HAI #1691-000

FLAME GUARD AEROSOL GENERATOR ULC PREPARATORY TESTS

Prepared for

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Flame guard aerosol generator ULC Preparatory Tests

1.0 INTRODUCTION

Hughes Associates, Inc has been working under contract with Flame Guard with the goal of obtaining an Underwriters Laboratory Canada (ULC) Listing for the aerosol generator systems developed by Flame Guard. The recent tests performed with the U.S. Coast Guard on the "State of Maine" are considered as part of this listing/approval process [1]. The tests performed consist of dual wood crib fire tests, n-heptane pan fire tests, polymeric material array tests, and basic loading factor tests. All of these tests, with the exception of the basic loading factor test, have to be successfully performed three consecutive times with a representative of ULC present during the tests. Note that additional testing beyond that to be included in this project will be need to complete the listing process. These additional tests would include component tests and volume coverage tests for each individual generator to be listed.

2.0 APPARATUS

2.1 Test Enclosure

A 100 cubic meter test enclosure, illustrated in Figures 1 and 2, segregated from a larger metal lined enclosure with two walls constructed from 12mm (0.5 in) plywood over a wooden frame was utilized for these tests. The enclosure has an internal footprint of 4.1 x 7 m (13.5 x 23 ft) and a height of 3.5 m (11.5 ft) and was located at the U.S. Aberdeen Test Center, Aberdeen Proving Ground, MD. It was equipped with a ceiling mounted trap door/pressure relief vent. Access to the enclosure was provided by a plywood door which was utilized to provide post-test exhaust of the chamber. Air supply ventilation is provided through a floor level damper.

Figure 1 - Photograph of Test Enclosure

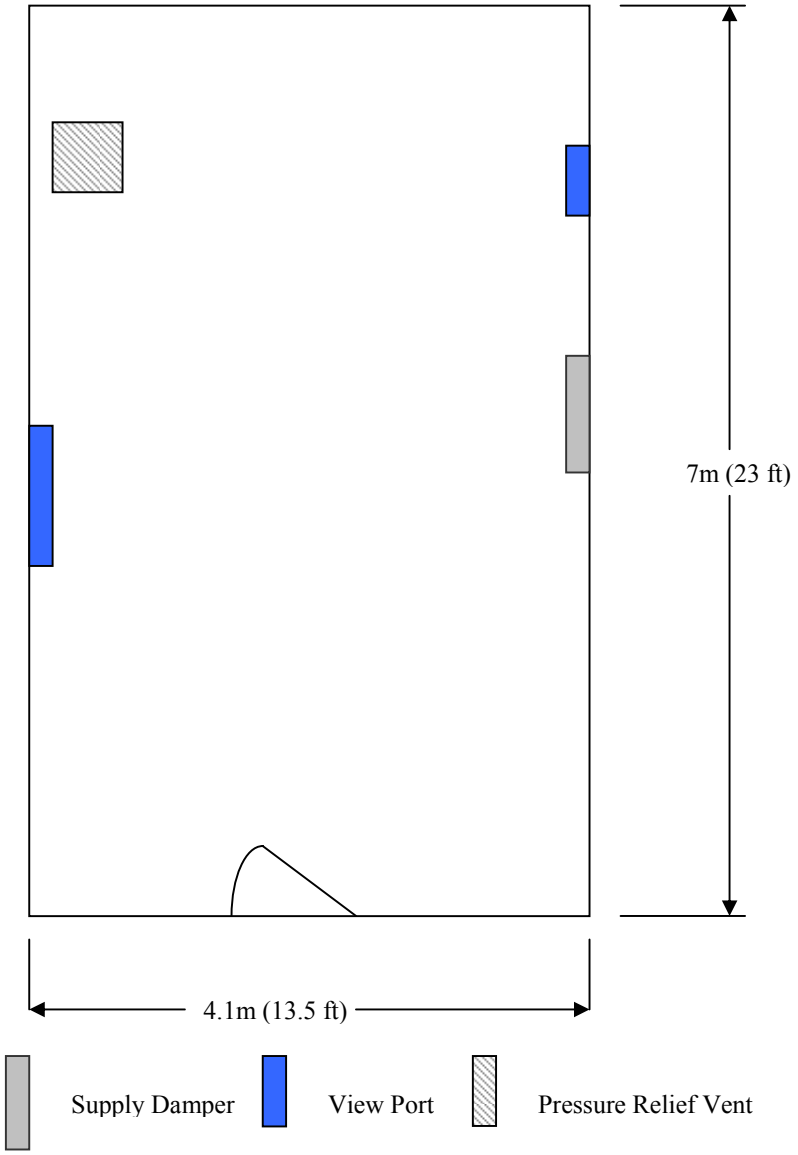

Figure 2 — 3.7 m Test Enclosure

2.2 Fire Scenarios

Five fire scenarios were utilized during these tests. The first scenario utilized two wood cribs similar in description to those utilized in UL-1254 standard for Pre-Engineered Dry Chemical Extinguishing System Units [1]. These cribs were constructed from 32 pieces of trade 5 x 5 cm (2 x 2 in) spruce, 30.5 cm (12 in) in length arrange in eight layers of four members each. This arrangement results in a crib that is a cube, 30.5 cm (12 in) on a side. The cribs were placed on top of four bricks, 5 cm (2 in) thick. The cribs were ignited with 113.5 g (0.25 lb) of shredded

paper placed underneath each crib and 236 ml of denatured ethyl alcohol poured over each crib. The cribs were pre-conditioned to a moisture content of 9 to 13 % by weight. One of the cribs was located 30.5 cm (1 ft) behind the floor to ceiling baffle. The floor to ceiling baffle was 0.8 m (2.7 ft) wide and was centered in the enclosure 1.8 m (5.8 ft) from the back wall of the enclosure. The other crib was located in the center of the test enclosure inside two square baffles 0.95 m (37.5 in) on a side and 0.3 m (12 in) tall, stacked on top of each other with the top baffle rotated 45^{o} relative to the other. The lower baffle was raised off the floor 9 cm (3.5 in) supported by four bricks, one at each corner. These baffles were identical to those utilized for the Class A polymeric materials tests of UL-2166 [3] and UL-2127 [2]. In addition to these baffles a horizontal baffle measuring 0.76 x 0.76 m (2.5 x 2.5 ft) was placed directly above the crib, 1 m (3.3 ft) above the floor. This set-up is illustrated in Figures 3 and 4.

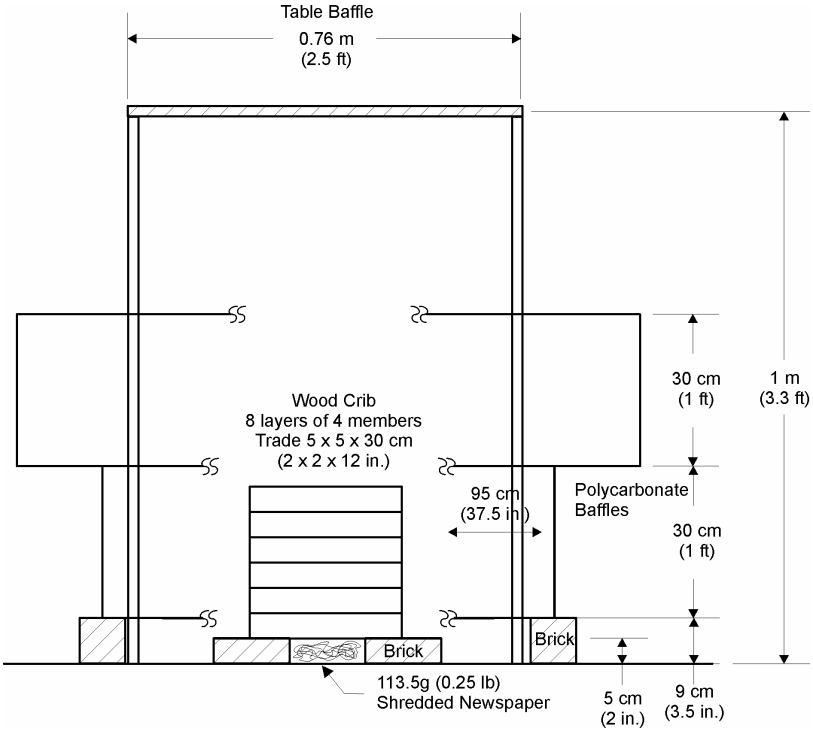

Figure 3 – Center Crib Detail – Elevation View

Figure 4 – Photograph of Wood Crib Scenario

The second fire scenario utilized consists of a polymeric material array as described in theUL test protocols for Halocarbon Based Clean Agents, UL-2166 [3] and for Inert Gas Clean Agents, UL-2127 [4]. The array consisted of four sheets of material, each 20 x 40 cm (8 x 16 in) and 0.95 cm (0.38 in) thick, arranged vertically with a center gap of 3.2 cm (1.25 in) and outer gaps of 1.2 cm (0.5 in). The array is suspended 1.2 cm (0.5 in) above a 5.1 x 11.2 cm (2 x 4.5 in) rectangular pan 2.2 cm (0.88 in) deep fueled with 40 ml of water and 7 ml of n-heptane. This larger pan was utilized such that these tests could be compared to the requirements of the European CEN Standard [6] and the ISO Standard [7] as well as conservatively to the UL/ULC standard requirements. The UL/ULC Standards utilize a smaller 5.1 x 5.1 cm (2 x 2 in) square 2.2 cm (0.88 in) deep pan fueled with 3 ml of n-heptane is used to ignite the polymeric material array. In either case, the igniter provides 90 seconds of burn duration. The array was shielded on the two sides parallel to the polymeric sheets and on the top by sheet steel attached to an angle iron frame with dimensions of 61 x 38 x 85 cm (24 x 15 x 33.5 in). The array was further shielded by two square polycarbonate baffles, 95 cm (37.5 in) on a side and 30 cm (12 in) tall, placed on top of each other with the upper baffle rotated 45^{o}. The polycarbonate baffles were raised off the floor 8.9 cm (3.5 in) by four cinder blocks located on the corners of the baffle. This setup is illustrated in Figure 5.

Three polymeric materials were utilized in the scenario: polymethyl methacrylate (PMMA), acrylonitrile butadiene styrene copolymer (ABS) and polypropylene (PP). Properties of these polymers are given in Table 2.

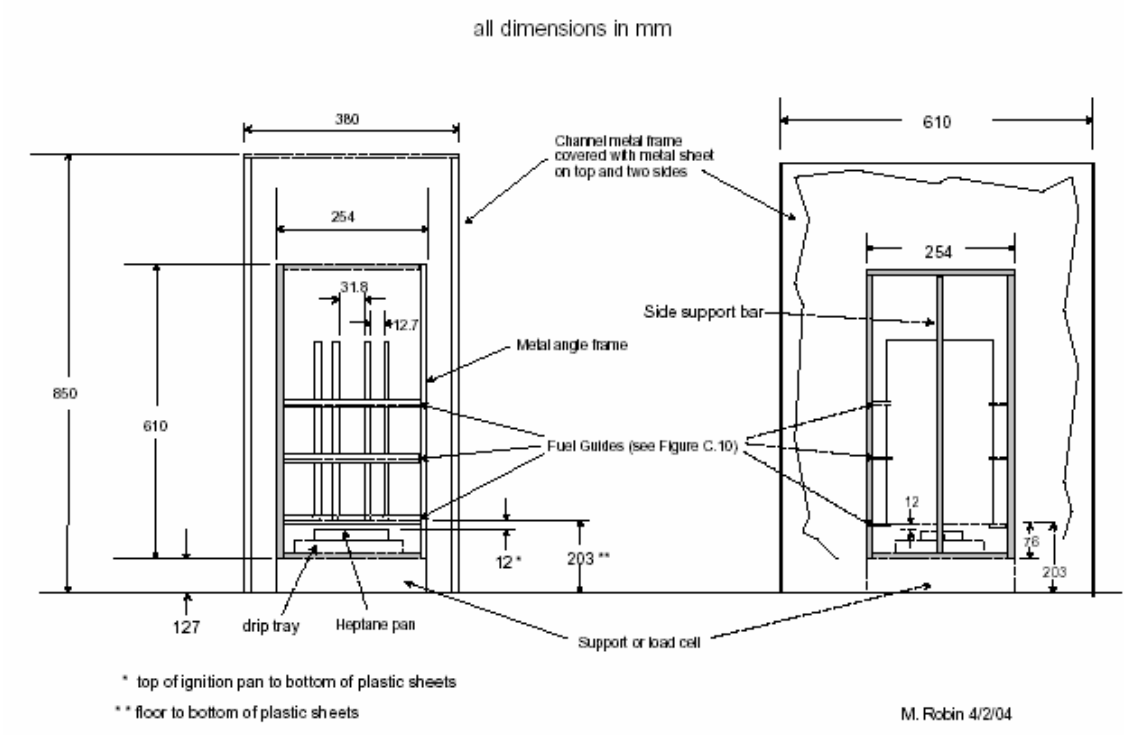

Figure 5 - Polymer Material Fire Setup

Table 1 – Polymeric Fuel Properties

Fuel	Color	Density (g/cm^3)	Ignition Time (s)		180 Second Average Heat Release Rate (kW/m^2)		Effective Heat of Combustion (MJ/kg)	
			Specification	Tolerance	Specification	Tolerance	Specification	Tolerance
PMMA	Black	1.19	77	+-30%	286	+-25%	23.3	+-25%
ABS	Cream	1.04	115	+-30%	484	+-25%	29.1	+-25%
PP	White	0.905	91	+-30%	225	+-25%	*39.8*	+-25%

The third fire scenario consisted of a square n-heptane pan fire located in the center of the enclosure at an elevation of 76 cm (30 in.) above the floor. The pan was 0.23 m^2 (2.5 ft^2) in area and was filled with 5 cm (2 in) of n-heptane on a water substrate to leave a 5 cm (2 in) freeboard between the top of the n-heptane and the lip of the pan. The pan was constructed from 0.64 cm (0.25 in.) steel with the upper edge reinforced with 3.8x3.8x0.48 cm (1.5x1.5x0.62 in.) angle iron. The fire was allowed a 30 second pre-burn prior to system activation. This fire scenario is compliant with the UL-2166 [3] and UL-2127 [4] Class B Fire Extinguishment Test.

2.3 Aerosol Generators

The Flame Guard aerosol generators utilize the burning of a solid fuel compound to atomize and distribute a powder based extinguishing agent throughout the protected enclosure. The powder based extinguishing agent, representing ~30% of the weight of the solid fuel. The

burning of the solid fuel generates a gas stream consisting primarily of nitrogen, water vapor, carbon dioxide and carbon monoxide. The generators are classified as an oxidizer.

Two Flame Guard Generators were utilized in these tests. The first generator was model DSPA 11-6 which contains 2.4 kg of solid fuel propellant and agent. The generated aerosol is discharged radially outward in a horizontal orientation by this generator. The second generator was model DSPA 8-1 which contains 3.25 kg of solid fuel propellant and agent. The generated aerosol is discharged vertically downward by this generator. Both models of generators were activated electrically utilizing a 14 V DC power supply capable of 30 amp.

Up to four generators were utilized per test with aerosol loading factors ranging from 47.5 g/m^3 to 128.6 g/m^3. These combinations are given in Table 2 with generator location shown schematically in Figure 6.

Table 2 - Generator Combinations

	Model 8-1		Model 11-6	
Loading	[kg/gen]	3.25	[kg/gen]	2.4
[g/m^3]	[# gen]	Location	[# gen]	Location
47.5	0		2	G2,G6
55.9	1	G2	1	G6
64.3	2	G2,G6	0	
79.6	1	G4	2	G3,G7
88.0	2	G3,G7	1	G4
96.4	3	G3,G4,G7	0	
128.6	4	G1,G3,G5,G7	0	

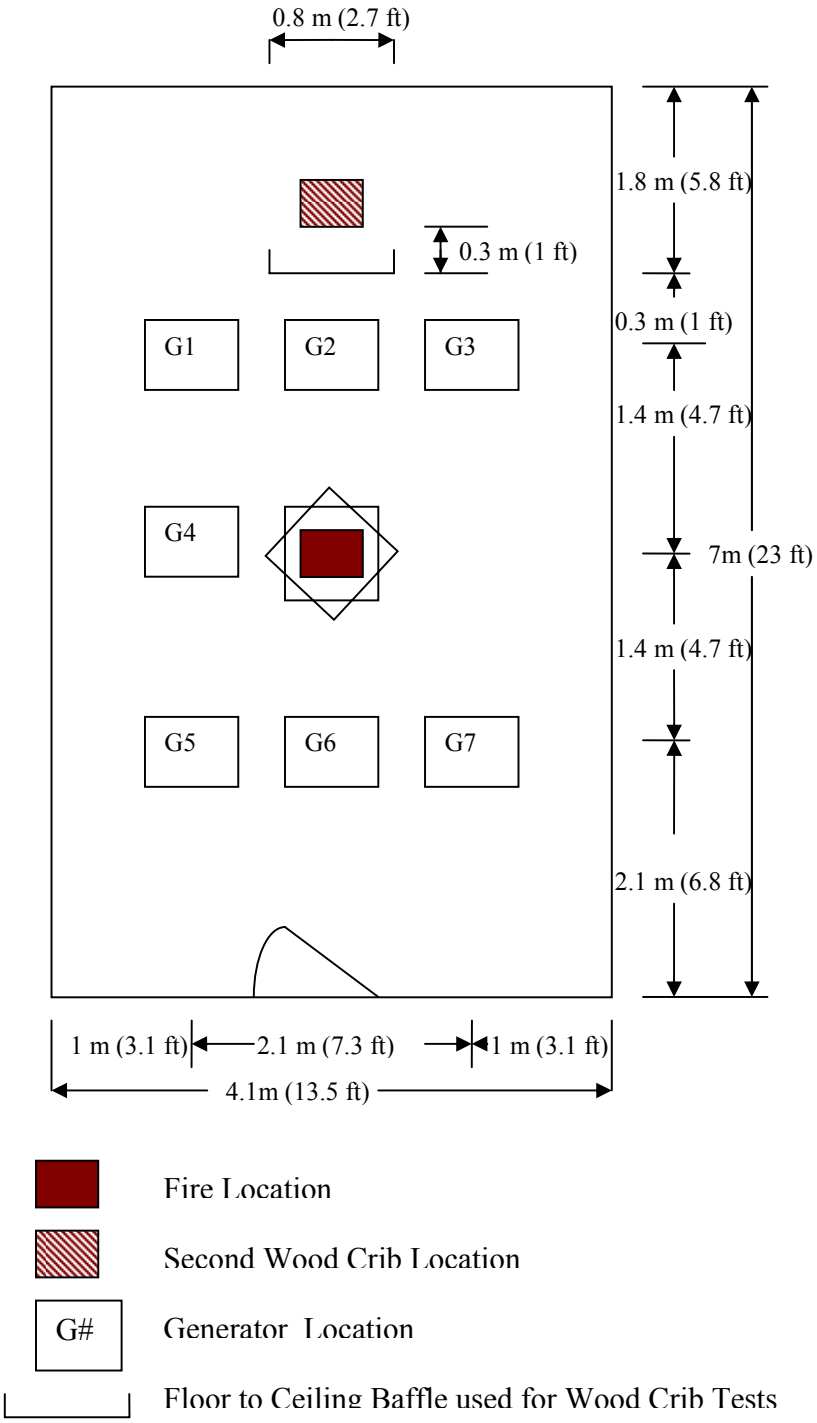

Figure 6 - Generator Test Configurations

2.4 Instrumentation

Two thermocouples were installed at each generator. One thermocouple was used to monitor the generator casing temperature, and the other to monitor the temperature of the exhaust.

Ten type K thermocouples were utilized to monitor the burning of the test fires with a minimum of one per test fire.

A Sartorius Combics load cell with a range of 0-20 kg (0-44 lb) was utilized to monitor the mass loss of the plastic array fires.

A low range differential pressure transducer with a range of -1.2 to 1.2 kPa (-5 to 5 iwc), Omega Engineering Model PX653, was used to monitor the enclosure pressure.

Three oxygen analyzers were utilized to monitor the oxygen concentration inside the test enclosure at elevations of 0.37 m (1.2 ft), 0.7 m (2.5 ft) and either 1.83 m (6 ft) for the n-heptane pan fire test, or 3.3 m (10.8 ft) for the remaining fire tests.

3.0 PROCEDURE

The enclosure was prepared with the generators installed and the fire scenario setup. The actuation power supply was connected to the activation circuit upstream of the activation switches after the space was cleared of personnel. The data acquisition system was initiated. After ten seconds of background data, the test fires were ignited. The n-heptane pan fire was given 30 seconds of pre-burn prior to activation of the generators. The wood cribs were given 2 minutes of pre-burn prior to activation of the generators. The polymeric material array fires were given 3.5 min (210 sec) of pre-burn prior to activation of the generators. The test enclosure remained closed for a hold time of ten minutes. At the end of the hold time, the enclosure was purged and the wood cribs were checked for any signs of continued burning.

If it was obvious, from the thermocouples monitoring the test fires, that the test fires were not extinguished by the end of the hold time or would not be extinguished by the end of the hold time, then the fire was extinguished with a portable extinguisher operated from outside of the enclosure.

4.0 RESULTS AND DISCUSSION

Table 3 summarizes the results of these tests relative to the performance requirements of a UL/ULC listing. The ULC Standard requires that the n-heptane pan fire be extinguished within 30 seconds of the end of the generator burn. The polymeric material array is required to be extinguished within the 10 minute hold time and that the mass loss from 10 seconds after the end of the generator burn until the end of the 10 minute hold time to be less than 15 g. The dual wood crib fire is required to be extinguished within the 10 minute hold time with no embers or other signs of continued burning at the end of the 10 minute hold time. The polymer array tests included in Table 3 were conducted with the larger ignition pan of the ISO/CEN protocol. Table 4 gives the anticipated generator loading requirements that could be carried forward during a witness test program to obtain a UL/ULC listing: 64.3 g/m^3 (Two Model 8-1 generators) for

Class B Hazards and 96.4 g/m^3 for Class A Hazards (Three Model 8-1 generators). Note that additional tests besides the fire tests described herein are required to complete the listing process.

Table 3 UL/ULC Listing Preparatory Tests

Test Name	Test Fire Scenario	Fuel	Generators		Total Loading	Effective Loading	Dis. Time	Ext. Time		Fuel Mass Loss		Test Result
			8-1	11-6				From Act	From Dis End	Total	End of Dis	
			[#]	[#]	[g/m^3]	[g/m^3]	[sec]	[sec]	[sec]	[g]	[g]	[P/F]
Test21	**ISO Plastics**	**ABS**	**4**	**0**	**128.6**	**128.6**	**109**	**129.8**	**20.8**	**138**	**-7.5**	**Pass**
Test9	ISO Plastics	PMMA	1	2	79.6	79.6	80	N/E	N/E	380	194.5	Fail
Test10	ISO Plastics	PMMA	2	1	88.0	88.0	80	N/E	N/E	223.5	45.5	Fail
Test3	**ISO Plastics**	**PMMA**	**3**	**0**	**96.4**	**96.4**	**80**	**448**	**368**	**53**	**9.5**	**Pass**
Test11	**ISO Plastics**	**PMMA**	**3**	**0**	**96.4**	**96.4**	**80**	**311**	**231**	**135**	**5.5**	**Pass**
Test20	**ISO Plastics**	**PMMA**	**4**	**0**	**128.6**	**128.6**	**112**	**578**	**466**	**199.5**	**13**	**Pass**
Test24	**ISO Plastics**	**PMMA**	**5**	**0**	**160.7**	**160.7**	**79**	**634**	**555**	**187**	**12.5**	**Pass**
Test7	UL/ISO Pan	n-Heptane	0	2	47.5	47.5	40	N/E	N/E			Fail
Test22	**UL/ISO Pan**	**n-Heptane**	**2**	**0**	**64.3**	**64.3**	**69**	**97.8**	**28.8**			**Pass**
Test5	**ULC Wood Crib**	**Spruce**	**1**	**2**	**79.6**	**79.6**	**80**	**162**	**82**			**Pass**
Test4	**ULC Wood Crib**	**Spruce**	**3**	**0**	**96.4**	**96.4**	**80**	**156**	**76**			**Pass**

Table 4 UL/ULC listing Fire Performance Test Status

Hazard Classification	Test Type	Fire Scenario	Flame Guard Status
Class B - Flamable Liquid	Heptane Pan Fire	0.23 m^2 Pan	Close Pass with two Model 8-1
Class A - Solid Fuels	Polymer Array Ignited by 5x5 cm Heptane pan (Larger ISO pan utilized)	PMMA	Pass with three Model 8-1
		ABS	Pass with four Model 8-1 (Not tested with less than four)
		PP	Not Tested
	Dual Crib Test		Extinguished with three Model 8-1
Volume Coverage Tests (Each Generator Size to be Listed)	Telltales	5 or 10 telltales with room sized for single generator	Not Tested

Additional Data from these tests are given in Appendix A

5.0 CONCLUSIONS

The ULC listing appears to be obtainable with a 64.7 g/m^3 loading for Class B Hazards and a 96.4 g/m^3 loading for Class A Hazards.

REFERENCES

1. Back, G.G., Boosinger, M., Beene, D., and Nash, L., "An Evaluation of Aerosol Extinguishing Systems for Machinery Space Applications", U.S. Coast Guard Research and Development Center, Groton, CT, 2005.

2. Underwriters Laboratories Inc. “Pre-Engineered Dry Chemical Extinguishing Units,” UL 1254, Underwriters Laboratories Inc. Northbrook, IL, 1999.

3. Underwriters Laboratories Inc. “Standard for Halocarbon Clean Agent Extinguishing System Units,” UL 2166, Underwriters Laboratories Inc. Northbrook, IL, 1999.

4. Underwriters Laboratories Inc. “Standard for Inert Gas Clean Agent Extinguishing System Units,” UL 2127, Underwriters Laboratories Inc. Northbrook, IL, 1999.

5. International Standards Organization, "Gaseous Media Fire Extinguishing Systems - Physical Properties and System Design - Part 1: General Requirements", ISO 14520-1:2005(E), International Standards Organization, Geneva, Switzerland, 2005.

6. CEN TC 191 "Fixed firefighting systems — Condensed aerosol extinguishing systems — Part 1: Requirements and test methods for components", Draft PrEN 15276-1:2005, European Committee for Standardization (CEN), Brussels, June 2005.

7. ISO TC 21/SC 8 N 225, "Aerosol Fire Extinguishing Systems - Physical Properties and System Design - General Requirements", ISO/CD 15779, International Standards Organization, Geneva, Switzerland, June 2005.

APPENDIX A - DATA SUMMARY

A series of graphs are presented for each of the tests conducted. The first graph contains the generator temperatures measured on the outer shell and in the aerosol discharge stream of up to three of the installed generators. The second graph contains the temperatures measured above each test fire to note extinguishment. The third graph contains the fuel mass for the tests utilizing either the polymeric material arrays or the wood panel arrays. The fourth graph contains the fire size deduced from the fuel mass trace in the third graph.

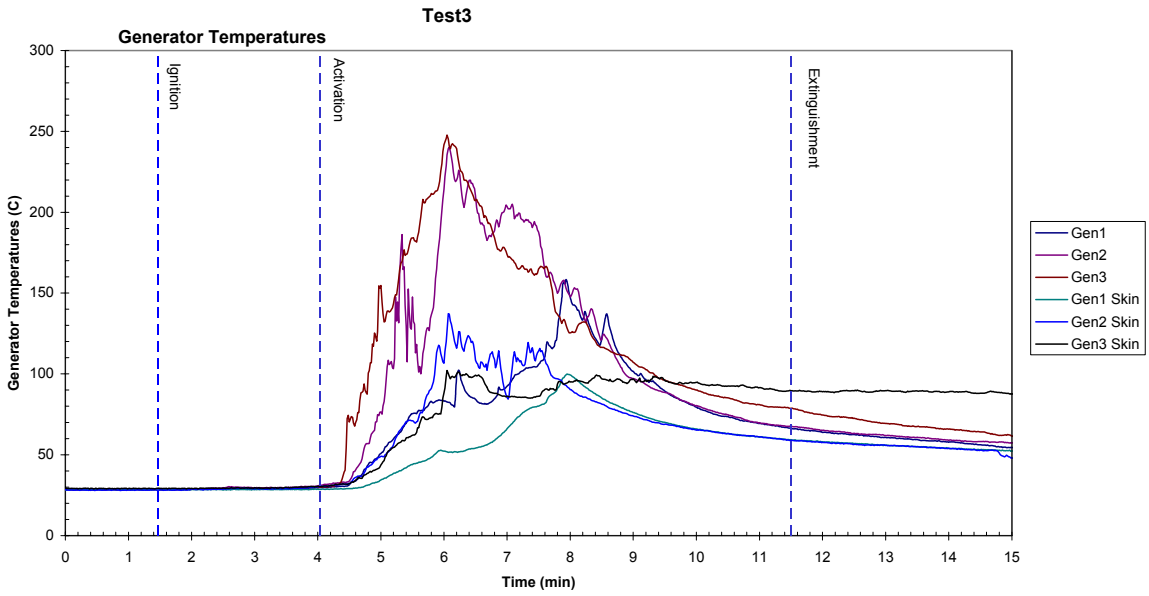

Figure A 1 - Generator Temperatures during PMMA Polymeric Material Test with Three Model 8-1 Generators for a Total Loading of 96.4 g/m^3 (Test 3)

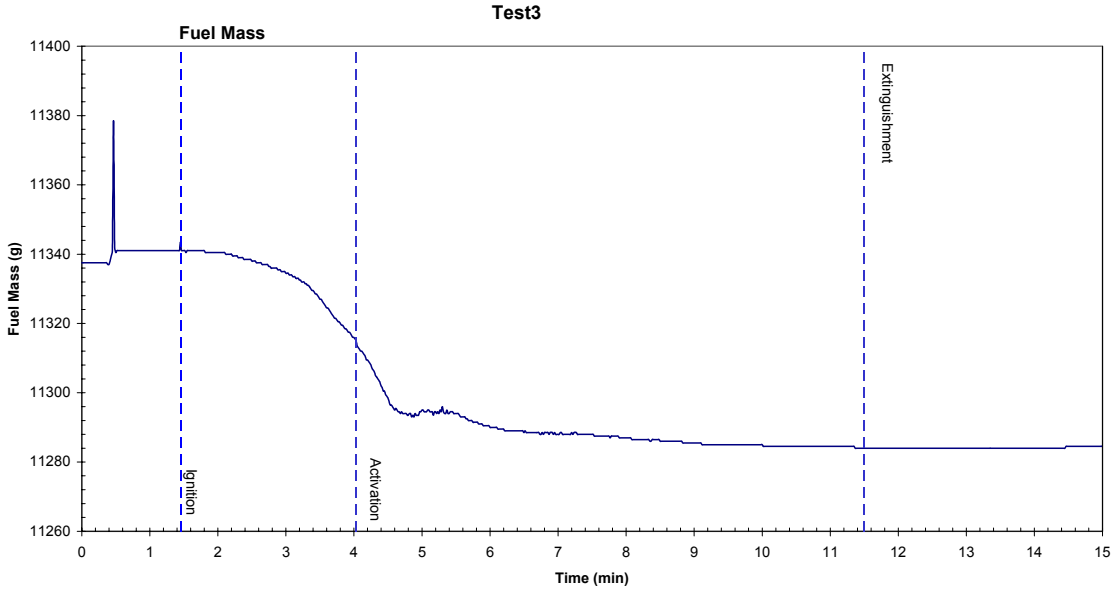

Figure A 2 - Fuel Mass during PMMA Polymeric Material Test with Three Model 8-1 Generators for a Total Loading of 96.4 g/m^3 (Test 3)

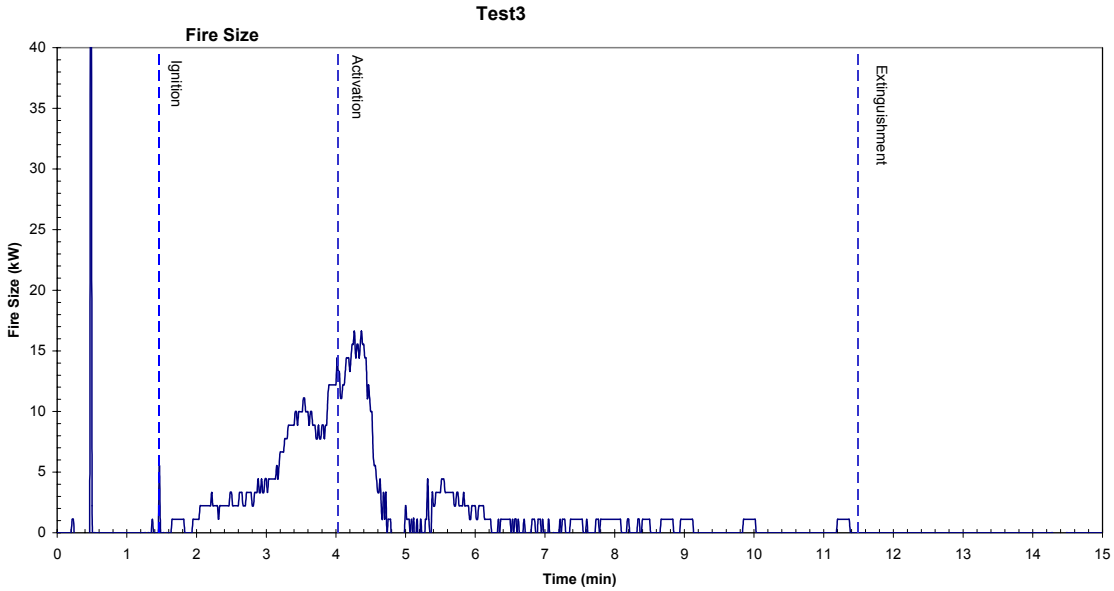

Figure A 3 - Fire Size during PMMA Polymeric Material Test with Three Model 8-1 Generators for a Total Loading of 96.4 g/m^3 (Test 3)

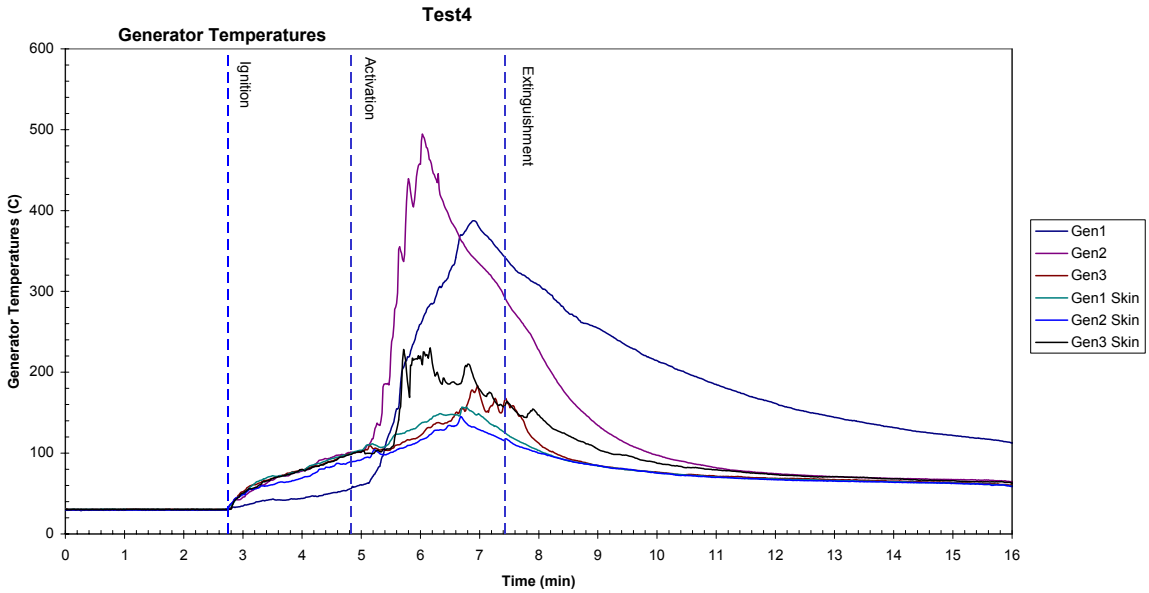

Figure A 4 - Generator Temperatures during ULC Dual Wood Crib Test with Three Model 8-1 Generators for a Total Loading of 96.4 g/m^3 (Test 4)

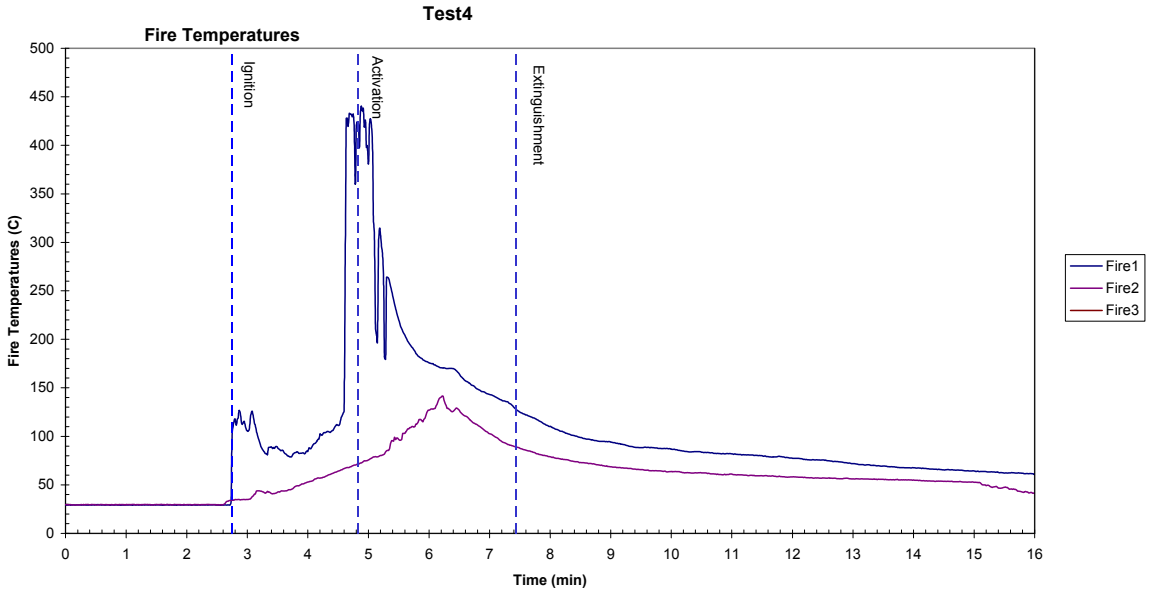

Figure A 5 - Fire Temperatures during ULC Dual Wood Crib Test with Three Model 8-1 Generators for a Total Loading of 96.4 g/m^3 (Test 4)

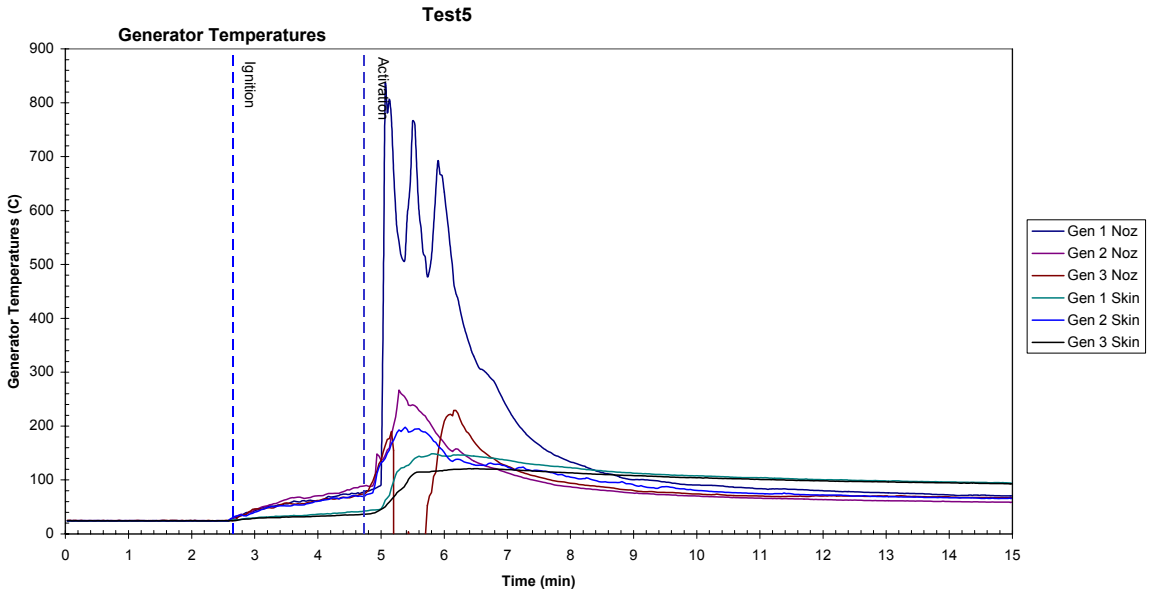

Figure A 6 - Generator Temperatures during ULC Dual Wood Crib Test with Two Model 11-6 and One Model 8-1 Generators for a Total Loading of 79.6 g/m^3 (Test 5)

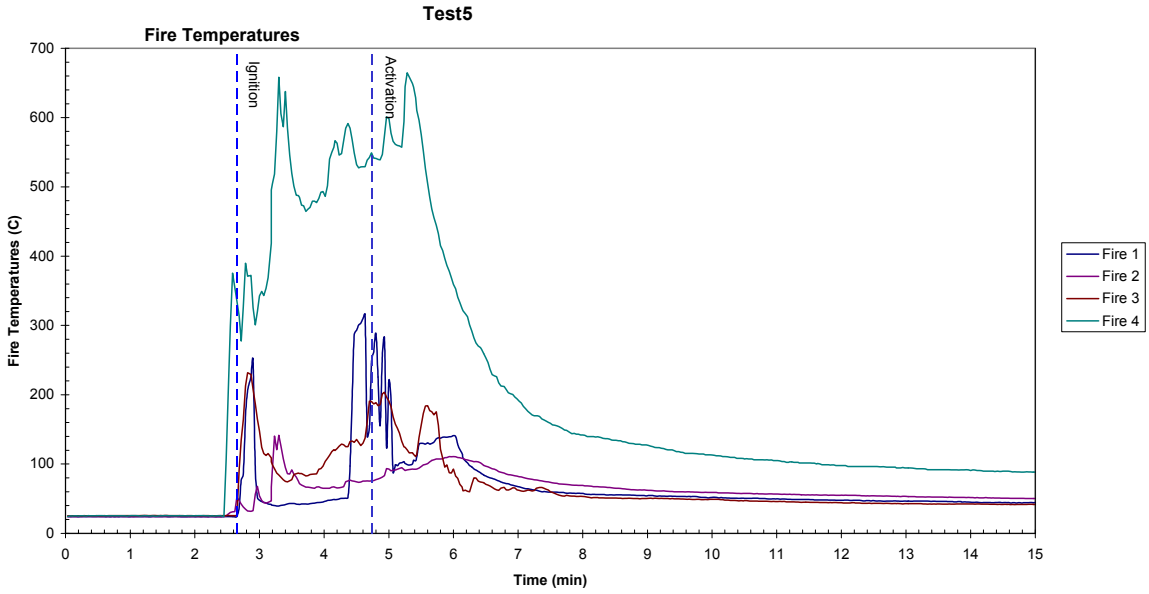

Figure A 7 - Fire Temperatures during ULC Dual Wood Crib Test with Two Model 11-6 and One Model 8-1 Generators for a Total Loading of 79.6 g/m^3 (Test 5)

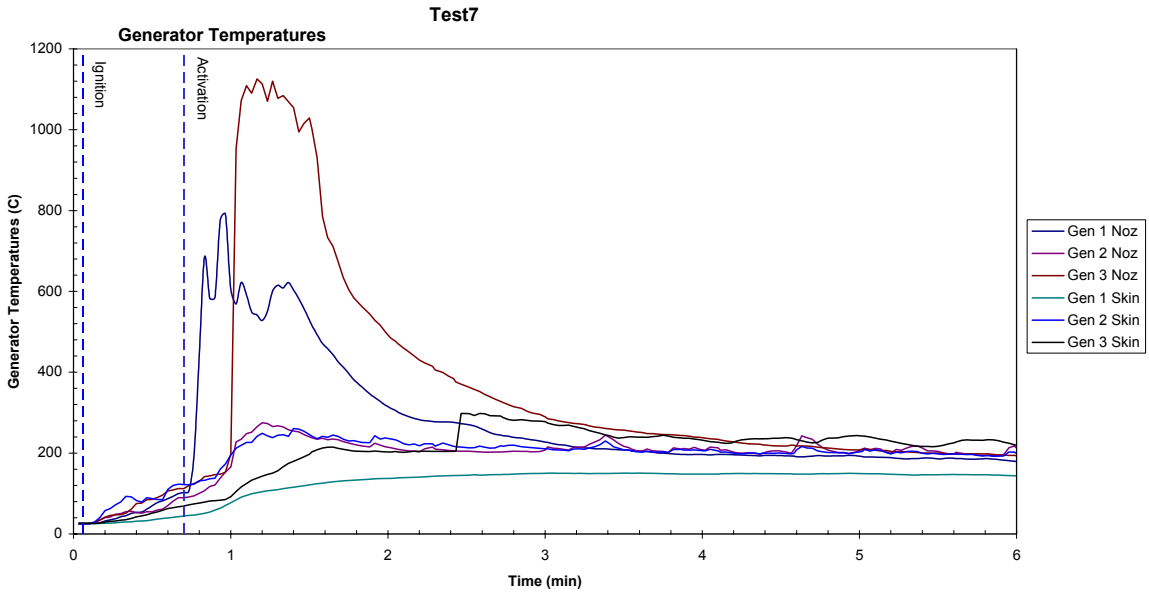

Figure A 8 - Generator Temperatures during n-Heptane Pan Fire Test with Two Model 11-6 Generators for a Total Loading of 47.5 g/m^3 (Test 7)

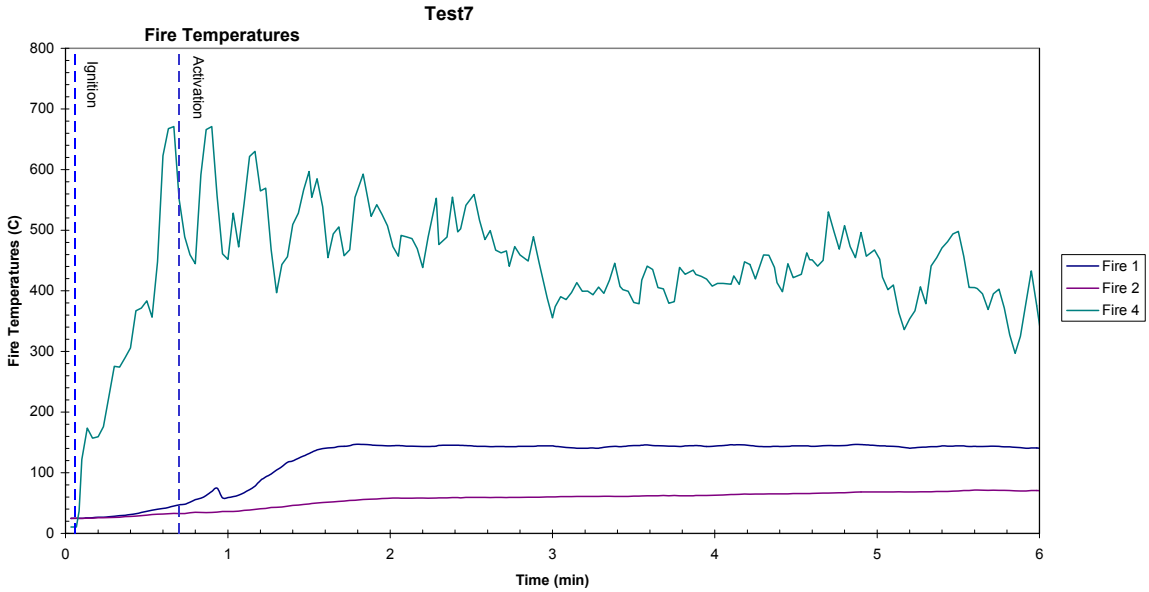

Figure A 9 - Fire Temperatures during n-Heptane Pan Fire Test with Two Model 11-6 Generators for a Total Loading of 47.5 g/m^3 (Test 7)

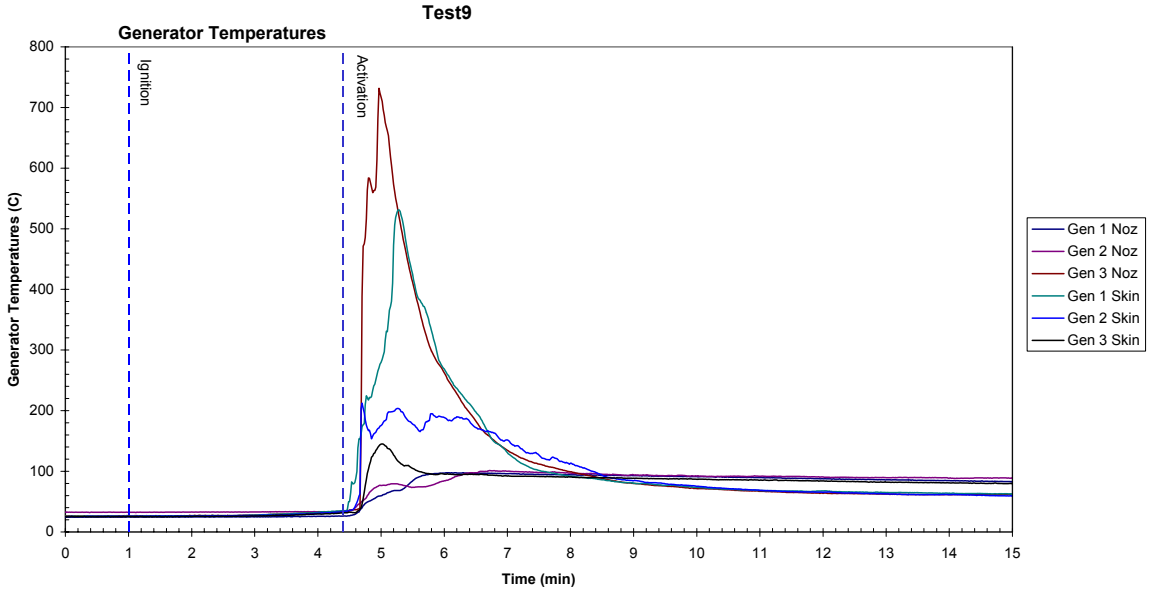

Figure A 10 - Generator Temperatures during PMMA Polymeric Material Test with Two Model 11-6 and One Model 8-1 Generators for a Total Loading of 79.6 g/m^3 (Test 9)

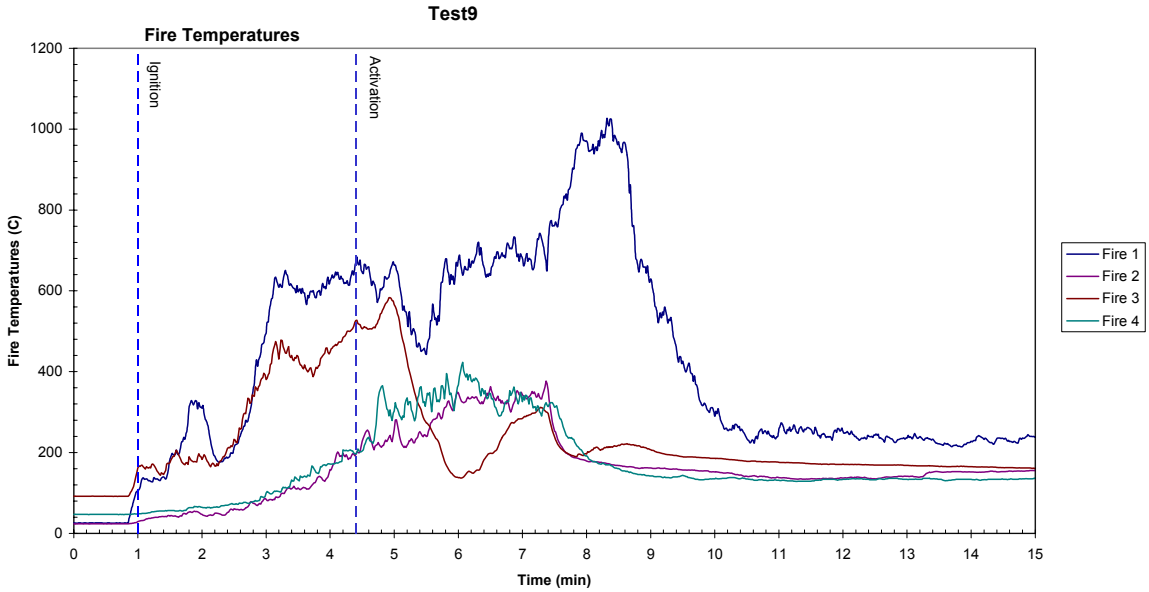

Figure A 11 - Fire Temperatures during PMMA Polymeric Material Test with Two Model 11-6 and One Model 8-1 Generators for a Total Loading of 79.6 g/m^3 (Test 9)

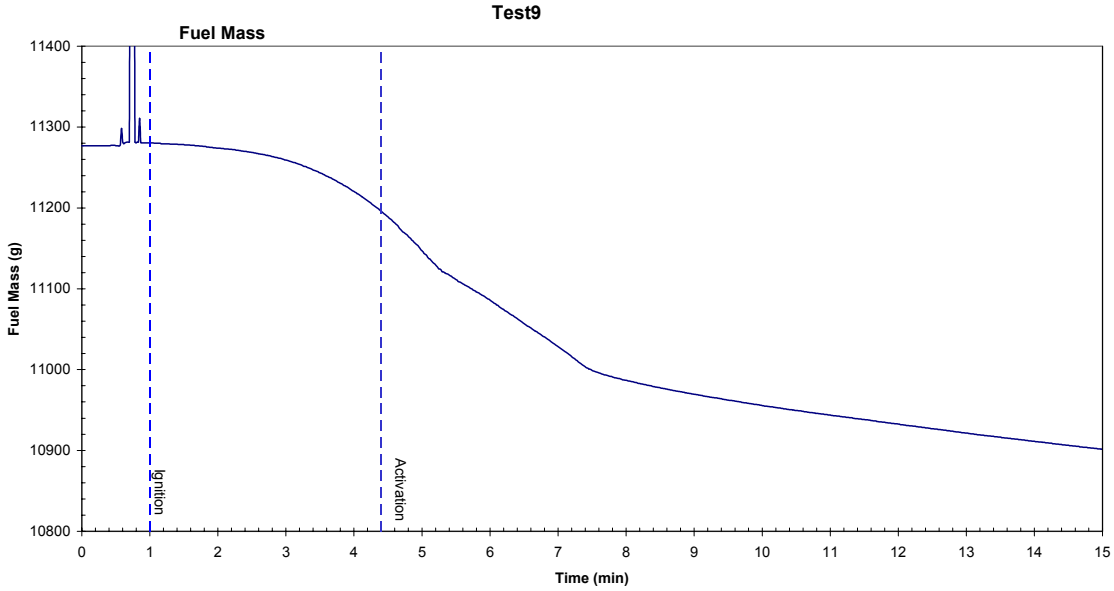

Figure A 12 - Fuel Mass during PMMA Polymeric Material Test with Two Model 11-6 and One Model 8-1 Generators for a Total Loading of 79.6 g/m^3 (Test 9)

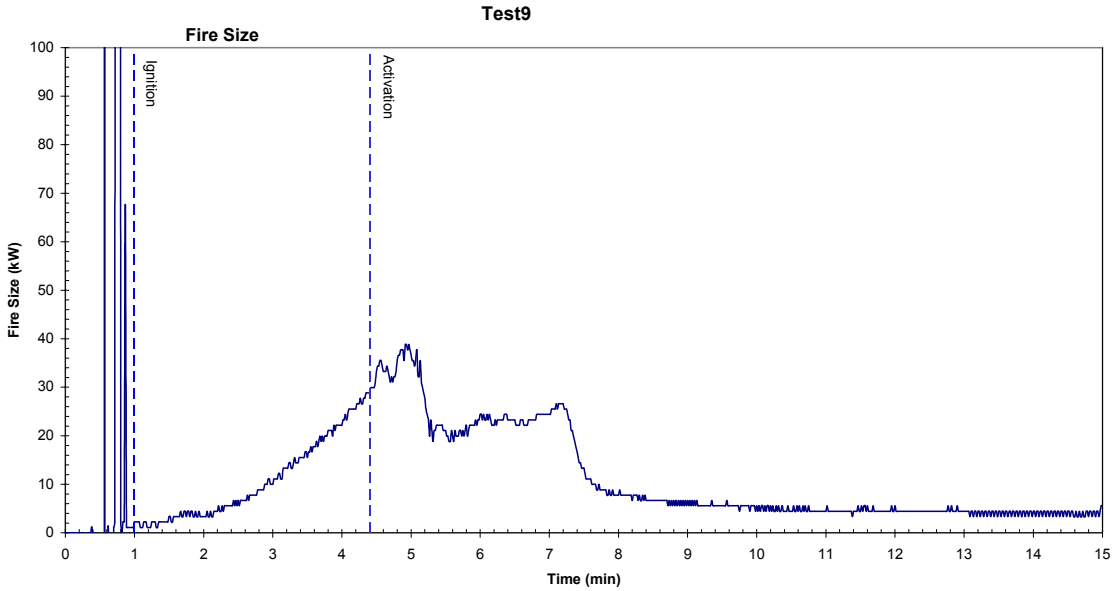

Figure A 13 - Fire Size during PMMA Polymeric Material Test with Two Model 11-6 and One Model 8-1 Generators for a Total Loading of 79.6 g/m^3 (Test 9)

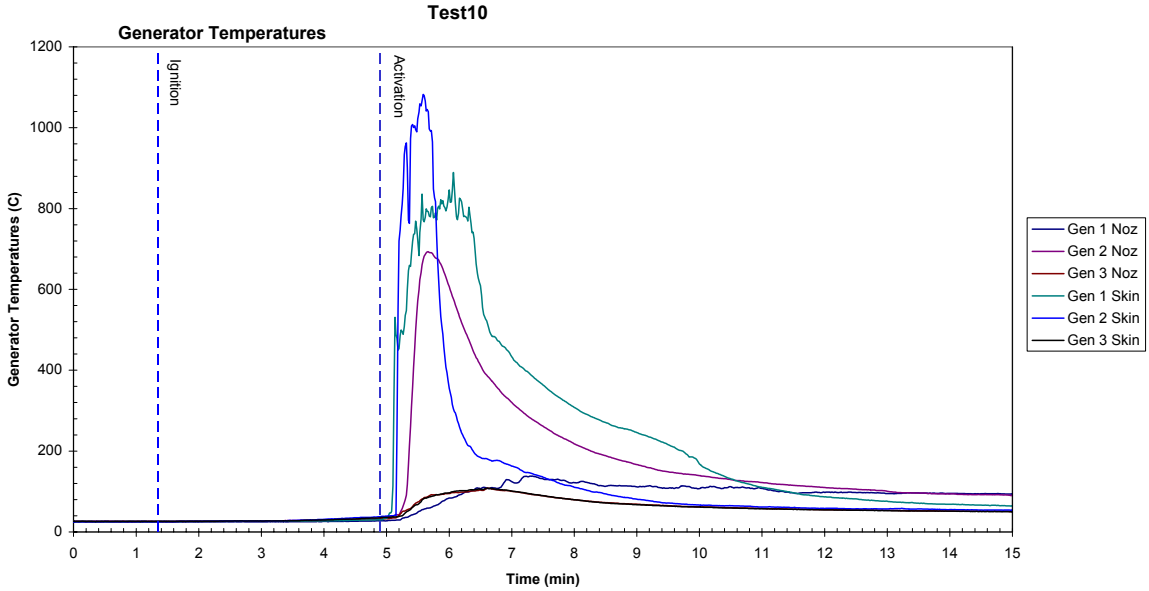

Figure A 14 - Generator Temperatures during PMMA Polymeric Material Test with One Model 11-6 and Two Model 8-1 Generators for a Total Loading of 88.0 g/m^3 (Test 10)

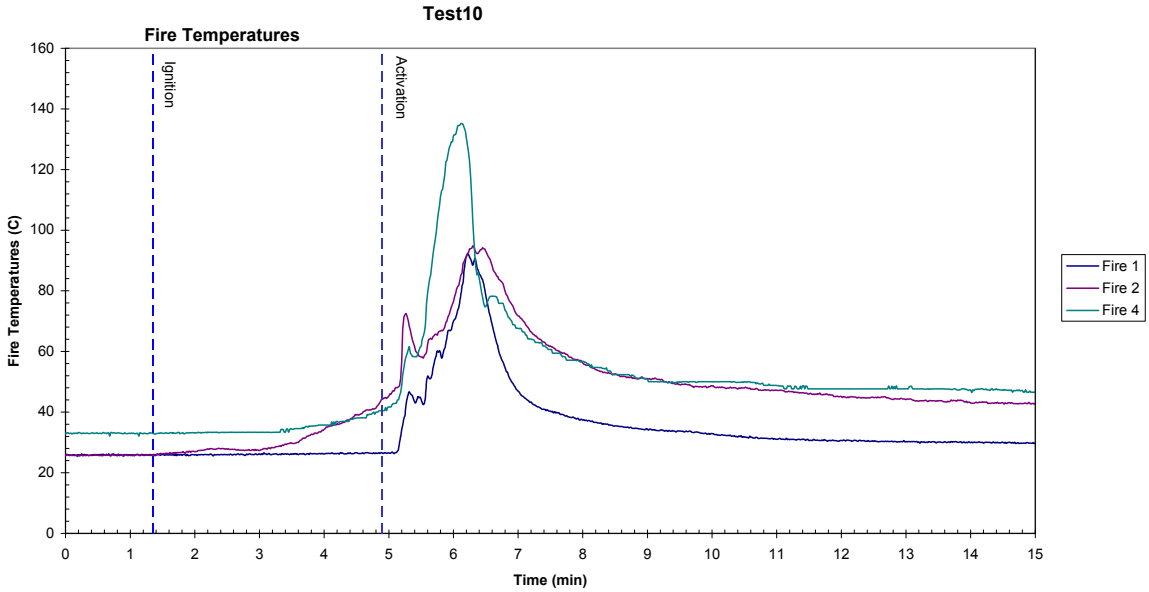

Figure A 15 - Fire Temperatures during PMMA Polymeric Material Test with One Model 11-6 and Two Model 8-1 Generators for a Total Loading of 88.0 g/m^3 (Test 10)

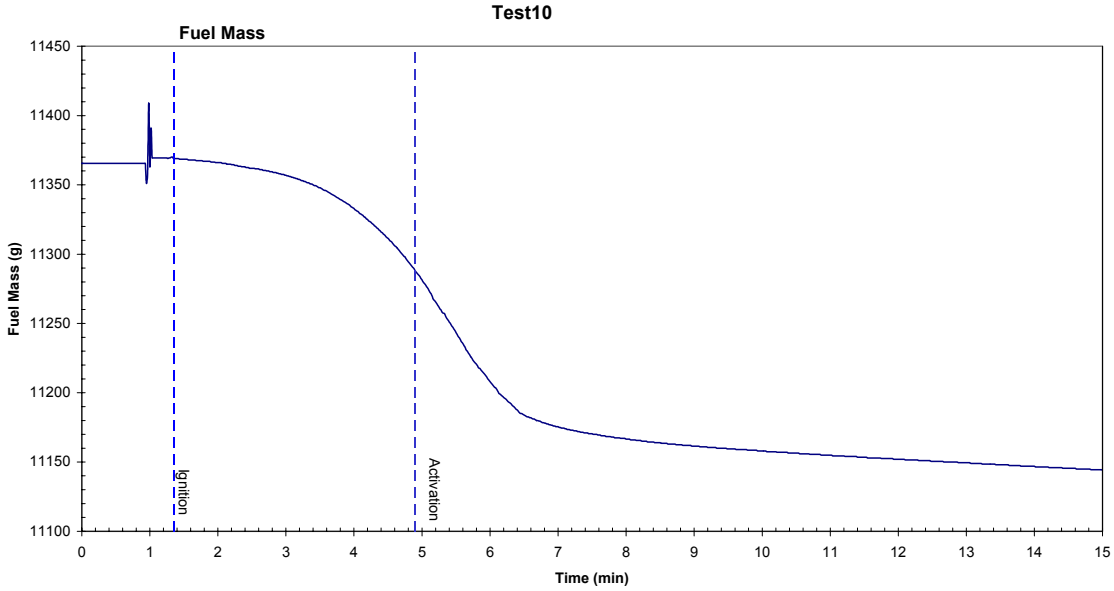

Figure A 16 - Fuel Mass during PMMA Polymeric Material Test with One Model 11-6 and Two Model 8-1 Generators for a Total Loading of 88.0 g/m^3 (Test 10)

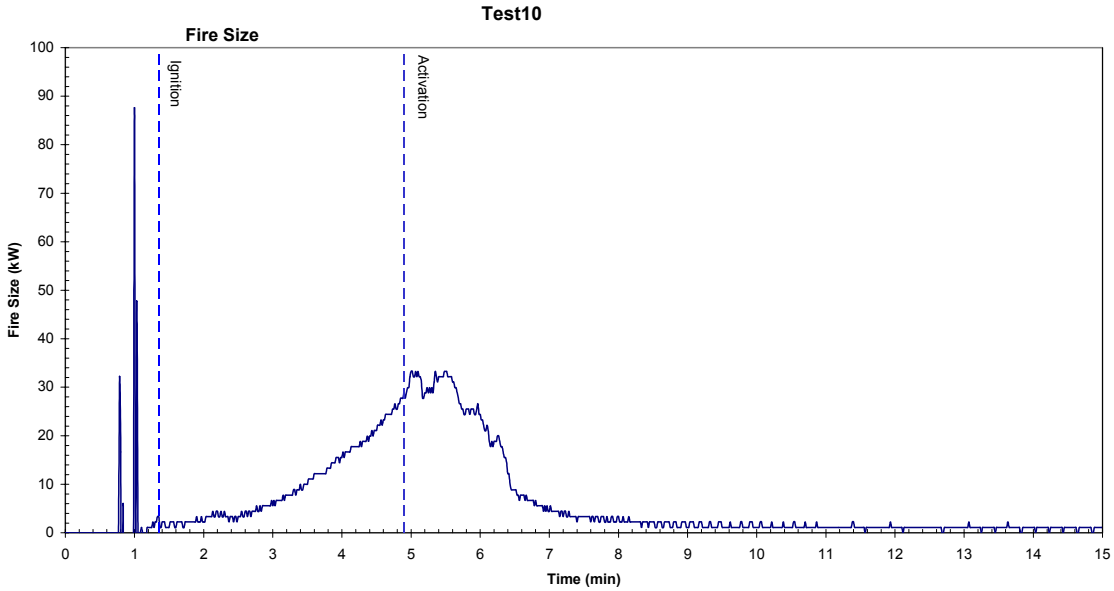

Figure A 17 - Fire Size during PMMA Polymeric Material Test with One Model 11-6 and Two Model 8-1 Generators for a Total Loading of 88.0 g/m^3 (Test 10)

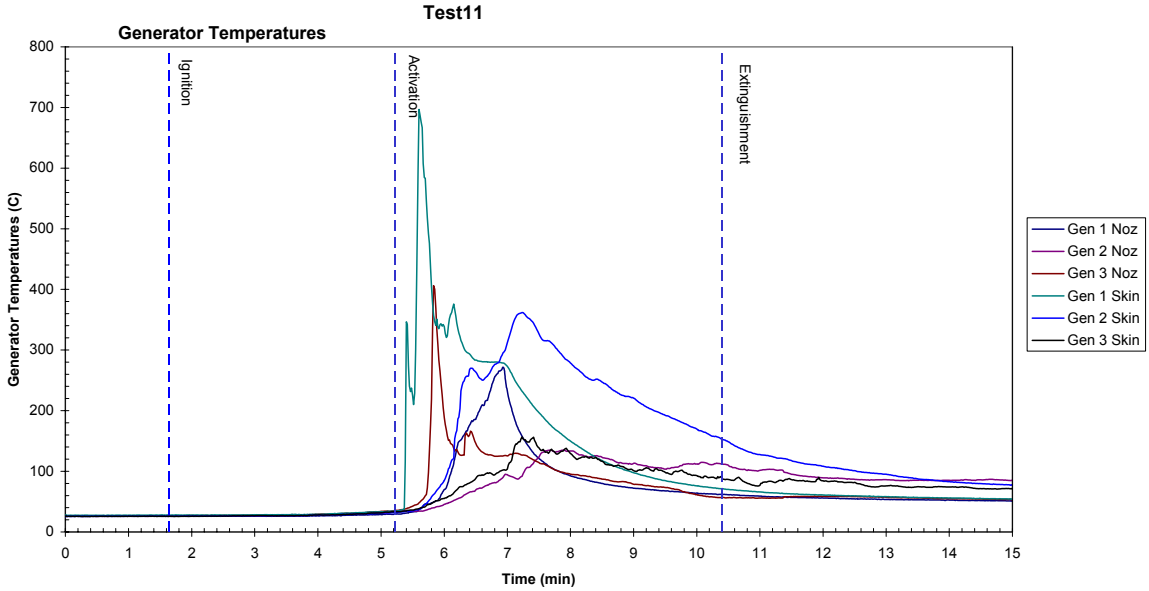

Figure A 18 - Generator Temperatures during PMMA Polymeric Material Test with Three Model 8-1 Generators for a Total Loading of 96.4 g/m^3 (Test 11)

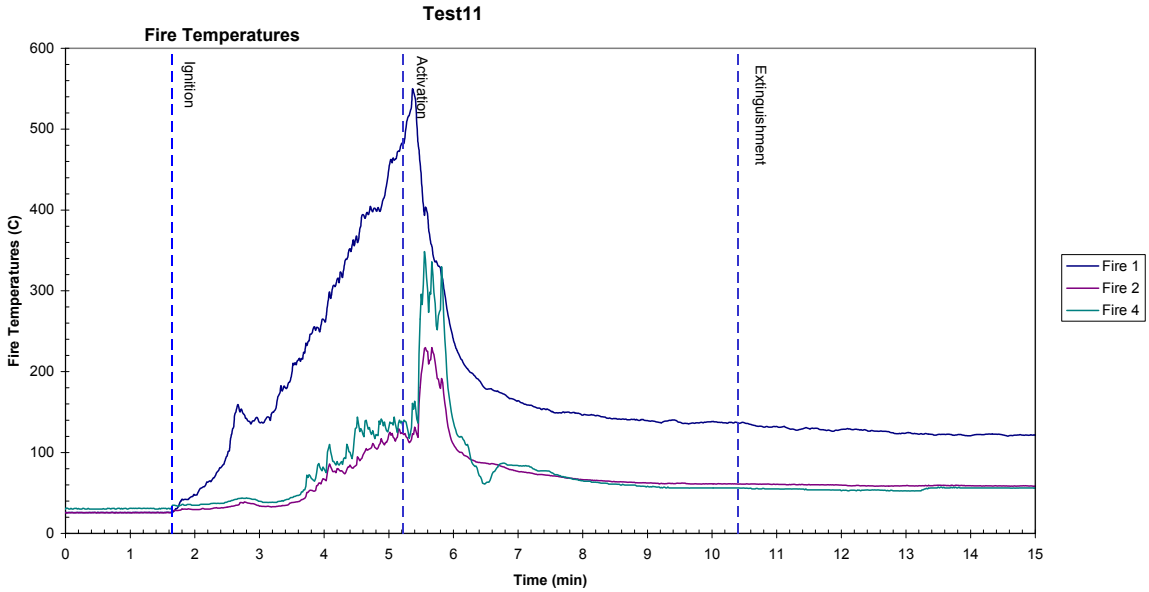

Figure A 19 - Fire Temperatures during PMMA Polymeric Material Test with Three Model 8-1 Generators for a Total Loading of 96.4 g/m^3 (Test 11)

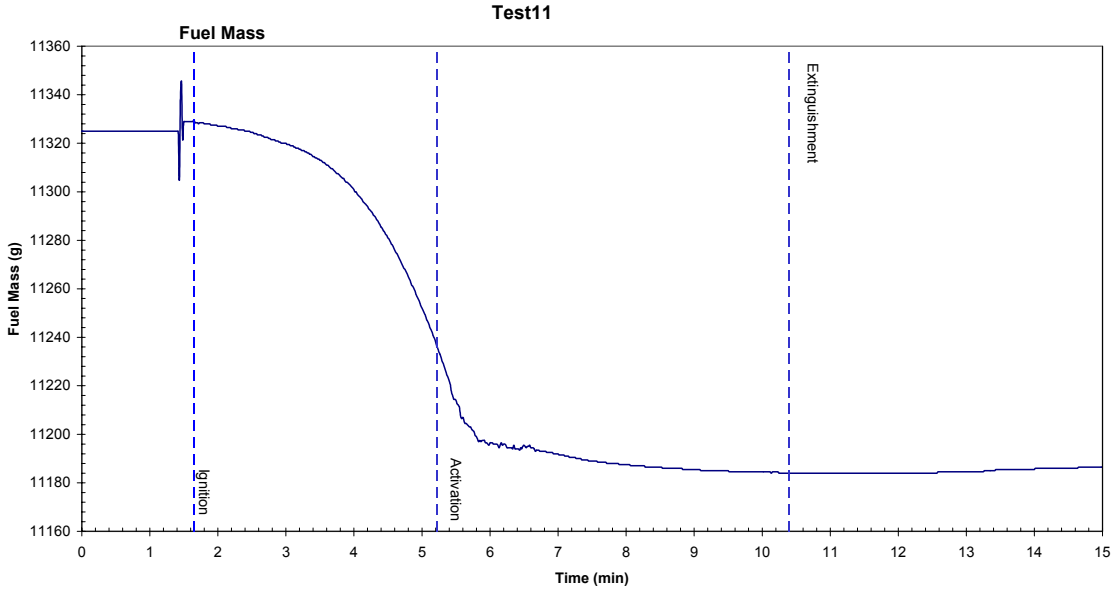

Figure A 20 - Fuel Mass during PMMA Polymeric Material Test with Three Model 8-1 Generators for a Total Loading of 96.4 g/m^3 (Test 11)

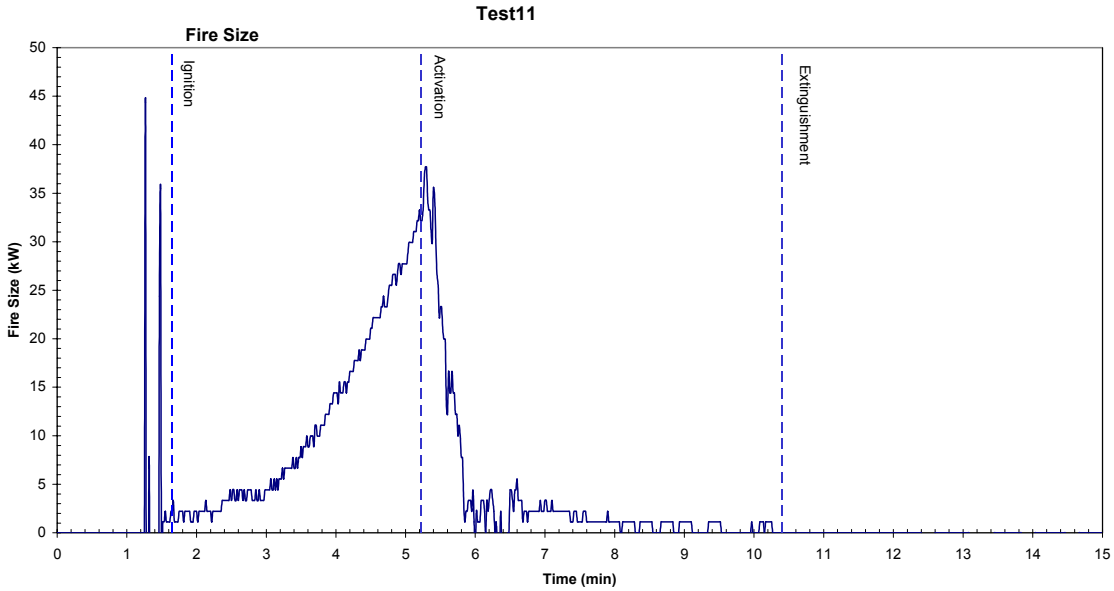

Figure A 21 - Fire Size during PMMA Polymeric Material Test with Three Model 8-1 Generators for a Total Loading of 96.4 g/m^3 (Test 11)

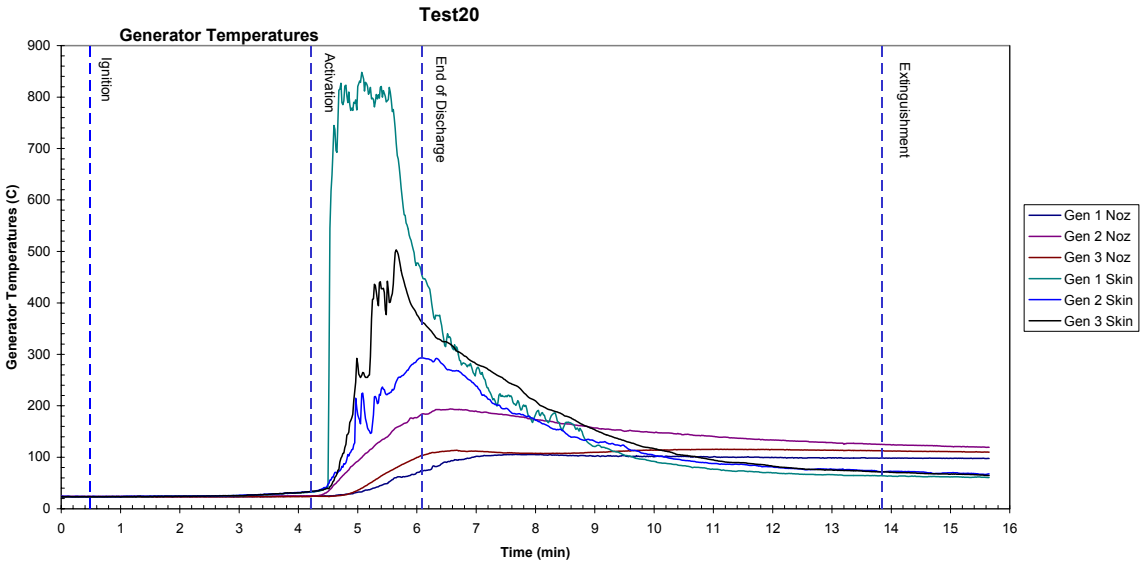

Figure A 22 - Generator Temperatures during PMMA Polymeric Material Test with Four Model 8-1 Generators for a Total Loading of 128.6 g/m^3 (Test 20)

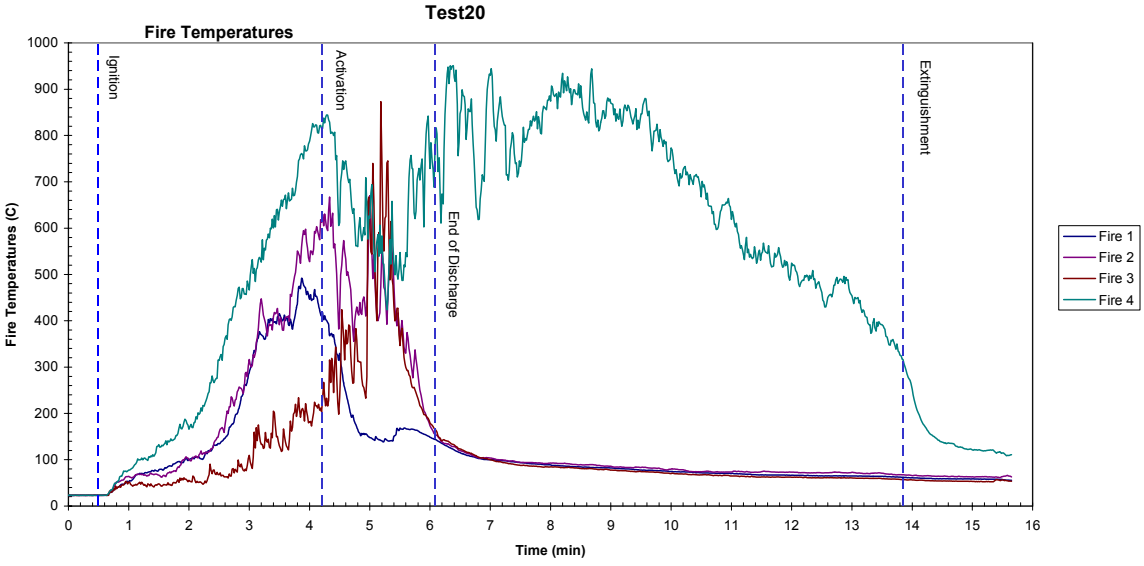

Figure A 23 - Fire Temperatures during PMMA Polymeric Material Test with Four Model 8-1 Generators for a Total Loading of 128.6 g/m^3 (Test 20)

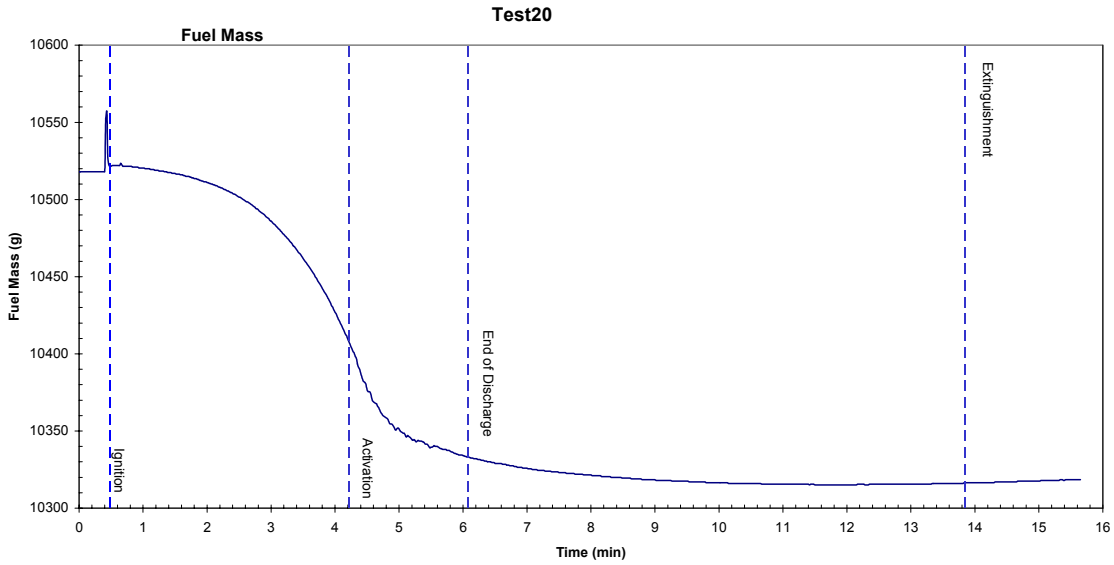

Figure A 24 - Fuel Mass during PMMA Polymeric Material Test with Four Model 8-1 Generators for a Total Loading of 128.6 g/m^3 (Test 20)

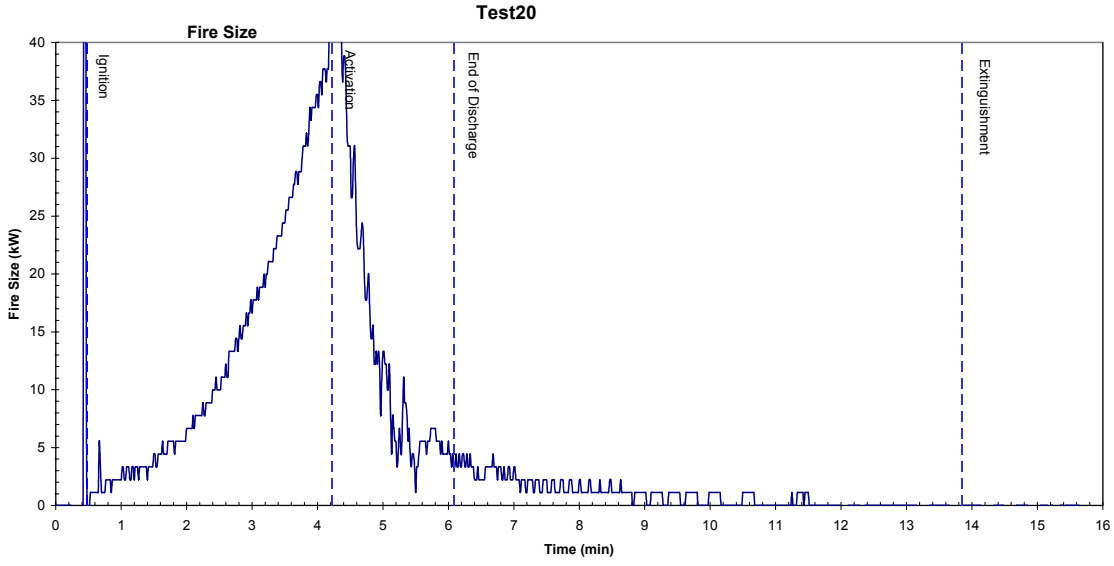

Figure A 25 - Fire Size during PMMA Polymeric Material Test with Four Model 8-1 Generators for a Total Loading of 128.6 g/m^3 (Test 20)

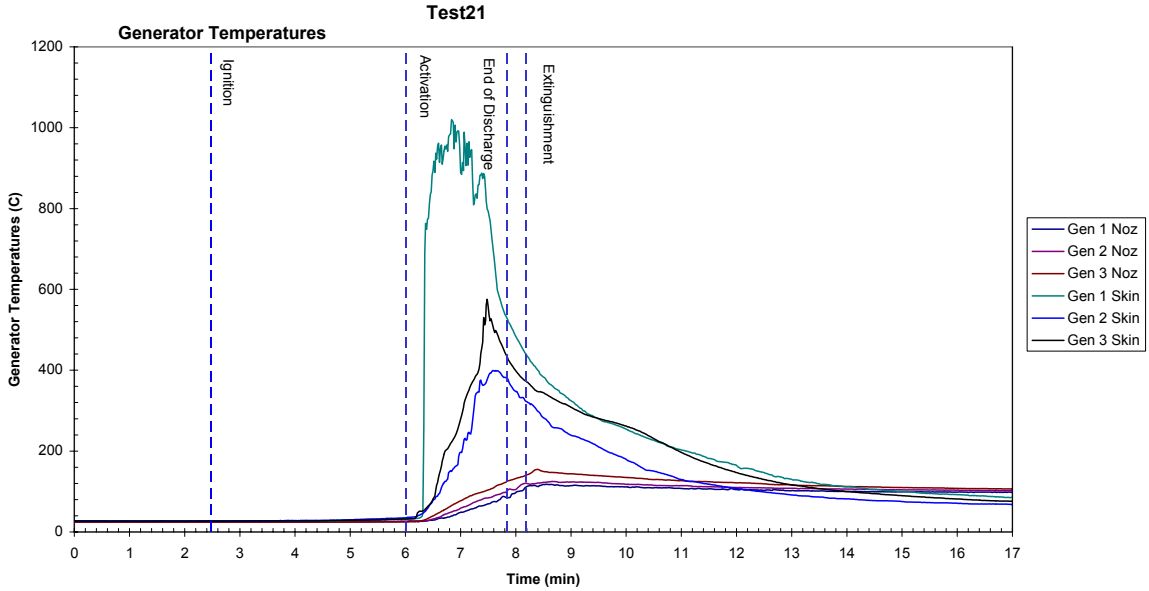

Figure A 26 - Generator Temperatures during ABS Polymeric Material Test with Four Model 8-1 Generators for a Total Loading of 128.6 g/m^3 (Test 21)

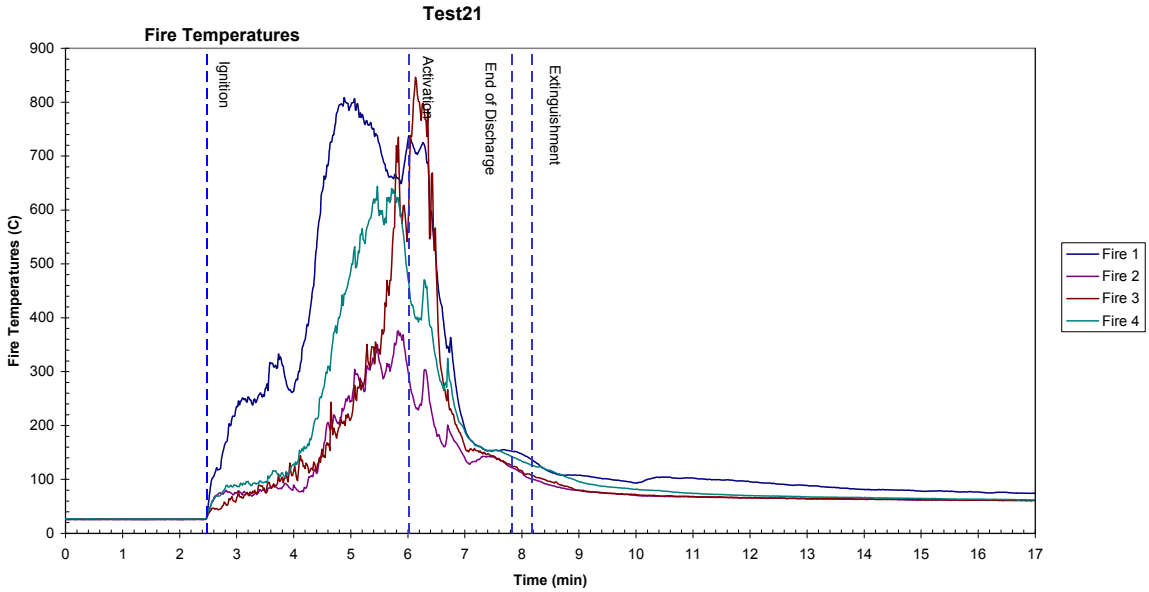

Figure A 27 - Fire Temperatures during ABS Polymeric Material Test with Four Model 8-1 Generators for a Total Loading of 128.6 g/m^3 (Test 21)

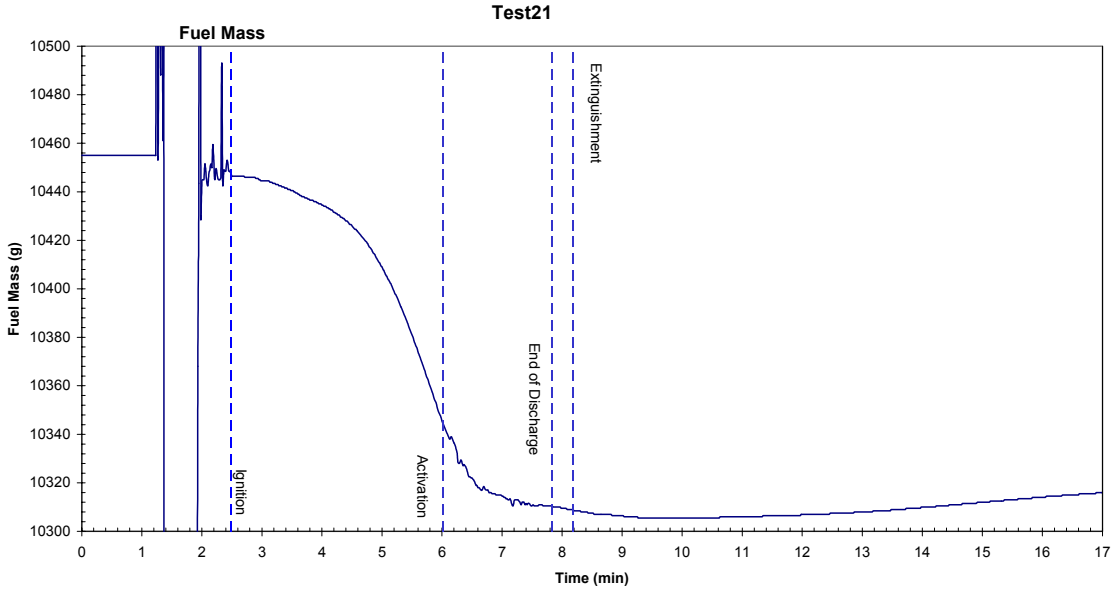

Figure A 28 - Fuel Mass during ABS Polymeric Material Test with Four Model 8-1 Generators for a Total Loading of 128.6 g/m^3 (Test 21)

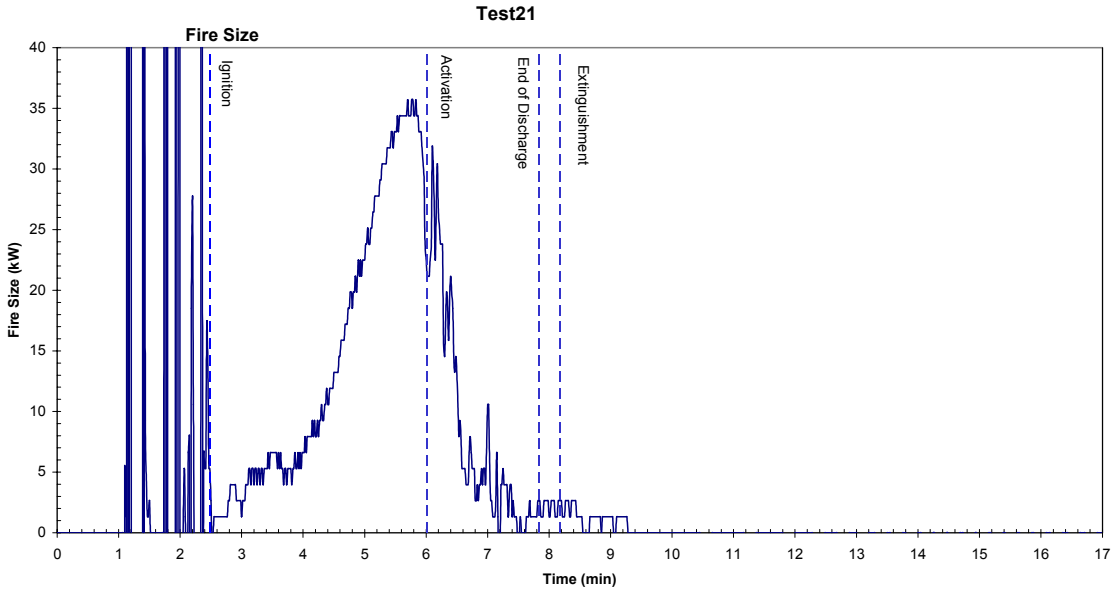

Figure A 29 - Fire Size during ABS Polymeric Material Test with Four Model 8-1 Generators for a Total Loading of 128.6 g/m^3 (Test 21)

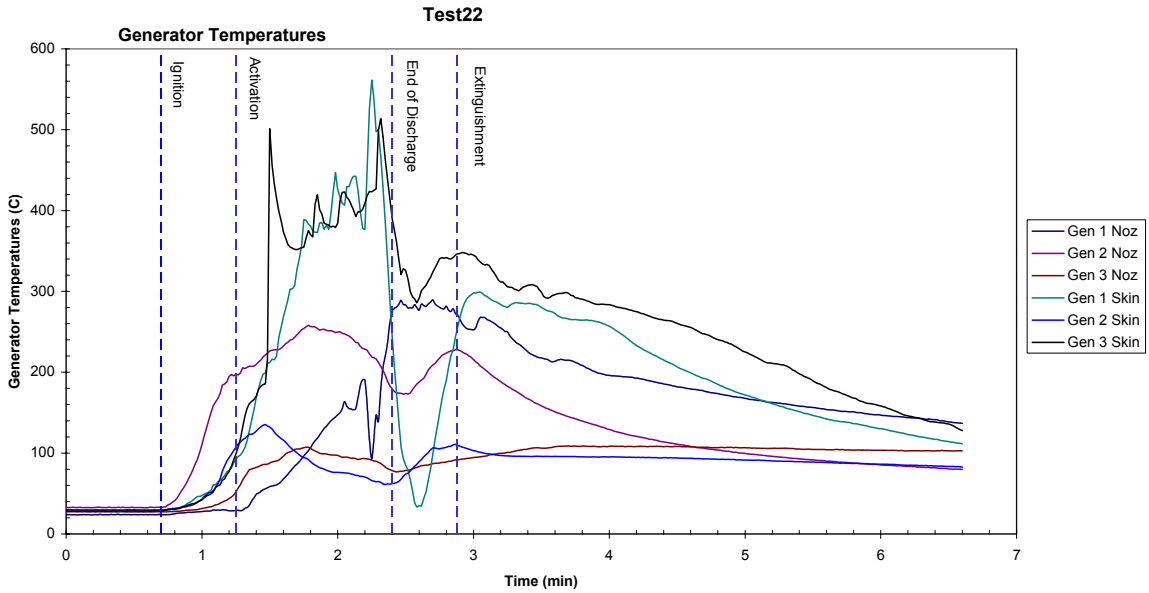

Figure A 30 - Generator Temperatures during n-Heptane Pan Fire Test with Two Model 8-1 Generators for a Total Loading of 64.3 g/m^3 (Test 22)

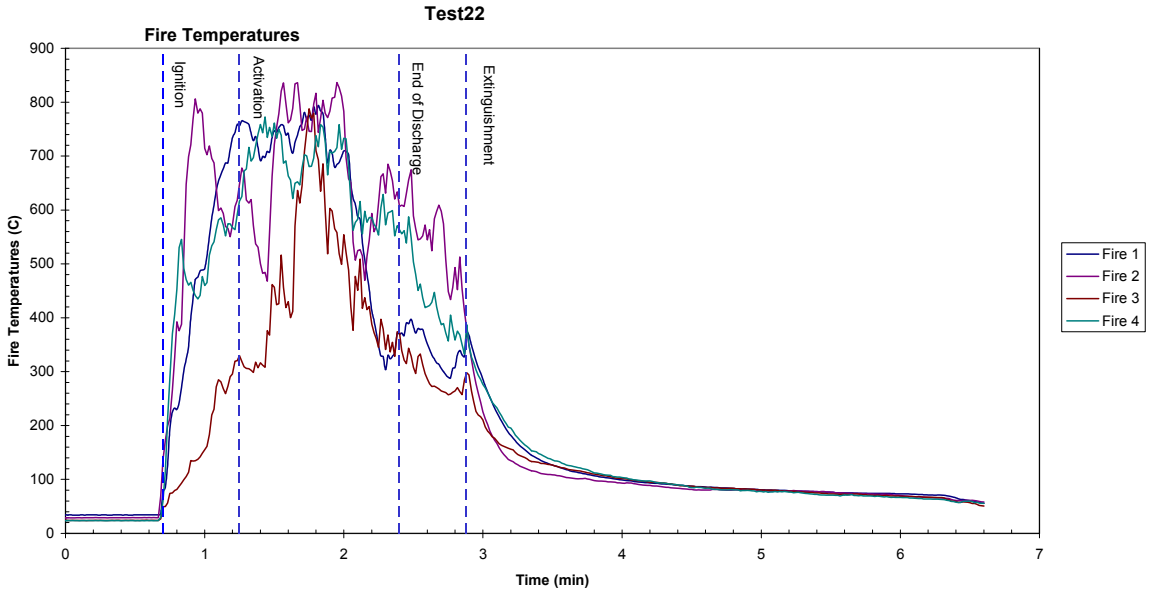

Figure A 31 - Fire Temperatures during n-Heptane Pan Fire Test with Two Model 8-1 Generators for a Total Loading of 64.3 g/m^3 (Test 22)