Smoke Alarm Response and Tenability

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CA Smoke Alarm Task Force
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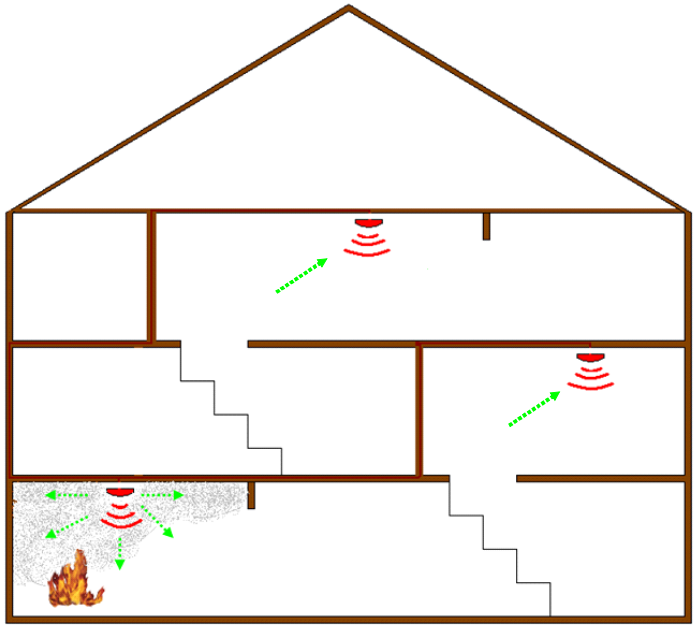
Smoke Alarm Overview – Fire Statistics

- ~3000 deaths in home structure fires [1]
- ~2/3 of deaths occur with no operable alarm [1]
- 52% of deaths occur from 11:00 pm to 7:00 am (20% of reported fires occur during these hours). [3]
- Fatal fire victims [2]
  - 35% were asleep
  - 22% unconscious or impaired by alcohol and drugs (known to be underreported)
  - 54% in area of origin

[1] Ahrens (2009) "Smoke Alarms in U.S. Home Fires"
[2] Flynn (2010) "Characteristics of Home Fire Victims"
[3] Ahrens (2009) "Home Structure Fires"

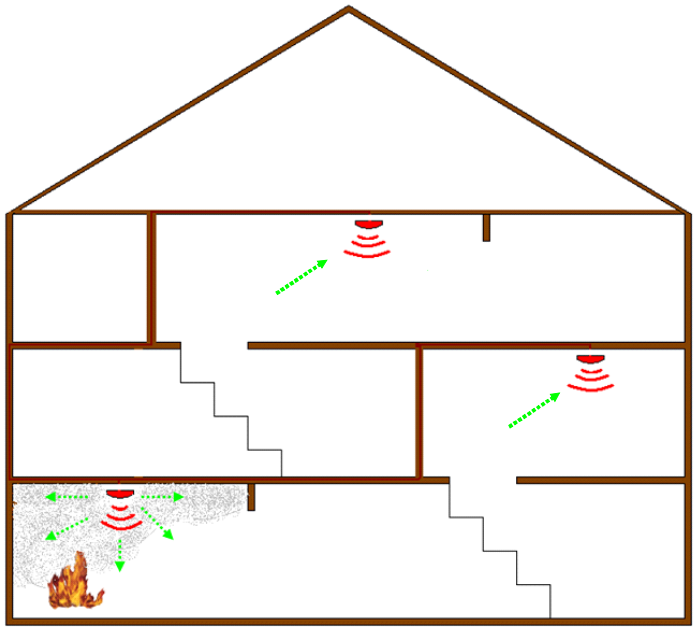
Smoke Alarm Overview – Installation

- Any ANSI/UL 217 listed smoke alarm
- Every level
- Every sleeping room
- Outside each sleeping area (within 21 ft.)
- Additional alarms for larger floor areas (>1000 ft^2)
- Interconnected



Smoke Alarm Overview – Protection

- 96% of homes have at least one smoke alarm [1]
- Less than 20% of homes have proper protection [1]



[1] Ahrens (2009) "Smoke Alarms in U.S. Home Fires"

Full Coverage & Interconnection

- CPSC Study on Unreported Residential Fires (Greene and Andres, 2009)
  - Interconnected alarms alerted residents more than twice as often as non-interconnected alarms
  - Alarms sounded in 37 percent of incidents when alarms were located on all floors, in contrast to 4 percent of incidents when they were not on all floors

Full Coverage & Interconnection

- Victoria University study [1]:
  - Emphasized the need for interconnected alarms
  - Interconnecting smoke alarms in every room in every dwelling would lead to about 50% fewer fatalities.

- NIST Smoke Alarm Study (Bukowski, 2008 rev.)
  - “Adding smoke alarms in bedrooms increased the escape time provided, especially for smoldering fires.
  - In addition, occupants of bedrooms sleeping with the door closed would benefit from improved audibility of alarms within the room.”

Performance Considerations

- Response to fires
- Resistance to nuisance sources
- Ease of maintenance
  - Testing
  - Power consumption
  - Life

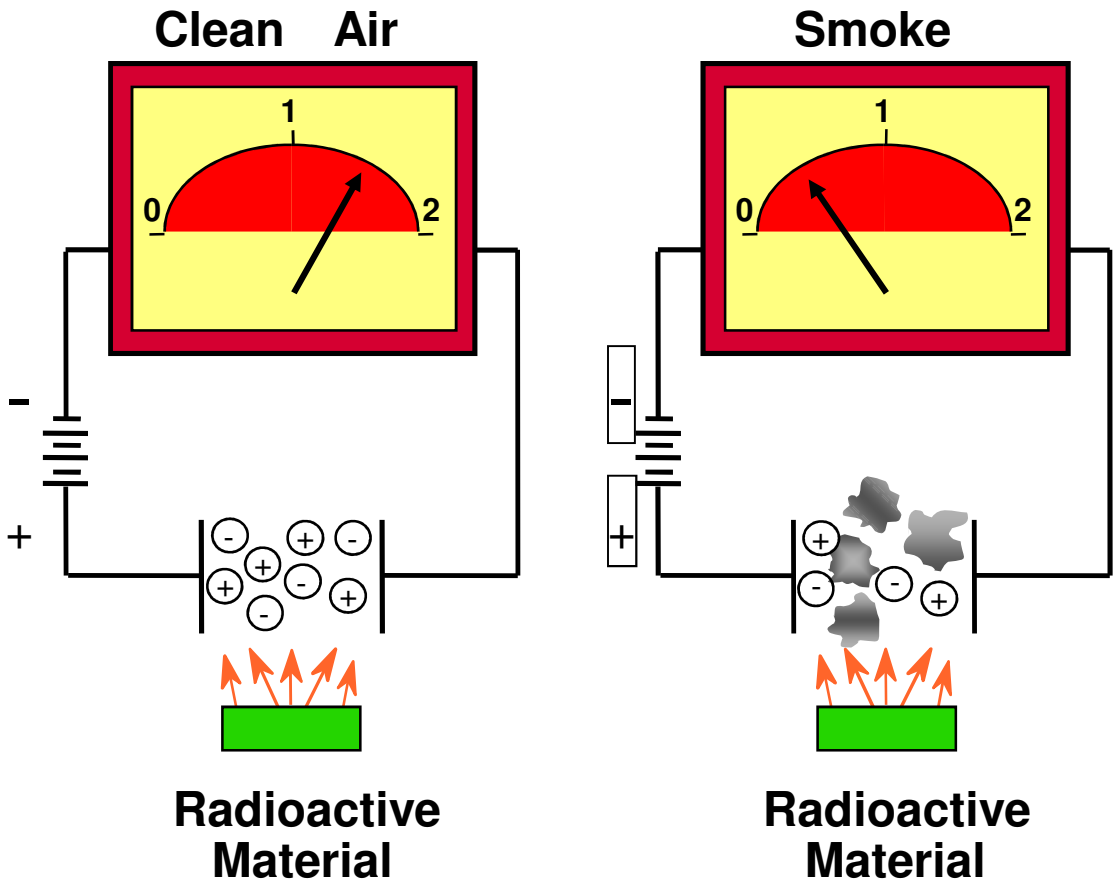
Nuisance Immunity

- General Conclusions
  - All alarms susceptible
  - Ion more susceptible to cooking
  - Photo more susceptible to steam / vapor
  - More studies are needed (validate issues relative to code compliant installations)
- NFPA 72 requirements for spacing relative to cooking appliances
  - None within 3 m (10 ft) with exceptions
  - Between 3-6 m (10-20 ft), have silencing or be photo

Power Consumption – Life

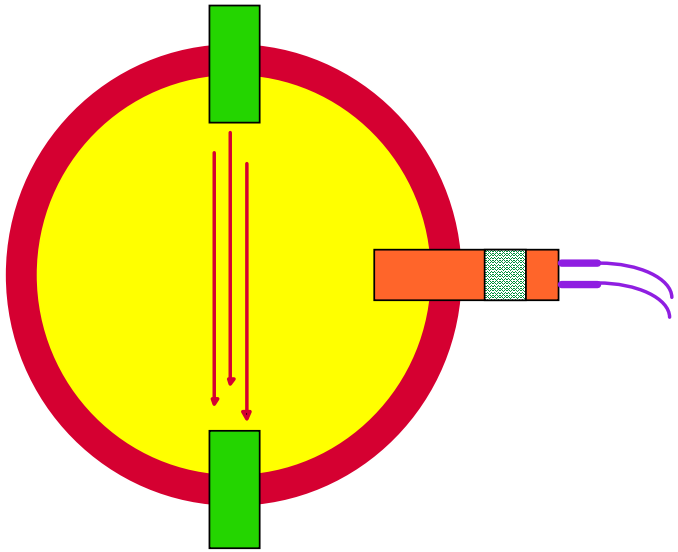
- Photoelectric alarms consume more power than ionization
- UK study over 15 months (Rowland et al., 2002)
  - 56% of ion working vs 36% of photo working
  - Alarms using an ionization sensor and a 10 year lithium battery were most likely to remain working (69%)

Smoke Alarm Overview – Principles of Operation

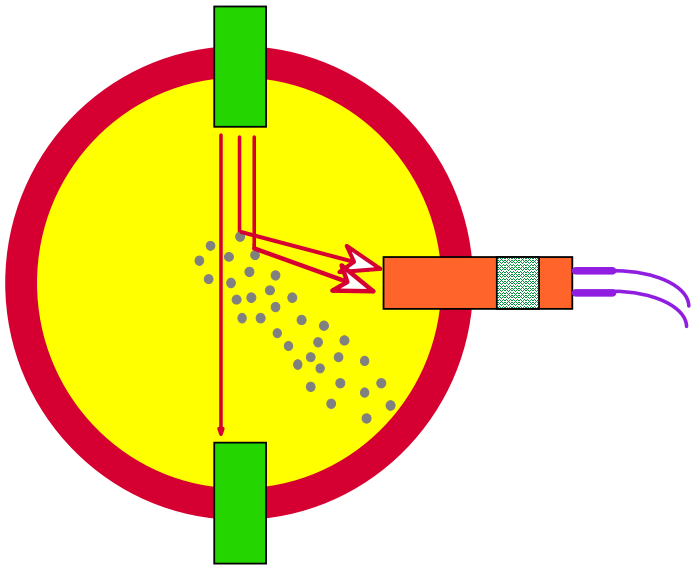


Ionization Smoke Alarms

Smoke Alarm Overview – Principles of Operation



Normal State



Alarm State

Photoelectric Smoke Alarms

Smoke Alarm Performance

- Debate over type of technology
  - Ion
  - Photo
  - Combo (ion and photo)
  - Multi-sensor, multi-criteria
- Evaluation must be technical with clear performance criteria

Smoke Alarm Performance Experimental Objective & Approach

- Document smoke alarm performance relative to untenable conditions within a residential fire

- Conducted full-scale apartment fires
- Installed UL listed smoke alarms
- 3 alarm technologies
- Utilized realistic fuel sources
- Allowed fires to reach untenable conditions

Description of Testing

Test ID	Fire Type	Fuel	Ignition Source	Fire Location	Ventilation Scheme
SM1	Smoldering	Cotton Batting	Cal Rod	Bedroom	Closed
SM2	Smoldering	Sofa A	Cal Rod	Living Room	Closed
SM3	Smoldering	Sofa A	Cal Rod	Living Room	Closed
SM4	Smoldering	Sofa B	Cal Rod	Living Room	Closed
S1	Flaming	Sofa A	Tissue Box	Living Room	Closed
CH1	Flaming	Wooden Cabinet	Tissue Box	Kitchen	Closed
CH2	Flaming	Wooden Cabinet	Tissue Box	Kitchen	Half-Open Window

Description of Testing

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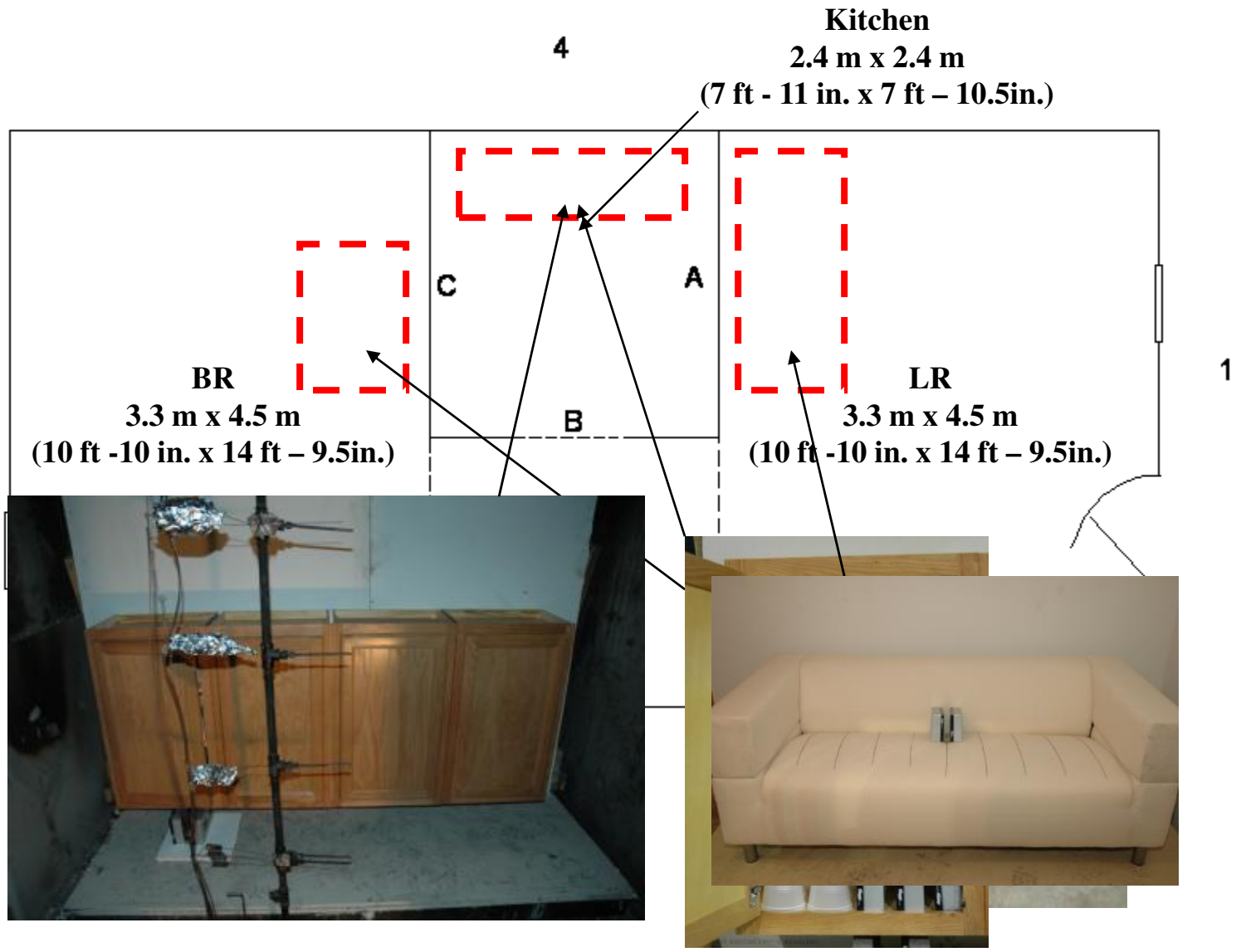
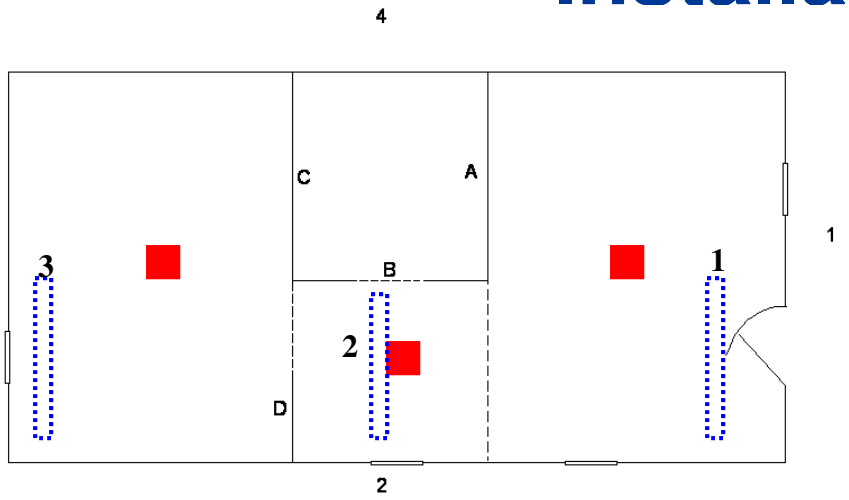
SM3	Smoldering	Sofa A	Cal Rod	Living Room	Closed
SM4	Smoldering	Sofa B	Cal Rod	Living Room	Closed
S1	Flaming	Sofa A	Tissue Box	Living Room	Closed
CH1	Flaming	Wooden Cabinet	Tissue Box	Kitchen	Closed
CH2	Flaming	Wooden Cabinet	Tissue Box	Kitchen	Half-Open Window

Experimental Setup & Fuel Sources



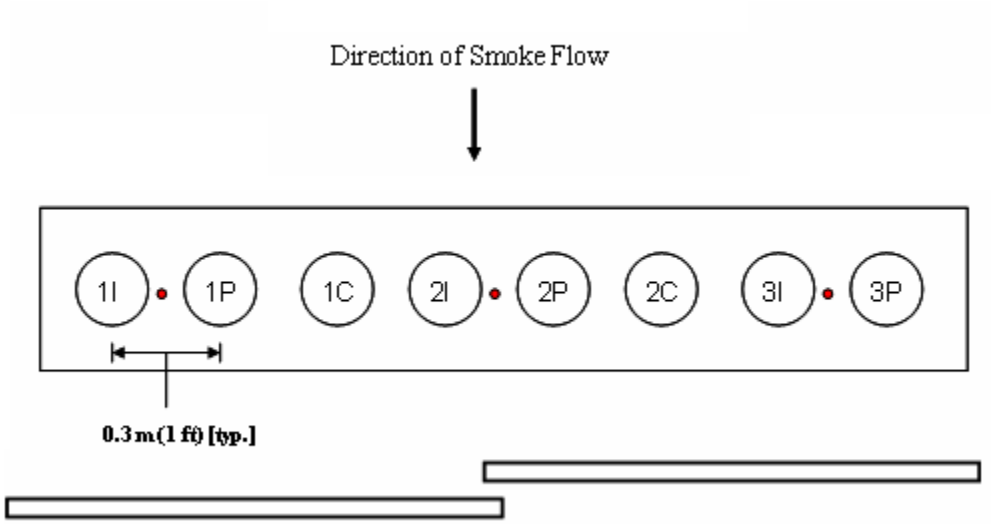
Instrumentation and Alarm Installation



- Tenability Measurement Locations
- Alarm Cluster Location (alarms only in two rooms outside of room of origin)

- Thermocouple
- Optical Density Meter

Alarm Identification Key
- Manufacturer
I – Ionization technology
P – Photoelectric technology
C – Dual Sensor technology



Tenability Analysis

- Tenability based on thermal and toxic gas conditions
- At elevations of 0.6 m (2 ft) and 1.5 m (5 ft)
- Thermal tenability limit - 120°C (248°F)
- Toxic gas limit – CO Fractional Effective Dose (FED) of 0.3 and 1.0 based upon 35,000 ppm-min
- Smoke not considered life threatening, but mechanism that can slow occupant egress

Smoke Development

- Alarm responses compared to different smoke levels

Smoke Density		Visibility	
OD/m	**%/ft**	**m**	**ft**
0.25	16.1	4 - 5.2	13 - 17
0.43	26.1	2.3 - 3.0	7.5 - 10
0.87	45.7	1.1 - 1.5	3.6 - 5

Smoke Development

- Alarm responses compared to different smoke levels

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OD/m	**%/ft**	**m**	**ft**
0.25	16.1	4 - 5.2	13 - 17
0.43	26.1	2.3 - 3.0	7.5 - 10
0.87	45.7	1.1 - 1.5	3.6 - 5

Time to Untenable Criteria (min.) at 1.5 m (5 ft)

Smoldering Fires

Criteria	Location	SM1	SM2	SM3	SM4	S1	CH1	CH2
Temperature (> 120° C)	Living Room	N/R	N/R	N/R	N/R	13.9	N/R	N/R
	Dining Room	N/R	N/R	N/R	N/R	15.1	15.8	N/R
	Bedroom	N/R	N/R	N/R	N/R	N/R	N/R	N/R
FED = .3	Living Room	95.8	N/R	N/R	103.7	19.4	11.6	17.7
	Dining Room	82.5	N/R	N/R	N/A	22.5	N/A	N/A
	Bedroom	79.2	N/R	N/R	N/R	22	13.4	19.7
FED = 1	Living Room	115.1	N/R	N/R	N/R	27.6	13.1	19.3
	Dining Room	116.3	N/R	N/R	N/A	34.8	N/A	N/A
	Bedroom	113.5	N/R	N/R	N/R	36.5	15.9	22.4

N/R - Criteria not reached

N/A - Data not collected at this location in this test

Time to Untenable Criteria (min.) at 1.5 m (5 ft)

Flaming Fires

Criteria	Location	SM1	SM2	SM3	SM4	S1	CH1	CH2
Temperature (> 120° C)	Living Room	N/R	N/R	N/R	N/R	13.9	N/R	N/R
	Dining Room	N/R	N/R	N/R	N/R	15.1	15.8	N/R
	Bedroom	N/R	N/R	N/R	N/R	N/R	N/R	N/R
FED = .3	Living Room	95.8	N/R	N/R	103.7	19.4	11.6	17.7
	Dining Room	82.5	N/R	N/R	N/A	22.5	N/A	N/A
	Bedroom	79.2	N/R	N/R	N/R	22	13.4	19.7
FED = 1	Living Room	115.1	N/R	N/R	N/R	27.6	13.1	19.3
	Dining Room	116.3	N/R	N/R	N/A	34.8	N/A	N/A
	Bedroom	113.5	N/R	N/R	N/R	36.5	15.9	22.4

N/R - Criteria not reached

N/A - Data not collected at this location in this test

Flaming fires pose greater threats faster than smoldering fires.

Tenability Analysis

- Smoldering Scenarios
  - Negligible temperature rise
  - Negligible reduction in oxygen concentration
  - Notable CO production in 2 of the 4 tests (after ~1.3 to 2 hrs)
- Larger spaces would have lower CO levels and take longer times to achieve hazardous levels.
- Cotton batting relatively conservative bounding case (i.e., more CO than many sources)

Tenability Analysis

- Flaming Scenarios
  - Elevated temperatures with 2 of 3 tests exceeding 120°C
  - Oxygen reduced to 14 to15 percent along path of egress
  - FED_{CO} values greater than 1.0 achieved
  - Smoke densities greater than 2.1OD/m at levels below 0.6m (2ft) (i.e., loss of visibility)
- Flaming tests had no or limited ventilation.
  - Therefore, fires were not allowed to grow to flashover. Consequently, temperatures were lower and did not rise as fast compared to well ventilated fires or fires in larger occupancies with more air available.
- Exponential growth after ~10 minutes.
  - If initiating fire was larger, the time to untenable conditions could be significantly smaller.

Tenability Analysis

Flaming fires pose greater threats faster than smoldering fires.

- Flaming fires are where seconds count.
- Smoldering fires occur on the order of hours.

Smoke Alarm Response (Smoldering Scenarios)

Smoldering Scenario (SM4)

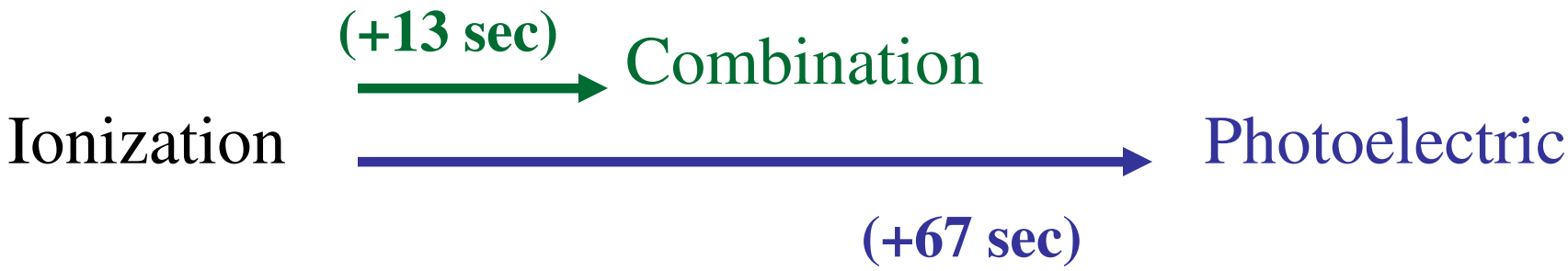
at Alarm

at Alarm + 2minutes

PHOTO ALARM

ION ALARM

Smoke Alarm Response (Flaming Scenarios)



Flaming Scenario (S1)

at Alarm

at Alarm + 2minutes

ION ALARM

(8.3 min)

PHOTO ALARM

(11.8 min)

Smoke Alarm Performance Criteria

- Alarm performance cannot be based solely upon response time
- Response time relative to untenable conditions

Smoke Alarm Performance Criteria

- Available Safe Egress Time (ASET):

  [Time to Untenable Conditions – Time to alarm]

- Required Safe Egress Time (RSET):

  135s (2.25 min)

- Acceptable performance:

  ASET - RSET $\geq$ 0

Calculated ASET based on Tenability (Smoldering Scenarios)

Test ID	Alarm Scenario	Tenability Criteria		
		120°C	FED_{CO} = 0.3	FED_{CO} = 1.0
SM1	1st Ion	N/R	52.9	82.7
	Last Ion	N/R	5.3	35.1
	1st Photo	N/R	54.5	84.4
	Last Photo	N/R	11.5	41.4
	1st Combo	N/R	57.2	87.0
	Last Combo	N/R	36.3	66.2
SM2	1st Ion	N/R	N/R	N/R
	Last Ion	N/R	N/R	N/R
	1st Photo	N/R	N/R	N/R
	Last Photo	N/R	N/R	N/R
	1st Combo	N/R	N/R	N/R
	Last Combo	N/R	N/R	N/R
SM3	1st Ion	N/R	N/R	N/R
	Last Ion	N/R	N/R	N/R
	1st Photo	N/R	N/R	N/R
	Last Photo	N/R	N/R	N/R
	1st Combo	N/R	N/R	N/R
	Last Combo	N/R	N/R	N/R
SM4	1st Ion	N/R	89.5	N/R
	Last Ion	N/R	67.3	N/R
	1st Photo	N/R	91.4	N/R
	Last Photo	N/R	86.1	N/R
	1st Combo	N/R	92.7	N/R
	Last Combo	N/R	89.6	N/R

N/R - Tenability criteria not reached.

Calculated ASET based on Tenability (Flaming Scenarios)

Test ID	Alarm Scenario	Tenability Criteria		
		120°C	FED_{CO} = 0.3	FED_{CO} = 1.0
S1	1st Ion	5.7	11.1	19.3
	Last Ion	3.6	9.0	17.3
	1st Photo	2.2	7.6	15.8
	Last Photo	1.7	7.2	15.4
	1st Combo	5.2	10.6	18.8
	Last Combo	3.3	8.7	16.9
CH1	1st Ion	10.7	6.5	8.0
	Last Ion	8.4	4.2	5.7
	1st Photo	10.3	6.2	7.7
	Last Photo	8.5	4.4	5.9
	1st Combo	10.4	6.2	7.7
	Last Combo	9.0	4.8	6.3
CH2	1st Ion	N/R	4.8	6.4
	Last Ion	N/R	3.9	5.5
	1st Photo	N/R	5.0	6.6
	Last Photo	N/R	3.4	5.0
	1st Combo	N/R	4.9	6.5
	Last Combo	N/R	3.5	5.1

N/R - Tenability criteria not reached.

Calculated ASET based on Specified Smoke Levels (Smoldering Scenarios)

Test ID	Alarm Scenario	Smoke Criteria		
		0.25 OD/m	0.43 OD/m	0.87 OD/m
SM1	1st Ion	43.8	59.8	102.0
	Last Ion	-3.8	12.2	54.4
	1st Photo	45.5	61.5	103.7
	Last Photo	2.5	18.5	60.7
	1st Combo	48.1	64.1	106.3
	Last Combo	27.3	43.3	85.5
SM2	1st Ion	6.3	N/R	N/R
	Last Ion[1]	-60.8	N/R	N/R
	1st Photo	12.5	N/R	N/R
	Last Photo	-33.4	N/R	N/R
	1st Combo	12.7	N/R	N/R
	Last Combo	9.2	N/R	N/R
SM3	1st Ion	22.5	N/R	N/R
	Last Ion	-5.1	N/R	N/R
	1st Photo	21.5	N/R	N/R
	Last Photo	15.5	N/R	N/R
	1st Combo	24.5	N/R	N/R
	Last Combo	21.2	N/R	N/R
SM4	1st Ion	73.4	76.9	N/R
	Last Ion	51.2	54.7	N/R
	1st Photo	75.3	78.8	N/R
	Last Photo	69.9	73.5	N/R
	1st Combo	76.5	80.0	N/R
	Last Combo	73.5	77.0	N/R

N/R - Criteria not reached.

1 - Ion alarm did not activate thus time is based upon test duration.

Calculated ASET based on Specified Smoke Levels (Flaming Scenarios)

Test ID	Alarm Scenario	Smoke Criteria		
		0.25 OD/m	0.43 OD/m	0.87 OD/m
S1	1st Ion	4.0	4.2	6.1
	Last Ion	1.9	2.1	4.0
	1st Photo	0.5	0.7	2.6
	Last Photo	0.0	0.3	2.1
	1st Combo	3.5	3.7	5.6
	Last Combo	1.6	1.8	3.7
CH1	1st Ion	3.5	3.9	4.6
	Last Ion	1.2	1.6	2.3
	1st Photo	3.2	3.5	4.3
	Last Photo	1.4	1.7	2.5
	1st Combo	3.2	3.6	4.3
	Last Combo	1.8	2.2	2.9
CH2	1st Ion	2.4	2.9	4.3
	Last Ion	1.5	2.0	3.3
	1st Photo	2.6	3.1	4.4
	Last Photo	1.0	1.5	2.8
	1st Combo	2.5	3.0	4.4
	Last Combo	1.1	1.6	2.9

N/R - Criteria not reached.

Conclusions

- Tests demonstrated that hazardous conditions are most prevalent in flaming fire scenarios.
- In general, most of the smoke alarm technologies provided sufficient time to escape the fires before untenable conditions were reached.

Conclusions

- Photoelectric alarms in the flaming sofa test activated less than 2.25 minutes before thermal untenability.

All other alarms:

- For smoldering fires, ASET values ranged from 5 to 93 minutes. Most alarms provided 60 to 90 minutes of warning.
- For flaming fires, ASET values ranged from 3.3 to 19.3 minutes.

Conclusions

For First Alarm to Sound

(outside of the room of origin)

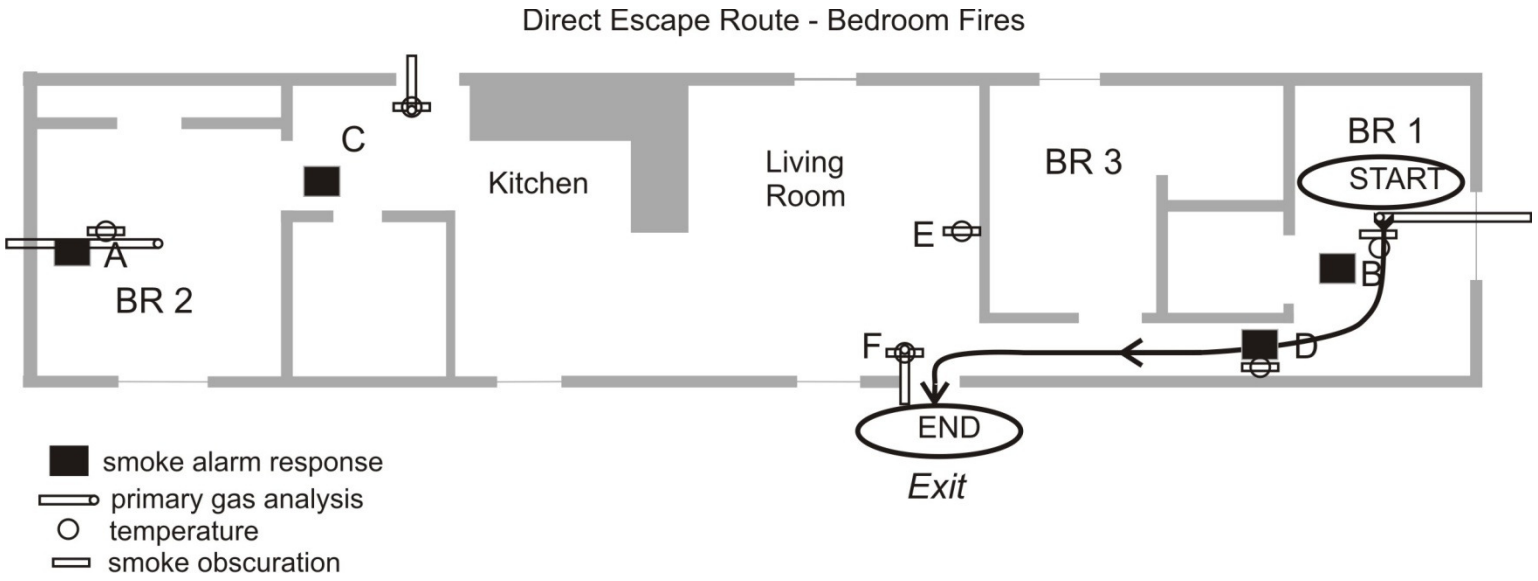
- For smoldering fires, ASET values ranged from 53 to 93 minutes.
- For flaming fires, ASET values ranged from 5 to 11 minutes for ion and combo (photo was 2 to 10).

Other Recent Smoke Alarm Studies

- Similar Conclusions

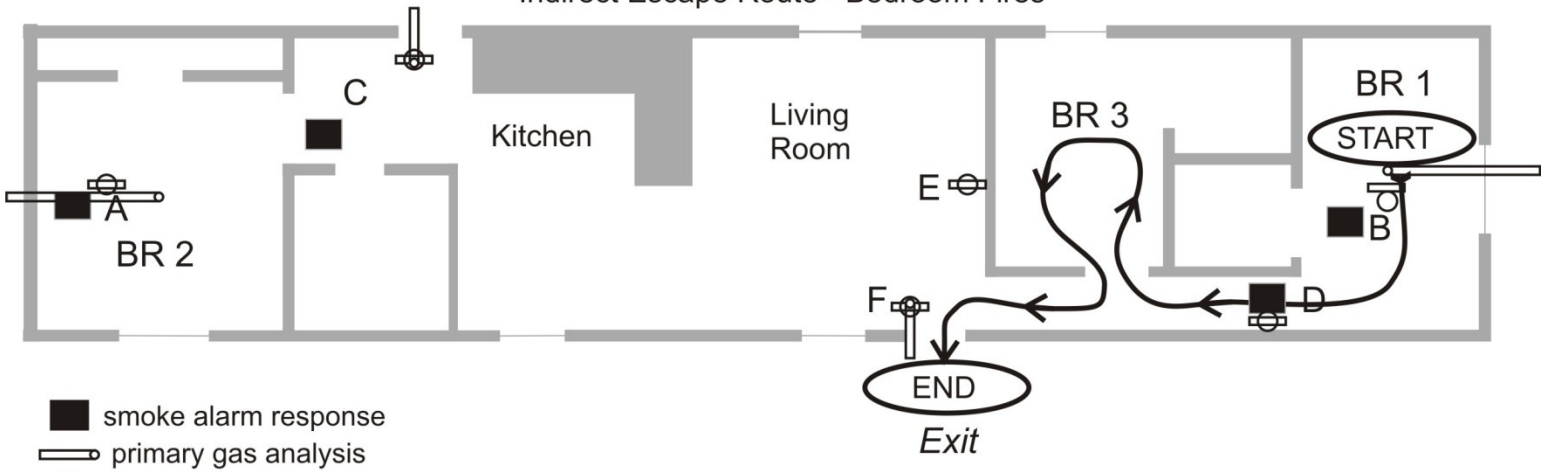
- NFPA (2008), “Task Group Report – Minimum Performance Requirements for Smoke Alarm Detection Technology,” National Fire Protection Association, Quincy, MA, February 22.
- NFPA (2009), “Task Group on Smoke Detection Follow-up Report – Subtask Group 1-Task Group on Smoke Installation Strategy, Subtask Group 2-Task Group on Performance Follow-up,” National Fire Protection Association, Quincy, MA, July 1.
- Clearly, “Full-Scale Residential Smoke Alarm Performance,” AUBE ’09, Duisburg Germany, September 8-10, 2009.

NFPA 72 TG Report



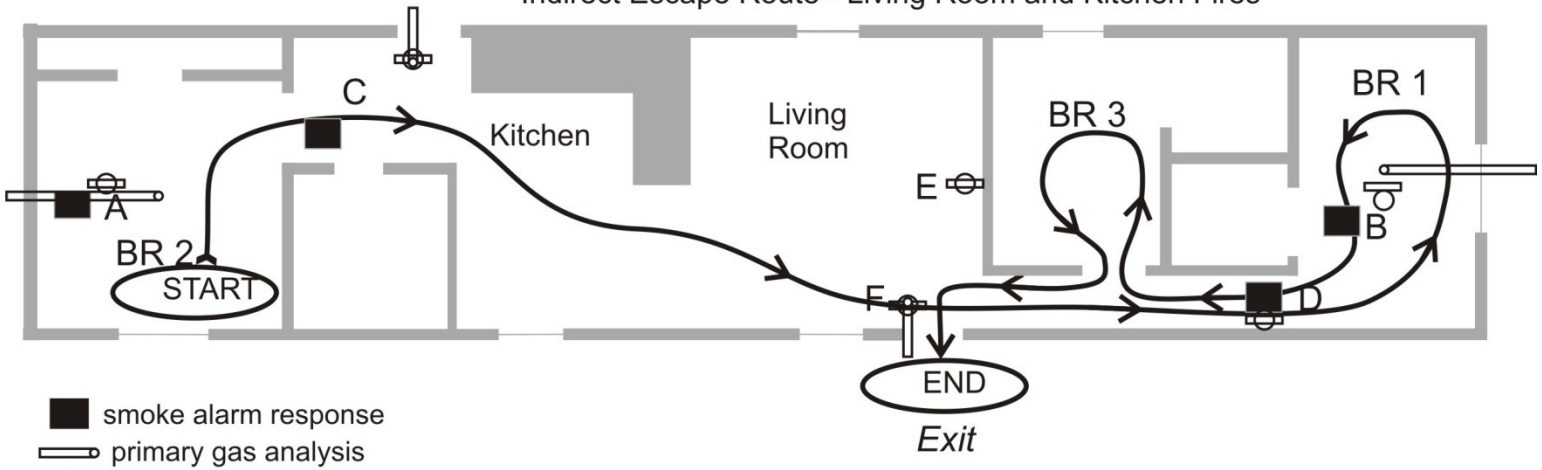
NFPA 72 TG Report

Indirect Escape Route - Bedroom Fires



smoke alarm response
primary gas analysis
temperature
smoke obscuration

Indirect Escape Route - Living Room and Kitchen Fires



smoke alarm response
primary gas analysis
temperature
smoke obscuration

NFPA 72 TG Report Conclusions

"With respect to the indirect egress cases, the task group agreed that neither ionization nor photoelectric technology offered an advantage relative to the other when the type of fire is not known. The indirect egress analysis technically falls outside of the scope of NFPA 72 Section 11.4.1"

"The task group agreed that it should be recognized that not all occupants in a fire are always capable of self rescue, and in those cases, there was a definite benefit to having both technologies because the type of fire cannot be predicted. This should be affirmed as a recommendation in NFPA 72. The use of the two current technologies should not be mandatory code language."

Recommendations

- **Full coverage**
- **Interconnected**
- **Maintain and Test**

Questions?

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