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Report of Fire Tests on Eight TGS Semiconductor Gas Sensor Residential Fire/ Smoke Detectors

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Abstract

At the request of the Bureau of Engineering Sciences Consumer Product Safety Commission, twenty-four Taguchi gas sensor (TGS) detectors, representing eight manufacturers were tested to the requirements of Section 22 (base sensitivity tests) and Section 24 (full-scale fire tests) of Underwriters' Laboratories Standard No. 217, "Standard for Single and Multiple Station Smoke Detectors." Two conventional single-station smoke detectors, one an ionization chamber type and the other a photoelectric type, were included in the test series for comparison. Only one of the TGS detectors was able to meet the requirements of Section 22, base sensitivity tests. None of the TGS detectors were able to meet the requirements of Section 24, full-scale fire tests. The two conventional smoke detectors met the requirements of Section 22 and 24.

Key words: Detectors; fire detectors; gas detectors; smoke detectors; Taguchi gas sensors.

1. INTRODUCTION

Recently, there has appeared on the U.S. market a new type of fire detector, which utilizes as its basic sensing mechanism, a semiconductor, solid-state device commonly referred to as a Taguchi gas sensor (TGS). A complete description of the sensor and its method of operation is contained in the report, NBSIR 74-591 [1][1].

These TGS detectors, while essentially combustible gas detectors, are being marketed in increasing numbers as either a fire detector or as a smoke detector, and sometimes as both. There has been some concern with the use of these as fire/smoke detectors due to their apparent limitation in sensing or detecting freely-burning fires with adequate oxygen supply. This concern is heightened by the fact that conventional smoke detectors utilizing the ionization chamber principle or the photoelectric principle do not exhibit this same limitation and yet the TGS detector is being advertised and sold as a satisfactory substitute for these conventional smoke detectors. (See reference [2] for a technical description of conventional smoke detectors.)

In an attempt to explore the response characteristics of commercially available TGS detectors more fully, arrangements were made with the Underwriters' Laboratories, Inc. (UL), to conduct a series of tests on several representative TGS detectors. The test series was requested by the Bureau of Engineering Sciences, Consumer Product Safety Commission. The test series UL was asked to conduct are the same ones to which conventional smoke detectors are subjected and must pass before receiving UL approval. The results of the test series are reported herein.

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[1] Bracketed numbers refer to references located at the end of this paper.

2. DESCRIPTION OF TEST SERIES

2.1. TGS Detectors

Three samples each, of eight different manufacturers' models, were obtained for the test series. Six of the eight models are advertised as smoke detectors. Four of the models have been tested and approved by the Factory Mutual System as fire detectors and are so listed in their current Approval Guide [3]. Table 1 presents a synopsis of this information.

2.2. Conventional Smoke Detectors

For comparison purposes, two conventional smoke detectors were included in the test series. One of these detectors was an ionization-chamber-type smoke detector and the other was a photoelectric-type smoke detector. Both of the conventional smoke detectors were a single-station smoke type, i.e., designed for residential application.

2.3. Base Sensitivity Tests

All twenty-four of the TGS detectors, as well as the two conventional smoke detectors, were subjected to the base sensitivity tests using gray-colored smoke as described in Section 22 of UL Standard No. 217 [4]. In this test sequence, the detectors are placed, one-by-one, in a closed chamber. The air in the chamber is circulated past the detector by a fan. Smoke is introduced into the chamber from a smoldering cotton lamp wick. The smoldering lamp wick produces a linear increase in the smoke density in the chamber with time. At some point, depending on the alarm threshold of the detector, the smoke density is sufficient to produce an alarm in the detector. The smoke density or opacity of the smoke is measured by a photometer system. The output of the

Table 1. List of TGS Detectors

Manufacturer	Sample No.	FM Approved	Advertised as Smoke Detector
A	1	No	Yes
A	2	No	Yes
A	3	No	Yes
B	4	No	Yes
B	5	No	Yes
B	6	No	Yes
C	7	No	No
C	8	No	No
C	9	No	No
D	10	Yes	Yes
D	11	Yes	Yes
D	12	Yes	Yes
E	13	Yes	Yes
E	14	Yes	Yes
E	15	Yes	Yes
F	16	Yes	No
F	17	Yes	No
F	18	Yes	No
G	19	No	Yes
G	20	No	Yes
G	21	No	Yes
H	22	Yes	Yes
H	23	Yes	Yes
H	24	Yes	Yes

photometer is converted to smoke obscuration in percent-per-foot and, in addition, to optical density-per-foot.

Where individual sensitivity test trials varied by more than ± 1 microampere five trials were conducted with the final sensitivity value being the average of the three mean readings. If the individual variance was less than 1 microampere, three trials were taken.

If the TGS detector design was directional, base sensitivity tests were taken in the worst expected condition and the position tested was recorded. One TGS detector model had a consumer adjustable sensitivity control. This model was tested at both its minimum and maximum sensitivity settings.

2.4. Full-Scale Fire Tests

All TGS detector samples, which were still operational following the base sensitivity test, were then subjected to the full-scale fire tests as described in Section 24 of UL Standard No. 217 [4]. These full-scale fire tests consist of four test fires, conducted in a large room, using four different combustible materials. Two trials are made with each combustible material. The combustible materials are 8 oz. (250 g) of shredded paper, a small wood crib, 200 cc of gasoline, and 2 oz (60 g) of polystyrene. Complete details of the test room, the test materials and conditions of test are fully described in Section 24 of UL Standard No. 217 [4] and in the Bukowski-Bright report [5] and therefore, will not be detailed here.

3. RESULTS

3.1. Base Sensitivity Tests

Table 2 presents the results of the base sensitivity tests. Section 22 of UL Standard No. 217 requires that for acceptance a detector must have a base sensitivity between 0.2%-ft^{-1} (0.0009 optical density-ft^{-1}/0.0073 optical density-m^{-1}) and 4.0%-ft^{-1} (0.0177 optical density-ft^{-1}/0.058 optical density-m^{-1}). For those detectors having consumer sensitivity adjustments, both maximum and minimum consumer-set sensitivities would have to be within the 0.2 and 4.0 percent-per-foot ranges.

3.2. Full-Scale Fire Tests

Table 3 presents the results of the full-scale fire tests. The requirements for approval in these tests, according to Section 24 of UL Standard No. 217 [4], are detection of the paper fires, gasoline fires, and polystyrene fires in 120 seconds and detection of the wood crib fires in 240 seconds.

4. DISCUSSION AND CONCLUSIONS

4.1. Base Sensitivity Tests

Of the 24 samples submitted for test, two were defective upon delivery and could not be tested. Of the remaining 22 samples, only sample No. 9 met the requirements of the base sensitivity test. Samples 4, 5 and 6, with the consumer sensitivity adjustment, had maximum sensitivities within the requirements but at minimum sensitivities these detectors

Table 2. Base Sensitivity Test Results

Sample No.	Sensitivity at 30-35 fmp (%/ft)	Orientation - Smoke Flow Into
1	10.6	Right Side
2	24.8	Right Side
3	12.6	Right Side
4	1.44 (Maximum) 6.89 (Minimum)	Right Side
5	1.87 (Maximum) 4.48 (Minimum)	Right Side
6	1.87 (Maximum) 5.14 (Minimum)	Right Side
7	Defective on Receipt	Right Side
8	20.48	Right Side
9	1.34	Right Side
10	23.62	Top
11	26.13	Top
12	29.04	Top
13	6.10 (Defective After Sensitivity)	Top
14	4.06	Top
15	6.36	Top
16	Defective on Receipt	Right Side
17	32.52	Right Side
18	11.27	Right Side
19	11.73	Right Side
20	13.09	Right Side
21	4.53	Right Side
22	5.77	Right Side
23	5.02	Right Side
24	5.95	Right Side
Photo	3.89	Top
Ion	1.87	Top

Table 3. Full-Scale Fire Test Results
(Response Time - In Seconds)

Sample No.	Paper		Wood		Gasoline		Polystrene	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
1	No*	No	No	No	No	No	No	No
2	No	No	No	No	No	No	No	No
3	No	No	No	No	No	No	No	No
4	No	No	84	No	No	No	No	No
5	No	No	83	84	No	No	No	No
6	No	No	No	No	No	No	No	No
8	No	No	93	100	No	No	No	No
9	47	58	90	90	74	No	51	59
10	No	No	No	No	No	No	No	No
11	No	No	No	No	No	No	No	No
12	No	No	No	No	No	No	No	No
14	No	No	No	No	No	No	No	No
15	No	No	No	No	No	No	No	No
17	No	No	No	No	No	No	No	No
18	No	No	No	No	No	No	No	No
19	No	No	No	No	No	No	No	No
20	No	No	No	No	No	No	No	No
21	No	No	No	No	No	No	No	No
22	No	No	No	No	No	No	No	No
23	No	No	No	No	No	No	No	No
24	No	No	No	No	No	No	No	No
Photo	33	No	156	169	116	101	61	75
Ion	28	27	81	86	32	34	28	28

*No operation

did not meet the requirements. Both of the conventional smoke detectors were within the acceptable range.

4.2. Full-Scale Fire Tests

None of the TGS detectors were able to detect all of the test fires. Sample No. 9 detected all of the test fires with exception of trial 2 of the gasoline fires. The requirements of Section 24 are, however, that each sample of a manufacturer's submittal must respond to at least one of each of the test fires. The other sample of this manufacturer's detectors, sample No. 8, was only able to detect the wood fire and did not respond to the paper fire, the gasoline fire or the polystrene fire.

It is of interest to compare the performance of the two conventional smoke detectors to the TGS detectors. The ionization chamber smoke detector has a base sensitivity of 1.87%-ft^{-1} (0.008 optical density-ft^{-1}/0.027 optical density-m^{-1}). This lies about half-way through the acceptable range. Yet, its responses to the four full-scale fires were quick.

The photoelectric smoke detector had a base sensitivity of 3.89%-ft^{-1} (0.017 optical density-ft^{-1}/0.055 optical density-m^{-1}). This detector, therefore, was fairly insensitive lying almost at the outer limit of the acceptable sensitivity range, but it was able to detect all the test fires within the time limits, except the second paper trial.

4.3. Other

Sixteen of the TGS detectors carried the label of the Factory Mutual (FM) indicating the detectors had been tested and approved by FM and are so listed in the current edition of Factory Mutual's Approval Guide [3]. Although FM lists the TGS detectors as fire detectors, and not as smoke detectors, FM conducts tests on the TGS detectors using the guidelines set forth in FM Approval Standard —— Smoke Actuated Detectors for Automatic Fire Alarm Signaling [6] in addition to certain other tests.

The FM Approval Standard requires that the detectors "respond to a source of visible smoke which produces a maximum light obscuration of 4%/ft." FM conducts this base sensitivity test in a test chamber similar to UL's. Even so, none of the sixteen FM-approved TGS detectors met the FM base sensitivity test requirements when tested in the UL test chamber.

Detector samples 13, 14, 15, 22, 23 and 24 were only slightly above the FM requirements. This may be attributable to subtle differences between the UL and FM base sensitivity test procedures. One known difference is in the wavelength of the light source used in the photometric system. FM uses a light source having a shorter wavelength (whiter) than UL's (redder). For the same smoke concentration, a whiter light will produce a lower apparent optical density than a redder light. The result would be that a detector tested in the FM chamber would appear to be more sensitive than the same detector tested in the UL chamber. This variation in optical density (smoke concentration) with wavelength of light has been described by the British Fire Research Station

[7]. This explanation is not adequate, however, to explain the base sensitivity test results for the other detector samples.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] Bukowski, R. W. and Bright, R. G., Some Problems Noted in the Use of Taguchi Semiconductor Gas Sensors as Residential Fire/Smoke Detectors, National Bureau of Standards (U.S.), NBSIR 74-591 (Dec. 1974).

[2] Custer, R. L. P. and Bright, R. G., Fire Detection: The State-of-the-Art, National Bureau of Standards (U.S.), NBS Technical Note 839 (June 1974).

[3] Approval Guide 1975, Factory Mutual System, 1151 Boston-Providence Turnpike, Norwood, Mass. 02062.

[4] Standard for Single and Multiple Station Smoke Detectors, UL 217, Proposed First Edition, Underwriters' Laboratories, Inc., Chicago, Ill. 60062 (March 7, 1975).

[5] Bukowski, R. W. and Bright, R. G., Results of Full-Scale Fire Tests with Photoelectric Smoke Detectors, National Bureau of Standards (U.S.), NBSIR 75-700 (June 1975).

[6] Approval Standard Smoke Actuated Detectors for Automatic Fire Alarm Signaling, Class No. 3230-3250, Feb. 1973, Factory Mutual System, 1151 Boston-Providence Turnpike, Norwood, Mass. 02062.

[7] Fire Research 1971, Report of the Director, Fire Research Station, Borehamwood, Herts., England, pp. 62-63, 1972.

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15. SUPPLEMENTARY NOTES

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.)*

At the request of the Bureau of Engineering Sciences Consumer Product Safety Commission, twenty-four Taguchi gas sensor (TGS) detectors, representing eight manufacturers were tested to the requirements of Section 22 (base sensitivity tests) and Section 24 (full-scale fire tests) of Underwriters' Laboratories Standard No. 217, "Standard for Single and Multiple Station Smoke Detectors." Two conventional single-station smoke detectors, one an ionization chamber type and the other a photoelectric type, were included in the test series for comparison. Only one of the TGS detectors was able to meet the requirements of Section 22, base sensitivity tests. None of the TGS detectors were able to meet the requirements of Section 24, full-scale fire tests. The two conventional smoke detectors met the requirements of Section 22 and 24.

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)* Detectors; fire detectors; gas detectors; smoke detectors; Taguchi gas sensors.

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