

EVALUATION OF SMOKE DETECTOR RESPONSE ESTIMATION METHODS

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Goals

- Evaluate recommended thresholds
- Examine the predictive capabilities and quantify uncertainty.
- Provide guidance on the use of smoke detector response estimation techniques.



Scope

- Phase 1 – Determine values of optical density, temperature rise, & velocity at alarm
 - ◆ Over 400 smoke detector responses
 - ◆ Spot-type ionization and photoelectric detectors
- Phase 2 – Predict alarm times from experimental measurements
 - ◆ Use threshold values from the literature
 - ◆ Assess uncertainty in estimation method
 - How close are the estimated alarm times?



Background

- Approximation/Estimation Methods
 - ◆ Optical Density
 - ◆ Temperature Rise
 - ◆ Critical Velocity
- Methods do not address the operating principle of the detectors
- Uncertainty in approximation?



Alarm Thresholds

- Optical Density
 - ◆ Nominal sensitivity (UL 217 / UL 268)
 - ◆ 0.14 m^{-1} (Max. black smoke OD from UL tests)
 - ◆ 20th, 50th, & 80th percentiles of optical density at alarm values from experiments
- Temperature Rise
 - ◆ $4 \text{ }^{\circ}\text{C}$
 - ◆ $13 \text{ }^{\circ}\text{C}$
- Velocity
 - ◆ 0.15 m/s



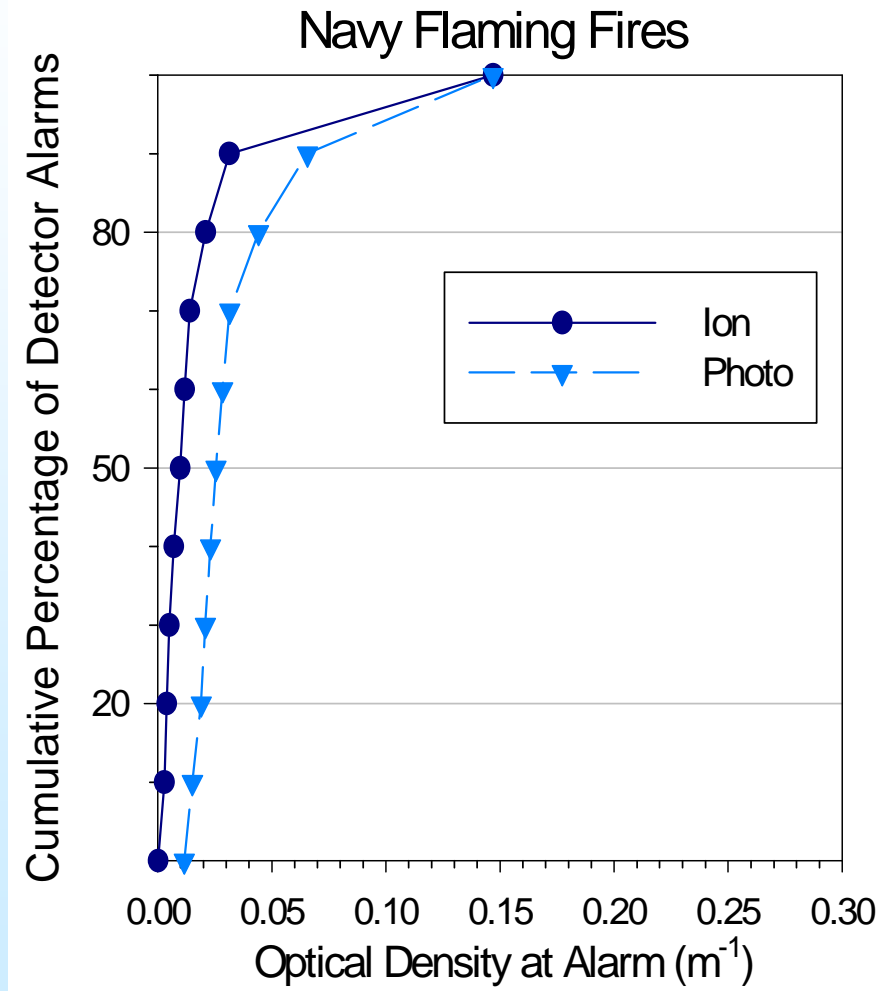
Experimental Data

- Navy (HAI, NRL)
 - ◆ 41 small flaming & smoldering fires
 - ◆ Ship compartments
 - ◆ Ventilation: 0 or 12 air changes / hour
 - ◆ Detectors: 2 models each for ion & photo
 - ◆ Instrumentation: OD, temp, & velocity
- Kemano (NRC Canada)
 - ◆ 12 small smoldering-to-flaming fires
 - ◆ Residential dwellings
 - ◆ Residential Smoke Alarms
 - ◆ Instrumentation: OD & temp



OD at Alarm – Flaming Fires

- Detector type only significant variable
 - ◆ Ventilation & detector model not significant
- OD at alarm lowest for ion detectors



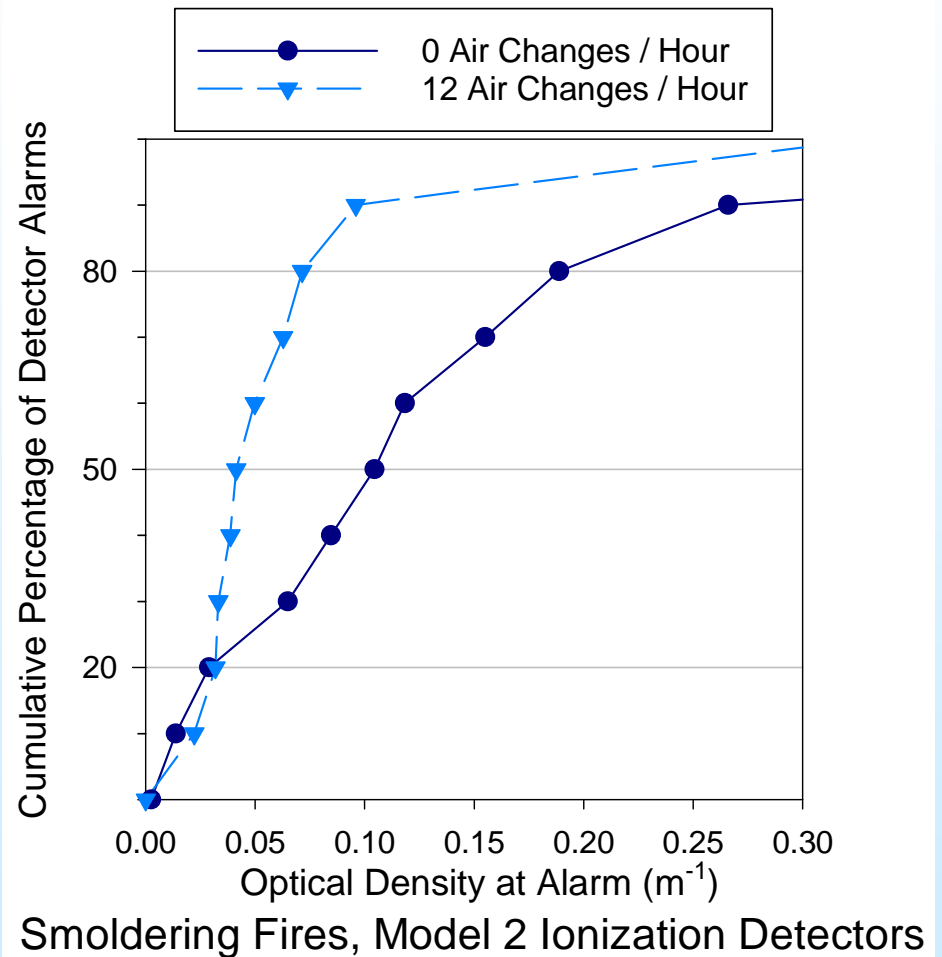
OD at Alarm – Smoldering Fires

■ Significant variables

- ◆ Detector type
- ◆ Ventilation (Ion & Photo)
- ◆ Detector model (Ion only)

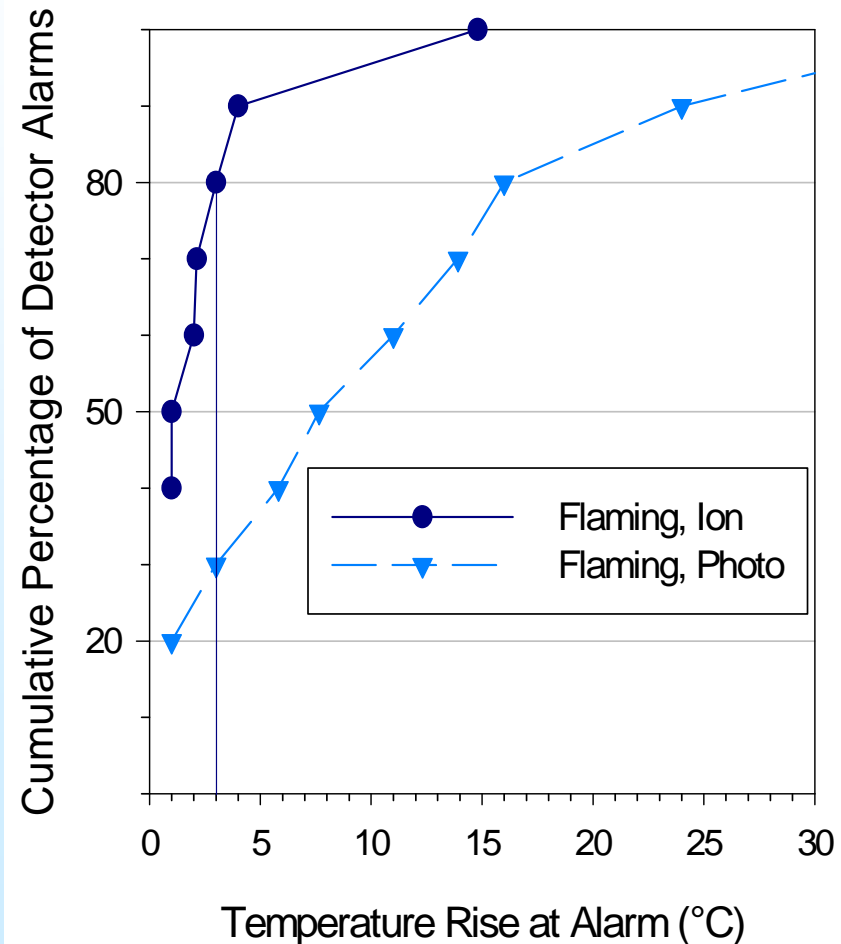
■ OD at alarm

- ◆ Large variation
- ◆ 2 – 3x higher without ventilation.



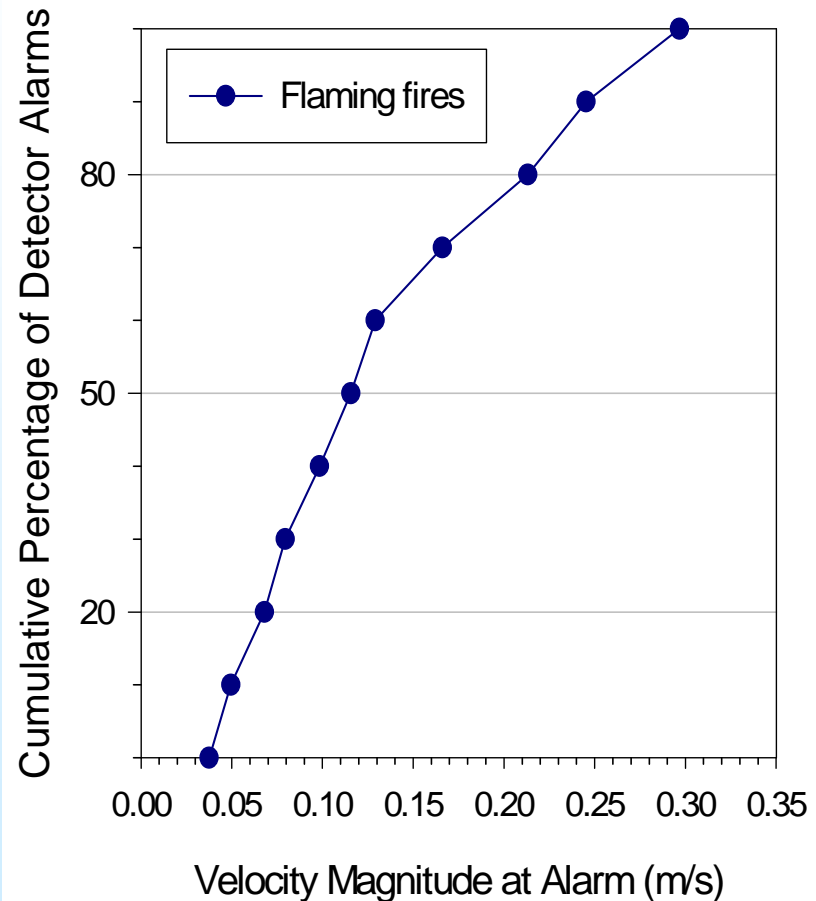
Temperature Rise at Alarm

- Significant variables
 - ◆ Fire type
 - ◆ Detector type
- Flaming, ion lower than most report ($80\% < 3^{\circ}\text{C}$)
- Smoldering and smoldering-to-flaming fires not presented
 - ◆ Max values 1 – 3 °C



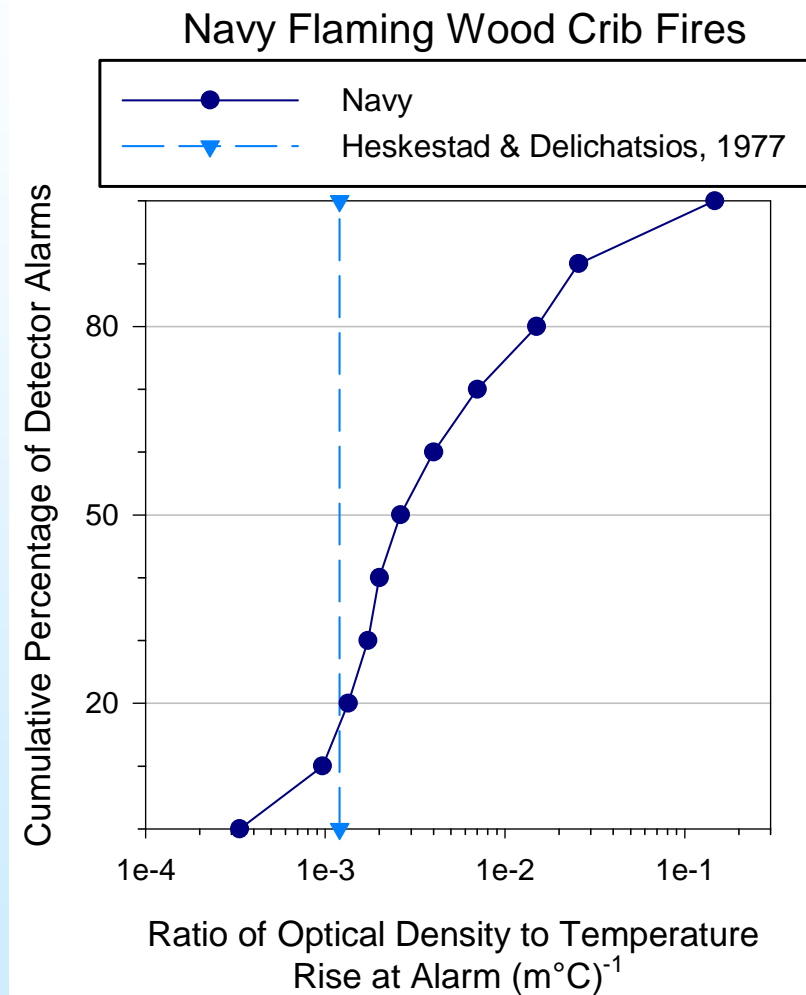
Velocity Magnitude at Alarm

- Small population of data (30 flaming)
- Fire type only significant variable
- Flaming fires: mean value consistent with previous reports
 - ◆ 0.13 ± 0.07 m/s
- Smoldering fires: No measurable velocity over ambient conditions



OD to Temp Rise Ratio

- Variation of 1 – 2 orders of magnitude (at alarm time)
- Temp. rises $< 3\text{ }^{\circ}\text{C}$ included



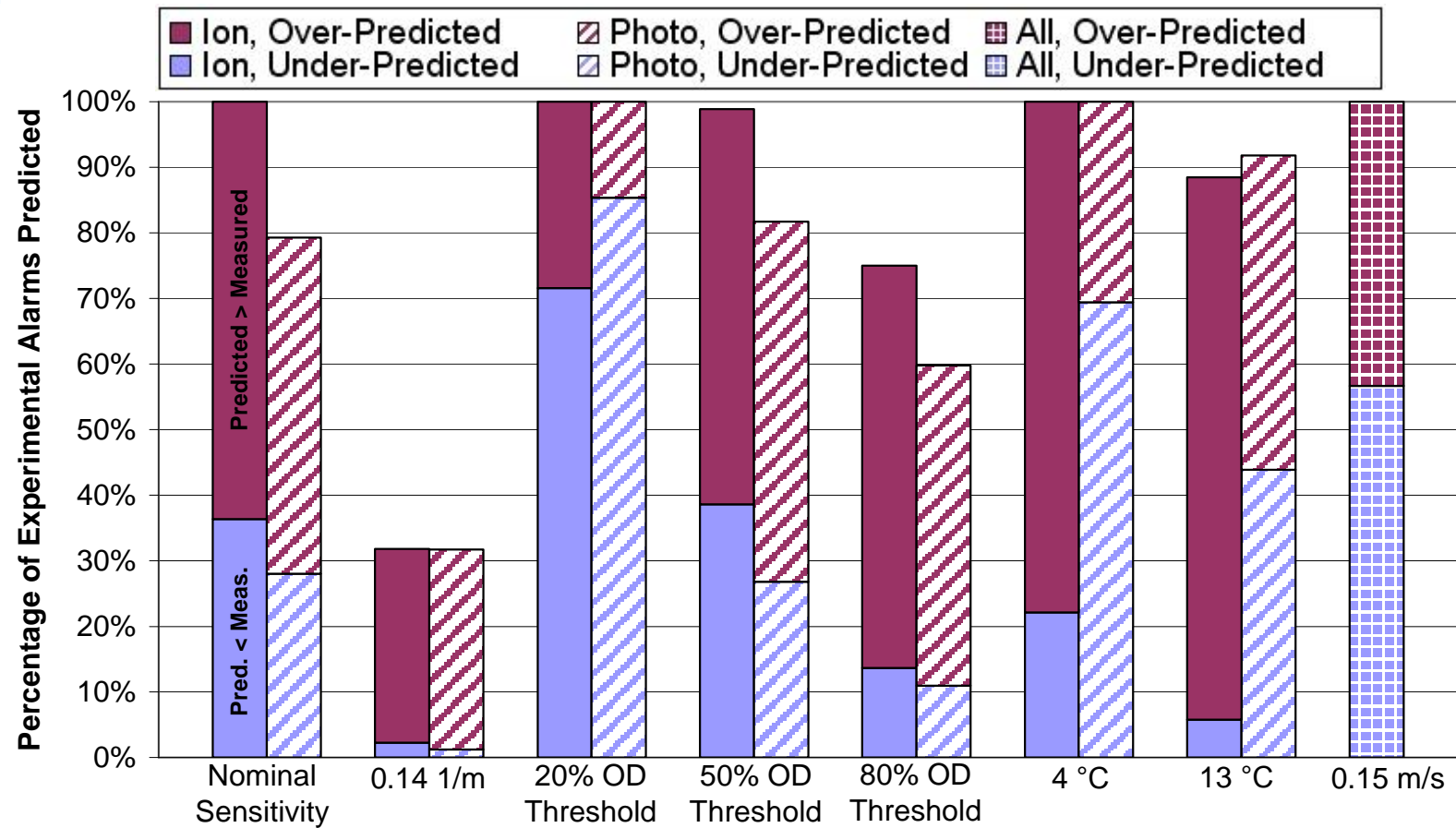
Phase 2 - Methodology

- Predict alarm times with each threshold
- Characterize Uncertainty
 - ◆ Percentage of alarms predicted
 - Under-predicted alarm time
 - Predicted Alarm Time < Measured Alarm Time
 - Over-predicted alarm time
 - Predicted Alarm Time > Measured Alarm Time
 - ◆ Percentage of predicted alarm times within ± 60 s of measured alarm time



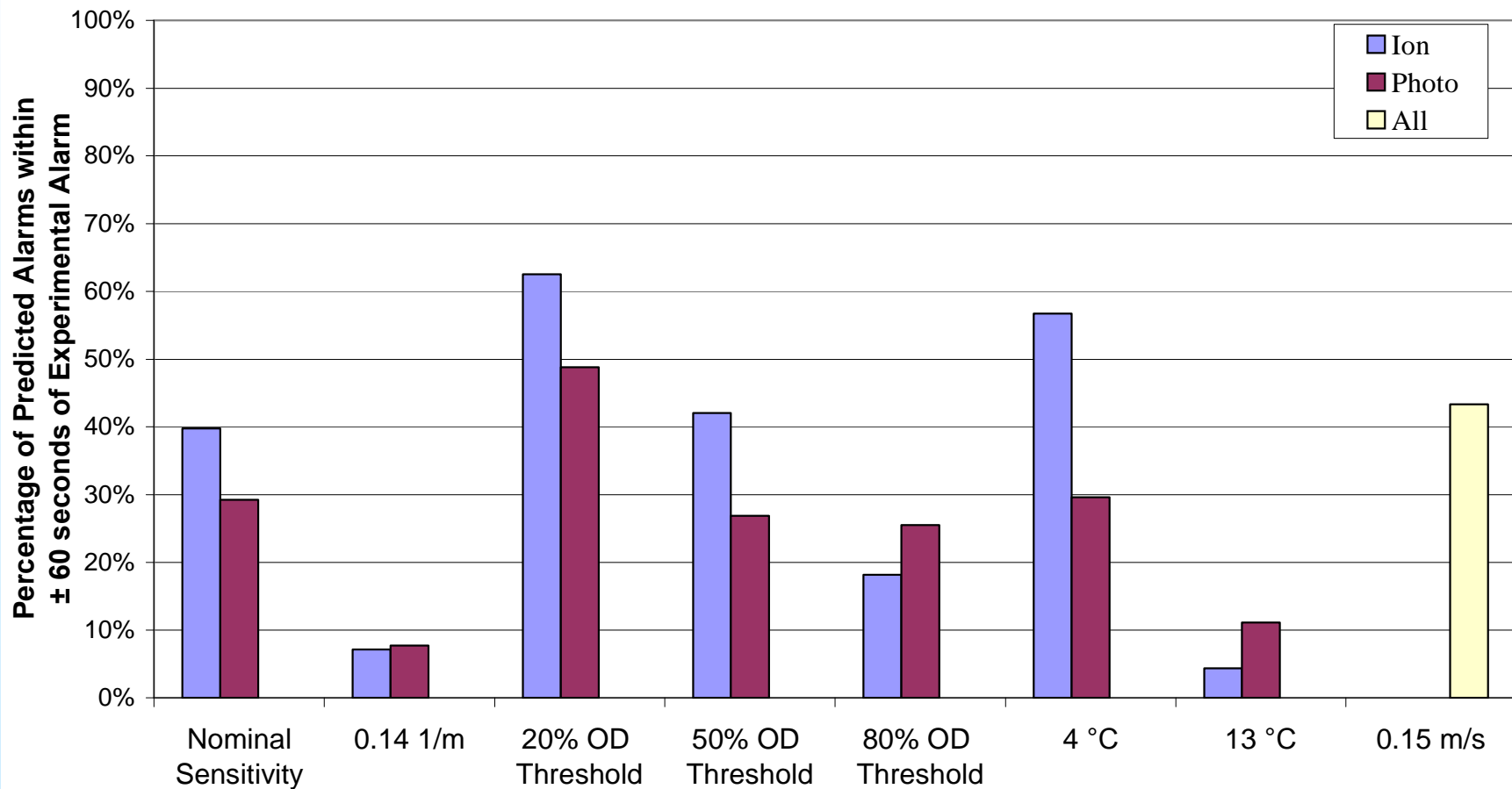
Phase 2 – Flaming Fires

Percentage of Under- and Over-Predicted Alarm Times w.r.t Measured Alarm Time



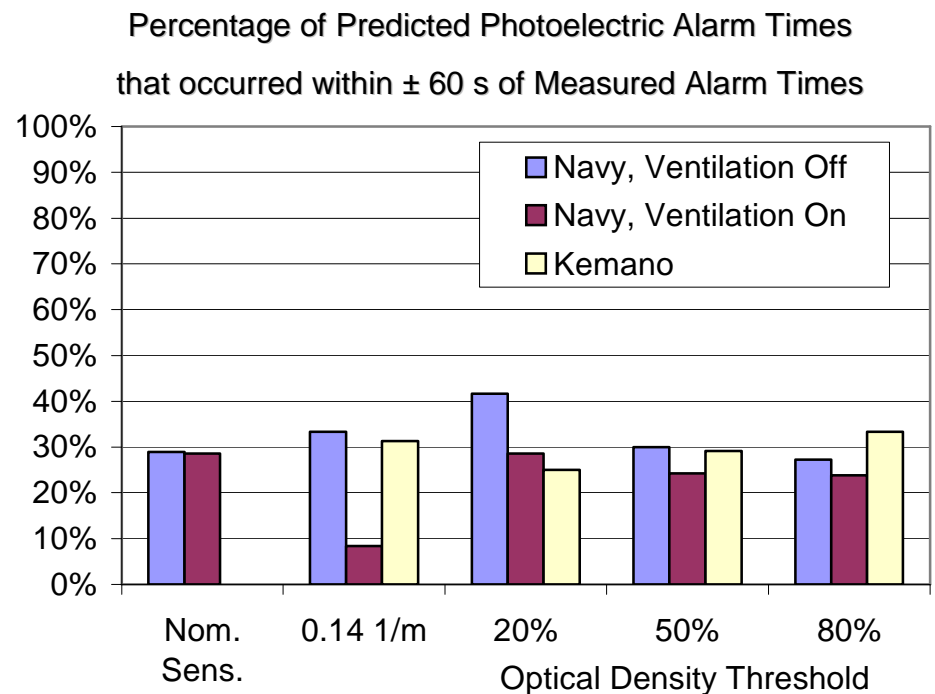
Phase 2 – Flaming Fires

Percentage of Predicted Alarm Times that occurred within ± 60 s of the Measured Alarm Times



Phase 2 – Smoldering Fires

- 13 °C & 0.15 m/s predicted no alarms, 4 °C predicted ~10%
- % alarms predicted with OD thresholds varied (40 – 100%)
- Most alarm times under-predicted
- Generally, < 40% of predicted alarms within ± 60 s of experimental alarm



Phase 2 - Summary

- None of the thresholds distinguished themselves as vastly superior
- Generally, < 50% of predicted alarms within ± 60 s of experimental alarm



Recommendations

- Account for uncertainty when applying these estimation methods
- When estimating detector response...
 - ◆ Consider a range of thresholds
 - Establish Bounding Scenarios (if possible)
 - Determine sensitivity of results to thresholds
 - ◆ Do not expect precise alarm times
- Additional research on smoke entry
- Prediction methods needed based on detector operating principles.

