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# Smoke Detection System Performance

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# When will a smoke detector alarm?

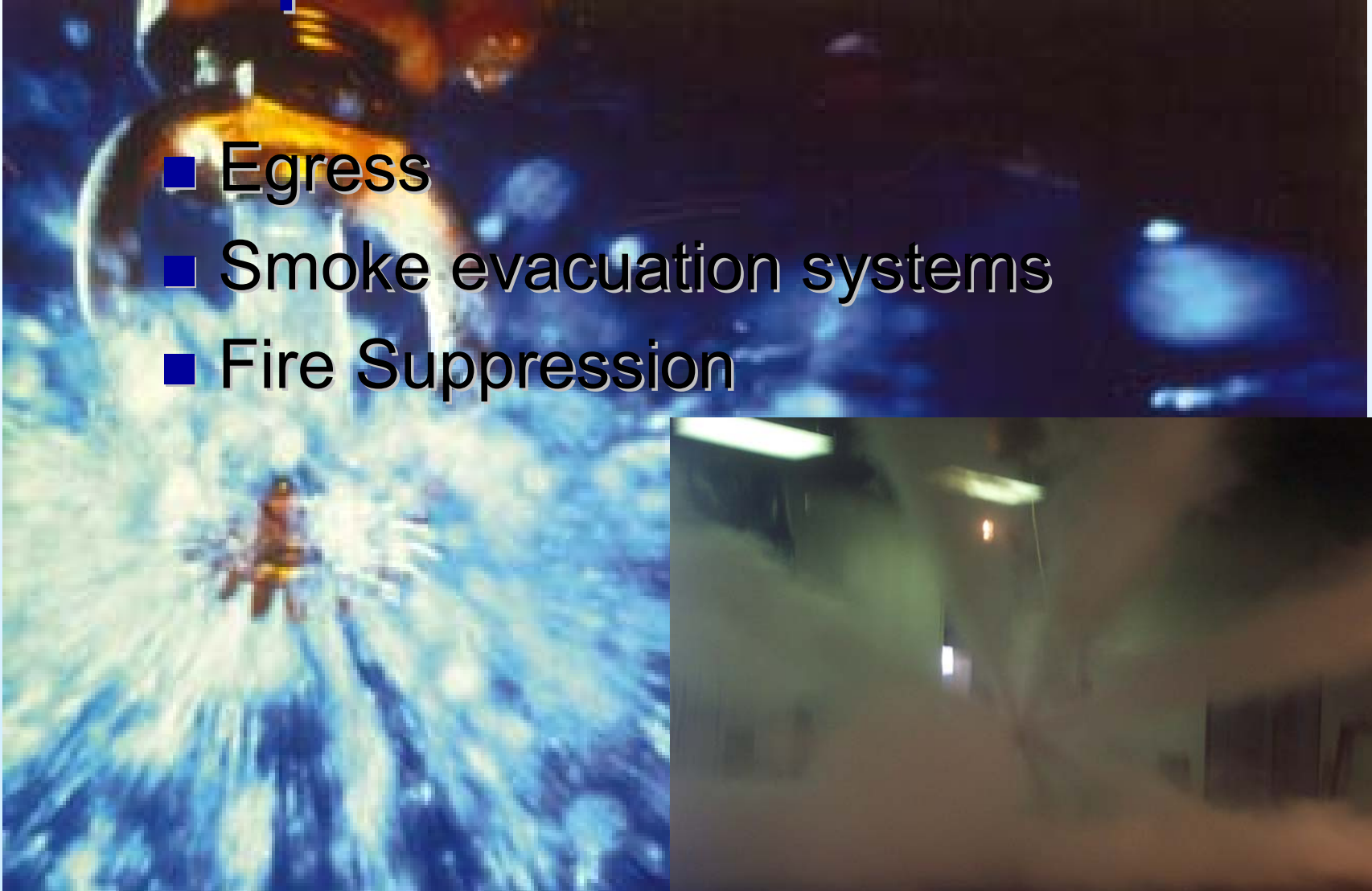


Why is it important to know ... ?



# Fire detection system performance affects

- Egress
- Smoke evacuation systems
- Fire Suppression



# Performance-based Designs

- Alternative to following prescriptive code requirements
- Process of establishing design
  - ◆ goals, objectives, and performance criteria
  - ◆ designing a system, and
  - ◆ evaluating the ability of the design to meet the objectives



# Performance-based Designs

- Alternative to prescriptive code requirements
- Necessary for many unique structures and applications to meet varying goals and specific performance requirements



# Unique Applications

- Historic structures
  - ◆ Meet intent of new codes
  - ◆ Inconspicuously install hardware
  - ◆ Maintain historic fabric – aesthetics concerns



# Unique Applications

## ■ Amusement parks/attractions



- Partial outdoor conditions
- Pyrotechnics
- Artificial smoke
- Moving boundaries



# Unique Applications

## ■ Navy ships



- Varied weather and working conditions
- Overheads with beams and clutter
- Changing use of space



# Performance-based Designs

- Alternative to prescriptive code requirements
- Necessary for many unique structures and applications
- Require a higher level of engineering and validation



# Validating Fire Detection Systems

- Optical fire detection
- Heat detection
- Smoke detection
  - ◆ Spot detectors
  - ◆ Beam detectors
  - ◆ Aspiration systems
- Video image fire detection



# Validating Fire Detection Systems

- Optical fire detection
  - ◆ Approval testing of performance for
    - Fire type
    - Fire size, and
    - Position and distance of fire w.r.t. the detector
  - ◆ Calculation methods for radiant energy transmission



# Validating Fire Detection Systems

- Heat detection
  - ◆ Alarm temperature
  - ◆ Thermal response time to achieve the alarm temperature (RTI ... TRC)



# Validating Fire Detection Systems

- Smoke detection
  - ◆ Spot detectors
  - ◆ Beam detectors
  - ◆ Aspiration systems
  
- ◆ No established performance metrics



# Predicting Smoke Detector Response

- Need accurate engineering methods
- Have estimation methods for response
  - ◆ Temperature Rise Method
  - ◆ Critical Velocity Method
  - ◆ Optical Density Method



# Temperature Rise Method

- Based on idea that  $\Delta T$  correlates with smoke production (i.e.,  $OD / \Delta T = \text{constant}$  for fuel and mode of burning)
- 13 C has been used universally in the past
- NFPA 72 reports 2 C – 42 C range for different fuels and detector type
- Correlation disputed and not broadly established
- Detection can occur at much lower temperatures



# Critical Velocity Method

- Based on theory that a minimum critical velocity is required to push smoke into detector sensing chamber
- Assumes that if critical velocity is achieved than sufficient smoke exists for alarm
- 0.15 m/s is minimum velocity in UL tests



# Optical Density Method

- Directly calculate the smoke concentration (OD) at the detector
- Compare the smoke concentration to an alarm threshold for the detector



# Predicting Smoke Detector Response

- Little guidance on threshold optical densities for detector alarm
  - ◆ Nominal detector sensitivity
    - Alarm level marked on the detector
    - Determined in UL smoke box test
    - Not a performance metric
  - ◆ 0.14 OD/m (~10% obs./ft from UL tests)



# Project Goals

- Evaluate the accuracy of using smoke optical density values as criteria for predicting smoke detector responses
- Evaluate two detector alarm thresholds offered in the literature.



# Scope

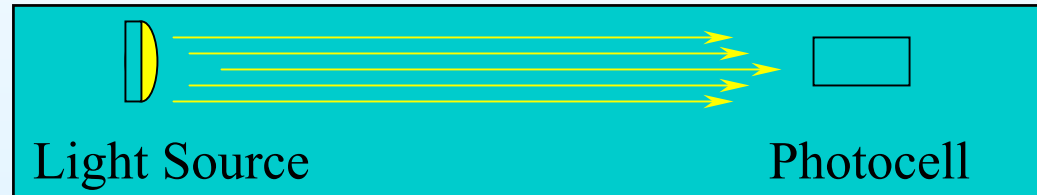
- Data from three full-scale test series
- Develop database of optical density measurements at detector alarm
- Determine range of optical density alarm thresholds
  - ◆ Detector type (ion/photo)
  - ◆ Fire type (flaming/smoldering)
  - ◆ Nominal detector sensitivity



# Data Sets

- Rationale for selection

- ◆ Full-scale fire tests with detectors and ODMs



- ◆ Range of test conditions
- ◆ UL-listed detectors

- Indiana Dunes

- U.S. Navy

- Fire Research Station (FRS)



# Indiana Dunes Data

- Conducted by IIT, UL, NBS in mid-1970's
- Residential test setup & fire sources
  - ◆ Upholstered furniture, mattress, carpet, wiring
- Detectors
  - ◆ Ion & Photo
  - ◆ 0.0143 OD/m & 0.0288 OD/m (1 %/ft & 2 %/ft)
- Optical density meters
  - ◆ White light lamp, 1.52 m (5 ft) path length
  - ◆ Ceiling and 1.52 m (5 ft) height



# U.S. Navy Data

- Conducted by NRL & Hughes Associates, Inc.
- Shipboard test setup & fire sources
  - ◆ Flammable liquids, mattress, linen, cardboard/paper
- Detectors
  - ◆ Ion: 0.0071 & 0.0186 OD/m (0.5 & 1.3%/ft)
  - ◆ Photo: 0.0071, 0.0361, & 0.0508 OD/m (0.5, 2.5, 3.5%/ft)
- Optical density meters
  - ◆ White light lamp, 1.52 m (5 ft) path length
  - ◆ Ceiling height



# FRS Data

- **Conducted by Fire Research Station (FRS)**
- **UK Residential test setup & BS5445 fire sources**
  - ◆ Foam, cotton wicks, flammable liquids, smoldering wood
  - ◆ Ad-hoc fires: cooking oil, upholstered furniture
- **Detectors: UL 268 & UL 217**
  - ◆ Ion: 0.0129 & 0.023 OD/m (0.9 & 1.6%/ft)
  - ◆ Photo: 0.027 & 0.0295 OD/m (1.88 & 2.05%/ft)
- **Optical density meters**
  - ◆ White light lamp, 1 m path length
  - ◆ Ceiling height



# Database

## ■ **Detector**

- ◆ Type, Nominal & Measured Sensitivity, Alarm Time

## ■ **Fire Source**

- ◆ Flaming/Smoldering, Material

## ■ **Detector Location**

- ◆ Room of origin/adjacent room..., floor

## ■ **Smoke Measurement**

- ◆ Value, Apparatus Description, Location

## ■ **Ventilation**

- ◆ On/Off, AC/Heat



# Data Collection

- **Alarm Times, Detector Info, & Test Conditions**
  - ◆ Available in test reports
- **Optical Density Measurements at Alarm**
  - ◆ Indiana Dunes
    - Determined from ODM history graphs.
  - ◆ Navy
    - Determined electronically from test data files
  - ◆ FRS
    - Data tabulated & presented in test report



# OD Alarm Threshold Definition

- **Definition:**

- ◆ The smoke optical density level at which a certain percentage of detectors would have alarmed, based on test data.

- **Selected Percentages**

- ◆ 20%, 50%, & 80%
- ◆ Limited by small sample sizes & variability of data



# FRS OD Alarm Thresholds

Detector Type	Nominal Sensitivity (OD/m)	Fire Source <sup>a</sup>	ODM Alarm Thresholds (OD/m)			ODM Value at Alarm (OD/m)		# Dets
			20%	50%	80%	Mean	Std Dev	
Ion	0.0129	F	0.013	0.025	0.062	0.039	0.039	15
Ion	0.023	F	0.006	0.023	0.053	0.032	0.034	15
Photo	0.027	F	0.056	0.120	0.165	0.117	0.061	15
Photo	0.0295	F	0.034	0.072	0.104	0.069	0.038	15
Ion	0.0129	S	0.098	0.205	0.267	0.212	0.125	11
Ion	0.023	S	0.032	0.094	0.164	0.100	0.074	12
Photo	0.027	S	0.038	0.089	0.160	0.100	0.058	13
Photo	0.0295	S	0.014	0.044	0.136	0.103	0.146	13

<sup>a</sup> F = Flaming Fires; S = Smoldering Fires



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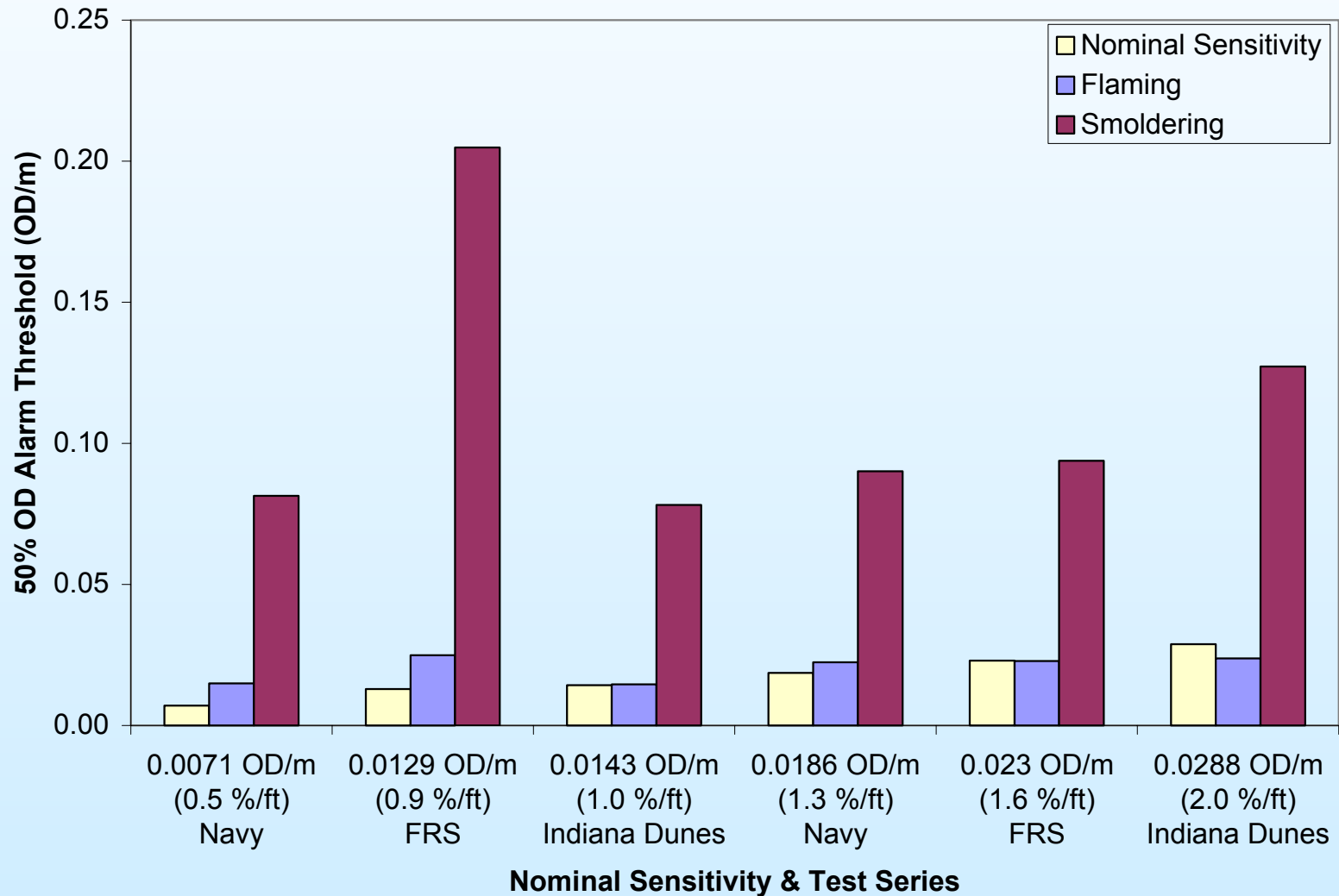


# Comments on Results

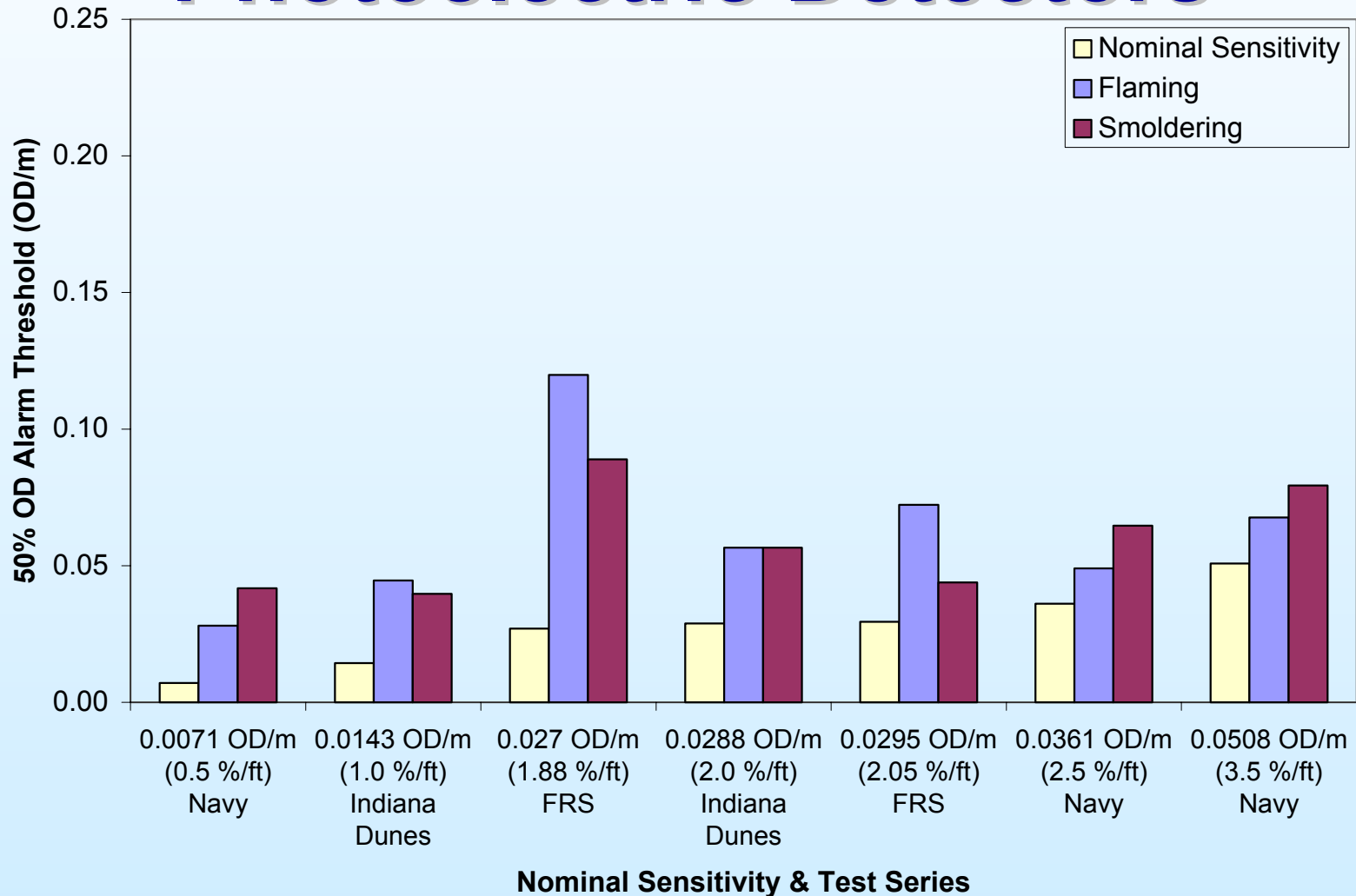
- Tremendous variation in data
- Detector Alarms at ODM values  $\sim 0$
- Application of OD Alarm Threshold
  - ◆ 20% - Early detector response estimate
  - ◆ 50% - Typical detector response estimate
  - ◆ 80% - Conservative detector response estimate



# 50% OD Alarm Thresholds for Ionization Detectors



# 50% OD Alarm Thresholds for Photoelectric Detectors



# Mean OD Alarm Thresholds

OD Alarm Threshold	Fire Type	Ionization Detectors	Photoelectric Detectors
20%	Flaming Fires	$0.007 \pm 0.004$ OD/m	$0.031 \pm 0.016$ OD/m
	Smoldering Fires	$0.045 \pm 0.028$ OD/m	$0.032 \pm 0.016$ OD/m
50%	Flaming Fires	$0.021 \pm 0.005$ OD/m	$0.063 \pm 0.029$ OD/m
	Smoldering Fires	$0.113 \pm 0.048$ OD/m	$0.059 \pm 0.019$ OD/m
80%	Flaming Fires	$0.072 \pm 0.027$ OD/m	$0.106 \pm 0.039$ OD/m
	Smoldering Fires	$0.176 \pm 0.052$ OD/m	$0.110 \pm 0.034$ OD/m

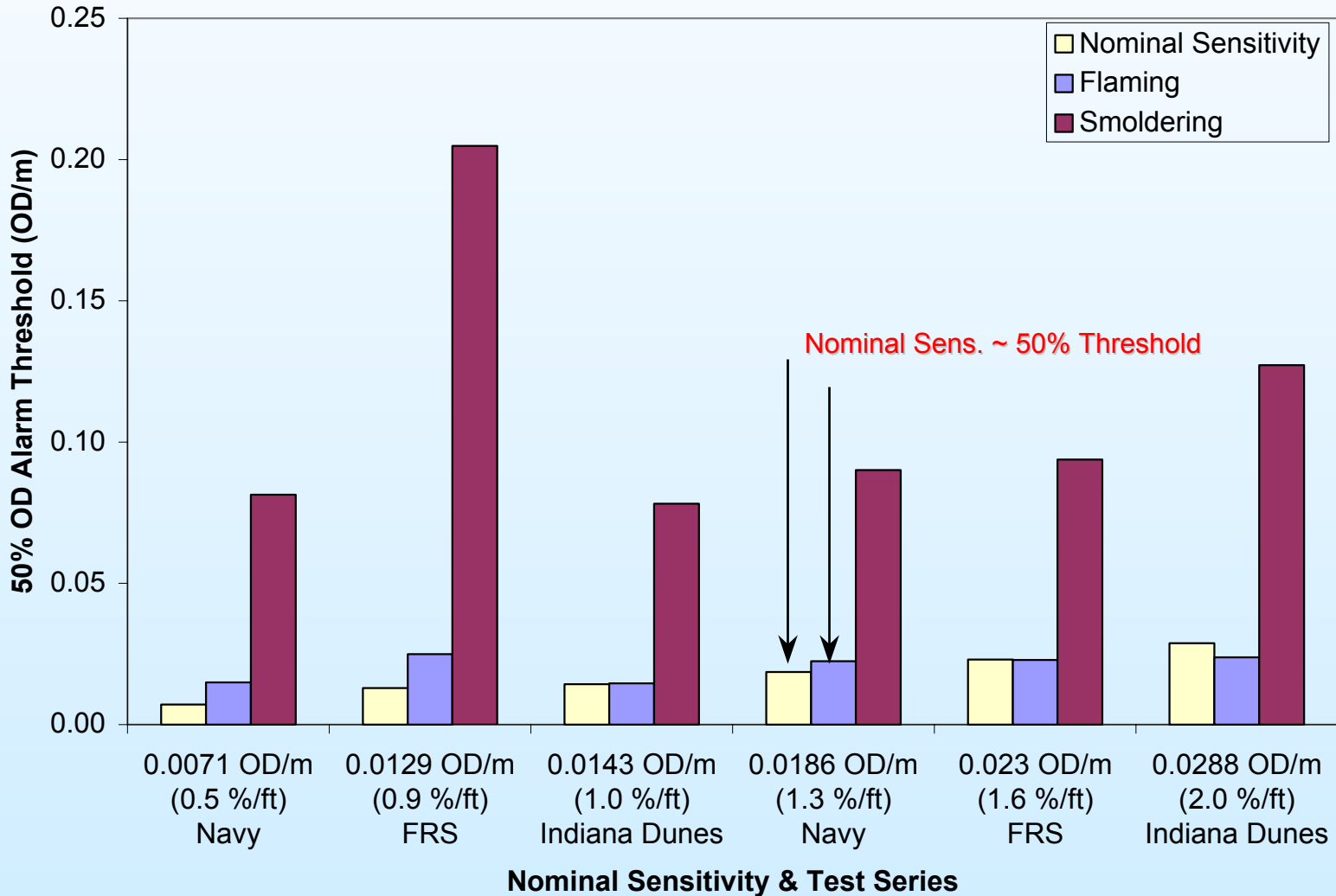


# Use of the Detector Nominal Sensitivity as Alarm Threshold

- Majority of 20% OD Alarm Thresholds greater than nominal sensitivity levels
- Percentage of detectors that alarmed at an OD equal to the nominal sensitivity varied widely (0-53%)
- Generally results in prediction of alarms before they occur.
- Typical response (i.e., 50%) of ionization detectors to flaming fires can be predicted



# Nominal Sens. OK for 50% Threshold of Ion with Flaming Fires



# Use of 0.14 OD/m as Alarm Threshold

- ◆ Compared to nominal sensitivity, provides much greater certainty that a detector will have alarmed
- ◆ Overall percentages of detector alarms at 0.14 OD/m
  - Ion / Flaming – 91%
  - Ion / Smoldering – 65%
  - Photo / Flaming – 86%
  - Photo / Smoldering – 87%
- ◆ Very conservative estimate of detector response, but may predict longer response times than actually occur.



# Other Effects on Results

- ◆ Effect of detector distance from the fire
  - Based on FRS data
  - Overall, effect minor compared to variation
  - Only notable for smoldering fires
  - Conclusions limited by sample size
- ◆ Ceiling vs. 5 ft ODMs
  - Based on Indiana Dunes data
  - Overall, ODM values at ceiling not significantly greater than at 5 ft.
  - Flaming / Ion showed greatest difference



# Alarm Threshold Study

## Conclusions

- ◆ Due to large variability in smoke measurements at alarm, prediction of detector response based on optical density is only an estimate
- ◆ 20%, 50%, & 80% OD Alarm Thresholds presented for ion/photo/flaming/smoldering



# Alarm Threshold Study

## Conclusions

- ◆ Generally, the nominal detector sensitivity performs poorly as an alarm threshold and predicts alarms before they would likely occur.
- ◆ Using 0.14 OD/m as an alarm threshold provides a conservative estimate of detector response and will likely predict longer response times than actually occur.



# Recommendations

- ◆ Need additional research to develop performance metrics for detectors
- ◆ Use a conservative approach for validating performance-based designs of smoke detection systems
- ◆ Consider the type of detector and type of fire



# Questions?

Geiman, J.A., and Gottuk, D.T., “Alarm Thresholds for Smoke Detector Modeling,” *Fire Safety Science - Proceedings of the Seventh International Symposium*, International Association of Fire Safety Science, June 2002.

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