INTERNATIONAL INTERMEDIATE BULK CONTAINER FIRE TEST PROJECT

Required Delivered Density Tests

TECHNICAL REPORT

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FOREWORD

The International Intermediate Bulk Container Fire Test Project was initiated in 1995 with the aim of improving fire protection associated with the storage of combustible liquids in non-metallic intermediate bulk containers (IBCs). The project has independently documented protection criteria which might be incorporated into a wide range of codes, standards and insurance guidelines.

Currently, IBCs are recognized by transportation regulatory authorities for intrastate, interstate and international shipping. Generally, fire and building codes have been silent on protection guidelines for these containers. Where there is recognition of IBCs, their use and storage in buildings has been severely limited or prohibited because of the lack of fire test data on their protection. Insurers and fire inspectors also have had limited information on which to base protection guidelines.

This is the second report for the project and documents Required Delivered Density (RDD) tests of single IBCs, and IBCs stacked two-high. A previous report documented fire tests to help quantify potential failure mechanisms of IBCs for a range of products and potential exposure fires. It is anticipated that Phase II of the project will be conducting large-scale fire tests of representative real-world storage/use scenarios. Those tests will be reported under separate cover.

The Research Foundation expresses its gratitude to project technical director Joseph Scheffey of Hughes Associates, and David Sheppard and Daniel Steppan of Underwriters Laboratories, Inc. for their professional conduct of the fire tests and presentation of the data. The Foundation and the authors thank the project's Technical Advisory Committee listed on the following page for their contributions of expertise and the financial resources required to complete this first phase of the project. Of course, participation does not necessarily constitute a participant's endorsement of every statement in this or the cited reports.

THE INTERNATIONAL INTERMEDIATE BULK CONTAINER FIRE TEST PROJECT

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Fire Testing of Intermediate Bulk Containers

– Suppression Scoping Tests –

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FINAL REPORT

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– Suppression Scoping Tests –

BACKGROUND

The National Fire Protection Research Foundation (NFPRF) is conducting a research project aimed at improving fire protection associated with combustible and flammable liquids stored in non-metallic intermediate bulk containers (IBCs). New technologies, internodal transportation opportunities, and space utilization needs have resulted in the introduction of intermediate-sized plastic and composite containers for combustible and flammable liquids. These containers may also be used individually as part of a process operation.

The overall objective of the research project is to develop protection criteria which could be incorporated into a wide range of codes and insurance guidelines. The trend is to use fire test data and engineering analysis to develop appropriate protection criteria. Such criteria could include the type and size of container, the liquid type, the storage configuration, and the specific storage location and use (e.g., bulk warehousing or operations and use).

In the first series of fire tests, failure mechanisms of 23 different IBCs were identified [1]. Time to failure, i.e., for liquid to discharge from units, ranged from approximately 1.5 minutes to over 20 minutes. Rapid catastrophic failure, i.e., rapid discharge of liquid from the container, was an infrequent occurrence. Relatively thin, unprotected blow-molded and RIM IBCs experienced the most rapid failure times. Time to failure of other units was extended, in part due to a greater thickness of the container structure. It was concluded that it was appropriate to continue work in terms of developing a suppression system to protect these units. After discussion among the Technical Advisory Committee (TAC), it was decided to use the "Required Delivery Density" (RDD) test apparatus and approach to scope the potential water suppression system. This would provide an estimate of the protection which might be required in a warehouse storage scenario with IBCs. This test series was intended to be an interim scoping series in preparation of larger arrays under a 30 ft (9.1 m) high ceiling. It also allowed the continued evaluation of different types of IBCs.

APPROACH

RDD Test Method

The RDD test method and apparatus was developed by the Factory Mutual Research Corporation (FMRC) as an intermediate scale method to assess protection requirements for high challenge commodities storage. RDD relates to the extinguishment characteristics of the storage hazard [2]. It is the water density required to be delivered at the top of the burning storage array to achieve suppression. The value of RDD depends on the convective heat release rate at the time of water application. It can be determined using a large capacity calorimeter and a special water applicator which delivers a uniform water density at the top of the storage array. The water applicator is actuated at a specific, predetermined convective heat release rate as measured by the calorimeter, corresponding to the response time of a sprinkler installed in a warehouse.

In theory, RDD data can be combined with Actual Delivered Density (ADD) to determine if ceiling sprinkler protection is adequate for a given storage array. ADD is the density of water which actually penetrates the fire plume and is delivered onto the top of the burning array. ADD is measured with a fuel/simulated storage array which creates the desired fire plume and heat output for the selected actual storage array (as determined in the RDD tests). Sprinklers are installed at the desired ceiling height, and the water which penetrates the plume is measured. This water represents the density which would actually be delivered at the top of the array. If RDD exceeds ADD, the fire should be suppressed. RDD and ADD values are a function of heat release rate. Sprinkler response is controlled by the heat output of the fire, ceiling height, and response time characteristics of the sprinkler (sprinkler response time index, RTI).

In this test series, the RDD apparatus at Underwriters Laboratories Inc. (UL) was used to scope the water suppression system characteristics of IBCs exposed to a flammable liquid fuel spill. No ADD tests were performed. It was recognized that the theory to relate RDD data to full scale results for water suppression/control of flammable liquid has not yet been developed. The intent in these tests was to provide "go/no go" decisions for protecting representative IBCs stacked one and two high. It was also recognized that interpolation would be required for any

RDD data in these tests which indicated success in preventing a breach in a liquid filled IBC. UL provided in-house data which suggested that a ceiling sprinkler density increase of up to 50 percent of the RDD value would be required for the anticipated fire threat, ceiling height, and sprinkler response characteristics considered in these tests. It is believed the spray from actual ceiling sprinklers would provide more wetting to the container sides than the spray from the RDD apparatus. This may have positive effects when units are tested in large scale.

Selection of IBCs

Seven IBCs, representing a range of construction types, were selected from the first test series for evaluation in these scoping tests. They are described in Table 1 and included blow molded and rotational molded (rotomold) units. The blow molded units were unprotected (Unit 1), encapsulated (Unit 8), or provided with in-situ protection (Unit 1 with steel mesh cage protected with an intumescent coating). Rotomolded Units 14 and 17 were single layer units with no outer encapsulation, which represent a large use group in the industry. Rotomold Unit 5 had a steel outer encapsulation, and Unit 11 had a multi-layer poly outer container. Both of these units demonstrated a high degree of resistance in the first test series.

Detailed construction, material, size, and capacity information, along with standard terminology, is contained in Reference [1].

Fire Threat and Protection Scenario

The anticipated fire threat is a flammable liquid spill scenario which exposes an array of IBCs. It is assumed that there already is a breach in a liquid container which creates a liquid spill fire. As such, a point ignition source was not considered. The spill fire was simulated in these tests with a worst case fuel (heptane), exposing either a single or two-high array of IBCs. The spill was contained in a 5 ft x 5 ft (1.5 m x 1.5 m) pan used in the first test series. The objective was to maintain a relatively constant heat flux and fire exposure to the units, recognizing that there would be some test-to-test variation since the dimensions of the IBCs were not exactly the same. The measure of performance was the time, if any, of breach of container. If containers were breached, it was considered unlikely that the container array could be protected in a large scale array with ceiling sprinklers at or above the RDD used in the test.

Table 1. UBC Units Used in Tests

Test	Unit Number[1]	UN/DOT Shipping Designation	Description	Unprotected Failure Time (s)[1]
1, 8	5	31HA1	Rotomold, single layer, 400 gal (1514 L) rectangular container with metal outer	890
2	1	31HA1	Blow molded, 275 gal (1041 L) rectangular unit with steel mesh cage outer	89
3	9	31HA1	Blow molded, 330 gal (1249 L) rectangular unit with steel sheet outer	352
4, 5	14	31H2	Rotomold, single layer, 330 gal (1249 L) rectangular container representative of single layer rotomold units with no outer encapsulation/container	589
6	17	31H2	Rotomold, single layer, 220 gal (833 L) square unit, all plastic	314
7	Modified 1	31HA1	Blow molded, 275 gal (1041 L) rectangular unit with steel mesh cage outer with the steel protected by an intumescent coating	Not tested
9	11	31HH1	Rotomold 330 gal (1249 L) rectangular unit with a multiple layer poly outer container	1106

Note: [1] Unit designation and unprotected time to failure from first test series [1].

In these tests, the desired protection characteristics included 286°F (141°C) ordinary response (200 RTI) sprinklers installed at a ceiling of a 30 ft (9.1 m) high warehouse. This was considered a common warehouse situation. RDD water densities of 0.3 and 0.6 gpm/ft^2 (12 and 24 mm/min) were initially selected for one-high and two-high storage configurations, respectively. These values were selected recognizing that, if successful, the actual ceiling sprinkler densities would have to be adjusted upward to account for fire plume penetration (i.e., ADD concept). It was felt that RDDs above the values selected would result in impractically high water densities in actual warehouse scenarios.

TEST SETUP AND PROCEDURE

Facility and Test Apparatus

The tests were conducted in UL's large scale fire test facility located in Northbrook, IL. The tests were conducted in a room nominally 50 ft x 50 ft x 65 ft high (15 m x 15 m x 20 m high). A schematic of the test room is provided in Figure 1.

The RDD test apparatus and methodology have not been standardized. FM has generically described the technique in the literature [2,3] and in proprietary reports. The best available description of the apparatus and technique is provided by the Swedish National Testing and Research Institute (SP) in Reference [4]. UL has essentially adopted this setup and procedure for their RDD apparatus. The SP report provides a detailed description of the test apparatus, instrumentation, and suppression system design for the RDD testing used in this investigation. The methodology was modified as discussed in the Procedures to address the response of the IBCs to the flammable liquid fuel fire.

The suppression system consisted of a special water applicator to provide a uniform density of water spray over the IBC(s) under test. The water spray applicator consisted of four parallel, double jacketed, steel pipes fitted with four spray nozzles along each pipe to form a uniform 4 by 4 array of nozzles (Figure 2). Nozzles were of the full cone type designed to provide a uniform spray over a specific area. The pipe design used a double jacket to flow cooling water over the outer annular region while flowing the suppression water in the center pipe. This prevented the suppression water from boiling and vaporizing prior to discharge from the open nozzles. The applicator was designed with special air purge devices in each pipe and solenoid controlled inlet ports to provide for quick pressurization of the piping.

Calibration testing of the applicator was conducted to determine flow rates and distances above the top of the commodity required to obtained the desired uniform density of 0.30 or 0.60 gpm/ft^2 (12 or 24 mm/min). The distances for which the water densities were applicable were measured from the top of the IBC.

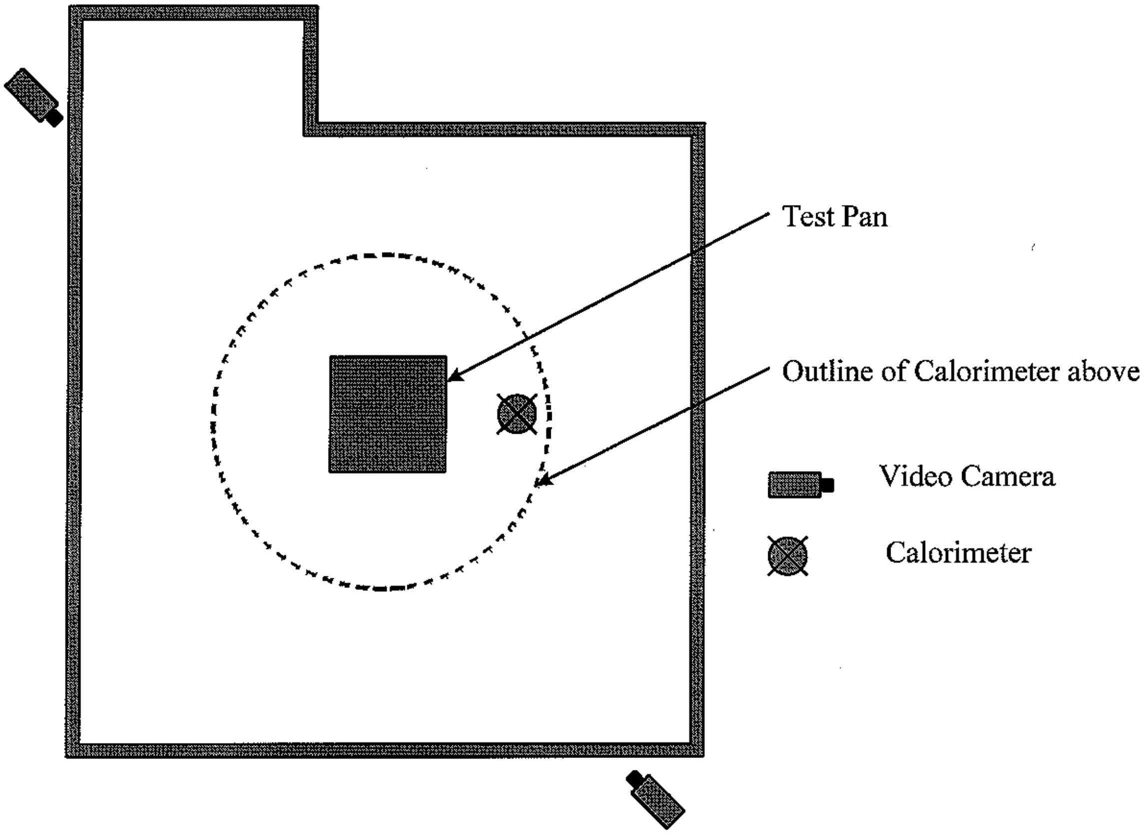

Figure 1. Fire test setup

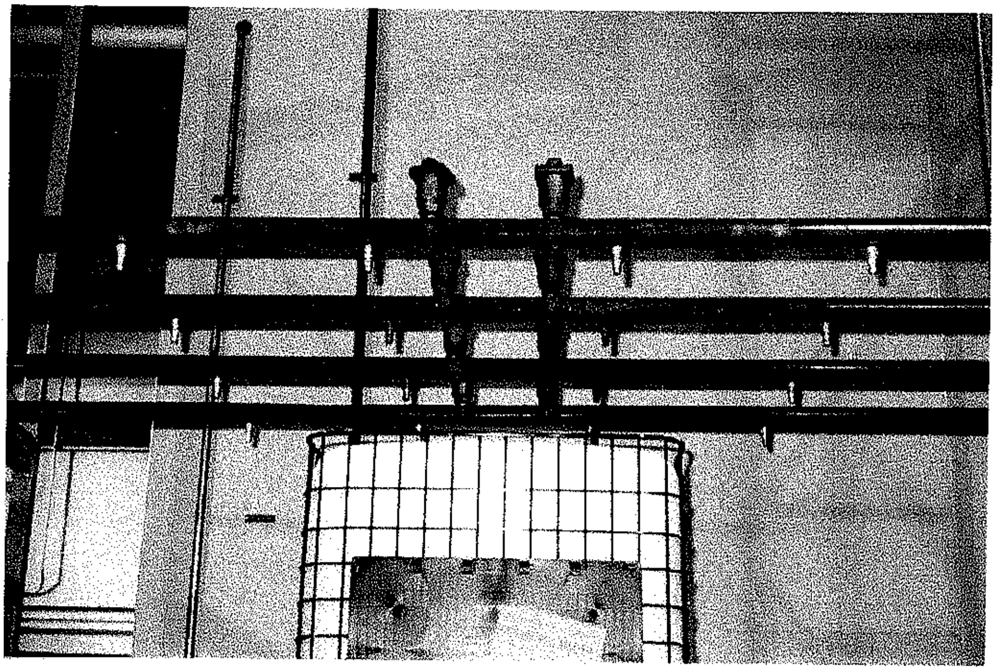

Figure 2 - Nozzle arrangement

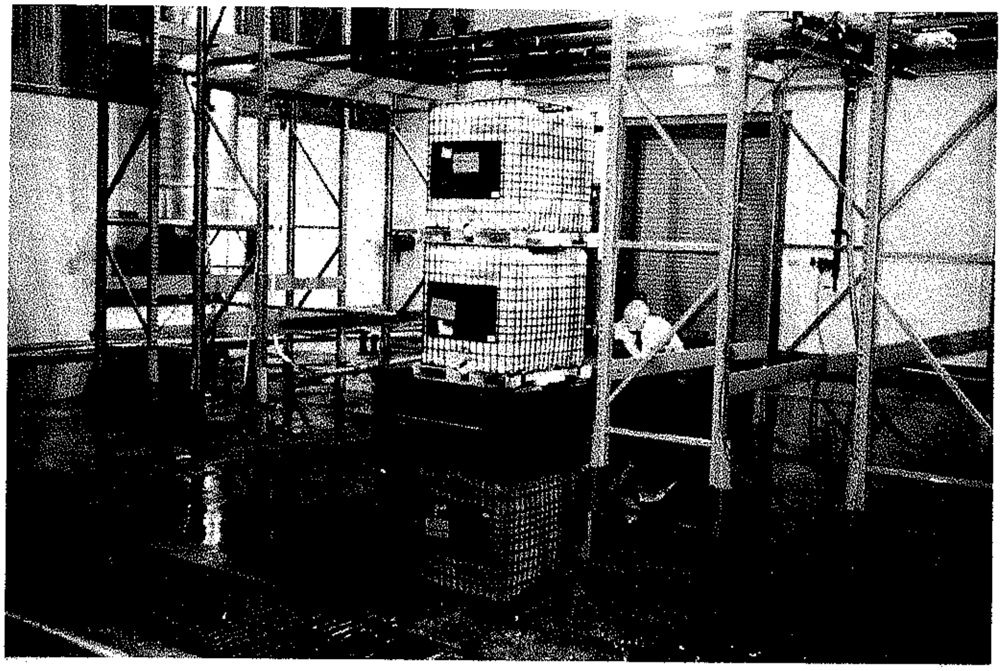

Figure 3 - Test and pan suppression system arrangement

The test samples were mounted in a 60 by 60 by 12 in. high (152 by 152 by 30 cm high) steel pan (Figure 3). Cinder blocks were positioned in the pan under the IBC. The pan was filled with water until the cinder blocks were covered (approximately 9 in. (23 cm)). The pan was located under the geometric center of the collection hood. Heptane was floated on top of the water. Exact heights of the water, cinder blocks, and freeboard are provided in Appendix A.

During the tests, measurements of the convective heat release rate, total heat release rate, and fire temperature were recorded. Tests were videotaped using VHS video.

Convective and total heat release rates were measured using a calorimeter mounted directly over the specimen. The calorimeter was designed to collect all products of combustion and had a maximum range of 10 MW. The calorimeter consisted of a 25 ft (7.6 m) diameter cone shaped hood mounted 35 ft (10.7 m) above the floor. The hood was connected to a 60 in. (152 cm) diameter exhaust duct in which the heat release equipment was installed. Total heat release rate was measured using oxygen consumption techniques. Convective heat release rate was calculated from the thermodynamic energy increase in the exhaust flow.

Temperatures near the surface of the test samples were measured with four thermocouples. Each thermocouple was mounted 1 in. (2.5 cm) away from the sample and 18 in. (46 cm) above the lip of the pan. One thermocouple was mounted at the centerline of each side of the IBC. Type K inconel sheathed thermocouples, 1/16 in. (0.16 cm) in diameter, were used.

The test data were collected using an electronic data acquisition system at a two-second scan rate.

Tests were recorded using two VHS video cameras. The locations of the video cameras are shown in Figure 1.

Test Procedure

The IBC units being tested were placed either as a single unit or stacked two-high in the pan as shown in Figure 3. As in the failure mechanism tests, the IBCs were filled with water. In these tests, they were filled to 98 percent of their overfill capacity, as is done in DOT drop tests. The thermocouples were placed in position. Ten gallons (38 L) of heptane were placed in the pan. After the data acquisition systems were started, the heptane in the pan was ignited. The water flow from the nozzles was intended to be discharged at a time when 286°F (141°C) sprinklers in a 30 ft (9.1 m) ceiling would operate from a fire located in the center of a 10 ft x 10 ft (3.1 m x 3.1 m) grid. In the initial test, the combined heat release from the pool fire and IBC was insufficient to activate the suppression system. The options were to increase the pool size to assure sprinkler operation or activate the suppression system at a time consistent with that anticipated for a growing pool fire resulting from a spill. Because of limited time and resources to change the pool fire scenario, it was agreed to by the participants and test engineers to activate the suppression system at a time consistent with a pool spill in a warehouse scenario. Data from previous tests (Table 2) indicated that sprinklers would activate on the order of one minute after ignition for a spill of 4 gal (15 L) or more or for a running fuel fire. After the first test, the suppression system was activated one minute after ignition.

The test was allowed to continue until the fire was extinguished (due to fuel depletion), the unit(s) fell outside the pan, or a breach was observed.

Table 2. Sprinkler Activation Times for Fuel Spill Fires

Test [Reference]	Scenario	Ceiling Height (ft (m))	Sprinkler Characteristics (10 ft x 10 ft (3 m x 3 m) spacing)	Activation Time of First Sprinkler (s)
NFPRF Wholesale/ Retail Flammable Liquid Tests [5]	4 gal (15 L) spill	27 (8.2)	286°F (141°C) standard response	63-65
FM Foam Water Sprinkler Tests [6]	2 gpm (7.5 Lpm) running fuel with initial 10 gal (37 L) spill	30 (9.1)	280-286°F (138-141°C) standard response	34 - 80
NFPRF Foam Water Sprinkler Tests [7]	10 gal (37 L) spill	27 (8.2)	286°F (141°C) standard response	44 - 50

RESULTS

A summary of results is shown in Table 3. Detailed test observations are included in Appendix A. Heat release and temperature data are included in Appendix B.

Table 3. Test Summary

Test	IBC Unit	Stack Height	Water Density (gpm/ft^2 (mm/min))	Water Activated (min)	Comment
1	Unit 5	2	0.6 (24)	10	Breach 14:00, Fire between IBCs
2	Unit 1	2	0.6 (24)	1	Breach 3:41
3	Unit 9	2	0.6 (24)	1	No breach
4	Unit 14	2	0.6 (24)	1	No breach, Tipped over at 5:20
5	Unit 14	1	0.6 (24)	1	No breach, tilted at 5:40
6	Unit 17	1	0.3 (12)	1	No breach, tilted at 7:40
7	Modified Unit 1	1	0.3 (12)	1	No breach
8	Unit 5	2	0.6 (24)	1	No breach
9	Unit 11	2*	0.6 (24)	1	No breach

* The inner tank from the top IBC was removed. Only the plastic shell of the top IBC was used.

Typically, the pool fire would continue to burn when the suppression system was activated (see Figure 4). The liquid level in the pan would rise until it was even with the pan lip, at which time the burning of the pool intensified because of the increased surface area. Shortly thereafter, fuel would overflow onto the floor (Figure 5). This created a short duration, higher intensity fire as the fuel burned out. Time to overflow the pan was on the order of four to six minutes for the 0.6 gpm/ft^2 (24 mm/min) tests and on the order of seven and one-half minutes for the 0.3 gpm/ft^2 (12 mm/min) tests. The higher intensity floor fire is typically characterized by spikes in the heat release data shown in Appendix B. The fire would then burn out soon (typically about 1 minute) after the overflow of fuel on the floor.

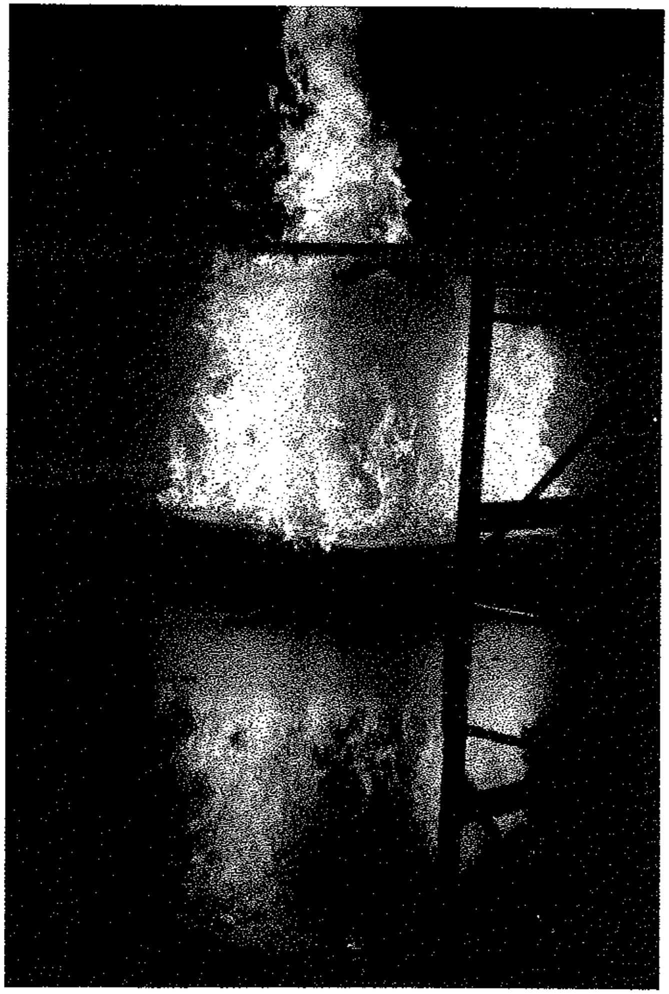

Figure 4 - Pool burning during suppression (Test #6)

Figure 5 - Fuel overflowing onto the floor

Unit 5

Unit 5 was a rotomold, single layer plastic container with a metal outer shell (Figure 6). It was evaluated in Tests 1 and 8.

Test 1

In Test 1, a two-high stack was evaluated. There was insufficient fuel/commodity involvement at the end of 10 minutes to activate the suppression system. The activation algorithm was set for 286°F (141°C), 200 RTI sprinklers in a 30 ft (9.1 m) warehouse. The suppression system was manually activated 10 minutes after ignition.

There was fuel contribution from the IBC unit as evidenced by the increase in RHR five minutes into the test. This corresponded to fire development in the top of the plastic of the lower unit. Prior to this, the total RHR had risen gradually to 2 MW. When the plastic between the two units became involved, the RHR increased up to 4 MW just before the suppression system activated. Exposure temperatures at the face of the IBC were on the order of 1000-1500°F (538-816°C). A breach in the lower unit was observed 14 minutes after ignition.

A post-test inspection of the units indicated that the liquid had completely discharged from the lower unit. Plastic had melted near the top of this unit to create a hole, which occurred at a stress point associated with an internal stiffener. The upper unit had a leak in the doghouse area.

The results of this test were similar to the results of the previous failure mechanism tests, where failure occurred 14 min 50 sec after ignition. Sprinkler water application had no impact on the results due to delayed application. It is likely that, had fuel been stored in the container, it would have ignited when the top of the container became involved in fire. This shielded fire also contributed to impingement and damage to the bottom of the upper unit (Figure 6). Some water did flow down the inside of the top unit which was open to the water spray.

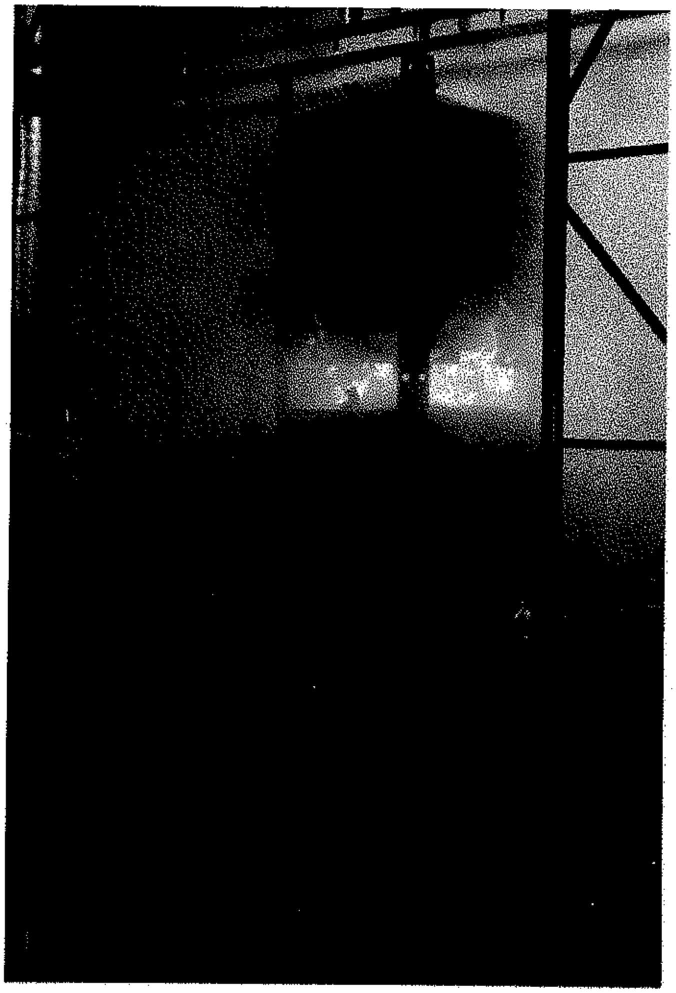

Figure 6 - Shielded fire in Test #1 (Unit #5)

Test 8

Test 1 was repeated in Test 8, with the suppression system activated at 1 minute. The convective heat release at water on was 600 kW, which was reduced until the fire started to spill out of the pan (4.5 minutes into the test). The total RHR steadily climbed during this period to about 3 MW. At this point, the convective heat release rate was 3 MW, and the total RHR was 8 MW. After the fire spilled onto the floor, it quickly died down. There was only a persistent fire at the lower doghouse area that was shielded, but no failure occurred.

A post-test inspection of the lower unit indicated that there was slight melting at the top of the doghouse and the top cap had melted and was damaged (see Figure 7). The bottom of the upper unit was in good shape, with little damage. There was slight melting at the open "hook" holes in the steel.

With this unit, early application of water prevented involvement of the inner plastic container for the time period in this test.

Unit 1

Unit 1, a blowmolded unit with steel cage, was evaluated in Tests 2 and 7. In Test 2, a two-high stack was tested with a sprinkler suppression rate of 0.6 gpm/ft^2 (24 mm/min). A single unit, with the steel cage protected with an intumescent coating, was tested with a water application rate of 0.3 gpm/ft^2 (12 mm/min) in Test 7.

Test 2

The convective heat release at water on (1 minute) was 700 kW (1.8 MW total RHR). The RHR remained relatively constant until a breach was observed at 3:41 into the test. The breach occurred approximately halfway up the back face of the lower unit (most likely at a steel cage/plastic interface). Exterior temperatures were not affected by the suppression system. At 5

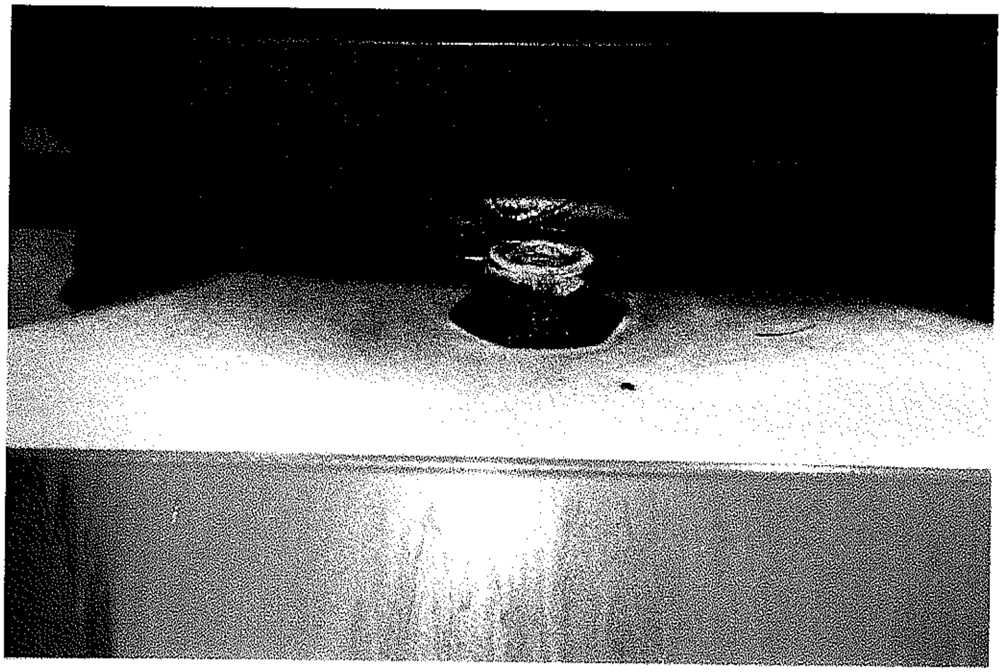

Figure 7 - Damage to cap assemblies, Test #8

Figure 8 - Post-test damage, Test #2

minutes, the pool fire had spilled out onto the floor, and at 7 minutes, the fire was extinguished with hose lines. The lower plastic bottle melted; the upper bottle was not breached (Figure 8).

The application of suppression system water extended the time to failure for an unprotected unit from 89 seconds (as determined from the previous failure mechanism tests) to 3:41 for the unit when stacked two high.

Test 7

Test 7 was used to evaluate a protected blow molded unit, stacked one high with 0.3 gpm/ft^2 (12 mm/min) protection. The convective rate of heat release was 600 kW (1.8 MW total RHR) at water activation (1 min). After an initial knockdown by the suppression system, the convective rate of heat release gradually rose to a maximum of 1.8 MW (4.0 MW total) just before the fuel fire began to recede (10 min). There was some contribution from fuel spilled on the floor.

There was no breach of the container (Figure 9). The egg crate cushion appeared to help protect the bottom of the unit. There was some bulging of the bottle and some sagging at the top of the doghouse. There is a very slight drip (e.g., one drop per second) out of the valve gasket area. Interestingly, there appeared to be very little intumescent action from the coating material.

Exterior temperatures were unaffected by the water spray.

Unit 9

Test 3 was conducted with Unit 9, a blowmolded unit with a sheet steel outer shell. The units were stacked two high with 0.6 gpm/ft^2 (24 mm/min) water application applied at 1 minute after ignition. The convective rate of heat release at sprinkler activation was 700 kW (1.2 MW total RHR). The convective rate of heat release remained steady until fuel spill over (starting at 4 min) when it increased to about 1 MW. Total RHR increased after water application to a

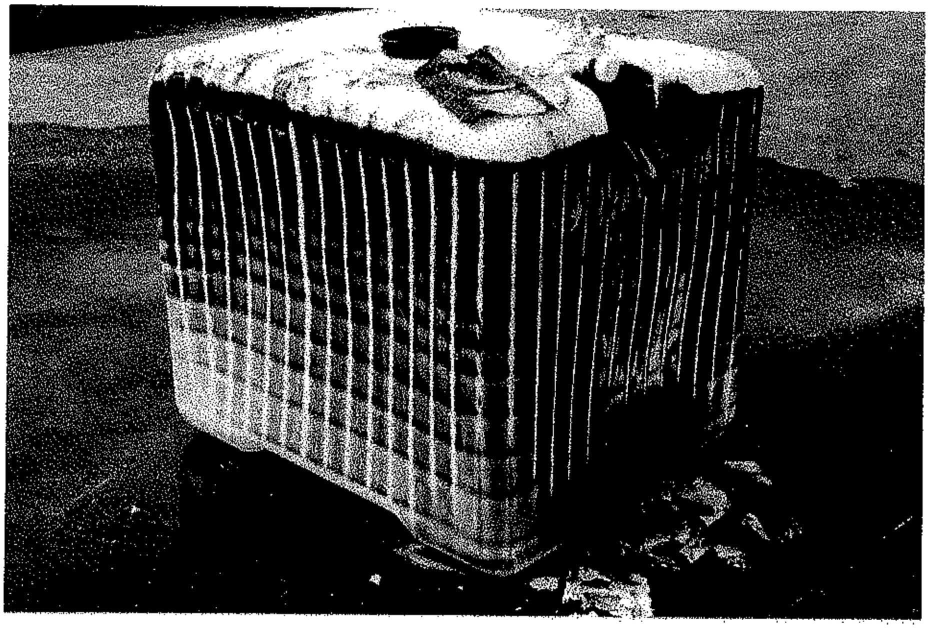

Figure 9 - Post-test damage, Test #7 (unit inverted)

maximum of 3.5 MW. Exterior temperatures were not affected by the cooling water. The fire receded at about 9 minutes, and the fire was out at 9:50.

There were no breaches or leaks. Damage to the lower unit was limited to surface charring of the wood pallet. The polystyrene cushions inside each unit remained mostly intact. Both plastic bottles, when removed from the steel shell, had smooth surfaces that indicated that some melting had occurred (Figure 10). The pallet of the upper unit was essentially undamaged.

The lower unit apparently benefitted from water which discharged through the open top of the upper unit, which leaked through the doghouse area and onto the lower unit (Figure 11).

Unit 14

Tests 4 and 5 were conducted with a single layer, rotomolded plastic unit with no outer protection or encapsulation. Tests were conducted with two units stacked one on top of the other (Test 4) and with a single unit (Test 5) with a 0.6 gpm/ft^2 (24 mm/min) application rate.

Test 4

The convective heat release at water on (1 minute) was 600 kW (1.2 MW total RHR). During the next four minutes, the fire began to grow in spite of the suppression system. At 5:20, the lower unit became structurally unstable, and the pile collapsed (Figure 12). The convective heat release just prior to collapse was about 1.5 MW (4.8 MW total RHR). The suppression water did act to temporarily cool part one face of the array (see Figure B-13, Appendix B).

The post-test inspection of the units revealed no breach in the containers.

Test 5

Test 5 was a repeat of Test 4 with a single unit. The intent was to observe whether the two-high configuration created the basic structural problem observed in Test 4. The results were

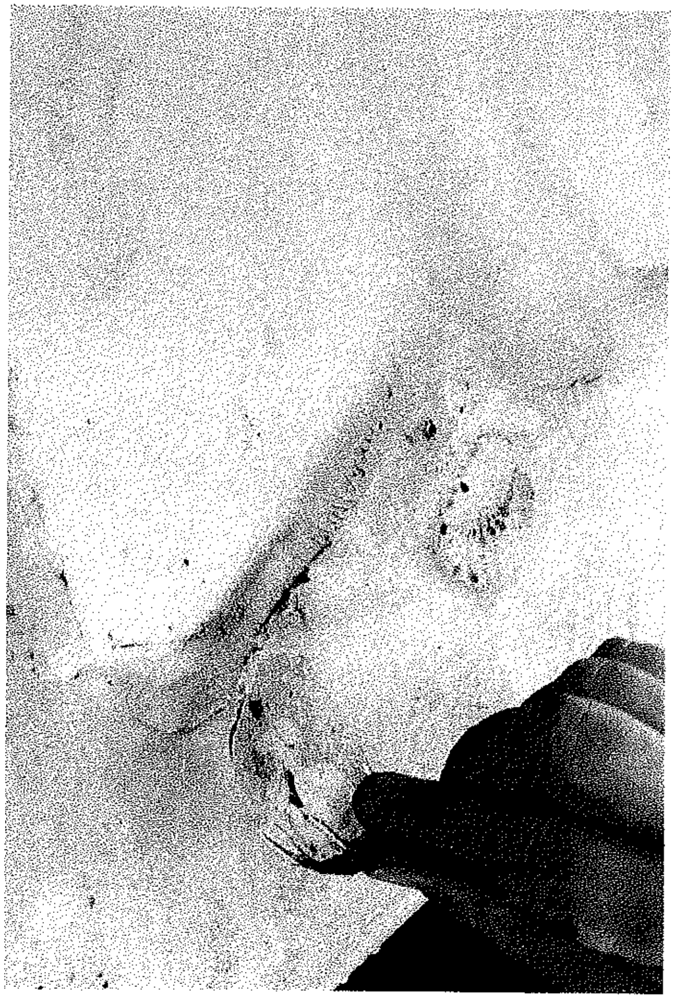

Figure 10 - Melting of Unit #9 after Test #3

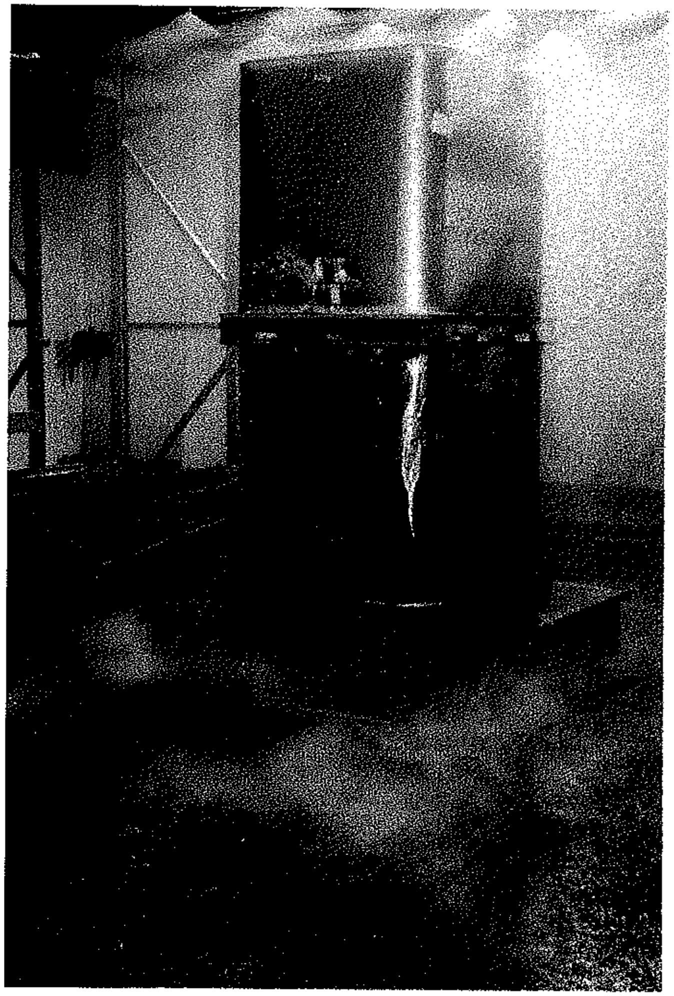

Figure 11 - Water discharging from upper unit onto lower unit, Test #3

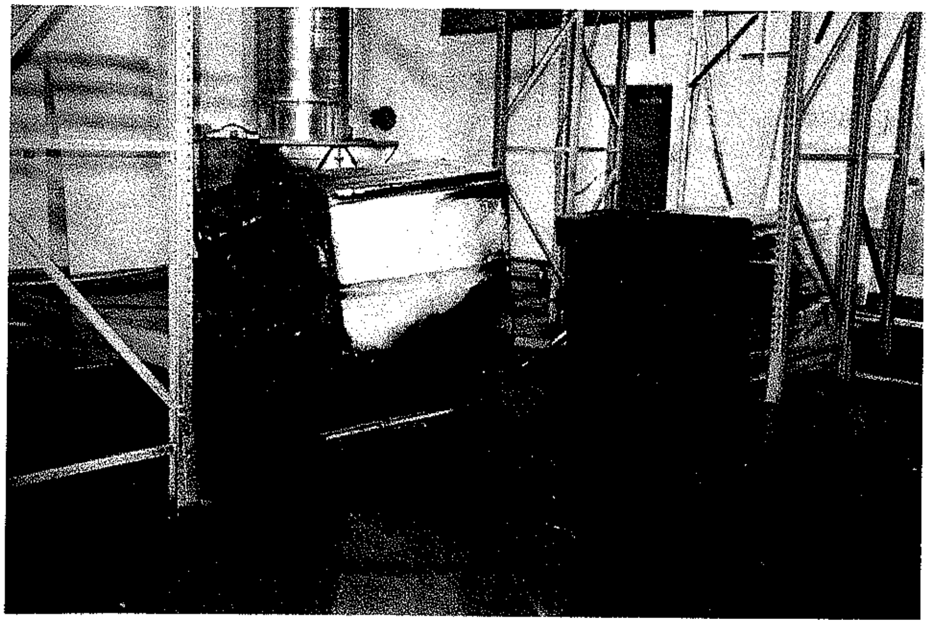

Figure 12 - Collapse in Test #4, Unit #14

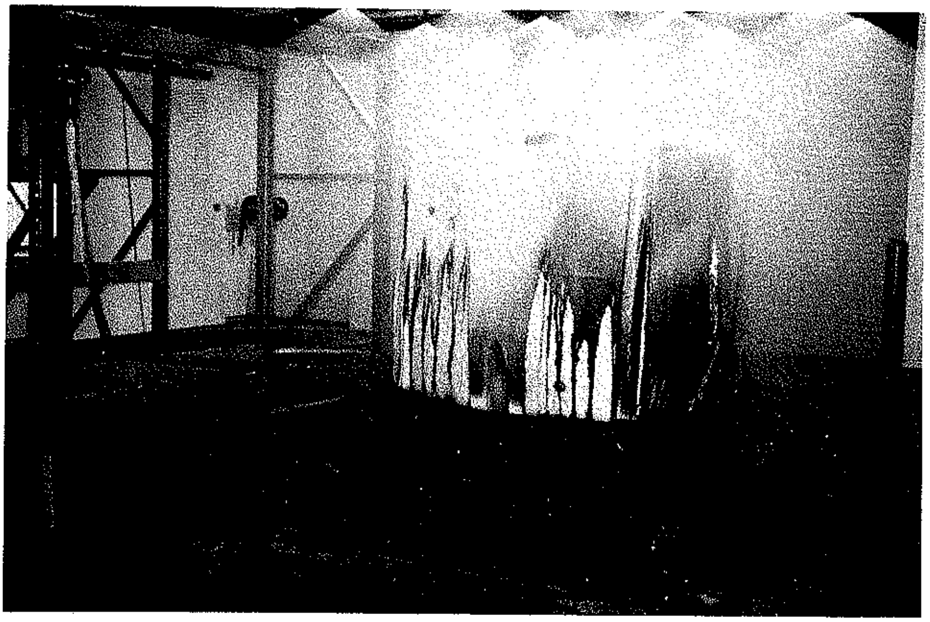

Figure 13 - Unit #14 after tilting in Test #5

similar to Test 4 in terms of structural performance. The unit tilted at 3:00 into the test. At 5:00, the unit was leaning heavily; the front of the base had collapsed. This occurred at about the same time as the fire started to recede. At about 7:00, the back base of the unit collapsed so that the unit stood in a relatively even position (Figure 13). No breach of the container occurred.

The heat release characteristics in this test after water on were about half of those observed in the previous test. Unlike in Test 4, there was no growing fire where the container contributed fuel.

The characteristics of the structural integrity of this unit would likely result in the creation of obstructed flue spaces if multiple units were stacked side-to-side. The tipping characteristic would likely result in a unit leaning against an adjacent unit so that suppression water would be prevented from cooling the shielded sides of the containers. This is an undesirable characteristic.

The one advantage of the increased water application observed in this test was the shorter time for the fuel to spill out of the pan (approximately four minutes) and the resulting intensity of the floor spill fire. This indicates that more suppression water reached down to the base of the unit, compared to Test 4 where the pan did not overflow.

Unit 17

Unit 17 was evaluated in Test 6 in a single unit array with 0.3 gpm/ft^2 (12 mm/min) water application rate. This unit is a single layer rotomold, all plastic, square container, similar to Unit 14 in construction type. The objective was to compare the performance in this test with the results of Test 5 to determine the impact of protecting a one-high all plastic unit with a lower application rate.

The convective heat release at water on was 450 kW (1.2 MW total RHR). After an initial period (1.5-2 minutes) of reduced convective heat release, the heat release started to increase. Between 7 and 8 minutes into the test, the fire intensity increased (due to fuel spilling out of the pan) and the unit tipped as a result of structural weakening of the base (Figure 14).

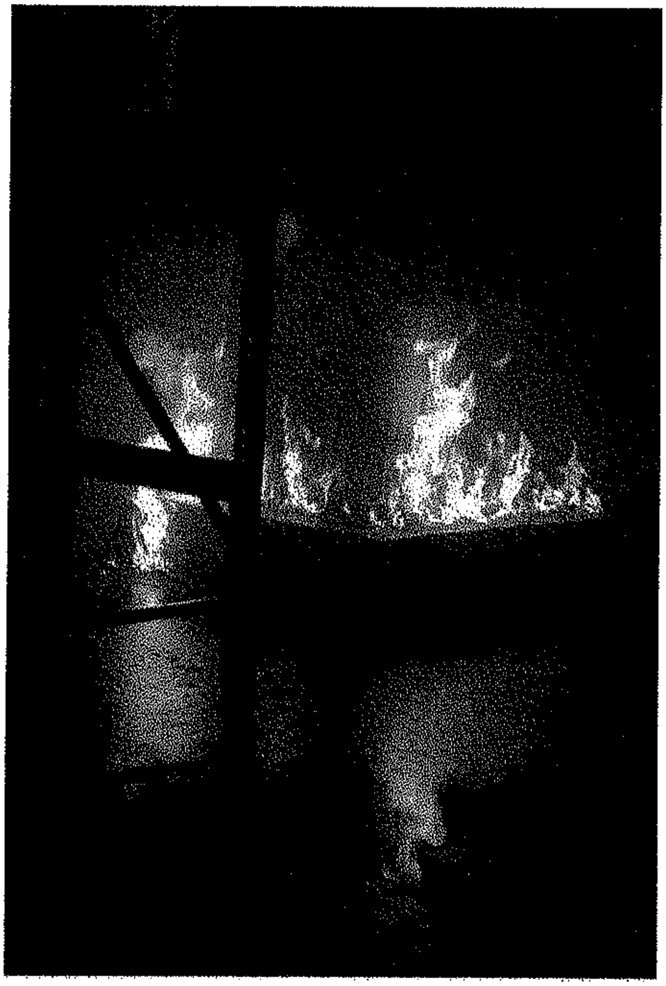

Figure 14 - Tilting of Unit #17 in Test #6

Just prior to the fire spilling out of the pan and the unit tipping, the convective heat release was 1.0 MW (2.4 MW total RHR). The fire then receded, with a persistent fire under the base of the unit. At about 20 minutes, the fire was manually extinguished. No breach of the container was observed. A post-test inspection of the unit indicated that the plastic base had melted and there was some melting of the lower half of the bottle (Figure 14).

The lower application rate in this test was unable to prevent structural instability of the unit. As in Test 5, this structural instability would be undesirable in a large array where shielded areas could continue to burn. The structural instability and flame attachment at the base of Unit 17 was observed in the previous failure mechanism tests. The base of the unit melted and started to lean at about 5 minutes into the test. This indicates that the 0.3 gpm/ft^2 (12 mm/min) water application delayed structural instability for only three additional minutes.

Unit 11

Unit 11 was evaluated in Test 9. A two-high array was evaluated with 0.6 gpm/ft^2 (24 mm/min) protection. Unit 11 is a multiple layer rotomold container. In the failure mechanism tests, it resisted breaching for 1106 seconds. However, because of the multiple plastic layers, there was significant fuel contribution from the container itself. This test was designed to determine if the suppression system could control the potential contribution from the containers. Because of concerns that the unit might collapse, the bottle in the upper unit was removed. This reduced the weight on the lower unit. The outer structural unit remained in place above the lower unit.

The convective rate of heat release at water on was 450 kW (900 kW total RHR). During the initial two minutes of water application, there was no significant burning of the unit. Between three and four minutes into the test, flames began to attach to the plastic unit. The fire started to grow, coincident with the fuel spilling out of the pan (5:50). There was a resulting period of 2-3 minutes when there was a steady state fire, with a convective RHR of 450 kW (2.5 MW total RHR). The fire peaked at eight minutes into the test, with a maximum convective RHR of 1 MW (4.4 MW total RHR). After this fire growth spike, the pool fire receded, and the remaining burning was a plastic fire. As in the previous failure mechanism tests, a solid mass of plastic formed over the pan area (Figure 15). The suppression system was able to control this fire. Small fires persisted on the lower unit for a period of about 25 minutes until three small fires were manually extinguished. There was no breach of the lower liquid bottle or in the upper unit.

There were positive and negative results from this test. A steady state plastic fire was clearly established in this test. The suppression system was able to hold the fire growth in check to the lower unit albeit at a relatively high heat release rate. A fire growth spike was observed when the liquid fuel burned out. It is unclear whether this suppression system would be able to control a similar fire in a larger array, i.e., with adjacent units exposed by a liquid pool fire.

One negative factor observed in this test was the inability of suppression water to flow down the inside of the upper unit, discharge out the bottom, and cool the lower unit. This action was observed in Tests 1 and 3 (see Figure 11). Unit 11 has a solid bottom, and suppression water discharged from the top unit only from the doghouse area (see Figure 16).

DISCUSSION

The results of these suppression scoping tests must be evaluated considering several limitations in the test methodology and procedures. The RDD concept has been adopted for the classification of ordinary combustibles and plastics by some insurers. A standard methodology has not been published or adopted outside the insurance industry. The algorithm used for these tests relied on the DETACT thermal response algorithm [8]. Proprietary sprinkler response algorithms are used by other insurers.

The methodology has not been developed for control of flammable/combustible liquid fuel fires, particularly when water suppression is used. If foam were used as the suppression agent, the true impact of the suppression effects might be more readily identified [9]. The current trend in flammable liquid protection is to attempt to use water in conjunction with other

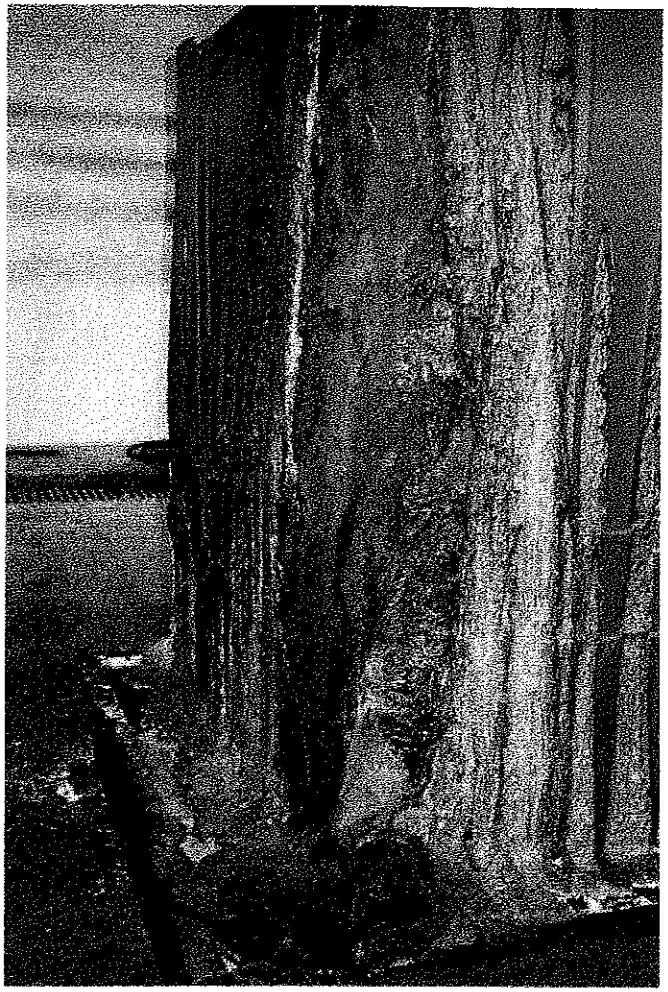

Figure 15 - Solid plastic over pool area, Test #9

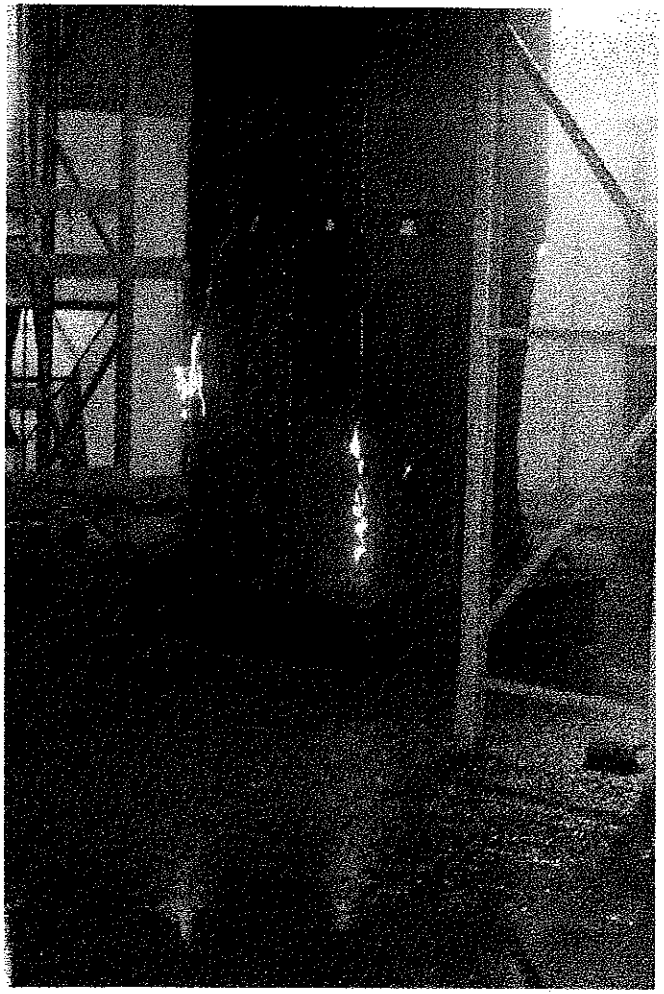

Figure 16 - Water discharging from upper doghouse area only,Test #9

protection features. Any generalized approach to use water RDD with flammable liquid spill protection, e.g., for commodity classification, would require modification of the setup (e.g., containment versus free flowing spill) and assessment of the cooling impact and suppression of the container commodity alone. Overall this would require a substantial experimental effort. While baseline testing was proposed for this test series (e.g., pool fire alone with a noncombustible "dummy" commodity), the timing and budget prevented this experimentation from being completed.

Clearly, the operation of the suppression system at one minute after ignition and the containment of the spill limit the general applicability of the results. Using the RHR data from Test 1 and the DETACT model, the impact on sprinkler response was estimated for various protection scenarios. Estimates of sprinkler actuation times ranging from 25 seconds (ESFR sprinkler in 20 ft (6.1 m) high warehouse) to 147 seconds (165°F (74°C), 300 RTI sprinkler in 30 ft (9.1 m) high warehouse) were determined. The data from these tests might be related to those different scenarios. Otherwise, the data are limited by the unknown impact of a larger spill/fire involvement prior to activation of 286°F (141°C) sprinklers in a 30 ft (9.1 m) high warehouse.

The heat release data are consistent for the initial 60 seconds of burn time: the convective RHR is on the order of 500 kW while the total RHR is on the order of 1.0 MW. Test 3 probably represents the best situation in this test series where there is little if any contribution from the container. Convective cooling by the water spray was observed in many of the tests.

Temperatures in the pool fire near the container package were not significantly reduced until the fuel spill fire was removed or exhausted.

Several design issues were identified. The all-plastic, single layer rotational molded units exhibited structural instability even with application of suppression system water. This is an undesirable attribute that might be addressed in design of the units. Shielding of fire at the top of the lower unit in the two-high tests could create potential problems. This might be mitigated in designs where suppression water can leak down through the bottom of upper containers.

However, just as suppression water can filter down through a unit, so can fuel if there is a breach. The advantages and disadvantages of a "leaky" outer container remain unclear.

SUMMARY AND CONCLUSIONS

Given the limitations of the test methodology and procedures, the results provide valuable insight on potential successful and unsuccessful protection scenarios. For the two-high scenario where the suppression system is not activated early (Test 1), failure times are likely to be similar to those observed in the failure mechanism tests. The situation with two high fuel-laden storage may be worse if a fill cap on the lower unit burns and fuel becomes involved, exposing the unit directly above.

It is unlikely that unprotected blow molded units stacked two high can be adequately protected with water only suppression systems (Test 2). Protection designs might be developed which could be used to overcome the inherent rapid failure time of blowmolded units (Test 7). The data from these tests indicate that steel-encapsulated blowmolded units might be protected in a warehouse scenario (Test 3).

The single layer, rotational molded all-plastic units all exhibited weakening of the base structural support system (Tests 4-6). This weakening caused the units to tilt or become unstable. In a larger array, with adjacent units, it is likely that shielded flue spaces will be created. This would prevent cooling to the containers, which is likely to ultimately result in multiple container failures. The structural support of these all-plastic units need to be reassessed in light of these findings.

The results from Test 8 with a rotational molded unit with steel supporting structure indicated that these units might be protected when stored two-high. There was a steady increase in the total rate of heat release, but there did not appear to be significant contribution from the plastic container based on a post-test inspection of the unit.

The results of the rotational molded unit with multiple layers of outer plastic (Test 9) are more difficult to interpret. While there was no breach of the container, there was clearly involvement of plastic from the lower unit. The fire was ultimately controlled when the spill fire receded. There were no breaches, and there was little if any contribution from the top unit. A multiple array would have to be tested to see if the fuel contribution, combined with a longer duration spill exposure fire, would overcome the suppression effects.

The shielding from suppression water of the upper and lower units in a two high array is an undesirable characteristic. This may result in ignition of fuel in the top of the container. This might be overcome by rapid suppression, i.e., before the top ignites, or changes in container design. These changes could include a change in design/material of the top of the container or allowance that suppression water can flow down from the upper container.

RECOMMENDATIONS

There are several alternatives for continued testing and evaluation:

a) Continue with RDD scoping type tests;
b) Test "best case" IBCs in a larger multiple unit array with an actual suppression system; or
c) Evaluate specific units with actual stored liquids and protection designs.

Continued RDD testing is probably not worthwhile unless a complete experimentation program is developed to address the limitations identified in these experiments. These issues include the impact and control/suppression of the exposing pool fire with water suppression; standardization of the test procedure, including sprinkler actuation algorithm; and development of correlations of RDD with ADD, i.e., what actual sprinkler application rates are required. While this approach has the potential to provide the best long term scientific basis for generalized commodity classification, it would require a substantial financial and time commitment.

An intermediate approach would be to continue tests using the units identified in these tests as having the greatest chance of success in a full scale scenario. The units would be tested in a multiple unit array under a 30 ft (9.1 m) ceiling with an actual water sprinkler system. As a "first cut," the water sprinkler system should be designed for an application rate of 50 percent greater than that used in these tests. The ignition scenario should be a spill or running fuel fire. A fallback would be the use of a foam suppression system.

A third alternative is to test specific units in a simulated warehouse scenario with a stored commodity, which is less hazardous than a Class IB nonmiscible combustible or flammable liquid. In particular, alcohols are commonly stored in IBCs. The resulting threat may not be as challenging as a Class IB nonmiscible liquid. Other alternative materials include resins and volatile compounds having flash points but a relatively low total volatile content.

Transition to larger arrays should include longer duration scenarios combined with an spill scenario which is not limited to a pan configuration. While the pan confines the fire so that flames continue to impinge on the unit, the true cooling effects and dispersion characteristics from the suppression agent cannot be identified. Issues which will be encountered with an unconfined spill include larger area of sprinkler operation/discharge and the potential for an overall larger pool fire. At that point, other mitigation effects, e.g., drainage, might have to be considered. Foam fire suppression also remains as a viable alternative.

REFERENCES

1. Scheffey, J.L., "International Intermediate Bulk Container Fire Test Project, Scoping Tests," National Fire Protection Research Foundation Technical Report, Quincy, MA, September 1996.

2. Yao, C., "The Development and Application of the ESFR Sprinkler System," Factory Mutual Research Corporation, Norwood, MA, March 1988.

3. Yao, C., "The Development of the ESFR Sprinkler System," *Fire Safety Journal*, **14**, 1988, pp. 65-73.

4. Swedish National Testing and Research Institute, "Commodity Classification – A More Objective and Applicable Methodology," SP Report 1993:70, Swedish National Testing and Research Institute, Sweden, 1993.

5. Carey, W.M., "National Wholesale/Retail Occupancy Fire Research Project: Task 1 – Flammable Liquids," Technical Report, National Fire Protection Research Foundation, Quincy, MA March 1993.

6. Newman, R.M., Fitzgerald, P.M., and Young, J.R., "Fire Protection of Drum Storage Using 'Light Water' Brand AFFF in a Closed Head Sprinkler System," FMRC Technical Report Serial 22464, Factory Mutual Research Corporation, Norwood, MA, March 1975.

7. Underwriters Laboratories Inc., "International Foam Water Sprinkler Research Project: Task 4 – Palletized Storage Fire Tests 1 through 13," Technical Report 91NK14873/NC987, prepared for the National Fire Protection Association, Underwriters Laboratories Inc., Northbrook, IL, February 1992.

8. Evans, D.D., and Stroup, D.W., "Methods to Calculate the Response Time of Heat and Smoke Detectors Installed Below Large Unobstructed Ceilings," *Fire Technology*, **22** (1), 1986, pp. 54-65.

9. Hill, J.P., "International Foam Water Sprinkler Research Project: Task 3 – Range Finding Tests," Technical Report OTOR6.RR, prepared for the National Fire Protection Research Foundation, Factory Mutual Research Corporation, Norwood, MA, July 1991.

Appendix A – Test Observations

Table A1. Test Configuration

Test	Water Level	Free Board*	Cinder Block Height	IBC Water Fill Level
1	7.5 in. (19 cm)	3.75 in. (9.5 cm)	7.5 in. (19 cm)	bottom of neck
2	8.25 in. (21 cm)	3.0 in. (7.6 cm)	12.5 in. (32 cm)	1 in. (2.5 cm) below top of middle level
3	9.0 in. (23 cm)	2.25 in. (5.7 cm)	12.5 in. (32 cm)	bottom of neck
4	9.0 in. (23 cm)	2.25 in. (5.7 cm)	12.5 in. (32 cm)	1.5 in. (3.8 cm) below top of neck
5	9.0 in. (23 cm)	2.25 in. (5.7 cm)	12.5 in. (32 cm)	1.5 in. (3.8 cm) below top of neck
6	9.0 in. (23 cm)	2.25 in. (5.7 cm)	12.5 in. (32 cm)	bottom of neck
7	9.0 in. (23 cm)	2.25 in. (5.7 cm)	12.5 in. (32 cm)	1 in. (2.5 cm) below top of middle level
8	9.0 in. (23 cm)	2.25 in. (5.7 cm)	7.5 in. (19 cm)	5 in. (13 cm) below bottom of neck
9	7.5 in. (19 cm)	3.75 in. (9.5 cm)	7.5 in. (19 cm)	bottom of neck

* Distance between the top of the pan and the level of the heptane.

TEST OBSERVATIONS

Test No. 1
Sample Unit 5
Stack Height 2
Test Date: July 30, 1996
Data File: 07309606
Water Density (gpm/ft^2) 0.6

Time	Observation
0:00	Test Started
0:59	Burning @ top unit
2:20	Lower doghouse door open
5:30	Flaming Between IBCs
6:50	Top of lower IBC well involved with fire
7:20	Top of upper IBC beginning to burn
7:44	Top of lower IBC sagging down
10:00	Water on (manually initiated)
10:50	Leakage out of lower unit (from sprinkler water)
14:00	Leakage out of the lower unit at weap hole

Post Test Note: Breach of lower container near bottom

Test No. 2
Sample Unit 1
Stack Height 2
Test Date: July 30, 1996
Data File: 07309613
Water Density (gpm/ft^2) 0.6

Time	Observation
0:00	Test Started
0:30	Flame height 2/3 up the units
1:00	Water on
1:49	No burning of upper unit
2:00	Flame attachment to lower unit front face
3:41	Breach observed
5:00	Pool fire extended to floor
7:00	Hose used to control floor fire

Post Test Note: Breach of lower unit on side where metal cage touched container.

Test No. 3

Sample Unit 9

Stack Height 2

Test Date: July 31, 1996

Data File: 07319602

Water Density (gpm/ft^2) 0.6

Time	Observation
0:00	Test Started
1:00	Water on
3:20	Water from spout hole (from sprinkler water)
4:00	Limited fire spread on floor
8:03	More fire on floor
8:50	Fire receding
9:50	Fire Out

Post Test Note: No breach

Test No. 4

Sample Unit 14

Stack Height 2

Test Date: July 31, 1996

Data File: 07319603

Water Density (gpm/ft^2) 0.6

Time	Observation
0:00	Test Started
1:00	Water on
2:00	Lower unit doghouse door fell off
2:45	Buckling at front, left corner
4:00	Front face burning
5:00	Flame attachment near legs; base well involved
5:20	Upper IBC tipped over
5:30	Fire extinguished

Post Test Note: No breach

Test No. 5
Sample Unit 14
Stack Height 1

Test Date: August 1, 1996
Data File: 08019601
Water Density (gpm/ft^2) 0.6

Time	Observation
0:00	Test Started
1:00	Water on
2:00	Door over doghouse fell off
3:00	Front base of IBC bowing in
4:00	Limited flame spread to floor; increase in fire intensity
5:00	Flame attachment to front left
5:00	Pool fire starting to die down
5:40	IBC settled into a crooked position
7:00	IBC settled to approximately an even position
8:00	Small fires - burned until 11:00

Post Test Note: No breach

Test No. 6
Sample Unit 17
Stack Height 1

Test Date: August 1, 1996
Data File: 08019602
Water Density (gpm/ft^2) 0.3

Time	Observation
0:00	Test Started
0:30	Flame attachment at base
0:39	Flames extending above the unit
1:00	Water on
2:50	Flames steady just above tank; flames attached to base
4:48	Fire intensity moderately increased as liquid level reached the lip of the pan
7:01	Fire outside of pan on floor
7:17	Fire intensity increased, particular at front face
7:30	Plastic burning on floor
7:40	IBC tipped and settled to a crooked position
8:00	Significant face fire
8:30	Fire receding
10:00	Pan fire receding, fire under IBC
20:50	Initiated manual fire extinguishment; no apparent leaks

Post Test Note: No breach

Test No. 7
Sample Unit 1
Stack Height 1

Test Date: August 1, 1996
Data File: 08019603
Water Density (gpm/ft^2) 0.3

Time	Observation
0:00	Test Started
0:30	Flames above top of unit
0:55	Flame attachment
1:00	Water on
3:30	Steady burning, same as before suppression activation
6:30	Fire growing as fuel/water level approaches pan lips
7:30	Limited burning on floor
8:00	Steady burning
9:30	Increased front face burning; flame height 2 times unit height
10:39	Fire dying down
12:00	Fire out

Post Test Note: No breach

Test No. 8
Sample Unit 5
Stack Height 2

Test Date: August 2, 1996
Data File: 08029602
Water Density (gpm/ft^2) 0.6

Time	Observation
0:00	Test Started
0:30	Flames 3/4 up the array
0:45	Slight flaming at pressure relief device on lower unit
1:00	Water on
2:58	Flaming at lip of pan
4:20	Limited burning on floor; flames well above top of unit
5:35	Fire dying down
6:44	Fire confined to under IBC
8:48	Fire confined to doghouse area
13:45	Fire out

Post Test Note: No breach

Test No. 9
Sample Unit 11
Stack Height 2

Test Date: August 2, 1996
Data File: 08029604
Water Density (gpm/ft^2) 0.6

Time	Observation
0:00	Test Started
1:00	Water on
2:48	Fire attached at lower viewing port
3:30	Fire to pan lip; extended flame height
4:45	Flame height to top of array on left face
5:50	Flame attached at sides; fire out of pan
6:31	Upper unit doghouse door burning
7:46	Flames to top of array
9:00	Fire receding
11:00	Primarily a plastic fire; heptane burned out; top unit untouched except for doghouse
14:00	Fire on back face of lower unit
17:00	Part of the plastic side fell off
17:30	Persistent fires at two corners of lower unit
20:00-35:00	Small persistent fires in lower unit
35:00	Test ended; extinguished 3 small fires with hand line

Post Test Note: No breach

Appendix B – Heat Release and Temperature Data

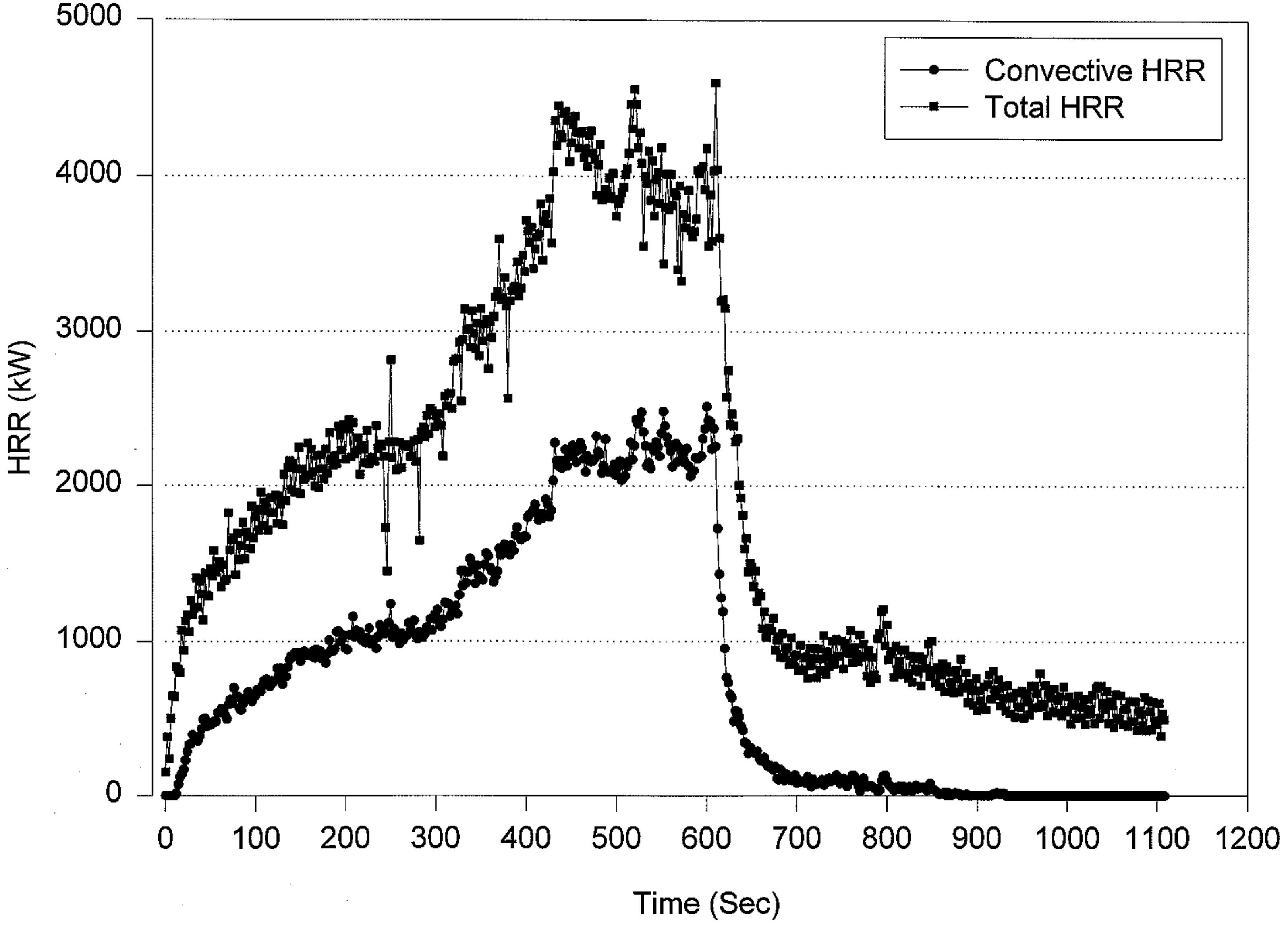

Figure B-1. Convective and Total Heat Release Rate - Test #1

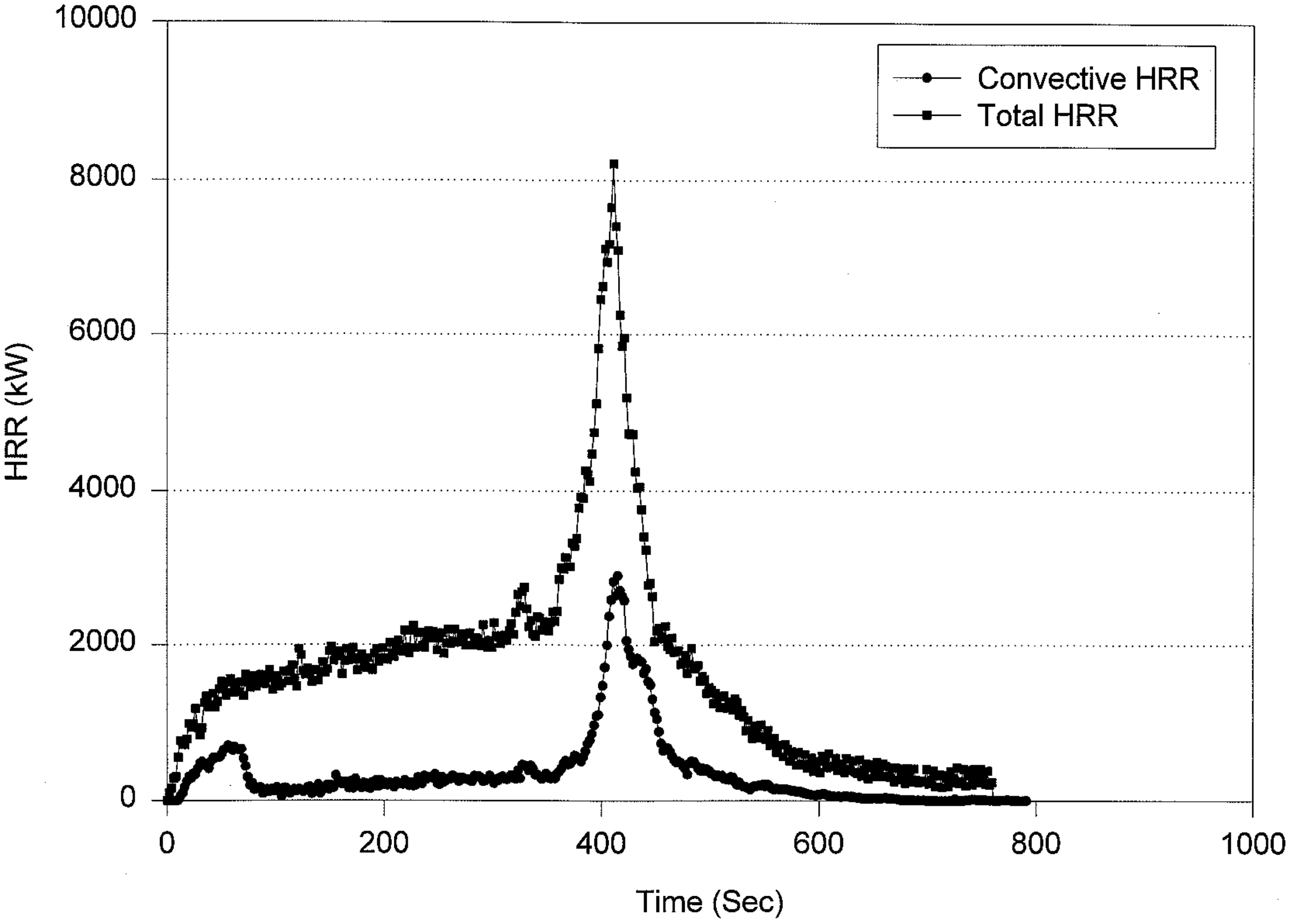

Figure B-2. Convective and Total Heat Release Rates - Test #2

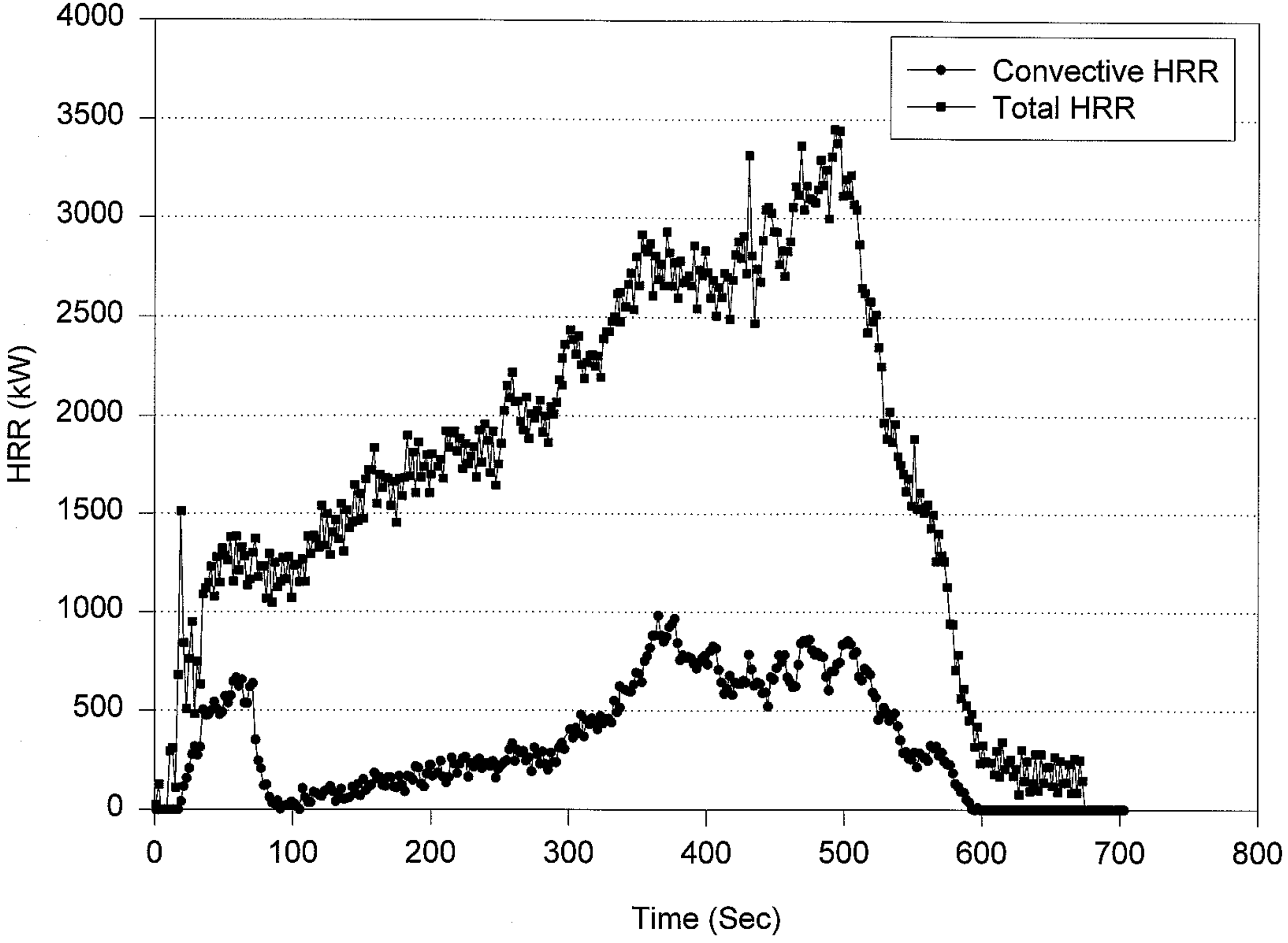

Figure B-3. Convective and Total Heat Release Rate - Test #3

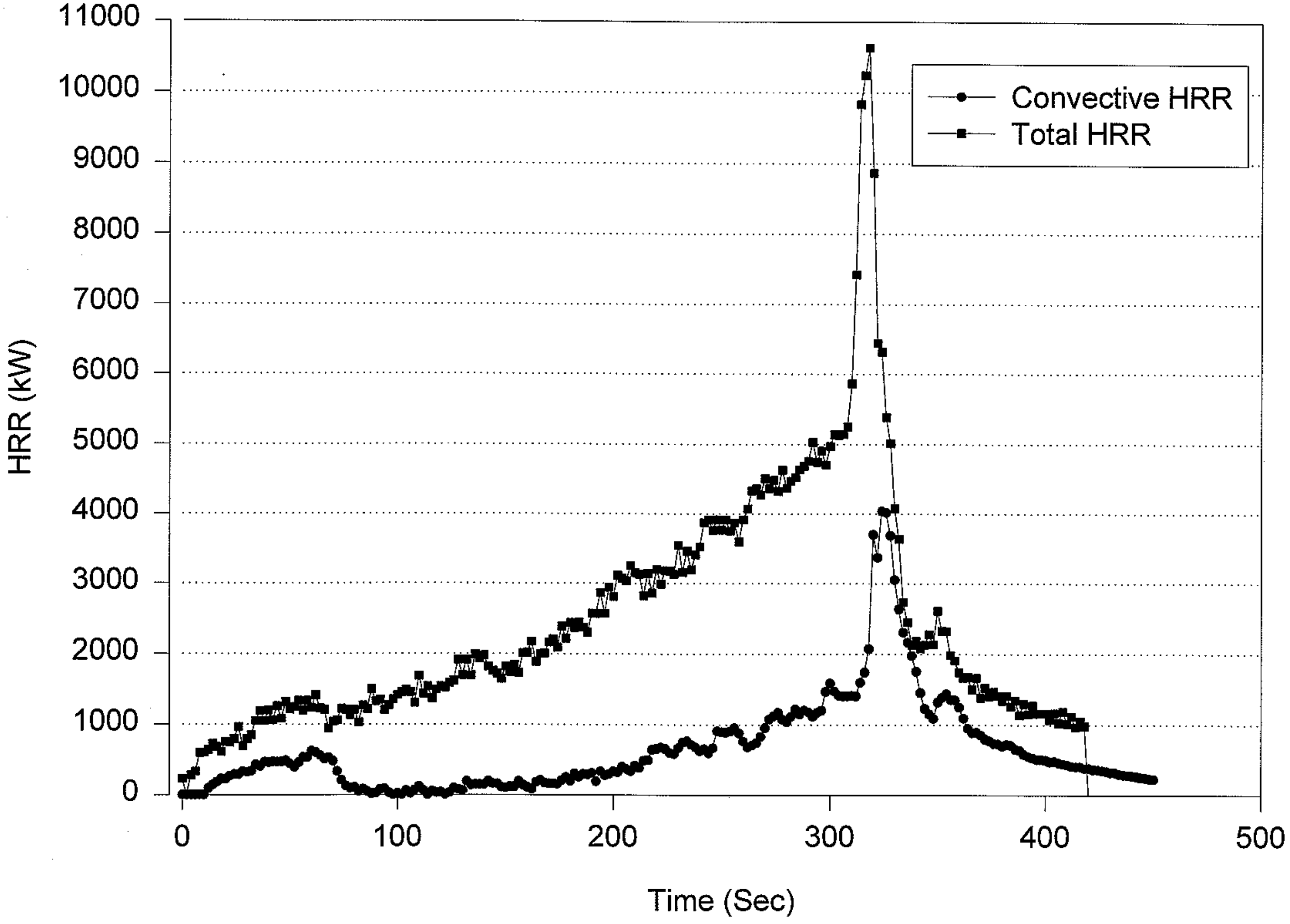

Figure B-4. Convective and Total Heat Release Rate - Test #4

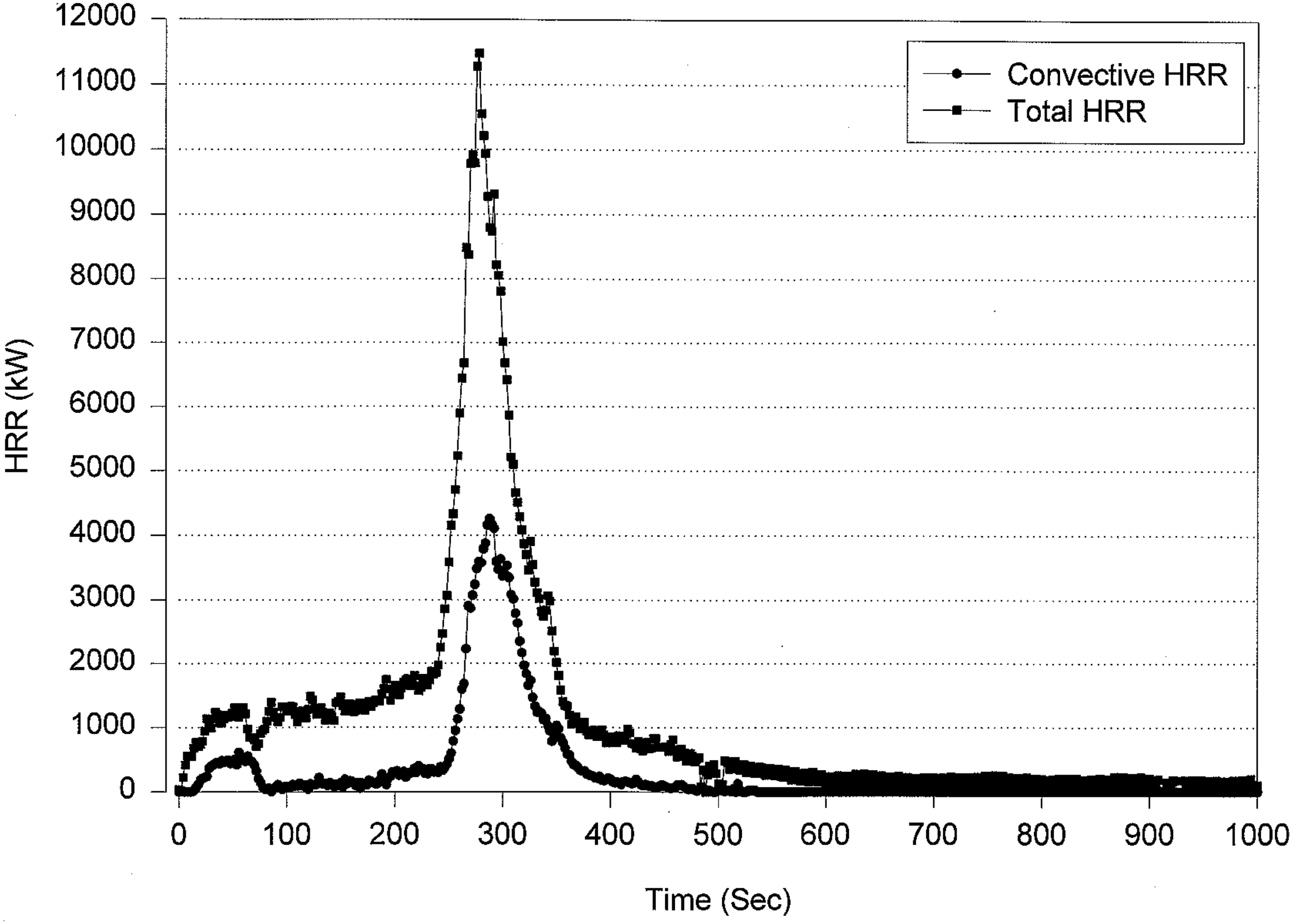

Figure B-5. Convective and Total Heat Release Rate - Test #5

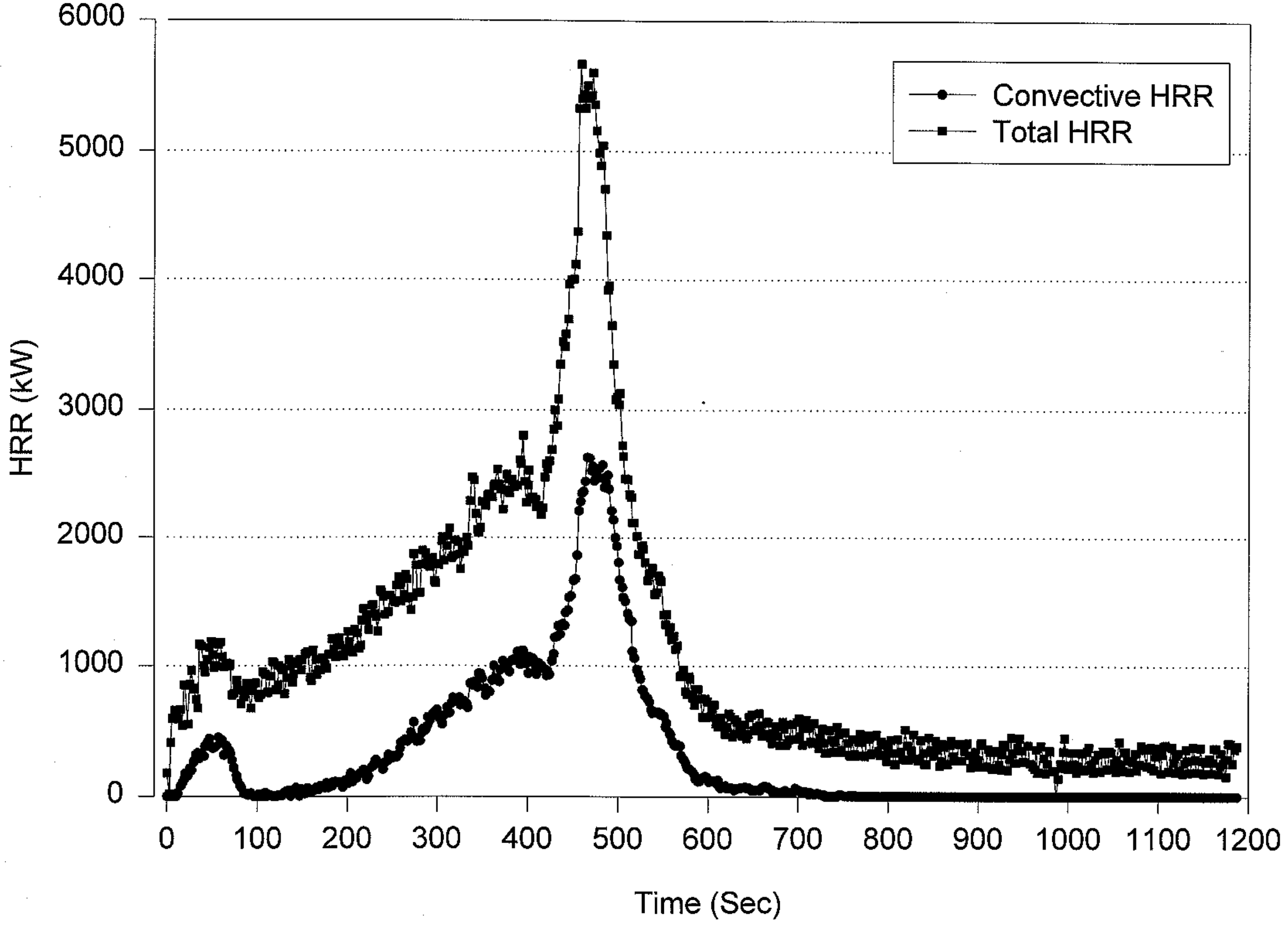

Figure B-6. Convective and Total Heat Release Rate - Test #6

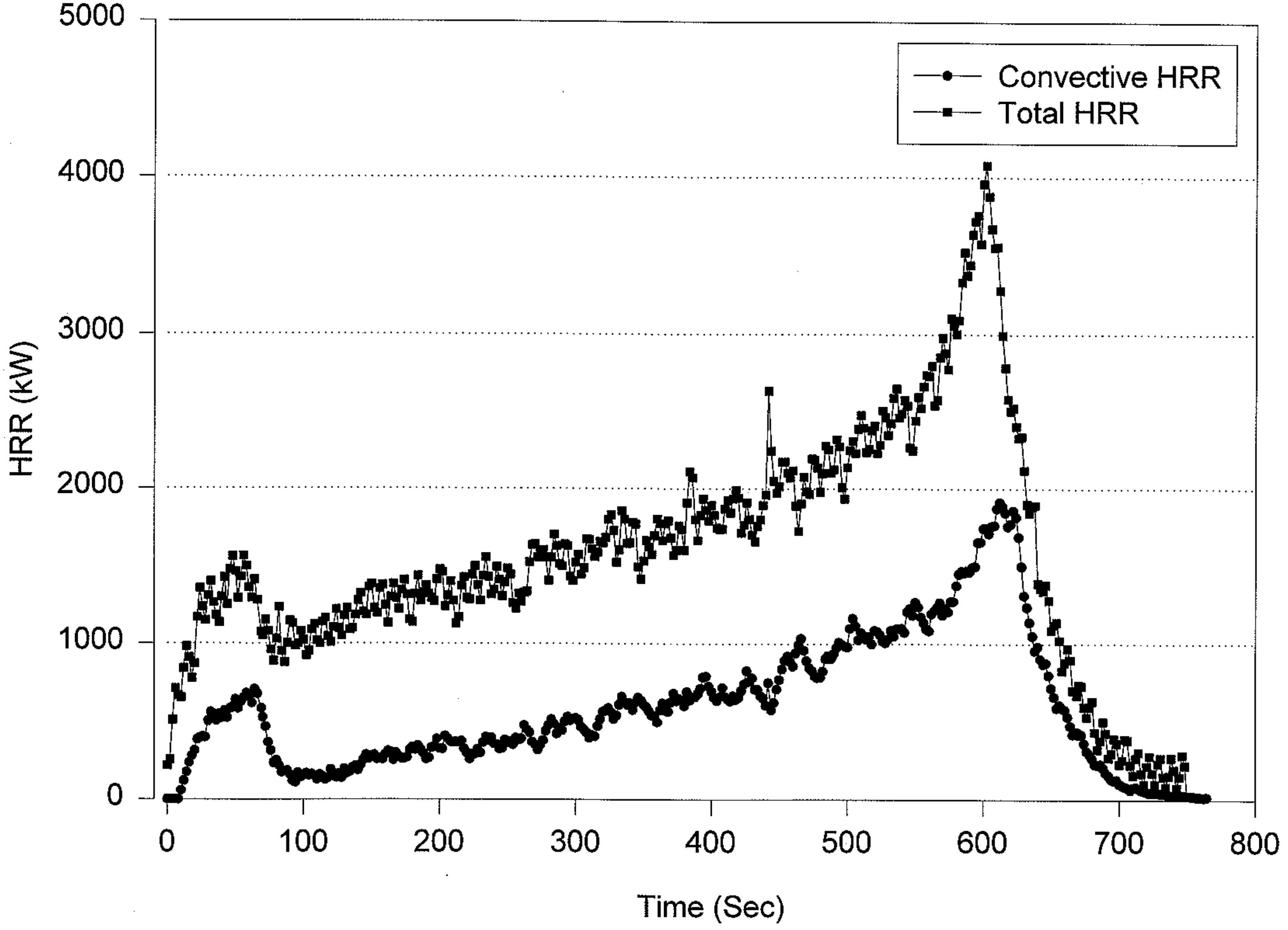

Figure B-7. Convective and Total Heat Release Rate - Test #7

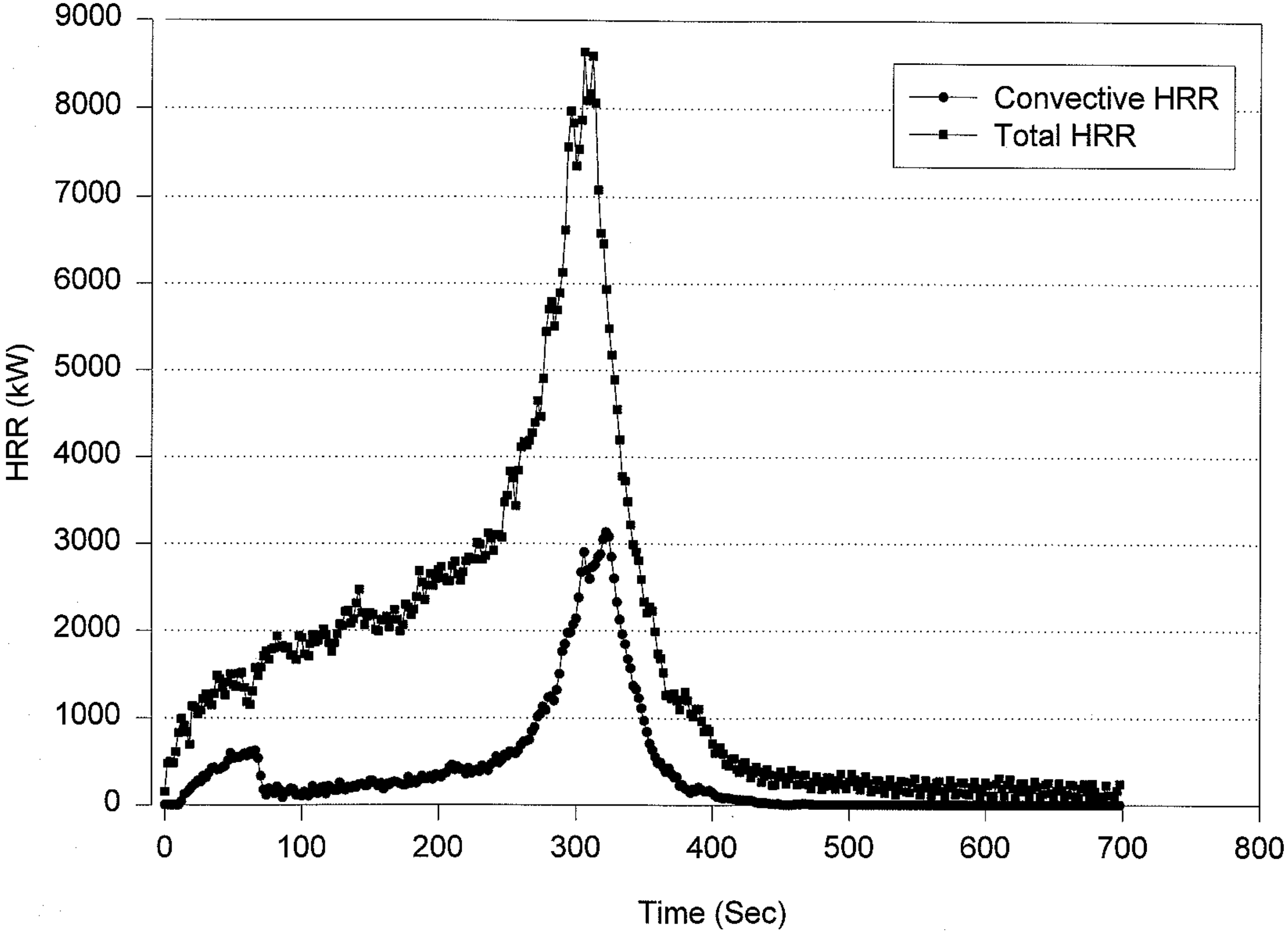

Figure B-8. Convective and Total Heat Release Rate - Test #8

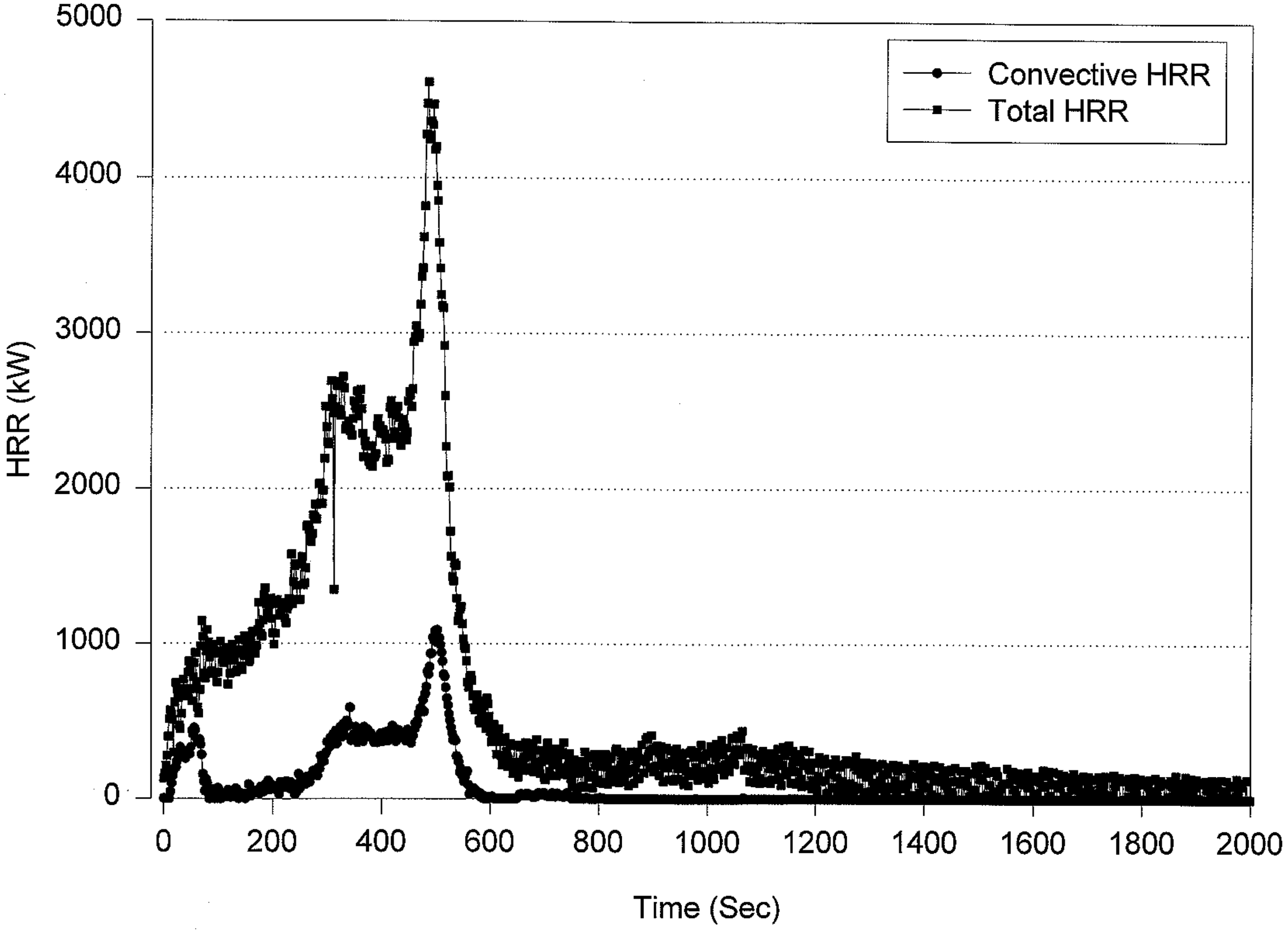

Figure B-9. Convective and Total Heat Release Rate - Test #9

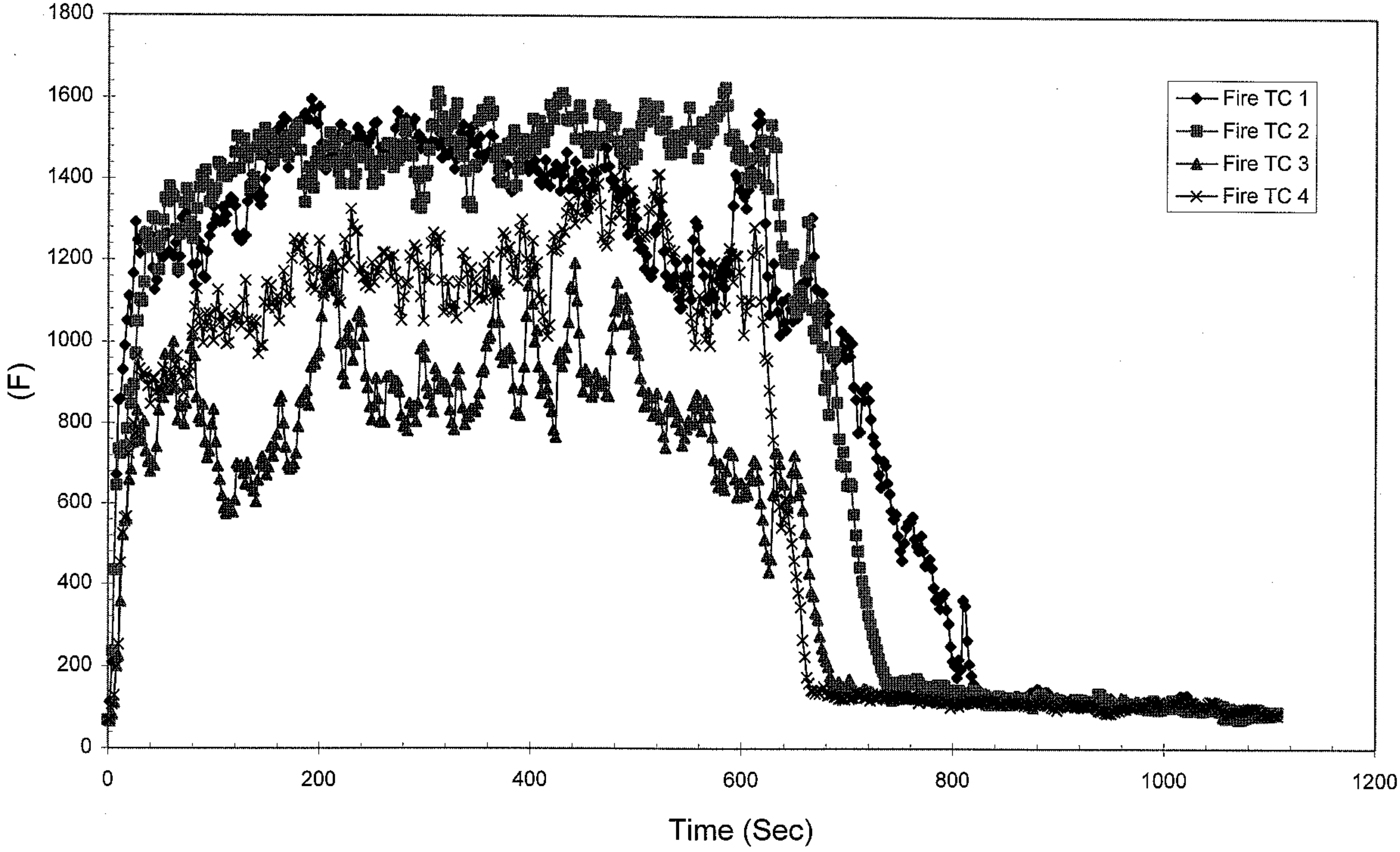

Figure B-10. Temperatures Measured Near Sample - Test #1

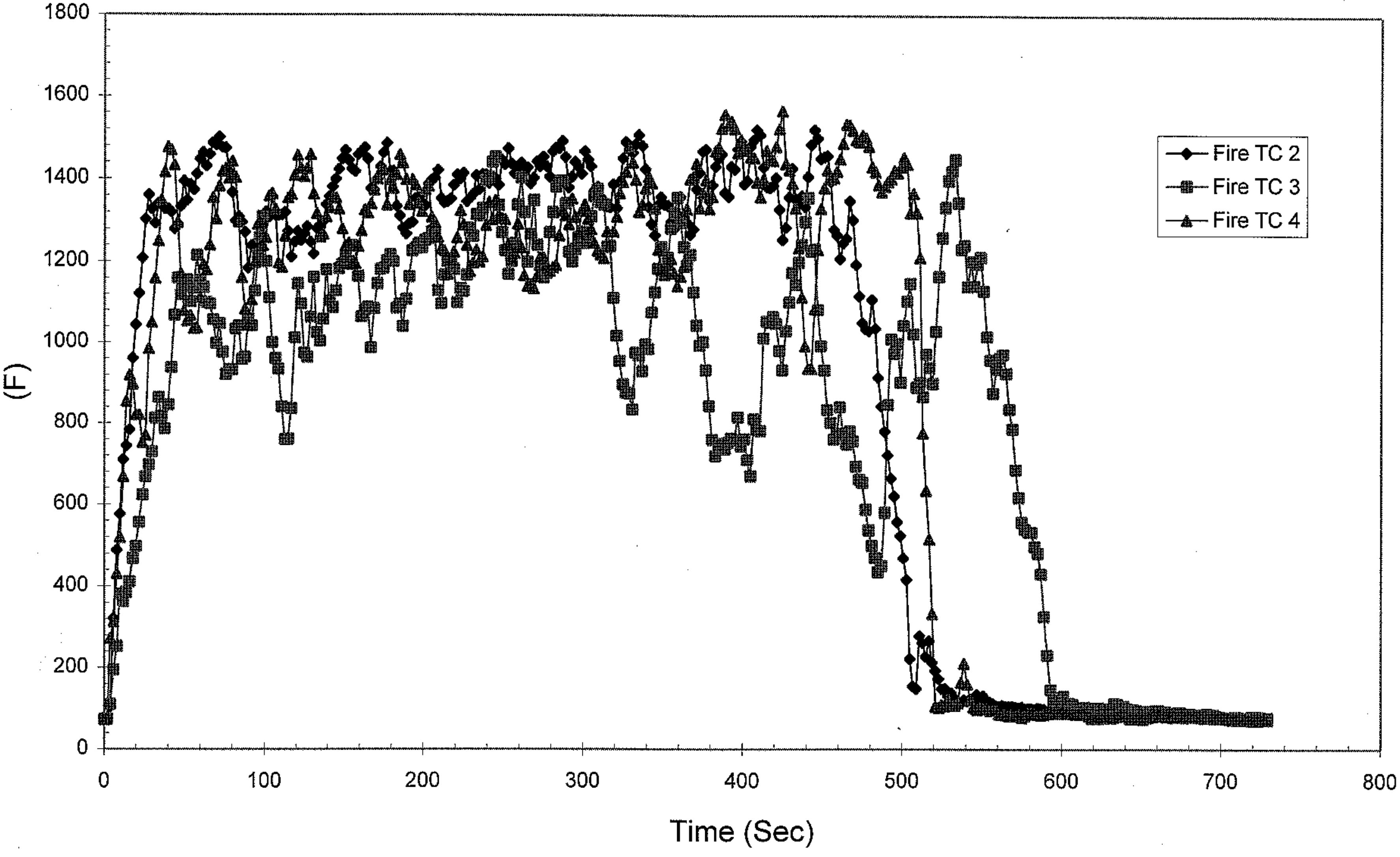

Figure B-11. Temperatures Measured Near Sample - Test #2

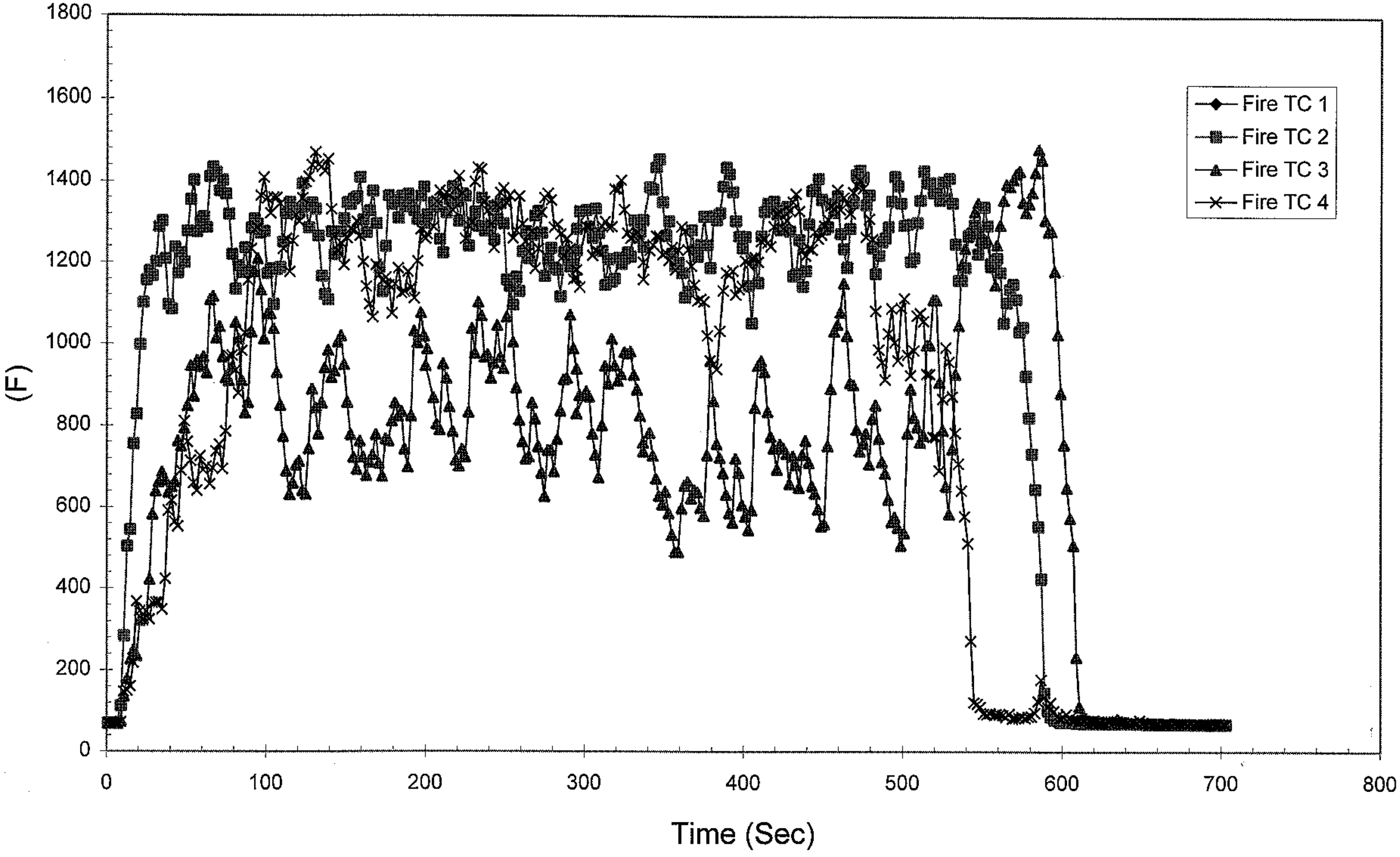

Figure B-12. Temperatures Measured Near Sample - Test #3

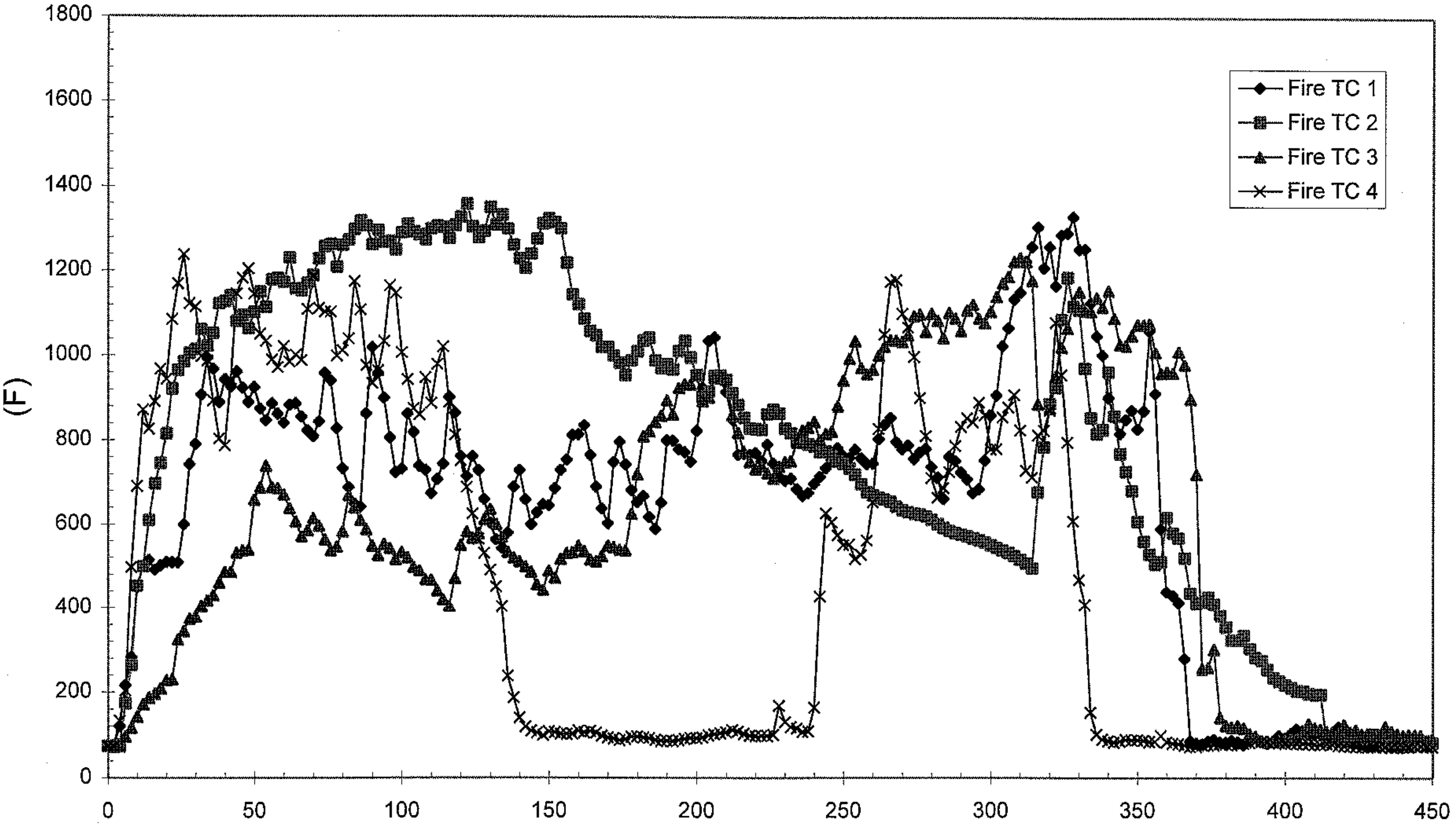

Figure B-13. Temperatures Measured Near Sample - Test #4

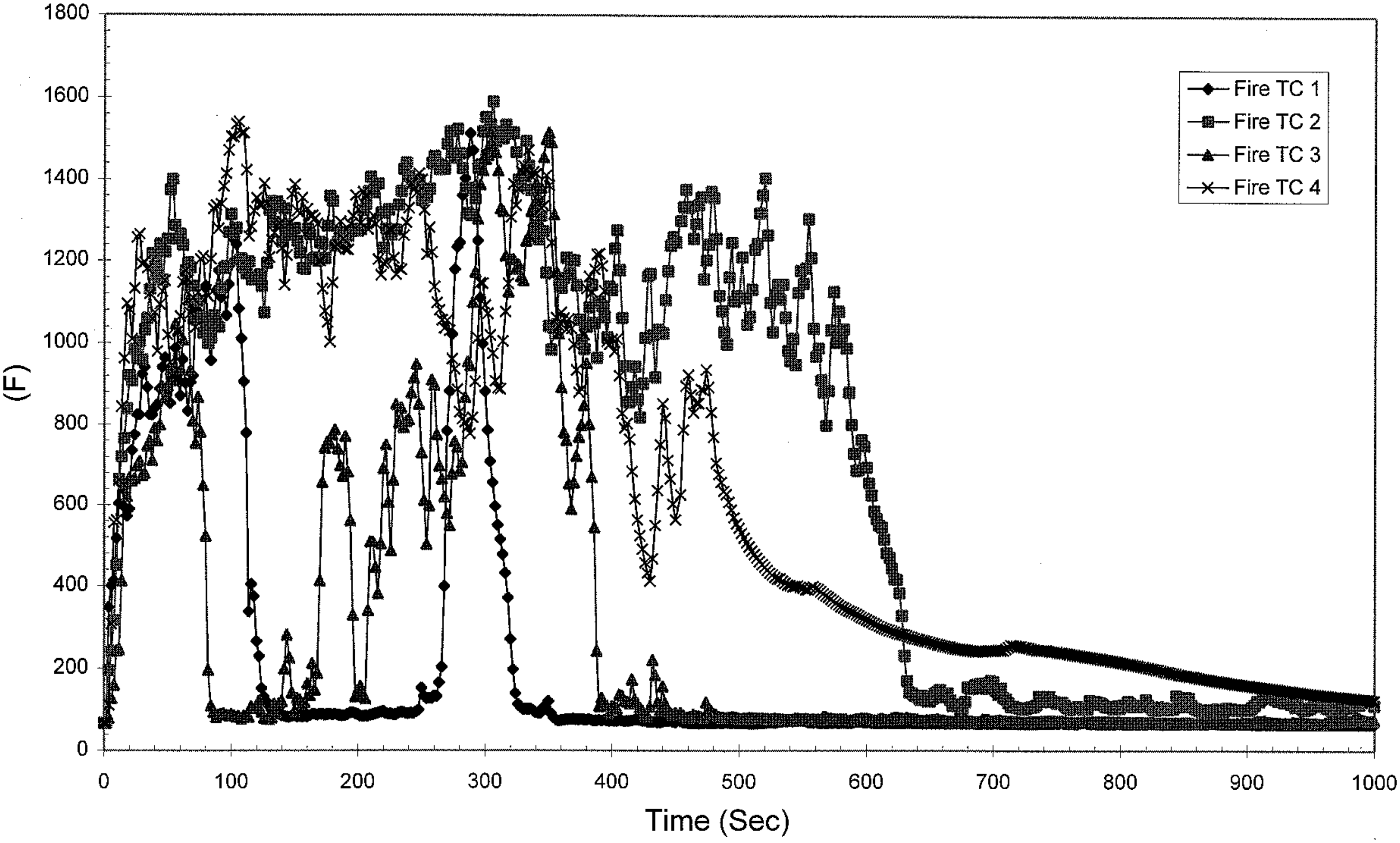

Figure B-14. Temperatures Measured Near Sample - Test #5

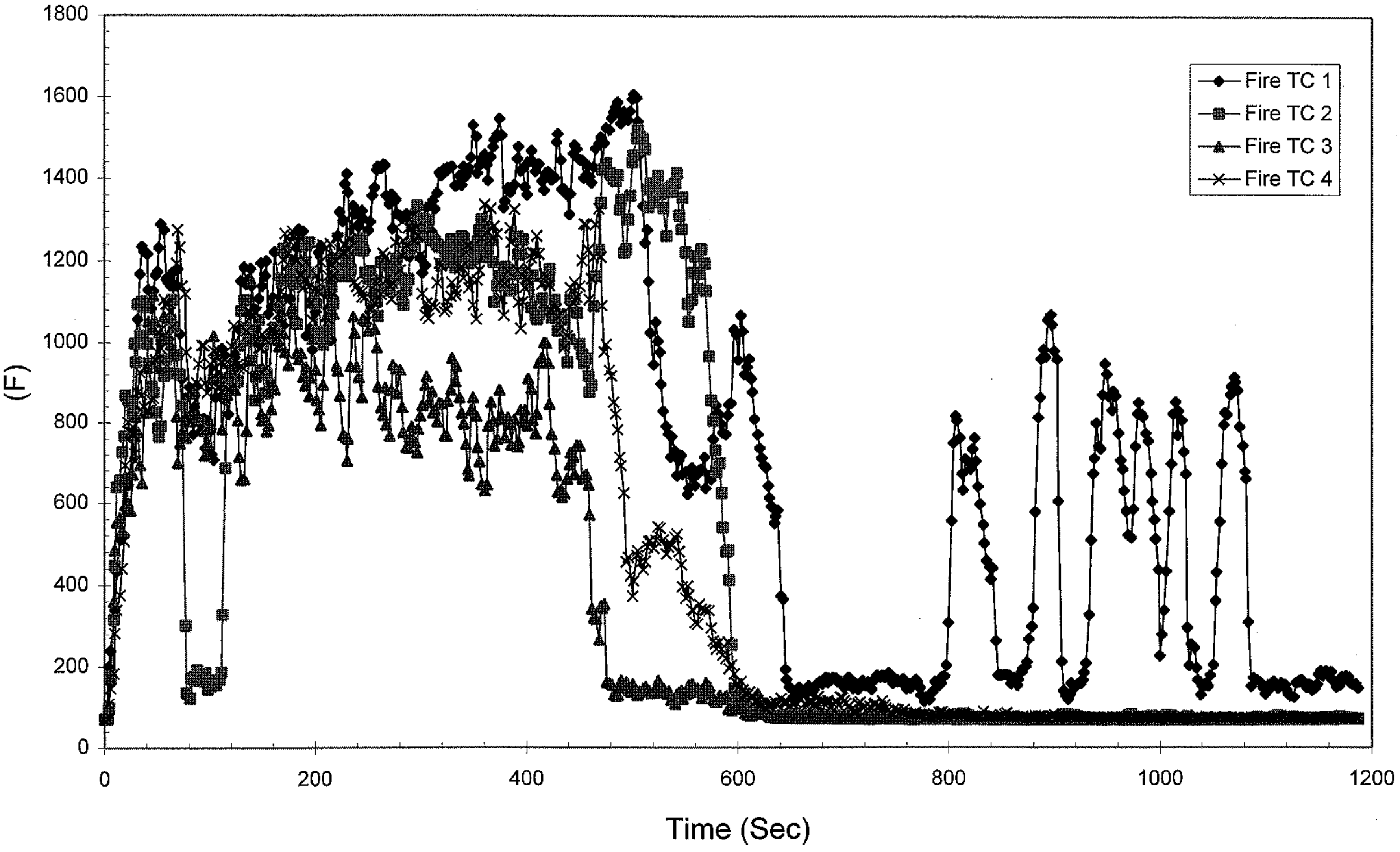

Figure B-15. Temperatures Measured Near Sample - Test #6

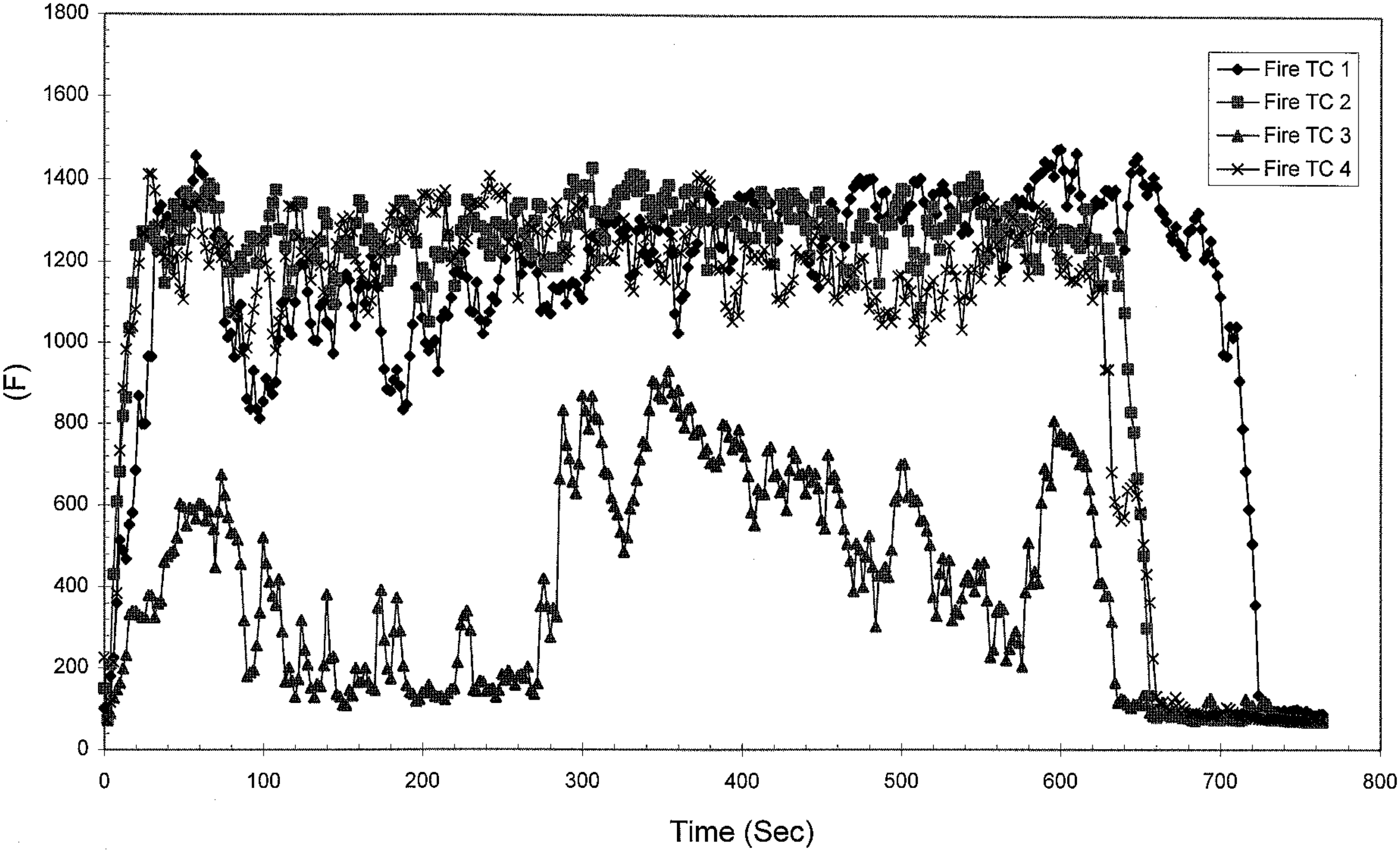

Figure B-16. Temperatures Measured Near Sample - Test #7

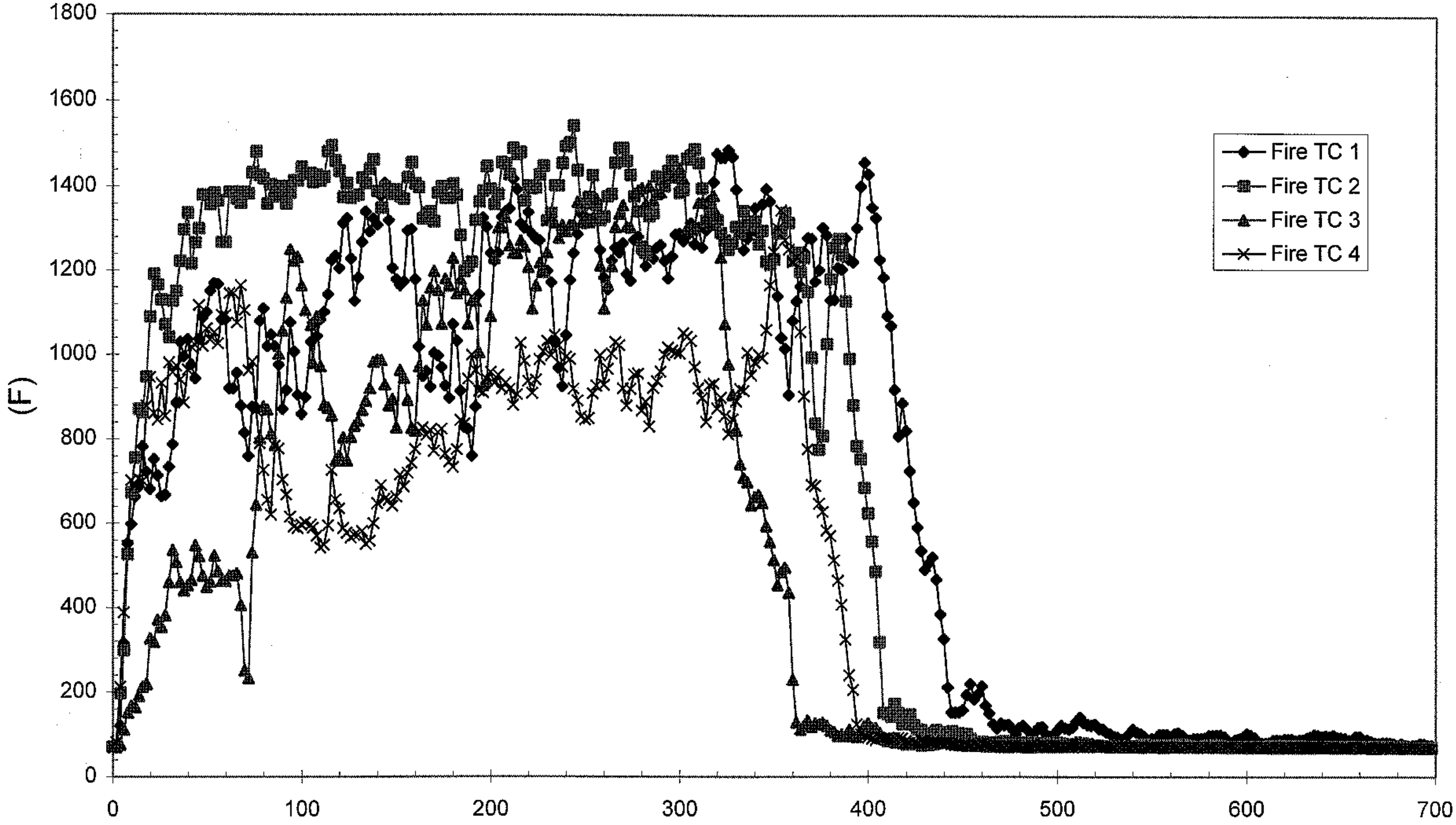

Figure B-17. Temperatures Measured Near Sample - Test #8

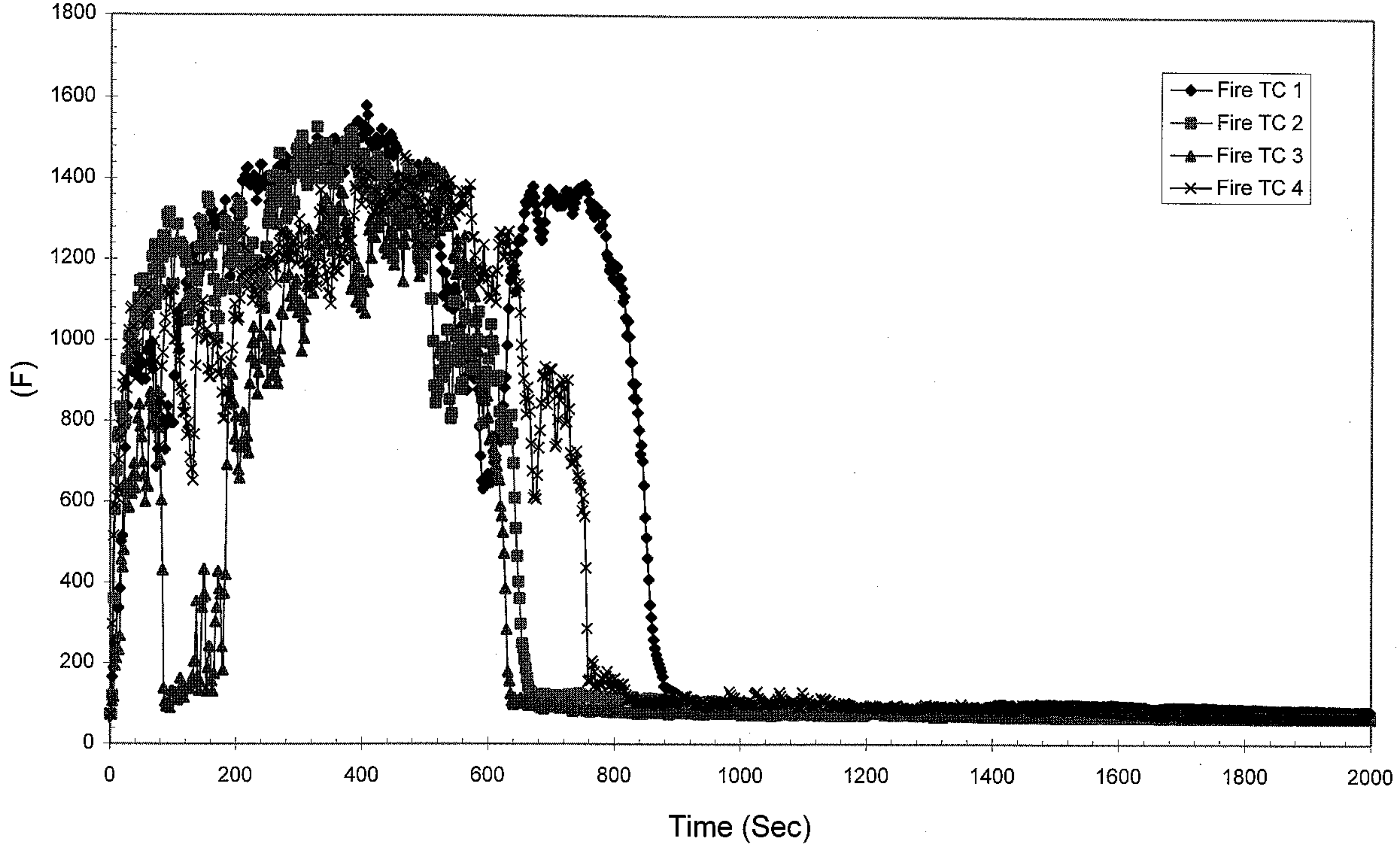

Figure B-18. Temperatures Measured Near Sample - Test #9