

Contents

Revision History	v
Contents	ix
Figures and Tables	xiii
Executive Summary	xxiii
Acknowledgments	xxvii
1 Introduction	1
1.1 History	2
1.2 Concerns Raised	3
1.3 Organizing the Research Project	4
1.3.1 Evaluate the Performance of Current Smoke Alarm Technology	4
1.3.2 Test Conditions Representative of Current Fatal Residential Fires	5
1.3.3 Evaluate the Efficacy of Current Requirements for Number and Location of Smoke Alarms.	6
1.3.4 Develop Standard Nuisance Alarm Sources to Be Included in the Test Program.	7
1.3.5 Examine Other Fire Detection Technologies in Combination with Smoke Alarms	7
1.3.6 Obtain Data on the Potential for Improvements in Performance by New Technologies	8
1.3.7 Include Fuel Items That Incorporate Materials and Constructions Representative of Current Residential Furnishings	8
1.3.8 Fully Characterize Test Detectors and Alarms in a Consistent Manner to Facilitate Comparisons	8
1.3.9 Utilize Fire Models to Extend the Applicability of the Test Arrangements and Maximize the Test Instrumentation	8
1.3.10 Make All of the Data Collected as Widely Accessible as Possible	8
1.3.11 Provide Opportunities to Enhance Public Fire Safety Education	9
1.4 Project Oversight	9
2 Residential Fire Alarms, Sensor Response and Calibration in the FE/DE	11
2.1 Residential Alarms Included in the Study	11

2.2	The fire emulator/detector evaluator	12
2.3	Smoke Aerosols	14
2.4	Calibration of Smoke and CO alarms	18
2.5	Alarm Identification	24
2.6	Evaluation of Unmodified Alarm Response	28
2.7	Effect of Sensor Board Location on Response	47
2.8	Thresholds for Modified Alarms	62
3	Fire Source Test Scenarios and Geometries	65
3.1	Scenario Development	65
3.2	Material Selection	67
3.2.1	Upholstered Furniture	67
3.2.2	Mattress	69
3.2.3	Cooking Materials	69
3.3	Ignition Methodology	70
3.3.1	Flaming Ignition	70
3.3.2	Smoldering Ignition	71
3.3.3	Cooking Ignition	72
3.4	Test Geometry	72
3.4.1	Manufactured Home	72
3.4.2	Two-story Home	73
4	Fire Source Testing Instrumentation	77
4.1	Temperature	77
4.2	Sample Mass	82
4.3	Primary Gases – CO, CO ₂ , and O ₂	83
4.4	FTIR Gas Analysis	84
4.5	Optical Density	84
4.6	Smoke Properties	87
4.7	Smoke and CO Alarm Response	89
4.8	Sprinkler Response	90
4.9	Mechanical Heat Alarm Response	91
5	Fire Source Test Results and Calculations	93
5.1	Tests Conducted	93
5.2	Test Data	95
5.3	Calculation of Alarm Times	104
5.4	Calculation of Time to Untenable Conditions	119
5.4.1	Tenability Limits	119
5.4.2	Tenability Times	121
5.5	Assessment of Overall Alarm Performance	122
5.6	Aerosol Concentration and Size Measurements	124

5.6.1	Mass and Number Concentration	125
5.6.2	Particle Size Analysis	137
5.7	Measurement Uncertainty	147
6	Residential Smoke Alarm Nuisance Source Testing	149
6.1	Nuisance Scenario Tests	150
6.2	Instrumentation	150
6.2.1	Aerosol Instruments	151
6.2.2	Temperature and Humidity	153
6.2.3	Flow Velocity	153
6.2.4	Analog Output Photoelectric, Ionization and Sensors	154
6.3	Results	155
6.3.1	Toasting Scenarios	155
6.3.2	Frying Bacon	165
6.3.3	Frying Butter and Margarine	170
6.3.4	Frying Hamburgers	176
6.3.5	Deep-frying Tortillas and French-fried Potatoes	180
6.3.6	Broiled and Baked/Broiled Pizza	183
6.3.7	Broiling Hamburgers	187
6.3.8	Boiling Spaghetti Pasta	189
6.3.9	Candle Burning	193
6.3.10	Cigarette Smoking	194
6.4	Controlled Incipient Fire Sources	194
6.4.1	Cotton Smolder	195
6.4.2	Wood Smolder	199
6.4.3	Polyurethane Foam Smolder	201
6.5	FE/DE Emulation of Nuisance Sources	207
6.5.1	Cotton Wick Calibration	207
6.5.2	Cotton Smolder Smoke Fire Scenario	211
6.5.3	Wood Smolder Smoke Fire Scenario	211
6.5.4	Candle Flame Nuisance Scenario	220
6.5.5	Heated Margarine or Butter Nuisance Scenario	221
6.5.6	Toasting Bread Nuisance Scenario	221
7	Discussion	231
7.1	Smoke Alarm Activation Time	231
7.2	Tenability Times	236
7.3	Time Needed for Escape	236
7.3.1	Movement Speed	237
7.3.2	Premovement Activities	237
7.3.3	Escape Times	238
7.4	Smoke Alarm Performance	240

7.5 Other Alarm Technologies	246
7.5.1 Carbon Monoxide Alarms	247
7.5.2 Heat Alarms	247
7.5.3 Tell-tale Sprinklers	248
7.6 Comparison with Earlier Tests	248
7.7 Nuisance Alarms	251
8 Summary	253
9 Conclusions	259
10 References	261
Appendix A: Alarm Activation and Time to Untenable Conditions During Tests of Residential Smoke Alarms Included in the Study	A-1
Appendix B: FTIR Gas Measurement in Home Smoke Alarm Tests	B-1