present study was designed to reflect life threatening parameters correlated with a commonly known ignition source — a smoldering cigarette. From the statistics previously mentioned and from important information supplied by survivors of such fires, it is clear that cigarettes, acting as ignition devices to upholstered home furnishings, constitute the single most predominant fire life hazard. As would be expected, the use of cigarettes as ignition devices in testing has substantial precedent. The "cigarette test" was adopted for mattresses by the Consumer Product Safety Commission [4]. This test requires using cigarettes on top of the mattress uncovered and also covered with white 100% cotton bed sheeting muslin or percale. J. Loftus at the National Bureau of Standards extended cigarette ignition to classify upholstery fabrics by using a furniture mock-up [5]. The Loftus protocol evaluated fabrics over a fiberglass or non-flame retarded[1] cotton batting substrate. Going beyond this scope, the furniture mock-up also allowed horizontal and vertical pieces of polyurethane foam to be butted against one another to form a crevice partially into which a smoldering cigarette could be placed. Using different substrates (including polyurethane foam), Gordon Damant [6, 7] at the California Bureau of Home Furnishings evaluated several polyurethane foams with and without covering fabrics using a smoldering cigarette as an ignition source. When evaluating fabric/cushion combinations, Damant used (similar to that required in the Loftus protocol) distance and area of material charred as critieria of damage. Thus, from the standpoints of both fire statistics and its use in currently acceptable testing procedures, the cigarette became a reasonable choice as the ignition device in our investigation of the potential life hazard of the cushioning/covering material combination evaluated in this study.

Type of Fabric Overlay — Fabrics are normally used to cover polyurethane foam cushioning in real life. Therefore, fabrics were included in this study in a manner previously reported by Damant. The fabric chosen was a cotton/rayon blend; a type comprised of materials which has the greatest use for household upholstery in the United States. The combined market share of rayon and cotton is 60% [8].

It has been documented [9] in full-scale and laboratory tests that a fabric response to a smoldering ignition source, such as a cigarette, influences the involvement of the underlying polyurethane foam cushioning. A cigarette placed on top of uncovered conventional polyurethane foam exposes the foam to a heat flux sufficient for foam decomposition limited to an area around the cigarette ember. Thermoplastic fabrics such as acrylic or nylon tend to melt and recede away from heat of the cigarette, thereby limiting the foam exposure to the radiant heat of the cigarette ember. However, with a cotton/rayon blend fabric covering which does not melt, the underlying cushioning can realize a radiant heat flux from both the cigarette and the smoldering fabric. It then follows that the well known smoldering propensity along a cotton or cotton/rayon fabric would represent the "worst possible" non-flaming exposure condition for underlying polyurethane foam cushioning.

Combustion and Animal Exposure Environment — Both of these environments

should be comprised of air as would be the expected initial ambient condition prior to the initiation of an experiment. This was adhered to by positioning the assembled furniture mock-up in the exposure chamber as shown in Figure 1.

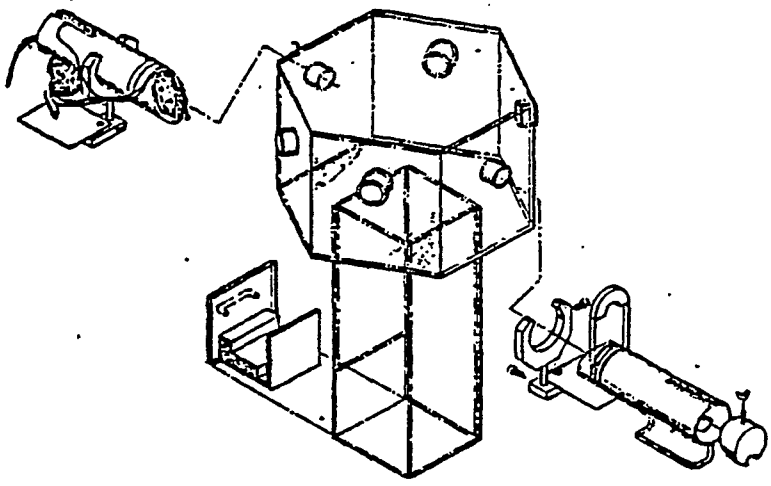

Figure 1. Animal exposure chamber showing tube restrainer with and without animal and location of furniture mock-up prior to insertion at the beginning of an experiment.

Sample Orientation within Sample Holder Assembly — Slabs of test samples of flexible polyurethane foams, covered with the cotton/rayon blend fabric, were placed in the L-shaped plywood sample holder shown in Figure 2. This type of sample holder and sample configuration was selected based on its established use at the National Bureau of Standards and the California Bureau of Home Furnishings and for the obvious similarity to cushioning configurations in household upholstered furniture.

Animal Location, Exposure Mode and Number of Animals/Exposure — Animals were positioned in the exposure chamber as depicted in Figure 1. They were approximately one meter from the combustion site which was located below them. This separation minimized heat stress, and allowed for thorough mixing and distribution of combustion products thus hopefully simulating the gradual build-up of combustion product concentrations in a room during an accidental fire. Since all combustion products were held inside the chamber throughout the exposure session, it was by definition a static exposure. (The chamber was not, however, hermetically sealed which allowed for resease of the small positive pressure which would have resulted from the combustion process).

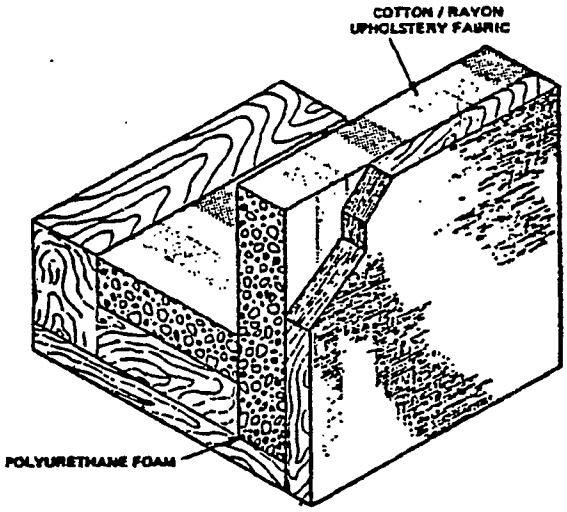

Figure 2.

Head only exposures were used as opposed to whole body. For this protocol, this made attainment of behavioral responses and blood withdrawal convenient and also minimized the effect of heat stress. (However, heat stress is considered minor when the enviornmental temperature is less than 30°C as was the case for this study).

Six animals were exposed in each test. Consideration was given to the total number of animals from a statistical perspective. Of the six animals exposed, five were used to determine time to incapacitation. It was reasoned that an N=5 would permit inter-run as well as between run comparisons. Three replicate runs were made on each foam/fabric combination resulting in an N=15 for between run comparisons.

Two of the behavioral animals carried intra-arterial cannulas. Blood was taken from them initially and at the moment of incapacitation. Blood was taken from the non-behavioral sixth animal (also cannulated) initially and every 10 minutes, thus providing an analysis of blood parameters over time.

Dependent Animal Responses — In a recent report of human fire fatalities, Halpin [10] observed that 70 to 80% of the analyzed cases, fire victims "... attempted to escape ..." but were presumably overcome from smoke intoxication. He also noted that CO was one of the most prevalent intoxicants contributing to death. On the basis of these types of data the experimental procedure selected for the present study included: time to behavioral incapacitaiton: percent COHb over time and at incapacitation; and blood pCO_2, pO_2 (both in mm Hg) along with

blood pH. The behavioral paradigm provides an objective assessment of the incapacitating nature of the combustion products while blood COHb, blood gases, and pH determinations can be used to make some diagnostic interpretations as to the cause of incapacitation, that is from CO or other toxicant(s).

Measurement of Exposure Environmental Physical and Chemical Parameters — The measurement of carbon monoxide was essential to correlate the presence of this toxicant with COHb blood determinations. Other toxicants like NO and HCN were also measured to aid in the interpretation. This was done anticipating other toxicants would play some role manifested by shorter times to incapacitation and consequent lower COHb levels at incapacitation than if CO was the only toxicant present. Total hydrocarbons (THC), O_2 depletion, and CO_2 were also measured. THC would include irritants as well as toxicants and O_2 depletion and/or elevated CO_2 will accelerate the time to behavioral incapacitation.

Results reported here will demonstrate the utility of animal biological responses in assessing the potential life hazard. In so doing, the implication follows that the combustion test protocol described by Damant [6, 7] and developed by Loftus [5] can be extended to include a bio-assay yielding a toxicological assessment of fabric/cushioning material combinations used in upholstered furniture.

EXPERIMENTAL

Materials Evaluated

Table 1. Foam Formulations of Foams Used in Furniture Mock-up Study.

Chemical						
Poly-G 30-56 (polyol)	100	100				
Poly-G 32-48 (polyol)			100	100		
Poly-G 32-56 (polyol)					100	100
TDI "(index) (isocyanate)	62.6	62.6	62.1	62.1	62.6	62.6
L-5720 (surfactant)	1.0 →					
Water (blowing agent)	4.5 →					
CH_2Cl_2 (blowing agent)	6.4 →					
Niax A-1 (amine catalyst)	0.1 →					
C-2 (tin catalyst)	As Required →					
Thermoline 101 (flame retardant)*	11 phr	0	12 phr	0	11 phr	0

Note: All values are given as parts by weight. The flame retardant* is given as parts per hundred polyol (phr) which is the same as parts by weight in these formulations.

*The term "flame retardant" (or similar term) is a relative term and is not intended to indicate hazards presented by foams containing these products or any other material under actual fire conditions. Foams containing flame retardants will burn.

**All foams formulated at 120 index.

As mentioned previously in the experimental design, three experiments were

performed in random order for each combination of polyurethane foam and fabric combination giving a total of 18 experiments. A cotton/rayon upholstery fabric (16 oz/yd^2) was purchased from a local merchant. Several fabrics were screened in order to select one which smoldered readily to allow for evaluation of a "worst condition" for the polyurethane foam by being covered with a fabric which showed self-propagating smoldering character. The same material was used for all the experiments. The formulations of the polyurethane foams are given in Table 1 which indicates the THERMOLIN® 101 flame retardant[2] presence or absence and polyol type [11], thereby accounting for the material variables designed into the study. To further characterize the foams, the physical properties are provided in Table 2. The flame retarded[2] foams were formulated to pass California Bulletin 117 [3] and in fact did so.

Table 2. Physical Properties of Foams Used for Furniture Mock-up Study.

Polyol	POLY-G® 70-56		POLY-G® 32-48		POLY-G® 32-56	
Flame Retardant*	11 phr T-101	NFR	12 phr T-101	NFR	11 phr T-101	NFR
Density (lbs/ft^3)	1.29	1.42	1.28	1.27	1.26	1.48
ILD 25% (lbs/50 in^2)	29.30	32.6	30.40	28.25	29.40	32.08
65% (lbs/50 in^2)	66.80	80.3	63.80	59.60	78.30	70.78
Sem. Auto 25% (% loss)	12.73	22.27	21.19	20.44	20.30	16.89
65% (% loss)	9.82	21.76	13.64	13.21	12.77	12.79
Tear PSI	1.71	1.65	1.54	1.75	1.63	1.50
Tensile PSI	11.56	13.02	9.56	11.29	10.07	14.11
Elongation (%)	150.00	126.67	126.67	138.33	140.00	128.33
Comp. Set 50% (% loss)	8.02	4.50	4.89	6.43	4.59	4.51
90% (% loss)	12.94	8.97	7.26	9.61	8.57	8.03
Air Flow CFM	4.00	5.00	5.37	4.37	5.68	4.83

*The term "flame retardant" (or similar term) is a relative term and is not intended to indicate hazards presented by foams containing these products or any other material under actual fire conditions. Foams containing flame retardants will burn.

Exposure Apparatus

An isometric drawing of the apparatus is shown in Figure 1. This shows the animal exposure chamber, furniture mock-up sample holder and tube restrainers with and without an animal. A description of each of these components is described as follows.

Exposure Chamber — A 325 liter exposure chamber made of ½" polymethylmethacrylate was used to contain pyrolysis products for animal exposures. The symmetrical chamber, shown in Figure 1, resembles the shape of a mushroom[3]. The

[3] This generalized shape and mixing arrangement was adopted from a similar set-up at Stanford Research Institute, International.