RESEARCH TECHNICAL REPORT

Fire Protection Requirements of Empty Intermediate Bulk Containers (IBCs)

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Fire Protection Requirements of Empty Intermediate Bulk Containers (IBCs)

by

Seth E. Sienkiewicz

FM Global Research Division
1151 Boston-Providence Turnpike
Norwood, MA 02062

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DISCLAIMER

EXECUTIVE SUMMARY

Program Summary

FM Global has been working on a broad scope project aimed at developing fire protection criteria for composite intermediate bulk container (IBC) storage. A subset of that project consisted of six tests focused on the hazard and required protection of empty IBCs. As FM Global's contribution to the Property Insurance Research Group (PIRG) in 2011, these data obtained on empty IBCs are provided for the use of all group members.

A composite intermediate bulk container (IBC) is a common shipping and storage container for liquids. It is an extrusion blow-molded high-density polyethylene bottle inside of a wire support cage. IBCs are available in a variety of storage volumes, but the most common have a 1041 L (275 gal.) capacity. A pallet is also integrated into the IBC. The pallet can be made of metal, wood, or plastic.

Commonly, IBCs are used for the shipping and storage of ignitable liquids. FM Global's past testing has found new protection options for these types of containers with high flash point liquids and ethyl alcohol that can be found in FM Global Property Loss Prevention Data Sheet 7-29[1]. That same test work also revealed that composite IBCs that empty in a fire involving relatively low hazard ignitable liquids can create a significant fire challenge when the containers burn. Past fire testing has shown that the protection of large empty plastic containers creates a fire hazard greater than what would be expected from an exposed unexpanded plastic, but protection criteria have not been defined.

To address this concern, six tests were conducted to study several different aspects of the hazard of empty IBCs. The goals of the tests were to provide guidance on the protection of stacked or rack-stored empty IBCs, to quantify the hazard posed by IBCs with different pallet types (metal, wood, plastic), and to determine how sprinkler attributes impact the performance of the protection system.

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[1] "Ignitable Liquid Storage in Portable Containers," FM Global Property Loss Prevention Data Sheet 7-29, Factory Mutual Insurance Company, 2012.

Stacked IBCs on Plastic Pallets

Three tests were conducted with empty IBCs on plastic pallets stacked 3-high below a 9.1 m (30 ft) ceiling. To begin this phase of the testing, an initial estimate at the protection required was made based on the composition of the IBCs. Since the IBC on a plastic pallet is comprised of almost entirely exposed plastic (minus the wire cage), the initial protection was selected based on existing guidance for solid-piled uncartoned plastic in FM Global Property Loss Prevention Data Sheet 8-9[2].

Test 1 was conducted with K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$), quick response, 74 ^{o}C (165 ^{o}F) temperature rated, pendent sprinklers operating at 5.2 bar (75 psi), which resulted in a design density of 49 mm/min (1.2 gpm/ft^2). During the test, a single sprinkler operated and controlled the fire. To optimize the required protection for the hazard, the system design pressure was reduced in Test 2.

Test 2 was conducted with the same test parameters, but the system pressure was reduced to 2.2 bar (32 psi), which provided a design density of 33 mm/min (0.8 gpm/ft^2). As with Test 1, a single sprinkler was able to control the fire. Test 3 was conducted to further optimize the protection.

In Test 3, the design pressure of 1.2 bar (18 psi) provided a design density of 24 mm/min (0.6 gpm/ft^2). During the test, six sprinklers operated but were unable to prevent the fire from spreading through the test array. Therefore, the result obtained in Test 2 was deemed optimal and it was concluded that reducing the pressure further would not provide adequate protection.

Stacked IBCs on Wood Pallets

The next phase of the test program was to determine the required protection for empty IBCs on wood pallets stacked 3-high below a 9.1 m (30 ft) ceiling. Since these IBCs have wood pallet bases, it was assumed that the hazard would be lower than that of the IBCs with plastic pallets.

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[2] "Storage of Class 1, 2, 3, 4, and Plastic Commodities," FM Global Property Loss Prevention Data Sheet 8-9, Factory Mutual Insurance Company, 2011.

Based on that assumption, the adequate protection determined for Test 2 with IBCs on plastic pallets would be adequate for IBCs on wood pallets.

Test 4 was conducted to determine if the level of protection provided in Test 3 (inadequate for IBCs on plastic pallets) would be adequate for the protection of IBCs on wood pallets. Ceiling level protection was provided by K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$), quick response, 74 ^{o}C (165 ^{o}F) temperature rated, pendent sprinklers operating at 1.2 bar (18 psi). This provided the same density of 24 mm/min (0.6 gpm/ft^2) used in Test 3.

In Test 4, a single sprinkler operated and was able to control the fire. Based on this result, adequate protection of the hazard can be provided by the protection used. Further optimization of the level of protection was not pursued during this program.

Stacked IBCs on Metal Pallets

Similar to the assumption that wood pallet IBCs were less hazardous than plastic pallet IBCs, metal pallet IBCs were considered to be even less hazardous. Therefore, the protection point obtained for the wood pallet IBCs was deemed adequate for the hazard of stacked IBCs with metal pallets.

Rack Storage of IBCs on Wood Pallets

Upon completion of the stacked empty IBC testing, an additional test was conducted with rack storage of empty IBCs on wood pallets. As with previous tests, the ceiling height was set to 9.1 m (30 ft). The empty IBCs were stored in a double-row, open-frame rack that was 3-tiers high. The goal of the test was to determine adequate protection for the hazard.

In Test 11[3], ceiling level protection was provided by K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$), quick response, 74 ^{o}C (165 ^{o}F) temperature rated, pendent sprinklers operating at 2.2 bar

[3] The data provided in this report are a subset of a test program conducted at FM Global with intermediate bulk containers. Test numbering for this report was kept consistent with the original test numbers and is not sequential within this report.

(32 psi). This provided the density of 33 mm/min (0.8 gpm/ft^2). During the test, a single sprinkler operated and was able to control the fire.

The results show that adequate protection of the hazard was provided with the K202 (K14) QR sprinklers operating at 2.2 bar (32 psi). This was the last test of the project and no additional commodity was available for further testing. Therefore, optimization of this protection point was not pursued.

Sprinkler Response

One additional aspect of sprinkler protection was investigated during the project. Test 4 and Test 10 were conducted with identical storage arrays and the same design density [24 mm/min (0.6 gpm/ft^2)], but with different sprinkler attributes. Both tests were conducted with empty IBCs on wood pallets stacked 3-high below a 9.1 m (30 ft) ceiling. In Test 4, adequate protection was provided by K202 (K14) quick response sprinklers at 1.2 bar (18 psi).

The goal of Test 10 was to determine if adequate protection could be provided by a lower K-factor standard response sprinkler. In Test 10, ceiling level protection was provided by K-factor 161 lpm/bar$^{1/2}$ (11.2 gpm/psi$^{1/2}$), standard response, 68 ^{o}C (155 ^{o}F) temperature rated, pendent sprinklers operating at 1.9 bar (28 psi).

As expected, first sprinkler operation occurred later with the standard response sprinkler used in Test 10. This delay allowed the fire to become more involved in the array prior to the application of water. Additionally, a standard response sprinkler generally puts less water directly below the sprinkler where the fire is developing compared to a quick response sprinkler. The delay, plus the distribution pattern, caused the sprinkler to have little impact on the fire. Several additional sprinklers operated, but the damage exceeded the evaluation threshold prior to the sprinklers bringing the fire under control.

Conclusions

The test results and data analysis support the following conclusions for storage of empty IBCs under a 9.1 m (30 ft) ceiling:

- Plastic pallet IBCs stacked 3-high can be adequately protected with K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$) pendent, quick response, 74 ^{o}C (165 ^{o}F) sprinklers operating at 2.2 bar (32 psi).
- Wood pallet IBCs stacked 3-high can be adequately protected with K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$) pendent, quick response, 74 ^{o}C (165 ^{o}F) sprinklers operating at 1.2 bar (18 psi). The same level of sprinkler protection is also adequate for metal pallet IBCs stacked 3-high.
- Wood pallet IBCs stored to 4.3 m (14 ft) in a rack storage array can be adequately protected with K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$) pendent, quick response, 74 ^{o}C (165 ^{o}F) sprinklers operating at 2.2 bar (32 psi). The same level of sprinkler protection is also adequate for rack storage of metal pallet IBCs.
- Quick response (QR) sprinklers should be used instead of standard response (SR) sprinklers for the protection of empty composite IBCs.

ABSTRACT

The goal of this test program was to assess the fire hazard and required protection of empty intermediate bulk containers (IBCs) in storage configurations. Six large-scale fire tests were conducted during the program that assessed several aspects of IBC storage. The testing investigated the difference in the hazard of plastic pallet IBCs compared to wood pallet IBCs, determined the required protection for stacked storage of both types, assessed the impact of changing the sprinkler response, and determined the required protection for empty wood pallet IBCs in a rack storage arrangement.

All tests in the program were conducted beneath a 9.1 m (30 ft) ceiling and the test results can be used to specify the following protection guidelines and recommendations:

- Plastic pallet IBCs stacked 3-high can be adequately protected with K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$) pendent, quick response, 74 ^{o}C (165 ^{o}F) sprinklers operating at 2.2 bar (32 psi).
- Wood pallet IBCs stacked 3-high can be adequately protected with K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$) pendent, quick response, 74 ^{o}C (165 ^{o}F) sprinklers operating at 1.2 bar (18 psi). The same level of sprinkler protection is also adequate for metal pallet IBCs stacked 3-high.
- Wood pallet IBCs stored to 4.3 m (14 ft) in a rack storage array can be adequately protected with K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$) pendent, quick response, 74 ^{o}C (165 ^{o}F) sprinklers operating at 2.2 bar (32 psi). The same level of sprinkler protection is also adequate for rack storage of metal pallet IBCs.
- Quick response (QR) sprinklers should be used instead of standard response (SR) sprinklers for the protection of empty composite IBCs.

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Table 1: Tabulated Test Results – Tests 1, 2, and 3

TEST SETUP	TEST NO TEST ID	**01** **ProtectIBC001**	**02** **ProtectIBC002**	**03** **ProtectIBC003**
	DATE	08/02/2011	08/04/2011	08/09/2011
	LOCATION	LBL – South Ceiling	LBL – South Ceiling	LBL – South Ceiling
	TEST COMMODITY	Empty PP IBC Class 2 Target	Empty PP IBC Class 2 Target	Empty PP IBC Class 2 Target
	MAIN ARRAY SIZE [pallets] TARGET ARRAY SIZE [pallets]	2 x 3 x 3-High Stacked 3-High Stacked	2 x 3 x 3-High Stacked 3-High Stacked	2 x 3 x 3-High Stacked 3-High Stacked
	ARRAY TYPE FLUE SPACE [cm (in.)]	Open 15 (6)	Open 15 (6)	Open 15 (6)
	CEILING HEIGHT [m (ft)]	9.1 (30)	9.1 (30)	9.1 (30)
	STORAGE HEIGHT [m (ft)]	3.5 (11.5)	3.5 (11.5)	3.5 (11.5)
	IGNITION LOCATION	Under 1, Offset	Under 1, Offset	Under 1, Offset
	WESP [m^3/min (scfm)]	5,663 (200,000)	5,663 (200,000)	5,663 (200,000)
	RELATIVE HUMIDITY [%]	36	36	69
	AMBIENT TEMPERATURE [^oC (^oF)]	22 (71)	23 (73)	24 (76)
PROTECTION	K-FACTOR [lpm/bar$^{1/2}$ (gpm/psi$^{1/2}$)]	202 (14.0)	202 (14.0)	202 (14.0)
	ORIENTATION	Pendent	Pendent	Pendent
	SPRINKLER RESPONSE	Quick (QR)	Quick (QR)	Quick (QR)
	SPRINKLER TEMP RATING [^oC (^oF)]	74 (165)	74 (165)	74 (165)
	SPACING [m x m (ft x ft)]	3.0 x 3.0 (10 x 10)	3.0 x 3.0 (10 x 10)	3.0 x 3.0 (10 x 10)
	DISCHARGE PRESSURE [bar (psi)]	5.2 (75)	2.2 (32)	1.2 (18)
	DESIGN DENSITY [mm/min (gpm/ft^2)]	49 (1.2)	33 (0.8)	24 (0.6)
TEST RESUTLS	FIRST SPRINKLER OPERATION [min:sec]	9:24	8:56	9:19
	LAST SPRINKLER OPERATION [min:sec]	9:24	8:56	17:16
	TOTAL SPRINKLER OPERATIONS	1	1	6
	PEAK 10-SEC GAS TEMP [^oC (^oF)] @ TIME [min:sec]	101 (214) 9:19	116 (240) 8:52	172 (341) 17:01
	PEAK 1-MIN AVG GAS TEMP [^oC (^oF)] @ TIME [min:sec]	69 (156) 8:56	69 (156) 8:29	139 (282) 16:49
	PEAK 1-MIN AVG STEEL TEMP [^oC (^oF)] @ TIME [min:sec]	32(89) 10:00	36 (97) 10:08	46 (114) 18:31
	TARGET INVOLVEMENT	N	N	Y
	TEST RESULT	PASS	PASS	FAIL
	TEST DURATION [min:sec]	40:00	30:00	30:00

Table 2: Tabulated Test Results – Tests 4, 10, and 11

TEST SETUP	TEST NO TEST ID	**04** **ProtectIBC004**	**10** **ProtectIBC010**	**11** **ProtectIBC011**
	DATE	08/10/2011	10/05/2011	10/07/2011
	LOCATION	LBL – South Ceiling	LBL – South Ceiling	LBL – South Ceiling
	TEST COMMODITY	Empty WP IBC Class 2 Target	Empty WP IBC Class 2 Target	Empty WP IBC Class 2 Target
	MAIN ARRAY SIZE [pallets] TARGET ARRAY SIZE [pallets]	2 x 3 x 3-High Stacked 3-High Stacked	2 x 3 x 3-High Stacked 3-High Stacked	2 x 4 x 3 DRR (2) 1 x 4 x 3 SRR
	ARRAY TYPE FLUE SPACE [cm (in.)]	Open 15 (6)	Open 15 (6)	Rack Storage 15 (6)
	CEILING HEIGHT [m (ft)]	9.1 (30)	9.1 (30)	9.1 (30)
	STORAGE HEIGHT [m (ft)]	3.5 (11.5)	3.5 (11.5)	4.3 (14)
	IGNITION LOCATION	Under 1, Offset	Under 1, Offset	Under 1, Offset
	WESP [m^3/min (scfm)]	5,663 (200,000)	5,663 (200,000)	5,663 (200,000)
	RELATIVE HUMIDITY [%]	37	31	25
	AMBIENT TEMPERATURE [^oC (^oF)]	23 (73)	23 (74)	24 (75)
PROTECTION	K-FACTOR [lpm/bar$^{1/2}$ (gpm/psi$^{1/2}$)]	202 (14.0)	161 (11.2)	202 (14.0)
	ORIENTATION	Pendent	Pendent	Pendent
	SPRINKLER RESPONSE	Quick (QR)	Standard (SR)	Quick (QR)
	SPRINKLER TEMP RATING [^oC (^oF)]	74 (165)	68 (155)	74 (165)
	SPACING [m x m (ft x ft)]	3.0 x 3.0 (10 x 10)	3.0 x 3.0 (10 x 10)	3.0 x 3.0 (10 x 10)
	DISCHARGE PRESSURE [bar (psi)]	1.2 (18)	1.9 (28)	2.2 (32)
	DESIGN DENSITY [mm/min (gpm/ft^2)]	24 (0.6)	24 (0.6)	33 (0.8)
TEST RESUTLS	FIRST SPRINKLER OPERATION [min:sec]	8:24	9:30	7:28
	LAST SPRINKLER OPERATION [min:sec]	8:24	10:42	7:28
	TOTAL SPRINKLER OPERATIONS	1	17	1
	PEAK 10-SEC GAS TEMP [^oC (^oF)] @ TIME [min:sec]	94 (202) 8:19	474 (885) 10:30	97 (206) 7:25
	PEAK 1-MIN AVG GAS TEMP [^oC (^oF)] @ TIME [min:sec]	73 (163) 7:55	294 (562) 10:40	57 (135) 7:08
	PEAK 1-MIN AVG STEEL TEMP [^oC (^oF)] @ TIME [min:sec]	37 (98) 9:29	79 (174) 12:24	32 (89) 8:45
	TARGET INVOLVEMENT	N	Y	N
	TEST RESULT	PASS	FAIL	PASS
	TEST DURATION [min:sec]	20:00	20:00	25:00

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1 INTRODUCTION

1.1 PROJECT OVERVIEW

FM Global has been working on a broad scope project aimed at developing fire protection criteria for composite intermediate bulk container (IBC) storage. The overall program was comprised of twelve large-scale fire tests, which can be used to understand the hazard of ignitable liquids in IBCs and to define the required protection of the hazard. Included in this test program is a subset of that project consisting of six tests focused on the hazard and required protection of empty IBCs. This report documents the conditions, observations, data, and results from the six tests conducted with the empty IBCs.

This empty IBC portion of the overall project was conducted as FM Global's contribution to the Property Insurance Research Group (PIRG) in 2011. The PIRG is comprised of property insurance companies with a collective interest in acquiring general knowledge for issues spanning the entire property insurance industry. The group is coordinated through the National Fire Protection Association (NFPA) Fire Protection Research Foundation (FPRF). FM Global participates through the donation of the resources available at the FM Global Research Campus, including test material, lab space, support staff, and other associated costs.

In 2011, the PIRG prioritized a project to address the hazard of intermediate bulk containers. Concurrently, the overall project discussed above was also being initiated by FM Global to develop protection criteria for our clients that use IBCs. To support the PIRG, FM Global broadened the scope of the project to include a series of tests focusing on empty IBCs.

Commonly, IBCs are used for the shipping and storage of ignitable liquids. FM Global's past testing has found new protection options for these types of containers with high-flash-point liquids and ethyl alcohol that can be found in FM Global Property Loss Prevention Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers* [1]. That same test work also revealed that composite IBCs that empty in a fire involving relatively low hazard ignitable liquids can create a significant fire challenge when the containers burn. Past fire testing has shown that the storage of large empty plastic containers poses a fire hazard greater than what would be expected from an exposed unexpanded plastic, but protection criteria have not been defined.

The tests with empty IBCs were designed to address several different aspects of the empty IBC hazard to gain as much information as possible from a small series of tests. The six tests summarized herein provide guidance on the protection of stacked or rack-stored empty IBCs, the hazard posed by IBCs with different pallet types (metal, wood, plastic), and how sprinkler attributes impact performance of the protection system.

1.2 REPORT FORMAT AND OVERVIEW

Following the Introduction, Section 2 provides information about the test conditions and procedures, including information about the test facility, commodities used, the test setups, and an overview of the methods of analysis used for each test type. Data, observations, and results from each test are provided in Section 3. Section 4 provides a summary of results and discussion beyond raw test data. The conclusions and recommendations from the project are provided in Section 5. Appendices A and B provide support material for the program.

2 TEST CONDITIONS AND PROCEDURES

2.1 LARGE BURN LABORATORY

The tests for this program were conducted under the South movable ceiling in the Large Burn Laboratory (LBL) located in the Fire Technology Laboratory at the FM Global Research Campus in West Glocester, Rhode Island. Figure 2-1 is a plan view of the LBL showing the North movable ceiling, the South movable ceiling, and the 20-MW Calorimeter. The air emission control system (AECS) exhaust ducting shown above the North movable ceiling consists of four extraction points that merge into a single duct with a cross-sectional area of 6.1 m^2 (66 ft^2). A duplicate extraction system is present above the South ceiling, but is not shown in the figure. Gas concentration, velocity, temperature, and moisture measurements are made downstream of the manifold. Beyond the measurement location, the exhaust duct connects to a wet electrostatic precipitator (WESP) prior to clean gases venting to the atmosphere. The movable ceilings measure 24.4 m x 24.4 m (80 ft x 80 ft) and are adjustable for heights above the floor ranging from 3.1 m (10 ft) to 18.3 m (60 ft). All tests were conducted at an exhaust rate of 5700 m^3/min (200,000 ft^3/min).

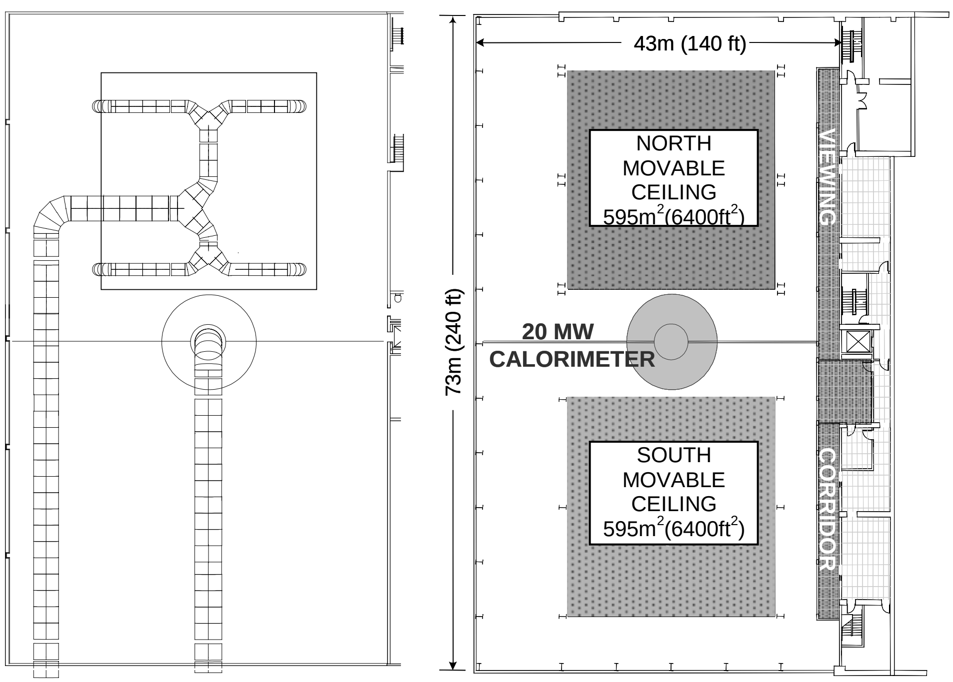


Figure 2-1: Illustration of AECS ducting and LBL Test Locations

2.2 TEST COMMODITY

2.2.1 Intermediate Bulk Container (IBC)

The commodity evaluated during this test program was empty intermediate bulk containers (IBCs). The IBC was an extrusion blow-molded high-density polyethylene bottle inside of a wire cage. IBCs are available in a range of storage volumes, but for this program, each IBC had a 1041 L (275 gal.) capacity. The IBC and wire cage are secured to a pallet to aid in transporting the product. Metal, wood, and plastic pallets are available for IBCs, but only the plastic pallet IBCs and wood pallet IBCs were evaluated in the program. The IBC measures approximately 122 cm x 102 cm x 116 cm high (48 in. x 40 in. x 45.75 in. high).

An opening (DN 150 with screw tap) is provided at the top for filling and an outlet (DN 50 butterfly valve) is provided at the bottom for dispensing. The outlet of the IBC is located at an indent in the bottle so the wire cage can provide protection from damage. This area is commonly referred to as the dog-house of the IBC, located on the 102 cm (40 in.) side of the IBC. A photo of an IBC with a wood pallet is provided in Figure 2-2.

Figure 2-2: Photo of IBC on wood pallet (internet image [2])

Tests in this program were conducted with new IBCs from the supplier. However, after a fire test, IBCs that did not sustain significant damage during the test were reused in subsequent tests. In instances where IBCs were reused, any part of the IBC that had slight damage (discoloration/deformation) was repositioned so the undamaged portion of the IBC was closest to ignition and subsequent fire development.

2.2.2 Class 2 Commodity

In addition to the IBCs, Class 2 commodity was used during the test program as ‘targets’ to assess fire spread. The FM Global standard Class 2 test commodity consists of three double-wall corrugated paper cartons. The dimensions for the inner, middle, and outer box are 1.02 m x 1.02 m x 0.96 m (40.3 in. x 40.3 in. x 37.8 in.), 1.04 m x 1.04 m x 0.99 m (41.0 in. x 41.0 in. x 39.1 in.), and 1.06 m x 1.06 m x 1.05 m (41.8 in. x 41.8 in. x 41.5 in.), respectively. Inside the cartons is a five-sided sheet metal liner, representing a non-combustible content. The cartoned liner is supported on an ordinary, two-way, slatted deck, hardwood pallet, measuring 1.07 m x 1.07 m x 13 cm (42 in. x 42 in. x 5 in.). A photo of the Class II commodity is provided in Figure 2-3.

Figure 2-3: Photo of Class 2 Commodity

2.3 TEST STORAGE ARRANGEMENT

Two types of storage arrangements were tested during the program. Stacked storage was used to assess the hazard of the intermediate bulk containers stored in a typical fashion for IBCs. A rack storage test was conducted to compare the hazard of IBCs to that of other standard commodities tested in rack storage.

2.3.1 Stacked Storage[4]

Stacking of the intermediate bulk containers is a common method of storage where the IBCs are set directly on top of each other. Often, the pallets of the IBCs and the wire cages are designed so they align during stacking to improve stability. By stacking the IBCs, floor space can be saved by storing the product vertically, but without the use of racks. Typically, IBCs can be stacked 3-high, though higher storage is possible depending on the product in the IBCs. For this program, IBCs stacked 3-high were utilized for all tests. The nominal height of a 3-high stacked array was 3.5 m (11.5 ft). A photo of a single stack of the IBCs is provided in Figure 2-4.

Figure 2-4: Photo of a Single Stack of IBCs

[4] This storage method is also commonly referred to as Solid-Piled storage.

For the solid-piled fire tests, the fuel array was broken down between the main array and the target array. The main array was an 18-IBC array stored 2 x 3 x 3-high. The main array was comprised entirely of empty IBCs.

Surrounding the main array were 3-high stacks designated as targets during the test. These targets were installed to simulate representative airflow during the test and to assess fire propagation through the array. These targets were mainly comprised of FM Global Class 2 commodity; however, the stacks directly east and west of ignition were empty composite IBCs[5]. The IBCs were stored in an open array with nominal 15 cm (6 in.) flues in both directions.

A schematic plan view of the test array is provided in Figure 2-5. The main array was comprised of the core IBCs (2 x 3) in the schematic. The stacks around the edge of the array were the targets during the tests. Photos of the actual IBC array are provided in Figure 2-6 and Figure 2-7.

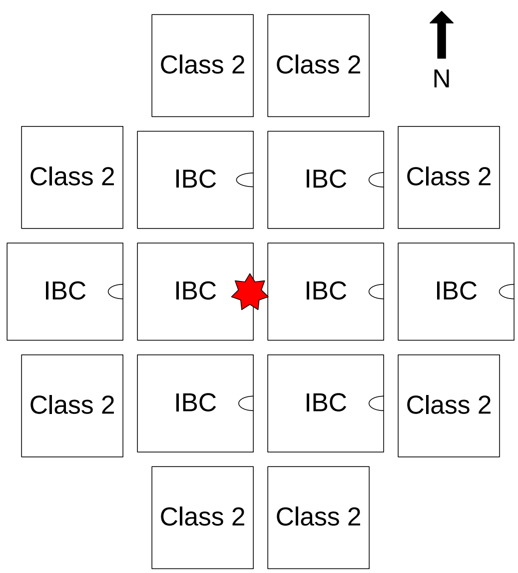


Figure 2-5: Schematic Plan View of Empty IBC Array

[5] For Test 1, all of the target array stacks were Class 2 commodity. During the test, fire propagation was observed into the Class 2 target that likely would not have occurred if an IBC had been in place instead. For subsequent tests, the target stacks directly East and West of ignition were comprised of composite IBCs. Additional information is provided in Section 3.

Figure 2-6: Photo of IBC Array

Figure 2-7: Photo of IBC Array (from elevation)

2.3.2 Rack Storage

A single rack storage test was also conducted as part of the test program. Rack storage is a very common storage method in industrial and commercial warehouses and is designed to utilize the entire available height in a building for storage. The storage of commodity is within free-standing steel racks.

As with the stacked IBC tests, the fuel array was broken down between the main array and the target arrays. The main array consisted of commodity stored in a double row, open frame rack that was six pallet loads wide. The target array consisted of commodity stored in a single-row, open frame rack, that was four pallet loads wide. Target arrays were placed on either side of the main array, separated by a 1.2 m (4 ft) aisle. Commodity was placed on the floor in the 1st tier, and additional tiers were located 1.5 m (5 ft) from the floor. For this program, the test array was 3-tiers high, to match the storage height of the stacked IBC tests. Commodity was placed within the array so the longitudinal and transverse flues had nominal 15 cm (6 in.) spacing. The nominal height of a 3-tier rack storage array was 4.3 m (14 ft).

The main array was comprised of both empty composite IBCs and Class 2 commodity. In each row of the main array, the inner four pallet loads were the empty composite IBCs. Capping the ends of the double row rack was Class 2 commodity to assess fire propagation during the test. Additionally, Class 2 commodity was used for both target arrays. A plan view schematic of the rack storage test array is provided in Figure 2-8. A photo of the rack storage test array is provided in Figure 2-9.

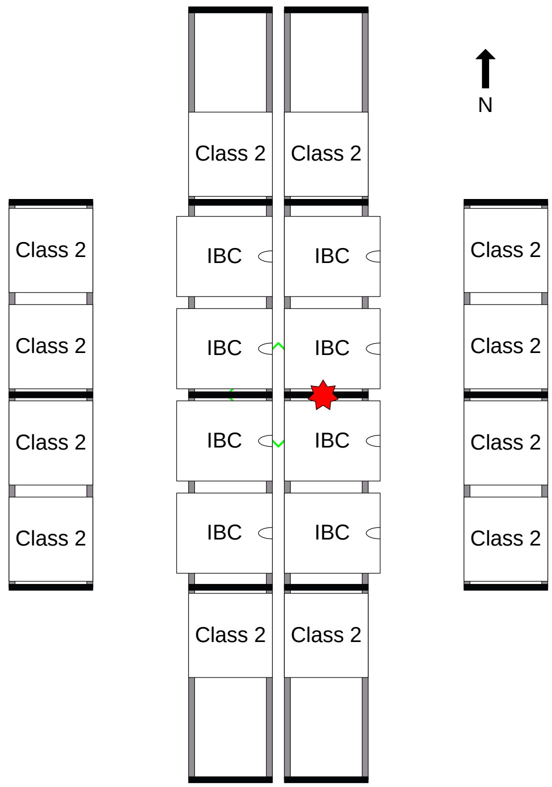


Figure 2-8: Schematic Plan View of Rack Storage Empty IBC Array

Figure 2-9: Photo of Rack Storage IBC Array

2.4 AUTOMATIC SPRINKLER PROTECTION

Several parameters impact the performance of an automatic sprinkler system, including ceiling height, storage height, sprinkler K-factor, sprinkler response, orientation, operation temperature, spacing, and position relative to the ignition location. The specific parameters used in this test program are covered in this section.

2.4.1 Ceiling Height

For all tests in this program, the ceiling height was set at 9.1 m (30 ft). This ceiling height was deemed to be representative of common industrial facilities.

2.4.2 Storage Height

Two storage heights were used, depending on the storage method selected. For the 3-high storage arrays, the storage height was 3.5 m (11.5 ft). For the 3-tier rack storage arrays, the storage height was 4.3 m (14 ft).

2.4.3 Sprinkler Attributes

Two different sprinklers were used for this test program.

For the majority of the tests (5 of 6), ceiling sprinkler protection was provided by K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$), quick response, pendent sprinklers, with a 74 ^{o}C (165 ^{o}F) link. Photos of the sprinkler are provided in Figure 2-10.

Figure 2-10: Photos of K-factor 202 QR Sprinkler

For one test, ceiling sprinkler protection was provided by K-factor 161 lpm/bar$^{1/2}$ (11.2 gpm/psi$^{1/2}$), standard response, pendent sprinklers, with a 68 ^{o}C (155 ^{o}F) bulb. Photos of the sprinkler are provided in Figure 2-11.

Figure 2-11: Photos of K-factor 161 SR Sprinkler

The sprinklers were installed on 3.0 m x 3.0 m (10 ft x 10 ft) spacing for all tests. A total of 49 sprinklers were installed for each test. The design pressure for the sprinklers was varied for each test and specific test conditions are provided in Section 3.

2.4.4 Sprinkler Location

Following current FM Global large-scale fire test procedures, the sprinkler location relative to ignition was determined by the clearance between the top of the commodity and the ceiling. For clearances grater than 1.8 m (6 ft), as in this program, the igniter(s) are placed “Under 1” ceiling sprinkler. As noted in Section 2.4.2, the storage height for the stacked IBCs and rack stored IBCs was 3.5 m (11.5 ft) and 4.3 m (14 ft), respectively, below a 9.1 m (30 ft) ceiling.

Additionally, since all testing was conducted with pendent sprinklers, the igniter was positioned offset 0.6 m (2 ft) east from the overhead sprinkler, so the sprinkler discharge did not directly impinge on the igniter. For the stacked IBC test, the overhead sprinkler was centered over the western row of the core IBCs. For the rack stored IBCs, the overhead sprinkler was centered over the flue intersection with the igniters located in the transverse flue.

A plan view of the test array, igniter location, and ceiling sprinkler layout for the stacked IBC tests is provided in Figure 2-12. A plan view of the test array, igniter location, and ceiling sprinkler layout for the rack storage test is provided in Figure 2-13.

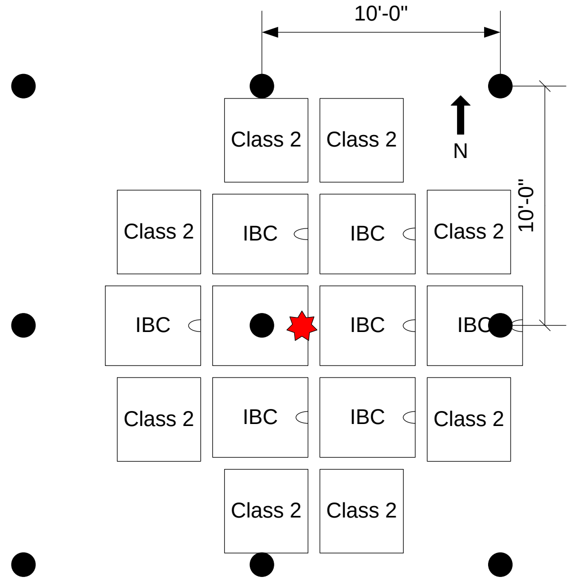


Figure 2-12: Igniter/Sprinkler Location for Stacked Empty IBC Test Array

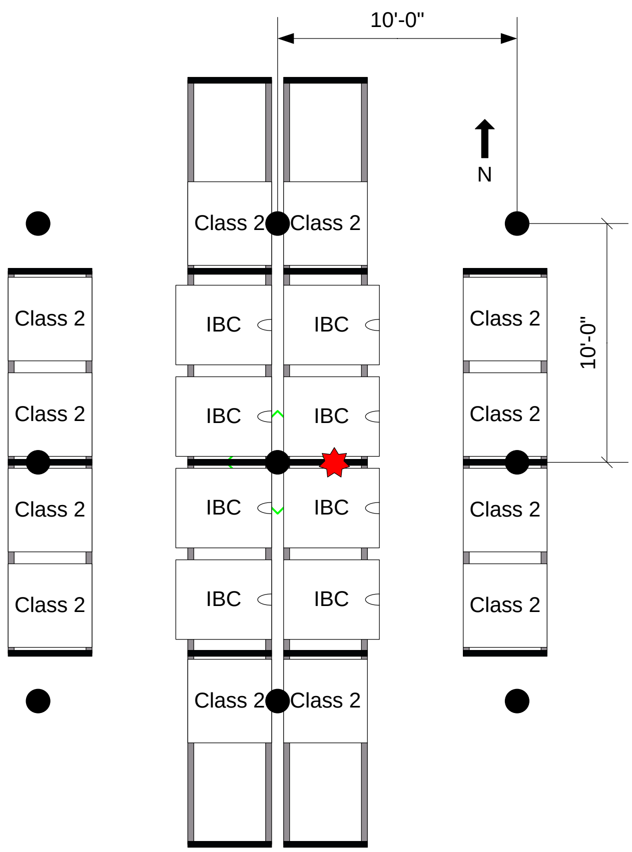


Figure 2-13: Igniter/Sprinkler Location for Rack Storage Empty IBC Test Array

2.5 IGNITION

A different ignition source was used for the stacked IBC tests and the rack test.

2.5.1 FM Global Standard Igniter

For the stacked IBC tests, ignition was achieved with an FM Global standard full igniter. The igniter is a 76 mm x 152 mm (3 in. x 6 in.) cylinder of rolled cellucotton. The igniter is soaked in 237 ml (8 oz.) of gasoline and sealed in a plastic bag. It was placed in the doghouse of the intermediate bulk container located at floor level and facing the longitudinal flue, as indicated in Figure 2-12. A photo of the igniter placed in the doghouse of the IBC is provided in Figure 2-14. The igniters were lit with an electric match at the start of the test and the fire was allowed to develop naturally.

Figure 2-14: Photo of Igniter Placement for Stacked IBC Tests

2.5.2 FM Global Standard Half Igniter

For the rack storage test, ignition was achieved using two FM Global standard half igniters. Each half igniter is a 76 mm x 76 mm (3 in. x 3 in.) cylinder of rolled cellucotton. Each igniter is soaked in 118 ml (4 oz.) of gasoline and sealed in a plastic bag. The igniters were placed in the center of the transverse flue, at the rack upright, 0.6 m (2 ft) from the longitudinal flue, closest to the east face of the main array, as indicated in Figure 2-13. A photo of the igniters placed in the array prior to the test is provided in Figure 2-15. The igniters were lit with a propane torch at the start of the test and the fire was allowed to develop naturally.

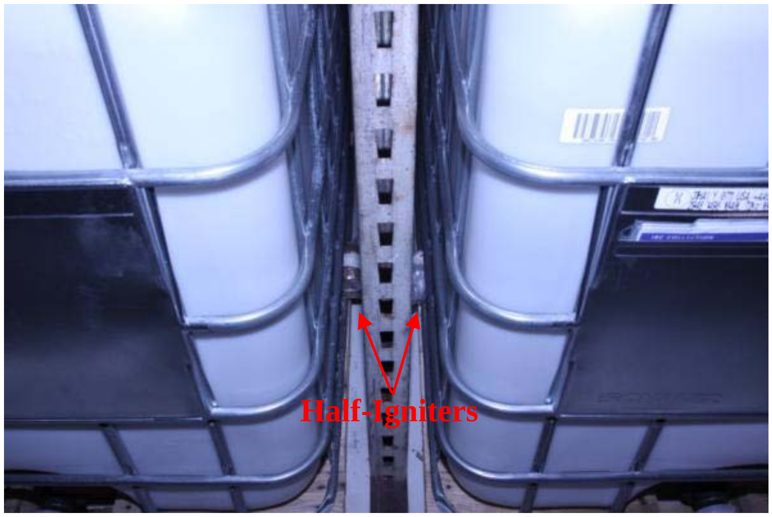


Figure 2-15: Photo of Igniter Placement for Rack Storage Test

2.6 DOCUMENTATION AND INSTRUMENTATION

2.6.1 Documentation

Documentation for each test included video, still photography, and audio recordings of the visual observations made during the test. The video documentation included three digital video cameras and an infrared (IR) camera for qualitative assessments of the fire. The three digital video cameras were placed North (main), Northwest, and Northeast of the test array. The IR camera was placed alongside the Northeast video camera. Visual observations were relative to the main camera position.

2.6.2 Instrumentation

The following instrumentation was installed for this test program:

- Bare-bead, 0.8 mm (20 gauge), thermocouples installed 16.5 cm (6.5 in.) below the ceiling at 125 locations. The thermocouples had a response time corresponding to a Response Time Index (RTI) of 8 $(m\text{-}s)^{1/2}$ (14.5 $(ft\text{-}s)^{1/2}$).

- Thermocouples imbedded in a cross-shaped steel angle, made from two 0.6 m (2 ft) long pieces, attached at the ceiling center.
- Flow meters and pressure controllers to monitor and control the sprinkler system.
- Electrical circuits on each sprinkler to determine individual sprinkler activation times.
- Gas analyzers to measure the generation of carbon dioxide (CO_2), carbon monoxide (CO), total hydrocarbons (THC), and the depletion of oxygen (O_2) in the test space.

2.7 TEST EVALUATION CRITERIA

The following criteria were evaluated and compared for each test. Pass/Fail criteria are specified with an *, and descriptions indicate pass/fail thresholds. All other criteria described were used for analysis purposes only.

2.7.1 Extent of Fire Damage*

For full-scale fire tests conducted at FM Global to be deemed acceptable, the fire damage must be confined within the test array and must not demonstrate any potential for further propagation at the time of test termination. If during a test, the fire propagates to the extent of the test array, the fire likely could have traveled farther if more fuel had been provided and would potentially have operated additional sprinklers. Therefore, a limit of acceptable damage is defined prior to each test.

For the stacked IBC array, the extent of acceptable damage was defined as the 18 IBCs that made up the core of the test array, defined as the main array in Section 2.3.1. The fire was initiated nominally in the center of the core IBCs and allowed to develop naturally. The fire grew in intensity and involved several IBCs prior to the sprinklers operating. Based on the level of fire protection provided, the fire was either controlled or continued to spread throughout the array. If the fire propagated to the target IBCs the damage was unacceptable. A plan view of the test array is provided in Figure 2-16 and damage during the test must be contained within the box indicated in the figure[6].

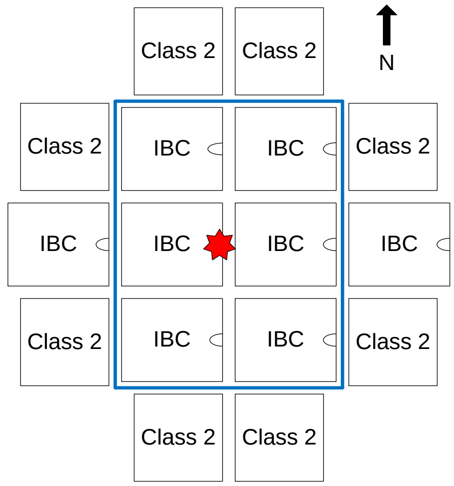


Figure 2-16: Acceptable Damage Area for Stacked IBC Array

For the rack storage array, the extent of acceptable damage was confined to the Intermediate Bulk Containers (IBCs) used in the test. As described in Section 2.3.2, the main array was comprised of both empty composite IBCs and Class 2 commodity, with the inner four pallet loads of each row being empty composite IBCs. Since Class 2 commodity was used throughout the rest of the main array and for the target arrays, fire propagation to the Class 2 commodity was unacceptable. If the fire propagated into the Class 2 commodity, the fire would likely have been more severe if empty composite IBCs had been present instead. Therefore, fire damage had to be contained within the outermost transverse flues of the array, and jump to the target was not permitted. A plan view of the test array is provided in Figure 2-17 and damage during the test must be contained within the box indicated in the figure.

[6] Note: Some thermal damage was observed (slight discoloration and deformation) in the empty composite IBCs east and west of the main array. However, this level of damage was deemed acceptable as the fire did not propagate to these IBCs.

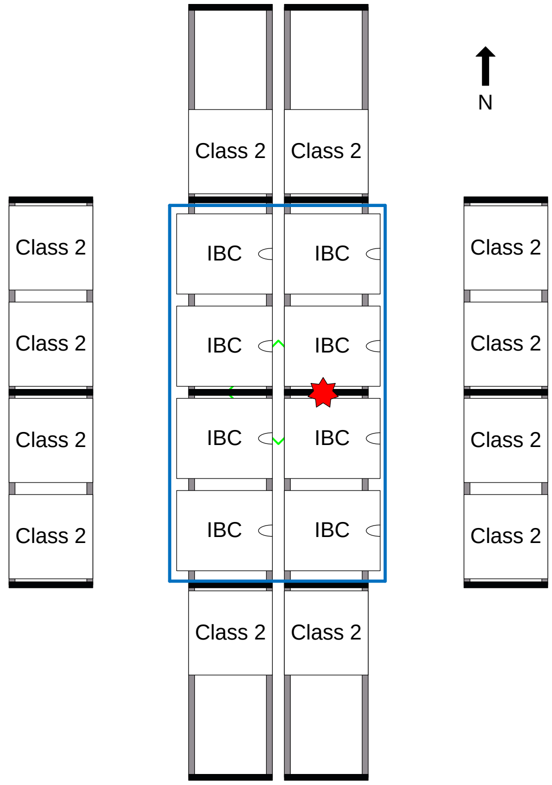


Figure 2-17: Acceptable Damage Area for Rack Storage Array

2.7.2 Sprinkler Operations*

The total number of sprinkler operations allowed was dependent on the sprinkler type. The allowed number of operations is specified for each test in Section 3. Additionally, sprinklers along the perimeter of the test ceiling were not allowed to operate. Sprinklers operating at the ceiling perimeter indicate that high temperature gases made it to the edge of the ceiling and could have traveled further along the ceiling, operating additional sprinklers, had they been present.

The operation of a sprinkler was verified three ways. First, a wire was installed onto the sprinkler link/bulb and frame, creating a circuit that was monitored. Upon operation of the sprinkler, the circuit was broken and the event was monitored via electrical signal. Second, select sprinklers at the ceiling core had differential pressure gauges installed in the connecting fitting. Upon operation of a sprinkler, the pressure drop created by the water flow through the open sprinkler orifice was monitored. This method was used to verify the time of operation recorded by the electrical monitoring. Finally, a post-test ceiling checkout verified the location of all operated sprinklers and was compared to events registered by the data acquisition system.

2.7.3 Steel Temperature*

The maximum 1-min average allowable ceiling steel temperature was 538 ^{o}C (1000 ^{o}F). This is based on the assessment that structural steel loses 50 percent of its load bearing strength upon reaching the 538 ^{o}C (1000 ^{o}F) threshold. The loss of strength could cause failure of the ceiling structure resulting in collapse of the roof. Ceiling steel temperatures in excess of this threshold during a test were taken as an indication of ineffective fire protection. The peak 1-min average steel temperature was recorded for every test.

2.7.4 Gas Temperatures

Ceiling temperatures were measured at numerous locations on the ceiling, as described in Section 2.6.2. Gas temperature trends were analyzed for comparison purposes. Additionally, the peak 10-sec average temperature and the peak 1-min average temperature were recorded for every test.

3 TEST DATA, OBSERVATIONS, AND RESULTS

3.1 TEST 1 – *STACKED PP[7] IBCS, K202 QR SPRINKLERS @ 49 MM/MIN*

Test 1 was conducted as an initial estimate of the required protection for stacked composite intermediate bulk containers with plastic pallets. Based on the make-up of the IBC (plastic wall container supported by plastic pallet), it was assumed that the product would be comparable to an uncartoned plastic [3], since no packaging is present. Protection options are provided for Uncartoned Unexpanded Plastic (UUP) or Uncartoned Expanded Plastic (UEP) in FM Global Loss Prevention Data Sheet 8-9 [4].

Table 5 and Table 6 in Data Sheet 8-9 provide ceiling level protection options for solid-piled UUP or solid-piled UEP, respectively. For a 9.1 m (30 ft) ceiling height, one protection option for the hazard is given for K202 (K14) quick response, pendent sprinklers. For the UUP, the recommended design is 12 sprinklers operating at 3.5 bar (50 psi). For UEP, the recommendation is 12 sprinklers operating at 6.9 bar (100 psi).

For the first test, a protection point between the two commodities was selected. The first test was conducted at a design pressure of 5.2 bar (75 psi). Since the protection options for the quick response sprinkler are based on 12 operating sprinklers, that quantity was used to base the sprinkler operation criteria (see Section 2.7.2). To provide a safety factor of 1.5, only eight sprinklers were allowed to operate for acceptable performance.

3.1.1 Test 1 Details

The test was conducted on August 2, 2011, under the South Ceiling of the Large Burn Lab. The fuel array was stacked empty composite IBCs on plastic pallets. Additional stacks of Class 2 commodity were placed around the array as targets[8]. The IBCs were stacked 3-high for a storage height of 3.5 m (11 ft 6 in.). The ceiling was set to 9.1 m (30 ft), providing a ceiling

[7] PP = Plastic Pallet
[8] As noted in Section 2.3.1, Class 2 commodity was used for all targets for Test 1.

clearance of 5.6 m (18 ft 6 in.). Ignition was Under 1 sprinkler, placed in the doghouse of the IBC nominally in the center of the array.

Ceiling level protection was provided by K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$), pendent, quick response sprinklers, with a 74 ^{o}C (165 ^{o}F) link. The sprinklers, installed on 3.0 m x 3.0 m (10 ft x 10 ft) spacing, and discharging at a pressure of 5.2 bar (75 psi), resulted in a design discharge density of 49 mm/min (1.2 gpm/ft^2).

3.1.2 Test 1 Highlights

The fire was initiated with an igniter placed in the doghouse of the 1st tier[9] IBC in the western row[10]. The fire developed slowly and flames reached the top of the 1st tier IBC at 1 min 34 s. As the IBC became more involved, the fire intensity increased and flames were burning beneath the 2nd tier IBC at 2 min 35 s. Plastic was observed dripping into the center longitudinal flue creating a small plastic pool fire in the flue. At 4 min 33 s, the pool had spread across the flue and the flames were impinging on the eastern row of IBCs across from ignition. At 5 min 16 s, the IBC at the base of the eastern row became involved. The fire intensity increased in the longitudinal flue and flames reached the top of the 1st tier within the flue. At 8 min 54 s, the flames reached the top of the array and at 9 min 13 s, flames were 1.2 m (4 ft) above the array, as shown in Figure 3-1.

The 1st sprinkler operation was at 9 min 24 s and quickly knocked the flames down below the top of the array. At 9 min 48 s, surface ignition on the 2nd tier Class 2 target commodity east of the main array was observed. At 11 min, minimal burning was observed in the array, with only small flames present below the pallets of the 2nd tier commodity. Small fires were present for the remainder of the test in areas below the IBC pallets that were shielded from the sprinkler spray. At 40 min, the test was terminated.

[9] Although the test was a stacked array, observations and notes throughout the report are based on “tiers,” with the 1st tier located at floor level, the 2nd tier stacked on top of the 1st, and the 3rd tier at the top of the array.

[10] See Figure 2-12 for reference to N-S-E-W.

Figure 3-1: Photo of Array at ~9 min 13 s (Test 1)

3.1.3 Test 1 Results

During the test, a single sprinkler operated and quickly reduced the fire intensity. The sprinkler operation pattern is provided in Figure 3-2. The peak ceiling steel temperature measured was 32 ^{o}C (89 ^{o}F). Post-test observations show that the main area of involvement was in the core IBCs defined as the main array. Ignition of the Class 2 targets was observed, which would indicate an unacceptable result, as specified in Section 2.7.1. However, the involvement of the Class 2 commodity occurred at the same time as the first sprinkler operation and was quickly extinguished upon water application. Based on the material property differences between the corrugated carton of the Class 2 commodity and the walls of an IBC, it was assumed that the target would not have ignited had it been an IBC. For subsequent tests, the stacks of Class 2 directly east and west of ignition were replaced with stacked IBCs. A photo of the post-test damage is provided in Figure 3-3 and the extent of damage is provided in Figure 3-4 through Figure 3-6.

Based on the evaluation criteria, and assuming the flame spread to the Class 2 commodity was not representative of a stacked IBC fire, the sprinkler protection provided was deemed acceptable. Test data plots and test observations are provided in Appendix A and B.

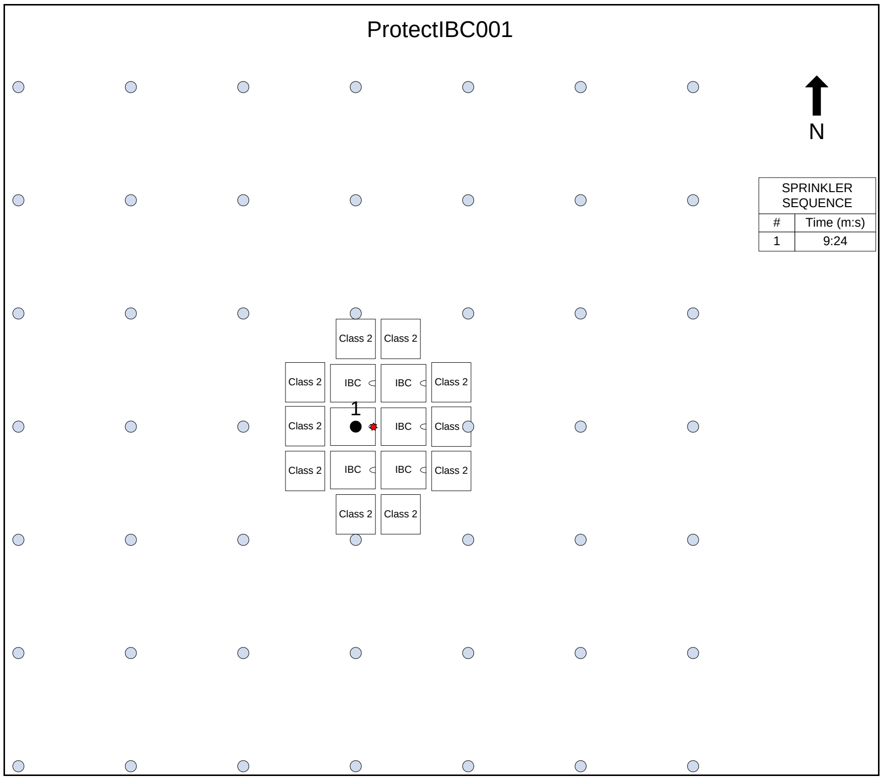


Figure 3-2: Test 1 - Sprinkler Operation Pattern

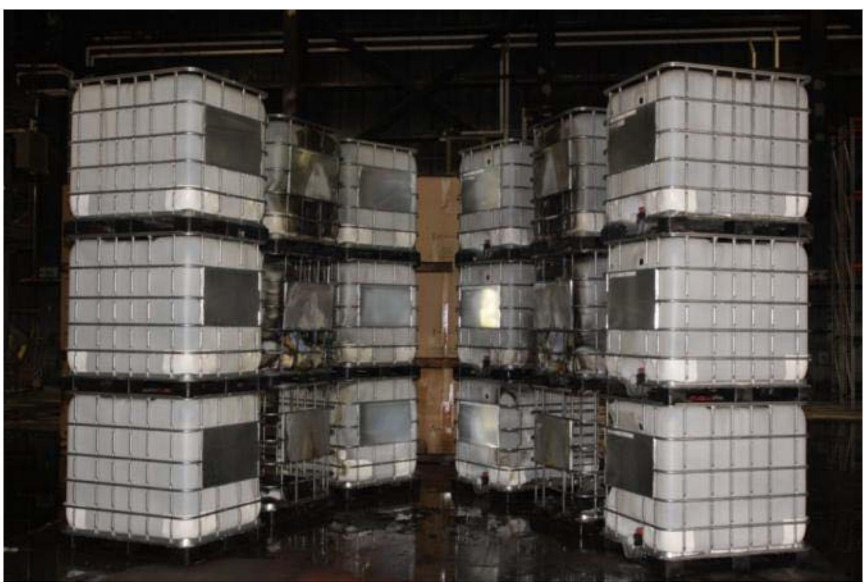


Figure 3-3: Test 1 - Post-Test Photo of Array (Opened for Photo)

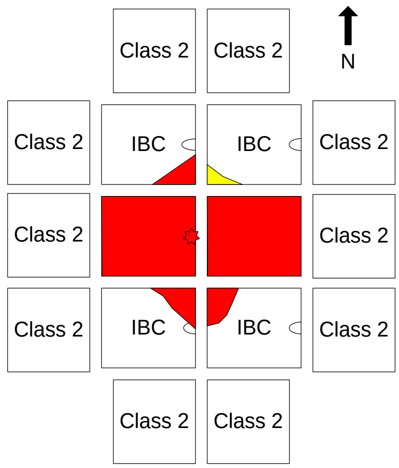
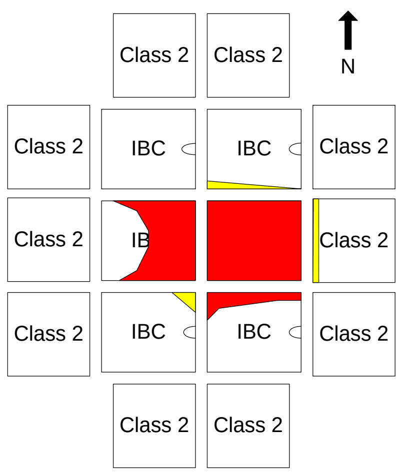


Figure 3-4: Test 1 Damage - 1st Tier



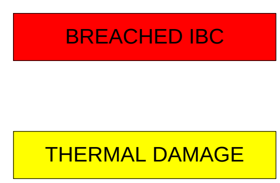


Figure 3-5: Test 1 Damage - 2nd Tier

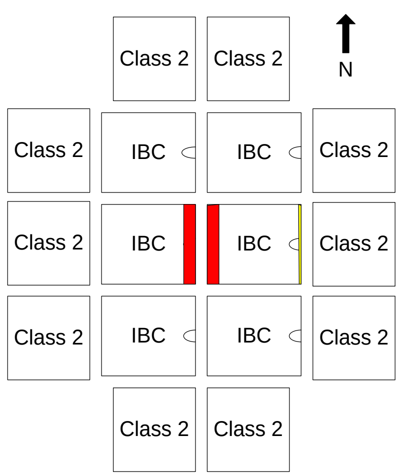


Figure 3-6: Test 1 Damage - 3rd Tier

3.2 TEST 2 – *STACKED PP[11] IBCS, K202 QR SPRINKLERS @ 33 MM/MIN*

Based on the acceptable results of Test 1, the test was repeated for Test 2 with the same conditions, but with a lower design discharge pressure. The test was conducted at a design pressure of 2.2 bar (32 psi). As with Test 1, only eight sprinklers were allowed to operate for acceptable performance.

3.2.1 Test 2 Details

The test was conducted on August 4, 2011, under the South Ceiling of the Large Burn Lab. The fuel array was stacked empty composite IBCs on plastic pallets. Additional stacked composite IBCs and Class 2 commodity were placed around the array as targets. The IBCs were stacked 3-high for a storage height of 3.5 m (11 ft 6 in.). The ceiling was set to 9.1 m (30 ft), providing a ceiling clearance of 5.6 m (18 ft 6 in.). Ignition was Under 1 sprinkler, placed in the doghouse of the IBC nominally in the center of the array.

Ceiling level protection was provided by K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$), pendent, quick response sprinklers, with a 74 ^{o}C (165 ^{o}F) link. The sprinklers, installed on 3.0 m x 3.0 m (10 ft x 10 ft) spacing, and discharging at a pressure of 2.2 bar (32 psi), resulted in a design discharge density of 33 mm/min (0.8 gpm/ft^2).

3.2.2 Test 2 Observations

The fire was initiated with an igniter placed in the doghouse of the 1st tier IBC in the western row. Flames from the igniter were 3 ft (0.9 m) in height and extended to the top of the 1st tier at 52 s. At 1 min 58 s, flames were observed entering below the pallets of the 2nd tier commodity. Flames were well established in the pallets below the 2nd tier at 4 min 50 s and, at 5 min 30 s, the flames had traveled up the face of the 1st tier IBCs on both sides of the ignition flue. At 6 min 12 s, the fire intensity increased and flames grew to over 5 ft (1.5 m) in height. At 7 min 14 s, 2nd tier IBCs were involved and flames were over 8 ft (2.4 m) in height. At 7 min 45 s, flames

[11] PP = Plastic Pallet

below 2nd tier commodity were extending into the east and west longitudinal flues. At 8 min 35 s, flames were above the top of the array.

The 1st sprinkler operated at 8 min 55 s. The flames were quickly knocked down and at 9 min 40 s, the fire was no longer above the top of the array. At 10 min 3 s, flames were no longer present in the east or west longitudinal flues. For the duration of the test, fire persisted below the pallets of the 2nd tier commodity where it was shielded from the overhead sprinkler. However, the fire showed no potential for additional spread through the array and the test was terminated at 30 min.

3.2.3 Test 2 Results

During the test, a single sprinkler operated and quickly controlled the fire. The sprinkler operation pattern is provided in Figure 3-7. A photo of the test array at 1st sprinkler operation is provided in Figure 3-8. The sprinkler was able to prevent fire spread to the target commodity surrounding the main array and most observed damage was prior to the 1st sprinkler operation[12]. A photo of the post-test damage is provided in Figure 3-9 and the extent of damage is provided in Figure 3-10 through Figure 3-12.

The peak 1-min average steel temperature measurement of 36 ^{o}C (97 ^{o}F) was below the evaluation threshold of 538 ^{o}C (1000 ^{o}F). Based on the evaluation criteria, the sprinkler protection provided was acceptable. Test data plots and test observations are provided in Appendix A and B.

[12] Replacing the Class 2 commodity used in Test 1 with empty composite IBCs did not result in target involvement, even though the sprinkler design discharge density was reduced in Test 2.

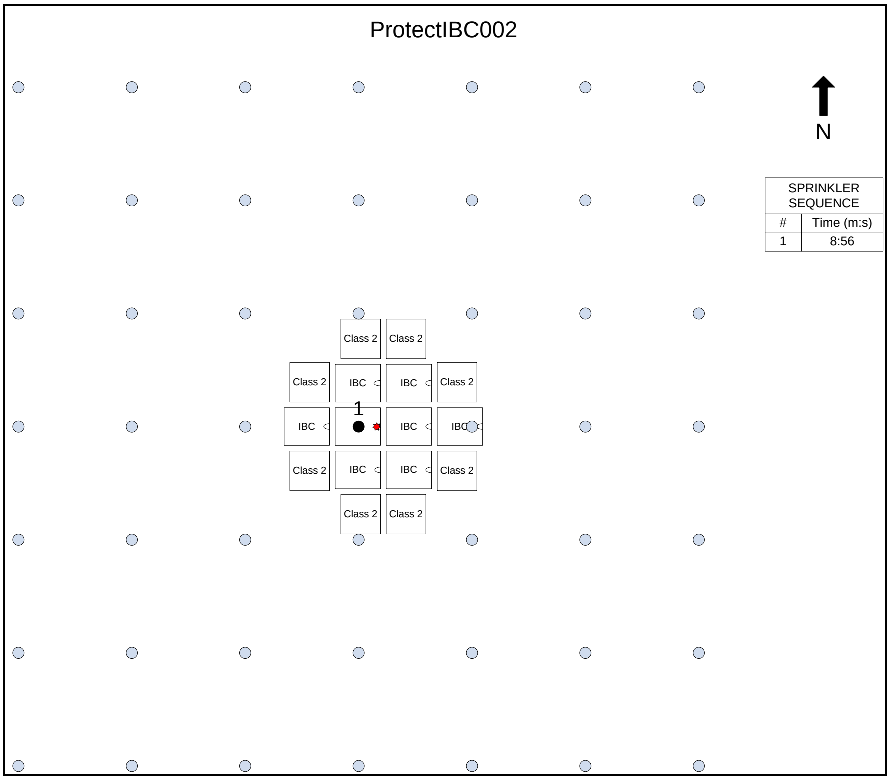


Figure 3-7: Test 2 - Sprinkler Operation Pattern

Figure 3-8: Photo of Array at 1st Sprinkler Operation (Test 2)

Figure 3-9: Test 2 - Post-Test Photo of Array (Opened for Photo)

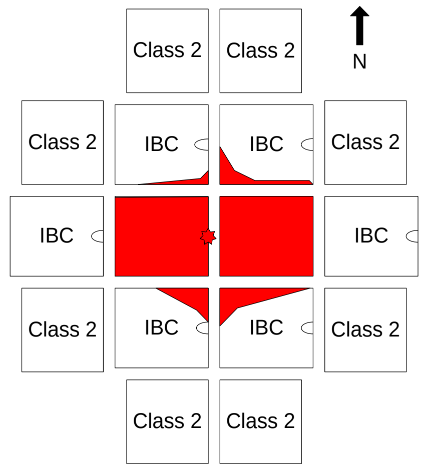


Figure 3-10: Test 2 Damage - 1st Tier

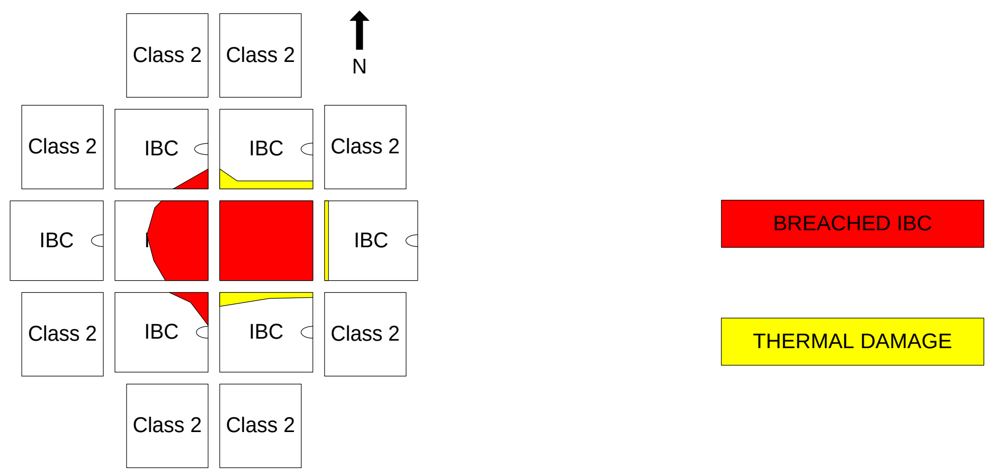


Figure 3-11: Test 2 Damage - 2nd Tier

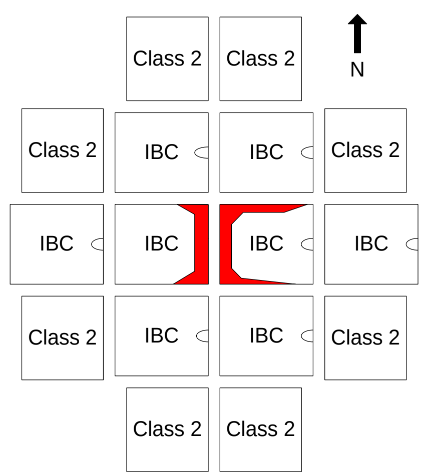


Figure 3-12: Test 2 Damage - 3rd Tier

3.3 TEST 3 – *STACKED PP[13] IBCS, K202 QR SPRINKLERS @ 24 MM/MIN*

Based on the acceptable results of Test 1 and Test 2, the test was repeated for Test 3 with a further reduction in the design discharge pressure. The test was conducted at a design pressure of 1.2 bar (18 psi). As with the previous tests, only eight sprinklers were allowed to operate for acceptable performance.

3.3.1 Test 3 Details

Test 3 was conducted on August 9, 2011, under the South Ceiling of the Large Burn Lab. The fuel array was stacked empty composite IBCs on plastic pallets. Additional composite IBCs and Class 2 commodity were placed around the array as targets. The IBCs were stacked 3-high for a storage height of 3.5 m (11 ft 6 in.). The ceiling was set to 9.1 m (30 ft), providing a ceiling clearance of 5.6 m (18 ft 6 in.). Ignition was Under 1 sprinkler, placed in the doghouse of the IBC nominally in the center of the array.

Ceiling level protection was provided by K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$), pendent, quick response sprinklers, with a 74 ^{o}C (165 ^{o}F) link. The sprinklers, installed on 3.0 m x 3.0 m (10 ft x 10 ft) spacing, and discharging at a pressure of 1.2 bar (18 psi), resulted in a design discharge density of 24 mm/min (0.6 gpm/ft^2).

3.3.2 Test 3 Observations

The fire was initiated with an igniter placed in the doghouse of the 1st tier IBC in the western row. Flames extended to the top of the 1st tier at 1 min 52 s. At 2 min 4 s, plastic was observed dripping into the longitudinal flue and at 3 min 37 s, the plastic at floor level was burning. At 4 min 46 s, the fire in the flue was impinging on the eastern row and at 5 min 29 s, the floor level IBC in the east row became involved. At 7 min 6 s, the fire was growing in intensity and flames were 1.8 m (6 ft) in height. At 8 min 49 s flames were exiting the top of the array.

[13] PP = Plastic Pallet

The 1st sprinkler operation was at 9 min 19 s, but had little impact on the fire. Flames remained above the top of the array and continued to spread into the longitudinal flues on either side of the main array. As the IBCs in the main array were consumed, they began to collapse, with several collapsing between 10 min 42 s and 11 min 11 s. The IBCs involved were continually dripping plastic into the flue space and spreading into the target IBCs. At 13 min 30 s, the fire spread to the 1st tier IBCs of the eastern target. At 14 min 13 s, flames were exiting the array above the east longitudinal flue. At 14 min 50 s, flames were observed exiting below the target IBCs beyond the extent of the test array.

At 16 min 59 s, the 2nd sprinkler operated and at 17 min 15 s, a total of six sprinklers was operating. At 17 min 20 s, the fire had spread to the Class 2 target commodity. The operating sprinklers did have an impact on the fire and at 19 min 12 s, the fire intensity had decreased and flames were no longer present above the array. At 20 min, flames were only present below the pallets where they were shielded from the sprinkler spray. The test was terminated at 30 min.

3.3.3 Test 3 Results

During the test, six sprinklers operated but were not able to prevent fire spread through the array. The sprinkler operation pattern is provided in Figure 3-13. A photo of the test array after the 1st sprinkler operation is provided in Figure 3-14. A photo of the array prior to the 2nd sprinkler operation showing the fire spread into the target IBCs is provided in Figure 3-15. A photo of the post-test damage is provided in Figure 3-16 and the extent of damage is provided in Figure 3-17 through Figure 3-19.

The peak 1-min average steel temperature measurement of 46 °C (114 °F) was below the evaluation threshold of 538 °C (1000 °F). Based on the evaluation criteria, the sprinkler protection provided was not acceptable. Test data plots and test observations are provided in Appendix A and B.

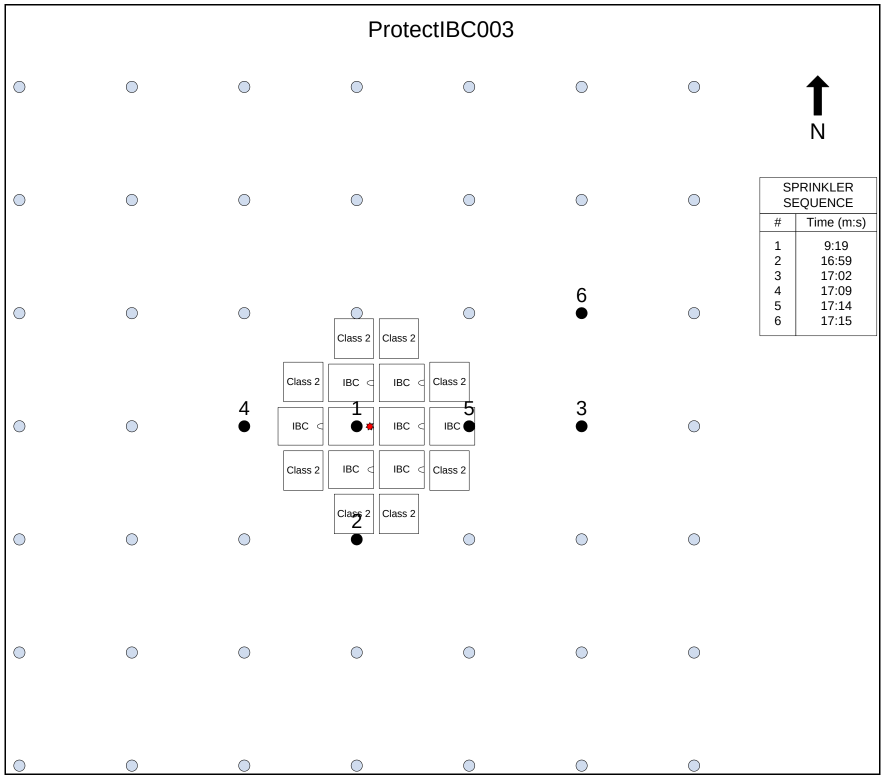


Figure 3-13: Test 3 - Sprinkler Operation Pattern

Figure 3-14: Photo of Array after 1st Sprinkler Operation ~9 min 40 s (Test 3)

Figure 3-15: Photo of Array at ~16 min 38 s (Test 3)

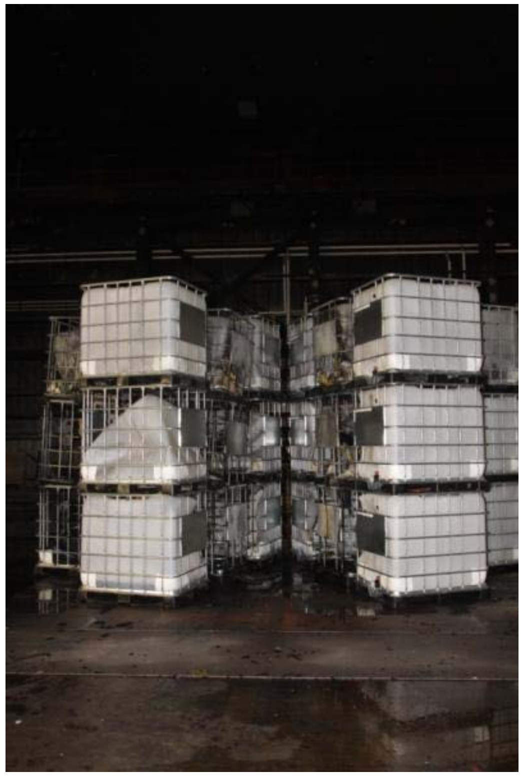


Figure 3-16: Test 3 - Post-Test Photo of Array (Opened for Photo)

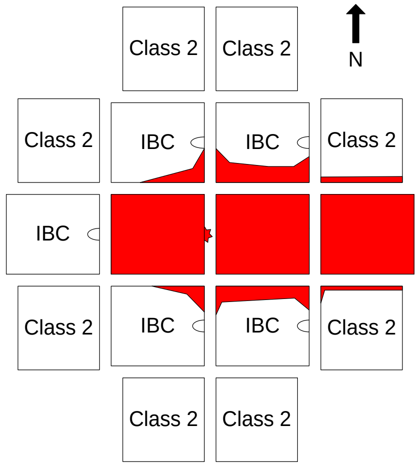


Figure 3-17: Test 3 Damage - 1st Tier

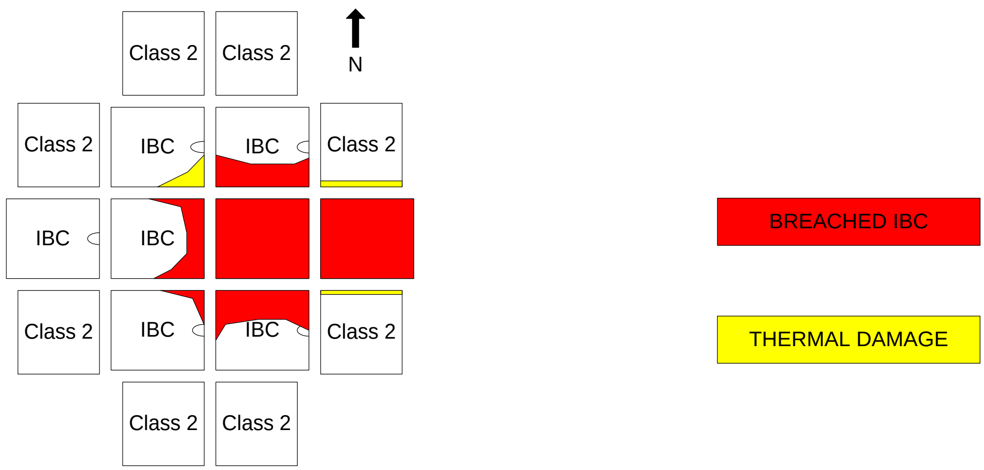


Figure 3-18: Test 3 Damage - 2nd Tier

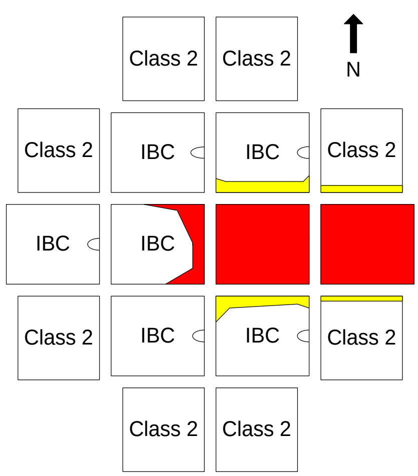


Figure 3-19: Test 3 Damage - 3rd Tier

3.4 TEST 4 – *STACKED WP[14] IBCS, K202 QR SPRINKLERS @ 24 MM/MIN*

Tests 1-3 were used to determine the sprinkler protection required for stacked composite IBCs on plastic pallets. Test 2 generated an acceptable result at a design density of 33 mm/min (0.8 gpm/ft^2); however, acceptable results were not observed when the design density was reduced to 24 mm/min (0.6 gpm/ft^2).

Test 4 was conducted with stacked composite IBCs on wood pallets. It was assumed that the wood pallet IBCs would pose less of a hazard than the plastic pallet IBCs. Therefore, the successful result in Test 2 can be applied to the wood pallet IBCs. To verify if the wood pallet IBCs were less hazardous, Test 4 was conducted with the design density that was not successful for the plastic pallet IBC test. The test was conducted at a design pressure of 1.2 bar (18 psi). As with the previous tests, only eight sprinklers were allowed to operate for acceptable performance.

3.4.1 Test 4 Details

Test 4 was conducted on August 10, 2011, under the South Ceiling of the Large Burn Lab. The fuel array was stacked empty composite IBCs on wood pallets. Additional composite IBCs and Class 2 commodity were placed around the array as targets. The IBCs were stacked 3-high for a storage height of 3.5 m (11 ft 6 in.). The ceiling was set to 9.1 m (30 ft), providing a ceiling clearance of 5.6 m (18 ft 6 in.). Ignition was Under 1 sprinkler, placed in the doghouse of the IBC nominally in the center of the array.

Ceiling level protection was provided by K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$), pendent, quick response sprinklers, with a 74 ^{o}C (165 ^{o}F) link. The sprinklers, installed on 3.0 m x 3.0 m (10 ft x 10 ft) spacing, and discharging at a pressure of 1.2 bar (18 psi), resulted in a design discharge density of 24 mm/min (0.6 gpm/ft^2).

[14] WP = Wood Pallet

3.4.2 Test 4 Observations

The fire was initiated with an igniter placed in the doghouse of the 1st tier IBC in the western row. Flames extended to the top of the 1st tier at 1 min 30 s. At 3 min 10 s, the plastic from the ignition IBC began to melt and drip into the flue. At 4 min 55 s, the fire had spread to the IBCs in the first tier of the eastern row. Flames continued to spread through the array and were observed in the western longitudinal flue at 7 min 20 s. Flames reached the top of the array at 7 min 40 s.

The 1st sprinkler operation was at 8 min 24 s. The fire was quickly knocked down with some flames remaining below the 2nd tier pallets in the longitudinal flues. At 12 min, only small flames were observed beneath pallets where the fire was shielded from the sprinkler spray. The test was terminated at 20 min.

3.4.3 Test 4 Results

During the test, a single sprinkler operated and quickly controlled the fire. The sprinkler operation pattern is provided in Figure 3-20. Only localized burning in shielded areas remained for the duration of the test and the fire was contained to the main array. A photo of the test array at 1st sprinkler operation is provided in Figure 3-21. A photo of the post-test damage is provided in Figure 3-22 and the extent of damage is provided in Figure 3-23 through Figure 3-25.

The peak 1-min average steel temperature measurement of 37 ^{o}C (98 ^{o}F) was below the evaluation threshold of 538 ^{o}C (1000 ^{o}F). Based on the evaluation criteria, the sprinkler protection provided was acceptable. Test data plots and test observations are provided in Appendix A and B.

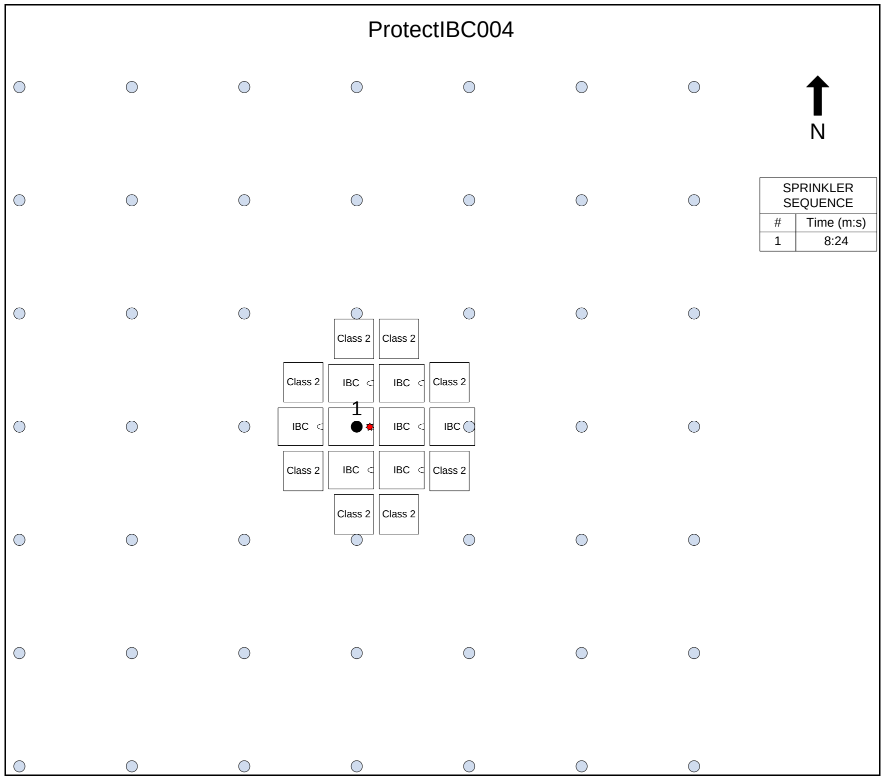


Figure 3-20: Test 4 - Sprinkler Operation Pattern

Figure 3-21: Photo of Test Array just Prior to 1st Sprinkler Operation (Test 4)

Figure 3-22: Test 4 - Post-Test Photo of Array (Opened for Photo)

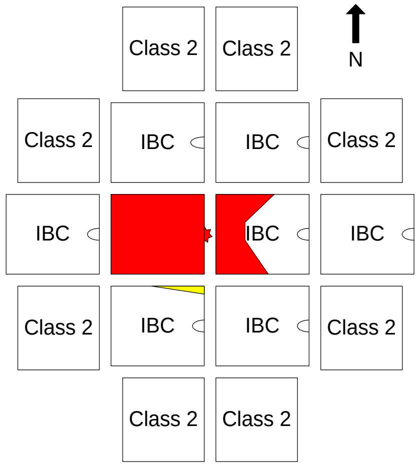


Figure 3-23: Test 4 Damage - 1st Tier

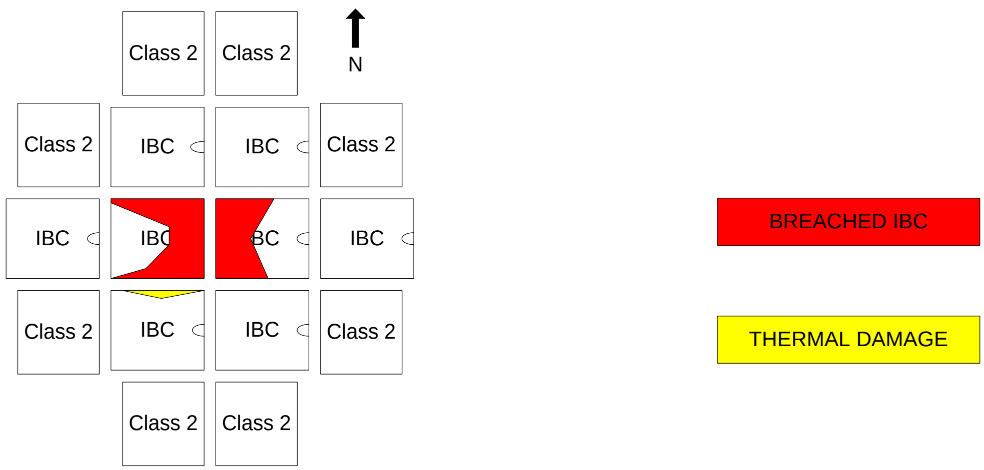


Figure 3-24: Test 4 Damage - 2nd Tier

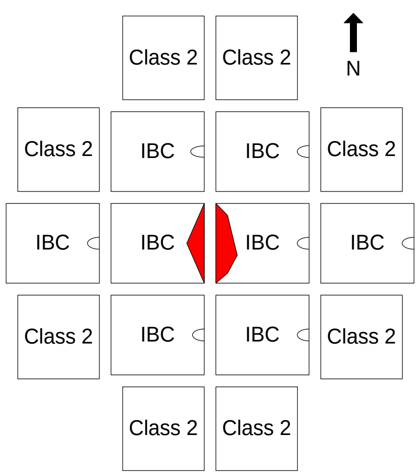


Figure 3-25: Test 4 Damage - 3rd Tier

3.5 TEST 10[15] – *STACKED WP[16] IBCS, K161 SR SPRINKLERS @ 24 MM/MIN*

The results from Test 4 generated acceptable results for the protection of stacked empty composite IBCs on wood pallets. For Tests 1-3, the level of protection was reduced to optimize the system design to the lowest pressure that provided adequate protection. However, for the wood pallet IBCs, it was decided that a further reduction in the system design was not desired and the test product was used to assess the viability of smaller K-factor standard response sprinklers.

Test 10 was conducted with stacked composite IBCs on wood pallets (same as Test 4). The sprinkler system was changed to K-factor 161 lpm/bar$^{1/2}$ (11.2 gpm/psi$^{1/2}$), pendent, standard response sprinklers. The system design pressure of 1.9 bar (28 psi) provided a 24 mm/min (0.6 gpm/ft^2) design density (same as Test 4).

Protection options for solid-piled storage of plastic commodities are provided in Data Sheet 8-9 [4]. For the cartoned plastics and for uncartoned unexpanded plastic, Table 3 through Table 5 specify a design of 20 K11.2 sprinklers operating at 3.5 bar (50 psi). For solid-piled uncartoned expanded plastic, the design is increased to 25 sprinklers operating at the same pressure. Test 10 was conducted at a lower pressure, based on previous test results. However, the design for standard response sprinklers is greater than for quick response sprinklers (20 or 25 versus 12). Therefore, for Test 10, the sprinkler operation criterion (see Section 2.7.2) was set at 17 sprinklers for acceptable performance (safety factor of 1.5 for a 25 sprinkler design).

3.5.1 Test 10 Details

Test 10 was conducted on October 5, 2011, under the South Ceiling of the Large Burn Lab. The fuel array was stacked empty composite IBCs on wood pallets. Additional composite IBCs and Class 2 commodity were placed around the array as targets. The IBCs were stacked 3-high for a

[15] These data provided in this report is a subset of a test program conducted at FM Global with intermediate bulk containers. Test numbering for this report was kept consistent with the original test numbers and is not sequential within this report.
[16] WP = Wood Pallet

storage height of 3.5 m (11 ft 6 in.). The ceiling was set to 9.1 m (30 ft), providing a ceiling clearance of 5.6 m (18 ft 6 in.). Ignition was Under 1 sprinkler, placed in the doghouse of the IBC nominally in the center of the array.

Ceiling level protection was provided by K-factor 161 lpm/bar$^{1/2}$ (11.2 gpm/psi$^{1/2}$), pendent, standard response sprinklers, with a 68 ^{o}C (155 ^{o}F) bulb. The sprinklers, installed on 3.0 m x 3.0 m (10 ft x 10 ft) spacing, and discharging at a pressure of 1.9 bar (28 psi), resulted in a design discharge density of 24 mm/min (0.6 gpm/ft^2).

3.5.2 Test 10 Observations

The fire was initiated with an igniter placed in the doghouse of the 1st tier IBC in the western row. At 2 min 25 s, flames were impinging on the bottom of 2nd tier pallets. At 3 min 45 s, a small pool of melted plastic ignited in the longitudinal flue. At 6 min 14 s, flames from the melted plastic pool involved the eastern row of IBCs. The fire continued to grow in intensity and spread through the array. At 7 min 36 s, flames were spreading below the 2nd tier IBCs and had spread into the west longitudinal flue at 7 min 54 s. Flames were above the array at 8 min 20 s. Flames in the array had spread to the east and west longitudinal flues and were impinging on the target IBCs at 9 min 4 s.

At 9 min 30 s, the 1st sprinkler operated. At 9 min 45 s, flames from the center longitudinal flue were 3.0 m (10 ft) above the array and flames in the west and east longitudinal flue were above the array. At 9 min 56 s, flames were reaching ceiling level and at 10 min 4 s, all 18 IBCs in the main array were involved. Ignition of the east and west targets was observed at 10 min 13 s.

At 10 min 22 s, multiple sprinkler operations were observed and quickly decreased the fire intensity. At 10 min 50 s, a total of 17 sprinklers had operated. The sprinklers caused the smoke at the ceiling level to drop to floor level obscuring the array. No additional visual observations could be made for the remainder of the test; however the ceiling temperature had returned to ambient conditions at 14 min 14 s. The test was terminated at 20 min.

3.5.3 Test 10 Results

During the test, 17 sprinklers operated but were not able to prevent fire spread through the array. The sprinkler operation pattern is provided in Figure 3-26. A photo of the test array at 1st sprinkler operation is provided in Figure 3-27. A photo of the array prior to the 2nd sprinkler operation showing the fire spread into the target IBCs and flames at ceiling level is provided in Figure 3-28. The extent of damage is provided in Figure 3-29 through Figure 3-31.

The peak 1-min average steel temperature measurement of 79 ^{o}C (174 ^{o}F) was below the evaluation threshold of 538 ^{o}C (1000 ^{o}F). Based on the evaluation criteria, the sprinkler protection provided was not acceptable. Test data plots and test observations are provided in Appendix A and B.

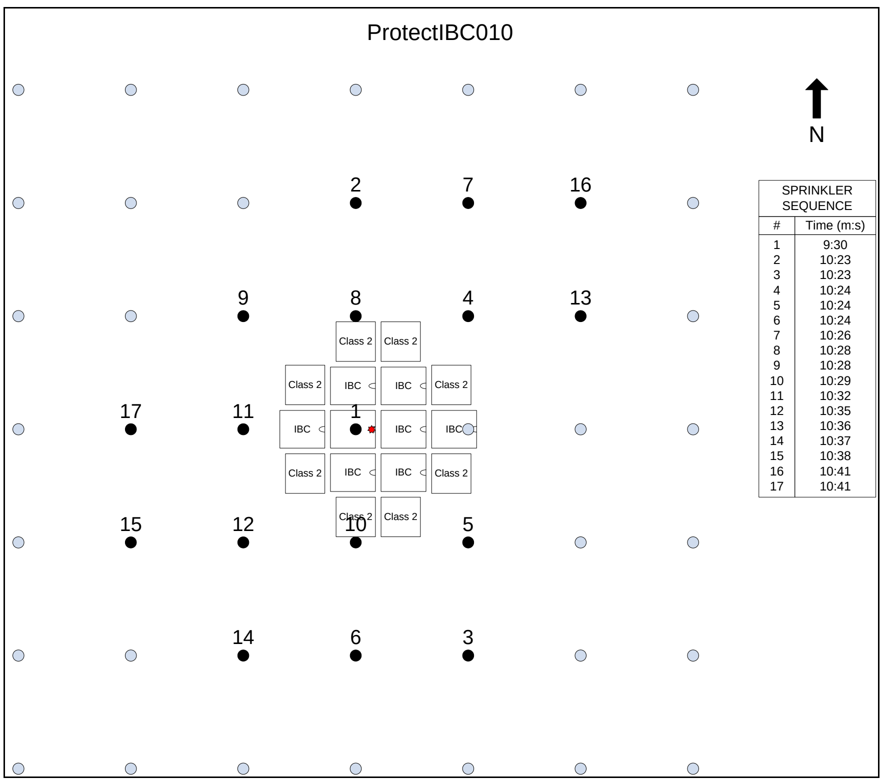


Figure 3-26: Test 10 - Sprinkler Operation Pattern

Figure 3-27: Photo of Array Prior at 1st Sprinkler Operation ~9 min 30 s (Test 10)

Figure 3-28: Photo of Array Prior to 2nd Sprinkler Operation ~10 min 12 s (Test 10)

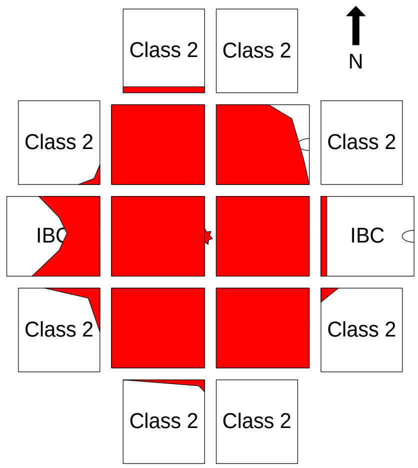


Figure 3-29: Test 10 Damage - 1st Tier

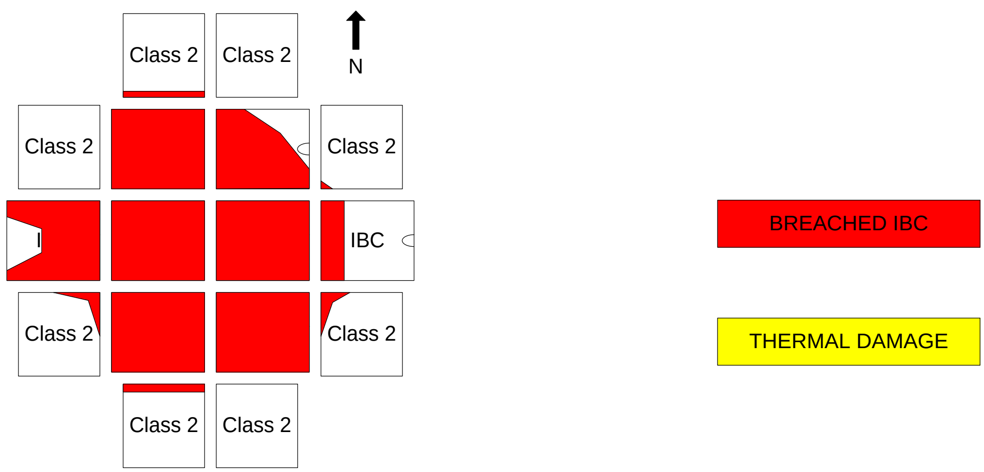


Figure 3-30: Test 10 Damage - 2nd Tier

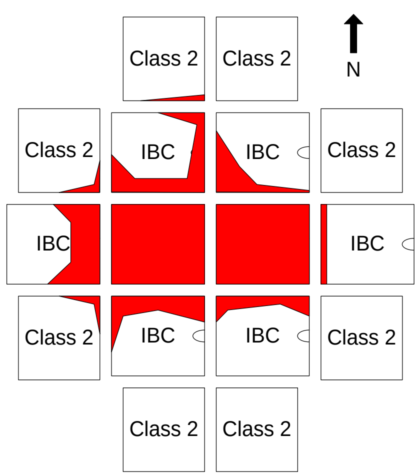


Figure 3-31: Test 10 Damage - 3rd Tier

3.6 TEST 11 – *RACK STORED WP[17] IBCS, K202 QR SPRINKLERS @ 33 MM/MIN*

Tests 1-4 and Test 10 assessed different protection options for stacked empty IBCs. The final test of the test program was to assess the hazard of empty IBCs in a rack storage array. The majority of tests conducted by FM Global has been with rack storage arrangements with different commodities and have aided in the development of Data Sheet 8-9 [4]. To complete the program, a rack storage test was conducted to add to the existing data set of rack storage tests and for a comparison point between solid-piled and rack storage arrays with a commodity.

3.6.1 Test 11 Details

Test 11 was conducted on October 7, 2011, under the South Ceiling of the Large Burn Lab. The fuel array was a rack storage arrangement of empty composite IBCs on wood pallets with Class 2 targets. As described in Section 2.3.2, the array was a double row, open frame rack that was six pallet loads wide. The target arrays were placed on either side of the main array, separated by a 1.2 m (4 ft) aisle.

The nominal height of a 3-tier rack storage array was 4.3 m (14 ft). The ceiling was set to 9.1 m (30 ft), providing a ceiling clearance of 4.8 m (16 ft). Ignition was Under 1 sprinkler, offset within the rack, at the rack upright. Unlike previous tests, the igniter was placed on the side walls of the ignition IBCs instead of in the doghouse.

Ceiling level protection was provided by K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$), pendent, quick response sprinklers, with a 74 ^{o}C (165 ^{o}F) link. The sprinklers, installed on 3.0 m x 3.0 m (10 ft x 10 ft) spacing, and discharging at a pressure of 2.2 bar (32 psi), resulted in a design discharge density of 33 mm/min (0.8 gpm/ft^2).

3.6.2 Test 11 Observations

The fire was initiated with two igniters placed in the transverse flue of the main array against the side walls of two empty composite IBCs. The flames in the transverse flue were 1.2 m (4 ft) in

[17] WP = Wood Pallet

height at 1 min. The fire remained steady for several minutes, burning into the sides of the IBCs. At 5 min 15 s, the wood pallets below the igniters were involved. The IBCs began to collapse at 5 min 44s, increasing the fire severity. The fire spread into the 2^{nd} tier, and at 7 min 8 s flames were involved below the 2^{nd} tier pallets and were traveling up the flues at 7 min 17 s.

The 1^{st} sprinkler operation was at 7 min 28 s. The sprinkler quickly impacted the fire and at 8 min 30 s, flames were no longer observed in the flue spaces of the array. Small fires still persisted beneath the 2^{nd} tier pallets where the fire was shielded from the sprinkler spray. These fires caused melted plastic to drip into the 1^{st} tier where small fires were formed at floor level. None of the small fires spread or increased in intensity for the remainder of the test. The test was terminated at 25 min.

3.6.3 Test 11 Results

During the test, a single sprinkler operated and quickly controlled the fire. The sprinkler operation pattern is provided in Figure 3-32. Only localized burning in shielded areas remained for the duration of the test and the fire was contained to the ignition flue. A photo of the test array at 1^{st} sprinkler operation is provided in Figure 3-33. A photo of the localized burning beneath the pallets is provided in Figure 3-34. A photo of the post-test damage is provided in Figure 3-35, and the extent of damage is provided in Figure 3-36 through Figure 3-38.

The peak 1-min average steel temperature measurement of 32 ^{o}C (89 ^{o}F) was below the evaluation threshold of 538 ^{o}C (1000 ^{o}F). Based on the evaluation criteria, the sprinkler protection provided was acceptable. Test data plots and test observations are provided in Appendix A and B.

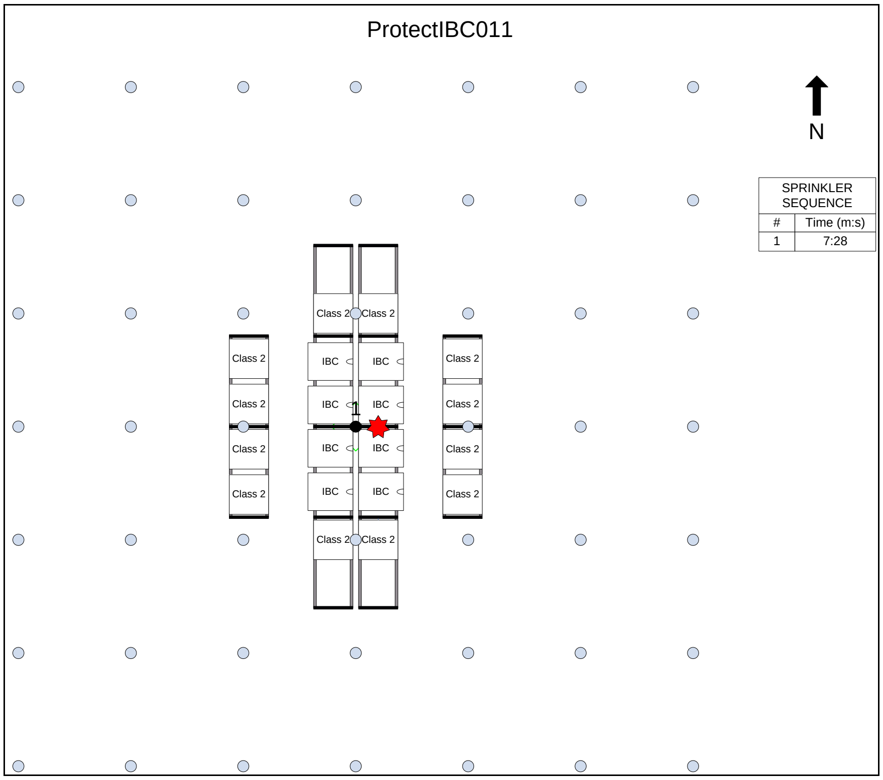


Figure 3-32: Test 11 - Sprinkler Operation Pattern

Figure 3-33: Photo of Array Prior at 1st Sprinkler Operation ~7 min 28 s (Test 11)

Figure 3-34: Photo of Test Array at ~ 22 min 16 s (Test 11)

Figure 3-35: Test 11 - Post-Test Photo of Array (East Face)

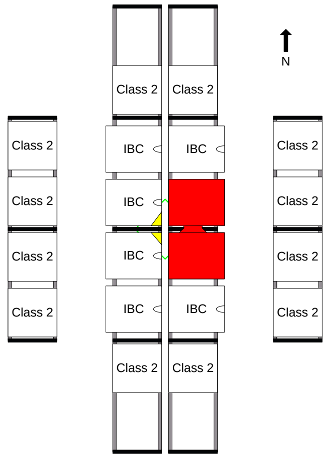


Figure 3-36: Test 11 Damage - 1st Tier

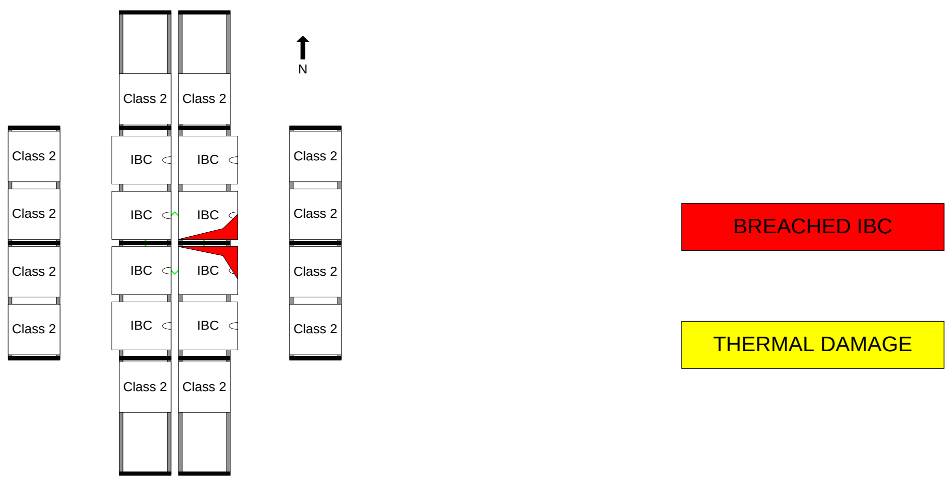


Figure 3-37: Test 11 Damage - 2nd Tier

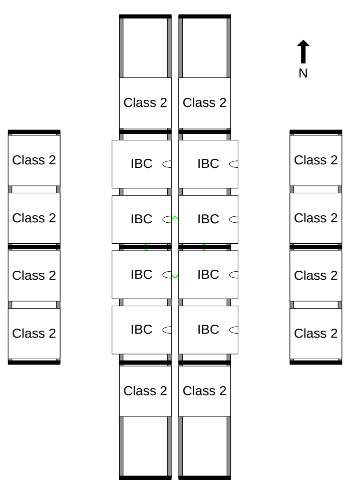


Figure 3-38: Test 11 Damage - 3rd Tier

4 SUMMARY AND DISCUSSION

This test program was designed to determine adequate sprinkler protection for empty intermediate bulk containers. A total of six tests were conducted investigating several parameters including; plastic pallet versus wood pallet IBCs, quick response versus standard response sprinklers, and the impact of storing the IBCs in a stacked IBC array or rack storage array. Where possible, the level of protection required was optimized.

4.1 STACKED IBCS ON PLASTIC PALLETS

Three tests were conducted with empty IBCs on plastic pallets stacked 3-high below a 9.1 m (30 ft) ceiling. To begin this phase of the testing, an initial guess at the protection required was made based on the makeup of the IBC. Since the IBC on a plastic pallet is comprised of almost entirely exposed plastic (minus the wire cage), the initial protection was selected based on existing guidance for solid-piled uncartoned plastic in Data Sheet 8-9 [4].

Test 1 was conducted with K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$), quick response, 74 ^{o}C (165 ^{o}F) temperature rated, pendent sprinklers operating at 5.2 bar (75 psi). This pressure is between that required for uncartoned unexpanded plastic (3.5 bar [50 psi]) and uncartoned expanded plastic (6.9 bar [100 psi]). The design pressure of 5.2 bar (75 psi) resulted in a design density of 49 mm/min (1.2 gpm/ft^2). During the test, a single sprinkler operated and controlled the fire. Based on this result, the system design pressure was reduced to optimize the required protection for the hazard.

Test 2 was conducted with the same K202 (K14) sprinkler, but the pressure was reduced to 2.2 bar (32 psi) which provided a design density of 33 mm/min (0.8 gpm/ft^2). As with Test 1, a single sprinkler was able to control the fire. In an attempt to further reduce the system design pressure required, a third test was conducted at a lower pressure than used in Test 1 and Test 2.

Test 3 was conducted at a design pressure of 1.2 bar (18 psi) which provided a design density of 24 mm/min (0.6 gpm/ft^2). In Test 3, six sprinklers operated and the fire was not contained within the test array. Fire traveled into the target IBCs and could potentially have traveled farther had additional commodity been provided.

The results from the tests conducted with stacked empty IBCs on plastic pallets are useful in determining the required protection for 3-high storage. Since two different test outcomes were obtained with two different design densities, the required protection was bracketed by Test 2 and Test 3. Adequate protection for the hazard can be achieved with K202 (K14) QR sprinklers operating at 2.2 bar (32 psi).

4.2 STACKED IBCS ON WOOD PALLETS

The next phase of the test program was to determine the required protection for empty IBCs on wood pallets stacked 3-high below a 9.1 m (30 ft) ceiling. Since these IBCs have wood pallet bases, it was assumed that the hazard would be lower than that of the IBCs with plastic pallets. Based on that assumption, the adequate protection determined for Test 2 with IBCs on plastic pallets was expected to be adequate for IBCs on wood pallets.

Test 4 was conducted to determine if the level of protection provided in Test 3 (inadequate for IBCs on plastic pallets) would be adequate for the protection of IBCs on wood pallets. As with Test 1-3, the IBCs were stacked 3-high below a 9.1 m (30 ft) ceiling. Ceiling level protection was provided by K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$), quick response, 74 ^{o}C (165 ^{o}F) temperature rated, pendent sprinklers operating at 1.2 bar (18 psi). This provided the density of 24 mm/min (0.6 gpm/ft^{2}) used in Test 3.

In Test 4, a single sprinkler operated and was able to control the fire. Based on the result from the test, two conclusions can be made. First, adequate protection of the hazard was provided with the K202 (K14) QR sprinklers operating at 1.2 bar (18 psi). Second, the result confirms that the hazard posed by the IBCs on wood pallets is less than that posed by the plastic pallet version.

Similar to the assumption that wood pallet IBCs were less hazardous than plastic pallet IBCs, metal pallet IBCs were considered to be even less hazardous. Therefore, the protection point obtained for the wood pallet IBCs was deemed adequate for the hazard of stacked IBCs on metal pallets. Further optimization of the level of protection was not attempted during this program.

4.3 RACK STORAGE OF IBCS ON WOOD PALLETS

An additional test was conducted with rack storage of empty IBCs on wood pallets. As with previous tests, the ceiling height was set to 9.1 m (30 ft). The empty IBCs were stored in a double-row, open-frame rack that was 3-tiers high. The goal of the test was to determine adequate protection for the hazard, to add to the existing data set of rack storage tests in Data Sheet 8-9.

In Test 11, ceiling level protection was provided by K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$), quick response, 74 ^{o}C (165 ^{o}F) temperature rated, pendent sprinklers operating at 2.2 bar (32 psi). This provided the density of 33 mm/min (0.8 gpm/ft^2). During the test, a single sprinkler operated and was able to control the fire.

The results show that adequate protection of the hazard was provided with the K202 (K14) QR sprinklers operating at 2.2 bar (32 psi). This was the last test of the project and no additional commodity was available for further testing. Therefore, optimization of this protection point was not attempted.

4.4 SPRINKLER RESPONSE

One additional aspect of sprinkler protection was investigated during the project. Test 4 and Test 10 were conducted with identical storage arrays and the same design density [24 mm/min (0.6 gpm/ft^2)], but with different sprinkler attributes. Both tests were conducted with empty IBCs on wood pallets stacked 3-high below a 9.1 m (30 ft) ceiling. In Test 4, adequate protection was provided by K202 (K14) quick response sprinklers at 1.2 bar (18 psi).

The goal of Test 10 was to determine if adequate protection could be provided by a lower K-factor standard response sprinkler. In Test 10, ceiling level protection was provided by K-factor

161 lpm/bar$^{1/2}$ (11.2 gpm/psi$^{1/2}$), standard response, 68 ^{o}C (155 ^{o}F) temperature rated, pendent sprinklers operating at 1.9 bar (28 psi).

As expected, the time to first sprinkler operation was longer with the standard response sprinkler used in Test 10. This delay allowed the fire to become more involved in the array prior to the application of water. The roughly one minute delay allowed the fire to develop through the array, with the result that flames were beginning to impact the target IBCs prior to the first sprinkler operation. Additionally, a standard response sprinkler generally puts less water directly below the sprinkler where the fire is developing compared to a quick response sprinkler. The delay, plus the distribution pattern, caused the sprinkler to have little impact on the fire. Several additional sprinklers operated, but the damage exceeded the evaluation threshold prior to the sprinklers bringing the fire under control.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The test results and data analysis support the following conclusions:

- Test 2 generated an acceptable result for the protection of stacked empty composite IBCs on plastic pallets stored 3-high below a 9.1 m (30 ft) ceiling. Protection was provided by ceiling level K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$) pendent, QR sprinklers operating at 2.2 bar (32 psi) and providing a design density of 33 mm/min (0.8 gpm/ft^2). One sprinkler operated during the test.
- Test 4 generated an acceptable result for the protection of stacked empty composite IBCs on wood pallets stored 3-high below a 30 ft (9.1 m) ceiling. Protection was provided by ceiling level K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$) pendent, QR sprinklers at 1.2 bar (18 psi) and providing a design density of 24 mm/min (0.6 gpm/ft^2). One sprinkler operated during the test.
- The results from Test 4 (wood pallet IBCs) can be applied for adequate protection of stacked empty composite IBCs on metal pallets stored 3-high below a 9.1 m (30 ft) ceiling.
- Test 11 generated an acceptable result for the protection of rack storage of empty composite IBCs on wood pallets stored to 4.3 m (14 ft) below a 9.1 m (30 ft) ceiling. Protection was provided by ceiling level K-factor 202 lpm/bar$^{1/2}$ (14.0 gpm/psi$^{1/2}$) pendent, QR sprinklers operating at 2.2 bar (32 psi) and providing a design density of 33 mm/min (0.8 gpm/ft^2). One sprinkler operated during the test.
- The results from Test 11 (wood pallet IBCs) can be applied for adequate protection of 4.3 m (14 ft) high rack storage of empty composite IBCs on metal pallets below a 9.1 m (30 ft) ceiling.
- Based on the results of Test 10, standard response sprinklers do not operate at a sufficiently early time in the fire development to prevent fire spread through the array and do not provide adequate protection for the hazard of stacked IBCs.

5.2 RECOMMENDATIONS

Based on the previous conclusions, the following recommendations are made:

- The results from Test 2 should be used in the specification of protection for stacked empty composite IBCs on plastic pallets stored 3-high below a 9.1 m (30 ft) ceiling.
- The results from Test 4 should be used in the specification of protection for stacked empty composite IBCs on wood pallets and on metal pallets stored 3-high below a 9.1 m (30 ft) ceiling.
- The results from Test 11 should be used in the specification of protection for 4.3 m (14 ft) high rack storage of empty composite IBCs on wood pallets and metal pallets below a 9.1 m (30 ft) ceiling.
- Quick response (QR) sprinklers should be used instead of standard response (SR) sprinklers for the protection of empty composite IBCs.

6 REFERENCES

[1] "Ignitable Liquid Storage in Portable Containers," FM Global Property Loss Prevention Data Sheet 7-29, Factory Mutual Insurance Company, 2012.

[2] Direct Industry. (2012). Retrieved April 9, 2012, from http://www.directindustry.com

[3] "Commodity Classification," FM Global Property Loss Prevention Data Sheet 8-1, Factory Mutual Insurance Company, 2004.

[4] "Storage of Class 1, 2, 3, 4, and Plastic Commodities," FM Global Property Loss Prevention Data Sheet 8-9, Factory Mutual Insurance Company, 2011.

A APPENDIX A – TEST DATA PLOTS

A.1 TEST 1 DATA PLOTS

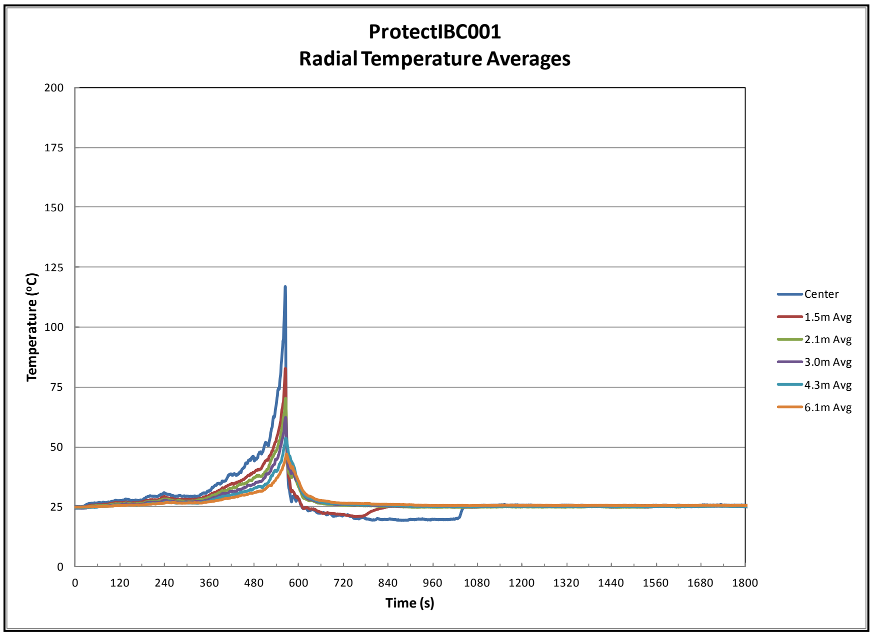


Figure A-1: Test 1 - Ceiling Gas Temperatures

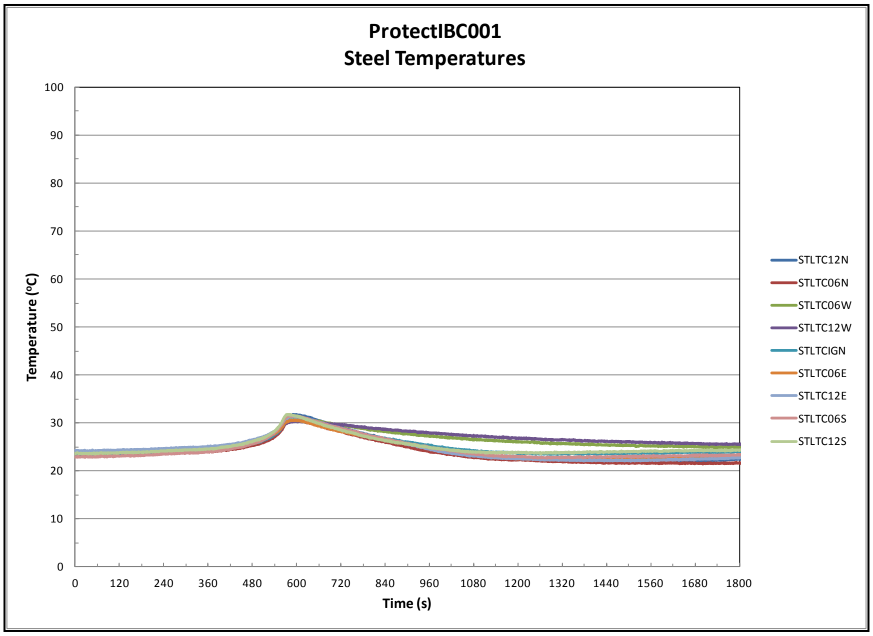


Figure A-2: Test 1 - Ceiling Steel Temperatures

A.2 TEST 2 DATA PLOTS

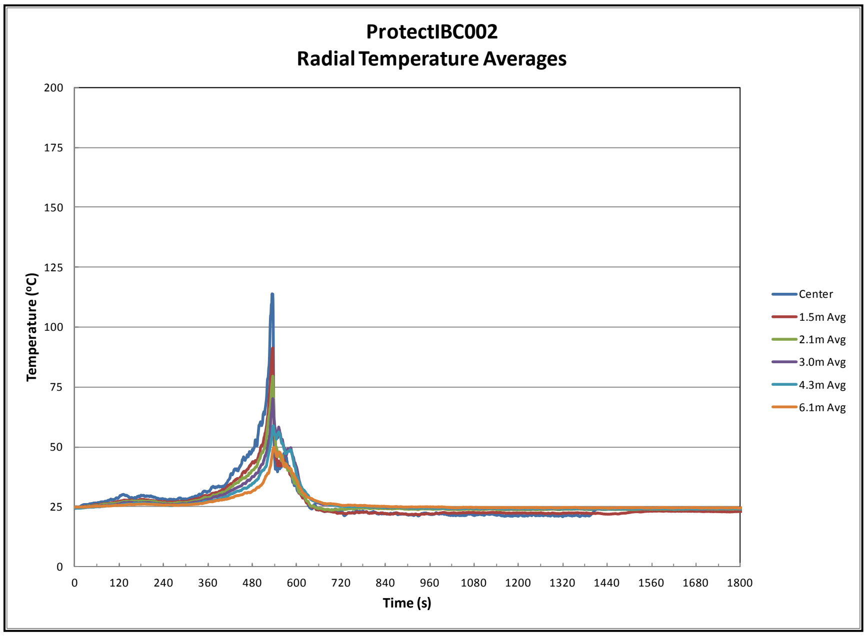


Figure A-3: Test 2 - Ceiling Gas Temperatures

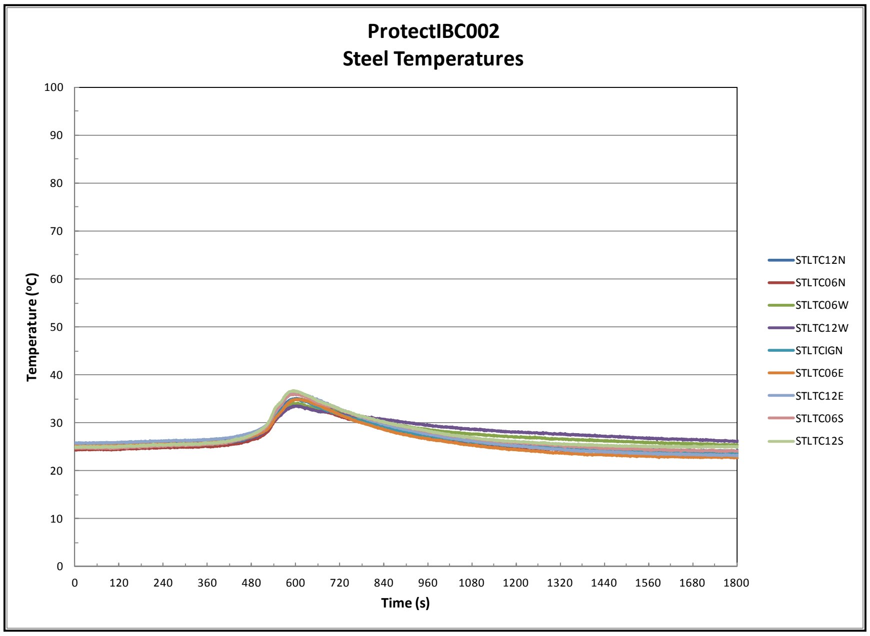


Figure A-4: Test 2 - Ceiling Steel Temperatures

A.3 TEST 3 DATA PLOTS

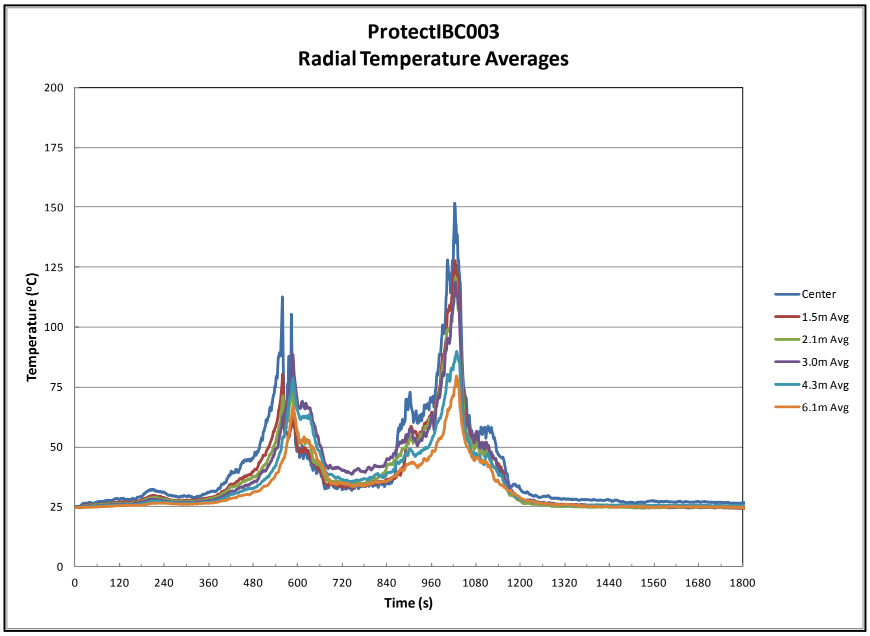


Figure A-5: Test 3 - Ceiling Gas Temperatures

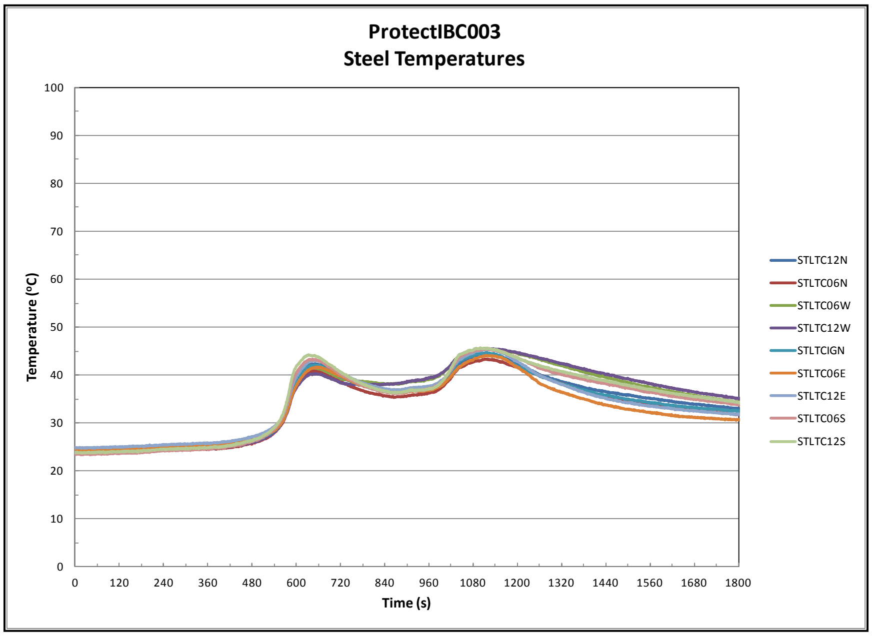


Figure A-6: Test 3 - Ceiling Steel Temperatures

A.4 TEST 4 DATA PLOTS

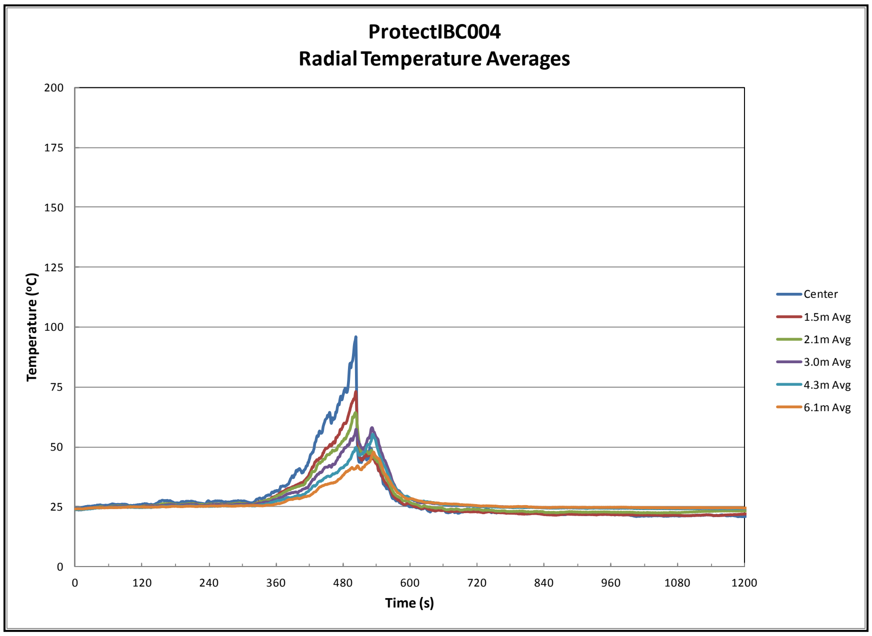


Figure A-7: Test 4 - Ceiling Gas Temperatures

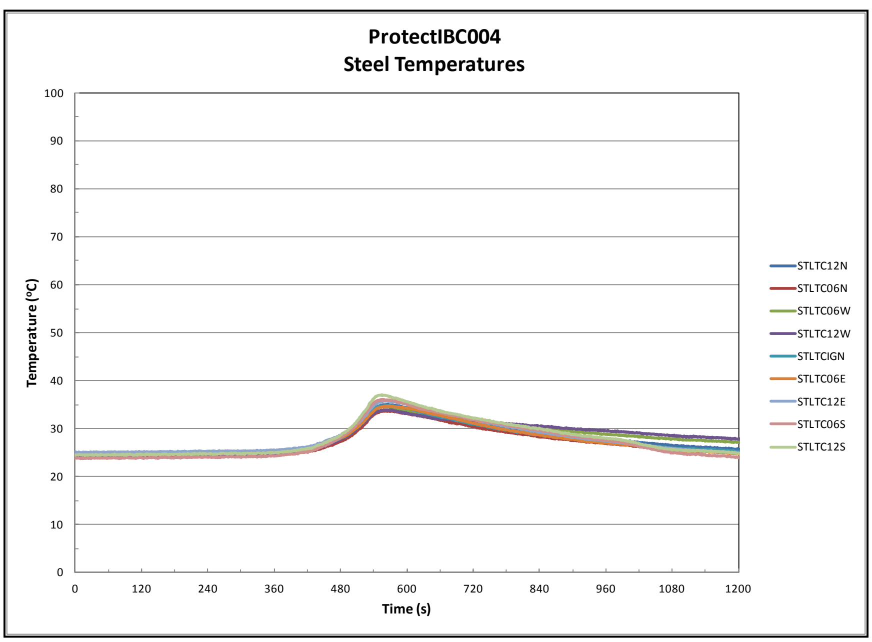


Figure A-8: Test 4 - Ceiling Steel Temperatures

A.5 TEST 10 DATA PLOTS

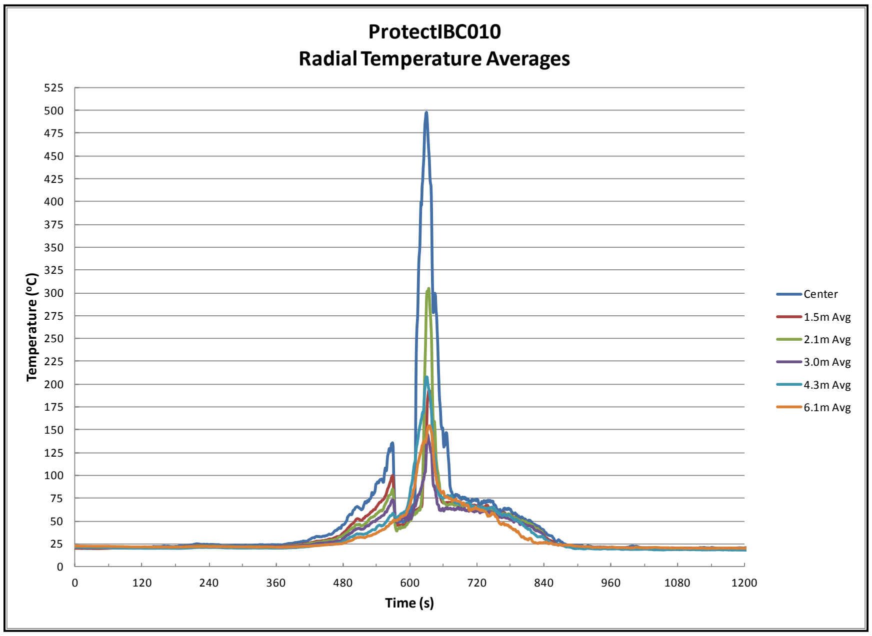


Figure A-9: Test 10 - Ceiling Gas Temperatures

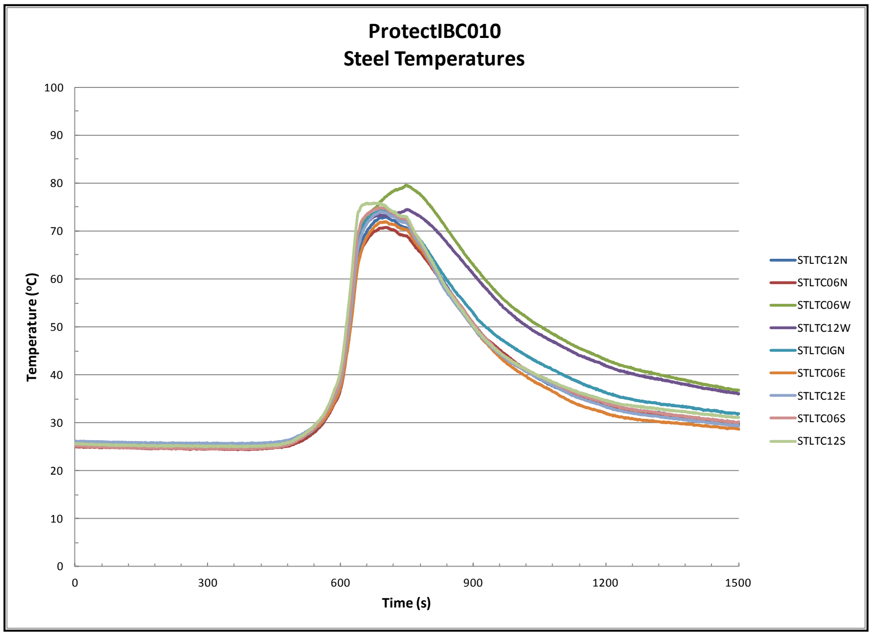


Figure A-10: Test 10 - Ceiling Steel Temperatures

A.6 TEST 11 DATA PLOTS

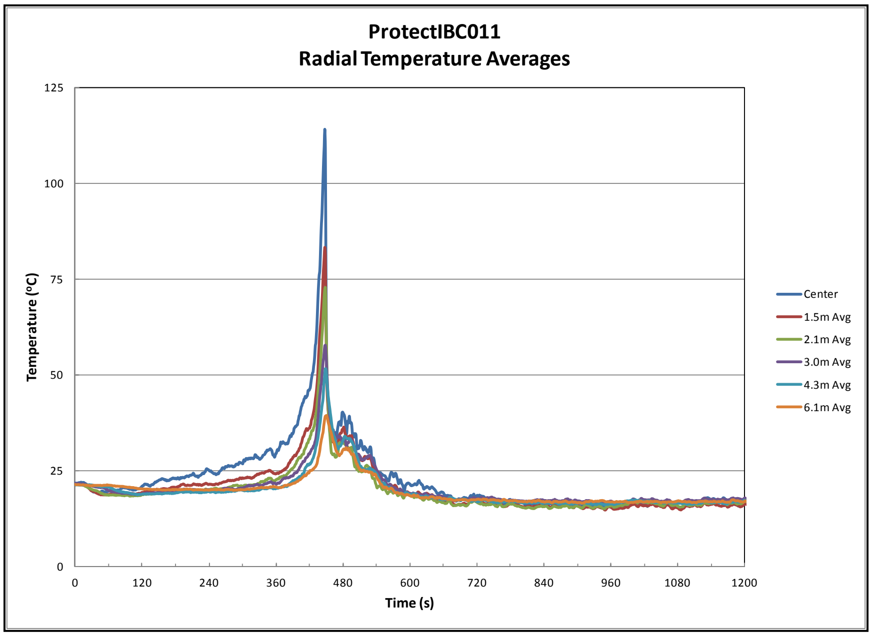


Figure A-11: Test 11 - Ceiling Gas Temperatures

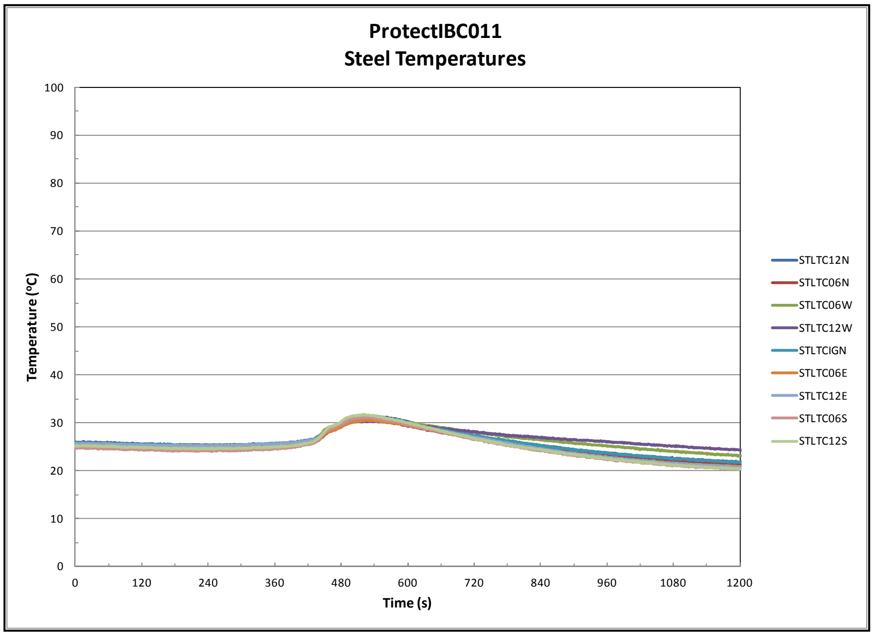


Figure A-12: Test 11 - Ceiling Steel Temperatures

B APPENDIX B – TEST OBSERVATIONS

B.1 TEST 1 OBSERVATIONS

Project # 3042951
Test # 2
Date: 08/02/2011
Facing South, Large Burn Lab

Ignition	Comments
0:00	Ignition (with spark igniter) in doghouse of IBC (western row)
0:18	Flames are 2 ft from the ground, burning at the top of the doghouse
0:35	Smoke just reaching ceiling level
0:49	Dripping of plastic in center longitudinal flue
1:10	Flames growing in center transverse flue. Flames are 3 ft in height.
1:34	Flames approaching top of 1^{st} tier IBC.
2:04	Flame intensity increasing and burning at top of 1^{st} tier IBC
2:35	Flames burning beneath 2^{nd} tier IBC
2:52	Increase in quantity of plastic dripping into center longitudinal flue
3:20	Flames have not propagated into western longitudinal flue though glowing can be observed in target IBCs.
3:37	Flames are continually up eastern face of IBC
3:56	Smoke volume and velocity increasing
4:20	Flame height around center IBC has decreased
4:33	Small plastic pool fire in the longitudinal flue that is impinging on eastern row of the array
5:05	Ceiling temperature at 90 ^{o}F
5:16	IBC in eastern row of ignition has become involved at the 1^{st} tier
5:45	Fire intensity increasing. Eastern and western row IBCs involved.
5:58	Flames are 3 ft in height
6:17	Fire intensity increasing in longitudinal flue and flames are at the top of the 1^{st} tier.

6:54	Fire intensity continues to increase. Glowing observed in eastern and western longitudinal flue on either side of ignition flue.
7:12	Flames impinging on 2nd tier IBCs
7:22	Fire has not propagated north or south into the transverse flues
7:46	Flames are 5 ft in height
8:04	Flames traveling up longitudinal flue and continuing to grow in intensity
8:39	Glowing in western longitudinal flue, but no flames observed.
8:54	Flames have reached top of the array, 12 ft
9:05	Flames involve both 1st and 2nd tier and flames are continually above the top of the array
9:13	Flames are 4 ft above the top of the array
9:20	Flames exiting eastern row of IBCs into east longitudinal flue and impinging on targets
9:24	1st sprinkler operation
9:30	Flames knocked down below top of array
9:48	Class 2 commodity east of array has surface ignition
10:04	Burning in longitudinal flue is decreased substantially
10:15	Burning of Class 2 target east of ignition only at the 2nd tier.
10:29	Fire on Class 2 target has decreased.
10:45	No involvement of western targets
11:05	Minimal burning in longitudinal flue only at the bottom of the 2nd tier
11:30	Fire is almost extinguished on Class 2 commodity. Minimal burning below 2nd tier IBC in longitudinal flue.
12:00	Non-essential personnel evacuated from test floor
20:00	Fire remains seated below 2nd tier IBC in ignition row.
28:28	Ignition of SW tote in the eastern flue.
29:43	Fire increasing in intensity in the eastern longitudinal flue. Flames are impinging into the 3rd tier.
31:00	Some burning in flue south of ignition. Very small flames observed.

32:50	No additional propagation of fire. Small fire is shielded from sprinkler spray and extinguishment cannot be achieved.
38:00	Small fire below 2nd tier IBCs south of ignition
40:00	Test terminated.

B.2 TEST 2 OBSERVATIONS

Project # 3042951
Test # 2
Date: 08/04/2011
Facing South, Large Burn Lab

Ignition	Comments
0:00	Ignition (with spark igniter) in doghouse of IBC (western row)
0:17	Flames 3 ft in height
0:52	Flames extending to top of 1st tier IBCs
1:35	Fire increasing in intensity. Flames 4 ft in height
1:58	Flames exiting pallet of 2nd tier commodity
2:25	Dripping of plastic observed in longitudinal flue
2:50	Glowing observed in backside of ignition IBC in western longitudinal flue
3:20	Fire intensity decreased, but still present at top of 1st tier
3:35	Smoke generated in western longitudinal flue
3:49	Plastic has pooled in longitudinal flue and is burning on the floor
4:50	Fire observed beneath 2nd tier commodity within the pallets
5:14	Flames impinging on eastern row of main array
5:30	Flames now above 1st tier commodity and into 2nd tier commodity
5:40	Ignition of the IBC west of ignition
6:12	Fire increasing in intensity. Flames present on both IBCs in ignition flue and over 5 ft in height
6:35	Fire is not present in either the east or west longitudinal flue
6:51	Flames present in 2nd tier IBCs on east side of array
7:14	Fire growing in longitudinal flue. 2nd tier IBCs now involved
7:33	Flames at 8 ft in height
7:45	Flames extending below 2nd tier commodity into east and west longitudinal flues
8:15	Flames impinging on eastern target array

8:35	Flames above the top of the array.
8:50	Flames 8 ft above array
8:56	1st sprinkler operation
9:04	Flames knocked down, still 3 ft above array
9:17	Four IBCs still heavily involved
9:22	IBC in eastern row still involved below 2nd tier pallet
9:40	Flames knocked down below top of array
10:03	Flames no longer observed in east or west longitudinal flue
10:08	Flames still present below 2nd tier commodity
11:00	Non-essential personnel evacuated from test floor
30:00	Test erminated.

B.3 TEST 3 OBSERVATIONS

Project # 3042951
Test # 3
Date: 08/09/2011
Facing South, Large Burn Lab

Ignition	**Comments**
0:00	Ignition (with spark igniter) in doghouse of IBC (western row)
0:10	Flames from the igniter are 2-3 ft in height
0:20	Smoke just reaching ceiling level
1:00	Flames are still confined to the doghouse of the IBC
1:52	Flames increasing in height and reaching top of 1^{st} tier IBC
2:04	Dripping of plastic in center longitudinal flue
2:27	Flames present at top of 1^{st} tier commodity
2:46	Flame intensity increasing and rate of plastic dripping into longitudinal flue is increasing.
3:00	Flames present along entire eastern face of ignition IBC at 1^{st} tier level
3:37	Plastic dripping into longitudinal flue has ignited and is burning at floor level.
3:54	Smoke generation from fire has increased and is exiting along top of western row
4:19	Fire size decreased as fire burns inside of the ignition IBC.
4:34	Flames are only 2-3 ft in height.
4:46	Plastic pool fire in the longitudinal flue that is impinging on eastern row of the array
5:29	IBC east of ignition is becoming involved and flames are growing up the face of the IBC
6:05	IBCs at floor level are involved on either side of longitudinal flue
6:19	Flame intensity is increasing and flames are 3 ft in height
6:36	Flames present at top of 1^{st} tier commodity
6:48	Flames exiting below the pallet of the 2^{nd} tier commodity

7:00	Significant increase in the smoke generation
7:06	Flames impinging on 2nd tier commodity. Flames are 6 ft in height
7:46	Flames traveling up longitudinal flue and are reaching bottom of the 3rd tier.
8:00	Glowing observed in eastern and western longitudinal flues but fire has not propagated to those flues.
8:16	Flames are 7 ft in height but starting to travel into the 3rd tier
8:36	Flames exiting into the eastern longitudinal flue and impinging on IBCs of the eastern target array.
8:49	Flames exiting the top of the array, roughly 12 ft in height
9:00	Flames in eastern longitudinal flue are present below the 2nd tier pallets
9:07	Flames are 3 ft above the top of the array
9:19	1st sprinkler operation
9:26	Flames are still 10 ft above the array
9:37	Flames present in western longitudinal flue
9:43	Flames are beginning to be knocked down, but remain 5 ft above the array
9:55	Flames in eastern longitudinal flue involve the 2nd and 3rd tier
10:05	Flames are no longer present in western longitudinal flue
10:12	Flames still involve 2nd and 3rd tier IBCs, but are only 1 ft above the array
10:42	IBCs in 2nd and 3rd tier are beginning to collapse
11:00	White smoke being generated from array.
11:11	Beginning to see collapse of the wire cages in IBCs east of ignition
11:30	Fire not observed in western longitudinal flue, but still involved below 2nd tier in eastern longitudinal flue
11:53	Plastic dripping into eastern longitudinal flue
12:36	Flames are present at the top of the 1st tier in the east longitudinal flue. Rate of plastic dripping in flue is increasing
13:30	1st tier IBCs in east longitudinal flue involved. Flames are growing and are 8 ft in height
13:46	North-east IBC becoming involved
14:13	Flames exiting top of the array above east longitudinal flue

14:26	Continual plastic pool fire burning in east longitudinal flue
14:50	Flames exiting below eastern target IBCs beyond array
15:15	Eastern target IBC in 2nd tier is starting to collapse from involvement
16:05	Flames exiting from top of IBC in eastern target
16:20	Flames exiting below the 3rd tier on the eastern face of the array
16:30	Flames involved in entire east longitudinal flue and exiting 4 ft above the array
16:40	Flames exiting eastern face of the array below the 2nd and 3rd tiers.
17:01	2nd sprinkler operation
17:16	6 sprinklers have operated
17:20	Entire eastern half of array is involved including Class 2 target
17:40	No involvement in western targets
18:40	Flames still present above top of the array
19:12	Fire intensity decreasing. Flames present below 2nd and 3rd tier pallets
19:30	Smoke driven to floor level and beginning to obscure array
20:00	IBCs that were involved have collapsed and fire is only burning below pallets
20:32	Flames only present below 3rd tier pallet in longitudinal flue, below the 2nd and 3rd tier pallets in the east longitudinal flue.
21:16	Plastic completely consumed in east target IBCs
22:32	Non-essential personnel evacuated from test floor. Fire contained below the plastic pallets of IBC.
23:00	Ceiling temperatures have returned to ambient conditions.
30:00	Test terminated.

B.4 TEST 4 OBSERVATIONS

Project # 3042951
Test # 4
Date: 08/04/2011
Facing South, Large Burn Lab

Ignition	**Comments**
0:00	Ignition (with spark igniter) in doghouse of IBC (western row)
0:19	Flames from the igniter are reaching the top of the 1st tier IBCs
0:34	Plastic observed dripping into the longitudinal flue
1:30	Flames contained in the area of ignition with flames 4 ft in height
3:10	Front on ignition IBC is beginning to melt and burn. Smoke opacity increasing
3:45	Burning observed on inside of ignition IBC
4:04	Flames still contained to bottom tier
4:55	Fire burning in longitudinal flue and has spread to IBCs in east row of the array
6:30	Fire contained to 1st tier IBCs, with occasional flame impingement into the 2nd tier.
6:52	2nd tier IBCs now involved
7:20	Fire propagated below 2nd tier to western longitudinal flue
7:40	Flames have reached the top of the array
	Flames at 2nd tier in west longitudinal flue are burning below pallet
8:10	Flames 1-2 ft over top of the array
8:24	1st sprinkler operation
9:00	Flames observed in eastern longitudinal flue below 2nd tier pallets
9:20	Flames in center flue has been diminished with only small flames present at bottom of IBCs in multiple tiers
10:10	Flames only present at 3rd tier in center flue
10:20	No flames observed in eastern or western longitudinal flues
12:00	Small candle flame observed in center longitudinal flue

20:00	Test terminated

B.5 TEST 10 OBSERVATIONS

Project # 3042951
Test # 10
Date: 10/05/2011
Facing South, Large Burn Lab

Ignition	**Comments**
0:00	Ignition (with spark igniter) in doghouse of IBC (western row)
0:33	Flames from the igniter are 2 ft in height
1:00	Flames at 1 ft in height, burning inside IBC doghouse. Some plastic observed dripping into longitudinal flue.
2:00	Flames are slightly growing in height and reaching the top of the 1st tier.
2:25	Flames impinging on bottom of 2nd tier pallets
3:03	Flames consistently at bottom of 2nd tier. Flame intensity from 1st tier IBC increasing and plastic pool forming in longitudinal flue.
3:45	Small pool of plastic ignited on floor from dripped plastic
4:06	Flame intensity decreased.
4:37	Smoke generation rate increasing
5:12	Smoke exiting western longitudinal flue, but no flames present in that flue.
6:00	Pool of melted plastic has covered the floor of the 6 inch flue space
6:14	Flames from pool impinging on IBCs of the eastern row and flames are growing up face of IBC.
6:41	Intensity of fire in longitudinal flue is increasing. Flames are 3 ft in height
7:36	Flames reaching bottom of 2nd tier IBCs.
7:54	Flames observed in the western longitudinal flue
8:02	Flames are 8 ft in height and reaching the bottom of the 3rd tier
8:20	Flames extending beyond the top of the array
8:28	Flames consistently in west longitudinal flue beneath the 2nd tier IBC
8:45	Flames in west longitudinal flue are burning into the 3rd tier
8:54	Flames 2-3 ft above the top of the array
9:04	Flames in west longitudinal flue are impinging on target IBCs

9:14	Flames are 6 ft above the array
9:26	Flames in the east longitudinal flue
9:30	1st sprinkler operation
9:45	Flames still 10 ft above the array
9:49	Flames in longitudinal flue extending above the top of the array
9:56	Flames above the array are reaching ceiling level.
10:04	Flames involving all 18 IBCs of the main array
10:13	Ignition of eastern and western targets
10:22	Multiple sprinkler operations
10:39	Decrease in fire intensity
10:50	17 sprinklers have operated
10:55	Thick smoke has descended from ceiling level and beginning to obscure the array, though flames are still observed in the west longitudinal flue.
11:33	Smoke obscures the entire array. Smoke layer at ceiling is 4-5 ft in depth.
11:50	Significant involvement of IBCs still observed in ignition array.
13:00	Minimal observations can be made, but glowing can still be observed in the array.
13:37	From IR camera, fire intensity has diminished, with fire rooted below pallets of the IBCs
14:14	Ceiling temperatures have returned to ambient conditions.
14:22	Smoke beginning to clear from test array
14:30	No flames can be observed exiting IBC array
15:33	Small flames observed below pallets, but no additional propagation is expected.
16:00	Non-essential personnel evacuated from test floor.
20:00	Test terminated.

B.6 TEST 11 OBSERVATIONS

Project # 3042951
Test # 11
Date: 10/07/2011
Facing South, Large Burn Lab

Ignition	**Comments**
0:00	Ignition (propane torch) between 2 IBCs in transverse flue of array
0:15	Flames from the igniter are 2 ft in height
0:27	Thin smoke exiting top of the array
0:35	Flames reach the top of the 1st tier IBCs
1:00	Flames in the transverse flue are 3-4 feet in height
1:14	Walls of IBCs involved and plastic is dripping into the transverse flue
1:52	Smoke generation rate increasing
2:12	Flames continually above 1st tier IBCs
2:32	Glowing observed in IBCs on either side of ignition
3:18	Fire continues to burn in the center transverse flue, but fire has not propagated to east face of the array or into the longitudinal flue
4:00	Fire intensity decreased slightly
4:14	Smoke becoming darker in nature, though flames cannot be observed above the 1st tier
4:56	(from East) Holes have been breached in both North and South IBCs surrounding ignitions
5:15	Wood pallet below igniters is involved.
5:44	Partial collapse of south ignition IBC
5:59	Collapsed IBC increased the fire severity and flames are above the 1st tier
6:18	IBC north of ignition has collapsed in on itself
6:28	Flames are pulsing into the 2nd tier. Flames are 7-8 ft in height at the peak
6:46	Fire intensity increasing as the IBCs continue to collapse
7:00	Fire continually impinging on 2nd tier IBCs
7:08	Flames below the 2nd tier pallets.

7:17	Flames are growing up the longitudinal flue and up the east face of the 2nd tier
7:28	1st Sprinkler Operation
7:47	Fire continuing to spread through the 1st and 2nd tier IBCs. Flames are still exiting the top of the array
8:20	Fire intensity has decreased. Fire still involved below 2nd tier IBCs
8:30	No flames observed in the longitudinal flue
9:00	Significant decrease in fire intensity. Flames below 2nd tier are 6-8 inches in height
9:30	Small fire on east face of main array at 2nd tier level
10:24	Small increase in fire intensity of fire burning on east face of main array. Fire 1-2 feet in height
11:24	Plastic dripping from 2nd tier into the 1st tier
11:40	Increase in the rate of plastic dripping into 1st tier
11:54	Fire is becoming larger. Flames are 3 ft in height on east face of array
13:05	Fire still present is shielded from overhead sprinkler
13:15	Melted plastic from 2nd tier has caused a pool fire in the 1st tier. Majority of 1st tier IBCs around ignition have collapsed and been consumed.
15:34	Small fire present below 2nd tier IBCs. Walls have been breached and small flame present along wall edge
18:00	3 distinct fires in test array. Small fire below 2nd tier IBCs on either side of the ignition flue. Small fire present at base of 1st tier north of ignition
19:16	Slight increase in fire north of ignition. Fire is present inside of the IBC where it has not collapsed. Flames are shielded from the overhead sprinkler.
21:00	Fire intensity decreased in all locations
25:00	Test terminated