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Residential Nuisance Source Characteristics for Smoke Alarm Testing

Abstract

Nuisance scenario tests were performed in the manufactured home used in the Home Smoke Alarm fire test series. The scenario selections were based on what are commonly thought to be causes of residential nuisance alarms, and were designed to mimic normal activities (i.e. no intentional food burning, with the exception of toasted bread.) The bulk of the scenarios were related to cooking activities including: frying, deep-frying, baking, broiling, boiling, and toasting. In addition, cigarette smoking and candle burning were included. Smoldering fire scenarios were examined for comparative purposes. Aerosol concentrations, temperature, humidity, flow velocity and analog output from several photoelectric, ionization and carbon monoxide sensors were gathered. It was observed that nuisance alarms in residential settings were affected by the properties of the aerosol produced, its concentration, the location of an alarm relative to the source, and the air flow that transports smoke to an alarm. This study provides a detailed set of data that can be used to address several issues involving nuisance alarms and reinforces current suggested practices.

Introduction

Smoke alarms are susceptible to alarming when exposed to non-fire aerosols. In residential settings, this typically involves cooking activities or transient, high humidity conditions (i.e., “show steam”). The objective of this research, performed as part of the Home Smoke Alarm project [1], was to develop a basis for standard residential nuisance source testing. The approach taken was to define a set of nuisance scenarios, replicate the events that cause nuisance alarms, and quantify the important variables that cause nuisance alarms. Translating the results to a set of nuisance source conditions reproducible in a suitable test-bed (i.e., a test room or the fire emulator/detector evaluator) would allow for more comprehensive detector performance testing.

Experimental

Nuisance scenario tests were performed in the manufactured home used in the Home Smoke Alarm fire test series [1]. The selections were based on what are commonly thought to be causes of residential nuisance alarms, and scenarios were designed to mimic normal activities (i.e. no intentional food burning, with the exception of toasted bread). No consideration was given to the probability of occurrence for any given scenario; the objective was to gather data on a number of scenarios. The bulk of the scenarios were related to cooking activities including: frying, deep-frying, baking, broiling, boiling, and toasting. Cigarette smoke and candles were included. Smoldering fire scenarios (smoldering polyurethane foam, beech wood blocks and cotton wick) were examined for comparative purposes.

A schematic of the manufactured home is shown in Figure 1. Its exterior dimensions were 20.1 m long and 4.2 m wide, with and interior ceiling that was pitched from the centerline height of 2.4 m to a height of 2.1 m at the long exterior walls. The dark shaded areas were closed off. During these tests, all external doors and windows were closed. Most scenarios were repeated with and without a floor fan blowing air from the master bedroom into the kitchen/living room area.

Aerosol concentrations, temperature, humidity, flow velocity and analog output from photoelectric, ionization and carbon monoxide sensors were gathered. Figure 1 shows the approximate ceiling location of all the measurement positions. Details of the measurement are given in NIST TN 1455 [1].

Two portable aerosol instruments were used to gather aerosol number and mass concentrations during the tests. Number concentration was recorded with a TSI model 3007 portable condensation particle counter (CPC)*. This instrument is capable of

* Certain commercial equipment are identified in this paper in order to accurately describe the experimental procedure. This in no way implies recommendation by NIST

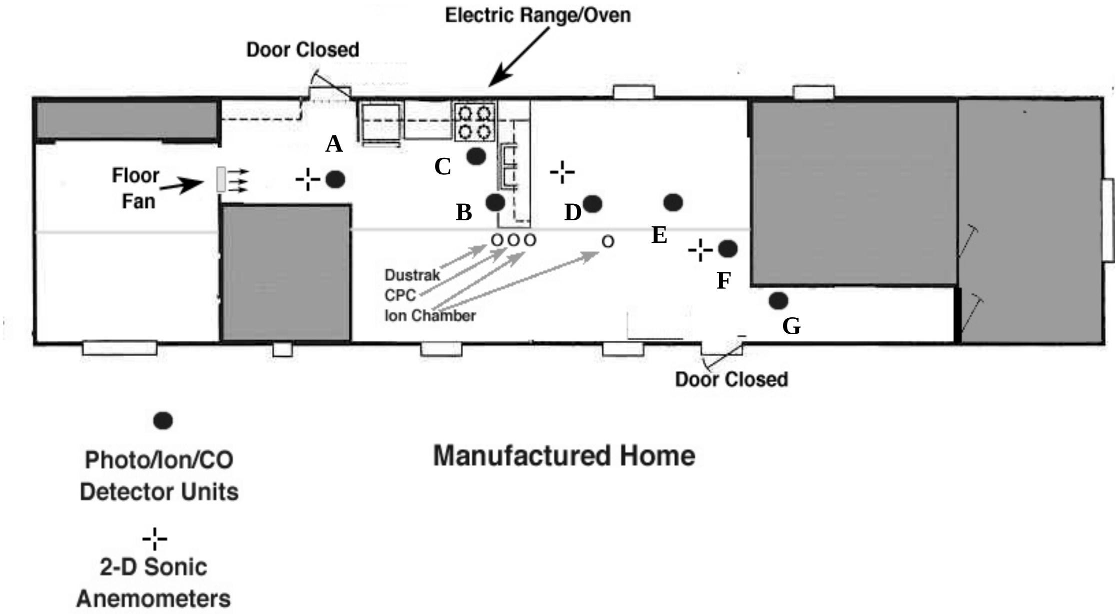

Figure 1. Schematic of the test home.

counting particles greater than 10 nanometers up to concentrations of $5x10^5$ particles/cm^3 with an uncertainty of 10% of the reading. The upper concentration limit of the instrument is insufficient for many fire and nuisance conditions so the air sample was diluted with a fixed amount of clean air prior to entering the CPC resulting in an approximate 20 to 1 dilution ratio of the sample. The dilution ratio for each test was obtained by measuring undiluted and diluted background room aerosol prior to the start of the test. The uncertainty in the dilution corrected number concentration is estimated to be 12%. A TSI model 8520 "Dustrak" portable aerosol mass monitor was used to gather the aerosol mass concentration. This device consists of a light scattering photometer that analyzes the laser light scattered at an angle of 90^o from particles flowing through the device. Its default calibration is set to the respirable fraction of standard ISO 12103-1 A1 test dust. It has a range from 0.001-150 mg/m^3. The effective particle size measurement range is 0.1 μm up to 10 μm. The device can be calibrated for any aerosol with scattering properties different from the test dust provided the true mass concentration is determined. Here, the default calibration was used, so any given mass concentration measurement reported are relative to an equivalent mass of test dust. Since the device in not calibrated to each of the aerosols produced in the nuisance tests, the uncertainty in the measurement in not determined. However, the results are proportional to the mass concentration and correspond directly to the scattering signal strength of photoelectric detectors with an equivalent amount of aerosol in its sensing region.

Seven dual photo/ion smoke alarms were modified at NIST to provide continuous analog output of photoelectric, ionization, carbon monoxide, and temperature sensor values [1]. Each detector was calibrated in the FE/DE with the cotton wick smoke, and the sensor values are presented in engineering units of extinction coefficient (m^{-1}), volume fraction of CO, and temperature in Celsius. The positions of the sensor packages are indicated on Figure 1 and represented in the results by the letters A-G. Carbon monoxide and temperature sensor data are not presented here. All of the data collected in this test series is available in the NIST Report of Test FR 4019 [2].

The time to reach photoelectric and ionization alarm points was determined from ion and photoelectric sensor calibration test data, and estimated alarm sensitivities appropriate for the FE/DE cotton wick smoke. Estimated high, medium and low sensitivities for both photoelectric and ionization alarms in terms of extinction coefficient and obscuration are given in Table 1. These values cover the range expected for residential smoke alarms for each sensor type.

Sensor	High sensitivity m^{-1}, (%/ft)	Medium sensitivity m^{-1}, (%/ft)	Low sensitivity m^{-1}, (%/ft)
Photoelectric	0.05, (1.5)	0.083, (2.5)	0.117, (3.5)
Ionization	0.016, (0.5)	0.033, (1.0)	0.050, (1.5)

Table 1. Alarm sensitivity for photoelectric and ionization sensors

Results and Analysis

The results presented here are for selected tests showing the time to alarm for each photoelectric and ionization sensor at the three sensitivity levels, and the aerosol mass and number concentration at a central ceiling level location. Location E only had an

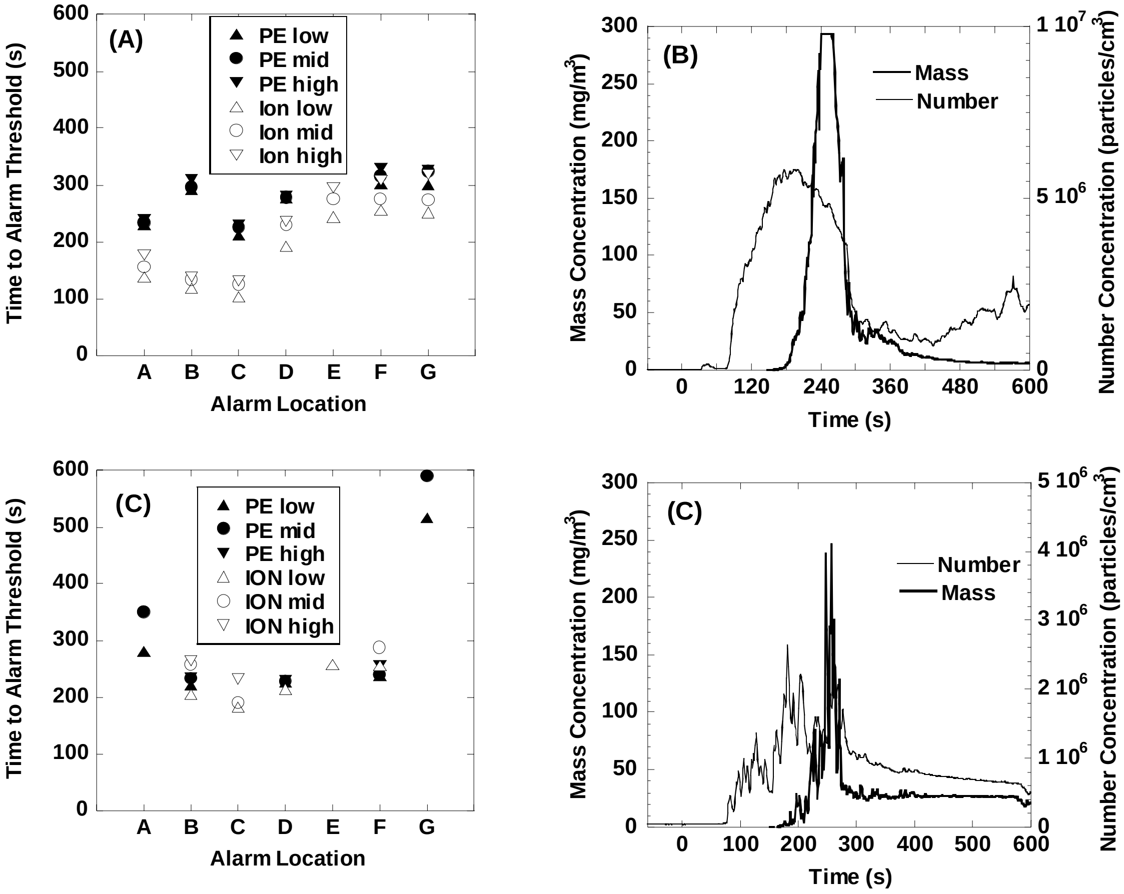

Figure 2. Results for toasting bread. Figures labeled A and B are for the test with no fan, and figures labeled C and D show repeated test results with the fan on.

ionization smoke sensor. Nominal repeat tests are shown without the floor fan on (labeled A and B) and with the floor fan turned on (labeled C and D.)

The toasted bread results are shown in Figure 2. The toaster with two slices of bread was placed on the counter to the left of the range. It was turned on at time = 0 and turned off 250 s later. With no fan flow, the ionization alarms tended to reach their threshold levels before photoelectric alarm. The time to reach the threshold increased as the distance of the toaster from the alarms increased. The number concentration reached its peak before the mass concentration began to rise, and started to fall before the mass concentration peak was reached. With the fan turned on, fewer alarm thresholds were met, and contrary to the no fan case, some photoelectric alarm thresholds were reached before the ionization thresholds, and at some locations the

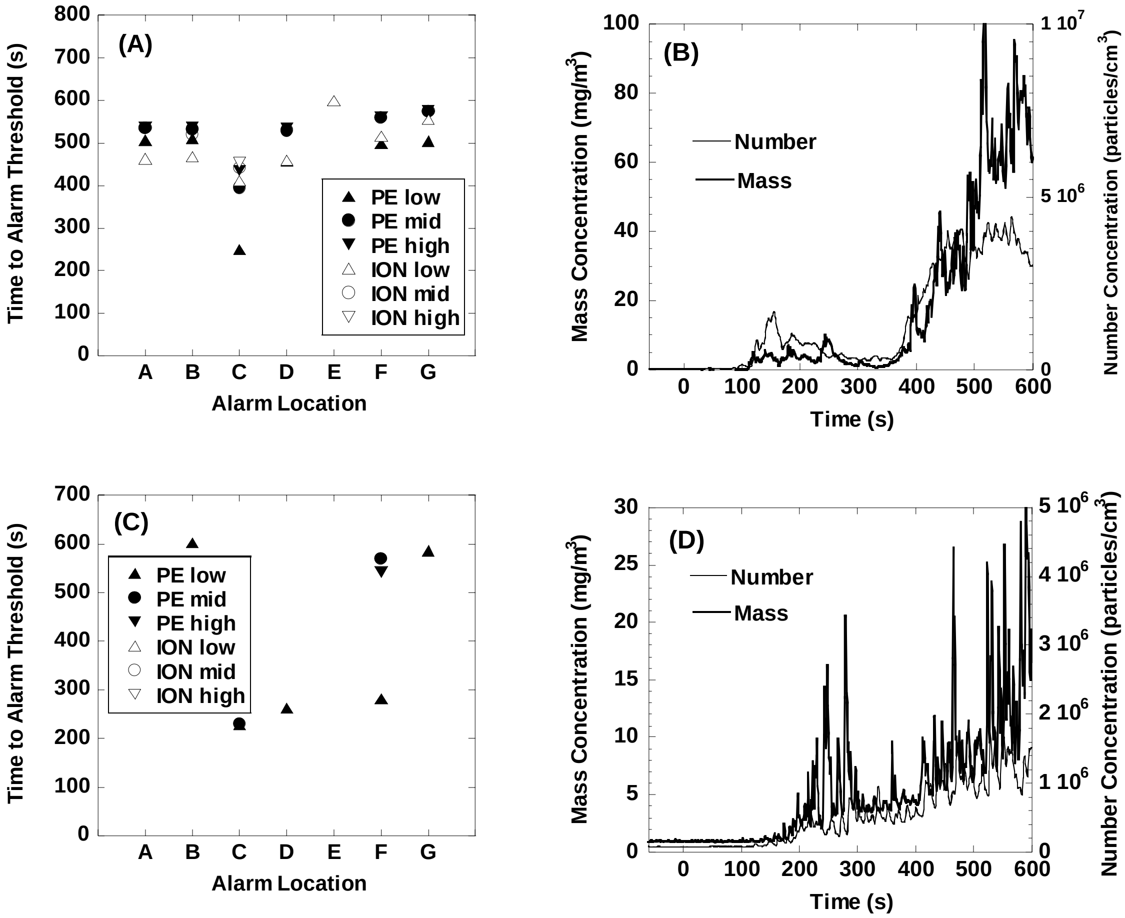

Figure 3. Results for frying hamburgers (A and B – fan off, C and D - fan on)

ionization alarms never reached their low threshold. The number and mass concentration trends were similar to the no fan case, but the levels were lower.

Three 110 g frozen hamburgers were fried in an aluminum skillet pan on an electric range. With no fan flow, all locations reached photoelectric and ionization alarm thresholds, most within 100 s of one another. The photoelectric sensor closest to the electric range reached a threshold first. The number and mass concentration increased steadily after 350 s. With the fan on, no ionization alarm thresholds were reached, and photoelectric alarm thresholds were reached at all locations they were present except location A. The number and mass concentration started to increase at 150 s and the mass concentration showed brief sharp increases periodically.

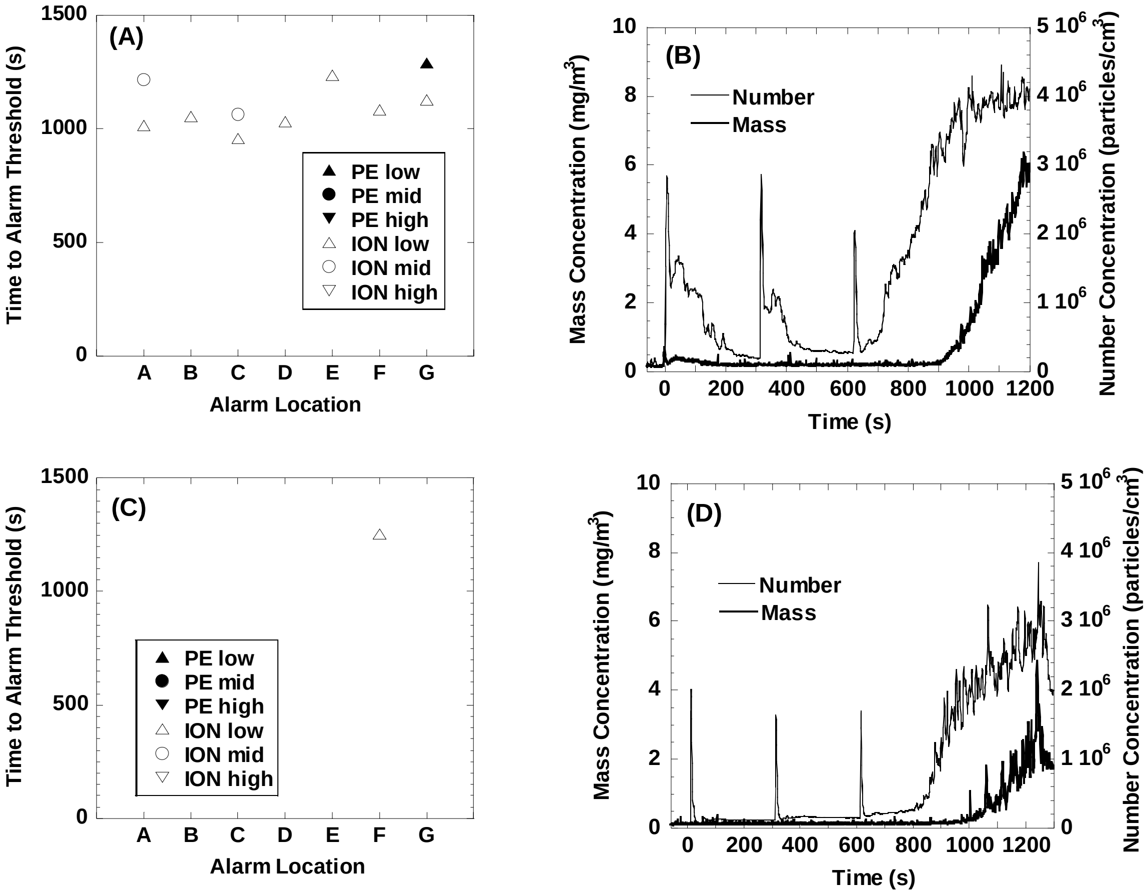

Figure 4. Results for pizza cooking (A and B – fan off, C and D - fan on)

A small (158 g) frozen cheese pizza was cooked on a pan in the oven. To begin, the oven was pre-heated to 350 ^{o}F, the pizza was placed in the oven, then baked. The oven door was opened twice during baking time to check the pizza. After 630 s, the oven broiler element was turned on and the door was left slightly open. Figure 4 shows the results for the pizza cooking tests. With the fan off, all locations reached an ionization threshold, and only one location reached a photoelectric threshold. The number concentration results show three spikes at the time the oven door was being opened. The mass concentration doesn't start to increase significantly until about 900 s. With the fan on, only one location reached an ionization alarm threshold, and it was at a location some distance from the oven. The number concentration showed three spikes due to the door opening, but both the number concentration and mass concentration were lower compared to the fan off case.

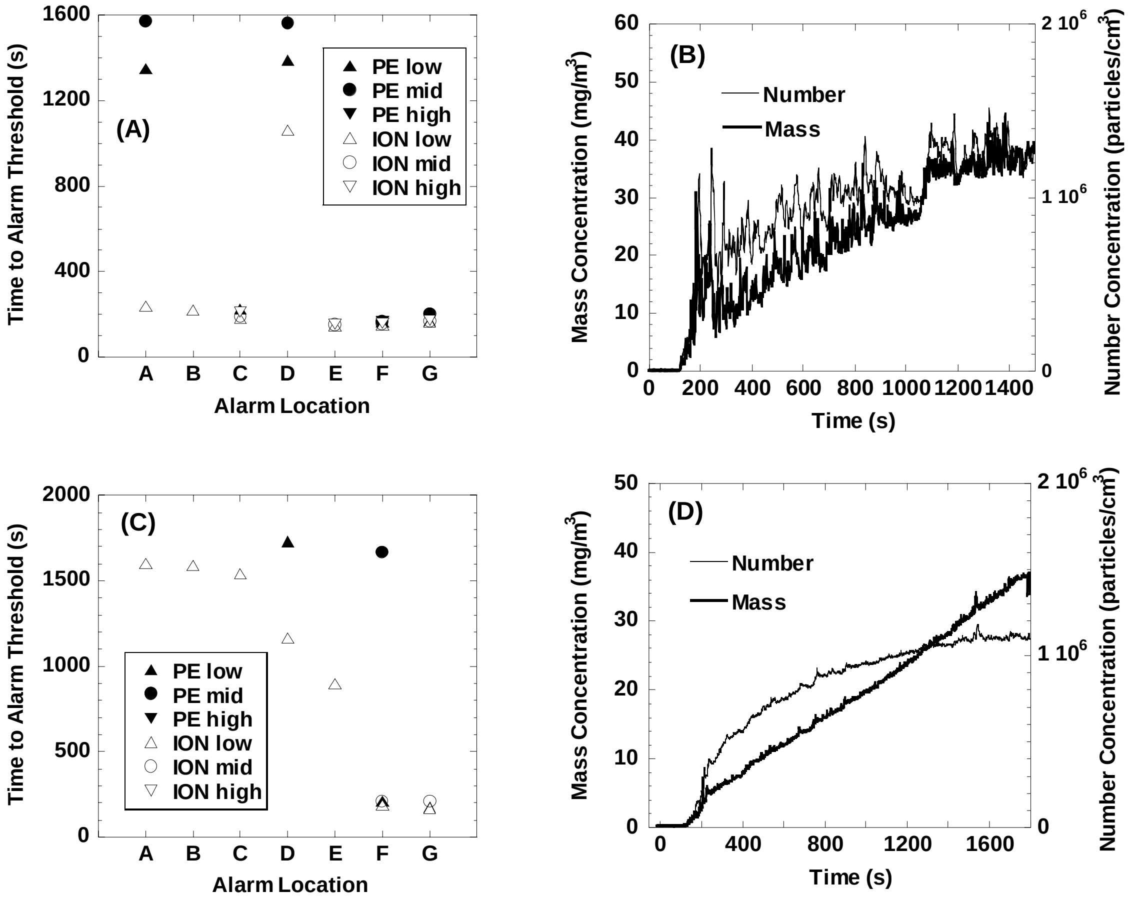

Figure 5. Results for smoldering wicks (A and B – fan off, C and D - fan on)

The cotton smolder smoke was generated with the staged wick ignition device [3] placed on the floor in the living room area. After an initial delay of 30 s, 8 sets of 4 wicks were ignited with 12 s delay times between sets. With no fan flow, ionization alarm thresholds were reached at all locations. Photoelectric alarm thresholds were reached at the locations nearest the source first, then much later at locations further from the source (Location B did not have a working photoelectric alarm during this test.) The number and mass concentration began to increase around 150 s, and steadily increased during the test. With the fan on, the two ionization alarms closest to the smoldering wicks reached thresholds, followed by the locations further from the source. Only two locations reached photoelectric alarm thresholds. The number and mass concentration began to increase around 150 s. The mass concentration steadily

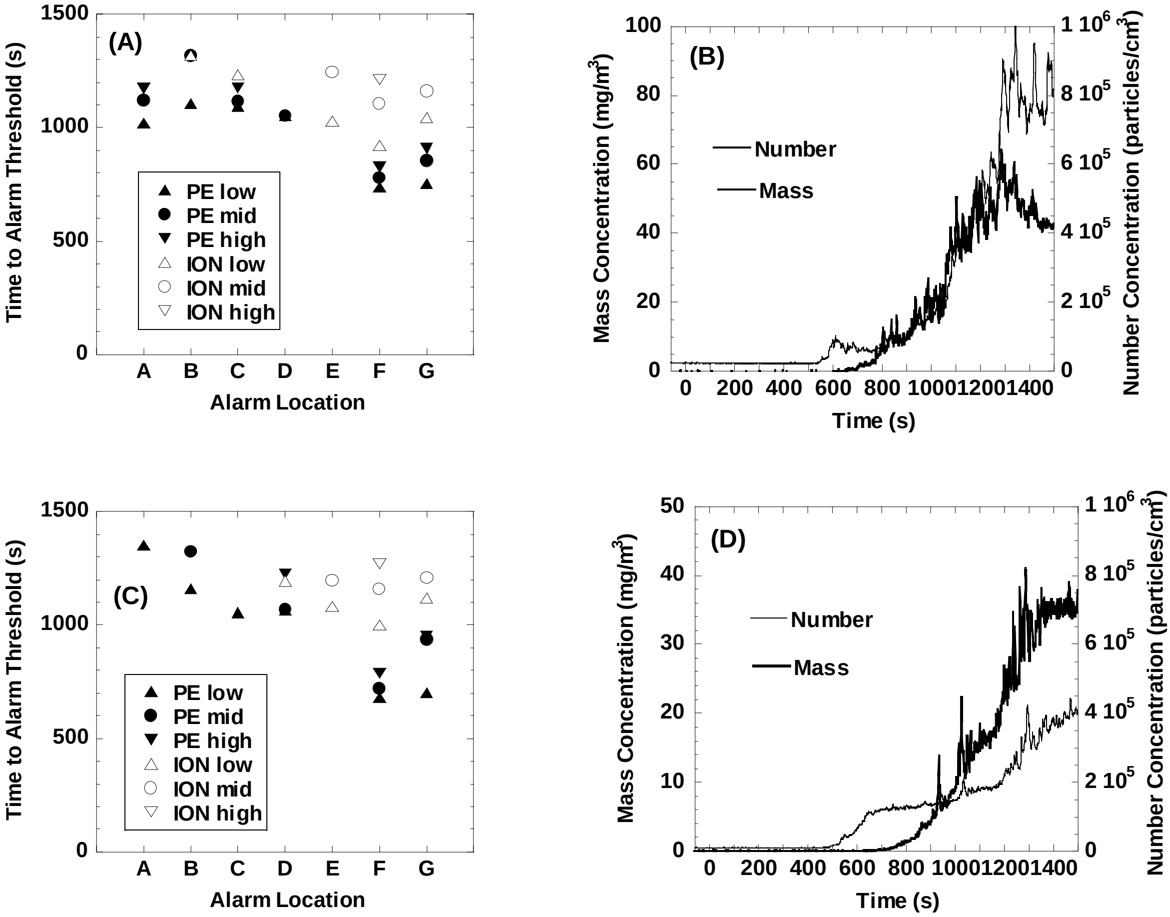

Figure 6. Results for smoldering wood (A and B – fan off, C and D - fan on)

increased during the test, while the number concentration rate of rise started to decrease after 200 s.

Wood smoke was produced by placing eight 3.5 cm by 2.0 cm by 1.0 cm beech wood blocks on a 750 W electric hot plate. The hot plate was located on the living room floor, and at the beginning of the test the hot plate was turned on. For the fan off case, the photoelectric alarms reached their thresholds before the ionization alarms at all locations. The number and mass concentration started to increase between 500 s and 600 s, and both increased steadily until the hot plate was turned off at 1200 s. For the case with the fan on, all locations that have photoelectric alarms reached threshold values, and ionization alarms closest to the source reached threshold values. Results were similar to the no fan case. The number concentration started to increase at about

500 s, while the mass concentration started to increase at 700s; the concentration levels were below the no fan case.

Conclusions

The results presented for nuisance source tests and comparative smoldering tests here display several characteristics related to nuisance alarms. Nuisance alarms in residential settings from typical cooking activities, smoking or candle flames were affected by the properties of the aerosol produced and its concentration, the location of an alarm relative to the source, and the air flow that transported smoke to an alarm. These conclusions hold for the additional tests from this series [1]. Threshold adjustment to lower sensitivities reduced the number of nuisance alarms in some cases, but in others, the rate of smoke production was so great, that all threshold levels were reached in a short period of time. With ventilation air flow, dilution of the aerosol as it was dispersed throughout the home tended to reduce the smoke levels below alarm threshold values. This study provides a detailed set of data that can be used to address several issues involving nuisance alarms and reinforces current suggested practice of moving alarms as far away from cooking appliances as practical. Additionally, the results are being programmed into the fire emulator/detector evaluator to reproduce the nuisance source conditions, which will allow for more comprehensive detector performance testing.

References

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[2] Cleary, T., "Home Smoke Alarm Project, Alarm Responses to Nuisance Sources," Natl. Inst. Stand. Technol., Report of FR 1419, 2003.

[3] Cleary, T., Donnelly, M., and Grosshandler, W., "The Fire Emulator/Detector Evaluator: Design, Operation, and Performance," 12th International Conf. on Automatic Fire Detection AUBE '99, Gaithesburg, MD, USA , pp. 312-323, 2001.