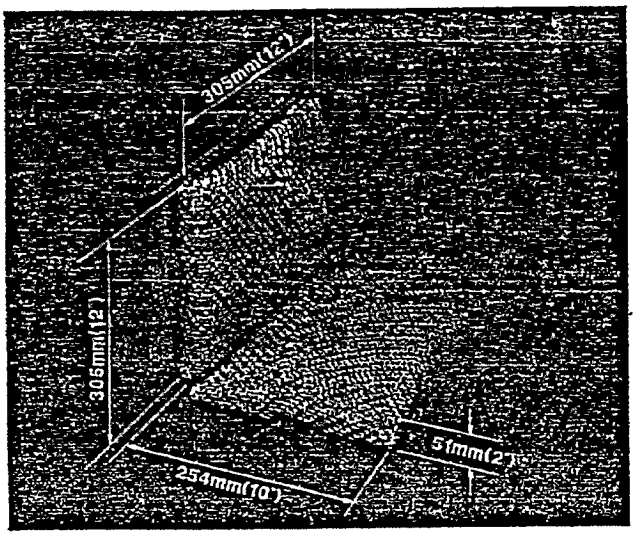
Figure 2. Furniture Mockup for Ignition Testing



commercial cigarette packings[3] were chosen that fit the following criteria: (a) high, low, or middle expected ignition propensity; and/or (b) large market share. The cigarettes were supplied gratis to the NBS-CFR by their manufacturers without brand identification. With much difficulty, NBS-CFR found fabric-padding combinations that would differentiate among the ignition propensities of the twelve cigarettes. Cigarettes were tested in both the flat and crevice configurations, both covered and uncovered by a cloth sheet.[18] **The results indicated that the differences in ignition propensity among current commercial cigarettes are unimportant.**

To identify which cigarette characteristics could reduce ignition probability, 41 types of experimental cigarettes were obtained whose properties were varied one at a time. The properties included tobacco density, tobacco type, circumference, paper porosity, number of paper layers, and paper burning additive (sodium/potassium citrate). Two values of each of these properties were selected. All of the cigarettes were 100 mm long with filter tips. Variation of the length or removal of the filter was achieved by cutting off one end. The properties of the 41 cigarette types are summarized in Table 1. The cigarettes were manufactured (at no cost to the TSG) by the cigarette industry mostly on commercial equipment operated under less than production conditions. Those with double-wrapped or embossed paper were made using research equipment. Independent laboratories determined that each cigarette type was as ordered and of little variance. The cigarettes' tar, nicotine, and carbon monoxide yields were determined by the Federal Trade Commission, as well as by the cigarette industry. The two sets of results were in excellent agreement. Both sets of data showed marginally lower than normal puff counts; the industry data also showed a higher than normal resistance to puffing. The properties of these cigarettes are described more fully in Chapter 2 of reference 19.

Each of these cigarette types were tested for ignition performance on a variety of substrates. These fabric/padding/geometry combinations represented commonly in-use and both intermediate and easy to ignite furnishings. The resulting fractions of ignitions were compared with each other and with similar data for representatives of the commercial cigarettes. (Table 2)

Table 2. Ignition Propensities of Selected Test Cigarettes [19]

	Designation	No. Ignitions in 20 Tests	%
Experimental Cigarettes	201	0	0
	106	1	5
	202	2	10
	130	4	20
	114	4	20
	105	6	30
	113	6	30
	108	7	35
	122	7	35
	129	10	50
	107	11	55
	120	20	100
	127	20	100
Least Ignition-Prone Commercial Cigarettes	2	12	60
	1	16	80
Typical Ignition Propensity Commercial Cigarettes	3	18	90
	6	20	100

The data show a wide range of ignition propensities. Many of the cigarettes burned their entire length without igniting the substrate. **Several of the experimental cigarettes performed distinctly better than their peers or the commercial cigarettes, even on the easiest-to-ignite substrates.**[19]

Table 3 summarizes the results by cigarette property.

[3]A cigarette packing is defined as a commercial cigarette, described by its name, its diameter, its length, whether menthol or non-menthol, whether filter or non-filter, and by its package type (e.g., soft pack)

Several properties reduce the likelihood of ignition: low tobacco density, small circumference, low paper porosity, and in some cases elimination of citrate addition to the paper. Considerably larger reductions were achieved with combinations of these properties. Within the limits tested, the tobacco type had little effect.[19] Because only two values of each property were studied, the effect on ignition propensity of intermediate or more extreme values of those properties is unknown.

Table 3. Ignition Propensity as a Function of Cigarette Characteristics [19]

Cigarette Parameters	Number of Ignitions/ Tests	Ignitions
Tobacco Density		
High	282/320	88
Low	153/320	48
Cigarette Circumference (mm)		
25	243/320	76
21	192/320	60
Paper Porosity		
High	256/320	80
Low	179/320	56
Paper Citrate Conc. (%)		
0.8	231/320	72
0.0	204/320	64
Paper Citrate Conc. (%) (Low Ignition Propensity Cigarettes)		
0.8	47/100	47
0.0	23/100	23
Tobacco Type		
Flue-cured	222/320	69
Burley	213/320	66

Testing, on only one substrate, of seven of these experimental cigarettes with the filters removed showed some increase in ignition propensity.[19] No such difference between filter and non-filter commercial cigarettes was found.[18] However, only in the experimental cigarettes were all other features of the cigarette held constant.

During the last century, approximately one hundred patents have been issued for claims of fire-safe cigarettes. The TSG decided to examine some of these for potential effectiveness. Accordingly, notices were placed in the *Federal Register* (Appendix F) requesting patent holders to submit the single best embodiment of their ideas, along with identical cigarettes without the patented feature (controls). A total of five such submissions was made from four sources. The cigarettes were coded immediately upon receipt. The submitters have been notified of the code for their cigarette only, and the code has since been destroyed.

The five patented design features, as provided by the patent holders, were:

- Very low porosity, high weight paper with a high citrate level, then electrostatically perforated to a high porosity;
- Sodium silicate added to 5 mm in the center of the tobacco rod;
- Two 6.5 mm bands, 15 mm apart, of low porosity paper attached at fixed intervals to the inside surface of the cigarette wrapper, which has a medium porosity and 0.8% sodium potassium citrate (sic);
- Application to the exterior surface of a water suspension containing non-fat dry milk and mono-ammonium phosphate; and
- Addition to the tobacco column of an intumescent silicate.

All these cigarettes and their controls were tested in the same manner as the cigarettes above, including some more ignition-prone substrates. **All five of the patented cigarettes showed distinct improvement over their submitted controls (Table 4) and the typical current commercial cigarettes.**[19]

Table 4. Ignition Propensities of Patented Cigarettes [19]

Cigarette Designation	No. Ignitions/ No. Tests	Percent Ignitions
301-Control	25/25	100
301	29/50	58
302-Control	24/25	96
302	10/50	20
303-Control	25/25	100
303	32/60	53
304-Control	25/25	100
304	33/50	66
305-Control	25/25	100
305	13/60	22

Neither the patented cigarettes nor their submitted controls were analyzed to verify their composition. Therefore, their measured effectiveness may not have the same validity as the results on the experimental cigarettes. Nonetheless, the **TSG feels that the concepts embodied in these patents offer promising directions for pursuit, despite some concerns about the difficulty of mass manufacturing such cigarettes and possible adverse changes in the toxicity of the smoke.**

A computer model of the smoldering combustion of a cigarette and the response of an idealized substrate was devised [19] to screen future combinations of characteristics for their effect on ignition. To guide the model and to identify the right input data, the ignition process was studied in depth.[19] This included measuring the temperature and energy flux while cigarettes smoldered on different substrates. Infrared imaging was used to map the temperature of the substrate.

Ignition was found to depend on both the cigarette and the substrate. Therefore, an accurate ignition propensity model and measurement apparatus must involve the two components. Important features include the area of the cigarette's burning coal, the smolder velocity of the cigarette, and the heat absorbance of the substrate. By contrast, oxygen depletion in the fabric does not vary with the ignition propensity of the cigarette.

The prototype computer program, with all its simplifications, is sufficiently realistic to (1) calculate the most important and most sensitive physical features of the ignition process and (2) reproduce some of the cigarette characteristics that do and do not affect ignition propensity. At present, however, the model is very slow, expensive to run, and not user-friendly.

Validity of Small-Scale Test Data

Reduced-scale flammability test results need to be checked using full-scale items to assure the accuracy of the tests. Two such comparisons with full-scale data were performed. In the first, NBS-CFR tested chairs made of the same materials as the mockups using some of the best and worst experimental cigarettes and commercial cigarettes. (Table 5) The furniture was supplied by the furniture industry (Upholstered Furniture Action Council and the Business and Institutional Furniture Manufacturers Association) at no cost to the Technical Study Group.

There is a strong, but not perfect, correlation (coefficient = 0.86) between the mockup and chair data.[19]

In a second series, the California Bureau of Home Furnishings (BHF) tabulated data on a hundred pieces of furniture and mockups made from those pieces; one commercial cigarette was used.[20] In over 90% of the cases where ignition occurred with the mockup, ignition also occurred on the chair.

The TSG concludes that mockup measurements are a reasonable indicator of the performance of full-scale furniture made of the same materials. In addition, the mockup measurements are a good screening tool for low ignition propensity cigarettes.

To check the repeatability of the mock-up measurements, sample cigarettes and substrate materials were shipped by the NBS-CFR to the BHF for testing using the same procedure. The first of the two substrates was moderately easy to ignite; the second was one of the easiest. Table 6 shows the results of those tests.

The interlaboratory agreement is excellent. **The TSG concludes that, with careful control of materials and testing procedures, test results can be reproduced in different laboratories.**

The combined results from these studies demonstrate the importance of the following properties in reducing the ignition propensity of cigarettes: low tobacco density, small circumference, low paper porosity, and in some cases elimination of citrate addition to the paper.

Table 5. Comparison of Ignition Propensities of Tested Cigarettes at Full- and Reduced-Scales [19]

Cigarette Number	Percent Ignitions	
	Bench-Scale	Full-Scale
6	74	73
129	13	23
114	6	14
106	3	6
201	0	6

Table 6. Interlaboratory Comparison of the Number of Ignitions for Various Cigarettes and Substrates [19,20]

(flat surface/uncovered cigarettes; 5 tests each)

Cigarette Number	Cotton Batting California Fabric		Polyurethane Foam Splendor Fabric	
	CFR	BHF	CFR	BHF
3	5	5	5	5
102	2	1	5	5
105	0	0	3	4
106	0	0	1	1
108	3	4	4	5
114	1	2	3	0
118	5	4	5	5
122	3	4	2	3
126	5	5	5	5
201	0	0	0	0