MEASURING THE IGNITION PROPENSITY OF CIGARETTES

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INTRODUCTION

Cigarettes are the largest single cause of fire deaths in the United States, about 800 people per year over the past decade. The 30 000 fires annually have also resulted in nearly 2000 reported injuries per year.[1] As long as 15 years ago, the total direct cost of these fires was $4 billion annually.[2] The typical scenario is that a dropped cigarette ignites a bed or upholstered chair. The smoke from the ensuing smoldering threatens those who remain in close proximity to the point of ignition. If the smoldering transitions to flaming, those elsewhere in the fire room or the dwelling are at risk.

The historical approach to mitigating these losses has been to manufacture soft furnishings (upholstered furniture and mattresses) that are resistant to cigarette ignition.[3,4,5,6] These designs, coupled with the rise of household smoke detectors, have reduced the losses to the levels cited above. Further gains depend on reducing the severity of the ignition source itself.

HISTORY OF THE TEST METHOD

Under the leadership of Congressman Joseph Moakley (Massachusetts), the U.S. Congress passed the Cigarette Safety Act of 1984 (P.L. 98-567). This legislation directed studies to "determine the technical and commercial feasibility, economic impact, and other consequences of developing cigarettes and little cigars that will have a minimum propensity to ignite upholstered furniture or mattresses. Such activities include identification of the different physical characteristics of cigarettes and little cigars which have an impact on the ignition of upholstered furniture and mattresses, an analysis of the feasibility of altering any pertinent characteristics to reduce ignition propensity, and an analysis of the possible costs and benefits, both to the industry and the public, associated with any such product modification." The research led to extensive understanding of the ignition process and a number of practical findings. Figure 1 depicts the contact between a cigarette and an upholstered surface.

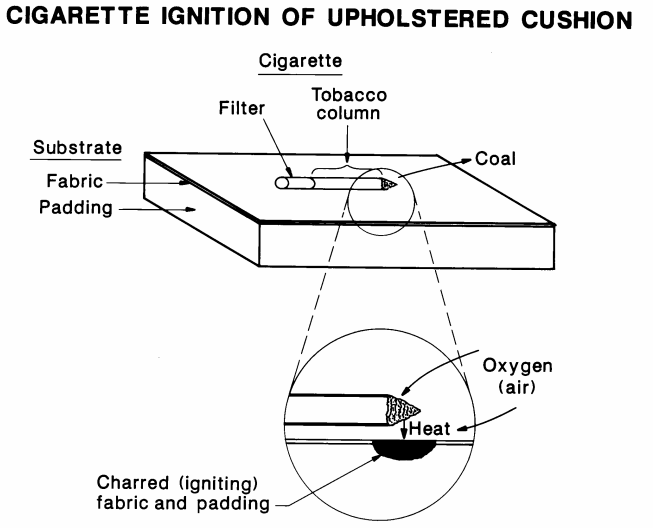


Figure 1. Cigarette Ignition of an Upholstered Cushion.

In simple terms, heat is being generated by the burning cigarette coal and radiatively and convectively lost to the surroundings. When the cigarette is lying on a piece of furniture, there is additional conductive heat loss. If the combined heat losses are too great, the cigarette will not have the strength to heat the furniture surface above its ignition point. Conversely, if the burning intensity of the cigarette is sufficient, a smoldering fire may begin. While the cigarette is being smoked, much of the air for combustion of the tobacco is forcibly drawn through the lit end of the cigarette. When the cigarette is not being puffed, an increased fraction of the air reaches the coal through the pores in the paper that wraps the tobacco column.

The set of reports issued in 1987[7] found, among other conclusions, that:

- Reduced circumference, lower density tobacco, less porous paper, and reduction of burning additive to the paper each reduced cigarette ignition propensity, and that there were some synergisms among these factors.
- Measurement of cigarette ignition propensity on upholstered furniture mockups correlated well with performance on full-scale furniture made of the same materials.
- There were patented cigarette design features that successfully reduced cigarette ignition propensity.
- A valid and reliable measurement method was needed to determine that a cigarette is less ignition-prone.

Following the completion of this research, the Congress passed the Fire Safe Cigarette Act of 1990 (P.L. 101-352). This Act directed the development of a standard test method to determine cigarette ignition propensity and performance data for (commercial) cigarettes.

The National Institute of Standards and Technology (NIST) developed two such methods.[8]

- The Mock-up Ignition Method measures whether a cigarette causes ignition by transferring enough heat to a fabric/foam simulation of a piece of furniture (substrate). A lit cigarette is placed on one of three different mock-ups, each consisting of a sheet of a standard fabric (three different weights of cotton canvas, or "duck") on a thickness of polyurethane foam. Ignition (failure) is defined as the char propagating 10 mm away from the tobacco column. The procedure is repeated a set number of times, and the percent of failures is calculated.
- The Cigarette Extinction Method measures whether a cigarette, when placed on a heat-absorbing substrate, burns long and strong enough to cause ignition had it been dropped on a piece of furniture. A lit cigarette is placed on one of three substrates consisting of a fixed number (3, 10 or 15) of pieces of common filter paper. Failure is defined as the cigarette burning the full length of the tobacco column. The procedure is repeated a set number of times, and the percent failures is calculated. (While the metric in this test is the cessation of burning, it is not just a test for "self-extinguishing" cigarettes. Some cigarette designs that performed well in this procedure also performed well in the Mock-up Method, burning their full length without causing an ignition.)

A round robin examination of the two methods was conducted in 1993, following the procedures in ASTM E 691. The study involved nine laboratories testing each of five cigarette types on three substrates for each method. There were 40 determinations for each combination of cigarette, substrate, laboratory, and method.

Table 1 compiles test results for the five experimental cigarettes in the round robin plus five (of six) cigarettes identified by NIST as likely to be of reduced ignition propensity, based on industry-supplied property data. The two methods produced similar results. The numbers in the table are the percent ignitions (Mock-up Ignition Method) or percent full-length burns (Cigarette Extinction Method). The mock-up method shows better discrimination among cigarettes of high ignition propensity (i.e., near then-current commercial cigarettes), while the filter paper method spreads out

the performance of cigarettes of significantly reduced ignition propensity. The former method is visually more realistic, but requires inventory of carefully specified fabrics and foams, as well as extensive storage space for these materials. The latter method is simpler and requires fewer replicates to obtain a similar degree of repeatability and reproducibility. These values for the filter paper method are shown in Table 2.

Table 1. Percent Ignitions or Full-length Burns on Test Method Substrates.

Cigarette	Substrate					
	3 Layers	Duck 10	Duck 6	10 Layers	15 Layers	Duck 4
1	100	100	92	100	94	73
2	100	100	100	100	100	53
3	100	100	100	100	100	11
4	100	100	73	94	88	46
5	100	100	96	100	94	0
6	99	98	95	94	88	0
7	100	100	92	94	38	4
8	100	100	79	50	19	0
9	57	30	8	6	2	0
10	6	3	0	0	0	0

Table 2. Repeatability and Reproducibility Limits for the Cigarette Extinction Method.

P	r (n)	R (N)
0.05 or 0.95	0.10 (4)	0.11 (5)
0.10 or 0.90	0.13 (5)	0.16 (6)
0.20 or 0.80	0.18 (7)	0.21 (8)
0.30 or 0.70	0.20 (8)	0.25 (10)
0.40 or 0.60	0.22 (9)	0.26 (10)
0.50	0.22 (9)	0.26 (10)

P: fraction of (40) determinations resulting in full-length burns.

r: repeatability: band within which differences among repeat test results (same laboratory) will fall about 95 % of the time.

R: reproducibility: band within which differences among test results from different laboratories will fall about 95 % of the time.

n: number of full-length burns within which differences among repeat test results (same laboratory) will fall about 95 % of the time.

N: number of full-length burns within which differences among test results from different laboratories will fall about 95 % of the time.

The initial efforts to develop a U.S. standard test method within ASTM focused on the Mock-up Ignition Method. However, commercial production of the "standard' fabrics used in the developmental research had virtually ceased. The search for alternative fabrics was not successful, and, in 2000, attention shifted to developing the filter paper method.

In December, 2002, ASTM published ASTM E 2187-02b, Standard Test Method for Measuring the Ignition Strength of Cigarettes. The method was very much like the original Cigarette Extinction Method. Reference 9 documents the changes that occurred during the development of the Standard and the effect on the test results. Photographs of the apparatus are shown in Figure 2.

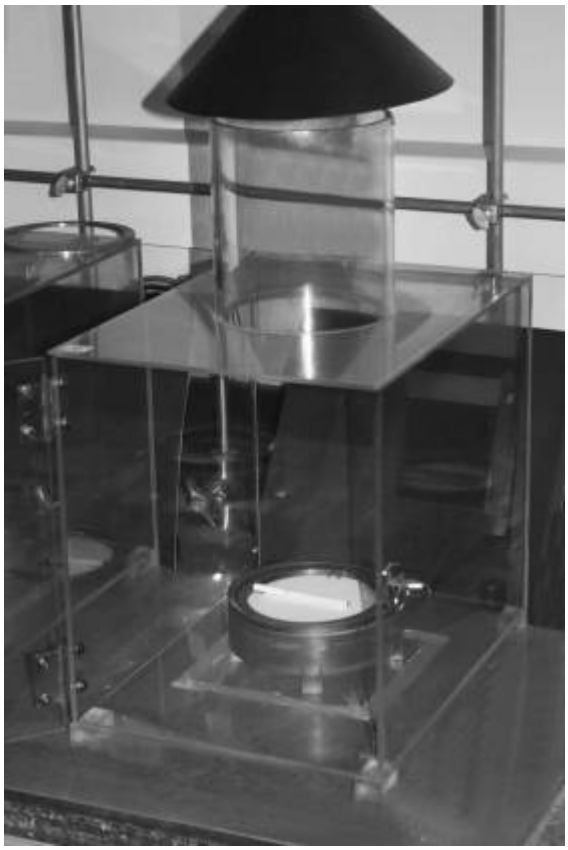
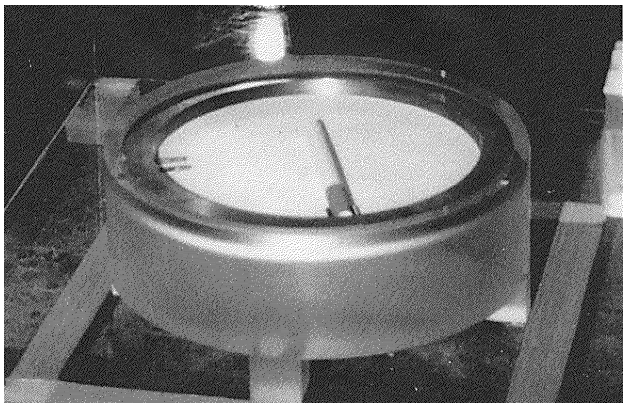


Figure 2. Apparatus for ASTM E2187 (left); Close-up of Cigarette on Filter Paper (below).



Briefly, a single determination consists of placing a lit cigarette on 3, 10, or 15 layers of standard filter paper. The cigarette lighting process is prescribed to minimize the cigarette "remembering" how it was lit. The lighter is held to the tip of the cigarette until 5 mm of the tobacco column has burned. The cigarette is then placed in a horizontal holder until the coal reaches a mark 15 mm from the original tip of the cigarette. Next, the cigarette is carefully and promptly placed on the filter paper. (The principal difference between the original method and the ASTM Standard is the orientation of the test cigarette during this pre-burn period.) The test operator records whether the cigarette burns the full length of the tobacco column (to the tipping paper) or not.

Forty such determinations comprise a test. The fraction of cigarettes achieving a full-length burn is the reported test result.

The clear plastic apparatus is designed to minimize the effect of air currents in the test room. The filter paper and cigarettes are conditioned within a specified range of temperature (23 ºC ± 3 ºC) and relative humidity (55 % ± 5 %). The absolute results of the test are sensitive to the substrate material. Hence Whatman #2 paper is specified, as are both the dry and conditioned mass of the filter paper.

In 2004, several procedural refinements and textural clarifications led to the current version of the method, E 2187-04.

THE FIRST COMMERCIAL REDUCED IGNITION PROPENSITY CIGARETTES

During the two decades prior to the 1984 Congressional Act, a small number of cigarette brands had been noted as being less likely to ignite furniture mock-ups. As mentioned above, six such cigarettes were demonstrated to be of reduced ignition propensity under the 1990 Act. There had been no indication that any of these cigarettes had been manufactured for reduced ignition propensity.

In January 2000, a major manufacturer of cigarettes announced that it would soon be test marketing a modification of one of their cigarettes that would make them less likely to start a fire. Having evolved from one of the patented ideas tested under the Cigarette Safety Act of 1984, the modification entailed adding circumferential bands of low air permeability paper to the paper that wraps the tobacco column. These bands were said to reduce the rate of burning, making it more difficult for the cigarette to heat furnishings and cause ignition.

In May 2000, soon after the test marketing of the modified cigarettes began, the Federal Trade Commission Bureau of Consumer Protection requested that the NIST Building and Fire Research Laboratory (BFRL) "conduct tests to determine whether and to what extent this cigarette does reduce the risk of ignition." NIST replied that "While NIST does not routinely perform product tests, we recognize the important role of the Federal Trade Commission in assuring the public of the veracity of product claims and the high potential for less fire-prone cigarettes to reduce fire deaths and injuries."

The NIST tests showed that the cigarettes were indeed of reduced ignition propensity, with the results generally lying between cigarettes 9 and 10 in Table 1.[10] While the only publicly stated difference between the two types was the banding of the wrapping paper, NIST performed no tests to ascertain that there were not additional differences.

REGULATION

In 2000, after many years of effort under the leadership of Assemblyman Pete Grannis, New York State enacted the world's first legislation requiring less fire-prone cigarettes. This was also the first time that cigarettes had been regulated in any manner. The legislation directed the Office of Fire Prevention and Control (OFPC), in consultation with the Department of Health, to promulgate fire safety standards for cigarettes sold, offered for sale or manufactured in the State. The standards were to insure that either:

- Such cigarettes, if ignited, will stop burning within a time period specified by the standards if the cigarettes are not smoked during that period; or
- Such cigarettes meet other performance standards prescribed by the Office of Fire Prevention and Control to limit the risk that such cigarettes will ignite upholstered furniture, mattresses or other household furnishings.

Performance standards were developed under the leadership of Chief John Mueller of OFPC. The final rule requires that for all cigarettes sold in New York State after June 28, 2004:

- Testing of cigarettes be conducted using ASTM standard E2187-02b, subject to modifications that made it identical to ASTM E 2187-04. A complete test consisted of 40 replicate determinations on 10 layers of filter paper.
- No more than 25 % of the cigarettes in a test could exhibit full length burns.
- Cigarettes that use lowered permeability bands in the cigarette paper to achieve compliance with the performance standard have at least two nominally identical bands on the paper surrounding the tobacco column, with requirements for the location of the bands.
- For a cigarette that cannot be tested in accordance with the test method, the manufacturer must propose an alternate test method and criterion. OFPC would determine whether that was

equivalent to the performance standard.

- Laboratories conducting testing were to implement a quality control and quality assurance program that included a procedure that will determine the repeatability of the testing results. The repeatability value was to be no greater than 0.19.

Prior to the deadline, manufacturers certified that virtually all of the nominally 1000 brand styles of cigarettes sold in New York State met the standard. The circle had been closed. The Congressionally funded research had demonstrated technical feasibility of less fire-prone cigarettes. Now the response to the New York State legislation demonstrated commercial feasibility.

In 2006, the National Fire Protection Association (NFPA) announced the creation of a Coalition for Fire-Safe Cigarettes.[11] Coordinated by NFPA, this is a national group of fire service members, consumer, elderly, and disabled rights advocates, medical and public health practitioners, and others, that are committed to saving lives and preventing injuries by reducing the threat of cigarette-ignited fires. The goal is for cigarette manufacturers to immediately produce and market only cigarettes that adhere to an established cigarette fire safety performance standard. In addition, the Coalition is working to see that these standards for fire-safe cigarettes are required in every state in the country.

At present, 14 states and the Dominion of Canada have enacted such legislation. (See Table 3.) This represents approximately 42 % of the population of North America. As of the date of the writing of this paper, bills in Alaska, Maine and Texas await the Governors' signatures. Legislation has been introduced in 13 additional states.

Table 3. Less Fire-prone Cigarette Regulations.[11]

Jurisdiction	Date Enacted	Effective Date	Estimated Population (millions)
New York	8/17/01	6/28/04	19.0
Canada	6/13/05	10/1/05	32.8
Vermont	6/17/05	5/1/06	0.6
California	10/7/05	1/1/07	33.9
Illinois	5/19/06	1/1/08	12.4
New Hampshire	5/31/06	10/1/07	1.2
Massachusetts	7/8/06	1/1/08	6.3
Utah	3/07		2.2
Kentucky	3/27/07	4/1/08	4.0
Oregon	4/17/07		3.6
New Jersey	5/4/07	6/1/08	8.4
Minnesota	5/7/07	12/1/08	5.2
Maryland	5/17/07		5.3
Iowa	5/21/07	1/1/09	3.1
Montana	5/11/07	5/1/08	1.0
Total			139

There is also current activity with the European Union and Australia, citing the same test method.

EFFECTIVENESS OF REGULATION

As of the date of this paper, the only available information is for New York State. The OFPC web site does not contain the effect of the switch to compliant cigarettes on cigarette-initiated fires and fire deaths. However, presentations at conferences have indicated a significant reduction in both categories.

Connolly and co-workers at the Harvard School of Public Health have analyzed a variety of data from New York State.[12] They found that the change to compliant cigarettes had no significant effect on sales, tax revenue, or price. There may have been a small reduction in the availability of older or niche cigarette brands styles. Small changes in puff count and tar, nicotine and carbon monoxide yields were reported, but appear to this author to be within experimental uncertainty.

STANDARD CIGARETTES

Beginning in September 2003, cigarette companies, the New York OFPC, and Health Canada urged that NIST develop a standard reference cigarette. Much of the research that led to the ASTM Standard had been conducted using series of experimental cigarettes prepared by the industry during the two Congressionally mandated studies. These fell into short supply, far too few in number to help test laboratories meet requirements for quality assurance programs.

The planned cigarette was to have a target ignition strength near (a) the required pass/fail criterion and (b) the value to which cigarette companies would need to design products in order to assure success during compliance testing, a value which is somewhat lower than the pass/fail criterion. It would be used by testing laboratories to assure that their measurements were of the proper quality control and were not varying over time.

Philip Morris USA agreed to manufacture several candidate cigarettes.* The low ignition strength was obtained using paper of reduced porosity to air and expanded tobacco. The cigarettes did not use any proprietary technology. In particular, the paper was not banded, the technique utilized in most cigarettes to comply with the NYS regulation. NIST tested some of the batches and selected one that was expected to meet the performance criteria described above. The nominal properties of the selected cigarettes, as described by the manufacturer, are:

Length:	100 mm, including filter tip
Circumference:	25 mm
Mass:	580 mg
Tobacco:	100 % expanded Bright
Paper porosity:	52 CORESTA Units
Citrate in paper:	0 %
Oven volatiles:	11.5 %

NIST purchased 5000 cartons of the cigarettes and stored them in a chiller that meets the storage requirements in the ASTM standard. Each carton, the unit of sale, contains 10 packs of 20 cigarettes each. The cartons and packs were printed to NIST specifications, with labels identifying them as SRM 1082. There is no printing on the cigarettes. Figure 3 shows one pack.

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* Certain commercial entities, equipment, or materials are identified in this document in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

NIST selected cartons at random and selected one pack at random from each of these cartons for development of a certification value. Some of these packs were sent to the National Research Council of Canada and to Kidde-Fenwal (with whom New York State has contracted for cigarette testing) for testing as well. Each laboratory purchased the needed filter paper and determined that it met the mass specifications in the ASTM standard.

The certified value and its uncertainty, 12.6 % ± 3.3 %, were obtained by fitting a Bayesian hierarchical model to the data from the three laboratories.[13] The certified value meets the performance criteria mentioned above. The expanded uncertainty given is reported at the 95 % probability level. Figure 4 shows the results of a typical determination. More detail on the certification procedure and information regarding on-line purchase of these cigarettes can be found at https://srmors.nist.gov/view_detail.cfm?srm=1082. A recent collection of data from purchasers of the SRM indicated a mean value of 12.2 %. However, there was significant scatter among the laboratories, perhaps indicating non-uniform test operation.

Figure 3. One Pack of SRM 1082 Cigarettes.

Figure 4. Typical ASTM E 2187 Test Results. Top: Standard Non-filter Cigarette Used to Test Furnishings for Cigarette ignition resistance; Left: Conventional Commercial Cigarette; Right: SRM 1082.

IMPLICATIONS FOR TESTING OF FURNISHINGS

As noted in the opening of this paper, mattresses and upholstered furniture (and furniture components) are tested for resistance to ignition by cigarettes. The two regulators are the U.S. Consumer Product Safety Commission (CPSC) and the California Bureau of Home Furnishings and Thermal Insulation (BHFTI). Both require testing of all mattresses using a commercial cigarette known to be a strong igniter. Testing of upholstered furniture, using that cigarette, is mandatory in California and voluntary but widespread in the rest of the country.

The progress of state legislation mandating less fire-prone cigarettes makes it reasonable to expect that within about two years, these new cigarettes will occupy much if not all of the marketplace. These actions will result in a sizable reduction in the number of cigarette-initiated fires and a similar reduction in fire deaths, injuries and property loss.

This projection of improved fire safety assumes both the ignition source becoming less potent and the furniture not becoming easier to ignite. However, compliance with the legislation will reduce the ignition strength of the standard cigarette used in mattress and upholstered furniture testing, along

with that of all the other cigarettes. Testing furnishings with a weaker cigarette will allow more ignitable upholstery fabrics to come into use. The net result will be to offset the benefit of the new low ignition strength cigarettes.

The solution is to make available an ignition source that performs like the current, potent test cigarette. There is Federal effort along this line. Amendment of the U.S. and California furniture regulations will then be necessary.

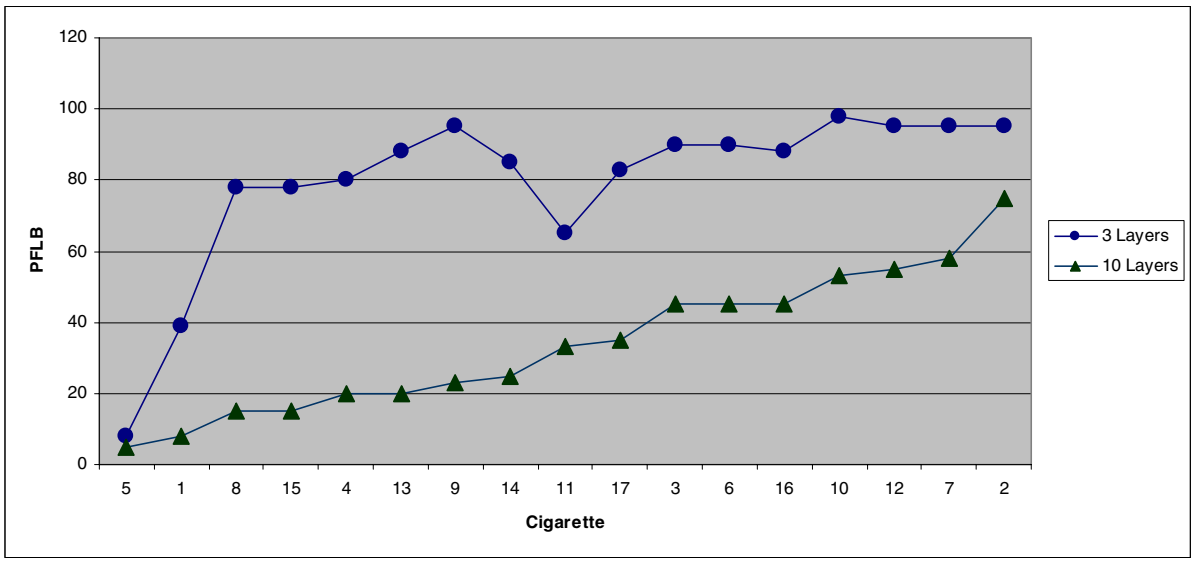
PROVISION FOR FUTURE TESTING

The current regulations require no more than 25 % full-length burns on 10 layers of filter paper. To be 95 % confident that products will meet this criterion when tested, cigarettes must be designed to yield approximately 16 % full-length burns, assuming tests that follow a binomial distribution. A recent sampling of the marketplace indicated that most cigarettes are generating fewer than 10 % full-length burns. The manufacturers are being careful to minimize the chances of an errant failure.

Should the regulators wish to reduce fire losses further than the degree achieved with the current regulations, the effectiveness of the current testing approach could become limited. For example, changing the requirement to no more than 10 % full-length burns leads to test results that may be statistically indistinguishable from the apparent current design level. It may not be possible to know that such a reduction in the pass/fail criterion would lead to an improvement in fire safety. It will be necessary to expand the performance scale of the test method.

NIST performed an analysis comparing the results of some low ignition propensity cigarettes tested on both 10 layers of filter paper and 3 layers.[14] In Figure 5, the cigarettes are arrayed in increasing order of ignition strength measured on 10 layers of filter paper.

Figure 5. Performance of Reduced Ignition Propensity Cigarettes on 3 and 10 Layers of Filter Paper.

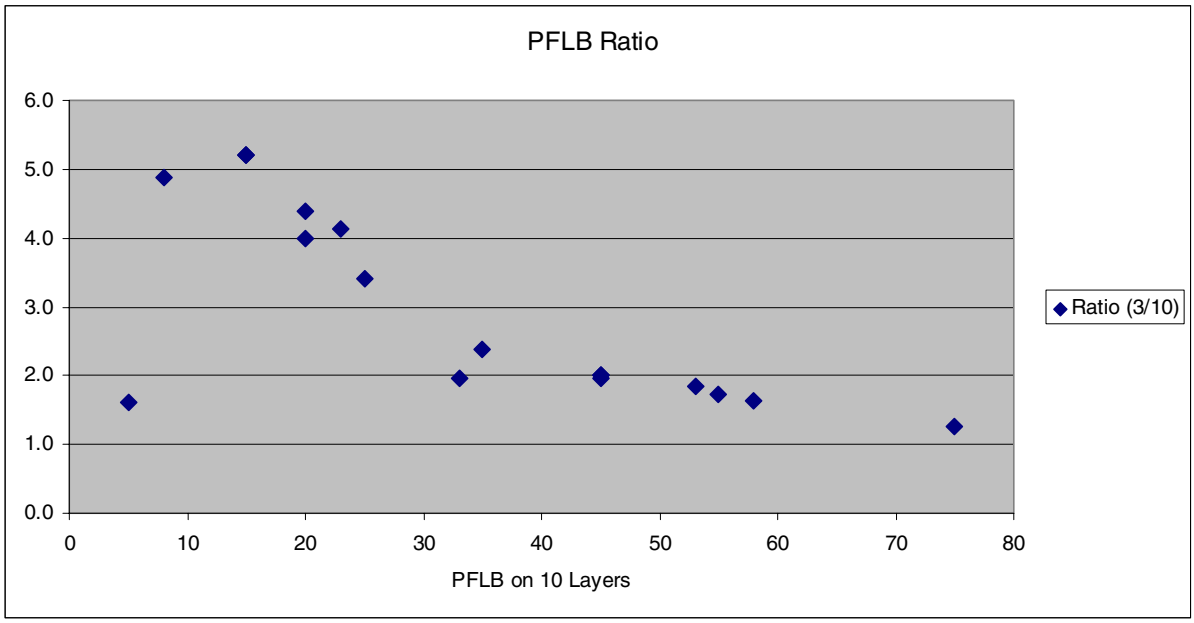


There is a roughly monotonic rise in the percentage full-length burns (PFLB) from left to right. The test results on 3 layers are quite different. There is a steep rise, followed by apparent "saturation" at about 90 % full-length burns. This suggests that in the range from 0 PFLB to 20 PFLB on 10 layers (the range of current interest), more sensitivity might be obtained by testing on a thinner substrate.

Figure 6 is an alternative plot of the same data. Here, the ratio of the test results (3 layers divided by 10 layers) shows that a factor of four or five may be attainable in the 0 PFLB to 20 PFLB range on 10 layers. (As can be seen in Figure 5, the leftmost point in Figure 6 is a ratio of two small numbers with large uncertaintities and is not significant for this exploratory analysis.) There is thus potential for

statistically valid testing of even lower ignition strength cigarettes than the current requirement. Experiments are underway using, e.g., 5 layers of filter paper to determine a thermally thinner substrate.

Figure 6. Ratio of Full-length Burns Measured on Two Filter Paper Substrates.



SUMMARY

Extensive research, funded under U.S. Federal legislation, has led to the development of a standard test method for measuring the ignition propensity of cigarettes. Regulations citing this method have been enacted in 12 U.S. States and Canada. Preliminary results indicate that the regulation is effective and has not resulted in large changes in cigarette consumption, price, or health effects. Further research is underway to support possible future strengthening of the regulatory test criterion. Laboratories are routinely conducting tests, with quality control aided by the NIST Standard Reference cigarette. A replacement ignition source for testing of ignition resistance of upholstered furniture and mattresses is needed.

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