Supplementary Questions and Answers Clarifying "Detector Sensitivity and Siting Requirements for Dwellings," Phase I (NBS GCR 75-51) and Phase II (NBS GCR 77-82)

1. **Does the National Institute of Standards and Technology (NIST) have regulatory powers and does it certify smoke detectors?**

   No. NIST is a non-regulatory agency of the U.S. Department of Commerce. NIST does not "certify" smoke detectors.

2. **Could working ionization detectors fail to detect the type of smoke most commonly produced by the early fire? If so, state the conditions under which this may occur.**

   Both ionization and photoelectric sensors detect particles. Photoelectric technology is sensitive to the mass density of particles of a diameter of the same order as the wavelength of the light source in its sensor. Ionization technology is sensitive to the sum of all particle diameters and so it can respond to smaller particle diameters present in greater numbers. Because smoke from a smoldering fire produces relatively fewer particles and the particles are relatively larger, it is possible for an ionization-type detector to alarm at a time well after smoke from a smoldering fire is sensed by a photoelectric sensor.

3. **Did NIST ever compare the performance of a single ionization detector with a "throughout-the-home" fire detection system with a detector (heat, ionization, or photoelectric) in every room? If so, what did NIST find from its studies?**

   No. A pioneering Canadian study published in 1962 (McGuire and Ruscoe) postulated the performance of a single smoke alarm outside the sleeping room(s) based on the judgment of experts reviewing fire reports. In 1974 this study was cited as the basis for a minimum requirement for a single smoke alarm outside the bedrooms in homes. In 1975, NIST (then NBS) funded tests to examine if one smoke alarm was sufficient. The tests indicated that it was not sufficient for multi-level homes, leading to the "every level" requirement common to most modern regulations. The 1975 tests examined the performance of a heat detector in the room of fire origin, and in the second year (1976) looked at heat and smoke detectors in the room of fire origin, both equivalent to an "every room" alarm placement. These studies concluded that, while detectors in every room provided some increase in escape time, the increase was incremental and not justified by the cost as a minimum code requirement. The 2004 NIST tests also examined several installation strategies, including "every level", "every level plus bedrooms", and "every room." Due mostly to the systematically lower escape times observed in the more recent tests, it appears that there is justification to apply the "every level plus bedroom" strategy (that is currently the minimum requirement for new homes) to existing homes. Both the Phase I and Phase II tests utilized heat, ionization, and photoelectric technologies and concluded that particulate sensors (either ionization or photoelectric) were adequate when placed appropriately and that heat sensors did not provide any additional protection.

4. **Did NIST ever conclude from any of its studies that the warning provided by a single ionization detector "would be so rapid that an occupant would be able to correct the pre-fire condition before any fire actually developed"?**

No. Over the years numerous claims were made by marketers of ionization and photoelectric technologies to demonstrate the superiority of their products. Some ionization manufacturers claimed that their detectors could sense "invisible particles of combustion that are present before any visible smoke or flames." While the latter statement may be true in some flaming fire situations (such as burning alcohol fuels), NIST (NBS) never attempted to reproduce nor commented on these claims.

5. **Did the operating times when the fires were smoldering in Phase I of the Indiana Dunes Tests[1,2] average more than one hour? If so, state the observed conditions when the fires were smoldering.**

The average test duration for the smoldering fires in the Phase I study was 5266 s ± 1907 s. In all of these tests, the test item smoldered for an extended period of time, averaging 4298 s ± 1929 s before transitioning to flaming. For the Phase I smoldering tests, the average time to first alarm was 2489 s ± 1324 s for ionization alarms and 1927 s ± 1065 s for photoelectric alarms.

6. **Did the ionization detectors in the Phase I smoldering tests remain silent for over an hour? If so, why did they remain silent?**

In the Phase I smoldering tests, the average time to first alarm was 2489 s ± 1324 s for ionization alarms and 1927 s ± 1065 s for photoelectric alarms. The time to first alarm was greater than 3600 s in 4 of the 23 tests for the ionization alarms and in 2 of the 23 tests for photoelectric alarms. The reasons for the delay with both alarm technologies are associated with the slow rate at which smoldering fires produce smoke and the much longer transport time to the ceiling due to the low buoyancy of a smoldering plume. In addition, because the number of particles that eventually reach either detector is relatively smaller from a smoldering source, the technology that is based upon number density (i.e., ionization detectors) is slower to respond.

7. **Were most Phase I smoldering tests terminated shortly after one hour? If so, why were they terminated?**

The average test duration for the smoldering fires in the Phase I study was 5266 s ± 1907 s with tests as long as 8520 s. Tests were terminated after one or more pre-established tenability limits were exceeded, since any devices responding after that time would not affect the escape time provided. In Phase I, the first 36 and the last of the 40 tests exceeded a tenability limit prior to termination. Tests 37 (overloaded electrical motor), 38 and 39 (overloaded extension cord) did not exceed a tenability limit and these tests were terminated after the test items burned out on their own.

---

[1] Bukowski, R.W., Waterman, T.E., and Christian, W.J., "Detector Siting and Sensitivity Requirements for Dwellings." IIT Research Institute Report prepared for Natl. Bur. Stand. (U.S.), NBS GCR 75-51 (1975)
[2] Harpe, S.W., T.E., and Christian, W.J., "Detector Siting and Sensitivity Requirements for Dwellings – Phase 2." IIT Research Institute Report prepared for Natl. Bur. Stand. (U.S.), NBS GCR 77-82 (1977)

8. Was there a one-hour "average" time to warn of a smoldering fire when using ionization detectors in the Phase I tests? Was this based on "prematurely terminated tests"? If not, state why that is not the case?

As stated above, the average time to first alarm was 2489 s ± 1324 s for ionization alarms. No tests were prematurely terminated since in every case (except the three electrical fires mentioned above) test termination did not occur until tenability had been exceeded. For the smoldering tests, the average time from first alarm to the onset of untenable conditions was 1926 s ± 1454 s for the ionization alarms. Note that many of the smoke detectors (ionization and photoelectric) were located well away from the origin of the fire and not in the path of egress. For those tests where not all these alarms activated prior to test termination (8 of 23 smoldering tests for the ionization detectors and 2 of 23 smoldering tests for the photoelectric detectors), it is possible that the time to alarm would have exceeded one hour, which could increase the average time to warn of a smoldering fire.

9. Did the Phase I report find that "photoelectric type detectors seem to respond better to the smoldering type fires and the ionization detectors seem to respond slightly better to the flaming fires"? What was the technical basis for this finding?

Yes, at any given detector location, most photoelectric detectors responded sooner than most ionization detectors to smoldering fires and most ionization detectors responded sooner than most photoelectric detectors for flaming fires. On average, the first ionization alarm responded 147 s ± 92 s before the first photoelectric alarm in the flaming fires (in all cases, an ionization alarm responded before a photoelectric alarm). On average the first photoelectric alarm responded 562 s ± 800 s before the first ionization alarm in the smoldering fires (in 20 of the 23 smoldering tests, photoelectric alarms responded before an ionization alarm).

The technical basis for this result lies with the differences in the character of smoke from a smoldering versus a flaming fire, and from the different operating principles of the detectors. Both ionization and photoelectric sensors detect particles. Photoelectric technology is sensitive to the mass density of particles of a diameter of the same order as the wavelength of the light source in its sensor. Ionization technology is sensitive to the number density of particles and so responds to smaller particle diameters present in greater numbers. Smoke from a smoldering fire produces relatively fewer particles and the particles are relatively larger, as compared to particles from a flaming fire which are much more numerous though generally smaller.

10. Did the Phase I report conclude that "In general, all detectors responded well to fires" and "A residential smoke detector of either the ionization or photoelectric types with small lag time would provide more than adequate life saving potential under most real residential fire conditions when properly installed"? What was the technical basis for this conclusion?

Yes. For the "every level" and "every room" criteria, escape times provided by both smoke sensing technologies (ionization and photoelectric) were positive for nearly all tests. In the end, NIST (NBS) pointed out that the adequacy of the time provided would depend on the time needed by a specific group of people in a specific household. The report presents escape times in a probability plot (percent of the tests in which a specific escape time was provided for a specific installation location, sensor type, or sensitivity). An independent analysis of the Phase I data by a State Fire Protection

Board considering detector legislation selected a 3 min (minimum) escape time criterion[3]. On this basis they concluded that every level smoke detectors (either ionization or photoelectric) provided 3 min of escape time in 89 % of the tests (average escape time +18.6 min), a single smoke detector outside the bedroom provided 3 min of escape time in 35 % of the tests (average escape time +4.5 min), a rate-of-rise heat detector in every room provided 3 min of escape time in 19 % of the tests (average escape time -0.6 min) and a fixed temperature heat detector in every room provided 3 min of escape time in 11 % of the tests (average escape time -2.2 min).

11. What criteria did the Phase I study use to determine "life saving potential"? How were the criteria judged to be "more than adequate"?

"Life saving potential" was judged by the time for escape provided in advance of any untenable condition appearing anywhere along the "primary escape path," which was defined as the path from any room to one of the doors to the exterior. While building regulations require a second means of egress from any residential room (normally a window) the researchers did not judge escape out a window as a success. The tenability criteria selected were the occurrence of a smoke optical density of 0.07 per foot, a temperature of 150 °F, or a CO concentration of 0.04 % averaged over one hour. The substantiation for these limits including literature references is provided in Appendix D of the reports. For CO, the report observes that the available data is all for exposure to a constant CO level for a given time and the observed CO levels in the tests rose almost linearly with time. This is the basis for using a (one hour) time averaged concentration. Smoke was always the first tenability limit exceeded (in two tests the CO limit was approached but not exceeded before the smoke limit was reached.) All three criteria were considered conservative, based on the literature cited in the report. This is especially true of smoke since it only relates to loss of visibility and because escape paths in homes are generally short and are generally familiar to the occupants.

12. What criteria did the Phase I study use to determine "most real residential fire conditions"?

The tests involved real detectors available for purchase installed in the locations cited in the national standard in real homes in which real contents were ignited in ways that are observed in data collected in real fires. On this basis the researchers felt that the tests represented real fire scenarios to the maximum extent possible.

13. Did the report(s) from the Indiana Dunes Tests find or conclude that the smoke detector (ionization or photoelectric) is "the ONLY type of detector" capable of providing adequate warning of a flaming fire? If so, state the technical basis for this finding or conclusion.

The report did not state that "the ONLY type of detector" capable of providing adequate warning of a flaming fire is the smoke detector (ionization or photoelectric). It presents escape times in a probability plot (percent of the tests in which a specific escape time was provided for a specific installation location, sensor type, or sensitivity). An independent analysis of the Phase I data by a State Fire Protection Board considering detector legislation selected a 3 min (minimum) escape time criterion. On this basis they concluded that every level smoke detectors (either ionization or photoelectric) provided 3 min of escape time in 89 % of the tests (average escape time +18.6 min), a

[3] Wilson, R., Computer Analysis of Data on Fire Detectors Available for Purchase in Massachusetts, Data from the National Bureau of Standards Indiana Dunes Tests Record, Contract No. 4-36092, Massachusetts Fire Prevention Fire Protection Board, January 1976.

single smoke detector outside the bedroom provided 3 min of escape time in 35 % of the tests (average escape time +4.5 min), a rate-of-rise heat detector in every room provided 3 min of escape time in 19 % of the tests (average escape time -0.6 min) and a fixed temperature heat detector in every room provided 3 min of escape time in 11 % of the tests (average escape time -2.2 min).

14. Is the heat detector (mechanical or electrical) used as the trigger for fire sprinkler systems? Above what average temperature (°F) do the ideal and typical detectors trigger?

Heat detectors are not typically used to trigger fire sprinkler systems. While there have been attempts at commercialization of such systems, they have not proved viable. Rather, they are most typically separate systems. Heat detectors are most often rated to operate at fixed temperatures from 135 °F to 175 °F. Some fire sprinklers utilize heat sensors of a type similar to those used in the mechanical heat detectors used in Phase II (eutectic solder). The most common fire sprinklers have a rated activation temperature of 165 °F with some residential use sprinklers rated as low as 135 °F.

In Phase I the response of fixed temperature heat detectors was estimated from thermocouples at temperatures of 135 °F and 150 °F. Actual rate-of-rise heat detectors were present beginning with test 14. In Phase II actual (fixed temperature) mechanical heat detectors with activation temperatures of 135 °F were installed in the fire room through test 63 at which time all devices supplied by the manufacturers were expended.

15. How does the heat detector (either type) in a fire sprinkler system perform in the two major types of fires (smoldering fires and flaming fires)? Is the heat detector reliable for this application?

Heat detectors are not typically used to trigger fire sprinkler systems. Rather, they are most typically separate systems. Heat detectors are most often rated to operate at fixed temperatures from 135 °F to 175 °F. Some fire sprinklers utilize heat sensors of a type similar to those used in the mechanical heat detectors used in Phase II (eutectic solder). A heat detector or a fire sprinkler cannot detect a smoldering fire while it is smoldering since it does not raise the room temperature appreciably. The purpose of residential fire sprinklers is distinctly different from residential smoke alarms however. From the National Fire Protection Association standard, NFPA 13D[4], these sprinklers are “expected to prevent flashover (total involvement) in the room of fire origin,” thus suppressing the fire and limiting the spread of fire and toxic conditions in rooms remote from the fire.

Activation of heat detectors or fire sprinklers is often significantly later in the fire than smoke alarms. In the Phase I tests, heat detector activation was well after the time to untenable conditions in all fires and after the recorded transition to flaming in all but one of the smoldering tests. Neither the Phase I nor Phase II tests included residential fire sprinklers since these were not developed until several years later. There were rare residential sprinkler systems that utilized commercial sprinkler heads, but these did not represent a significant force in the market. In the NIST 2004 study[5] so-called “tell tale” sprinklers (commercially available fire sprinklers typical of those installed in residential systems but not connected to a water supply) with a temperature rating of 155 °F were installed in the fire room

---

[4] “NFPA 13D, Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes, 2007 Edition,” Volume 2 of the National Fire Codes, Natl. Fire Protection Association, Quincy MA 2007.

[5] Bukowski, R. W., Peacock, R. D., Averill, J. D., Cleary, T. G., Bryner, N. P., Walton, W. D., Reneke, P. A., and Kuligowski, E. D. Performance of Home Smoke Alarms, Analysis of the Response of Several Available Technologies in Residential Fire Settings, Natl. Inst. Stand. Technol., Tech. Note 1455 (2004)

for all tests. Activation times recorded for flaming fires ranged between 126 s and 247 s, and for smoldering fires they did not activate until after transition to flaming. Specific times are documented in the report.

16. Did the Dunes study find that the heat detector (mechanical or electrical) is not a reliable alarm device to warn of a flaming fire? What was the technical basis for this finding?

The tests showed that heat detectors in every room were far less effective than smoke alarms on every level in the majority of tests (see answer to question 10).

17. Did the Phase I study find that the smoldering fires involving heat detectors did not produce "any significant heat"? If so, why was that the case? Is this representative of typical fires in a residential dwelling to evaluate detector performance?

Smoldering fires by their nature do not produce any significant heat as smoldering is a very slow combustion process. At the time, NFPA data showed smoldering fires might make up 2/3 of all (fatal) residential fire starts as estimated from fire reports where the ignition source was smoking materials and the first item ignited was upholstered furniture or mattresses. For this reason the test scenarios in the 1975/76 tests were approximately 2/3 smoldering ignitions and 1/3 flaming ignitions.

18. Did the Phase I study find that the flaming fires involving heat detectors did not "raise the ceiling temperatures in the fire rooms to the modest 135 °F which was the set temperature[s] for the heat detectors"? If so, why was that the case? Is this representative of typical fires in a residential dwelling to evaluate detector performance?

An independent analysis (Patton 1992) listed 27 tests (12 in Phase I and 15 in Phase II) that reached or exceeded 200 °F. Some of these began as flaming and others were smoldering and transitioned to flaming. Several conditions must occur to raise the temperature of the air below the ceiling. First there must be sufficient heat release from the fuel, second the plume entrains cooler ambient air that reduces the temperature by mixing, and third is heat lost to the ceiling by convection (initially as much as 90 % of the energy in the plume is lost to the ceiling). These processes are typical of fires in compartments.

19. Did the Phase II study find that in the six flaming fires involving heat detectors "the ceiling temperatures went above 200 °F but never above 500 °F"? If so, why was that the case? Is this representative of typical fires in a residential dwelling to evaluate detector performance?

The analysis cited above (Patton 1992) indicated that all 27 tests that reached or exceeded 200 °F did not exceed 500 °F. This should be expected since the tenability criterion for temperature was 150 °F (at the 5 foot level) that was never exceeded prior to test termination based on exceeding the smoke criterion. Since the activation temperature of all of the heat detectors was 135 °F (150 °F for the thermocouple reading to simulate thermal inertia) this would have provided an opportunity for the heat detectors to respond had the temperature exceeded their activation temperature.

20. Were any of the heat detectors (electrical or mechanical) removed from the fire rooms before lighting the fires in the six Phase II flaming fire tests? If so, why were they removed?

None of the heat detectors were removed. In the Phase II tests actual mechanical heat detectors were used. Since these are not sold in retail stores they were obtained from the manufacturers. Each of two manufacturers (that utilized a horn or bell as the sounding device) provided a case of 24 units. One of each was included in each Phase II test starting with test 41 and ending with test 63 at which time all 24 samples had been used. Both devices used eutectic solder sensors which have a characteristic that the activation temperature can decrease if they are exposed to an elevated temperature without activating. Thus each unit could be used in only one test even if it did not activate.

21. In how many of the six Phase II flaming fire tests were there no electrical heat detectors? Mechanical detectors? If so, what was the technical basis for this condition(s)?

Officially there were 15 flaming tests in Phase II (44, 45, 49, 50, 58, 59, 63, 64, 66, 68, 69, 70, 71, 74, and 76). The mechanical heat detectors were present in 7 (44, 45, 49, 50, 58, 59, and 63). Electrical heat detectors were not used in Phase II since the mechanical devices were present. Estimated response of heat detectors from thermocouple readings was not made although a thermocouple was present in the room of fire origin and the data were published in the report.

22. How many smoldering fire tests were conducted in the Phase I test series?

23 of 37 tests (not counting the three electrical fires) in Phase I were smoldering.

23. Were nine ionization detectors installed in each of the Phase I smoldering fire tests? If not, state how many were installed in each of the tests.

The smoke alarms used in the Phase I tests were arranged on one large board and two “half” boards. The large board had 4 ionization, 4 photoelectric, and a dual gate (an older technology that used an early ionization detector paired with an electrical resistance circuit) detector. One half board had 3 ionization and 2 photoelectric detectors, and the other half board had 2 ionization, 2 photoelectric, and a dual gate detector. The alarm boards were located in the first and second floor hallways (outside sleeping rooms) and one of the half boards was moved to the top of the basement stairs for fires in the basement. The half boards were constructed to assess any differences between wall mounting and ceiling mounting (one half board on the wall and one on the ceiling at the same location). For some first floor fires the half boards were in the first floor hallway and for some on the second floor hallway to examine wall vs. ceiling at that location. The large board was used at the other hall location. In some tests the half boards were switched (wall for ceiling) to eliminate systematic errors. These detectors; 9 ionization, 8 photoelectric, and two dual gate (plus heat detectors in the fire room), were present in all tests.

Not all detectors were operational in all tests. For tests 28 through 40, one of the detector locations (clock No. 25, a photoelectric detector) was taken out of service due to physical breakage of the detector.

24. Did the Phase I study find that:

(a) not a single ionization detector sounded within five minutes of the initiation of the Phase I smoldering fire tests?

(b) Only one time did an ionization detector sound within 10 minutes of the initiation of the Phase I smoldering fire tests?

(c) Only 26 times (or about 16 percent of possible times) did the ionization detector sound within the first 30 minutes of the initiation of the Phase I smoldering fire tests?

(d) The ionization detector never sounded 44 times at the time of the termination of the Phase I smoldering fire tests?

State the technical basis for each of the above with the responses.

(a) Neither ionization detectors nor photoelectric detectors alarmed within the first five minutes in any test. The shortest alarm times in the smoldering tests were 473 s in test 6 for an ionization and 468 s in test 6 for a photoelectric alarm

(b) Only tests 5 and 6 had alarm times of less than 10 min for both ionization detectors and photoelectric detectors.

(c) A total of 21 ionization detectors of a possible 207 alarmed within the first 30 min of test initiation. A total of 30 photoelectric detectors of a possible 166 alarmed within the first 30 minutes of test initiation.

(d) A total of 21 ionization detectors out of a possible 207 did not alarm prior to test termination. A total of 5 photoelectric alarms out of a possible 166 did not alarm prior to test termination in all the tests.

It is important to note that the number of detectors that alarm within a particular time may not be that valuable. More important is a comparison of alarm time to the time to untenable conditions. In all tests, multiple detectors of both types provide alarms well before untenable conditions. For the smoldering tests, the average time from first alarm to the onset of untenable conditions was 1926 s ± 1454 s for the ionization alarms and 2511 s ± 1667 s for the photoelectric alarms.

25. Did the Phase I study find that the ionization detector did not respond to the smoldering fires in the Phase I tests so long as they remained smoldering fires? If so, why was that the case?

No, the Phase I study did not find this. In all tests, at least one ionization alarm responded well before the transition to flaming.

26. Did the Phase I study find that "long before an hour has passed (average time to operate) potentially deadly levels of carbon monoxide and other toxic gases were created" in the smoldering fire tests? Is this statement a reasonable representation of knowledge among experts at the time the tests were conducted? Today?

The tenability limit used for the Phase I study for CO was a time averaged (one hour) concentration of 400 ppm (based on a review of literature available at the time). This limit is roughly consistent with limits in today's literature[6]. In only 2 of the 40 experiments carbon monoxide concentrations

[6] Most typically, tenability is judged using the ISO Technical Specification 13571. For CO, this is a fractional effective dose calculation, FED, of $FED = \sum_{t1}^{t2} \left([CO]/35000\right)\Delta t$ where the CO concentration, $[CO]$ is in ppm and the time, t, is in min. Incapacitation is considered to have occurred at FED values between 0.3 and 0.5; lethality at a value of 1. The 400 ppm one hour average limit is equivalent to an FED of 0.68.

approached but did not exceed the time averaged (one hour) concentration of 400 ppm before the optical density reached 0.07 per ft. Nevertheless, the occurrence of the critical optical density preceded the occurrence of critical carbon monoxide levels in all of the experiments.

Today, the guidance regarding CO toxicity is more conservative, with an accepted tenability limit of 175 ppm for one hour for the most sensitive population. We are reexamining the data from Phase I and the more recent NIST home smoke alarm study[5] to determine how often this limit may have been exceeded inside the room of origin and outside the room of origin along the egress path prior to alarm.

27. Did the Phase I study find that the ionization detector sounded only after the smoldering fire was heating up and converting, or had already converted, to a flaming (hot) fire? If not, why was this not the case?

No, in all tests, at least one alarm of each type, ionization and photoelectric, responded well before the transition to flaming. On average, the time from first alarm to the transition to flaming was 1962 s ± 1678 s for ionization alarms and 2445 s ± 1967 s for photoelectric alarms. In all cases, the time to first alarm preceded the transition to flaming in the smoldering tests. The minimum time from first alarm to the transition to flaming was 40 s for the ionization alarms and 41 s for the photoelectric alarms (both in test JR-22).

28. Is the type of smoke created in the standard smoldering fire test developed by Underwriters Laboratories (i.e., where Ponderosa Pine sticks on a hot plate are raised closed to their auto-ignition temperature of about 700 °F) similar to the type of smoke created by a burning cigarette on upholstered furniture or bedding? If not, state the major differences.

At the time of publication of the study (1975/76) there was no smoldering test in the UL standard (UL217). The Dunes tests clearly showed the importance of response to such fires. UL conducted a study to develop a suitable test. They smoldered cotton-stuffed mattresses similar to those used in the Dunes tests in their fire test room to develop smoke vs. time profiles. They then experimented with different techniques and materials to generate the observed conditions in a reproducible manner. Heating ponderosa pine wood strips on a temperature-programmed hotplate obtained the desired result[7]. Recently, UL has conducted tests following the NIST Home Smoke Alarm Project and concluded that smoldering and flaming polyurethane foam smoke has characteristics different from the smoke in their standard test fires[8]. UL is now investigating the possibility of adding additional standard tests using polyurethane foam.

---

[7] Harpe, S.W., and Christian, W.J., “Development of a Smoldering-Fire Test for Household Smoke Detectors,” Fire Journal, Vol. 73, No. 3, 1979

[8] Smoke Characterization Project Final Report, Underwriters Laboratories Inc. 333 Pfingsten Road, Northbrook, IL 60062, April 24, 2007)

29. Does the industry standard used to certify fire alarms in flaming fires allow the smoke obscuration to go as high as 37 percent? If so, why is that the case when the International Association of Fire Chiefs set 4 percent smoke obscuration as the maximum for travel along an exit path on the basis of the live fire tests conducted by the Los Angeles Fire Department in the aftermath of the December 1958 school fire?

The UL fire tests are not tests of sensitivity but rather reproduce a range of conditions observed in real fires. The paper fire produces a high smoke density (about 30 % per foot at the ceiling and 37 % at the wall mounting location) for a short duration (about 10 s). Detecting this fire assures that the device will not ignore a high initial pulse of smoke due to internal time delays. The basic sensitivity (alarm threshold) is measured in the sensitivity test in a test compartment where the alarm threshold must be within the range of sensitivities that passed the fire tests and that which passed the false alarm tests, but not outside the range on 0.5 to 4.0 percent per foot of grey smoke (black smoke sensitivity can go to 10% but the mass density ratio of black to grey smoke is about 5:1, meaning that the mass density of 10 % black smoke is equal to that of 2 % grey smoke).

30. Why were detectors with a sensitivity of 1 %/ft used in Phase I and Phase II testing when typical sensitivities of smoke alarms used by consumers are 2 %/ft?

The studies used detectors that covered a range of sensitivities, nominally 1 %/ft or 2 %/ft in order to evaluate the life safety impact of detector sensitivity. Actual sensitivities were measured and reported in the appendices of each report.

31. Has any study conducted by NIST (or the predecessor National Bureau of Standards) concluded that a combination of both the ionization and the photoelectric smoke detector provides more than adequate life saving potential under most real residential fire conditions when properly installed? If so, what is the technical basis for this conclusion?

The subject of combination (ion and photo) detectors was never raised in the 1975/76 test reports. However in the 1979 report (NBSIR 79-1915) on the results of similar tests conducted in mobile (manufactured) homes, conclusion 6 stated,

"Based on the series of fire tests conducted in this program and the evaluation criteria discussed in section 2.3, a properly functioning smoke detector of either the ionization or photoelectric type should provide an alarm in sufficient time to permit an alert and mobile occupant to escape from the mobile home. While either type detector provided enough time for escape, the use of a detector which combines both ionization and photoelectric sensors in the same unit (or one of each) could provide significant improvement in alerting the occupants of a mobile home to either a flaming or smoldering fire."

32. Has any publication or presentation by a NIST researcher suggested that a "combination of both the ionization device and the photoelectric smoke detector" may provide more than adequate life saving potential under most real residential fire conditions when properly installed? If so, provide complete citations for all publications that make this suggestion.

Yes. See: Bukowski, R.W., Investigation of the Effects of Heating and Air Conditioning on the Performance of Smoke Detectors in Mobile Homes, NBSIR 79-1915, Nat Bur Stand, Gaithersburg, MD, 1979.

Also, there is a fact sheet jointly produced by the USFA, HUD, and NIST which states:

> "There are two kinds of smoke alarms -- ionization and photoelectric. The ionization activate quicker to fast, flaming fires and the photoelectric are quicker for slow, smoldering fires. Either one will provide enough time to get out, but having a mix of the two types is a good idea. Models with both sensors are better than single sensor units, but of course they cost more."

This fact sheet can be found at: http://www.fire.nist.gov/factsheets/Smoke&CO.pdf and http://www.usfa.dhs.gov/downloads/pdf/smokeco-mh.pdf

33. Does the ionization detector provide more than adequate life saving potential under most real residential fire conditions when properly installed? If not, cite specific limitations of the ionization detector for flaming fires and for smoldering fires.

In the 1975/76 tests the answer is clearly yes. In the 2000 tests the performance of both types is often close to the margin, possibly due to the much more rapid development of fires in modern furniture as opposed to the detectors. If the furniture produces conditions that exceed tenability limits in a much shorter time, then detectors that meet the current UL test standards may be inadequate to provide sufficient warning to occupants intimate with the fire or who need 3 minutes or more to escape.

For example, victims located in the room of fire origin are considered intimate with the fire and may not have adequate warning based on the established tenability criteria for smoldering or flaming fires, especially if the room of fire origin does not contain a smoke alarm. Impaired occupants, small children, and mobility-limited occupants incapable of self-rescue may be unable to evacuate safely.

In summary, the NIST studies conclude that both ionization and photoelectric alarms provide enough time to save lives for most of the population under many fire scenarios; however, ionization alarms may not always alarm even when a room is filled with smoke from a smoldering fire, exposing the most sensitive populations with mobility limitations to an undetermined risk. Photoelectric detectors can provide a lot more warning time than ionization detectors in a smoldering fire; at the same time a smoldering fire can take a longer period to become dangerous. Ionization detectors can provide a little more time than photoelectric detectors in a flaming fire; in this case there can be little time to spare. Changes in furnishing materials and construction over the past decades have reduced the time available for safe egress in any fire. NIST is currently conducting research to assess whether or not modifications may be needed in the standard test method for certifying residential smoke alarms to accommodate the changing threat.

34. Does the photoelectric detector provide more than adequate life saving potential under most real residential fire conditions when properly installed? If not, cite specific limitations of the photoelectric detector for flaming fires and for smoldering fires.

If the room of fire origin is to be explicitly addressed in the adequacy of life saving potential then, photoelectric detectors would most likely be deemed adequate for smoldering fires. For flaming fires, the photoelectric detector would tend to alarm after an ionization alarm, so the rate of fire growth would determine the outcome.

In summary, the NIST studies conclude that both ionization and photoelectric alarms provide enough time to save lives for most of the population under many fire scenarios; however, ionization alarms may not always alarm even when a room is filled with smoke from a smoldering fire, exposing the most sensitive populations with mobility limitations to an undetermined risk. Photoelectric detectors can provide a lot more warning time than ionization detectors in a smoldering fire; at the same time a smoldering fire can take a longer period to become dangerous. Ionization detectors can provide a little more time than photoelectric detectors in a flaming fire; in this case there can be little time to spare. Changes in furnishing materials and construction over the past decades have reduced the time available for safe egress in any fire. NIST is currently conducting research to assess whether or not modifications may be needed in the standard test method for certifying residential smoke alarms to accommodate the changing threat.

35. Why is the ionization detector, which senses the products of combustion and not the large smoke particles caused by a fire, called a "smoke detector"? If the ionization detector does not sense smoke, is it still technically appropriate to call it a smoke detector? Why?

All US Codes and Standards consider both ionization and photoelectric detectors as smoke sensing fire detectors responding to particles produced by combustion. The official NFPA definition of smoke (found in NFPA 90A) is:

> ***Smoke**. The airborne solid and liquid particles and gases evolved when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass.*

In particular, the ionization alarm senses smoke particles of all sizes that enter its sensing chamber. Its sensitivity is linear with the particle diameter. The photoelectric, light-scattering, detector's sensitivity is proportional to the smoke particle diameter raised an exponent that decreases from a power of 6 to a power of two as the diameter increases from smallest to largest sizes[9].

36. Did the results from one or more studies conducted by NIST indicate that "more than 50 percent of the time" a new ionization detector with a fresh battery will fail to warn in a timely manner?

No.

---

[9] Mulholland, G. W., and Liu, B. Y. H. "Response of Smoke Detctors to Monodisperse Aerosols," Journal of Research of the National Bureau of Standards, Vol. 85, No. 3, 223-238, May/June 1980.