Questions and Answers Clarifying Findings of NIST Home Smoke Alarm Study[1,2]

1. In how many scenarios contained in the July 2004 NIST Technical Note 1455 on "Performance of Home Smoke Alarms: Analysis of the Response of Several Available Technologies in Residential Fire Settings" does the available time for egress exceed the time required for egress?

The difference between the available safe egress time (ASET) and the required safe egress time (RSET) is dependent on three important factors: (1) the time to activate the alarm, (2) the time to untenable (unsafe) conditions, and (3) the estimated egress time. The time to activate the alarm is a function of detector sensitivity, detector placement, and characteristics of the fire. The time to untenable conditions varies with the characteristics of the fire, the location within the structure and the selection of tenability criteria (NIST defined "untenable" as the temperature, heat flux, CO, or smoke conditions[3] at the 5 ft level outside of the room of origin that would affect particularly sensitive populations: the young, elderly, asthmatics, and sufferers of other lung conditions). The required egress times (RSET) were estimated to range between 10 s and 140 s. This large variability[4] (See Table 26 of the report[2]) was meant to account for differences in the time of day, the capability of the occupants, the design of the residence, the character and location of the fire, and the location of the occupant relative to the location of the fire and smoke alarms. For any given test, the times to activate the alarms and to reach one of the tenability criteria (most often, smoke obscuration) were measured, from which the value of ASET was determined. Table 1 shows the number of tests (out of a total of 32 tests) when the available time was <u>less</u> than the time required for safe egress. For the 12 smoldering tests, this number increased from one instance to five instances for the photoelectric alarm, and from two instances to nine instances for the ionization alarm, over the range of values assumed for RSET. For the 16 flaming chair and mattress fires, this number increased from one instance to eleven instances for the photoelectric alarm, and from zero to five instances for the ionization alarm as the time needed for safe egress was increased. Both the ionization and photoelectric detectors provided more than enough time for safe egress from the four scenarios involving kitchen fires for all assumed values of RSET.

[1] Reported in February 26, 2004 *Tech Beat* article "Current Smoke Alarms Pass Life-Saving Tests."
[2] 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)
[3] Life-threatening components of fire -- Guidelines for the estimation of time available for escape using fire data, ISO/TS 13571:2002." International Organization for Standardization, 2002.
[4] The estimated evacuation times listed in the NIST report for nighttime fires (90 s to 140 s) are more conservative than the times found in actual studies of nighttime residential evacuation when occupants were sleeping, which reported times ranging from 36 s to 119 s, including waking time, time to call the fire department and for the family to escape outside the house. See Nober, E. H.; Peirce, H.; Well, A. D.; Johnson, C. C.; Clifton, C., "Waking Effectiveness of Household Smoke and Fire Detection Devices," Fire Journal, Vol. 75, No. 4, 86-91,130, (1981).

Table 1. Number of tests (out of 32) with ASET < RSET

Fire Type	Number of Tests	RSET = 10 s Photoelectric Alarms	RSET = 10 s Ionization Alarms	RSET = 65 s Photoelectric Alarms	RSET = 65 s Ionization Alarms	RSET = 140 s Photoelectric Alarms	RSET = 140 s Ionization Alarms
Smoldering	12	1	2	4	6	5	9
Flaming	16	1	0	4	1	11	5
Cooking	4	0	0	0	0	0	0

With alarms placed on every level plus in bedrooms or in every room, the number of tests where ASET was less than RSET is smaller. For example, with alarms placed in every room, ASET was less than RSET in two tests for photoelectric alarms and three tests for ionization alarms with an RSET value of 65 s. Most current building codes require smoke alarms at every level in existing homes and at every level plus bedrooms in newly constructed homes. No codes require smoke alarms in every room but this is included as (theoretically) the best performance achievable.

2. Do ionization detectors provide enough time to save lives? How did NIST come up with the "three minute warning" criteria that was cited in a February 26, 2004 Tech Beat article "Current Smoke Alarms Pass Life-Saving Tests"?

There are numerous combinations of fire scenarios and smoke alarm placement locations. In the NIST experiments, the following variables were included: smoke alarm location; room of fire origin, smoldering, flaming, or cooking fire; and bedroom doors open or closed. Table 2 (taken from Appendix A of NIST TN 1455) lists the averages and standard deviations for the measured times to first alarm and to untenable conditions in these tests. In all cases, the average ASET was positive, although the average ASET for the photoelectric alarm in the case of the flaming fires was less than the maximum assumed for the RSET. The average estimated time available for safe egress in the smoldering scenario was greater than the RSET by much more than one standard deviation in the case of the photoelectric alarms. For the ionization alarms in the smoldering situation, the average ASET was about one minute greater than the longest assumed RSET, but in ten of the twelve tests was less than the longest RSET assumed (See last column of Table 1). The general trends from the NIST experiments are consistent with previous studies showing that: (1) both ionization and photoelectric alarms provide enough time to save lives for most of the population under many fire scenarios, (2) ionization alarms may not always provide enough time for the most sensitive populations with mobility limitations to escape a smoldering fire, and (3) photoelectric alarms may not always provide enough time to escape a flaming furniture fire for this same population.

Table 2. Average time to first alarm and time to untenable conditions, with standard deviations.

	Time to First Alarm (s) Photoelectric Alarms	Time to First Alarm (s) Ionization Alarms	Time to Untenable Conditions (s)	Available Safe Egress Time (s) Photoelectric Alarms	Available Safe Egress Time (s) Ionization Alarms
Smoldering Fires	2219 ± 1061	4010 ± 1120	4316 ± 1256	2136 ± 1011	276 ± 331
Flaming Fires	94 ± 33	47 ± 36	217 ± 67	129 ± 74	177 ± 69
Cooking Fires	738 ± 103	681 ± 475	1477 ± 249	739 ± 148	796 ± 241

For the NIST test series, the average ASET (assuming placement of detectors in all rooms) for ionization alarms ranged between 177 s for flaming fires and 276 s for smoldering fires; for photoelectric alarms the ASET averaged between 129 s and 2136 s. For the purpose of the Tech Beat article, 180 s (or 3 minutes) was selected as representative of the amount of time available, and to convey to the reader the importance of leaving their residence quickly after first hearing a smoke alarm of any design.

3. Are ion and photo detectors qualitatively similar since the February 26, 2005 *Tech Beat* article states that "Ionization smoke alarms respond faster to flaming fires, while photoelectric smoke alarms respond quicker to smoldering fires"? Why does NIST describe the 30-45 minute of photos in smoldering fires as "quicker" and in the same sentence describe the 20-30 seconds benefit of ion detectors as "faster"?

No, the ionization alarms and photo alarms are qualitatively different because they respond to different aspects of a fire. The *Tech Beat* article was correct in stating that "ionization alarms respond faster to flaming fires, while photoelectric smoke alarms respond quicker to smoldering fires." While the photo detectors sensed the smoldering fires on average 30 minutes earlier than the ionization detectors, the threat from a smoldering fire grows much more slowly than from a flaming fire. That is, the margin of safety associated with a 30 minute earlier warning in a slow growing smoldering fire may not be necessarily any more significant than a 30 s earlier warning for a fast growing flaming fire.

4. Should "necessary escape time" be replaced with "available escape time" in the February 26, 2004 NIST news release where it states that "The researchers determined the necessary escape times by considering the time that the alarms sounded in various locations and the development of untenable (unsurvivable) conditions"?

Yes. Necessary escape time refers to the time required for occupants to safely evacuate from a building. This is usually termed the required safe egress time (RSET). Available safe egress time (ASET) is the elapsed time between when occupants are notified of a fire and when conditions along the path of their egress become sufficiently untenable that escape may no longer be possible. The correct term in the press release should have been the available safe egress time rather than necessary escape time. The press release has been corrected effective March 8, 2007.

5. Why does NIST appear to install "un-modified" detectors in areas which prevent comparison between the unmodified and modified detectors? Where in the report does NIST present this comparison and associated data in a manner that justifies its analysis of "modified" detector response? Is the manner in which NIST models the response of "modified" detectors valid?

The unmodified smoke alarms used in the study consisted of a photoelectric model and two ionization types, all purchased from retail establishments by NIST for use in the test series. Some of the identical models of smoke alarms were modified by their manufacturers so that the voltage produced by the sensor could be monitored to determine the response of the sensor to the changing environment in a continuous manner, rather than registering a single alarm point. This analog signal provided a means to monitor the environment during the build up period prior to the detector alarming, and had no effect on the sensitivity of the smoke alarms or the reported detector response times. Thus, it was appropriate to compare detector response times at different locations for both un-modified and modified detectors. A more appropriate term for "modified" would have been "continuously monitored" detectors. It was not necessary to monitor the output voltage of all of the smoke alarms since the monitored alarms were located judiciously.

Chapter 2 of the July 2004 NIST report discussed the alarm calibrations in detail. Section 2.8 discusses the response of the "modified" alarms. All of the alarms were calibrated multiple times throughout the test series. Any changes in the response of the alarms were incorporated into the analysis. NIST spot-tested "unmodified" alarms in the fire-emulator/detector-evaluator (FE/DE)[5] to compare alarm point smoke levels to the equivalent alarm level for the "modified" alarms. The "unmodified" (off-the-shelf) ionization alarms had sensitivities near the low level sensitivity setting for the "modified" ionization alarms used in the analysis; otherwise, the alarm levels were comparable.

Beyond simple alarm point calibration, the minimum sensitivity of smoke alarms is established in US and International standards by performance in fire tests. Specifically, smoldering smoke tests utilize cotton wicks or wood pieces on a hotplate (UL217/268[6] and EN54/ISO TS7240-9[7]) as sources, and these were used by NIST as detailed in the report. The Underwriters Laboratories (UL) smoldering test with wood on a hotplate was developed by UL in the late 1970's to mimic the smoldering mattresses and furniture (both the smoke characteristics and temporal increase) in the original Indiana Dunes Tests.[8] Since UL uses this smoke to quantify smoke alarm points, NIST chose the nominal sensitivities stamped on the back of typical alarms to be the alarm points for this study. While NIST used the unique FE/DE apparatus as described in the preceding paragraph to calibrate the test alarms, the output has been correlated with the UL apparatus.

Both US and International standards also include flaming sources in their fire tests. These include cellulosic (wood and paper – flaming wood is used by both UL and EN/ISO, paper only by UL), liquid hydrocarbon (heptane), and plastic (polyurethane foam – EN/ISO only). UL stopped conducting its flaming plastic (polystyrene foam) test in 1999.

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[5] Cleary, T. G., "Fire Emulator/Detector Evaluator: Design, Operation, and Performance." Proceeding of the International Conference on Automatic Fire Detection "AUBE '01", March 25-28, 2001, Gaithersburg, MD, Beall, K.; Grosshandler, W. L.; Luck, H., Editors, Natl. Inst. Stand. Technol., NIST SP 965; February 2001. 312-323 pp, (2001)

[6] UL 217: Standard for Safety Single and Multiple Station Smoke Alarms, and UL 268: Standard for Smoke Detectors for Fire Protective Signaling Systems, 4th ed., Underwriters Laboratories Inc., Northbrook, IL., 1996

[7] EN 54: Components of Automatic Fire Detection Systems, Part 9, Fire Sensitivity Test, European Committee for Standardization, Brussel, 1982.

[8] Bukowski, R.W., Waterman, T.E., and Christian, W.J., "Detector Sensitivity and Siting Requirements for Dwellings: A Report of the NBS 'Indiana Dunes Tests'" NFPA No. SPP-43 Nat. Fire Prot. Assn., Quincy, MA, 1975.

6. How relevant is the calibration of detectors with smoke from flaming hydrocarbon and smoldering cotton for smoke from smoldering plastic? How likely is it that the ionization detector's response is overestimated and the photoelectric detector's response is underestimated if the detectors are not calibrated with smoke caused by smoldering plastic?

Differences in characteristics of the smoke from a smoldering plastic (which is not used for calibration) and from smoldering cotton and for wood on a hot plate (which are used for calibration) is an active area of research and does have implications for the design and standard test methods for smoke alarms. Given smoke from, for example, smoldering upholstered furniture, an ionization alarm of a given design will respond based primarily on the smoke concentration and size distribution. A photoelectric alarm's response will also depend on its design, the smoke concentration, size distribution and optical properties. It is possible, and likely, that a photoelectric alarm would respond before an ionization alarm (exactly what was observed multiple times in the NIST Home Smoke Alarm study) to a rising concentration of such a smoke. This does not imply any underestimate or overestimate of the various alarm type calibrations.

The flaming hydrocarbon smoke calibrations were performed to allow further study of these fire tests, specifically modeling of the flaming fire tests, and the response of the smoke alarms. These calibrations were never used in any of the analysis in NIST TN 1455.

7. How was a detection time of 1830 seconds determined for both types of detectors (ionization and photoelectric) in the smoldering bedroom fire involving the 2-story house, especially since many of the detectors did not respond? Does this raise questions about the adequacy of the methodology used to determine detection times?

The method NIST used to determine the detection time in the smoldering fire involving the 2-story house was in error. The results of the smoldering mattress test (test SDC 21) should not have been included in the analysis since the fire development did not allow enough alarms to respond by the time the test concluded. In addition, test SDC 13 was inadvertently excluded from the original analysis. The report will be revised to reflect these changes, although this is unlikely to change any key conclusions or recommendations.

8. Was the "end of test" assumed as the time to untenability, since the smoking bedroom test did not reach untenable conditions?

For most tests, one or more criteria for untenable conditions were reached prior to the end of test. For six of the tests, untenable conditions were not reached outside the room of fire origin. For these tests, the time to untenable conditions was assumed to be as long as the time to the end of test. This provides a conservative estimate of the time to untenable conditions.

9. Has NIST concluded that adding smoke alarms to the bedrooms provides no benefit in smoldering mattress fires with detectors placed in the room of fire origin, since the test results show that for an installation with detectors in every room and in every bedroom, the ASET is the same as when they are only on every level? It appears the same conclusion can be drawn about the benefit of placing detectors in the room of fire origin from the flaming living room fire test.

No. The results from the single-story manufactured home show the value of adding smoke alarms in the bedroom. NIST did not place any detectors in the room of origin (bedroom or living room) for the 2-story tests. The two-story home was an open floor plan. Alarms were placed in the foyer and den, with no doors blocking the smoke path. In the analysis, this was considered the same space (room) as the living room. There were also smoke alarms in the entranceway, comparable to the den mid-level detector locations. Scheduling constraints and the number of available unmodified alarms precluded inclusion of alarms in all locations for some of the field tests.

10. Are both types of detectors (i.e., ionization and photoelectric) *equally* susceptible to nuisance alarms?

In the smoke alarm research, and in applications in the field, it is documented that most common ionization detectors have a propensity to produce nuisance alarms during cooking activities. NIST examined a broad range of activities (including cooking) that yield nuisance alarms. The published field observations guided the nuisance alarm scenarios studied. Specifically, the sensitivity to alarm threshold, distance from the source, background air flows, and alarm sensor (photoelectric or ionization) were examined. Additional measurements were made with aerosol instrumentation to provide a more fundamental understanding of nuisance alarm sources than has been previously published. Given the scenarios examined, both photoelectric and ionization alarms produced nuisance alarms, but NIST does not mean to imply that they are *equally* susceptible to such nuisance alarms. Most field data suggest that ionization alarms have a greater propensity to nuisance alarm than photoelectric alarms, possibly indicating that certain activities such as cooking dominate reported nuisance alarms in the field.

11. Why did NIST run half the nuisance tests with a large fan only on one side of the kitchen to blow smoke away from the detectors? Would this not favor the ionization detectors in the tests?

The fan was added to provide an additional variable to the data set. About half of the manufactured home tests were conducted with all exterior doors and windows closed and no ventilation of any kind, which is unrepresentative of situations including open windows, HVAC flows, cooking range fans, movement of occupants, etc. Flow velocities were monitored just below the ceiling at three locations. Air speeds at the ceiling were typically below 0.1 m/s without the fan and up to 0.5 m/s with the fan. The fan had a tendency to break up the plumes generated from the cooking activities, and to dilute the aerosols. To the extent that the fan diluted the nuisance aerosols and distributed them throughout the connected rooms and subsequently impacted the nuisance alarms produced, it was precisely the result intended.

12. Have ionization detectors been de-sensitized over time (since the late 1980s) and are they relatively poor at detecting the kind of smoke given off by today's synthetic furnishings?

NIST is not aware of any definitive data on the actual sensitivities of the detectors over the past 20 or 30 years. All of the smoke alarms used in the current study met the sensitivity requirements specified in the 2002 version of UL 217, and those in the 1975 study met the requirements of the applicable UL standard at that time.[9] The average ionization alarm sensitivity based on smoke obscuration was found to be 4.2 %/m in the current study and 6.8 %/m in the 1975 study. In other words, the ionization detectors were, on average, slightly more sensitive in the current study. Photoelectric alarms were, on average, slightly less sensitive in the current study (6.8 %/m versus 4.8 %/m in 1975).

13. Given the clear evidence that ionization alarms should not be used near kitchens since they often are intentionally disabled to avoid nuisance alarms, why does HUD allow them to be installed in manufactured homes?

NIST is a non-regulatory agency and does not set the rules for smoke alarm placement. HUD released the final rule "Manufactured Construction and Safety Standards: Smoke Alarms Rules and Regulations." [10] It was based on the requirements of NFPA 501. Concerning kitchens the final rule requires:

> "At least one smoke alarm must be installed in each of the following locations: (i) To protect both the living area and kitchen space. Manufacturers are encouraged to locate the alarm in the living area remote from the kitchen and cooking appliances. A smoke alarm located within 20 feet horizontally of a cooking appliance must incorporate a temporary silencing feature or be of a photoelectric type." [11]

This requirement should reduce nuisance alarms, which should reduce the negative effects (disabling of alarm) of repeated nuisance alarms. This requirement is consistent with the requirements of the National Fire Alarm Code, NFPA 72.[12]

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[9] The UL standard requires that alarm point based upon smoke obscuration be within the range of 1.6 %/m to 12.5 %/m. This has not changed. In the 1980s, manufacturers were allowed to shift production windows (based on a sample of 24 alarms originally submitted by a manufacturer for testing) by 1.6 %/m to reduce susceptibility to nuisance alarms. The production window is the sensitivity range the manufacturer must meet during production after Listing with UL. A shift in the production window to a less-sensitive range is allowed to ensure that alarms produced represent the least sensitive range.

[10] 67 FR 12811 (March 19, 2002)

[11] Manufactured Home Construction and Safety Standards, 24 CFR 3280.208(b)(1)(i) (2002).

[12] "NFPA 72, National Fire Alarm Code, 1999 Edition," Volume 5 of the National Fire Codes, Natl. Fire Protection Association, Quincy MA 2002.

14. Did NIST consider (1) the different ignition methodologies and (2) unlikelihood of change in materials as being factors that changed/decreased the time to untenable conditions in the recent NIST tests compared with the Indiana Dunes[8] tests of the mid-1970s?

NIST considered a number of factors for the increased fire growth rates, including ignition methodology and materials of construction.

Although the ignition methodologies were not identical between the NIST tests[2] and the original Indiana Dunes tests,[8] NIST does not feel they were sufficiently different to fully account for the difference in time to untenable conditions. The smoldering ignition technique for both test series utilized a heated wire loop in contact with the item ignited for a similar time period (typically 2 minutes). For flaming ignition, a larger wastebasket ignition source was used in the original Indiana Dunes tests compared to the single matchbook ignition source used in the current NIST study. By design, the amount of paper ignition source in the wastebasket in the original Indiana Dunes tests was controlled so that the ignition source was fully consumed within 2 min of ignition. For particularly difficult to ignite items of furniture, additional newspaper was added until ignition was achieved. NIST did not attempt to adjust the ignition times reported in the original Indiana Dunes tests to account for these difficult ignitions.

While the 1975 study also used actual upholstered furniture and mattresses, these were purchased from a (charity) resale shop from donated articles. Such items purchased in 1975 would have been new in the early 1960s or even late 1950s and represented materials and constructions of that period with typically natural materials. The chairs used in the present study were purchased from a furniture rental store and, while used, were only a year or two old and of synthetic materials. The mattresses were purchased new. Thus, the materials were certainly significantly different.

While the internationally accepted ISO tenability criteria used for the NIST study[2] were not identical to those used in the 1975 study,[8] the criteria were equivalent or slightly higher in the current study, which, if anything, would have a tendency to increase the time to untenable conditions for the current study. Table 3 shows a comparison of tenability criteria used in the two studies. For the temperature and smoke obscuration criteria, values used in the current study were similar to or slightly higher than those used in the 1975 study. For CO concentration, the range for the FED-based model used in the current study includes the value used in the 1975 study, but is also quite a wide range, depending

Table 3. Comparison of Tenability Criteria Used in the 1975 and Current Studies

	1975 Study[8]	Current Study[2]
Temperature	T ≥ 66 °C	T ≥ 88 °C[a]
Gas Concentration	CO ≥ 0.04 % volume fraction	CO ≥ 0.02 % – 0.3 % volume fraction[b]
Smoke Obscuration	O.D. ≥ 0.23 m^{-1}	O.D. ≥ 0.25 m^{-1}

a – value for flaming fires calculated from ISO TS 13571 equation for convected heat
b – range of average values calculated from ISO TS 13571 equation for asphyxiant gases with tenability times for flaming fires and smoldering fires

on duration of the fire. For nearly all tests, the smoke or temperature criterion was met prior to the CO criterion.

The conclusion of faster fire growth rates for flaming fires in the current test series was based on a comparison of gas temperature histories near ceiling level in the room of fire origin. With the exception of one room in each of the two test homes in the original Indiana Dunes tests, ceiling heights were similar in both tests, so comparisons of this gas temperature provides a relative indication of fire growth rate. From Table 32 of TN 1455,[2] flaming fires reached a near-ceiling gas temperature of 65 °C more than 7 times faster in many of the current tests than in the original Indiana Dunes tests (130 s versus 970 s). Including an adjustment for delayed ignition for some of the flaming fire in the original Indiana Dunes tests brings this ratio down to a factor of four. Fire development in the current tests was generally similar to the growth of heat release rate determined in other recent studies for upholstered furniture[13] and mattresses[14]. The same trend was not evident for smoldering fires.

15. Why does NIST in its February 26, 2004, *Tech Beat* article highlight the increase in growth rate of fires and fail to point out that this finding applies only to flaming fires? Why does NIST fail to mention that smoldering fires are not growing faster?

The *Tech Beat* article was designed to highlight trends that were different between the two studies, especially one which was so dramatic and critical to life safety. The executive summary of the NIST report provides a more detailed description of the findings, including the statement:

> "...the smoldering fire scenarios are very difficult to reproduce experimentally and tenability times in the present study have an uncertainty (based upon one standard deviation) which overlaps the uncertainty from the 1975 study. Therefore, caution should be exhibited in drawing conclusions based upon comparisons of smoldering tenability times between the two studies."

16. Do the data indicate that the increase in fire growth rate, which may be far less than NIST estimates due to the different ignition methodologies for the flaming fire tests, cannot be the reason for the increase in fatalities when the detector operates?

NIST did not study fatalities with working smoke alarms in the study. Average times to untenable conditions in the current NIST study for flaming and smoldering furniture fires were found to be 17 % and 49 %, respectively, of those found in the 1975 Indiana Dunes tests, [4] as can be seen in Table 4 based on a revised analysis of the NIST data (as noted in Question 7, test SDC 13 was added and test SDC 21 was removed from the analysis). On the other hand, the average time for the cooking fires to reach untenable conditions was 23 % longer in the current study. Since the cooking materials were similar in the two studies, the shorter time to untenable

[13] Cleary, T. G., Ohlemiller, T. J, and Villa, K. M., "The Influence of Ignition Source on the Flaming Fire Hazard of Upholstered Furniture." Natl. Inst. Stand. Technol., NISTIR 4847, 1992.
[14] Ohlemiller, T. J, and Gann, R. G.., "Estimating Reduced Fire Risk Resulting From an Improved Mattress Flammability Standard." Natl. Inst. Stand. Technol., Tech. Note 1446, 2002.

Table 4. Comparison of alarm times and times to untenable conditions for 1975 and current studies

		1975 Tests (s)	Current Tests (s)
Alarm Times	Flaming	146 ± 93	47 ± 35
	Smoldering	1931 ± 1103	2042 ± 876
Tenability Times	Flaming	1036 ± 374	177 ± 69
	Smoldering	4419 ± 1790	2148 ± 1023

conditions in the furniture fires supports the NIST statement that a major factor in the increase in fire growth rate is due to differences in modern furniture materials and construction compared to furniture manufactured four decades ago.

17. Why is NIST highlighting the difference in tenability criteria, when the obscuration criterion that matters for the smoldering case is essentially the same as in the Indian Dunes study?

Tenability criteria are important since it is the difference between the alarm time and the time to untenable conditions that determines the available safe egress time. As noted in the response to Question #15, above, these times were quite different for the current study and the original Indiana Dunes tests, even with similar tenability criteria in the two studies (see Question #13).

18. NIST states in its February 26, 2004 *Tech Beat* article that "The tests also showed how closed bedroom doors and proper placement of smoke alarms affect one's chance of survival. In both cases, the time to escape untenable conditions was increased, providing that the individual was not in the room where the fire originated." This finding would help a very small group of homeowners who (1) can be rescued from the bedroom window and (2) have interconnected detectors including the bedroom. What is the basis for this finding since the approach is harmful to the larger group of homeowners that has battery-powered smoke alarms and needs to hear the detector to exit the home safely?

In the July 2004 Technical Note 1455, NIST concluded that the available safe egress time was often quite short. In many cases, available escape time would be sufficient only if households follow the advice of fire safety educators, including sleeping with doors closed while using interconnected smoke alarms to provide audible alarm in each bedroom, and pre-planning and practicing escape so as to reduce pre-movement and movement times. It is this interconnection that insures all alarms respond to a fire event. Further, building codes require two ways out of a sleeping room, one of which is generally a window. With the bedroom door closed there is more time in which to use the window exit should the primary exit be blocked.

The latest version of NFPA 72 requires the installation of fire alarms at more locations in order to improve audibility in bedrooms where occupants sleep with the door closed, and to provide warning to the occupants of bedrooms with closed doors when the fire starts in that bedroom. However, audibility of smoke alarms remains an issue, particularly for sleeping children and adults impaired with alcohol or other drugs.[15] For existing residences that do not fall under the "new construction" requirements of NFPA 72, the following approaches are suggested to reduce problems associated with inaudibility: placing smoke alarms in bedrooms, interconnecting smoke alarms, changing alarm tones, and providing better home fire escape planning.

19. Why does NIST conclude that increased usage of smoke alarms between 1975 and 2000 can be credited with decrease in home fire deaths by nearly a half when data indicate that (1) the rate of reduction of fire deaths was relatively independent of the rate of increase in smoke alarm usage, and (2) the rate of death and injury per 100 cigarette fires increased as smoke alarm usage tripled?

This is not a NIST finding. NIST is citing data based on a 2004 study by the National Fire Protection Association[16]. A newer white paper from a broad coalition of public and private organizations, including NFPA, also supports this conclusion[17].

20. What fraction of fatal residential fires is initially smoldering in nature and occurs when people are asleep?

While nationally-collected data on fire incidents do not specifically classify fire sources as smoldering and/or flaming, one can get an indication from the reported cause of death (reported for example as smoke inhalation, burns, or a combination), the extent of damage, and victim location. An analysis of U.S. data from 1986 to 1990 shows that two-thirds to three-quarters of fire deaths in the United States were due to smoke inhalation[18]. It is estimated that more than one-fourth of home fire deaths involve an extended period of initial smoldering[19]. According to an analysis of home structure fires from 1999 to 2002, 29 % of civilian fire deaths are due to fires from smoking materials[20]. Intentionally set fires and fires originating from heating equipment were responsible for 19 % and 11 % of civilian fire deaths, respectively.

Although kitchens were seen as the leading area of origin for home structure fires (34 %) and for civilian home fire injuries, 21 % of reported home fires and 51 % of home fire deaths occur between 11 pm and 7 am when people are unlikely to be cooking in the kitchen and are likely to asleep in their bedrooms.

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[15] A Review of the Sound Effectiveness of Residential Smoke Alarms, CPSC-ES-0502, U.S. Consumer Product Safety Commission, Washington, DC (2004).
[16] Ahrens, M., "U.S. Experience with Smoke Alarm and Other Fire Detection/Alarm Equipment." National Fire Protection Association, Quincy, MA (2004).
[17] Home Smoke Alarms and other Fire Detection and Alarm Equipment, Public/Private Fire Safety Council, available from National Fire Protection Association, Quincy, MA (2006)
[18] Gann, R. G., Babrauskas, V., Peacock, R. D., and Hall, J. R., "Fire Condition for Smoke Toxicity Measurement," Fire and Materials, Vol. 18, 193-199 (1994).
[19] Home Smoke Alarms and other Fire Detection and Alarm Equipment, Public/Private Fire Safety Council, available from National Fire Protection Association, Quincy, MA (2006)
[20] Ahrens, M. "U.S. Fires in Selected Occupancies, National Fire Protection Association, Quincy, MA (2006)

21. A true understanding of the historical tests shows the ionization alarm to be deficient whenever synthetic material is smoldered for 30 minutes or more. The recent NIST study is consistent with this finding. Why has NIST ignored the results of research conducted in Norway (1991), Australia (1986) and England (1978) which concluded that ionization detectors provide inadequate warning and escape times for smoldering fires while photoelectric detectors provide a more effective alternative for such fires?

NIST had no intention of overlooking research conducted elsewhere. The shortening in time to untenable conditions from a fire (either flaming or smoldering) in modern, synthetic materials indicates the need to determine the ability of the standard test methods to ensure safe performance of modern (and legacy) residential fire alarms. Both NIST and UL are involved in research that will assess whether or not changes are required in the standard to accommodate the changing threat.

22. Why do dual ion/photo alarms appear to perform worse than individual photo or ion alarms in tables 23, 24, 27 and 28 of the report?

The dual ion/photo alarms appear to perform worse than individual photo or ion alarms in the tables because the dual-alarms were often located further from the fire source than the individual photo or ion alarms listed in tables 23, 24, 27 and 28. The affected tables and figures 206-208 have now been revised by removing the instances where a particular alarm type was not co-located. It is stressed that the individual alarm times reported in the appendix of the report have not been changed and remain available for direct comparison of the individual alarms and the dual ion/photo alarm in every case where these alarms were co-located.

Table 5 shows examples of the comparison of alarm time for the two ionization alarms, the single photoelectric alarm and the dual ion/photo alarm for when all the alarms were co-located and functioning. The specific test number is indicated in parentheses. The alarm times come directly from Appendix A of NIST TN 1455-1 (2008). Examples from the manufactured home (single-story) and the two-story home are presented. The shaded block indicates the alarm (either one of the ionization alarms, the photoelectric alarm or the dual photo/ion alarm) that reached the alarm threshold first at the particular location of the alarms. Thus, the values presented in the dual ion/photo column refer to either the photo or ionization sensor, whichever one sounded first in the dual sensor device.

NIST TN 1455-1 was not meant to provide a detailed comparison of individual alarms to dual technology alarms. Rather, it was intended to provide an overall assessment of the performance of smoke alarms placed according to the broad placement categories specified in building and fire codes.

Table 5. Sample comparison of individual ionization and photoelectric alarm times with collocated dual photo/ion alarms

Fire Scenario	Location of Alarms	Alarm Time (seconds)			
		Ion #1	Ion #3	Photo #1	Dual Photo/Ion
Flaming Chair in Living room (SDC02)	Util. Hall	70	78	122	66
	Master Bedroom	106	124	154	102
Smoldering Chair in Living Room (SDC01)	Util. Hall	6087	6112	5262	5282
	Master Bedroom	6262	6287	5447	5512
Smoldering Mattress in bedroom (SDC04)	Util. Hall	3393	3413	3418	3398
	Master Bedroom	3523	3518	3523	3503
Flaming Mattress in bedroom (SDC05)	Util. Hall	117	117	127	107
	Master Bedroom	147	147	167	147
Kitchen Fire (SDC12)	2nd bedroom	977	797	839	797
	Bedroom hall	737	795	847	657
Flaming Chair in Living room (SDC25)*	Den	122	124	152	118
Smoldering Chair in Living Room (SDC23)*	Upstairs Hallway	4824	4886	1542	1508
Kitchen Fire (SDC24)*	Den	1290	1500	1194	876
	Upstairs Hallway	1554	1554	880	898

*Two-story home test

23. Did the modifications to the dual-sensor smoke alarms that were used in the test affect their ability to react to smoke conditions, and did the modified dual-sensor smoke alarms meet the UL listing criteria?

The photoelectric and ionization sensing chambers in the dual ion/photo alarms were calibrated in the same manner as the individual ionization and photoelectric alarms (see answer to question 5 of this FAQ). Additionally, in the computation of alarm times the same alarm levels were specified for either the individual photoelectric alarm and dual alarm photoelectric sensor, or the individual ionization alarms and the dual alarm ionization sensor as specified in table 5 of the report. Given that the alarm levels specified in table 5 fall within the range allowed by UL 217, the modified dual ion/photo alarms would meet the UL requirements just like the individual photoelectric and ionization alarms. In dual ion/photo alarms that meet UL 217 requirements, manufacturers are allowed to set the sensitivity of the photoelectric and ionization sensing chambers to any allowable values so long as the dual alarm passes all applicable sensitivity tests. Thus manufacturers are free to set alarm sensitivities in dual photoelectric/ionization alarms less sensitive than in individual sensor alarms in order to reduce nuisance alarms.