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 Asphyxiant 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 "Dumes 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

NIST

Preliminary Analysis

Tenability Limits

- Original work in mid-70's predated significant research on human tenability (see Appendix D of 1975 report for discussion)
  - Temperature ≈ 65°C (150°F)
  - OD = 0.23 m^{-1} at 5 ft
  - CO ¡ 400 ppm (only reached in 2 cases)
- In the 80's combustion toxicology research was based on lethality of test animals (HAZARD I)
  - FED_{gases} = 5(CO-1700)/4(100000-CO_2) ? t
  - FED_{gases} = 1.0 lethality, 0.5 incapacitation
  - Included in this analysis with FED_{gases} = 0.3 to be consistent with ISO/TS 13571

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
  - FED_{gases} = S CO/35000 ? t (times $e^{CO2/5}$ if CO_2 > 2%)
  - FED_{heat} = S $5*10^7 T^{-3.4}$? t
  - OD = 0.25 m^{-1} at 5 ft (but NOT 0.5 at 3 ft)
  - FED = 0.3 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"

	Photo	Ion	Heat	Sprink
Flaming	.8	1.7	-3.4	-.5
	1.5	2.5	-2.9	.3
Smold	18.3	-12.4	-48.9	-22.4
	32.8	2.2	-15.4	-7.8
Grease	7.5	12.3	-4.7	-3
	11.3	16.2	-.3	0

Preliminary Analysis

Escape Times (min) Every Level + Bedrooms
bottom numbers exclude "intimate"

	Photo	Ion	Heat	Sprink
Flaming	1.6	1.9	-3.4	-.5
	2.4	2.7	-2.9	.3
Smold	27.4	-11.6	-48.9	-22.4
	41.9	3	-15.4	-7.8
Grease	8.8	12.9	-4.7	-3
	12.6	16.8	-.3	0

Preliminary Analysis

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

	Photo	Ion	Heat	Sprink
Flaming	1.6 2.9	2.1 2.9	-3.4 -2.9	-.5 .3
Smold	30 44.5	-11.1 3.5	-48.9 -15.4	-22.4 -7.8
Grease	9.6 13.4	12.9 16.8	-4.7 -.3	-3 0

Preliminary Analysis

Observations

- Escape times are generally shorter than 25 yrs ago
  - More conservative tenability criteria
  - Faster fire development times
    - Average tenability times for smoldering reduced from 72 to 53 minutes and for 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

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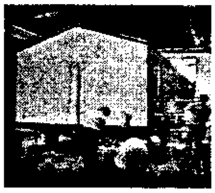
Preliminary Analysis
Instrumentation

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Preliminary Analysis
Instrumentation

- Detectors
- Thermocouples
- Load Cell
- Primary Gas Analysis
  - CO
  - CO_2
  - O_2
- Smoke Properties
- Velocity Probes
- Sprinklers
- Video
- FTIR
  - HCl, HF, NOx, HCN, HBr

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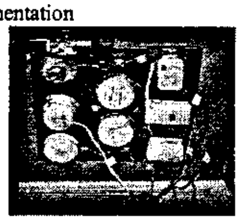
Preliminary Analysis
Instrumentation

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



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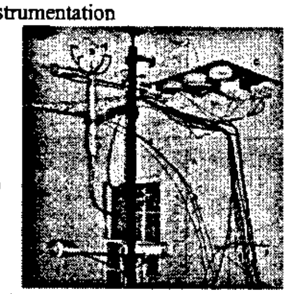
Preliminary Analysis
Instrumentation

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



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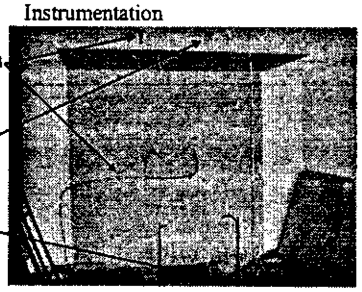
Preliminary Analysis
Instrumentation

- Suppression
- Sprinkler
- Load Cell



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Preliminary Analysis
Instrumentation

- Flaming Chair
- Smoldering Chair


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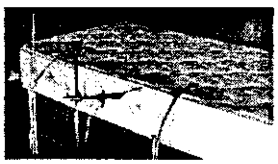
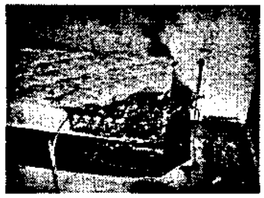
Preliminary Analysis
Instrumentation

- Smoldering Mattress
- Flaming Mattress





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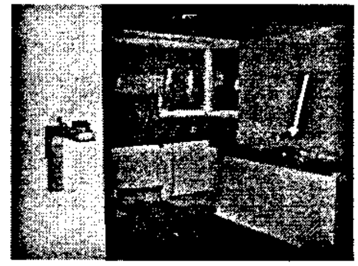
Preliminary Analysis
Instrumentation

- Corn Oil Fire



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Preliminary Analysis
Instrumentation

- Data Collection

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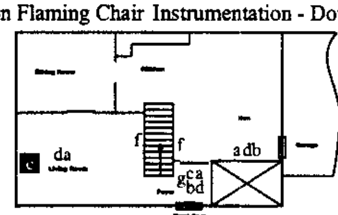
Preliminary Analysis
Kinston Flaming Chair Instrumentation - Downstairs

a tc
b det
c gas
d sm
e mass
f cam
g vel
— soffit



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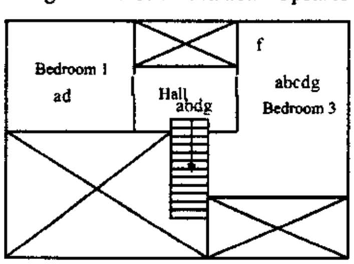
Preliminary Analysis
Kinston Flaming Chair Instrumentation - Upstairs

a tc
b det
c gas
d sm
e mass
f cam
g vel
— soffit



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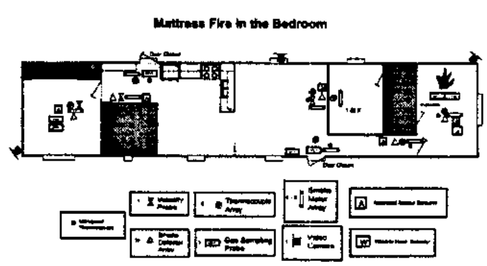
Preliminary Analysis
Detector Locations - Manufactured Home

Mattress Fire in the Bedroom



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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

Project Objective

- *Develop the basis for standard nuisance sources.*

  Currently there are no agreed set of nuisance alarm sources for smoke alarms in any standard. Such a set will be developed and characterized for incorporation into existing test programs

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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.

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Nuisance Scenario Activities

- Toasting
- Frying
  - Electric and gas appliance
- Boiling pasta
- Deep frying
- Baking
- Broiling
- Smoking
- Candles
- Dust exposure
  - ISO test dust in FE/DE
- "Shower steam" exposure
  - High humidity/condensing water vapor in FE/DE

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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.

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Instrumentation

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

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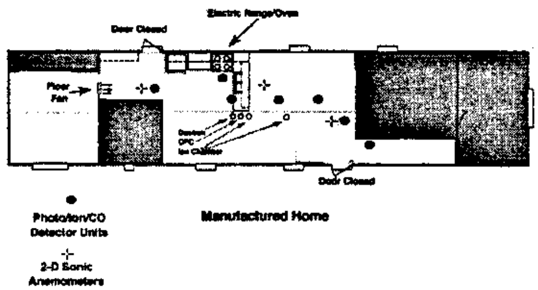

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Range/Oven and LPG Burner

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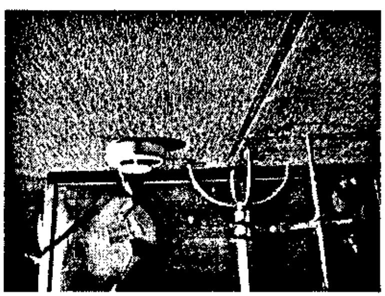
Detector and Sonic Anemometer



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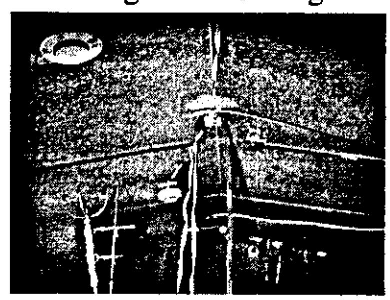
Living Room Ceiling



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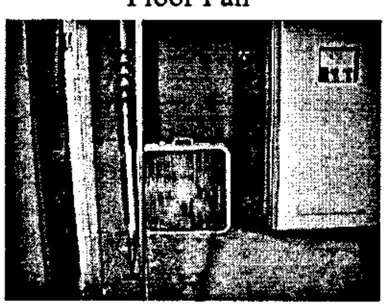
Floor Fan



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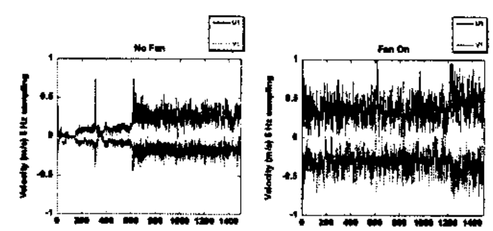
Ceiling Jet Velocity for Pizza Bake/Broil Test



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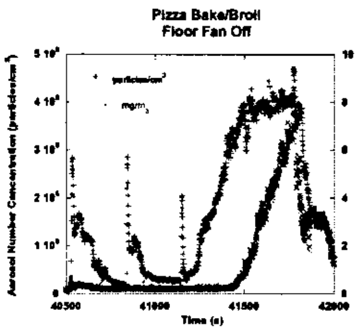
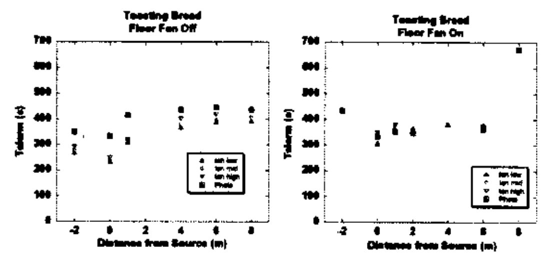
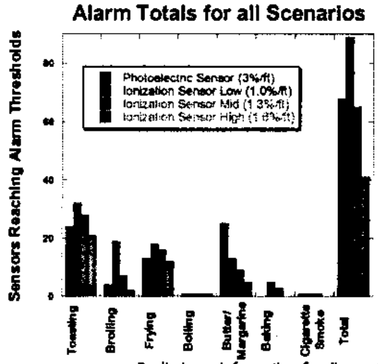


Toasting Bread



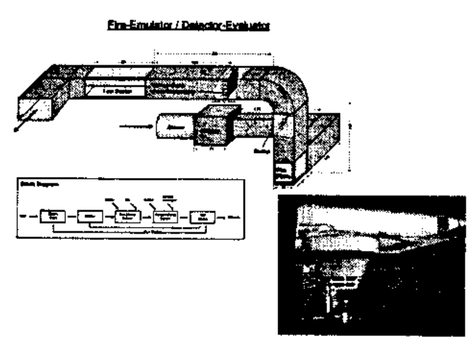


Summary

- 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 Asphyxiant 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 Neily, A Lee, L Saltzman

1

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

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Irritant and Asphyxiant 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

3

Irritant and Asphyxiant Gases

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

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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

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Carbon Monoxide

- 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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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@wam.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?

$$(t_{Detection} + t_{Evacuation}) < t_{Hazard}$$

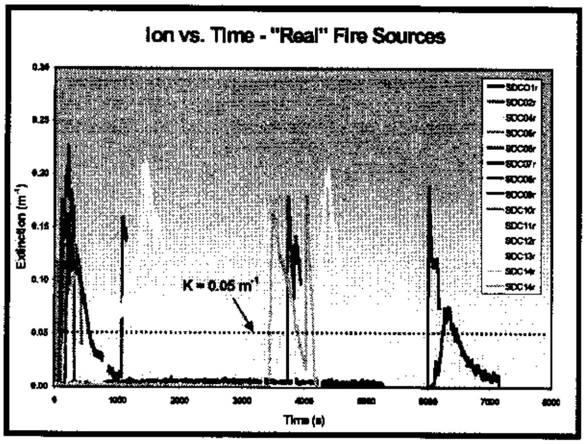
Response times of standard ion and photo detectors chosen as design criteria for development of alarm algorithms.

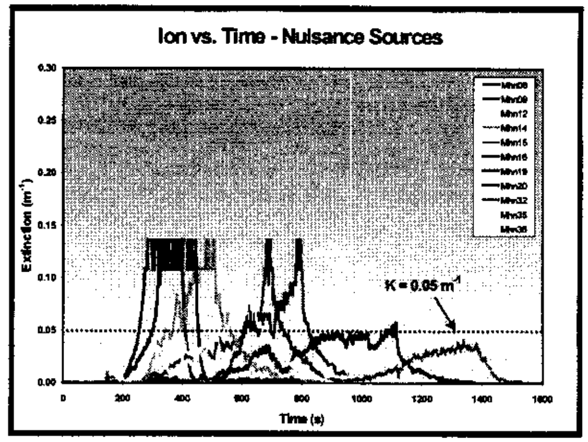
Algorithm Development

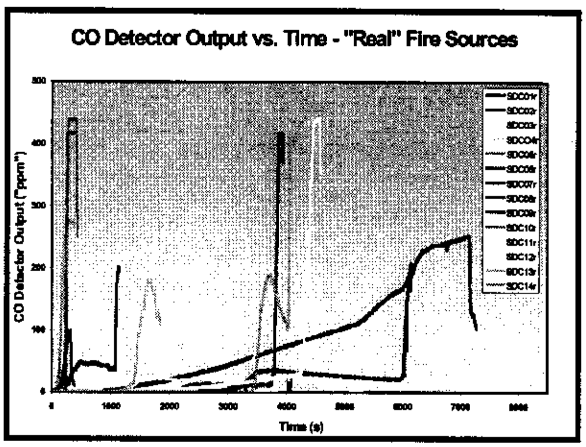
- Performance of Individual Sensors
- Multiple Sensor Algorithms
- Principle Component Analysis (PCA)

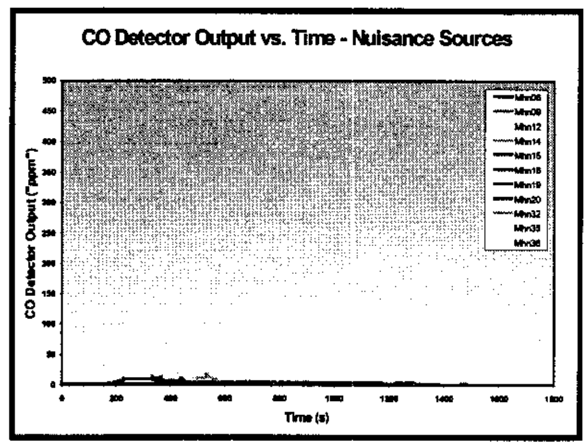
Available Measurements

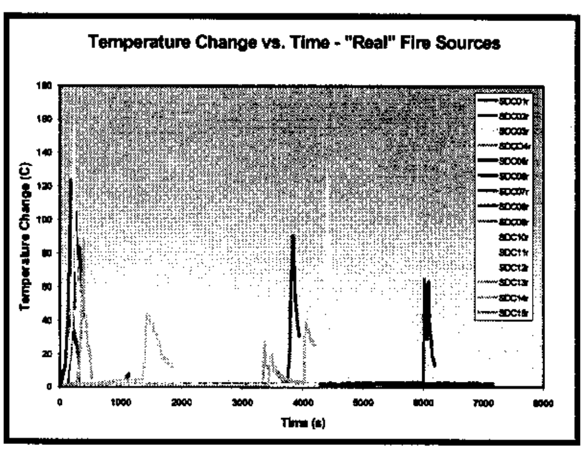
- Ion
- Photo
- CO Detector
- Temperature

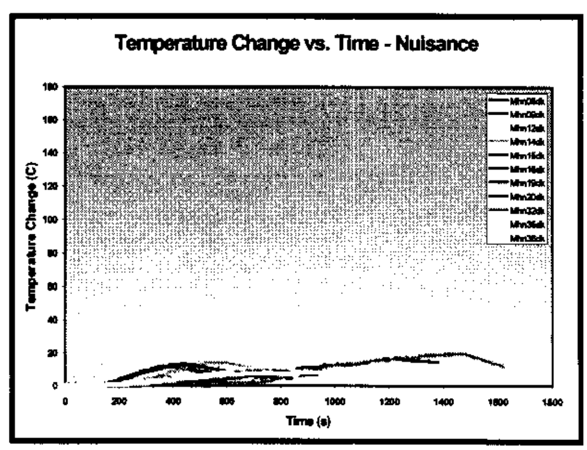

Ion vs. Time - "Real" Fire Sources
Extinction (m⁻¹)
K = 0.05 m⁻¹
Time (s)


Ion vs. Time - Nuisance Sources
Extinction (m⁻¹)
K = 0.05 m⁻¹
Time (s)


CO Detector Output vs. Time - "Real" Fire Sources
CO Detector Output ("ppm")
Time (s)


CO Detector Output vs. Time - Nuisance Sources
CO Detector Output ("ppm")
Time (s)

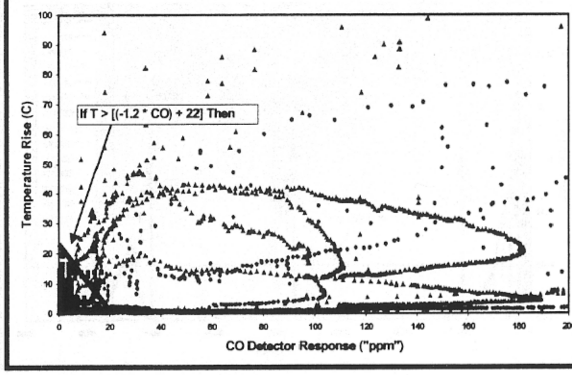

Temperature Change vs. Time - "Real" Fire Sources
Temperature Change (C)
Time (s)


Temperature Change vs. Time - Nuisance
Temperature Change (C)
Time (s)

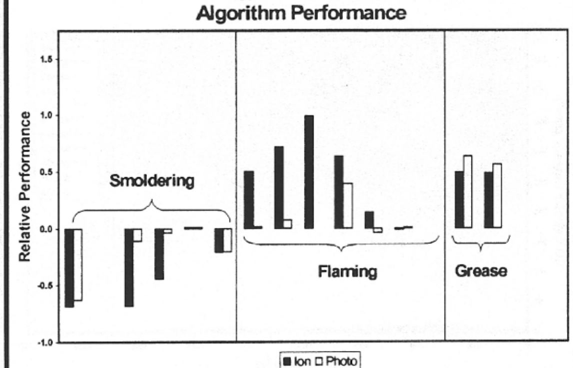
Individual Sensor Performance

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

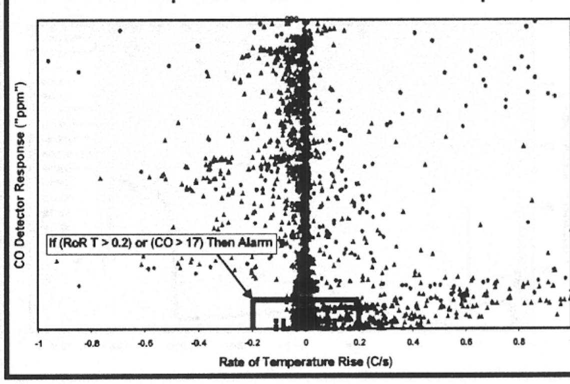
Temperature Rise vs. CO Detector Response



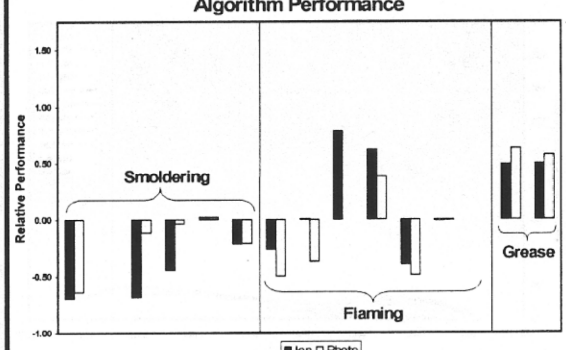
T > [(-1.2 * CO) + 22]
Algorithm Performance



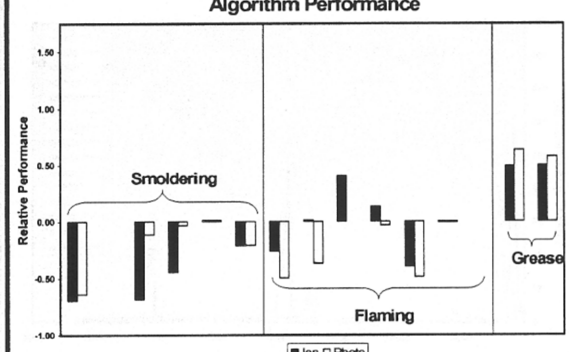
Rate of Temperature Rise vs. CO Detector Response

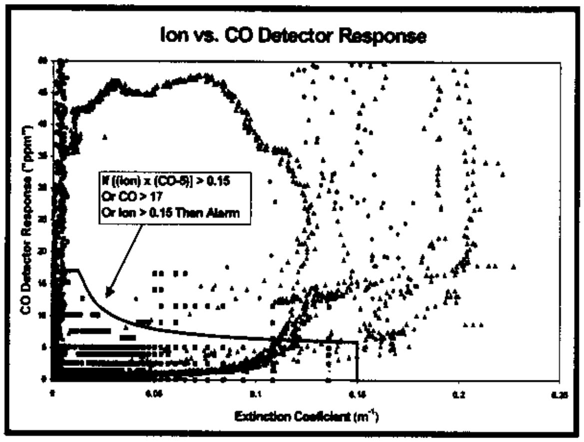


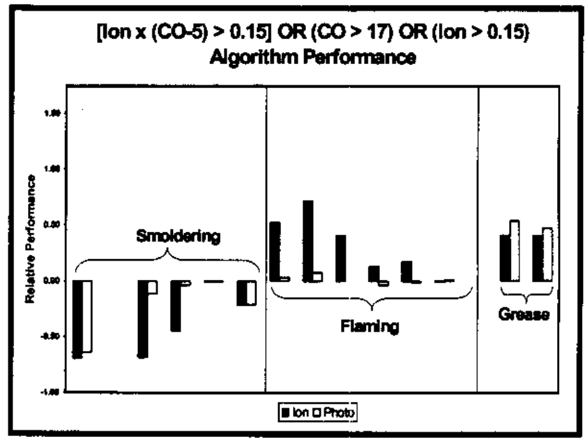
(dT/dt > 0.20) OR (CO > 17)
Algorithm Performance

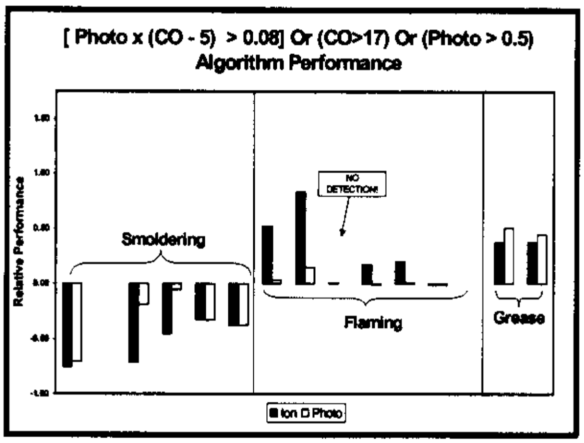


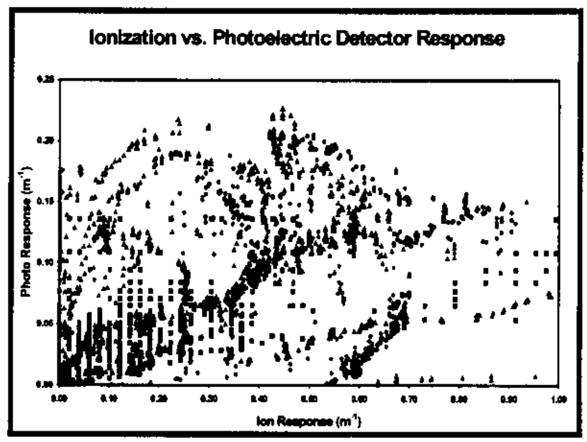
(dT/dt > 0.20) OR (CO > 17) OR (Ion > 0.15)
Algorithm Performance











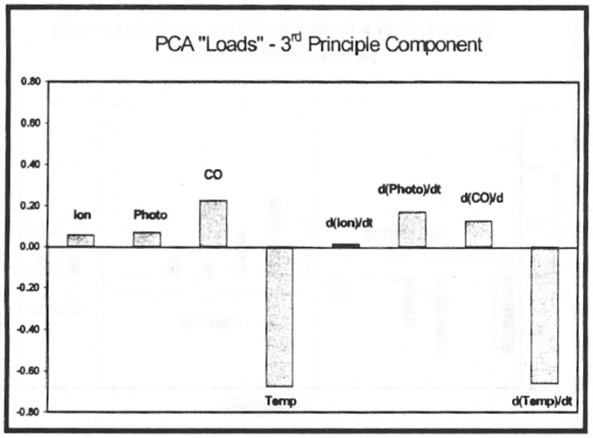
Principle Component Analysis (PCA)

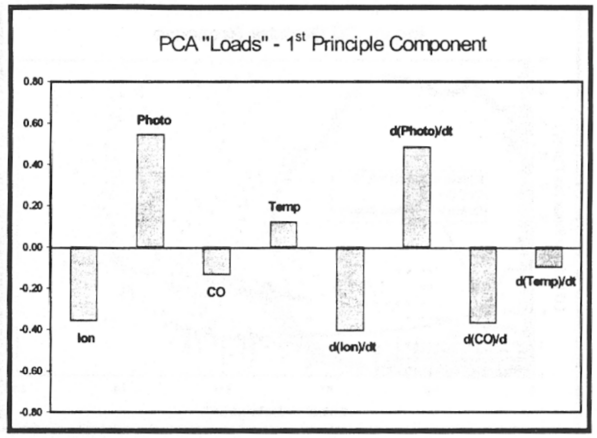
PCA = Data Compression

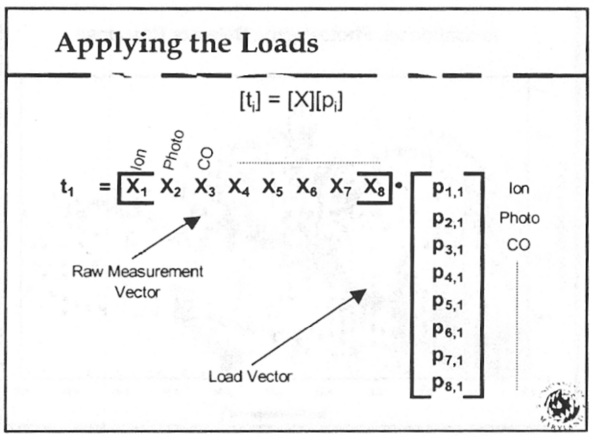
Principle Component Analysis (PCA)

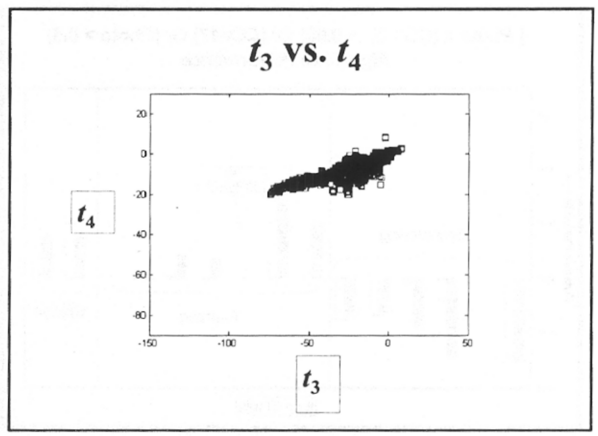
$$X = t_1 p_1^T + t_2 p_2^T + \ldots + t_k p_k^T + E$$

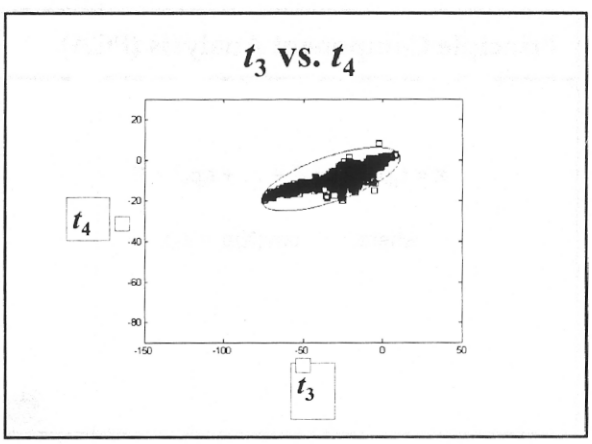
where, $\mathrm{cov}(X)p_i = \lambda_i p_i$

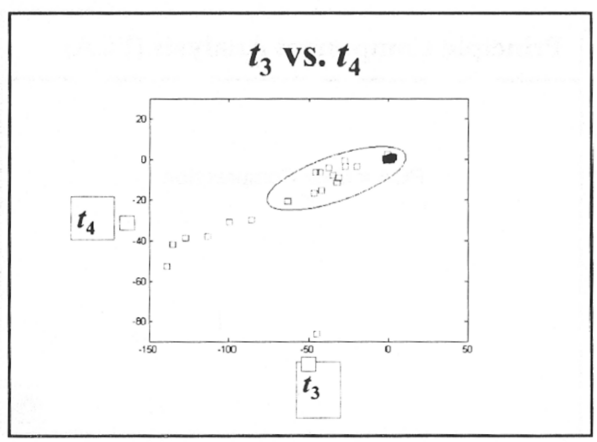

PCA "Loads" - 3rd Principle Component
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
Ion
Photo
CO
Temp
d(Ion)/dt
d(Photo)/dt
d(CO)/d
d(Temp)/dt


PCA "Loads" - 1st Principle Component
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
Photo
d(Photo)/dt
Temp
CO
Ion
d(Ion)/dt
d(CO)/d
d(Temp)/dt


Applying the Loads
[ti] = [X][pi]
Ion
Photo
CO
t1 = X1 X2 X3 X4 X5 X6 X7 X8 •
p1,1
p2,1
p3,1
p4,1
p5,1
p6,1
p7,1
p8,1
Ion
Photo
CO
Raw Measurement Vector
Load Vector


t3 vs. t4
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
t4
t3


t3 vs. t4
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
t4
t3

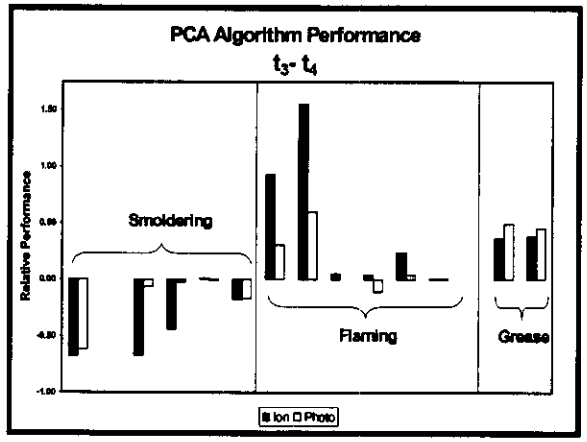

t3 vs. t4
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
t4
t3

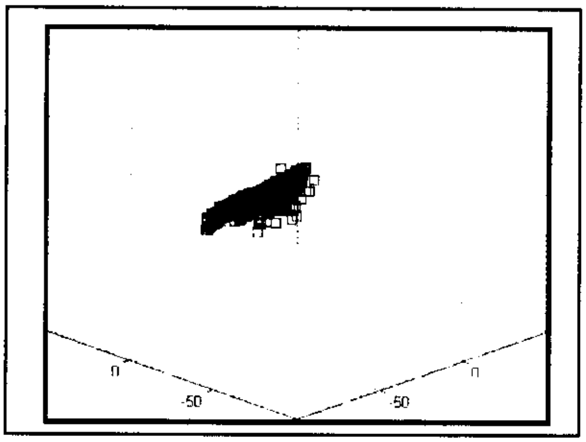
2D PCA Algorithms

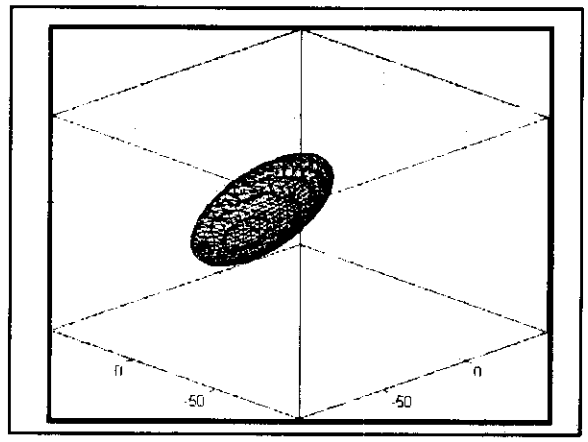
- t_1-t_2
- t_1-t_3
- t_1-t_4
- t_2-t_3
- t_2-t_4
- t_3-t_4

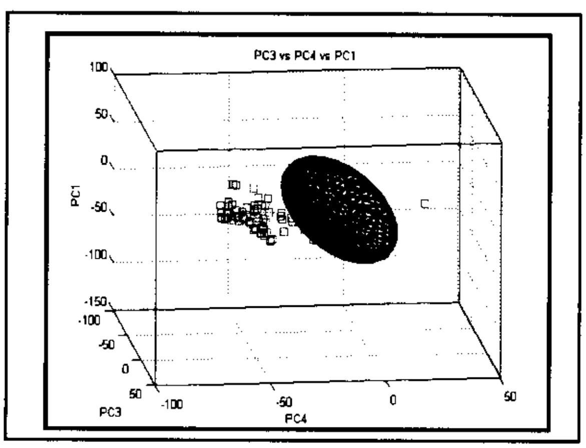
$$\frac{t_x^2}{a} + \frac{t_y^2}{b} = 1,$$

Coordinate Transformation to Rotate







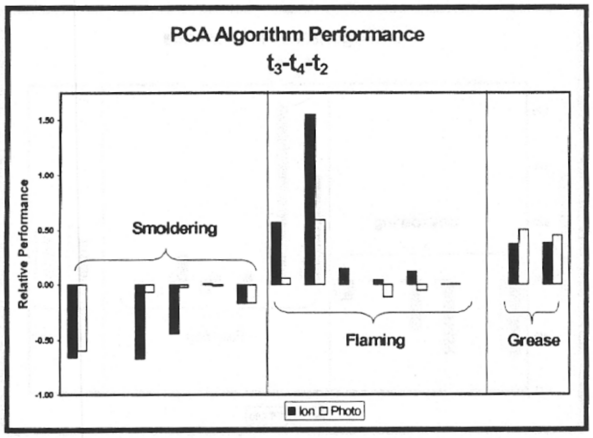


3D PCA Algorithms

- t_1-t_2-t_3
- t_1-t_2-t_4
- t_1-t_3-t_4
- t_2-t_3-t_4

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

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?

SMOKE ALARM RESEARCH MEETING
@CPSC, MAY 7th, 2002
SIGN-IN SHEET

NAME	ORGANIZATION	PHONE	E-MAIL
CARL BENNER	TEXAS A&M	979 845 6224	carl.benner@ieee.org
Clarence Worrell	UMD	301-~~3~~ 422-3179	CWORRELL@WAM.UMD.EDU
Sara Yerkes	ICC	703-931-4533 ext 12	yerkes@intlcode.org
MIKE SWIEBODA	First Alert	630-851-7330 x1304	swiebodam@firstalert.com
PAUL E. PATTY	UL	847-272-8800	Paul.E.Patty@us.ul.com
DAVID TUCHOLSKI	CPSC	301-424-6421 x 135	dtucholski@cpsc.org
TOM CLEARY	NIST	301 975-6858	thomas.cleary@nist.gov
JASON AVERILL	NIST	301 975 2585	jason.averill@nist.gov
Rick Peacock	NIST	301 975 6664	richard.peacock@nist.gov
George Williams	Arl. Co. Fire Marshal	703-228-4647	
Dan Gottuk	Hughes Assoc.	410-737-8677	dgottuk@haifire.com
TOM BARAKAT	MAPLE chase	630-420 7981	TBARAKAT@MAPLECHASE.COM
Peter Winik	First Alert	202 637-2224	peter.winik@lw.com
Dave Blake	FAA	609 485 4525	Dave.Blake@tc.faa.gov
Russ Thomas	NRC	613-993-0819	Russ.Thomas@NRC.CA
JOHN WALSH	WALSH CONSULTING	416 491 4466	john@walshconsulting.net
Bill King	CPSC-Eng	301-504-0508	wking@cpsc.gov
LINDA EDWARDS	CPSC-ESEE	301-504-0508	eedwards@cpsc.gov
ED KRAWIEC	CPSC-LSE	301-424-6421 x119	EKRAWIEC@CPSC.GOV
WM FREEBAIRNE	HUD	202-708-4370 x575	William_E._Freebairne@HUD.GOV
Shelton Cartwright Jr	NAHB Research Ctr.	304 430 6232	scartwright@nahbrc.org
James F Hoebel	Retired	703 818-2639	jfhoebel@erols.com
RICK MENDLOWITZ	HUD	202 708-4423	
JOHN STEVENS	HUD	202 708 4423	
Mark Nunn	MHI	(703) 558-0400	mark@mfghome.org
Margaret Neily	CPSC	(301)504-0508	mneily@cpsc.gov
LARRY RATZLAFF	Kidde Safety	847-742-5165	LARRY.RATZLAFF@KIDDEUS.COM
Joseph Fleming	BFD	617-343-2812	jayf.bfd@ci.boston.ma.us

THANK YOU FOR SIGNING IN

SMOKE ALARM RESEARCH MEETING
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SIGN-IN SHEET

NAME	ORGANIZATION	PHONE	E-MAIL
LARRY MARUSKIN	FEMA	(301) 447 1141	LARRY.MARUSKIN@FEMA.GOV
ALEX FURR	FEMA	(301) 447-1353	alex.furr@fema.gov
David Miller	CPSC	(301) 504-0470 x1258	dmiller@cpsc.gov
Stephen Olenick	CSE	410-884-3266	solenick@csefire.com
VIJAY D'SOUZA	CSE	301 648-5153	VDSOUZA@CSEFIRE.COM
Pam Weller	CPSC	301 504-0290	pweller@cpsc.gov
Bob McCarthy	USFA/FEMA	301.447.1130	BOB.MCCARTHY@FEMA.GOV
Jim Milke	UMD	301 405 3995	milke@eng.umd.edu
D.W. TROUTMAN	NEMA	703. 841. 3245	dw_troutman@nema.org
John Stevens	HUD	202 708 6423	John_R._Stevens@hud.gov
ROBERT A. NEALE	USFA/FEMA	301 447 1209	ROBERT.NEALE@FEMA.GOV
Sharon White	CPSC/ESHF	(301) 504-0468	swhite@CPSC.gov

THANK YOU FOR SIGNING IN