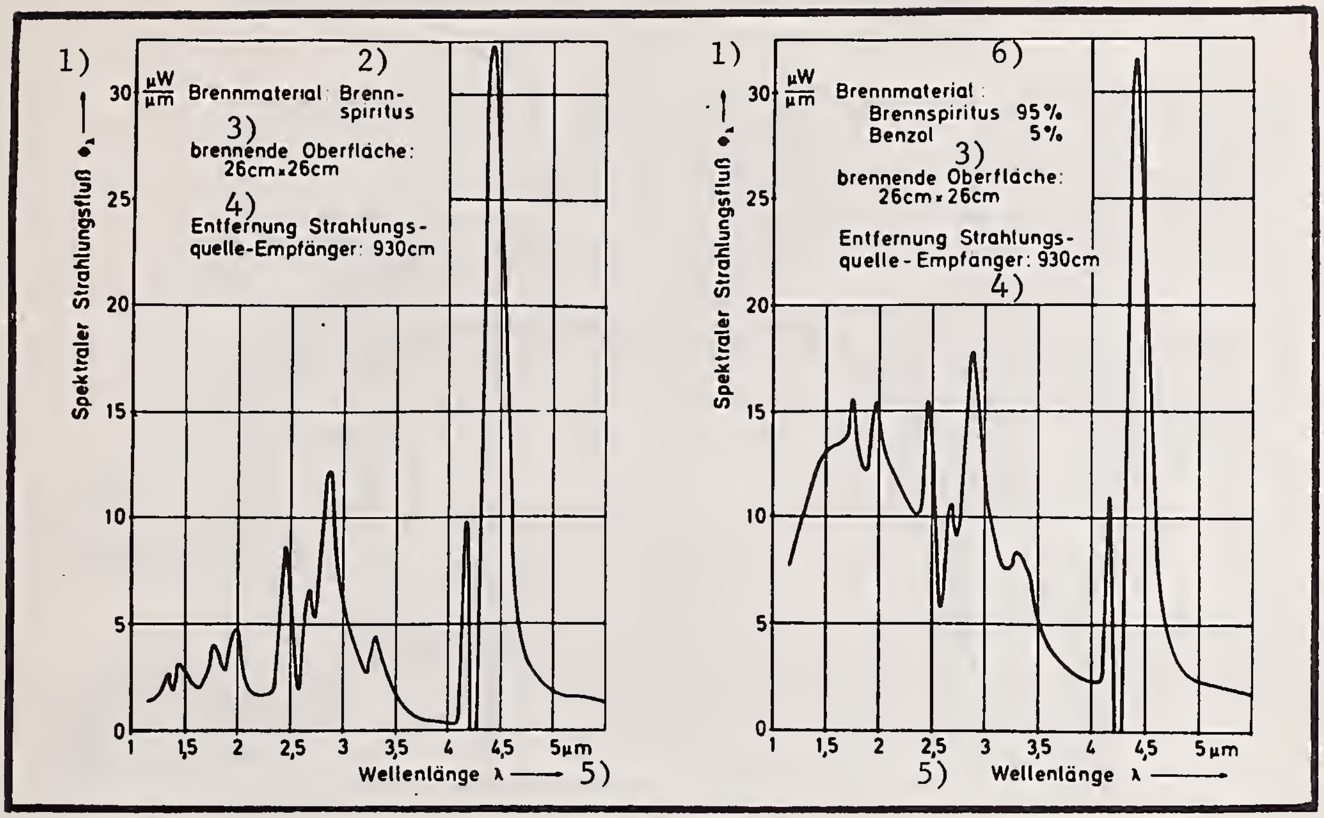

Figure 2. Emission Spectrum of an Alcohol Fire and of an Alcoholbenzene Fire (According to Kirsch)

1. Spectral Radiation Flow
2. Fuel Material: Methyl Alcohol
3. Burning Surface: 26 cm x 26 cm
4. Radiation Source — Detector Distance: 930 cm
5. Wavelength
6. Fuel Material: Methyl Alcohol 95% Benzene 5%

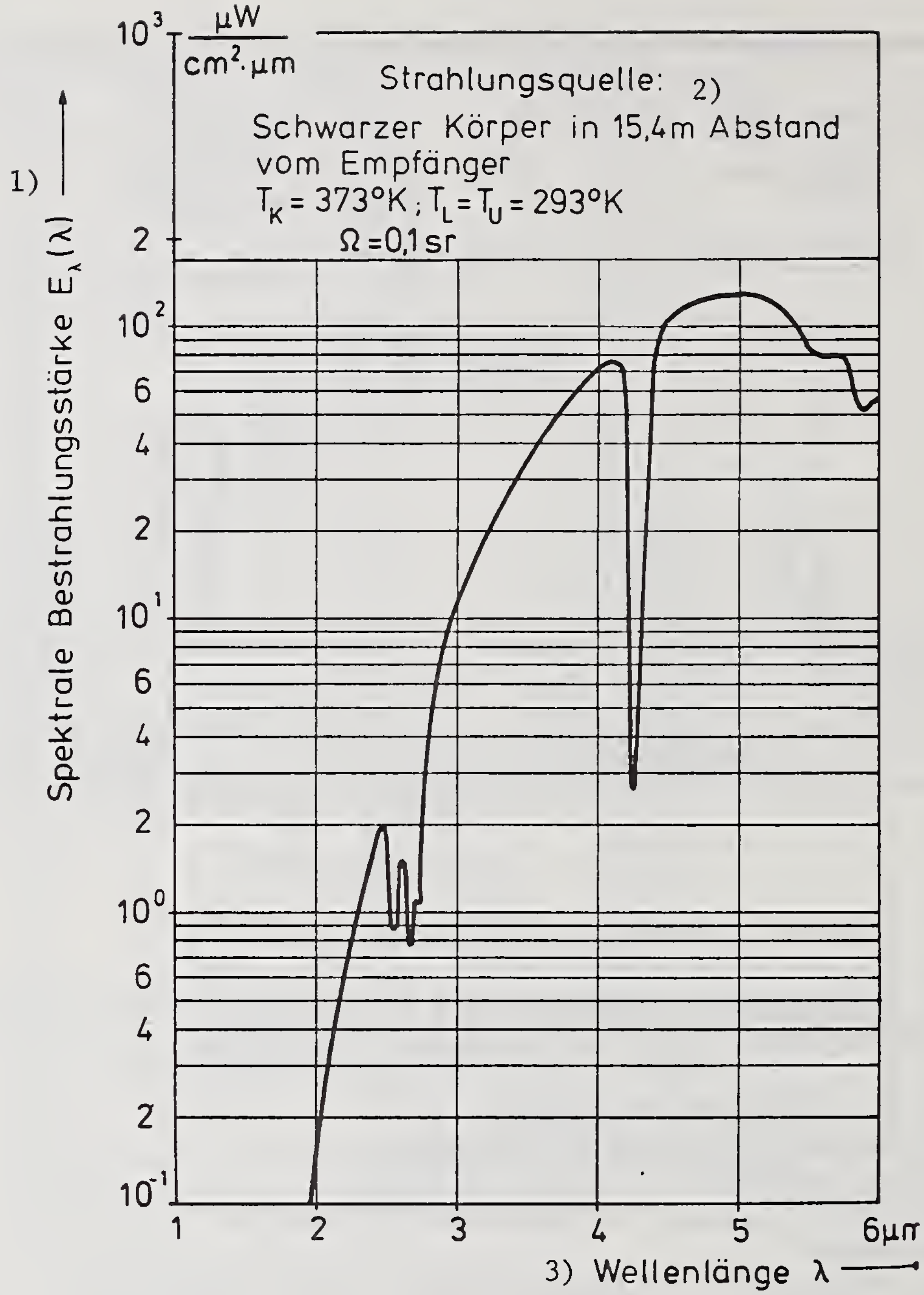

Figure 3. Interfering Radiation Spectrum, (According to Kirsch)

1. Spectral Irradiation Intensity
2. Radiation Source: Black Body at a Distance of 15.4 m from the Detector
3. Wavelength

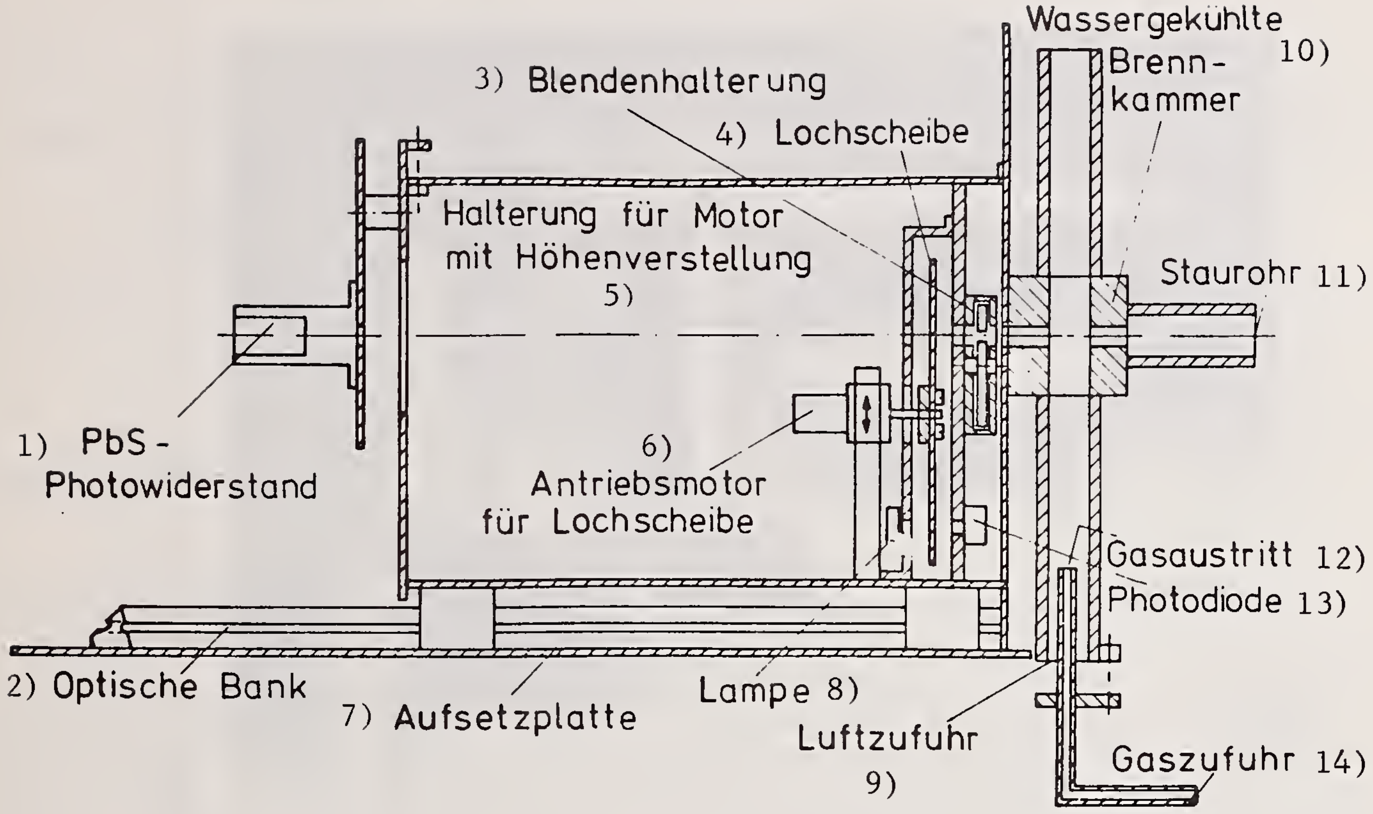

Figure 4. Infrared Radiation Detector — Test Apparatus

1. PbS Photoresistor
2. Optic Bench
3. Aperture Mounting
4. Perforated Disk
5. Mounting for Motor with Height Adjustment
6. Drive Motor for Perforated Disk
7. Mounting Plate
8. Lamp
9. Air Intake
10. Water-Cooled Combustion Chamber
11. Pressure Tube
12. Gas Exit
13. Photo Diode
14. Gas Intake

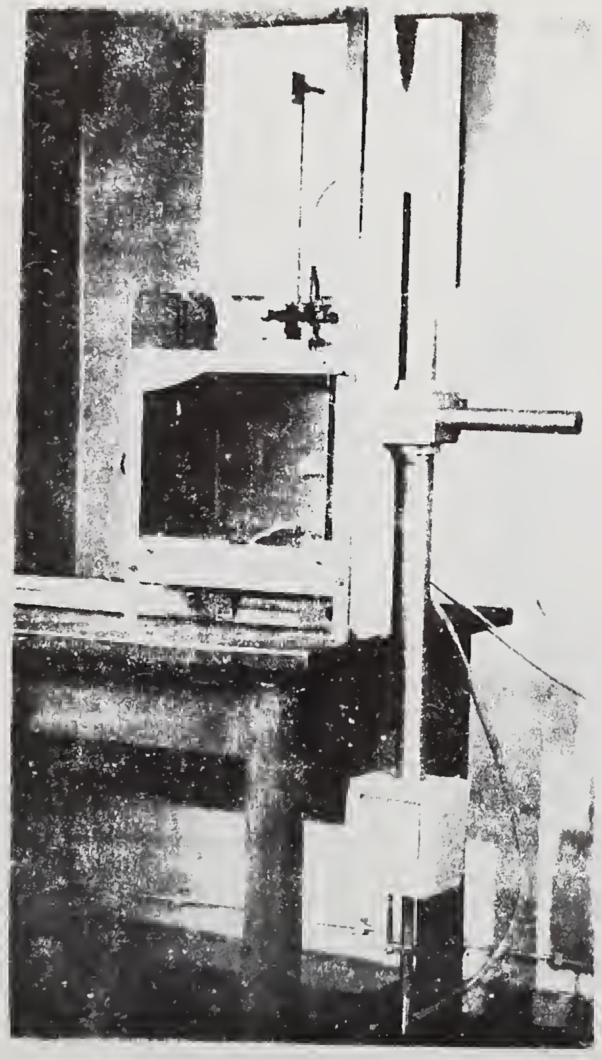

Figure 5. Infrared Radiation Detector — Test Apparatus

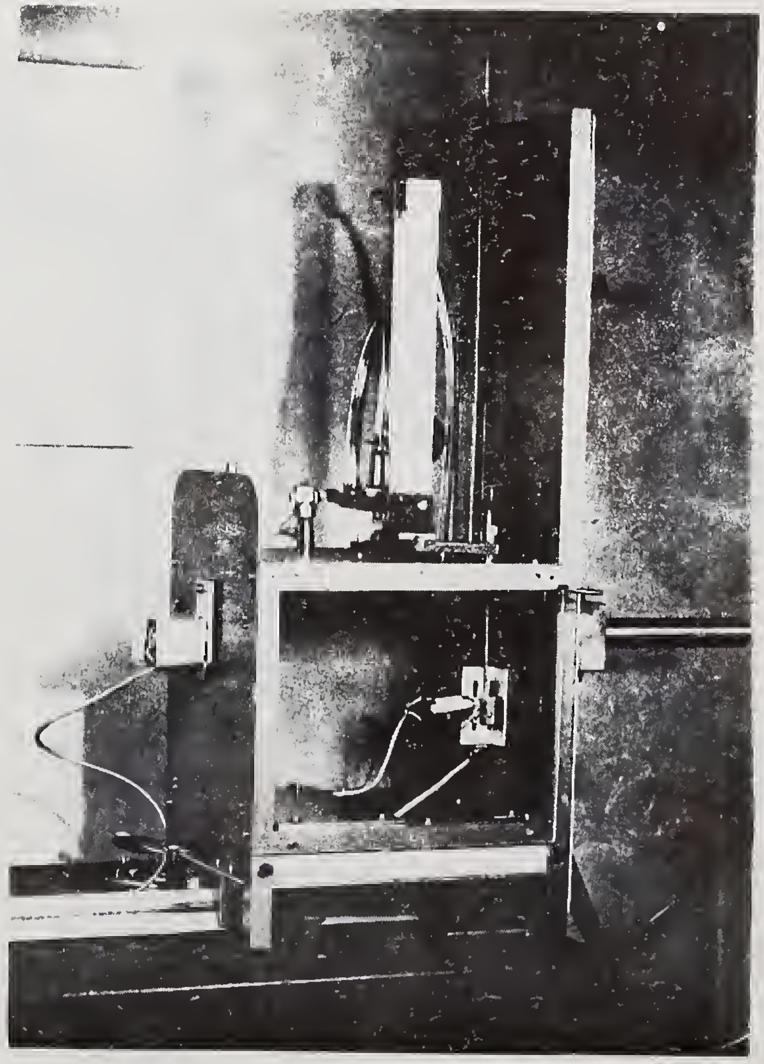

Figure 6. Infrared Radiation Detector — Test Apparatus

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The general principles for type testing the fire detectors which are already in use in the assessment of heat and smoke detectors are summarized. These include the so-called basic tests and the trial tests. The trial tests were intended to include all test fires in order to ensure comparability of tested fire detectors. Additional test fires are proposed which are intended to permit differentiated comparison of flame detectors between one another. The main problem in assessing the performance of flame detectors during environmental influences is the selection of a suitable radiation source for reproducibly simulating the characteristic "flame." The requirements that this radiation source must fulfill are dealt with and various realizations involved are discussed. The practical testing of infrared flame detectors to the basic tests is described. In addition, a suggested test apparatus for ultraviolet flame detectors is dealt with.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Detection; fire detectors; flame detectors; heat detectors; infrared detectors; smoke detectors; testing; ultraviolet detectors.

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