NBS TECHNICAL NOTE 1103

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Full-Scale Burning Behavior of Upholstered Chairs

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FULL-SCALE BURNING BEHAVIOR OF UPHOLSTERED CHAIRS

Vytenis Babrauskas

A test program was conducted to determine the fire behavior of a variety of upholstered chairs subjected to a flaming ignition. Major variables were materials and construction of chairs, room ventilation, and type of ignition sources. A total of 16 types of traditional and modern design chairs were tested in a full-scale, otherwise unfurnished room. A folded up newspaper at the seat area was used as the standard ignition source. Room tenability criteria were based on smoke, concentrations of gaseous combustion products, and heat flux. One or more tenability criteria were exceeded for 14 chairs, in times ranging from 100 sec to 650 sec; two chairs burned without exceeding any of the tenability criteria. A review is included of previous upholstered furniture experiments using flaming ignition sources and of existing or proposed small-scale standard tests.

Key words: Chairs; compartment fires; flammability; fire tests; furnishings; upholstered furniture.

1. INTRODUCTION

It has been estimated [1][1] that some 110,000 fires annually occur in the United States where upholstered furniture is the first item to ignite. The majority, some 70% of these, are attributed to cigarette ignition. This undesirable loss picture has resulted in a proposed standard [2,3] for cigarette ignition resistance of upholstered furniture. Such a standard, if adopted and enforced, would apparently seem to mitigate the worst aspects of the problem. An examination of the case histories of some fires [4,5], however, points to an additional problem. The course of a typical cigarette ignition fire is a slow one, beginning with smoldering of the upholstery fabric cover or of the padding and only later, if at all, breaking out in open flame. While property damage for smoldering fires is usually minor and multiple fatalities are not usual, most furniture fire deaths (estimated to be 1500 annually) occur in this manner. The case histories of particular concern in this study, on the other hand, involved flaming ignition and rapidly developing fires, with major property losses and potential multiple fatalities. The prime hazard in these cases is rapid flame spread and high rates of burning for the furniture in question.

These fast-developing fires are seen to often have one ingredient in common--heavy use of plastics and especially flexible foam cushioning in the furniture involved. This is the reason why fires of this kind have come into prominence only in the last decade or so. Concern with minimizing these tragic fires suggests that for upholstered furniture the flaming combustion behavior has to be controlled, in addition to the resistance to ignition. Before any program for control of the flaming combustion behavior can be formulated, a systematic quantitative study of that behavior must be undertaken. The present report documents an exploratory study in this area. A separate study of flaming ignition behavior is necessary since flaming ignition and cigarette ignition behavior are not correlated--good performance in one case does not necessarily imply good performance for the other.

[1] Numbers in brackets refer to the literature references listed at the end of this report.

2. REVIEW OF PREVIOUS WORK

For a long time there has been concern with the fire properties of furniture since furniture forms a major portion of the fuel load in residential premises and the role of fuel load has long been recognized [6]. The hazards considered were connected with the severity of a post-flashover[2] fire, its impact on the building structure, and protection of occupants remote from the fire room. In more recent times post-flashover testing of furniture [7,8] has been conducted to enable burning rates to be calibrated against those for wood cribs, which had often been considered a standardized type of fuel load.

During the late 1960's, furniture flammability started to be reevaluated in the light of four developments. First, rapid advances were being made in fire protection engineering, so that not only was an engineered approach to post-flashover fires emerging, but also the time for considering the details of the spreading, pre-flashover fire was becoming ripe. Second, the use of plastics, especially polyurethane foam, was becoming common in furniture. Third, some spectacular fires occurred, whose rapid spread and fast burning rates were attributed directly to furniture. The most notable of these was probably the 1970 fire in the BOAC Facility at Kennedy International Airport [9]. Finally, the role in the nation's fire death loss of small, pre-flashover furniture fires was being realized. Since the largest fraction of deaths connected with upholstered furniture fire is found [10,11] to stem from cigarette ignitions, NBS started a research program in 1972 [12] on cigarette ignition resistance requirements which culminated in a 1976 recommendation for a test standard [2].

Efforts in testing the behavior of upholstered furniture for flaming ignitions began somewhat earlier. Some of these first efforts came from a broad Office of Civil Defense program of studying war-related fires. Thus, in 1965 Vodvarka and Waterman [13] undertook a set of furnished room burns to determine expected times to flashover for several types of furniture. The furniture was ignited at one point with 100 cm^3 of JP-4 fuel. Four types of fully furnished rooms were tested: living rooms with cotton batting construction upholstered furniture, living rooms with foam latex (rubber) upholstered furniture, and bedrooms with two types of mattress constructions. An unspecified number of replicate tests were run for each condition, with a goal of producing probability curves for time to flashover. The median time to room flashover for living rooms with cotton batting furniture was 17 minutes, but for the foam latex furniture it dropped to 8.5 minutes. Interactive burning of at least two furniture items was found necessary since rooms furnished with only a single upholstered chair did not go to flashover at all.

The question of what are the minimum conditions for igniting the second item in a room is clearly an important one. In 1968 Theobald [14] measured the ignition of several targets placed at different distances from a burning piece of furniture. The work was sponsored by a British civil defense activity, and consequently an unusual ignition procedure was used. The ignition involved strips of combustible fiber board placed around the test piece and ignited with 600 g of alcohol. A total of 2 kg of excelsior was spread around the edges of the room and ignited simultaneously with the specimen. Test specimens included chairs, both upholstered and not, a bookcase, and a wardrobe, all of conventional wooden construction. The

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[2] Flashover is defined as a change from localized burning to fully stirred burning in a room. Prior to flashover temperatures and heat fluxes are generally near-ambient except near localized zones of burning. After flashover essentially the entire room is filled with flames and the fire is out of occupant control.

non-upholstered wood chair was not consumed. Targets considered were cotton cloth, wood blocks, and thin plywood sheets. Flame from the burning upholstered chairs ignited cloth targets up to 0.15 m away, while the burning wardrobe ignited both cloth and wood targets at 1.20 m; the bookcase showed intermediate behavior.

In 1970, NBS sponsored a furniture flammability study at Southwest Research Institute, conducted by Hafer and Yuill [15]. The series focused mainly on mattresses but did include eight tests on upholstered chairs. The cushioning materials were polyurethane and latex foams, covered by a variety of upholstery fabrics. Most of the chairs were ignited with cigarettes, but two were lit with matches. Temperature, smoke obscuration and CO, CO_2, and O_2 were monitored. The results of the cigarette ignition tests showed generally similar rankings, but the match ignitions produced much faster fire development.

Efforts in measuring flame spread over upholstered furniture were started in 1972 by Lee and Wiltshire [16]. They measured horizontal flame spread, with no external radiation, over fabrics alone and over fabrics backed with cushioning. For the cushioning-backed samples the flame spread velocities did not appreciably depend on the fabric type, but were two to three times higher for polyurethane foam cushioning than for cotton padding.

In 1974, Southwest Research Institute conducted another series [17] of full-scale tests of mattresses and upholstered furniture, this time sponsored by the Society of the Plastics Industry. A series of 13 sofas and upholstered chairs were tested. The basic construction was similar for all. Cushioning material studied included non-retardant treated cotton batting, polyurethane, retardant-treated polyurethane and latex foams. Test specimens were ignited with a gas burner, which was shut off when the specimen ignited. Weight loss, smoke obscuration, and gas concentrations were measured. The results showed cotton batting specimens burning slowest and latex foam specimens developing fastest fires, with polyurethane foam being slightly slower than latex. Conventional fire retarded grades of polyurethane foam did not perform better than untreated ones. However, a foam with 38% filler showed improved behavior.

Hillenbrand and Wray [18] have reported on a set of four tests of fully furnished bedrooms. The tests differed in the extent to which highly fire resistive materials and components were incorporated into the furnishings. The baseline, conventional case consisted largely of cellulosic products, but with polyurethane foam cushioning for the upholstered chair. The results are difficult to interpret since there were more variables than number of tests.

Hägglund, Jansson, and Onnermark [19] and Jansson, et al., [20] at the Swedish Defense Agency conducted two series of burns with upholstered furniture. In the first series full size and model scale upholstered chairs and sofas were used. The construction was either traditional, with ordinary cotton batting type stuffing, or modern, using polyurethane foam. Specimens were tested singly in a noncombustible room and were conditioned to varying, prescribed relative humidity levels. The main variables considered were time to flaming ignition, length of flaming period, maximum weight loss rate, and presence or absence of flashover. Since a non-flaming radiant ignition source was used, the cotton batting furniture achieved flaming ignition in 34 to 120 minutes, while the polyurethane specimens ignited in less than one minute.

The flaming period was somewhat longer for cotton batting than for polyurethane foam furniture. Elevated humidity delayed ignition and prolonged the flaming period of the cotton batting pieces but did not affect the polyurethane foam ones. The mass loss rate was expressed as a fraction of the initial specimen mass. For cotton batting specimens the rate was adequately expressible as 0.03 min^{-1}, while for polyurethane ones it ranged from 0.05 to 0.10 min^{-1}. A final series of measurements obtained from the first study was concerned with the establishment of a minimum gas temperature for room flashover. It was found that 600° C corresponded to flashover, as determined by visual observation of flames emerging from the window.

The second test series explored the ignition of test targets by upholstered furniture, extending, in effect, Theobald's work [14]. Four burning objects were used, a sofa and an armchair, each in cotton batting and polyurethane construction. Targets included paper, fiber stuffing, foam plastic and wood. The maximum ignition distances ranged from 0.15 m for the burning cotton batting armchair and wood block target, to 1.2 m for a burning polyurethane foam sofa and fiber stuffing target.

In 1975, Hilado, et al., [21] conducted a series of full-scale furniture fire tests in a corner configuration within a large open room. Three upholstered pieces, two armchairs and a sofa, were included. Ignition was with a small polyethylene wastebasket filled with combustibles, 1 kg total weight. The results reported were primarily the peak temperatures at different heights and an integrated value of temperature over time.

Also in 1975, Fang [22] at NBS reported on a series of room fires with upholstered chairs. Sixteen chairs with various upholstery fabrics and either cotton, or cotton and polyurethane, or cotton/latex foam paddings were tested. Ignition was with a methenamine timed burning tablet identical to that used for testing carpets [23]. Maximum temperatures, heat fluxes, and smoke concentrations were recorded at several locations, as were peak mass loss rates. Also measured were maximum ignition distances for paper, cotton cloth, and wood targets. The results were compared to those from similar tests on wood cribs and were used to establish "wood crib equivalents" for typical upholstered chairs.

The Southwest Research Institute conducted yet another furniture flammability study in 1976, this time sponsored by the Products Research Committee [24]. Two fully furnished living rooms were tested, one with furniture, including upholstered furniture, characterized as "traditional," the second as "plastic." The construction in both types was, in fact, traditional. The "plastic" furniture merely utilized polyurethane foam instead of cotton batting cushioning. The furniture was ignited with a gas burner. The plastic-furnished room showed a faster developing and more severe fire.

The most ambitious studies to date have been the interrelated full-scale test programs conducted at the British Fire Research Station (FRS) and those at the Rubber and Plastics Research Association (RAPRA). The FRS series [25-28] consisted of several investigations, including curtain, carpet, and bed combustion tests in hotel and office rooms, and ignition and smoldering studies of upholstered furniture. The main effort, however, was full-scale testing of upholstered chairs and sofas, both singly and in fully-furnished living rooms. Some 22 pieces were tested singly, subjected to different ignition sources, including cigarettes, matches, burning paper, and wood cribs. A total of 19 fully-furnished living rooms were burned, with the upholstered specimen being first ignited. In these tests no rooms equipped with traditional (no foam plastic) furniture reached flashover, but certain of the ones using foam plastic materials did. An adequate room ventilation was one condition necessary for flashover. Some of the foam plastic padded pieces burned so fast that their wooden frames could not be adequately ignited before the fire burned out. The traditional specimens, by contrast burned out slowly and completely. A limited amount of experimentation was carried out with flame retardant treated polyurethane foams and with varied upholstery fabrics. Poly(vinyl chloride) and viscose/wool fabrics were seen to reduce the burning rate, while polypropylene fabrics enhanced it.

The RAPRA series [29-36] involved rather similar studies. On the largest scale, a series of tests was conducted in a furnished four room house. Smaller in scale was a series of burns of three-piece living room suites. The majority of the testing, however, was in a single room and used two identical chairs a small distance apart. The chair construction was kept similar while different combinations of padding and upholstery fabric were tried. Foam latex padding generally showed the worst behavior, foam polyurethane was somewhat better, while rubberized hair, wool batting, and similar natural materials generally performed best.

Polypropylene and other thermoplastic fabrics were shown to behave poorly when covering foam plastics. This was because, subjected to heating, these materials rapidly shrank and pulled away, leaving the bare foam. Since the presence of almost any covering over the foam can reduce flame spread rate several fold, it is evident why the shrinking away behavior was undesirable. Wool fabrics and natural hide products were most successful in protecting the underlying foam. It was then found that the performance of polyurethane foam/thermoplastic fabric combinations could be significantly improved by providing a cotton fabric interliner, or better yet, one treated with ammonium bromide/urea retardant. Ignition in most cases was with newspaper; cigarettes were able to ignite only one foam/fabric combination. Chair frame involvement was not relevant in this series since metal frames were used. The resulting advisory publication to industry [34] points out that, among factors to be considered, upholstery fabrics should not be drawn too tight, less it promote splitting; that flaked foam cushions especially need a good interliner; that cigarette "traps" be avoided, and that, in view of the fact that vertical surfaces burn approximately three times as fast as horizontal ones, the possibilities of using furrows as fire breaks be considered.

The RAPRA work, in fact, summarized much of all the previous studies on padding and fabric effects, with emphasis on materials in common European usage. More recent efforts have focused largely on the use of improved interliners. Ashida [37], at the Mitsubishi Chemical Industries, for instance, undertook testing of phenolic interliners in a two-chair test set up similar to that of RAPRA. Newspaper was used to ignite the chairs, which duplicated some polyurethane foam/modacrylic fabric specimens used by RAPRA. Heavier thicknesses of phenolic interliner sufficed to prevent adjacent chair ignition and to cause the initial fire to die out without consuming much of the chair. A glass cloth interliner had similar effect. Thinner grades of phenolic interliner did not prevent total burnout but did delay it by about one hour.

The investigations reviewed above involved primarily attempts to characterize the relative hazards of different types of furniture specimens. Some investigators, however, have been concerned mainly with determining pre-flashover mass loss rates, to be used in various modeling efforts. Pape [38] presented summary rate data from couch and chair burns at the IIT Research Institute, and has also derived analytic approximations for typical rates. Klein [39] burned a single type of upholstered chair and compared its burning rate to several types of wood cribs. Tanaka [40] recently reported on the mass loss rate and the temperature distribution above a burning sofa as part of a Japanese project on systems fire safety analysis.

No theoretical studies are available in the area of furniture burning rates. Even the geometrical arrangement of most interest for furniture burning (spread from a small source upwards and sideways on a vertical surface) has only been reported in a single paper [41].

3. SCOPE OF WORK

The previous available studies, while elucidating some important variables, did not establish as broad a data base as was desired for judging the full-scale flaming combustion of upholstered chairs. Specifically, explorations were lacking of the effects of chair shape and type of structural support and controlled comparisons between chairs of similar construction but different padding materials. Also, the more comprehensive of the previous studies were done with furniture constructions as prevalent in Europe, rather than in the United States. To answer some of these needed questions, a series of full-scale test burns was conducted during 1975-76. The features of these experiments were:

- Chairs were tested singly in a bare room, with fully open doorway ventilation
- Ignition with newspaper at seat/arm joint for most tests
- Extensive room instrumentation
- Measurement of those variables needed for a consistent set of tenability criteria.

With the exception of several tests designed to explore ignition characteristics, this test series was focused on the performance of chairs once they are fully ignited with a flaming ignition source. Numerous scenarios can be envisioned which lead to such ignitions, including a natural switch-over from a smoldering state to open flaming. Detailed explorations of the potential for flaming ignition are needed and are currently not available. Thus, the present tests are not to be constructed to represent total fire histories, but merely that portion after sustained flaming ignition and before the involvement of any additional fuel objects.

The tests were not designed for nor intended to be used for regulatory purposes or for development of prescriptive specifications.

4. DESCRIPTION OF EXPERIMENTAL FACILITIES AND INSTRUMENTATION

4.1 Test Room

The test burn room is shown in figures 1 and 2. It was 3.40 m x 3.50 m x 2.44 m high (11.2 ft x 11.5 ft x 8.0 ft), and is described in table 1. The only opening to the room was an open doorway 0.91 m wide by 2.13 m high (3.0 ft x 7.0 ft). The doorway opened into another chamber, which connected to a corridor discharging into a hood and exhaust chimney containing an afterburner for smoke abatement. The flows through the doorway were essentially unobstructed in this arrangement and previous work has determined that the effect of the exhaust system on room temperatures and flow was negligible. The ambient laboratory conditions during these tests were a temperature of 20 to 25° C and a relative humidity of approximately 40%. For most tests, except as mentioned later, there was no door in the room doorway.

Wall and ceiling linings consisted of 13-mm thick noncombustible cement-asbestos board (Atlas Asbestos Co. "Superbestos")[3]. On the walls and ceiling this was applied over a 16-mm thick layer of Type-X gypsum wallboard. The thermal properties of the cement asbestos board used were as follows [42,43]:

[3] Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

	Temperature (°C)			
	30	183	433	721
Density (kg/m^3)	658	626	600	557
Thermal conductivity (W/m-K)	0.14	0.16	0.14	0.14
Heat capacity (J/kg-K)	1060	1330	1340	1440

Emissivity was not measured but is estimated to be ≈0.9. Floor covering was also cement-asbestos board.

4.2 Instrumentation

The instrumentation used in these experiments is indicated in figures 1 and 2 and table 2. The experiments were also recorded both on video film and with still photographs. All instrument data were taken at 10-second intervals on a high speed data acquisition system.

a) Thermocouples. Chromel-alumel 30-gage (0.25 mm) thermocouples were located at the points shown. These thermocouples were shielded with a metallic tube for most of their length except for the last 20-30 mm before the junction end. This allowed fast response time but did not introduce problems of insulation degradation, which can be troublesome with unshielded flexible thermocouples. Radiation corrections were made only to the doorway thermocouples.

b) Heat flux meters. Gardon foil type water-cooled radiometers and total heat flux meters were used.

c) Load cell. The weighing arrangement consisted of a BLH model U3G1 load cell mounted above the ceiling of the burn room. The specimen was placed on a cement-asbestos board platform (1.22 m wide by 1.22 m long) suspended by cable from the load cell.

d) Velocity probes. Bidirectional flow probes were located in the doorway as shown in figure 2. This type of probe was developed by Heskestad [44] for obtaining accurate low-velocity flow measurements under fire conditions which can involve water condensation and flow reversal. McCaffrey and Heskestad [45] have provided calibration techniques for these problems. The probes used were 12.7 mm in diameter, with construction details as given in the above reference. The basic equation is:

$$\frac{\sqrt{2\Delta p/\rho}}{u} = C(Re)$$

where Δp = measured differential pressure, ρ = gas density (obtained from thermocouple reading adjacent to the probe), u = the gas velocity, and $C(Re)$ is a constant which depends on the Reynolds number. For Reynolds numbers in the range of interest the constant can be approximately taken as $C = 1.08$ according to the recommendation of McCaffrey and Heskestad. Pressures were sensed with a Celesco P90D pressure transducer.

e) Gas sampling. Concentrations of CO, CO_2, and O_2 were measured at a single location in the doorway. Gas analysis for CO and CO_2 was made with Beckman 315-B non-dispersive infrared analyzers. A Beckman OM-11 oxygen analyzer was used for O_2. The sampling line was fitted with a series of traps: a glass wool trap for removing particulates, a dry ice trap to remove water, and, finally, another glass wool trap.

f) Smoke meters. Photometers were located horizontally and vertically in the doorways at the locations shown in figures 2 and 4. The extinction beam smoke meters were specially constructed for room burn experiments. The light sources consisted of incandescent bulbs with color temperature in the range of 2900-3200 K. A collimated system was used since it has been shown [46] that in such case the error due to extraneous scattered light is small. Calibration was achieved by placement of known optical density filters in the light path.

5. TEST PROGRAM

5.1 Test Procedure

The chairs were individually tested in the room described above. No other combustibles except for the ignition source were used. A total of 24 tests were conducted, using 16 different types of chairs. A schedule of tests is given in table 3.

5.2 Ignition Sources

Several ignition sources were used in the series in attempting to evolve a small reproducible source. A 120 ml cup of alcohol, placed at the side of the chair, was tried in some preliminary testing. This gave a rather large ignition flame, but one which did not establish reliable flame spread. It appeared that a source placed in the concave, inside portion of the chair would be better than one at the convex, outside surface. With an inside ignition it could be expected that radiative reinforcement of burning would occur as several surfaces were ignited. Thus, for most of the tests a source was adopted consisting of a folded up newspaper placed on the seat next to the arm, and ignited at its back edge. Eighteen double newspaper sheets were used, weighing 396 $\pm$ 22 g. Other sources tried were a metal wastebasket filled with trash and placed next to the outside of the chair arm (one test), and a lighted cigarette (two tests), placed in the crevice between the seat cushion and the side arm.

Source	Test
Wastebasket	03
Cigarette	08,13
Newspaper	all others

5.3 Ventilation Conditions

The standard conditions consisted of natural ventilation through a single opening, the open doorway. For two tests, however, more restricted ventilation was used, to determine the effect of smaller openings. In test 06 the doorway was closed off and a window opening was provided. The window size was 0.72 m x 0.91 m high, with the window top being at the same height as the doorway top. In test 07 a door was installed in the opening and only partly opened, leaving a 0.18 m wide opening.

5.4 Description of Test Chairs

For convenience in the chair descriptions the type of construction is often categorized as traditional or modern. By traditional construction, it is meant that there exists a primary load-bearing frame, made of wood, and using springs, webbing or similar devices to support padding materials. This type of construction usually also entails a separate, stuffed, lay-in seat cushion. It is to be noted that the traditional construction chair may be part or all plastic materials for cushioning and upholstery. By modern construction is meant any type except the above traditional construction.

Chair C01

Chair C01 was typical for a traditional-style easy chair with a lay-in cushion. The structural frame was made of wood and provided with metal springs for seat support. Upholstery fabric was a cotton lightweight print of 0.18 kg/m^2. For comfort reasons, the filling layer directly under the upholstery fabric was cotton batting. Polyurethane foam comprised the seat cushion and also was contained underneath the batting in the seat cushion area and inside back area. Minor upholstery components included cardboard, non-woven polyethylene, woven polypropylene, and cotton denim. The chair is illustrated in figure 3.

Material	Weight (kg)
Wood (poplar)	7.1
Cotton batting	1.6
Polyurethane foam (21 kg/m^3)	1.3
Upholstery, cotton print (0.18 kg/m^2)	0.6
Cardboard	0.8
Polyethylene (non-woven) and polypropylene (woven)	0.2
Metal parts	0.9
Total weight	12.6*

*Weight totals do not always add due to rounding

Chair C02

Chair C02, shown in figure 4, was identical to chair C01 except for the upholstery fabric. A medium weight polypropylene fabric of 0.35 kg/m^2 was used.

Material	Weight (kg)
Wood (poplar)	7.1
Cotton batting	1.6
Polyurethane foam (21 kg/m^2)	1.3
Upholstery, polypropylene (0.35 kg/m^2)	1.1
Cardboard	0.8
Polyethylene and polypropylene (excl. upholstery)	0.2
Metal parts	0.9
Total weight	13.1

Chair C03

Chair C03, shown in figure 5, was again similar to chair C01 except for the upholstery fabric. A heavy nylon fabric of 0.50 kg/m^2 was used.

Material	Weight (kg)
Wood (poplar)	7.1
Cotton batting	1.6
Polyurethane foam (21 kg/m^3)	1.3
Upholstery, nylon (0.50 kg/m^2)	1.6
Cardboard	0.8
Polyethylene and polypropylene	0.2
Metal parts	0.9
Total weight	13.6

Chair C04

Chair C04, shown in figure 6, was similar to chair C03, except that all the cotton batting was replaced by polyurethane foam. The same nylon upholstery fabric was used as in chair C03. The components were not individually weighed, but the construction details were similar to chair C03.

Total weight	12.2 kg

Chair C05

Chair C05, shown in figure 7, was a bean bag chair, comprised of only two components: a "wet look" cotton-backed vinyl fabric and low density polystyrene foam beads.

Material	Weight (kg)
Cotton-backed vinyl fabric (0.65 kg/m^2)	2.0
Polystyrene foam beads	5.2
Total weight	7.3

Chair C06

Chair C06, shown in figure 8, was a large modern design chair that can be made into a bed. There was a loose cushion but no structural frame. The pillow was stuffed with shredded polyurethane foam, while the body of the chair consisted of a block of slab urethane foam. Both were upholstered with an acrylic "fake fur."

Material	Weight (kg)
Slab polyurethane foam (35 kg/m^3)	13.5
Shredded polyurethane foam	2.4
Upholstery, acrylic fake fur (0.65 kg/m^2)	4.6
Total weight	20.4

Chair C07

Chair C07, shown in figure 9, was of modern design, with a one-piece molded frame and two loose cushions. The molded polystyrene structural foam frame was strengthened with plywood inserts and overlaid with polyurethane foam padding glued in place. The upholstery fabric was a simulated leather, made of thin foamed polyurethane, with a non-woven polyolefin backing. The seat and back cushions were similarly upholstered, over polyurethane foam slabs, and were held in place by thongs.

Material	Weight (kg)
Polystyrene foam (35 kg/m^3)	4.5
Polyurethane foam (26 kg/m^3)	4.9
Plywood	0.8
Polyolefin	0.1
Upholstery fabric (0.65 kg/m^2), 85% polyurethane, 15% polyolefin	3.0
Metal parts	0.1
Total weight	11.4

Chair C08

Chair C08, shown in figure 10, was a modern style pedestal swivel chair. The structural frames of the chair body and the base were both molded polyethylene. Polyurethane foam, mostly shredded, was the cushioning material, with upholstery of vinyl fabric with denim backing.

Material	Weight (kg)
Polyethylene	10.6
Polyurethane foam	3.1
Vinyl fabric, denim backing	1.7
Metal parts	0.9
Total weight	16.3

Chair C09

Chair C09, shown in figure 11, was a modern design simulated leather overstuffed chair. The body was a single piece of flexible cold-molded polyurethane foam. The structure was rigidified with pieces of wood in the arms and at the base. Metal springs were anchored to the wood base. The polyurethane structure was covered by 25-50 mm of polyester batting and upholstered with a polyurethane foam imitation leather material. There were no individual cushions.

Material	Weight (kg)
Polyurethane foam (58 kg/m^3)	8.7
Polyester batting	1.1
Polyurethane upholstery (0.41 kg/m^2)	1.5
Wood	5.0
Metal parts	0.4
Total weight	16.6

Chair C10

Chair C10, shown in figure 12, was another modern design pedestal chair. The shell was a one-piece molding of rigid polyurethane foam molded on a plywood bottom piece and supported on a metal pedestal. The rigid foam shell was covered with a layer of flexible polyurethane foam, 25 mm thick on the inside and 6 mm on the outside. A single polyurethane foam cushion was provided. Upholstery material was polyurethane foam imitation leather with a woven cotton backing.

Material	Weight (kg)
Polyurethane foam, rigid (80 kg/m^3)	4.0
Polyurethane foam, flexible (10 kg/m^3)	1.5
Polyurethane/cotton upholstery (0.81 kg/m^2)	1.6
Plywood	1.6
Metal base	3.5
Total weight	12.1

Chair C11

Chair C11, shown in figure 13, consisted of a solid polyurethane foam block, covered with nylon upholstery fabric. The upholstery fabric was bonded to the foam block everywhere, except at the bottom. No separate frame or support was used. Foam density was 28 kg/m^3; the upholstery density had a surface density of 0.67 kg/m^2.

Total weight 14.3 kg

Chair C12

Chair C12, shown in figure 14, was of traditional construction, similar to chair C03, except that no polyurethane foam was used. A wood structural frame was padded with cotton batting and upholstered with a nylon fabric with a density of 0.50 kg/m^2.

Total Weight 17.9 kg

Chair C13

Chair C13, shown in figure 15, was similar to chair C04 except for the inclusion of an interliner. A neoprene foam interliner, 4.8 mm thick, was bonded to the inside of the nylon upholstery fabric.

Total weight 19.1 kg

Chair C14

Chair C14, shown in figure 16, was similar to chairs C04 and C13 except for the upholstery fabric, which was polypropylene. The neoprene interliner in this case was separate, not bonded to the fabric.

Total weight 21.8 kg

Chair C15

Chair C15, shown in figure 17, was similar to chairs C04 and C13 except for the upholstery fabric, which was polypropylene. The neoprene interliner was bonded to the inside of the polypropylene upholstery fabric.

Total weight 21.8 kg

Chair C16

Chair C16, shown in figure 18, was similar to chairs C04 and C13, and was upholstered with nylon fabric. The neoprene interliner was separate, not bonded to the fabric.

Total weight 19.1 kg

6. CRITERIA FOR EVALUATION

The criteria for evaluating test burn results largely followed those adopted in a previous study [47]. A brief summary is given below. Detailed reasoning for selecting these criteria values has been set forth in the referenced study. The approach was based on the following tenets:

- Time-to-a-condition is a more realistic measure than is the maximum value of some measurement variable.
- The only possible safety factor on which agreement might possibly be reached is a zero safety factor. The user, however, can always apply a desired safety factor onto the basic data. The tenability criteria thus are based on "incipient incapacitation."
- "Super toxicity", that is incapacitation by noxious gases or aerosols other than CO, CO_2 or O_2 deprivation, has not been considered. A proper, reliable, and routinely feasible method is still wanting.
- Gas sampling and smoke obscuration were measured near the top of the doorway. This was done for reasons of convenience and reproducibility. It is understood, however, that this procedure introduces an unwanted safety factor.
- Since CO symptoms are primarily associated not with instantaneous concentrations, but with equilibrated carboxyhemoglobin (COHb) values, an uptake equation, discussed in [47] was used to calculate reference COHb values.
- The criteria used are considered relevant to the situation of an occupant of the room of fire origin, but one not intimately connected with the ignition.

The success criteria used were as follows:

Room Flashover

Heat Flux $\leq$ 20 kW/m^2 at the floor

Tenability

A. Heat flux exposure $\leq$ 2.5 kW/m^2
B. Gas concentrations
$CO_2 \leq 8\%$
$O_2 \geq 14\%$
COHb calculated level $\leq 25\%$ (subject to an instantaneous ceiling for CO of 50,000 ppm)
C. Smoke obscuration
extinction coefficient $\leq 1.2\ m^{-1}$

7. RESULTS

The basic test results are given in table 4 and in figures 19 through 38. The variables given are: temperature, taken as the average of TC 09,37,51; radiant heat flux, as measured at the west wall; weight loss rate; smoke, as measured 0.31 m below doorway top; and gas concentration for CO_2, O_2, and CO, as measured near the top of the doorway.

7.1 Ignition Source Effects

The difference between cigarette and newspaper ignition were examined on chair C01 in tests 08, 10, 13, and 23. The times to peak wall heat flux (table 5) can be considered as indicative. For the two newspaper ignition tests, 10 and 23, these times were 360 and 290 s, respectively. For the cigarette ignition tests, 08 and 13, the times were 5070 and 2970 s. Thus, the newspaper ignition results are seen to be close, while the cigarette ignition ones are nearly a factor of 2 apart. The difference in times in the latter case can be attributed to the unpredictability of the transition from smoldering to flaming. Open flaming occurred at 4980 s in test 08, but at 2820 s in test 13. This difference serves to emphasize the fact that although smoldering-to-flaming transition is an important event in hazard analysis, it is highly variable and difficult to model or predict.

Another ignition comparison has been made, between wastebasket and newspaper ignition. Chair C03 was ignited in test 03 with a wastebasket and in test 04 with newspaper. As expected, the larger wastebasket source produced a faster fire development rate. However, the record of observations (Appendix) also shows that the wastebasket source fire retreated after the initial high burning rate and then later built up again. The newspaper ignited fire burned more steadily. This is attributable to the source placement at an inside, concave location, rather than at the outside periphery. The concave location provides for increased flame re-radiation effect, encouraging a steady fire growth. Thus, limited exploration of alternate ignition sources indicated that the choice of newspaper ignition was appropriate for the purposes desired.

7.2 Ventilation Effects

As described earlier, one of the chair types, C02, was run at two levels of reduced ventilation, a part-open door and a window opening. The two restricted openings had the same ventilation factor $A\sqrt{h} = 0.56\ m^{5/2}$. ($A$ = opening area, h = opening height.) By comparison, the ventilation factor for the standard opening was $2.83\ m^{5/2}$. The heat fluxes for the restricted openings were slightly higher than for the standard opening. Thus, a door size effect can be detected and the value, of course, should be held constant for accurate specimen comparisons. Scaling rules, however, are not yet available which would enable the effect to be predicted.

7.3 Reproducibility

Replicate tests under standard conditions were run for chairs C01 (tests 10, 23), C03 (tests 02, 04), and C04 (tests 09, 14). An examination of the data shown in tables 5, 6, 7, 8, 9 and 11 shows a median disagreement of 7% between replicates. This is considered to be a satisfactory value for full-scale furnishings fire tests.

7.4 General Observations

The course of the test fires is indicated by the measured variables shown in figures 19 through 38. Photographs of the chairs at near peak burning time are given in figures 3 through 18. A detailed log of observations for each test is given in the appendix. The majority of specimens--those with thermoplastic upholstery or foam padding--tended to melt and drip burning droplets. The intensity of this melting and of a resultant pool fire under the chair varied significantly among the specimens. Only one specimen, C06, led to room flashover. Only two chairs, C01 and C12 did not exceed any tenability limits. The remaining exceeded the limits at times ranging from 2690 s to 120 s. Tables 6, 8, and 11 list detailed times to failure based on tests with standard ignition and ventilation conditions. Of the chairs burned under standard conditions, most were at least 2/3 consumed at the end of the test. Table 4 lists weight losses and mass loss rates. All specimens substantially burned up; the fraction of combustible mass consumed ranged from 47 to 100%, averaging 82%. Mass loss rates are not available for some tests where the weighing mechanism failed. The peak mass loss rates varied from 13.1 g/s for chair C15 to 151 g/s for chair C06. The second highest mass loss rate, 112 g/s, was recorded for chair C08, which did not lead to flashover.

7.5 Performance Ranking

The performance of the test chairs can be categorized into four groups (table 12). Earlier studies [47] have established that for categorizing the performance of furnishings in full-scale tests such a division is meaningful. To establish with a degree of certainty the relative position within a group would generally require a substantial amount of replicate testing. In the present study, however, certain behavior patterns emerge when within-group performance is considered. For this reason, the results in table 12 are arranged within groups not in numerical order but according to actual times. For any potential future standard testing methods, however, it would not be appropriate to try to identify more than the performance group.

It must be emphasized that the groupings below reflect solely the flaming ignition behavior. Cigarette ignition resistance was not measured in these tests. Well performing specimens might still require additional measures to achieve adequate cigarette resistance.

Group A--two chairs did not exceed any of the tenability criteria. Both were of traditional construction.

Group B--six chairs exceeded the smoke obscuration criterion, but did not exceed any of the other criteria. Five of these chairs were of traditional construction. The remaining specimen was a bean bag chair and showed the second worst behavior in this group.

Group C--chairs in this group did not lead to room flashover but exceeded either the gas concentration or the radiant heat flux criteria. In most cases they also exceeded the smoke criterion. Since the ill effects of exceeding these two criteria are better characterized and more certain, it is appropriate to distinguish this group as more hazardous than Group B. Two traditional and five modern construction specimens were in this group. Both the best and the worst performing specimens in this group were traditional, with the modern pieces falling in between.

Group D--one chair, of massive foam block construction, failed all criteria and led to room flashover.

7.6 Effect of Type of Construction

The best performing chairs--Group A and five of six in Group B--were of traditional construction. The one chair in Group D was of modern foam block construction. Within Group C the best performing chair was also of traditional construction. A salient exception was C04, which ranked at the end of the group. Chair C04 did have a higher polyurethane foam content than the similar type chairs C01, C02, and C03 since, unlike in the others, no cotton batting was used in it. Thus, a trend can be seen for less desirable fire performance from the modern than from the traditional construction chairs. The trend is only a trend, however, and there were individual modern specimens that performed better than some of the traditional ones.

7.7 Effect of Upholstery Material

Chairs C01, C02, C03 were of the same construction with the exception of upholstery fabric. The fabric was cotton for C01, polypropylene for C02, and nylon for C03. C02 and C03 exceeded tenability limits at 150 and 215 s, respectively, a difference which is not considered significant. C01 did not exceed any tenability limits, demonstrating the markedly better performance of the cotton upholstery fabric over the thermoplastic fabrics.

7.8 Effect of Interliners

Chairs C13, C14, C15 and C16 each contained a 4.8 mm thick neoprene foam interliner under the upholstery fabric. Chair C04 was, by comparison, of the same construction but without an interliner. The interliner was bonded to the fabric of C13 and C15 and was not attached in C14 and C16. The performance (table 12) varied quite a bit, with C13 showing the best performance within this group and C14 the worst. All the chairs with interliners showed better performance than C04, without an interliner. The scatter of the data was considerable, however, and differences between the performance of bonded and unbonded specimens could not be detected.

7.9 Effect of Padding Material

Chairs C03, C04, and C12 were of the same construction with the exception of the padding material. The padding was polyurethane foam for C04, cotton batting for C12, and polyurethane foam topped with cotton batting for C03. The performance of C12 was good, with no tenability criteria being exceeded (Group A). Chair C03 fell in Group B, while Chair C04 ranked at the bottom of Group C. This progression illustrates well the desirability of minimizing the amount of polyurethane foam used in the chair construction. The construction features of Chair C06 should be considered in view of this being the only chair that flashed over the test room. Chair C06 contained a larger amount, 15.9 kg, of polyurethane foam than any of the other test chairs. Thus, excessive amounts of polyurethane foam can be seen to lead to detrimental behavior.

8. IMPLICATIONS FOR STANDARDIZED TESTING

Upholstered furniture can likely be considered one of the most difficult furnishing objects to subject to standarized fire testing. Significant progress has been made in the case of some furnishings items, such as carpeting and mattresses. In those cases, however, the item is always of a fixed, simple geometry. In the case of upholstered furniture the geometry is variable and yet its effects are important (as demonstrated, for instance, by the differences between outside wastebasket and inside newspaper ignition). It should be noted that the geometry problem is particularly acute for flaming ignition testing. In the case of smoldering ignition, flame radiation, surface re-radiation and similar geometry effects do not play a role. Thus, standard tests [3,48] for smoldering resistance of upholstered furniture have been possible.

So far, there has been only limited impetus for mandated requirements of flaming ignition resistance for upholstered furniture. In the few cases that requirements have been set or proposed, small test specimens have been used and no account taken of geometric effects. The following examples can be cited:

- --The Port of New York Authority [49] has for some years had a furniture flammability specification requiring the testing of upholstery fabric materials by Federal Specification CCC-T-191b Method 5903 and the testing of the padding materials by either ASTM E 84 (Tunnel Test) or ASTM E 162 (Radiant Panel Test).

- --The State of California [50] requires that upholstered furniture meet a standard which separately regulates upholstery fabric and padding materials. Upholstery fabrics are tested according to Commercial Standard 191-53, while padding material is tested by CCC-T-191b Method 5903 using a specially modified sample holder.

- --The British Plastics Federation [51] proposed tests for upholstered furniture where flaming ignition sources are included. However, in their procedure the article was extinguished once ignition was achieved. The test, therefore, largely avoids confronting the issue of geometric effects.

--RAPRA [52] has proposed a series of tests for furnishings, including upholstered furniture, which would determine the ignitability and burning rate of specimens in several orientations. The test geometry and the full-scale geometry are not tied in, however, so validity is not proven.

--British Standards Institution [53] has recently proposed a test method that includes flaming ignition resistance and uses a gas burner and small wood cribs. Again, the behavior past the point of ignition is not determined.

Any of the above tests might have legislative validity in the sense that enforced compliance would result in the elimination of some high hazard designs. The more important long range technical issue that still needs to be solved, however, is whether bench-scale tests could be produced that take into account geometric aspects and can accurately predict full-scale behavior. Such tests are still wanting.

9. SUMMARY AND CONCLUSIONS

The upholstered test chairs, when burned under standarized full-scale test conditions, showed widely varying flammability behavior. The best performing chairs did not cause any tenability criteria to be exceeded, while the worst performing one exceeded the criteria at 100 s and then led to room flashover at 280 s.

All chairs substantially burned up in the course of the test, with the average combustible mass loss weight 82%.

An inside, seat area ignition proved to be desirable for causing a steady, propagating fire.

Reproducibility was satisfactory for identical replicates; however, similar but not identical chairs often burned quite differently.

A low fuel load for foam padding and any thermoplastic structural components and slow flame spread behavior of the upholstery material were both needed to ensure satisfactory specimen performance. Those chairs where only one of these factors was controlled did not perform well in the tests.

A neoprene interliner was of modest benefit in improving the burning behavior.

Specimen geometry played a large role in determining its behavior. This fact makes it unlikely that predictive bench-scale tests could be developed which use only cut through-the-thickness samples and which do not model flame radiation and surface re-radiation.

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Table 1. Summary of burn room characteristics

Height/width/depth (m)	2.44/3.40/3.50
Floor area (m^2)	11.90
Doorway height (m)	2.13
Doorway width (m)	0.91
Doorway area (m^2)	1.94
Doorway $A\sqrt{h}$ ($m^{5/2}$)	2.83
Soffit depth* (m)	0.31
Surface area (excluding floor and doorway) (m^2)	43.63
Doorway area/surface area	0.0445
Doorway $A\sqrt{h}$/surface area ($m^{1/2}$)	0.0649

*Distance from ceiling to top of door

Table 2. List of instrumentation

Number	Thermocouples
01	On E wall, 1.22 m from S wall, 1.83 m from ceiling
02	On unexposed wall surface, behind TC 01
03	On E wall, 1.22 m from S wall, 0.61 m from ceiling
04	On unexposed wall surface, behind TC 03
05	On floor, 0.92 m from E wall, 2.75 m from S wall
06	0.92 m from E wall, 2.75 m from S wall, 2.14 m from ceiling
07	0.92 m from E wall, 2.75 m from S wall, 1.53 m from ceiling
08	0.92 m from E wall, 2.75 m from S wall, 0.92 m from ceiling
09	0.92 m from E wall, 2.75 m from S wall, 0.31 m from ceiling
10	On ceiling, 0.92 m from E wall, 2.75 m from S wall
11	On unexposed wall surface, behind TC 10
12	On S wall, 0.92 m from E wall, on floor
13	On S wall, 0.92 m from E wall, 2.14 m from ceiling
14	On S wall, 0.92 m from E wall, 1.83 m from ceiling
15	On S wall, 0.92 m from E wall, 1.53 m from ceiling
16	On S wall, 0.92 m from E wall, 1.22 m from ceiling
17	On S wall, 0.92 m from E wall, 0.92 m from ceiling
18	On S wall, 0.92 m from E wall, 0.61 m from ceiling
19	On S wall, 0.92 m from E wall, 0.31 m from ceiling
20	On S wall, 0.92 m from E wall, 0.15 m from ceiling
21	On S wall, 0.92 m from E wall, 0.08 m from ceiling
22	On S wall, 0.92 m from E wall, on ceiling
23	On N wall, 1.22 m from E wall, 1.83 m from ceiling
24	On unexposed wall surface, behind TC 23
25	Center of room, on floor
26	Center of room, 2.14 m from ceiling
27	Center of room, 1.53 m from ceiling
28	Center of room, 0.92 m from ceiling
29	Center of room, 0.31 m from ceiling
30	Center of room, on ceiling
31	On unexposed ceiling surface, behind TC 30
32	1.83 m from E.wall, 0.92 m from S wall, on floor
33	1.83 m from E wall, 0.92 m from S wall, 2.14 m from ceiling
34	1.83 m from E wall, 0.92 m from S wall, 1.53 m from ceiling
35	1.83 m from E wall, 0.92 m from S wall, 0.92 m from ceiling
36	1.83 m from E wall, 0.92 m from S wall, 0.31 m from ceiling
37	On ceiling, 1.83 m from E wall, 0.92 m from S wall
38	On unexposed ceiling surface, behind TC 37
39	1.83 m from E wall, 0.15 m from S wall, 2.14 m from ceiling
40	1.83 m from E wall, 0.15 m from S wall, 1.53 m from ceiling
41	1.83 m from E wall, 0.15 m from S wall, 0.92 m from ceiling
42	1.83 m from E wall, 0.15 m from S wall, 0.31 m from ceiling
43	On N wall, 2.44 m from E wall, 0.61 m from ceiling
44	On exposed wall surface, behind TC 43
45	On S wall, 2.44 m from E wall, 1.03 m from ceiling
46	On S wall, 2.44 m from E wall, 0.61 m from ceiling
47	On S wall, on floor, 2.44 m from E wall
48	2.75 m from E wall, 2.75 m from S wall, 2.14 m from ceiling
49	2.75 m from E wall, 2.75 m from S wall, 1.53 m from ceiling
50	2.75 m from E wall, 2.75 m from S wall, 0.92 m from ceiling
51	2.75 m from E wall, 2.75 m from S wall, 0.31 m from ceiling
52	On ceiling, 2.75 m from E wall, 2.75 m from S wall
53	On unexposed ceiling surface, behind TC 52

Table 2. (continued)

54	2.75 m from E wall, 0.92 m from S wall, 2.14 m from ceiling
55	2.75 m from E wall, 0.92 m from S wall, 1.53 m from ceiling
56	2.75 m from E wall, 0.92 m from S wall, 0.92 m from ceiling
57	2.75 m from E wall, 0.92 m from S wall, 0.31 m from ceiling
58	At doorway centerline, 0.13 m below top
59	At doorway centerline, 0.31 m below top
60	At doorway centerline, 0.66 m below top
61	At doorway centerline, 1.07 m below top
62	At doorway centerline, 1.37 m below top
63	At doorway centerline, 1.91 m below top
64	At doorway centerline, 0.46 m below top
65	At doorway centerline, 0.92 m below top
66	At doorway centerline, 1.68 m below top
67	On W wall, 0.61 m from S wall, 0.61 m from ceiling
68	On ceiling, 1.70 m from S wall, 2.89 m from E wall
69	On floor, 1.70 m from S wall, 2.59 m from E wall
82	At doorway centerline, 0.08 m below top
	Smoke Meters
90	Horizontal in doorway, 0.31 m from ceiling (1.0 m light path)
91	Horizontal in doorway, 0.61 m from ceiling (1.0 m light path)
92	Horizontal in doorway, 1.22 m from ceiling (1.0 m light path)
93	Vertical in doorway centerline (2.44 m light path)
	Velocity Probes
100	At doorway centerline, 1.91 m below top
101	At doorway centerline, 1.37 m below top
102	At doorway centerline, 1.07 m below top
103	At doorway centerline, 0.66 m below top
104	At doorway centerline, 0.31 m below top
105	At doorway centerline, 0.13 m below top
	Heat Flux Meters
110	Radiometer, on W wall, 0.61 m from S wall, 0.61 m from ceiling
111	Total heat flux meter, same location as HFM110
112	Radiometer, on floor, 1.70 m from S wall, 2.58 m from E wall
113	Total heat flux meter, same location as HFM112
114	Radiometer, on ceiling, 1.70 m from S wall, 2.89 from E wall
115	Total heat flux meter, same location as HFM114
116	Radiometer, on ceiling, center of room
117	Total heat flux meter, same location as HFM116
	Load Cell
118	Load Cell
	Gas Concentration Probes
120	Carbon dioxide, at doorway centerline, 0.025 m below top
121	Carbon monoxide, at doorway centerline, 0.025 m below top
122	Oxygen, at doorway centerline, 0.025 m below top

Table 3. Schedule of tests

Specimen	Construction (padding; cover)	Test	Conditions
C01	traditional (polyurethane, cotton; cotton)	08	cigarette ignition
		10	standard
		13	cigarette ignition
		23	standard
C02	traditional (polyurethane, cotton; polypropylene)	05	standard
		06	window-sized opening
		07	door part-open
C03	traditional (polyurethane; cotton; nylon)	02	standard
		03	wastebasket ignition
		04	standard
C04	traditional (polyurethane; nylon)	09	standard
		14	standard
C05	bean bag (polystyrene beads; PVC)	11	standard
C06	modern (polyurethane foam block; acrylic)	25	standard
C07	modern (polystyrene, polyurethane; polyurethane)	17	standard
C08	modern (polyethylene; polyurethane)	18	standard
C09	modern (polyurethane, polyester; polyurethane)	16	standard
C10	modern (polyurethane; polyurethane)	19	standard
C11	modern (polyurethane foam block; nylon)	12	standard
C12	traditional (cotton; nylon)	15	standard
C13	traditional (polyurethane, interliner; nylon)	20	standard
C14	traditional (polyurethane, interliner; polypropylene)	21	standard
C15	traditional (polyurethane, interliner; polypropylene)	22	standard
C16	traditional (polyurethane, interliner; nylon)	24	standard

Table 4. Specimen weights and weight loss

Specimen	Test	Total Weight (kg)	Combustible Weight (kg)	Weight Loss (kg)	Combustible Content Consumed (%)	Peak Mass Loss Rate (g/s)	Time at Peak Mass Loss Rate (s)
C01	08	12.6	11.7	10.85	93	21.8	5090
	10	12.6	11.7	N.A.	N.A.	N.A.	N.A.
	13	12.6	11.7	10.96	94	15.3	2900
	23	12.6	11.7	11.60	99	17.5	310
C02	05	13.1	12.2	6.08	50	13.2	350
	06	13.1	12.2	N.A.	N.A.	N.A.	N.A.
	07	13.1	12.2	6.42	53	11.8	320
C03	02	13.6	12.7	6.01	47	N.A.	N.A.
	03	13.6	12.7	11.8	93	34.5	550
	04	13.6	12.7	N.A.	N.A.	N.A.	N.A.
C04	09	12.2	11.3	N.A.	N.A.	N.A.	N.A.
	14	12.2	11.3	10.44	92	75.7	340
C05	11	7.3	7.3	7.3	100	22.2	510
C06	25	20.4	20.4	14.02	69	151	150
C07	17	11.4	11.2	11.2	100	86.9	360
C08	18	16.3	15.4	15.4	100	112	760
C09	16	16.6	16.3	15.82	97	N.A.	N.A.
C10	19	12.1	8.6	7.22	84	15.2	600
C11	12	14.3	14.3	N.A.	N.A.	N.A.	N.A.
C12	15	17.9	17.0	12.04	71	19.0	1720
C13	20	19.1	18.2	14.28	78	15.0	1200
C14	21	21.8	20.9	13.85	66	13.7	1380
C15	22	21.8	20.9	N.A.	N.A.	13.1	650
C16	24	19.1	18.2	13.10	72	N.A.	N.A.

N.A. - Not Available

Table 5. Heat flux peak values

Specimen	Test	West Wall			Floor			Ceiling, Room Center			Ceiling, Near Doorway		
		Total Flux (kW/m^2)	Radiant Flux (kW/m^2)	Time (s)	Total Flux (kW/m^2)	Radiant Flux (kW/m^2)	Time (s)	Total Flux (kW/m^2)	Radiant Flux (kW/m^2)	Time (s)	Total Flux (kW/m^2)	Radiant Flux (kW/m^2)	Time (s)
C01	08	5.7	2.4	5070	1.86	1.57	5080	12.3	2.8	5070	8.0	4.3	5100
	10	3.4	1.84	360	1.16	1.06	400	6.0	N.A.	360	4.5	2.5	390
	13	3.8	1.66	2970	1.41	1.24	3000	9.1	3.1	2920	5.8	3.1	2910
	23	5.3	1.66	290	1.11	0.97	300	6.1	5.8	210	5.1	2.0	310
C02	05	6.5	2.3	180	3.4	3.1	320	13.7	2.3	320	12.2	3.8	310
	06	11.0	2.4	200	6.7	3.6	320	15.4	3.1	310	15.0	4.5	340
	07	11.9	2.9	290	3.7	3.4	290	16.4	2.6	290	14.4	5.4	290
C03	02	5.7	2.4	240	2.1	3.2	260	8.9	2.4	230	9.3	3.3	260
	03	8.6	2.6	420	3.8	3.3	540	11.1	2.5	410	13.2	4.7	540
	04	7.0	2.3	230	2.7	2.3	470	11.2	2.5	460	10.2	3.5	480
C04	09	18.6	7.0	310	10.3	10.0	320	30.	4.5	310	26.	8.6	320
	14	24.	8.8	300	11.5	11.1	290	31.	26.	280	28.	4.6	290
C05	11	7.1	1.07	530	2.7	2.1	630	10.3	3.3	550	11.3	1.86	530
C06	25	66.	26.	230	35.	24.	360	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
C07	17	14.6	2.7	280	5.9	5.9	260	33.	16.0	280	28.	8.5	260
C08	18	15.2	3.1	720	7.1	6.1	780	16.9	6.1	750	18.7	6.3	770
C09	16	12.1	4.5	620	6.3	6.5	610	18.6	10.0	600	16.4	8.1	610
C10	19	5.1	1.0	540	1.43	1.09	600	4.0	1.63	540	6.1	1.51	550
C11	12	39.	11.0	1120	19.6	14.5	1130	69.	12.7	1110	38.	11.6	1110
C12	15	4.2	1.56	1720	1.43	1.11	1730	6.8	2.9	1710	7.2	2.2	1700
C13	20	5.2	0.86	1220	1.61	1.39	1230	2.3	2.2	1230	6.6	1.56	1210
C14	21	3.7	0.78	1340	1.20	1.00	1390	5.0	1.58	1330	N.A.	0.8	1330
C15	22	3.6	0.90	310	0.95	0.85	630	4.2	4.1	300	4.2	1.02	380
C16	24	3.2	0.81	600	0.87	0.72	1470	4.6	1.83	640	3.4	1.32	620

N.A. - Not Available

Table 6. Times to exceed critical radiant heat flux (2.5 kW/m^2) (measured at west wall)

Specimen	Test	Time (s)
C01	08	--
	10	--
	13	--
	23	--
C02	05	--
	06	--
	07	150
C03	02	--
	03	370
	04	--
C04	09	230
	14	230
C05	11	--
C06	25	110
C07	17	250
C08	18	720
C09	16	550
C10	19	--
C11	12	950
C12	15	--
C13	20	--
C14	21	--
C15	22	--
C16	24	--

Table 7. Peak smoke extinction coefficients

Specimen	Test	Doorway Horizontal 0.30m below top		Doorway Vertical	
		k (m^{-1})	Time (s)	k (m^{-1})	Time (s)
C01	08	1.33	4980	1.02	4980
	10	0.83	350	0.39	350
	13	4.1	2840	2.1	2820
	23	1.0	280	0.45	280
C02	05	3.2	190	1.41	190
	06	N.A.	N.A.	N.A.	N.A.
	07	2.4	190	1.55	160
C03	02	2.9	230	1.11	230
	03	2.9	380	1.33	380
	04	2.8	240	1.20	230
C04	09	2.7	340	1.60	340
	14	2.6	310	1.48	310
C05	11	>6.7	N.A.	>2.8	N.A.
C06	25	5.6	200	2.5	210
C07	17	>6.7	N.A.	>2.8	N.A.
C08	18	6.4	220	2.6	250
C09	16	1.58	600	0.96	610
C10	19	>6.7	N.A.	2.0	610
C11	12	4.4	1110	2.5	1120
C12	15	0.50	540	N.A.	N.A.
C13	20	2.7	790	1.36	750
C14	21	1.18	610	0.68	380
C15	22	3.3	330	1.47	320
C16	24	1.73	600	0.89	590

N.A. - Not Available

Table 8. Times to exceed critical level of smoke extinction coefficient

Specimen	Test	Time to Reach $k = 1.2m^{-1}$ 0.30m Below Top of Doorway (s)
C01	08	4980
	10	--
	13	1660
	23	--
C02	05	150
	06	N.A.
	07	150
C03	02	210
	03	380
	04	220
C04	09	210
	14	220
C05	11	210
C06	25	100
C07	17	120
C08	18	140
C09	16	470
C10	19	480
C11	12	940
C12	15	--
C13	20	650
C14	21	--
C15	22	280
C16	24	490

N.A. - Not Available

Table 9. Peak gas concentrations

Specimen	Test	Oxygen Min. (%)	Oxygen Time (s)	Carbon Dioxide Peak (%)	Carbon Dioxide Time (s)	Carbon Monoxide Peak (ppm)	Carbon Monoxide Time (s)
C01	08	17.0	5110	3.2	5110	600	5820
	10	18.3	420	2.4	420	670	690
	13	18.0	2940	3.0	2940	1530	2840
	23	17.9	320	2.7	320	850	660
C02	05	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
	06	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
	07	13.4	320	6.3	330	1030	1740
C03	02	16.5	280	4.4	280	460	1680
	03	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
	04	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
C04	09	11.0	340	N.A.	N.A.	1200	350
	14	9.6	310	12.0	310	560	520
C05	11	17.3	590	2.8	620	2200	530
C06	25	1.78	300	17.0	310	22400	280
C07	17	12.0	300	7.6	300	5800	310
C08	18	13.2	750	5.8	750	900	780
C09	16	14.1	620	6.0	630	610	620
C10	19	18.1	570	2.3	590	3000	580
C11	12	6.4	1140	16.9	1140	3300	1140
C12	15	17.9	1710	2.6	1730	800	2080
C13	20	17.2	1400	1.73	970	810	1180
C14	21	17.3	1630	1.52	1630	1020	1570
C15	22	18.5	330	2.0	330	1040	320
C16	24	18.9	670	1.85	650	1070	940

N.A. - Not Available

Table 10. Calculated COHb values at different times
(In percent)

Specimen	Test	600 s	1200 s	1800 s	2400 s	3000 s	3600 s	4200 s	4800 s	5400 s	6000 s	6600 s
C01	08	0.75	0.75	0.75	0.75	0.75	2.3	5.4	8.1	10.9	14.5	17.2
	10	1.57	5.3	9.0								
	13	0.75	0.75	1.58	5.7	11.8	16.1	18.6	22.9			
	23	2.6	8.0	12.6	16.5							
C02	05	N.A.										
	06	N.A.										
	07	4.5	10.2	16.4	20.3							
C03	02	1.66	4.5	7.4								
	03	N.A.										
	04	N.A.										
C04	09	3.2	6.1	8.6								
	14	3.0	5.0	9.0								
C05	11	8.3	13.8									
C06	25	>25.0										
C07	17	16.4	18.9									
C08	18	7.9	11.3	12.6	13.1	13.5						
C09	16	2.0	4.1	6.1								
C10	19	4.8	18.3	21.7	24.3	>25.0						
C11	12	0.92	4.7	5.4								
C12	15	2.3	5.8	9.8	14.7							
C13	20	2.2	6.1	11.4	16.4	20.2	22.9					
C14	21	3.3	8.3	15.1	22.0							
C15	22	3.2										
C16	24	2.7	8.3	14.2	21.4							

Table 11. Times to exceed critical gas concentrations

Specimen	Test	O_2 = 14% Time (s)	CO_2 = 8% Time (s)	COHb = 25% Time (s)
C01	08	--	--	--
	10	--	--	--
	13	--	--	--
	23	--	--	--
C02	05	N.A.	N.A.	N.A.
	06	N.A.	N.A.	N.A.
	07	310	--	--
C03	02	--	--	--
	03	N.A.	N.A.	N.A.
	04	N.A.	N.A.	N.A.
C04	09	310	N.A.	--
	14	290	290	--
C05	11	--	--	--
C06	25	170	210	340
C07	17	270	--	--
C08	18	740	--	--
C09	16	--	--	--
C10	19	--	--	2590
C11	12	1000	1010	--
C12	15	--	--	--
C13	20	--	--	--
C14	21	--	--	2690
C15	22	--	--	--
C16	24	--	--	--

N.A. - Not Available

Table 12. Tenability groups

Group	Specimen	Type	Flashover Criterion: Time to Reach Full Involvement (s)	Tenability Criteria--Time to Reach Critical Values: Gas Concentration (s)	Radiant Heat Flux (s)	Smoke Obscuration (s)
A	C01	Traditional	--	--	--	--
	C12	Traditional	--	--	--	--
B	C13	Traditional	--	--	--	650
	C16	Traditional	--	--	--	490
	C15	Traditional	--	--	--	280
	C03	Traditional	--	--	--	215
	C05	Bean Bag	--	--	--	210
	C02	Traditional	--	N.A.	--	150
C	C14	Traditional	--	2690	--	--
	C10	Modern	--	2590	--	480
	C11	Foam Block	--	1000	950	940
	C08	Modern	--	740	720	140
	C09	Modern	--	--	550	470
	C07	Modern	--	270	250	120
	C04	Traditional	--	290	230	210
D	C06	Foam Block	280	170	110	100

N.A. - Not Available

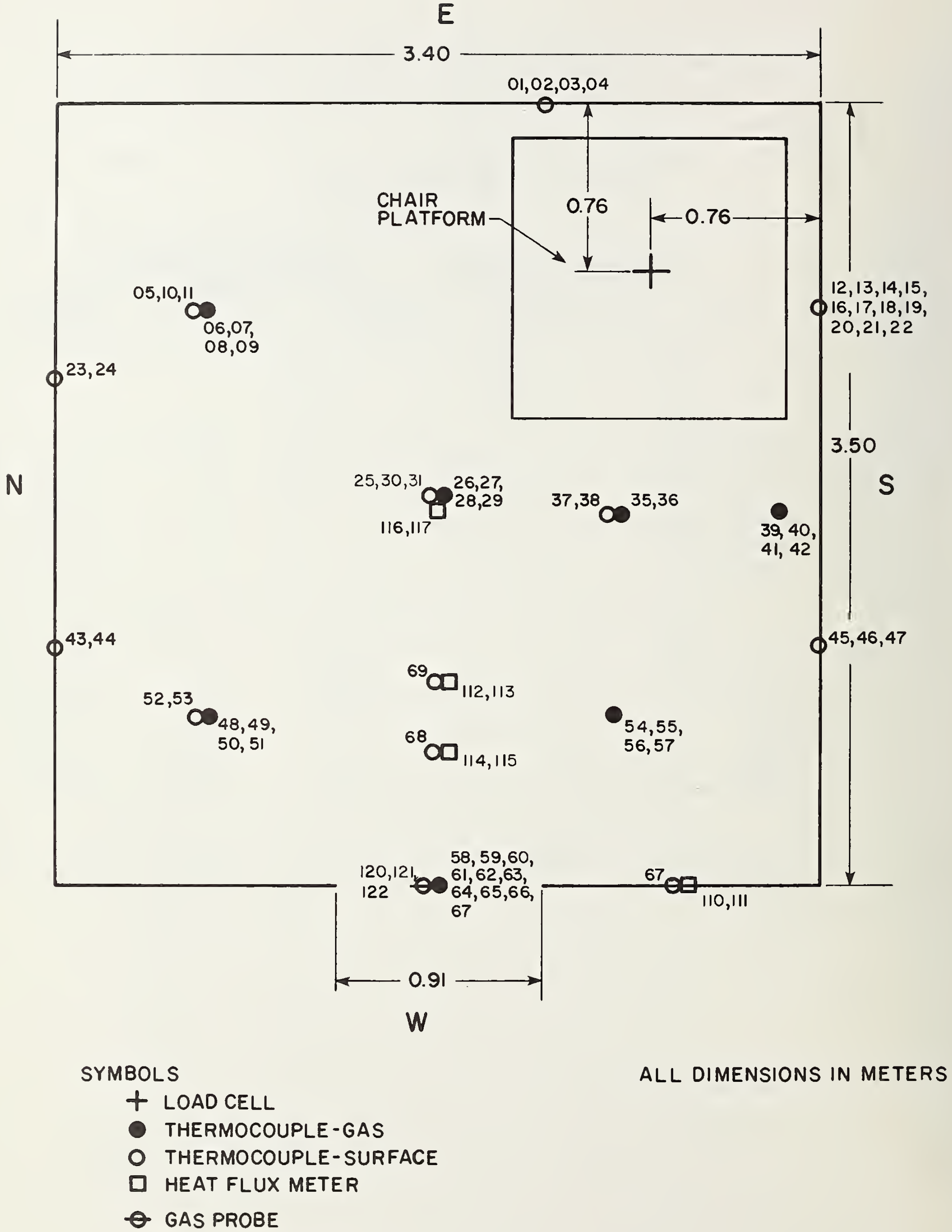


Figure 1. Burn room plan view

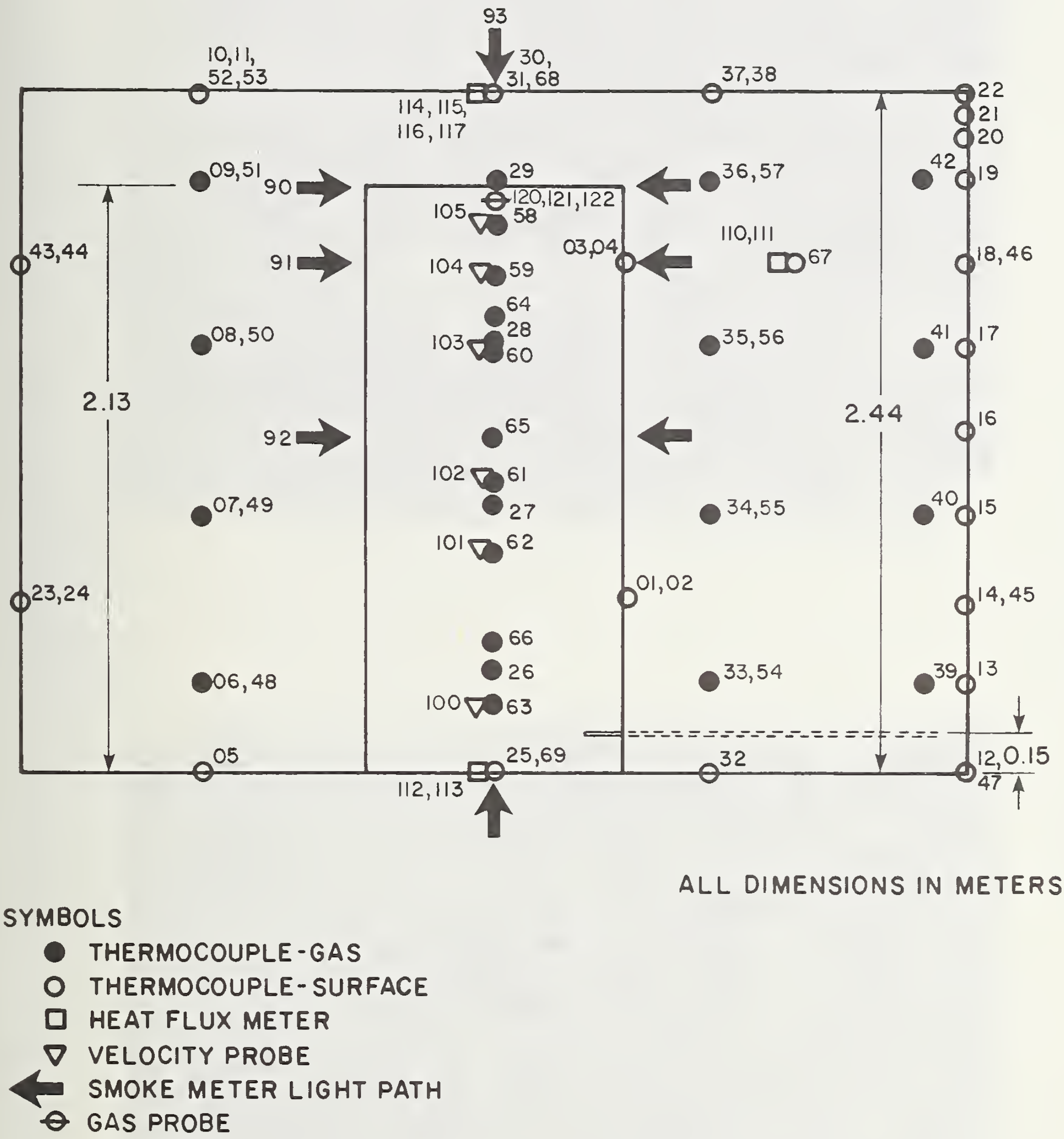


Figure 2. Burn room elevation

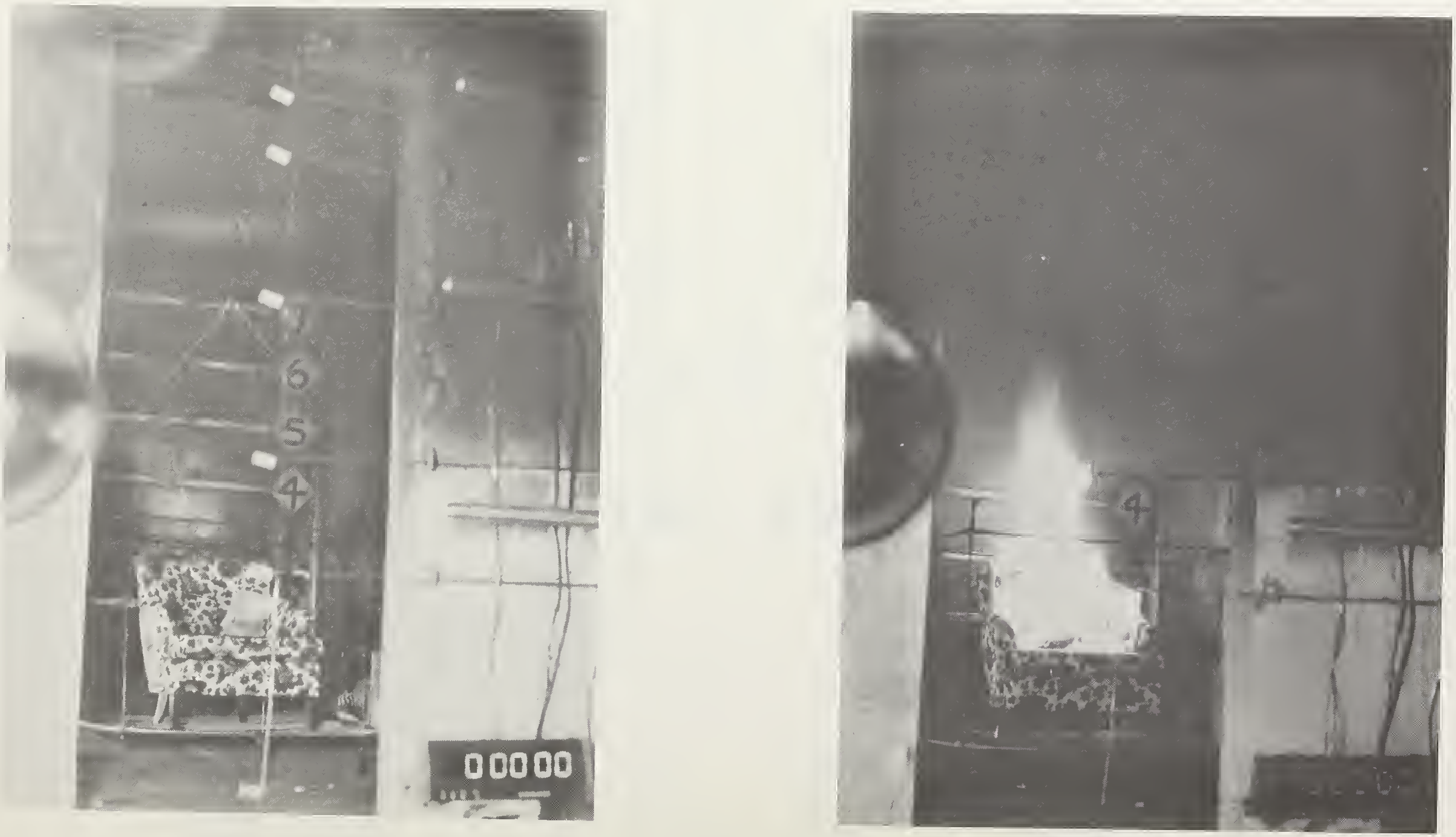


Figure 3. View of chair C01

Figure 4. View of chair C02

Figure 5. View of chair C03

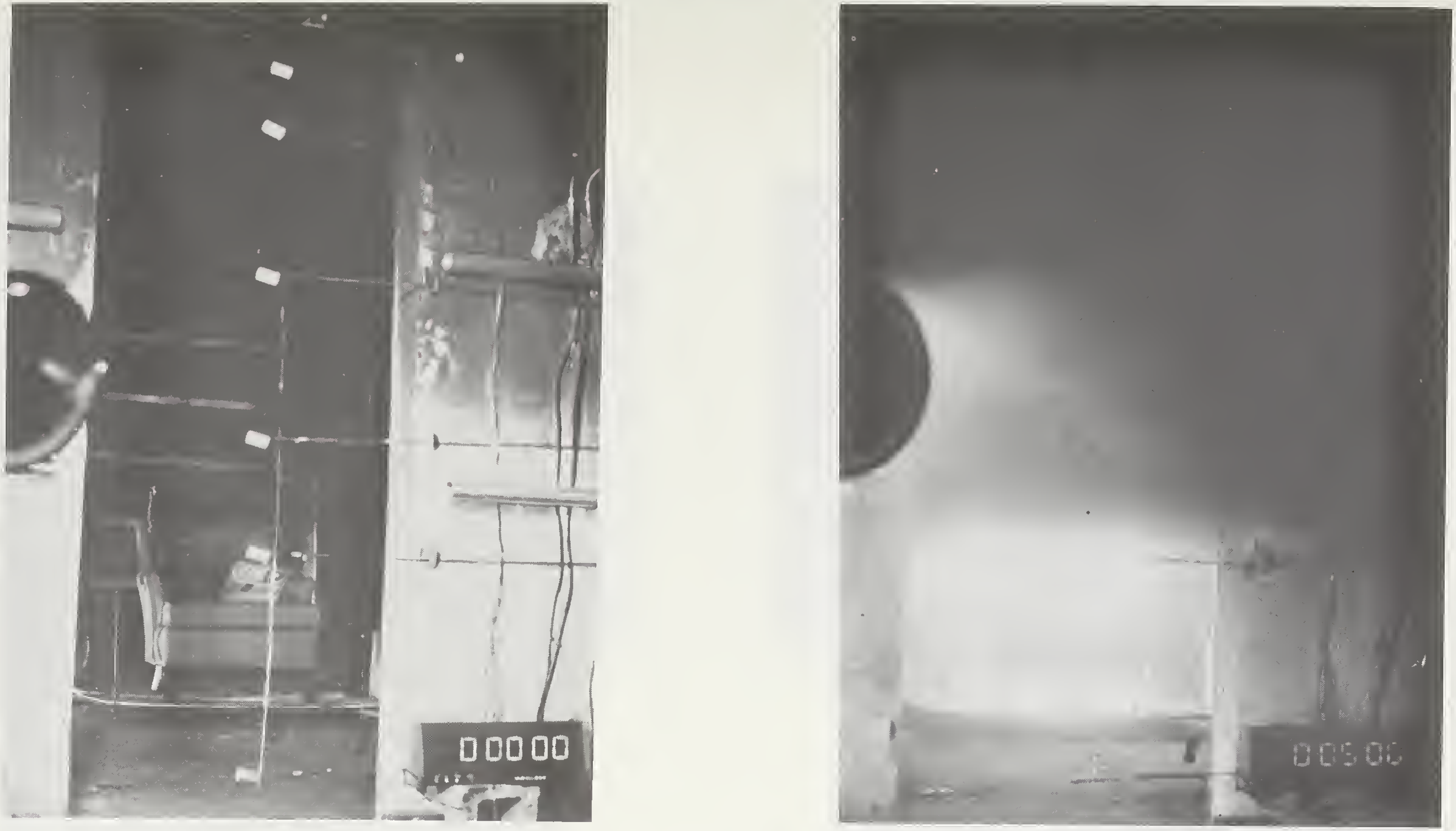


Figure 6. View of chair C04

Figure 7. View of chair C05

Figure 8. View of chair C06

Figure 9. View of chair C07

Figure 10. View of chair C08

Figure 11. View of chair C09

Figure 12. View of chair C10

Figure 13. View of chair C11

Figure 14. View of chair C12

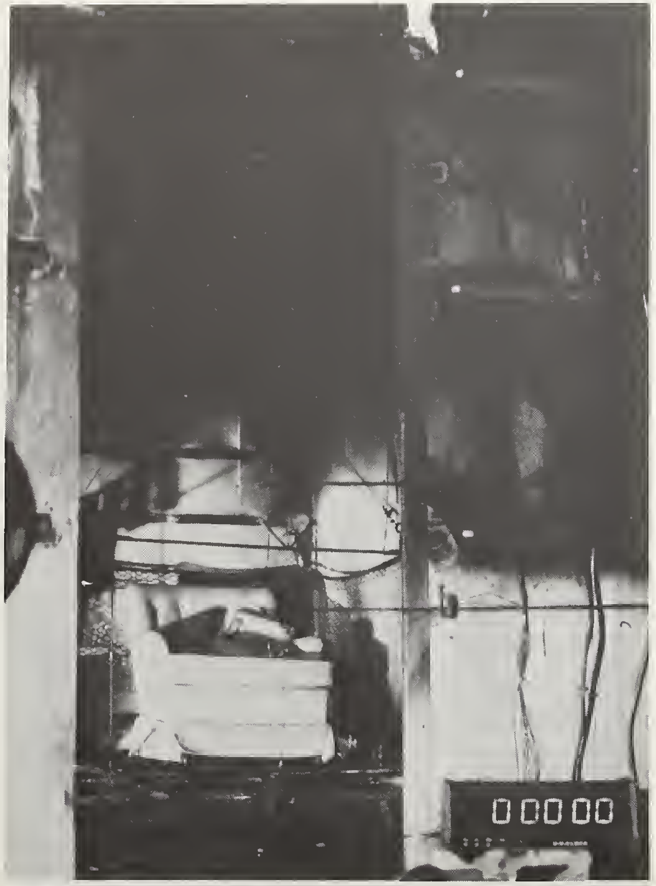


Figure 15. View of chair C13

Figure 16. View of chair C14

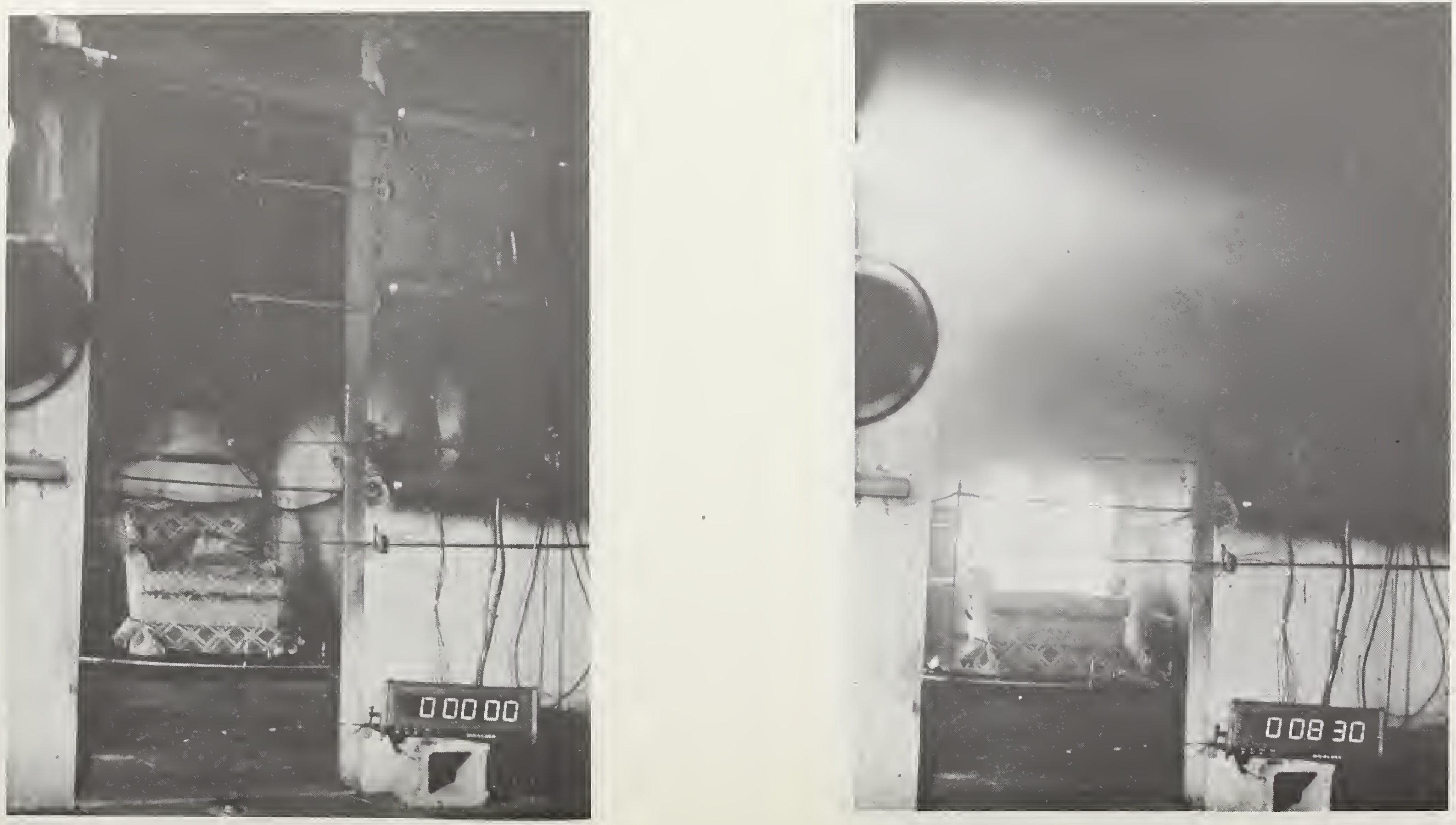


Figure 17. View of chair C15

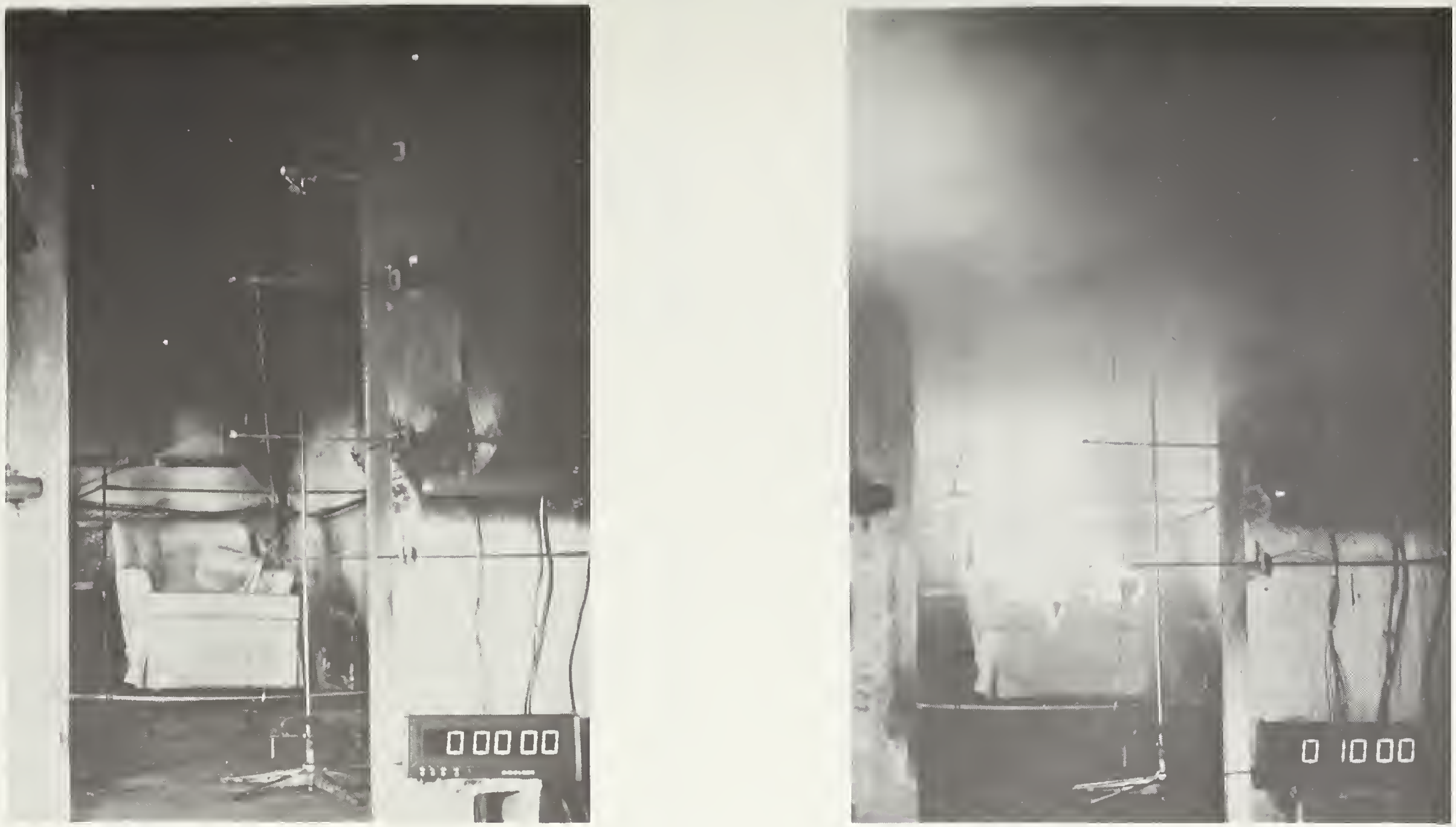


Figure 18. View of chair C16

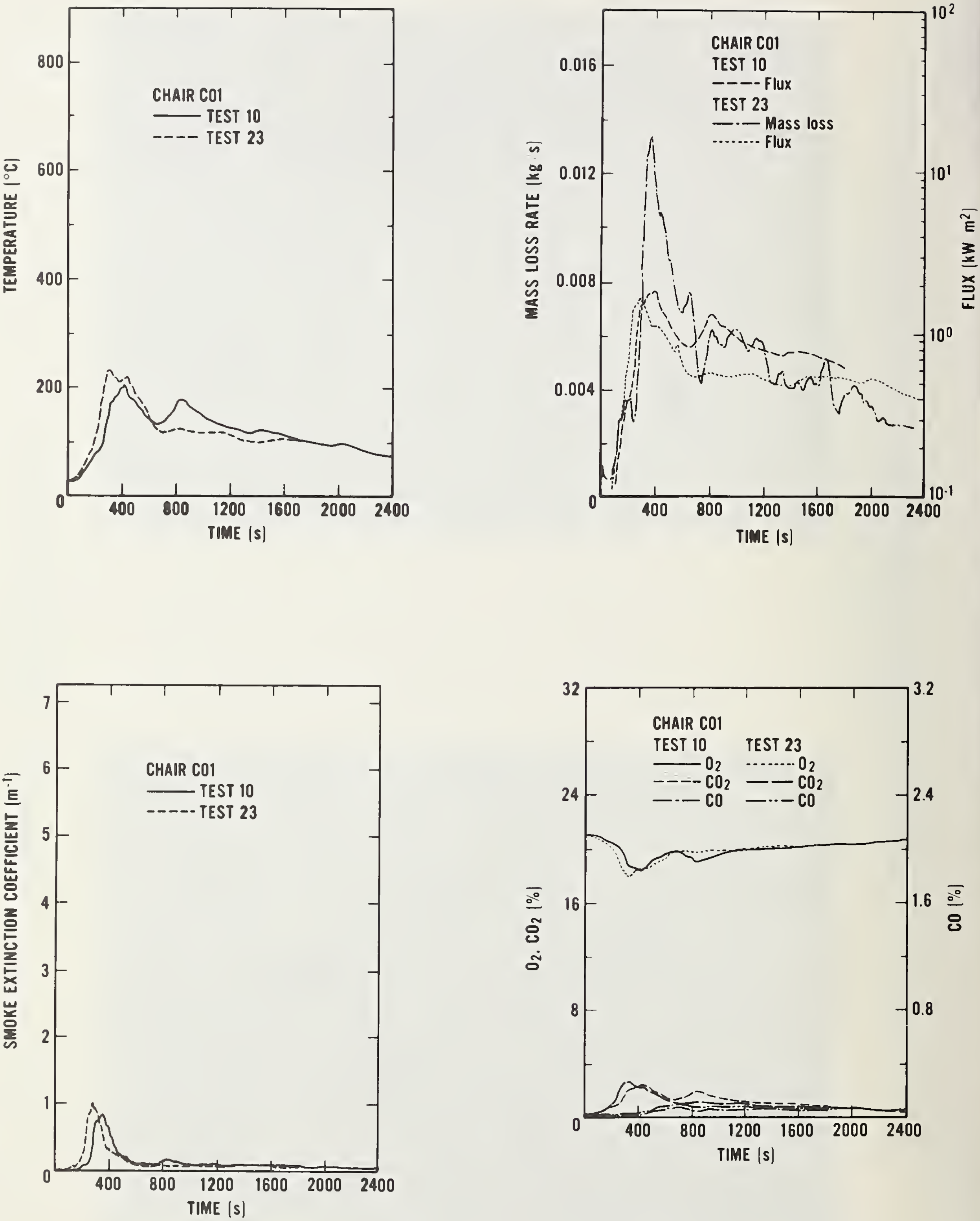


Figure 19. Results for chair C01, standard ignition

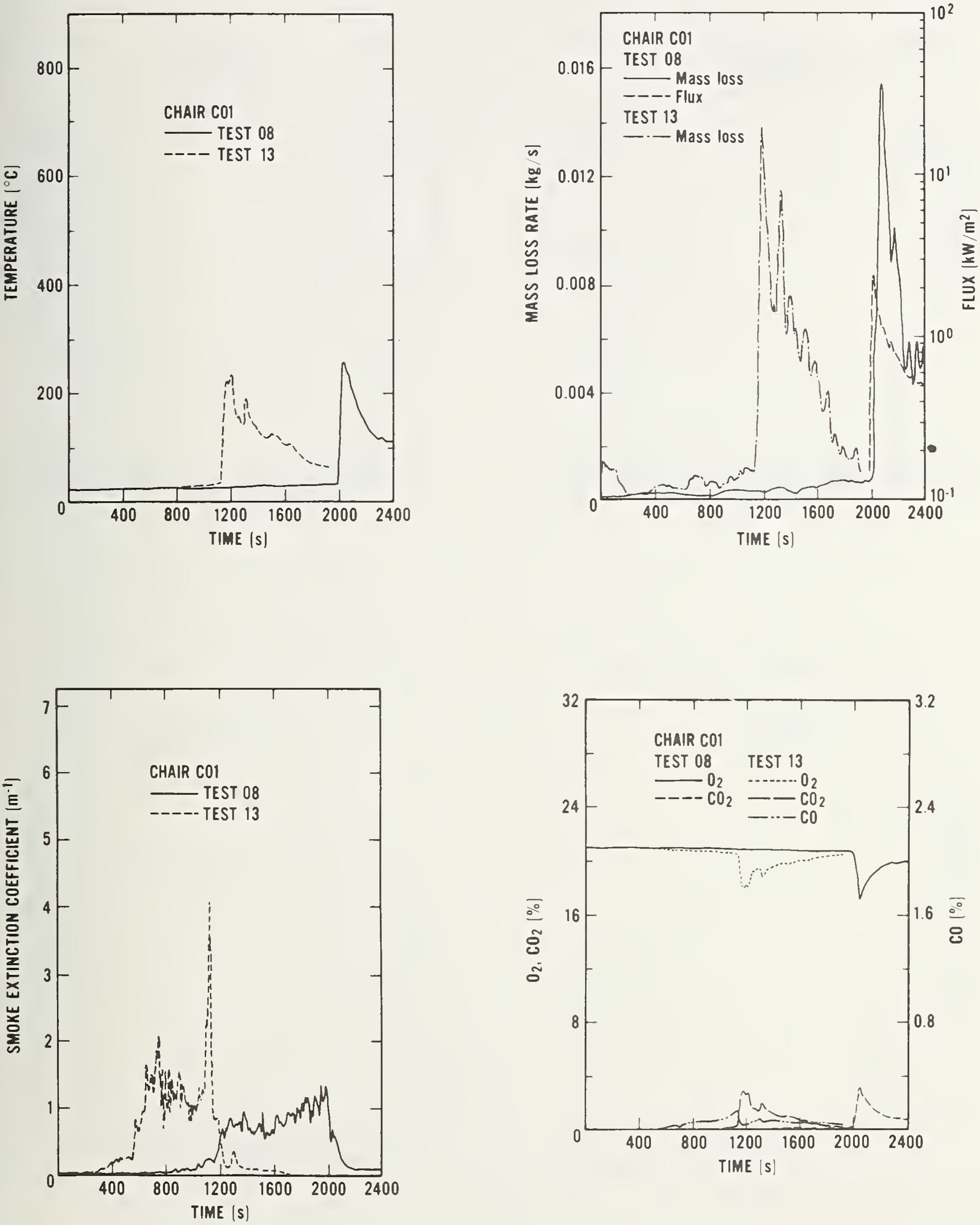


Figure 20. Results for chair C01, cigarette ignition

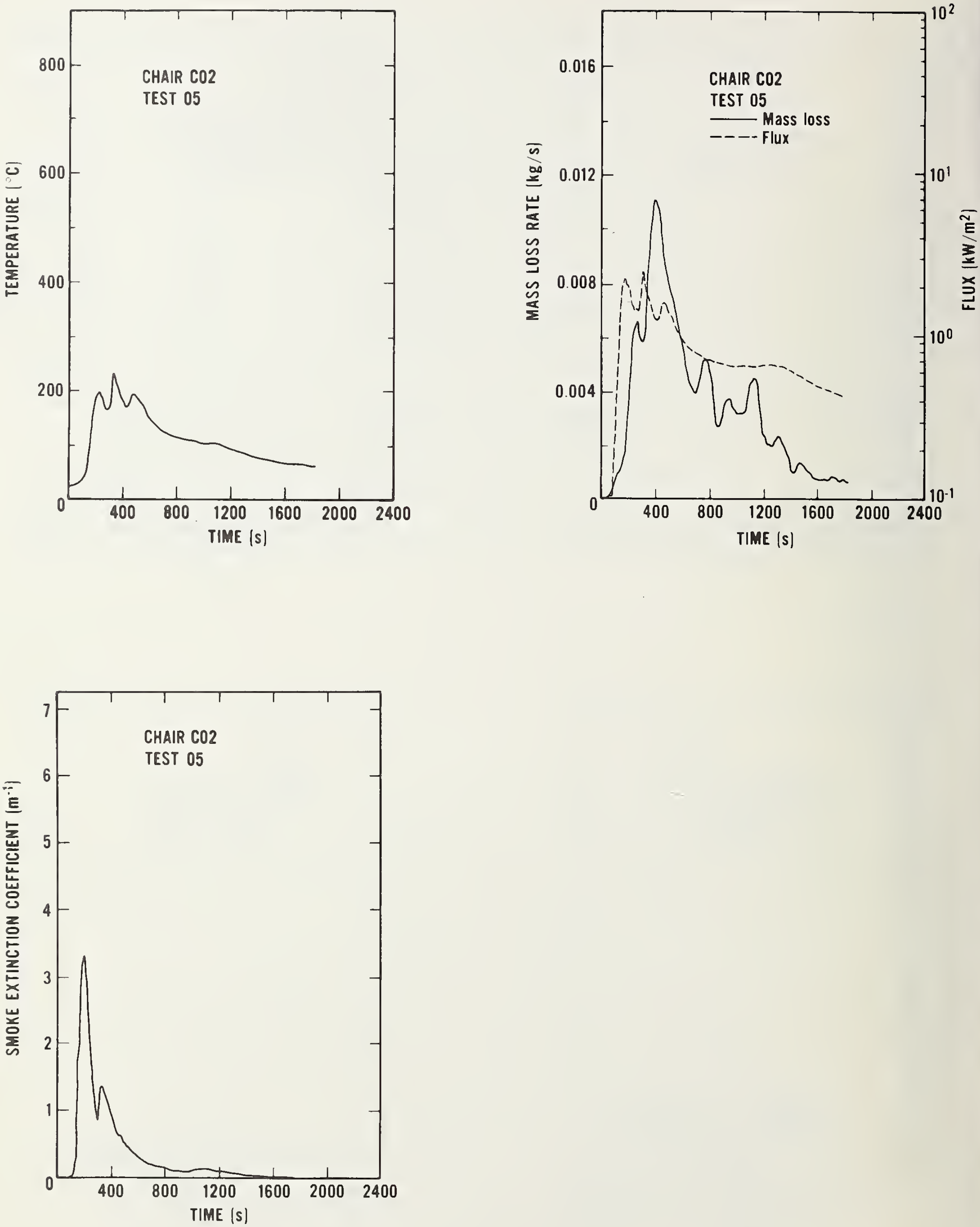
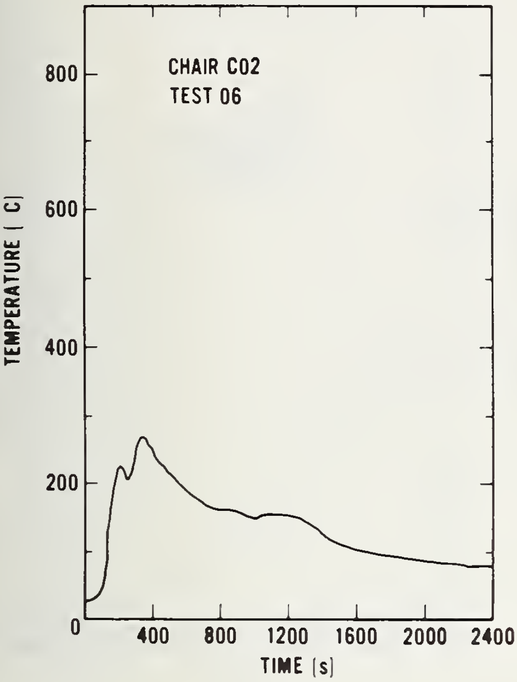
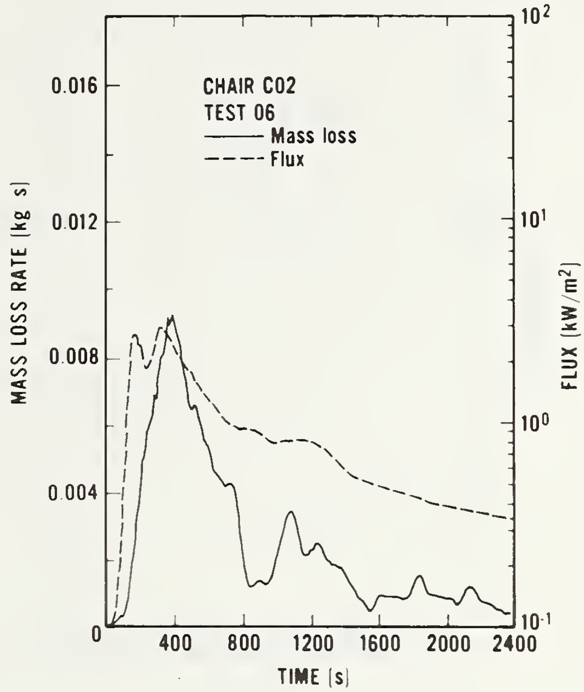


Figure 21. Results for chair C02, standard ventilation





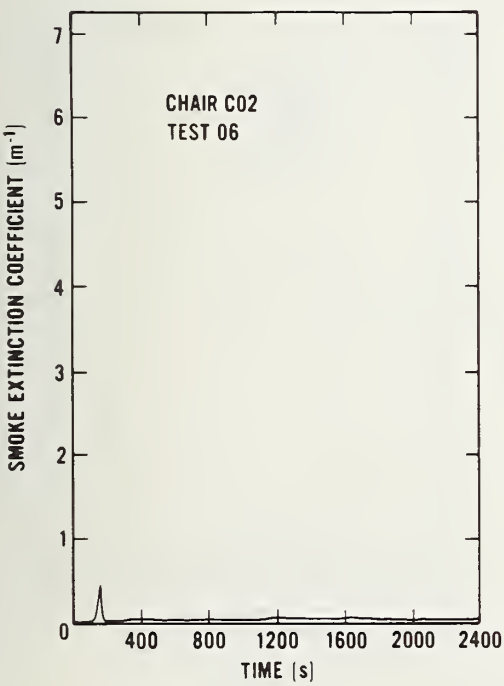


Figure 22. Results for chair C02, window ventilation

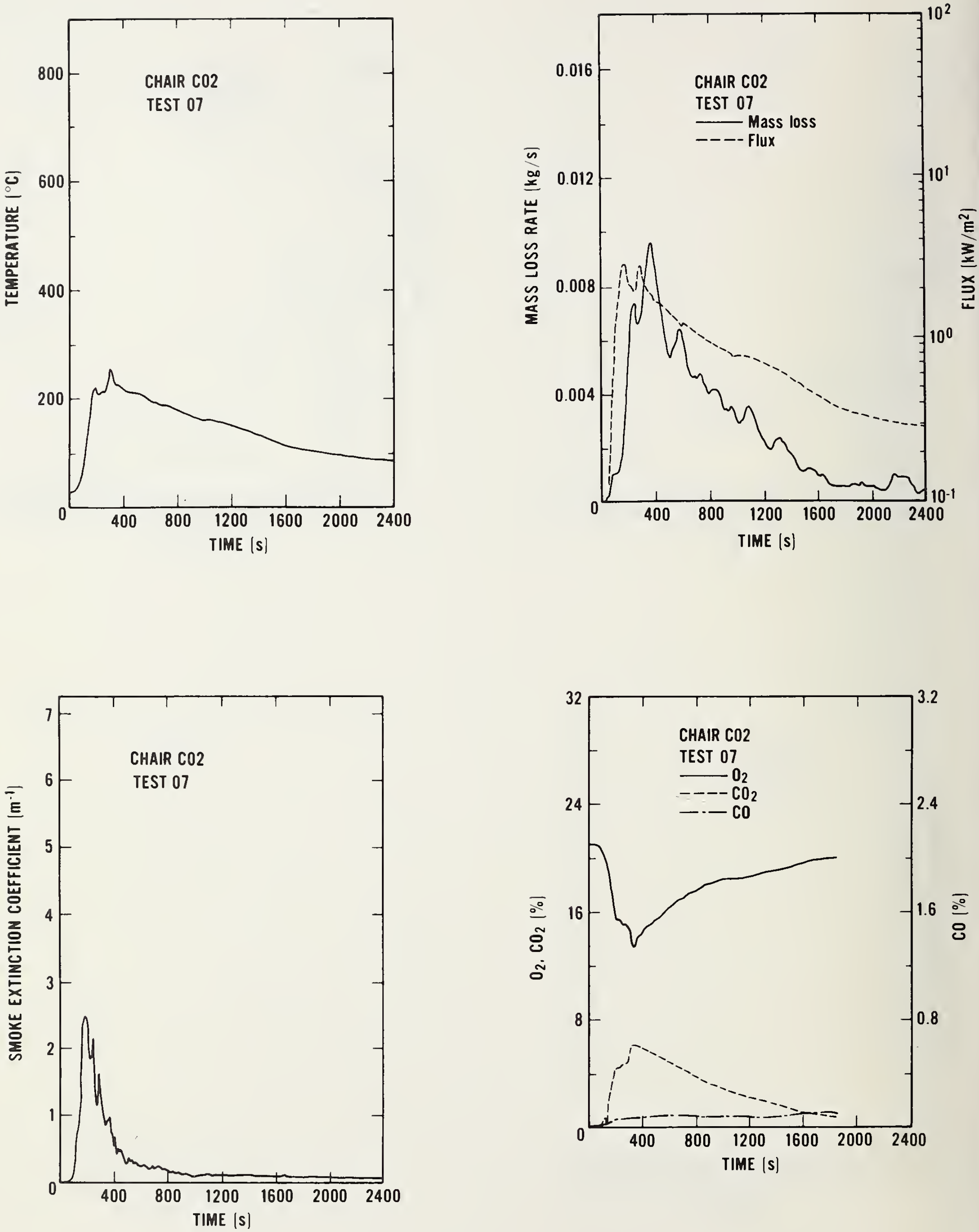


Figure 23. Results for chair C02, part-open door

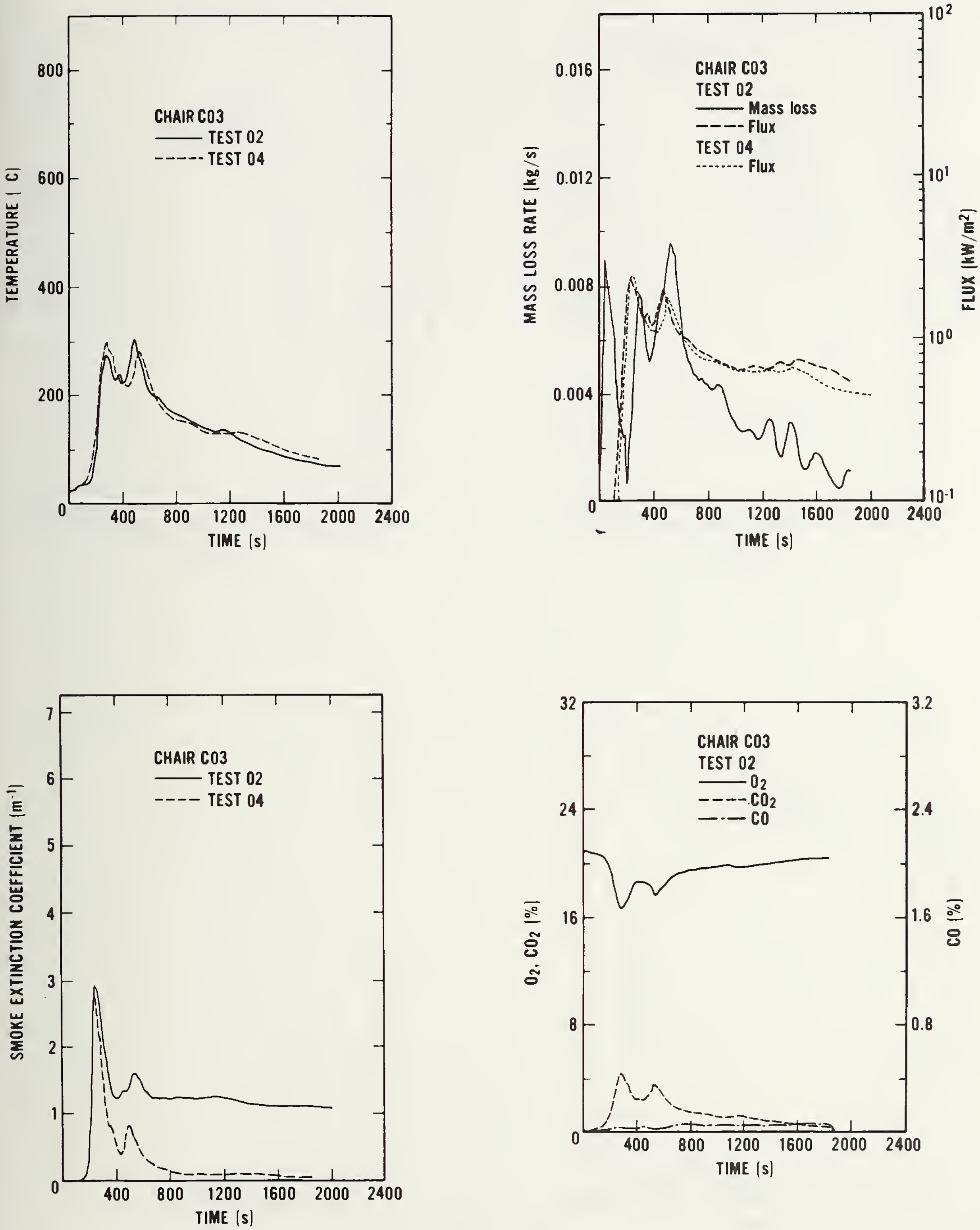


Figure 24. Results for chair C03, standard ignition

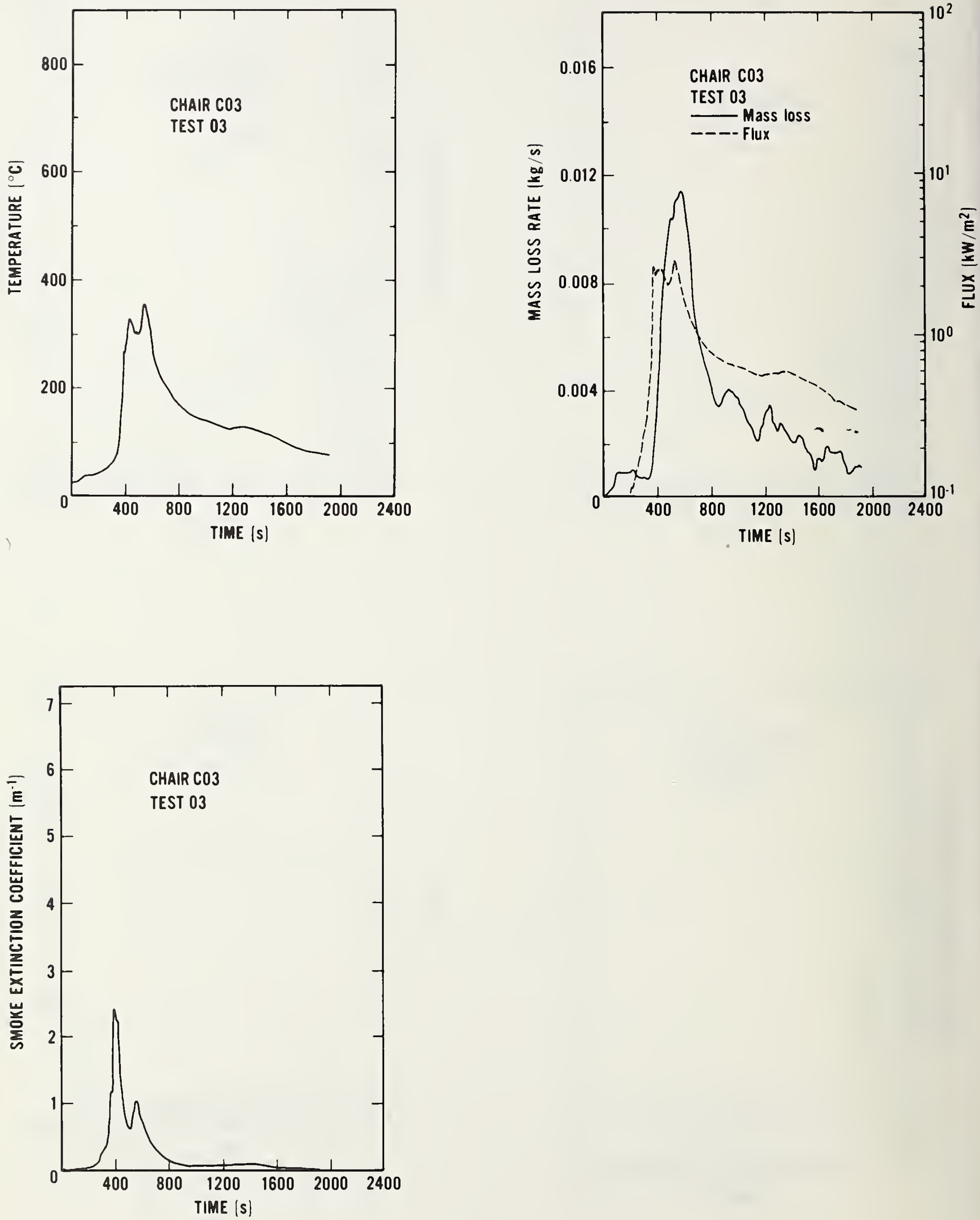


Figure 25. Results for chair C03, wastebasket ignition

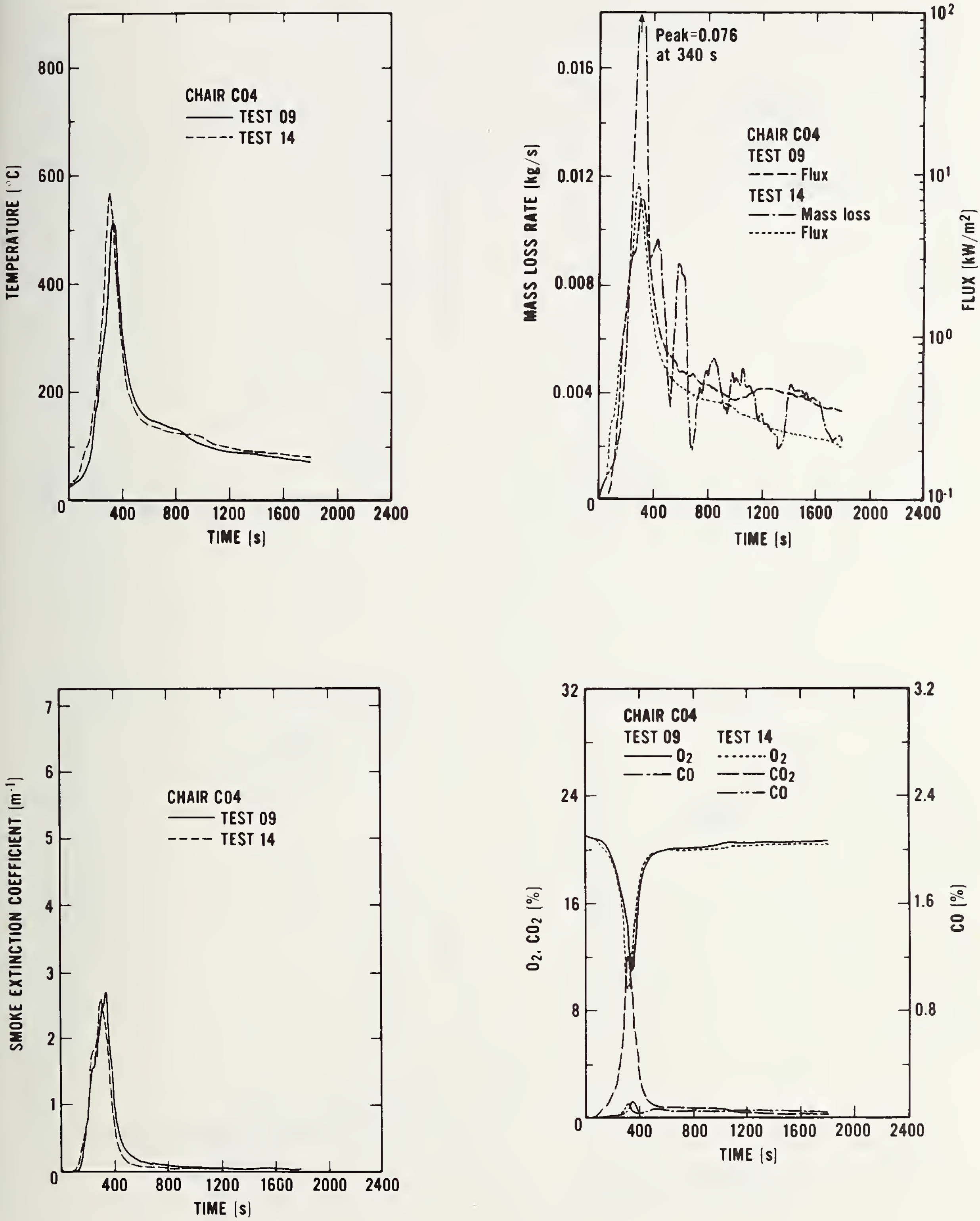


Figure 26. Results for chair C04

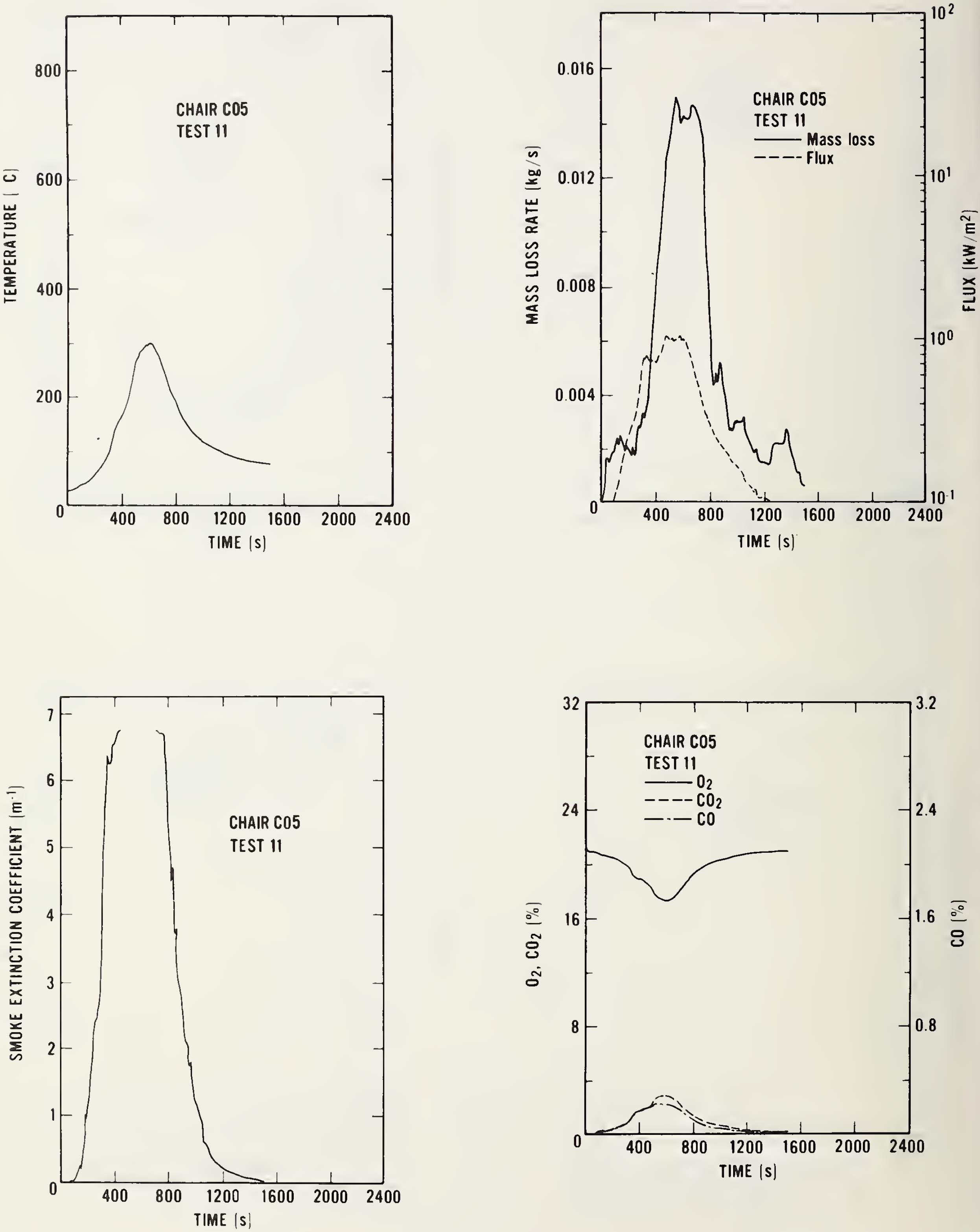


Figure 27. Results for chair C05

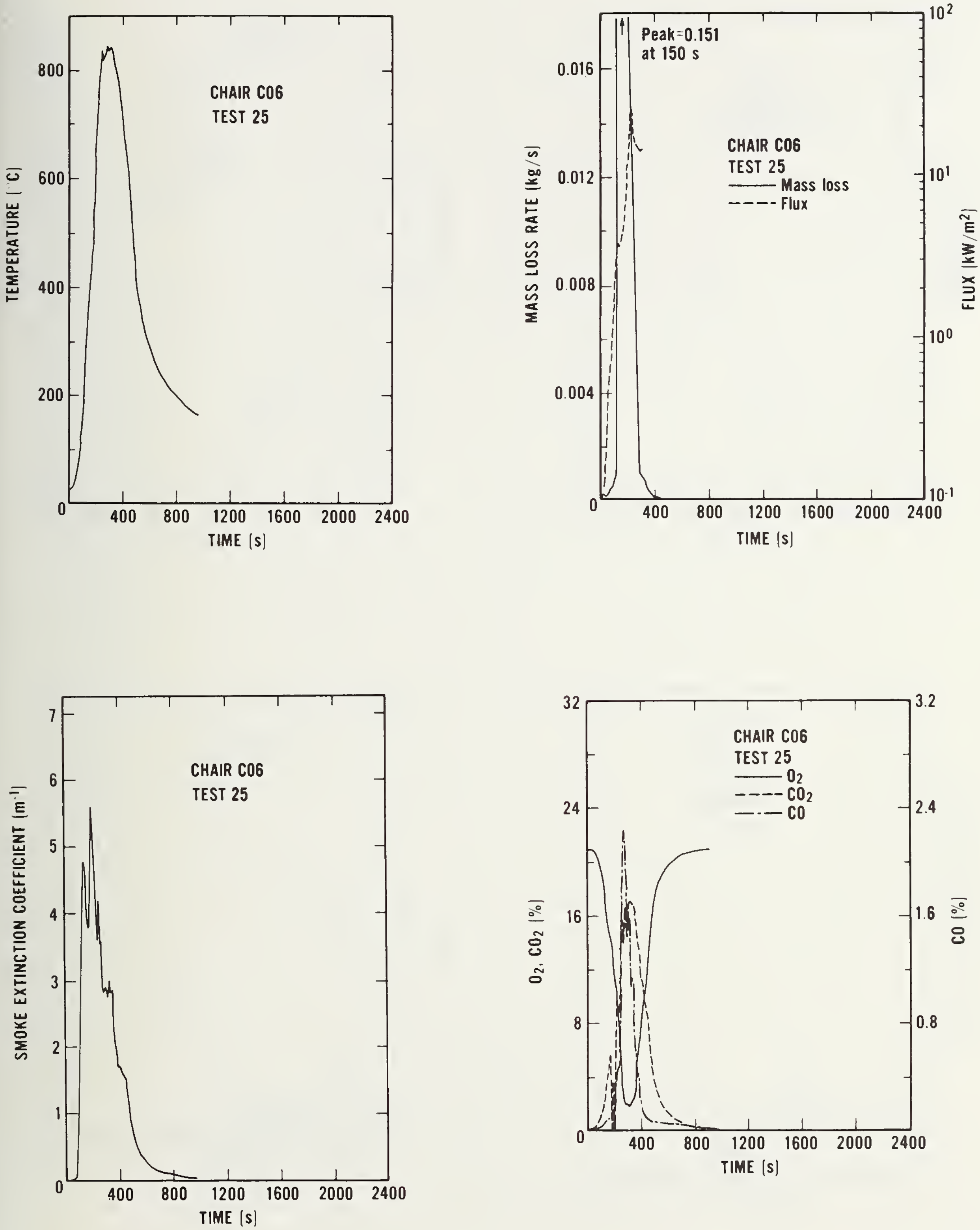


Figure 28. Results for chair C06

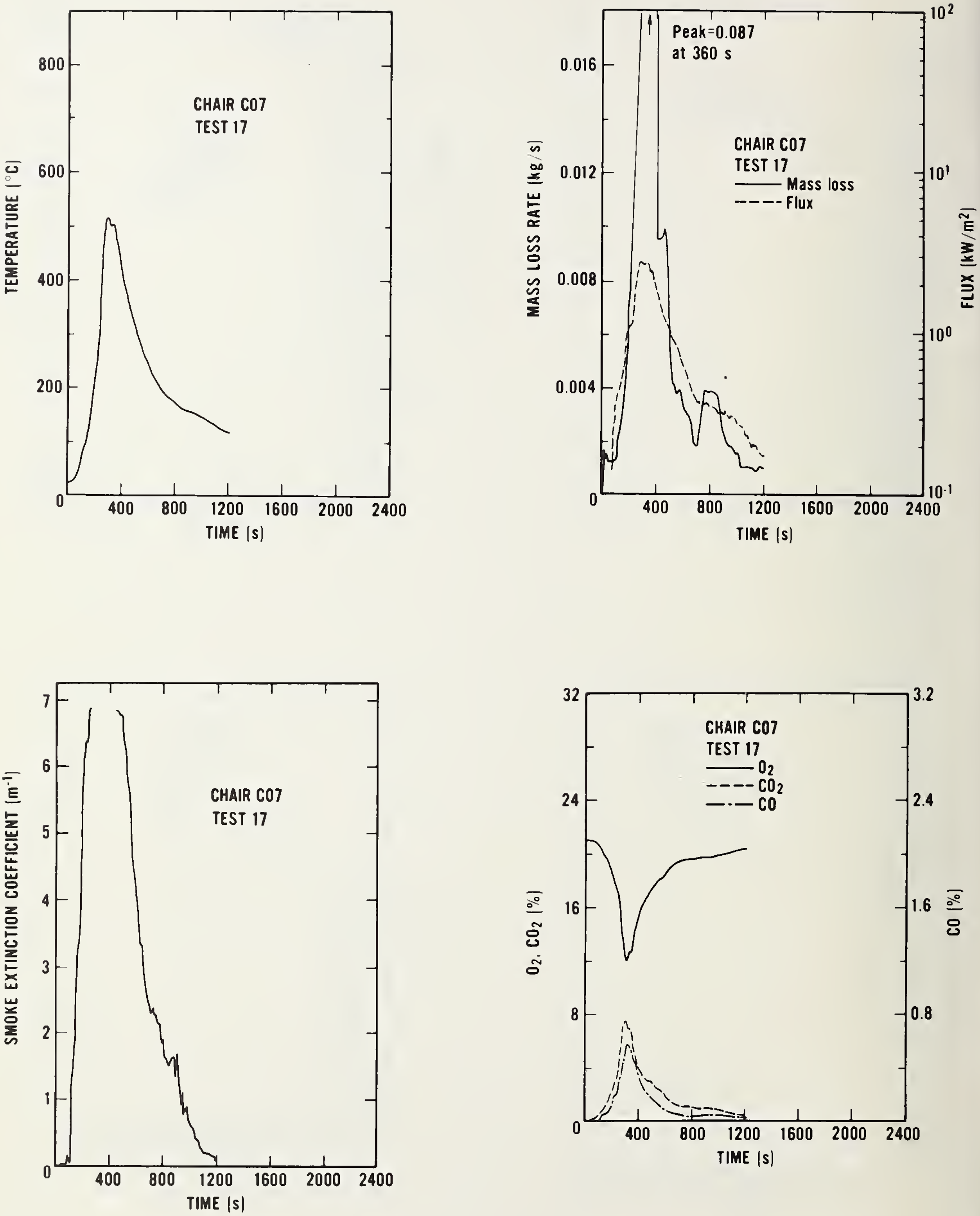


Figure 29. Results for chair C07

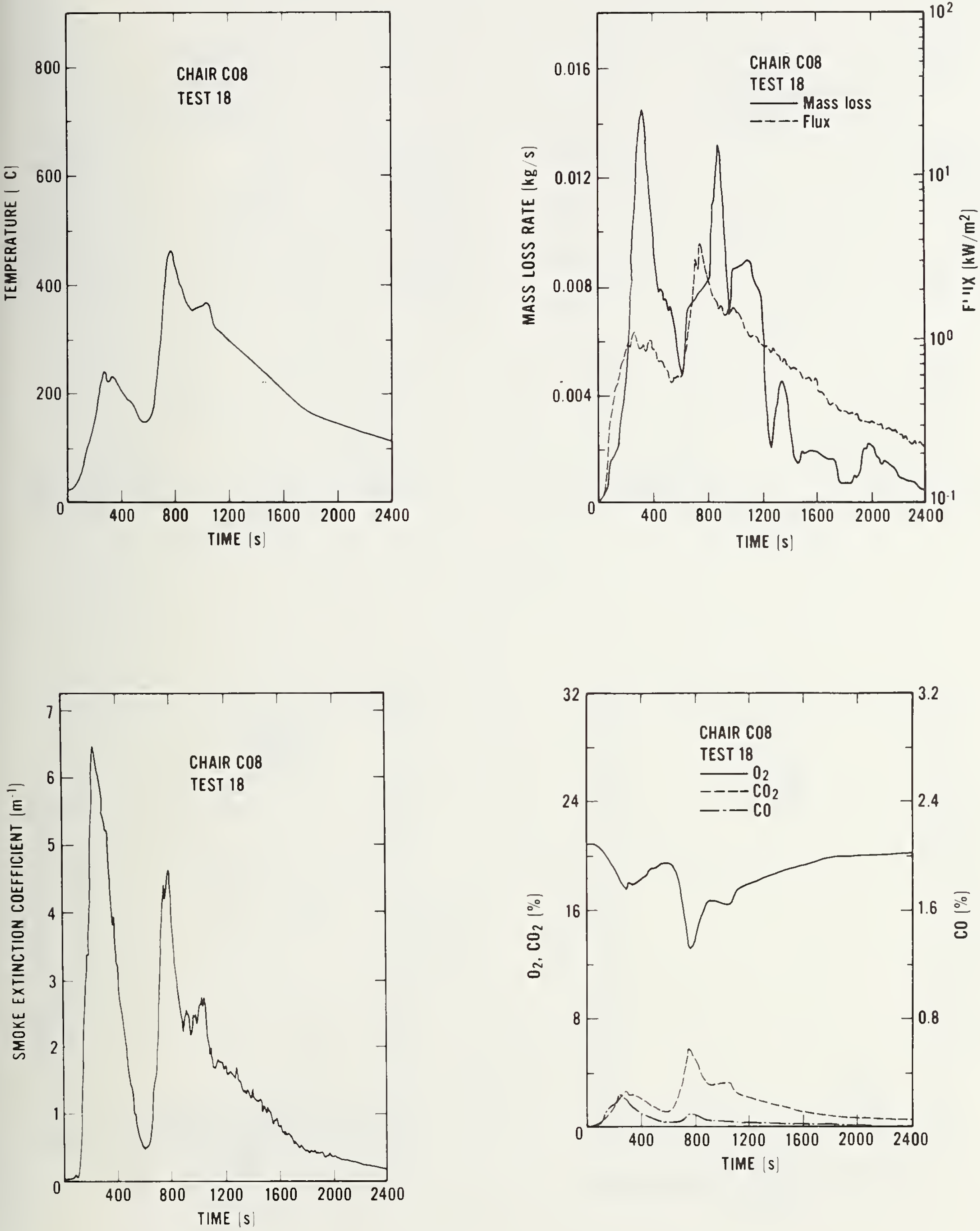


Figure 30. Results for chair C08

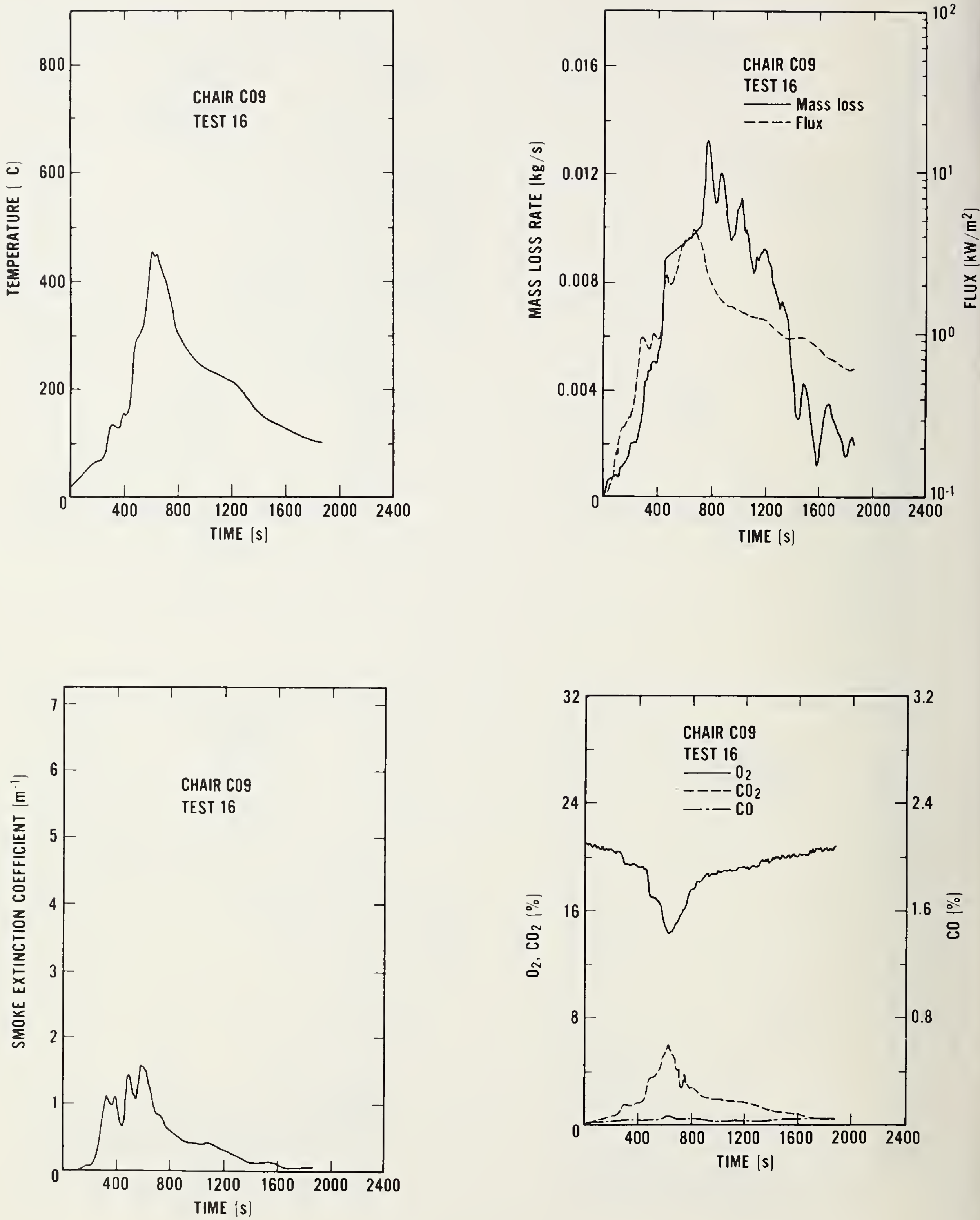


Figure 31. Results for chair C09

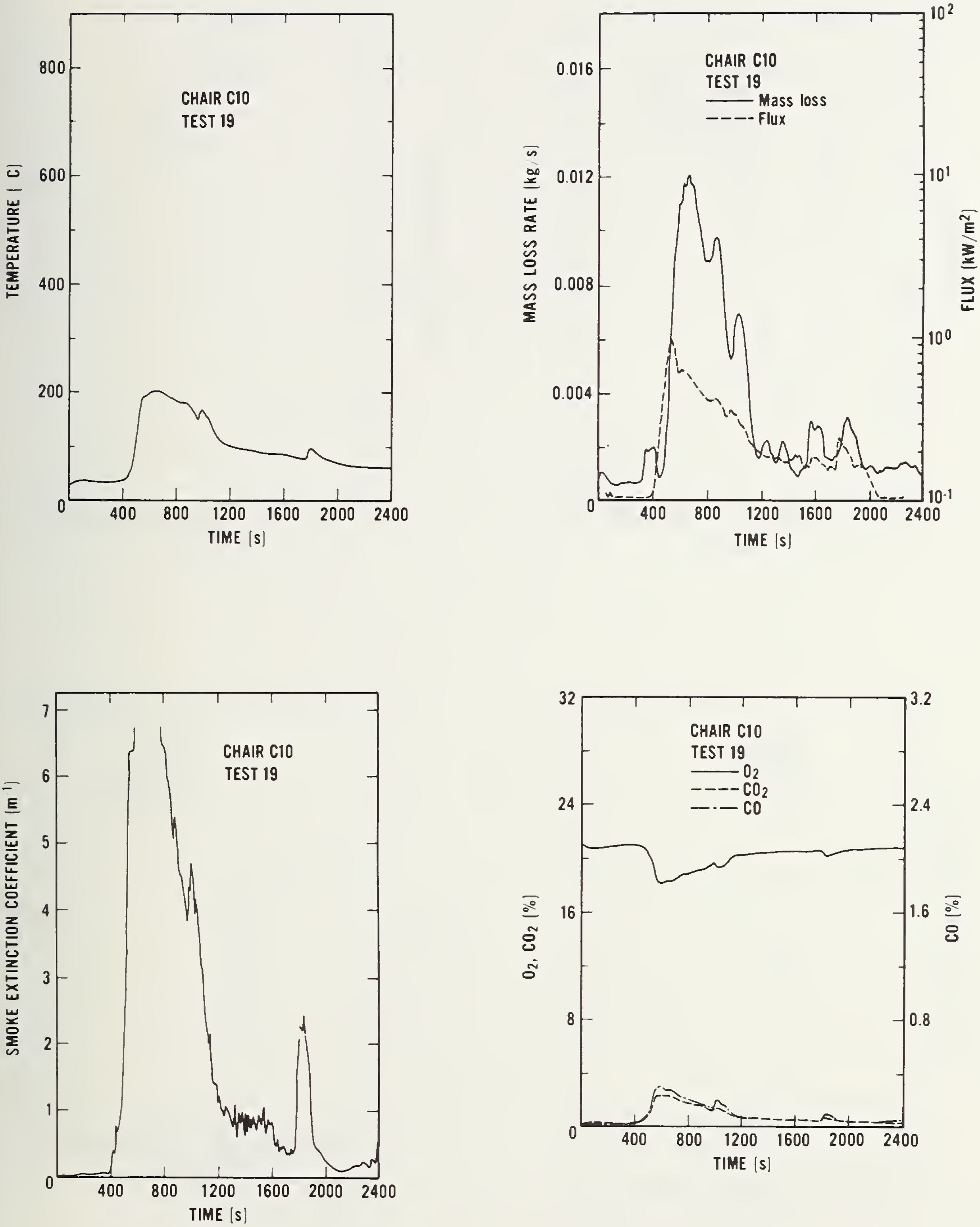


Figure 32. Results for chair C10

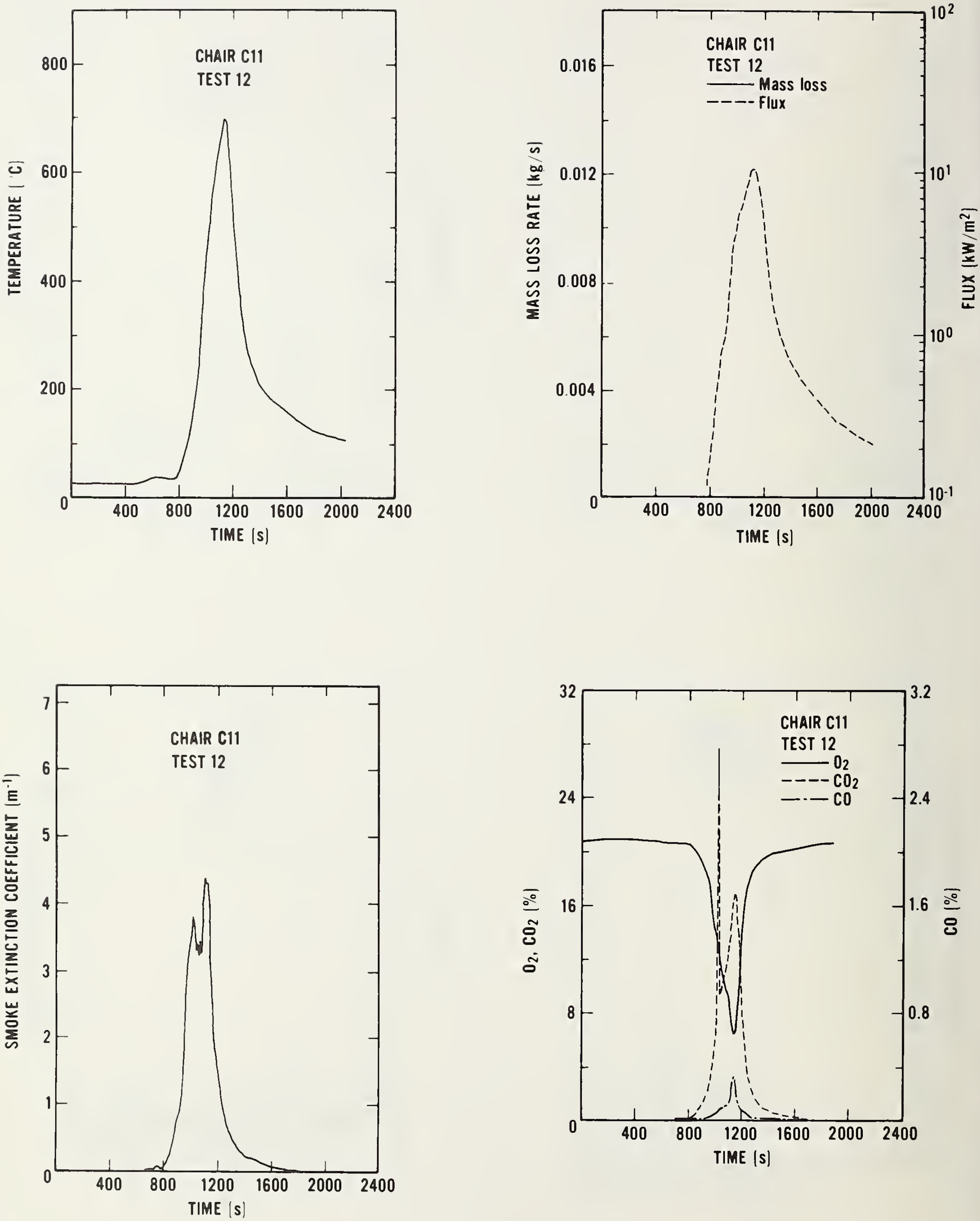


Figure 33. Results for chair C11

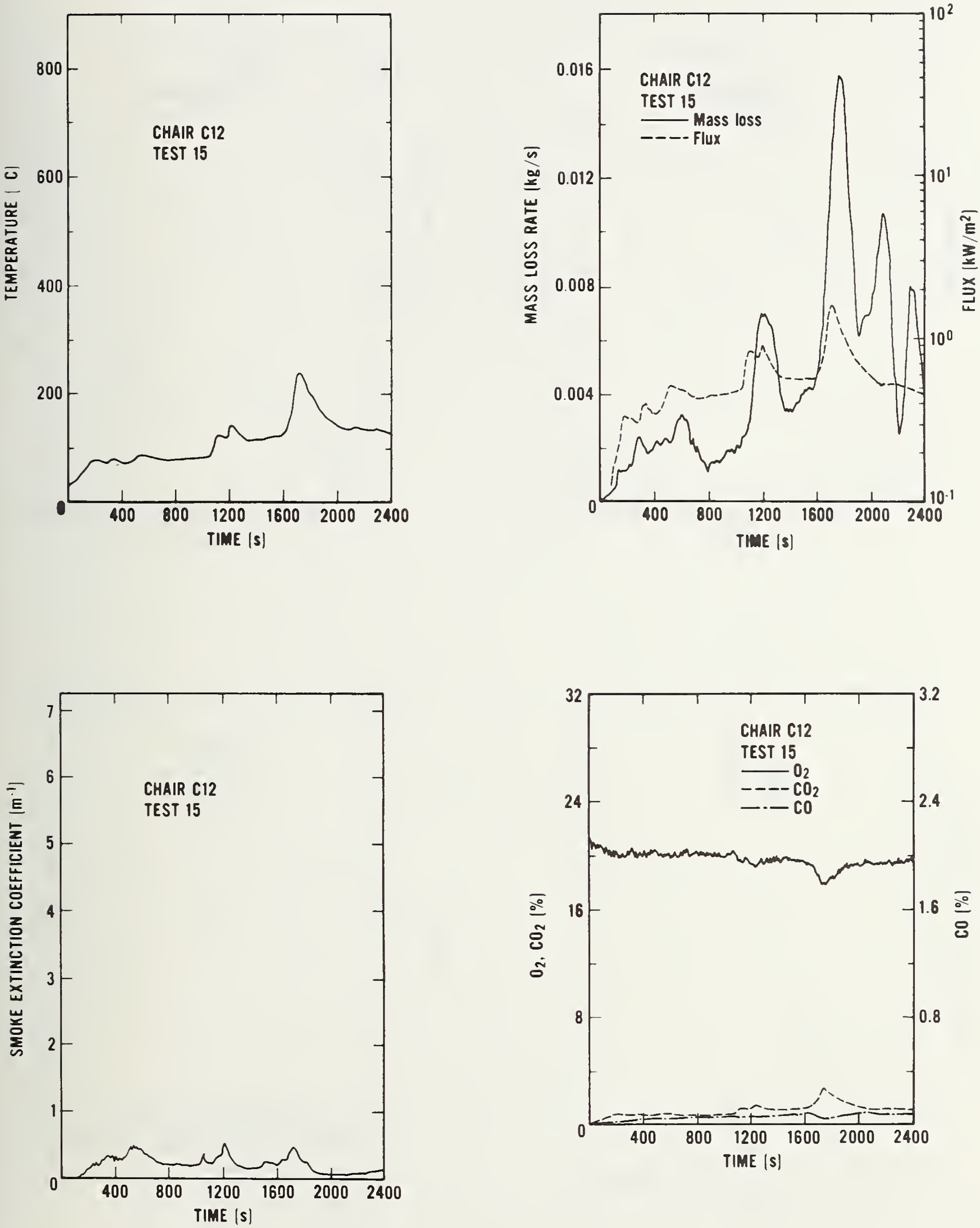


Figure 34. Results for chair C12

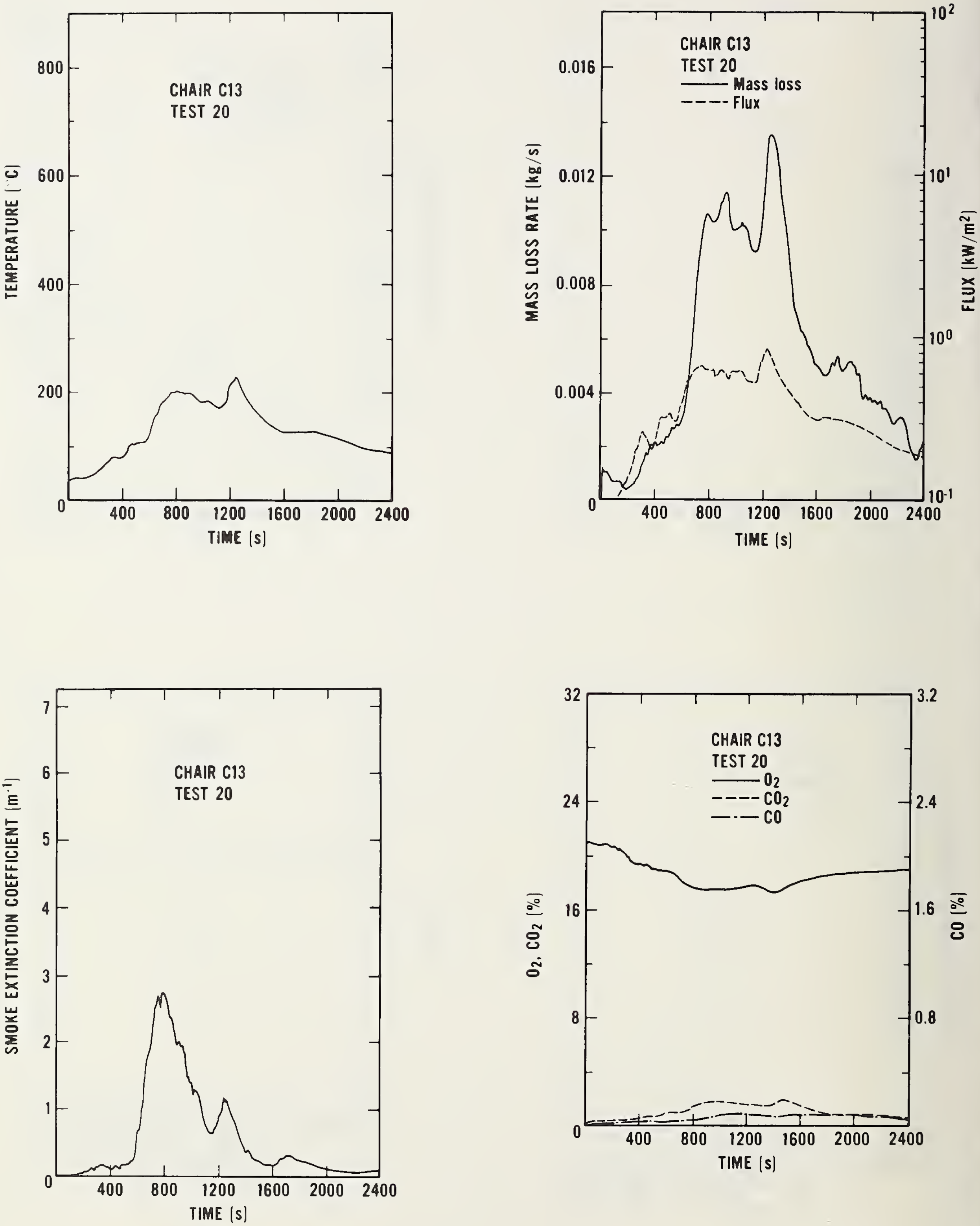


Figure 35. Results for chair C13

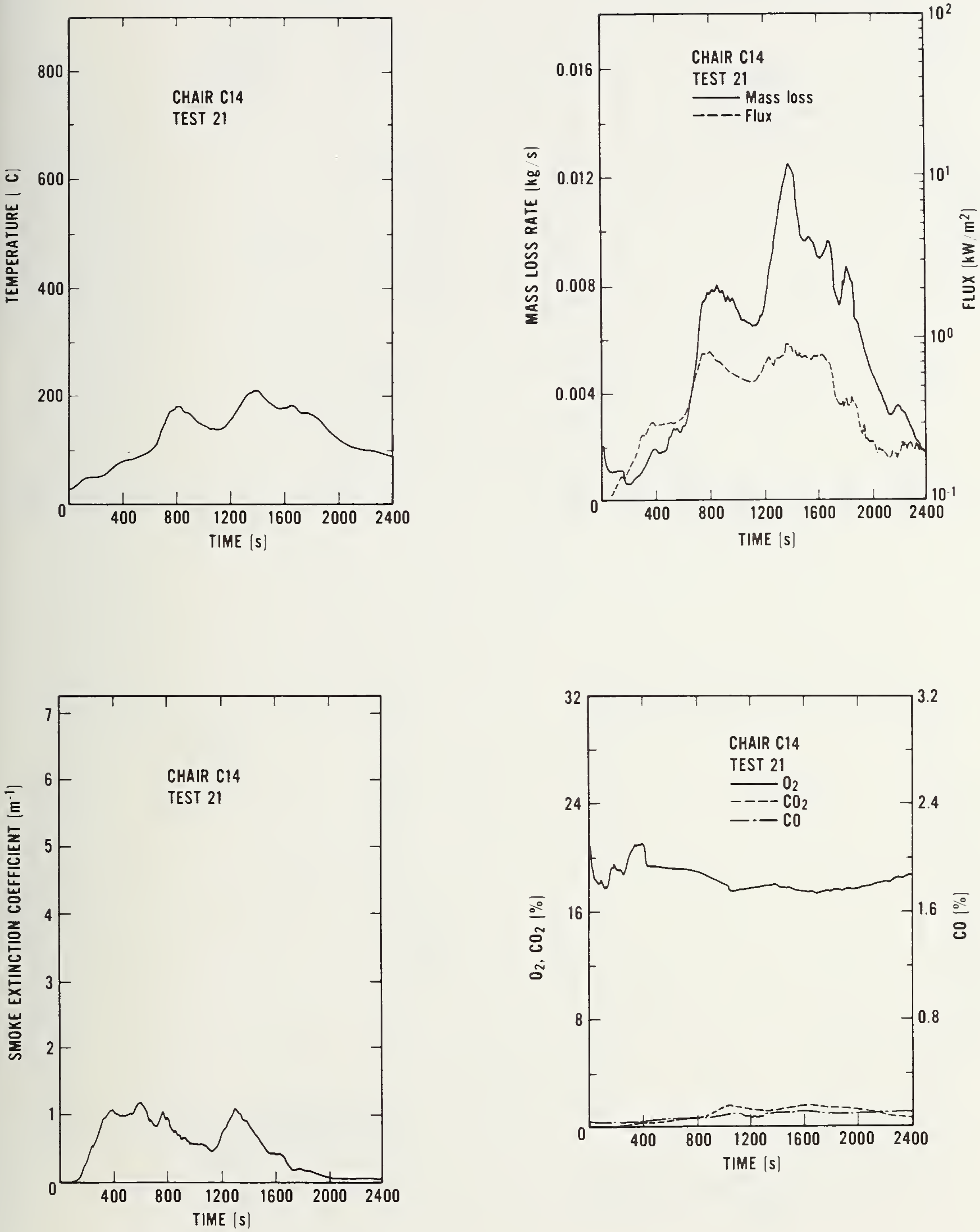


Figure 36. Results for chair C14

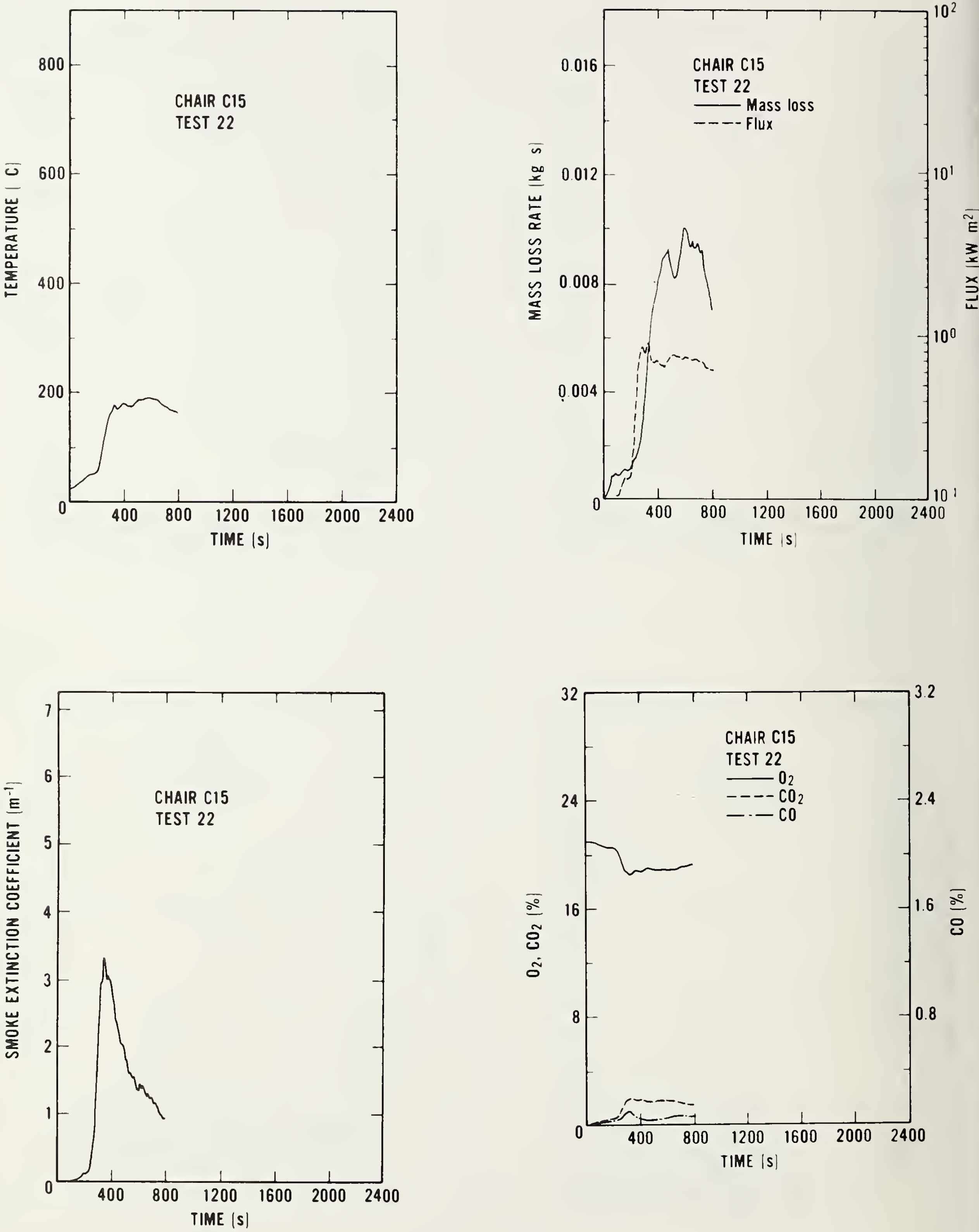


Figure 37. Results for chair C15

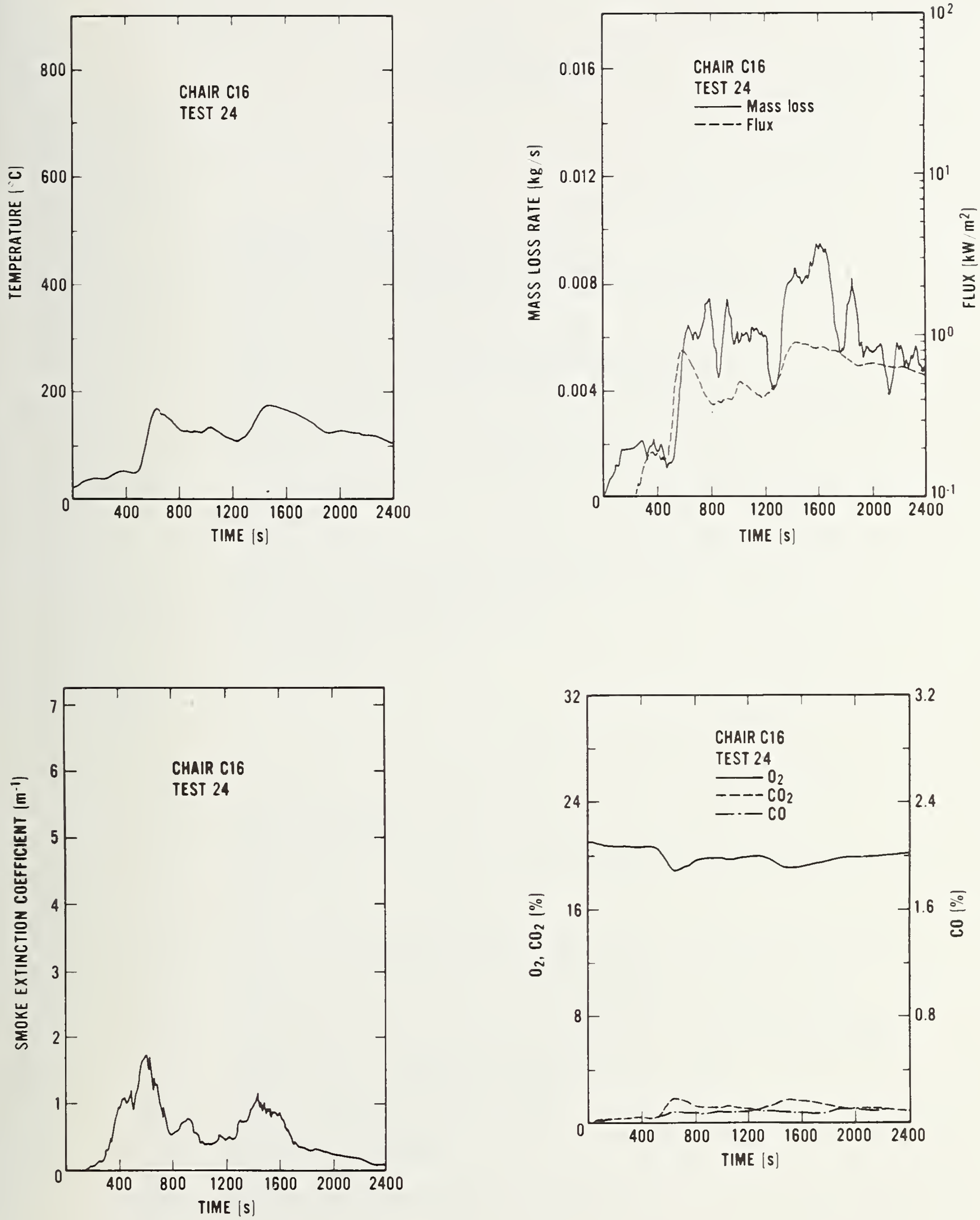


Figure 38. Results for chair C16

APPENDIX

LOG OF OBSERVATIONS

Test 02
Chair C03

TIME(S)	
0	Ignition of newspaper
60	Approximate time of chair ignition
120	Flames about 0.3m above top of chair
160	Inside back of chair burning fully and vigorously
170	Smoke production rapid
180	Flames about 0.7m above top of chair
215	Entire seat area forms base of flame column
230	Molten flaming drops start falling from chair arms
250	Gradual flame spread down on sides and front peak flame height about 1m above top
350	Increasing melting and burning on floor
360	Sides burn through to the outside; minimal visibility
380	Flame height decreases
480	Pool underneath now continuous, but fire still strongest on top of seat
600	Chair frame clearly visible, most padding has burned away
700	Flames now not much higher than top of chair
960	Only material adhering to frame itself is still burning
1030	Chair frame begins to collapse
1500	Minor burning of debris
2000	Test terminated

Test 03
Chair C03

TIME(S)	
0	Wastebasket trash ignited
30	Chair side ignites
90	Dripping starts from chair
150	Flames decrease after having reached almost to the top of the chair
180	Front of arm gets involved
265	Fire spreading over seat cushion
300	Most of seat cushion burning; flames about 0.2m above chair top
330	Increased smoke production
360	Flames about 1m above top, vigorous burning, increased smoke observation
390	All sides burning and dripping but not much floor pool burning; flames nearly to ceiling
420	Sides heavily burning, arms burning out of fuel
510	Marked floor pool burning begins
590	Burning decreasing
780	Limited burning, flames less than 0.5m high
990	Frame clearly visible
1230	Chair collapses
1680	Limited flaming of debris on the floor
1920	Test terminated

Test 04
Chair C03

TIME(S)	
0	Newspaper ignited
120	Flaming established on seat cushion
140	Vigorous burning at cushion
160	Flames about 0.4m above chair top
195	Cushion, inside sides and back all burning vigorously
240	Significant smoke developed, flames more than 1m above chair top
280	Front of seat cushion burning
300	Burning drops falling front and back
355	Upholstery exfoliating in front
370	Flame spread on outside of arms
420	Pool fire begins to envelop chair
460	Arms burn through
750	Most filling material burned away except at seat cushion
1110	Chair back falls off
1170	Further collapse
1850	End of test

Test 05
Chair C02

TIME(S)	
0	Newspaper ignited
100	Seat area becomes ignited
118	Flames about 1m above chair top
130	All inside surfaces burning vigorously
160	Minor melting from chair back
185	Spread to arms and melting, dripping from arm outside
205	Spread down front of seat, layers exfoliating and dropping.
220	Flame volume encompasses chair, all horizontal surfaces fully involved
235	Pool burning at front edge of seat
290	Intense pool burning under whole bottom
300	Chair enveloped in flames on all its sides; flames start at floor pool and are over 2m high
400	Sides of chair burning less
460	Arms burned through
550	Flames now only about 0.2m above top
690	Most of covering, filling materials burned away
990	Chair falls over
1820	Test terminated; some debris still burning

Test 06
Chair C02

TIME(S)	
0	Newspaper ignited
80	Flames about 0.2m above chair
105	Inside back burning vigorously
125	Flame spread covers seat
135	Dripping starts at back
165	Dripping from all sides
180	Heavy smoke obscuration; only flames are visible
215	Pool burning at front of chair; sides not yet involved in flame
280	Flames spreading on sides
300	Pool flames merge with general burning
570	Chair largely burned through
1000	Chair begins to collapse
1800	Only limited debris flaming
2700	Test terminated

Test 07
Chair C02

TIME(S)	
0	Newspaper ignited
50	Burning of seat begins
75	Flames about 0.6m above chair top
105	Inside back fully involved
120	Drippings start from arms and back
130	Seat fully involved in flame
150	Dripping from all sides
160	Vigorous burning of entire inside area; smoke obscures top part of flames
195	Pool burning at front of chair, due to fall-off of large piece
240	Very limited visibility
270	Pool burning envelops chair from all sides
380	Arms burned through
550	Pool fire getting smaller, mainly in back
2700	Test terminated

Test 08
Chair C01

TIME(S)	
0	Ignited cigarette placed in crevice
20	Light smoke
60	Heavy white smoke in upper 2/3 of room
65	Rapid smoldering of seat cushion
4980	Flaming ignition of seat
5100	Flames above top of chair and some molten drop burning on floor
5160	Pool fire burning on floor
5280	Significant black smoke obscuration, peak of burning has passed
5700	Only very limited flaming
6200	Chair falls over
6600	Test terminated

Test 09
Chair C04

TIME(S)	
0	Newspaper ignited
70	Burning on inside back established
120	Flames cover all of inside back
125	Pool burning begins below the back
140	Large burning pieces exfoliating at the back
180	Heavy smoke
210	Flame spread reaches front of seat cushion
220	All exposed horizontal surfaces fully involved
240	Flame spread on sides, coming from rear
280	Arms burned through
290	Pool fire under entire chair
293	Chair surrounded in flames on sides and back
325	Entire chair totally involved
390	Burning decreasing
440	Most of chair is burned out
745	Chair falls over
1800	Test terminated; only minor debris still burning

Test 10
Chair C01

TIME(S)	
0	Newspaper ignited
75	Fire established on seat
160	Inside back covered with flame
390	Dripping begins at front of seat
420	Slight burning at outside back
450	Dripping begins in the back
480	Seat cushion beginning to be consumed; outside of chair mostly intact
545	Flame spreads around from outside back to involve outside arms
660	Rapid melting burning drops but no major pool fire
700	Back flaming vigorously, sides and cushion burning slowly
770	Limited pool burning under chair, seat now flaming vigorously
910	Flames getting shorter
1030	Most of chair, except seat, burned through
1320	Chair begins to collapse
1347	Further collapse
1365	Flaming increases around seat area
1800	Test terminated; only limited debris burning

Test 11
Chair C05

TIME(S)	
0	Newspaper ignited (placed on the floor adjacent to chair)
32	Chair ignites
60	Flames at top of chair
89	Filling falls out, chair collapses, some filling falls outside of platform
150	Flames still only slightly above top of chair
210	Burning more vigorous
240	Unignited side of chair pyrolizing heavily
300	Heavier smoke
315	All of chair upper surfaces heavily involved in fire
360	Visibility very poor
410	Fire spreads to spilled filling
420	Almost negligible visibility
480	View obscured due to smoke in lower half of corridor
695	Smoke in lower half clears up
1020	Mostly debris; flames less than 0.3m high
1500	Test terminated

Test 12
Chair C11

TIME(S)	
0	Newspaper ignited (placed on floor against side of chair)
270	Flames to top of chair
370	Side burning vigorously
420	Flame spread starts across seat; flames about 1.2m high
450	Heavy smoke obscuration
510	Flame now involves whole side and seat; top of flame hidden in black smoke
660	Vigorous burning, almost no visibility
690	Visibility slightly increased in lower part
735	Burning less vigorously
1200	Fire almost out
2020	Test terminated

Test 13
Chair C01

TIME(S)	
0	Cigarette ignition
780	Light smoke
2700	Heavy smoke
2820	Open flaming starts
2910	Heavy smoke, seat fully involved
3060	Smoke and flaming dies down
3300	Pool fire under chair, back all burned through
3600	Limited flaming only
4080	Chair now collapses
4800	Fire out; test terminated

Test 14
Chair C04

<u>TIME(S)</u>

0	Newspaper ignited
15	Flames to the top of chair
80	Flames about 0.6m above chair top
95	Dripping starts
120	Steady dripping at back
160	Pool fire at back
230	Major flaming above chair
255	Flames break out of side arms
280	Pool fire merges with top fire
308	Chair frame now visible
360	Peak burning is over
400	Flames below top of chair now
450	Only limited flaming
1360	Chair fully collapsed
1800	Fire essentially out; test terminated

Test 15
Chair C12

<u>TIME(S)</u>

0	Newspaper ignited
14	Flame to top of chair
85	Cushion involved
100	Back involved
200	Back burning vigorously
280	Flame height decreasing slightly, but flame spread across seat
370	Back flaming less
1070	Flaming on seat increases; flaming subsides
1160	Some flame spread down front of cushion
1200	Melting and dripping from the back
1230	Side arms beginning to burn through
1310	Flaming subsiding
1560	Drippings in back
1640	Pool burning starts up
1680	Chair now mostly engulfed in flames
1860	Flaming subsiding, chair largely consumed
2090	Chair begins to collapse
2400	Limited flaming at arms and under chair
2700	Fire almost out; test terminated

Test 16
Chair C09

TIME(S)

0	Newpaper ignited
120	Flames spreading on seat cushion
225	Flame spread reaches front of cushion
250	Seat surface now burning vigorously
470	Some melting, burning underneath
570	Flame spreading down the side
590	Pool fire established underneath
605	Chair begins to collapse
1320	Fire dying down somewhat
1870	Test terminated, fire basically out

Test 17
Chair C07

TIME(S)

0	Newspaper ignited
40	Flames to top of chair
75	Vigorous burning of back
170	Entire seat cushion involved
180	All exposed inside surfaces burning
220	Melting, dripping at the rear
246	Large burning chunk of arm falls off
280	Almost complete obscuration
300	Intermittent complete obscuration
450	Slight regain of visibility
500	Only base and puddle burning; still quite smoky
700	Smoke clearing
1200	Small pool fire remaining in one corner, test terminated

Test 18
Chair C08

TIME(S)

0	Newspaper ignited
40	Flames to top of chair
60	Black smoke from chair back
220	Flame spread finally covers cushion and back completely
365	Dripping resumes
390	Large flow of burning liquid at rear
440	Outside structural frame has almost all melted away at rear
475	Side arm melting and dripping
540	Flaming decreasing; most of foam burned away
575	Pool fire building up
650	Chair remainder collapsing
720	Only general pool burning
2100	Pool burning diminishes
2580	Only small localized flames remain
3000	Test terminated

Test 19
Chair C10

TIME(S)	
0	Newspaper ignited
140	Flames almost out without igniting upholstery
305	Flames appear, smoke increases
410	Heavy grey smoke from small burning region
440	One side arm burning consistently
485	Seat back fully involved
630	Vigorous burning from all inside surfaces
840	Spread begins down outside of arms
900	Minor dripping from side arm
956	Seat back peels off and falls down
960	Chair collapsed into canted position
1120	Fire substantially dying down
1570	Some charred structure pieces fall off
1765	Further collapse, results in a burst of flaming
1870	Flaming dying down again
2400	Only debris still flaming
3030	Test terminated

Test 20
Chair C13

TIME(S)	
0	Newspaper ignited
180	Flames to top of chair
480	Flames about 1m above top of chair
660	Seat back burning vigorously, melting, dripping begins
720	Seat and back fully involved
1080	Side arms beginning to burn through
1140	Seat cushion burning through in front
1200	Pool fire burning underneath chair
1260	Flaming up one side
1320	Pool fire going out
1370	Arms fully burned through, flame heights decreasing
3000	Debris smoldering slightly
3630	Test terminated

Test 21
Chair C14

TIME.(S)

0	Newspaper ignited
25	Flames to top of chair
150	Flame spread to front of seat cushion; back not burning much
180	Melting, dripping starts in front
290	Chair front all involved, but short flames
350	Small pool fire under chair
360	Flaming from all sides of chair, but very short flames
480	Main flaming is in pool, at dripping edges and at top of chair
630	Flaming greatly increases at top of chair; other burning almost subsides
1200	Flame height decreasing somewhat, but more extensive cushion flaming
1800	Flames dying down, chair almost burned through
2100	Only small flamelets remain
2400	End of flaming; a largish charred mass still remains
2800	Test terminated

Test 22
Chair C15

TIME(S)

0	Newspaper ignited
65	Flames to top of chair
220	Back fully involved; cushion not flaming much
360	Flame spread across cushion reaches front
405	Some melting, dripping in rear
490	Large burning pieces falling in rear
530	Flame spread on side arms progressing towards the front
600	Side arms mostly engulfed in flame
720	Flame height decreasing somewhat
1020	Upper half of chair mostly burned away
1440	Parts of chair collapsed
1740	Now mostly burning rubble
2340	Small flames on rubble

Test 23
Chair C01

TIME(S)

0	Newspaper ignited
60	Flames at top of chair
65	Heavy pyrolyzing from side arm
120	Back almost fully involved
270	Flame spread to front of cushion
330	Melting, dripping from seat cushion front
460	Thin flames spreading down outside of side arms
510	Melting, dripping in rear
560	Side arms burning through
600	Flames now quite short, mostly on seat and at drippings
830	Increased burning of seat cushion
1020	Slight increase in side arm burning
1380	Chair begins to collapse
2040	Only bottom of frame remains
2400	Limited debris flaming
2700	Test terminated

Test 24
Chair C16

TIME(S)

0	Newspaper ignited
60	Flames to top of chair
420	Flame spread to front of cushion, back not yet involved
540	Back and seat now fully involved
660	Melting, dripping at rear
690	Flame spread down front of cushion
840	Flame spread over side arms
1140	Most surfaces now charred
1320	Increased flaming of seat cushion
1800	Flaming dying down; back burned off
2800	Limited flaming of the debris (which is substantial); Test terminated

Test 25
Chair C06

TIME(S)

0	Newspaper ignited
30	Flames about 0.8m above seat
60	Back fully involved
120	Smoke layer approx. 0.7m above chair top
140	Flame spread over all exposed horizontal surface
150	Smoke layer down flush with the top of the chair
155	Melting, dripping, flaming on all sides
198	Loss of visibility
366	Regain of some visibility
420	Short pile of material on floor burning
480	Smoke largely cleared; short flames, approx. 1m high
570	Flames only about 0.5m high
960	Test terminated

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A test program was conducted to determine the fire behavior of a variety of upholstered chairs subjected to a flaming ignition. Major variables were materials and construction of chairs, room ventilation, and type of ignition sources. A total of 16 types of traditional and modern design chairs were tested in a full-scale, otherwise unfurnished room. A folded up newspaper at the seat area was used as the standard ignition source. Room tenability criteria were based on smoke, concentrations of gaseous combustion products, and heat flux. One or more tenability criteria were exceeded for 14 chairs, in times ranging from 100 sec to 650 sec; two chairs burned without exceeding any of the tenability criteria. A review is included of previous upholstered furniture experiments using flaming ignition sources and of existing or proposed small-scale standard tests.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Chairs; compartment fires; flammability; fire tests; furnishings; upholstered furniture.

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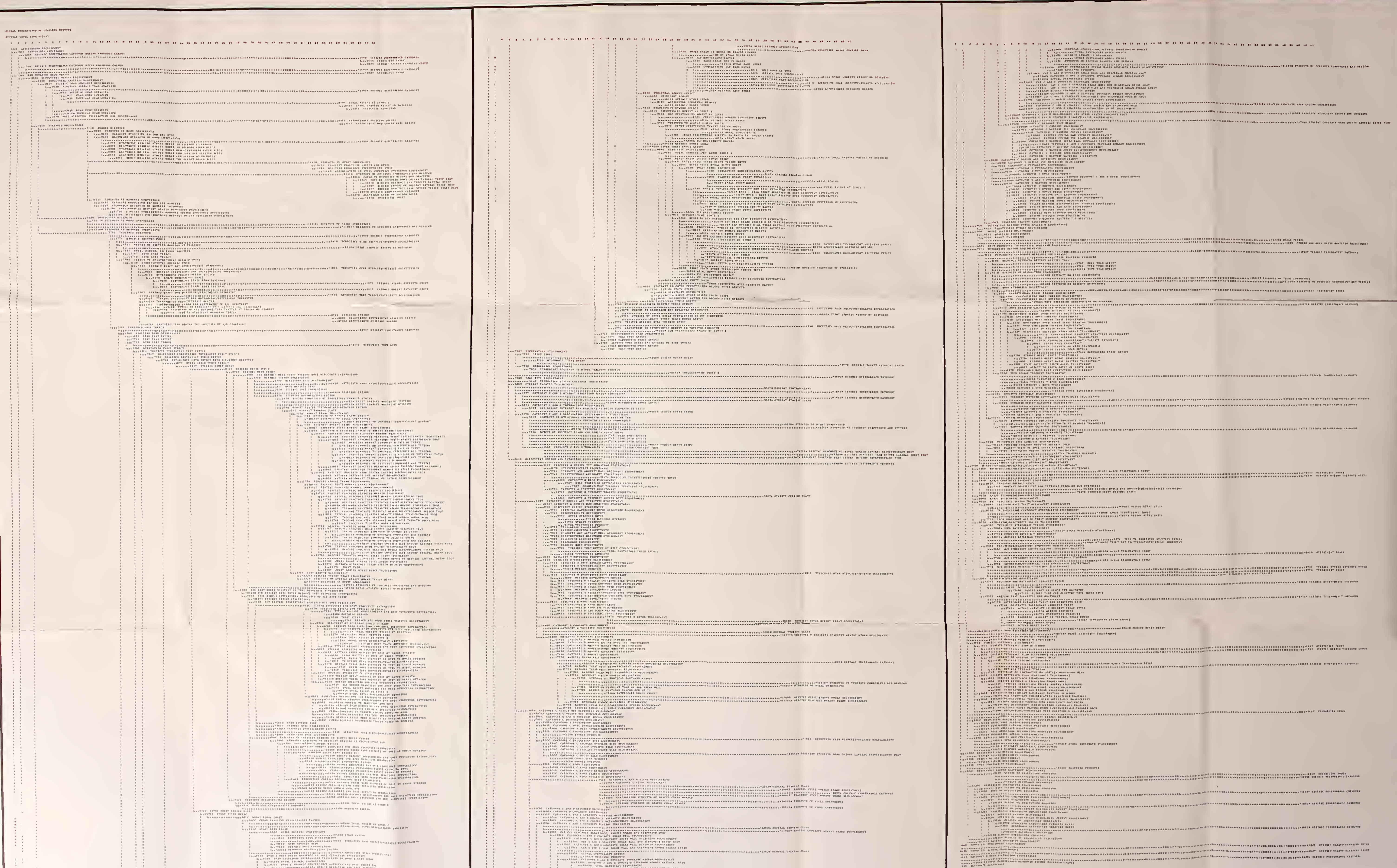

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Information Network

Notes
1. This includes all chapters, but no input nodes are shown.
2. See page 439 for instructions on reading the network.
3. See page 488 for comments relating to this network.