NIST Technical Note 1454

Robustness of Measuring the Ignition Strength of Cigarettes with ASTM Method E2187-02b

National Institute of Standards and Technology
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ABSTRACT

The Standard Test Method adopted by the State of New York (NYS) in its promulgation of fire safety standards under Chapter 284 of the Laws of 2000, was originally developed in 1992. The original method draft needed additional detail to be acceptable as a U.S. standard. Since then, the text has undergone a series of clarifications, with a few substantive changes in the methodology. In December 2002, ASTM International issued ASTM E2187-02b, Standard Test Method for Measuring the Ignition Strength of Cigarettes, the method adopted by the New York Office of Fire Prevention and Control (OFPC). This report documents this evolution, during which there has been no significant change in the repeatability or reproducibility of the method. There is limited evidence that for cigarettes of both conventional and banded design, the measured ignition strength has not changed significantly.

Keywords: fire, fire research, cigarette, ignition

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I. INTRODUCTION

The Standard Test Method adopted by the State of New York (NYS) in its promulgation of fire safety standards under Chapter 284 of the Laws of 2000, was originally developed in 1993. The original method draft needed additional detail to be acceptable as a U.S. standard. Since then, the text has undergone a series of clarifications, with a few substantive changes in the methodology. In December 2002, ASTM International issued ASTM E2187-02b, Standard Test Method for Measuring the Ignition Strength of Cigarettes[1], the method adopted by the New York Office of Fire Prevention and Control (OFPC). This paper presents the test method activity during that decade.

II. THE CIGARETTE EXTINCTION TEST METHOD

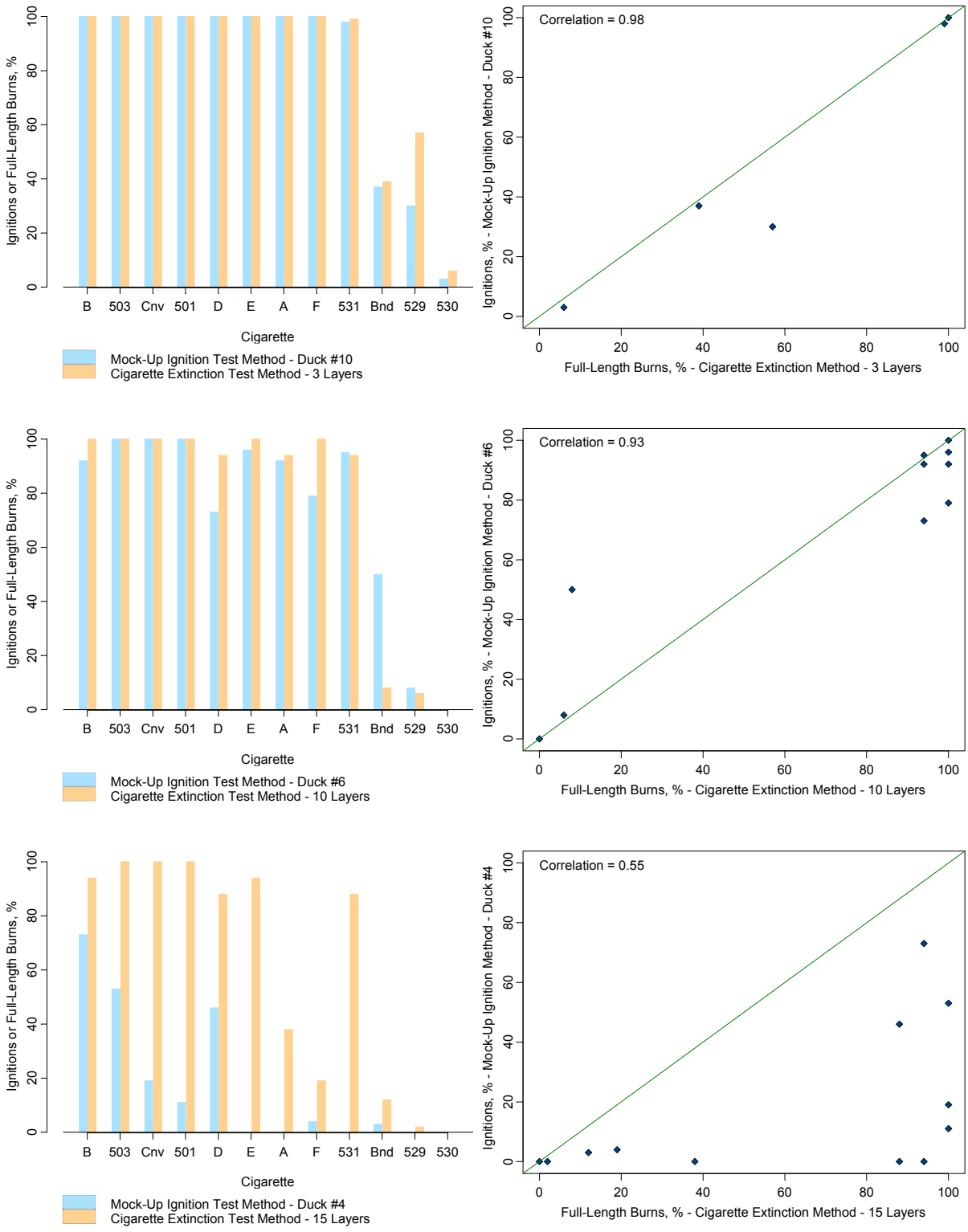
Under the Fire Safe Cigarette Act of 1990, P.L. 101-352, the National Institute of Standards and Technology developed two test methods for measuring the likelihood that a type of cigarette could ignite soft furnishings, *i.e.*, upholstered furniture and beds.[2]

- The Mock-up Ignition Test Method, in which a lit cigarette was placed on one of three standard furniture simulations consisting of one of three standard (cotton duck) fabrics over a block of a standard polyurethane foam. The metric is whether the cigarette ignites the mock-up, such that the smoldering is self-sustaining, extending beyond the thermal influence of the cigarette. The test is repeated a set number of times, and the number of ignitions is reported.
- The Cigarette Extinction Test Method, in which a lit cigarette is placed on several layers of common filter paper. The paper cannot ignite to smoldering, but draws heat from the cigarette. The persistence of cigarette burning is an indication of energy available to ignite soft furnishings. Thus, the metric is whether the cigarette burns its full length or not. The test is repeated a set number of times and the number of full-length burns is recorded.

The validity of the methods was established based on the following:

- The heat transfer physics is closely related to that of a lit cigarette lying on a chair or bed.[3]
- There is a good correlation between cigarette ignition propensity on fabric/foam mock-ups and actual furniture fabricated from the same materials.[3]
- An analysis of a cigarette industry study involving a large number of commercial upholstery fabrics showed that about 80 % of those fabrics ranked cigarette ignition propensity in a manner consistent with the Mock-up Ignition Method test fabrics.[4]
- Measures of ignition propensity of a range of cigarette types gave similar results under the two methods[2] as shown in Figure 1.

Figure 1. Bar and scatter plots illustrating the relationship between the Mock-up Ignition Test Method [Left Bar] and the Cigarette Extinction Test Method [Right Bar]



The data in Figure 1 were obtained from an Interlaboratory Evaluation (ILE) of the two methods conducted in 1993[2] and from subsequent testing at NIST. Nine laboratories participated in the ILE: three government labs, five from the cigarette industry, and one private testing lab. For each method, five experimental cigarettes were tested on each of three substrates. 48 determinations were performed of each cigarette/substrate combination in the Mock-up Ignition Method, 16 determinations in the Cigarette Extinction Method. In addition, NIST measured data for five commercial cigarettes of low ignition strength in 1993[2] and for two more commercial cigarettes in 2000.[5] The numbers of determinations run in these tests ranged from 8 to 48 for the Mock-up Ignition Method and from 6 to 24 for the Cigarette Extinction Method.

The results in Figure 1 (and Table X1.1 in reference 1) show that the six substrates in the two test methods provide an interwoven scale for measuring ignition strength. In order of test severity (*i.e.*, ease of ignition or ease of full length burn), the resulting scale is:

(3 layers of paper = duck #10) > (10 layers = duck #6) > 15 layers > duck #4

While there had been no intent for the three substrates in the two methods to have a one-to-one correspondence, there is good correlation between the first two levels (3 layers/duck #10 and 10 layers/duck #6) for the two test methods. Although measuring different quantities, the rates of ignitions and full-length burns are essentially comparable for the tested cigarettes at these two levels, as indicated by the clustering of results along the line $y=x$ (the 45° line). For the third levels of the two test methods, duck #4 is always less severe than 15 layers.

As part of the ILE, NIST also developed repeatability limits and reproducibility limits for each test method. Repeatability limits, r, specify the band within which differences among repeat test results from a single laboratory will fall about 95 % of the time and reproducibility limits, R, specify the band within which differences among repeat test results from different laboratories will fall about 95 % of the time. The written descriptions of the two test methods were rough, and much of the quality of the ILE resulted from the careful training of the test operators and by attentive monitoring of the procedures followed within the nine laboratories. The results of the ILE will be discussed further in Section IV.

III. ASTM STANDARD TEST METHOD FOR MEASURING THE IGNITION STRENGTH OF CIGARETTES

In 1995, a Task Group under ASTM Subcommittee E5.15 began developing a standard based on the Mock-up Ignition Method. The standard fabrics, which had originally been selected in part because of the likelihood of their long-term availability, were in fact no longer in production. Further effort on this method continues, but appropriate standard fabrics are still not available.

With state and Federal legislation under development that required a test method document, an effort was begun to standardize the Cigarette Extinction Method. A review of the descriptions of the procedure and apparatus from reference 2 showed that additional detail was needed to ensure uniform implementation of the method. In 2000, ASTM circulated a first ballot of this more explicit version of the Cigarette Extinction Method. [NIST used this version, with the exception

of varying the number of determinations, to examine the performance of the first commercially available cigarettes that were intended to be of reduced ignition strength.[5]] Refinements over the next two years led to a successful third ballot. This resulted in the issuing of ASTM E2187-02. Further clarifications and corrections resulted in the current ASTM E2187-02b.

It is instructive to document the evolution of the test method documents. This evolution of 13 test conditions is presented in Table 1.

During the balloting process, a small number of changes were made in the test procedure:

- The cigarette ignition procedure was changed from prescribing the use of a continuous air draw to achieving a lit cigarette. This allowed the use of cigarette puffing machines or any other procedure that ensured burning to the 5 mm mark on the cigarette. The pre-burn period, during which the cigarette burned to the 15 mm mark, was sufficient to erase the cigarette's "memory" of how it was initially ignited.
- The requirement for measuring the mass of the cigarette was discarded. For testing of commercial products, variation in the product is part of the test condition.
- A shorter time procedure for conditioning the filter paper was added. Routine use of the method showed that the one week conditioning period could limit the rate at which cigarettes might be tested. Tests in two laboratories showed that thin packets of filter paper, with good access to the ambient conditioning environment, reached constant mass in less than eight hours.
- The cigarette was to be rotated as needed during the ignition process. Observation of test operators showed that, depending on how that laboratory chose to achieve ignition, some eccentricity of the coal could result. This made it difficult for the test operator to know when the burn passed the 5 mm mark.
- The location of the cigarette holder was specified. Previously, a test operator could place the cigarette holder such that it was clumsy to place the cigarette on it or to remove the cigarette from it without affecting the ash.
- For laboratories operating multiple apparatus concurrently, a limit was placed on the number of cigarettes that could be in the pre-burn stage at the same time. Observation of test operators indicated that at times they might be rushed to move the lit cigarettes from the holder to the filter paper. This haste could lead to rough handling and damage to the cigarette coal during placement on the filter paper.
- The orientation of the cigarette during the pre-burn period was changed from vertical to horizontal. This was deemed to be a more realistic rendition of the cigarette position in actual use. NIST tests using the Mock-up Ignition Method with cotton duck 6 indicated no significant effect on the number of ignitions: a conventional cigarette produced virtually 100 % ignitions in 32 determinations of each orientation. A banded cigarette produced 19 (see Table 6) ignitions (out of 32 determinations) with a horizontal pre-burn and 16 ignitions with a vertical pre-burn.
- Recording of the time to extinguishment of the cigarette was eliminated. No relationship had been established between this value and the ignition strength of the cigarette.

Table 1. Evolution of the Test Method Documentation

Feature	NIST SP851 August, 1993	ASTM Ballot 1 August, 2000	ASTM Ballot 2 April, 2001	ASTM E2187-02 February, 2002	ASTM E2187-02b December, 2002
Test Chamber	Photograph and dimensional schematic shown in reference 2. Chambers provided by NIST to ILE participants.	Same photo and schematic; no further verbal description.	Schematic replaced by quantitative description; dimensions unchanged	Unchanged	Unchanged
Test Apparatus	Photograph and dimensional schematics shown in reference 2.	Same photo and schematic. Dimensional description of metal rim added, including unintentional decrease of rim thickness from 6.2 mm to 3 mm.	Schematic replaced by quantitative description; dimensions unchanged. Error in rim thickness continued.	Unchanged	Error in rim thickness changed to original ILE dimension. No other changes.
Cigarette Ignition System	Specific apparatus described	Performance requirement of ignition hardware replaced detailed description.	Airflow prescription removed. Tolerance added to butane flame height.	Unchanged	Unchanged
Conditioning Environment	55 ± 5 % RH; 23 ± 3 °C	Unchanged	Unchanged	Unchanged	Unchanged
Cigarette Selection	Cigarettes of extreme mass discarded	Mass requirement eliminated.	Unchanged	Unchanged	Unchanged
Cigarette Conditioning	24 hours in conditioned room or constant humidity box	Unchanged	Unchanged	Unchanged	Unchanged
Filter Paper Selection	Select any sheets from box	Unchanged	Unchanged	Unchanged	Reject paper of extreme mass Can re-use paper if no cigarette was placed on it.
Filter Paper Conditioning	1 week in open box in conditioned room or constant humidity box	Unchanged	Unchanged	Unchanged	8 hour conditioning time allowed for vertical arrays of up to 15 sheets.

Feature	NIST SP851 August, 1993	ASTM Ballot 1 August, 2000	ASTM Ballot 2 April, 2001	ASTM E2187-02 February, 2002	ASTM E2187-02b December, 2002
Ignition Method	Small flame only.	Small flame or hot coil.	Unchanged	Unchanged	Rotate cigarette to get symmetrical burn
Cigarette Pre-burn Process	Cigarette in vertical position	Unchanged	Unchanged	Cigarette in horizontal position	Clarified location of cigarette holder in test chamber. Maximum of two cigarettes in the pre-burn stage at any time.
Cigarette Test Process	Measure time to extinguishment Number of determinations not specified	Time measurement eliminated 16 determinations	40 determinations	Unchanged	Cover the chimney while the cigarette is being moved from the holder to the paper.
Test Criterion	Consumption of tobacco column	Burn full length of tobacco column	Unchanged	Burn to beginning of tipping paper (filter tip cigarettes) or within 5 mm of end of tobacco column (non-filter tip cigarettes)	Burn to front plane of tipping paper (filter tip cigarettes) or past tips of metal pins (non-filter tip cigarettes)
Test Report	Full-length burn or extinguishment; time to extinguishment	Eliminate time to extinguishment	Add note of extinguishment in holder, disturbed smoke plume	Unchanged	Unchanged

IV. TEST DATA

The effect of these clarifications, corrections, and changes in the test method on the measurement of cigarette ignition strength (fraction of full length burns) has been evaluated over time. These tests involved the 500 series cigarettes manufactured for the Technical Advisory Group under the Fire Safe Cigarette Act of 1990. The results reported here are for cigarettes that had been stored in freezers at NIST from then until their use.

The results for the nine laboratories in the 1993 ILE are presented in Tables 2 and 3.

Table 2. Mean Fraction of Full-Length Burns for 16 Replicate Determinations in the 1993 ILE of the Cigarette Extinction Test Method (Nine Laboratories)[2]

Cigarette	Layers of Filter Paper		
	3	10	15
529	0.57 ± 0.09	0.056 ± 0.078	0.021 ± 0.034
530	0.056 ± 0.045	0.00 ± 0.00	0.00 ± 0.00
531	0.99 ± 0.02	0.94 ± 0.05	0.88 ± 0.08

Note: Quoted ignition strength uncertainties are approximate 95 % expanded uncertainties based on the reproducibility standard deviations from reference 2 and ISO methods[6] with a coverage factor of k=2.306 obtained from Student's t distribution with 8 degrees of freedom.

Table 3. Repeatability Limits, r, and Reproducibility Limits, R, based on 1993 ILE of the Cigarette Extinction Test Method[2]

P	n = 16		n = 24		n = 40	
	r	R	r	R	r	R
0.05 or 0.95	0.15	0.16	0.12	0.14	0.10	0.11
0.10 or 0.90	0.21	0.22	0.17	0.19	0.13	0.16
0.20 or 0.80	0.28	0.30	0.23	0.25	0.18	0.21
0.30 or 0.70	0.32	0.34	0.26	0.29	0.20	0.24
0.40 or 0.60	0.34	0.37	0.28	0.31	0.22	0.25

As part of its support for the NYS OFPC, NIST identified cigarette types from the 500 series that could be used to calibrate testing activities during the standard development process. The first results of five sets of 24 determinations are shown in Table 4. The procedure used was that in ASTM Ballot 2. However, NIST continued to use the 6.25 mm thick metal rims from the 1993 ILE. The repeatability limits for 24 and 40 determinations were estimated from the results.

Table 4. Ignition Strength and Repeatability Limits (NIST; November 2001)

Cigarette	Paper Sheets	Full Length Burns	Ignition Strength	r (n=24)	r (n=40)
529	**3**	17, 14, 13, 21, 14	0.66 ± 0.09	0.27	0.21
516	**10**	8, 6, 9, 12, 6	0.34 ± 0.09	0.27	0.21
532	**15**	20, 19, 22, 20, 18	0.82 ± 0.07	0.22	0.17

Note: Quoted ignition strength uncertainties are approximate 95 % expanded uncertainties based on observed binomial repeatabilities and ISO methods[6] with a coverage factor of k=1.9801 obtained from Student's t distribution with 119 degrees of freedom.

Soon thereafter, OFPC selected the Combustion Research Center of Kidde-Fenwal (KF) as the laboratory to examine the ignition strength of current commercial cigarettes. NIST assisted KF in setting up their laboratory and provided training for their test operators. During this process, it was noticed that some of the results from the two laboratories were outside the expected reproducibility. Two possible factors were noted:

- The sheets of filter paper from one batch were noticeably lighter than sheets from the other batches.
- KF, following the ASTM draft procedure, had fabricated metal rims that were 3 mm thick.

NIST performed tests to identify the extent to which either of these factors might be the source of the interlaboratory differences. The results for one set of 24 determinations with cigarette 532 on 15 layers of filter paper are shown in Table 5.

Table 5. Ignition Strengths for Filter Paper of Varying Mass and Metal Rim of Varying Thickness; March 2002

Filter Paper Mass	Metal Rim Thickness	
	3.0 mm	**6.2 mm**
Light	0.79 ± 0.17	0.79 ± 0.17
Normal	0.46 ± 0.21	0.71 ± 0.19

Note: Quoted ignition strength uncertainties are approximate 95 % expanded uncertainties based on observed binomial repeatabilities and ISO methods[6] with a coverage factor of k=2.069 obtained from Student's t distribution with 23 degrees of freedom.

Although the approximate 95 % uncertainty intervals for the treatments shown in Table 5 all overlap slightly, the differences between the results obtained using the thinner metal rim and the normal weight paper differ significantly from the results for the light paper with either rim at the

95 % confidence level when confidence intervals for the differences between different pairs of treatments are computed. [A Bayesian model of this data, treating each of the four test conditions as an independent binomial population and using uniform prior distributions, confirms the approximate uncertainty estimates shown in Table 4. The Bayesian model also allows probabilistic comparisons of the proportions of full-length burns that will be observed under different testing conditions. For example, there is a probability of 0.9444 that the proportion of full-length burns that would be observed using the light paper and the thin rim is lower than the proportion of full-length burns that would be observed under any of the other test conditions.]

These results led to the return to the original metal rim thickness in ASTM E2187-02b and a tightening of the filter paper mass specification. Since then, Whatman[7] has indicated the possibility of producing a special grade of their paper that meets this tighter mass control specification. These changes to the standard should make test results observed at different times or at different laboratories more consistent.

In 2000, NIST performed some exploratory tests to estimate the effect of the orientation of the cigarette during the pre-burn period on measured ignition strength. The tests used the method in TN 1436[5] with the normal 6 mm metal rim (despite the thickness cited in the method description). The cigarette was the test market version of a banded brand.

Table 6. Measured Values of Banded Cigarette Ignition Strength for Vertical and Horizontal Orientation during the Pre-burn Period; December 2001

Mock-up Ignitions, Duck #6				Full-length Burns on 3 Layers of Filter Paper			
Horizontal		Vertical		Horizontal		Vertical	
19/32	0.59 ± 0.18	16/32	0.50 ± 0.18	18/24	0.75 ± 0.18	9/24	0.38 ± 0.20

Note: Quoted ignition strength uncertainties are approximate 95 % expanded uncertainties based on observed binomial repeatabilities and ISO methods[6] with a coverage factors of k=2.040 obtained from Student's t distribution with 31 degrees of freedom and k=2.069 obtained from Student's t distribution with 23 degrees of freedom.

The limited data show no significant effect of pre-burn orientation on ignition of the mock-ups. 3 layers of filter paper is a strong discriminator relative to 10 or 15 layers, and there is a significant effect of pre-burn orientation here. [The extent to which this kind of result would be seen on thicker paper substrates is examined below.] None of the extinguishments in any of the trials occurred during the pre-burn period. Thus, for this cigarette, the effect is due to the intensity of the coal at the end of the pre-burn period rather than a different extinguishment rate during the pre-burn period.

In 2003, NIST conducted tests to compare results obtained using the procedure in NIST TN 1436 with those obtained using ASTM E2187-02b. Three commercial cigarette packings, two banded and one non-banded, were tested on 10 layers of filter paper (Table 7). 80 determinations were performed for each method/cigarette combination. [The number of determinations was doubled to increase the probability of detecting possible differences in extinguishments during the pre-

burn period vs. on the filter paper.] All of the packing 1 cigarettes came from a single carton; the same is true for the packing 2 cigarettes. The packing 3 cigarettes came in cartons of 100 cigarettes; the first 100 cigarettes tested came from one carton, the later 60 came from a second carton and are treated in the analysis as if they were a different packing.

Table 7. Performance of Commercial Cigarettes in Two Versions of the Ignition Strength Test Method for 80 Determinations on 10 Layers of Filter Paper; July 2003

Cigarette	NIST TN 1436			ASTM E2187-02b		
	FLB	Ext.	Holder	FLB	Ext.	Holder
1 (B)	8 (10)	46 (58)	26 (33)	11 (14)	65 (81)	4 (5)
2 (B)	55 (69)	14 (17)	11 (14)	60 (75)	19 (24)	1 (1)
3a (NB)	33 (63)	13 (25)	6 (12)	30 (62)	18 (38)	0 (0)
3b (NB)	2 (7)	14 (50)	12 (43)	18 (56)	14 (44)	0 (0)

FLB: Number (percent) of full-length burns
Ext: Number extinguished on the filter paper
Holder: Number extinguished during pre-burn period
B: Banded cigarette
NB: Non-banded cigarette

As shown in Table 8, the two methods produced the same measure of ignition strength for the two banded cigarettes and the first carton of the non-banded cigarette. The two methods gave different ignition strength results for the second carton of non-banded cigarettes. [The 95% probability intervals for the *differences* in the ignition strengths obtained with the two methods (listed in the right-most column of the table) indicate a statistically significant difference in the two methods when the interval does not contain the value zero. This is because the probability that the two methods actually differ must be 95 % or more whenever the endpoints of the probability interval are either both negative or both positive.]

As shown in Table 9, below, the two methods exhibited significant differences in the distributions of extinguishments between the pre-burn and test periods for all four cigarettes. In all cases the combination of a vertical pre-burn and the thin metal ring in TN 1436 produced more extinguishments during the pre-burn period. [As noted above, the 95 % probability intervals for the difference in the proportion of pre-burn extinguishments obtained with the two methods (listed in the right-most column of the table) indicate a statistically significant difference in the two methods if the interval does not contain the value zero.]

Table 8. 95 % Probability Intervals for Ignition Strengths Using the Two Versions of the Ignition Strength Test Method and for the Difference Between the Methods

Cigarette	NIST TN 1436	ASTM E2187-02b	Difference
1 (B)	0.05 to 0.18	0.08 to 0.23	-0.14 to 0.06
2 (B)	0.58 to 0.78	0.64 to 0.83	-0.06 to 0.08
3a (NB)	0.50 to 0.75	0.48 to 0.75	-0.17 to 0.19
3b (NB)	0.02 to 0.23	0.39 to 0.72	-0.65 to -0.26

Note: The probability intervals for the ignition strength of each method and their difference were computed using Bayesian Markov Chain Monte Carlo methods since the normal approximation needed to use ISO methods[6] will not work well for some of the low ignition strengths observed in this experiment. The Bayesian analysis was carried out using binomial likelihoods for the data and non-informative uniform priors on the interval (0,1) for the ignition strength parameters.

Table 9. 95 % Probability Intervals for Proportion of Pre-Burn Extinguishments in the Two Versions of the Ignition Strength Test Method and Their Difference

Cigarette	NIST TN 1436	ASTM E2187-02b	Difference
1 (B)	0.23 to 0.44	0.02 to 0.12	0.16 to 0.38
2 (B)	0.08 to 0.23	0.00 to 0.07	0.04 to 0.21
3a (NB)	0.05 to 0.23	0.00 to 0.07	0.02 to 0.22
3b (NB)	0.26 to 0.61	0.00 to 0.10	0.22 to 0.59

Note: The probability intervals for the ignition strength of each method and their difference were computed using Bayesian Markov Chain Monte Carlo methods since the normal approximation needed to use ISO methods[6] will not work well for some of the proportions of pre-burn extinguishments observed in this experiment. The Bayesian analysis was carried out using binomial likelihoods for the data and non-informative uniform priors on the interval (0,1) for the proportions of pre-burn extinguishments.

NIST re-tested the three experimental cigarette types from Table 4 using the ASTM E2187-02b provisions in order to obtain repeatability values for this version of the method. The results are shown in Table 10 for five sets of 40 determinations.

As KF conducted their examination of commercial cigarettes, they randomized samples of these three cigarettes into their testing sequence. Each set consisted of 40 determinations. The apparatus and procedure used were those of ASTM E2187-02b. The results of those tests are shown in Table 11.

Table 10. Measured Ignition Strength and Repeatability Limits (NIST; August 2002)

Cigarette	Paper Sheets	Full Length Burns	Ignition Strength	r (n=40)
529	**3**	33, 27, 31, 33, 33	0.78 ± 0.06	0.18
516	**10**	7, 10, 11, 5, 8	0.21 ± 0.06	0.18
532	**15**	24, 26, 24, 28, 32	0.67 ± 0.07	0.21

Note: Quoted ignition strength uncertainties are approximate 95 % expanded uncertainties based on observed binomial repeatabilities and ISO methods[6] with a coverage factor of k=1.9720 obtained from Student's t distribution with 199 degrees of freedom.

Table 11. Measured Ignition Strength and Repeatability Limits (KF; May 2002 to March 2003)[8]

Cigarette	Paper Sheets	Full Length Burns	Ignition Strength	r (n=40)
529	**3**	24, 24, 20, 25	0.58 ± 0.08	0.22
516	**10**	12, 8, 9, 6	0.22 ± 0.06	0.18
532	**15**	30, 32, 25, 27, 29, 25, 31, 30, 32, 24	0.71 ± 0.04	0.20

Note: Quoted ignition strength uncertainties are approximate 95 % expanded uncertainties based on observed binomial repeatabilities and ISO methods[6] with a coverage factor of k=1.9750 obtained from Student's t distribution with 159 degrees of freedom or a coverage factor of k=1.9659 obtained from Student's t distribution with 399 degrees of freedom.

The Canadian government is considering a standard for cigarettes of reduced ignition strength. NIST provided training for the laboratory staff of the National Research Council of Canada (NRC). They also used the apparatus and procedure of ASTM E2187-02b. The results of their five sets of 40 determinations are shown in Table 12.

Table 12. Measured Ignition Strength and Repeatability Limits (NRC; February 2003)[9]

Cigarette	Paper Sheets	Full Length Burns	Ignition Strength	r (n=40)
516	**10**	7, 9, 12, 10, 13	0.25 ± 0.06	0.19

Note: Quoted ignition strength uncertainties are approximate 95 % expanded uncertainties based on observed binomial repeatabilities and ISO methods[6] with a coverage factor of k=1.9720 obtained from Student's t distribution with 199 degrees of freedom.

V. TEST METHOD CONSISTENCY

Nearly all of the changes in the written test protocol were to clarify possible ambiguities or to minimize the need to repeat determinations. The test operators at both NIST and KF worked on the re-wording of the test criterion. None felt that the increased precision of the language would have affected the test results, *i.e.,* there were virtually no cases where the outcome of a determination was in doubt. The results in Table 13, summarized from Section IV above and with estimated reproducibilities, allow comparison of the results between laboratories and over time.

Table 13. Summary of Ignition Strength Measurements

Laboratory	Protocol	Cigarette Type/Layers of Paper		
		529/3	516/10	532/15
ILE (1993)	1993	0.57 ± 0.09	---	---
NIST (2001)	Ballot 2/thick ring	0.66 ± 0.13	0.34 ± 0.13	0.82 ± 0.10
NIST (2002)	E2187-02b	0.78 ± 0.10	0.21 ± 0.10	0.67 ± 0.11
KF (2002-03)	E2187-02b	0.58 ± 0.12	0.22 ± 0.10	0.71 ± 0.10
NRC (2003)	E2187-02b	---	0.25 ± 0.10	---

Note: Quoted ignition strength uncertainties are approximate 95 % expanded uncertainties based on observed reproducibilities estimated using the heterogeneity factor from the 1993 ILE[2] and ISO methods[6]. Coverage factors and degrees of freedom are as listed in Tables 2, 4, 10, 11, and 12.

Although not conducted as a formal ILE, the test results from the three laboratories for cigarette 516 on 10 layers of filter paper using ASTM E2187-02b give some insight into the reproducibility of the current results that can be compared to those from the 1993 ILE. The mean ignition strength is 0.23 with an approximate expanded uncertainty of 0.06 based on the reproducibility observed between laboratories and a coverage factor of k=4.3027 obtained from Student's t distribution with 2 degrees of freedom. Based on these data, the estimated reproducibility limit for a cigarette with this observed ignition strength and a sample size of 40 replicate tests is 0.19. Using the results of the 1993 ILE, the estimated 95 % reproducibility limit for a cigarette of the same ignition strength and 40 determinations is 0.22.

There are no significant differences between the NIST results obtained in 2001 and 2002 for any of the three cigarette/substrate combinations when compared relative to their *reproducibilities* (using the heterogeneity factor from the 1993 ILE). When compared relative to their *repeatabilities*, the differences for each cigarette/substrate pair are significant. This suggests that the factors that make reproducibility between laboratories larger than short-term repeatability within a laboratory may also affect comparisons of results at the same laboratory over time.

From the above data, one can extract the following information relevant to use of this method as the basis for an ignition strength performance standard:

- The 95 % confidence intervals for a single laboratory have remained stable over the past decade. This includes laboratories that only participated in the 1993 ILE, two laboratories that have only performed testing more recently, and one laboratory that has been performing tests throughout the interval.
- The estimated reproducibility of test results using the ASTM E2187-02b procedure is consistent with the reproducibility obtained from analysis of the 1993 ILE.
- In general, for both banded and non-banded cigarettes tested on 10 layers of filter paper, there is no significant difference between the ignition strength values obtained using the procedure in the 2nd ASTM ballot/ NIST TN 1436 (with the thick or thin metal rim) and the values obtained using ASTM E2187-02b. In one sample of one cigarette packing, NIST TN 1436 produced a significantly lower measure of ignition strength than did ASTM E2187-02b.

VI. REFERENCES

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[7] Identification of commercial equipment, instruments, or materials in this document does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products identified are necessarily the best available for the purpose.

[8] Private communication from KF to NIST.

[9] Private communication from NRC to NIST.