

NHTSA - 98 - 3.588-184

197804

**NISTIR 6745**

# **The Effect of Polymer Resin Substitution on the Flammability of a Standardized Automotive Component in Laboratory Tests**

T.J. Ohlemiller  
J.R. Shields

02 OCT 21 AM 10:13  
DEPT OF COMMERCE  
NIST

**NIST**

**National Institute of Standards and Technology**  
Technology Administration, U.S. Department of Commerce

**NISTIR 6745**

# **The Effect of Polymer Resin Substitution on the Flammability of a Standardized Automotive Component in Laboratory Tests**

T.J. Ohlemiller  
J.R. Shields  
Building and Fire Research Laboratory  
Gaithersburg, MD 20899

June 2002



U.S. Department of Commerce  
*Donald L. Evans, Secretary*

Technology Administration  
*Phillip J. Bond, Under Secretary for Technology*

National Institute of Standards and Technology  
*Arden L. Bement, Jr., Director*

This report describes results from a Cooperative Research and Development Agreement between the National Institute of Standards and Technology and General Motors Corporation that addresses issues of post-crash automobile fire safety. This report was financed by General Motors pursuant to an agreement between General Motors and the United States Department of Transportation.

The National Institute of Standards and Technology (NIST) is applying its expertise in fire science to this program because of the potentially high impact of this program on vehicle safety in the United States. As a matter of policy, NIST does not test commercial products, especially without the consent of the manufacturers of those products. The National Highway Traffic Safety Administration and General Motors have selected the vehicles to be crash tested and the procedures for those tests. These exploratory tests are only meant to produce a variety of types of vehicle damage that might occur. Not all crash conditions were studied, and the repeatability of the tests cannot be determined since in most cases replicate tests were not conducted due to budgetary constraints. Thus, the results of the tests may facilitate identification of opportunities for improvements in vehicle fire safety, but cannot by themselves be extrapolated to the full fleet of vehicles and all crash conditions. In analyzing the data from these tests, certain vehicles, equipment, instruments or materials are identified in this report in order to specify the experimental procedure adequately. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the fire safety of a particular vehicle is superior or inferior to any other.

## Table of Contents

<b>Abstract .....</b>	<b>1</b>
<b>Introduction .....</b>	<b>1</b>
<b>Experimental Details .....</b>	<b>3</b>
<b>Standard Part .....</b>	<b>3</b>
<b>Ignition and Burning Conditions .....</b>	<b>4</b>
<b>Results and Discussion .....</b>	<b>8</b>
<b>Effect of Burn Configuration for an Isolated Part .....</b>	<b>8</b>
<b>Isolated Part: Resin Formulation Effect on Burning Behavior. ....</b>	<b>10</b>
<b>Array of Parts: Resin Effect on Burning Behavior .....</b>	<b>14</b>
<b>Summary and Conclusions .....</b>	<b>17</b>
<b>Acknowledgments .....</b>	<b>19</b>
<b>References .....</b>	<b>19</b>

# **The Effect of Polymer Resin Substitution on the Flammability Behavior of a Standardized Automotive Component in Laboratory Tests**

T. J. Ohlemiller and J. R. Shields

## **Abstract**

Four commercially-available polymer resins (impact resistant polypropylene, with and without flame retardants; nylon 66, with and without flame retardants) were examined in two types of flammability tests that measured the evolved heat release rate. The first test subjected each resin, in the form an isolated, container-like, engine compartment component, to a 2.4 kW flaming ignition source. The second test subjected an array of three of these parts, contained within a metal box, to a 6 kW flaming ignition source. The observed physical behavior and the relative ranking of the resins with regard to heat release rate was the same in both types of test. The flame-retarded polypropylene was distinctly less flammable than its unretarded counterpart, as measured by the rate of heat release subsequent to ignition. This was not the case for the two nylon resins where the observed behavior was more complex.

## **Introduction**

This is the third report of results from Project B.10, "Study of Flammability of Materials," which is being performed as part of a Cooperative Research and Development Agreement (CRADA) between General Motors Corporation and NIST. This study was financed by General Motors pursuant to an agreement between General Motors and the United States Department of Transportation.

Prior NIST reports in this series examined the flammability characteristics of automotive components from both the exterior and interior of two different vehicles (a minivan [1] and a sports coupe[2]). The results of this Project complement those of Project B.3 in which a limited number of vehicles, selected by General Motors in consultation with the National Highway Transportation Safety Administration (NHTSA), have been subjected to controlled crash tests.

The present report concerns a study of the potential reduction in flammability to be obtained by the substitution of different polymer resins in automotive components. The resins used in automobile applications are chosen for their cost and a variety of physical properties such as flexural modulus, tensile strength, heat deflection temperature and impact strength [3]. Interior trim materials must also meet MVSS 302 [4] which imposes certain limitations on fire spread rate in a specific laboratory test configuration.

Two common types of resins are impact-modified polypropylene and nylon 66; certain formulations of these have satisfactory cost and mechanical characteristics for specific automobile uses [5]. The former types of resin find widespread use in both passenger compartment and engine compartment components; the latter types are used in engine compartment locations requiring higher heat resistance than can be provided by polypropylene. The present study focused on examples of these two resins. One example of each had no flame retardant in its formulation; a second example of each did. All four resins are commercially available products. After consultation with NIST and Factory Mutual, the resins were chosen by GM. Among the criteria were that the resins meet or come close to meeting specific minimum mechanical property requirements (flexural modulus, tensile strength, heat deflection temperature and impact strength) for some (unspecified) automotive applications [6]. All were able to be injection molded satisfactorily, at least in the shape used here.

In making these resin comparisons, it was necessary to use the resins to make a “standard part” for which a mold was available. In this way the shape of the part was eliminated as a variable in the resin comparisons, i.e., the shape was “standardized”.

The specific shape of the part was not of central importance, i.e., any of a variety of shapes could have sufficed for the present tests. It was necessary only that the relative results with this part (i.e., the influence of resin type on relative flammability behavior) be reasonably representative of those to be expected with many shapes that might be encountered in automobiles. General experience with the fire testing of materials indicates that the thickness of the material and the convexity or concavity of its surfaces are the geometric elements of shape which can be expected to have a primary influence on fire growth and, thus, heat release rate behavior since these affect the ease of local surface ignition and rate of heat loss from the surface during burning. This is the reason for using a complexly shaped part rather than a simple, flat polymer slab. The testing of flat slabs of these resins is being conducted separately by Tewarson at Factory Mutual Research Corporation (see below). The part used here has both concave and convex surfaces which were exposed to the ignition source and it has a web thickness (here 2 mm to 3 mm) which is not unusual. The variety of possible molded plastic shapes in automobiles is endless; parts are often designed to fit unique niches within engine compartments, inside instrument panels, etc. It is, of course, impossible to demonstrate that the relative flammability results here will carry over to every other part shape<sup>1</sup>, but efforts have been made, as indicated below, to see that this is more likely to be the case.

The flammability behavior of primary interest is the rate of heat release as a function of time. Heat release rate is, as its name implies, a direct measure of the rate at which the

---

<sup>1</sup> This is a classic problem with fire tests of any kind and, in fact, extends to all materials testing. Materials tests are almost never able to replicate the exact circumstances of the end use of a material in a real product. Robust tests are those which capture the essence of the most critical features of the material usage and thus successfully predict the actual behavior in the end product. The efforts here with test design are along these lines, based on the author’s experience in fire testing, in general, and with automobile component and full-scale vehicle fires in particular.

polymer combustion process is giving off heat in the form of hot gases and radiation. The peak heat release rate and its time of occurrence are good measures of how strongly a given part might contribute to the overall development of a fire within an engine or passenger compartment. The higher the heat release rate, for example, the larger is the plume of hot gases available to ignite other nearby objects, by convective and radiative heat transfer, thus causing the fire to grow. Rapid achievement of this peak will assist rapid ignition of other components. The absolute heat release rate values measured for a specific object are not unique; as explained in [1], they depend on a host of factors such as ignition scenario, part orientation, secondary energy inputs, etc. Here we fix all of these other factors and vary only the resin type to measure the relative contribution of this one important factor to heat release rate behavior.

In an effort to make the qualitative results here more severe and more general than one would see with a flat sample, we have chosen a part which has a complex shape, including concave portions of its surface, frequently found in vehicle engine compartment and instrument panel components [7]. Such concavities can increase the radiative interaction of opposed burning surfaces, increasing the local heat release rate. The increased radiative transfer to the burning surface can also overwhelm a flame retardant in a polymer resin, yielding sustained burning of a surface that would self-extinguish in the absence of the radiation. The ignition scenario is limited to part of the component surface, as is to be expected in vehicle fires which originate from a localized ignition source such as an electrical short or small flammable liquid spill on a hot surface (as opposed to fully engulfing the entire surface of the part). This brings flame spread processes into prominence as substantial determinants of the time-dependent heat release rate process. Both lateral (opposed flow) and upward flame spread (which tend to respond differently to resin properties) are deliberately included, since some mix of these modes is expected in most real vehicle fires. A catch surface is provided below the part so that any burning polymer melt which flows off of the part might still contribute to fire growth on it. This process also might be expected to occur frequently in vehicle fires because such surfaces (though typically of lesser lateral extent) are present throughout engine compartments or instrument panels. Such burning melt/drip behavior has been seen with many of the vehicle components examined in the laboratory tests discussed in Refs. 1 and 2. The dynamics of this type of fire have been studied separately [8]. Finally, we have burned the parts in more than one way to see if the relative behaviors of the various resins remain the same.

In a related study, Factory Mutual Research Corporation has tested the same four resins in a more standard way (flat slabs of material uniformly exposed and burning on one side) which emphasizes resin behavior under simpler, forced combustion conditions [9, 10]. Results of ignitability and heat release rate measurements as a function of incident heat flux were cast into the form of indices which have been found to give a measure of expected fire behavior for other materials. These results will be introduced in the discussion below.

## **Experimental Details**

**Standard Part.** Figures 1 and 2 show various views of the part used throughout the tests described in this report. For size reference, the circular igniter seen in the photos has an external diameter of 6.2 cm. Wall (or web) thickness in most locations of the part is about 2 mm to 3mm. Maximum dimensions of the roughly rectangular “top” opening (facing the viewer in Fig. 2; note: we continue to designate this as the top in the discussion below, regardless of the part orientation) are 21 cm by 24 cm; the maximum depth of the “container” portion (on the side with the legs) is 10.3 cm. The weight of the part depended strongly on the specific resin. It varied from 380 g (unretarded polypropylene) to 600 g (retarded nylon).

This “standard part” is the lower portion of an enclosure or container from the engine compartment of a current model sedan. In that application, it sits horizontally, opening upward, on top of the right front inner wheel house panel in the engine compartment. Here, since the part represents an arbitrary component from a vehicle, its orientation was altered from its normal, concave upward state to facilitate the mix of direct ignition and flame spread areas alluded to above.

Note that the part has two “container” sections, one deeper than the other. This terminology is used below in describing part behavior during the fire tests.

It is evident in Fig. 1 that this part consists of two separable sub-parts, the double “container” section (best seen in Fig. 2) and a roughly U-shaped leg section. The leg section is attached to the bottom of the deeper container by two metal rivets. This appeared to be a link whose failure during fire exposure could cause erratic and non-reproducible relative movement between the leg section and the bulk of the part. This could have introduced a degree of scatter into the tests that could make the resin effects more difficult to discern. Thus the rivets were supplemented with a single ¼-20 screw and nut, between the two rivets; the screw head is visible on the right in Fig. 2. Since, as explained above, the specific details of the part were not an issue, this modification was not significant to the test goals except insofar as it facilitated achieving those goals with fewer tests.

The polypropylene was a propylene-ethylene co-polymer. The flame-retarded version contained decabromodiphenylene oxide, antimony trioxide<sup>2</sup> and unspecified zinc compounds. The flame-retarded parts weighed 34 % more than the unretarded parts (510 g vs. 380 g) and were opaque white versus translucent white for the unretarded parts. Details on the flame retardant system in the nylon 66 parts were not available from the resin manufacturer. The retarded parts weighed 19 % more than the unretarded parts (588 g vs. 493 g) and were rust-brown in color versus translucent white.

**Ignition and Burning Conditions.** The photos in Figs. 1 and 2 are, in fact, of two different part orientations. The resins tested here are thermoplastic in nature which implies that the part might collapse during the fire test in some unpredictable manner; this collapse makes the interaction of the igniter flame and the part equally unpredictable.

---

<sup>2</sup> Bromine and antimony trioxide are a widely used, synergistic combination of flame retardant additives for a variety of commodity polymers [12].



We wish to make the resin comparisons in a more severe (though not unrealistic) burning condition (rather than a less severe condition) since some flame retardants can be less effective when the burning process is more intense. Thus four burning configurations were assessed with isolated, unretarded polypropylene parts. (A fifth condition, using an array of three parts, is described below.) The first two comprised the orientations shown in Figs. 1 and 2. The third and fourth used these same part orientations but added to each a metal plate across the same portion of the “top” of the part as is shown, for example, in Fig. 3 (configuration 3); this plate is 10 cm by 20 cm by 0.24 cm thick. The plate simulates inorganic components present in automotive parts that may play the role of altering the flow path of the heated resin; if this extends the burning resin area, it will also increase the rate of heat release.

The first burning condition (Fig. 1) focuses the igniter flame on both sides of the deeper container portion of the part and tends to capture part of the igniter plume within this container area. The second burning condition (Fig. 2) focuses the igniter flame on a deep cleft in the part structure separating its two “containers”; the dark nut and washer visible in the center of Fig. 2 are in the middle of this cleft (the cleft opens toward the bottom of the part). In the third and fourth configurations, the metal plate functions as a substitute for non-combustible sub-parts within or associated with some vehicle components. Such sub-parts provide a surface on which the polymer melt can be retained as it flows downward under the influence of gravity. This can extend the area of burning melt and thus increase the heat release rate. Here, in all configurations, the top of the part was tilted into the orientation seen in Figs. 1 to 3, so that polymer melt would make contact with this added metal plate.

Since we sought to keep all variables constant except the polymer resin, it was necessary to take special measures so that the part orientations described above could be achieved reproducibly. The part was mounted with three attachment points to a stiff metal plate (see Fig. 1a); this plate was in turn fastened to an arm protruding from a heavy-duty, three angle vise. Scales on all three angles permitted re-positioning of the vise to better than  $0.5^\circ$  in any orientation. In addition, the ring-shaped igniter was positioned reproducibly (within a range of 2 mm) below the desired point on the test part by use of a jig that fitted snugly into the center of the ring. Similarly, the spacing between the ignition point on the part and the catch surface below the part was held constant within about 2 mm.

Two concentric layers of screens (inner layer visible in Figs. 1 and 3) were used to damp ambient flow disturbances to the igniter. For the same reason, the air flow into the bay where the tests were conducted was turned off. The result was an igniter flame that varied (up and down) only as a result of the vortex shedding that such flames are inherently prone to.

The igniter in these isolated parts tests was a 5 cm inner diameter ring with 12 holes pointing inward and upward (at  $45^\circ$ ) around its periphery (the igniter is visible in Figs.

1-3). For the isolated part tests it burned propane at a flow rate of 1.7 L/min (2.4 kW)<sup>3</sup>; this flow was set with a Brooks 5850E mass flow controller<sup>4</sup>. The flame tip height, in the absence of an intervening test part, was 35 cm to 40 cm. The igniter was left on steadily until a time in a test where its presence had minimal impact on the course of events. That is, it was turned off at a point (12 min after its initiation) where the igniter flames were no longer near or in contact with the part surfaces because they had melted out of the way or, if they were (as was the case with the flame-retarded nylon), it was clear that no further effect of the flames could be expected. The igniter flame was just above the pool fire that frequently developed on the horizontal catch surface. Thus it did feed some heat to this pool fire via radiation.

Fire testing experience and fire growth models indicate that the heat flux from an ignition source and the area of a test sample on which it impinges both influence the likelihood and extent of fire growth on a material. For a given heat source such as the propane flame used here, for which the heat flux is largely fixed, the heat release rate that will follow from ignition exposure increases with exposed sample surface area. The chosen exposure area here (a few tens of square centimeters) is an intermediate fraction of the total part area. As indicated previously, this partial exposure (rather than full exposure) brings both ignitability and fire growth processes into the response seen. In a vehicle crash, a part might be exposed in a highly localized manner ( $0[1 \text{ cm}^2]$ ) by a source such as an electrical arc or it could be fully engulfed in flames by a flammable liquid spill. The subsequent behavior in the former case would be dominated by fire growth processes. In the latter case, ignitability and subsequent burning rate would dominate. The response evoked here is a mix of all of these material-dependent processes.

The horizontal catch surface was a glass fiber reinforced cement board (Durock), 1.3 cm thick. It was nominally level so that any polymer melt would not flow preferentially in one direction away from where it flowed off of the part. The Durock sat on top of an additional layer of calcium silicate board, 1.3 cm thick; these two layers were separated by a sheet of aluminum foil to preclude any water interchange. The spacing between the lowest point on the part and the catch surface was made small (ca. 4.7 cm) so as to provide a stronger possibility for a melt fire on the catch surface to interact with fire growth on the part itself. Comparison of Figures 1 and 2 shows that burning configuration 2 (and 4) brought the bulk of the part closer to the catch surface than did configuration 1 (and 3). Note that the burner required some spacing above the catch surface to ensure a good air supply from below; typically the spacing was about 2.2 cm.

The Durock, as purchased, appeared to have more moisture content than past experience had indicated was normal. Consequently, prior to each test, each new board was dried in its center region (where any pool fire would occur) for 20 min to 25 min or more using a 500 °C heat gun. The board was cooled to room temperature before the test.

---

<sup>3</sup> This propane flow rate is equivalent in heat release rate to a burning gasoline flow of 4.4 cm<sup>3</sup>/min.

<sup>4</sup> Certain trade names and company products are mentioned in the text or identified in an illustration in order to specify adequately the experimental procedure and equipment used. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products are necessarily the best available for the purpose.

All four of the above configurations were used only for the unretarded polypropylene part in isolation. One of these configurations (configuration 3, same as configuration 1 but with the metal plate) was then used to assess resin substitution effects for isolated parts.

A fifth configuration was also used in this study, to further examine resin substitution effects. This employed 3 parts at once in a "packed" configuration within an enclosure. This was intended to more closely resemble conditions of actual usage in an engine compartment, for example, where an array of plastic components might be juxtaposed. Figure 4 shows external and internal views of this configuration. The three parts were held in three different orientations within the box and were nearly touching at some locations. The goal was to get them close enough together so that their burning processes would interact and potentially reinforce each other by mutual energy exchange. Again careful attention was given to reproducibility of the part positioning. The igniter was positioned reproducibly below the bottom of the box using a jig to hang a plumb bob from the top. The same igniter was used except that its propane flow rate was raised to 4.3 L/min (6 kW) to extend the flame height upward and provide a stronger start, involving, if possible, all three parts immediately.

The box (41 cm square, 64 cm high with 5 cm gaps at bottom and top) provided further potential for enhancement of the burning process via radiative feedback from heated surfaces. The walls were 0.15 cm thick steel; the top was covered on its inner surface with a 1.3 cm thick ceramic fiber blanket to provide a low density, rapidly heating and re-radiating surface in a manner similar to a hood liner above an engine compartment.

The box rested on top of a Durock layer (1.3 cm thick) which was itself insulated from a 6.3 mm thick aluminum plate by a 1.3 cm thick layer of calcium silicate board. Again the horizontal Durock surface was nominally level.

All tests were conducted under a hood which captured all of the fire plume thus permitting sampling of the gases and measurement of the rate of heat release [5]. (The multiple part tests were conducted under a hood with a higher flow capacity, the NIST Furniture Calorimeter). The calibration of the heat release instrumentation on both hoods was checked several times during the course of the experiments. There is an inherent uncertainty (2 standard deviations) in oxygen consumption calorimetry of  $\pm 5\%$  for generic polymeric materials [12]. In addition there is some noise in the calibration process. After application of calibration and zero-drift corrections, the uncertainty in heat release rate measurements in both systems is estimated to be  $\pm 8\%$  to  $10\%$  (2 standard deviations). When the heat release rates are very small, e.g., comparable to the igniter flame signal as measured in the Furniture Calorimeter, the uncertainty is substantially higher.

In addition to heat release rate information, one or two Hi-8 video cameras was used to record the behavior of the part(s) as it was exposed to the igniter. In the case of the box enclosure, viewing was limited but a Vycor window in one side allowed some

information on events inside.

## Results and Discussion

**Effect of Burn Configuration for an Isolated Part.** As noted above, four burn configurations were applied to the unretarded polypropylene parts to find the configuration giving the worst case behavior. The primary criterion for worst behavior was peak rate of heat release since the potential for fire initiation on other parts depends on this peak [13]. Time to peak heat release rate also is a measure of hazard since short times imply a more rapid fire growth. As will be seen below, however, there were no substantial and reproducible differences in time to peak for the tests here. The area under the heat release rate curves is a measure of the total heat released; this was not computed since it is not a rate property and thus not a measure of fire growth rate potential.

In configuration 1 (Fig. 1) the igniter plume impinged heavily on the inner and outer surfaces of the deeper container portion of the part. It did not contact the shallower container portion at all (i.e., that portion toward the camera in Fig. 1a), at least initially.

Figure 5a is an annotated heat release rate curve for one of the replicate tests of configuration 1. As expected, this unretarded polypropylene quickly went into a flaming melt/drip mode of burning. The polymer melt viscosity was (or became via crystalline phase melting and/or polymer degradation) sufficiently low that a normal upward flame spread process on the part surface was largely countered by downward flow of material. The dominant behavior was a combination of rapid, localized flows of flaming melt material onto the Durock catch surface punctuated by slumping of major sections onto this surface. Collapsed sections lay on the surface and continued to both melt into the pool there and burn locally while doing so. By 7 min to 8 min into the test, virtually all of the remaining polymer material formed a pool fire on the Durock.

The bulk of the collapse onto the Durock surface was very rapid, having been completed by 136 s after the start of the test. (Only the leg section of the part remained suspended and it was then out of contact with the igniter plume.) The developing pool fire on the Durock surface appeared to play very little part in this collapse although the presence of this surface (as opposed to empty space) did appear to play a role in slowing the flaming strings of polymer melt, allowing them to more effectively heat the bulk of the material above them.

The potential for boosting heat release rate via interaction between a self-generated pool fire and the burning part was emphasized (and demonstrated) in Ref. 1; this type of fire was also studied more extensively in Ref. 8, though not with automotive components. The minimal role here appears to be a consequence of the relative rates of part collapse and pool fire development. The early pool fire flames tended to be small (ca. 5 cm) since the catch surface was a substantial heat sink initially<sup>5</sup>. These flames were kept small when there was a rapid collapse of relatively cool material into the pool area. Here the

---

<sup>5</sup> Note that in this way the overall fire behavior depends to some extent on the thermal properties of the catch surface. This was demonstrated in the study described in Ref. 8.

pool fire flames eventually grew to 30 cm or more (by 10 min to 12 min) but all test part material with which these tall flames might have been able to interact had long since flowed from the space where this plume existed. This need not be the case for other parts or other catch surfaces [8].

There was an interesting dynamic involved in the pool fire behavior. The pool flames were shaped roughly like a conical tent. In the outer peripheral area of the pool where the base of this tent closely approached the liquid surface, the edges of the flames created a radial temperature gradient in the pool surface. This appeared to set up a surface tension driven flow pushing the melt outward<sup>6</sup>. The surface of the molten central pool thinned quite noticeably as it passed under this flame attachment region. At the same time outward flow beyond the flame position brought the melt over cooler portions of the Durock surface. Since polymer melt viscosity increases strongly with decreased temperature, the melt tended to slow down beyond the flame zone and freeze in place. Erratic breakthroughs occurred in this frozen periphery yielding lobed melt flows penetrating beyond it. The net result of these events was that the pool fire burned out in the center even though there was molten material available just outside the flaming zone which could seemingly flow inward to fuel the flames. A doughnut-shaped residue pattern resulted, leaving a significant amount of unburned material behind.<sup>7</sup>

Figure 5b shows the heat release rate curve for the other test of unretarded polypropylene in burning configuration 1. As indicated there, the underlying physical events comprising the collapse of the part are the same but they differ slightly in timing and in the location where sub-parts (particularly the shallow container portion) fell onto the Durock surface. The result was a measurably different heat release curve, though it is qualitatively similar to that in Fig. 5a.

Figure 6a shows an annotated heat release rate curve for burning configuration 2 (see Fig. 2 for the differing part orientation). It began to exhibit flaming melt drips at essentially the same time as configuration 1 but after this the collapse process differed substantially from the first configuration. Within the first two minutes of igniter exposure the bulk of the part (minus the legs) had collapsed onto the Durock with the two container segments on opposite sides of the igniter. This reduced fire growth to a slow lateral spread process in the pool, which had to melt and ignite these segments with minimal help from the igniter. The pool fire did not spread anywhere near the full diameter of the melt pool and a greater than average amount of residue was left unburned, as judged by the visually-assessed volume of the melt residue.

Figure 6b shows the replicate test of configuration 2. The part collapsed in a qualitatively similar manner to that in Fig. 6a, on essentially the same time scale. The shallow container section stayed closer to the igniter upon collapse and this probably

---

<sup>6</sup> Surface tension driven flows are a well-studied phenomenon in the context of flame spread over liquid fuels; see Ref. 14.

<sup>7</sup> A record was kept of the Durock slab weight before the test and after, with the residue present. The results are not reported because moisture driven out of the Durock by various sized pool fires rendered the numbers unreliable.

accounts for the somewhat higher heat release rate peak.

Figure 7a shows an annotated heat release rate curve for configuration 3 (same part orientation as configuration 1 but with the metal plate across the top of the two container sections; see Fig. 3). Here a portion of the deeper container section (and later some of the shallower section) did flow onto the metal plate yielding an extended burning area which boosted the overall heat release rate, though not dramatically. The higher heat release rate ended rather abruptly when the shallow container section of the part fell onto the Durock surface; this decreased the burning area and left a pool fire which slowly melted and consumed this last section of the part.

Figure 7b shows the heat release curve from a replicate test of configuration 3. The same physical events led to a quantitatively similar curve with slightly different timing.

Figure 8a is an annotated heat release rate curve for configuration 4 (same as configuration 2 but with the metal plate in the same position as in the last pair of tests). Once again the metal plate caught a portion of the falling polymer melt, thereby extending the burning area somewhat and raising the heat release rate. The subsequent collapse of the part onto the Durock surface seemed quite random in some aspects (i.e., the path followed by the shallow container section onto the Durock surface). The attempt to replicate this test (Fig. 8b) indeed indicated that the behavior of this section was erratic; in the second test it rotated less and then fell farther away from the igniter, essentially falling outside the perimeter of the pool fire. The subsequent pool fire had a lesser rate of heat release (though it was climbing when the igniter was shut off).

Overall the above results indicate that fires involving melting, collapsing objects are prone to a substantial degree of variability in spite of the extensive efforts, described above, to keep the starting conditions the same in replicate tests. Part of this variability is a result of the complex, extended shape of the part being studied here and the manner in which its mode of mounting interacted with its mode of collapse. The tendency to yield minimal interaction between the object and melt pool fires was a consequence of the slow pool fire development (itself a result of the heat sinking capacity of the Durock catch surface) compared to the time to object collapse.

Comparison of Figs. 5 to 8 shows that burning configuration 3 gave (by a small amount) the highest heat release rate peak and the best reproducibility. The time to the peak for this configuration was not necessarily the shortest but the times were similar for all four configurations and appeared to be affected by small, random variations in the melt/drip behavior. Configuration 3 was chosen for use in the next step, a comparison of resin effects on the burning behavior of an isolated part.

**Isolated Part; Resin Formulation Effect on Burning Behavior.** Figure 9a shows an annotated heat release rate curve for a part made from flame-retarded polypropylene; compare this to Fig. 7 above (non-flame retarded case). The physical and burning behavior were greatly different from that of the unretarded polypropylene part.

The time of actual ignition is difficult to discern due to the pre-existing igniter flame but the time for the first flaming melt/drip was delayed to ca. 50 s (compared to about 20 s for the unretarded parts). After this the part showed a strong resistance to melt flow behavior. The limited area of the part (in the deeper container section) which was in essentially continuous contact with the upper portion of the igniter plume did finally begin burning rather intensely (with strong smoke emission) after about 2 min. However, by 2.5 min the burning material slumped down around the igniter ring where it burned weakly. For the most part, after this, there was no more contact between the igniter plume and the suspended portions of the part and no flames continued on this suspended portion. Eventually the weak, indirect heating from the plume caused the smaller container portion to collapse to the Durock surface; here only the edge in contact with the igniter burned during the remainder of the test, yielding a heat release rate too small to measure accurately. No pool fire was seen and a substantial amount of the original part was left at the end of the test (the large container section sank to the Durock and remained largely unaltered).

Figure 9b is a plot of the heat release rate curve from a replicate test with the flame-retarded polypropylene. The qualitative behavior is essentially the same, though the timing is somewhat different. There was also a small, brief flare-up of suspended material (attached to the leg area) late in the test since the igniter plume was deflected differently by slumped material in this test.

In tests of these two polypropylene resins in the Factory Mutual flammability apparatus (in the form of flat slabs of polymer resin), Tewarson [9] measured ignition behavior and heat release rate. On the basis of those results he assigned values to a heat release parameter and a flame propagation index for each resin. The flame-retarded polypropylene resin had a heat release parameter about one half that of the unretarded polypropylene resin, a substantial improvement though better results are possible.<sup>8</sup> The fire propagation index, a measure of the tendency to spread flames upward on the material surface, was reduced by only about one third and remained well within the range which, Tewarson's previous results implied, would support upward flame spread.

The reduction in flammability seen here (as judged by the decreased heat release rate) is generally better than Tewarson's results would lead one to expect. This is probably a result of the substantial differences in test conditions. Here the polymer resin is subjected to a heat input on only a portion of its surface. With the unmodified resin, the polymer melts to yield a flowing flammable fluid. Much of the mass is transferred to the catch surface where it continues to burn. Flames continue on the melting regions of the suspended part, spreading in all directions and feeding more material to the melt pool. Outer portions of the part soften and collapse into the flaming melt pool where they are largely consumed. The flame-retarded resin has both a higher effective viscosity and an apparent need for a significant external energy input to sustain local burning. The former feature slows and nearly halts the collapse onto the surface and the slumping movement of suspended material inward toward the igniter plume. The latter feature means that

---

<sup>8</sup> Factor of three reductions in heat release rate are possible with some resin formulations but these may not meet the physical property requirements for automotive usage.

flames will not grow laterally on the suspended portions of the part or on the collapsed material laying on the Durock surface since both areas are away from any significant heat source. The result is a much less intense fire here. Tewarson's test conditions do not allow this escape of material from a heat input level that will assure its sustained burning. His conditions are, at least in this one respect, worst case. The conditions in the present tests (flames contacting a portion of a part from below and causing its subsequent burning) comprised significant portions of the fire growth paths in many of the full-scale fire tests in Project B.3 but certainly not all. Other exposure conditions can occur, some of which are more conducive to ignition and burning of a part. For example, a substantial gasoline fuel spill over the entire surface of the part might lead to its complete consumption more in the manner of Tewarson's test.

Note also that the retarded polypropylene resin still exhibited some melt flow. This would make it less than ideal as an inhibitor of fire penetration through designed-in holes in the forward bulkhead of a vehicle passenger compartment.

Heat release rate curves for the part made from unretarded nylon are not provided because little, if any, measurable heat release occurred in either test (ca. ½ kW at most). Flaming melt drip material reached the Durock surface initially at about the same time as for the unretarded polypropylene, i.e., local ignition of the resin by the lower portion of the ring burner flame did occur. After that essentially everything was different for this resin than was seen above. The igniter plume basically melted a path through the area of the part above the igniter ring. Most of this melted material flowed (with a moderately low viscosity as judged by its flowrate) to the Durock surface but it exhibited little flaming once there (occasionally small areas near the igniter flame had ca. 3 cm high flames). Also there were some weakly flaming areas on the suspended portion of the part. The largest heat release rate contribution from the nylon part came 4 min to 5 min into the tests in the area above the top of the igniter plume; the peak heat release rate from this was of the order of ½ kW. This material soon slumped downward out of the path of the igniter plume and its heat release rate decreased substantially. Halfway through the 12 min exposure to the igniter, there was essentially no more contact of its plume with the part. Molten material on the Durock (black and somewhat intumesced) was concentrated around the igniter which supported its weak combustion. No significant pool fire developed.

This result should not be taken to indicate that this unretarded nylon is always less flammable than even the flame-retarded polypropylene, though in this test it was. The particulars of this test put an emphasis on the melt flow behavior of the resin and whether the melt burns readily. The nylon did well in this test because its melt does not burn readily without some added heat input. Thus, once again, lateral flame spread on the part was suppressed, as was a significant pool fire on the catch surface. As will be seen below, pre-heating of the resin, can be sufficient to shift the heat balance in favor of stronger combustion. Alternatively, were the nylon to collapse onto a hot surface such as an exhaust manifold one can anticipate that it could exhibit a greater heat release rate than in the present tests, again because the heat balance would be shifted in favor of continued burning. Indeed, in Tewarson's tests of this resin, which provide an added



heat input not unlike that from a hot surface, it gave the highest heat release parameter and flame propagation index of the four resins. Finally, it should be noted that this resin would not function as a fire blocking material, by virtue of its thermoplastic melt flow behavior, in any designed-in holes in any bulkhead of a vehicle.

Figure 10a is an annotated heat release rate curve for the flame-retarded nylon resin. This resin did not undergo much melt flow when subjected to the igniter flame. The degraded resin charred, intumesced somewhat and tended to stay in place. When material did come off under the influence of gravity, it did so in globular chunks that tended to retain a semblance of their original shape. When such chunks fell to the Durock surface their flames died out slowly (tens of seconds). Note, however, that a substantial fire did result from the ignition of this resin, principally on the surfaces that remained suspended. The main surfaces which burned were those on the inside (and, to a lesser extent, the outside) of the deeper container section which were in the direct path of the igniter flame and thus received the most heat input. Lateral flame spread was significant in this area but it died out before it could carry the flame zone to the shallow container section. The charring tendency of the resin appeared to be at least partly responsible both for this limitation on lateral flame spread and for the dying flames on segments which fell to the Durock surface (where they no longer got a heat input from the igniter). Since information on the flame retardant system in this resin was not available, it cannot be ruled out that gas phase flame inhibitors (such as the bromine in the FR polypropylene resin) were also active in limiting fire growth.

The results of the replicate test with parts made from this flame-retarded nylon resin are shown in Fig. 10b. The quantitative differences from Fig. 10a are due to differences in the way globs of material fell off of the part. The same types of events shaped the overall similar curves, however.

Comparison with the unretarded resin case shows a paradox: a fairly effective retardant system (as judged by the results of Tewarson's measurements) made the performance in this test much worse. Much, if not all, of the change in behavior appeared to come about through the increase in effective melt viscosity<sup>9</sup> which caused the resin to stay in the path of the igniter flame and burn there where the external heat input was sufficient to sustain flaming.<sup>10</sup> The unretarded resin simply melted out of the way, in large part without igniting. In Tewarson's tests of this resin [9], he found its heat release rate parameter was 1/3 that of the unretarded resin, a substantial improvement; its fire propagation index was only 20 % less, however, implying a ready tendency for upward flame propagation remained in the retarded material. The tendency to char and stay in place could work in favor of this resin in the role of helping prevent fire propagation through holes in a vehicle bulkhead.

---

<sup>9</sup> The term "effective melt viscosity" refers to the observed melt flow behavior of the resin under the influence of gravity in the test. As such, it is affected by several parameters such as temperature, molecular weight and the presence of additives. No quantitative measurements of melt viscosity were made in this study, nor were they necessary to the observations and conclusions made here. Such measurements were made in Ref. 8.

<sup>10</sup> An implication of this type of behavior is that the heat release rate from the part would vary directly with the size of the igniter.

**Array of Parts; Resin Effect on Burning Behavior.** As explained above, the following tests were undertaken to compare the resins under more severe conditions in which an enclosure would provide some heat feedback and help tip the surface energy balance on a part in favor of more vigorous burning.<sup>11</sup> Note that the igniter was turned up to 4.3 L/min (equal to 6.0 kW heat release rate) of propane to increase its reach. Its placement was such that a substantial portion of it went up through a roughly central hole of highly variable cross-section in the parts array (some hint of this can be seen in Fig. 4c, a top view of the parts array). These tests were performed in the NIST Furniture Calorimeter because it was anticipated that the peak heat release rate would exceed the capacity of the smaller calorimeter used in the preceding tests.

Figure 11a is an annotated heat release rate curve for three non-flame retarded polypropylene parts mounted in the box shown in Figure 4. The Vycor window in the front of the box permitted only a limited view of the surfaces of the parts so the description here is minimal. Basically, the three parts melted down to the Durock surface during the first 30 % to 40 % of the test duration; the remainder of the test involved a pool fire on the Durock, centered under the box. The box incorporates a limited amount of internal metal structure (two cross bars and one vertical bar, all 5 cm wide) to support the parts. This provided a relatively small amount of surface on which flowing polymer melt could hang up and burn. The net effect of the box (and the larger igniter) during the first portion of the test was to bring down all three parts in about the same time as one part melted down in the isolated part tests above. Thus downward flow was enhanced more than burning and the peak heat release rate in this portion was increased by less than a factor of three. The strongest impact of the box was on the subsequent pool fire. For a single, isolated non-retarded polypropylene part, this pool fire portion of the burning barely reached 10 kW; here it reached over 100 kW.

The replicate test for these non-flame retarded polypropylene parts, shown in Fig. 11b, showed some quantitative differences that appeared to originate in the details of how various segments slumped and flowed to the Durock surface. Qualitatively the physical behavior and the heat release curve were the same as the first test.

Figure 12a is an annotated heat release rate curve for three flame retarded polypropylene parts in the box. As with the isolated part, this resin strongly reduced the heat release rate compared to that seen with the unretarded polypropylene. The retardant system had a similar physical impact, i.e., a major increase in effective melt viscosity that led to the slumping off of chunks (after some early, minor melt flow). An effect that was particularly striking here was the great increase in the sootiness of the smoke consistent with the presence of a gas phase oxidation inhibitor (bromine), in addition to a melt behavior modifier. When the surface of the parts started to burn in the areas impinged by the flames, these areas slumped downward, out of the igniter plume and onto the Durock,

---

<sup>11</sup> Note that this feedback from the enclosure (and from heated surfaces on other parts) is self-generated and tends to bootstrap itself as a fire grows; it is not imposed from without at a constant level, as in Cone Calorimeter testing, for example. Thus, if the part does not ignite, there will be essentially no feedback from the enclosure.

where they essentially stopped burning. (This is the source of the initial heat release peak.) Eventually this slumped material became hot enough to re-ignite, yielding the second heat release peak that was cut short when the igniter was turned off. Overall the flame retardant decreased the peak heat release rate by a factor of four to five compared to the non-retarded resin. Again this is a greater effectiveness than Tewarson's test results would lead one to expect.

The replicate test (which was actually run first) in Fig. 12b showed very similar behavior up to the time it was terminated. (Excessive soot was escaping from the building exhaust stack due to a failure of the pollution control system.)

As noted above, the parts made from the non-flame retarded nylon resin, when tested in isolation, gave a few small flames but virtually no significant heat release (1/2 kW at most). Instead the resin melted away from the igniter plume and fell to the catch surface where it burned only when in contact with or very near to the igniter flames. The first test of an array of three parts made from this resin gave essentially the same result. Flaming melt drip occurred early in the test but the flames died out when the material lay on the Durock surface. By six minutes into the igniter exposure, essentially everything the igniter flame could directly reach had melted out of the way. For the remainder of a 20 min exposure, the nearby material got hot enough to sag very slowly but no further burning occurred (except very small flames on material that fell next to the igniter). The remaining suspended material was obviously pre-heated by radiation from the igniter flame but did not ignite because there was no igniter flame contact.

To assess (in a rough manner) what the impact of earlier pre-heating would have on the behavior of this resin in this type of test, the second trial included an added heat source. This was 300 cm<sup>3</sup> of a 50/50 (by volume) mixture of motor oil (10W40) and heptane<sup>12</sup> which was poured, over the top of the parts array 45 s before the propane igniter was lighted. Figure 13 is an annotated heat release rate curve for three non-flame retarded nylon parts burned in this manner. The bulk of the liquid fuel mixture ended up on the Durock surface, forming a somewhat irregular pool about 40 cm to 45 cm in diameter. When ignited, this immediately burned intensely due to the heptane content, with flames sweeping up through much of the volume of the box. This pool fire quickly died back leaving a significant amount of the oil behind, unburned, over the original spill area. By the time this dieback occurred, a *ca.* 12 cm diameter pool of burning nylon melt was left below the igniter area. The size of this pool and the fact that it kept burning distinguished the behavior here from the previous test. The initial flames on this pool were quite small (4 cm to 5 cm tall) and thus they were a minimal supplement to the continuing heat going through the box from the propane igniter. Evidently these flames

---

<sup>12</sup> This is a substitute for an arbitrary post-crash mix of gasoline and oil. The less volatile component assures a slower burn process, more likely to heat the parts more extensively. A more controlled study would look at the effect of pre-heat temperature of the parts array on its burning response. However, controlled pre-heating over this volume is difficult to achieve. Within an engine compartment the air temperature can reach 80 °C or more [15]. Metal parts (e.g., the exhaust manifold), which plastic parts may be near, can get much hotter.

did, however, provide just enough heat to the right area of the lowest part in the array to assure a continuing flux of nylon melt and/or fragments such that a weakly self-accelerating melt fire was established.<sup>13</sup> The pool fire was able to grow slowly and bring an increasing amount of nylon down onto itself. It appeared that most, if not all of the actual burning of the nylon was on the pool. (Pool is a somewhat misleading term here; the burning nylon was a bubbling black layer of material of the order of 1 cm thick.) The strong heat release rate peak that ultimately resulted tends to confirm Tewarson's heat release parameter for this material as being the largest of all the resins.<sup>14</sup>

Given the sequence of results in the above test, it is probable that the principal effect of the burning liquid spill was to pre-heat the components within the container, thus tipping the energy balance toward sustained burning.<sup>15</sup> Pre-heating can be shown to be equivalent to an added external flux on the sample surface while it is burning<sup>16</sup>. It is well-established that such a flux virtually always increases the intensity of burning of solid materials<sup>17</sup> so, in effect, all of the resins examined here would be expected to burn more intensely if they were pre-heated. The properties of the non-flame retarded nylon just happen to place it on the edge between burning and not burning in the test used here.

Some pre-heating is inherent in engine compartment applications though the amount (tens of degrees Celsius; ref. 15) is probably equivalent to relatively low added external fluxes (a few kW/m<sup>2</sup>; see footnote 16). In a post-crash fire situation, the surroundings of the component of interest can be heated by other burning processes; thus, an external flux, which could be much larger, could impinge on the part of interest and increase its heat release rate substantially. Here the heat feedback from the box surfaces simulates this, to some extent. Since the box surfaces increase in temperature as the size of the fire inside increases, the box is a part of the self-accelerating feedback loop to the burning melt pool in this test, in much the same manner as one would expect in an engine compartment. In the first test, the nylon resin short-circuited this self-accelerating part of the feedback loop by not providing enough heat to the walls of the box. In the second nylon test, with the oil/heptane assist, the walls of the box, the nylon parts (and the Durock) were heated early in the test just enough to push the nylon melt fire over the edge toward self-acceleration.

From the above, one can infer that the non-flame retarded nylon resin will be less readily

---

<sup>13</sup> Such fires were studied more systematically in Ref. 8.

<sup>14</sup> There was some contribution to this peak from the oil that remained on the Durock after the initial fire but it is not believed to be a major effect. If it was 50 grams of oil, a plausible visual estimate, it would amount to about 3 % of the mass of the nylon parts.

<sup>15</sup> The complex mode of ignition used here (burner plus liquid spill) could have had two added effects that had some influence on the result seen. First, a small amount of oil was undoubtedly left on the part surfaces, particularly the horizontal sections. This could have burned, aiding the pool fire on the Durock, though there was no direct evidence that this happened. Second, the initial liquid fire could have melted down some of the nylon, bringing it into closer to the burner. This effect was unlikely to be large since: (a) it was not evident to observers and (b) the gas igniter required more than 300 s to cause substantial part collapse; the larger pool fire here had only 50 s or so to cause such collapse.

<sup>16</sup> There is no unique, one-to-one correspondence between a pre-heat temperature and a specific external flux level. The relation depends, among other things, on the mass loss rate of the solid as it burns.

<sup>17</sup> This is the basis of Tewarson's tests, for example [9].

involved than would the non-retarded polypropylene in the types of vehicle fires that the above tests simulate<sup>18</sup>. However, in circumstances which push it over its higher threshold for involvement (via pre-heating or external radiative input), it will exhibit the type of high heat release rate behavior seen above.

Figure 14a shows an annotated heat release rate curve for three flame retarded nylon parts in the box. Essentially all of the burning occurred within the box. There were several falling chunks of burning material which accumulated on the Durock surface but these did not yield an appreciable fraction of the measured heat release rate (as judged by their small flame volume in comparison to the total). Just as in the isolated part tests, this resin exhibited a greatly increased effective melt viscosity (abetted by a tendency to char) and this basically caused the fuel to stay in place. Under the influence of the heat input from the igniter, this material burned rather vigorously, as indicated by its peak heat release rate. (Again, sooty smoke and an elevated CO level in the exhaust<sup>19</sup> implied a gas phase oxidation inhibitor helping to limit the heat release rate.) The flames eventually tended to engulf much of the bulk of the parts (as seen through the window and from post-test examination). This probably occurred because accumulating preheating due to the burning of the more directly igniter-exposed areas enabled lateral flame spread over all surfaces. (Recall that lateral spread was more limited on the isolated parts.)

Figure 14b shows the heat release rate curve for the replicate test of three parts made from the same flame retarded nylon resin. The qualitative behavior underlying the heat release curve was basically the same. At the time of the peak there was probably more fallen material burning on the Durock making a small but significant contribution.

Again, as in the isolated part tests, the flame retardant in this resin led to much more ready fire involvement of the parts, as a comparison of Figures 13 and 14 shows. However, the peak heat release rate was reduced by the flame retardant. On balance, however, this resin does not appear to be desirable replacement for the non-flame-retarded nylon since the peak heat release rate has not been reduced sufficiently to greatly restrict fire growth.

### **Summary and Conclusions.**

The measured values of peak heat release rate and time to that peak for the four resins in the two types of test are shown in Table 1; recall that the heat release rate uncertainty is approximately  $\pm 10\%$ . In general, the data there indicate that both of the test methods used are sufficiently reproducible as to allow distinction between the behaviors of different resins. The three part array test does appear to have achieved its goal of providing a more harsh test environment (i.e., with more heat feedback to the parts surfaces causing an increased heat release rate) since it generally more than tripled the peak heat release rate obtained for a single part made from the same resin.

---

<sup>18</sup> The discussion in the Introduction defines the type of scenarios. In the present context, it is pertinent to repeat that the tests here do not simulate conditions with extensive preheating of the component.

<sup>19</sup> The peak CO concentration in the exhaust was twice that of the unretarded case.

**Table 1. Summary of Heat Release Rate Results**

Resin	Test Configuration	Peak Heat Release Rate (kW)	Time to Peak (s)
Non-FR Polypropylene	Isolated Part	18, 19	210, 150
FR Polypropylene	“	6, 4.5	170, 190
Non- FR Nylon	“	0, 0	-, -
FR Nylon	“	12, 13	200, 205
Non-FR Polypropylene	Array in Box	110, 95	630, 620
FR Polypropylene	“	25, 21	290, 315
Non-FR Nylon	“	0, 150	-, 1490 <sup>20</sup>
FR Nylon	“	74, 89	410, 510

The data in Table 1, along with the preceding discussion, indicate that, at least for polypropylene, the flame-retarded resin is likely to give improved flammability performance in the types of automotive exposures simulated here. For the single part test and the multiple part tests, the peak heat release rate was reduced by a factor between three and five for the retarded resin. The average time to reach this peak is not distinguishable for the two resins in the isolated part test. This short time to the peak for the flame-retarded polypropylene mainly reflects the fact that no pool fire was formed with this resin and thus it does not indicate a detriment. The earlier fire growth rates for the two resins were comparable.

The observed behavior of the two nylon resins was more complex. Under circumstances where the unretarded resin could melt away from a flame, it gave the lowest heat release rate of all resins. However, this pathway to low heat release rate cannot be guaranteed in any real automotive application. A particular application or a particular post-crash scenario could force the melt to stay in contact with the ignition source and pre-heat the nylon; under these circumstances it will burn vigorously. This resin does offer properties which will make it less prone than unretarded polypropylene to ignite and burn in some situations but they are not really predictable in advance. The particular flame-retarded nylon tested here does not offer a sufficient decrease in heat release rate (as compared to either unretarded nylon or unretarded polypropylene) to assure a minimal chance of its igniting surrounding components in a vehicle application and it ignites and burns more readily than the non-retarded nylon resin.

The behavior seen here is more complex than that predicted by Tewarson’s test results on the same resins. The test performed here bring into play more parameters of a resin than do Tewarson’s tests, especially its effective melt viscosity as indicated by its tendency to flow when subject to an ignition source. In general there was a tendency for the heat release rate decrease upon the addition of a flame retardant here to be better than expected on the basis of Tewarson’s results. Tewarson’s tests are more fundamental than those used here in the sense of being a measure of resin behavior in its more rudimentary form, a flat slab rather than an arbitrary three-dimensional shape. A resin

<sup>20</sup> This case was the result of the pre-heating of the parts with the heptane/oil mixture.

which performs very well in his tests (Fire Propagation Index below 5; ref. 9) is likely to behave well in the tests used here or in an analogous automotive application because his assessment includes the resin's response to a wide range of external heating levels. The results here indicate, however, that a resin which looks poor (Fire Propagation Index above 10, as was the case for all of the resins here) in his tests may still give significantly improved flammability behavior in automotive ignition exposure situations similar to those simulated here.

### **Acknowledgments**

The authors would like to express their thanks to Roy McLane for his considerable assistance in setting up and carrying out these tests and to Gary Roadarmel and Dave Stroup for their assistance in obtaining and reducing the test data.

### **References**

- 1) Ohlemiller, T. and Shields, J., "Burning Behavior of Selected Automotive Parts from a Minivan," National Institute of Standards and Technology report NISTIR 6143, August, 1998
- 2) Ohlemiller, T. and Shields, J., "Burning Behavior of Selected Automotive Parts from a Sports Coupe," National Institute of Standards and Technology report NISTIR 6316, April, 2001
- 3) Maxwell, J., Plastics in the Automobile Industry, Woodhead Publishing Ltd, Cambridge, England, 1994, Chapters 1 and 2
- 4) National Highway Traffic Safety Administration, Standard 302, Flammability of Interior Materials," Code of Federal Regulations 49 CFR Ch.V
- 5) Maxwell, J., ibid, Chapters 4 and 6
- 6) Private communication with I. Abu-Issa of General Motors, June, 1998
- 7) Maxwell, J., ibid, see photos of automotive components throughout book.
- 8) Ohlemiller, T., Shields, J., Butler, K., Collins, B. and Seck, M., "Exploring the Role of Polymer Melt Viscosity in Melt Flow and Flammability Behavior," Proceedings of the Fall Conference of the Fire Retardants Chemicals Association, Ponte Vehdra, Florida, October, 2000
- 9) Tewarson, A., Factory Mutual Research Corporation, report in preparation
- 10) Tewarson, A., "Generation of Heat and Chemical Compounds in Fires," Section 3/Chapter 4, SFPE Handbook of Fire Protection Engineering, 2<sup>nd</sup> Edition, 1995, pp.

3:53-124

- 11) Babrauskas, V. and Grayson, S. (eds.), *Heat Release in Fires*, Elsevier Applied Science, London, 1992
- 12) --, Modern Plastics World Encyclopedia 2000, A Chemical Weeks Associates Publication, Hightstown N.J., pp. B-37ff
- 13) --, "Guide on Methods for Evaluating Potential for Room Flashover," National Fire Protection Association, NFPA 555, Quincy, Mass., 1996
- 14) DiBlasi, C., *Comb. Sci. & Technol.*, 110-111 (1995), p. 555
- 15) Private communication from General Motors; data for a 1997 minivan



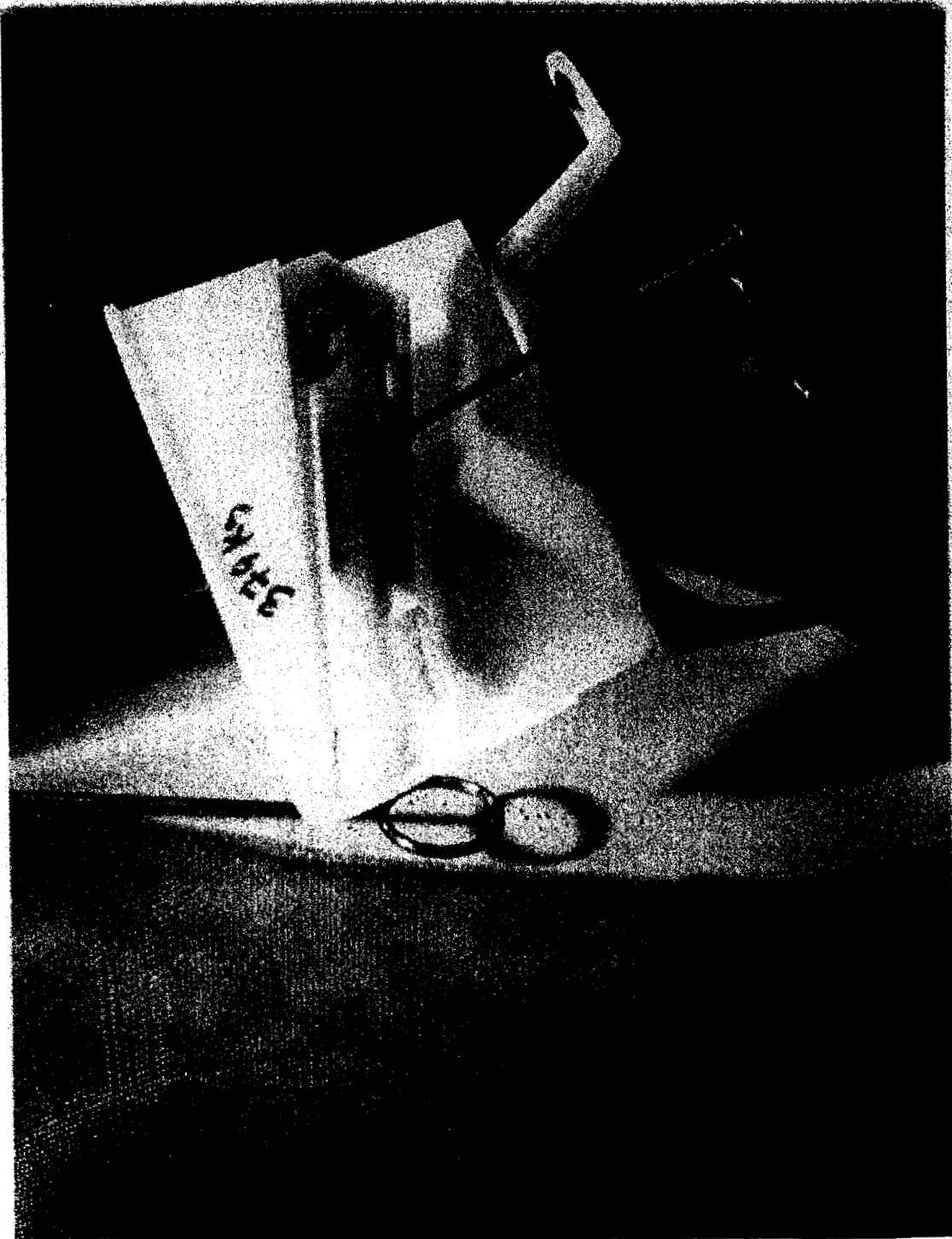


Figure 1a Side view of configuration 1 showing the manner in which the “standard” part was mounted to the support plate; that plate was in turn held on an arm extending from a three axis vise.

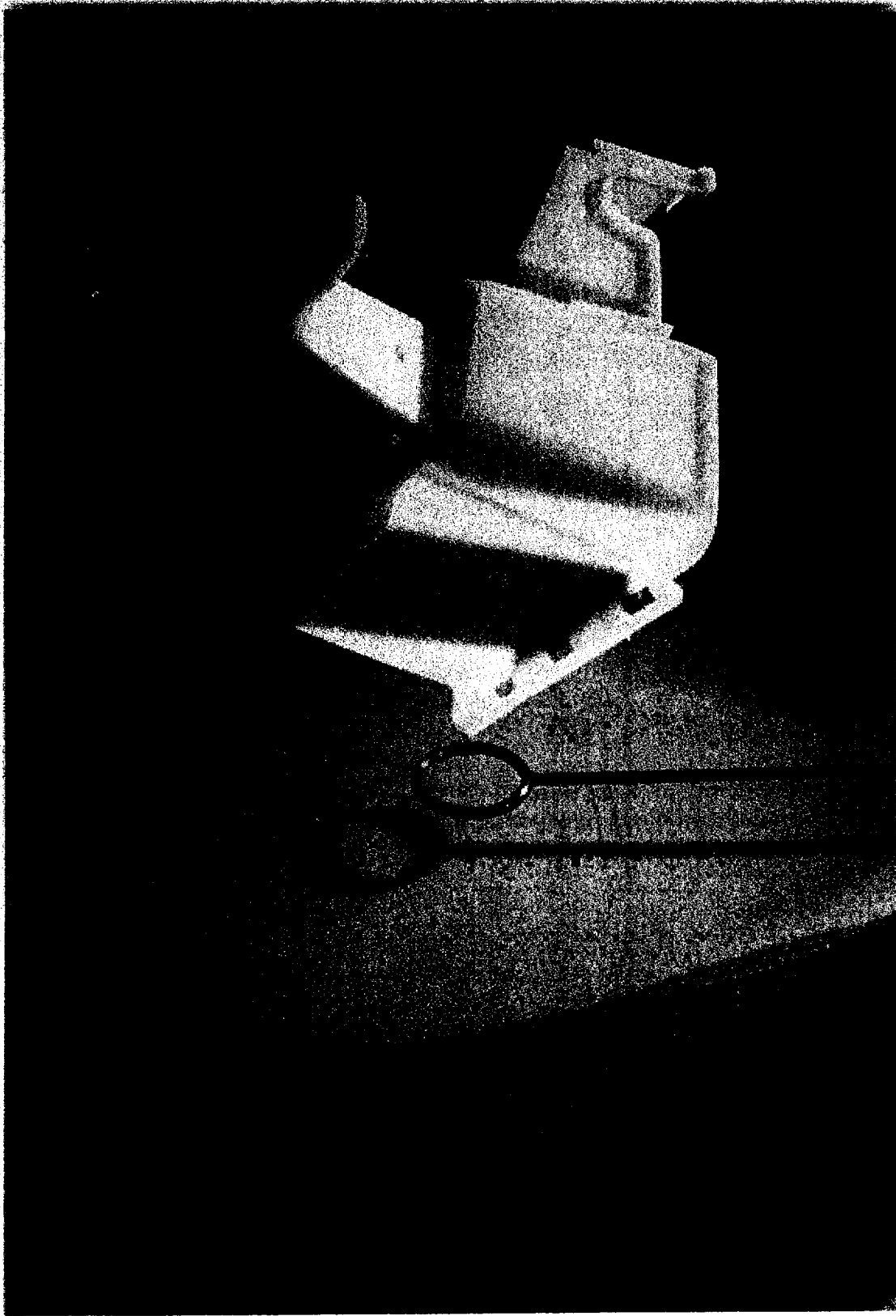


Figure 1b Second view of configuration 1 (from opposite side). Note that only the lower corner of the "standard" part approaches the Durock cement board surface.

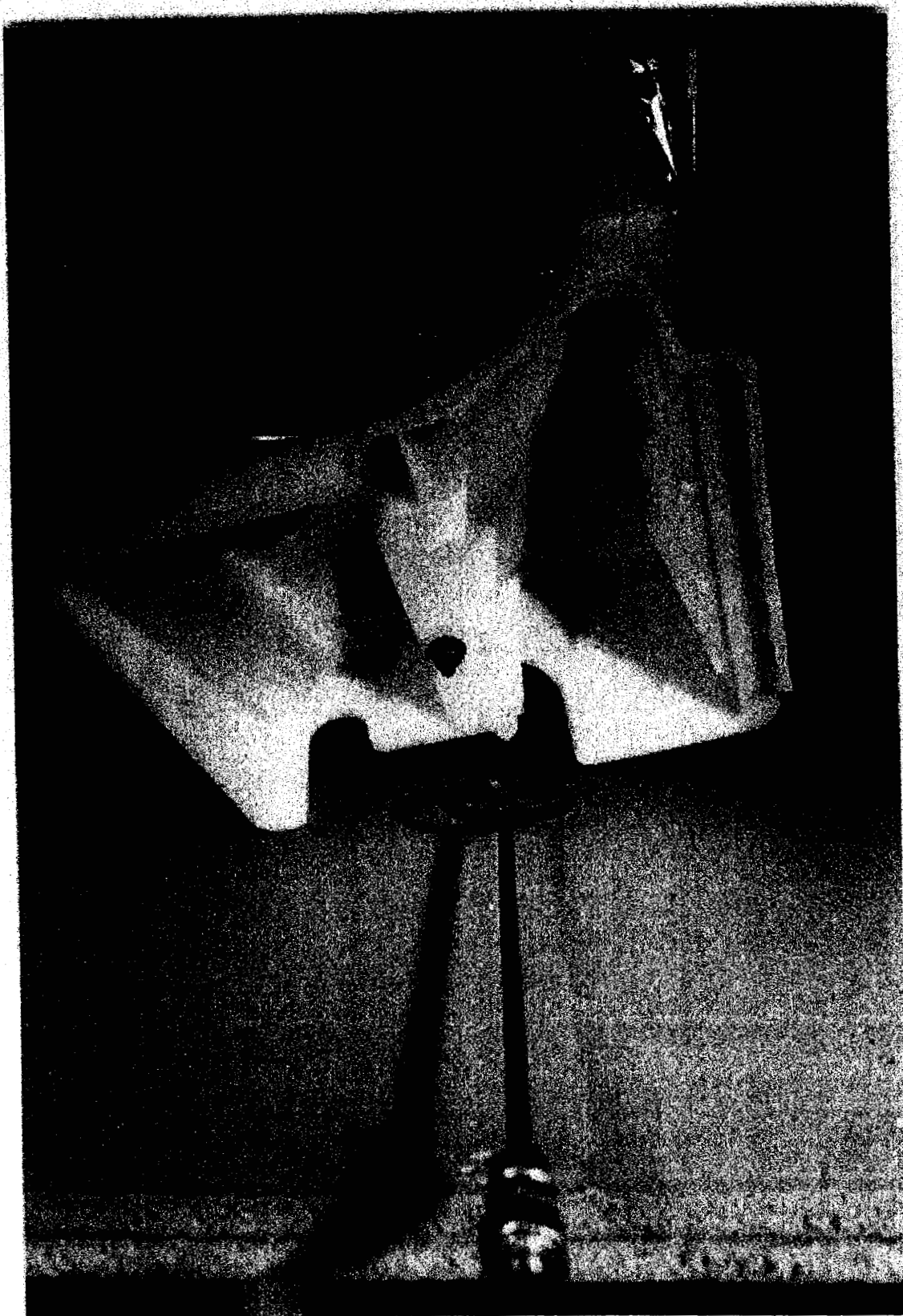


Figure 2 Configuration 2, showing the relative proximity of the body of the “standard” part to the Durock cement board surface. The inner screens are not visible in this picture.

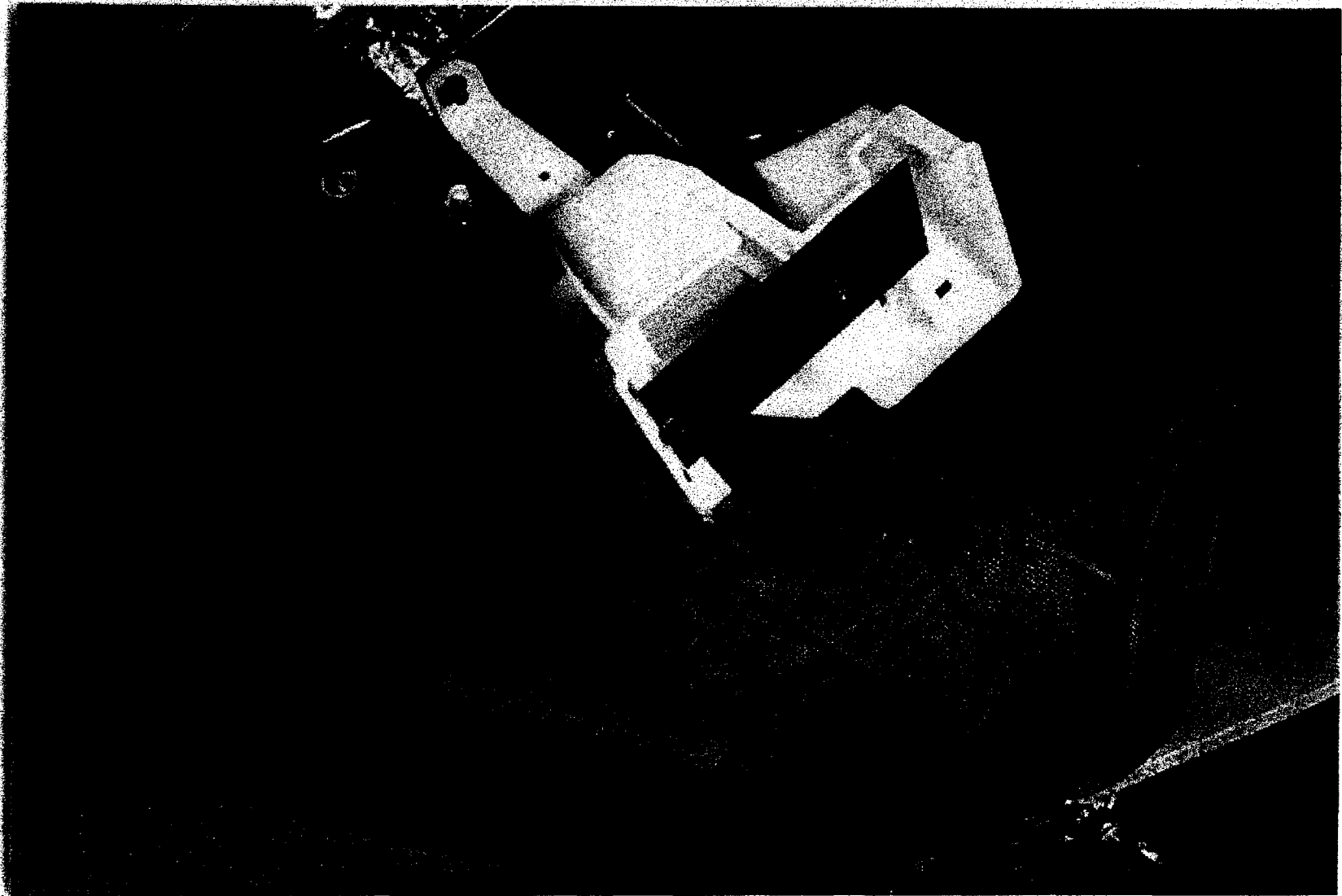


Figure 3 Overall view of configuration 3 which was used for the resin comparison tests. The inner screens are placed concentrically around the ring igniter which sits just above the Durock, fiber-reinforced cement board. The metal plate used in this configuration covers a portion of the "top" of the "standard" part. The part itself is at such an angle that some of its melt/drip material will flow onto the plate.

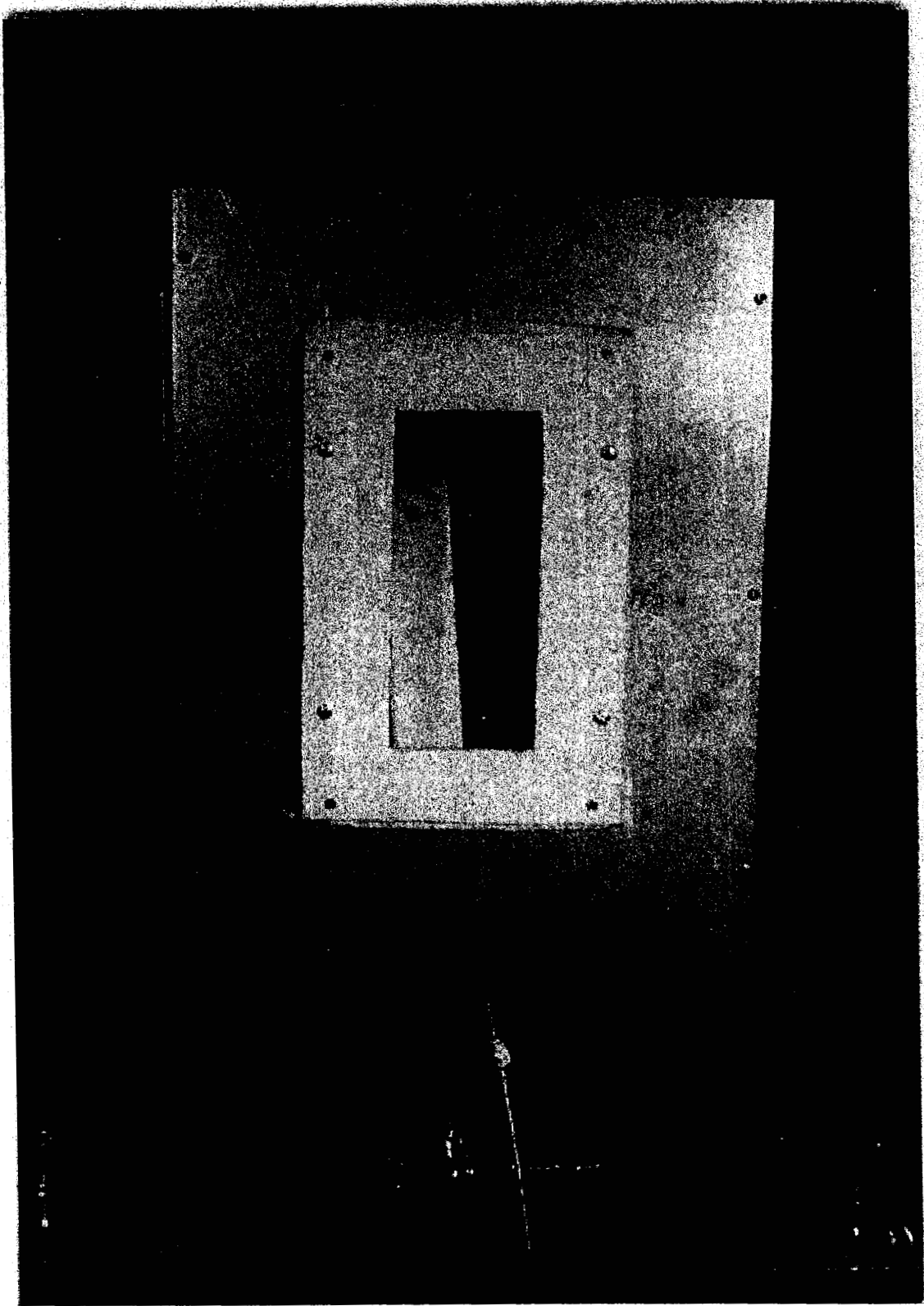


Figure 4a View of box containing an array of three of the "standard" parts. The tube leading to the gas igniter is visible on the bottom. The irregular white line at the top is the lower edge of the insulation on the underside of the top plate.

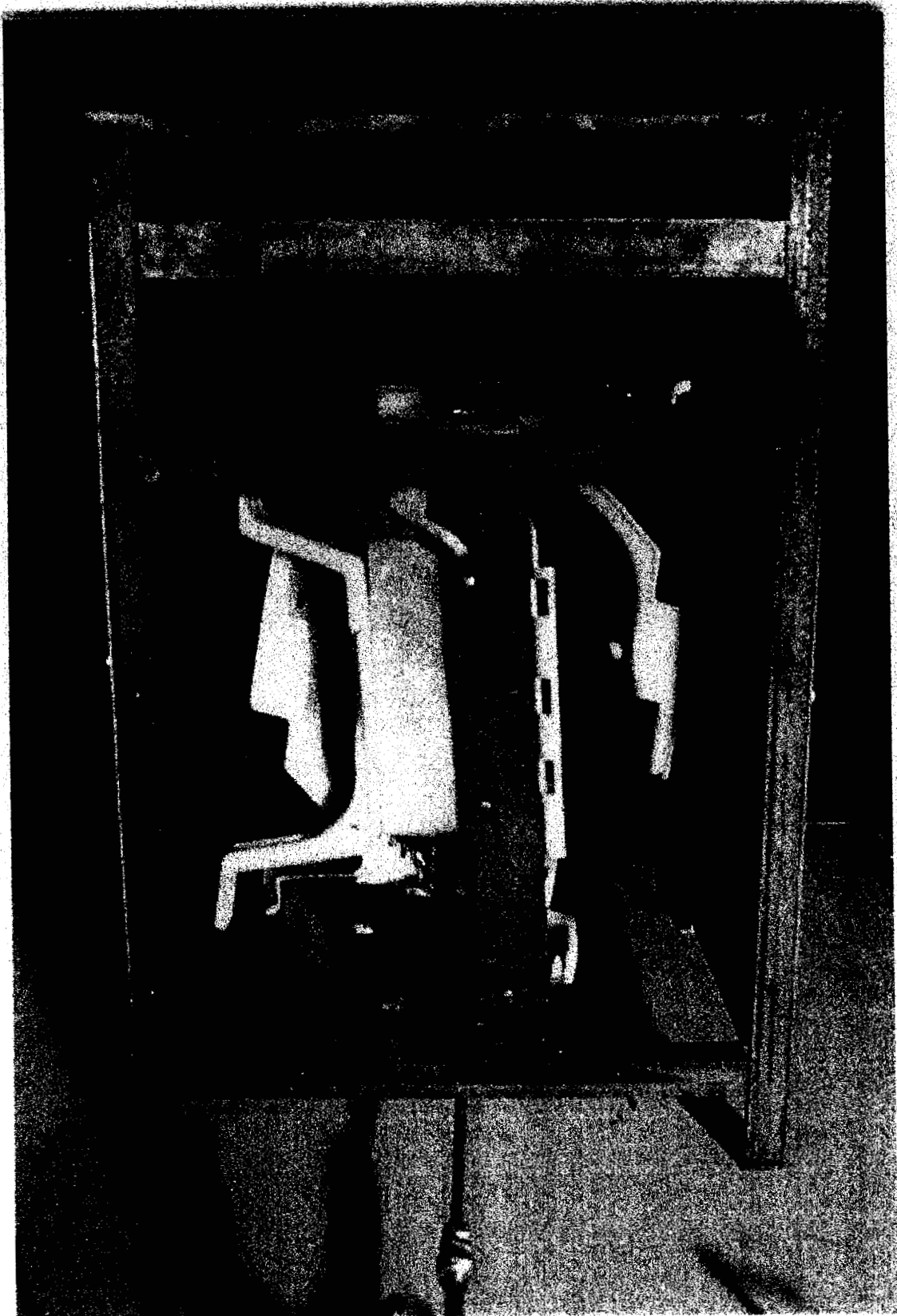


Figure 4b View of three part assembly installed in box; one side removed.

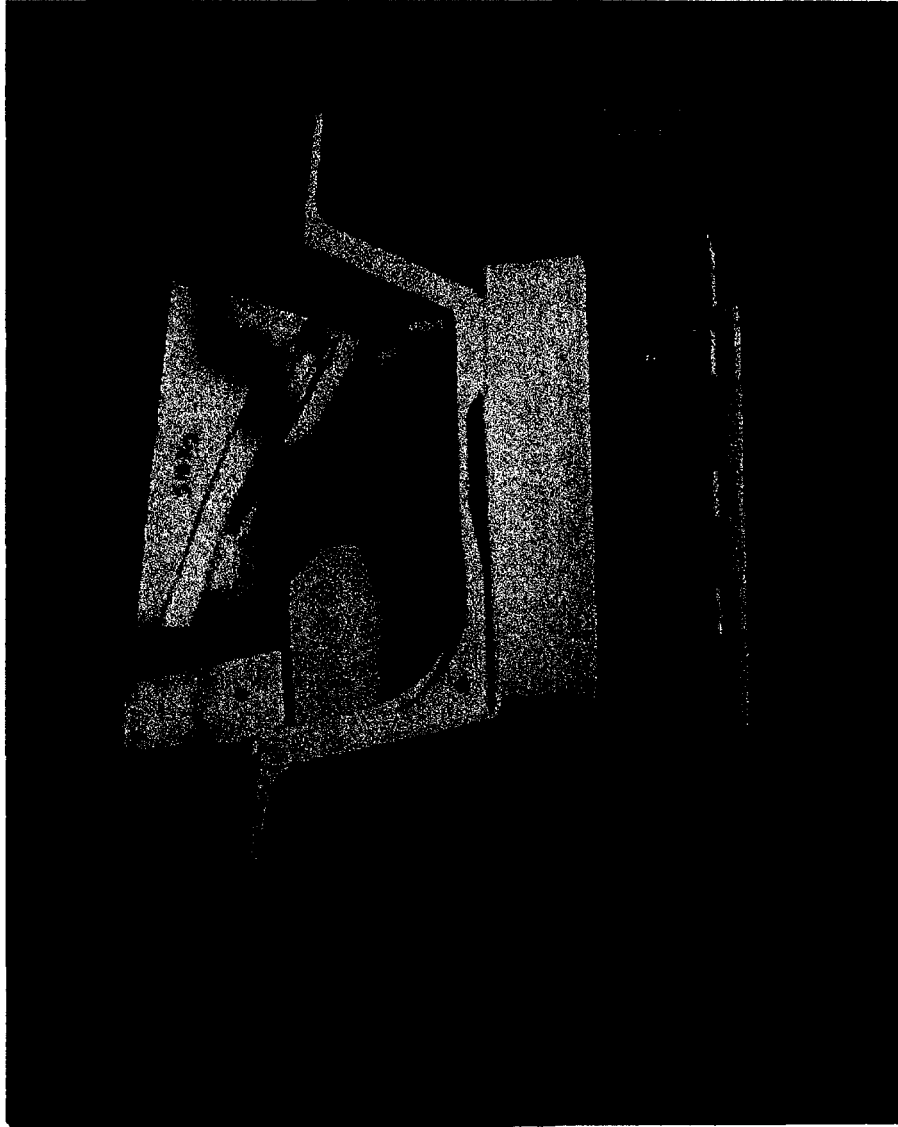


Figure 4c Top view of three part array. Hole through to bottom of array occupies about 10% of the dark area seen in the center of the assembled parts.

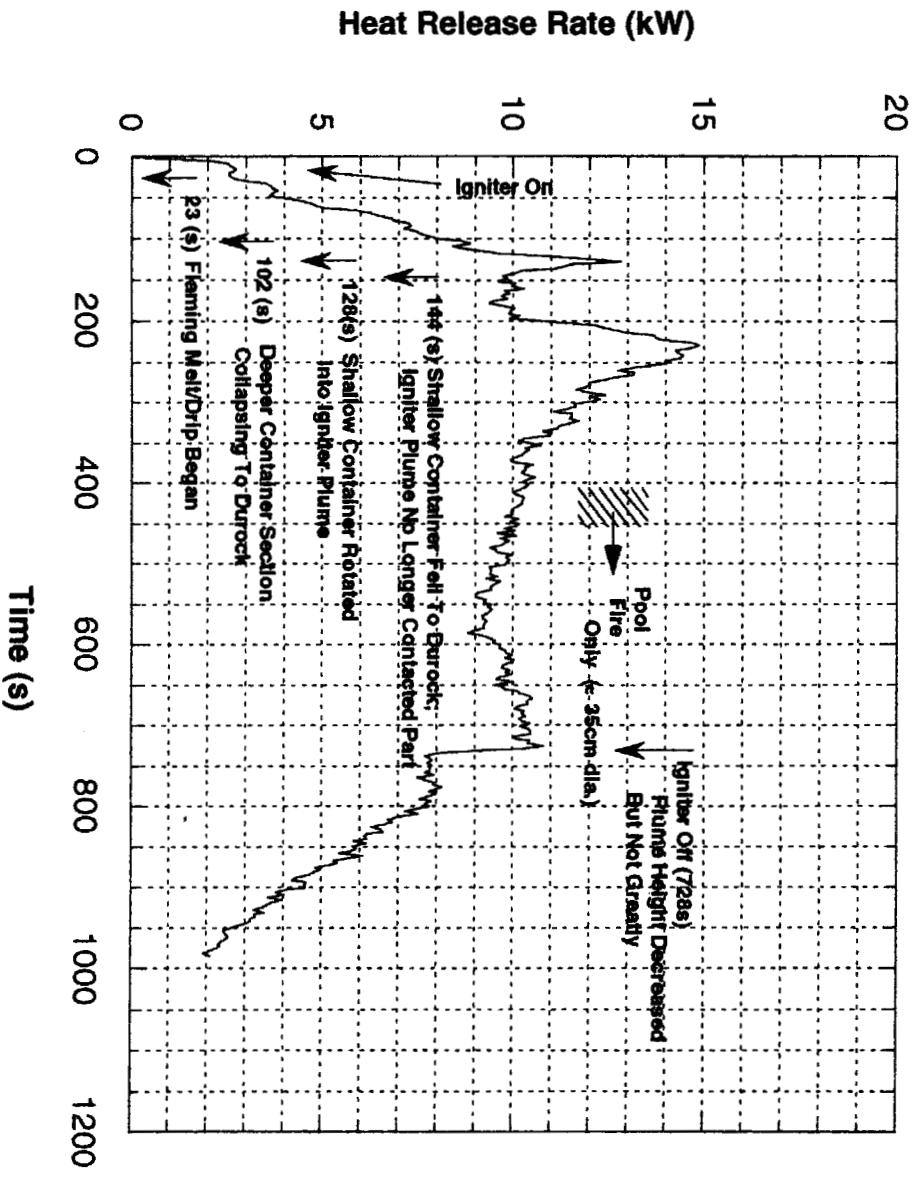


Figure 5a. Heat release rate for an unretarded polypropylene-based standard part in configuration 1.



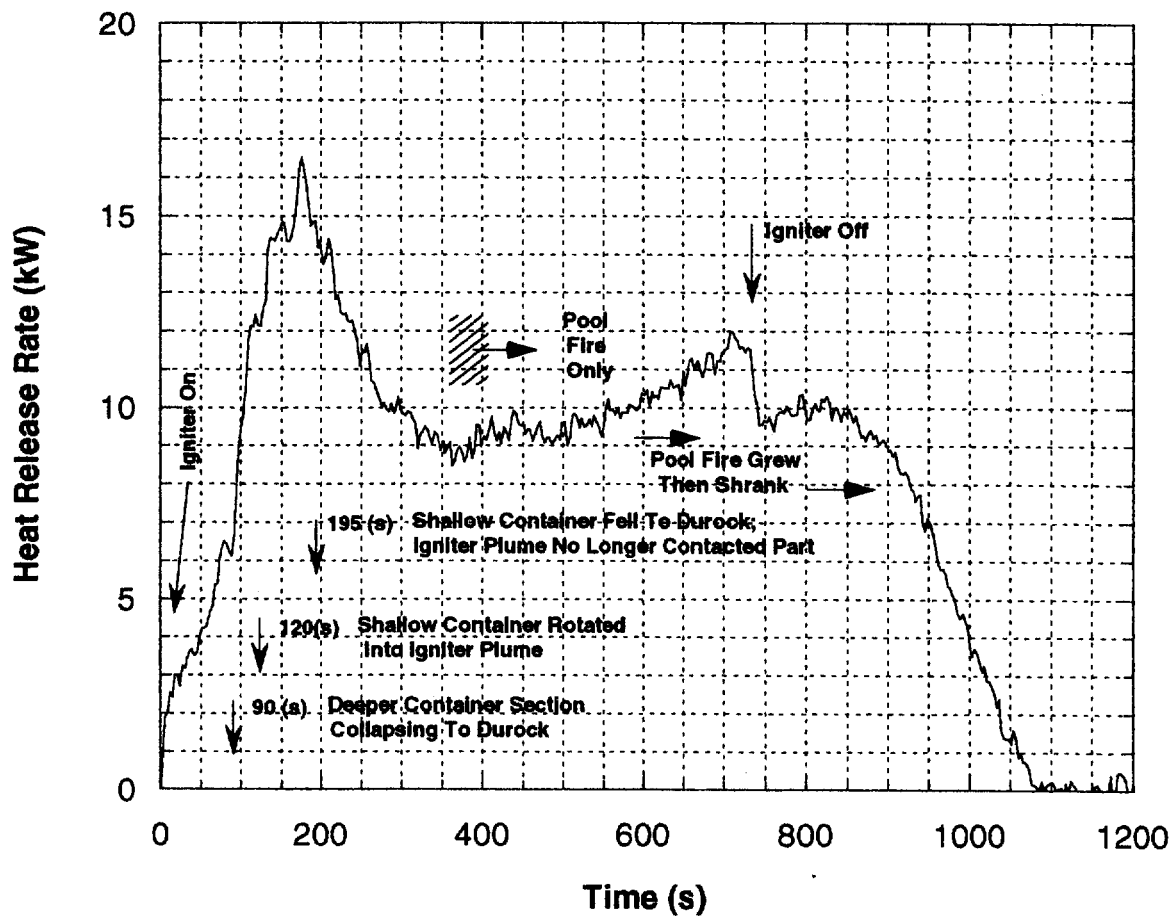


Figure 5b. Heat release rate for an unretarded polypropylene-based standard part in configuration 1 (replicate).

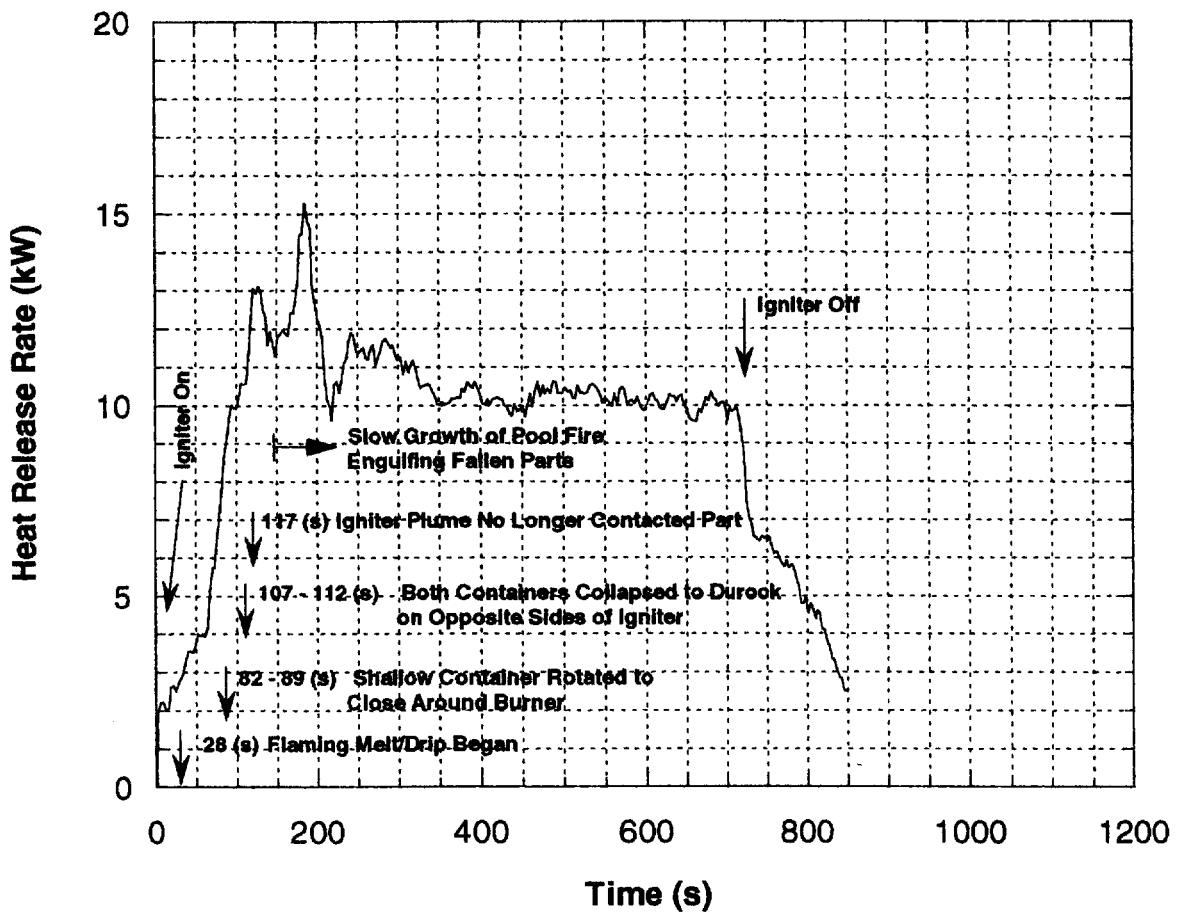


Figure 6a. Heat release rate for an unretarded polypropylene-based standard part in configuration 2.

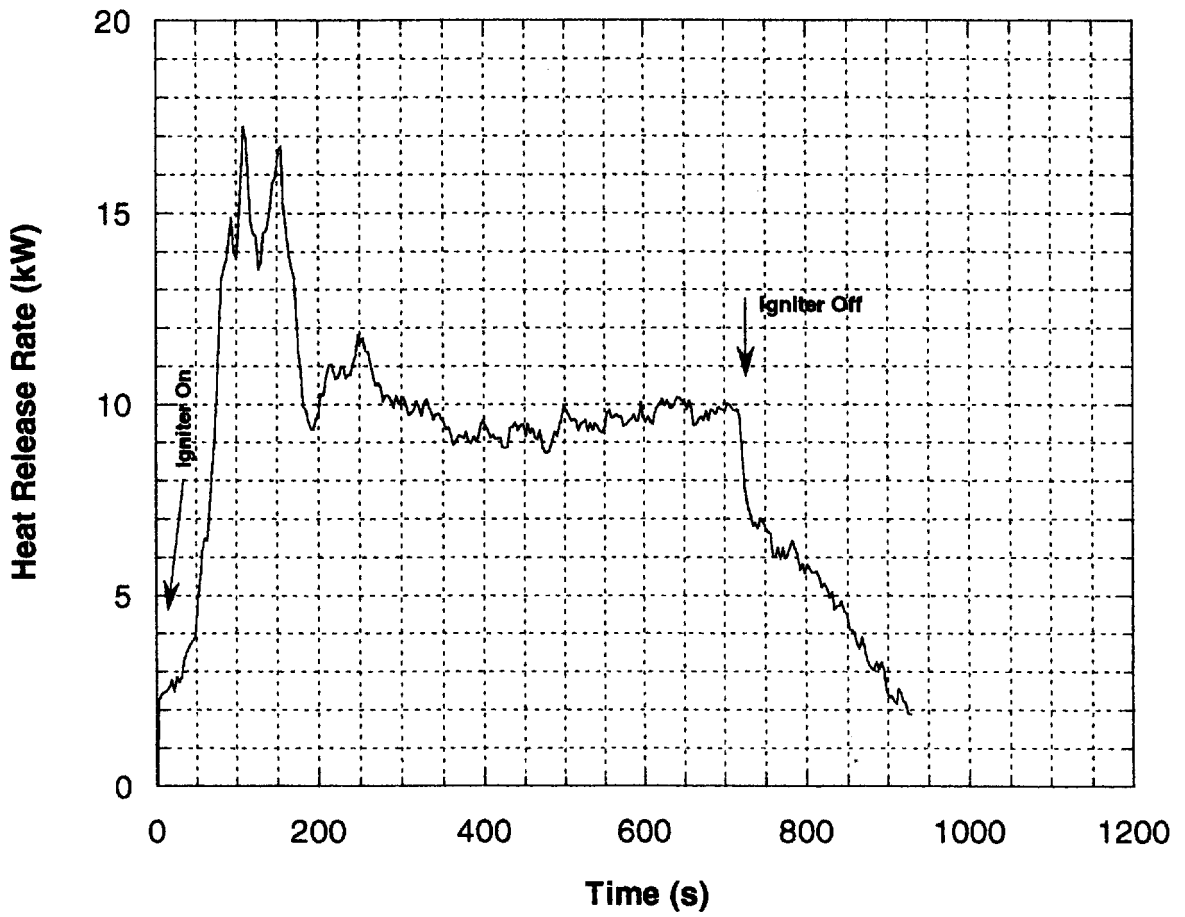


Figure 6b. Heat release rate for an unretarded polypropylene-based standard part in configuration 2 (replicate).

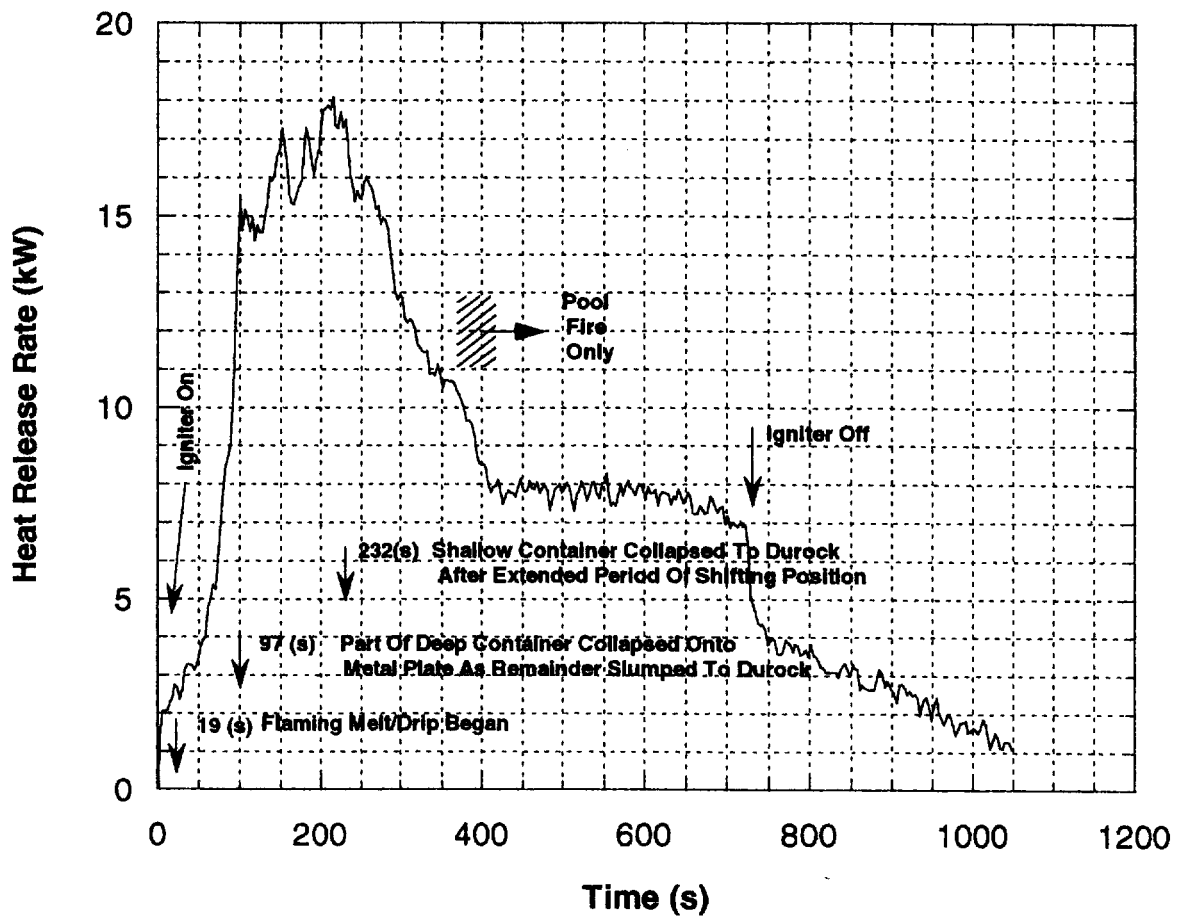


Figure 7a. Heat release rate for an unretarded polypropylene-based standard part in configuration 3.

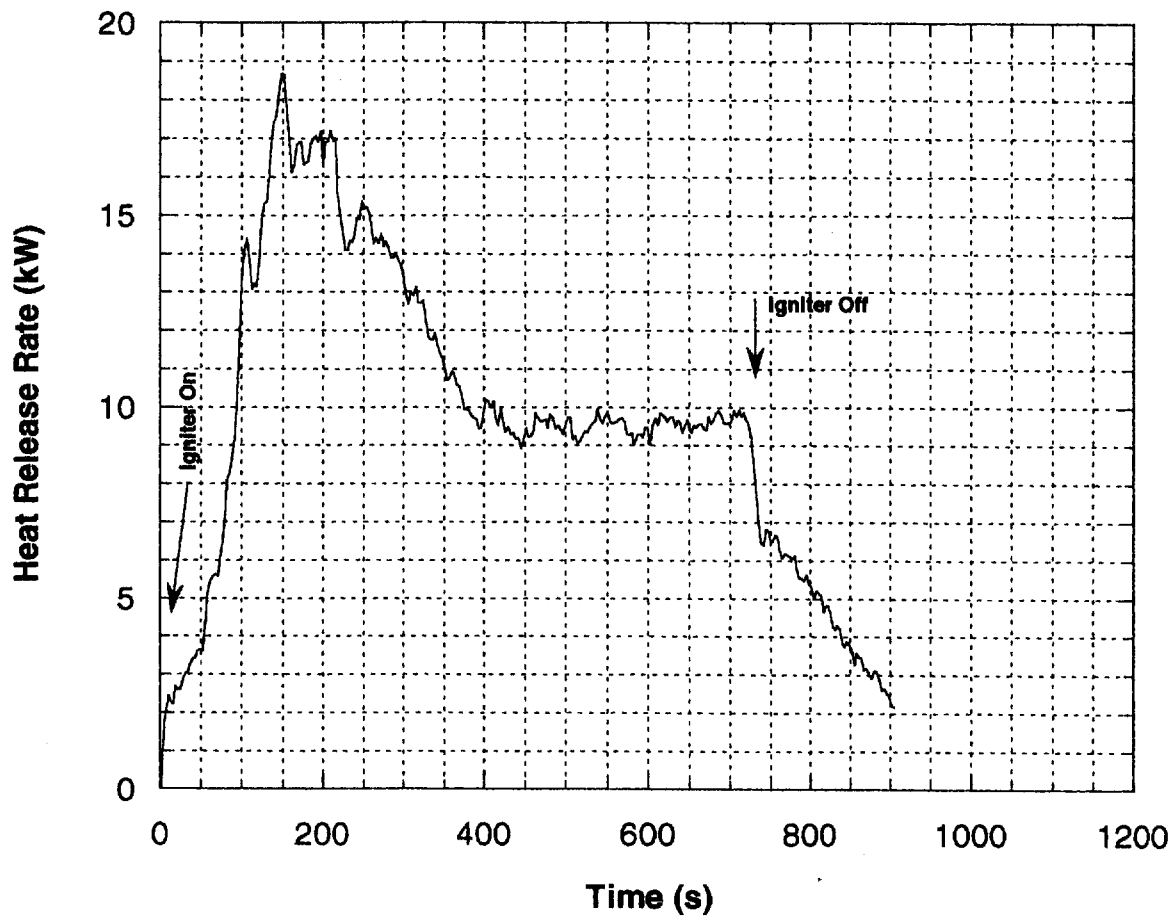


Figure 7b. Heat release rate for an unretarded polypropylene-based standard part in configuration 3 (replicate).

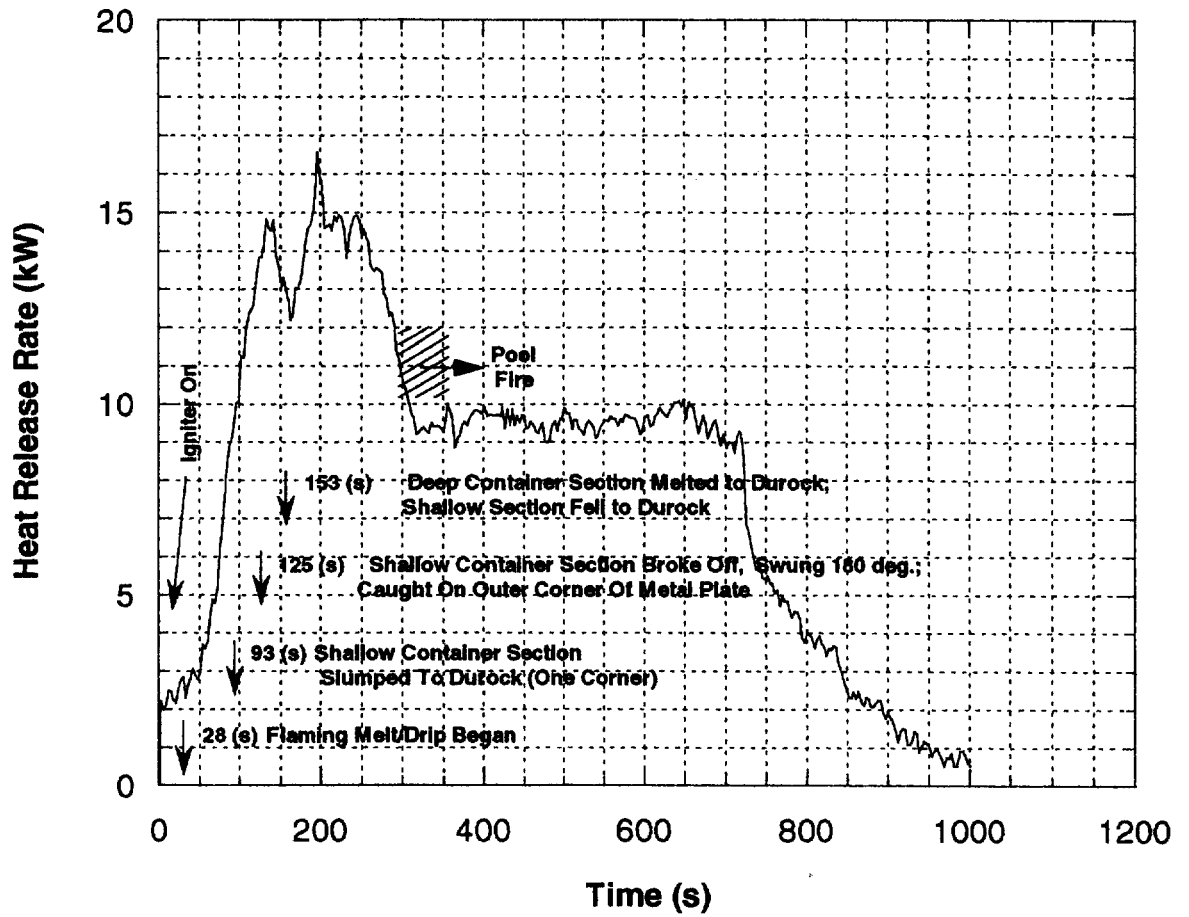


Figure 8a. Heat release rate for an unretarded polypropylene-based standard part in configuration 4 .

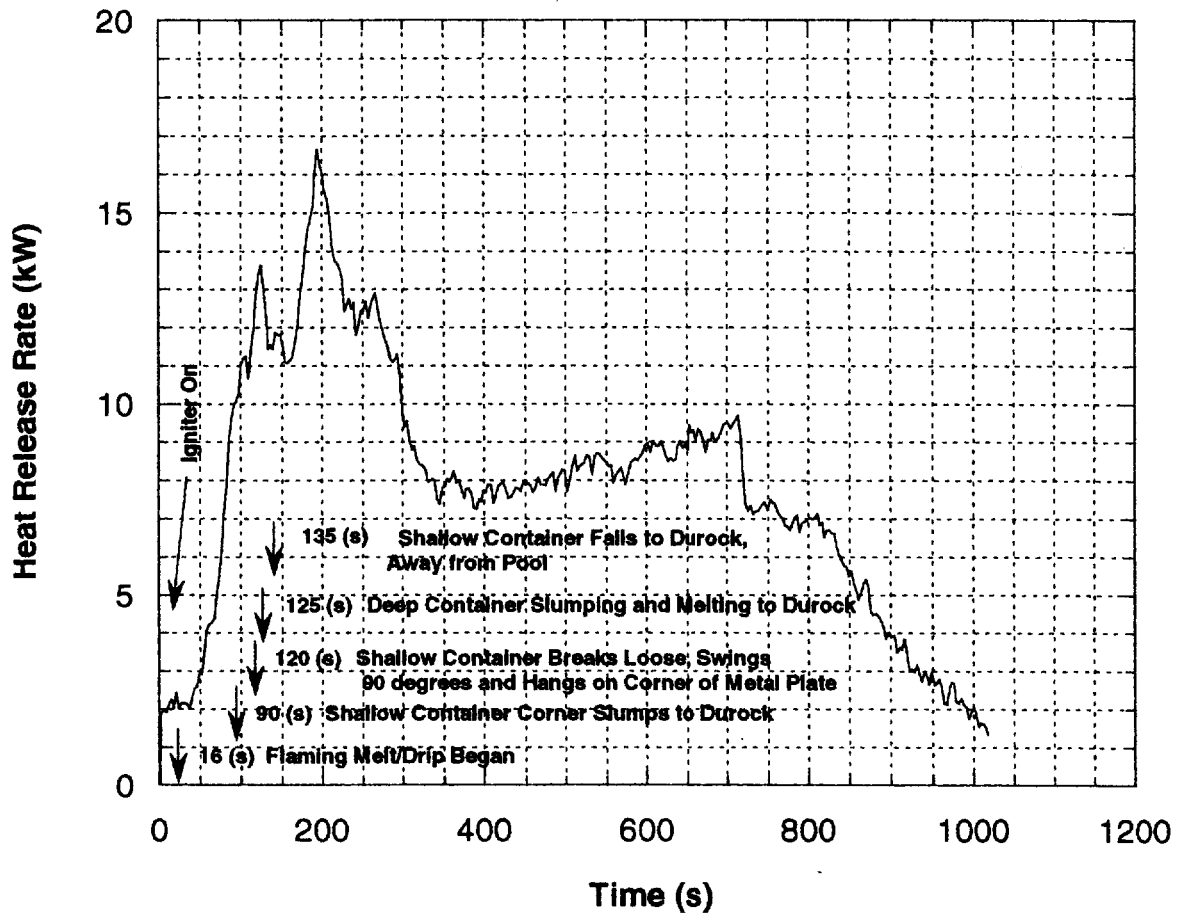


Figure 8b. Heat release rate for an unretarded polypropylene-based standard part in configuration 4 (replicate).

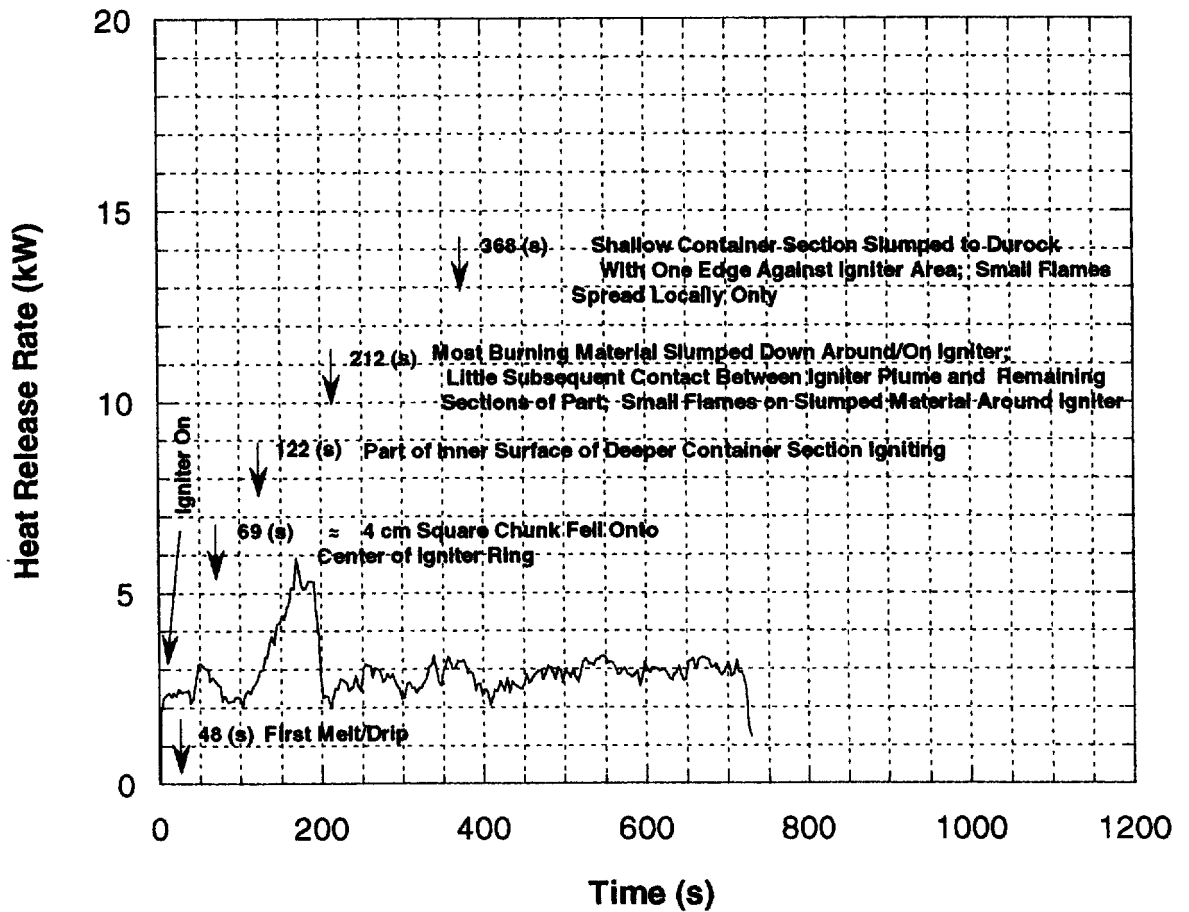


Figure 9a. Heat release rate for a flame-retarded polypropylene-based standard part in configuration 3.



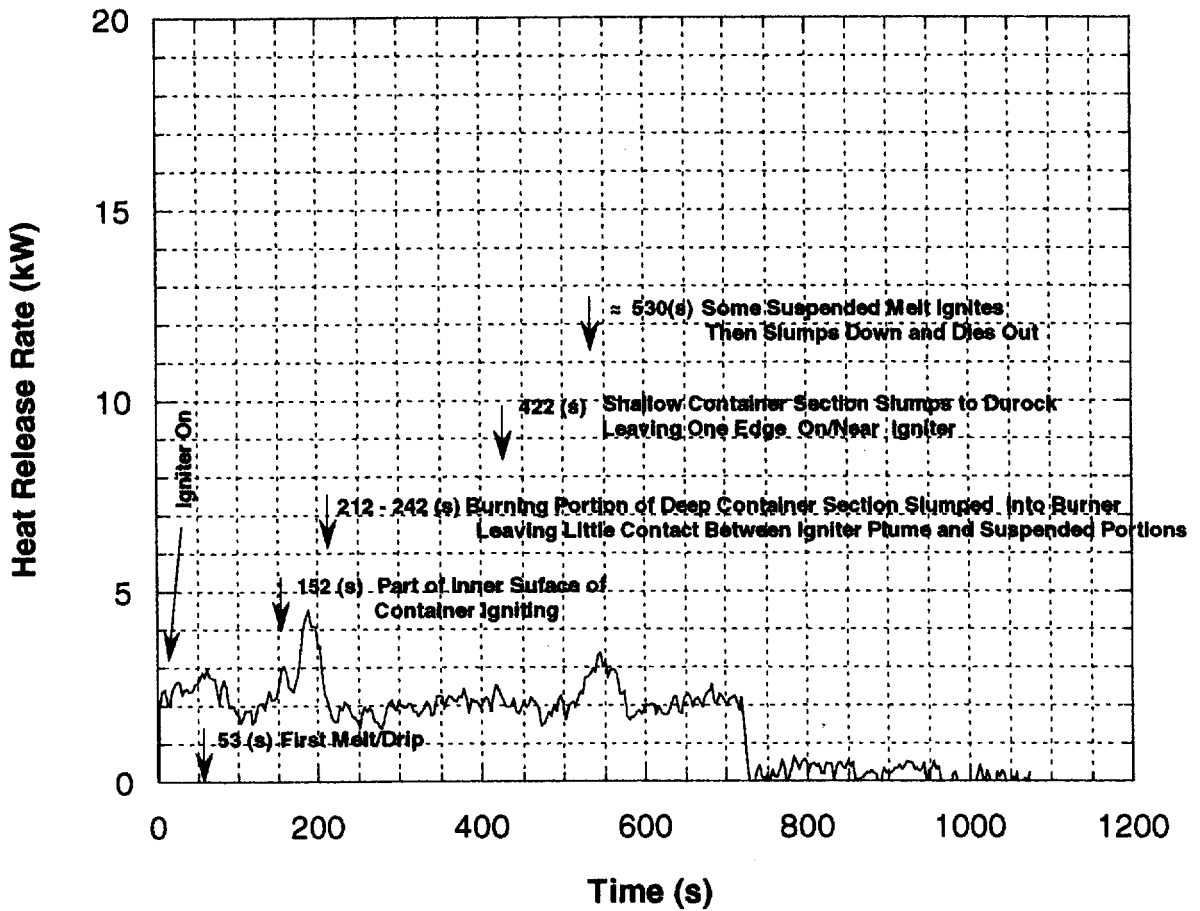


Figure 9b. Heat release rate for a flame-retarded polypropylene-based standard part in configuration 3 (Replicate).

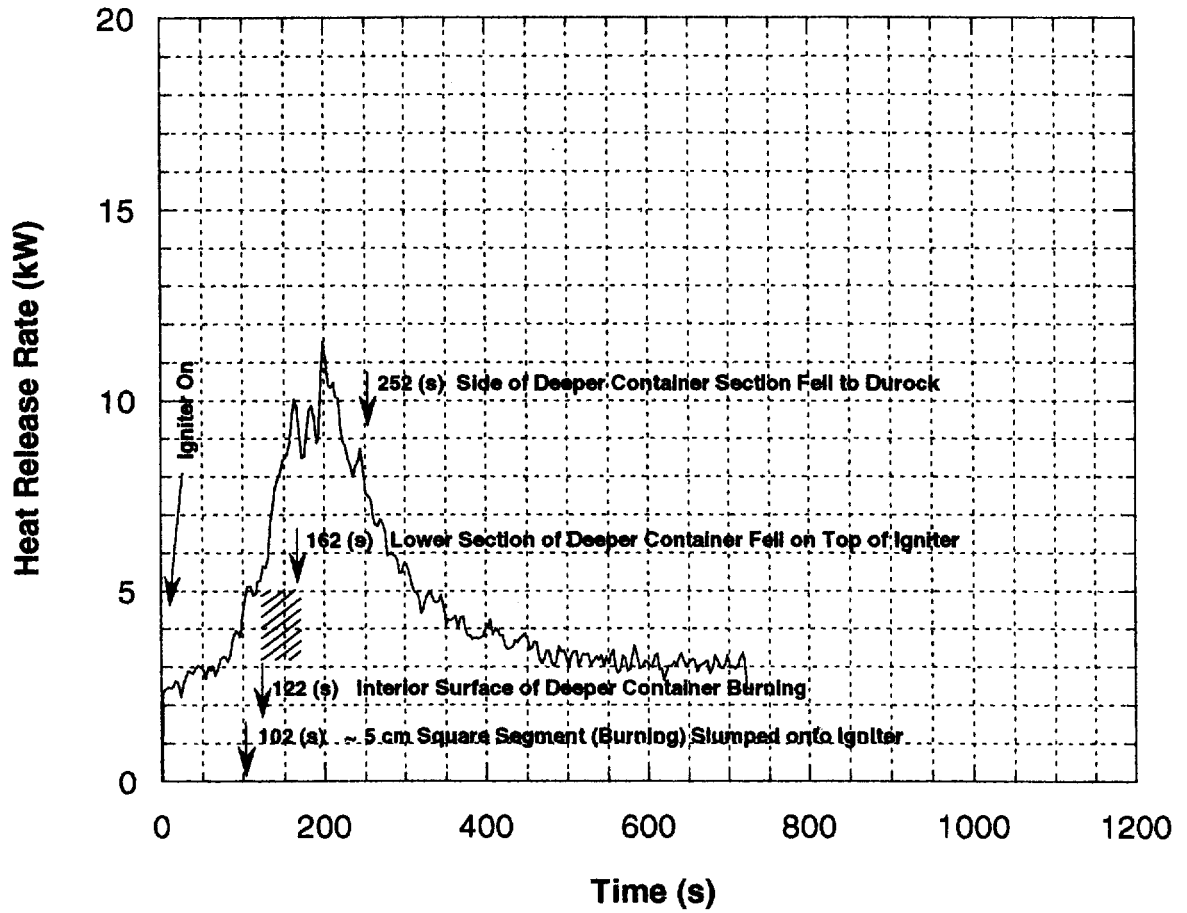


Figure 10a. Heat release rate for a flame-retarded nylon-based standard part in configuration 3.

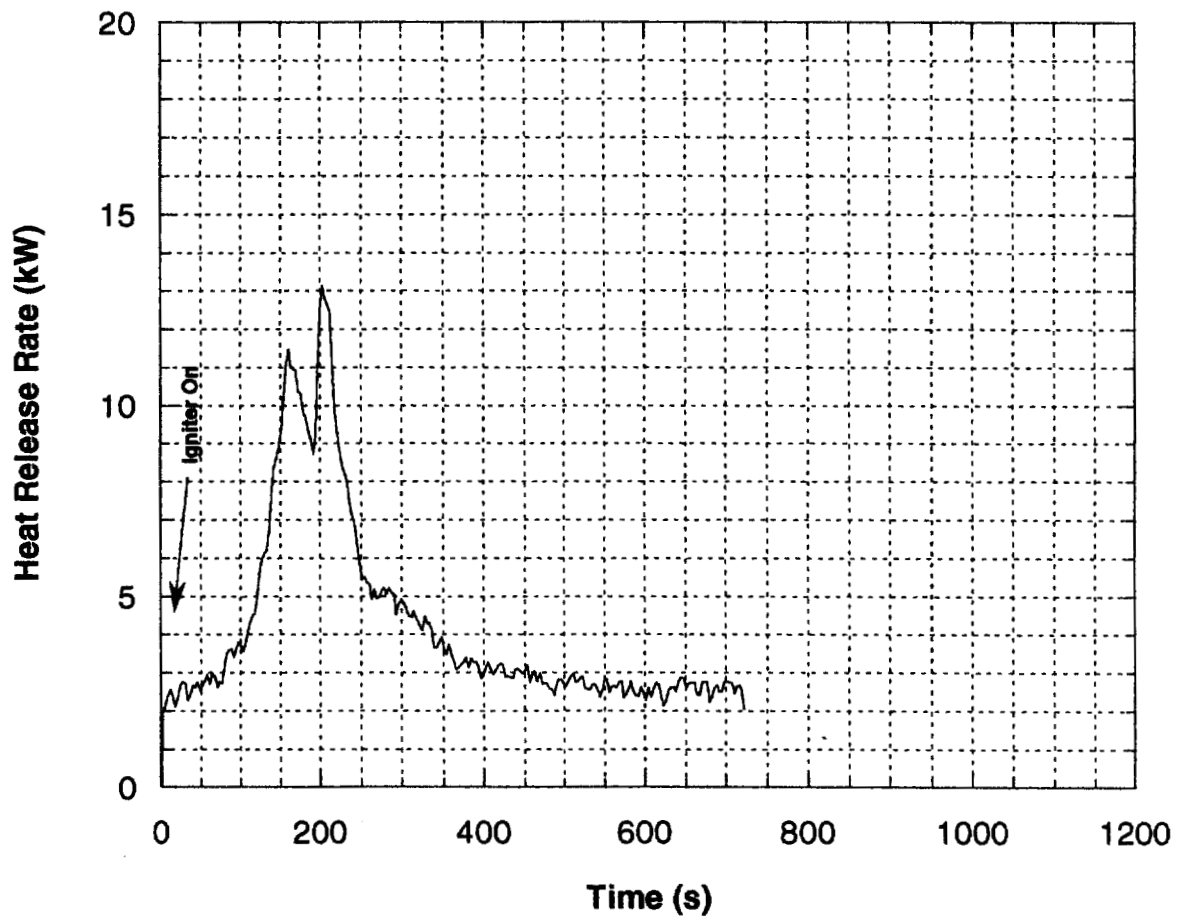


Figure 10b. Heat release rate for a flame-retarded nylon-based standard part in configuration 3 (replicate).

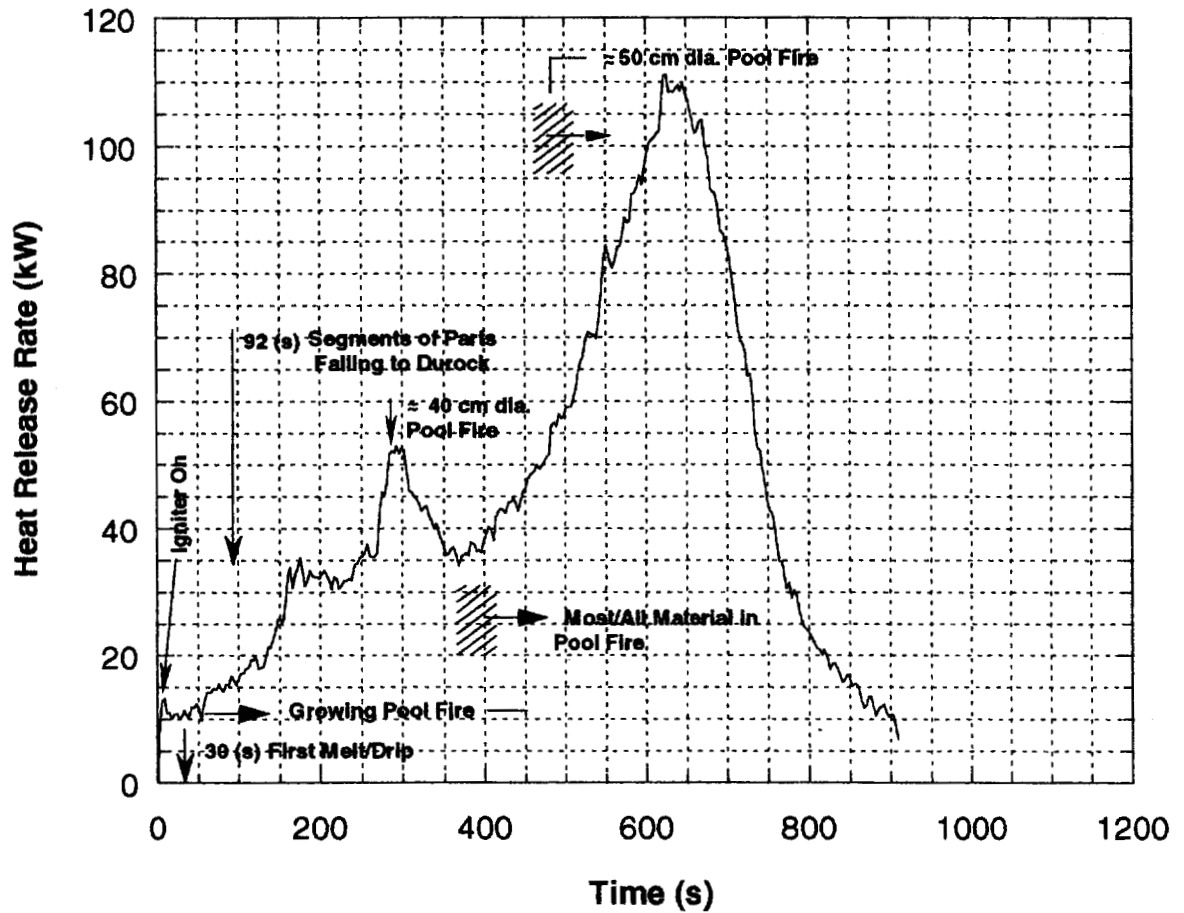


Figure 11a. Heat release rate for an array of three standard parts in an enclosure (all parts composed of a unretarded polypropylene-based formulation).

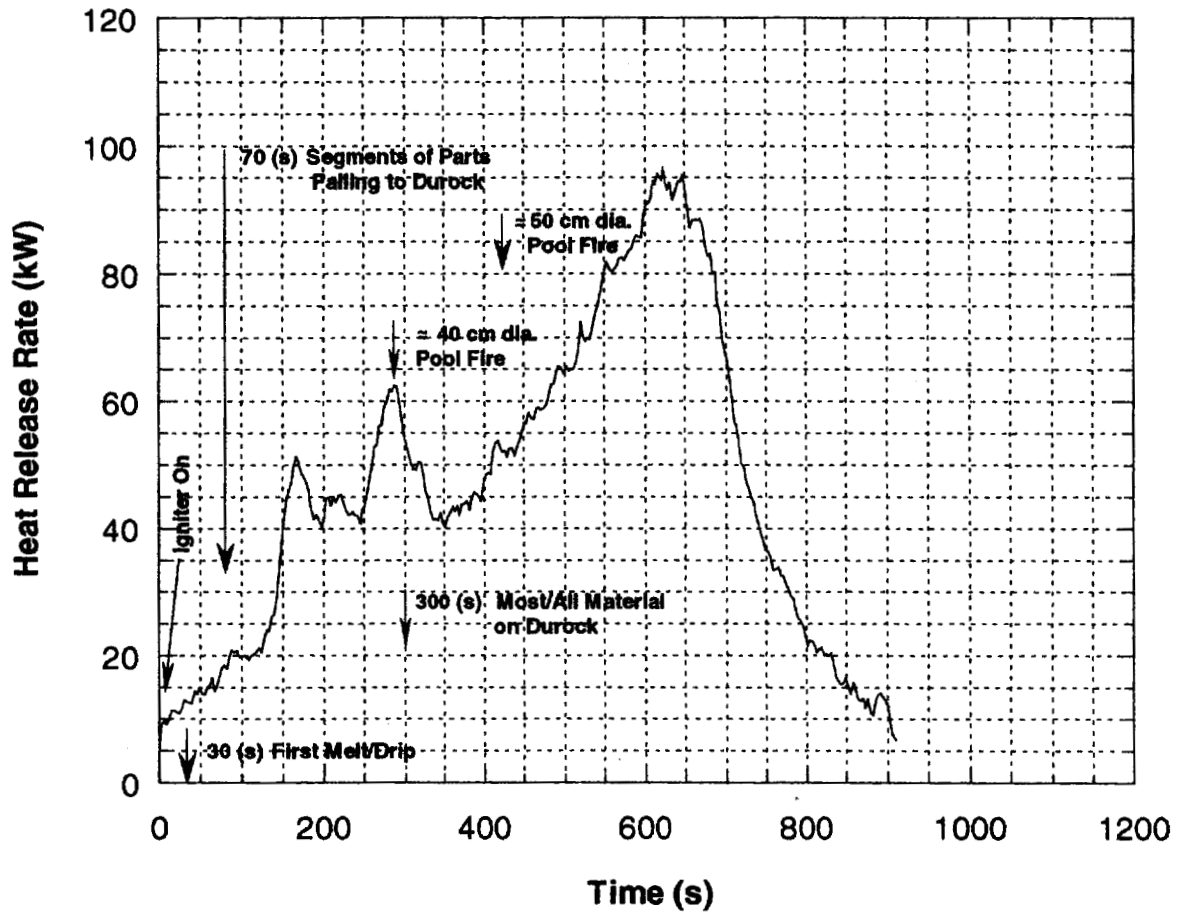


Figure 11b. Heat release rate for an array of three standard parts in an enclosure (all parts composed of a unretarded polypropylene-based formulation); replicate.

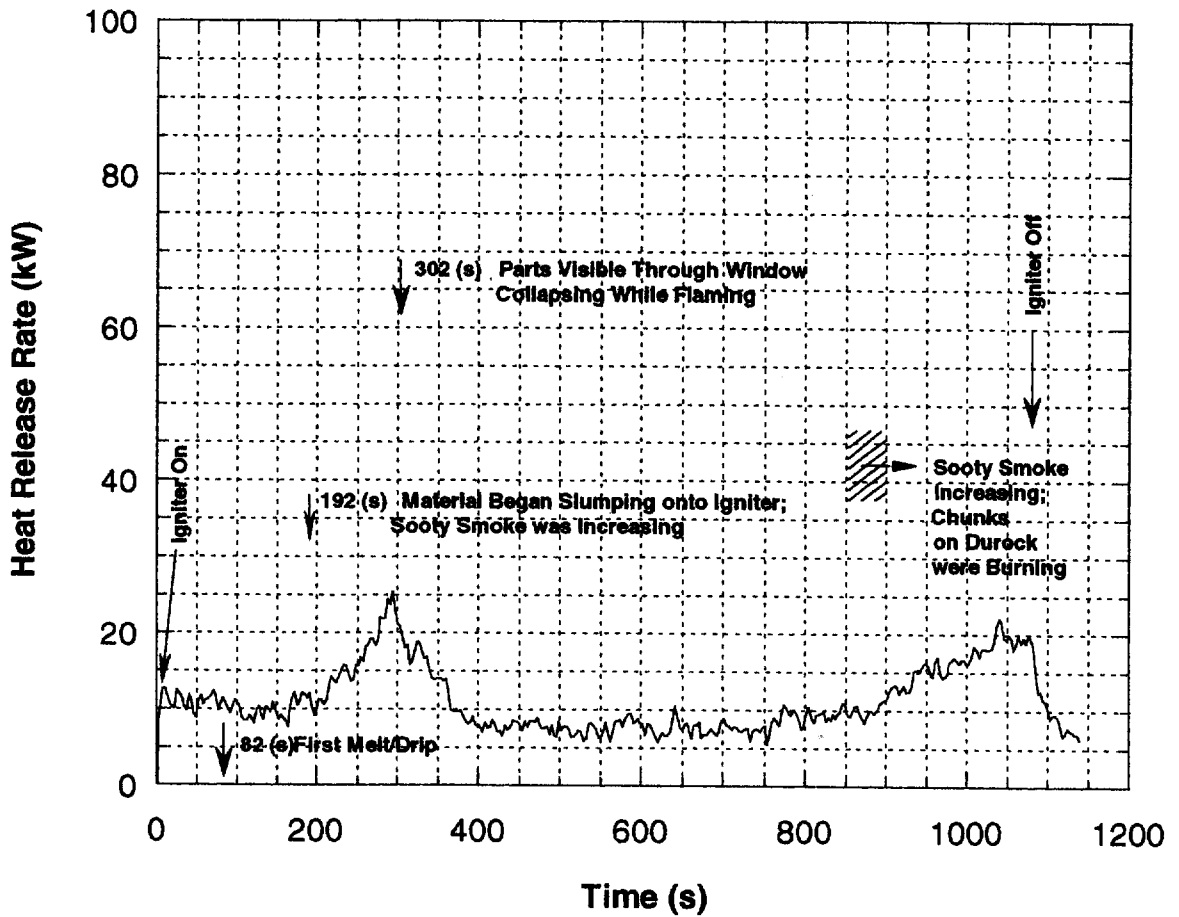


Figure 12a. Heat release rate for an array of three standard parts in an enclosure (all parts composed of a flame-retarded polypropylene-based formulation).

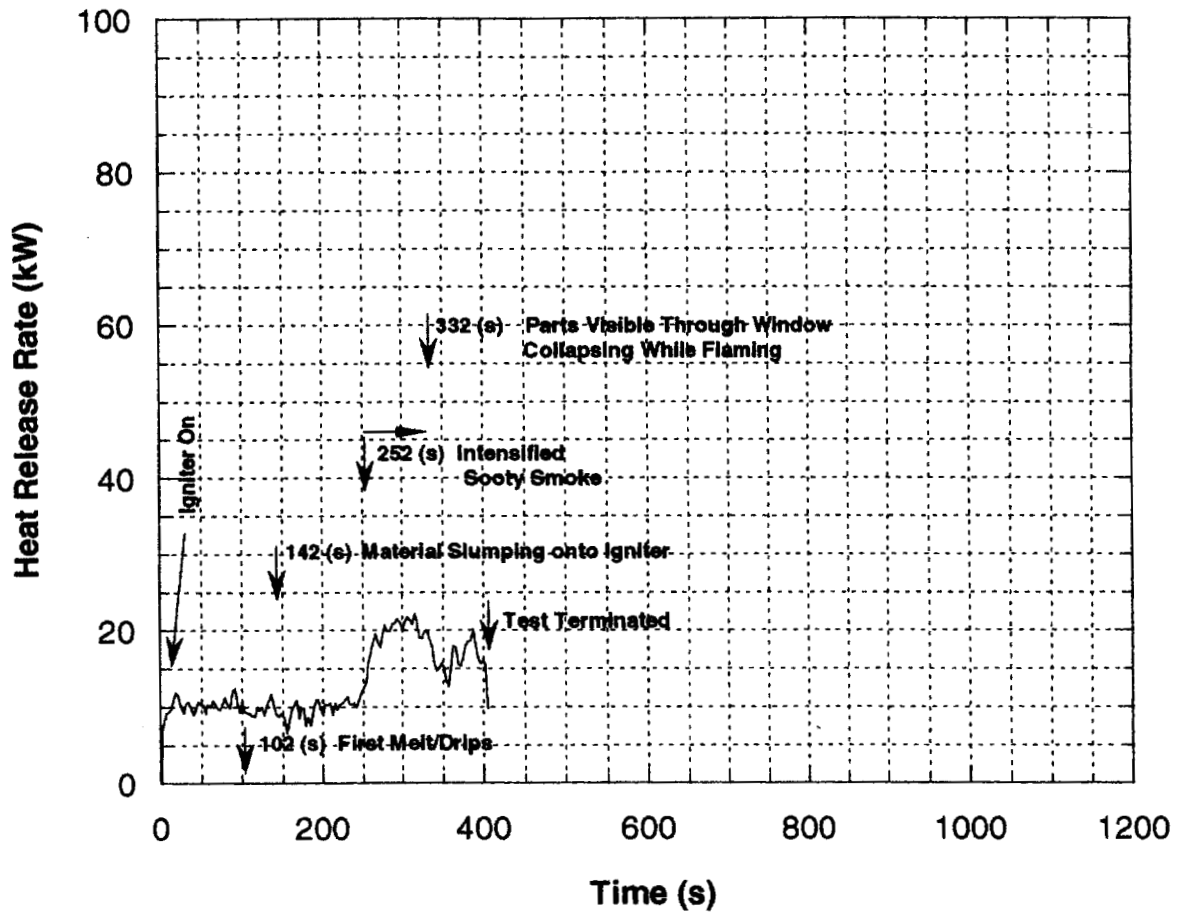


Figure 12b. Heat release rate for an array of three standard parts in an enclosure (all parts composed of a flame-retarded polypropylene-based formulation); replicate. Test terminated due to excessive smoke venting.

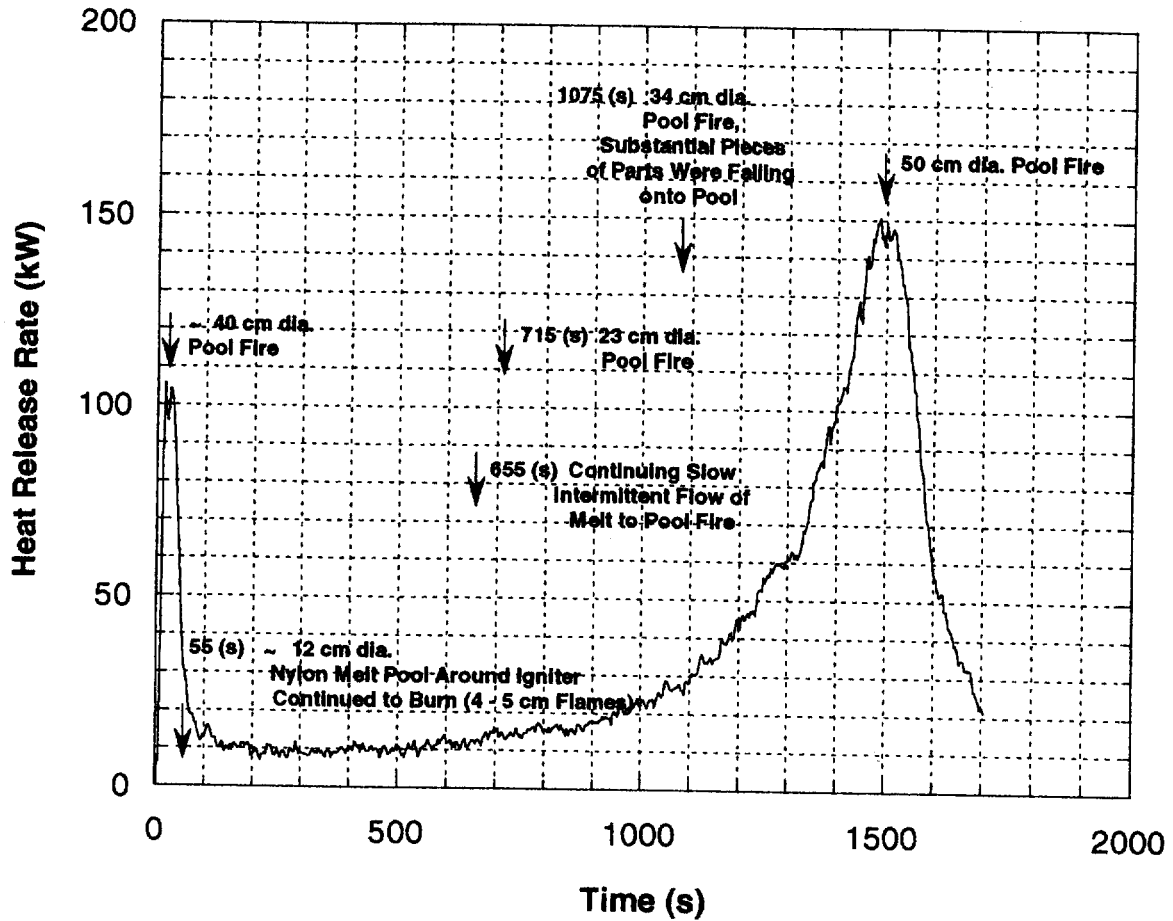


Figure 13. Heat release rate for an array of three standard parts in an enclosure (all parts composed of a non-flame retarded nylon-based formulation). Gas Igniter was supplemented by 300 cc of 50/50 (vol./vol.) motor oil - heptane mix; see text.



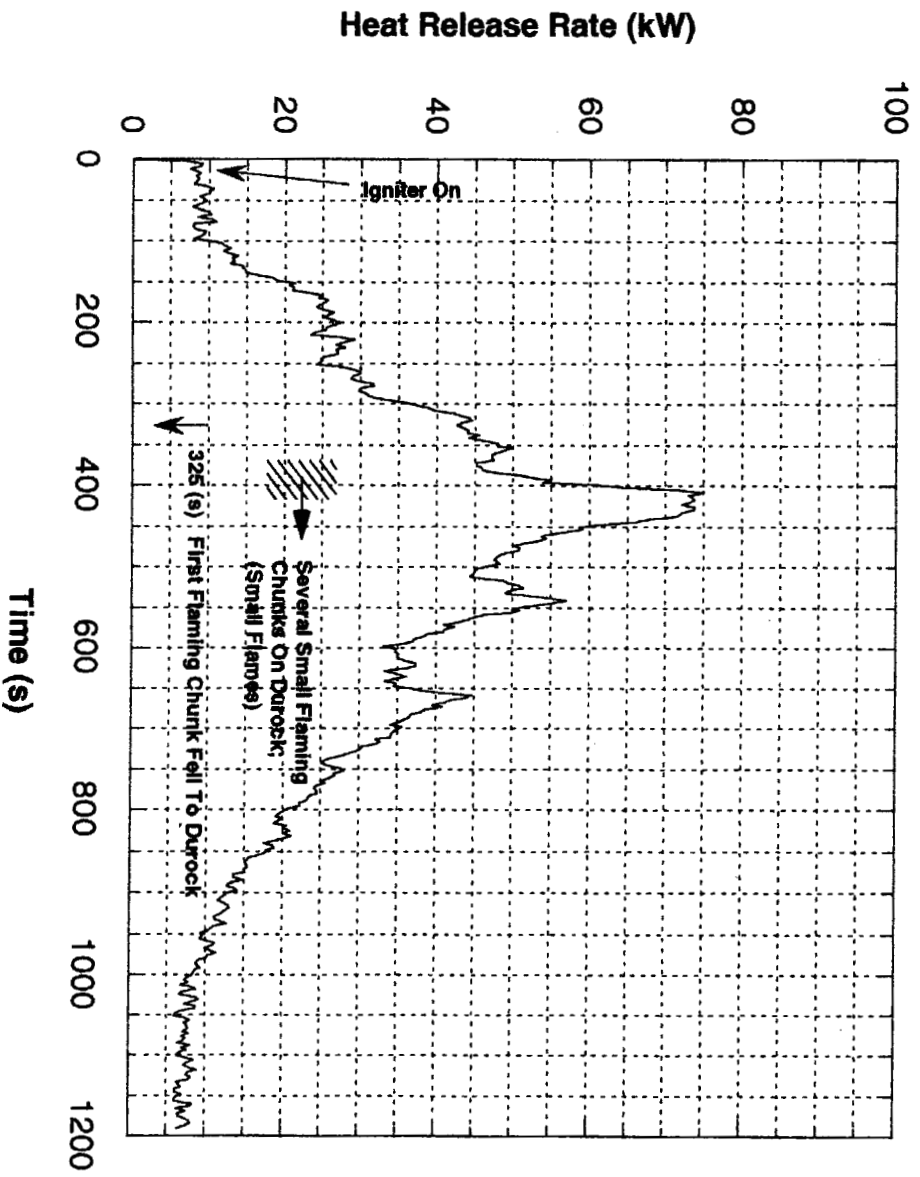


Figure 14a. Heat release rate for an array of three standard parts in an enclosure (all parts composed of a flame-retarded nylon-based formulation).

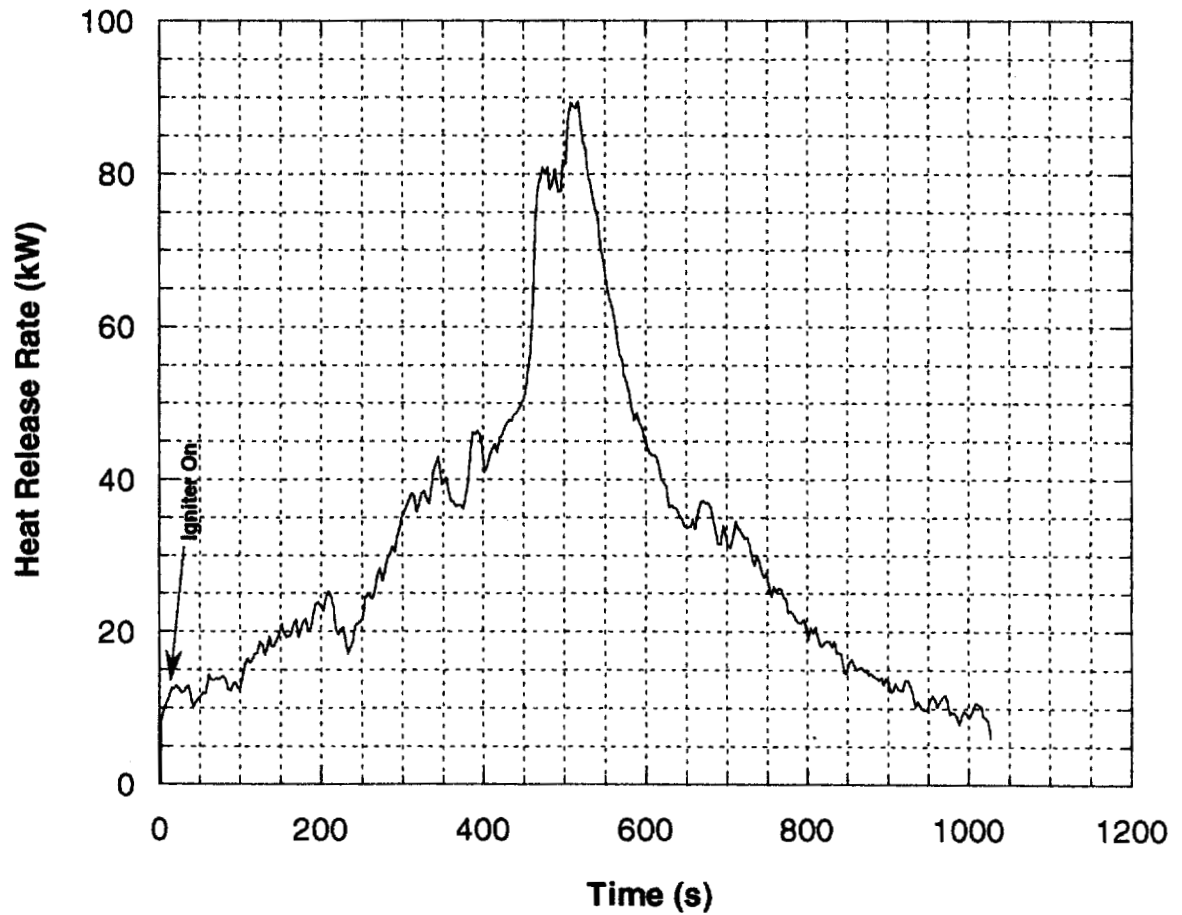


Figure 14b. Heat release rate for an array of three standard parts in an enclosure (all parts composed of a flame-retarded nylon-based formulation); replicate.