LOG OF MEETING

DIRECTORATE FOR ENGINEERING SCIENCES

SUBJECT: Update on Smoke Alarm Research Project

DATE OF MEETING: May 7, 2002

DATE OF LOG ENTRY: June 3, 2002

SOURCE OF LOG ENTRY: Arthur Lee, ESEE

LOCATION: US Consumer Product Safety Commission, Bethesda, MD

CPSC ATTENDEES: See Attachment

NON-CPSC ATTENDEES: See Attachment

SUMMARY OF MEETING: Richard Bukowski, gave a presentation overview on the Smoke Alarm Research Project, titled Performance of Residential Smoke Alarms Preliminary Results (see attachment). Jason Averill, NIST, gave a presentation on the Preliminary Analysis for the Smoke Alarm Research Project (see attachment). Tom Clearly, NIST, gave a presentation on Nuisance Source Tests for Residential Smoke Alarm for the Smoke Alarm Research Project (see attachment). Treye Thomas, CPSC, gave a presentation on Residential Smoke Alarm Project: Sublethal Effects of Irritant and Asphyxiating Gases on Egress time for the Smoke Alarm Research Project (see attachment). Clarence Worrell, UMD, gave a presentation Development of Advanced Fire Detection Algorithms using the "Dumex II" Data for the Smoke Alarm Research Project (see attachment).
Performance of Residential Smoke Alarms
Preliminary Results

Richard W. Bukowski, P.E., FSFPE
NIST Building and Fire Research Lab
Gaithersburg, MD 20899 USA

Preliminary Analysis
Tenability Limits

• Today the accepted approach is documented in ISO/TS 13571 (and SFPE Handbook of FP Eng) and is based on Purser's incapacitation analysis:
  \[ FDD_{incap} = \text{S CO/35000} \times (\text{times}^{0.025} \text{ if CO}_2 < 2\%) \]
  \[ FDD_{incap} = S \times 10^{1.8} \times \text{t} \]
  \[ OD = 0.25 \text{ m}^3 \text{ at 5 ft (but not 0.5 at 3 ft)} \]
  \[ FED = 0.3 \text{ at incapacitation} \]

Preliminary Analysis
Number, Location, Type

• Code requirements:
  - Every level (hall outside br), current for existing homes
  - Every level + bedrooms (added for new homes in 1993 based on audibility in bedrooms with doors closed)
  - Every room (heat and sprinkler always in fire room)
• Data for escape time provided, by type (ion, photo, aspirated, heat detector, sprinkler)
  - Escape time = Tenability time – Alarm time
  - Alarm time for analog based on output voltage and associated unmodified sample response

Preliminary Analysis
Escape Times (min) Every Level
bottom numbers exclude “intimate”

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Preliminary Analysis
Escape Times (min) Every Level + Bedrooms
bottom numbers exclude “intimate”

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**Preliminary Analysis**

Escape Times (min) Every Room
bottom numbers exclude "intimate"

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**Preliminary Analysis**

Observations

- Escape times are generally shorter than 25 yrs ago
- More conservative testability criteria
- Faster fire development times
  - Average visibility times for smoldering reduced from 72 to 53
  - PAN emissions and the flaming 17 to 3 minutes
- Ions fail in some smoldering tests
- Sprinklers operate consistently after smoke but would terminate fire and improve conditions
- Heat detectors provide protection for flaming fires but not for smoldering
Preliminary Analysis
Instrumentation

- Detectors
  - Photoelectric
  - Ionization
  - Combination
  - Carbon Monoxide
  - Heat
    - Mechanical, eustatic, and rate of rise
    - Aspirated (Photoelectric)

- Thermocouples
- Load Cell
- Primary Gas Analysis
  - CO
  - CO₂
  - O₂
- Smoke Properties
  - Velocity Probes
  - Sprinklers
  - Video
  - FTIR
    - HCl, HF, NO₂
    - HCN, H₂S

Preliminary Analysis
Instrumentation

- A. Thermocouples
- B. Smoke Meter
- C. Detector Board
- D. Velocity Probe
- E. Smoke Characterization
- F. Gas Sampling

Preliminary Analysis
Instrumentation

- Suppression
- Sprinkler
- Load Cell

Preliminary Analysis
Instrumentation

- Flaming Chair
- Smoldering Chair
Nuisance Source Tests for Residential Smoke Alarms

Thomas Cleary and Michael Selepak
Building and Fire Research Laboratory
National Institute of Standards and Technology
May 7, 2002

Test Plan
- Preliminary tests in the 3m by 3m by 2.4m high detector test room w/planned sources.
- Testing in the manufactured home following the second series of fire tests.
- Fire Emulator/Detector Evaluator tests of selected scenarios.

Nuisance Scenario Activities
- Toasting
- Frying
  - Electric and gas appliance
- Boiling pasta
- Deep frying
- Baking
- Broiling
- Smoking
- Candles
- Dust exposure
  - ISO sea dust in F5/D5
- "Shower steam" exposure
  - High humidity/condensing water vapor in F5/D5

Scenario Development
- Selection based on what are commonly thought to be causes of residential nuisance alarms.
- Scenarios mimic normal activities (i.e. no intentional food burning except toasted bread).
- Test series does not weight the probability of any given scenario, but is designed to provide data for a variety of scenarios.

Instrumentation
- Multiple analog Photo/ion/CO/sensor packages (calibrated NIST modified detectors)
- Ceiling jet velocities
- Humidity and temperature
- Aerosol number and mass concentration
- Flow through Ion chambers (~ MIC)
- Video Record
Summary

- Both photo and ion alarm levels reached in most of the scenarios
- Detector distance from source has some influence on whether an alarm level is reached, and the time to alarm.
- Increased room airflow tends to dilute aerosol concentrations at detector locations, and reduce the number of ion alarms relative to photo alarms
- Little or no carbon monoxide was sensed in any of the nuisance scenarios

Next

- Reproduce select scenarios in FE/DE matching flow condition, aerosol concentrations, humidity, and temperature
  - Toasting
  - Frying
  - Tobacco smoke
  - "Shower steam" – condensing water vapor
  - Dust
Residential Smoke Alarm Project: Sublethal Effects of Irritant and Asphyxiating Gases on Egress Time

Treye Andrew Thomas, M.S., Ph.D.
Division of Health Sciences
U.S. Consumer Product Safety Commission
May 7, 2002

Co-Authors: S White, S Inkster, M Neely, A Lee, L Saltman

The opinions are those expressed by the author, and do not necessarily represent the views of the Commission.

Background
Irritants, Asphyxiants and Egress

- ISO 13571
  - Reduce irritant gas production from burning building materials
- Recent events (9/11)
  - Escape from hazardous situations
  - Residual effects of smoke exposure
- Concentrations below tenability limits

Irritant and Asphyxiating Gas Effects on Egress: Approach

- Create basic escape scenario
- CPSC Human Factors (HF) staff
  - Estimate escape time
  - Quantify physiological effects
- CPSC Health Sciences (HS) staff
  - Non-fire related exposures (CO)
  - Magnitude of physiologic effects
- Estimate change in egress time

Irritant and Asphyxiating Gases

- Asphyxiating Gases
  - Hypoxia
  - Central nervous system depression
  - Cardio-vascular effects
- Effects of irritant gases
  - Important at early stages of fire before massive buildup of asphyxiating and/or HCN
  - Egress may be sufficiently delayed to allow onset of serious asphyxiating effects

Carbon Monoxide

- CO binds to hemoglobin in blood to produce COHb
  - Interferes with O2 uptake and delivery resulting in oxygen deprivation
  - Blood COHb (%COHb) serves as a useful approximation of CO poisoning severity
    - Generally progressively worsening symptoms with increasing COHb
- CO poisoning regarded as a continuum of effects
- Serious disorientation and possible loss of consciousness on reaching 30-40% COHb
  - May occur with prolonged elevations of 20-30%
  - Negatively impacts egress time of healthy individuals
- Dependent on time course profile of CO
Carbon Monoxide

- CPSC - Non-fire related exposures from combustion products generally lower than peak levels reached in fire scenarios
- CPSC - Non-fire related CO exposures
  - Combustion products
  - Lower than fires (100's vs 1000's ppm)
- Coburn Foster Kane (CFK) equation

Irritant Gases

- Irritants quantified by FTIR
  - HCl, HBr, HF, and NOx
- Health Effects
  - Eye irritation
    - Eye closing, compromised vision, disorientation
  - Upper Respiratory and Lung Irritation
    - Coughing, shortness of breath, body contortions, slowed movement
- Effects of each gas are cumulative

Irritant Gases

- Low concentrations can produce mild effects that may impair an individual's speed of movement through a home
- Moderate concentrations may further decrease escape speed.
  - Some researchers consider irritants to not significantly impair escape and provide a strong stimulus to escape
- High concentrations
  - Severe physiological effects
  - Significant effects on egress speed likely
  - Increased egress time

Egress Coefficient

- Difficulty in quantifying specific escape time
  - Egress time changes with each scenario
  - Dearth of data on irritant effects on egress in home fire scenarios
- Egress coefficient concept of CPSC staff
  - Weighting factor for physiological effects
  - Applied to escape time in drill scenarios

Egress Coefficient

- Calculated based on the concentrations of irritant gases
  - Integrate delay time for various physiological effects
    - Coughing severity, eye irritation, respiratory irritation
  - Multiply clean escape time by the egress coefficient

Egress Coefficient

- Utilize existing exposure limits for irritant gases
  - IDLH, AEGL, EEGL, TLV-TWA, etc.
- Ambient concentrations in
  - Environment
  - Workplace
- Emergency situations
  - Low level chronic exposures in homes (e.g., CO from furnaces)
  - Fire scenarios
- Post-exposure health effects
- Compare gas concentrations in fire to exposure limits
Egress Coefficient

- Integrate exposure limits with health impacts model
  - Quantify effect severity for coughing, eye irritation, respiratory irritation (e.g., mild, moderate, and severe)
  - Estimate magnitude of physical effects of gas concentrations (e.g., mild, moderate, and severe)
  - Magnitude of effects translated into egress coefficient in model

Example

- Basic Case
  - The "drill escape time" is estimated for the best case scenario
    - Lone, healthy young adult with predetermined escape route
    - No attempts to retrieve valuables or other items.
    - No impact from any other physical, chemical, or psychological factors
  - Concentration of irritant gases quantified or estimated
    - Gas concentrations used in model to predict severity of physiologic response
    - Response estimations used in model to calculate egress coefficient

Example

- Estimated "basic case" drill escape time is 2 minutes
  - CPSC Human Factors estimates
- Egress coefficient is 1.5
  - Xppm cumulative irritant gas concentration
  - Mild to moderate health effects
- Calculation:
  - 2 minute drill escape time x 1.5 egress coefficient = 3 minute escape time for a given concentration of irritant gas

Conclusions

- CPSC HS and HF to review irritant and asphyxiant gas data for potential effects
- Dearth of available data on irritant effects
- Model for delay includes egress coefficient
- Will compare escape scenarios and potential for incapacitation from effects of combustion gases
Development of Advanced Fire Detection Algorithms using the "Dunes II" Data

- Dr. James Milke — Associate Professor, Department of Fire Protection Engineering, University of Maryland; milke@eng.umd.edu
- Clarence Worrell — Graduate Research Assistant, Department of Fire Protection Engineering, University of Maryland; cworrell@wem.umd.edu

Acknowledgements

- NIST — Funding
- Dr. Kathy Notarianni and Mr. Richard Bukowski, NIST — Technical Monitors
- Mr. Tom Cleary, NIST — General assistance

Purpose

Develop "Advanced" Fire Detection Algorithm that provide:
1. Immunity to Nuisance Sources
2. Early Detection of Real Fire Sources

What is a "Nuisance" Source?

- Anything that causes unwanted alarming of the smoke detector
  - Examples: Cooking, Smoking, Shower Steam
- Nuisance alarms cause people to disable their smoke detectors
  - 105 deaths/year where detectors disabled due to nuisance alarms

Available Nuisance Sources

- Mhn06 — Toasting bread until black
- Mhn09 — Frying Bacon
- Mhn12 — Boiling spaghetti
- Mhn14 — Frying butter until heavy smoking
- Mhn15 — Cigarette
- Mhn16 — Broiling hamburgers until well-done

Available Nuisance Sources (cont.)

- Mhn19 — Frying hamburgers until well-done
- Mhn20 — Toasting bagel until black
- Mhn32 — Baking frozen pizza
- Mhn35 — Tea candles
- Mhn36 — Frying bacon until crisp, but eatable
Design Level of Nuisance Immunity

- Alarm to Mhn06, 14, 20.
  - Conventional detectors alarmed to all three
- Do not alarm to Mhn09, 12, 15, 16, 19, 32, 35, 36
  - Conventional detectors alarmed to four of above

What is a “Real” Fire Source?

- Fire that threatens life safety of occupants
  1. Flaming Fires
  2. Smoldering Fires
  3. “Aggressive” Nuisance Sources

Available “Real” Fire Sources

- 14 tests total
  - 2 smoldering furniture
  - 4 smoldering mattress
  - 2 flaming furniture
  - 4 flaming mattress
  - 2 flaming grease

What is “Sufficient” Detection Time?

\[(t_{Detection} + t_{Evacuation}) < t_{Hazard}\]

Response times of standard ion and photo detectors chosen as design criteria for development of alarm algorithms.

Algorithm Development

- Performance of Individual Sensors
- Multiple Sensor Algorithms
- Principle Component Analysis (PCA)

Available Measurements

- Ion
- Photo
- CO Detector
- Temperature
Individual Sensor Performance

- Smoke Obscuration is common to both nuisance sources and real sources.
- CO and Temperature are unique to real sources.

![Temperature Rise vs. CO Detector Response](image)

![Algorithm Performance](image)

![Rate of Temperature Rise vs. CO Detector Response](image)

![Algorithm Performance](image)
Principle Component Analysis (PCA)

PCA = Data Compression

\[ X = t_1 p_1^T + t_2 p_2^T + \ldots + t_n p_n^T + E \]

where, \( \text{cov}(X)p_i = \lambda_i p_i \)
Applying the Loads

\[ [t] = [X][\pi] \]

\[ t_1 = \begin{bmatrix} x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8 \end{bmatrix} \begin{bmatrix} \pi_{1,1} & \pi_{1,2} & \pi_{1,3} & \pi_{1,4} & \pi_{1,5} & \pi_{1,6} & \pi_{1,7} & \pi_{1,8} \end{bmatrix} \]

- Raw Measurement Vector
- Load Vector

\[ t_3 \text{ vs. } t_4 \]

\[ t_4 \text{ vs. } t_3 \]
2D PCA Algorithms

\[ \frac{t_x^2}{a} + \frac{t_y^2}{b} = 1, \]

Coordinate Transformation to Rotate

3D PCA Algorithms

\[ \frac{t_x^2}{a} + \frac{t_y^2}{b} + \frac{t_z^2}{c} = 1, \]

Coordinate Transformation to Rotate
Preliminary Conclusions

- Ion and Photo are poor discriminators.
- Rate of Temperature Rise provides good discrimination and fast detection of flaming fires.
- CO provides good discrimination and fast detection of smoldering fires.
- Combined $dT/dt$ – CO – Ion most promising.
- PCA does not provide significant benefit with current data set.

Questions?
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Thank you for signing in.
# SMOKE ALARM RESEARCH MEETING
@CPSC, MAY 7th, 2002
SIGN-IN SHEET

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*HANK YOU FOR SIGNING IN*