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Response-Time Comparisons of Ionization and Photoelectric/Heat Detectors

1. Introduction

Despite the recent introduction of new technologies, the vast majority of smoke detectors sold and in service today are based on either the photoelectric or the ionization principle. In the twenty-five years since smoke detectors began to attain widespread acceptance as essential life/safety fire protection devices [1], it has become generally accepted that "ionization smoke detection is more responsive to invisible particles (smaller than 1 micron in size) produced by most flaming fires" [2]. It is also generally accepted that photoelectric detection is "more responsive to visible particles (larger than 1 micron in size) produced by most smoldering fires", "somewhat less responsive to smaller particles typical of most flaming fires", and "less responsive to black smoke than lighter colored smoke" [2]. However, the relative merits of the two detector types continue to be a subject of discussion [3].

We recently reported the results of fire tests comparing the response time performance of three models of ionization smoke detector (from three different manufacturers) to a photoelectric smoke detector model [4]. As an extension of that work, we conducted an additional series of fire tests comparing the performance of two ionization detector models used in the earlier study to the performance of a single model of photoelectric/heat detector. The photoelectric/heat detector combines a thermistor-based heat detector with a photoelectric smoke detector which is otherwise identical to the model used in the earlier study. These series of fire tests are the latest in an ongoing investigation which Simplex is conducting to help develop objective criteria for which smoke detector technologies are most appropriate for different applications.

Consistent with the results of the earlier investigation comparing ionization smoke detectors to photoelectric detectors, the results reported here show that in UL 268 Smoldering Smoke tests, photoelectric detection occurred many minutes earlier than ionization detection. The results also show that in UL 268 Flammable Liquid Fire tests and TF-5 type liquid heptane fire tests, photoelectric and ionization detection occurred at about the same time. The three heat detector modes evaluated (15 °F/min ROR, 20 °F/min ROR, and 135 °F fixed temperature) generally did not exceed their alarm thresholds in either the TF-5 type fire tests or the UL 268 Smoldering Smoke and Flammable Liquid Fire tests. However, the maximum rate-of-rise measured for the heat detectors in the TF-5 type tests suggest that the heat detection component would be useful for fires with a heat release rate (HRR) somewhat larger than that generated in the test.

2. Test Procedures

Two commercially-available ion smoke detectors were compared to a commercially-available photoelectric/heat detector which incorporates a thermistor-based heat detector. For each test, the basis of comparison was the response-time-difference between the ion detector under test and an adjacent photoelectric/heat detector. The comparisons were conducted using standardized test fires in Simplex's UL 268 Fire Test Room.

For each test series, six samples of the ion detector under test were surface mounted on the fire room ceiling. Four of the ion detectors were arranged in a 15-foot square array and two were placed in the right and left positions of the ceiling "Test Panel" specified by UL 268 [5] (ceiling positions Ion 5 and Ion 6 in Fig. 1). A photoelectric/heat detector was placed adjacent (approximately 6-in. separation) to each of the ion detectors in the square array. A fifth photoelectric/heat detector was mounted midway between the Ion 5 and Ion 6 ceiling positions. For each test, the distances from the detector locations to the test fire are given in the results table for that test (Tables 1 - 8). For all tests, each photoelectric, and ion detector was placed so that its "least favorable position for smoke entry" was oriented towards the test fire location.

Three different fire types were used to evaluate each ion detector model. The first test-type was the UL 268 "Smoldering Smoke Test" found in section 40 of UL 268. This test used 10 sticks of ponderosa pine (3" x 1" x ¾") on a laboratory hotplate to produce a slow, smoldering fire. The second test-type was the UL 268 "Flammable Liquid Fire – Test C" found in section 39.4 of UL 268. This test used 38 milliliters of a mixture of 65% heptane and 35% toluene by volume to produce a hot, flaming fire. Both of these UL 268 fire tests were performed according to the test method outlined in UL 268, 4th Ed. paragraph 39.6. As specified in UL 268, photo beam and measuring ionization chamber (MIC) data were collected during all tests and analyzed to ensure that the buildup rate and the light-transmission vs. MIC curves conformed to the requirements of UL 268.

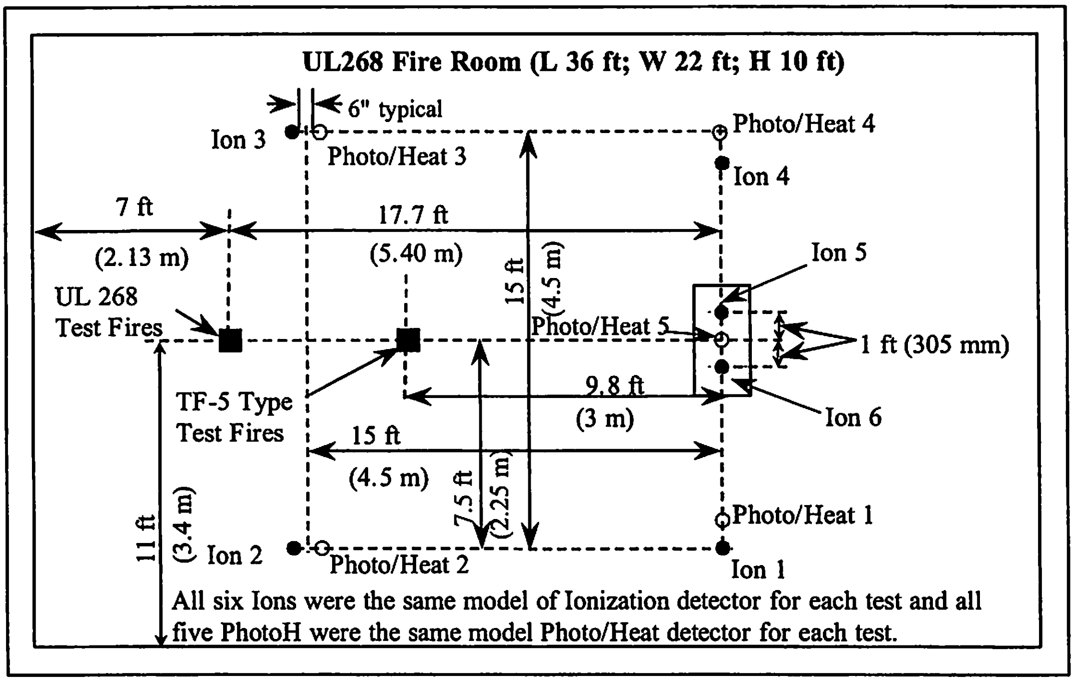

Figure 1. Detector Positions for Fire Tests

The third test type was similar to the "TF-5 - Liquid (Heptane) Fire" described in Appendix K of pr EN 54-7 (Draft A3). The ceiling of the UL 268 fire room is 1 meter less than that specified by prEN 54-7 so the amount of the heptane (97%)/toluene (3%) mixture was reduced to 463 ml to prevent heat and fire damage to our test facility. The fuel was burned in a round receptacle 33 cm in diameter and 7.5 cm deep to attain the required smoke density build-up rate. The test fire location was selected so that ceiling positions Ion 5, Ion 6, and Photo 5 were contained in the prEN-54-specified volume.

The fire room was instrumented with an NIR obscuration meter and MIC which met the prEN 54-7 criteria. Optical density (m-value in dB/m) and MIC data (y-value) were collected and analyzed for each test to determine if the "m against y" and "m against time" tolerance limits of prEN 54-7 were met. The TF-5 type fires typically came close to or met the tolerance limits as shown in Fig. 2.

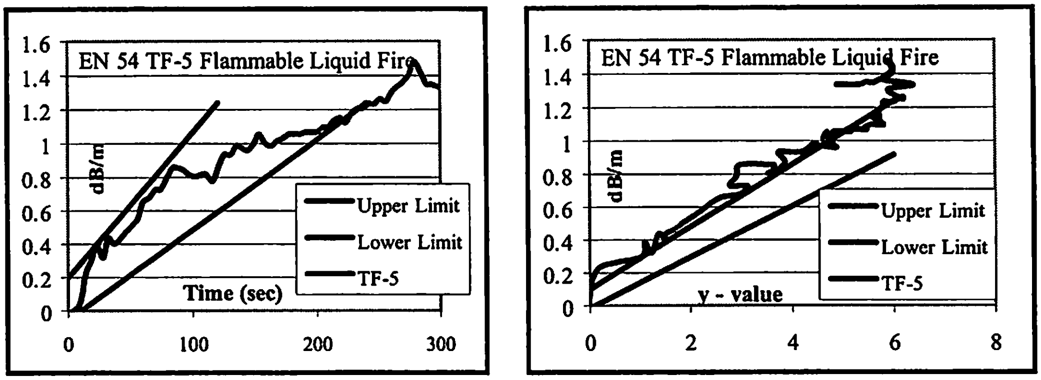

Figure 2. pr4EN 54-7 Fire TF-5 Tolerance Limits

3. Description of Devices Tested

Two ion sensor models from different manufacturers were tested. Ion detector Type A is currently sold by Simplex for use in Simplex fire alarm systems. Ion detector Type B was previously sold by Simplex for use in Simplex fire alarm systems. Each type of ion detector consists of a detector/base combination which sends a digital representation of smoke density to a Simplex control panel. The alarm activation time of each ion detector was evaluated at 0.5 %/ft (the most sensitive of its four standard settings) and at its default installation sensitivity of 1.3 %/ft. All six detectors of each ion type were selected at random from stock. Each ion detector was used as calibrated by its manufacturer.

The five photoelectric/heat detectors used were standard Simplex UL-listed units taken at random from stock. This detector type consists of a sensor/base combination which sends digital representations of smoke density and temperature to a Simplex control panel. The alarm activation time of the photoelectric component was evaluated at 0.5 %/ft (the most sensitive of its eight standard settings) and its default installation sensitivity of 2.5 %/ft. Each of the five photoelectric/heat detectors was calibrated in a

Simplex UL 268 Sensitivity Test Box using Simplex's standard manufacturing calibration procedure.

The thermistor-based heat sensor element of the photoelectric/heat detector is a fixed temperature/rate-of-rise type whose sensitivity can be selected at the control panel. In the present investigation, the alarm activation time of the heat detector component was evaluated using two rate-of-rise (ROR) sensitivities (15 °F/min and 20 °F/min) and one fixed-temperature (FT) sensitivity (135 °F). In addition, maximum ROR data for each heat detector component was collected for each TF-5 type test

4. Data Collection

In each test, a digital representation of each ion and photoelectric/heat detector's output voltage was transmitted to a PC-based data acquisition system. Ion, photoelectric, and heat detector response times were calculated by post-processing the data. The algorithms used, together with a 4 second polling interval and alarm thresholds based on the device calibration, simulated the performance of the Simplex Model 4010 fire panel operating with no pre-alarm and no alarm verification delay. A chief advantage of using this method for obtaining detector response times was that it enabled the determination of detector response times at multiple sensitivities during a single test fire, thus decreasing the total number of test fires. For each combination of ion detector type and test fire type, four trials were conducted.

The ion and photoelectric detectors were compared at two combinations of sensitivity levels. The comparison at the same sensitivity of 0.5 %/ft was selected because these are the most sensitive standard Simplex sensitivities of these two detector types. The comparison of the ion detector at 1.3 %/ft to the photoelectric detector at 2.5 %/ft was selected because these are the default sensitivities of these two detector types and therefore represent a typical Simplex installation.

5. Fire Test Results

The results for the comparison of ion detector Type A and the photoelectric/heat detector are summarized in Tables 1 - 4. Unless otherwise noted, each alarm time entry is the average of 4 trials. The detector positions are indicated in parentheses beneath the distance from the fire. Note that, for each test type, only one average photoelectric alarm time is listed for ceiling positions 5 and 6. This is because the ion detectors at ceiling positions 5 and 6 were compared to a single photoelectric detector midway between them at ceiling position 5. For the smoldering smoke tests, the individual Type A ion and photoelectric detector response times measured for the four trials generally varied over a range of a few hundred seconds at each ceiling position. For the UL 268 Flammable Liquid Fire and the TF-5 type tests, the range of variation was on the order of ten seconds. Each table includes the difference between the average response times of the ion and photoelectric detectors for each ceiling position.

The average response-times recorded for the Type A ion detector at 1.3 %/ft and the photoelectric/heat detector at 2.5 %/ft are listed in Table 1 for the UL 268 Smoldering Smoke and Flammable Liquid Fire tests. Note that not all ion detectors alarmed in each smoldering smoke test. For each ion detector position, the number of tests for which no alarm (N/A) was observed is indicated in parentheses beneath the average response time value. Table 2 lists the average response-times of the ion and the photoelectric detectors in the UL tests when both were set to a sensitivity of 0.5 %/ft.

UL 268 Tests **Ionization Type A: 1.3 %/ft** **Photoelectric: 2.5 %/ft**		**Distance from Test Fire** **(Ceiling Position #)**					
		8.0 ft		**17.7 ft**		**19.2 ft**	
Test	**Device**	**(2)**	**(3)**	**(5)**	**(6)**	**(1)**	**(4)**
UL 268 Smold. Smoke Averages of 4 Trials	Ion A (N/A)	3459	3317	3843 (3)	3614	3864 (2)	3591
	Photo	2421	2253	2916		2726	2823
Diff. of Avg. Time (Ion - Photo)		1038	1064	927	698	1138	768
UL 268 Flamm. Liquid	Ion A	31	36	61	56	65	65

	Photo	26	29	55		57	57
Diff. of Avg. Time (Ion - Photo)		5	7	6	1	8	8

Table 1. Ion Detector A, UL 268 Tests: Default Sensitivity Alarm Times (in sec.)

The data for the smoldering smoke tests show that typically the photoelectric detectors set to 2.5 %/ft responded 12 - 18 minutes earlier than the Type A ion detectors set to 1.3 %/ft. Table 2 shows that when both were evaluated at 0.5%/ft, the photoelectric detectors typically responded 25 - 30 minutes faster than the Type A ion detectors. As Tables 1 and 2 show, in the UL 268 Flammable Liquid Fire tests, there was no significant difference in response time between the photoelectric and Type A ion detectors whether compared at their default sensitivities (2.5 %/ft and 1.3 %/ft) or the same, higher sensitivity (0.5 %/ft).

UL 268 Tests Ionization Type A: 0.5 %/ft Photoelectric: 0.5 %/ft		Distance from Test Fire (Ceiling Position #)					
		8.0 ft		17.7 ft		19.2 ft	
Test	**Device**	(2)	(3)	(5)	(6)	(1)	(4)
UL 268 Smold. Smoke	Ion A	3318	3236	3691	3471	3677	3474
Averages of 4 Trials	Photo	1556	1577	2008		1854	2002
Diff. of Avg. Time (Ion - Photo)		1762	1659	1683	1463	1823	1472
UL 268 Flamm. Liquid	Ion A	29	31	60	56	65	63
Averages of 4 Trials	Photo	18	20	45		53	52
Diff. of Avg. Time (Ion - Photo)		11	11	15	11	12	11

Table 2. Ion Detector A, UL 268 Tests: 0.5 %/ft Sensitivity Alarm Times (in sec.)

TF-5 Type Tests Ionization Type A: 1.3 %/ft Photoelectric: 2.5 %/ft		Distance from Test Fire (Ceiling Position #)					
		9.1 ft		9.8 ft		12.3 ft	
Test	**Device**	(2)	(3)	(5)	(6)*	(1)	(4)
Modified TF-5 Fire	Ion A	19	20	26	22	38	32
Averages of 4 Trials	Photo	55	58	69		76	67
Diff. of Avg. Time (Ion - Photo)		-36	-38	-43	-47	-38	-35
Max ROR result (°F/min. Avg. of 4 trials)	ROR	14	7	14		12	10
Max. Temperature (°F, Avg. of 4 trials)	FT	115	89	114		101	99

Table 3. Ion Detector A, TF-5 Type Tests: Default Sensitivity Alarm Times (in sec.) Maximum ROR and Fixed Temperature Values

Table 4 lists the average response times in the TF-5 type tests of the Type A ion detectors evaluated at 1.3 %/ft and the photoelectric detectors evaluated at 2.5 %/ft. Table 4 lists the average response times in the TF-5 type tests of the ion and the photoelectric detectors when both were set to a sensitivity of 0.5 %/ft. In the TF-5 type tests, Type A ion detectors evaluated at 1.3 %/ft responded in 19 to 38 seconds; about 40 seconds faster than the photoelectric detectors set at 2.5 %/ft. When the sensitivity levels were set to 0.5 %/ft for both types, there was no significant difference in TF-5 test response time between the photoelectric and Type A ion detectors. It is interesting to note that in both the UL 268 Flammable Liquid Fire tests and the TF-5 type tests, there were no significant differences in the Type A ion detector alarm times whether set at 0.5% or 1.3 %/ft.

TF-5 Type Tests **Ionization Type A: 0.5 %/ft** **Photoelectric: 0.5 %/ft**		**Distance from Test Fire (Ceiling Position #)**					
		9.1 ft		**9.8 ft**		**12.3 ft**	
Test	**Device**	**(2)**	**(3)**	**(5)**	**(6)***	**(1)**	**(4)**
Modified TF-5 Fire	Ion A	16	19	24	22	35	30
Averages of 4 Trials	Photo	15	17	19		23	23
Diff. of Avg. Time (Ion - Photo)		1	2	5	3	12	7

Table 4. Ion Detector A, TF-5 Type Tests: 0.5 %/ft Sensitivity Alarm Times (in sec.)

The results for the comparison of ion detector Type B and the photoelectric/heat detector are summarized in Tables 5 - 8. Each alarm time entry is the average of 4 trials. For the four smoldering smoke tests, the response times measured for the individual Type B ion and photoelectric detectors generally varied over a range of a few hundred seconds at each ceiling position. For the UL 268 Flammable Liquid Fire and the TF-5 type tests, the range of variation was on the order of ten seconds.

The average response-times recorded in the UL 268 Smoldering Smoke and Flammable Liquid Fire tests for the Type B ion detector at 1.3 %/ft and the photoelectric/heat detector at 2.5 %/ft are listed in Table 5. Table 6 lists the average response times of the ion and the photoelectric detectors in the UL tests when both were set to a sensitivity of 0.5 %/ft. The data for the smoldering smoke tests show that the photoelectric detectors set to 2.5 %/ft responded 8 - 14 minutes earlier than the Type B ion detectors set to 1.3 %/ft. When both were evaluated at 0.5%/ft, the photoelectric detectors typically responded 17 - 25 minutes faster than the Type B ion detectors. In the UL 268 Flammable Liquid Fire tests, there was no significant difference in response time between the photoelectric and Type B ion detectors whether compared at their default sensitivities (2.5 %/ft and 1.3 %/ft) or the same, higher sensitivity (0.5 %/ft).

UL 268 Tests Ionization Type B: 1.3 %/ft Photoelectric: 2.5 %/ft		Distance from Test Fire (Ceiling Position #)					
		8.0 ft		17.7 ft		19.2 ft	
Test	Device	(2)	(3)	(5)	(6)	(1)	(4)
UL 268 Smold. Smoke Averages of 4 Trials	Ion B	3350	3368	3470	3518	3602	3553
	Photo	2566	2534	3008		2871	2970
Diff. of Avg. Time (Ion - Photo)		784	834	462	510	731	583
UL 268 Flamm. Liquid Averages of 4 Trials	Ion B	25	22	50	50	56	55
	Photo	29	32	56		58	58
Diff. of Avg. Time (Ion - Photo)		-4	-10	-6	-6	-2	-3

Table 5. Ion Detector B, UL 268 Tests: Default Sensitivity Alarm Times (in sec.)

Table 7 lists the average response times in the TF-5 type tests of the Type B ion detectors evaluated at 1.3 %/ft and the photoelectric detectors evaluated at 2.5 %/ft. Table 8 lists the average response-times of the ionization and the photoelectric detectors in the UL tests when both were set to a sensitivity of 0.5 %/ft. The Type B ion detectors evaluated at 1.3 %/ft responded in 19 to 27 seconds in these tests; about 45 seconds faster than the photoelectric detectors set at 2.5 %/ft. When the sensitivity levels were evaluated at 0.5 %/ft for both types, there was no significant response-time-difference between the photoelectric and Type A ion detectors. For both the UL Flammable Liquid Fire tests and the TF-5 type tests, there were no significant differences in the Type B ion detector alarm times whether set at 0.5% or 1.3 %/ft .

UL 268 Tests Ionization Type B: 0.5 %/ft Photoelectric: 0.5 %/ft		Distance from Test Fire (Ceiling Position #)					
		8.0 ft		17.7 ft		19.2 ft	
Test	Device	(2)	(3)	(5)	(6)	(1)	(4)
UL 268 Smold. Smoke Averages of 4 Trials	Ion B	3159	3211	3340	3343	3450	3395
	Photo	1676	1697	2331		1929	2198
Diff. of Avg. Time (Ion - Photo)		1483	1514	1009	1012	1521	1197
UL 268 Flamm. Liquid Averages of 4 Trials	Ion B	21	21	49	48	55	54
	Photo	19	18	49		55	49
Diff. of Avg. Time (Ion - Photo)		2	3	0	-1	0	5

Table 6. Ion Detector B, UL 268 Tests: 0.5 %/ft Sensitivity Alarm Times (in sec.)

The heat detector fixed temperature and ROR functions generally did not exhibit a significant response in the UL 268 Smoldering Smoke and UL 268 Flammable Liquid fire tests. In the TF-5 type fire tests, the fixed temperature and ROR functions did not generally exceed their alarm thresholds, but, these quantities reached significant levels which are tabulated in Tables 3 and 7 for the Type A ion tests and Type B ion tests, respectively.

TF-5 Type Tests Ionization Type B: 1.3 %/ft Photoelectric: 2.5 %/ft		Distance from Test Fire (Ceiling Position #)					
		9.1 ft		9.8 ft		12.3 ft	
Test	Device	(2)	(3)	(5)	(6)	(1)	(4)
Modified TF-5 Fire Averages of 4 Trials	Ion B	19	21	20	20	27	26
	Photo	67	58	72		71	65
Diff. of Avg. Time (Ion - Photo)		-48	-37	-52	-52	-44	-39
Max ROR result (°F/min, Avg. of 4 trials)	ROR	9	7	13		13	10
Max. Temperature (°F, Avg. of 4 trials)	FT	100	93	115		106	104

Table 7. Ion Detector B, TF-5 Type Tests: Default Sensitivity Alarm Times (in sec.); Maximum ROR and Fixed Temperature Values

TF-5 Type Tests Ionization Type B: 0.5 %/ft Photoelectric: 0.5 %/ft		Distance from Test Fire (Ceiling Position #)					
		9.1 ft		9.8 ft		12.3 ft	
Test	Device	(2)	(3)	(5)	(6)*	(1)	(4)
Modified TF-5 Fire Averages of 4 Trials	Ion B	16	17	18	17	23	23
	Photo	16	18	16		25	23
Diff. of Avg. Time (Ion - Photo)		0	-1	2	1	-2	0

Table 8. Ion Detector B, TF-5 Type Tests: 0.5 %/ft Sensitivity Alarm Times (in sec.)

6. Discussion: Photoelectric/Heat vs. Ion Response

A series of UL 268 Smoldering Smoke (gray smoke), UL 268 Flammable Liquid Fire (black smoke), and TF-5 type Liquid (Heptane) Fire (black smoke) tests were conducted to compare the performance of two models of commercially available ion detectors (designated Type A and Type B) to the performance of a commercially available photoelectric/heat detector. The basis of comparison was the length of time required for each detector to exceed its alarm threshold.

In the smoldering smoke tests, at both combinations of sensitivity tested, both models of ion detector took considerably longer to respond than the photoelectric component of the photoelectric/heat detectors. This result strongly supports the generally accepted view [2] that photoelectric detector technology possesses an advantage over ion detector technology with regards to smoldering smoke response.

In the UL 268 Flammable Liquid Fire tests, the performance of the photoelectric component of the photoelectric/heat detector was fully equivalent to that of both ion detector models at both combinations of sensitivity. The detectors of all three types typically alarmed in about a minute or less.

In the TF-5 type tests, the ion detectors (both types) responded about 40 - 45 seconds earlier than the photoelectric detectors when both technologies were evaluated at their default sensitivities (2.5 %/ft for the photoelectric and 1.3 %/ft for the ions). In Figure 3, the 8-bit digital representation of smoke density is plotted versus time for an ion detector and an adjacent photoelectric detector for typical UL 268 Flammable Liquid Fire and TF-5 type tests. The 0.5 and 1.3 %/ft alarm thresholds of the ionization detectors are indicated by dashed lines. Solid lines indicate the 0.5 and 2.5 %/ft photoelectric alarm thresholds of the photoelectric/heat detectors. In the UL 268 Flammable Liquid Fire tests, ion and photoelectric technologies responded approximately at the same time. In the TF-5 type fires, the photoelectric detectors generally responded more slowly than they did in the UL 268 Flammable Liquid Fire tests. The ion detectors took about the same length of time in both types of fire. The slower performance of the photoelectric detectors in the UL 268 Flammable Liquid Fire tests is possibly due to the fuel mixtures used. In the TF-5 fire, the heptane fuel (smoke yield .037 g/g) contains only 3% toluene (smoke yield .178 g/g) [6]. It seems likely, therefore, that the 65% heptane/35% toluene fuel mixture used in the UL 268 Flammable Liquid Fire test will produce a greater proportion of visible smoke than the TF-5 fire. Since ion detectors have a greater sensitivity to the invisible particles produced by a hot flaming fire, the conditions of the TF-5 type fire would therefore be more favorable for ion detectors than the UL 268 Flammable Liquid Fire test.

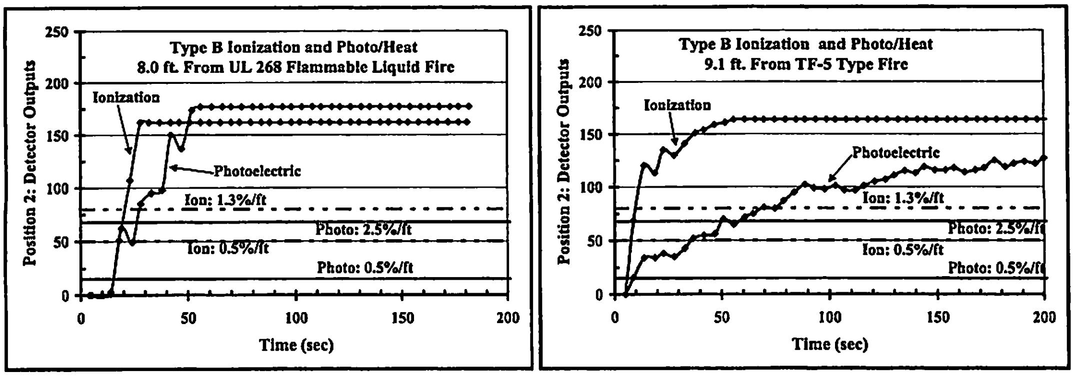

Figure 3. Detector Outputs for TF-5 and UL 268 Flammable Liquid Fire Tests

With the 4 second sample time used, the two technologies yield equivalent response times of about 20 seconds at the higher sensitivity of 0.5 %/ft. At the lower default sensitivities (1.3 %/ft for the ion, 2.5 %/ft for the photo), the faster response of the ion detector to the TF-5 fire products becomes more obvious. This interesting result illustrates the importance of fully specifying the experimental conditions when performing technology comparisons.

The three heat detector modes evaluated (15 °F/min ROR, 20°F/min ROR, and 135 °F fixed temperature) generally did not exceed their alarm thresholds in the fire tests performed. Furthermore, the response of the fixed temperature and ROR functions, though negligible in the UL 268 Smoldering Smoke and Flammable Liquid Fire tests, was significant in the TF-5 type tests. For example, the ROR heat detection function came relatively close to alarming at the 15 °F/min setting in the TF-5 fire tests. Two factors probably contribute most to this performance differential. First, in the TF-5 type tests, all detectors were closer to the fire than in the two UL 268 tests. Second, the heat release rate (HRR) of the TF-5 type test was much greater than for either UL 268 test. Using the heat release rate (HRR) calculation described in the SFPE Handbook [7], the HRR of the TF-5 type fire was estimated to be 123 kW and the HRR of the UL 268 Flammable Liquid Fire test was estimated to be 12.7 kW. The HRR of the UL 268 smoldering fire was estimated to be about 1.5 kW, based on the hotplate characteristics.

7. Conclusions

In this investigation, the response of the photoelectric smoke detection technology to smoldering smoke was much faster than the response of the ion technology. The photoelectric response to the black smoke produced by the UL 268 Flammable Liquid Fire was generally as fast as (or faster than) the ion response. In the TF-5 type fire tests, the photoelectric response lagged the ion response by only about 45 seconds when both were evaluated at their default sensitivities (1.3 %/ft for ion, 2.5 %/ft for photoelectric). However, the photoelectric response to the TF-5 type fire was typically as fast as the ion response when both were evaluated at the same sensitivity (0.5 %/ft). Furthermore, the TF-5 type fire test results also indicate that, even in the absence of visible smoke, the photoelectric/heat detector would be effective for the detection of fires with a heat release rate or duration slightly greater than that of the TF-5 type test fire used. Therefore, these results strongly support the conclusion that photoelectric and photoelectric/heat technologies possess a clear overall performance advantage over ion technology if the most likely sources of fire danger are smoldering fires (as some believe [3]) or flaming hydrocarbons.

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