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# FURNITURE FLAMMABILITY: AN INVESTIGATION OF THE CALIFORNIA BULLETIN 133 TEST. PART II: CHARACTERIZATION OF THE IGNITION SOURCE AND A COMPARABLE GAS BURNER

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# Characterization of the California Technical Bulletin 133 Ignition Source and a Comparable Gas Burner

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## ABSTRACT

The California Bulletin 133 upholstery ignition source is based on the use of crumpled newsprint. The present work examined the reproducibility of several aspects of this source when placed on an inert chair mock-up. The tendency of this source to heat the side arms of a chair, the area of the seat back subjected to high heat fluxes, the peak flux there and the flux duration all showed substantial variability. For inherently lesser variability a gas burner is preferred. A gas burner, derived from that developed at the British Fire Research Station, was shaped so as to deposit a similar pattern of heat to that of the CB 133 source. The two sources were tested for comparability both on chair mock-ups and on full-scale chairs made from a wide variety of materials. The results indicate that the gas burner, as used here, is a somewhat less severe ignition source than is the CB 133 igniter.

## 1) INTRODUCTION

The California Technical Bulletin 133 test, developed at the California Bureau of Home Furnishings, is a flammability test procedure for seating furniture being considered for possible use in public occupancies (hotels, prisons, nursing homes, etc.)[1]. The NIST, Center for Fire Research, in collaboration with the California Bureau of Home Furnishings, recently undertook a study of this test and its procedures with a view toward possible improvements, if the test is to be adopted more broadly. The present paper describes the results of a part of that study which was focussed on the CB 133 ignition source and the possibility of developing a comparable gas burner.

The CB 133 test exposes the item of furniture (or alternatively a similar mock-up) to an intense ignition source that is placed in contact with the seat and seat back. The test is conducted within the confines of a prescribed room in which temperatures, gas concentrations and smoke obscuration are measured. There are several failure criteria based on these measurements [1].

## 2) THE CB 133 IGNITION SOURCE

The ignition source used in the CB 133 flammability test procedure is based on crumpled newspaper. Five sheets of paper, each formed into a loose wad, are arranged as shown in Figure 1. This pile of crumpled paper is covered by a sheet metal and wire mesh box conforming to the specifications shown in Fig. 2. (There are two other variations on this basic box configuration which are to be used with furniture having somewhat uncommon design features; these have not been examined in this study.) Placement of the paper/box combination on upholstered chairs is indicated in Fig. 1. The approximate dimensions of the newspaper sheets and their combined weight (90 ± 5 grams) are specified, as is a fixed humidity pre-conditioning. The final specification is that no colored newsprint be included.

The newsprint is ignited with a match, on the left side of the box, about 25 mm from the back and from the seat of the chair. Flames spread over the pile then die down, leaving a mass of smoldering char. The flaming stage typically lasts about two minutes; the smoldering stage can last five minutes or more (the two stages are not cleanly separated). During the flaming stage, flames can extend out both wire mesh sides of the box and up through the slot in the top. These flames are not the only source of heat transferred to the furniture surfaces; the brightly glowing paper char is a good radiator, especially when there is a mix of flaming and smoldering.

## 3) EXAMINATION OF IGNITION SOURCE REPRODUCIBILITY

Since the geometry of the crumpled newspaper is not precisely reproducible, neither the flaming nor the smoldering stages of its combustion are precisely reproducible. This, in turn, implies that the heating effects which this source imposes on the surfaces of the upholstered furniture may not be the same from one test to the next. These heating effects can be quantified in terms of: (1) the area heated, (2) the flux pattern imposed on this area and (3) the duration of this pattern. An ideal ignition source would be completely reproducible in all of these effects so that scatter in igniter behavior would be eliminated as a potential cause of non-reproducibility in upholstery flammability testing.

This part of the study addressed heating effects of the CB 133 ignition source as seen on inert substrates and the reproducibility of these effects. Because of the complex nature of the source and its heating effects, it has not been possible to fully characterize all of these effects. It will be seen, however, that the heat effects this source imposes are not very reproducible, in an absolute sense. The impact of this non-reproducibility can only be fully judged by applying the source to a series of upholstery substrates of <u>marginal</u> ignitability, since the sensitivity to ignition source variability is greatest for these. A broad set of such marginal substrates was not available for use in this study. A set that was more widely varied in its flammability characteristics was utilized for both mock-up and chair studies, as described later.

It is worth noting that the use of inert mock-ups for the characterization of the CB 133 source removes one element of variability. When the newsprint has begun to ignite a combustible substrate, energy feedback from the new flames (mainly radiation) can accelerate the newsprint burning process. This effect can be expected to vary with the nature of the substrate. When the substrate is inert it is minimized.

Flame Extension From CB 133 Source. As a first step in judging the repeatability of the CB 133 ignition source, as well as the potential extent of the heated substrate area, a simple series of video observations was performed. As noted above, this and subsequent measurements of heat effects were performed on inert substrates. These substrates were placed on the CB 133 mock-up frame shown in Fig. 3. The inert back and seat consisted of a 3 mm thick layer of ceramic felt insulation wrapped around sheets of stainless steel (1.6 mm thk). Here the side-arm frames were present but no material was in these frames. A video camera viewed the box (plus a timer and a length reference) from a head-on vantage point so that the amount of flame extension out the wire-covered sides and out of the top slot could be accurately measured.

The results, from a limited number of such tests, proved to be highly transient and variable. Fig. 4 shows the visible flame area extending from the three sides as a function of time in two nominally identical tests. The large flame area shown extending from the top slot in the left part of Fig. 4 was relatively unusual; it was frequently much less. In fact, the top of the box, with its rather small, slotted opening is what forces flames mainly out the sides by blocking the buoyant plume. The flames out the sides thus tend mainly to emerge near the top of the wire covered sides but they can do so with enough momentum to cause flame impingement on the side arms of a chair. (Here the flames passed through the open side arm frames.)

The transient flickering of the flames, which is responsible for the rapid rise and fall of the flame areas, is not a problem; it is part of the natural behavior of buoyant diffusion flames. What is more problematical is that the time-averaged area tends to vary substantially from one test to the next, even though the initial conditions of the tests are nominally identical. Variability of the side wall flame areas implies variable heating of the side arms of a chair. Variability of the top flame area means the heated area on the back of a chair varies. In the limited number of tests of this type, the average deviation of the side wall flame area was as large as ± 65%; for the top flame area it was ± 40%.

Direct assessment of the heated area on the mock-up seat back. The above results are indicative of the degree of ignition source variability but are not very definitive. Ideally one would like to measure the two-dimensional, time-dependent heat flux pattern which this source imposes on all surfaces of the chair. Measurement of such a pattern on even one surface poses a major problem; there is no device available which can provide a continuous, two-dimensional heat flux measurement[1]. This problem was dealt with here in two steps which focussed on one mock-up surface -- the seat back. First, a semi-

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[1] After the completion of this work, it was brought to the authors' attention that a two-dimensional heat flux gage array has been developed in Finland[2]. The array consists of about 20 individual, somewhat rudimentary, total heat flux gages, each with a time response of about 60 seconds.

quantitative "picture" of the heat flux pattern was obtained with the aid of infrared thermography. Second, the actual heat flux impinging on the chair back was "sampled" by placing flux gages at six positions. The infrared thermography is discussed here.

Even though the continuous, two-dimensional heat flux pattern cannot be measured directly, its effects can, at least approximately. A thin sheet of inert material, substituted for the chair back, will heat up in response to impingement of the flux pattern from the ignition source. In the limit of an infinitely thin sheet, the temperature pattern developed in the sheet will be an exact analog of the flux pattern. The thinnest material available for this purpose was a ceramic felt, 0.38 mm thick. The chief drawback in a material this thick is its thermal capacity. It cannot respond with infinite speed to changes in heat flux; cooling is slower than heating. Tests with a gas burner as the heat source indicated that the cooling time of the ceramic sheet (after a period of flame heating) was about 20 seconds. This, in effect, means that the sheet averages the time-dependent heat flux over a period of this magnitude. The local temperature on the sheet no longer directly reflects the instantaneous flux but rather the flux over the last 20 seconds or so. This is acceptable here since the principal goal is to compare flux patterns in successive tests, rather than to infer the flux itself.

Figure 5 is a sketch of the arrangement used to monitor the two-dimensional, time-dependent temperature pattern induced in the sheet of ceramic felt by the ignition source. Note that the sheet is viewed from the back side; this means that the flux pattern is somewhat damped also by conduction through the sheet; gas burner tests indicated that this is a significantly lesser effect than the thermal capacitance effect mentioned above. Lateral heat conduction in the sheet has minimal effect.

The infrared camera indicated in Fig. 5 is an Inframetrics Model 525 imaging infrared radiometer[2]; this device is capable of quantitative measurements of two-dimensional surface temperature patterns, if the surface emissivity is known. It can be thought of as an infrared television camera (with somewhat lower spatial resolution than a normal TV camera); it records on video tape the pattern of emitted radiation (8-12 microns) that results from the temperature pattern in the ceramic sheet. By separately recording two black bodies at known temperatures, one obtains a calibration which relates local brightness on the image to local temperature. Actual temperatures are not of direct interest in the present context, but the software package used to analyze these infrared images automatically converts brightness to temperature; this calibration thus keeps the indicated temperatures realistic. In addition, it is possible to estimate the heat flux that corresponds to the measured temperature by means of a simple heat balance on a local segment of the ceramic sheet.

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[2] Certain commercial equipment is identified in this paper in order to adequately specify the experimental conditions. This does not imply endorsement by NIST nor does it imply the equipment is the best available for the purpose.

A dozen tests of this nature were run and the time-dependent infrared images recorded. The newsprint in all cases was from a local Washington publication and was somewhat heavier than the CB 133 specification; the total weight of five sheets was approximately 105 grams. A conscious effort was made to crumple the paper in a fixed manner for each test.

The infrared video tapes were analyzed with the aid of computer-based infrared image analysis system. This system can grab one to eight video frames (1/30 sec each) and subject them to various forms of quantitative analysis. In the present case eight successive frames were averaged to improve the signal to noise ratio. These frames show only amorphous glowing regions of varied shape which grow and shrink as the ignition source progresses through flaming and smoldering.

A simple way to characterize these images is provided by the histoplot function. The frame grabber digitizes the image, breaking it into a large number of segments or pixels; the brightness of each pixel is quantified with eight bit resolution. Using the calibration from the two blackbodies, mentioned above, the analyzer automatically converts the brightness level of each pixel to an equivalent temperature. A histoplot then displays the number of pixels in the selected image area as a function of temperature. Figure 6 shows the type of result obtained; pixel frequency there is the number of pixels per unit temperature interval. Note that all information on the shape of the heated areas having the various temperature levels is lost in this type of plot. The heated area shapes here, though varied, were not drastically different so that this is not a significant loss.

The results in Fig. 6 are for a fixed number of frames (and therefore a fixed time) after the first visible heating of the ceramic sheet in response to the ignition source. Thus the upper and lower histoplots, derived from two nominally identical tests, should correspond to approximately equal stages in the development of the flaming on the pile of crumpled newsprint. Clearly the resulting temperature patterns on the seat back of the inert mock-up are not equal. Since temperature is directly related to the impinging heat flux from the ignition source, the flux patterns must be unequal as well. Note the region of each plot above 450 °C (shaded) which, from an energy balance using a surface emissivity estimate of 0.7, corresponds approximately to $\geq 4$ W/cm$^2$. The cross-hatched area is a measure of the fraction of the image which is receiving heat fluxes of at least this magnitude. It is obviously much greater in the upper histoplot than in the lower plot. One can repeat such measurements at intervals of 20 to 30 sec (roughly the averaging time of the ceramic sheet, as noted above) throughout the video tapes of a pair of nominally identical tests. The results of such measurements are shown in Table 1. One can see that differences of the order of a factor of two are common. Although not all of the video tapes have been subjected to this tedious form of quantitative analysis, they qualitatively support the conclusion that the area of the seat back subjected to high fluxes by the CB 133 ignition source can vary substantially from test to test.

Heat Flux Measurements at Specific Locations. As noted above, the infrared radiometer results yield only approximate values of the heat flux on the seat back. It is desirable to have accurate flux measurements but these can be obtained only at a limited number of locations. The infrared images were used to infer a reasonable set of locations that would somewhat emphasize the higher flux regions produced by the ignition source. Six total heat flux gages (Medtherm Schmidt-Boelter type) were arrayed in the seat back as shown in Fig. 7. Note that these are water-cooled gages whose sensor surface remains cool; thus they measure the cold-wall flux, i. e., the impinging flux, not the net flux to the wall during heating. The sensor surfaces were flush with the front surface of the ceramic fiber sheet (3 mm thick for these tests); the holes through the sheet were such as to minimize any hot gas flow through them. The gages were re-coated and re-calibrated whenever their black, high emissivity coating was degraded by deposition of condensate from the burning newsprint.

This flux gage arrangement was used to record the flux-time behavior in 5 successive, nominally identical tests with the CB 133 ignition source. Fig. 8 a, b, c shows the range of individual results seen; the other tests results fall within this range of peak flux values. In essentially all cases, the flux behavior at all six locations is qualitatively similar. There is an delay at first as flames spread from the initially ignited area. This is followed by a rapid build-up toward a peak flux that usually occurs at location #2; the value of the peak flux there can vary by a factor of two. The long, slow decay in flux level after the peak is a result of the gradual dominance of smoldering and the attendant shrinkage of the charred newsprint. The highly variable fluctuations on this average rise and fall behavior are probably due mainly to flame flickering and attendant fluctuations in char temperature; the 1/10 second response time of the gages allows them to follow such transients with good accuracy.

The average peak heat flux (taken at position 2) is 7.4 W/cm$^2$ with an average deviation of ±1.3 W/cm$^2$. This average deviation is not excessively large but the range of peak flux values seen in the 5 tests (nearly a factor of two) is disturbingly large. At this same position the average time the flux was above half of its maximum value was 80 ± 15 seconds.

The peak flux levels are quite high relative to gas flames impinging on vertical wall surfaces. There the peak flux is usually in the range from 2½ to 3 W/cm$^2$ [Ref. 3]. Most of the difference is very likely due to the high temperature of the newsprint char and the radiation this can produce. Measurements of the char temperature with an infrared thermometer gave values well over 900 °C (assumed char emissivity of unity); a blackbody of this temperature can emit more than 10 W/cm$^2$. Interestingly, the peak fluxes reported here are also generally higher than those reported in Reference 4 for a wide variety of flaming ignition sources used to test upholstery. The reasons for these differences are unclear but probably involve at least two factors. First, flux gage placement relative to the sources is not the same. Second, the type of flux gage used may not have been the same. According to the manufacturer (Medtherm), Gardon style gages can give lower readings on the same source than Schmidt-Boelter style gages because the surface temperature of the former goes up with increasing flux level.

An alternative way to visualize the kind of heat flux results in Fig. 8 a, b, c is to use them to infer the approximate spatial pattern of flux on the chair back. This pattern is obviously a function of time and the six flux gages do not come close to fully defining this pattern at any given time. However, it is informative to use these limited results to obtain, by linear interpolation, the approximate positions of the lines of constant flux level; Fig. 9 a, b are obtained in this manner from Fig. 8 a and c, respectively, at a time when each gage is near its maximum reading[3]. The lines of constant flux are, of course, closed loops but there is insufficient data from the six gages to infer the position of the remaining part of each loop. Inspection of this Figure implies that the area enclosed by the lower flux levels did not vary greatly between these two tests which were extremes with regard to peak flux variation. The area enclosed by the higher flux levels ($\geq 5$ W/cm$^2$) does vary considerably.

Comparison with heat flux from accelerants. To give some perspective to the peak fluxes that the CB 133 source imposes on a chair back, a few tests were run with organic liquid pool fires in a pan on the chair seat. This was intended to represent approximately the type of ignition source that might result from the pouring of an accelerant on the chair seat. The pan was made from stainless steel; it was 30 cm. square by 1.9 cm deep. It was centered on the chair axis with its back edge 1.3 cm from the seat back. This pan rested inside a second, wider but shallower pan intended to catch any liquid spillover. Both ethanol and octane were burned (400 cc) in separate tests. Both types of fuel yielded rapidly fluctuating flames and, thus, fluctuating heat fluxes. Ethanol combustion yields very little soot and its flames are thus relatively weak radiators; the average peak flux was approximately 4 W/cm$^2$. Octane, a hydrocarbon found in gasoline, is a much stronger soot former; the average peak flux was approximately 8 W/cm$^2$. While the configuration used here cannot be said to closely represent any realistic arson situation, the results do suggest that the CB 133 source is not out of line with what might be encountered in such situations, at least with regard to peak flux level (heat exposure area and duration will vary with the amount and pattern of a liquid accelerant spill).

Comparison with upholstery substrate ignition data. Another type of perspective on these heat flux data can be obtained by comparing them to the ignition data in Fig. 10 taken from Ref. 5. Those ignition data were obtained on the indicated fabric/substrate combinations in the Cone Calorimeter; thus the heat flux was radiative and essentially uniform over the 10 cm square sample face. The data largely covered the range of commercial upholstery materials in the year they were obtained (1983). Note that the flux scale is in kW/m$^2$; 10 kW/m$^2$ equals 1 W/cm$^2$. Thus a heat flux of 2 W/cm$^2$ is sufficient to ignite this whole spectrum of upholstery materials in 45 seconds or less. The CB 133 source greatly exceeds these ignition conditions. Thus it is virtually assured of igniting virtually any flammable upholstery material with which its flames are in contact. The area first ignited can be expected to be tens of square centimeters. Assured ignition of this area does not necessarily mean assured spread of flames beyond this area, especially after the ignition source dies down. Necessary conditions for continued spread of

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[3] The time chosen is that when the gage in the number two position is about at its maximum. Most of the other gages are peaking at about the same time.

flames on upholstery materials have not yet been derived. This flame spread situation is analogous to, but more complex than, the problem of continued upward spread on vertical walls, which has been addressed with some success [6,7].

## 4) SIMULATION OF CB 133 SOURCE WITH A GAS BURNER

The results in the preceding Section indicate that the CB 133 paper-based ignition source varies significantly in the area it subjects to high heat fluxes, in the level and duration of these heat fluxes and in its tendency to heat the side arms of a chair. As was noted above, the impact of this variability will be most fully felt only on marginally-failing upholstery where it would lead to non-reproducible results. A suitable array of such upholstery was not available and so a full assessment of the impact of this ignition source variability has not been made.

A gas burner is an inherently more reproducible heat source because the flames are anchored to a series of jets arrayed in a fixed geometry. A gas burner which closely mimics the CB 133 source would be highly desirable for this reason. Designing a burner which can do this is not a simple task, however. The characterization above of the CB 133 source is incomplete, so the target is not fully defined. Moreover, gas burner flames lack the strong radiation contribution from the glowing paper char in the CB 133 source.

In spite of these difficulties, a more reproducible gas burner source which simulates the CB 133 source was pursued. As will be seen, the result is partially, though not fully, successful.

A gas burner cannot be made to mimic the complex, time-varying spread of flames over crumpled paper, followed by a transient glowing char. Instead an effort was made to mimic some of the heat flux characteristics discussed above and to place heat on the same surfaces (seat back, horizontal seat surface, side arm surfaces). Since measurements were not made on any but the seat back surface, the target is well-defined only there. The check for comparability thus has been in terms of the net result of application of the two different sources. Ideally, the net result in terms of the burning behavior of an item of upholstery would be the same for either source. The measure of burning behavior chosen here is the rate of heat release curve as the item burns; this is one of the most important factors in measuring the hazard represented by a burning object[5]. Assurance of complete comparability again requires an array of marginally-failing upholstery, however, which was not available. Comparability was tested here first by examining heat flux levels from a gas burner (seat back only) and then by comparing rate of heat release results (CB 133 source and the gas burner) with a series of upholstery mock-ups and chairs which covered a broad spectrum of flammability. The broad spectrum of materials was chosen in accord with other goals in the overall furniture flammability study of which this work was a part.

Heat Flux Characteristics of Gas Burner. Development of the gas burner proceeded in stages; it began with the burner developed by S. Ames at the British Fire Research Station[8]. That burner is T-shaped with a series of 1 mm dia. holes that send flame jets both straight down and straight out from the cross bar of the T. The final burner design used here retained this same arrangement of holes in this region so measurements on the T-burner are relevant here.

The Ames source was tested in the same inert mock-up configuration described above using the flux gage placement indicated in Fig. 11. The burner placement relative to the mock-up surfaces was set with spacers at 50 mm out from the seat back and 25 mm up from the horizontal seat surface; the burner was centered on the mock-up seat. This placement brings the forward facing gas jets into close proximity to the lowest heat flux gage (see Fig. 11). The data in Fig. 11 are for a flow rate of 6 liters/min. of propane. The average flux at each gage position is shown along with the linearly interpolated positions of specific flux levels. The flux is actually fluctuating significantly at each gage location (up to ± 20-25% with a rough periodicity of 10-15 sec.) due to the flickering nature of the gaseous diffusion flame. Gas jet impingement is probably why this source is capable of producing an incident flux over 8 $W/cm^2$ on the lowest gage. Propane is a moderate soot former but the flame thickness with this source is not as great as it was with the liquid octane in the 30 cm pan. Thus it is probable that this high flux comes from enhanced convection (jet impingement) rather than mainly from radiation, as was the case with octane and with the CB 133 source.

Comparison of Fig. 11 with either heat flux pattern in Fig. 9 reveals differences and similarities. Obviously the shapes of the iso-flux lines are different but this is of little consequence. In both Figures there is a tendency for there to be small areas of high flux and larger areas of lower fluxes. The actual areas enclosed by high fluxes in Fig. 11 are not resolved by the limited measurements; those areas in Fig. 9 vary from test to test, as was pointed out before. From this limited comparison on one heated surface it appears that the two sources are not greatly dissimilar.

This T-burner design was modified to more closely mimic the CB 133 source. The goal was to increase the heated chair seat area and to direct flames also toward the side arm positions. Side arm involvement is believed to be an important contributor to persistence of flaming on the upholstery after the ignition source has died down or been removed. The relatively favorable radiative view factor between two flaming surfaces at a right angle to each other should help assure their continued burning.

The final version is shown in Fig. 12. The "top" of the burner, as seen on the left side of Fig. 12 is identical to the Ames T-burner and the gas flow emitted from the holes in this section is about equal to the 6 l/min. value used above; thus the data in Fig. 11 are pertinent to this final version. One sees in Fig. 12 that the ends of the T have been extended to form a square ring whose outer dimensions are equal to those of the CB 133 box. Along these additional lengths of tube gas jets are directed inward/downward to ignite the full area enclosed by the ring. Groups of jets on each side also provide flames that can preheat and perhaps ignite the sidearms of a chair; these are analogous to but not identical to the flames coming out the mesh sides of the CB 133 box. Placement is the same as the T-burner.

A question not yet addressed for these gas flame igniters is that of the appropriate gas flow rate and flame duration. Flame duration was chosen on the basis of the CB 133 behavior. Recall that at the flux gage position yielding the highest heat fluxes (position 2 in Fig. 7), the average time the flux was above half of its maximum value was 80 sec. This time was chosen as the gas flame exposure time. Given this it is desirable that the total heat evolved in the gas flame during this time be comparable to the total heat from the CB 133 source (over its entire burn time). For 100 grams of dry newsprint the estimated total heat release is 1.3 megajoules; this leads to a flow rate for propane of about 12 ℓ/min. These conditions of gas flow and flame duration are not necessarily the optimum for simulating the CB 133 source but they are the only conditions used in the comparison tests described below.

## 5) COMPARISON OF IGNITION SOURCES ON MOCK-UPS AND FULL-SCALE CHAIRS

The rate of heat release response of both fabric/cushion mock-ups and full scale chairs was measured in the NIST Furniture Calorimeter facility. Each combination of materials was ignited, in separate tests, by the CB 133 source and by the gas burner employed as described above. The material combinations are given in Table 2; further details of these can be found in Ref. 9.

Upholstery Mock-ups. Seven combinations of these materials were investigated in mock-up upholstered cushion form. The material combinations were based upon two foams, melamine-treated polyurethane foam and California 117 polyurethane foam, a fiberglass interliner, and two fabrics, nylon and wool. The material combinations investigated were A through F, plus K, in Table 2; the most flammable (polyolefin) and least flammable (PVC) fabrics were not included. Note that combinations A-B, C-D and E-F differ only in the presence or absence of the fiberglass interliner. The combination A-K differs only in the type of foam.

A single furniture manufacturer supplied the fabrics, foams for the mock-up tests and chairs for the full-scale tests.

The mock-up cushions and the mock-ups themselves were assembled in accord with Ref. 1, using the frame shown in Fig.3; the foam blocks were 70 cm square by 10 cm thick. Four cushions were used in each mock-up providing a seat, a back and two side arms. The two vertical cushions forming the side arms extended down past the full depth of the seat cushion. The vertical back seat cushion sat atop the horizontal seat and was wired to the metal frame to hold it in place.

Duplicate tests were run with each of the two ignition sources for a total of 28 mock-up tests. The gas burner was placed as described above and run with 12 liters/min. of propane for 80 sec. It was removed at the end of this interval. The CB 133 box remained in place throughout a test, as per the CB 133 test protocol.

Table 3 summarizes the salient features of the results for the seven mock-up combinations. The total heat release and the percent weight loss columns both give an overall picture of the consequences of the igniter application. From these one sees that there was a variety of behavior exhibited by the various material combinations as elicited by the two igniters, from ignition resistance to total consumption.

Two of the combinations, B and K, were relatively resistant to both types of ignition source, however, the CB 133 source yielded a late-developing fire with one of the K mock-ups (see time of peak heat release).

Late-developing fires in the mock-up tests, i.e., those which develop many minutes after the igniter flames have died out, are problematical with regard to interpretation. In some, but not all, cases they seem to be due to the mock-up configuration which leaves part of the back of the foam block exposed. Combination D, which incorporates a flammable nylon fabric on top of a fiberglass liner poses conditions susceptible to late ignition. The nylon burns slowly but continually until the flames reach the area of the back of the cushion which is not protected by the fiberglass. Curiously, though the same sequence was initiated with combination D by both the CB 133 source and by the gas burner, only the former source led to foam involvement and a relatively large fire. The disparity in ignition consequences for combination D, though reproducible, seems dependent on peculiarities of the mock-up.

The late-developing fire in one test of combination K, mentioned above, did not involve slow flame spread around a barrier layer. Rather, there seemed to be some interaction between the substrate and the smoldering newspaper char which grew slowly into an extensive late fire. The fact that this occurred in only one of the CB 133 igniter tests is an indication of irreproducibility of that source.

Certain material combinations yielded fairly comparable rate of heat release curves for both igniter types; these included combinations A, E and F. What these materials heve in common is that, in these tests, flames ignite and spread readily over the material while the igniter flame is present (persisting after it dies). In the limit of a material highly prone to such behavior, flames would spread away from the igniter and become independent of it early in the ignition exposure and the response of the material would become insensitive to the igniter characteristics. Thus, comparable heat release rate curves for such flammable combinations are reassuring in that they indicate no unexpected new phenomena have entered in but this comparability does not prove ignition source equality.

Figure 13 shows sets of rate of heat release curves for three of the materials combinations[4]. The upper and middle sets show examples of good comparability; the lowest set, for combination C, reveals significantly different behavior, dependent on the ignition source. With combination C the CB 133 source seemed more readily able to ignite the inner surface of the sidearms of the mock-up and the intensity of the fire on the seat cushion, early in the test, was greater. The net result was an earlier, more intense fire.

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[4] It is worth noting that the heat from the ignition sources is generally small on the scale of the heat release rate curves; they are about 15 kW.

The differences in rate of heat release behavior, while seen with only a limited number of the material combinations in the mock-ups, all are such as to indicate that the gas burner is a somewhat less severe ignition source. Since some of the differences seem possibly to be due to the mock-up configuration itself, it is important to examine also ignition source comparisons made with actual chairs.

Full Scale Chairs. Upholstered chairs were specially ordered from a commercial manufacturer in material combinations A through J (see Table 2). All chairs had the same geometry, as shown in Fig. 14. The chair consists of a solid hardwood frame, with foam padded arms, foam block seat and seat back. No cotton or polyester batting wraps were utilized in the construction of these chairs. The support system consists of a custom coil foundation. The two foam block cushions can be physically removed from the chair: the back cushion, 57 cm wide, 36 high and 12 cm thick, and the seat bottom cushion, 57 cm wide, 66 cm long and 12 cm thick.

The combinations utilizing the fiberglass interliner required special assembling. The interliners of the back and seat bottom cushions were sewn with fiberglass thread to assure that the thread would not melt during exposure to the ignition source. The sewing of the liners with the fiberglass thread was done at the Center for Fire Research. The stitches were sewn at approximately 7 stitches/2.5 cm on a sewing machine. In contrast to the situation with the mock-ups, the chair cushions were totally enclosed by the fiberglass liner material. The chair assembly consisted of a foam sheet placed directly onto the chair frame and stapled into place. If a fire barrier was utilized, the fiberglass interliner was placed on top of the foam and attached to the chair frame with the use of a staple gun. Last, the selected fabric was secured to the chair frame. Thus, all exposed surfaces of the chair were encased by the fiberglass interliner.

Because of the limited number of chairs available in this part of the program, only a single test was run in our furniture calorimeter facility with each igniter in each chair combination. The issue of repeatability is thus left unanswered.

It should be noted that the width of the chair seat is significantly less than that of the mock-up seat. This can be expected to change the heat flux to the inner surface of the side arms. It is likely that the extent of the change depends on which ignition source is used. The flux to the side arms is a mix of radiation and convection. Unless that mix is the same for both sources, and is produced by geometrically comparable hot zones, it is unlikely that the flux will vary in the same way with distance from the source. This illustrates the considerable difficulty inherent in attempting to mimic the CB 133 source with a gas source.

Table 4 summarizes the main features of the results with the chair tests. Once again the more material combinations yielding early ignition and flame spread gave good comparability in overall behavior between the two ignition sources. These include combinations A, C, E and J; Figure 15 includes the heat release curves for combination E. It is interesting to note that combination C, which gave a significant difference between ignition sources when tested in the mock-up form did not do so in the chair form. In the chair both igniter types gave very similar slowly-developing fires analogous to that seen with the gas burner on the mock-up of this material.

Combination B gave comparable behavior for both igniter types; only minimal fires developed for both. Combination I gave late-developing fires with both igniters; the fires were somewhat different in intensity (peak heat release rate) and occurred at differing times. Since late-developing fires are subject to some randomness due to their marginal occurrence, this amounts to fairly good comparability for combination I.

Combinations D and H, both of which yielded only weak fires in these tests, show what appear to be significant differences with the two ignition sources (see Fig. 15). In the case of combination D, the gas burner gave a lower peak heat release rate and a lesser total heat release. Note that the fires with both of these material combinations were not very severe. Note that combination D gave two late-developing fires when subjected in mock-up form to the CB 133 source. The fact that this did not happen in the chair configuration (where all foam surfaces were fully covered with fiberglass) supports the idea, suggested above, that the open area on the back of the mock-up cushions was responsible for the late fires there.

Combination H is the one exception to the general trend seen here in which the CB 133 source generally gave a more severe fire for material combinations showing igniter-dependent behavior. This combination was not tested in mock-up form. The lesser severity of the fire with the CB 133 source in the one chair test of this type is clearly due to the fact that only one side arm ignited, not both, as with the gas burner. The repeatability of this result is undetermined.

In contrast to combination C which gave good comparability between igniters in the chair form but not in the mock-up form, combination F did the opposite. The poor igniter comparability in the chair form was mainly due to a late-developing fire with the CB 133 ignition source but even during the igniter flaming period the CB 133 source elicited more than twice as much heat from the substrate. The reason for this is not known but may be a consequence of the variability of the CB 133 source.

Finally it is noted that combination G, which was not tested in mock-up form, gave a late-developing fire only when subjected to the CB 133 source in chair form. Thus, both combinations F and G add to the indication that the gas burner is a somewhat less severe igniter than the CB 133 igniter.

## 6) DISCUSSION

The measurements reported here indicate that the CB 133 newspaper-based ignition source is subject to appreciable variability in its effects on the side arms of a chair, in the area of the seat back that it subjects to high heat fluxes and in the level and duration of the peak flux on the chair back. Nevertheless, there will be many upholstery combinations for which this variability is irrelevant, either because these combinations are so flammable or so non-flammable that the changes in ignition source behavior elicit no significant difference in overall response. For upholstery material combinations in the middle this source variability can be expected to lead to non-reproducible results and the consequent need for repeated tests (or potentially deceptive results from single tests).

The gas burner tested here attempts to distribute heat on the surfaces of a chair or mock-up in a manner similar to the CB 133 source. Unfortunately, in this program measurements could be made only on the chair back. This is the surface of most rapid spread so it is important to match the heating characteristics on this surface. The gas burner does this reasonably well. However, the comparison testing of the two sources, both on mock-ups and on actual chairs, generally (with one exception) implies that the gas burner is a less severe ignition source overall. For marginally ignitable substrates, which are those most sensitive to igniter variation, the gas burner in some cases yielded a lesser total heat evolution than the CB 133 igniter and, in other cases, no sustained ignition at all, whereas the CB 133 igniter yielded late-developing fires. The comparisons do not suggest major differences but differences which are significant nonetheless.

It is worth noting that, while the gas burner is a more reproducible ignition source, it must be properly maintained. The gas jets are emitted from numerous small holes (1 mm dia.) which could be partially blocked by soot or other solid/liquid combustion products. The holes must be cleaned after every test with a rod of material which will not alter the hole size.

The gas burner could presumably be made more comparable to the CB 133 source. Two simple ways to increase its severity are to increase the gas flow rate and to increase the burning duration. The detailed behavior seen in some of the tests suggests, however, that the needed changes are more subtle. The flux to the chair seat may be too low and the radiative component of the heat incident on the chair surfaces may be too low, as well, leading to a substantially different flux versus distance dependence than that given by the CB 133 igniter. Both of these issues could be addressed simultaneously by going to a gas with a stronger sooting potential, but it is not clear that true comparability could be achieved this way. In any event, comparability can only be firmly demonstrated by undertaking a large chair testing program utilizing a variety of marginally ignitable substrates in several geometries.

## Acknowledgements

The authors would like to acknowledge helpful discussions with W. Parker. The chair test data were obtained by K.-M. Tu and W. Parker.

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## Table 1
## Measured Area in Histograms From Infrared Tape Having a Temperature[5] Above 450°C

| Frame[6] | Area in Test 1 ($cm^2$) | Area in Test 2 ($cm^2$) |
|---|---|---|
| 4 | 7.8 | 15.0 |
| 5 | 8.3 | 15.3 |
| 6 | 14.9 | 16.9 |
| 7 | 16.4 | 8.1 |
| 8 | 11.9 | 6.4 |
| 9 | 12.0 | 6.6 |

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[5] A temperature of 450 °C corresponds approximately to a heat flux of 4 $W/cm^2$.

[6] The frames are about 20 seconds apart and each "frame" is the average from eight successive video frames, each 1/30 sec. long.

Table 2
Material Combinations Used in Igniter Comparison Study

| Designation | Materials[7] |
|---|---|
| A | Wool fabric / Calif. 117 PU foam[8] |
| B | Wool fabric / Fiberglass liner / Calif. 117 PU foam |
| C | Nylon fabric / Melamine-PU foam[9] |
| D | Nylon fabric / Fiberglass liner / Melamine-PU foam |
| E | Nylon fabric / Calif. 117 PU foam |
| F | Nylon fabric / Fiberglass liner / Calif. 117 PU foam |
| G | PVC fabric[10] / Calif. PU foam |
| H | PVC fabric / Melamine-PU foam |
| I | Polyolefin fabric / Fiberglass liner / Calif. 117 PU foam |
| J | Polyolefin fabric / Calif. 117 PU foam |
| K | Wool fabric / Melamine-PU foam |

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[7] Each time a material is referred to, it is the same material, i.e., the nylon is always the same nylon, the wool is the same wool, etc.

[8] This polyurethane foam passes the small flame ignition resistance test specified in California Technical Bulletin 117.

[9] This is a 3 $lb/ft^3$ polyurethane foam containing melamine as a flame retardant.

[10] This is a special, flame resistant grade of PVC fabric.

## TABLE 3. MOCK-UP TEST RESULTS

| Fabric/Liner/Foam "Designation" | Ignition Source | Moving Avg. Peak Heat Release[1] (MW) | Time Of Peak Heat Release (sec) | Total Heat Released (MJ) | Percent Weight Loss |
|---|---|---|---|---|---|
| Wool-California 117<br>"A" | CB 133[2] | 0.59 | 245 | 105 | 92 |
| | " | 0.74 | 280 | 108 | 92 |
| | Burner[3] | 0.63 | 210 | 97 | 87 |
| | " | 0.55 | 200 | 58 | 84 |
| Wool-Fiberglass<br>California 117<br>"B" | CB 133 | 0.07 | 110 | 21 | 2 |
| | " | 0.01 | 90 | 2 | 0 |
| | Burner | 0.07 | 75 | 17 | 1 |
| | " | 0.01 | 75 | 2 | 1 |
| Wool-Melamine<br>"K" | CB 113 | 0.15 | 1020 | 92 | 41 |
| | " | 0.01 | 190 | 1 | 1 |
| | Burner | 0.03 | 80 | 3 | 1 |
| | " | 0.05 | 100 | 8 | 1 |
| Nylon-California<br>"E" | CB 113 | 0.78 | 195 | 151 | 96 |
| | " | 0.85 | 185 | 147 | 96 |
| | Burner | 0.69 | 140 | 121 | 99 |
| | " | 0.71 | 150 | 121 | 95 |
| Nylon-Fiberglass<br>California 117<br>"F" | CB 133 | 0.73 | 320 | 162 | 100 |
| | " | 0.61 | 290 | 125 | 88 |
| | Burner | 0.74 | 300 | 127 | 93 |
| | " | 0.69 | 310 | 130 | 100 |
| Nylon-Melamine<br>"C" | CB 133 | 0.26 | 425 | 114 | 56 |
| | " | 0.27 | 370 | 124 | 56 |
| | Burner | 0.17 | 520 | 66 | 41 |
| | " | 0.14 | 530 | 54 | 35 |
| Nylon-Fiberglass<br>Melamine<br>"D" | CB 133 | 0.36 | 1620 | 128 | 92 |
| | " | 0.37 | 950 | 120 | 80 |
| | Burner | 0.16 | 200 | 147 | 13 |
| | " | 0.14 | 210 | 59 | 13 |

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[1] Moving average calculated over a 60 second period to reduce noise level.

[2] CB 133 newspaper ignition source.

[3] Propane gas burner ignition source.

TABLE 4. FULL SCALE CHAIR TEST RESULTS

| Fabric/Liner/Foam "Designation" | Ignition Source | Moving Avg. Peak Heat Release[1] (MW) | Time of Peak Heat Release (sec) | Total Heat Released (MJ) | Percent Weight Loss |
|---|---|---|---|---|---|
| Wool - California 117 "A" | CB 133[2] | 1.15 | 310 | 459 | 85 |
| | Burner[3] | 1.11 | 310 | 448 | 89 |
| Wool- Fiberglass - California 117 "B" | CB 133 | 0.03 | 100 | 7.9 | 0 |
| | Burner | 0.03 | 79 | 4.3 | 0 |
| Nylon - California 117 "E" | CB 133 | 1.50 | 361 | 460 | 92 |
| | Burner | 1.52 | 313 | 462 | 89 |
| Nylon - Fiberglass - California 117 "F" | CB 133 | 0.40 | 1870 | 400 | 81 |
| | Burner | 0.11 | 100 | 18.3 | 4 |
| Nylon - Melamine "C" | CB 133 | 1.15 | 848 | 499 | 87 |
| | Burner | 1.16 | 831 | 446 | 91 |
| Nylon - Fiberglass - Melamine "D" | CB 133 | 0.09 | 129 | 30 | 2 |
| | Burner | 0.04 | 154 | 39 | 3 |

TABLE 4 CONT"D

| Fabric/Liner/Foam "Designation" | Ignition Source | Moving Avg. Peak Heat Release (MW) | Time of Peak heat Release (sec) | Total Heat Released (MJ) | Percent Weight Loss |
|---|---|---|---|---|---|
| PVC Fabric - California 117 "G" | CB 133 | 0.72 | 1830 | 422 | 84 |
| | Burner | 0.16 | 69 | 12.6 | 3 |
| PVC Fabric - Melamine "H" | CB 133 | 0.08 | 61 | 6.3 | 1 |
| | Burner | 0.14 | 51 | 7.5 | 1 |
| Polyolefin - Fiberglass - California 117 "I" | CB 133 | 0.47 | 1690 | 396 | 82 |
| | Burner | 0.67 | 4430 | 434 | 89 |
| Polyolefin - California 117 "J" | CB 133 | 1.72 | 230 | 494 | 89 |
| | Burner | 1.65 | 222 | 436 | 93 |

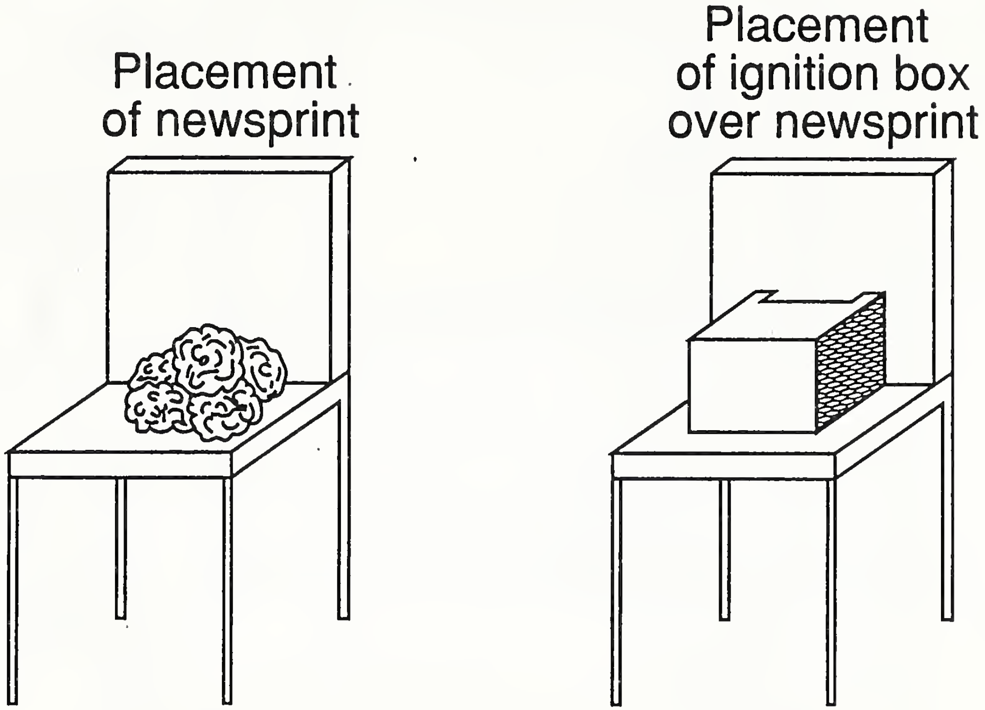
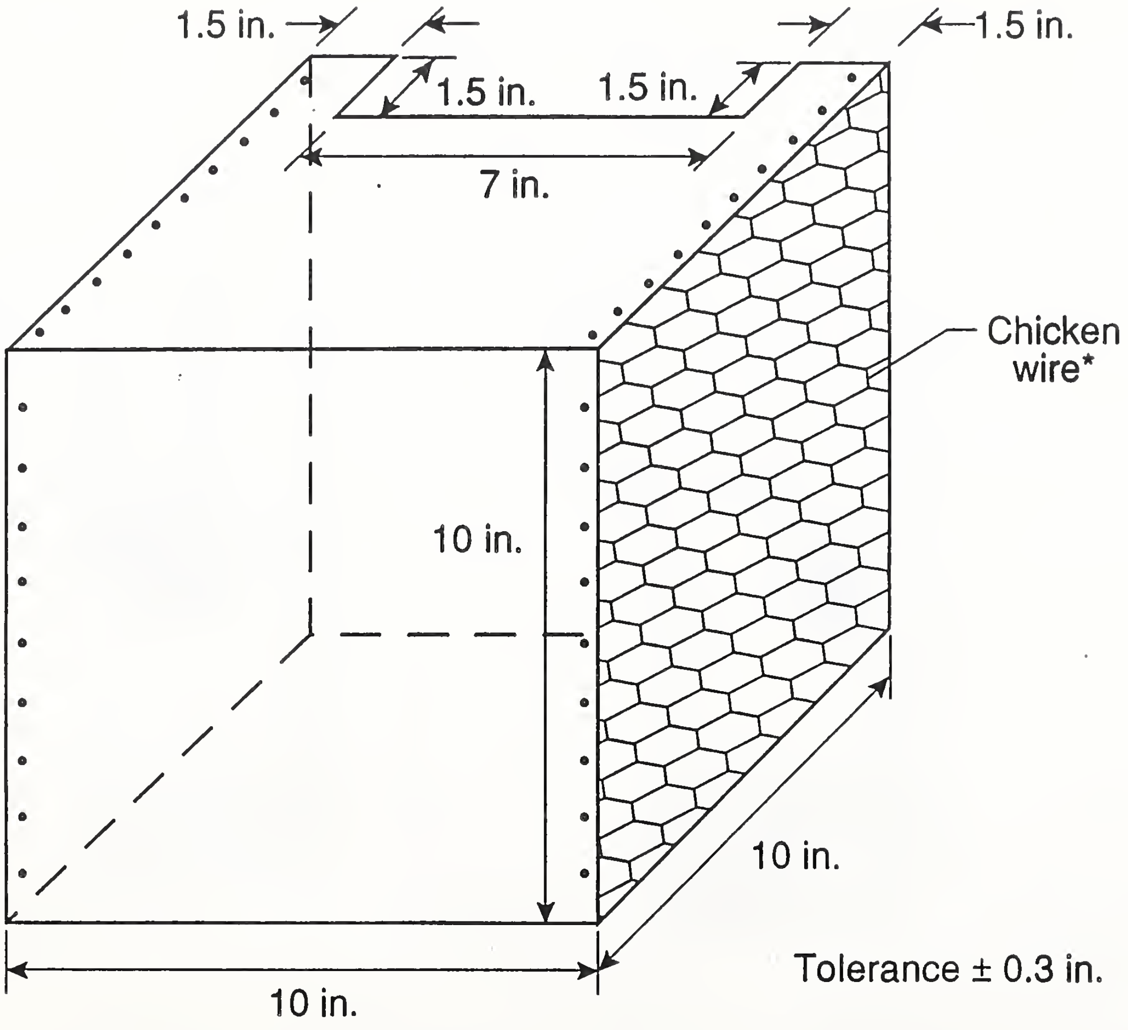


Fig. 1 Configuration and placement of CB 133 igniter.



* Two opposite side are chicken wire;
Bottom and back are open

Fig. 2 Details of metal box surrounding crumpled newsprint in CB 133 ignition test procedure. The two sheet metal surfaces are 0.063 mm thick.

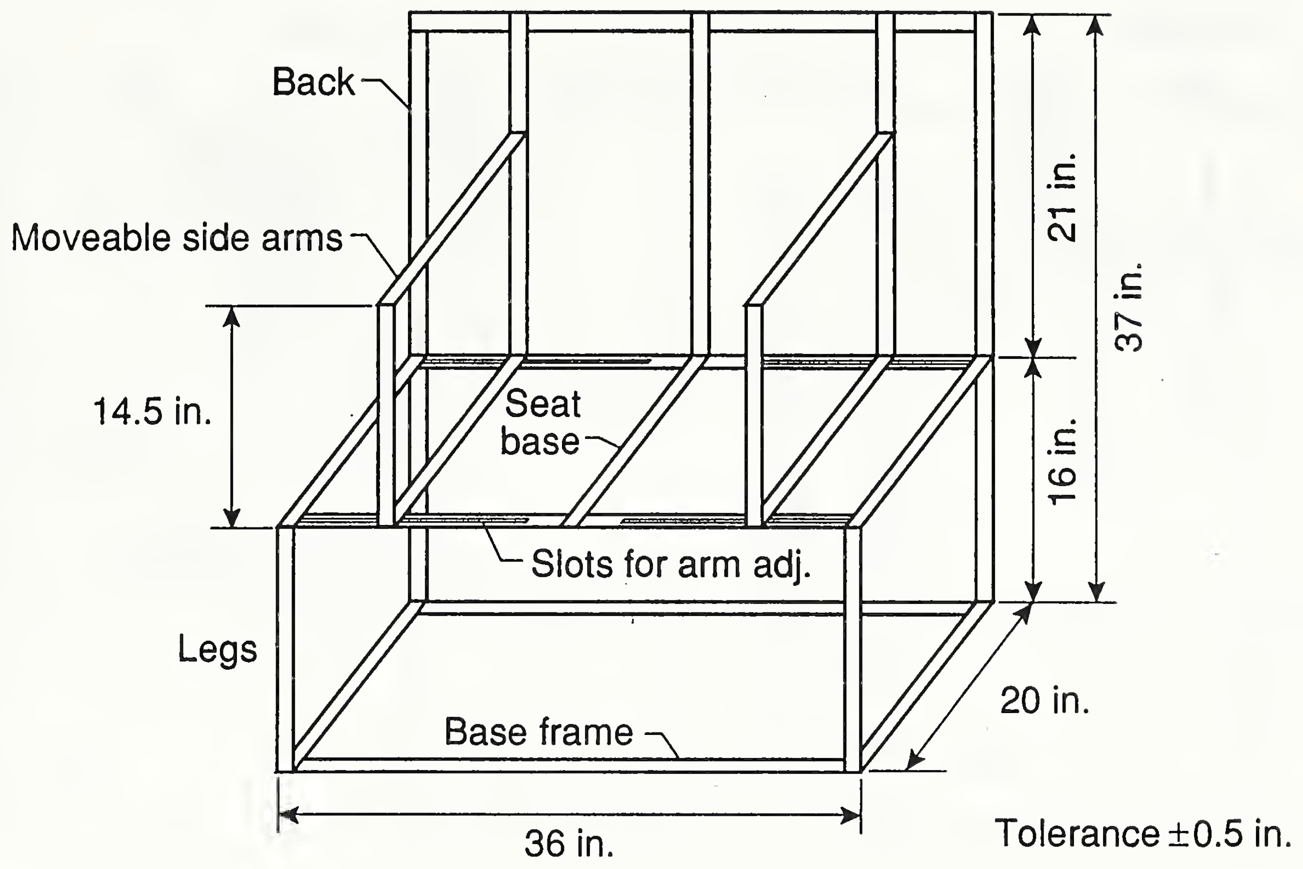


Fig. 3 Chair mock-up frame specified by CB 133 ignition test procedure.

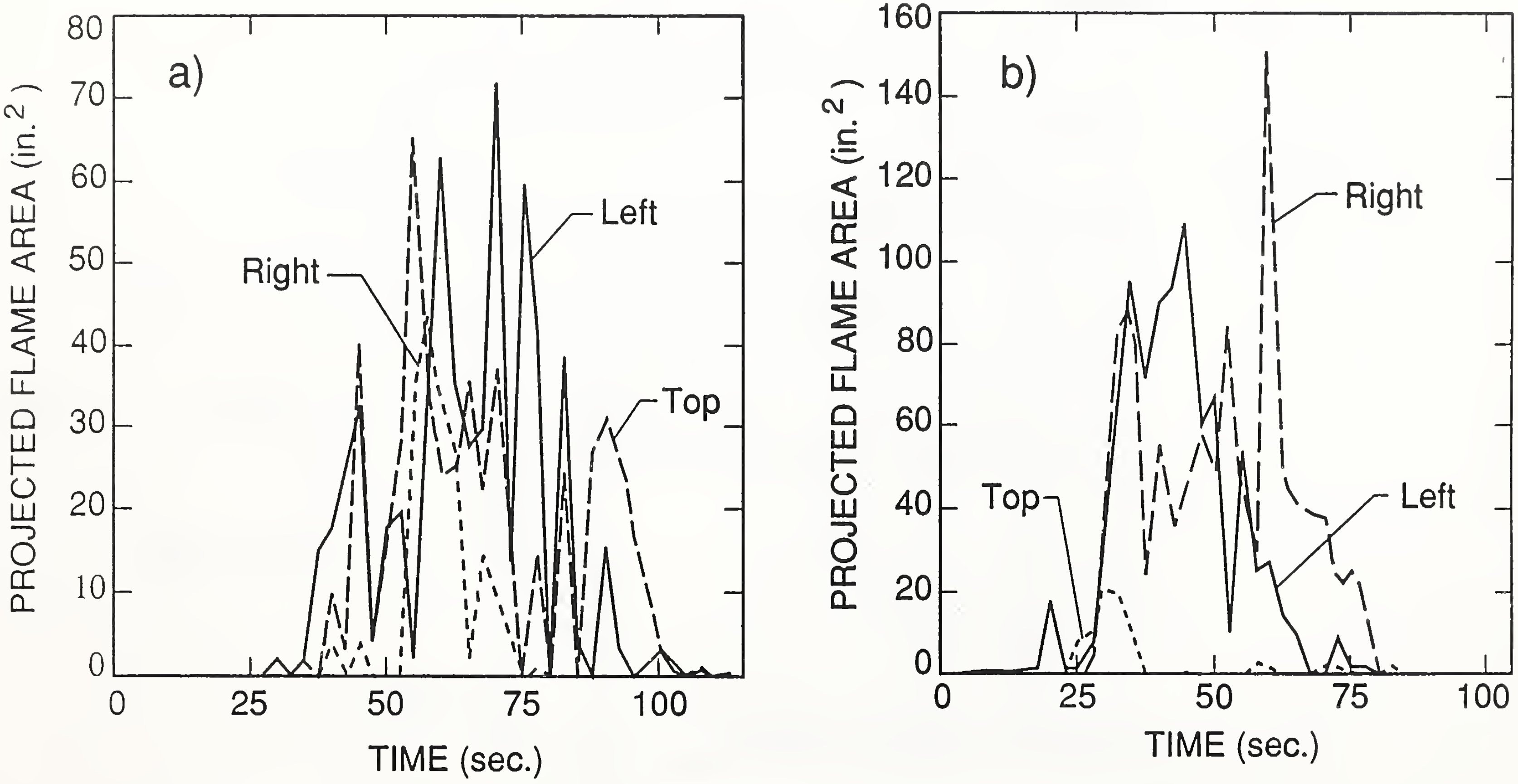


Fig. 4 Projected flame area extending out three surfaces of CB 133 metal box as flames progress from ignition through extinction. Graphs (a) and (b) are from nominally identical tests.

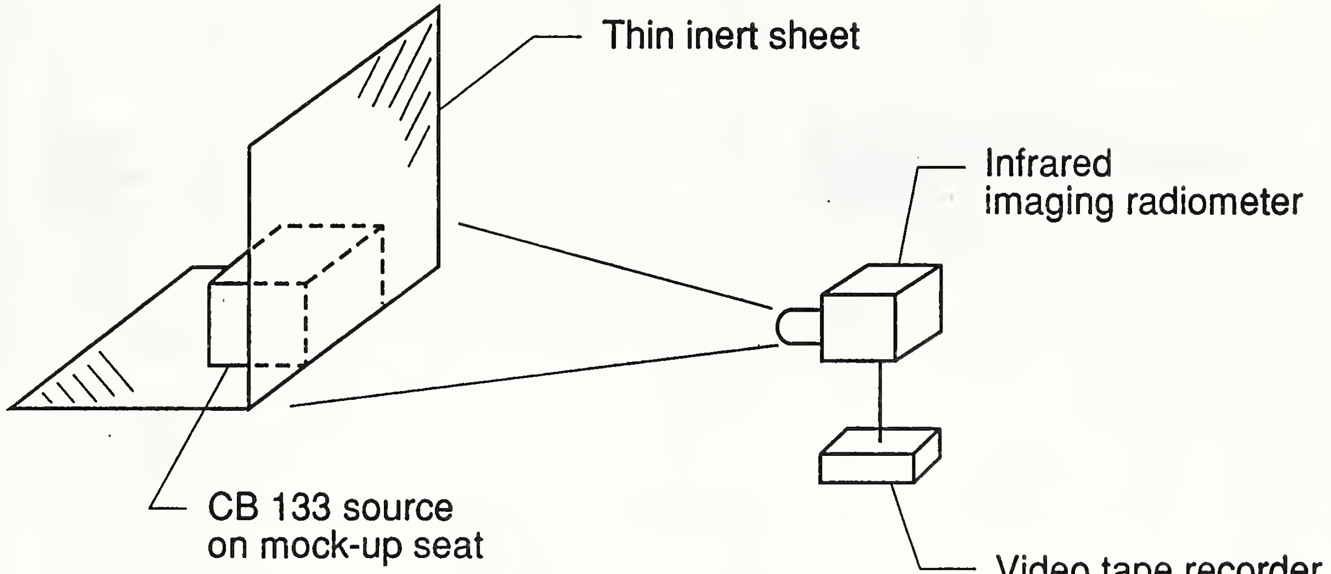
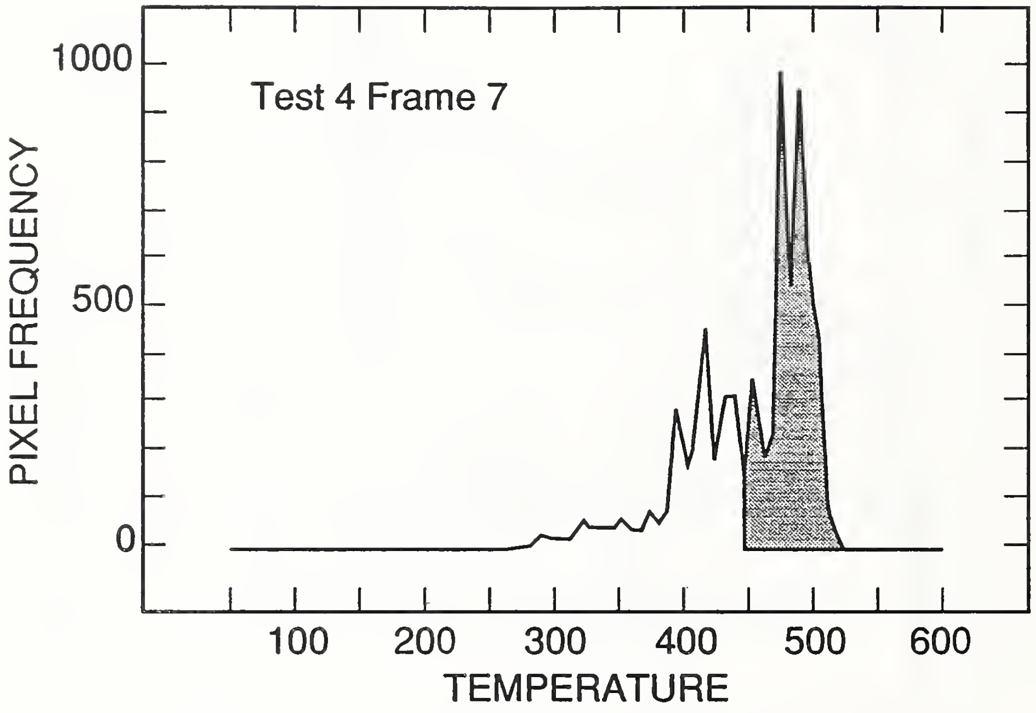


Fig. 5 Schematic of set-up used to obtain infrared images of temperature pattern produced on inert seat back by CB 133 igniter.



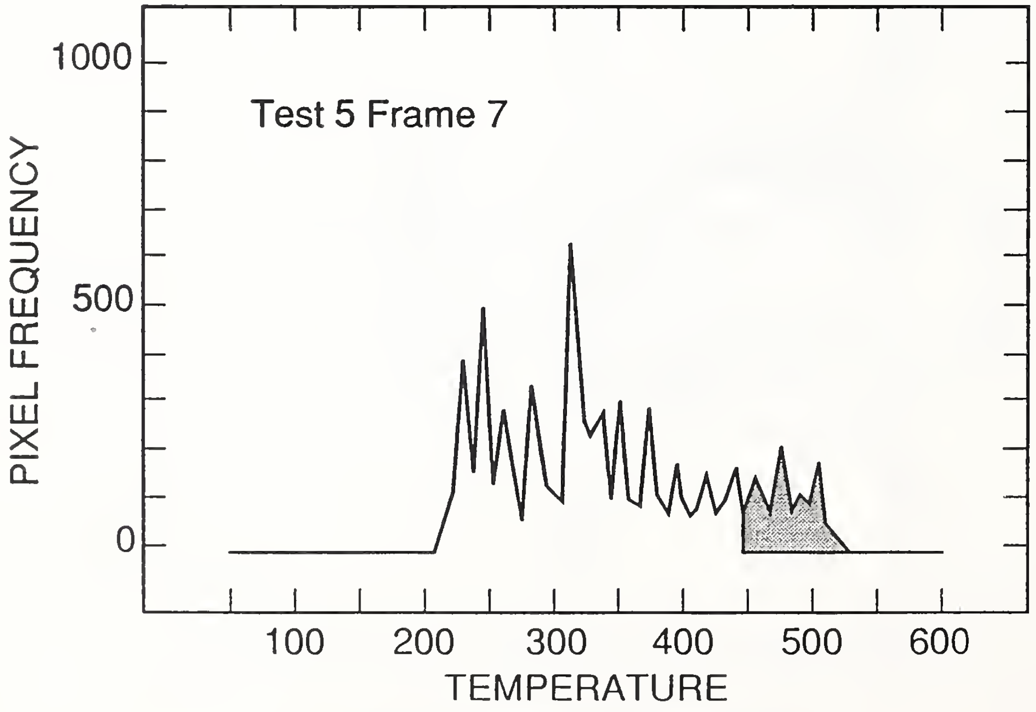


Fig. 6 Histoplots obtained from infrared images at comparable times in nominally identical tests with CB 133 igniter. Shaded area is a measure of the area on the seat back subject to heat fluxes above 4 W/cm$^2$.

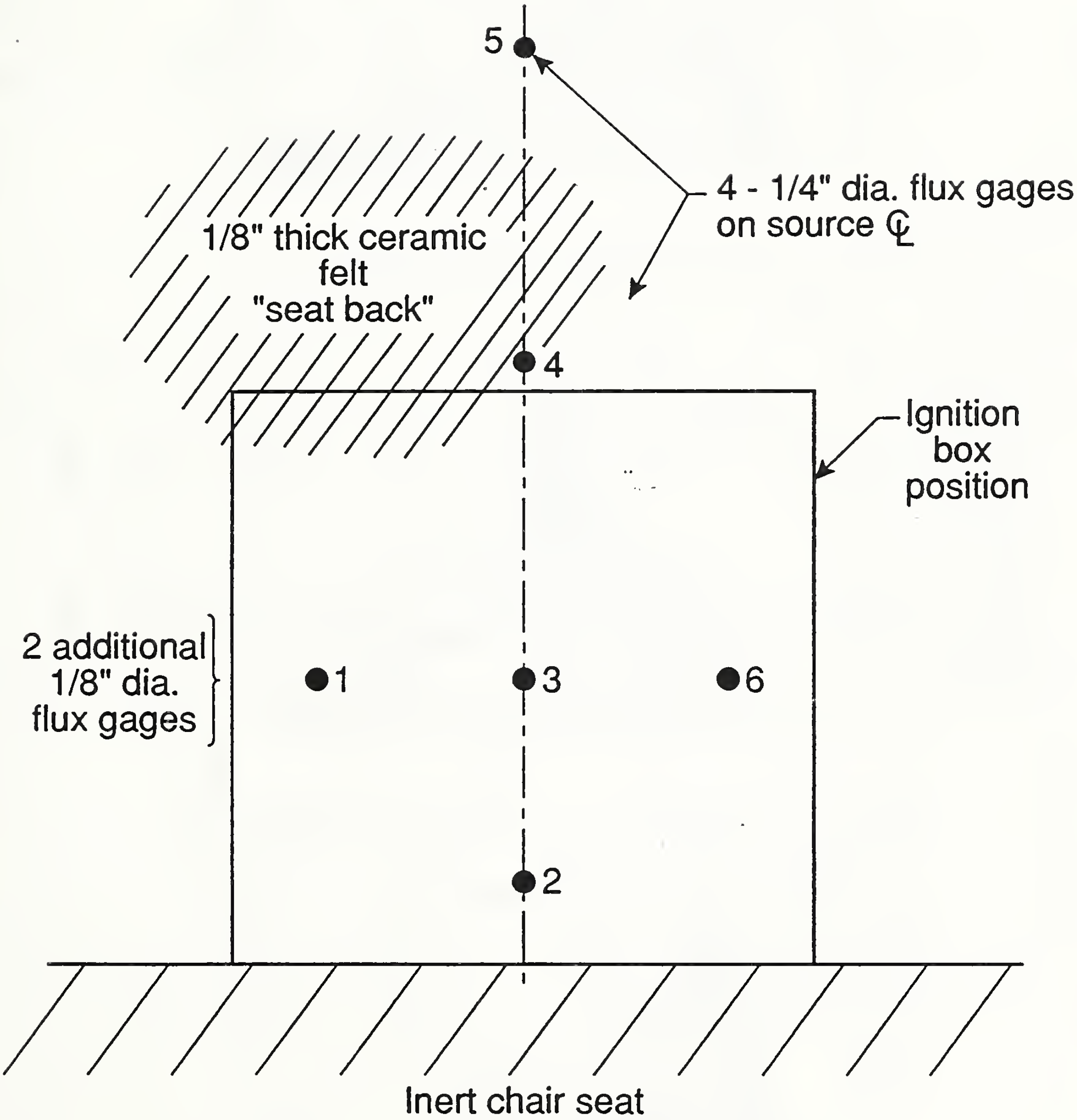


Fig. 7 Placement of heat flux gages in seat back of inert mock-up.

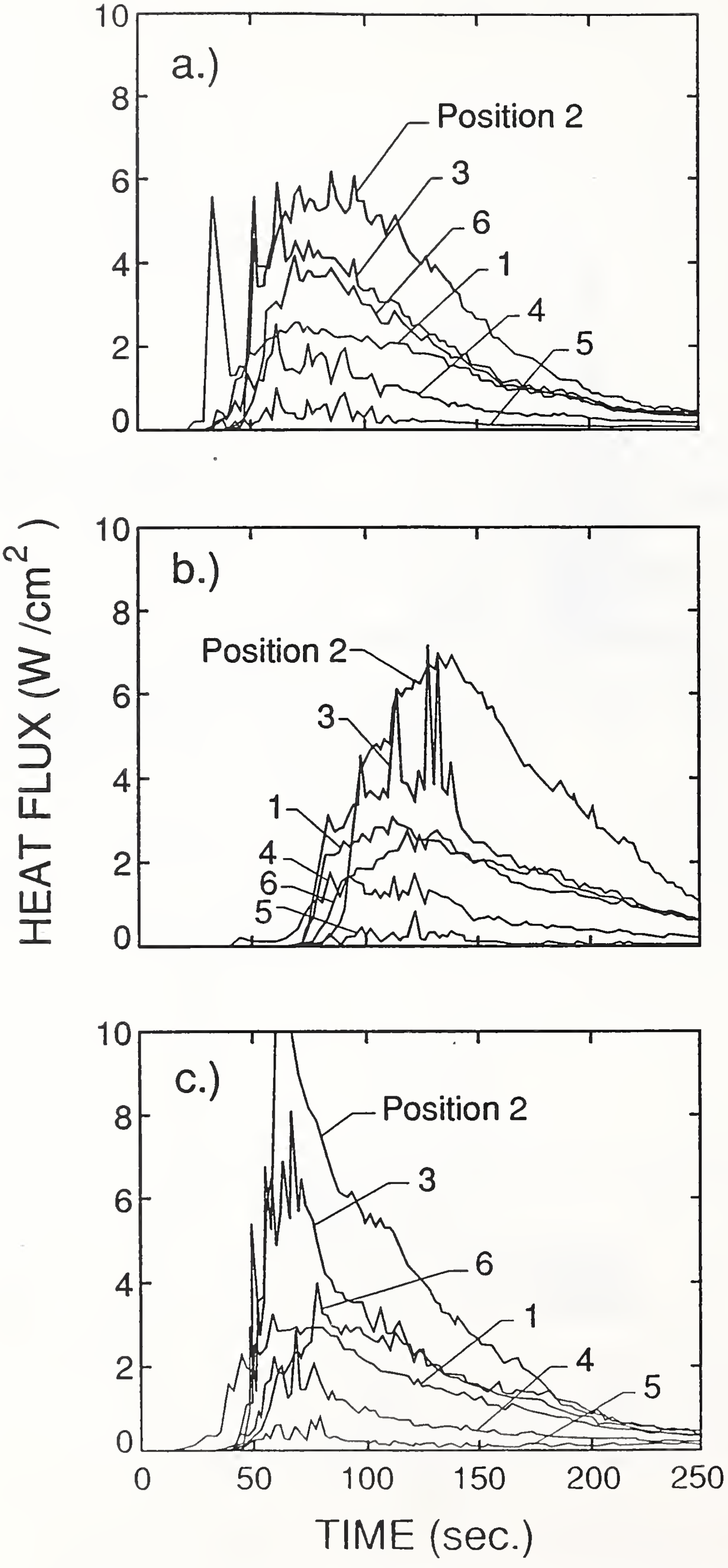


Fig. 8 Heat flux versus time seen at six seat back gage positions in three nominally identical tests with CB 133 ignition source.

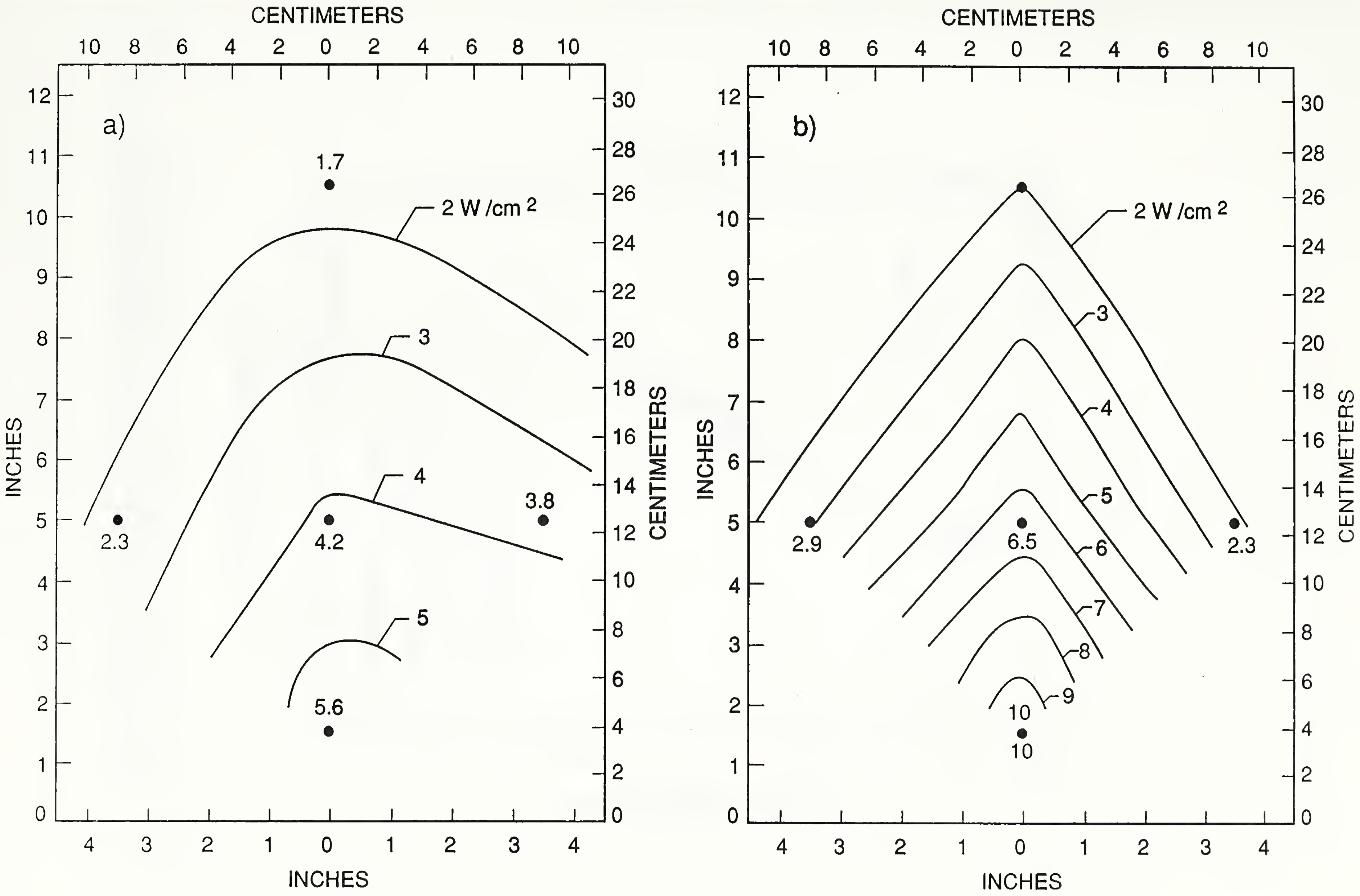


Fig. 9 Iso-flux lines on inert seat back derived by interpolation from data in Fig. 8 at time when position 2 gage is at maximum. Graph (a) here is from (a) in Fig. 8; graph (b) here is from (c) in Fig. 8.

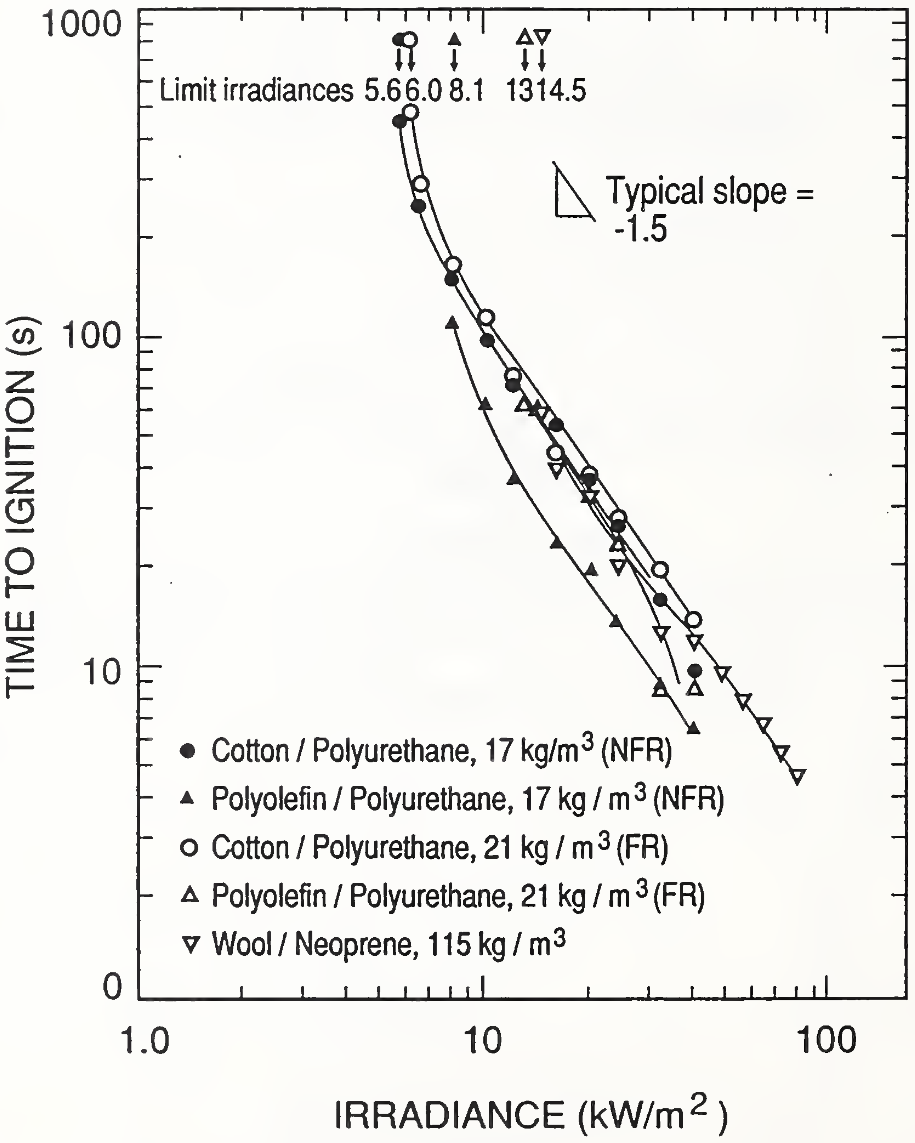


Fig. 10 Cone calorimeter ignitability data from Ref. 5 showing piloted ignition delay time versus incident radiant flux for a variety of fabric/foam combinations.

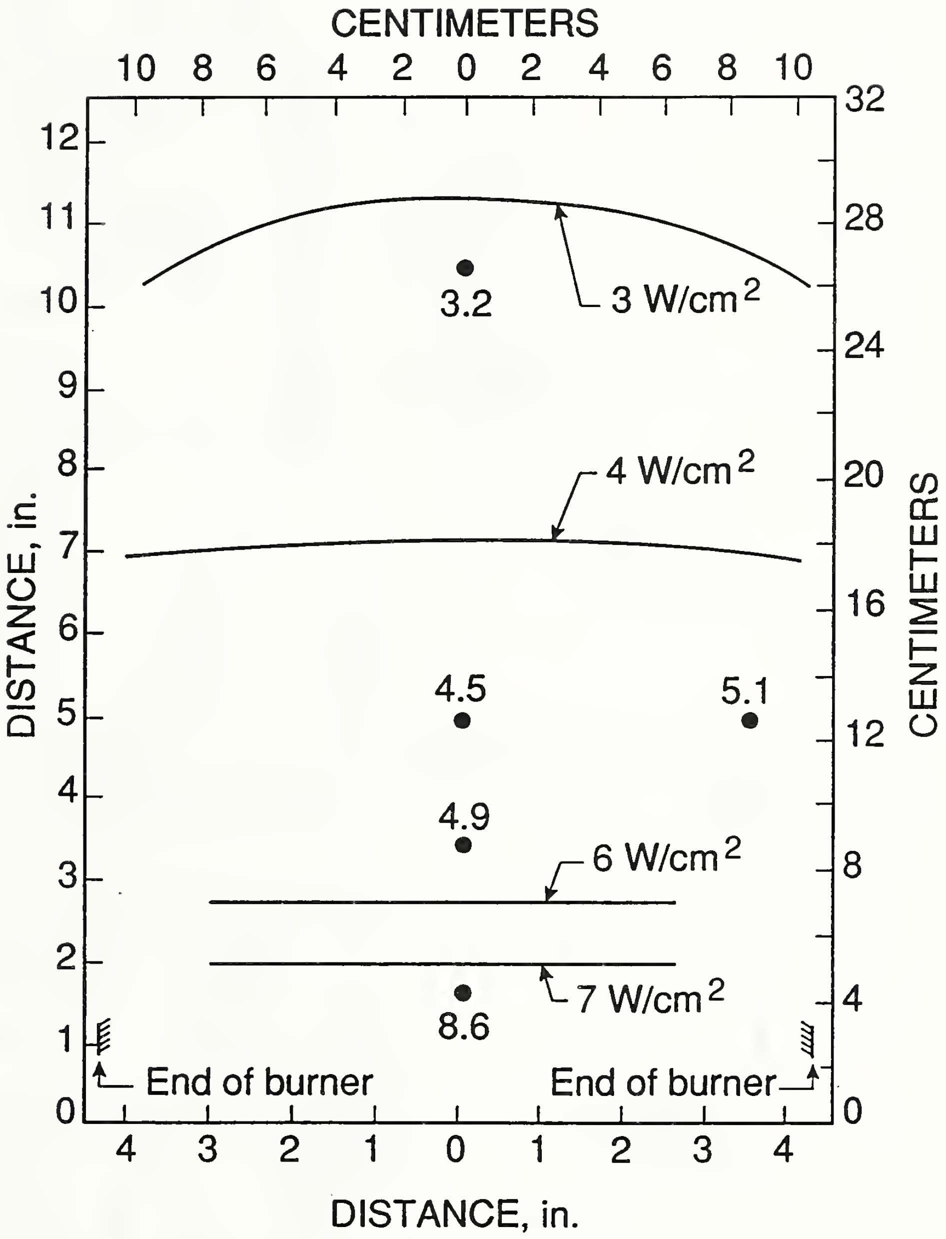


Fig.11 Iso-flux lines on inert seat back for Ames T-burner operated at 6 l/min of propane. Lines obtained by interpolation from readings at indicated locations (black dots).

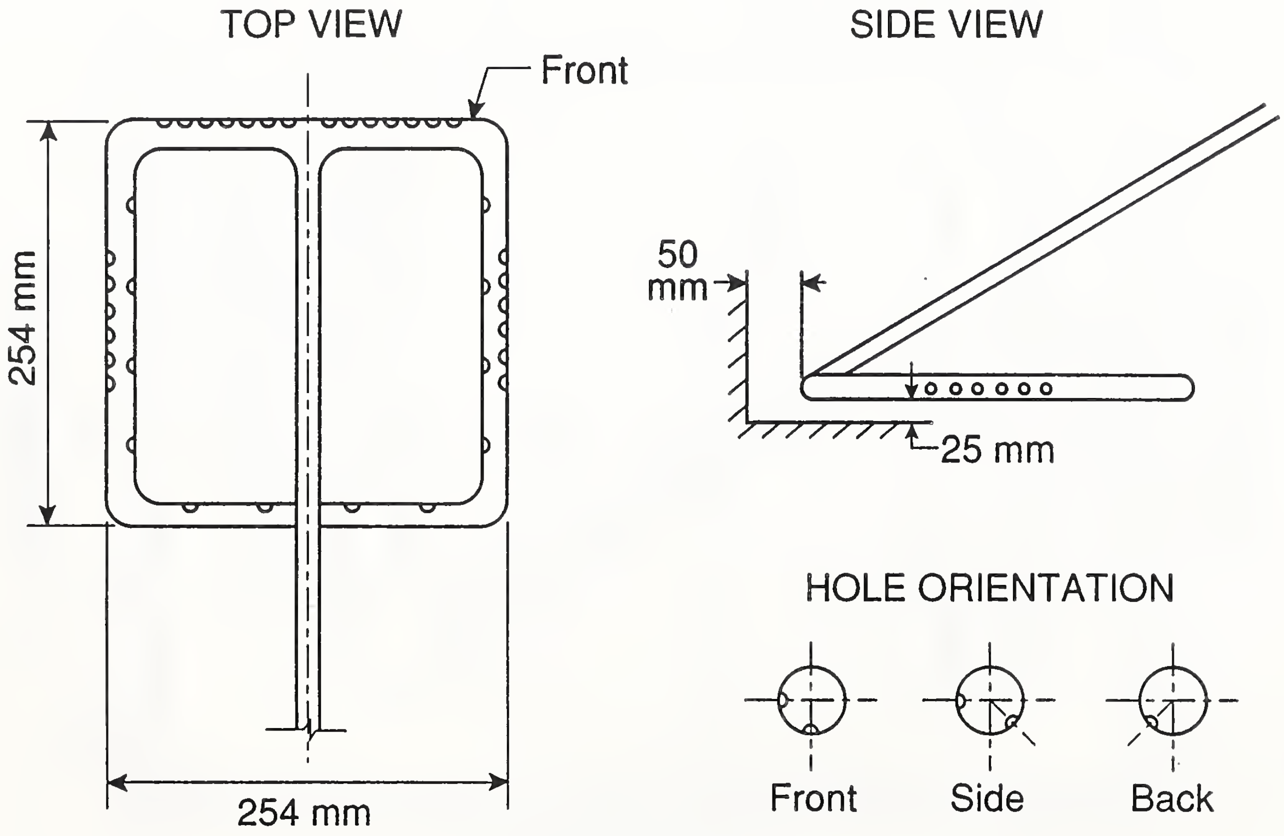


Fig. 12 Schematic of square ring gas burner showing approximate location and orientation of 1 mm dia. holes from which gas jets issue. Gas jets are arrayed as follows: 1) Cross-bar of Tee - 14 holes pointing straight out and 9 holes pointing straight down, all with 13 mm spacing; 2) Side jets pointing straight out; 6 holes each side with 13 mm spacing; first hole is 89 mm from outer edge of Tee; 3) Inward angled jets - 4 holes on each of three sides with 50 mm spacing, centered as shown. Burner ring is made from 12.7 mm OD stainless steel. Also shown is placement relative to back and seat of chair, on chair centerline.

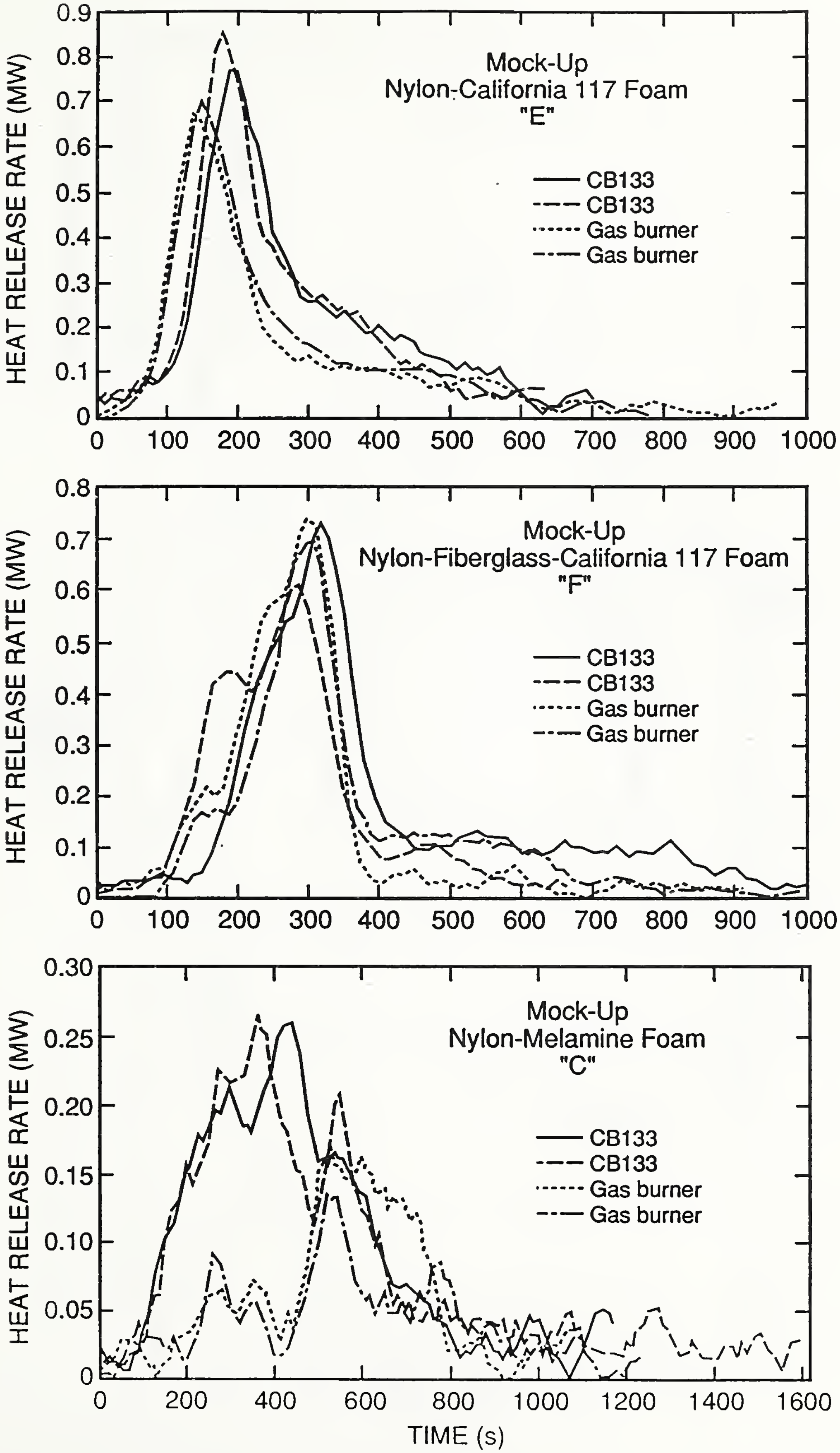


Fig. 13 Rate of heat release vs. time from three material combinations in mock-up form. Results from two tests each with the two ignition sources. Note the differing scales on the graphs.

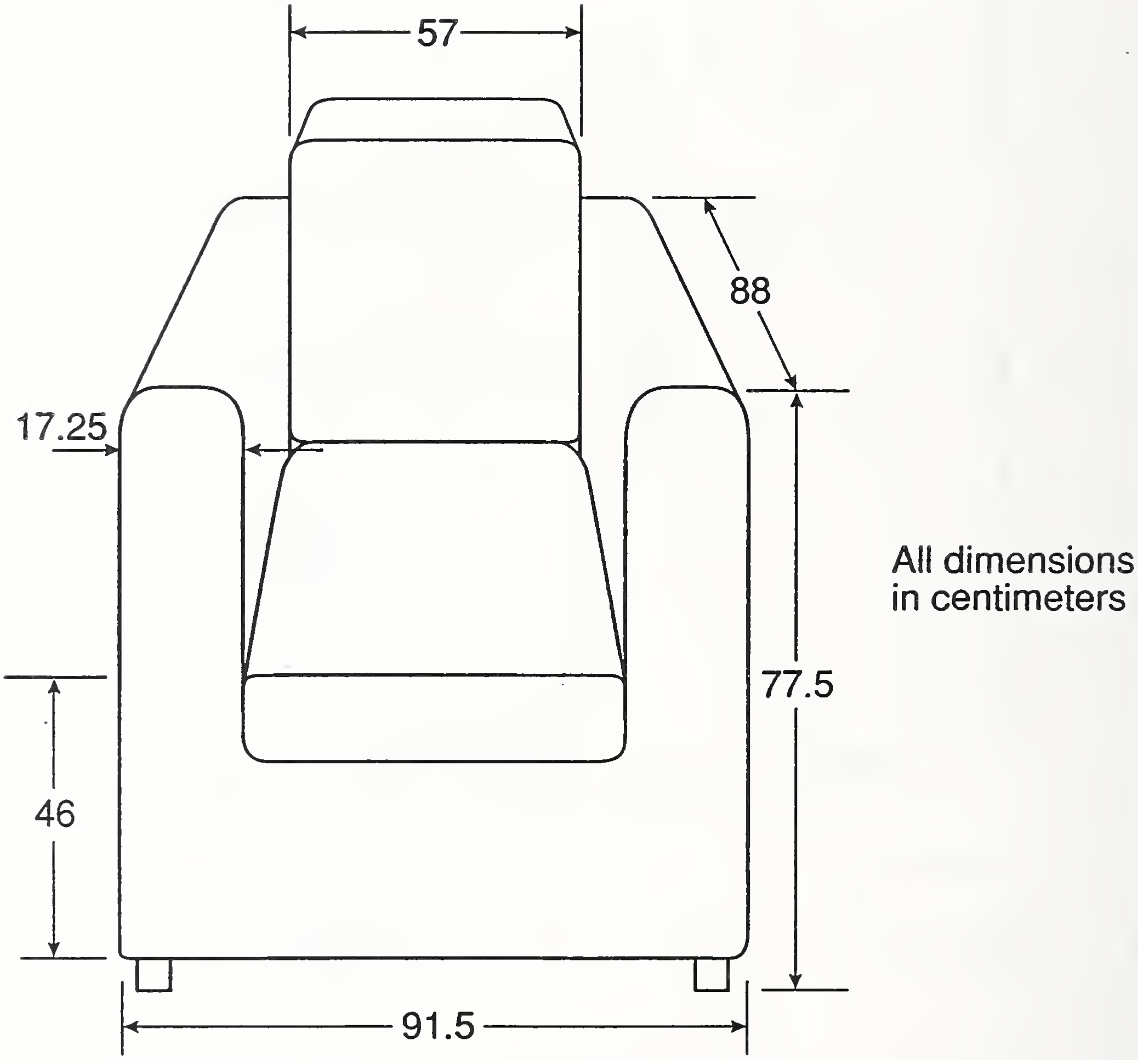


Fig. 14 Schematic of chair design for full-scale tests.

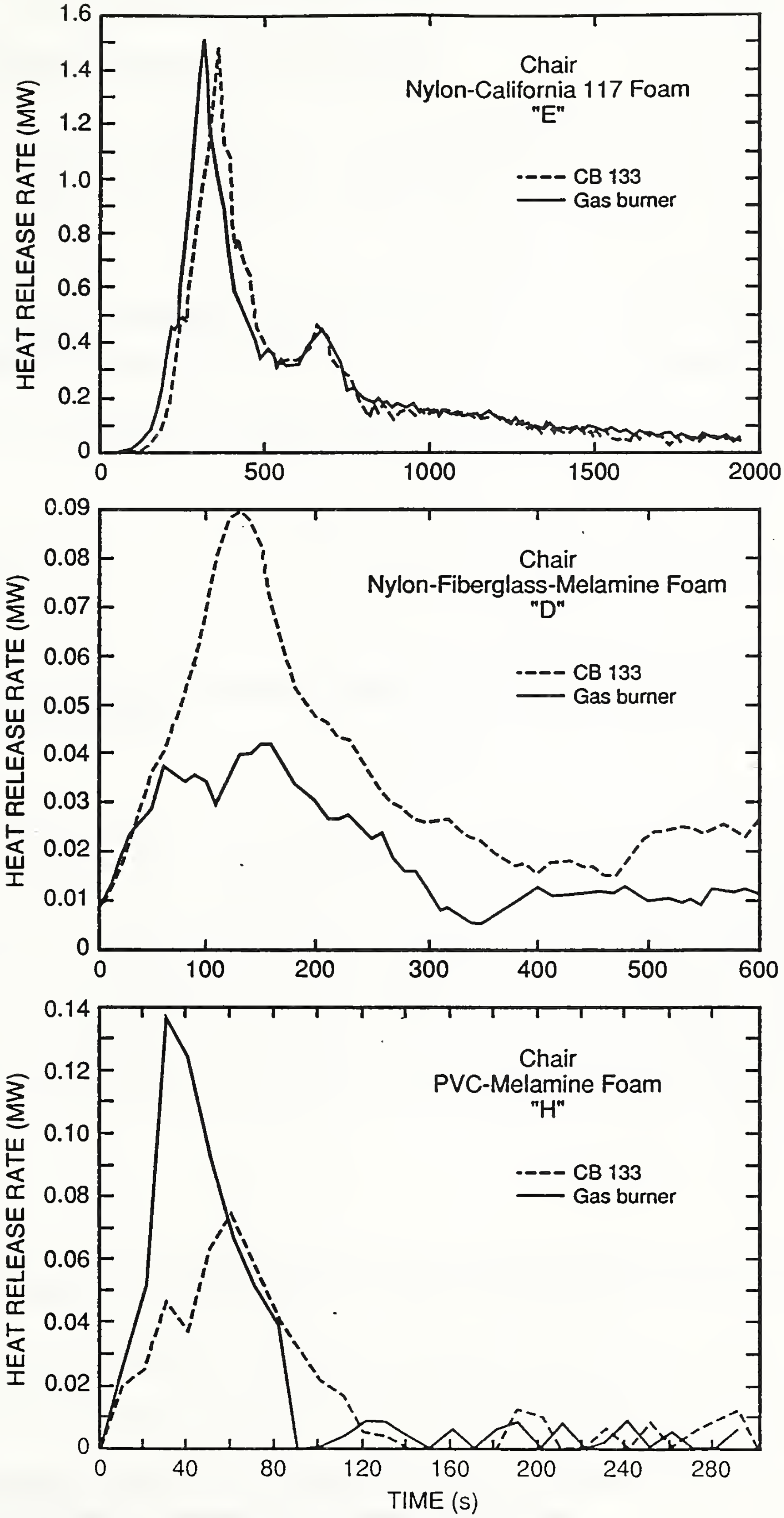


Fig. 15 Rate of heat release vs. time from three material combinations in chair form. Results from one test each of the two igniters. Note the differing scales on the graphs.

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## ABSTRACT

The California Bulletin 133 upholstery ignition source is based on the use of crumpled newsprint. The present work examined the reproducibility of several aspects of this source when placed on an inert mock-up. The tendency of this source to heat the side arms of a chair, the area of the seat back subjected to high heat fluxes, the peak flux there and the flux duration all showed substantial variability. A gas burner, derived from that developed at the British Fire Research Station, was shaped so as to deposit a similar pattern of heat to that of the CB 133 source. The two sources were tested for comparability both on chair mock-ups and on full scale chairs made from a wide variety of materials. The results indicate that the gas burner, as used here, is a somewhat less severe ignition source than is the CB 133 igniter.

12. **KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)**

flaming combustion; flammability; furniture; ignition; test methods

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