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AN INVESTIGATION OF THE EFFECTIVENESS OF FIRE RESISTANT DURABLE AGENTS ON RESIDENTIAL SIDING USING AN ICAL-BASED TESTING PROTOCOL

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Prepared for
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Notice

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An Investigation of the Effectiveness of Fire Resistant Durable Agents on Residential Siding Using an ICAL-Based Testing Protocol

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OMEGA POINT LABORATORIES

Abstract

A test protocol based on the Intermediate Scale Heat Release Calorimeter (ICAL) was used to evaluate the potential fire retardant effects of two water-based durable agents applied to wood, to plastic (vinyl) siding and to small windows mounted into wood siding. The protocol included exposure of one meter square specimens to constant heat fluxes of 15 and 25 kW/m^2 in the presence of an open-flame ignition source. Wood panels treated with the fire-retarding gel were compared to untreated panels and to panels treated only with water. Time delay to ignition of the specimen was the primary measured property, while mass changes prior to and during the fire exposure were recorded. The gel treatments extended the times to ignition of painted wood siding from around 30 seconds for untreated panels to more than 300 seconds of exposure at 25 kW/m^2. Drying the treated panels at 1 kW/m^2 for an hour generally did not significantly affect the performance of treated panels with respect to times to ignition.

The description of the test specimen and the results presented herein are true and correct to the best of our knowledge and within the bounds of normal engineering methods and techniques.

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INTRODUCTION

Wildland/urban interface fires are a unique problem in fire research and testing. Generally, fires in buildings start with fires from inside, rather than outside, the structure. One exception to this is NFPA 268, which deals with the issue of flammability of siding, usually in commercial buildings. In that test method, specimens are exposed to a 12.5 kW/m^2 radiant flux to simulate being near a building on fire. The wildland fire environment is not normally considered in problems related to buildings, especially housing. While "permanent" fire retardant treatments and coatings exist, it would be impractical to treat the exteriors of all buildings to be resistant to wildland fires. However, temporary treatments, such as water-based fire retarding agents, have been used to protect structures during wildland fires.

There are two primary means of attack on a structure by a wildland fire: radiant heat and burning brands. In the case of radiant heat, a heat flux of 25 kW/m^2 will ignite wood structures, even without a distinct ignition source. Heat fluxes down to about 15 kW/m^2, in the presence of an ignition source, will also ignite unprotected wood. Burning brands tend to collect in protected areas, such as under eaves and in corners. Allowed to burn, these brands could be sufficient to start a fire along the exterior of the house. Without any protection or treatment, the wood structure, once started, probably will continue to burn.

Recently, durable agents and water-based gels have been used to protect homes against the threat of wildland fires[1]. Without any standards, or even very much research, it is difficult to demonstrate the efficacy of these agents. Internal research studies at BFRL/NIST[23] included treatment of wood siding and exposure to moderately high intensity fire sources. A recent study at Omega Point Laboratories, Inc.[4] , sponsored by NIST, was a preliminary program to determine the feasibility of using the ICAL test apparatus (ASTM E1623) to characterize the efficacy of temporary, water-based, spray-on fire retardant treatments for wood and plastic sidings. Notes in the following report to "the previous OPL study" refer to this preliminary phase of the program.

OBJECTIVES

The objectives of the proposed study are to develop a standard test protocol for the evaluation of durable agents applied to residential structures and to develop research data on the technology for protecting these structures in order to extrapolate the data beyond laboratory scale. Acceptability criteria will need to be established for a standard test protocol, based on results for water-based treatments on wood and other siding materials. The information developed in this study should be beneficial to the development and testing of temporary fire retarding agents for the protection of residential structures from wildland fires.

Several potential fire scenarios can be replicated by the ICAL radiant panel, including the following: burning brands in close proximity to the siding, burning shrubbery near the house, mild to moderate radiant heat from the wildland fire, and intense radiation for a relatively brief duration.

APPARATUS

The ICAL apparatus at Omega Point Laboratories is in conformance with the principles of ASTM E1623, but is not in strict accord with the current version of the standard (which is in need of some modification). This apparatus includes an approximately 1.5 m x 1.5 m propane-fired radiant panel, the means to measure heat flux across the surface of a specimen as a function of distance from the panel, a load cell on a moveable cart, and an exhaust hood.

A schematic drawing of the modified specimen support frame, which was developed during the previous OPL study and altered slightly in this study, is shown in Figure 1. The previous modifications enabled the full specimen surface to be available for treatment and exposure (whereas the normal ICAL specimen holder wraps around the edges of the specimen). The modifications performed during the present program enabled the specimen support frame to be lifted onto the load cell platform after the specimen was sprayed with the gel-water mixture. Thus, the specimens could be sprayed in one area, wheeled on a cart to the exposure area, then lifted onto the load cell in preparation for the heat flux exposure regimen.

A propane "T" burner, the same as used in the mattress standard test method California Technical Bulletin 129, was used as the igniter for the specimens. The burner was positioned near the bottom of the specimen, and adjusted so that the flames were near, but not in direct contact with, the surface of the specimen (Figure 2). This is the same type of burner and orientation used in the previous OPL study.

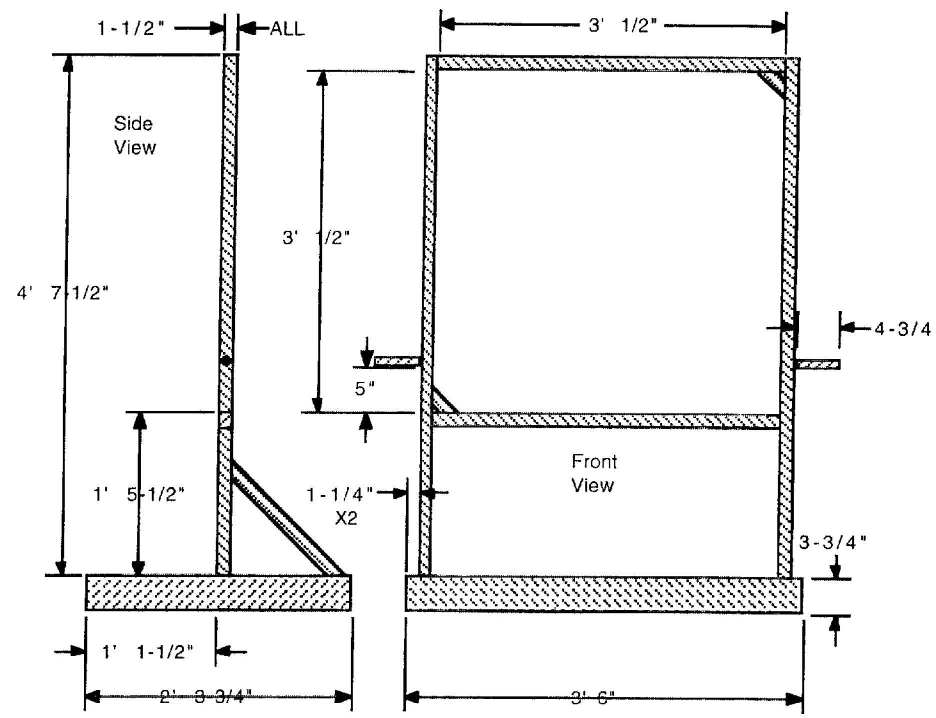

Figure 1. Specimen support frame

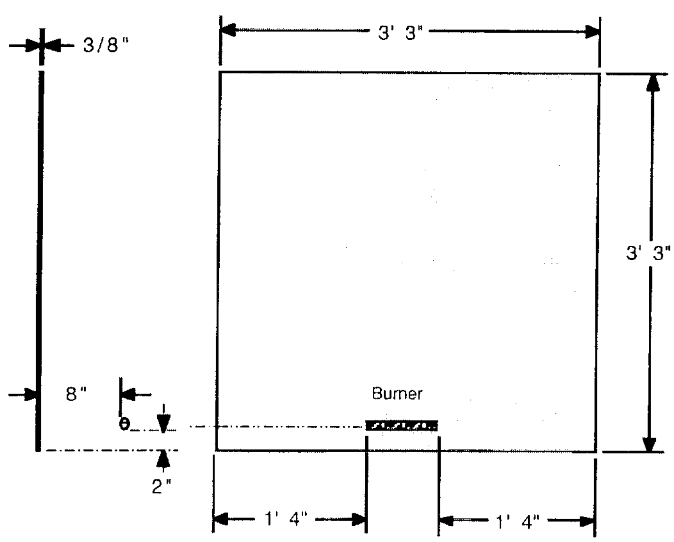

Figure 2. Location of ignition burner with respect to specimen, side view (left) and front view (right)

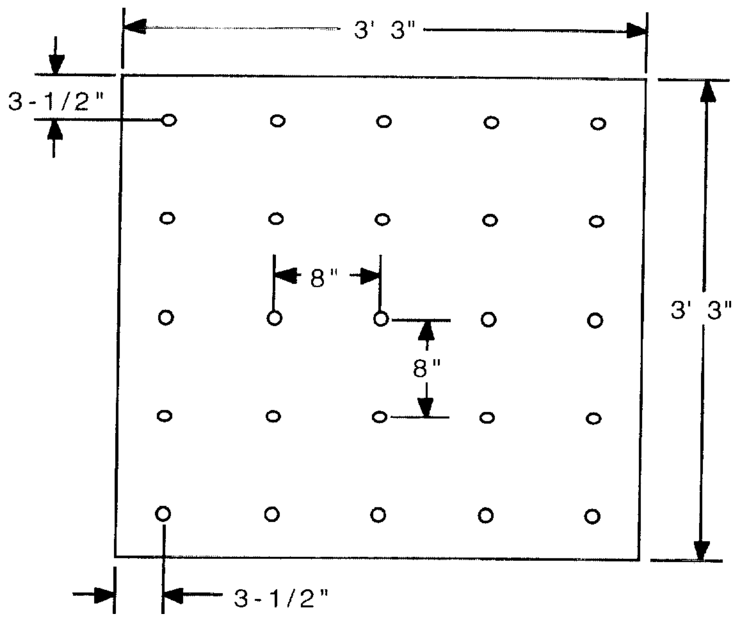

Figure 3. Calcium Silicate calibration board

To achieve accurate, average heat flux values during calibration, a calcium silicate board with 25 calibration holes was used. The physical dimensions of the board are shown in Figure 3. The multi-port calibration board is similar to the one used in ASTM E1623.

The modifications to the standard ICAL apparatus and test method (ASTM E1623) for this program may be summarized as follows:

1) The specimen support frame was modified to permit presentation of the complete surface area of the specimen, both for treatment and for exposure to the radiant heat (as described above and in Figure 1). Also, "handles" on the support frame permitted spraying the test panel in one location, then moving it onto the load cell for heat flux exposure.
2) Propane was used instead of methane for the radiant panel.
3) An open-flame burner (from CA TB 129) was used (Figure 2), instead of hot wire igniters.
4) The ICAL radiant panel was calibrated (Figure 3) to achieve a range of heat fluxes from a maximum of 25 kW/m^2 to as low as 1

kW/m^2 (the usual test method requires heat flux calibration up to 50 kW/m^2).

5) The actual fire exposure was conducted for as long as necessary to evaluate the efficacy of the coating as exhibited by delayed time to ignition of the substrate. The test was terminated soon after ignition. (In the standard ICAL test method, the important part of the experiment does not start until ignition).
6) Heat release measurements were not taken for these tests.

MEASUREMENTS

The primary measurements sought during these tests are listed below:

1. Time to smoke, ignition, and full flaming over the surface of the specimen under the selected heat flux exposure conditions (generally, unless otherwise noted, the specimens became fully involved in flames shortly after ignition).
2. Observations of sustained flaming over the exposed surface, and/or failure of the coating
3. Weight of specimen prior to treatment
4. Weight of specimen after treatment
5. Mass loss rate during drying (if applicable)
6. Mass loss rate during heat exposure, prior to ignition
7. Video tape and still photographs

Heat release rate, the primary measurement obtained in the standard ICAL test procedure, was not determined in these experiments. In certain tests, thermocouples were placed behind and on top of the coating in order to try to estimate the thermal conductivity of the coating.

TEST PROCEDURE

Plywood siding T1-11 sheets were cut into 1 m x 1 m panels. A single, heavy, coat of red latex paint was applied to each panel and allowed to dry in the conditioning room for between one and two weeks. In four of the test runs, the panels were instrumented with two type K thermocouples at the center of the panel. One thermocouple was placed at the surface of the panel (i.e., under the coating), while the other was located one centimeter away from the surface of the panel (i.e., on top of the coating).

The ICAL radiant panel was calibrated for heat flux as a function of the distance between the panel face and the specimen surface. The calibration curve is included in Appendix A. Specimens were exposed to heat flux exposures of 15 and 25 kW/m^2 at distances of 0.79 m and 0.46 m, respectively. A distance of 3.23 m corresponded to the "drying" heat exposure of 1 kW/m^2 (this heat flux was calculated previously to correspond to the approximate intensity of a hot summer sun in the southern U.S.).

The support frame was weighed, a specimen was mounted on the support frame, then it was re-weighed. The support frame and specimen were moved outdoors, sprayed, and weighed again to determine the weight of the coating on the specimen. The weight of the specimen was recorded at five minute intervals during the drying period, if applicable, and every 15 seconds during exposure to the predetermined heat flux. Temperature and relative humidity of the surrounding test area was recorded before each experiment.

In order to simulate the average household water delivery characteristics, our well water was introduced into a holding tank/pump arrangement. For gel application, the water spray was set at 10 gpm and 50 psi.

Photographs of various specimens on support frames were taken before, during and after the application of water or a gel-water mixture, and during and after exposure to the radiant heat. Photos are presented in Appendix C.

MATERIALS

The materials used in this study are as follows:

1. Plywood siding: T1-11, 3/8 in. (10 mm) thick, obtained locally (Home Depot)
2. Plastic (Vinyl) siding obtained locally (McCoys)
3. Small windows (12 in. x 24 in.; 305 x 610 mm), obtained locally (Home Depot)
4. Red latex exterior flat paint: obtained locally (Home Depot); a single, heavy coat was applied
5. "Barricade®" Fire-Blocking Gel concentrate: supplied by Fire Protection, Inc., Jupiter FL (contact: John Bartlett, 561 / 575-6055)
6. "Nochar" LE112 Thermal Barrier Concentrated Gel: supplied by Nochar Inc. Indianapolis, IN (contact: Dennis Campbell 317 / 613-3046)

RESULTS

The results are presented in the following formats:

- Table 1. Overall Summary
- Table 2. Complete Mass Gain and Mass Loss Results
- Table 3. Treatment vs. No Treatment and Effects of Drying
- Table 4. Treatment vs. No Treatment on Painted Wood, Vinyl & Windows
- Table 5. Comparison of Tests With and Without Igniter
- Table 6. Thermocouple Response Data
- Appendix A: Calibration Data and Plots; Observations of Tests with Windows
- Appendix B: Mass Loss and Temperature Plots
- Appendix C: Photographs
- Video tapes (separate)

Table 1 contains a summary of results from all experiments, including type of paneling, treatment, pre- and post-application masses, mass loss rate, drying time, exposure flux, and time to ignition; as well as details such as date of test, presence of thermocouples and igniter flame, room temperature and relative humidity, etc. The information in the other tables was derived from the results shown in Table 1.

Table 2 contains all of the mass results, including the gain in mass due to treatment, the loss in mass due to drying (if applicable) and mass loss due to the heat flux exposure up to the time of ignition.

Tables 3 and 4 contain condensed results from Table 1 to illustrate various influences. Table 3 contains data on the effects of treatment (i.e., gel or water) vs. no treatment, and the effects of the drying period on ignition times. Results for both 15 and 25 kW/m^2 are shown. This table also contains estimates of repeatability for certain tests. Table 4 contains a comparison of treatment effects on the various substrates (i.e., painted wood, vinyl or window in wood panel).

The standard test protocol was to use the open-flame igniter. However, several experiments were conducted either without the igniter or with the igniter in a different position with respect to the specimen. These results are summarized in Table 5, grouped in accordance with the nature of the treatment on any given substrate.

Results of estimates of thermal conductivity are presented in Table 6.

DISCUSSION

ICAL Protocol

During this study, a modified ICAL test protocol was employed to evaluate the fire retarding effects of temporary, water-based fire retarding products on wood and plastic sidings. Treated and untreated wood, plastic siding and windows mounted in wood siding were tested successfully at 15 and 25 kW/m^2 heat flux. The results of all of the test runs are summarized in Table 1. No conclusion has been reached at this time on a "standard" protocol. Both 15 and 25 kW/m^2 exposures provided useful information. Under this test procedure, a substantial difference was evident between specimens receiving no treatment, or even water alone, and those sprayed with the gel-water mixtures.

Application of Gels

Application rates of the gel-water mixtures were controlled by maintaining a constant water flow rate and pressure. It was established, in the earliest experiments in this series, that a fairly consistent coating thickness of 1/4 to 3/8 in. (6 to 10 mm) could be achieved by spraying the substrate for approximately 35 seconds. Measurements of mass pick up after each application verified the consistency of the application rate (results in Table 2). In a few cases, a substantial difference in mass (either lower or higher) than the average was observed. No explanation for this is apparent. The times to ignition for the coated substrates were 10 to 15 times longer than that of the untreated substrates; making the gel-water combinations very effective fire retardant treatments under these exposure conditions.

Igniter

A California Technical Bulletin 129 "T-burner" was modified for use as the ignition source (the head of the igniter was retained, only the length of the tube and the method of connection to the apparatus were changed). The location of the igniter with respect to the specimen is shown in Figure 2 of this report. This particular open-flame burner was selected for several reasons, as follows:

1. An open flame source seemed more reasonable than either a hot wire or spark igniter for the types of fires being simulated (e.g., from sparks or burning brands during the approach of a wildland fire).

2. Rather than invent a new burner, it was decided to select a burner already described in standard test methodology.
3. The specimen, with the igniter in place, could be sprayed without the spray treatment affecting the igniter's performance.
4. The burner was positioned so that it would not impinge directly on the specimen.
5. Other igniter options included (1) a line burner, similar to that originally used with the ICAL method; (2) one or more hot wires, similar to those currently used for the ICAL; or (3) spark igniters. The hot wire and spark igniters were considered to be less desirable than the open-flame burners because of potential problems with the water-based spray application. The line burner continues to be a possibility for future trials, but does not offer distinct advantages over the CA TB129 burner.

The presence of the igniter significantly reduced the time to ignition for both treated and untreated specimens, compared to experiments without the igniter (e.g., untreated, painted wood ignited at about 110 s without the igniter and around 30 s with the igniter). While this effect was anticipated, it reinforced the idea that piloted ignition would be preferred to non-piloted ignition for these studies. However, the repeatability of experiments using gel-treated panels, even with the igniter, was not good. For example, times to ignition for Barricade-treated wood panels ranged from 390 s to 905 s, with an average and standard deviation of 557±211 (Table 3).

The experimental deviation could be attributable to the fire retardancy performance of the coating. On the other hand, it was noted that the shape of the burner flames was different for experiments at the higher flux level (25 kW/m^2), where the burner flames appeared to flow further away from the surface of the specimen than for experiments at the lower flux (15 kW/m^2). Possibly, a boundary layer, created by the copious quantity of vapors emitted from the coating, re-directed the flames away from the surface of the specimen. This influence would be worse at the higher heat flux for two reasons: 1) the rate of evolution of the vapors was higher at higher flux (note mass loss rates in Table 2), and 2) the specimen was closer to the radiant panel creating higher convective currents between the specimen and the panel. In a few experiments late in the program, the T-burner was rotated from its original position near the bottom of the specimen (-30° with respect to the horizontal) to another position nearer the top of the specimen (+30° from the horizontal, a rotation of 60° from the original position). The ignition time results of these experiments (presented in Table 5) were not substantially different from the average of the results with the original burner position.

Treatment vs. No Treatment

The objective of this study was to develop a test protocol, not to compare the relative efficacy of the two gels tested (Barricade and Nochar). In fact, results summarized in Table 3 illustrate that there was little or no quantitative difference between the two coatings. Both gels exhibited substantial fire retardant effects under similar application conditions, causing the substrate material to withstand the radiant heat flux for an extended period, compared to untreated specimens. For example, untreated, painted wood ignited at around 30 s at 25 kW/m^2; water treatment extended the ignition time to around 60 s; while the gel-water treated wood specimens lasted an average of between 500 and 600 s under the same heat flux conditions (Table 3). Even the worst of the treated specimens took more than 300 s to ignite.

Both gels showed excellent adhesion properties when applied to the wood substrates. Generally, there was little run-off during application. The Nochar gel was observed to run off the panel in long strings during exposure (even before exposure in Run No. 12, see photos in Appendix C), something that was not observed for the Barricade product. However, this did not seem to affect its performance, as demonstrated by times to ignition. Mass loss data did not show this run-off because the product remained on the load cell platform. There were no significant differences in the times to ignition for the two treatments at 25 kW/m^2 (even after 60 min. of drying). At 15 kW/m^2, the Nochar product had a shorter average time to ignition than the Barricade; however, only two tests were run.

Drying the specimens for 60 or 120 min. was performed on selected treated panels. In only one case (Run #54) did the drying have a substantial impact on the time to ignition. Generally, the times to ignition following drying were indistinguishable from the range of ignition times obtained without drying.

Mass Loss Rates

The average mass loss rate at 25 kW/m^2, prior to ignition, for two experiments (Runs 7 and 8, see Table 2) treated only with water was 0.0168 lbs/s for a pick-up of 0.23 lbs. The average mass loss rates for the Barracade and Nochar, respectively, were 0.0176 and 0.0191 lbs/s for pick-ups of 11.8 and 11.5 lbs. From these data, it appears that the water is lost at about the same rate, under the same test conditions, for the different treatments, but that the gel treatment retains the water for much longer. These data, plus similar results at 15 kW/m^2 exposure, should permit extrapolation of results to other experimental or field test conditions.

Other substrates

To investigate the adhesion qualities on glass and window components, specimens of wood paneling were tested with a small window installed. Both gel brands adhered well to the glass and the window screen. The times to ignition for the treated samples were delayed, compared to untreated samples (Table 4). Also, the gels delayed the time to window breakage. More in-depth testing and analysis will be necessary to investigate adhesion qualities of the gel onto different types of glass with different surface areas, textures and mounting arrangements.

The adhesion qualities and performance of both gel brands on white plastic (vinyl) siding also were examined. The vinyl siding was attached to 1/2 in. (rather than 3/8 in. as in the other tests) painted wood siding. The untreated vinyl specimen melted and ignited at around 45 seconds at 25 kW/m^2. The two gels exhibited similar adhesion qualities during spraying of the vinyl, and similar to their adhesion on the wood panels (i.e., no excessive running or dripping). Upon exposure to 25 kW/m^2 heat flux, the treated panels displayed longer times to ignition than the untreated ones (range of 130 to 521 s, compared to 45 s). However, the vinyl siding sagged and deformed within a few minutes of the start of exposure. Thus, the times to ignition reflected the collapse of the plastic covering, more than the efficacy of the gel coating. Further testing should be performed to investigate the behavior of this type of specimen.

Thermal Conductivity Calculations

Four treated, painted wood panels (Run Numbers 22 through 25) had been instrumented with type K thermocouples, as described above. This provided temperature information for the surface of the wood panel, underneath the gel, as well as the temperature at the surface of the gel during a 25 kW/m^2 heat flux exposure (temperature data shown under the respective run numbers in Appendix B). An average thermal conductivity value was calculated using the one-dimensional, steady state heat conduction equation (Fourier's law, see Ref 5). For this analysis, the thickness of the gel was assumed to remain constant (at 3/8 in., 9.5 mm) during the exposure. Also, the temperature gradient data were averaged over the "equilibrium period" (i.e., following the initial temperature rise and prior to ignition) to achieve a more-or-less constant temperature profile. Table 6 contains the calculated average thermal conductivity values. The overall, average value, including two determinations each on the two gel types, was 3.7 W/m-°C. This value may be of limited use because the measurements on the surface of the gel were affected by the release of water vapor (in one of the experiments, the gel surface temperature hovered around 200 to 250 °F for a long time, presumably registering water vapor evolution).

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were developed from the results of this investigation:

1. Application of the gel/water mixtures was achieved with reasonable repeatability, based on measurements of mass gain following spraying.
2. The two gel treatments, Barricade and Nochar, performed similarly in their protection of wood siding to heat fluxes as high as 25 kW/m^2. Times to ignition of painted wood siding specimens were extended from around 30 seconds for untreated panels to more than 300 seconds for treated panels at 25 kW/m^2 (the average of the coated specimens at this heat flux was more than 500 s). Similar extensions of times to ignition were obtained for treated specimens subjected to 15 kW/m^2.
3. Drying the treated panels for up to 120 minutes at approximately 1 kW/m^2 generally had little effect on the subsequent times to ignition of the specimens, compared to no drying.
4. The gel-water treatments protected small windows mounted into wood panels, extending the time required for cracking and breakage.
5. The gel-water treatments were successfully applied to vinyl siding; however, the vinyl defeated the action of the FR treatment by sagging and melting, thereby exposing the wood substrate to ignition.
6. The open flame igniter, adapted from California T. B. 129 performed suitably, but could be improved.
7. The gel-water treatments under consideration in this study performed well in their primary objective of providing a temporary fire retardant treatment to wood siding.
8. The mechanism of action of these gels, based on mass loss data prior to ignition, appears to be one of retaining large quantities of water for release during the heat flux exposure.

This study has demonstrated the capability of a modified ICAL apparatus to test the efficacy of these treatments. In order to fully appreciate the magnitude of the protective influence of such coatings on realistic structures, the following recommendations for future study should be considered:

1. The portable CAFS foam unit, intended for fire fighter use, was never tested due to time and equipment constraints. This apparatus should be evaluated under the same protocol as that used in this study for comparison of the effectiveness of treatment.
2. Further examination of the effect of the gel treatments on windows and vinyl siding is warranted. Various size and shape windows and different framing options should be evaluated. The failure of the vinyl siding prior to the loss of coating effectiveness is an important practical problem that should be resolved.
3. The "standard" thickness, as recommended by the manufacturer, was evaluated in this study. This variable that should be studied further, especially to evaluate the potential of these treatments to protect areas such as vinyl siding.
4. Extended summertime drying conditions (e.g., 12-24 hours) should be performed in order to evaluate the durability of the treatment prior to fire exposure.
5. Further study of ignition burner types should be done prior to the recommendation of this technique as a standard, stand-alone test method.
6. It is presently unclear what would happen if a portion of a specimen failed prematurely either because of improper treatment or a much higher, localized exposure flux. The treated portion might fail early or it might continue to provide protection. This should be explored.
7. Full scale studies of treatments on larger wall structures should be undertaken. Treated wall structures up to 12 feet by 15 feet could be exposed for brief periods (or longer periods) in an ASTM E119 test setup. Although the E119 apparatus is designed for high temperature exposure, the conditions inside the furnace can be controlled to almost any heating level desired.
8. Full scale studies of treatments on building mock-ups should be considered. Unusual shapes such as inside and outside corners, eaves, and porches could be evaluated in simulated wildland fuel burns.
9. The potential for these gel-water treatments to protect fuel storage facilities can be evaluated by measuring the backside temperature of flat metal plates during exposure in either the ICAL or ASTM E119 equipment.

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Table 1. Overall Summary
NIST ICAL Project on Durable Agents
OPL No. 15933-105840; March-April 2000

Run No.	Date	Siding[a]	Treat-ment	Appl. Rate[b]	Room Cond. (°F, %RH)	Initial Mass (lbs)	Mass post-treat (lbs)	Mass Incr. (lbs)	Mass at Ign (lbs)	Drying MLR (lb/sec)	Exposure MLR (lb/sec)	Drying Period (min.)[c]	Heat Flux (kW/m^2)	Igniter?	Smoke (s)	Ign. (s)	Notes & Observations
1	Mar. 14	P	None	None	63, 80	11.48	11.48	0.00	8.30	N/A	0.0289	None	25	N	5	110	
2	Mar. 14	P	None	—	—	—	—	—	—	—	—	—	—	—	—	—	Error (propane flow)
3	Mar. 14	P	None	None	64, 82	12.54	12.54	0.00	11.14	N/A	0.0128	None	25	N	5	109	
4	Mar. 14	P	None	None	66, 85	13.02	13.02	0.00	12.49	N/A	0.0151	None	25	Y	3	35	
5	Mar. 14	P	None	None	66, 85	11.30	11.30	0.00	10.45	N/A	0.0258	None	25	Y	5	33	
6	Mar. 14	P	None	None	69, 76	12.69	12.69	0.00	10.49	N/A	0.0786	None	25	Y	4	28	
7	Mar. 14	P	Water	1 min.	70, 72	11.88	12.13	0.25	11.11	N/A	0.0176	None	25	Y	10	58	Water spray ca. 3 gpm for 1 min
8	Mar. 14	P	Water	1 min.	74, 68	11.84	12.06	0.22	11.15	N/A	0.0160	None	25	Y	7	57	Water spray ca. 3 gpm for 1 min
9	Mar. 14	P	Barricade	S	75, 61	12.62	23.15	10.53	12.62	N/A	0.0229	None	25	Y	10	460	
10	Mar. 14	P	Barricade	S	79, 55	10.69	22.22	11.53	13.90	N/A	0.0138	None	25	Y	8	603	
11	Mar. 15	P	Nochar	S	79, 55	11.46	22.20	10.74	16.86	N/A	0.0169	None	25	Y	5	316	Gel dripping during exposure
12	Mar. 15	P	Nochar	S	79, 55	11.52	23.12	11.60	16.40	N/A	0.0182	None	25	Y	5	370	Gel dripping before & during exp.
13	Mar. 15	U	None	None	78, 60	10.67	10.67	0.00	10.21	N/A	0.0075	None	25	Y	3	61	
14	Mar. 15	U	None	—	—	—	—	—	—	—	—	—	—	—	—	—	Error (propane flow)
15	Mar. 15	U	None	None	80, 59	12.73	12.73	0.00	12.00	N/A	0.0120	None	25	Y	5	61	
16	Mar. 15	U	Water	1 min.	82, 57	11.42	11.68	0.26	10.92	N/A	0.0051	None	25	N	5	150	Water spray (no igniter)
17	Mar. 15	U	Water	1 min.	81, 57	11.94	12.16	0.22	11.48	N/A	0.0075	None	25	Y	7	91	Water spray ca. 3 gpm for 1 min
18	Mar. 15	U	Barricade	S	88, 55	11.53	24.94	13.41	11.27	N/A	0.0217	None	25	Y	9	630	
19	Mar. 15	P	Barricade	S	79 , 57	10.78	23.83	13.05	10.50	0.00149	0.0152	60	25	Y	14	619	
20	Mar. 16	P	Nochar	S	101, 40	10.32	21.88	11.56	7.38	0.00158	0.0192	60	25	Y	23	459	
21	Mar. 16	P	Barricade	S	100, 40	11.71	21.83	10.12	11.94	N/A	0.0123	None	15	Y	15	806	
22	Mar. 17	P	Barricade	S	62, 60	11.61	23.06	11.45	7.98	N/A	0.0167	None	25	Y	7	905	TC data
23	Mar. 20	P	Barricade	S	62, 62	11.54	24.33	12.79	17.80	N/A	0.0154	None	25	Y	9	425	TC data
24	Mar. 20	P	Nochar	S	69, 55	11.25	24.5	13.25	8.60	N/A	0.0190	None	25	Y	14	836	TC data
25	Mar. 20	P	Nochar	S	74, 55	10.92	18.09	7.17	9.56	N/A	0.0196	None	25	Y	10	436	TC data
26	Mar. 20	P	Water	1 min.	78, 45	11.77	11.88	0.11	9.73	0.00030	0.0070	60	25	Y	3	150	
27	Mar. 20	P	Barricade	S	90, 38	11.51	21.00	9.49	11.28	0.00165	0.0093	60	15	Y	5	443	
28	Mar. 22	P	Nochar	S	91, 40	11.2	21.72	10.52	5.24	0.00183	0.0084	60	15	N	8	1226	Igniter off at 720 s
29	Mar. 22	P	Nochar	S	83, 56	11.79	24.37	12.58	11.84	0.00165	0.0099	60	15	Y	8	683	
30	Mar. 22	W	None	None	89, 55	16.76	16.76	0.00	15.90	N/A	0.0070	None	25	Y	5	122	See Appendix, 1st crack 22 s
31	Mar. 22	W	Barricade	S	90, 52	19.06	31.25	12.19	15.11	N/A	0.0184	None	25	N	7	879	Igniter off at Approx. 420 s
32	Mar. 22	W	Nochar	S	91, 52	16.6	28.14	11.54	12.21	N/A	0.0229	None	25	N	15	696	See Appendix, 1st crack 291 s
33	Mar. 22	W	Barricade	S	92, 46	16.8	30	13.20	17.87	N/A	0.0247	None	25	Y	7	491	See Appendix, 1st crack 230 s
34	Mar. 23	P	Barricade	S	92, 44	11.44	29.99	18.55	10.42	0.00197	0.0129	120	15	Y	3	421	See Appendix, 1st crack 291 s
35	Mar. 23	P	Nochar	S	94, 42	11.46	28.42	16.96	6.33	0.00187	0.0155	120	15	Y	7	620	
36	Mar. 24	P	None	S	95, 42	10.72	10.72	0.00	9.27	N/A	0.0725	None	25	Y	3	20	Igniter rotated (see text)
37	Mar. 24	P	Nochar	S	88, 55	11.95	23.54	11.59	12.25	N/A	0.0217	None	25	Y	8	521	Igniter rotated

Table 1. Overall Summary
NIST ICAL Project on Durable Agents
OPL No. 15933-105840; March-April 2000

Run No.	Date	Siding[a]	Treat-ment	Appl. Rate[b]	Room Cond. (°F, %RH)	Initial Mass (lbs)	Mass post-treat (lbs)	Mass Incr. (lbs)	Mass at Ign (lbs)	Drying MLR (lb/sec)	Exposure MLR (lb/sec)	Drying Period (min.)[c]	Heat Flux (kW/m^2)	Igniter?	Smoke (s)	Ign. (s)	Notes & Observations
38	Mar. 24	P	Barricade	S	91, 52	13.1	26.92	13.82	16.18	N/A	0.0158	None	25	Y	15	680	Igniter rotated
39	Mar. 24	V	None	None	94, 46	24.54	24.54	0.00	24.51	N/A	0.0007	None	25	Y	2	45	Melting/ign. within 45 s
40	Mar. 24	V	Barricade	S	95, 46	25.23	33.82	8.59	30.58	N/A	0.0249	None	25	Y	20	130	Plastic sagging/melting
41	Mar. 24	V	Nochar	S	98, 42	25.27	34.52	9.25	23.49	N/A	0.0212	None	25	Y	11	521	Plastic sagging/melting
42	Apr. 13	W	None	None	87, 53	15.82	15.82	0.00	15.71	N/A	0.0048	None	25	Y	4	23	Error (paint not dry)
43	Apr. 19	W	None	None	88, 54	16.92	16.92	0.00	16.11	N/A	0.0090	None	25	Y	3	90	See Appendix, 1st crack 20 s
44	Apr. 19	W	Barricade	S	98, 43	16.85	29.68	12.83	17.19	N/A	0.0221	None	25	Y	9	564	See Appendix, 1st crack 715 s
45	Apr. 19	W	Nochar	S	100, 42	16.68	26.81	10.13	18.20	N/A	0.0205	None	25	Y	8	419	See Appendix, 1st crack 82 s
46	Apr. 20	P	None	None	82, 40	10.93	10.93	0.00	10.40	N/A	0.0030	None	15	Y	9	175	
47	Apr. 20	P	None	None	89, 35	11.91	11.91	0.00	11.37	N/A	0.0033	None	15	Y	9	166	
48	Apr. 20	P	Barricade	S	89, 35	10.39	22.44	12.05	12.60	N/A	0.0134	None	15	Y	31	732	
49	Apr. 20	P	Nochar	S	96, 30	13.26	24.74	11.48	20.24	N/A	0.0153	None	15	Y	31	295	Gel dripping during exposure
50	Apr. 25	P	Barricade	S	90, 50	11.33	22.57	11.24	14.67	N/A	0.0115	None	15	Y	38	688	
51	Apr. 25	P	Nochar	S	95, 42	10.50	25.54	15.04	18.15	N/A	0.0110	None	15	Y	28	673	
52	Apr. 25	P	Barricade	S	100, 42	10.83	21.62	10.79	13.46	N/A	0.0209	None	25	Y	8	390	
53	Apr. 25	P	Nochar	S	102, 42	11.92	26.24	14.32	12.23	N/A	0.0192	None	25	Y	13	730	
54	Apr. 26	P	Barricade	S	80, 65	11.07	22.28	11.21	11.60	0.00174	0.0215	60	25	Y	20	149	
55	Apr. 26	P	Nochar	S	100, 42	10.67	19.19	8.52	9.40	0.00111	0.0185	60	25	Y	12	330	
56	Apr. 26	P	Water	1 min.	105, 40	11.56	11.88	0.32	10.16	0.00040	0.0040	60	25	Y	3	47	Water spray ca. 3 gpm for 1 min

Notes:

a) Siding: P = painted wood; U = unpainted wood; V = vinyl siding on wood; W = small window in painted wood

b) Appl. Rate: S = "standard" thickness, 1/4 in. to 3/8 in. (0.32 in. avg.)

c) Drying: performed at ca. 1 kW/m^2, unless otherwise noted.

N/A - not applicable

Table 2. Complete Mass Gain and Mass Loss Results
NIST ICAL Project on Durable Agents
OPL No. 15933-105840; March-April 2000

Run No.	Siding[a]	Treatment	Initial Mass (lbs)	Mass post-treat (lbs)	Mass Incr. (lbs)	Mass at Ign (lbs)	Exposure MLR (lb/sec)	Drying Period (min.)	Drying MLR (lb/sec)	Heat Flux (kW/m^2)	Igniter?	Notes
21	P	Barricade	11.71	21.83	10.12	11.94	0.0123	None	N/A	15	Y	
48	P	Barricade	10.39	22.44	12.05	12.60	0.0134	None	N/A	15	Y	
50	P	Barricade	11.33	22.57	11.24	14.67	0.0115	None	N/A	15	Y	
27	P	Barricade	11.51	21.00	9.49	11.28	0.0093	60	0.0017	15	Y	
34	P	Barricade	11.44	29.99	18.55	10.42	0.0129	120	0.0020	15	Y	
9	P	Barricade	12.62	23.15	10.53	12.62	0.0229	None	N/A	25	Y	
10	P	Barricade	10.69	22.22	11.53	13.90	0.0138	None	N/A	25	Y	
22	P	Barricade	11.61	23.06	11.45	7.98	0.0167	None	N/A	25	Y	
23	P	Barricade	11.54	24.33	12.79	17.80	0.0154	None	N/A	25	Y	
38	P	Barricade	13.10	26.92	13.82	16.18	0.0158	None	N/A	25	Y	
52	P	Barricade	10.83	21.62	10.79	13.46	0.0209	None	N/A	25	Y	
19	P	Barricade	10.78	19.91	9.13	10.50	0.0152	60	0.0015	25	Y	
54	P	Barricade	11.07	22.28	11.21	11.60	0.0215	60	0.0017	25	Y	
18	U	Barricade	11.53	24.94	13.41	11.27	0.0217	None	N/A	25	Y	
40	V	Barricade	25.23	33.82	8.59	30.58	0.0249	None	N/A	25	Y	
31	W	Barricade	19.06	31.25	12.19	15.11	0.0184	None	N/A	25	N	
33	W	Barricade	16.80	30.00	13.20	17.87	0.0247	None	N/A	25	Y	
44	W	Barricade	16.85	29.68	12.83	17.19	0.0221	None	N/A	25	Y	

Table 2. Complete Mass Gain and Mass Loss Results
NIST ICAL Project on Durable Agents
OPL No. 15933-105840; March-April 2000

Run No.	Siding[a]	Treatment	Initial Mass (lbs)	Mass post-treat (lbs)	Mass Incr. (lbs)	Mass at Ign (lbs)	Exposure MLR (lb/sec)	Drying Period (min.)	Drying MLR (lb/sec)	Heat Flux (kW/m²)	Igniter?	Notes
49	P	Nochar	13.26	24.74	11.48	20.24	0.0153	None	N/A	15	Y	
51	P	Nochar	10.50	25.54	15.04	18.15	0.0110	None	N/A	15	Y	
29	P	Nochar	11.79	24.37	12.58	11.84	0.0099	60	0.0017	15	Y	
28	P	Nochar	11.20	21.72	10.52	5.24	0.0084	60	0.0018	15	N	
35	P	Nochar	11.46	28.42	16.96	6.33	0.0156	120	0.0019	15	Y	
11	P	Nochar	11.46	22.20	10.74	16.86	0.0169	None	N/A	25	Y	
12	P	Nochar	11.52	23.12	11.60	16.40	0.0182	None	N/A	25	Y	
24	P	Nochar	11.25	24.50	13.25	8.60	0.0190	None	N/A	25	Y	
25	P	Nochar	10.92	18.09	7.17	9.56	0.0196	None	N/A	25	Y	
37	P	Nochar	11.95	23.54	11.59	12.25	0.0217	None	N/A	25	Y	
53	P	Nochar	11.92	26.24	14.32	12.23	0.0192	None	N/A	25	Y	
55	P	Nochar	10.67	19.19	8.52	9.40	0.0185	60	0.001	25	Y	
20	P	Nochar	10.32	21.78	11.46	7.38	0.0314	60	0.002	25	Y	
41	V	Nochar	25.27	34.52	9.25	23.49	0.0212	None	N/A	25	Y	
32	W	Nochar	16.60	28.14	11.54	12.21	0.0229	None	N/A	25	N	
45	W	Nochar	16.68	26.81	10.13	18.20	0.0205	None	N/A	25	Y	
46	P	None	10.93	10.93	0.00	10.40	0.0030	None	N/A	15	Y	
47	P	None	11.91	11.91	0.00	11.37	0.0033	None	N/A	15	Y	

Table 2. Complete Mass Gain and Mass Loss Results
NIST ICAL Project on Durable Agents
OPL No. 15933-105840; March-April 2000

Run No.	Siding[a]	Treatment	Initial Mass (lbs)	Mass post-treat (lbs)	Mass Incr. (lbs)	Mass at Ign (lbs)	Exposure MLR (lb/sec)	Drying Period (min.)	Drying MLR (lb/sec)	Heat Flux (kW/m^2)	Igniter?	Notes
1	P	None	11.48	11.48	0.00	8.30	0.0289	None	N/A	25	N	
3	P	None	12.54	12.54	0.00	11.14	0.0128	None	N/A	25	N	
4	P	None	13.02	13.02	0.00	12.49	0.0151	None	N/A	25	Y	
5	P	None	11.30	11.30	0.00	10.45	0.0258	None	N/A	25	Y	
6	P	None	12.69	12.69	0.00	10.49	0.0786	None	N/A	25	Y	
36	P	None	10.72	10.72	0.00	9.27	0.0725	None	N/A	25	Y	
13	U	None	10.67	10.67	0.00	10.21	0.0075	None	N/A	25	Y	
15	U	None	12.73	12.73	0.00	12.00	0.0120	None	N/A	25	Y	
39	V	None	24.54	24.54	0.00	24.51	0.0007	None	N/A	25	Y	
30	W	None	16.76	16.76	0.00	15.90	0.0070	None	N/A	25	Y	
42	W	None	15.82	15.82	0.00	15.71	0.0048	None	N/A	25	Y	
43	W	None	16.92	16.92	0.00	16.11	0.0090	None	N/A	25	Y	
7	P	Water	11.88	12.13	0.25	11.11	0.0176	None	N/A	25	Y	
8	P	Water	11.84	12.06	0.22	11.15	0.0160	None	N/A	25	Y	
16	U	Water	11.42	11.68	0.26	10.92	0.0051	None	N/A	25	N	
17	U	Water	11.94	12.16	0.22	11.48	0.0075	None	N/A	25	Y	
26	P	Water	11.77	11.88	0.11	9.73	0.0070	60	0.00030	25	Y	
56	P	Water	11.56	11.88	0.32	10.16	0.0040	60	0.00040	25	Y	

Notes:

a) P = painted wood; U = unpainted wood; V = vinyl siding; W = small window in painted wood

Table 3. Treatment vs. No Treatment and Effects of Drying: Painted Wood, 25 kW/m^2 and 15 kW/m^2 with Igniter
NIST ICAL Project on Durable Agents
OPL No. 15933-105840; March-April 2000

Run No.	Treatment	Drying Period (min.)*	Heat Flux (kW/m^2)	Smoke (s)	Ign. (s)
25 kW/m^2					
4	None	None	25	3	35
5	None	None	25	5	33
6	None	None	25	4	28
Average	*None*	*None*	*25*	*4*	*32±4*
7	Water	None	25	10	58
8	Water	None	25	7	57
Average	*Water*	*None*	*25*	*9*	*58±1*
26	Water	60	25	3	150
56	Water	60	25	3	47
Average	*Water*	*60*	*25*	*3*	*99±73*
9	Barricade	None	25	10	460
10	Barricade	None	25	8	603
22	Barricade	None	25	7	905
23	Barricade	None	25	9	425
52	Barricade	None	25	8	390
Average	*Barricade*	*None*	*25*	*9*	*557±211*
19	Barricade	60	25	14	619
54	Barricade	60	25	20	149
Average	*Barricade*	*60*	*25*	*17*	*384±332*

Table 3. Treatment vs. No Treatment and Effects of Drying: Painted Wood, 25 kW/m^2 and 15 kW/m^2 with Igniter
NIST ICAL Project on Durable Agents
OPL No. 15933-105840; March-April 2000

Run No.	Treatment	Drying Period (min.)*	Heat Flux (kW/m^2)	Smoke (s)	Ign. (s)
11	Nochar	None	25	5	316
12	Nochar	None	25	5	370
24	Nochar	None	25	14	836
25	Nochar	None	25	10	436
53	Nochar	None	25	13	730
Average	*Nochar*	*None*	*25*	*9*	*538±231*
20	Nochar	60	25	23	459
55	Nochar	60	25	12	330
Average	*Nochar*	*60*	*25*	*18*	*395±91*
15 kW/m2					
46	None	None	15	9	175
47	None	None	15	9	166
Average	*None*	*None*	*15*	*9*	*171±6*
21	Barricade	None	15	15	806
48	Barricade	None	15	31	732
50	Barricade	None	15	38	688
Average	*Barricade*	*None*	*15*	*28*	*742±60*
49	Nochar	None	15	31	295
51	Nochar	None	15	28	673
Average	*Nochar*	*None*	*15*	*30*	*484±267*

Table 3. Treatment vs. No Treatment and Effects of Drying: Painted Wood, 25 kW/m^2 and 15 kW/m^2 with Igniter NIST ICAL Project on Durable Agents OPL No. 15933-105840; March-April 2000

Run No.	Treatment	Drying Period (min.)*	Heat Flux (kW/m^2)	Smoke (s)	Ign. (s)
27	Barricade	60	15	5	443
34	Barricade	120	15	3	421
29	Nochar	60	15	8	683
35	Nochar	120	15	7	620

Notes: *Drying performed at ca. 1 kW/m^2, unless otherwise noted.

Table 4. Treatment vs. No Treatment on Painted Wood, Vinyl & Windows: 25 kW/m^2 with Igniter, No Drying
NIST ICAL Project on Durable Agents
OPL No. 15933-105840; March-April 2000

Run No.	Siding*	Smoke (s)	Ign. (s)	Notes & Observations
No Treatment				
Avg.	*Painted Wood*	*4*	*32*	
39	Vinyl	2	45	Plastic sagged/melted
30	Small Window	5	122	1st crack 22 s
43	Small Window	3	90	1st crack 20 s
Barricade Treatment				
Avg.	*Painted Wood*	*8*	*557*	
40	Vinyl	20	130	Plastic sagged/melted
33	Small Window	7	491	1st crack 230 s
44	Small Window	9	564	1st crack 715 s
Nochar Treatment				
Avg.	*Painted Wood*	*9*	*538*	
41	Vinyl	11	521	Plastic sagged/melted
32	Small Window	15	696	1st crack 291 s
45	Small Window	8	419	1st crack 82 s

*Notes:

"Painted" T1-11 wood siding
"Vinyl" installed on top of unpainted wood siding
"Window" installed in center of painted wood siding

Table 5. Influence of Ignitor on test parameters
25 kW/m^2 Heat Flux, no drying period
NIST ICAL Project on Durable Agents
OPL No. 15933-105840; March-April 2000

Run No.	Siding[a]	Treatment	Igniter?	New Position	Smoke (s)	Ign. (s)
Avg.	P	None	N		5	110
36	P	None	Y	X	3	20
Avg.	P	None	Y		4	32
16	U	Water	N		5	150
17	U	Water	Y		7	91
38	P	Barricade	Y	X	15	680
Avg.	P	Barricade	Y		8	557
37	P	Nochar	Y	X	8	521
Avg.	P	Nochar	Y		9	538

Igniter originally positioned at 30° below horizontal
"New position" at 30° above horizontal

Table 6. Thermocouple Response Data
25 kW/m² Heat Flux, no drying period
NIST ICAL Project on Durable Agents
OPL No. 15933-105840; March-April 2000

Run No.	Coating[a]	Time Range (s)[b]	Time to Ignition (s)	Avg. Thermal Conductivity (W/m-°C)
22	Barricade	90-720	905	5.3
23	Barricade	30-420	425	3.7
24	Nochar	120-580	836	2.2
25	Nochar	30-270	436	3.6
Avg.				3.7

Notes:
a) Nominal thickness 3/8 in. (0.0095 m)
b) "equilibrium" period, following initial temp. rise, prior to ignition

APPENDIX A

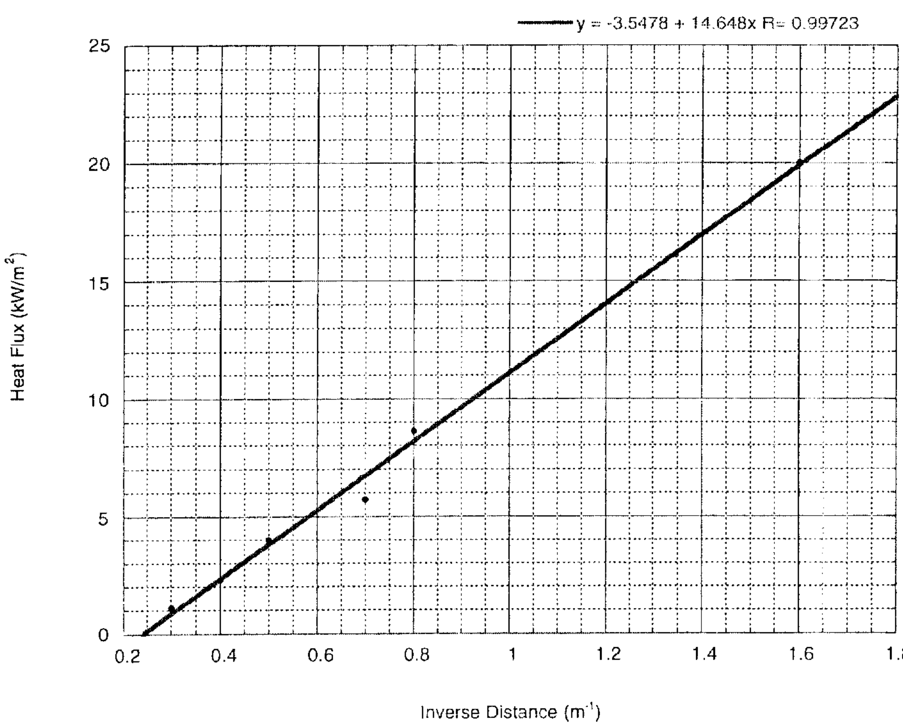
Calibration Data and Plots

Observations of Tests with Windows

Radiant Panel Calibration Results
Heat Flux Measured as a Function of Distance from the Panel

Distance (ft.)	Distance (m)	1/d (m^{-1})	Ht. Flux Transducer Output (mv)	Heat Flux (kW/m^2)
2	0.61	1.6	3.5	20.0
4	1.22	0.8	1.5	8.6
5	1.52	0.7	1.0	5.7
6	1.83	0.5	0.7	4.0
8	2.44	0.4	0.4	2.3
10	3.05	0.3	0.2	1.1

Heat Flux vs. Inverse of Distance from the Radiant Panel



OBSERVATIONS ON TESTS WITH WINDOW PANELS

Window centered in painted wood panel
25 kW/m^2 Heat Flux

Run No. 30: No Treatment

Time (min:sec)	Observations
00:00	Start Test
00:05	Smoke
00:17	Darkening
00:22	First Crack in the Window Glass
00:39	Second Crack in the Window Glass
2:02	Ignition
4:00	End Test

Run No. 31: Barricade Treatment
(Note: error due to igniter off at 5:06)

Time (min:sec)	Observations
00:00	Start Test
00:07	Smoke
2:45	First Crack in the Window Glass
5:06	Igniter Turned Off (in error)
6:52	Second Crack in the Window Glass
7:38	Third Crack in the Window Glass
9:26	Window Still Intact
10:35	Forth Crack in the Window Glass
14:39	Ignition
16:24	End Test. Window Still Intact.

Run No. 32: Nochar Treatment

Time (min:sec)	Observations
00:00	Start Test
00:15	Smoke
4:51	First Crack in the Window Glass
7:23	Second Crack in the Window Glass
9:03	Third Crack in the Window Glass
11:36	Ignition
12:05	Window Still Intact
14:00	End Test. Window Still Intact.

Run No. 33: Barricade Treatment

Time (min:sec)	Observations
00:00	Start Test
00:07	Smoke
3:40	Some Gel Slide Off The Glass
3:50	First Crack in the Window Glass
3:55	Second Crack in the Window Glass
4:00	Third Crack in the Window Glass
7:28	Gel Sliding Off and Glass Cracking
8:11	Ignition
10:31	End Test. Window Still Intact.

Run No. 42: No Treatment
(Note: error due to paint not completely dry)

Time (min:sec)	Observations
00:00	Start Test
00:04	Smoke
00:10	First Crack in the Window Glass
00:18	Second Crack in the Window Glass. Glass Breakage.
00:23	Ignition
1:23	End Test.

Run No. 43: No Treatment

Time (min:sec)	Observations
00:00	Start Test
00:03	Smoke
00:20	First Crack in the Window Glass
00:32	Second Crack in the Window Glass
1:16	Third Crack in the Window Glass
1:30	Ignition
1:36	End Test.

Run No. 44: Barricade Treatment

Time (min:sec)	Observations
00:00	Start Test
00:10	Smoke
5:00	Charring
5:57	Top and Bottom Edge Charring.
9:24	Ignition
11:55	First Crack in the Window Glass. Windows Intact.
12:30	End Test.

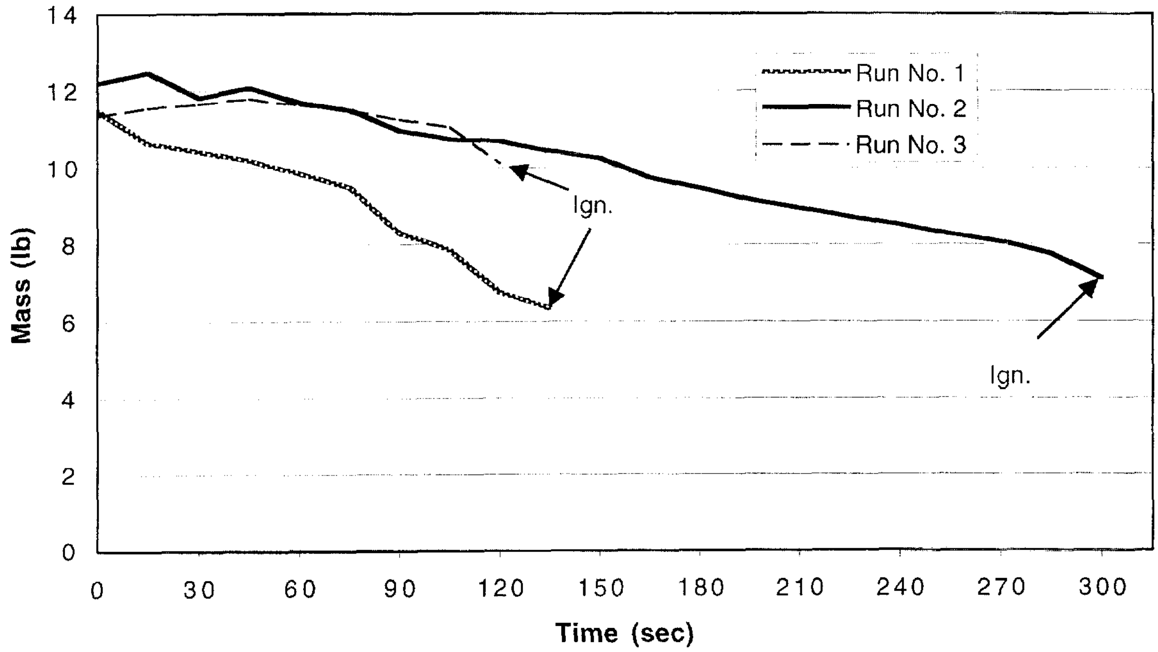
Run No. 45: Nochar Treatment

Time (min:sec)	Observations
00:00	Start Test
00:50	Gel Run Off
00:11	Smoke
1:22	First Crack in the Window Glass. Windows Intact.
1:33	Globs of Gel Sliding Off the Panel
5:07	Charring
5:19	Second Crack in the Window Glass
5:46	Third Crack in the Window Glass
6:59	Ignition
7:32	Glass Breaking.
8:00	End Test.

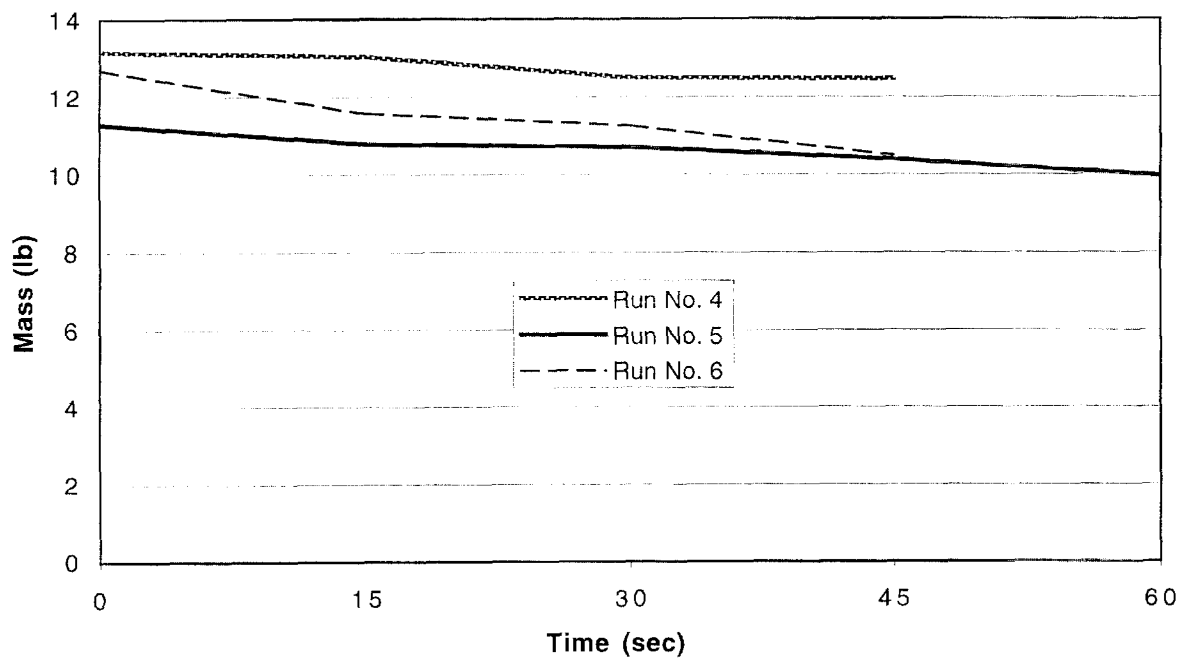
APPENDIX B

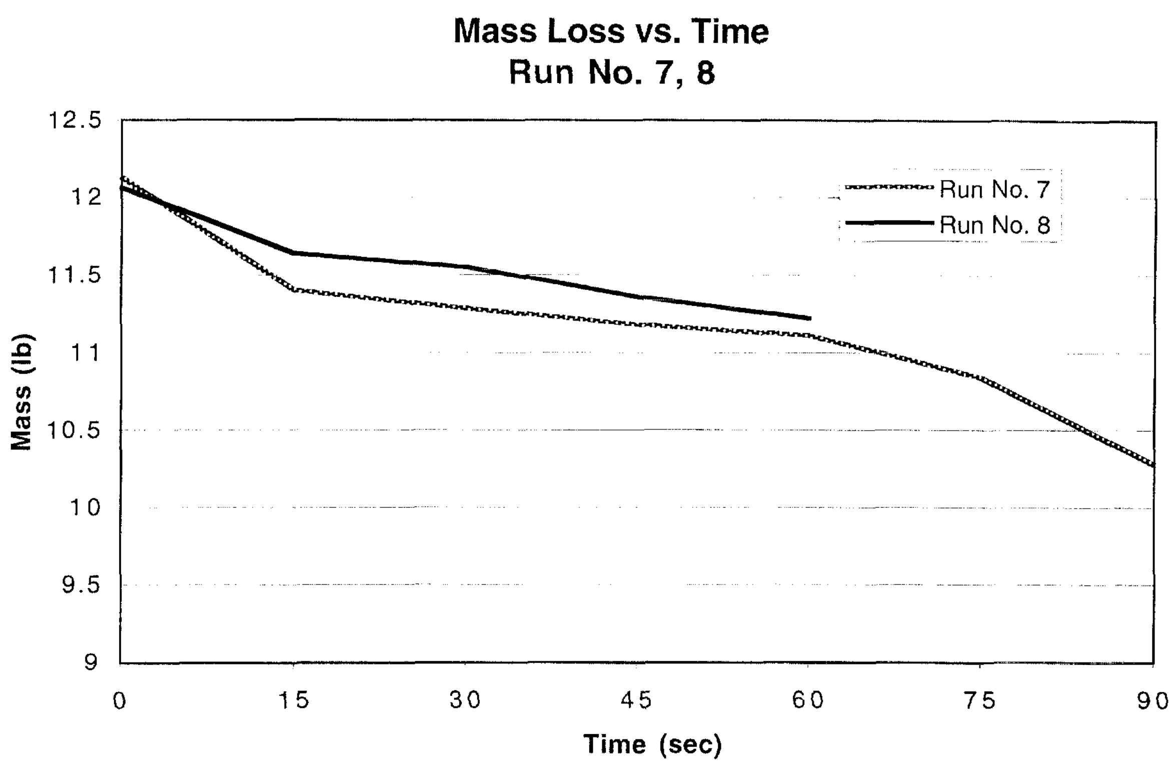
Mass Loss and Temperature Plots

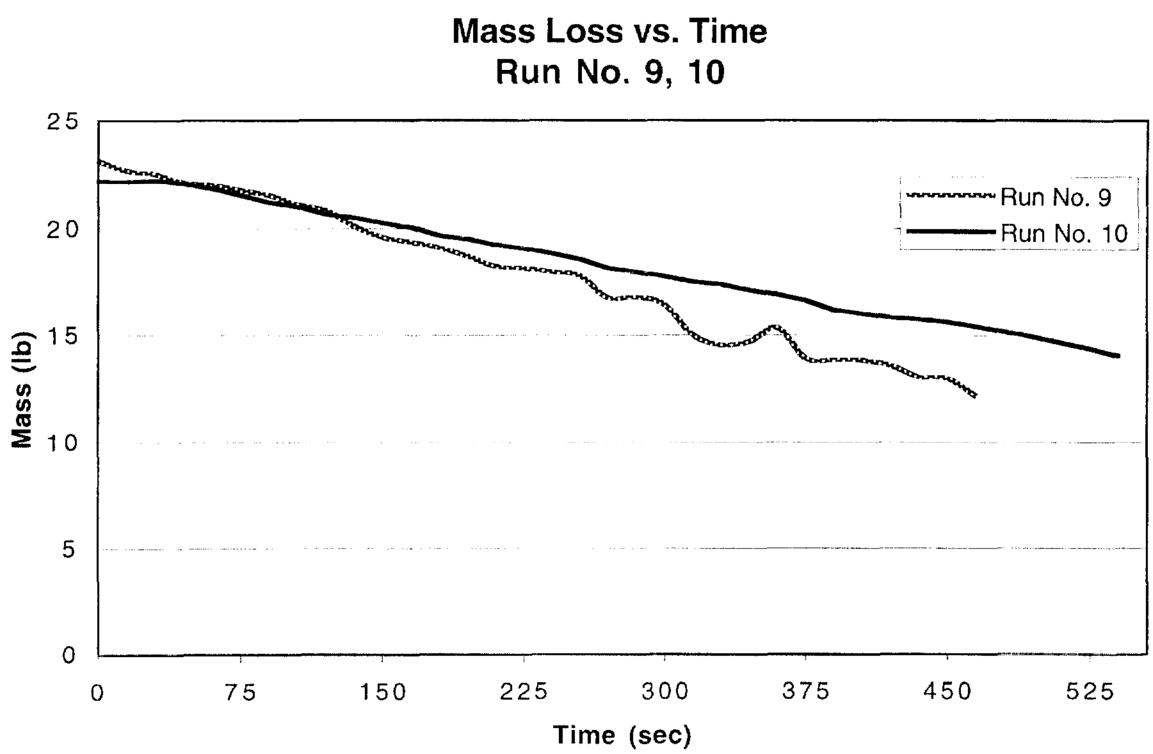
Mass Loss vs. Time
Run No. 1, 2, 3

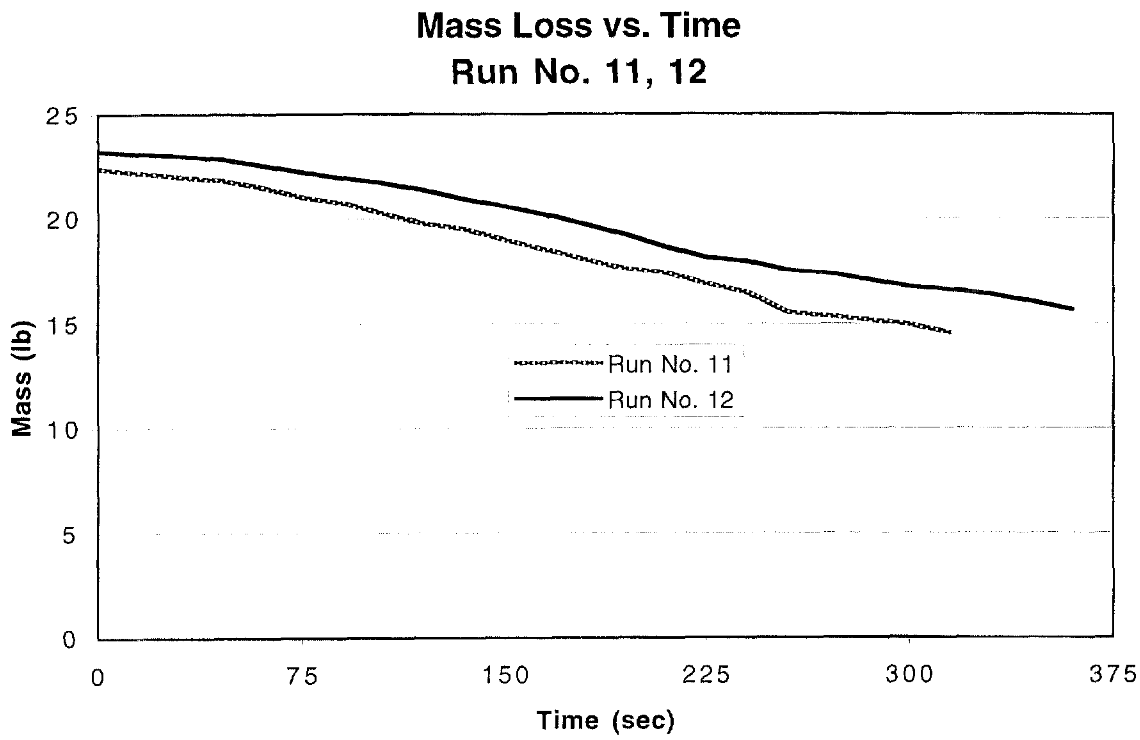


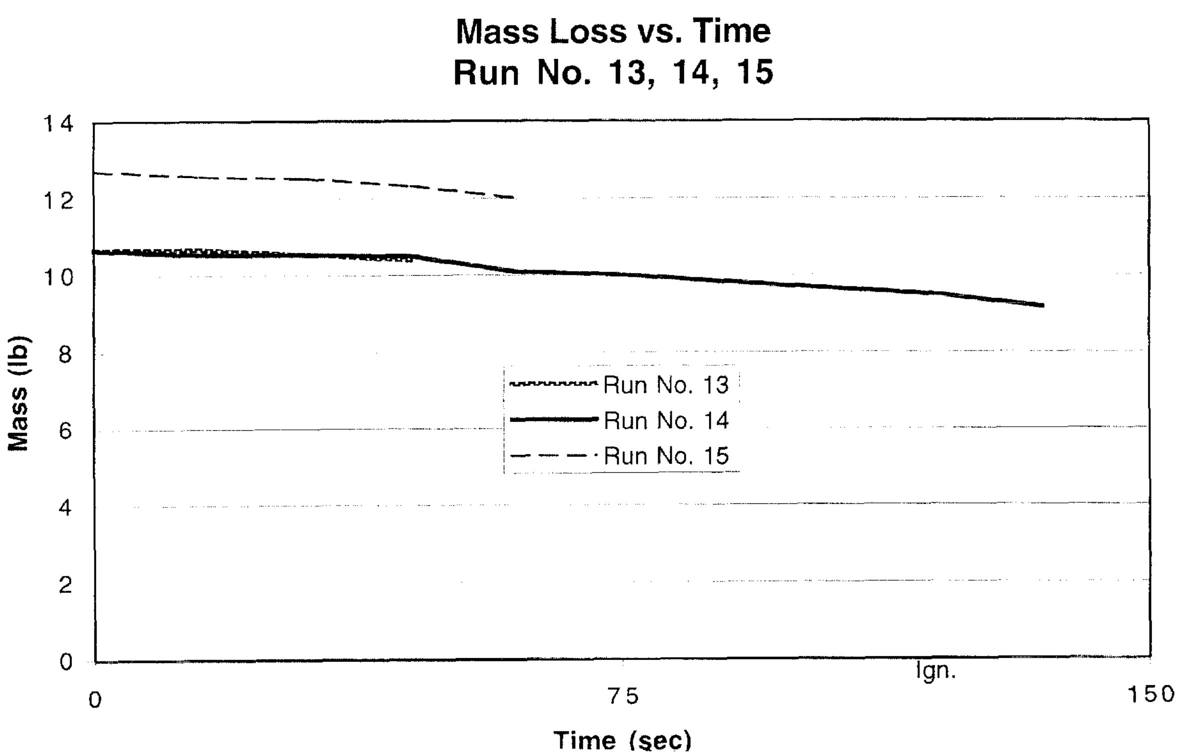
Mass Loss vs. Time
Run No. 4, 5, 6

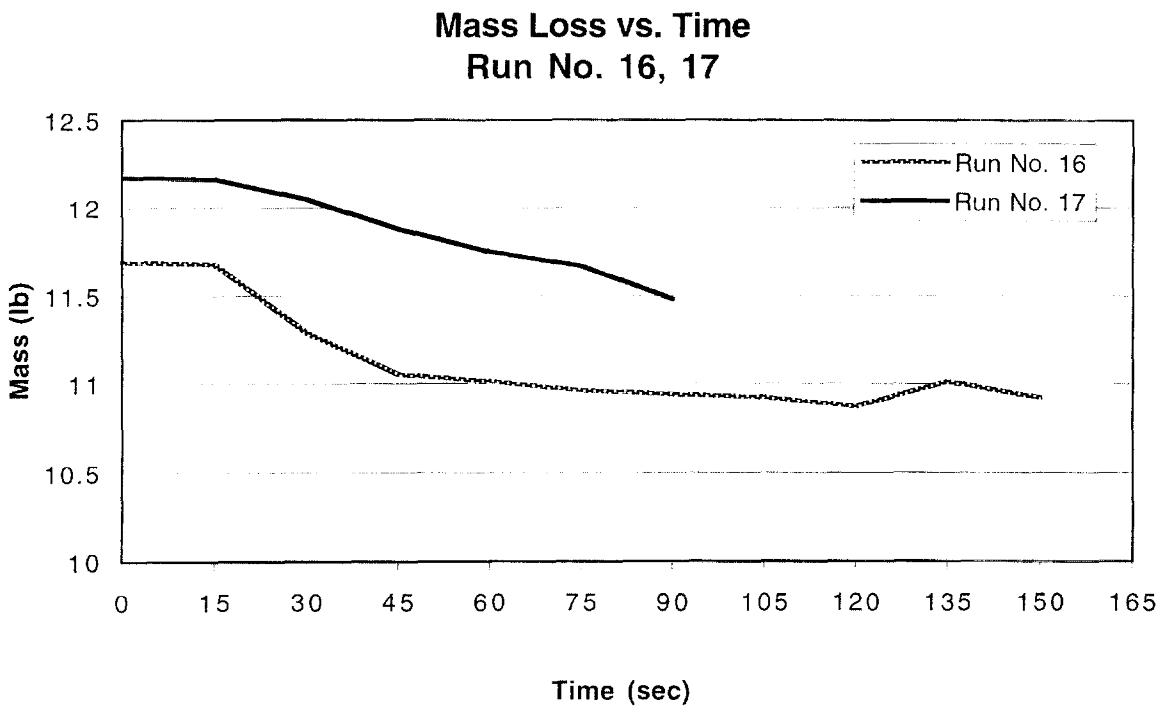


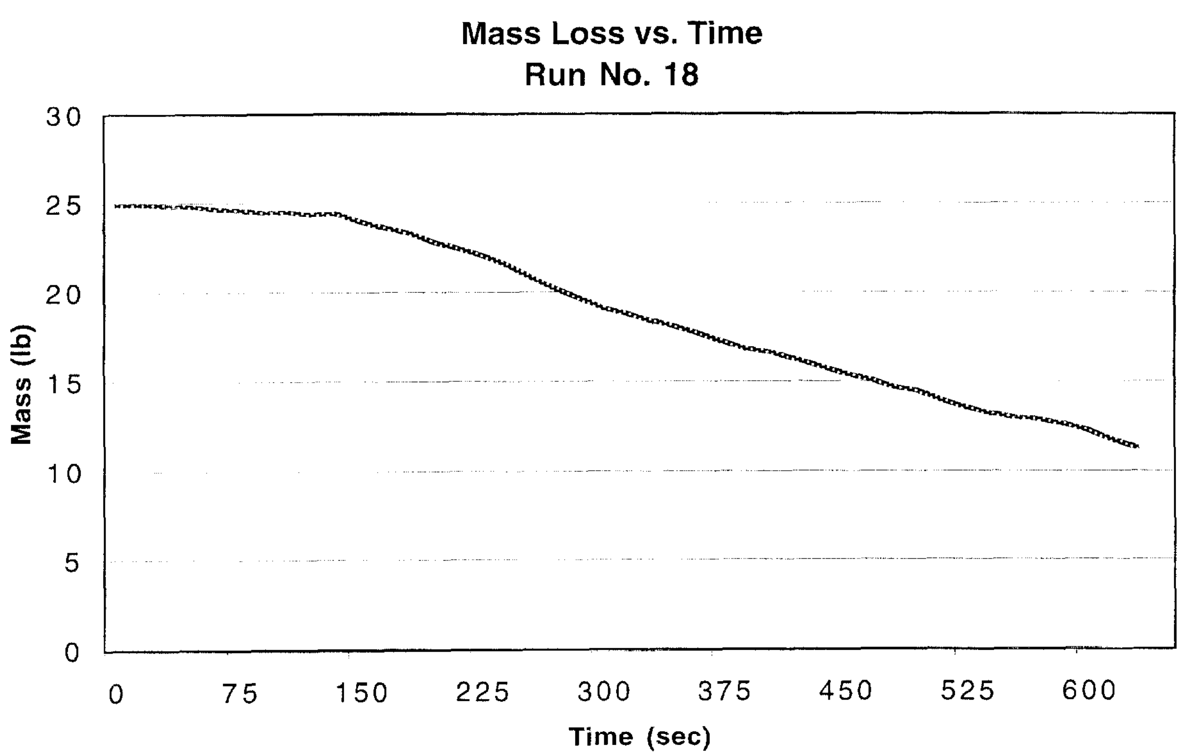

Mass Loss vs. Time
Run No. 7, 8
Run No. 7
Run No. 8
Mass (lb)
12.5
12
11.5
11
10.5
10
9.5
9
0
15
30
45
60
75
90
Time (sec)

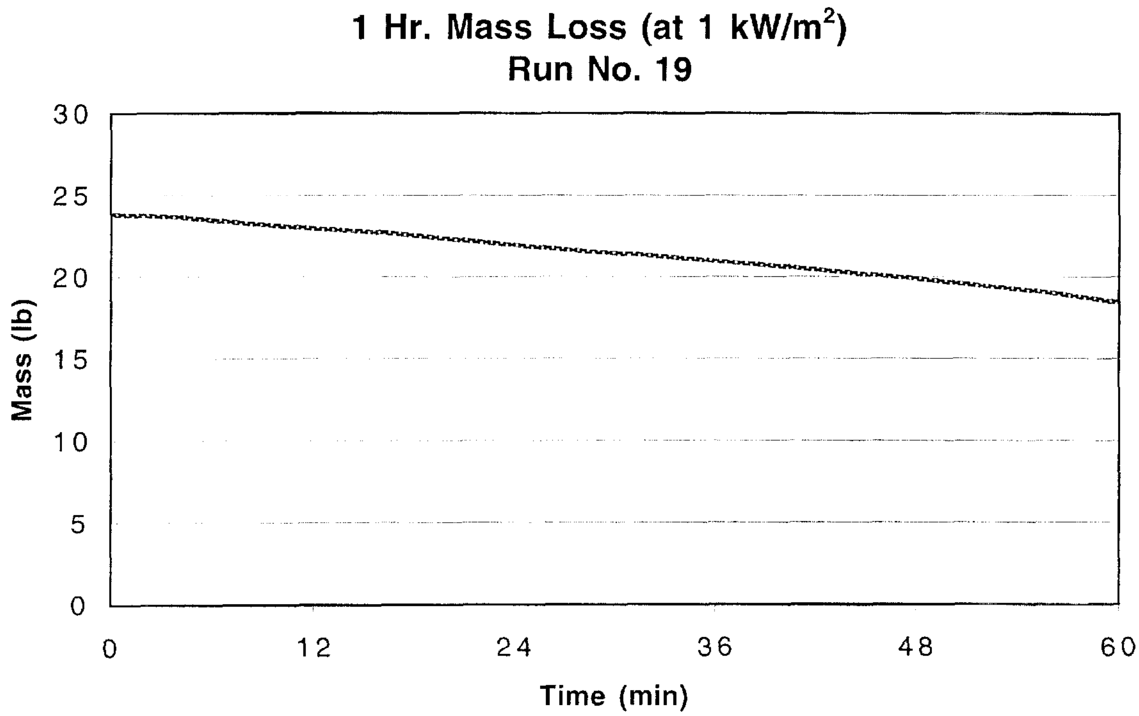

Mass Loss vs. Time
Run No. 9, 10
Run No. 9
Run No. 10
Mass (lb)
25
20
15
10
5
0
0
75
150
225
300
375
450
525
Time (sec)

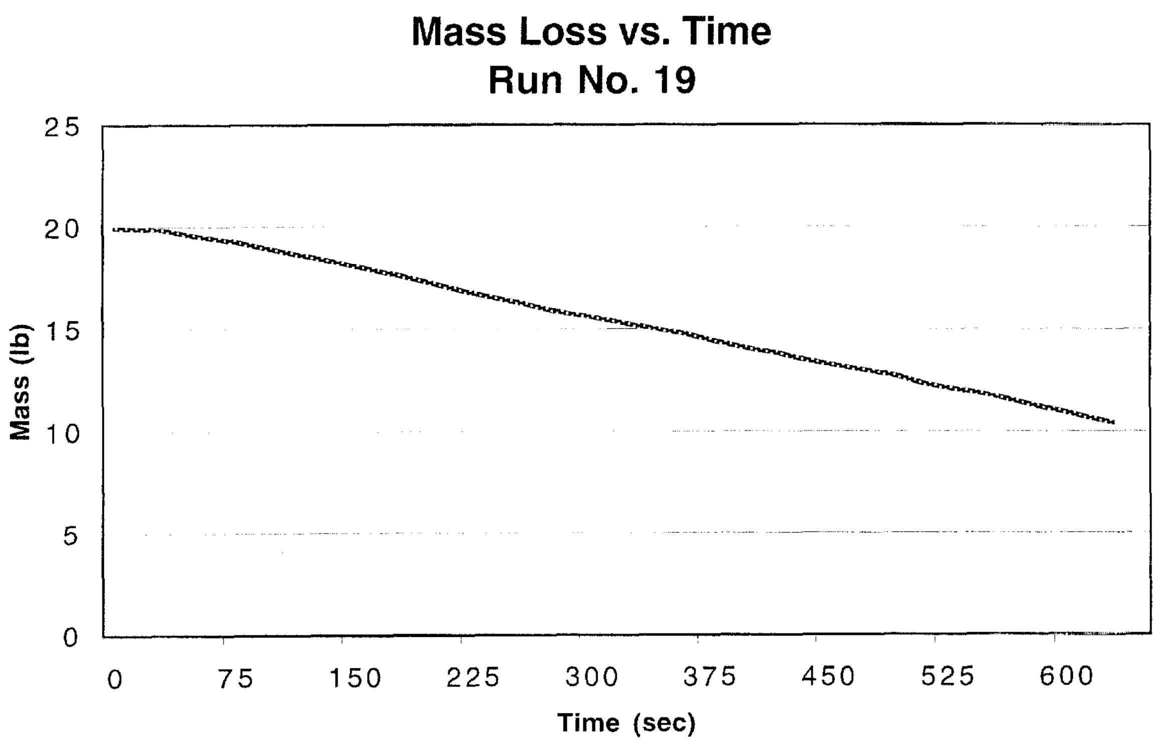

Mass Loss vs. Time
Run No. 11, 12
Mass (lb)
25
20
15
10
5
0
0
75
150
225
300
375
Time (sec)
Run No. 11
Run No. 12


Mass Loss vs. Time
Run No. 13, 14, 15
Mass (lb)
14
12
10
8
6
4
2
0
0
75
150
Ign.
Time (sec)
Run No. 13
Run No. 14
Run No. 15

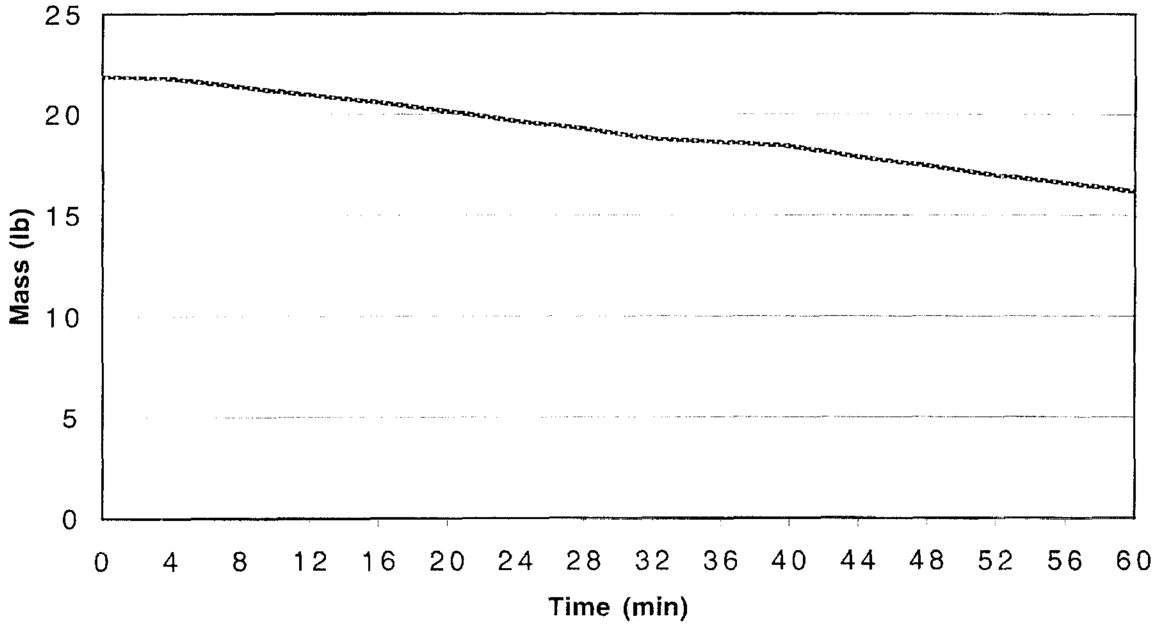

Mass Loss vs. Time
Run No. 16, 17
Run No. 16
Run No. 17
Mass (lb)
12.5
12
11.5
11
10.5
10
0
15
30
45
60
75
90
105
120
135
150
165
Time (sec)


Mass Loss vs. Time
Run No. 18
Mass (lb)
30
25
20
15
10
5
0
0
75
150
225
300
375
450
525
600
Time (sec)

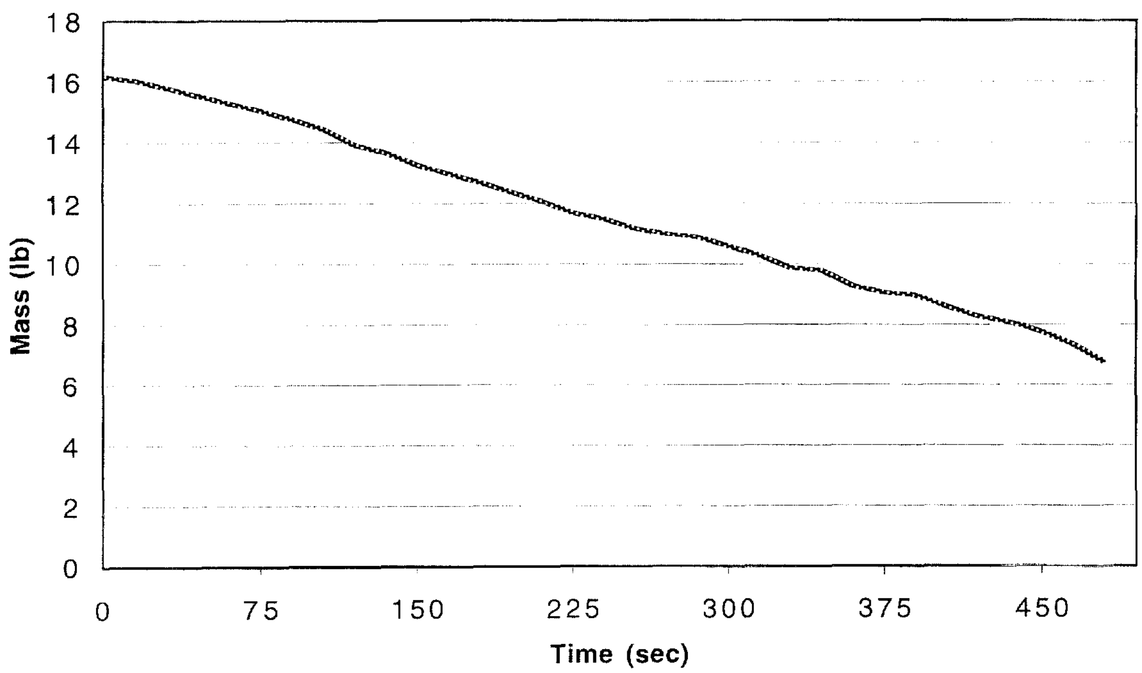

1 Hr. Mass Loss (at 1 kW/m2)
Run No. 19
Mass (lb)
30
25
20
15
10
5
0
0
12
24
36
48
60
Time (min)

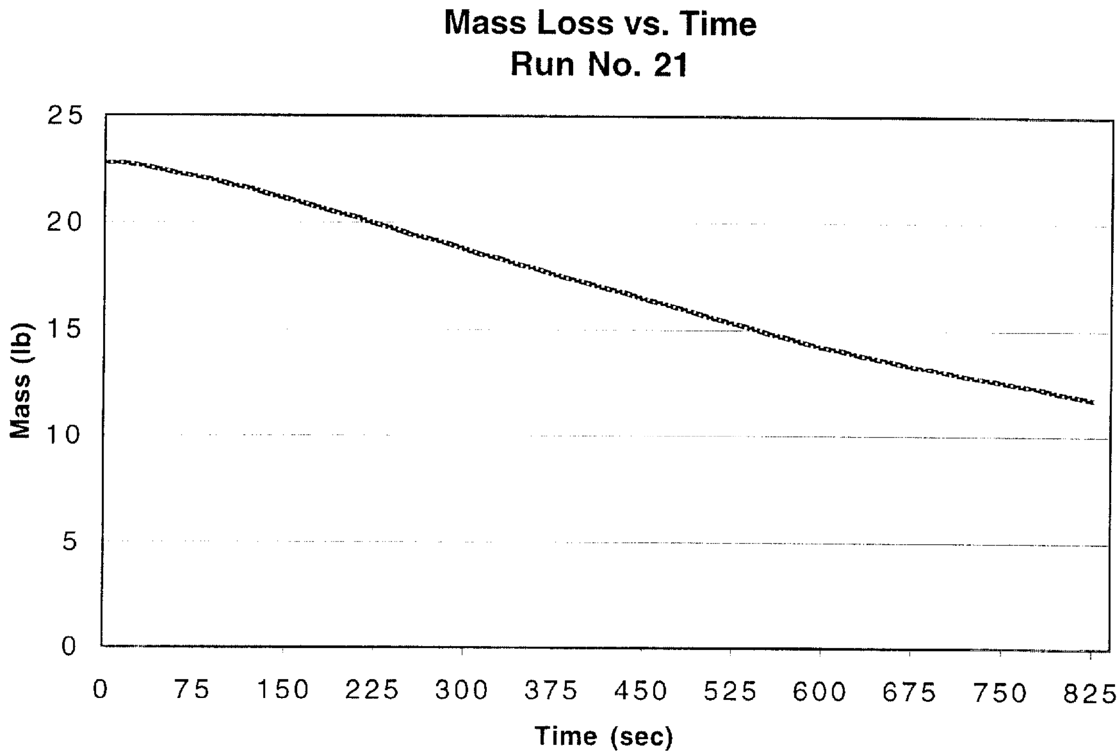

Mass Loss vs. Time
Run No. 19
Mass (lb)
25
20
15
10
5
0
0
75
150
225
300
375
450
525
600
Time (sec)

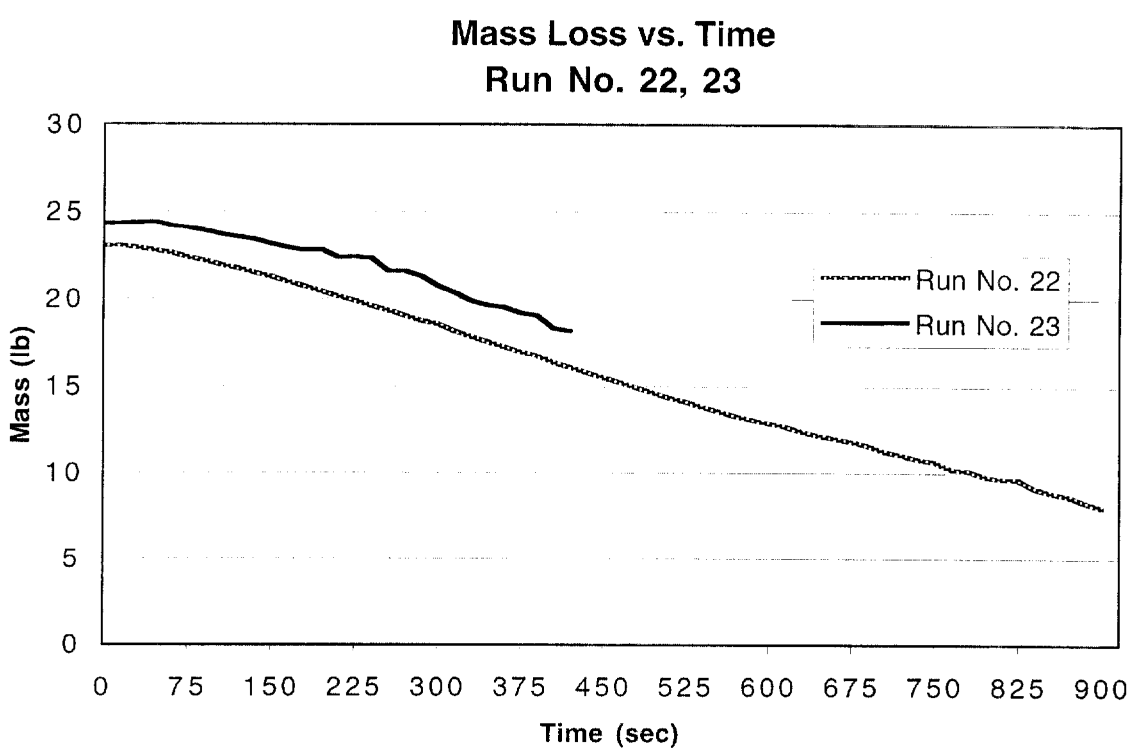
1 Hr. Mass Loss (at 1 kW/m^2)
Run No. 20

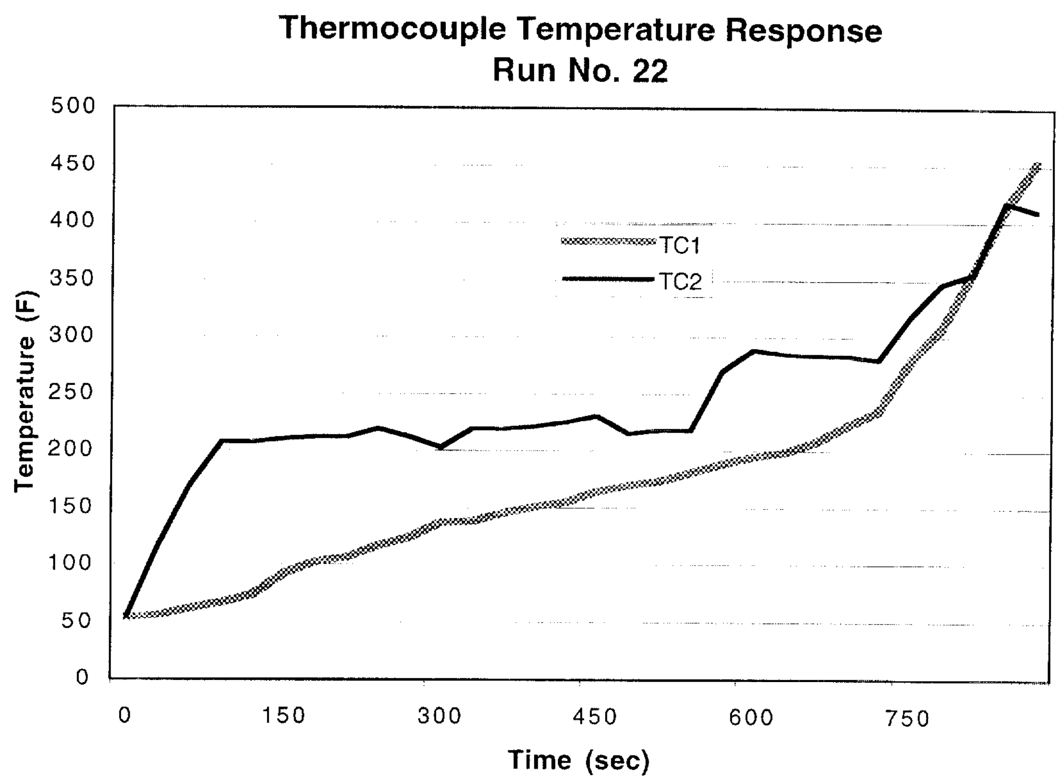


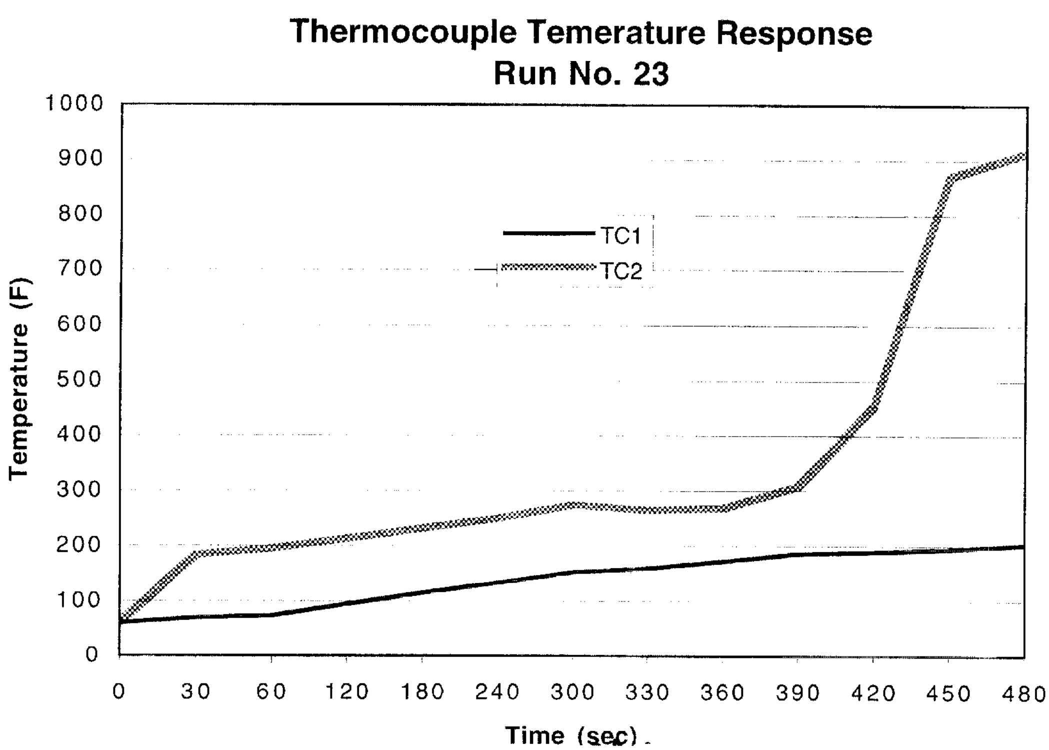
Mass Loss vs. Time
Run No. 20

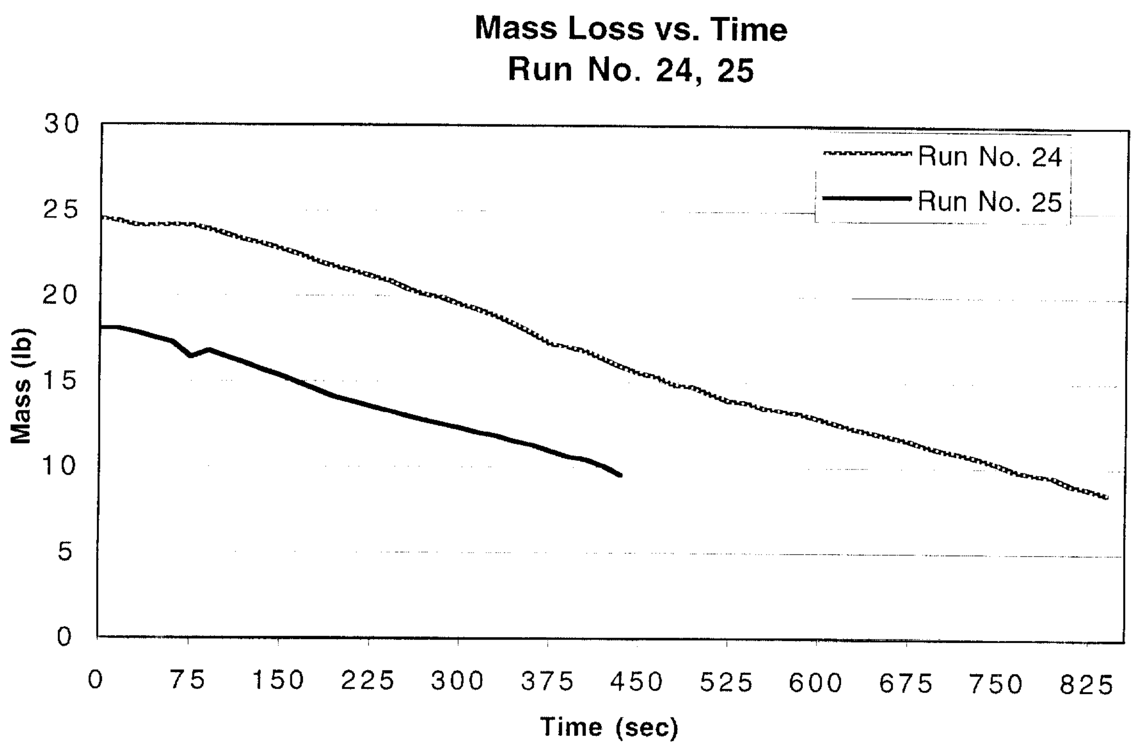


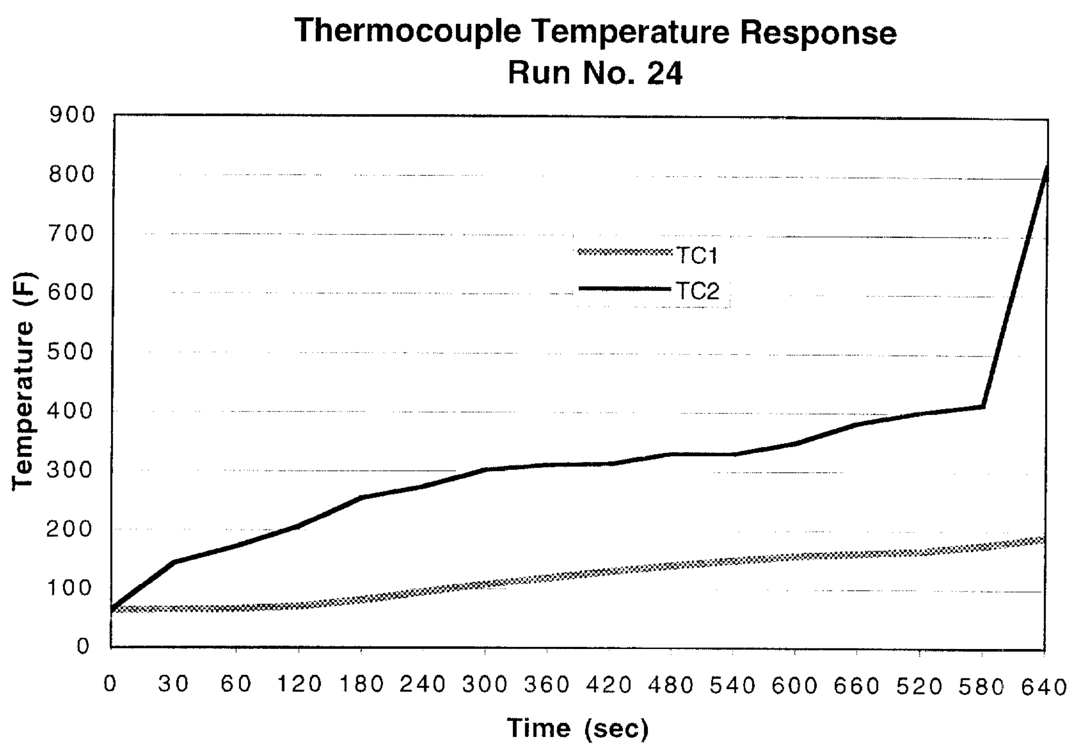

Mass Loss vs. Time
Run No. 21
Mass (lb)
25
20
15
10
5
0
0
75
150
225
300
375
450
525
600
675
750
825
Time (sec)

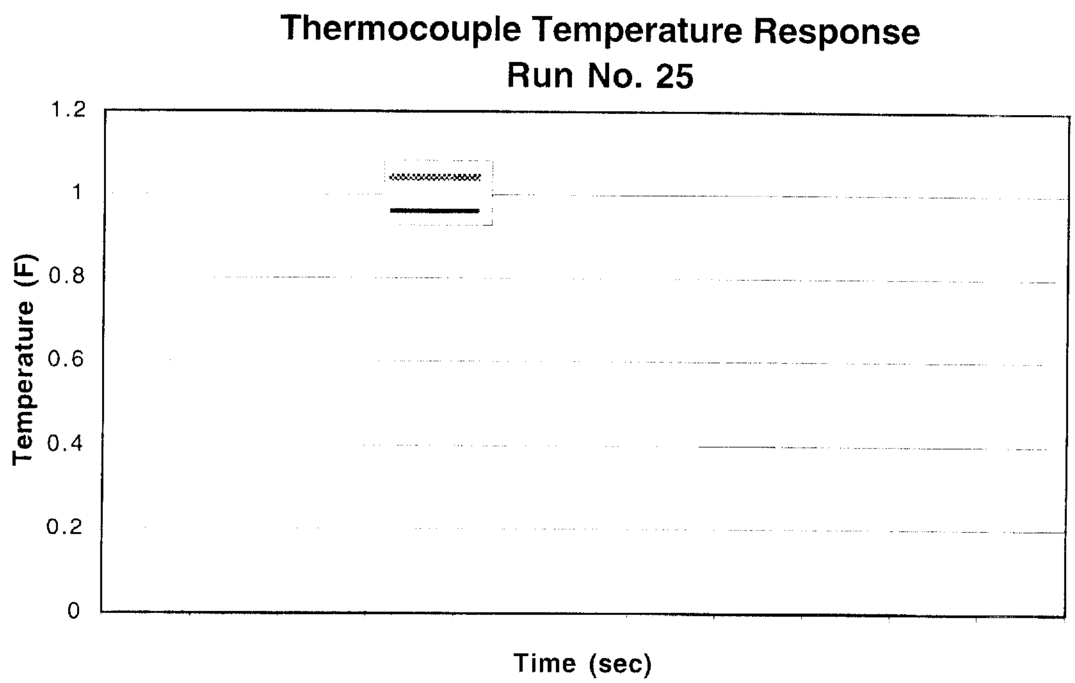

Mass Loss vs. Time
Run No. 22, 23
Mass (lb)
30
25
20
15
10
5
0
Run No. 22
Run No. 23
0
75
150
225
300
375
450
525
600
675
750
825
900
Time (sec)

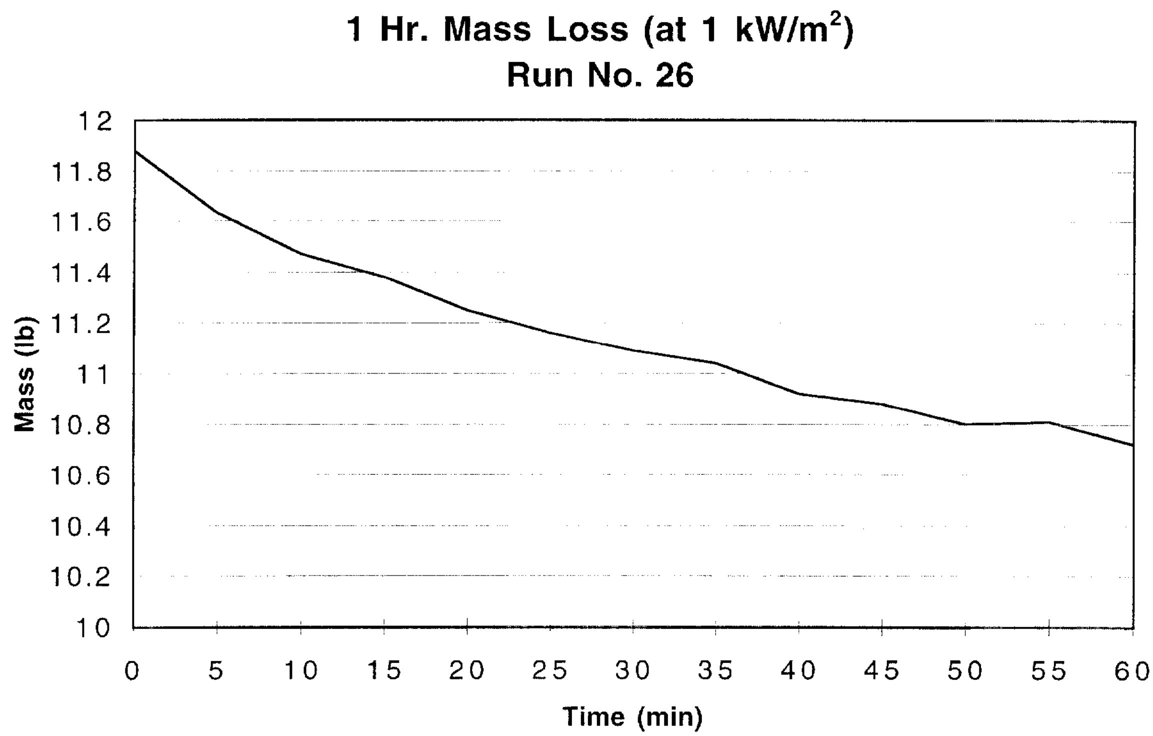

Thermocouple Temperature Response
Run No. 22
TC1
TC2
Temperature (F)
Time (sec)
0
50
100
150
200
250
300
350
400
450
500
0
150
300
450
600
750

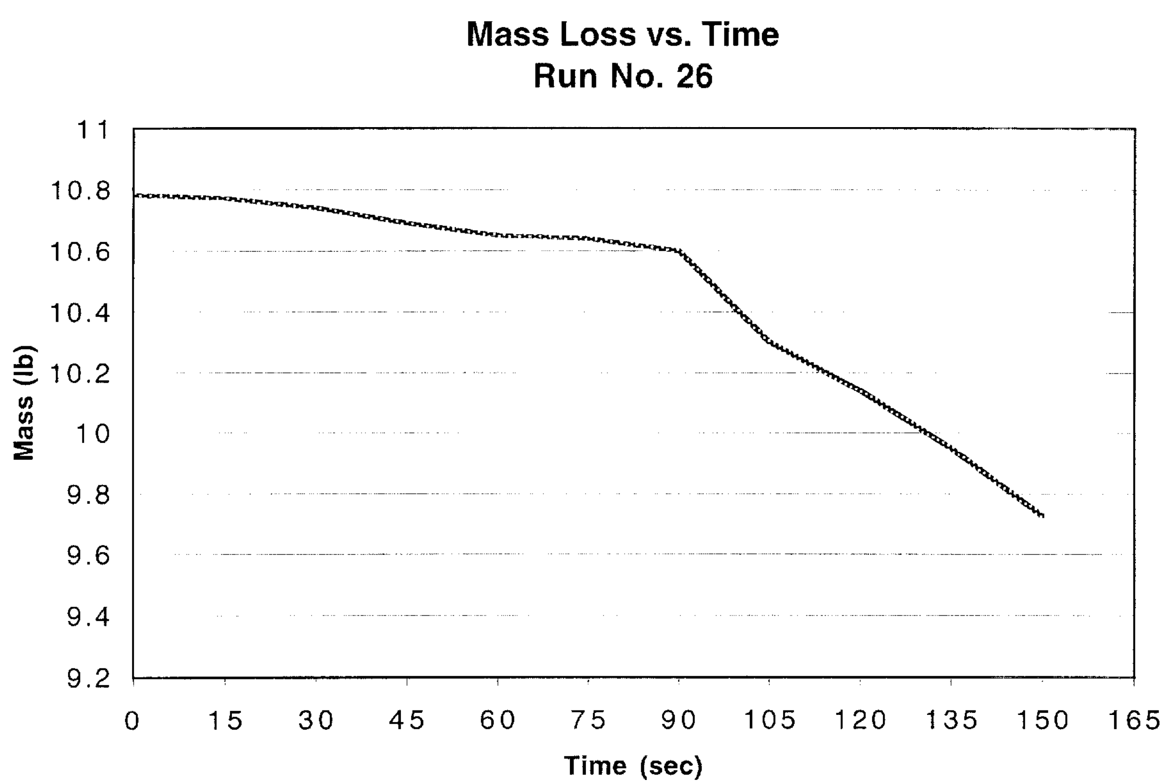

Thermocouple Temerature Response
Run No. 23
TC1
TC2
Temperature (F)
Time (sec)
0
100
200
300
400
500
600
700
800
900
1000
0
30
60
120
180
240
300
330
360
390
420
450
480

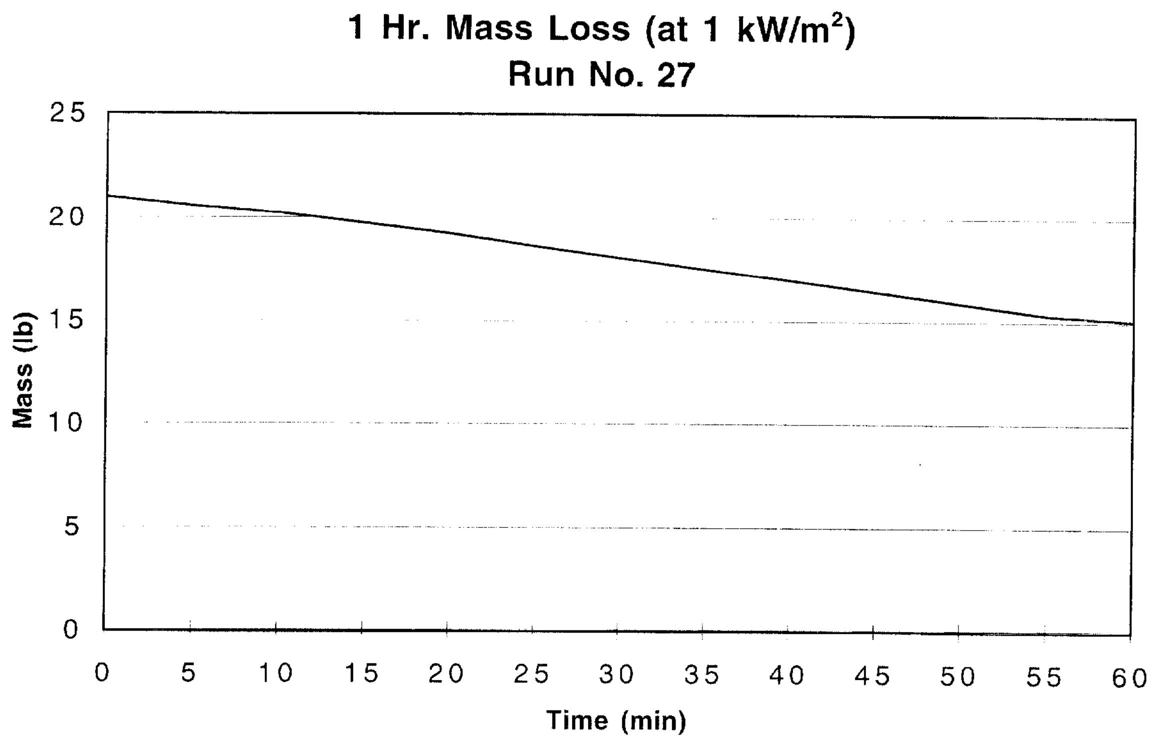

Mass Loss vs. Time
Run No. 24, 25
Run No. 24
Run No. 25
Mass (lb)
0
5
10
15
20
25
30
0
75
150
225
300
375
450
525
600
675
750
825
Time (sec)

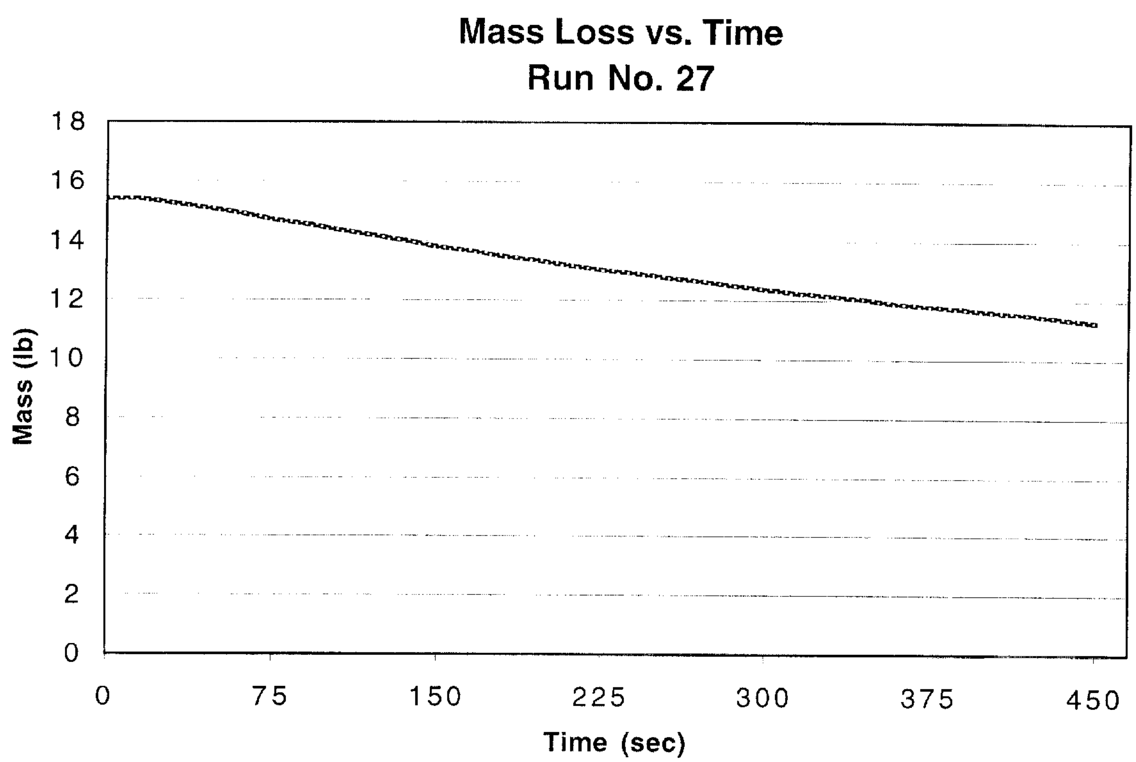

Thermocouple Temperature Response
Run No. 24
TC1
TC2
Temperature (F)
0
100
200
300
400
500
600
700
800
900
0
30
60
120
180
240
300
360
420
480
540
600
660
520
580
640
Time (sec)

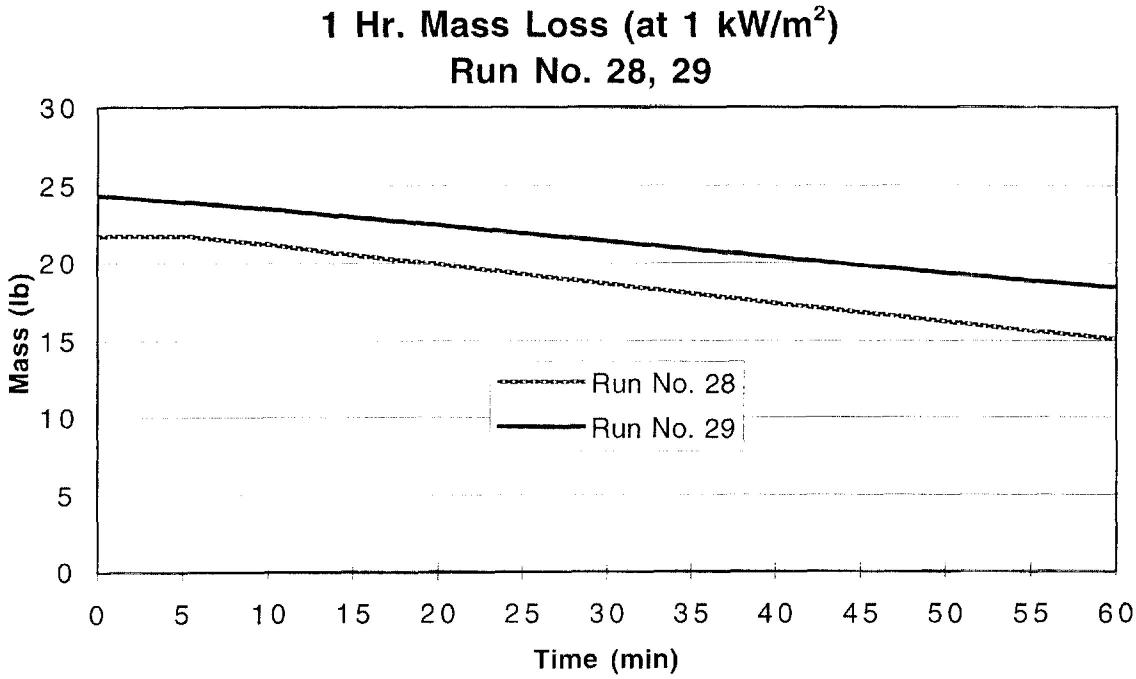

Thermocouple Temperature Response
Run No. 25
1.2
1
0.8
0.6
0.4
0.2
0
Temperature (F)
Time (sec)

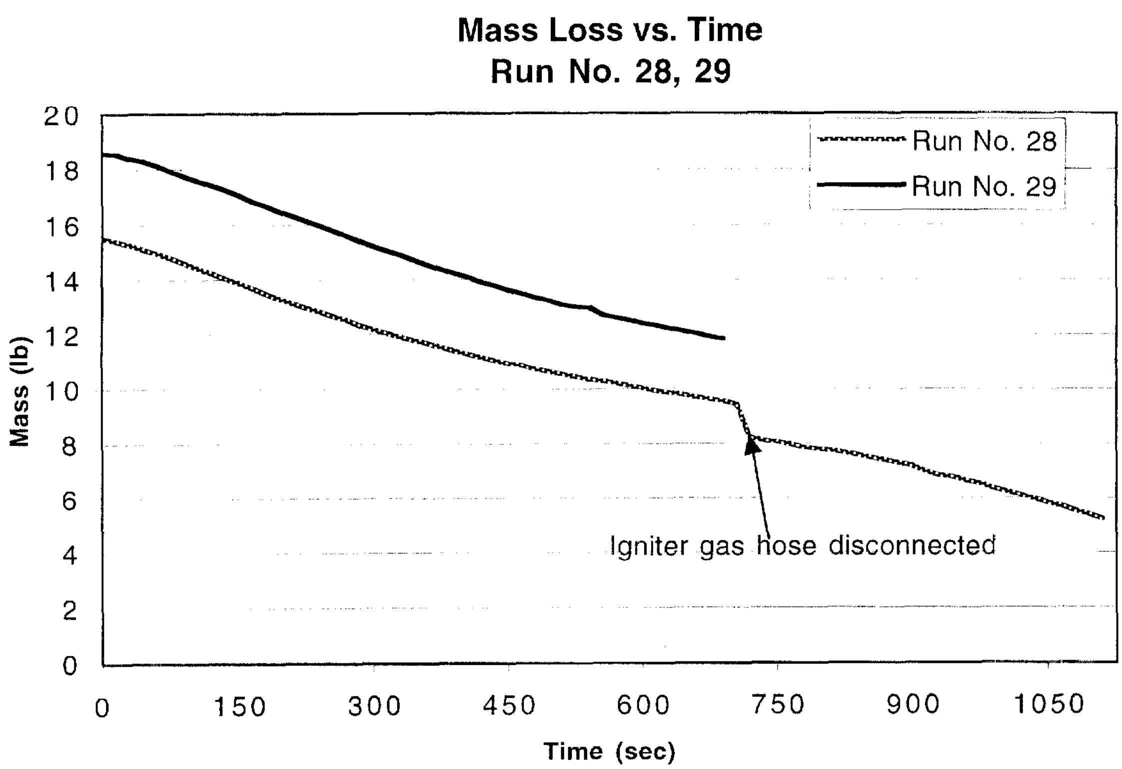

1 Hr. Mass Loss (at 1 kW/m2)
Run No. 26
Mass (lb)
12
11.8
11.6
11.4
11.2
11
10.8
10.6
10.4
10.2
10
0
5
10
15
20
25
30
35
40
45
50
55
60
Time (min)

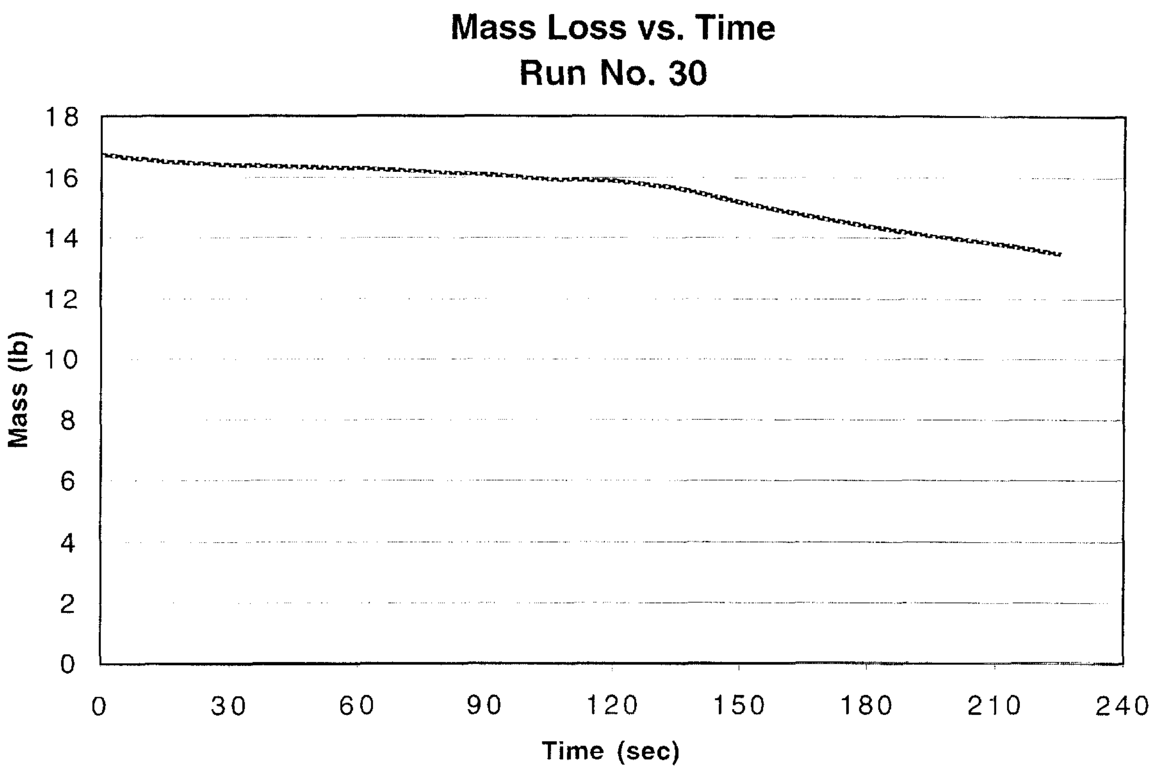

Mass Loss vs. Time
Run No. 26
Mass (lb)
11
10.8
10.6
10.4
10.2
10
9.8
9.6
9.4
9.2
0
15
30
45
60
75
90
105
120
135
150
165
Time (sec)

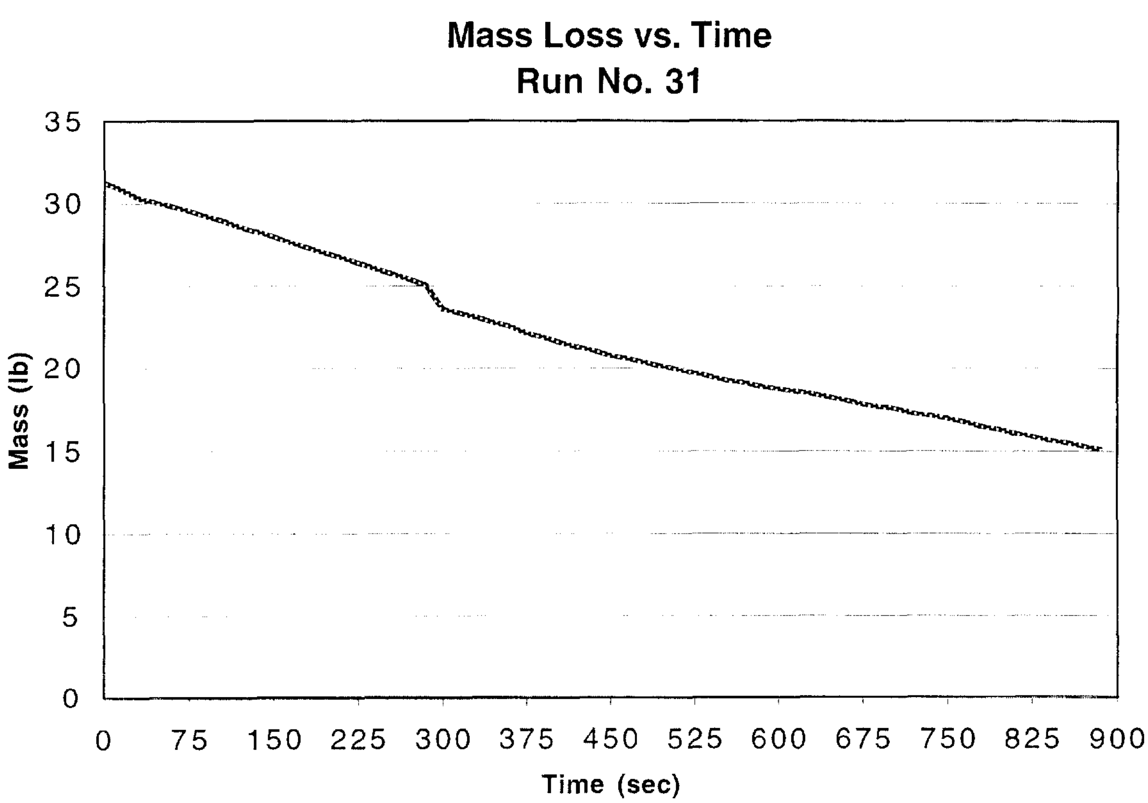

1 Hr. Mass Loss (at 1 kW/m²)
Run No. 27
Mass (lb)
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
50
55
60
Time (min)

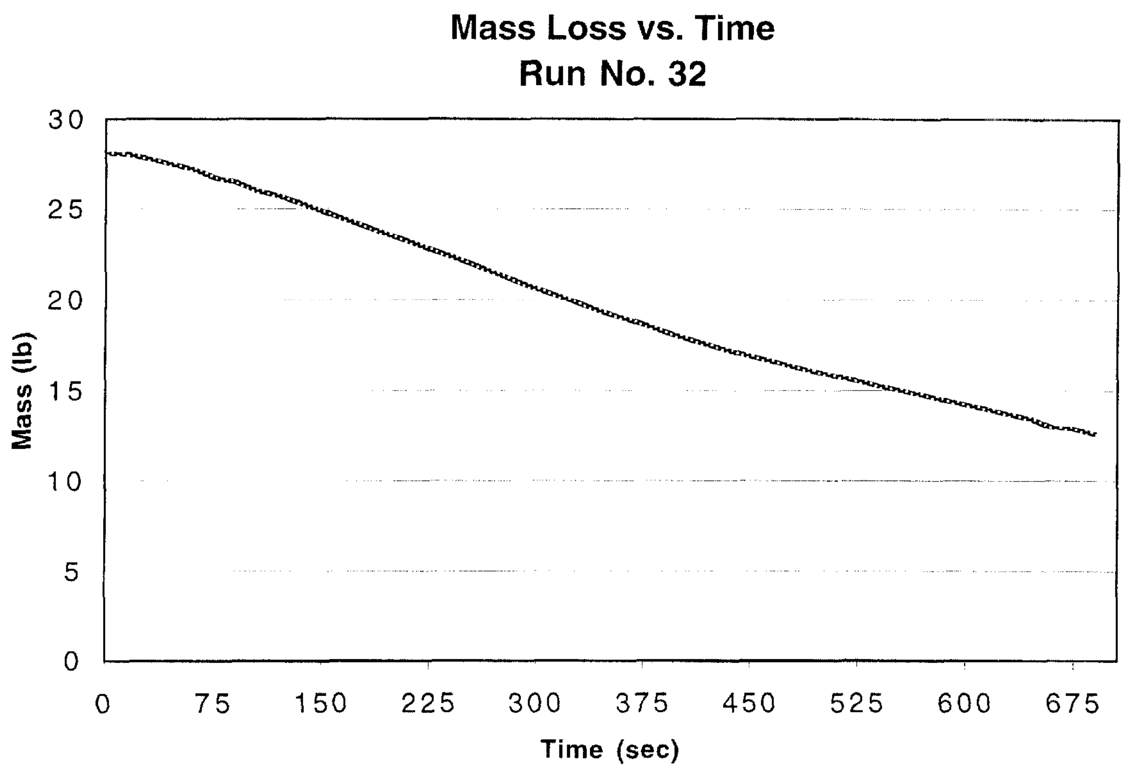

Mass Loss vs. Time
Run No. 27
Mass (lb)
18
16
14
12
10
8
6
4
2
0
0
75
150
225
300
375
450
Time (sec)

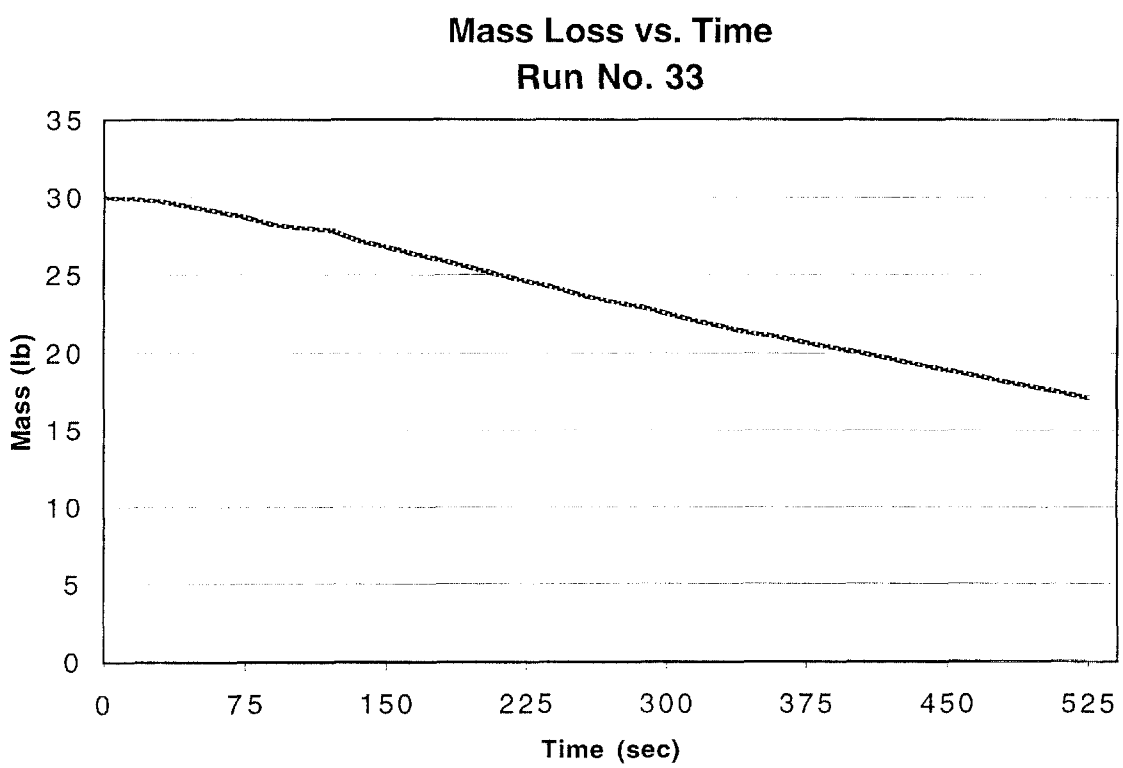

1 Hr. Mass Loss (at 1 kW/m2)
Run No. 28, 29
Mass (lb)
Time (min)
Run No. 28
Run No. 29
0
5
10
15
20
25
30
35
40
45
50
55
60

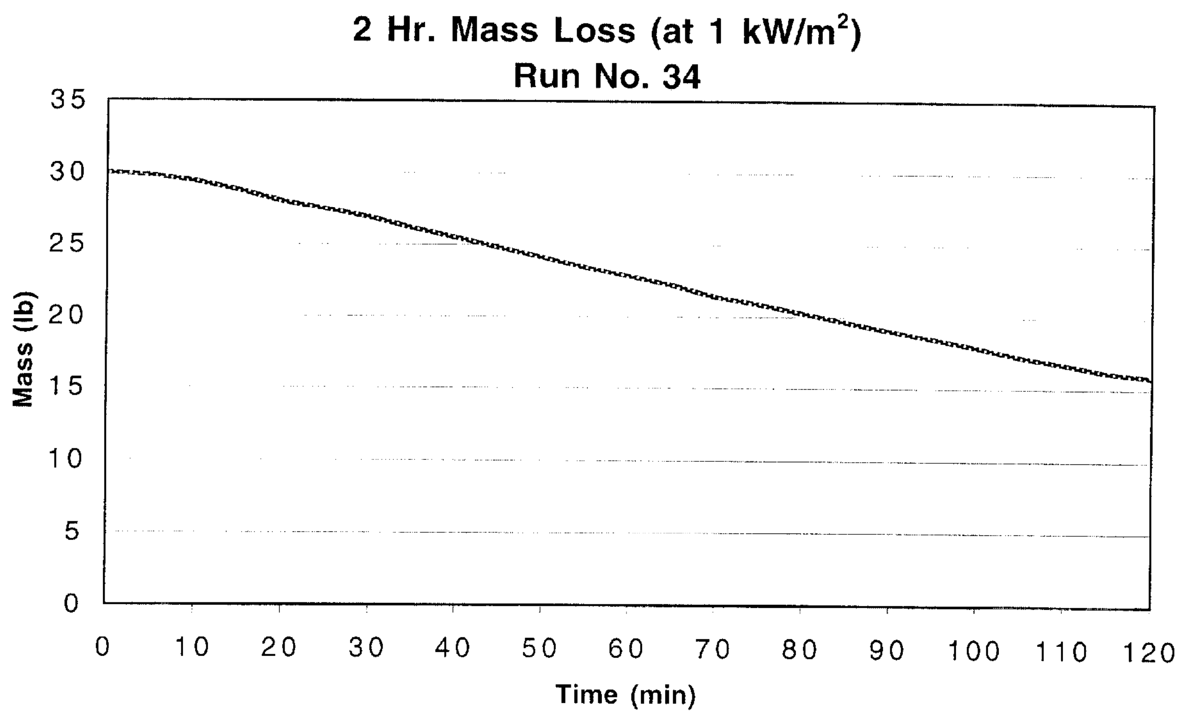

Mass Loss vs. Time
Run No. 28, 29
Mass (lb)
Time (sec)
Run No. 28
Run No. 29
Igniter gas hose disconnected
0
2
4
6
8
10
12
14
16
18
20
150
300
450
600
750
900
1050

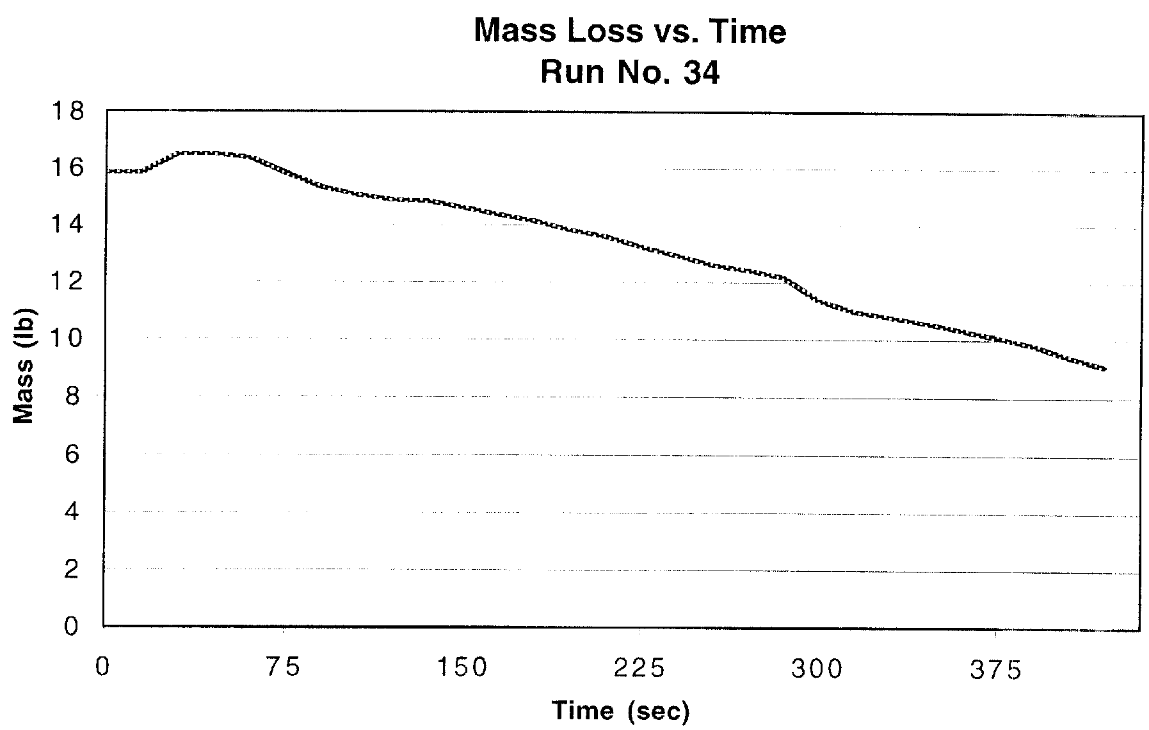

Mass Loss vs. Time
Run No. 30
Mass (lb)
Time (sec)
0
2
4
6
8
10
12
14
16
18
0
30
60
90
120
150
180
210
240


Mass Loss vs. Time
Run No. 31
Mass (lb)
Time (sec)
0
5
10
15
20
25
30
35
0
75
150
225
300
375
450
525
600
675
750
825
900

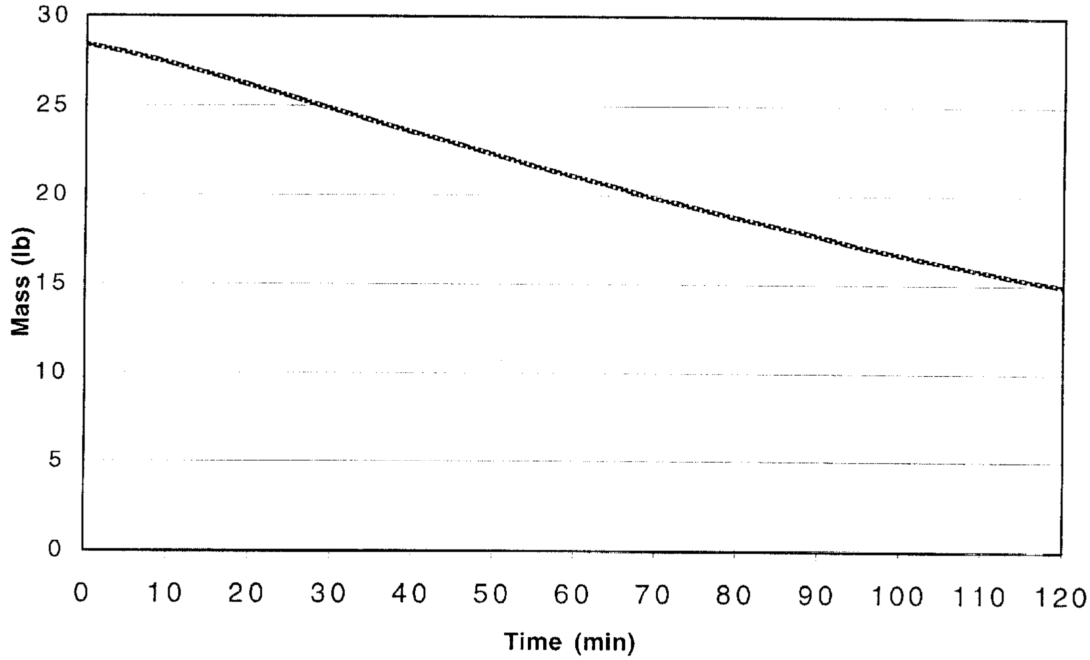

Mass Loss vs. Time
Run No. 32
Mass (lb)
30
25
20
15
10
5
0
0
75
150
225
300
375
450
525
600
675
Time (sec)


Mass Loss vs. Time
Run No. 33
Mass (lb)
35
30
25
20
15
10
5
0
0
75
150
225
300
375
450
525
Time (sec)

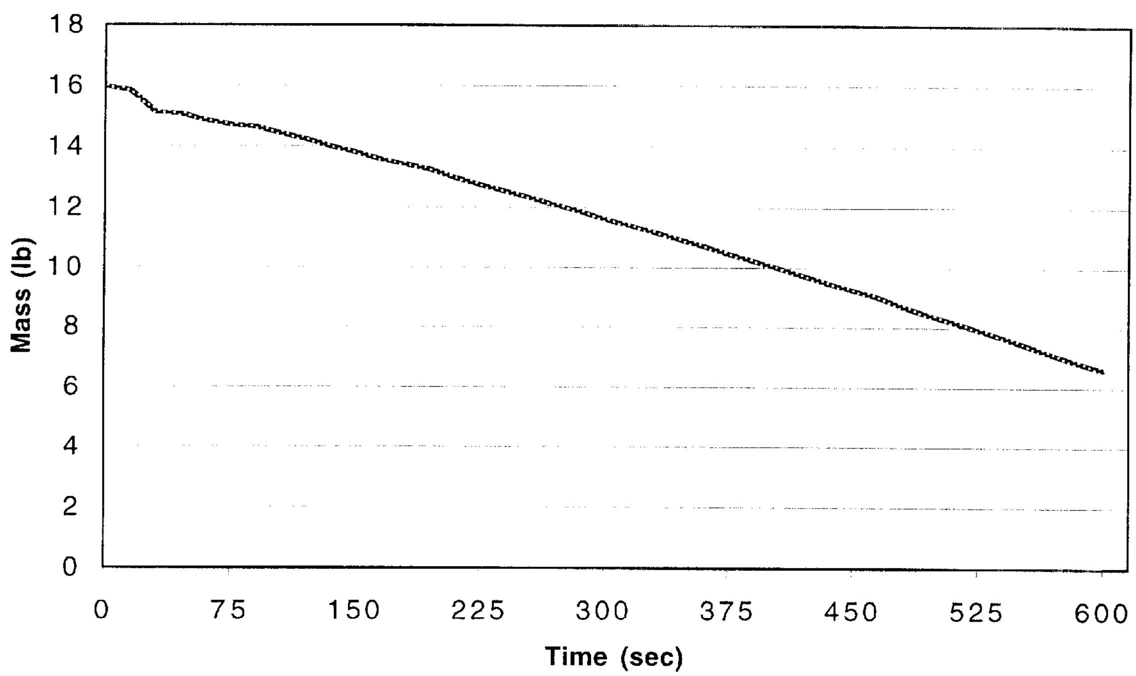

2 Hr. Mass Loss (at 1 kW/m2)
Run No. 34
Mass (lb)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
110
120
Time (min)

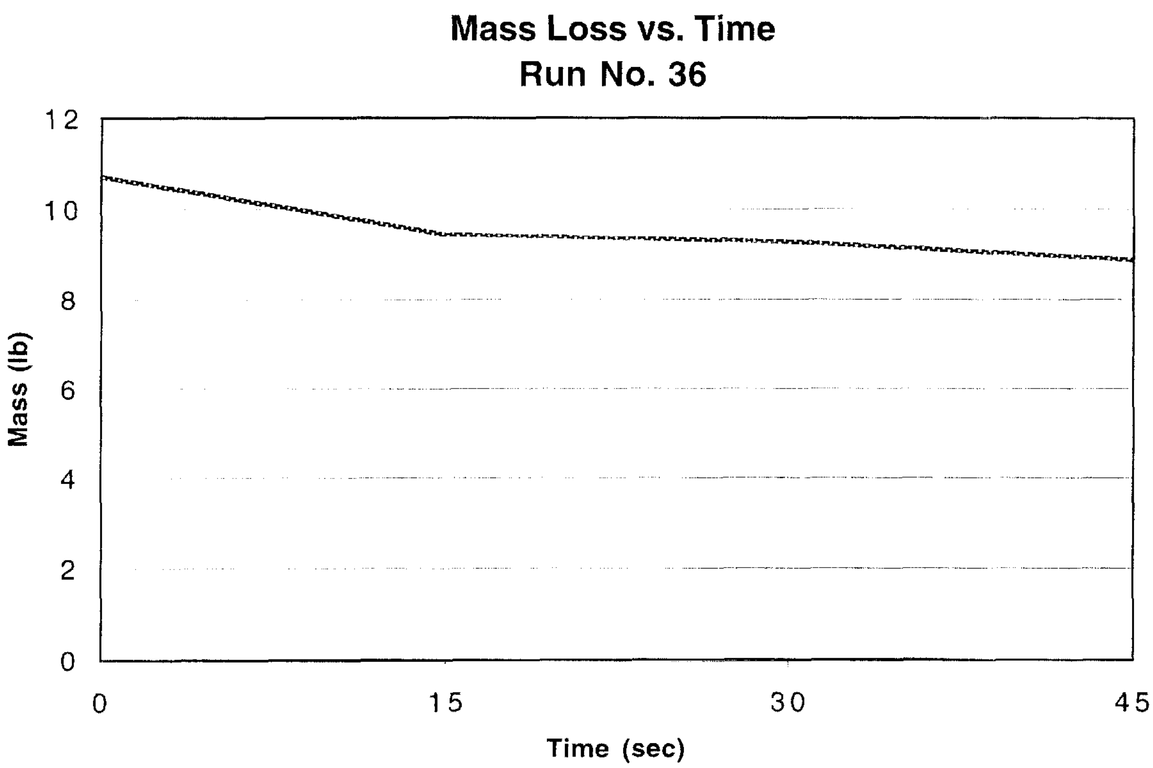

Mass Loss vs. Time
Run No. 34
Mass (lb)
18
16
14
12
10
8
6
4
2
0
0
75
150
225
300
375
Time (sec)

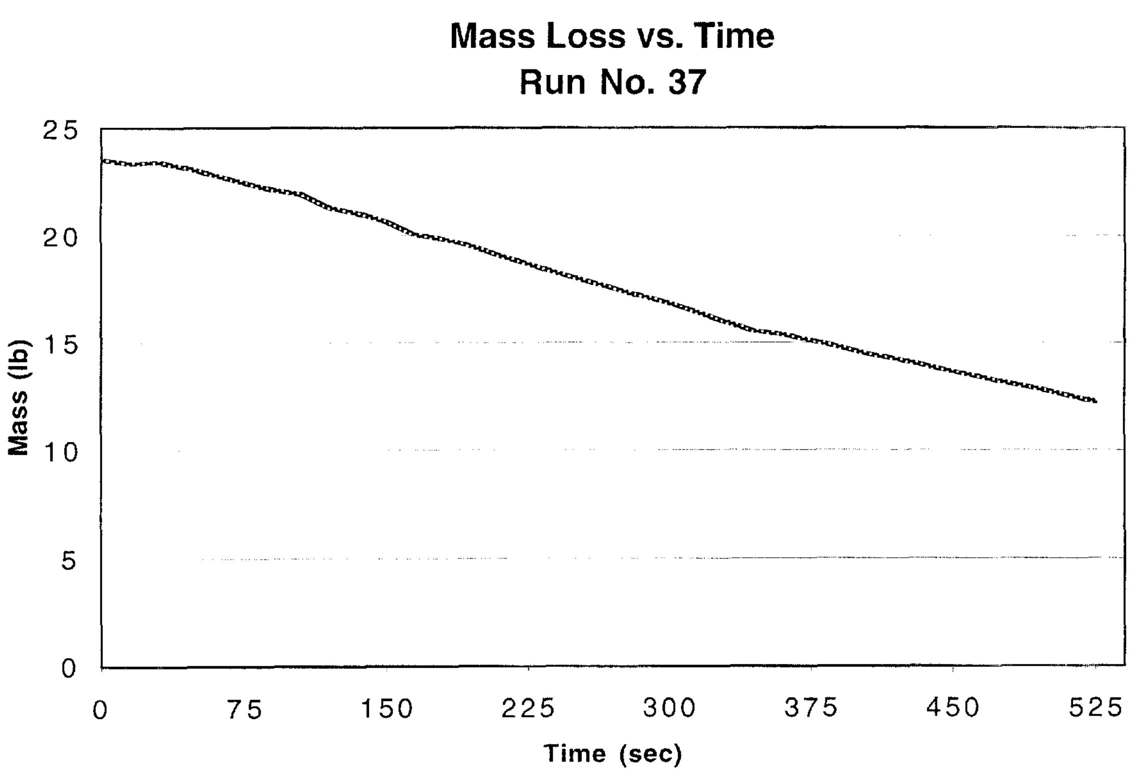
2 Hr. Mass Loss (at 1 kW/m^2)
Run No. 35

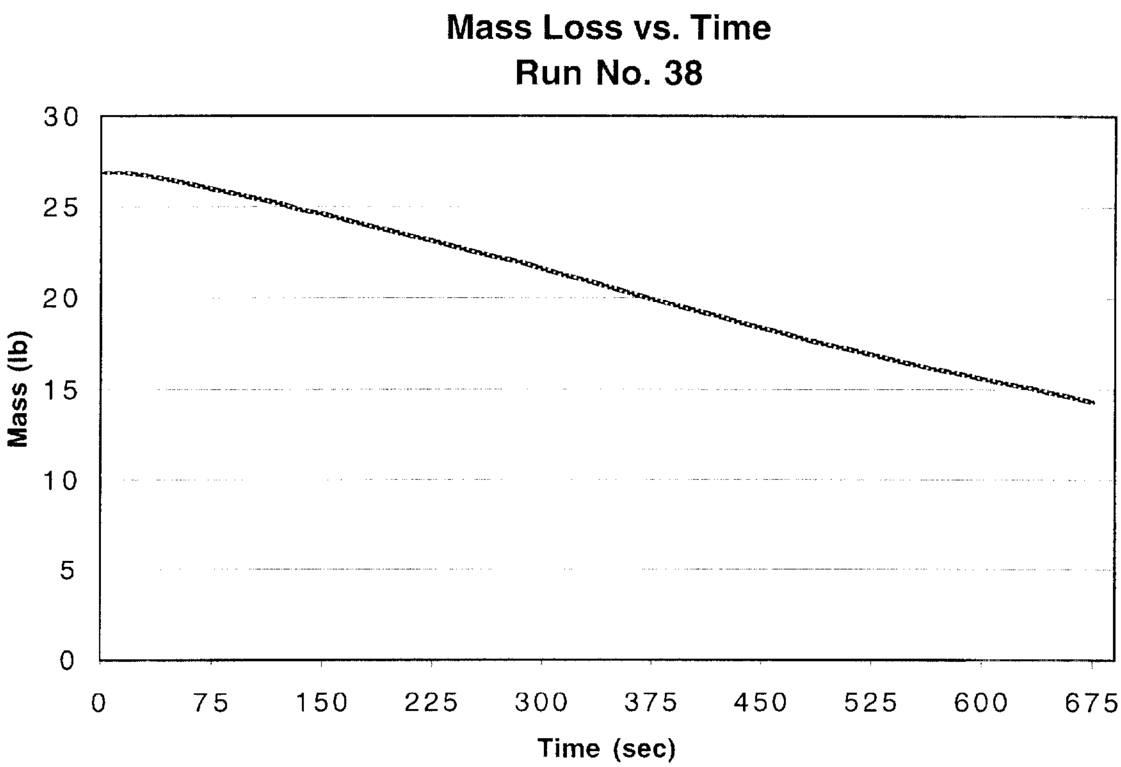


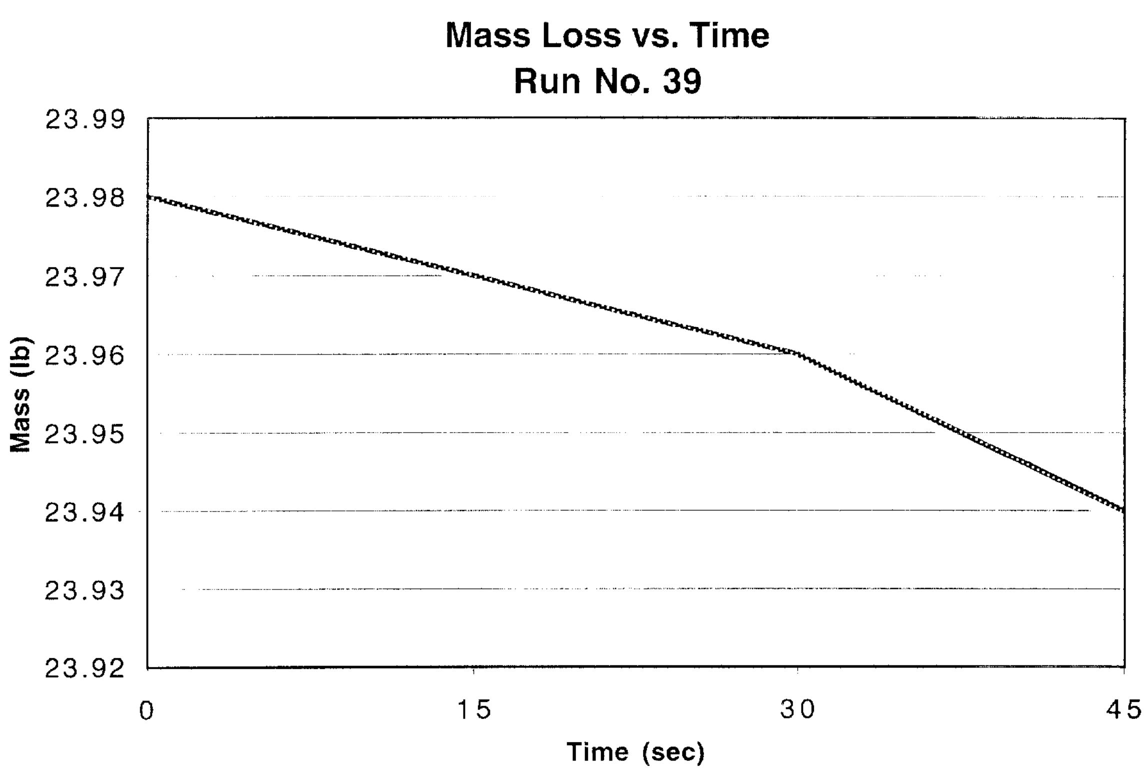
Mass Loss vs. Time
Run No. 35

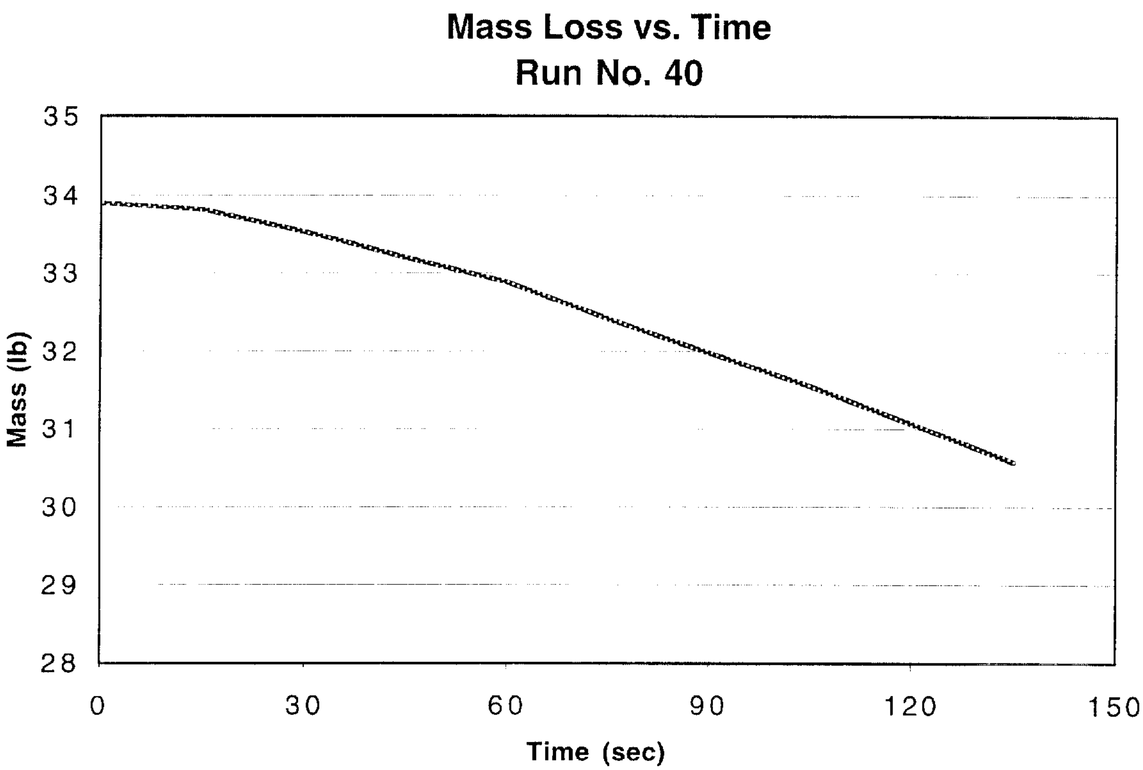


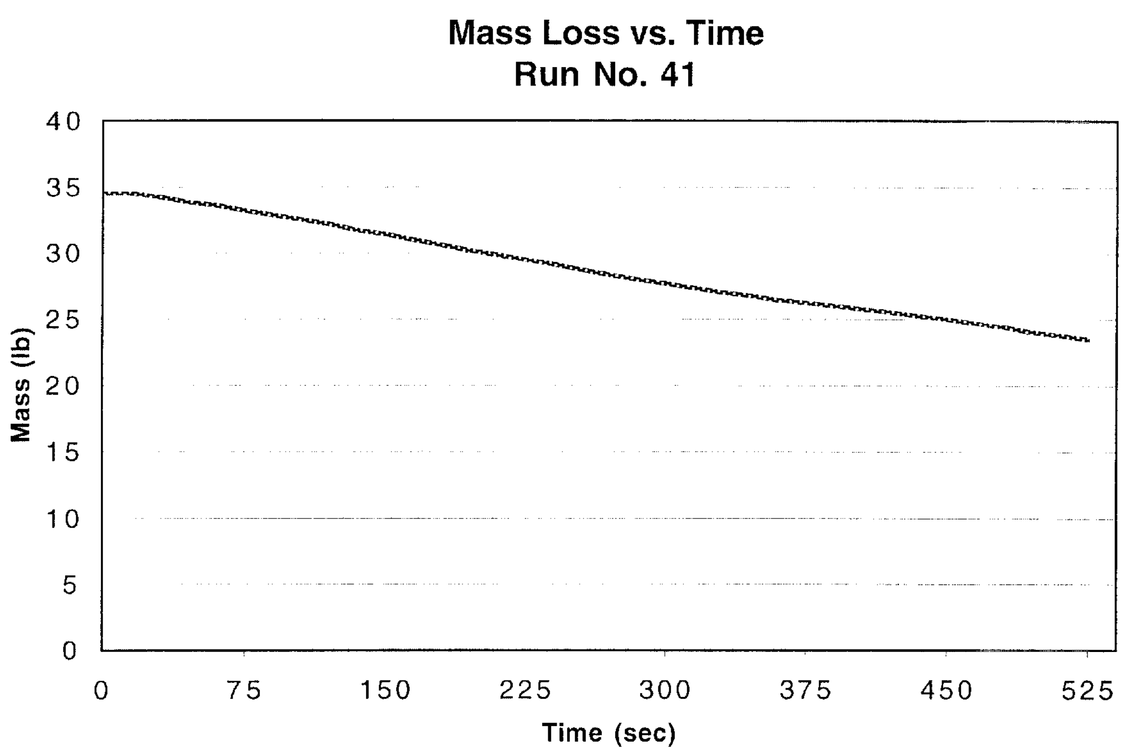

Mass Loss vs. Time
Run No. 36
Mass (lb)
12
10
8
6
4
2
0
0
15
30
45
Time (sec)

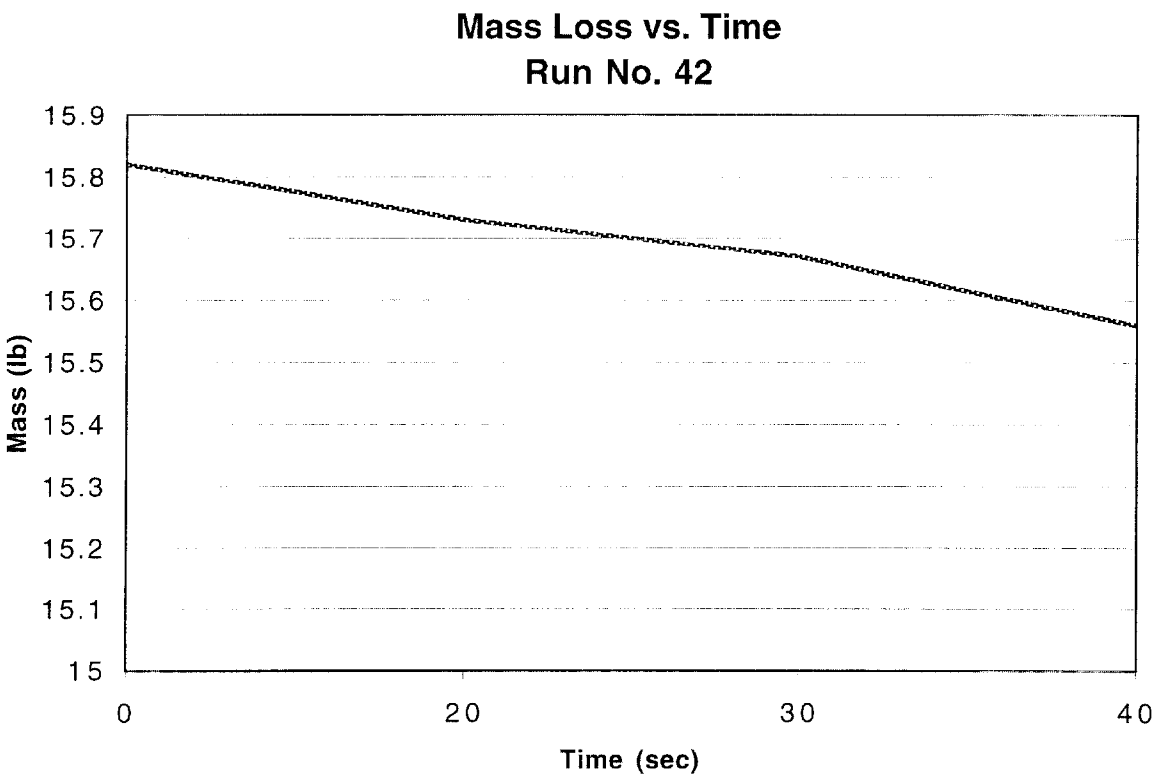

Mass Loss vs. Time
Run No. 37
Mass (lb)
25
20
15
10
5
0
0
75
150
225
300
375
450
525
Time (sec)

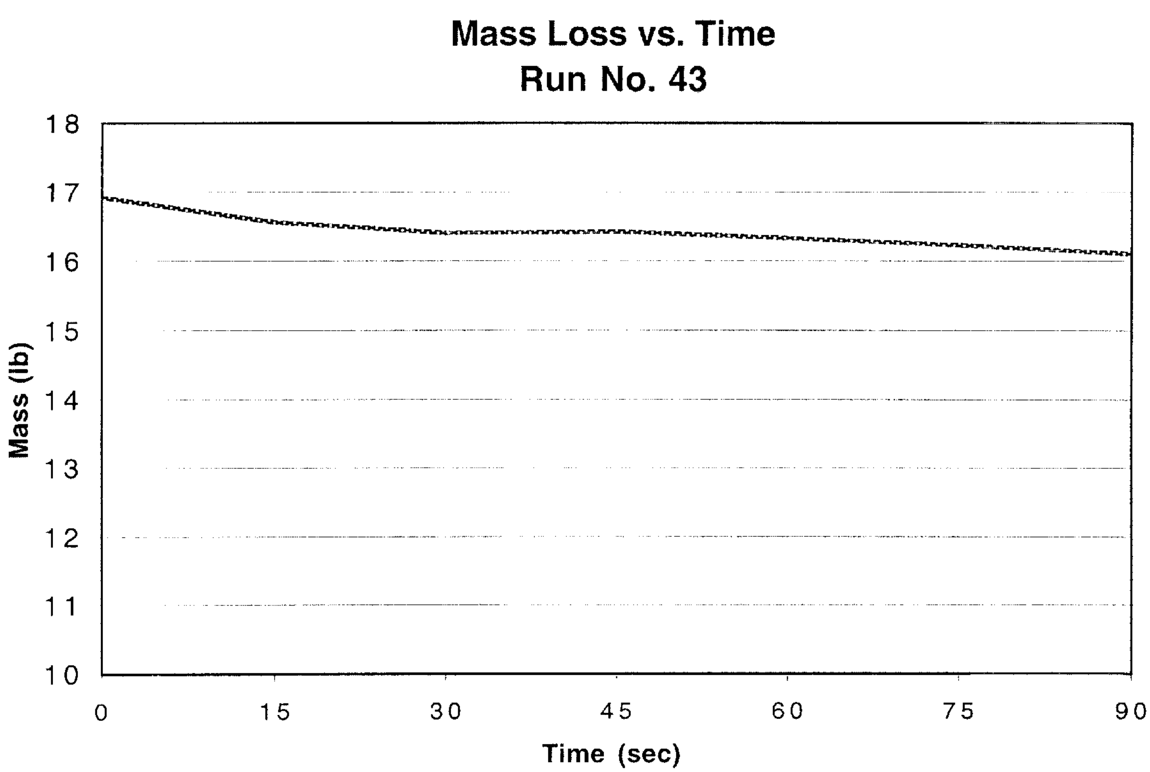

Mass Loss vs. Time
Run No. 38
30
25
20
15
10
5
0
Mass (lb)
0
75
150
225
300
375
450
525
600
675
Time (sec)

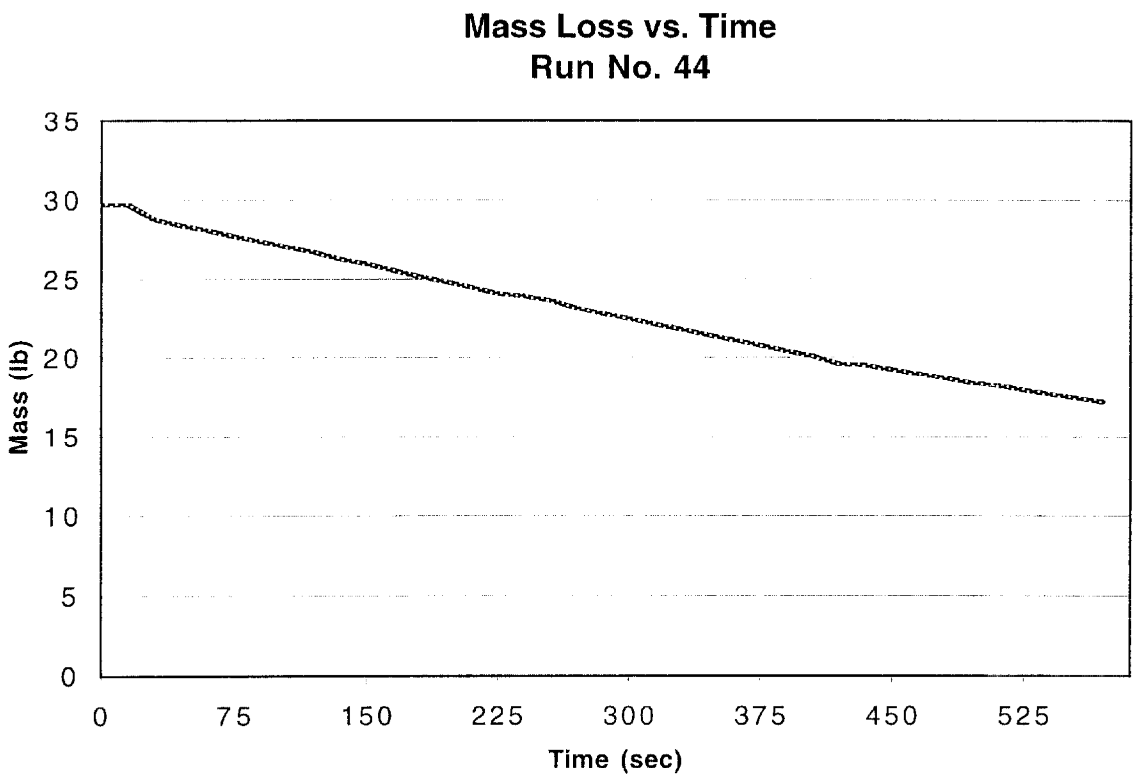

Mass Loss vs. Time
Run No. 39
23.99
23.98
23.97
23.96
23.95
23.94
23.93
23.92
Mass (lb)
0
15
30
45
Time (sec)

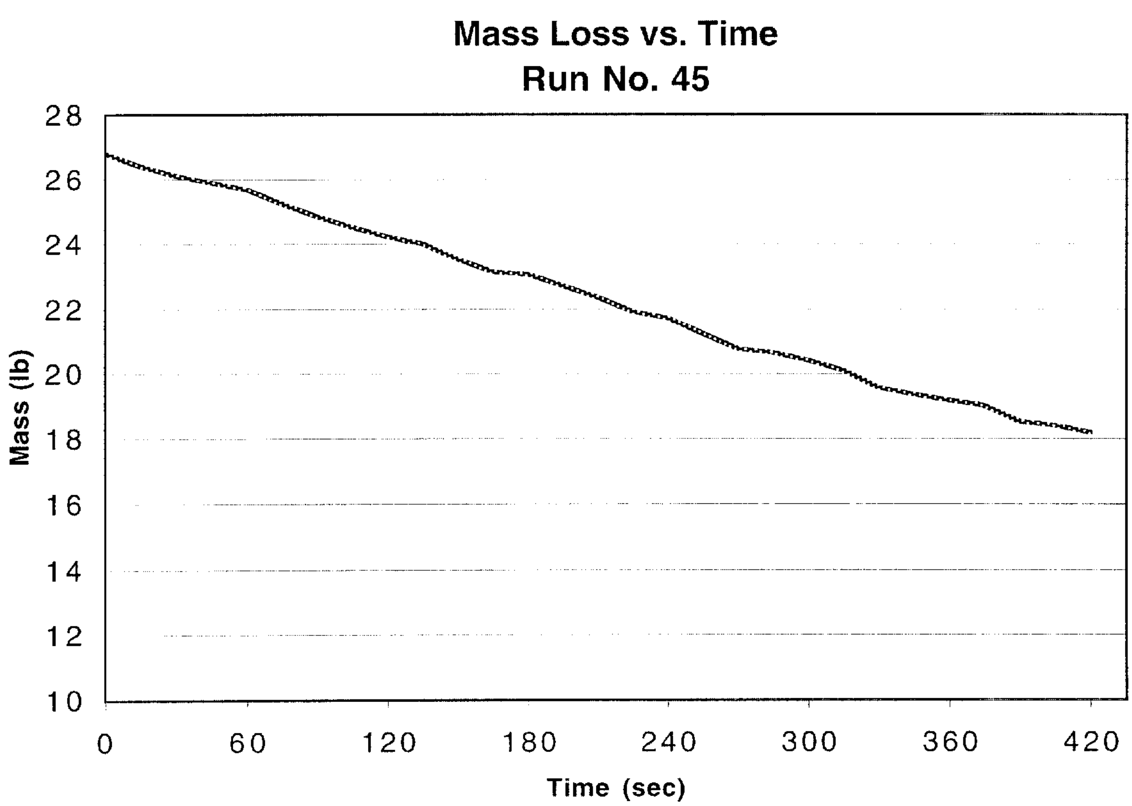

Mass Loss vs. Time
Run No. 40
35
34
33
32
31
30
29
28
Mass (lb)
0
30
60
90
120
150
Time (sec)

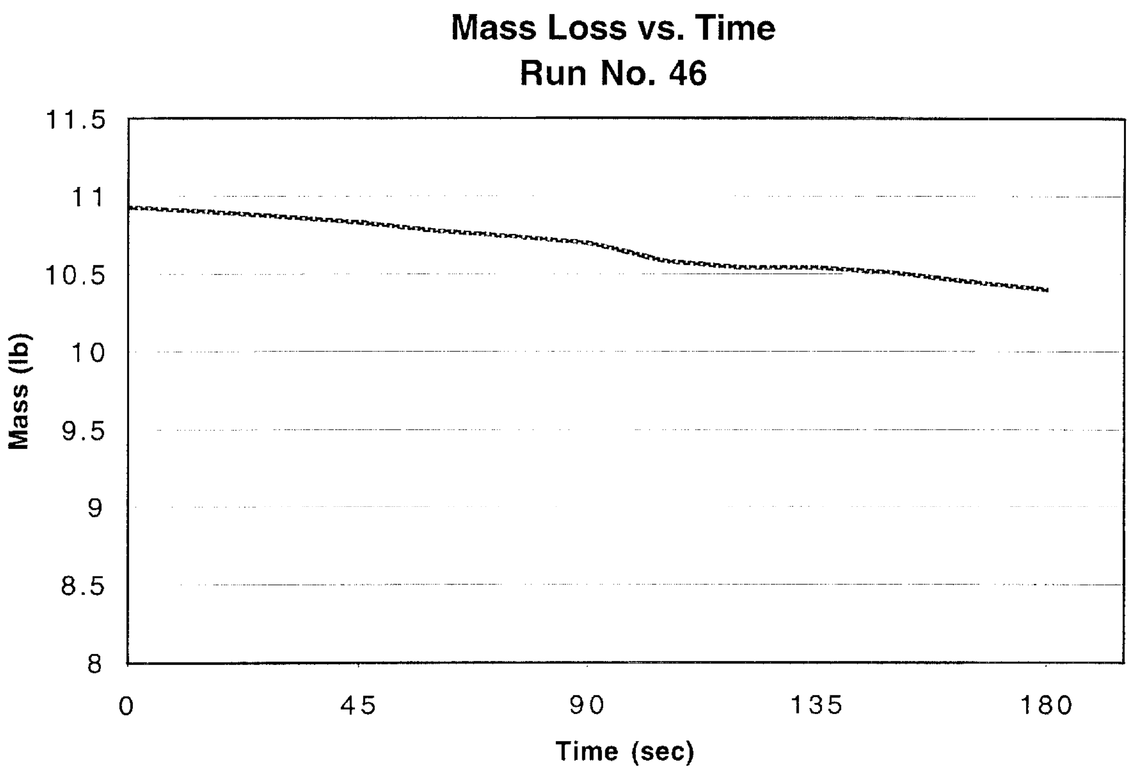

Mass Loss vs. Time
Run No. 41
40
35
30
25
20
15
10
5
0
Mass (lb)
0
75
150
225
300
375
450
525
Time (sec)

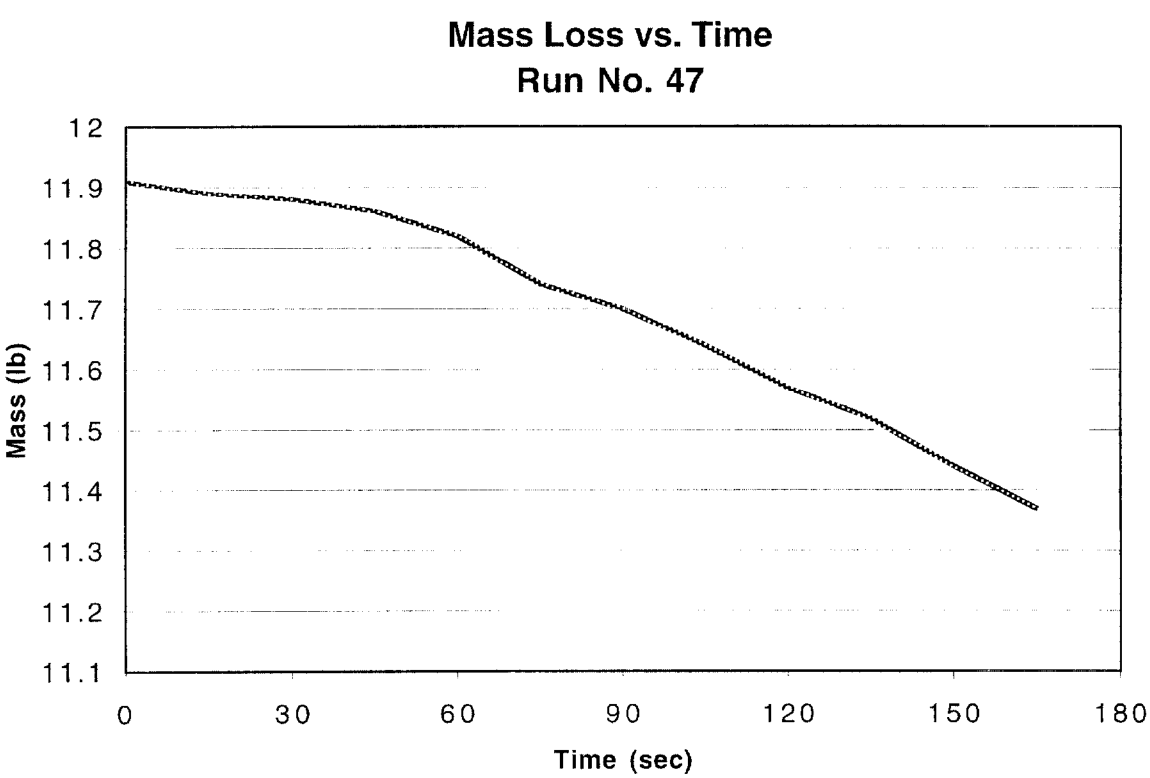

Mass Loss vs. Time
Run No. 42
15.9
15.8
15.7
15.6
15.5
15.4
15.3
15.2
15.1
15
Mass (lb)
0
20
30
40
Time (sec)

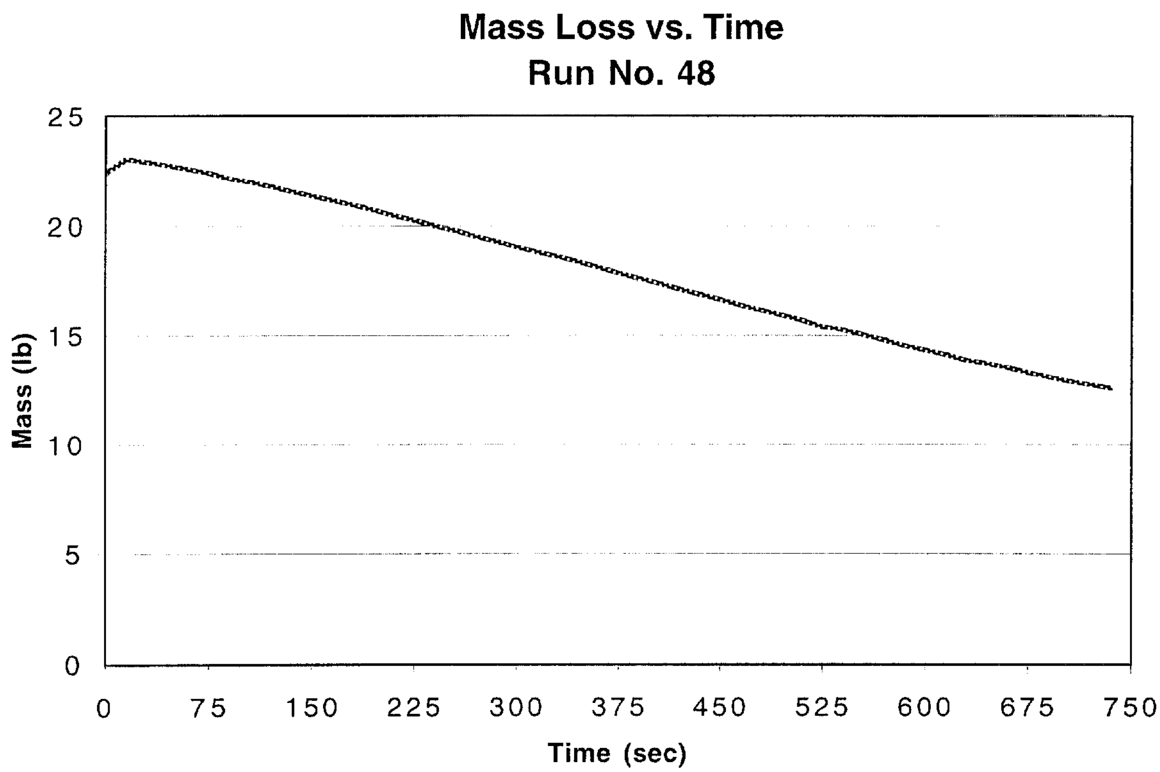

Mass Loss vs. Time
Run No. 43
18
17
16
15
14
13
12
11
10
Mass (lb)
0
15
30
45
60
75
90
Time (sec)

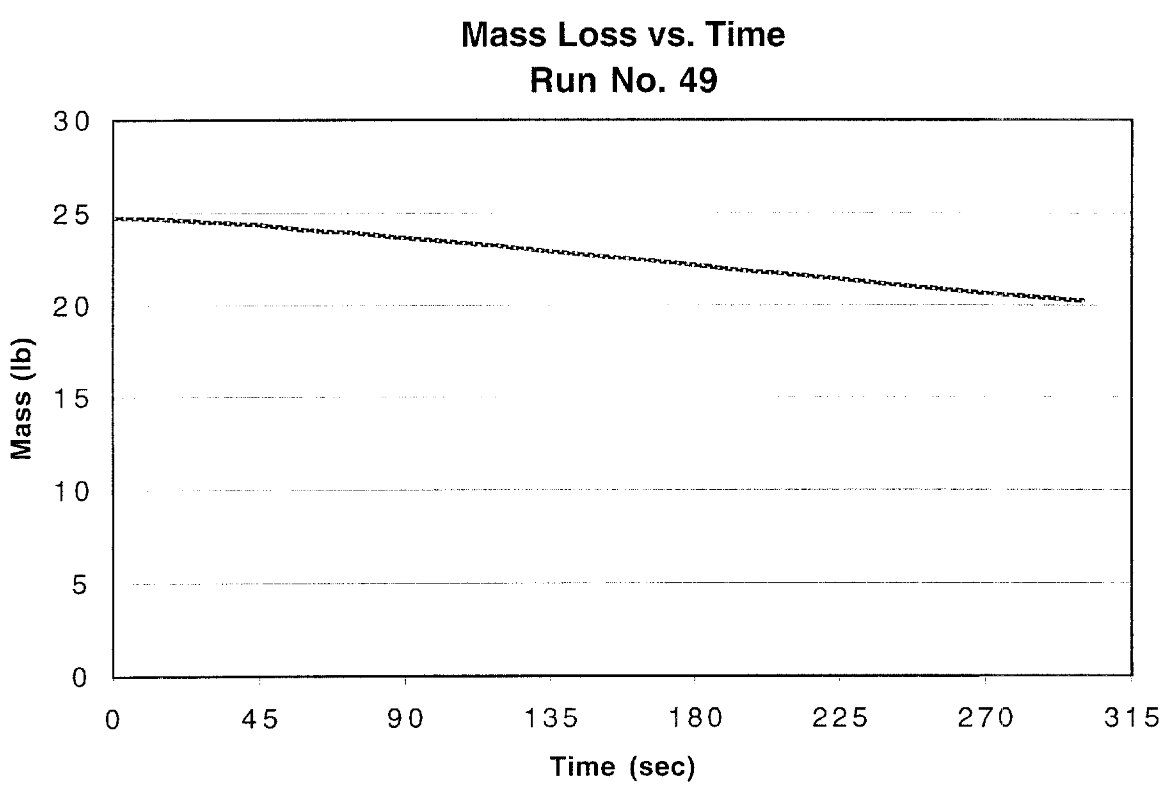

Mass Loss vs. Time
Run No. 44
35
30
25
20
15
10
5
0
Mass (lb)
0
75
150
225
300
375
450
525
Time (sec)

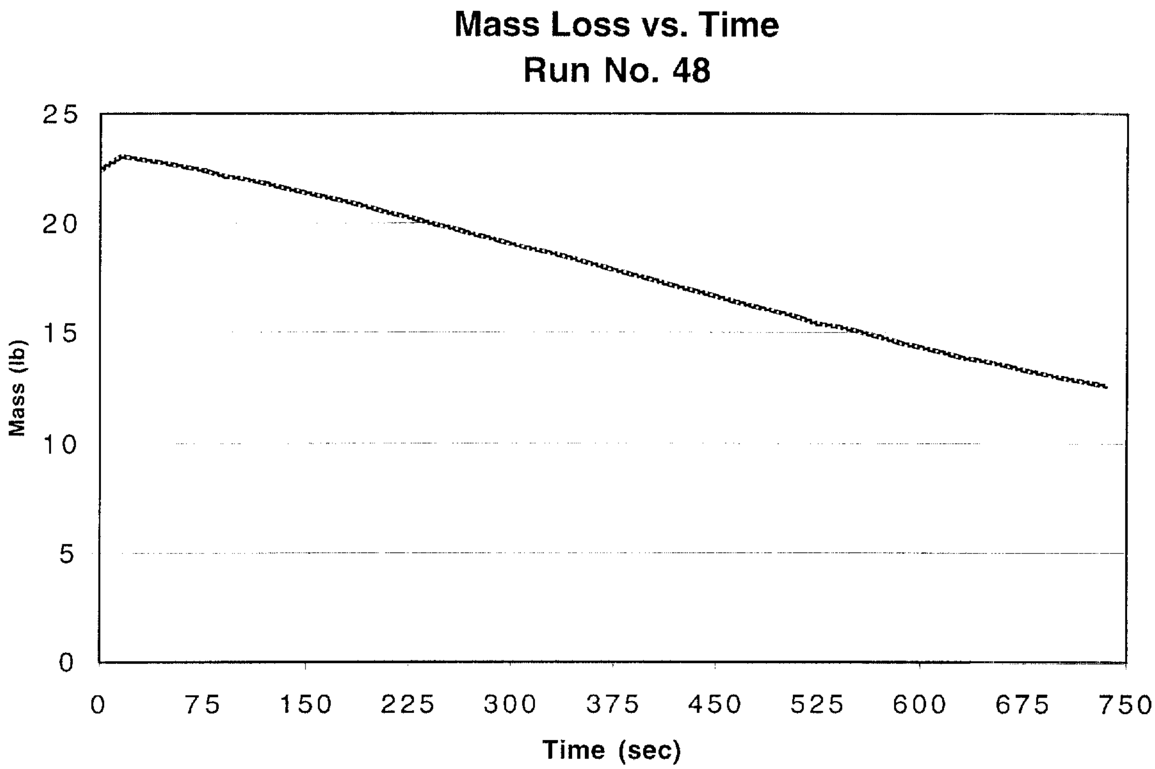

Mass Loss vs. Time
Run No. 45
28
26
24
22
20
18
16
14
12
10
Mass (lb)
0
60
120
180
240
300
360
420
Time (sec)

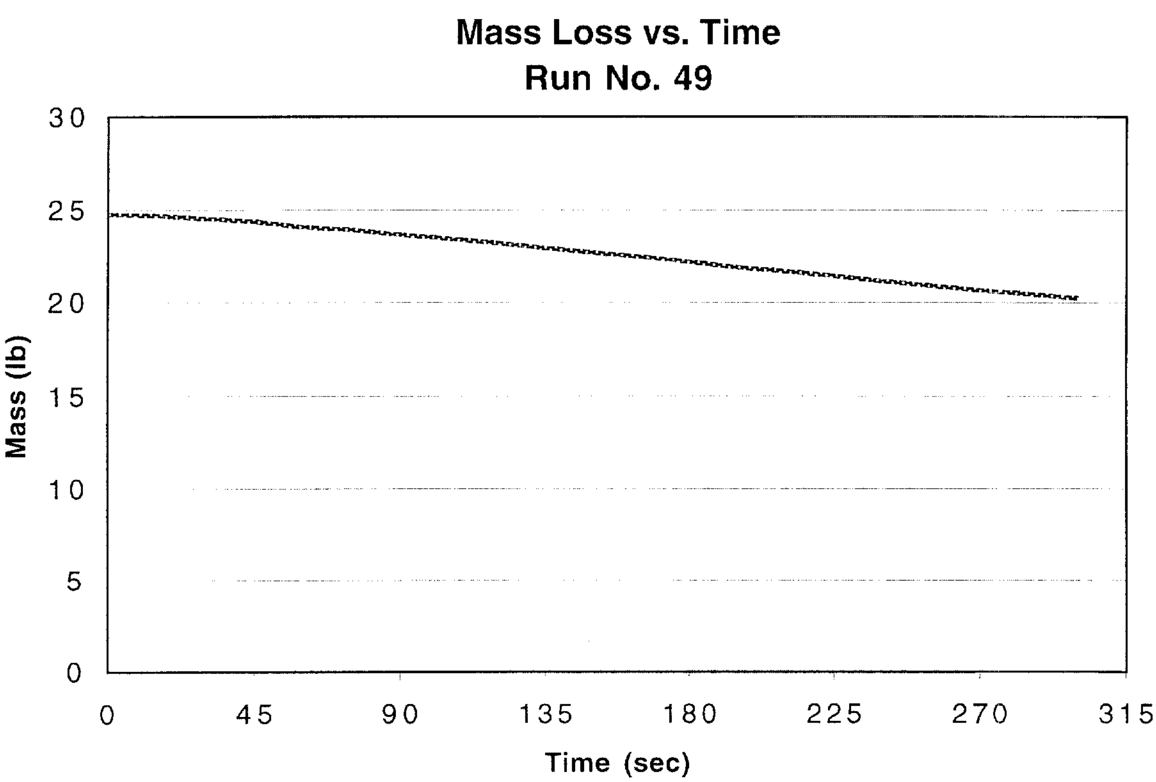

Mass Loss vs. Time
Run No. 46
11.5
11
10.5
10
9.5
9
8.5
8
Mass (lb)
0
45
90
135
180
Time (sec)

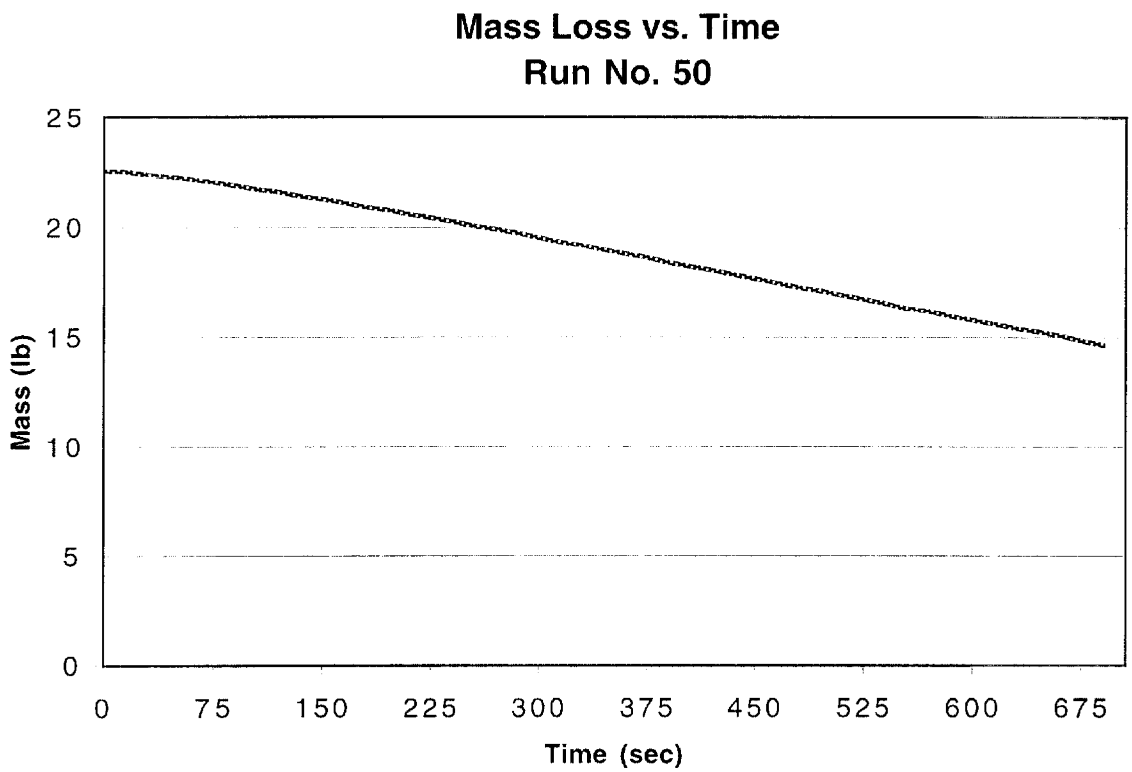

Mass Loss vs. Time
Run No. 47
12
11.9
11.8
11.7
11.6
11.5
11.4
11.3
11.2
11.1
Mass (lb)
0
30
60
90
120
150
180
Time (sec)

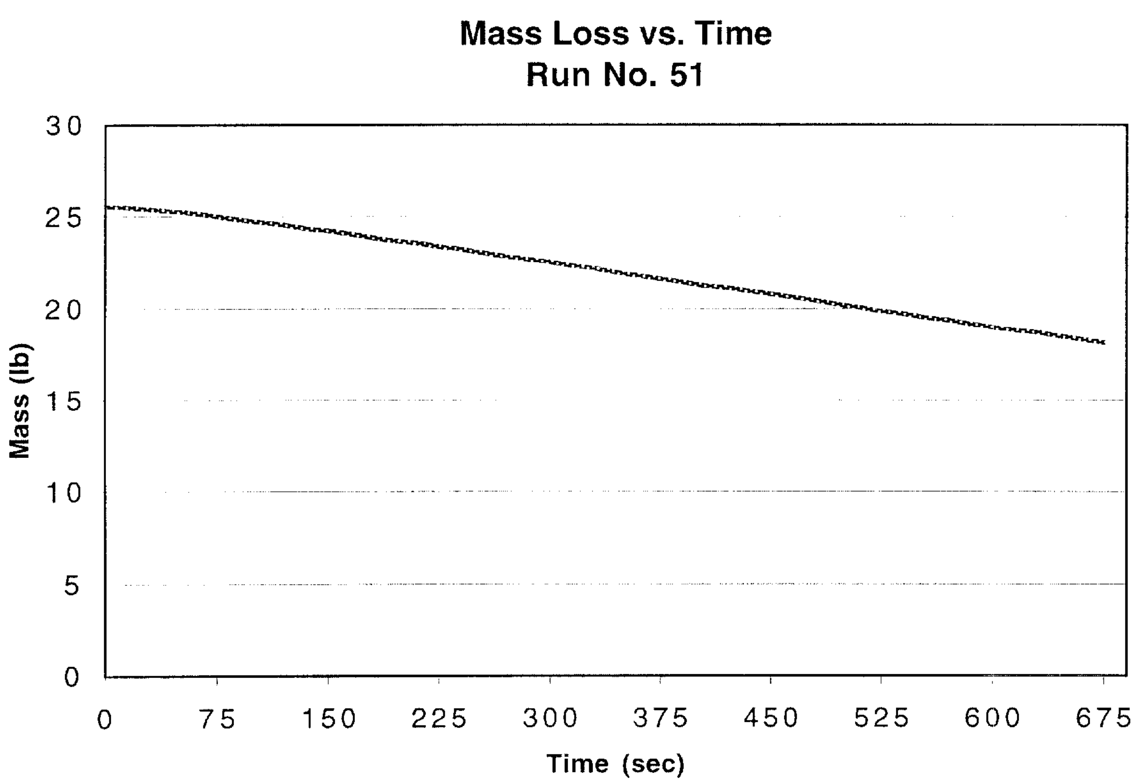

Mass Loss vs. Time
Run No. 48
Mass (lb)
25
20
15
10
5
0
0
75
150
225
300
375
450
525
600
675
750
Time (sec)

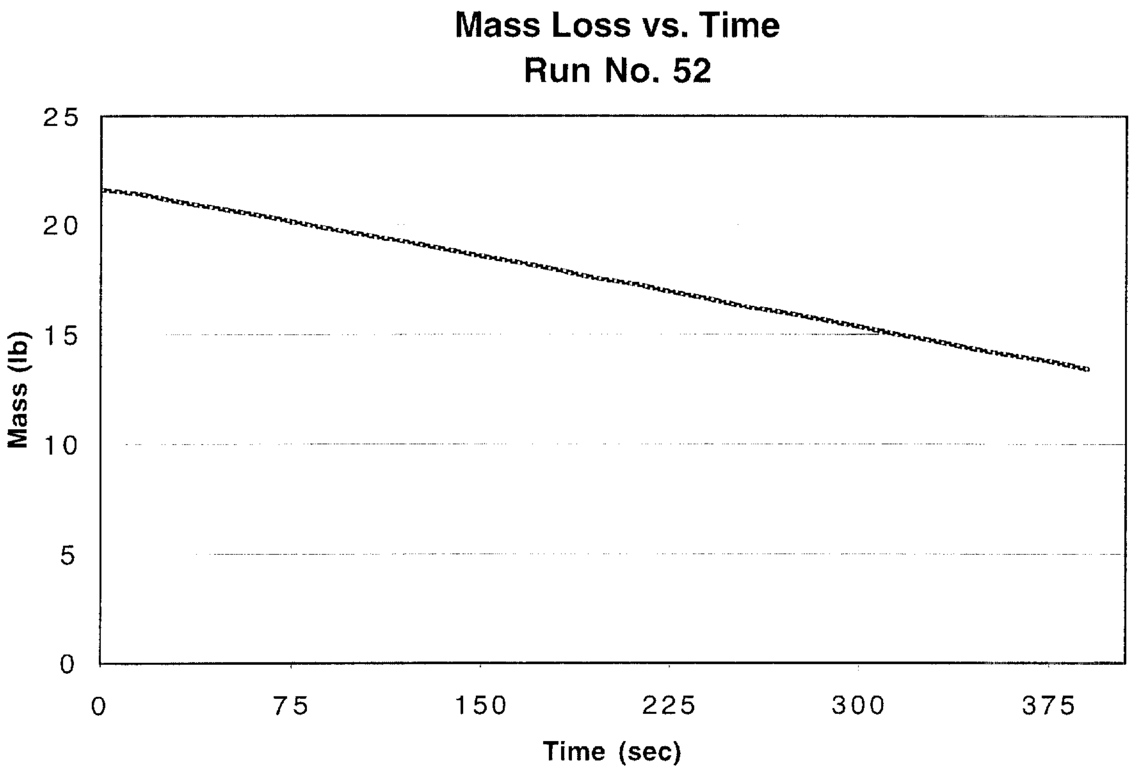

Mass Loss vs. Time
Run No. 49
Mass (lb)
30
25
20
15
10
5
0
0
45
90
135
180
225
270
315
Time (sec)

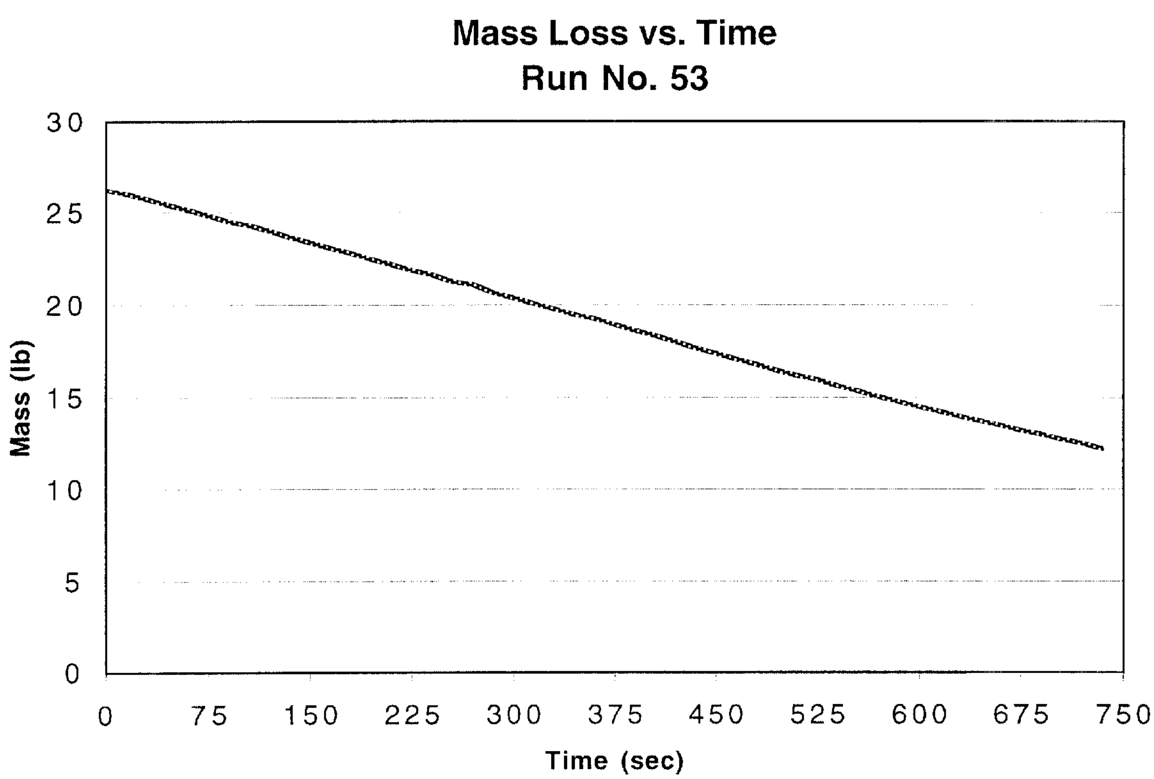

Mass Loss vs. Time
Run No. 48
Mass (lb)
0
5
10
15
20
25
Time (sec)
0
75
150
225
300
375
450
525
600
675
750

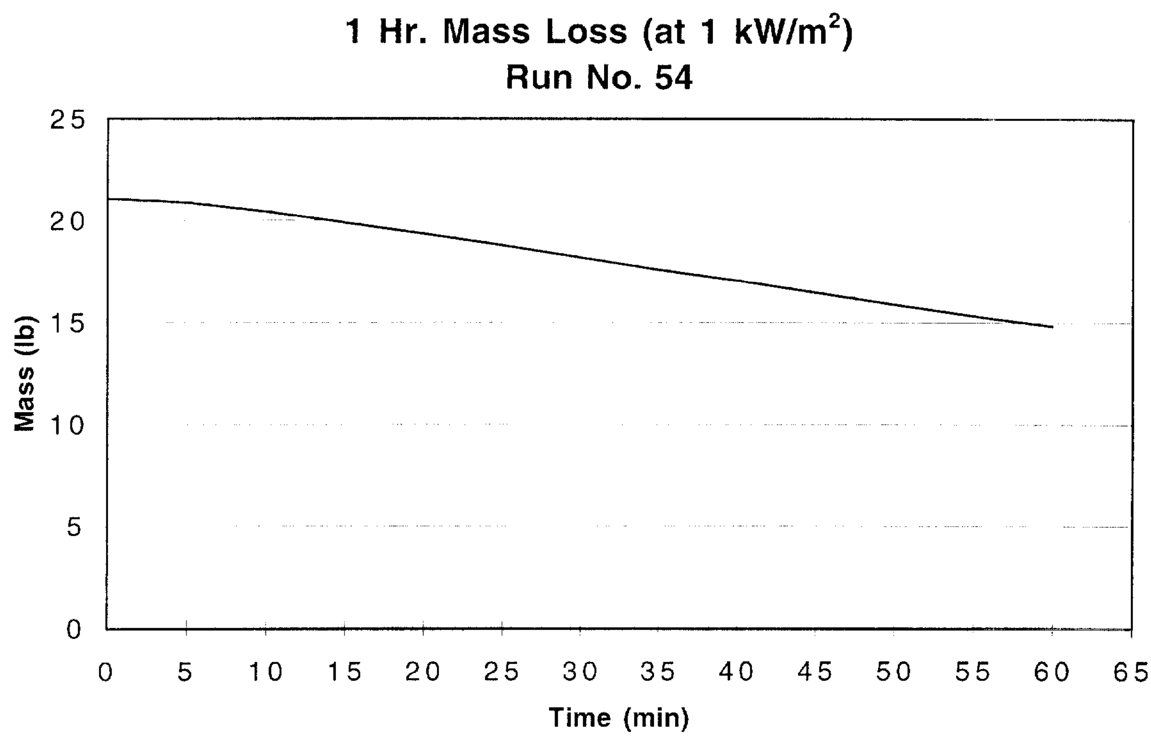

Mass Loss vs. Time
Run No. 49
Mass (lb)
0
5
10
15
20
25
30
Time (sec)
0
45
90
135
180
225
270
315

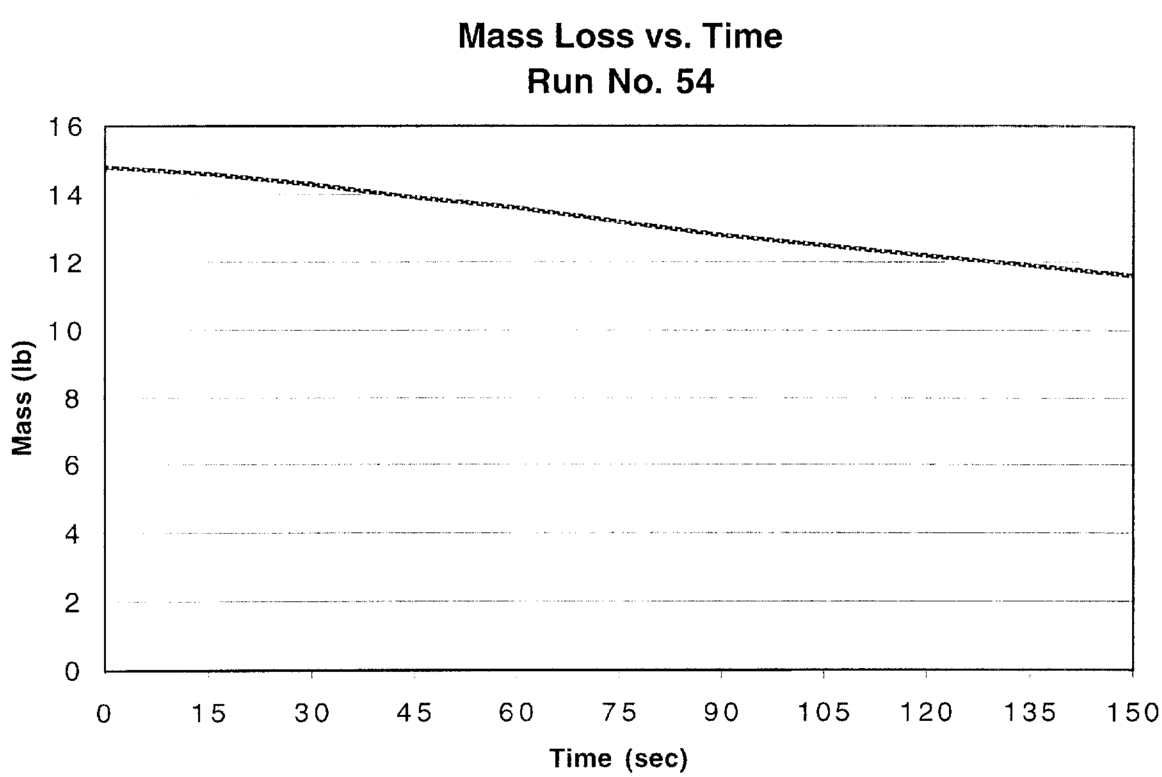

Mass Loss vs. Time
Run No. 50
Mass (lb)
25
20
15
10
5
0
0
75
150
225
300
375
450
525
600
675
Time (sec)

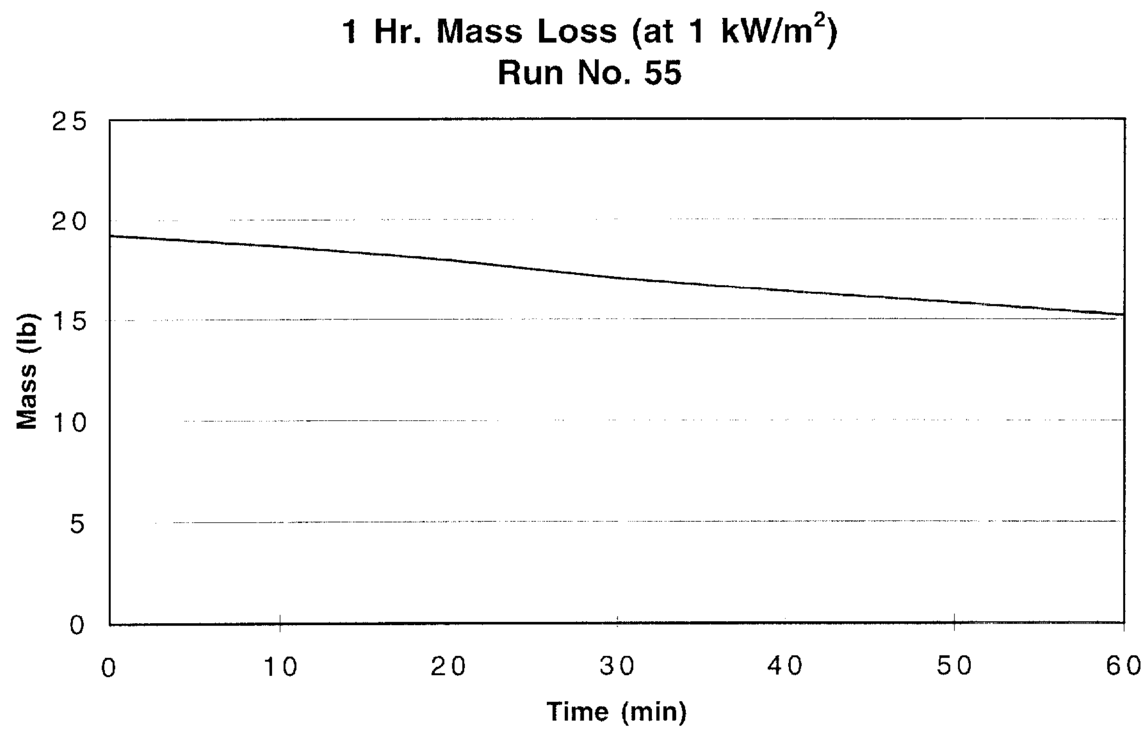

Mass Loss vs. Time
Run No. 51
Mass (lb)
30
25
20
15
10
5
0
0
75
150
225
300
375
450
525
600
675
Time (sec)

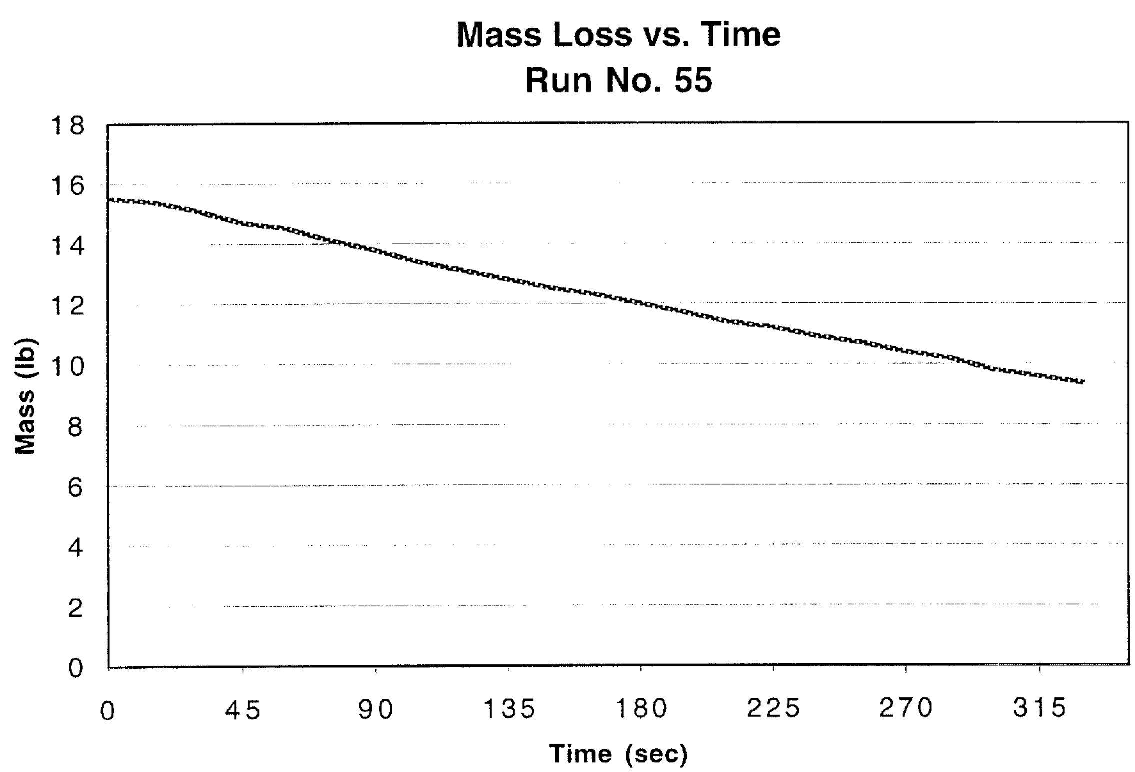

Mass Loss vs. Time
Run No. 52
25
20
15
10
5
0
Mass (lb)
0
75
150
225
300
375
Time (sec)

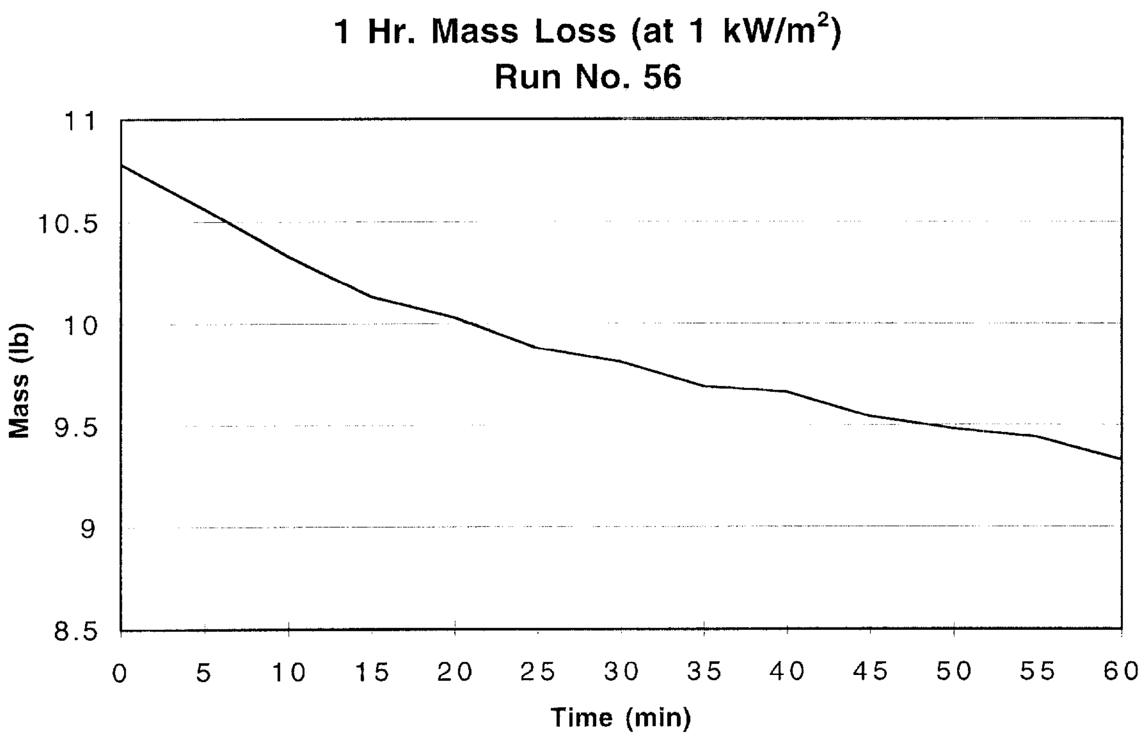

Mass Loss vs. Time
Run No. 53
30
25
20
15
10
5
0
Mass (lb)
0
75
150
225
300
375
450
525
600
675
750
Time (sec)

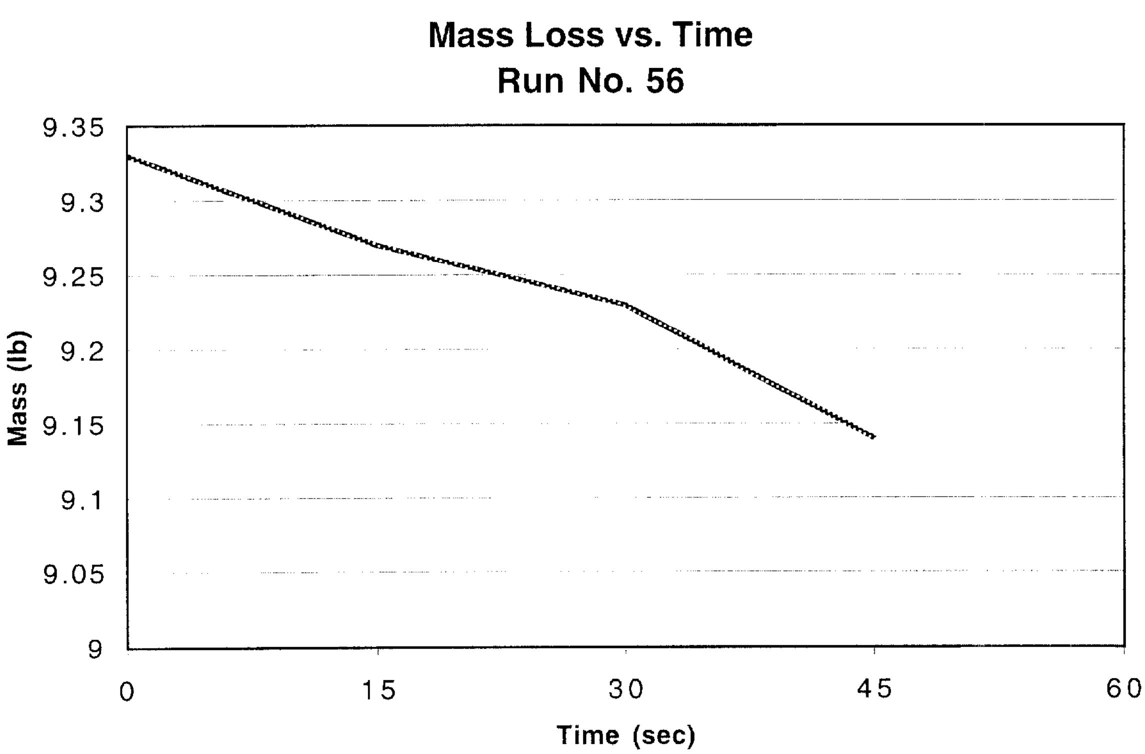

1 Hr. Mass Loss (at 1 kW/m2)
Run No. 54
Mass (lb)
0
5
10
15
20
25
0 5 10 15 20 25 30 35 40 45 50 55 60 65
Time (min)


Mass Loss vs. Time
Run No. 54
Mass (lb)
0
2
4
6
8
10
12
14
16
0 15 30 45 60 75 90 105 120 135 150
Time (sec)


1 Hr. Mass Loss (at 1 kW/m2)
Run No. 55
Mass (lb)
0
5
10
15
20
25
Time (min)
0
10
20
30
40
50
60

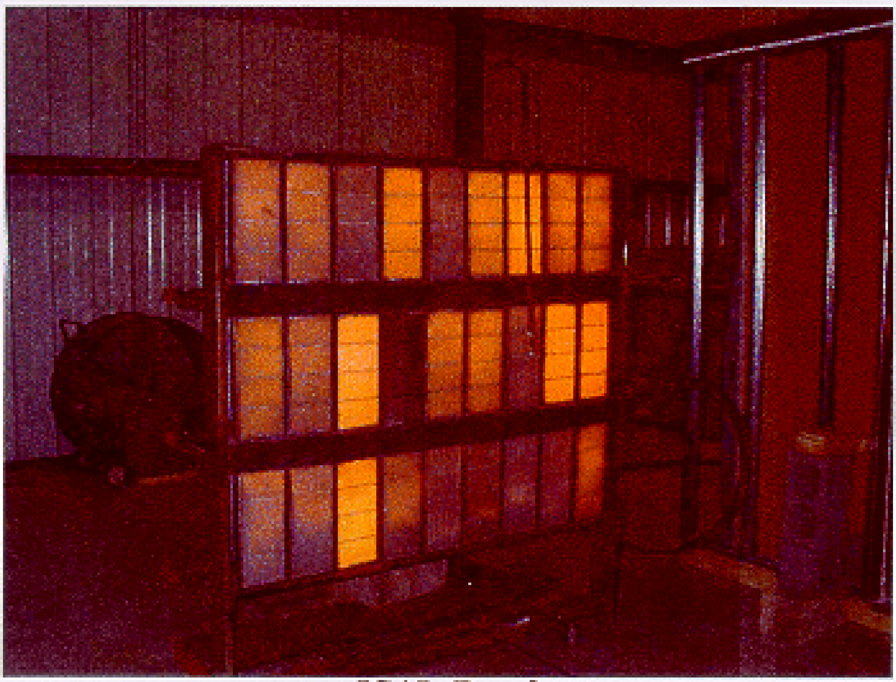

Mass Loss vs. Time
Run No. 55
Mass (lb)
0
2
4
6
8
10
12
14
16
18
Time (sec)
0
45
90
135
180
225
270
315


1 Hr. Mass Loss (at 1 kW/m2)
Run No. 56
Mass (lb)
11
10.5
10
9.5
9
8.5
0
5
10
15
20
25
30
35
40
45
50
55
60
Time (min)

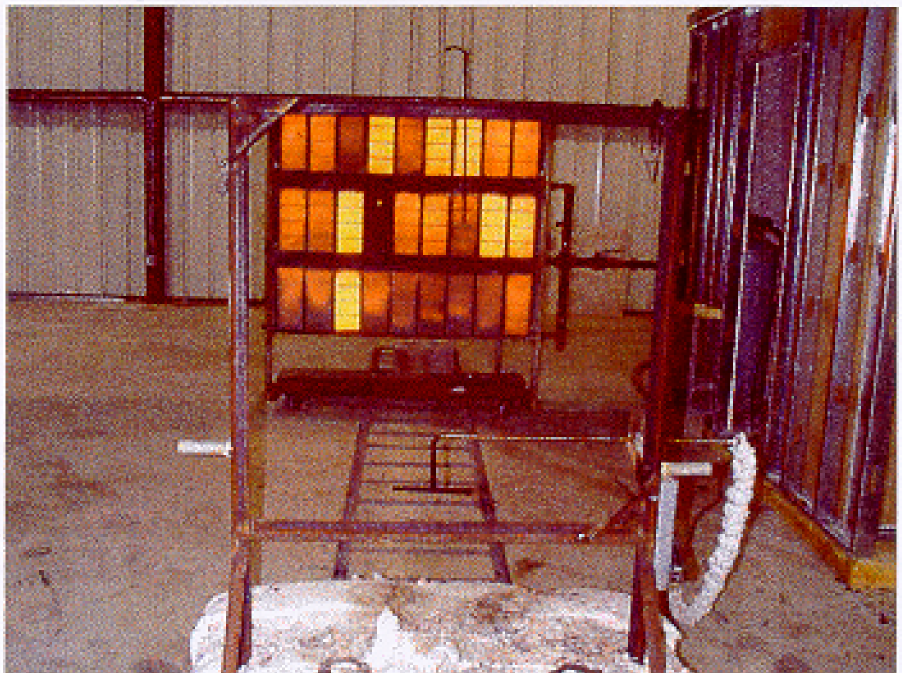

Mass Loss vs. Time
Run No. 56
Mass (lb)
9.35
9.3
9.25
9.2
9.15
9.1
9.05
9
0
15
30
45
60
Time (sec)

APPENDIX C

Photographs

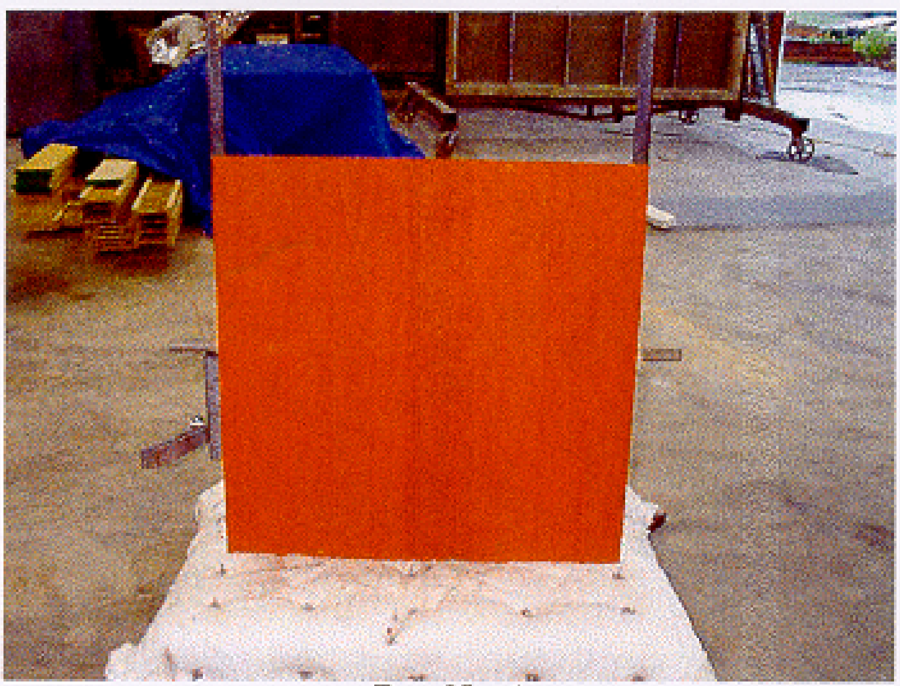


ICAL Panel

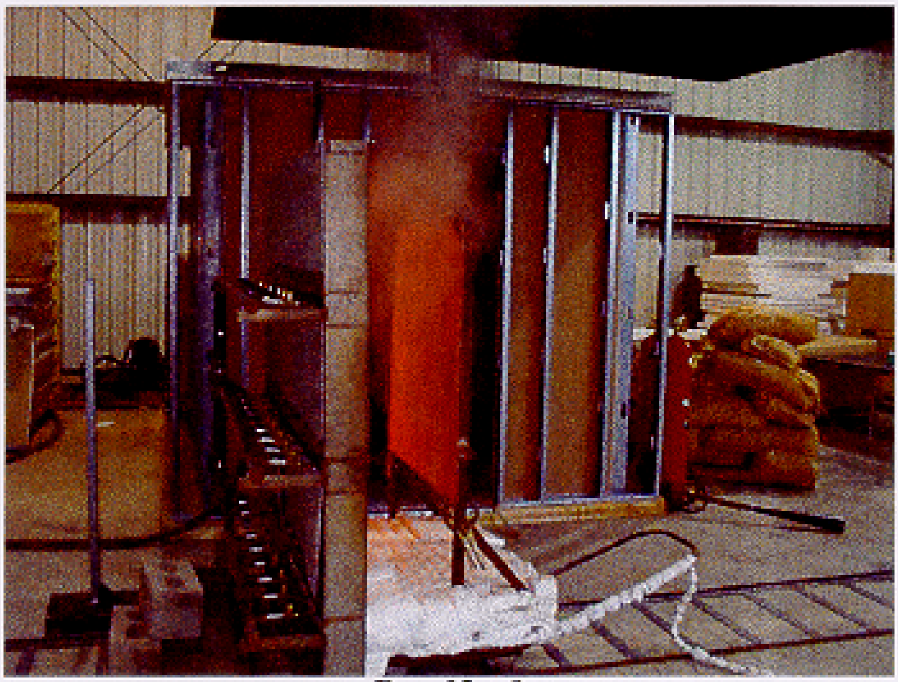


ICAL Panel, Specimen Holder, and Igniter Assembly

Specimen Holder



Run No. 1
Sample Ready to be Mounted onto the Specimen Holder

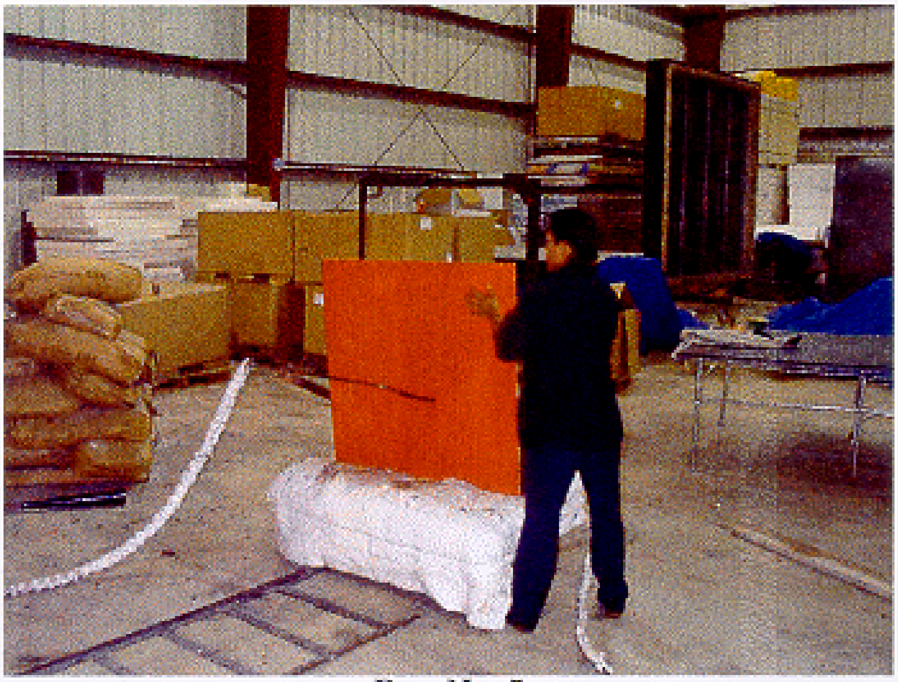


Run No. 2
25 kW/m^2 Exposure, No Igniter

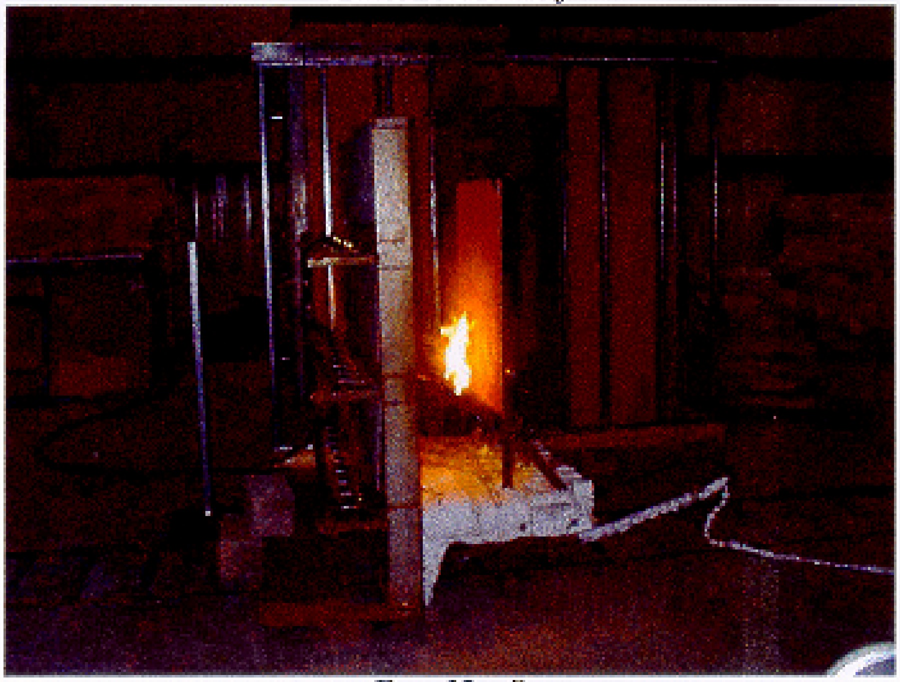
Run No. 2
Prior to Ignition

Run No. 3
After Ignition

Run No. 4
Exposure at 25 kW/m^2 and Igniter

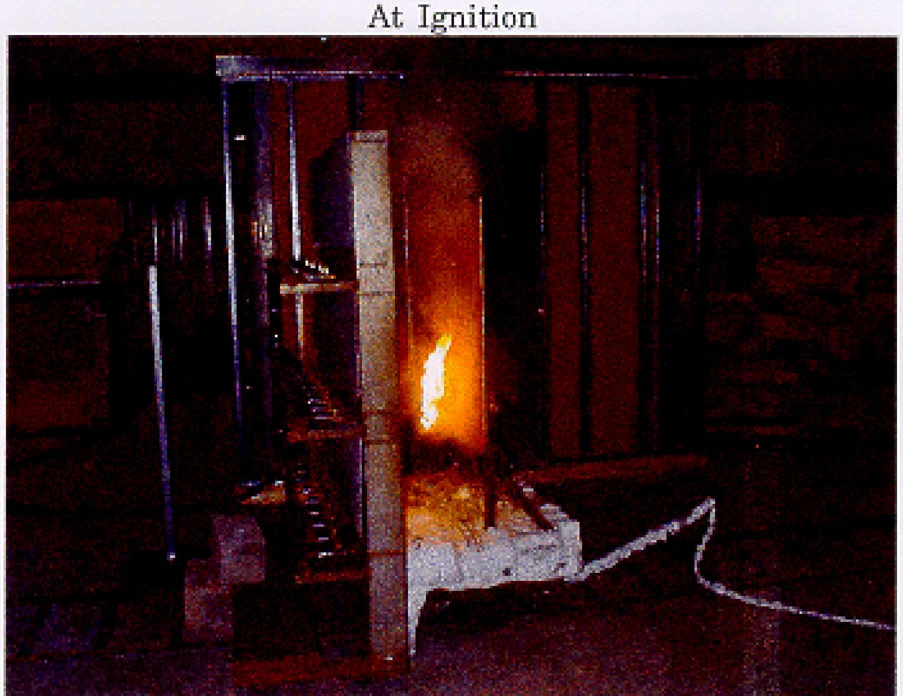


Run No. 5
Panel Assembly

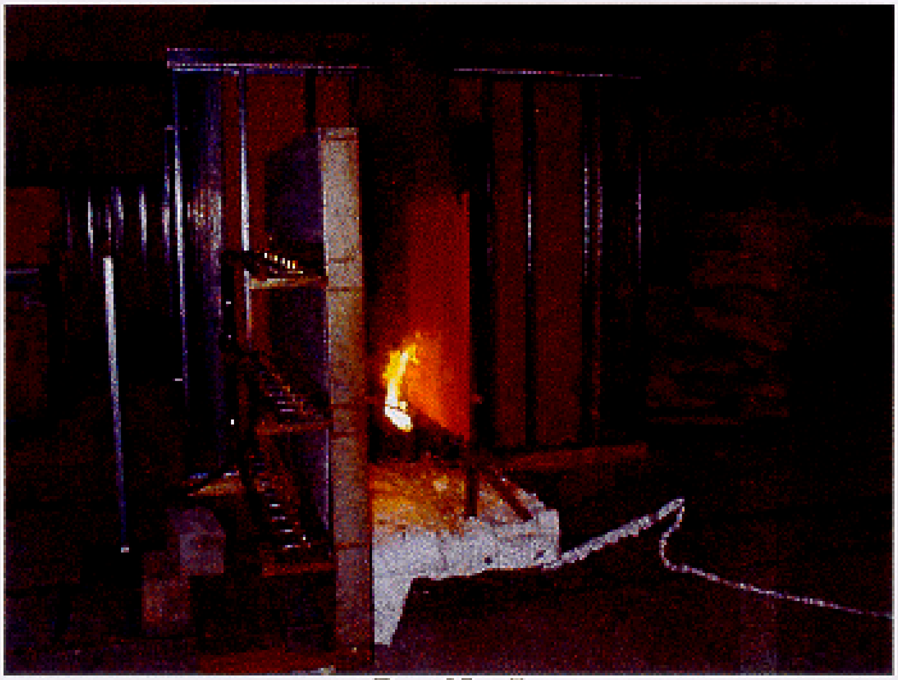


Run No. 5
Exposure at 25 kW/m² and Igniter

Run No. 5
At Ignition



Run No. 6
Exposure to 25 kW/m^2 and Prior to Ignition

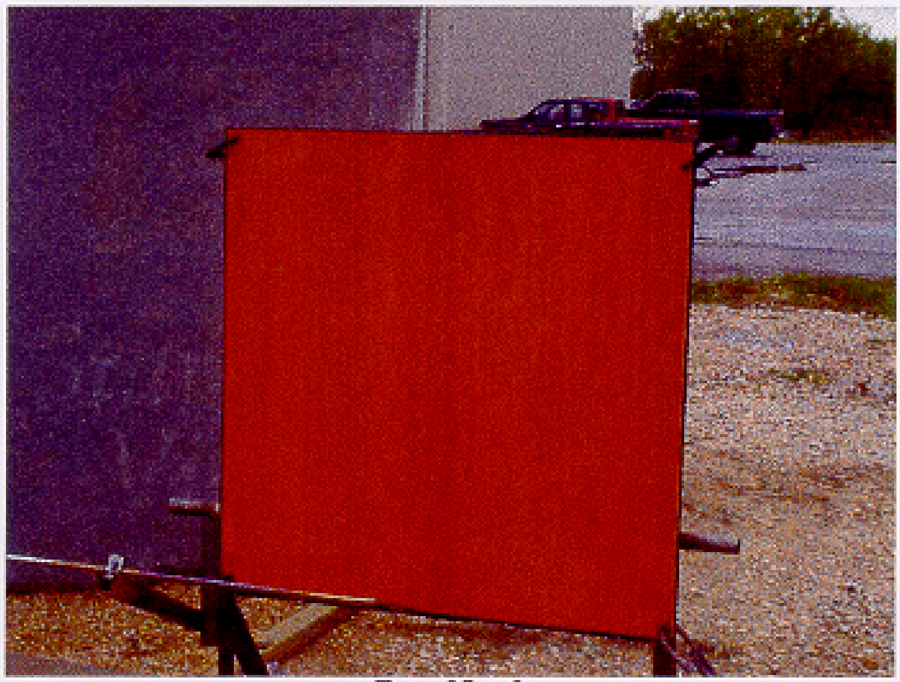


Run No. 7
Exposure to 25 kW/m^2

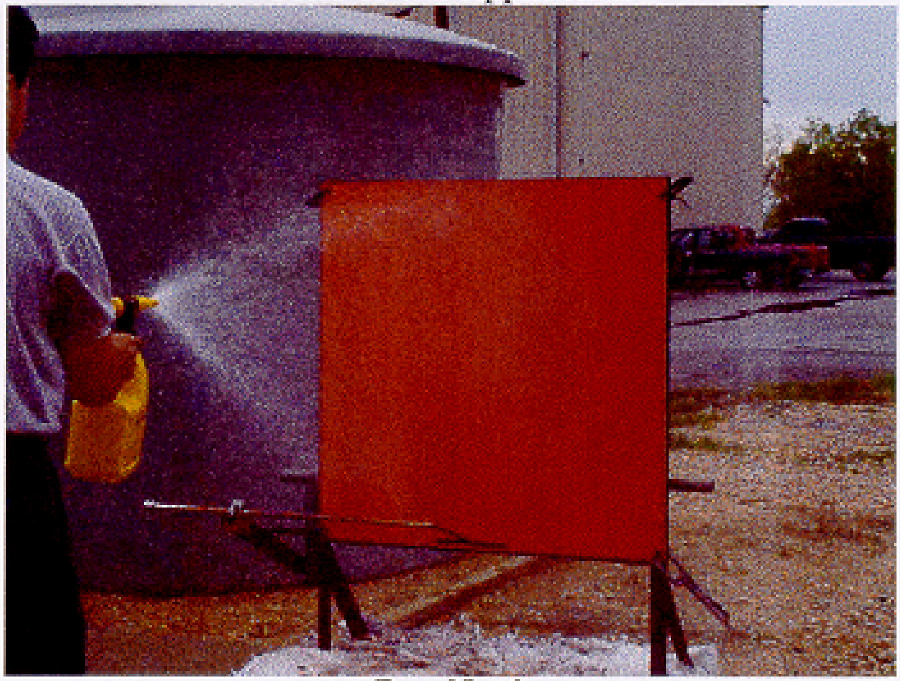
Run No. 8
Exposure at 25 kW/m^2 and Igniter

Run No. 8
Smoke and Darkening

Run No. 8
At Ignition

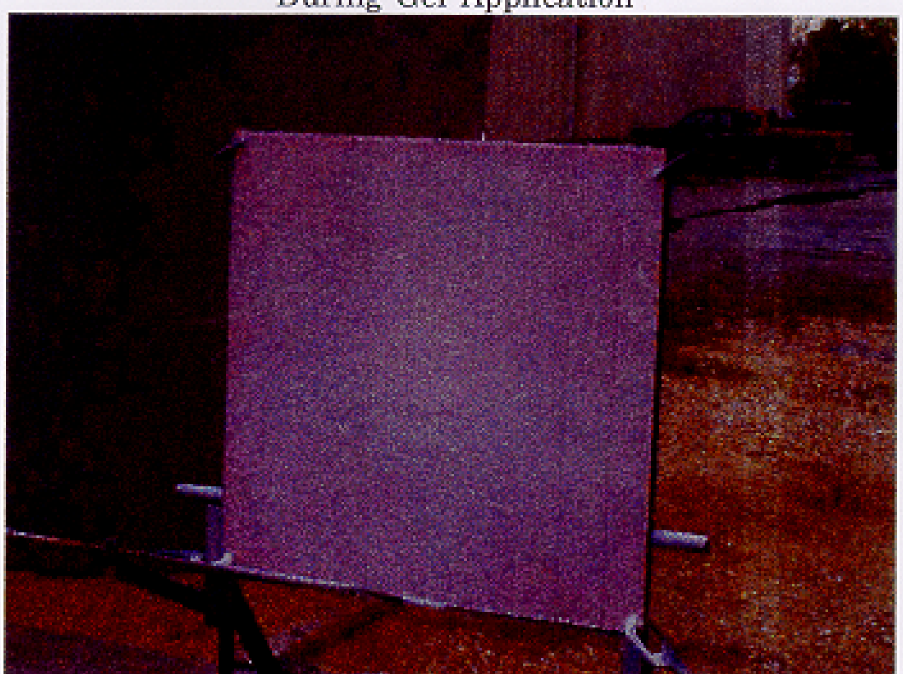


Run No. 9
Prior to Gel Application



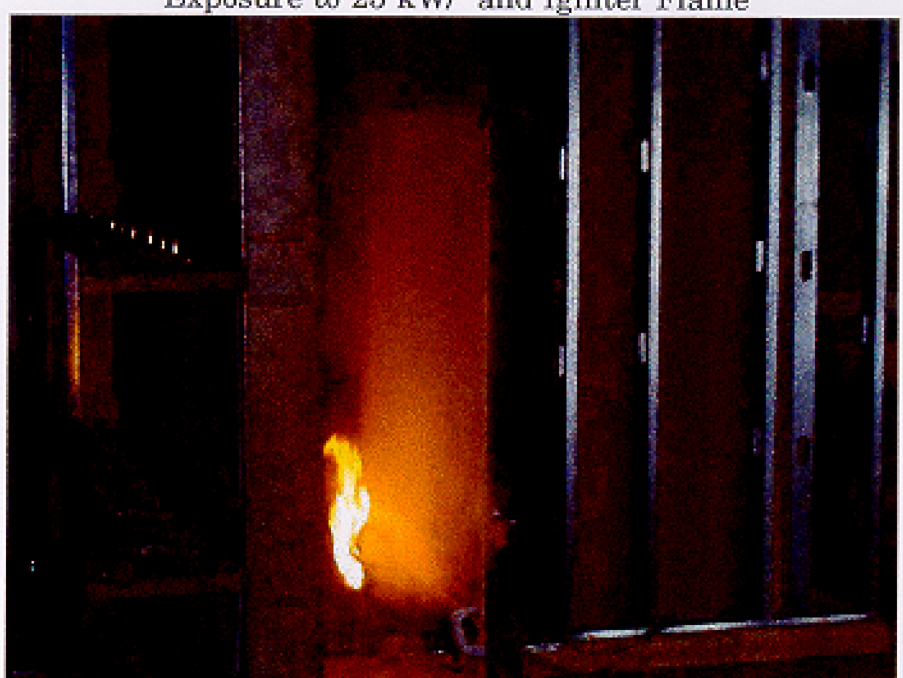
Run No. 9
During Gel Application

Run No. 9
During Gel Application



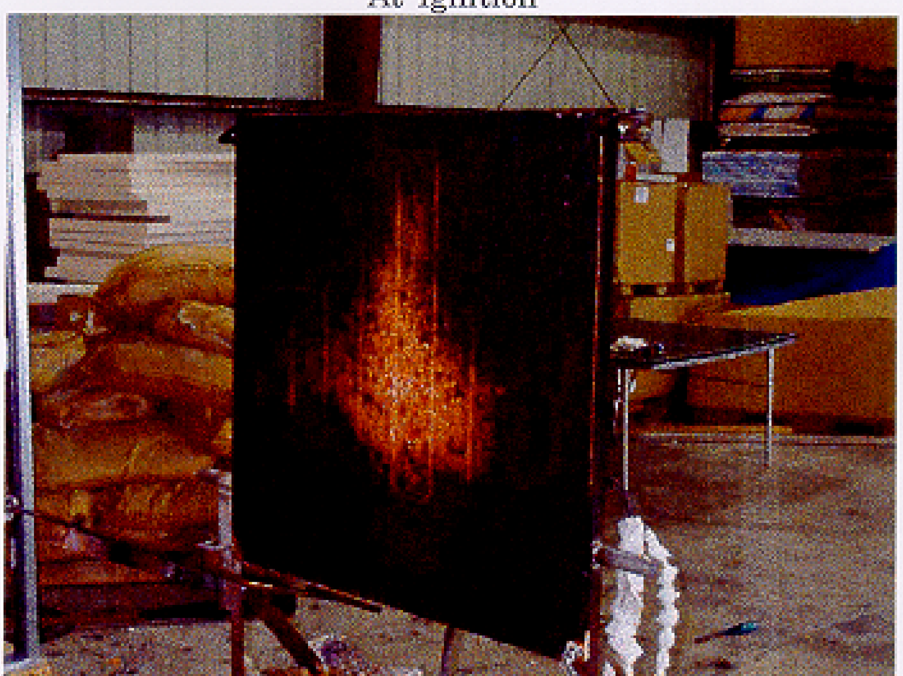
Run No. 9
After Gel Application

Run No. 9
Exposure to 25 kW/^{2} and Igniter Flame

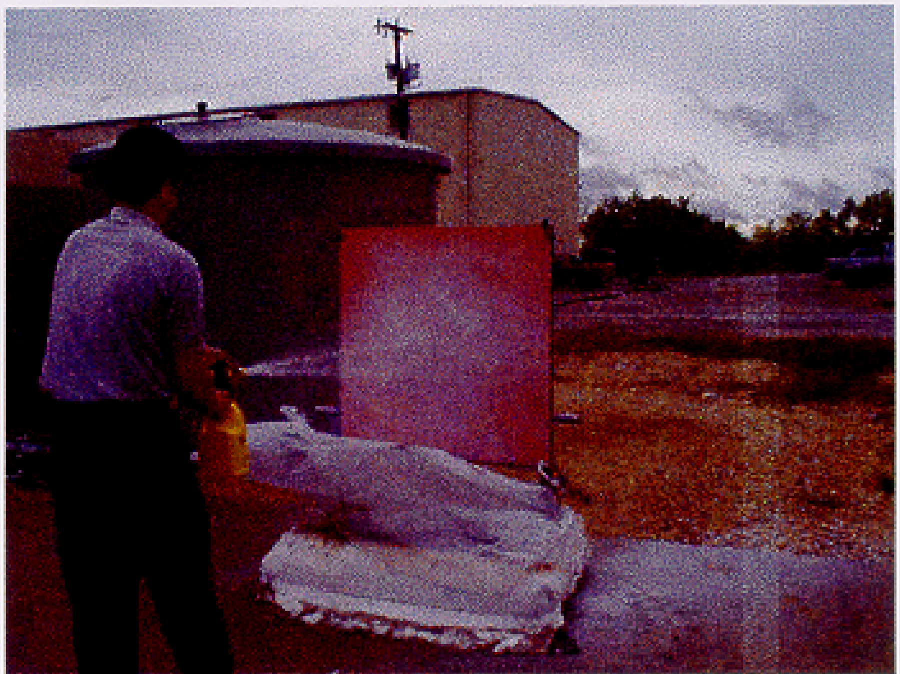


Run No. 9
Smoke

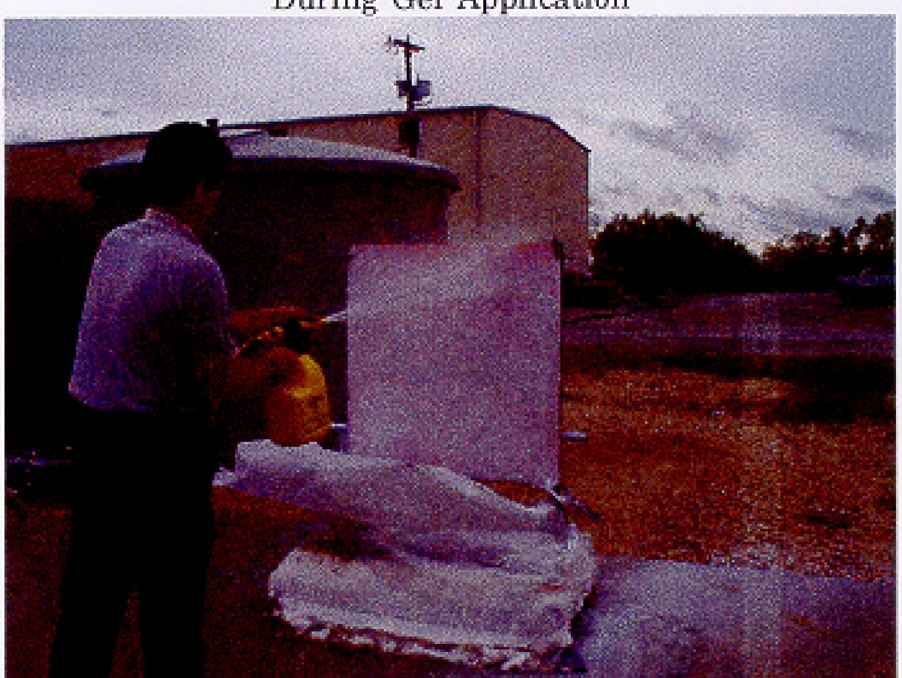
Run No. 9
At Ignition



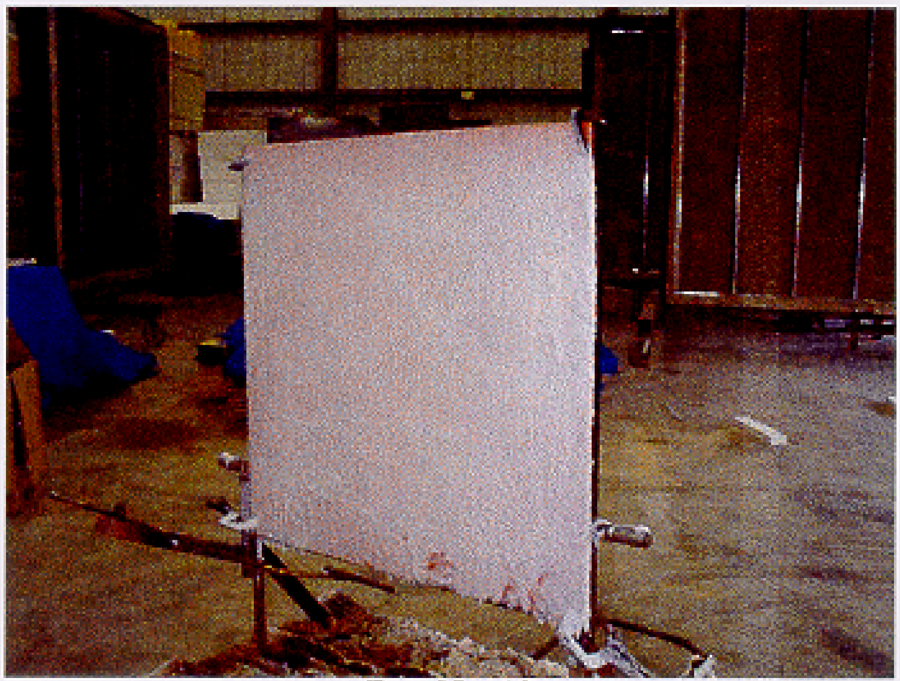
Run No. 9
Specimen After Exposure and Ignition



Run No. 10
During Gel Application



Run No. 10
During Gel Application



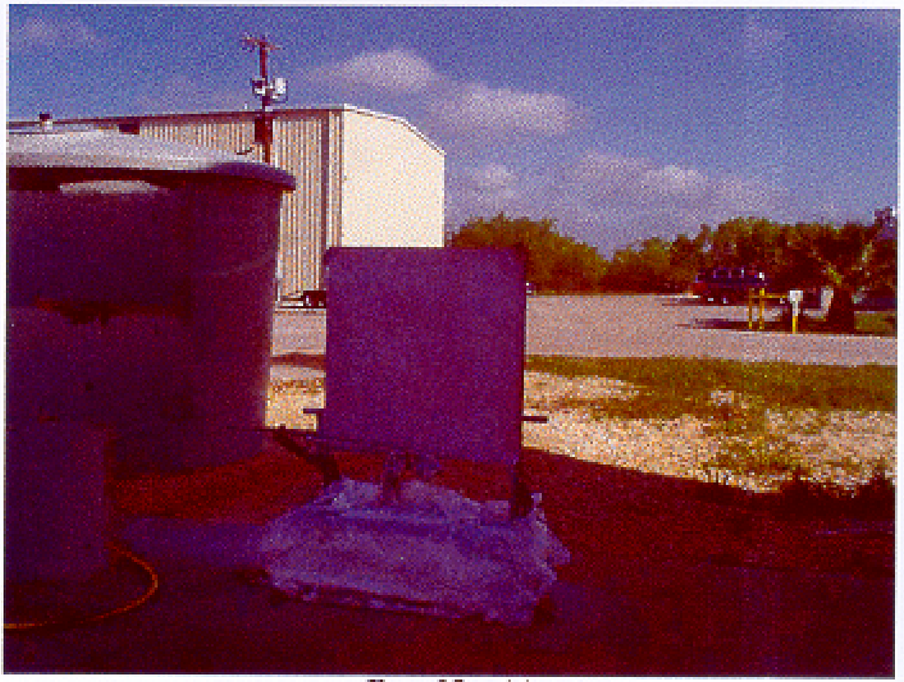
Run No. 10
Prior to Exposure

Run No. 10
Exposure to 25 kW/m^2 and Igniter

Run No. 11
Gel Application

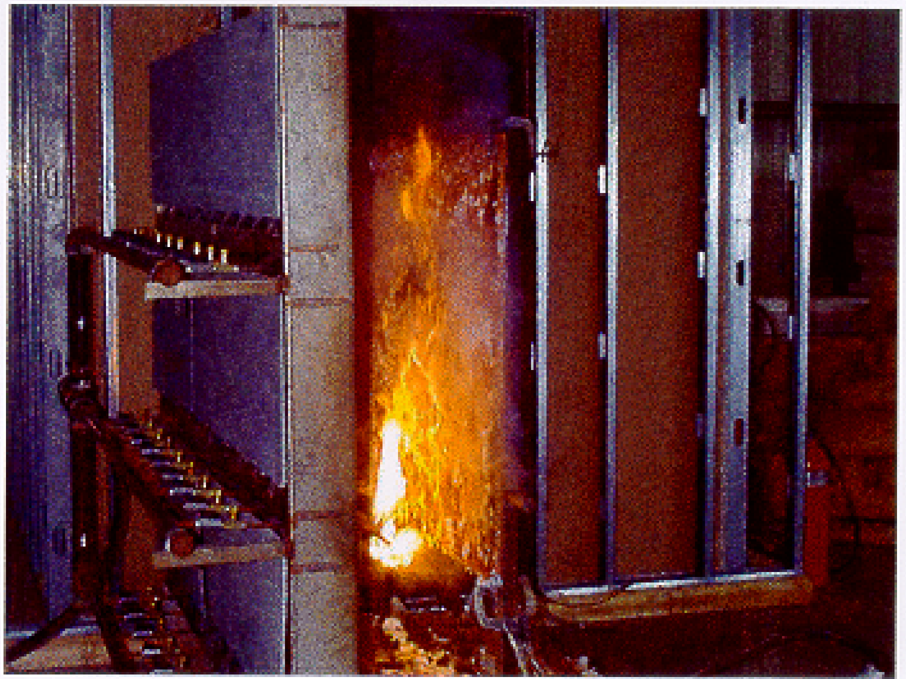
Run No. 11
During Gel Application

Run No. 11
During Gel Application



Run No. 11
After Gel Application

Run No. 11
Exposure to 25 kW/m^2, Igniter. Smoke, and Darkening



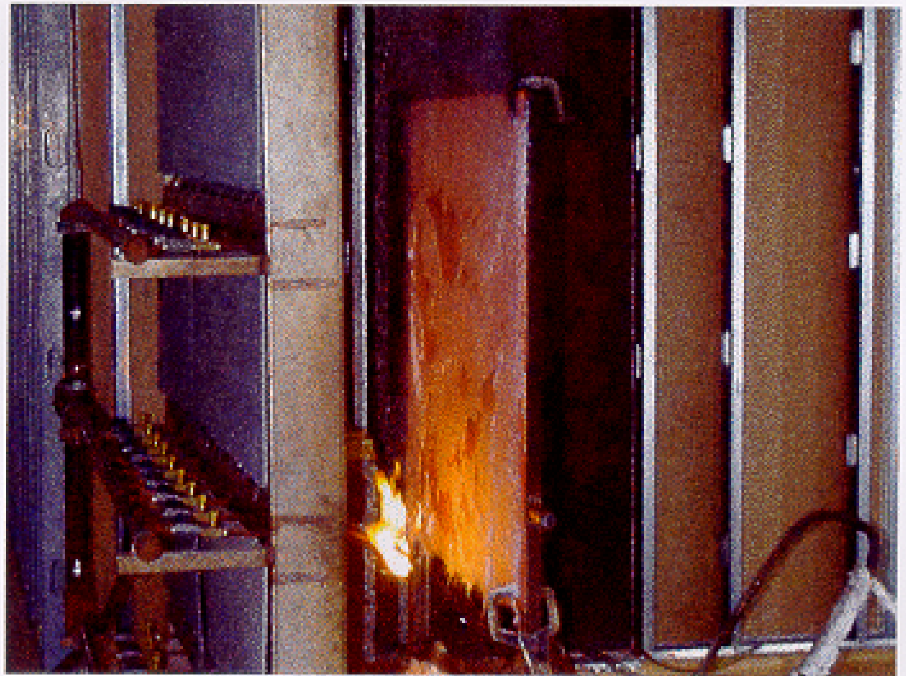
Run No. 11
At Ignition

Run No. 12
Start of Gel Application

Run No. 12
During Gel Application

Run No. 12
Prior to Exposure. Gel Sliding and Dripping

Run No. 12
Prior to Exposure. Gel Sliding and Dripping



Run No. 12
Exposure to 25 kW/m^2 and Igniter Flame

Run No. 12
Exposure to 25 kW/m^2, Gel Sliding and Dripping

Run No. 15
Exposure to 25 kW/m^2 and Igniter Flame

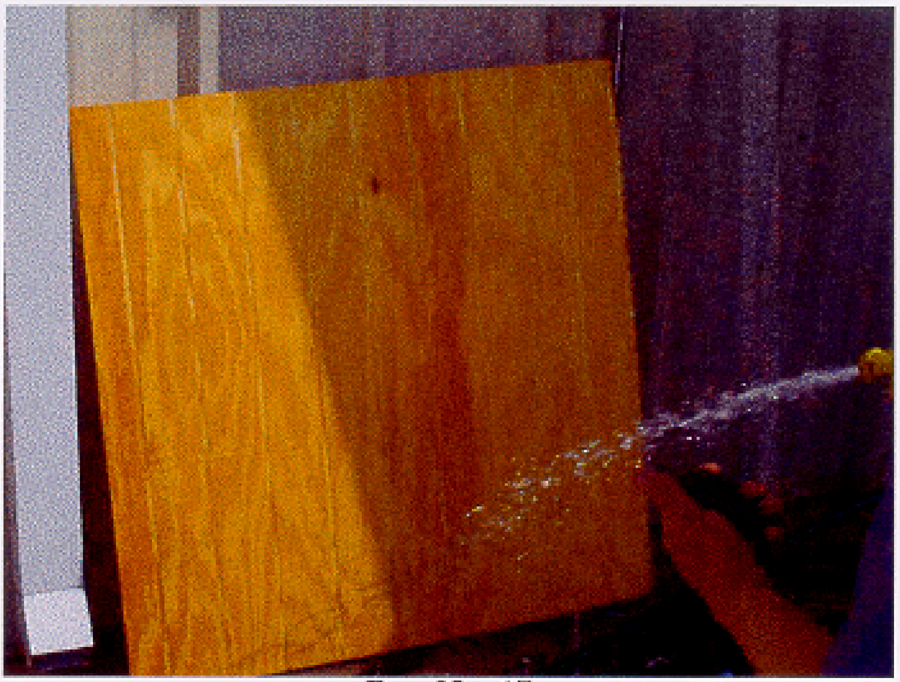
Run No. 15
Smoke, Darkening

Run No. 15
At Ignition

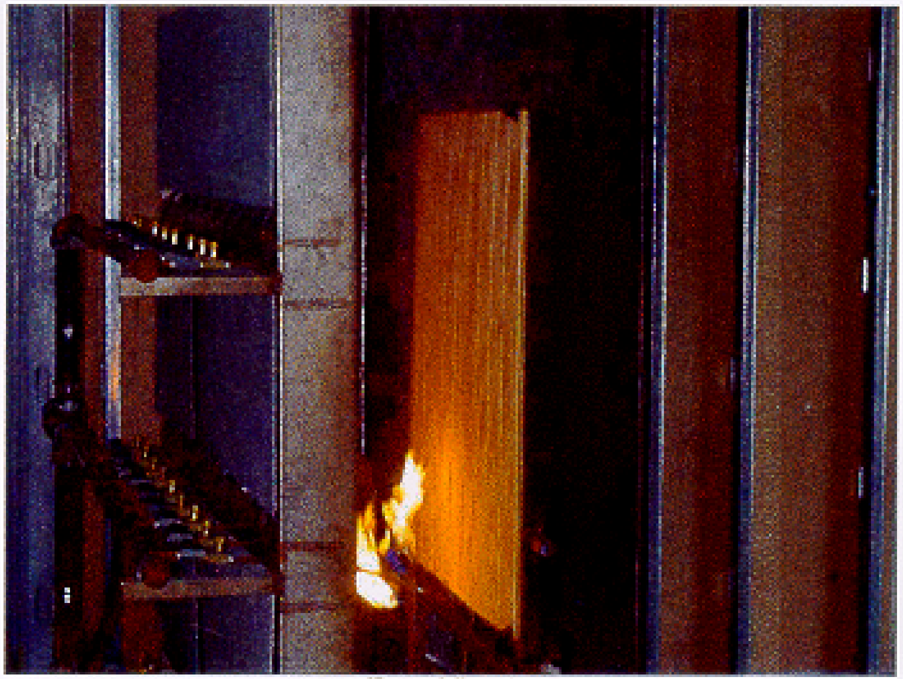
Run No. 15
After Testing

Run No. 16
Water Application

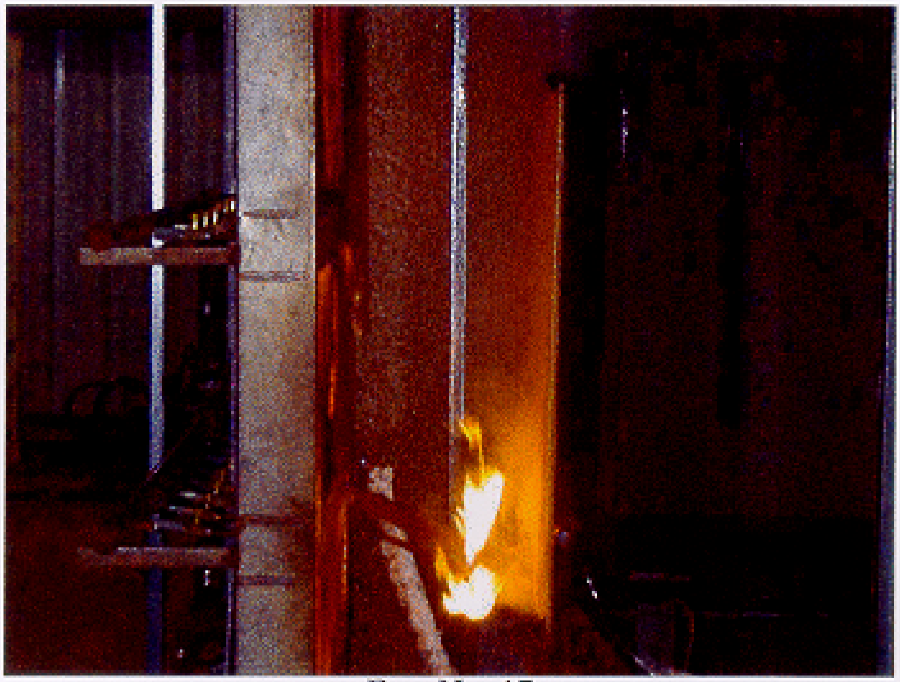
Run No. 16
At 25 kW/m^2 Exposure and Igniter



Run No. 17
Water Application

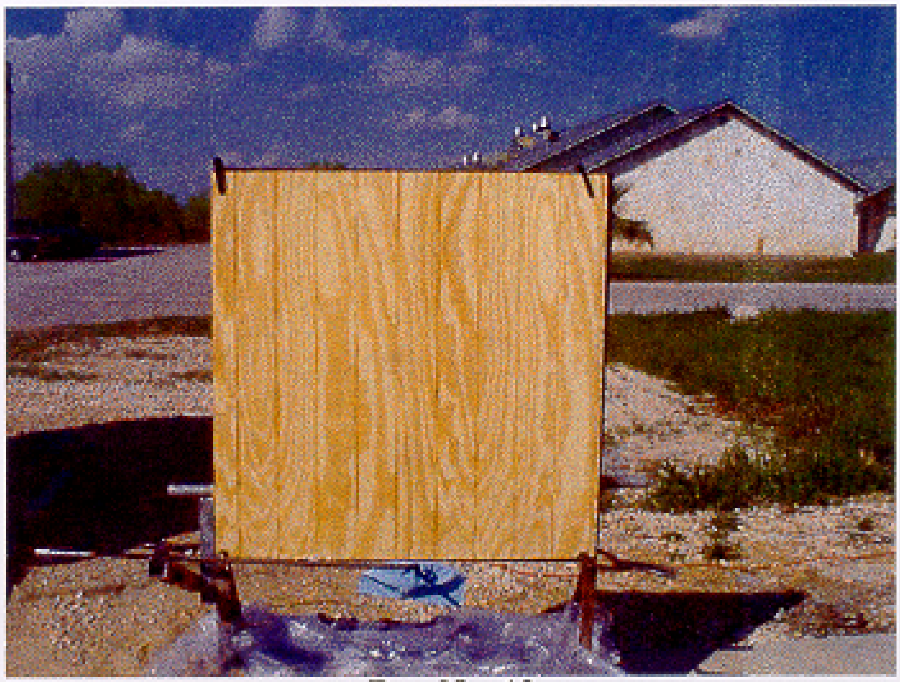


Run No. 17
At 25 kW/m^2 Exposure and Igniter



Run No. 17
Exposure, Smoke, Darkening, Prior to Ignition

Run No. 17
After Ignition



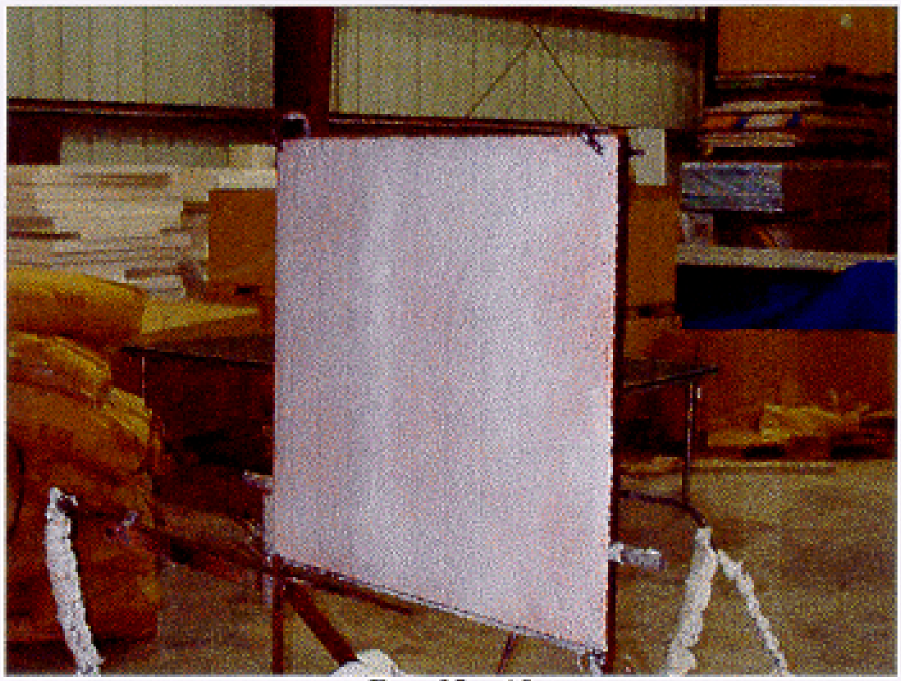
Run No. 18
Prior to Gel Application

Run No. 18
During Gel Application

Run No. 18
Exposure to 25 kW/m² and Igniter Flame

Run No. 18
After Ignition

Run No. 19
Exposed to 1 kW/m^2, at t = 3 min.



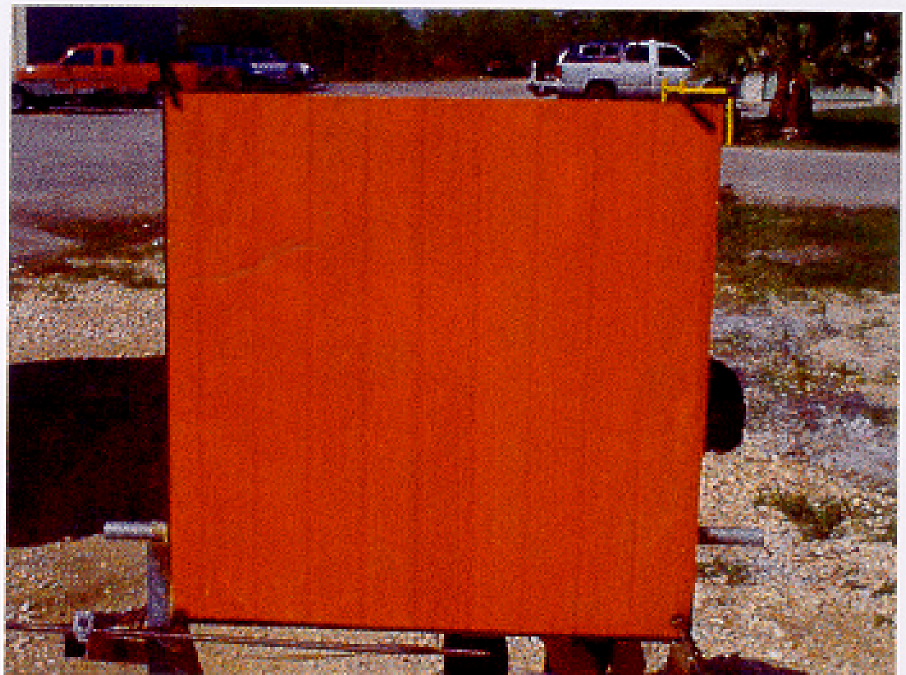
Run No. 19
Exposed to 1 kW/m^2, at t = 30 min.

OMEGA POINT LABORATORIES

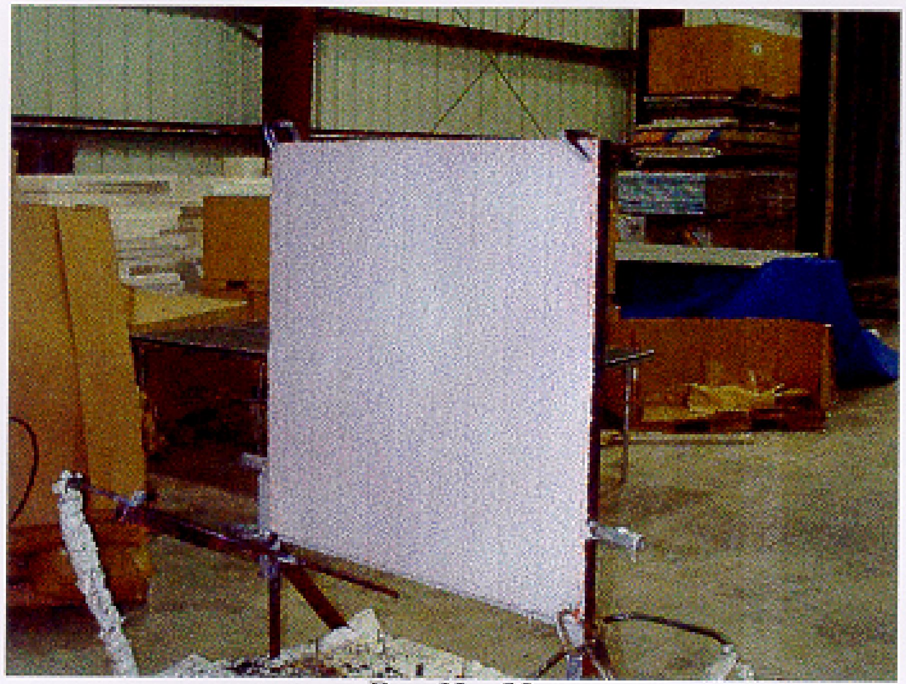
Run No. 19
Exposed to 1 kW/m^2, at t = 54 min.

Run No. 19
Exposed to 1 kW/m^2, at t = 60 min.

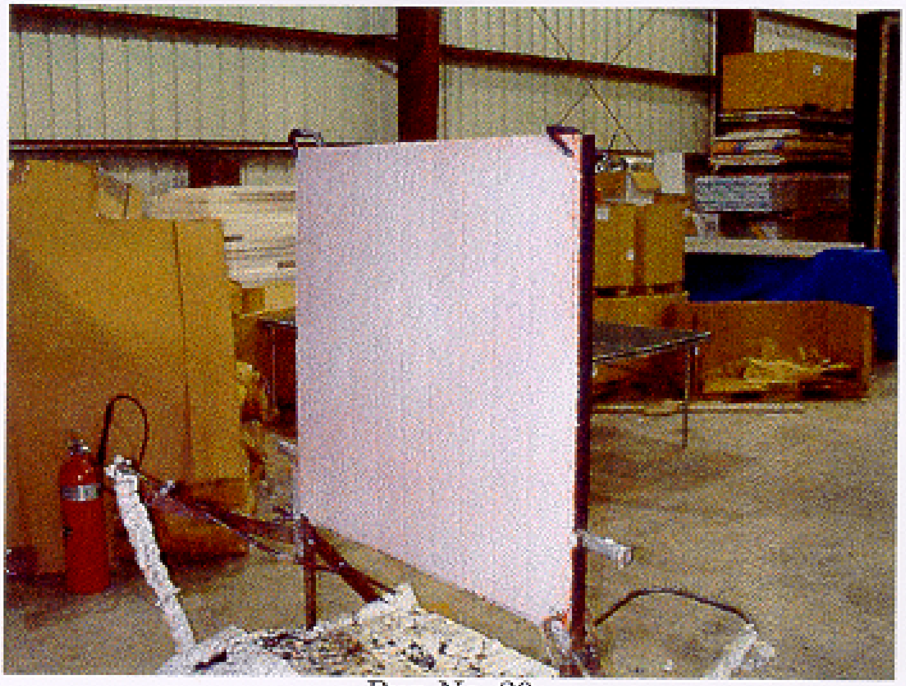
Run No. 19
Exposed to 25 kW/m^2, at t = 2 min.



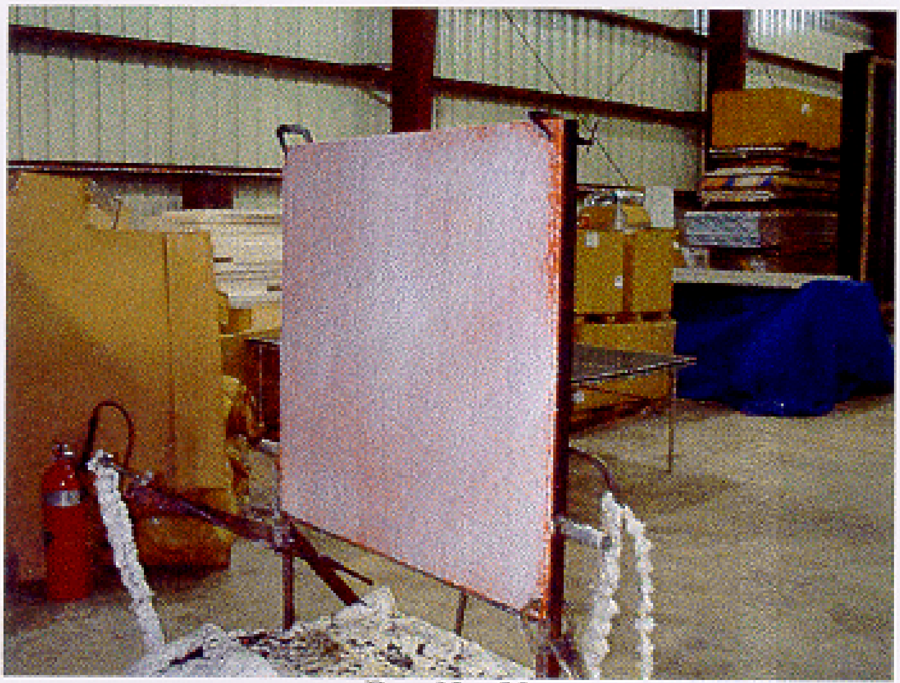
Run No. 20
Prior to Gel Application



Run No. 20
Exposed to 1 kW/m^2, at t = 4 min.



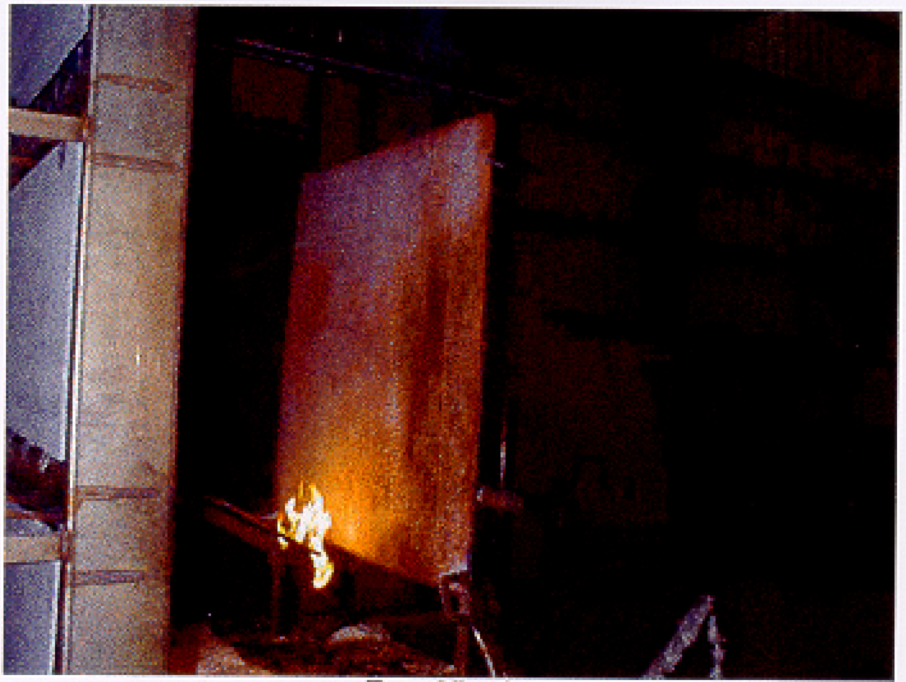
Run No. 20
Exposed to 1 kW/m^2, at t = 24 min.



Run No. 20
Exposed to 1 kW/m^2, at t = 52 min.

Run No. 20
Exposed to 25 kW/m^2. Smoke, Darkening

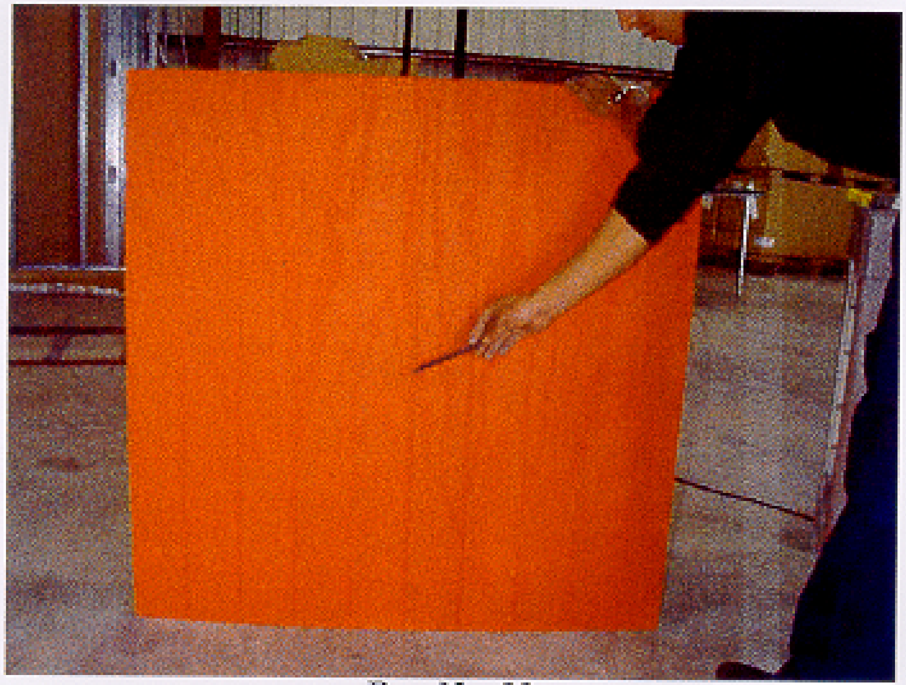
Run No. 21
Exposed to 15 kW/m^2



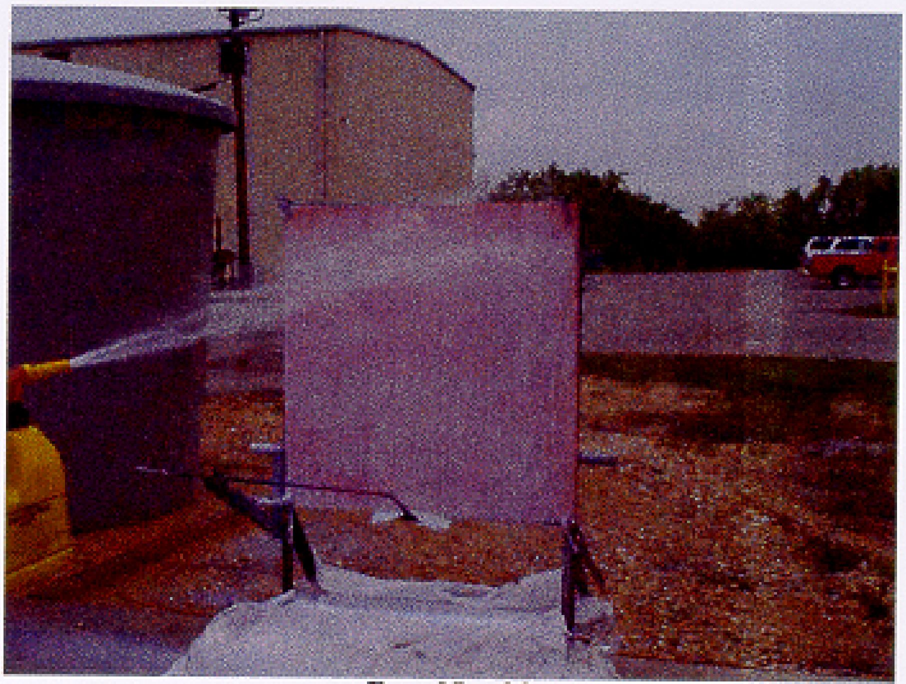
Run No. 21
Exposed to 15 kW/m2, Charring at t = 10 min. 33 sec.

Run No. 21
Exposed to 15 kW/m2, Charring at t = 11 min. 21 sec.

Run No. 21
Exposed to 15 kW/m^2, at Ignition



Run No. 22
Thermocouple Location (2)



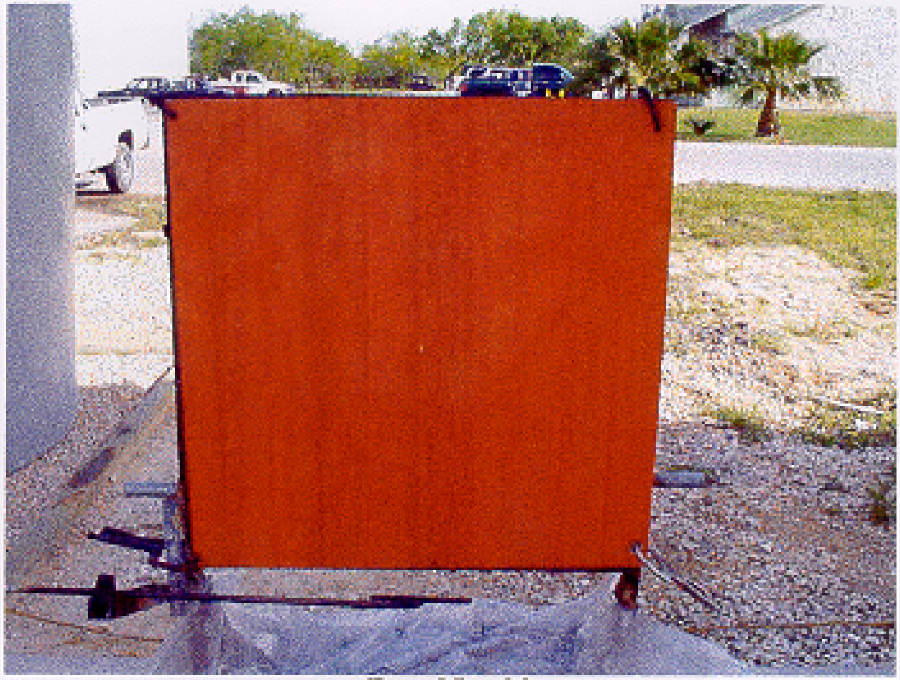
Run No. 22
During Application of the Gel

Run No. 22
Exposed to 25 kW/m^2 and Igniter Flame

Run No. 22
Exposed to 25 kW/m^2 and Igniter Flame. Dripping of Gel.

Run No. 22
Exposed to 25 kW/m² and Igniter Flame. Dripping of Gel.

Run No. 22
Boundary Layer Effect on the Igniter Flame



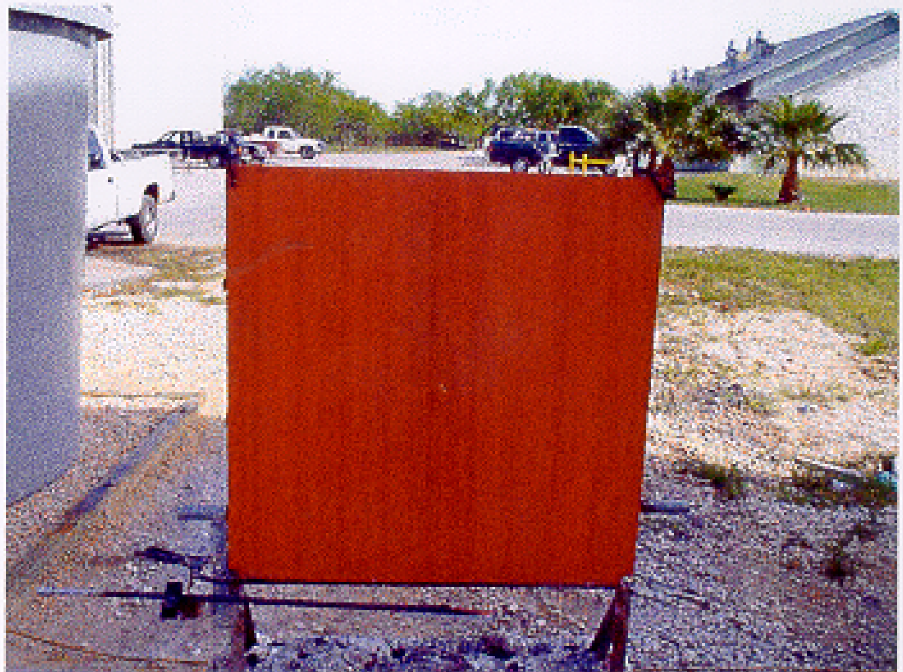
Run No. 23
Prior to Gel Application

Run No. 23
During Gel Application

Run No. 23
After Gel Application

Run No. 23
Exposure to 25 kW/m^2 and Igniter Flame

Run No. 23
Exposure to 25 kW/m² and Igniter Flame. Side View



Run No. 24
Prior to Gel Application

Run No. 24
During Application of the Gel

Run No. 24
After Application of the Gel

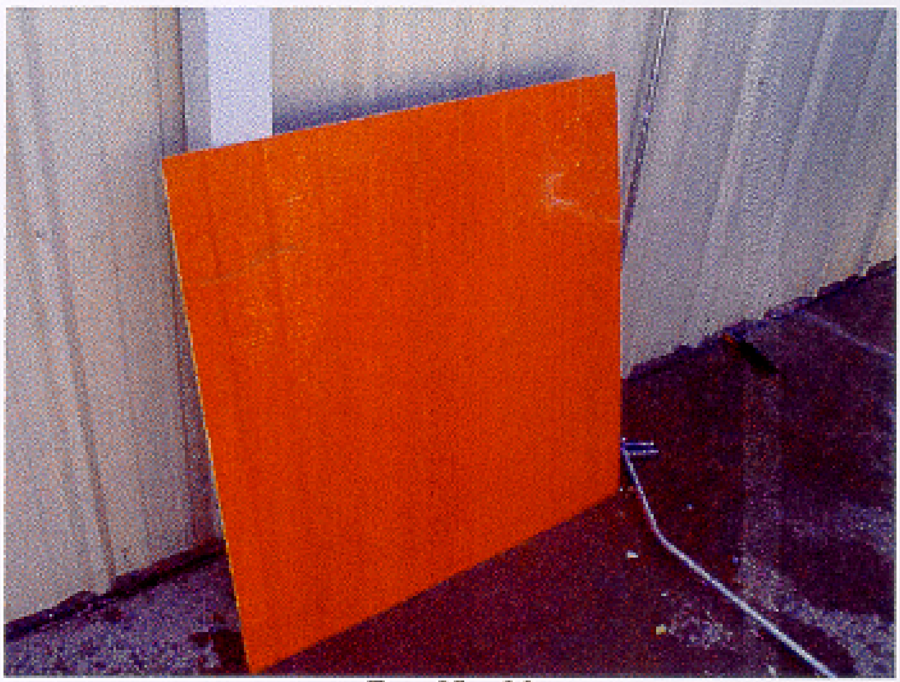
Run No. 24
Exposure to 25 kW/m^2 and Igniter Flame

Run No. 24
Effect of the Boundary Layer on the Igniter Flame

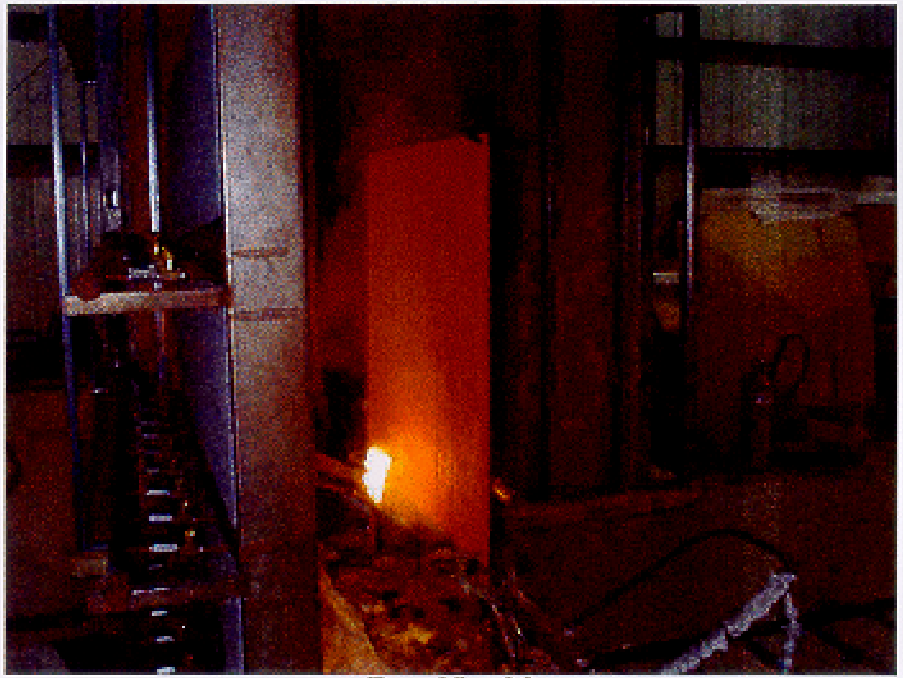
Run No. 25
Prior to Gel Application

Run No. 25
During Application of the Gel

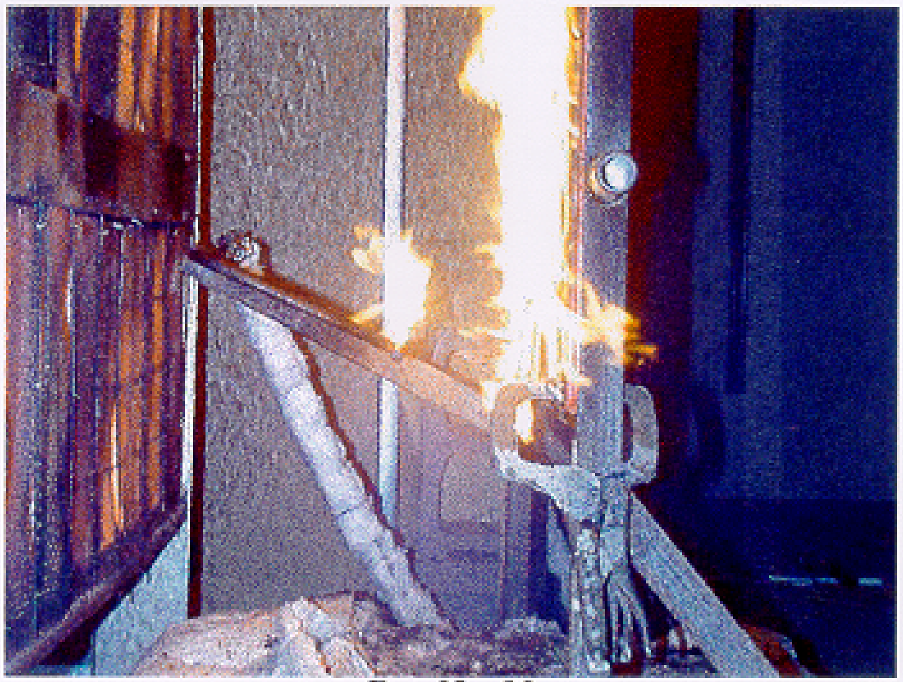
Run No. 25
Exposure to 25 kW/m² and Igniter Flame



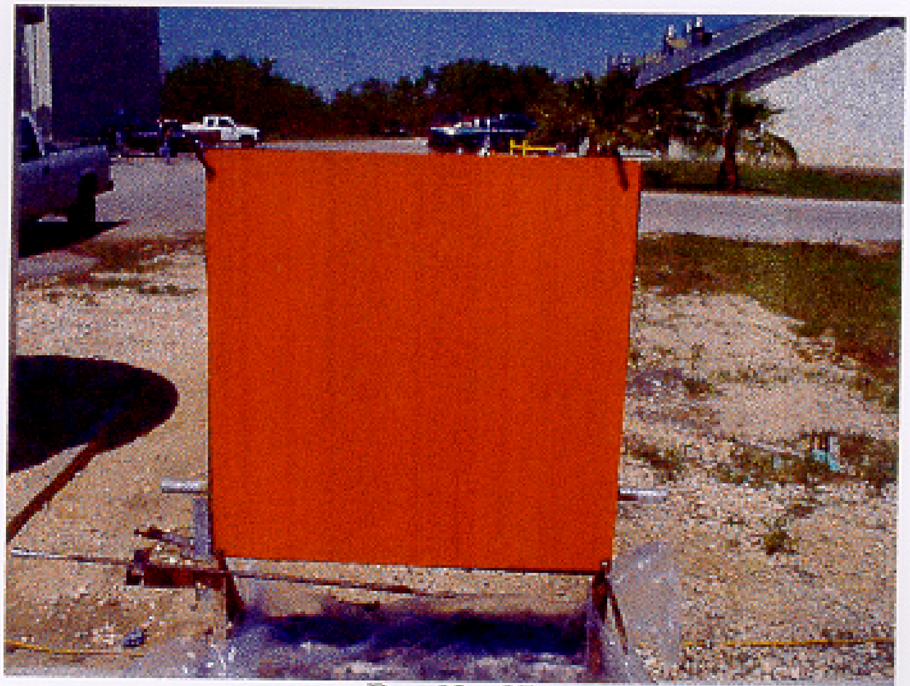
Run No. 26
After Application of Water on the Surface



Run No. 26
Exposure to Heat after 1 hr. Exposure at 1 kW/m²



Run No. 26
At Ignition



Run No. 27
Prior to Gel Application

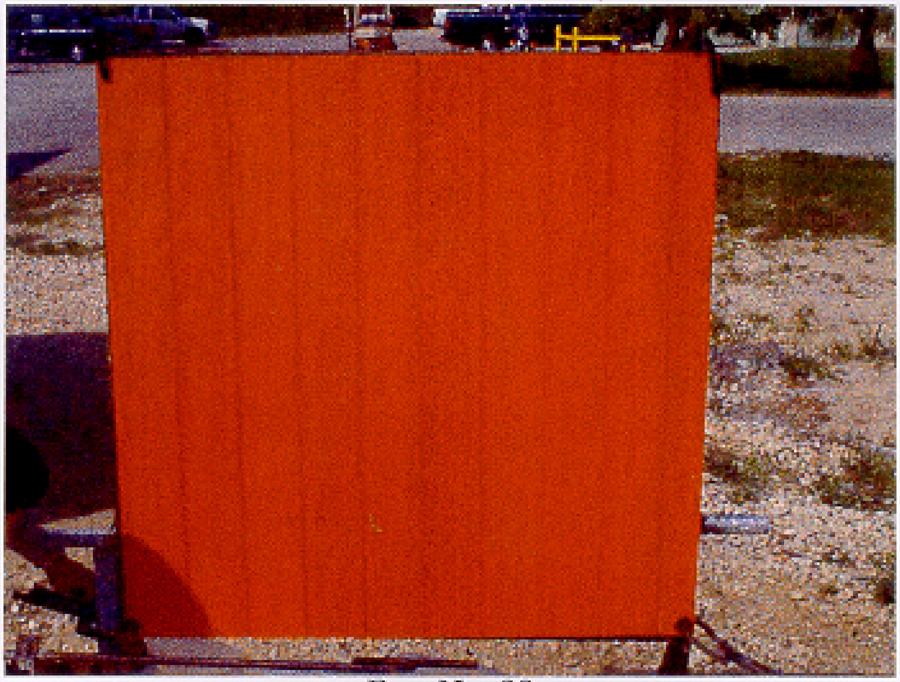
Run No. 27
During Application of the Gel

Run No. 27
After Application of the Gel

Run No. 27
After 1 hr. Exposure to 1 kW/m^2

Run No. 27
Exposure to 15 kW/m^2 and Igniter Flame

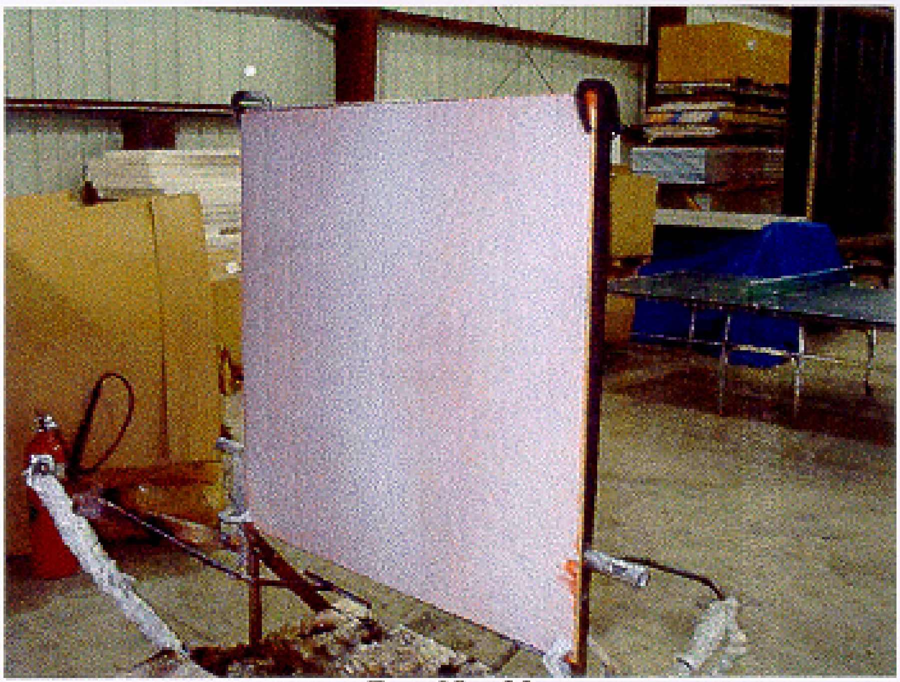
Run No. 27
Exposure to 15 kW/m^2 and Igniter Flame



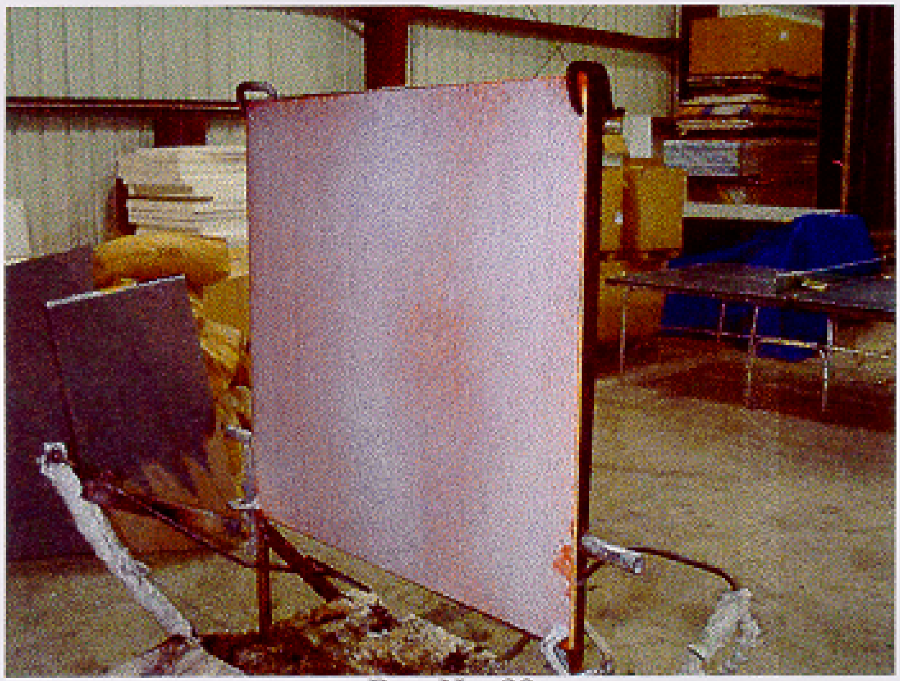
Run No. 28
Prior to Gel Application

Run No. 28
During Application of the Gel

Run No. 28
After Application of the Gel

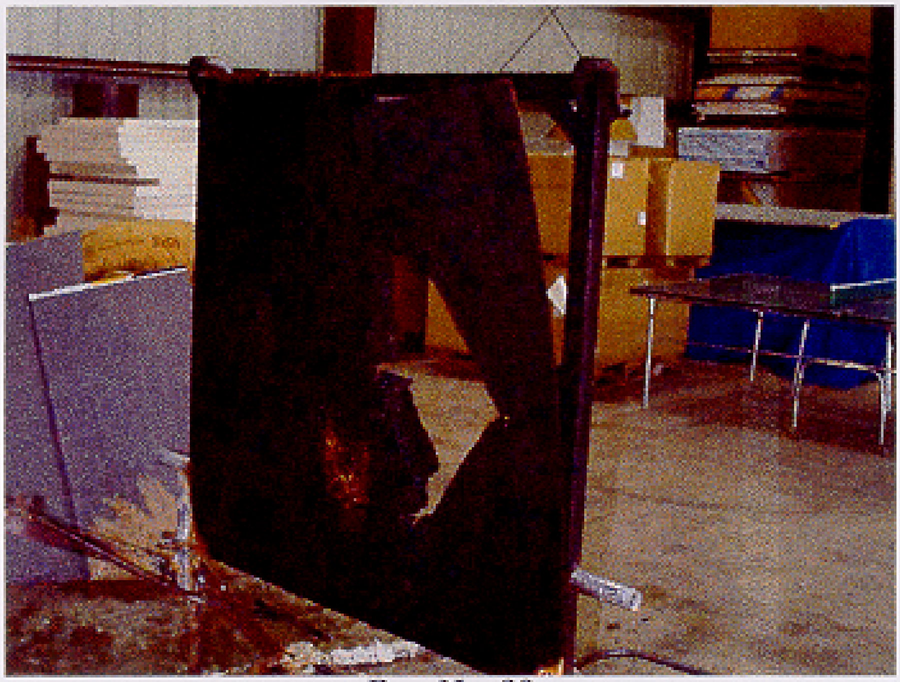


Run No. 28
Exposure to 1 kW/m^2 of heat

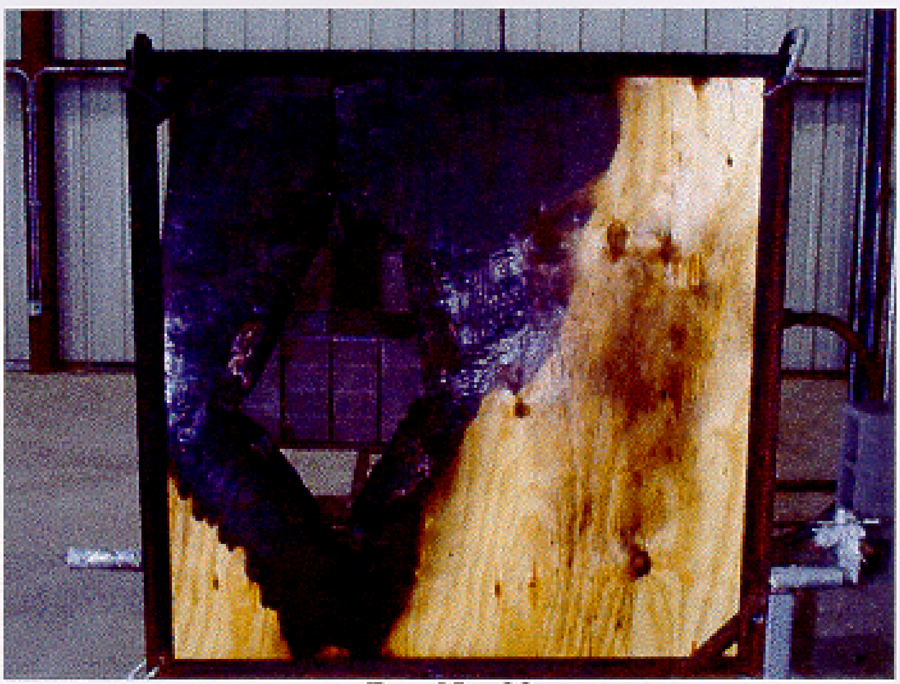


Run No. 28
Exposure to 1 kW/m^2 of heat

Run No. 28
Exposure to 15 kW/m^2 and Igniter Flame



Run No. 28
After Testing

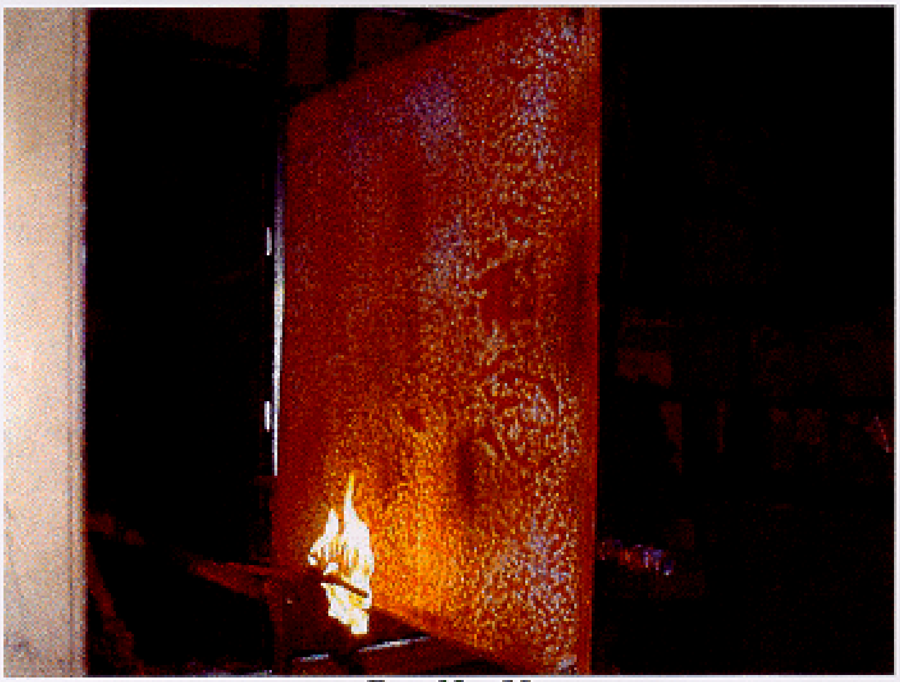


Run No. 28
Rear View of the Sample after Ignition

Run No. 29
After 50 min. of Exposure to 1 kW/m^2

Run No. 29
After 1 min. Exposure to 15 kW/m^2

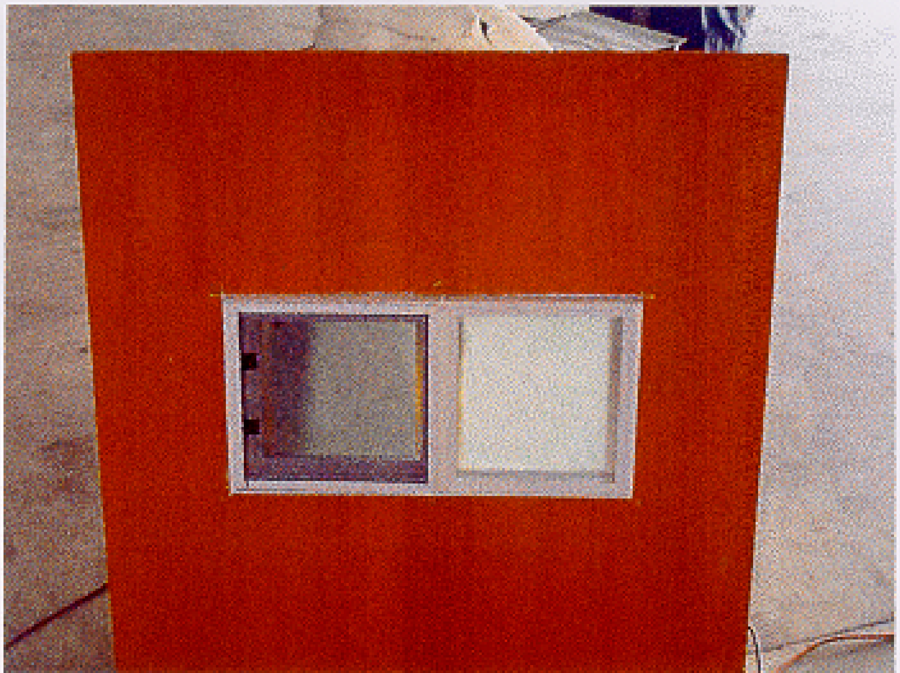
Run No. 29
After 5 Min. of Exposure to 15 kW/m²



Run No. 29
After 8 Min. of Exposure to 15 kW/m²

Run No. 29
After 10 min. of Exposure to 15 kW/m^2

Run No. 29
At Ignition



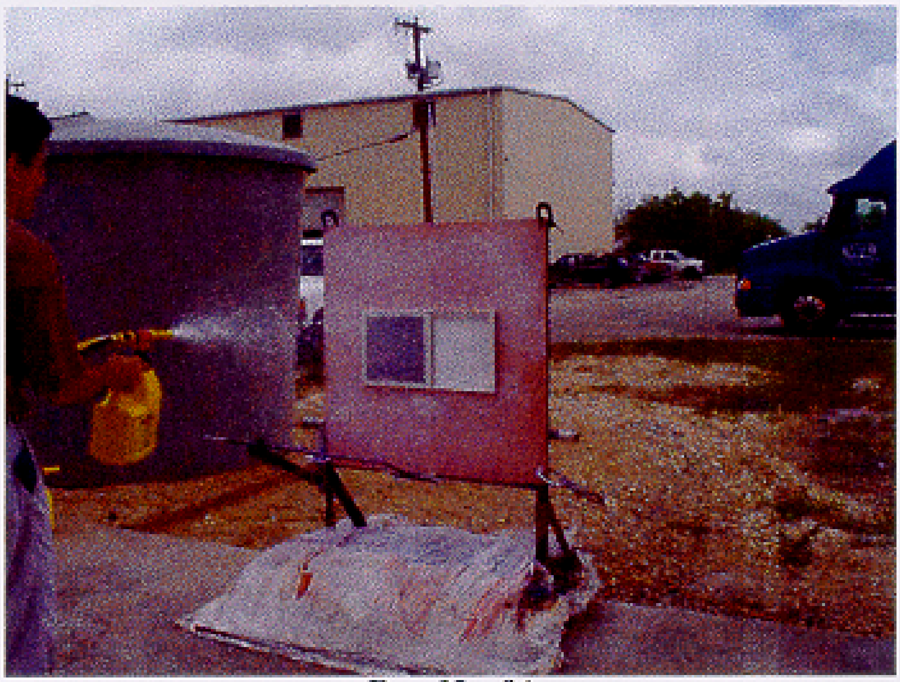
Run No. 30
Specimen prior to Testing

Run No. 30
Exposure to 25 kW/m^2, No Treatment

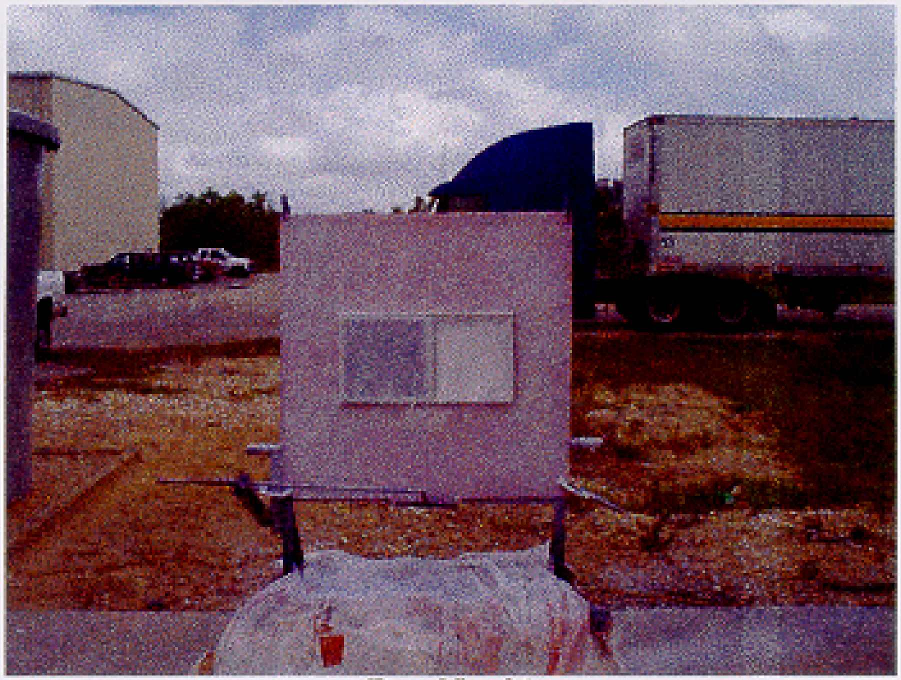
Run No. 30
At Ignition

Run No. 30
After Ignition

Run No. 31
Prior to Application of the Gel



Run No. 31
During Application of the Gel



Run No. 31
After Application of the Gel

Run No. 31
Exposure to 25 kW/m^2 and Igniter Flame

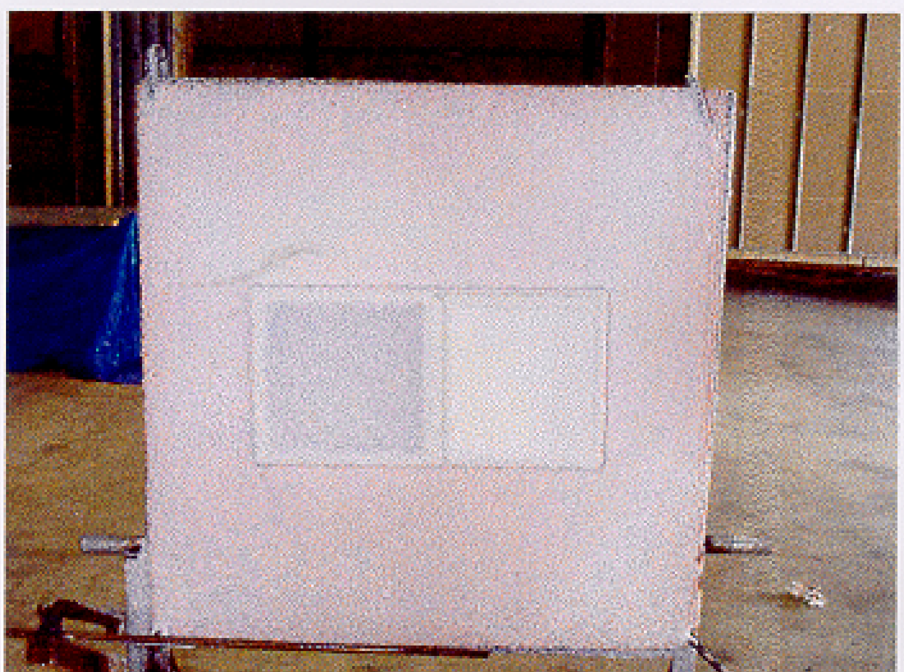
Run No. 31
Close up of the Window During Exposure

Run No. 31
Prior to Ignition

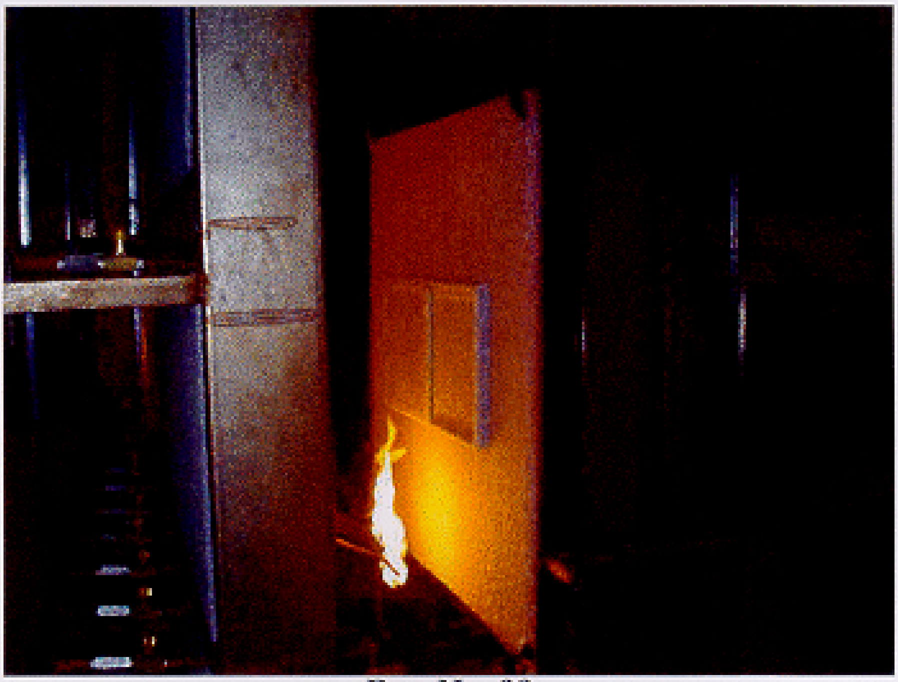
Run No. 31
At Ignition

Run No. 31
Full Ignition

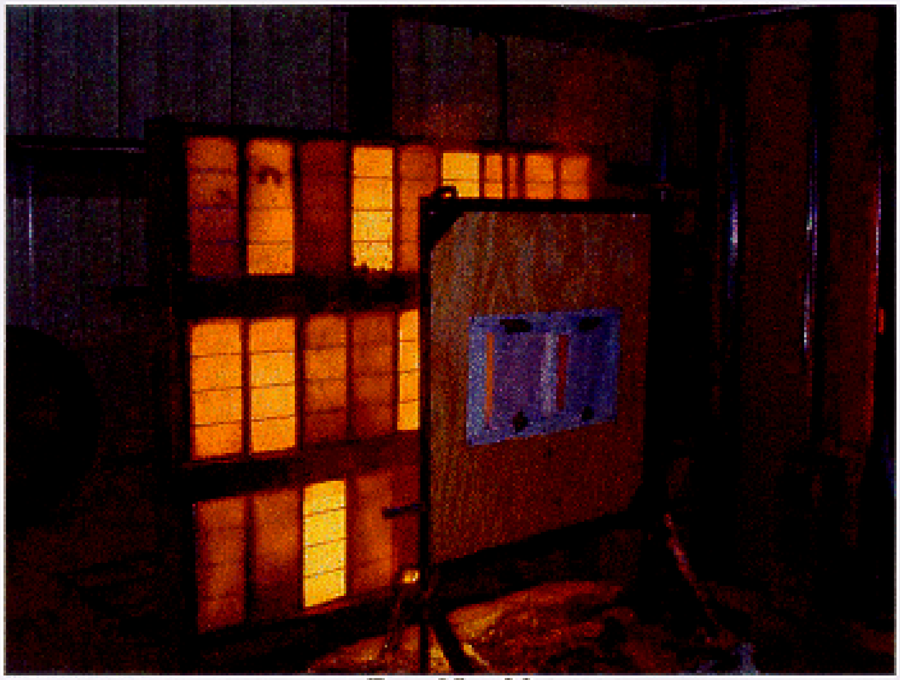
Run No. 32
Prior to Gel Application



Run No. 32
After Application of the Gel



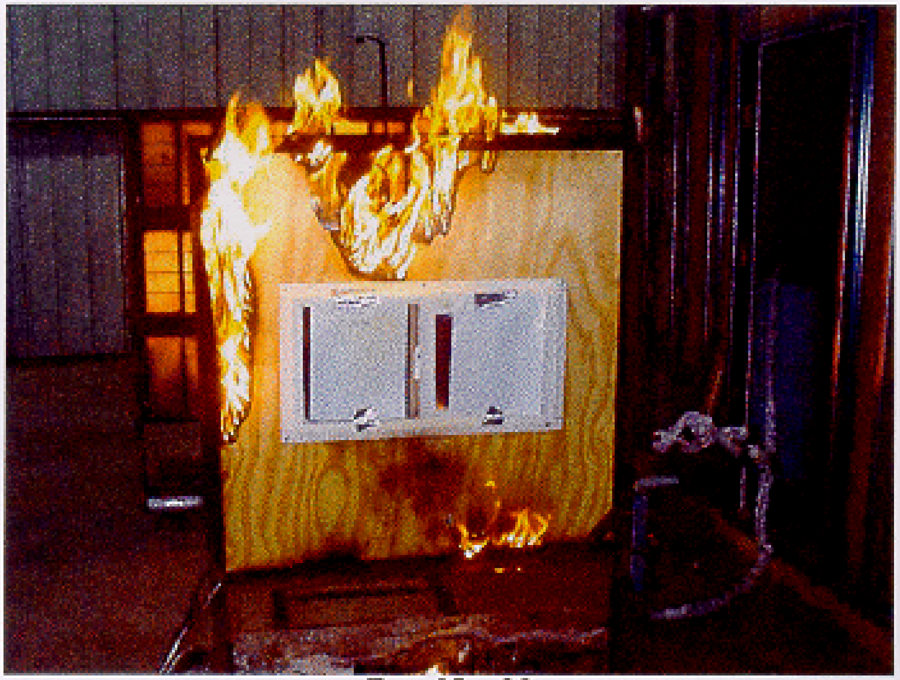
Run No. 32
Exposure to 25 kW/m² and Igniter Flame



Run No. 32
Exposure to ICAL Panel, t = 1 min.

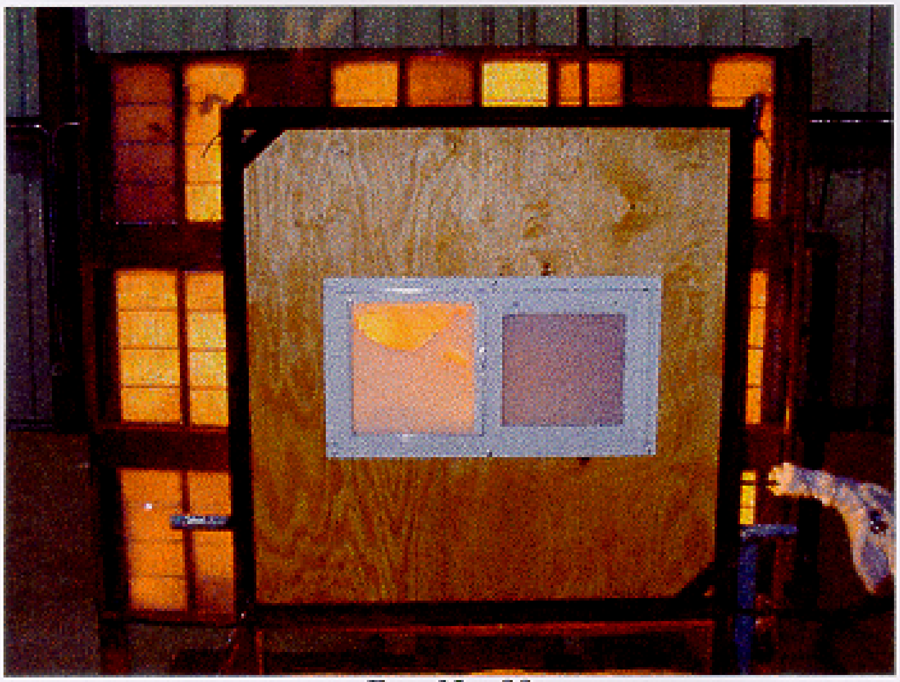
Run No. 32
Exposure to ICAL Panel, t = 4 min. 30 sec., Smoke, Darkening

Run No. 32
After Ignition

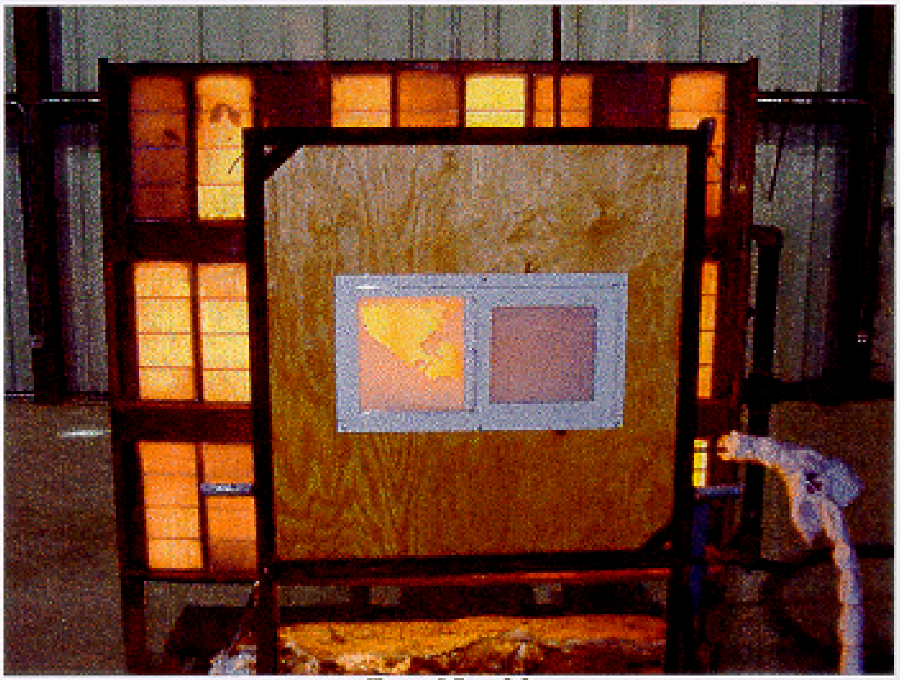


Run No. 32
Rear View of the Specimen After Ignition. Glass Intact.

Run No. 32
Close up of the Window Assembly

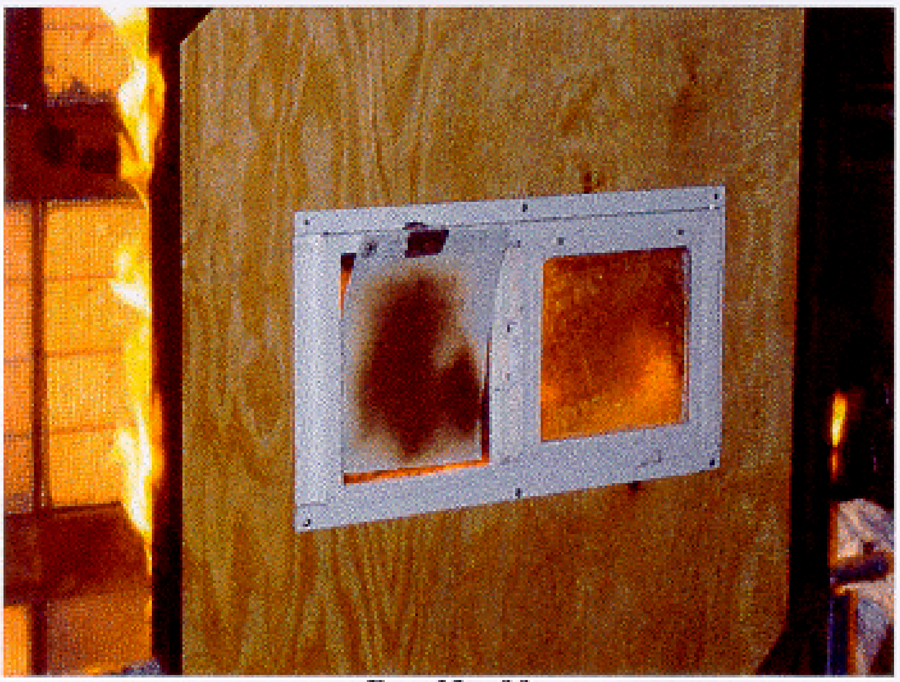


Run No. 33
Exposure to 25 kW/m^2 and Igniter Flame. t = 2 min. 40 sec.

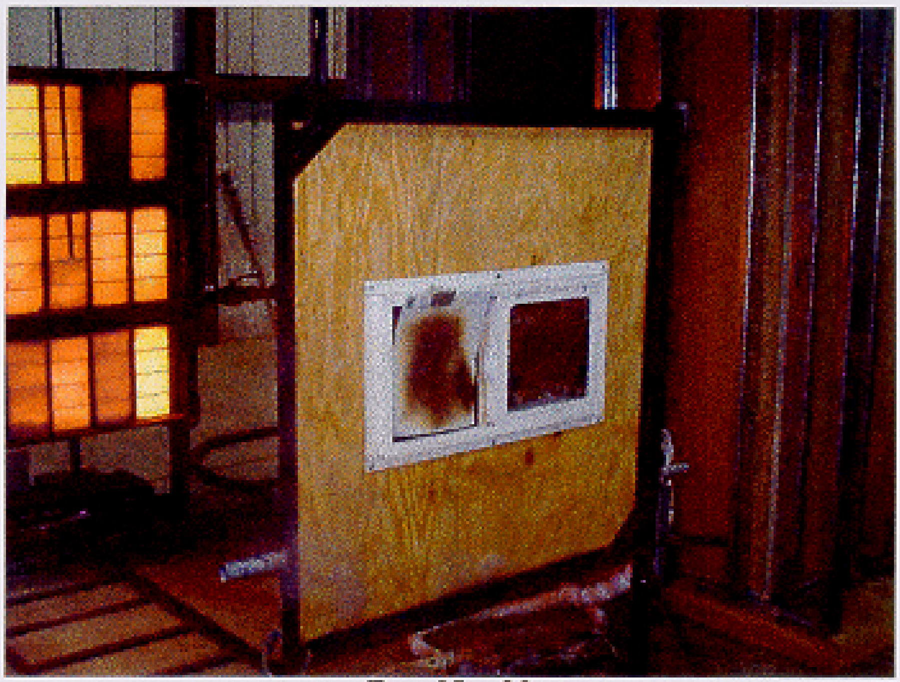


Run No. 33
Exposure to 25 kW/m^2 and Igniter Flame. t = 2 min. 50 sec.

Run No. 33
t = 3 min. 40 sec. Gel Slides Off the Glass

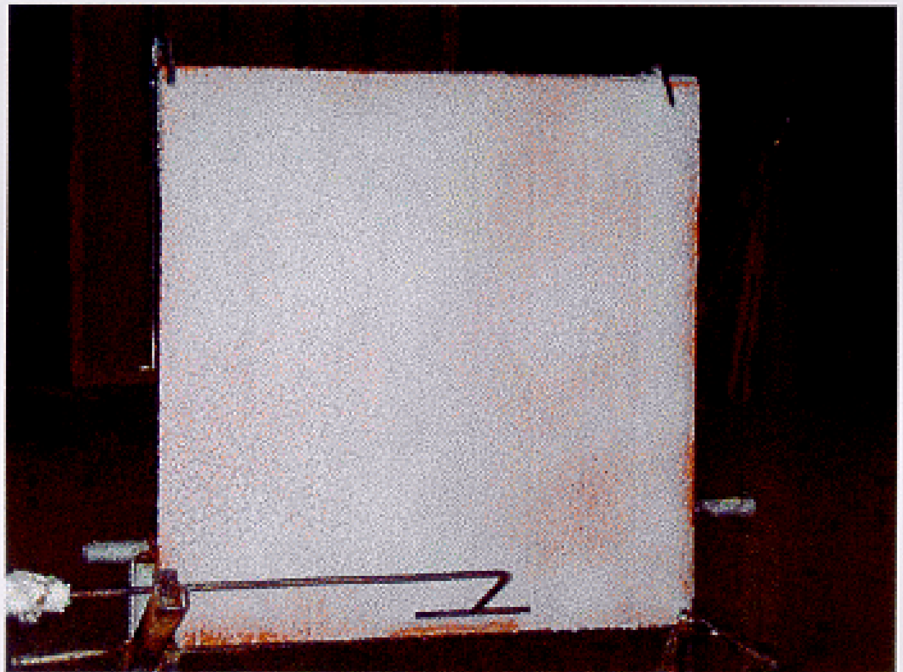


Run No. 33
At Ignition. Test Paper Charred. t = 8 min. 11 sec.

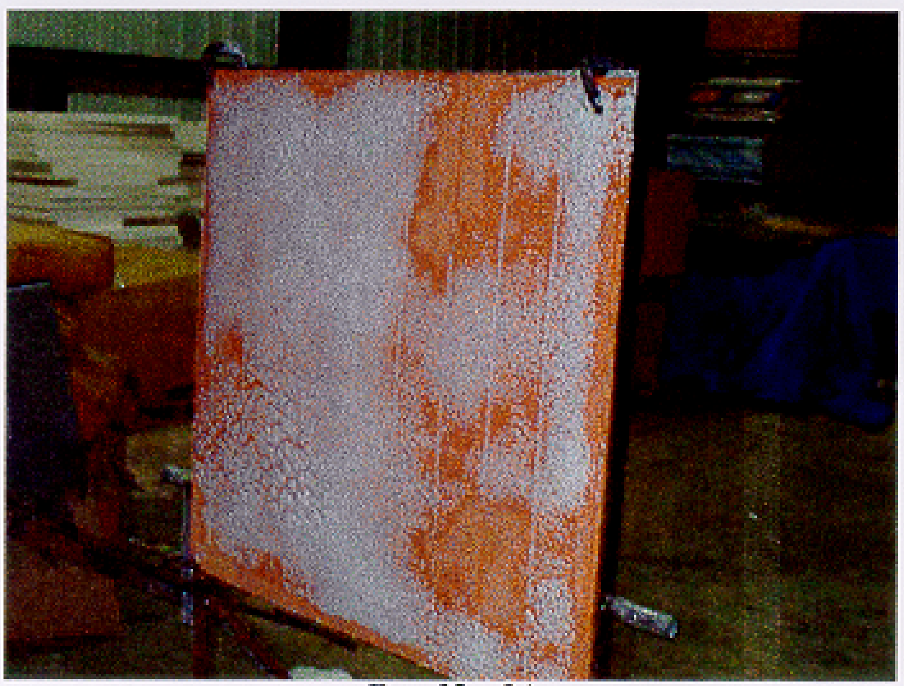


Run No. 33
Rear View After Ignition

Run No. 33
After Ignition. Igniter Flame On.

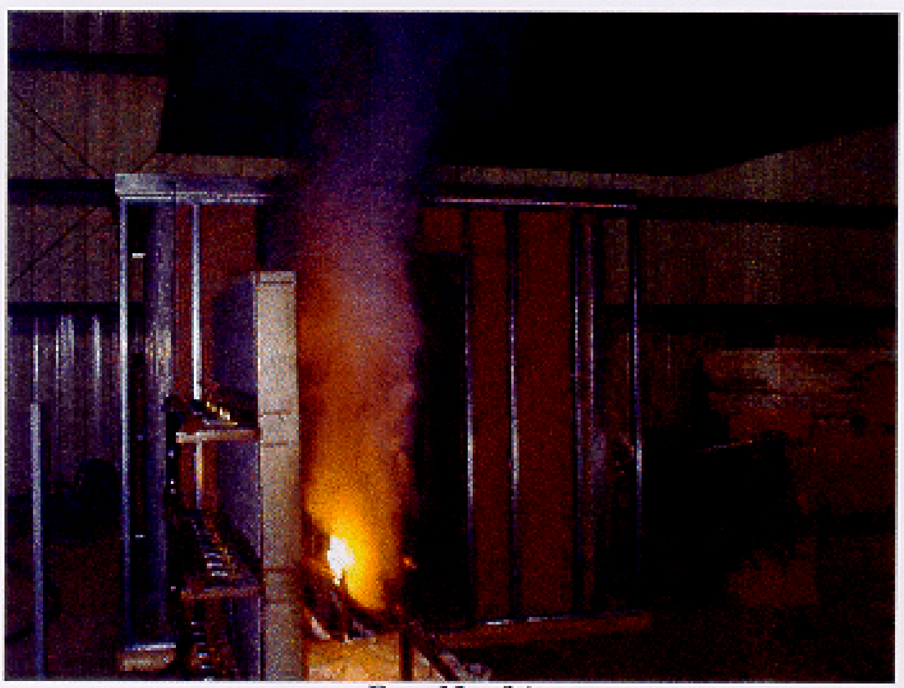


Run No. 34
Exposure to 1 kW/m^2, at t = 1 hr. 10 min.



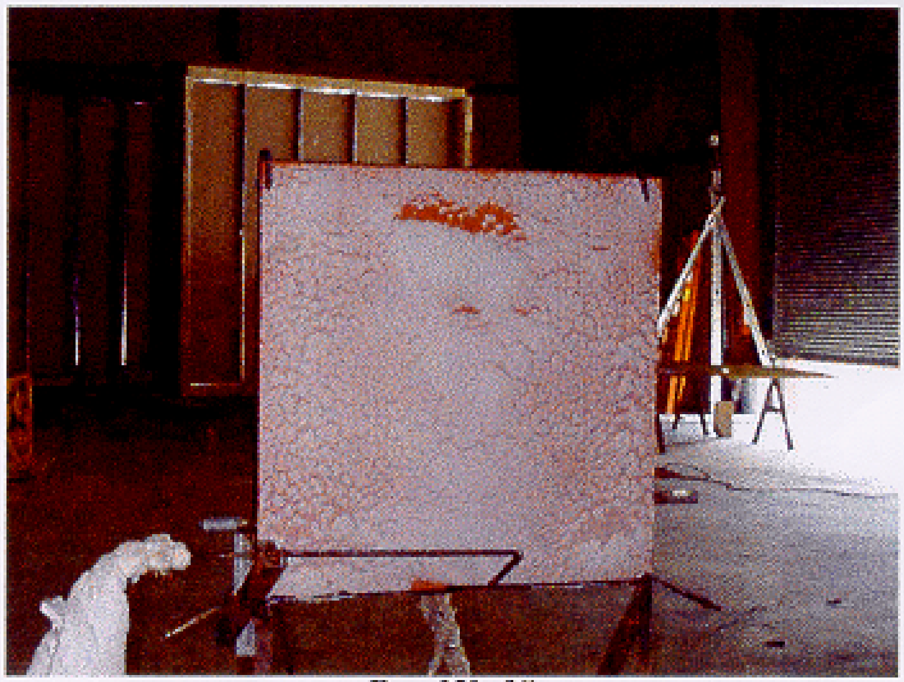
Run No. 34
Exposure to 1 kW/m^2, at t = 1 hr. 40 min.

Run No. 34
Exposure to 1 kW/m^2, at t = 1 hr. 53 min.

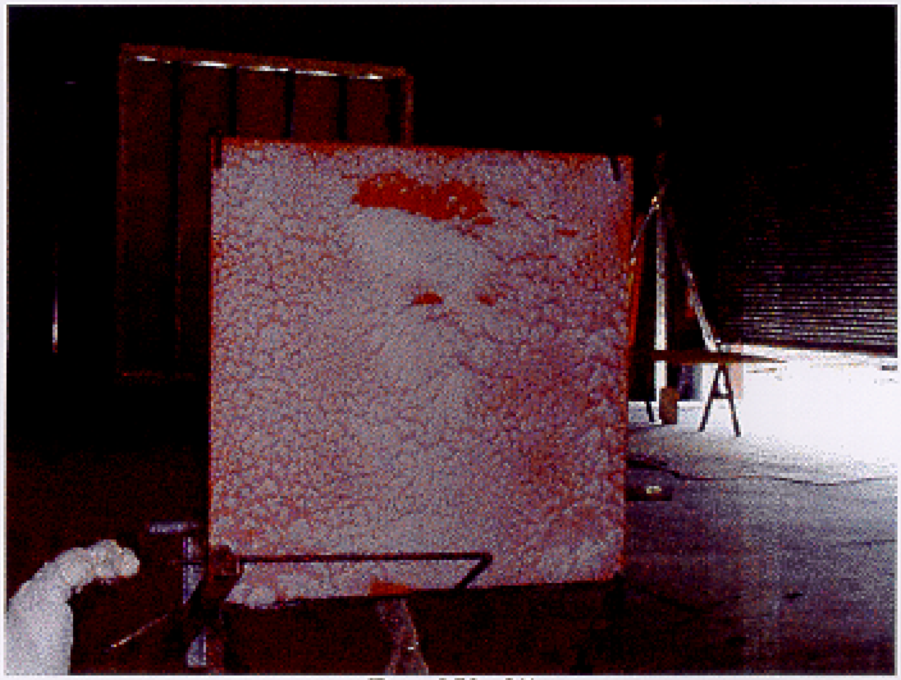


Run No. 34
Exposure to 25 kW/m^2 and Igniter Flame.

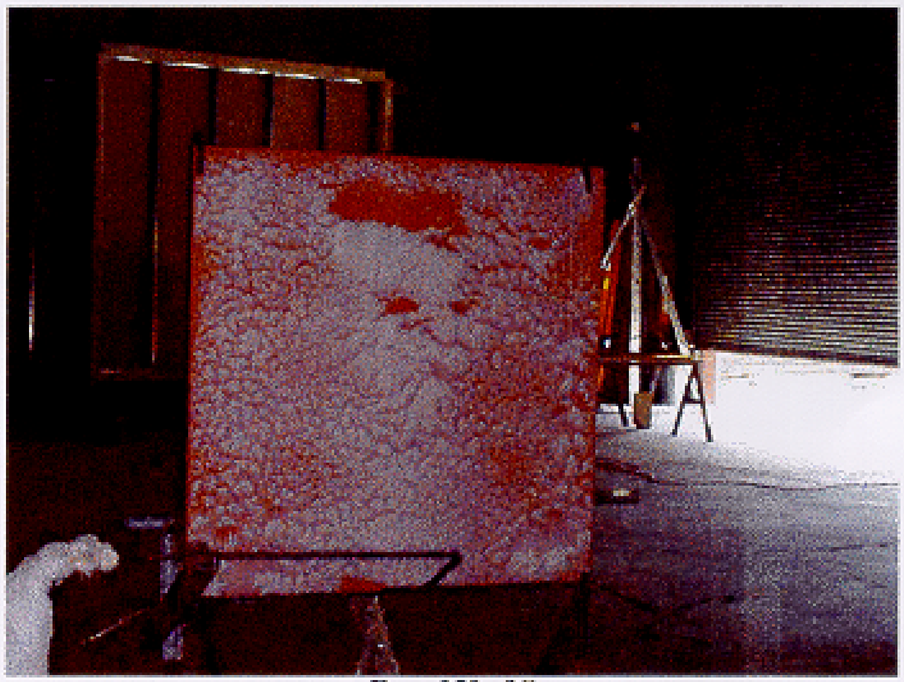
Run N0. 35
Exposure to 1 kW/m^2 at t = 40 min.



Run N0. 35
Exposure to 1 kW/m^2 at t = 1 hr.



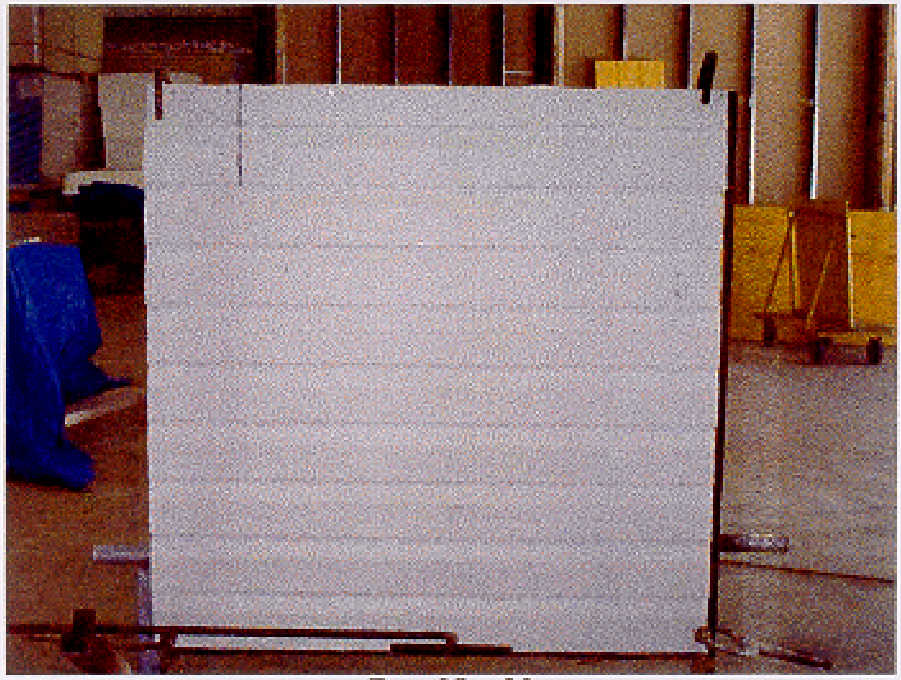
Run N0. 35
Exposure to 1 kW/m^2 at t = 1 hr. 15 min.



Run N0. 35
Exposure to 1 kW/m^2 at t = 1 hr. 30 min.

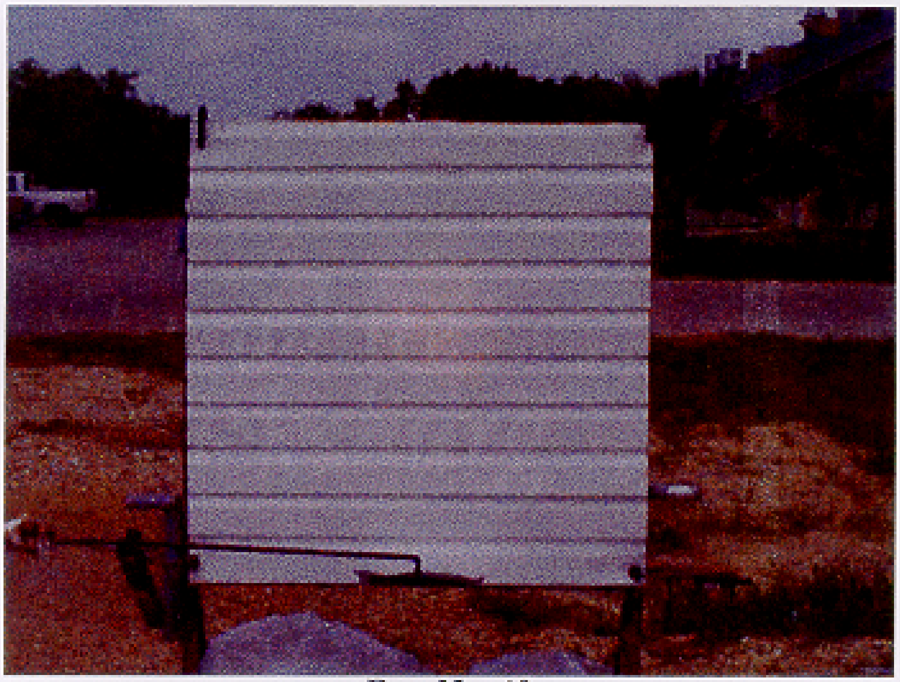
Run N0. 35
Exposure to 1 kW/m^2 at t = 2 hrs.

Run No. 35
Exposure to 25 kW/m^2 and Igniter Flame. Smoke, Darkening.

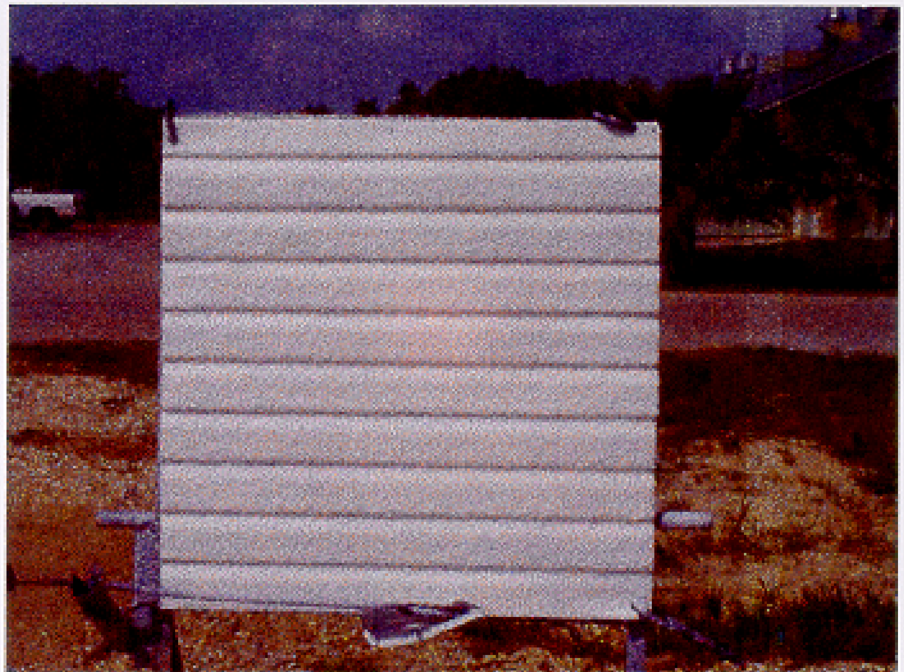


Run No. 39

Run No. 39
After Exposure to 25 kW/m^2 and Igniter Flame. t = 45 sec.



Run No. 40
Prior to Application of the Gel



Run No. 40
After Application of the Gel

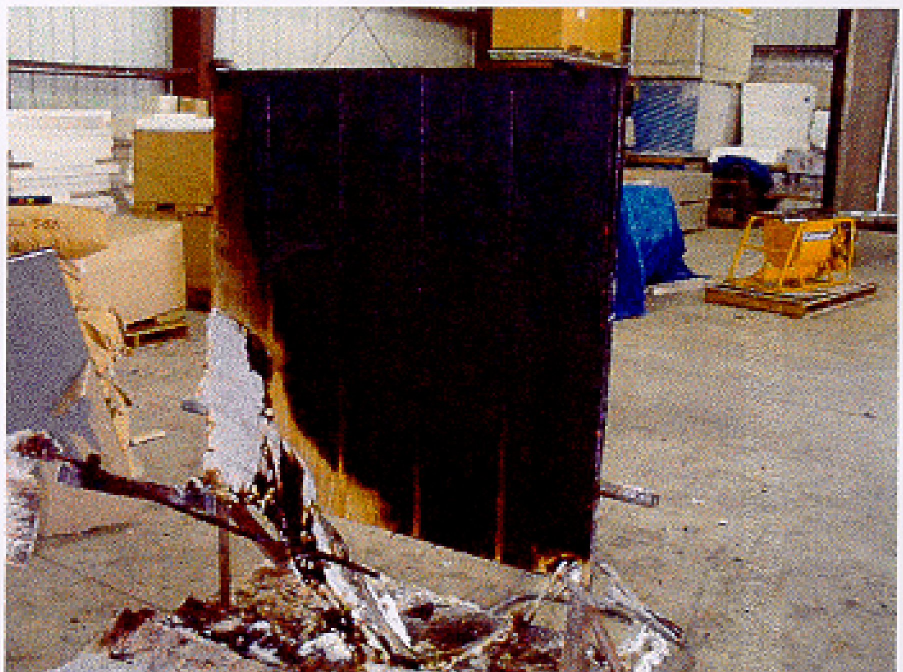
Run No. 40
Exposure to 25 kW/m^2 and Igniter Flame

Run No. 40
During Exposure

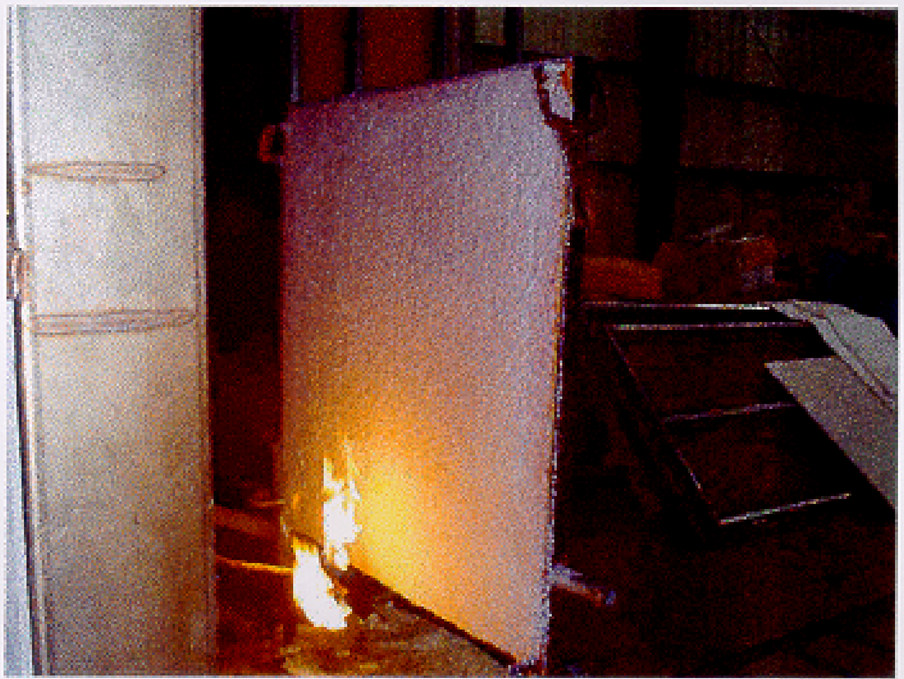
Run No. 40
During Exposure, t = 1 min. 30 sec.

Run No. 40
During Exposure, t = 2 min.

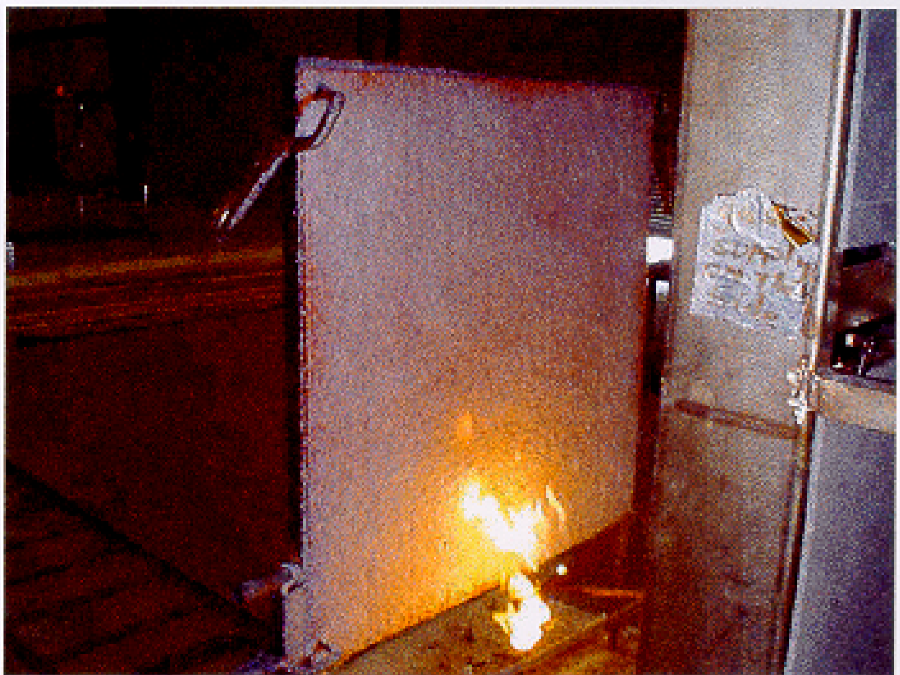
Run No. 40
Prior to Ignition



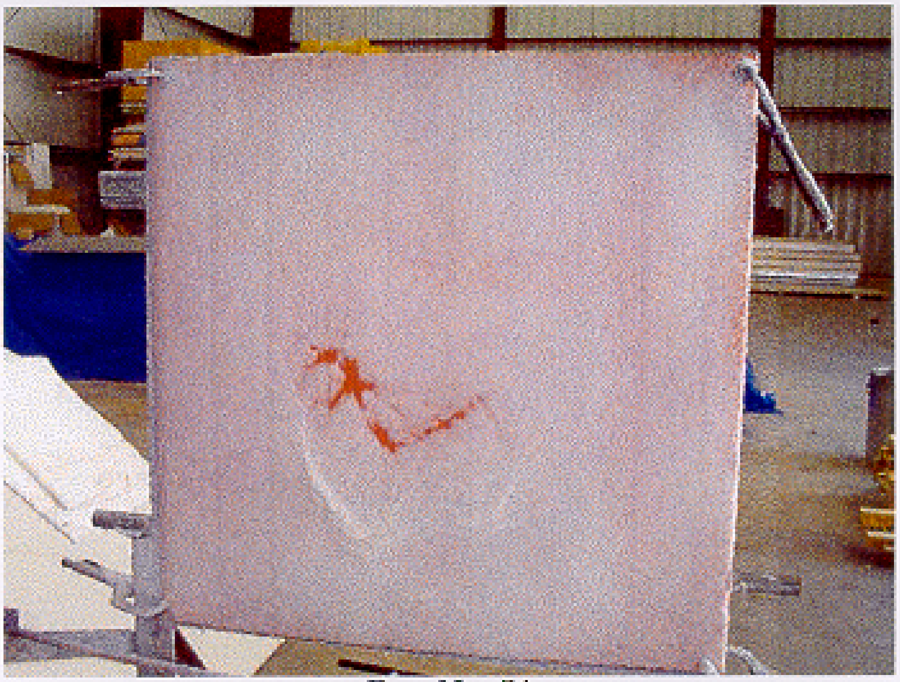
Run No. 40
After Ignition



Run No. 50
Exposure at 15 kW/m^2

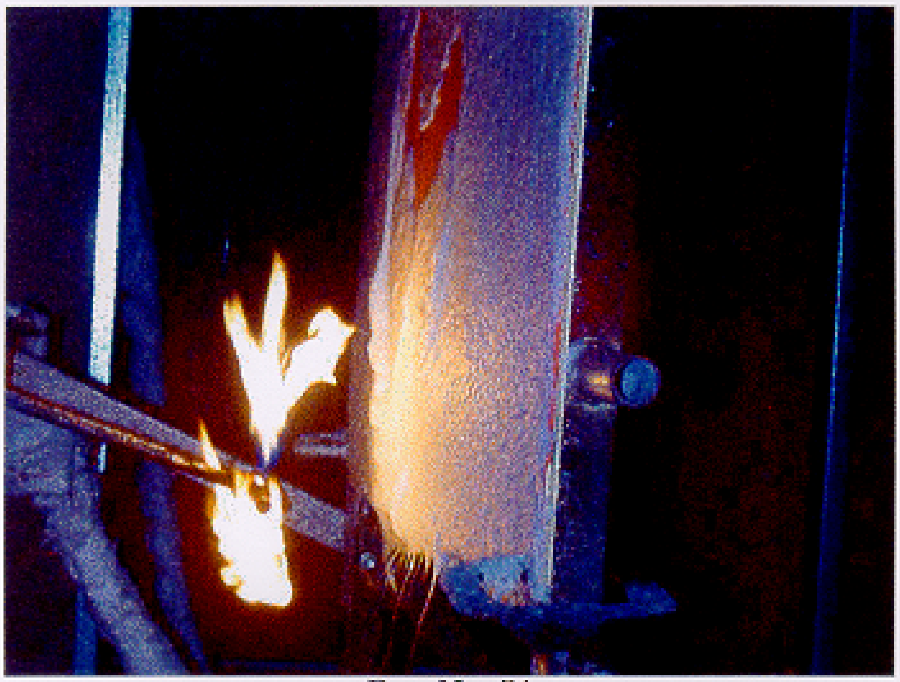


Run No. 50
Exposure at 15 kW/m^2, at t = 6 min. 50 sec.



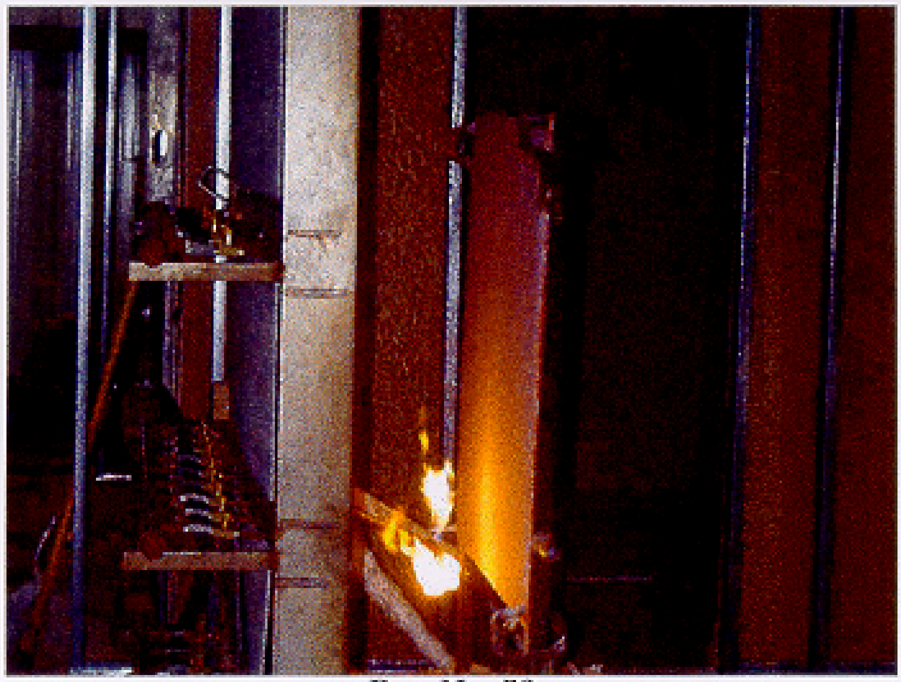
Run No. 51
Prior to exposure at 15 kW/m^2

Run No. 51
Exposure at 15 kW/m^2, t = 30 sec.



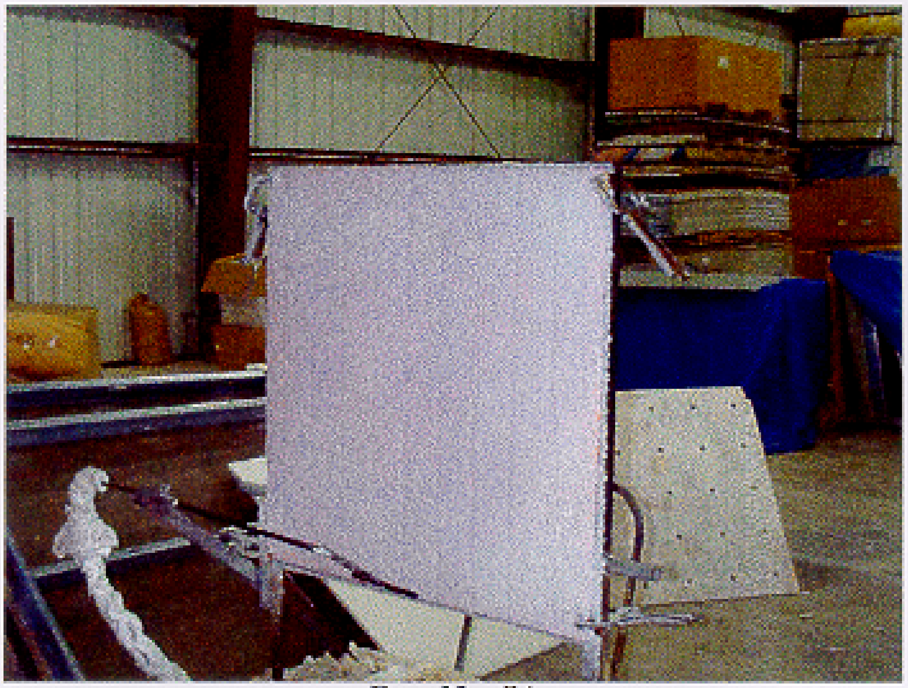
Run No. 51
Exposure at 15 kW/m², t = 4 min.

Run No. 51
Exposure at 15 kW/m², prior to ignition

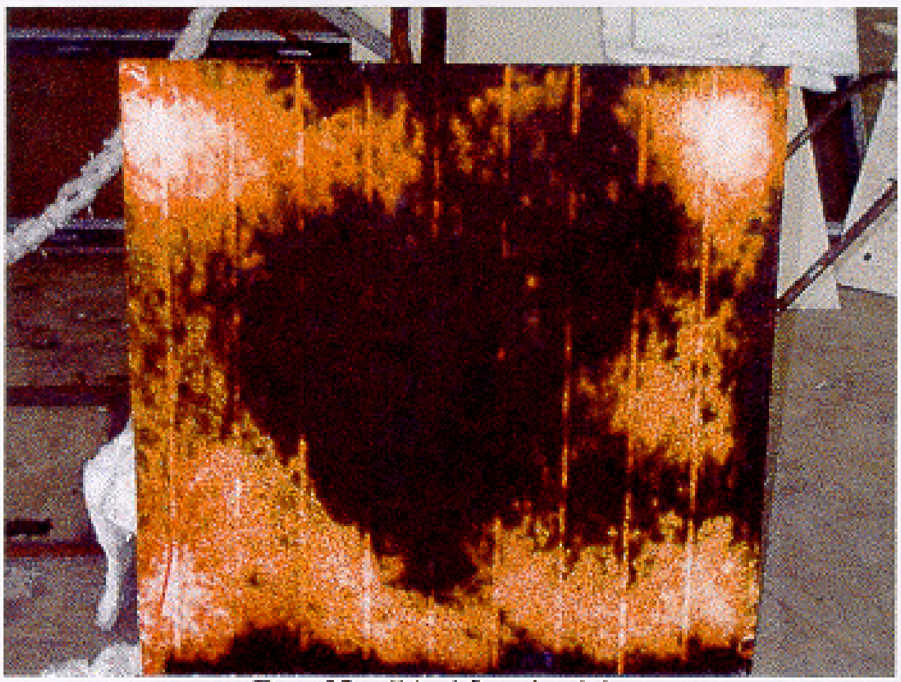


Run No. 52
Exposure at 25 kW/m^2

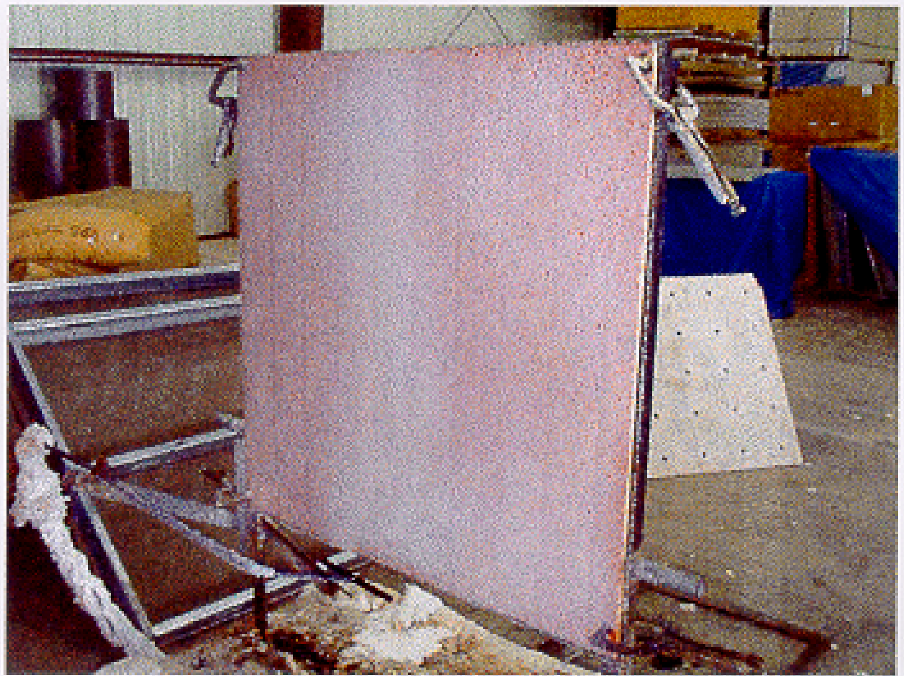
Run No. 52
After ignition



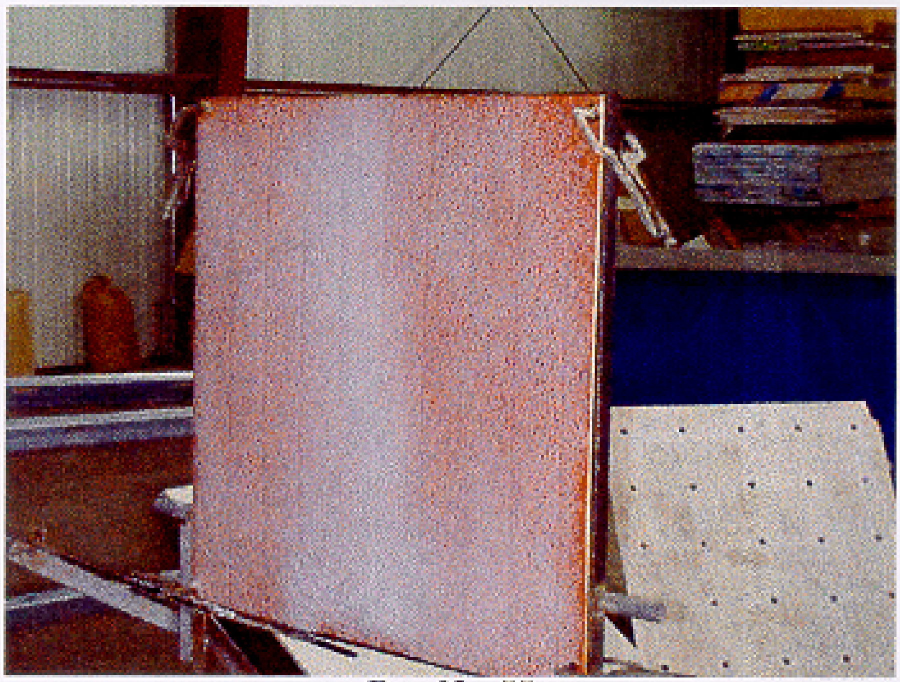
Run No. 54
Prior to exposure



Run No. 54. After ignition



Run No. 55
Drying exposure at 1 kW/m^2, at t = 20 sec.



Run No. 55
Drying exposure at 1 kW/m^2, at t= 30 min.

Run No. 55
Exposure at 25 kW/m², at t = 2 min. 10 sec.

Run No. 55
Drying exposure at 1 kW/m², at ignition