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Development of A Candidate Test Method for the Measurement of the Propensity of Cigarettes to Cause Smoldering Ignition of Upholstered Furniture and Mattresses

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
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Center for Fire Research
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DEVELOPMENT OF A CANDIDATE TEST METHOD FOR THE MEASUREMENT OF THE PROPENSITY OF CIGARETTES TO CAUSE SMOLDERING IGNITION OF UPHOLSTERED FURNITURE AND MATTRESSES

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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by

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ABSTRACT

A candidate test method for the measurement of the propensity of cigarettes to cause smoldering ignition of upholstered furniture and mattresses was developed. It consists of placing burning cigarettes on pieces of a standard, alpha cellulose, chromatographic paper and measuring the weight loss rate of the paper/cigarette system. The results were compared to the propensity of cigarettes to ignite upholstered furniture substrates. The agreement was satisfactory. Of the approximately 30 cigarette brands investigated, most had a similar propensity to ignite the upholstered furniture substrates, but a few ignited fewer substrates, and exhibited longer

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times to ignition on those which ignited. Many upholstered furniture substrates resisted ignition by any cigarette, while others were ignited even by those commercial cigarettes which ranked lowest in ignition propensity in these tests. However, a substantial number of upholstered furniture types did ignite with some cigarettes but not with others. Self-extinguishing time alone does not define the propensity of a cigarette to ignite upholstered furniture.

Keywords: cigarettes; flammability; ignition; self-extinguishment; smoldering; test development; upholstered furniture.

1. INTRODUCTION

The National Bureau of Standards' Center for Fire Research has maintained a long-standing program on the ignition and burning of mattresses and upholstered furniture. According to estimates by the U.S. Fire Administration, burning cigarettes and other smoking materials inadvertently dropped on upholstered furniture caused 29,000 residential fires in 1977 [1][1]. These fires led to 1170 deaths, 3000 injuries, and $150 million property damage. Upholstered furniture fires were the leading cause of deaths in residential fires, and dropped cigarettes caused about 75 percent of them. Another report states that cigarettes dropped on upholstered furniture and bedding caused 27 percent of U.S. fire deaths [2]. A more detailed breakdown of the data is given in a recent report by the Consumer Product Safety Commission (CPSC) [3].

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

Numerous voluntary and mandatory routes have been taken in the U.S. and abroad to reduce this toll. For example, mattresses sold in the U.S. are covered by a Federal standard designed to make them more resistant to cigarette ignition [4]. A substantial part of the furniture sold in the U.S. is now covered by a voluntary labeling program initiated by the Upholstered Furniture Action Council (UFAC) [5,6]. However, reported restrictions on choice of upholstery materials, and the delay in seeing the effects of such efforts because of the 15 to 20 years service life of upholstered furniture and mattresses, have prompted alternative approaches to be suggested as well. The most widely discussed of the alternatives is the "self-extinguishing cigarette" [7].

The pros and cons of self-extinguishing cigarettes have been widely discussed. However, the technical content of that discussion has, to date, been sparse. Of particular importance are two issues: 1) whether the manufacture of such cigarettes is technically feasible and commercially desirable and 2) whether, and to what extent, the burning properties of a cigarette translate into the reduced likelihood of furniture ignition.

NBS has no expertise in the technology of cigarette manufacture, so it cannot contribute to the debate on the former. However, we can contribute technical information in the latter area.

This report reviews the state of the art of increasing the cigarette ignition resistance of upholstered furniture and mattresses. This is followed by a progress report on laboratory work leading to the ranking of

the propensity of different cigarettes to ignite upholstered furniture substrates, and the efforts to develop a test which would predict this propensity. A draft of such a test method is appended. No attempt was made to evaluate systematically the performance of commercial or experimental cigarettes.

1.1 Current Cigarette Ignitability Tests for Mattresses and Upholstered Furniture

Current tests for the ignitability of mattresses and upholstered furniture employ one of two technical approaches. In one, the actual product (or a mock-up in which the fabric, filling material, etc. are arranged in the same manner as in the production item) is tested by placing one or more specified cigarettes in specific locations on the item. Among the measures following this approach are the U.S. [4], Canadian [8] and French [9] mattress standards, the Draft Proposed Standard for the Flammability (Cigarette Ignition Resistance) of Upholstered Furniture prepared by NBS for the U.S. Consumer Product Safety Commission (CPSC) [10], the voluntary upholstered furniture standard of the Business and Institutional Furniture Association which is based on the CPSC draft standard [11], the British upholstered furniture standard [12], and the essentially identical International Standards Organization (ISO) draft standard. Criteria such as "continuing combustion" and char length are used in these standards.

Another approach is to test single components of the furniture, e.g., the fabric, filling material, welt cord, etc. separately. This approach does not consider interaction effects between the materials, but is

somewhat simpler and cheaper. This approach has been adopted by UFAC [5] and the California Bureau of Home Furnishings [13]. For example, in the classification of filling materials like foam, a standard fabric covers the specimen to be tested. A lighted cigarette is then placed into the crevice formed by a horizontal and a vertical fabric/foam surface. UFAC specifies a maximum char length as the pass-fail criterion, while California uses a maximum allowed weight loss.

1.2 Cigarette-Upholstered Furniture Interaction

A considerable amount of information on the cigarette ignitability of a wide variety of upholstered furniture constructions can be found in the literature [5, 14-26]. Some of this information is summarized in Table 1, where fabric types, filling and welt cord materials, and furniture configuration features are listed in order from least to most cigarette ignition prone. Materials listed next to each other in the table may overlap in their ignitability. Cellulosic fabrics of a given weight may vary because of differences in construction, present of back-coatings which tend to reduce ignitability, or the presence of alkali metal ions (sodium, potassium) which increase smoldering tendency and are found on natural cotton or as a deposit originating with the dyeing or finishing processes [27].

Similarly, the various construction parameters of foam, such as choice of chemicals, density, cell structure, etc. can affect cigarette ignitability. Some foams are made smolder-resistant (SR) by addition of certain chemicals. Flame retardants (FR) which improve the resistance of foam and fabrics to ignition by flames do not necessarily increase the smolder resistance, and in the case of some early formulations, decrease it [14].

TABLE 1. Furniture Construction Parameters Listed in Approximate Order of Increasing Cigarette Ignitability

	Cover Fabrics*	Filling/Padding	Welt Cord	Construction Parameters
Least Ignitable	Thermoplastic: (nylon, olefin, polyester)	Heat dissipating materials, e.g., aluminized fabrics	PVC	Flat areas
	heavy	Neoprene type foam layers	Thermoplastics	Crevices at junction of cushion and back and
	↓			
	light	Polyester batting	SR** treated cellulosic (cotton paper)	crevices with 90° angle
		Urethane foam		crevices with acute angles
	Cellulosic: (cotton, rayon, hemp, linen)	SR** cotton batting	Untreated cellulosics	
Most Ignitable	light	Untreated cotton batting		
	↓			
	heavy			

*Backcoating decreases ignitability

**Smolder resistant

In order to pass any one of the above mentioned cigarette ignition tests, it is not necessary to use only the materials listed near the top of Table 1. In many cases a combination of medium weight thermoplastic fabrics with polyurethane foam, or a low to medium weight cellulosic fabric over foam covered with polyester batting will pass. In some cases combinations may pass when ignition is attempted in the flat area of the cushion but not the crevice.

The other obvious approach to the problem of cigarette ignition of upholstered furniture is to change the cigarette by reducing its propensity to cause smoldering ignition (which may or may not lead to flaming ignition). Legislation to this effect is currently before Congress [7]. The original versions of these bills require self-extinguishment of cigarettes within five minutes if not smoked. This choice of time was probably based on a report which stated that "95 percent of furniture ignitions occurred within ten minutes or more after exposure of the material to the lit cigarette" [28]. These results were obtained in a laboratory situation by estimating the time of ignition of the furniture fabric and filling material while cigarettes were smoldering on them. Such visual estimates are unreliable because the cigarette and its ashes obscure the smoldering zone. As is described in detail below, our experience shows that better results can be obtained when burning cigarettes are placed on upholstered furniture substrates and removed after 1,2,3...minutes, and continued smoldering or self-extinguishment of the substrate is observed for at least 10 minutes. By this method, cigarette ignitions of substrates were found to occur after as short as 1 to 2 minute exposures.

In addition, the term "self-extinguish" is not easily defined. Whether a cigarette self-extinguishes or not depends on the nature of the substrate which it contacts. That is, some cigarettes self-extinguish in air but may cause smoldering ignition of heavy cellulosic fabrics over cotton batting or foam. Self-extinguishment of the cigarette itself has been observed to occur for certain cigarettes on some fabric/foam substrates while the substrates continued to smolder.

Current versions of the two bills [7] contain a provision which would give the Consumer Product Safety Commission (the agency identified to administer the law if passed) considerable latitude to define an acceptable level of the propensity of cigarettes to cause smoldering ignition of furniture. Specifically, the bills provide for use of laboratory screening tests "to insure that cigarettes or little cigars do have minimum capacity for igniting smoldering upholstered furniture and mattress fires". Although begun before and independently from the proposed legislation, the work in this report provides a means of determining the likelihood of ignition by different cigarettes.

To our knowledge, there has been no previous effort to develop a test for the propensity of various cigarettes to ignite upholstered furniture or mattresses. Testing of the propensity of cigarettes to ignite wildland material, such as grass and forest cover, has been reported in the literature [29-31]. Several authors have described efforts to ignite various textile materials with cigarettes [32,33]. Apparel fabrics could not be ignited by cigarettes, but as discussed earlier, smoldering ignition of upholstered furniture and mattresses was found to be a common occurrence. Such smoldering may lead to flaming ignition, after periods of minutes or hours.

2. TEST DEVELOPMENT

2.1 Ranking of Cigarettes

2.1.1 Approach

During the initial stages of the development of a test for the propensity of cigarettes to cause smoldering ignition of various upholstered substrates, the following decisions were made:

(1) The general approach would be as follows: first, identify fabric/filling material substrates with graduated cigarette ignitability; second, test a number of different cigarettes to obtain, if possible, a rank over which the propensity to ignite upholstered furniture substrates varies; and third, develop a test which predicts this propensity of cigarettes to ignite upholstered furniture substrates.

(2) Only machine-made cigarettes would be used in the test development. No attempts would be made to obtain any of the cigarettes made under the about 20 patents for "self-extinguishing" cigarettes, as long as they would be hand produced and their reproducibility would be in question.

(3) The ranking of the cigarettes would be determined by placing them on the fabric/filling material substrates of varying ignitabilities. Ranking would be based both on smoldering ignition vs. non-ignition, and if ignition occurred, on the time to ignite.

(4) The fabric/filling material substrates would be tested in the horizontal configuration, as in the mattress tests [4,8,9] rather than in a crevice configuration (formed by a horizontal and a vertical member) as in the above mentioned upholstered furniture tests [5,10-13]. This was done because the intent was to provide relative rankings of cigarettes and of upholstered substrates, not to test fabrics and filling materials in a near worst case configuration.

(5) The experimental work was carried out under the following conditions: air flow at the test location was 10-15 m/min. In the early experiments, cigarettes were placed at random directions; later, they were placed so the burn direction was in the direction of the air flow. Laboratory temperature varied between 17 and 23°C, and relative humidity from 30 to 65 percent.

2.1.2 Experimental Procedure

About 25 cellulosic fabric-foam combinations were tested with a number of commercial cigarettes. The fabrics varied widely in weight and construction. Of these, five were identified in preliminary tests as representing a spectrum of cigarette ignitability. These fabrics were stretched over pieces of commercial polyurethane foam, all cut from the same piece. Cigarettes were placed on the fabrics for 1, 2, 3...minutes, and then removed, or the cigarettes were left to burn their whole length. If no smoke or heat was observed five (later extended to 10) minutes after cigarette removal, non-ignition (NI) was noted; otherwise the notation I (ignition) was used.

More than 30 U.S. and foreign filter and non-filter cigarettes, varying in weight, diameter, length, and tar and nicotine content were placed on at least two of the five fabrics. Cigarettes which varied in time to ignite on these two fabrics were tested on all five fabrics. The results for six such cigarettes are shown in Table 2. Most of the other brands behaved similarly to cigarettes A and B. Based on the matrix shown in Table 2, it appears that there were five graduations of propensity to ignite the various fabrics, in terms of both whether the cigarettes ignited the fabrics or not, and if they ignited the fabric, the time to ignite upholstered furniture substrates. Thus, a ranking of cigarettes with respect to ignition propensity can be established; it was the basis for development of a test to predict this propensity, as discussed in 2.2, below.

The non-filter and filter cigarettes A and B gave similar results in the present tests, as did the same non-filter and a different filter cigarette brand in a recent study on 72 furniture cushions [25]. Other studies, with different fabrics and filling materials, found filter cigarettes less likely to cause ignition [34]. In a non-filter cigarette, air has access to the burn cone from both ends of the stub, and a more intensive glow and presumably more heat flux occurs. This does not occur with filter cigarettes and they may not ignite some "borderline substrates" which ignite with non-filter cigarettes.

Cigarettes A, B, and C had normal circumference; cigarettes D, E, and F were smaller. Cigarette C was a very low tar/nicotine type, the others normal or high tar/nicotine. Cigarette C had ventilation holes at the base of the filter.

Times to ignite listed in Table 2 varied only from 2 to 7 minutes. With one exception, whenever a cigarette was found to have an ignition time of 4 or more minutes on one fabric, it did not ignite the fabric with a lower ignitability listed below it.

Table 3 shows results of an experiment performed to extend the work on the ranking of cigarettes. Cigarettes A, B and F, and two fabrics which were used in the experiments leading to Table 2 were used again in these tests. Four types of experimental foams were tested. They were described as flame retardant (FR) and non-flame retardant (NFR), each represented in two densities, with the denser foam intended for seats and the other for backs of furniture.

The results shown in Table 2 were essentially confirmed. Cigarette F clearly had lower propensity to cause smoldering ignition, although it ignited the denser NFR foam with both fabrics. Cigarettes A and B again performed very similarly, and it again took longer to ignite the damask than the velvet. Among the NFR foams, the lighter foam had longer ignition times than the heavier one; among the FR foams these differences were smaller, and reversed. Some of these foam-fabric combinations were re-tested by a different operator about six months later, and the same ignition times or times differing by no more than 1 minute were obtained.

Table 4 presents another attempt to rank cigarettes according to their propensity to ignite furniture substrates. Experimental cigarettes from the third set of cigarettes produced for the National Cancer Institute Smoking and Health Program [35] were chosen because of their

TABLE 2. Propensity of Commercial Cigaretttes to Ignite Various Fabric/Foam Substrates

			Cigarettes					
			A	B	C	D	E	F
	Type		non-filter	filter	filter	filter	non-filter	filter
	Diameter		normal	normal	normal	small	small	small
	Tar/nicotine		normal	normal	low	normal	normal	normal
Fabric								
Description	Weight		Ignition Time					
	g/m^2	oz/yd^2	min.					
Homespun, light backcoating	665	19.5	2	2	3	4	5	NI
Velvet	465	13.7	2	2	2	4	NI	NI
Damask, red-blue-green	630	18.2	3	3	7	NI	NI	NI
Damask, red/beige	490	14.5	5	5	NI	NI	NI	NI
Velvet(loop), back-coating	390	11.5	NI	NI	NI	NI	NI	NI
Weight loss - rate of cigarette/standard paper system, mg/min								
average			52.8	48.3	41.3	30.0	14.9	13.7*
stand. dev.			3.6	4.0	2.9	0.72	2.8	--
Burn rate in air, mm/sec x 10^{-4}			10.2	7.7	10.8	6.61	5.41*	4.77*
Weight loss rate, of four layers of standard paper stapled together								
per cm of cigarette, mg/cm			18	16	8.2	8.9	5.6	2.8
per volume of cigarette, mg/cm^3			41	35	18	28	8	16

*These cigarettes sometimes self-extinguished.

TABLE 3. Propensity of Commercial Cigarettes to Ignite Various Fabrics and Experimental Foams

Fabric	Foam			Cigarettes		
	Type	Use	Density kg/m^3	Ignition Times, min. A	B	F
Velvet, 465 g/m^2	NFR	Seat	1.18	2	2	3
		Back	1.04	4	4	NI
	FR	Seat	1.20	3	3	NI
		Back	1.12	3	4	NI
Damask, 630 g/m^2	NFR	Seat	1.18	3	3	4
		Back	1.04	5	5	NI
	FR	Seat	1.20	5	5	NI
		Back	1.12	4	4	NI

NFR: not flame retardant

FR: flame retardant

TABLE 4. Some Physical, Chemical, and Ignition Propensity Characteristics of Selected Experimental Cigarettes

Cigarette Code [a]	74	76	77	78	89 [b]	90 [b]
Paper porosity, cm^3/min [a]	--	5	60	100	--	100
Total particulate matter, mg/g tobacco burned [a]	35.35	49.94	30.88	28.48	28.96	31.16
Nicotine, mg/g tobacco burned [a]	2.00	2.65	1.76	1.80	1.63	1.90
Tar, mg/g tobacco burned [a]	30.52	42.92	26.79	24.58	23.97	24.72
CO, ml/g tobacco burned [a]	17.39	26.45	14.88	15.33	11.15	8.45
CO_2, ml/g tobacco burned [a]	35.19	48.55	33.58	34.61	26.11	23.35
Static burn rate, avg./s.e., mm/min [a]	4.266/0.07	3.063/0.10	4.489/0.10	4.617/0.15	4.883/0.21	4.566/0.15
Peak coal temperature, avg./s.e., °C, at: [a] 15 mm mark	782.0/22.3	802.6/9.1	842.0/13.5	823.0/12.7	800.1/5.2	827.1/8.6
55 mm mark	816.8/21.3	838.1/21.7	806.9/8.4	832.5/16.9	768.0/8.2	816.9/11.8
Ignition time, min., on:						
homespun fabric	2	2	2	2	2	2
damask	3	4	3	3	3	3
velvet: no ignitions/5 tries, min.	1	1	1	1	1	1
5 ignitions/5 tries, min.	2 1/2	7+	2 1/2	3	2 1/2	3
Weight loss rate:						
cigarette/paper system, avg./s.d., mg/min.	55.7/2.4	37.7/2.9	54.1/9.0	52.8/3.4	49.6/3.8 [c]	53.3/2.5 [c]
paper only, four layers, mg/min.	0.22	0.18	0.18	0.13	0.05	0.05

[a] Data from reference 35.

[b] These cigarettes had a dilution filter with a larger diameter than the rest of the cigarette.

[c] Tested with dilution filter removed; with dilution filter results were 44.9 and 44.6 mg/min. because of poor contact between paper and cigarette.

wide variation in a number of parameters. Among these were cigarette paper porosity and absence or presence of a "dilution filter"; wide variations in tar, nicotine, CO and other smoke constituents produced when these cigarettes were smoked on a smoking machine; and static burn rate and peak coal temperatures. In spite of the differences in burn behavior these cigarettes produced no differences in ignition time on three fabrics over commercial foam, except for the longer ignition time (with poor reproducibility) found for Cigarette 76 which has very low cigarette paper porosity.

To further investigate ignition times of these cigarettes, they were placed on the velvet fabric for 1, 1-1/2, 2, ... etc. minutes, instead of the usual one minute steps. The time at which none of the three to five cigarette replicates ignited the substrate, and the time at which all replicates ignited it, is shown in Table 4 (the differences in those two times tended to be larger in these experimental cigarettes than in commercial cigarettes for which it varied between 1/2 and 1-1/2 minutes). Still, no major differences in ignition time for these cigarettes, except No. 76, could be established.

These findings suggest that cigarette parameters usually measured by industry such as burn rate and coal temperature, do not control the propensity of the cigarettes to ignite furniture substrates. Probably such parameters as contact area between cigarette and substrate and heat flux in the contact area affect this propensity.

2.2 Choice of Test Concept

The above investigation was performed to identify cigarettes with a graduated propensity to ignite upholstered furniture substrates, and

to learn more about the interaction of various cigarettes and such substrates, since most previous work had been performed with only one cigarette. The next step was to develop a laboratory method which would correlate with the ranking of the cigarettes.

After considerable experimentation, two factors became apparent:

- a meaningful test would have to involve cigarettes lying on and interacting with a substrate, rather than the measurement of characteristics of cigarettes burning freely in air. The latter is the usual approach to cigarette testing for quality control, smoke chemical constituents analysis, etc.

- the test method should not be based on commercial "standard fabrics" or "standard filling materials" such as foam or batting. UFAC, the California Bureau of Home Furnishings, CPSC, and NBS have had great difficulties in the procurement of such "standard" materials in a reproducible form. Upholstery fabrics, foam, and batting have thus far not been produced to the close tolerances needed for use in tests of the kind envisioned here, and the market for such standard materials would generally be too small to make it worthwhile to introduce costly production controls only for this purpose. We are aware that UFAC and the Society of Plastics Industry are working to provide standard materials, but they are not available at this time.

The following characteristics of cigarettes were investigated, to see if they would correlate with the propensity to ignite upholstered furniture:

1. static burning rate of cigarettes
2. temperature of burn cone on the cigarette surface
3. burning behavior of cigarettes in contact with heat sinks, e.g., metal gauges of varying thickness
4. burning behavior of cigarettes placed on chromatography paper, which showed the most promise.

The details are discussed below.

2.2.1 Burning Rate of Cigarettes in Air

Table 2 shows that the burning rate of cigarettes suspended freely in air related to cigarette ignition propensity with one notable exception: cigarette C, which burned relatively fast, ignited fewer fabrics, and frequently had longer ignition times than cigarettes A and B, which had a somewhat lower burning rate. This may have been due to a combination of factors: perhaps the burn cone of this cigarette moved so rapidly that there was insufficient time to ignite some of the substrates. Cigarette C also had a low packing density so that may have been not enough fuel in the burn cone to cause ignition of some substrates. On the other hand, cigarette 76 of the experimental cigarette series (Table 4) had a lower burning rate than the others, and longer ignition times.

Commercial cigarettes E and F (Table 2) tended to self-extinguish in air, but ignited some fabric/foam substrates. This indicates that burning rate in air could not be used to differentiate between cigarettes on the lower end of the cigarette ignition propensity scale.

Furthermore, it was established that the cigarette diameter, and thus the area of contact with a surface, has at least a modest effect on the ignition propensity. An oval cigarette took about 1 minute longer to ignite a certain fabric/foam system when its narrow side was in contact with the fabric than when it was placed on its wide side. Cigarettes D, E, and F have small diameters and relatively low ignition propensity; however, they probably differ in other parameters as well. Based on this combination of findings, it appeared preferable to develop a test in which the cigarette is in contact with a surface.

2.2.2 Burn Cone Temperature

The peak coal temperature of the burn cone is listed in Table 4 for the experimental cigarettes. It varies greatly over the length of the cigarettes, and correlates poorly with ignition time. A brief attempt to relate burn cone temperatures of cigarettes A to F also showed little promise. Attempts to measure the temperature at the interface of fabric and cigarette demonstrated significant experimental difficulties -- the thermocouple may interfere with fabric-cigarette contact as the smoldering front passes, and the results show poor reproducibility.

2.2.3 Contact with Heat Sinks

In another attempt to develop a simple test method, cigarettes were allowed to burn freely in air until they contacted steel gauges of varying thickness. Even thin gauges extinguished all cigarettes. It may be possible to identify graduated heat sinks which would differentiate between the various cigarettes but this approach was not pursued.

2.2.4 Burning Behavior of Cigarettes in Contact with Chromatography Paper

It appeared that a useful test concept would incorporate use of a reproducible material which would interact with smoldering cigarettes. A material used in chemical analysis, an alpha cellulose paper which is also used for the calibration of the Smoke Density Chamber [36,37] seemed to be promising for the present purpose. This paper[2] is manufactured for use in chromatographic chemical analysis, and has been found to be reasonably reproducible with respect to smoke production under certain heat conditions. It was decided to use it as the substrate to be placed under smoldering cigarettes, as described in Appendix I of this report. The paper smolders along with the cigarette but does not continue smoldering when the cigarette goes out. In the proposed test, the cigarette is placed on one layer of the standard paper, suspended by four pegs above a platform. A load cell connected to the platform is used to record the weight loss of the cigarette-standard paper system. The rate of weight loss, in mg/min, is determined.

Table 5 shows some results with standard paper sheets taken from the same lot and from different lots, obtained by two operators over a period of several months. The reproducibility appears satisfactory, especially considering that the environmental conditions in the laboratory were not closely controlled, and that the cigarettes were taken from packs which had been opened for various periods.

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[2]This paper, certified for use in calibration of the smoke density chamber, is available as Standard Reference Material 1006a from the Office of Standard Reference Materials, National Bureau of Standards, Washington, D.C. 20234. See Appendix I.

TABLE 5.

WEIGHT LOSS RATE OF CIGARETTE/STANDARD PAPER SYSTEMS: EFFECTS OF STANDARD PAPER LOT AND SHEET, AND OPERATOR

	WEIGHT LOSS RATE (mg/min)	STANDARD DEVIATION (mg/min)
CIGARETTE - A		
LOT 1		
OPERATOR 1	52.8	3.6
OPERATOR 2		
SHEET A	48.3	3.2
SHEET B	52.6	3.9
LOT 2		
OPERATOR 2	52.7	3.7
CIGARETTE - C		
LOT 1		
OPERATOR 1	41.3	2.9
OPERATOR 2		
SHEET A	39.3	3.1
SHEET B	36.4	2.7
LOT 2		
OPERATOR 2	38.4	2.9
CIGARETTE - 76		
LOT 1		
OPERATOR 2	37.7	2.9
LOT 2		
OPERATOR 2	34.5	3.7
CIGARETTE - 77		
LOT 1		
OPERATOR 2	55.4	6.9
LOT 2		
OPERATOR 2	54.1	9.6

The weight loss time plots for the cigarettes tested were essentially linear. This is of interest because it agrees with the finding that ignition times for the furniture substrates did not vary with cigarette length, i.e., the ignition propensity also appears reasonably constant over the length of the cigarettes. Any change in the weight loss rate would be readily apparent. The time at which the cigarettes self-extinguish can also easily be determined from the plots. These factors could thus be taken into consideration in ranking cigarettes by this method.

Table 2 and Table 4 compare the weight loss rates (mg/min of cigarette/paper system) with the behavior of the cigarettes on upholstered furniture substrates. Weight loss rate correlates with ignition time, or number of fabrics which ignited in Table 2. Considering that control of ambient conditions was poor, that the foams used for testing the commercial and the experimental cigarettes were different (which may affect ignition times somewhat) and that the experimental cigarettes showed considerable variability, the weight loss rate method seems promising for prediction of cigarette propensity to ignite furniture substrates.

The dilution filters of cigarettes 89 and 90 (Table 4) had a larger diameter than the cigarettes and apparently reduced contact between the cigarette and the standard paper. With the filters in place, the weight loss rate was about 5 mg/min lower than when the filters were removed before testing. The effect of filter removal on ignition of the fabrics was not clear cut. One could assume that the fabrics have rougher surfaces than the paper, and that the presence of

protruding filters becomes less important on the fabric. The test method shown in Appendix 1 suggests removal of protruding filters, and selection of cigarettes with as close as possible to cylindrical shape for tests.

The choice of weight loss rate of the system consisting of one sheet of standard paper and a cigarette was preceded by considerable experimentation with multiple sheet layers. Up to four sheets were tried; for some cigarettes, this resulted in considerably larger weight loss than with single sheets. In fact, it was originally planned to rank cigarettes simply by the number of sheets which would show signs of charring, so that no recording equipment would be needed. However, multiple sheets tend to curl in contact with the burning cigarettes, so that contact between the sheets becomes poorly controlled. Attempts to overcome this by stapling or glueing at the edges were made but were found to be time consuming without ranking the cigarettes in exactly the same order as the fabric burn experiments. All things considered, the single sheet method appeared preferable.

2.3 Cigarette Ignition of Wildland Material

A brief attempt was made to confirm the relative propensity to ignite furniture substrates found for Cigarettes A to D with wildland materials, such as dried grass and pine needles. Qualitatively, it was easy to see that Cigarettes C and D caused a lower smoldering rate and smaller smoldering areas before self-extinguishment than Cigarette A. However, systematic experimentation to obtain quantitative results required more time for exploration of experimental conditions than was

available. It was found that wildland materials must be packed fairly tightly to obtain smoldering and/or flaming ignition, especially with the relatively high relative humidity in our laboratories. Considerable airflow was needed to obtain ignition. Other workers have defined some of the conditions for such experimentation but their results probably would not fully apply to present day cigarettes [29,30].

2.4 Background for Choices of Test Conditions and Areas of Additional Work

This section describes the background for choices of a number of test conditions in the attached test method. For some of these, only brief or no investigation of the effect of varying the conditions was conducted.

Laboratory conditions: laboratories of cigarette manufacturers are usually held at 24°C and 60% r.h. and these are the conditions specified in the attached test method. Twenty-four hour conditioning also is usual in cigarette testing.

Air flow: the test method specifies a 3.3 m/min air flow because it would minimize interference with the load recording mechanism and is considered easily attainable in most laboratory hoods. Air velocity and direction relative to the burn direction of the cigarette affect both cigarette ignition propensity for wildland materials [30,31] and cigarette burning rate [38]. The test method specifies draft direction along the burn direction, which according to the literature, results in the highest burn rate.

Cigarettes have double-layer paper seams. The test method specifies that this seam be on top of the test cigarette. The effect of the seam location on the test results has not been investigated.

Although originally intended for an unrelated purpose (chemical analysis), the standard paper used in this test was calibrated for producing a certain behavior under closely controlled conditions of radiative heating [36,37]. In our view, this paper is more appropriate for the present purpose than less closely controlled materials such as foams or fabrics, even though they would have closer resemblance to upholstery materials. Development of a calibration method to assure controlled smoldering of the paper would be desirable, but was not possible within the framework of the present project.

Although it was not a significant problem in our experiments better reproducibility could perhaps be obtained by placing the paper in a frame (large enough not to act as a heat sink) instead of letting it rest on four pegs, the present arrangement. This may minimize any bending or curling of the paper in the area of the burn cone.

The candidate test method was developed based on the behavior of presently available, commercial cigarettes. It is difficult to foresee potential future developments which could produce cigarettes which give anomalonus results with the present test method, compared to their tendency to ignite upholstered furniture substrates. Many of the same phenomena occur in both the test and in the actual furniture ignition scenario, but there is no guarantee that the results of the two must correlate. There are at least two cases where they conceivably will not.

One involves cigarettes which make little contact with substrates because of spacers or use of intumescent materials on the paper (as covered by several patents). Such cigarettes could have low propensity to ignite substrates but could still show a significant weight loss rate in the proposed test. If this becomes a problem, the appended test method could be changed to require that unusually low charring of the standard paper, as judged visually, be reported, so that the above situation would be recognized. For such cases, a comparison of the cigarette/ standard paper system weight loss and the weight loss of the paper may be preferable for characterization of the ignition propensity. As stated before, more specific recommendations for evaluating such cigarettes cannot be made since none were available for experimentation.

A second possibility is that some cigarettes produced now or in the future may self-extinguish soon after being placed on the standard paper, and that their ignition propensity could not be measured with the present arrangement. Such cigarettes may still differ in their propensity to ignite furniture substrates. A need for extending the sensitivity range of the test method would thus arise. If such cigarettes appear, the test could be changed to extend into lower ranges of ignition propensity by using a crevice or trough arrangement, with two strips of the standard paper at right angles. Cigarettes would presumably continue to burn in such crevices even if they self-extinguish on the horizontal paper strip used now. Since the cigarettes used in the present work presented no major problems of self-extinguishment, the crevice arrangement was not investigated in depth.

In the course of this work several factors could only be investigated to a limited extent. The most important of these are:

1. The Range of Substrates. It would be desirable to check the cigarette rankings with a wider range of fabrics and filling materials since there are thousands of fabric and filling combinations which previous work [14-26] has shown to be susceptible to cigarette ignition. Similarly, the ranking of cigarettes may be affected by furniture configurations, such as crevices between cushions and sides or backs forming various angles, concave cushion surfaces, etc.

2. The Wide Variety of Cigarettes. Only about one sixth of the about 180 available U.S. commercial cigarettes and a few foreign cigarettes, were investigated. Extension of this test population may be desirable, both in terms of their ranking on fabric/filling material substrates and weight loss rate. Work with additional cigarettes from the Smoking and Health Program may help in understanding the mechanism of cigarette ignition of various substrates, since these cigarettes are systematically varied in selected parameters, and many physical and chemical measurements have already been performed on these cigarettes. Similar information is not generally available for commercial cigarettes.

3. Further Exploration of the Candidate Test Method. Why did the weight loss rate of the cigarette/standard paper system rank the cigarettes in the order of their propensity to ignite furniture substrates while the weight loss of the paper alone did not? One possible reason may be the fact that the paper sheet smolders only where it is in contact

with the heat source, and thus there is only a limited amount of material which can lose weight, regardless of the burning intensity of the cigarette. (Using a thicker material would overcome this difficulty, but no well standardized source of thick, pure alpha cellulose was found; use of multiple layers of the standard paper presented experimental difficulties, as discussed earlier). This may make the method somewhat insensitive for cigarettes with relatively high heat flux. In such cases, the weight loss of the cigarette/standard paper system, which includes the weight loss of the cigarette (which in turn can be assumed to be related to heat flux), appears preferable. However, this point bears further investigation.

3. SUMMARY AND CONCLUSIONS

Most previous work on the ignitability of upholstered furniture was performed with one kind of cigarette. The present report describes experimentation with commercial and experimental cigarettes having a substantial of range of burning behavior, and their interaction with a number of upholstered furniture fabric/filling material substrates. A draft candidate test method for the measurement of the propensity of cigarettes to cause smoldering ignition of upholstered furniture is attached as Appendix I.

Upholstered furniture fabrics vary widely in their propensity to be ignited by lighted cigarettes. The lighter weight cellulosic fabrics (cotton, rayon, linen) and the medium to heavy weight thermoplastic

fabrics (nylon, olefin, polyester) rank relatively low in this propensity. Medium to heavy weight cellulosic fabrics are relatively cigarette ignition prone. The material under the fabric, the filling material, also greatly affects the cigarette ignitability of upholstered furniture, as do construction features.

A group of fabric/filling material substrates varying in cigarette ignitability was exposed to about 30 U.S. and foreign commercial cigarettes. The majority of the cigarettes behaved similarly, and ignited all fabrics. Several others ignited only a few of the fabrics. With the most ignition prone fabric, the ignition time was the same for all cigarettes. On the less ignition prone fabrics, the ignition times varied for the various cigarettes identified as having lower ignition propensity. Thus, a ranking of cigarettes according to ignition time and number of the fabric/filling material substrates ignited was possible. This ranking did not seem to correlate with such parameters often used to characterize cigarette burning phenomena, such as burn rate and burn cone temperature measured on cigarettes burning in air.

This type of classification was developed to rank cigarettes according to their propensity to ignite furniture substrates. It does not, however, permit more than a rough, qualitative estimate of the relative ignition hazard of the six cigarettes in terms of possible furniture fires in American homes. One can say with some assurance that, if all cigarettes performed like D, there would be "fewer" fires than if all performed like A or B. It is not possible to quantify "fewer"; this would require knowledge of the cigarette ignitability of upholstered furniture presently in American homes. Such information is

not available, nor will it be easily obtainable for furniture built in the future, since fabric and filling material change with fashion, relative price, etc. The recent trend has been to more ignition-resistant materials, such as thermo-plastic fabrics and upgraded filling materials. In addition, a substantial portion of furniture is being built to UFAC requirements.

A test method was developed which takes into account the behavior of cigarettes when they burn on a substrate (Appendix I). A burning cigarette is placed on a strip of a standard alpha cellulose paper used in chromatographic analysis. The weight loss rate of the cigarette/standard-paper system is determined. This correlates with the rankings of the cigarettes on fabric/filling material substrates.

The choices of test parameters are explained. In some cases, they were based on results of a laboratory investigation; in others, on the best available knowledge. Areas in which further investigation would be desirable are outlined. The most important such area is testing of a greater number of commercial and experimental cigarettes by the test method and comparison of the results to ignitability rankings obtained from placing the cigarettes on a wider variety of upholstered furniture substrates.

Ignition times will vary with cigarette and substrate and may be as short as 1 minute. Self-extinguishing time for a cigarette will depend on the substrate on which it rests. Self-extinguishment time alone will not define the propensity of a cigarette to ignite upholstered furniture.

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APPENDIX I

TENTATIVE METHOD FOR MEASUREMENT OF THE PROPENSITY OF CIGARETTES TO IGNITE UPHOLSTERED FURNITURE AND MATTRESSES

1. Scope

This test method is intended to measure the propensity of commercial cigarettes to ignite upholstered furniture and mattresses when lighted and dropped on them.

2. Definitions

Ignition: continued smoldering, as indicated by smoke and heat development, of an upholstered furniture or mattress substrate after a cigarette has been placed on it. The smoldering may or may not lead to flaming ignition.

Burning time: the time between the placement of the cigarette on the standard paper and the extinguishment of the cigarette, as indicated by the recorder trace.

3. Summary of Method

Burning cigarettes are placed on horizontal strips of a standard, alpha cellulose paper and the weight loss rate of the cigarette/paper system is measured.

4. Apparatus

The apparatus consists of a holder for strips of a standard paper, which is attached to a load measuring device (Figure 1). A recorder plots the weight change as the cigarette smolders on top of the standard paper.

4.1 Holder: a piece of polymethyl methacrylate (PMMA) or similar material, 5 x 10 cm, 2.5 mm thick, suspended horizontally over a load cell. On top of the PMMA sheet, at each corner, is a 6 mm high, 6 mm diameter PMMA rod.

4.2 Load measuring device: a load cell with at least a 10 g useable range. The load cell is connected to a compatible strip chart recorder. The load cell-recorder system shall be capable of indicating weight changes of 1 mg/min.

4.3 Standard paper: a paper used in chromatographic measurements, described in Attachment 1 to the method, cut into 150 x 50 mm strips.

4.4 Hood: a hood with a horizontal draft of 3.3 $\pm$ 0.3 m/min at the face of the loading platform shall be used.

5. Conditioning

Opened packages of cigarettes (from which the test specimens shall be taken) and standard paper strips shall be conditioned at 24 $\pm$ 2°C and 60 $\pm$ 2% r.h. for at least 24 hours.

6. Procedure

6.1 Cigarette selection: sample one cigarette from the package, and inspect it visually. Reject broken or otherwise deformed cigarettes. If filter has larger diameter than the body of cigarette, remove it.

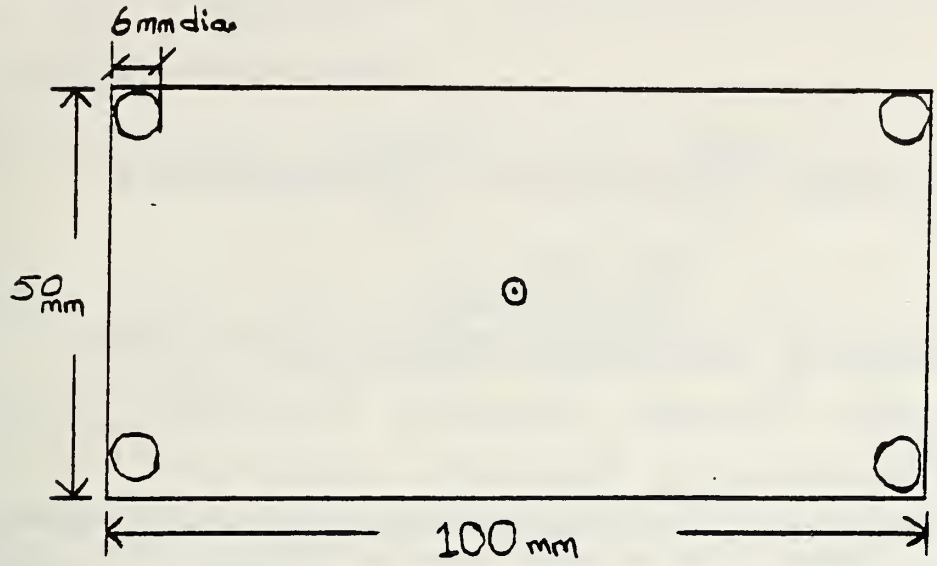
6.2 Place a strip of standard paper on the four rods of the load platform so that its longer direction is aligned with the movement of the air in the hood.

6.3 Start recorder, and place lighted cigarette, with approximately 4 mm of tip burned and the cigarette paper seam on top, on the standard paper strip, so that the direction of burning is the same as the direction of air flow.

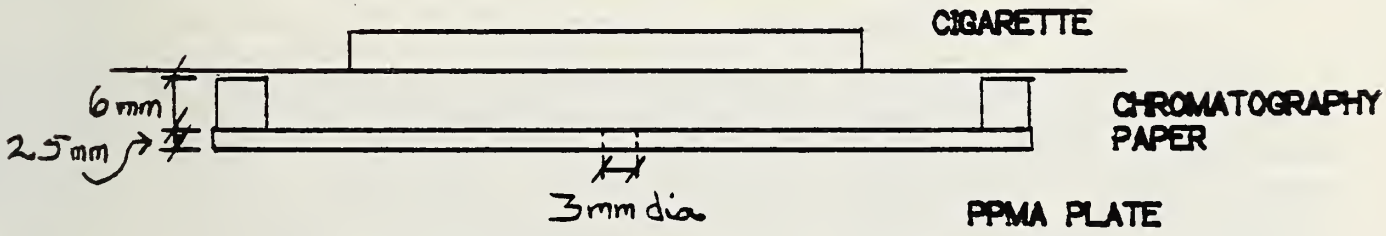
6.4 Stop recorder when there is no further weight loss.

6.5 If a test cigarette extinguishes before burning its whole length the test must be repeated with a fresh cigarette on a new strip of standard paper. If five successive cigarettes self-extinguish before burning their whole length, calculate weight loss rate on basis of the incompletely burned cigarette, and note burning times.

6.6 For each of five cigarettes, calculate weight loss rate. If weight loss rate varies over length of cigarette, other than within 1 minute before extinguishment, note all weight loss rates extending over two minutes or more, and the time during which they prevailed.



TOP VIEW



SIDE VIEW

SCALE 1":1"

FIGURE 1.

S. Department of Commerce
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National Bureau of Standards
Ernest Ambler, Director

National Bureau of Standards

Certificate

Standard Reference Material 1006a

Smoke Density Chamber Standard

Non-flaming Exposure Condition

This Standard Reference Material is recommended for checking the operation of smoke density chambers under non-flaming exposure conditions. However, it does not obviate the need for following the prescribed calibration and standardization techniques outlined in the test procedure. Due to gradual aging of cellulose-base papers, there may be some change in the certified value with time. Therefore, the smoke density measurements are determined periodically and changes made accordingly in the certified value. This value is certified for a period of four months from the date of certification.

The certified value for maximum specific optical density is:

Date of Certification: _____

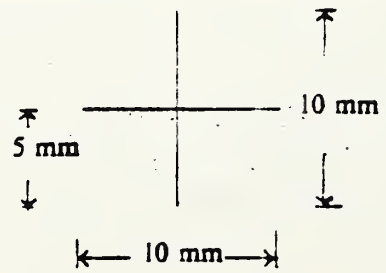
D_m = _____*

$D_{m\ (corr.)}$ = _____

These mean values are the result of 72 tests on representative samples of a lot of 0.036 inch (0.91 mm) thick cotton-linter paper (principally α-cellulose). The estimate of precision is the computed standard deviation based on 72 measurements. Smoke density measurements were made under non-flaming exposure conditions in accordance with the detailed procedures outlined in American Society for Testing and Materials (ASTM) Standard E 662-79, "Test Method for Determining the Specific Optical Density of Smoke Generated by Solid Materials," and in National Fire Protection Association (NFPA) 258-1976, "Standard Test Method for Meausring the Smoke Generated by Solid Materials."

Note: For this particular test material, a small cross must be cut through the thickness at the center of the specimen with a sharp razor blade. Each cut should have a total length of 10 mm and the arms of the cross should extend 5 mm from the center point (see figure below). Prior to test, the material must be dried for 24 hours at 60 °C and then conditioned to equilibrium at 23 ± 3 °C and 50 ± 5 percent relative humidity.

Cross 10 mm x 10 mm must be cut through SRM 1006a.



The original measurements for certification of this Standard Reference Material were performed by T. G. Lee of the Center for Fire Research using a commercially available smoke density chamber. Recertification of this material was performed by J. Randall Lawson of the Center for Fire Research.

*Without correction for window deposit.

Washington, D.C. 20234
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5. AUTHOR(S)

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10. SUPPLEMENTARY NOTES

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

11. 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 candidate test method for the measurement of the propensity of cigarettes to cause smoldering ignition of upholstered furniture and mattresses was developed. It consists of placing burning cigarettes on pieces of a standard, alpha cellulose, chromatographic paper and measuring the weight loss rate of the paper/cigarette system. The results were compared to the propensity of cigarettes to ignite upholstered furniture substrates. The agreement was satisfactory. Of the approximately 30 cigarette brands investigated, most had a similar propensity to ignite the upholstered furniture substrates, but a few ignited fewer substrates, and exhibited longer times to ignition on those which ignited. Many upholstered furniture substrates resisted ignition by any cigarette, while others were ignited even by those commercial cigarettes which ranked lowest in ignition propensity in these tests. However, a substantial number of upholstered furniture types did ignite with some cigarettes but not with others. Self-extinguishment time does not define the propensity of a cigarette to ignite upholstered furniture.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Cigarettes; flammability; ignition; mattresses; self-extinguishment; smoldering; upholstered furniture

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