Cigarette Ignition Risk Project

November 2012

Shivani Mehta*
Division of Combustion and Fire Sciences
Directorate for Engineering Sciences

U.S. Consumer Product Safety Commission
4330 East West Highway Bethesda, Maryland 20814

**These comments are those of the CPSC staff, have not been reviewed or approved by, and may not necessarily reflect the views of the Commission.*

EXECUTIVE SUMMARY

In 2004, New York became the first state in the United States to enact legislation requiring that cigarettes sold in the state be of low ignition strength, or "fire safe." The National Fire Protection Association (NFPA) developed "model" legislation based on the New York state law and advocated successfully for other state legislatures to adopt it. Since that time, all 50 states have enacted similar legislation, making the marketing, sale, and distribution of "fire-safe cigarettes" a de facto national requirement. "Fire-safe" cigarettes, also called Reduced Ignition Propensity (RIP), are designed to stop burning when left unattended, thus implying that these new cigarettes will be less likely to start fires, especially on soft furnishings, such as upholstered furniture and mattresses.

Because all cigarettes sold in the United States are now of the RIP type, the residential fire hazard associated with smoldering cigarettes may be changing. The U.S. Consumer Product Safety Commission (CPSC) does not have statutory authority to regulate cigarettes, but it has the authority, through the Flammable Fabrics Act (FFA), to regulate the flammability of residential soft furnishings, including mattresses, bedding products, and upholstered furniture, which are frequently involved in cigarette-ignited fires.

The CPSC addresses the cigarette ignition risk for mattresses and mattress pads in the *Standard for the Flammability of Mattresses and Mattress Pads* (16 CFR part 1632). The agency also has proposed a standard for the flammability of upholstered furniture that addresses cigarette ignition risk (proposed 16 CFR part 1634). The purpose of the Cigarette Ignition Risk project is to determine if RIP cigarettes present a reduced ignition risk relative to conventional (non-RIP) cigarettes when placed on a mattress or mattress pad. A reduced cigarette ignition hazard may warrant consideration of revisions to existing federal flammability regulations and voluntary flammability standards, and it also may impact the direction of current proposed rulemakings.

Staff began the project in 2007 with a market analysis to identify the top-selling brands of cigarettes in the United States. Thereafter, staff conducted a comprehensive literature review to determine what has already been learned about the characteristics that affect the burning behaviors of cigarettes and exposed products, such as residential soft furnishings. Using this information, staff developed a project plan and obtained both RIP and non-RIP samples of 13 packagings of cigarettes from the most popular brands identified in the market sketch. Then the CPSC contracted testing of the 13 packagings to the requirements of the states' legislation. The test results indicated the RIP cigarettes were significantly less likely to burn their full lengths when tested on a filter paper substrate according to the test method set forth in ASTM E2187-04, "*Standard Test Method for Measuring the Ignition Strength of Cigarettes*."

Having learned that the RIP cigarettes in the sample set of 13 packagings performed as expected on filter paper, the next phase of the project was to evaluate the smoldering behavior of these non-RIP and RIP cigarettes on soft furnishing substrates. Mattress and mattress pad substrates were chosen because the CPSC currently regulates these products for cigarette ignition resistance. Four different mattress and mattress pad substrates and four different pairs of RIP/non-RIP cigarette packagings were selected from the original 13 tested per ASTM E2187-04. A statistical analysis of the data, designed to determine whether mattresses and mattress pads smoldered in the presence of a cigarette, found that the cigarette packaging, the cigarette's location on a substrate, and the substrate itself, are all factors in whether or not the mattress or mattress pad substrate smoldered.

Further analysis indicates that differences between the ignition propensity of RIP and non-RIP cigarettes, when measured on filter paper substrates per ASTM E2187-04, do not predict similar differences between the ignition propensity of the same packagings of RIP and non-RIP cigarettes when measured on the mattress and mattress pad substrates included in this study. Whether a cigarette – RIP or non-RIP – burned its full length or extinguished before burning its full length was not predictive of smoldering behavior on the substrates. In addition, RIP cigarettes of different packagings did not exhibit the same results on each of the mattress and mattress pad substrates brands.

Results of this study suggest that it is premature to conclude that use of the RIP cigarette alone will greatly reduce the threat of unintentional fires ignited by cigarettes involving mattresses or soft furnishings, including mattresses and mattress pads that meet the current CPSC mattress flammability regulation.

Acknowledgements

In addition to the authors of the supporting documents, the author would like to thank the following people for their work on this project over the years: Linda Fansler, Greg Masenheimer, Andrew Bernatz, Scott Ayers, and Weiying Tao.

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Supporting Document F: Miller, D., Garland, S. “Cigarette Ignition Risk Phase II: Mattress and Mattress Pad Results and Analysis” Memorandum to S. Mehta. December 2012

Supporting Document G: Campbell, J. Mellish, R., “Characterization of Test Substrates Used in Cigarette Ignition Risk Project Testing” Memorandum to S. Mehta. August 2012

1. INTRODUCTION

This memo presents the results of testing under the U.S. Consumer Product Safety Commission (CPSC) staff's Cigarette Ignition Risk (CIR) project. The phases of this project included an evaluation of the characteristics of Reduced Ignition Propensity (RIP) cigarettes versus non-RIP cigarettes on filter paper, in accordance with the applicable voluntary standard, ASTM E2187-04, "*Standard Test Method for Measuring the Ignition Strength of Cigarettes*" and on mattresses and mattress pads per the methodology in CPSC's regulation 16 CFR part 1632, *Standard for the Flammability of Mattresses and Mattress Pads.*

From 2008 to 2010, 44 percent of deaths and 30 percent of injuries from residential fires, identified smoking ignition materials as the ignition source where upholstered furniture or mattresses were the first item ignited. As a heat source, cigarettes and other tobacco products are associated with an annual average (from 2008 to 2010) of 10,300 unintentional residential structure fires that were attended by fire services, resulting in 500 civilian deaths, 1,080 injuries, and $426.5 million in property losses.[1]

Cigarettes are used as the ignition source in several federal regulations and voluntary standards because so many deaths, injuries, and property losses are associated with cigarettes and other tobacco products. Currently, the federal standard for mattresses and mattress pads (16 CFR part 1632) includes a cigarette ignition test; and a proposed standard for upholstered furniture (proposed 16 CFR part 1634) uses a cigarette as an ignition source. Cigarettes are also used as the ignition source in the flammability standard for cellulose insulation (16 CFR part 1209). The ignition source cigarette cited in CPSC's regulations was originally specified by physical properties representing the ignition strength of an unfiltered Pall Mall® cigarette, which was identified as the most severe smoldering ignition source. However, 16 CFR part 1632 recently has been amended to include a Standard Reference Material (SRM) cigarette.[2] The SRM cigarette was developed by the National Institute of Standards and Technology (NIST) to have the approximate ignition strength of the original unfiltered Pall Mall cigarette and is sold as NIST SRM 1196.

2. BACKGROUND

All 50 states and Canada have passed identical legislation[3] adopting a fire safety standard for cigarettes that requires all cigarettes sold to be of "lower" ignition strength, making the marketing, distribution, and sale of RIP cigarettes a de facto national requirement. These cigarettes, referred to as "fire safe" or RIP, are designed to self-extinguish when left unattended. According to the National Fire Protection Association's (NFPA) "Coalition for Fire Safe Cigarettes" website[3]:

A fire-safe cigarette has a reduced ignition propensity to burn when left unattended. The most common fire-safe technology used by cigarette manufacturers is to wrap cigarettes with two or

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[1] Miller, D., "2008–2010 Residential Fire Loss Estimates." U.S. Consumer Product Safety Commission, August, 2012.

[2] 76 FR 59014; September 23, 2011. Standard for the Flammability of Mattresses and Mattress Pads; Technical Amendment.

[3] Coalition for Fire Safe Cigarettes, www.firesafecigarette.org.

three thin bands of less-porous paper that act as "speed bumps" to slow down a burning cigarette. If a fire-safe cigarette is left unattended, the burning tobacco will reach one of these speed bumps and self-extinguish.

The RIP technology currently employed by cigarette manufacturers is to use paper that has two or three thin bands of less-porous paper distributed along the length of the cigarette to act as "speed bumps" to slow down a burning cigarette's smoldering front. See Figure 1. Ideally, when the cigarette is left unattended, the burning tobacco will reach one of the speed bumps and self-extinguish. For cigarettes using this technology, the states' legislation require that a minimum of two bands be present on the tobacco column, with at least one complete band located at least 15 mm from the lighting end of the cigarette. For cigarettes on which the bands are positioned by design (*i.e.,* the location of the bands is specified exactly on the cigarette), a minimum of two full bands is required, and one must be located at least 15 mm from the lighting end, while the other is at least 10 mm from the filter end of the tobacco column, or 10 mm from the labeled end of the tobacco column for unfiltered cigarettes.

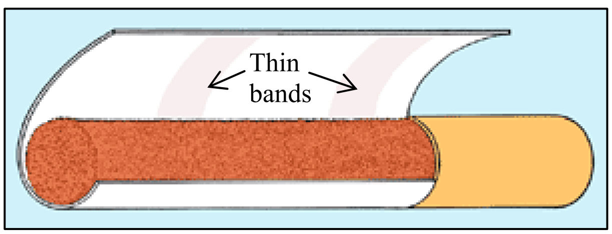

Figure 1. An illustration of a RIP cigarette showing the banded paper.

In addition to meeting the requirements for band placement, each state requires that the ignition propensity of cigarettes be tested according to ASTM E2187- 04. The states require that a minimum of 30 of 40 cigarettes tested shall self-extinguish before reaching the end of the tobacco column when placed on 10 layers of filter paper. In other words, RIP cigarettes should produce full-length burns (FLB) no more than 10 of 40 times if left unattended.[4]

With respect to the efficacy of banding technology, CPSC staff believes that the lengths of the tobacco column that are not banded will burn identically to the non-banded tobacco columns of non-RIP cigarettes. Because state legislation does not specify the band widths, the non-banded, and thus, unprotected length of the tobacco column is undefined, and the ignition propensity of this portion of the cigarette is not limited by ASTM E2187-04.

2.1 Cigarette Ignition Risk Project

In 2007, CPSC staff undertook the Cigarette Ignition Risk (CIR) project to evaluate the relative hazard of RIP cigarettes. At that point in time, conventional (non-RIP) cigarettes were still available for sale in most of the United States. The purpose of the project was to determine the effect of RIP cigarette performance on reducing the risk of smoldering (cigarette) ignited fires. The team conducted a literature review to identify research that had been conducted on cigarette ignition strength on soft furnishings. Also, the CPSC's Directorate for Economic Analysis (EC) performed a market sketch to identify the top-selling cigarette brands in the United States, as

[4] ASTM E2187 uses the term "determination" to denote a test of one cigarette.

well as the RIP cigarette brands sold in New York[5] at that time. This information was used to develop a sampling plan to acquire RIP and non-RIP cigarettes for evaluation.

Based on the sampling plan and market sketch information, CPSC field investigators were assigned to purchase both RIP and non-RIP cigarettes from stores across the country. The cigarettes were evaluated by an outside contractor and CPSC staff for physical characteristics and burn temperatures. An outside testing lab under contract to CPSC tested the cigarettes in accordance with ASTM E2187-04 to assess differences in ignition propensity of the RIP and non-RIP cigarettes by packaging. Staff then conducted tests on mattresses and mattress pads to compare the flammability characteristics of RIP cigarettes to non-RIP in contact with actual furnishings, as opposed to simply burning on filter paper over a brass plate. This report presents a summary of the work described above and sets forth staff's future plans.

3. LITERATURE REVIEW

CPSC staff conducted a comprehensive literature review to determine what has already been learned about the characteristics that affect the burning behaviors of cigarettes and exposed products, such as residential soft furnishings.[6] Below is a summary of the review.

3.1 Background of Federal Cigarette Legislation and CPSC's Role

In 1984, an amended Moakley-Cranston bill (The Federal Cigarette Safety Act of 1984; HR 293) was enacted into law. The legislation called for formation of a Technical Study Group to determine the technical and economic feasibility of making a "fire-safe cigarette" and the formation of an *Interagency Committee on Cigarette and Little Cigar Fire Safety*.

HR 293 called for the CPSC to issue standards and complete any necessary research. It also mandated that tobacco companies produce fire-safe cigarettes. In 1990, HR 293 was amended, suspending regulations mandating fire-safe cigarettes, but requiring the CPSC to develop a standard test method for cigarette ignition propensity and to perform the research to develop a performance standard for fire-safe cigarettes. This bill was enacted as the Fire-Safe Cigarette Act of 1990 (Public Law No: 101-352). This Act resulted in the development of two methods by the National Institute of Standards and Technology (NIST), described in Section 3.2, for measuring the ignition propensity of cigarettes.

In 1993, CPSC reported to Congress that a cigarette fire safety test method had been developed. However, the CPSC Chairman asked Congress to appoint a more appropriate agency to develop a performance standard for fire-safe cigarettes because the CPSC does not have regulatory authority over cigarettes. Although NIST does not have regulatory authority over cigarettes either, it agreed to take on this task. NIST worked with the American Society of Testing and Materials (ASTM), now called ASTM International, to write a standard test method to evaluate the ignition propensity of cigarettes.

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[5] New York was the first state to enact legislation requiring "fire-safe cigarettes." New York's regulation became effective on June 28, 2004.

[6] Mehta, S. "Literature Review of Reduced Ignition Cigarette Studies." Memorandum to J. Elder, U.S. Consumer Product Safety Commission, May 31, 2007.

3.2 NIST Test Methods

In the 1990s, a substantial amount of work was conducted by NIST to evaluate the burning characteristics of cigarettes. This work resulted in two methods for determining the ignition propensity of cigarettes.[7,8] The methods were designed as performance tests, independent of cigarette characteristics, and they have valid links to real-world fire scenarios.

3.2.1 The Mock-Up Ignition Test Method

This test method measures whether a cigarette causes ignition by transferring enough heat to a fabric/foam combination representative of a piece of furniture. In this test, a lit cigarette is placed on the center of each of the three mock ups. The performance metric in this test is the char length respective to the tobacco column of the cigarette.

3.2.2 The Cigarette Extinction Test Method

This test method evaluates ignition propensity strength of the cigarettes, independent of fabrics/foam substrates. A lit cigarette is placed on a filter paper substrate of varying layers, depending upon the test. The paper does not ignite from a smoldering source but draws heat from the cigarette. This test reveals whether the cigarette burns its full length. Because the filter paper is made of consistent quality, the burning propensities of multiple cigarettes were expected to be compared without the confounding interaction of the fabric substrate.

3.3 Current Test Method (ASTM E2187)

This NIST Cigarette Extinction Test Method became the basis for ASTM E2187, *Standard Test Method for Measuring the Ignition Strength of Cigarettes*. The test method is used to estimate the probability that a lit cigarette, when placed on the filter paper substrate, will generate enough heat to maintain burning of the tobacco column. A lit cigarette is placed on a substrate of layers of specified filter paper, and an observation is made of whether the cigarette burns to the beginning of the tipping paper (the paper on the filter, if one is there) or to the end of the cigarette for an untipped cigarette, as seen in Figure 2. Each cigarette tested is considered a "determination," and 40 determinations are specified per cigarette brand/style (also referred to as packaging). The standard does not prescribe a pass/fail requirement, only the methodology to determine the relative probability that the cigarette will continue burning despite heat removal by the substrate. The substrate starts at 15 layers of filter paper. If at least 10 percent of 40 determinations are full-length burns (FLB), then the test can be repeated with 10 layers and again with 3 layers of filter paper if the same results are observed. A greater number of layers of filter paper create a

Figure 2. ASTM S2187-04 setup with cigarettes placed on filter paper.[3]

[7] Jones-Smith, J.; Harwood, B. "Overview: Practicability of Developing a Performance Standard to Reduce Cigarette Ignition Propensity. Volume 1." CPSC, Washington, DC. Vol. 1, August 1993.

[8] Ohlemiller, T. J.; Villa, K. M.; Braun, E.; Eberhardt, K. R.; Harris, R. H., Jr.; Lawson, J. R.; Gann, R. G. "Test Methods for Quantifying the Propensity of Cigarettes to Ignite Soft Furnishings. Volume 2." NIST SP 851, August 1993.

greater heat sink for the cigarettes, so only higher ignition strength cigarettes should burn their full length.

3.4 Summary of Previous Research

Research conducted before the states enacted legislation for RIP cigarettes focused mainly on the effects of cigarette characteristics on their burning rates and temperatures or the substrate properties that affect ignitability when exposed to cigarettes. There are many factors that affect the burning rates and temperatures of cigarettes: circumference of the cigarette, presence of a filter, the tobacco packing density, the length of the cigarette, the chemical additives in the paper, and the permeability of the paper. All of these factors may differ between cigarette packagings. The studies were able to assess some of the characteristics.

- One study found that cigarette circumference alone does not have an impact on ignition propensity.[9]
- A study at NIST demonstrated that a combination of properties can effectively lower the ignition propensity of cigarettes.[10] Low tobacco density, reduced circumference, and low paper permeability together resulted in a considerable reduction in ignition propensity. Cigarettes with these properties were used in later furniture mock-up tests as "low ignition propensity" cigarettes.
- A tobacco industry group also investigated the effects of cigarette characteristics on the ignition propensity of various fabrics, including cotton duck, treated sail cloth, and commercial upholstery fabrics.[11] The group performed a thorough statistical analysis of the data and found inconsistent behavior between the duck and sail cloth fabrics. Reductions in density and circumference of the cigarettes reduced ignitions on duck fabrics but increased the ignition on treated sailcloth. The commercial fabrics showed mixed results; some showed similar results to the cotton duck, and the others showed their ignition behaviors close to the treated sail cloth.

After NIST developed the test methods to quantify the ignition propensity of cigarettes to ignite soft furnishings, many researchers, including researchers from the tobacco industry, evaluated the methods with alternate tests, fabrics, or cigarettes. The results of these studies demonstrated the smoldering ignition properties of fabrics. These tests were conducted with foam and fabric substrates. Their findings are as follows:

- High cellulose content in the fabric increased the possibility for a smoldering ignition.[12]
- There was no correlation between air permeability and smoldering ignitability for the fabrics.

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[9] Lewis, L. S.; Nestor, T. B.; Gee, J. W.; Morton, M. J.; Townsend, D. E. "Effects of Cigarette Circumference on Ignition Propensity." Fire Safety '91 Conference. Volume 4. November 4−7, 1991: 352−366.

[10] Gann, R., Harris, R., Krasny, J., Levine, R., Mitler, H., Ohlemiller, T. "The Effect of Cigarette Characteristics on the Ignition of Soft Furnishings." NBS, October 1987.

[11] Wanna, J. T.; Zelius, P. "Effect of Cigarette Variables on Ignition Propensity of Various Fabrics." Journal of Fire Sciences, Vol. 19, Sep./Oct. 2001: 341−354.

[12] Dwyer, R. W.; Fournier, L. G.; Lewis, L. S.; Furin, D.; Ihrig, A. M.; Smith, S.; Hudson, W. Z.; Honeycutt, R. H.; Bunch, "The Effects of Upholstery Fabric Properties on Fabric Ignitabilities by Smoldering Cigarettes: Part 1." Journal of Fire Sciences, Vol. 12, May/June 1994: 268−283.

- The mass burn rate and linear burn rate of the cigarettes can be used to characterize the ignition propensity of the cigarette. The rates appeared to be subject to the fabric properties and the geometry of the test configuration.[13]
- Fabric weight, cellulose content, and presence of alkali metal ions are important fabric parameters that affect smoldering ignition behavior. [14]
- The results revealed that cigarette design parameters, like paper porosity, circumference, tobacco packing density, and burn rate, for example, do not have major impacts on the smoldering ignition potential of upholstery fabrics.
- The tobacco industry-sponsored research found that the NIST mock-up test results (using the Mock-Up Method described earlier) were largely influenced by the characteristics of the fabrics and not the cigarettes. The NIST-style mock-ups were exposed to cigarettes of either inherently low- or high-ignition propensity properties. The industry researchers concluded that the fabric characteristics largely control the ignition behavior rather than the cigarette type.[15]

The research demonstrated some of the limitations of the NIST Mock-Up Method and provided information on the importance of fabric interaction with the smoldering cigarette. Cigarette smoldering ignition is largely dependent on fabric properties and geometries.

4. Market Data

At the outset of the project, a market sketch was prepared by the Directorate for Economic Analysis to determine the major U.S. cigarettes brands based on data from the National Survey on Drug Use and Health (NSDUH) and other market information, such as annual reports filed with the U.S. Securities and Exchange Commission.[16] According to this data, four manufacturers produce the 11 top brands in the market, representing about 80 percent of the market.

4.1 Cigarette Characteristics

The Economic Research Service of the U.S. Department of Agriculture compiles information on the characteristics of cigarettes that are produced, such as length and presence of a filter. About99.2 percent of cigarettes made between 2004−2006 had filter tips. About 62 percent of filter tip cigarettes made from 2004 to 2006 were 80 mm or 85 mm in length, and most of the remainder were 100 mm in length.

[13] Spears, A. W.; Rhyne, A. L.; Norman "Factors for Consideration in a Test for Cigarette Ignition Propensity on Soft Furnishings." Journal of Fire Sciences, Vol. 13, Jan./Feb. 1995: 59−84.
[14] Lewis, L. S.; Morton, M. J.; Norman, V.; Ihrig, A. M.; Rhyne, A. L., "The Effects of Upholstery Fabric Properties on Fabric Ignitibility by Smoldering Cigarettes: Part II." Journal of Fire Sciences, Vol. 13, Nov./Dec. 1995: 445−471.
[15] Greer, L. C.; Hudson, W. Z.; Jupe, R.; Pinion, D. O.; Wanna, J. T., "Ignition Responses of Fifty Upholstery Fabrics to Commercial Cigarettes." Journal Of Fire Sciences Vol. 14, Nov./Dec. 1996: 413−425.
[16] Smith, C., "Cigarette Market Information." Memorandum to S. Mehta, U.S. Consumer Product Safety Commission, May 10, 2007

5. CPSC STAFF EVALUATIONS

The goal of the CPSC CIR project is to determine the difference in hazard that RIP cigarettes present on residential soft furnishings, such as mattresses, mattress pads, and upholstered furniture, as compared to non-RIP cigarettes of the same packaging.[17] Based on the background information that the project team compiled, a phased approach was undertaken to achieve this goal. Cigarettes would first be evaluated according to ASTM E2187-04 to determine the relative ignition propensity of RIP and non-RIP cigarettes of the same packaging. Using the resulting data, the team would continue the evaluation of the cigarettes on mattresses and mattress pads.

The team chose 13 packagings of cigarettes to compare characteristics and burning properties of RIP and non-RIP cigarettes based on the market sketch. The 13 packagings vary in brand, size, filter, and menthol type, as seen in

Table 1. The Pall Mall, non-RIP unfiltered cigarette, is one of the 13 packagings.[18]

Table 1. Thirteen Packagings for CPSC Staff Assessments

Packaging	Filter	King size	Slim	Long	Regular	Light	Ultra light	Menthol
CP1	✓				✓			
CP2	✓				✓			
CP3	✓			✓			✓	
CP4	✓	✓				✓		✓
CP5	✓					✓		
CP6	✓				✓			
CP7	✓	✓			✓			✓
CP8	✓					✓		
CP9					✓			
CP10	✓	✓					✓	✓
CP11	✓				✓			✓
CP12	✓		✓	✓		✓		✓
CP13	✓	✓			✓			

As indicated previously, CPSC Field staff purchased cartons of cigarettes from various types of retailers, based on a plan designed by the Directorate for Epidemiology (EP).[18] The plan included states in which the legislation for RIP cigarettes was already effective. Field staff packed and shipped the cartons of cigarettes to the CPSC laboratory in Gaithersburg, MD. Once these cigarettes were received, they were stored in a freezer at -10 ºF ± 4 ºF until testing began.

[17] A "packaging" indicates the brand, style, and size of the cigarette, *e.g.*, Marlboro Light 100's®.

[18] Green, M., Andres, C., "Cigarette Ignition Risk Phase I: Analysis of Selected Reduced Ignition Propensity Cigarettes" Memorandum to S. Mehta, U.S. Consumer Product Safety Commission. July 2008.

5.1 Physical Characteristics

As indicated in previous studies, cigarette design characteristics that could influence ignition propensity include, but are not limited to, tobacco column length, tobacco density, RIP band characteristics, air permeability, and citrate levels of the filter paper enclosing the tobacco column. On the RIP cigarettes, the band-to-band distance and band width were measured. The paper permeability and some of the band information was determined by contracted laboratories, while the remaining evaluations were conducted by CPSC staff. The EP staff conducted an analysis of the data, and the general conclusions are presented below[18]:

- Five sample cigarettes were chosen from each of the 13 packagings for tobacco column length and tobacco density evaluation. The tobacco column length was shown to have little variability within packaging for RIP and non-RIP cigarettes (the coefficient of variation was less than 1 percent for the five cigarettes measured within each product and cigarette type).
- The tobacco density of the RIP cigarettes was about the same as the non-RIP cigarettes for each packaging. Across packagings, the average tobacco density of RIP cigarettes ranged from 0.21 to 0.25 g/cm,[3] while the range for the non-RIP design was 0.21 to 0.26 g/cm.[3] The band-to-band distance on RIP cigarettes was fairly consistent within most packagings, and was typically about 20 mm for the majority of packagings. The Pall Mall (CP9) has a larger average distance between bands of 24 mm. The band widths are typically around 6 mm, and these widths do not vary much within any of the packagings.
- The placement of the bands on the tobacco column was variable within packaging. The number of bands on a cigarette depends mainly on the length of the tobacco section of the cigarette and the distance from band to band.
- After review of the air permeability data obtained by a contractor, it appeared that there was a great amount of variability between measurements of cigarettes within the same packagings. The variability in the data is too great to make comparisons of the air permeability of the RIP and non-RIP cigarettes.
- A method was developed by the Division of Chemistry in the Directorate for Laboratory Sciences (LSC) to determine citric acid levels in the cigarette paper. Four of the 13 packagings of RIP cigarettes had substantially higher citric acid levels than the non-RIP cigarettes of the same packaging; three RIP packagings had slightly higher levels; and six had slightly lower levels. From this we can conclude that high citric acid cigarettes are likely to be RIP, but the RIP properties can be obtained with low citric acid cigarettes also.[19]

5.2 Phase I – Tests per ASTM E2187

The consensus standard to measure the ignition propensity of cigarettes is ASTM E2187-04, *Standard Test Method for Measuring the Ignition Propensity of Cigarettes,* and is specified in the states' legislation. As discussed above, this method involves placing a lit cigarette on a substrate of multiple layers of filter paper. Because the filter paper does not smolder when exposed to a cigarette and is a consistently produced material, the behavior of the cigarette is not expected to be influenced by the filter paper substrate. A contractor conducted tests with 80 sample cigarettes of each packaging, following a randomization plan supplied by CPSC EP staff

[19] Bhooshan, B., "Citric Acid Content in Cigarette Paper." Memorandum to S. Mehta, U.S. Consumer Product Safety Commission, May 12, 2008.

on 10 layers of filter paper, similar to the state "model" legislation. In addition to following the ASTM E2187 standard, the contractor recorded the time when a cigarette was ignited and when it extinguished.[18]

If a cigarette burned to the filter, it was considered a full-length burn (FLB). Unfiltered cigarettes that burned from tip to end were also recorded as having a FLB. The percentage of FLB for each packaging is shown in Figure 3**.** Almost every non-RIP cigarette burned to its full length. The RIP cigarettes showed a much lower percentage FLB but did not all have the same number of burns. This result shows that all RIP cigarettes, throughout packagings, do not exhibit the same burning behavior on filter paper.

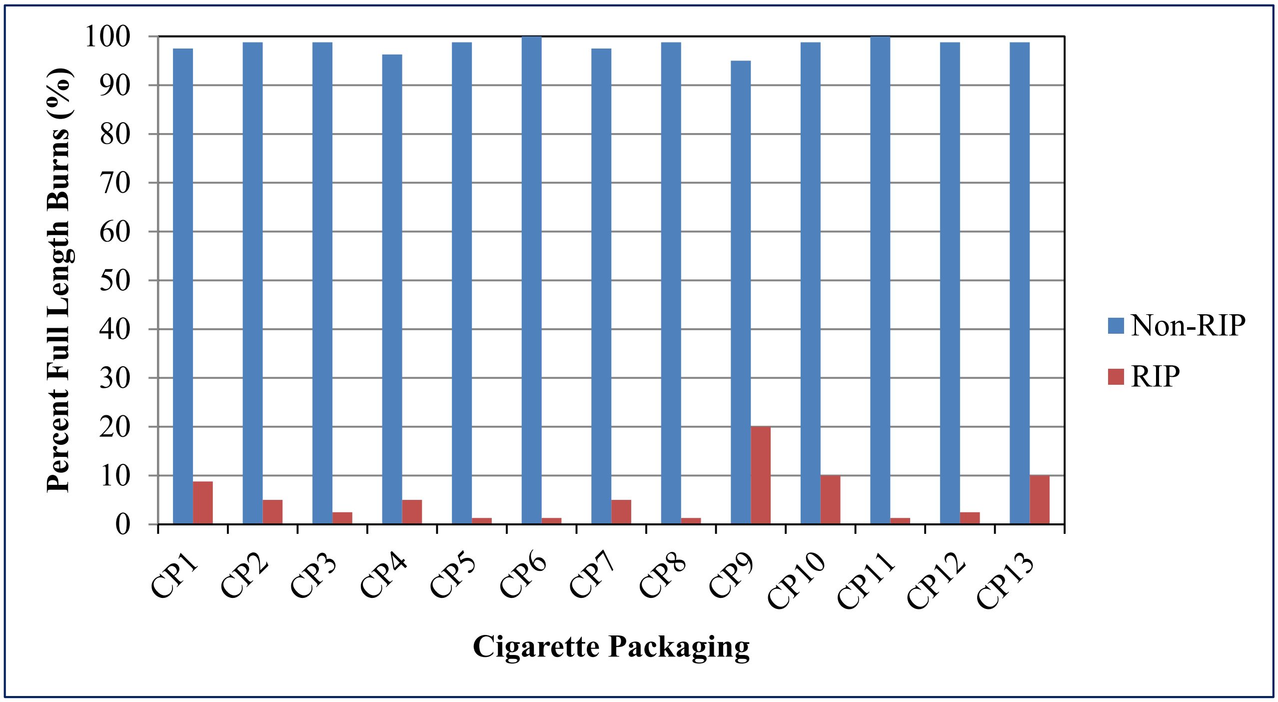

Figure 3. Observed Full-Length Burn proportions for 13 cigarette packagings tested under ASTM E2187-04.

5.2.1 Burn Times

The burn times of the cigarettes were recorded to the closest minute during the ASTM E2187-04 tests. On average, the RIP cigarettes, while in the controlled laboratory setting, burned six minutes less than non-RIP cigarettes of the same packaging.

5.2.2 Maximum Burning Temperatures

The maximum burning temperatures of the cigarettes were also evaluated. For many years, researchers have encountered difficulties measuring these temperatures; the tobacco packing causes voids (empty spaces) in the cigarettes; the temperature is not necessarily constant through the cigarette cross section; and the measured temperature is based on the placement of the sensor. CPSC staff evaluated the cigarette burning temperatures by suspending cigarettes on three thermocouples to measure the temperatures along the length of the tobacco column. The maximum burning temperatures ranged between 1186°F and 1339°F. Both of these maximum temperatures were observed in RIP cigarettes. Five of the RIP cigarette packagings had higher burning temperatures than non-RIP cigarettes in the same packaging; and eight had lower maximum burning temperatures. None of the differences in maximum burn temperature between RIP and non-RIP cigarettes of the same packagings were shown to be statistically significant.

The physical characteristic evaluations demonstrate that the RIP and non-RIP cigarettes of the same packaging are similar, except for the presence of the bands. However, the flammability tests involving the percent of full-length burns and the average burn times show that the RIP and non-RIP cigarettes behave differently when tested in accordance with ASTM 2187-04 on 10 layers of filter paper.

A ranking of the physical and flammability data was created based on the difference in percent FLB between the RIP and non-RIP cigarettes within a packaging, and the band to band distance on the RIP cigarettes. Based on these rankings, the cigarettes in Table 2 represent the "most" and "least" ignition prone, and two "medium" prone cigarettes.

Table 2. Rankings of Four Cigarette Packagings

Cigarette ID	Smolder Prone
CP5	Least
CP7	Medium
CP9	Most
CP13	Medium

5.3 Phase II – Tests with Mattress and Mattress Pad Substrates

CPSC regulates mattress and mattress pads for cigarette ignition resistance per 16 CFR part 1632, *Standard for the Flammability of Mattresses and Mattress Pads*. Staff prepared a plan to compare the ignition characteristics of RIP cigarettes to non-RIP cigarettes by testing them on mattresses and mattress pads per the methodology in 16 CFR part 1632; these tests were not designed to determine whether a mattress or mattress pad is in compliance with the federal flammability standard.[20] For this study, 18 cigarettes were placed on each substrate test surface. The surfaces to be tested include smooth, tape edge, and quilted or tufted locations, if they exist on the mattress or mattress pad surface. A two-sheet test was also conducted on similar surface locations. In the latter test, the lit cigarettes were placed between the sheets.

The four "ranked" packagings in Phase I, listed in Table 2, were tested in this series on four mattress and mattress pad substrates, resulting in 16 combinations of cigarette packaging and substrate. This experiment was designed to examine the differences between RIP and non-RIP cigarettes within specific packaging and substrate type. The data are specific to the items tested and do not necessarily reflect properties of all cigarettes. Each cigarette tested is considered to

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[20] S. Mehta "Cigarette Ignition Risk Phase II: Mattress and Mattress Pad Testing" Memorandum to the File, U.S. Consumer Product Safety Commission. September 2012.

be a distinct evaluation; in total 864 cigarettes were evaluated. Table 3 shows the number of evaluations for each combination. The metrics of importance were: (1) whether the substrate smoldered in the presence of the cigarettes, and (2) whether the cigarette demonstrated a FLB.

Table 3. Breakdown of Cigarettes Evaluated

Cigarette ID[21]	Substrate				Total
	A	B	C	D[22]	
CP5N	26	26	28	29	109
CP5R	24	27	28	30	109
CP7N	28	27	29	23	107
CP7R	28	26	26	25	105
CP9/SRM	21	28	24	35	108
CP9/PM	21	30	29	28	108
CP13N	33	27	27	21	108
CP13R	35	25	25	24	109
Total	216	216	216	215	863

5.3.1 Smoldering Evaluations

Of the 864 cigarettes tested, 434 resulted in smoldering of the substrate. Figure 4 shows the portion of evaluations that caused smoldering of the substrate, sorted by cigarette packaging.[23] Substrates that showed a high proportion of smoldering did so for all cigarette packagings, indicating that the substrate has a substantial influence on the occurrence of smoldering.

[21] To distinguish between results of RIP and non-RIP versions of each packaging in the data, the letter "N" is placed after the packaging designation for non-RIP cigarettes, and "R" is placed after the packaging designation for RIP cigarettes.

[22] One cigarette was not able to be tested on Substrate D.

[23] Cigarette CP9 is the Pall Mall. In the mattress and mattress pad testing, SRM 1196 cigarettes are tested as the non-RIP version of the Pall Mall, and the RIP version of the Pall Mall cigarettes tested were purchased in 2008.

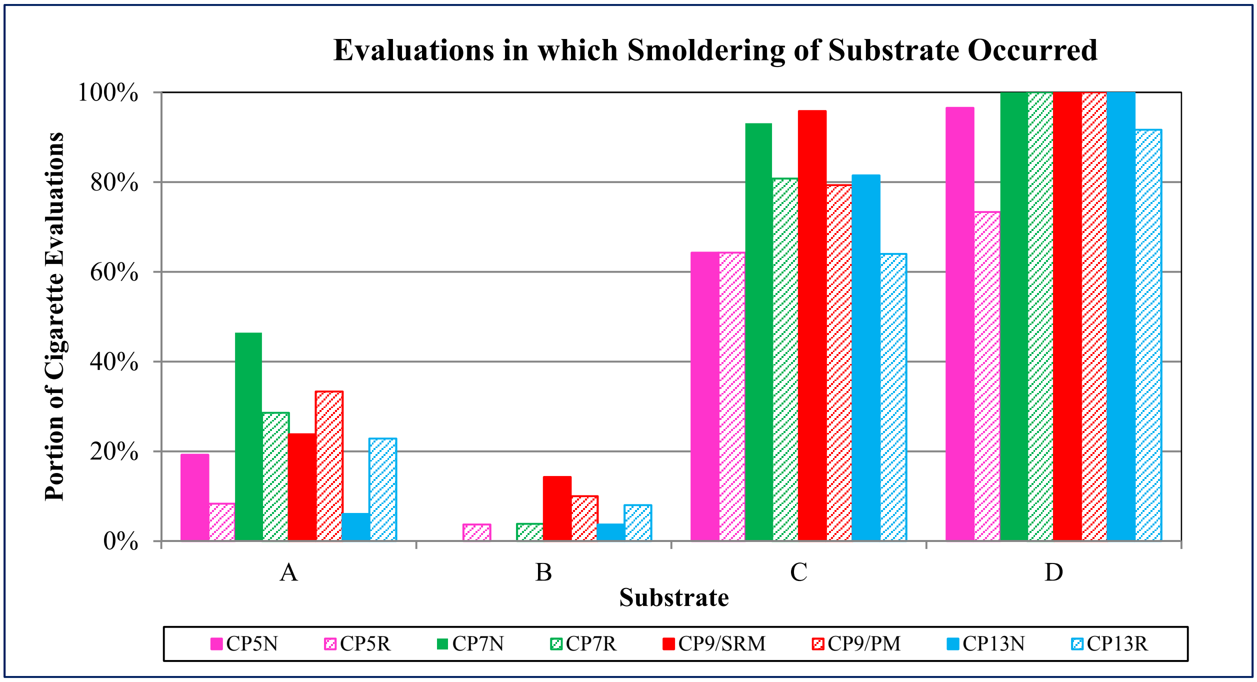

Figure 4. Portion of Cigarettes that Caused Smoldering
(the total number of evaluations for each combination is in Table 3)

Figure 4 summarizes the percentage of package RIP and non-RIP cigarettes that smoldered by substrate. These percentages aggregated smoldering performance by cigarette packaging and substrate across location (smooth, tape edge, quilted or tufted) and sheeting. This aggregation may obscure some of the effects of the location and sheeting. However, the empirical presentation of the percentages in Figure 3 demonstrates that there are circumstances where RIP cigarettes produced a high proportion of smoldering.

Statistical modeling and comparisons of the likelihood to smoldering for each of the 16 combinations of cigarette packaging and substrate were performed to determine which factors significantly explain the variation in smoldering. Four of the 16 combinations demonstrated a statistically significant difference, although not demonstrating a practical difference, between the RIP and non-RIP cigarettes of the same packaging. Two of these comparisons remain statistically significant after adjusting for multiple comparisons,[24] and both involved the SRM (non-RIP)/Pall Mall (RIP) packagings. When the data for these cigarettes are excluded from the analysis, the statistical model is much different, showing that overall, neither cigarette packaging, nor the RIP effect is statistically significant for explaining the observed variation of smoldering on substrates. Substrate type and location remain statistically significant, and there are significant interactions for substrate type and RIP and for cigarette packaging and location. In other words, a statistically significant overall RIP effect depends on whether the SRM/Pall Mall RIP (PMR) cigarette tests being included in the analysis.

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[24] When multiple significance tests are performed, the likelihood of a "false positive" test increases. Adjustments are frequently made by statisticians to account for this.

The statistical analysis of the data indicates that the location of the cigarette, type of substrate, cigarette packaging, and RIP effect (*i.e.,* presence of banding) are statistically significant in some of the combinations.[25] Additionally, there were significant interactions between substrate type and the presence of sheeting; between the location of the cigarette and the presence of sheeting; and between the cigarette packaging and the presence of sheeting. However, these differences were not found to be practically significant in empirical tabulations of the testing.

5.3.2 Full Length Burns Evaluations

In the 429 evaluations that did not result in smoldering, the occurrence of FLB was recorded. Figure 5 shows the portion of the evaluations that showed a FLB. Substrate D is not included in Figure 5 because no cigarettes showed a FLB in tests where the substrate did not smolder. These data show that although the substrate did not smolder, many cigarettes did burn their full lengths.

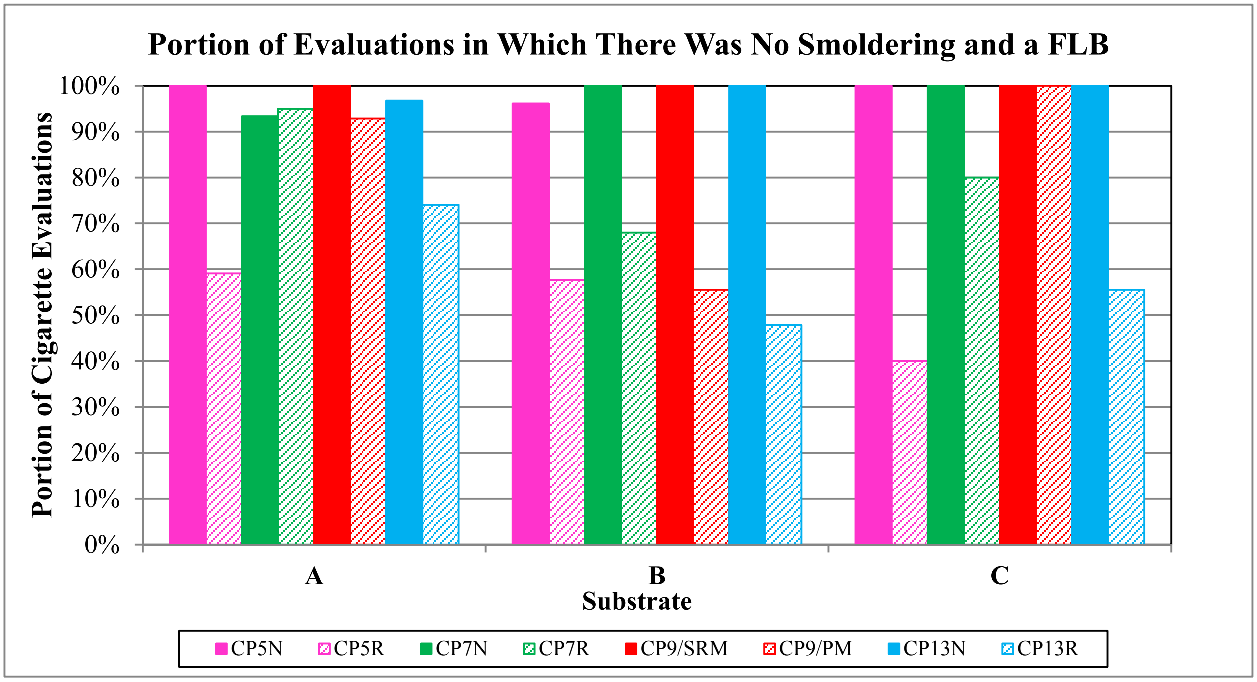

Figure 5. Portion of FLB for evaluations that did not result in smoldering of the substrates.
(the total number of evaluations for each combination is in Table 3)

5.3.2.1 Evaluations with Smoldering and FLBs

In addition to examining the evaluations that resulted in both smoldering of the substrate and a FLB, a review of the data was conducted to assess whether location on the substrates has an effect on smoldering and full-length burns.[20] Simple tabulation of the raw data did not demonstrate any practical, overall differences in smoldering based on the location of the cigarettes. Also, as described in 16 CFR part 1632, some cigarettes were placed between cotton sheeting. The presence of sheeting did not have the same effect on all the substrates or

[25] Miller, D., Garland, S. "Cigarette Ignition Risk Phase II: Mattress and Mattress Pad Results Analysis" Memorandum to S. Mehta, December 2012.

packagings. For Substrate B, almost all of the occurrences of smoldering occurred with sheeting in place. The other three substrates had varied results on the effect of smoldering and FLB.

A statistical analysis was performed on the FLB data to determine if there was a difference between the RIP and non-RIP of the same packaging. Cigarettes that smoldered were included to allow sufficient sample to control for location, sheeting, substrate type, and packaging. There were cases - those with sheeting in particular - where we were unable to distinguish a full-length burn from smoldering that consumed the cigarette. Those cases were treated as full-length burns for purposes of analysis. In this model, the RIP effect, as well as substrate type, cigarette type, and location, all were found to be statistically significant. Additionally there was a statistically significant interaction between substrate type and the RIP cigarette, as well as between substrate and sheeting, location and the RIP cigarette, and location and sheeting.

5.3.3 Pall Mall/SRM Packaging

Results of the statistical model showed that the SRM 1196/Pall Mall RIP packagings behaved differently than other within-packaging comparisons. The SRM cigarette was developed to mimic the ignition propensity of non-RIP Pall Mall cigarettes; thus, it is expected that the only physical difference between the Pall Mall RIP and SRM 1196 is the addition of bands to the paper around the tobacco column. The results here suggest that the bands are effectively changing the smoldering propensity of the Pall Mall RIP cigarettes to an extent that may not translate to other packagings or that there may be other differences between the cigarettes. Further research would be necessary to determine if there are other meaningful differences beyond the banding that exist between the SRM 1196 and PMR cigarettes.

5.4 Comparison of Mattress and Mattress Pad Evaluations to ASTM E2187-04 Evaluations

The ASTM E2187-04 standard specifies in its scope that the "method has a value as a predictor of the relative propensity of a cigarette to ignite upholstered furnishings." Although this series of tests evaluated the relative response of the cigarettes on mattresses and mattress pads, the relative results of ignition propensity should be similar to that of upholstered furniture. That said it is interesting to compare the results from the ASTM E2187-04 testing, as described in section 5.2 above, and the raw data from this test series.

The portion of cigarettes that demonstrated FLB in the ASTM methodology and the portion of cigarettes that could be determined as demonstrating a FLB in the mattress and mattress pad test series are compared in Figure 6. This set of data does not include the evaluations that could not be determined for whether they burned their full length, as described earlier, but it does include evaluations where smoldering and no smoldering occurred. This plot demonstrates that the ASTM test does not necessarily predict the instance of FLB on other substrates, such as soft furnishings. There are other important factors (location, cigarette packaging, and sheeting) that may confound these comparisons. Still, the frequency of FLB is not of the magnitude expected with the introduction of RIP cigarettes.

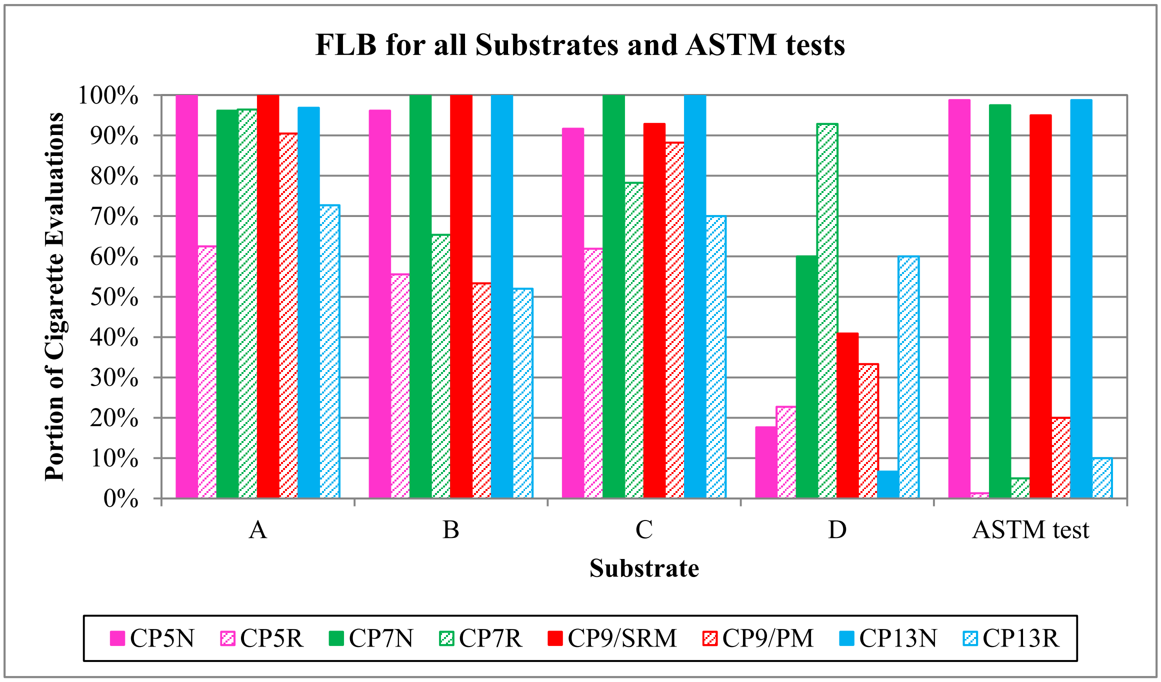

Figure 6. Comparison of FLB on Mattress, Mattress Pad, and ASTM E2187 Substrates
(the total number of evaluations is listed in Table 4)

Table 4. Number of Evaluations Considered for Figure 6

Cigarette ID	Substrate				
	A	B	C	D	ASTM
CP5N	24	26	23	17	80
CP5R	24	27	21	22	80
CP7N	26	27	24	15	80
CP7R	28	26	23	14	80
CP9/SRM	20	28	14	22	80
CP9/PM	21	30	17	21	80
CP13N	32	27	20	15	80
CP13R	34	25	21	10	80

According to the ASTM test, measuring the cigarette's ability to burn its full length to determine the safety it provides suggests that if a lit RIP cigarette is dropped, a fire will not start because the smoldering front will reach one of bands and self-extinguish. So another way to examine the data for the relationship between the predictions of the ASTM test to real life scenarios is to look at the portion of evaluations that resulted in smoldering, as compared to the ASTM portions of FLB. If a cigarette burns its full length frequently, one can expect that there is a greater likelihood that smoldering may occur. Figure 7 shows this comparison.

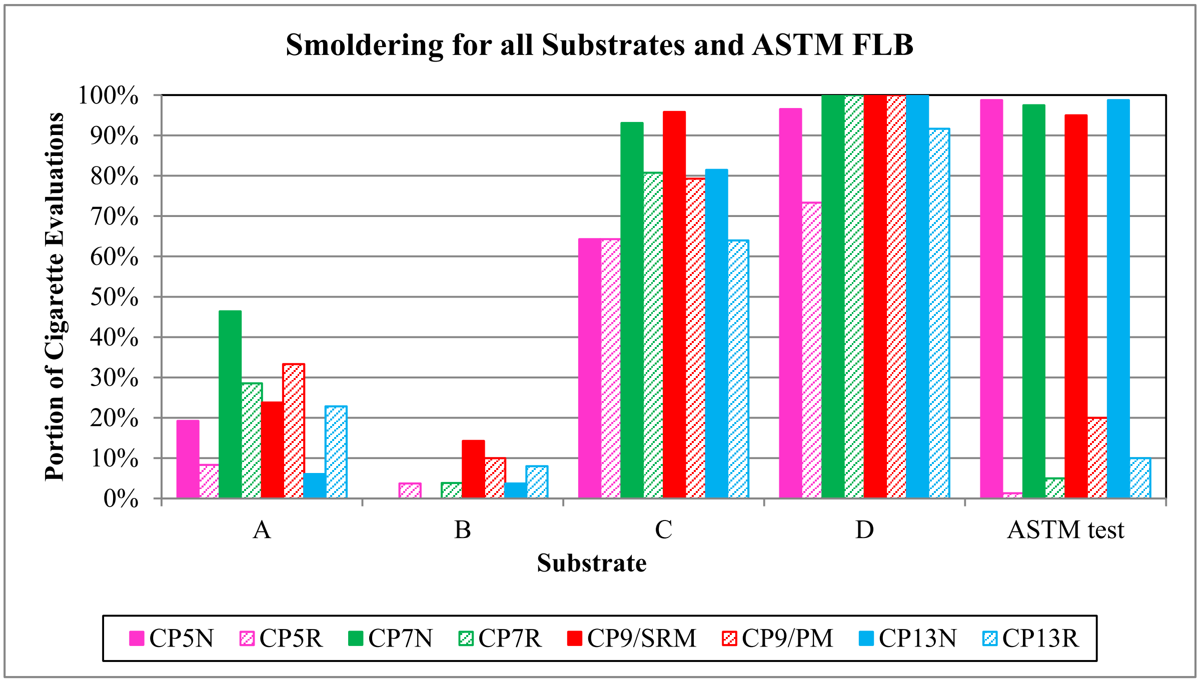

Figure 7. Comparison of Smoldering Portions on Mattress/Pad Substrates to FLB on ASTM substrate

This comparison demonstrates that for the tested substrates, the instance of smoldering for the different substrates using the ASTM methodology does not necessarily predict whether smoldering will occur. There are other important factors (location, cigarette packaging, and sheeting) that may confound these comparisons. However, they are not of the order of magnitude expected with the introduction of RIP cigarettes; while the percentage of FLBs were low for the RIP cigarettes when tested per ASTM E2187-04, there was not a corresponding level of low smoldering percentages on the actual mattress and mattress pad substrates.

5.5 Conclusions

The testing completed in this project aimed to evaluate the relative difference between the RIP and non-RIP cigarettes of the same packaging. First, staff evaluated 13 packagings per the specifications of the states' model legislation and found that all RIP packagings tested passed the legislative requirements and demonstrated low portions of FLB. Based on the results, four packagings were chosen to continue the evaluation of RIP cigarettes on soft furnishings. The methodology in 16 CFR part 1632 was then used to compare the chosen RIP and non-RIP packagings on mattress and mattress pad substrates.

The data are specific to the substrates and packagings tested and are not offered as a generalization on all non-RIP and RIP cigarette smoldering behavior. In this study, results indicated that:

- ✓ The RIP-type cigarettes of different packagings did not demonstrate similar full length burn (FLB) performance when tested per ASTM E2187-04.
- ✓ The RIP-type cigarettes of different packagings did not demonstrate similar FLB performance when tested on mattress and mattress pad substrates.

- ✓ Based on the model state legislation, it is expected that cigarettes with a low occurrence of FLB burn on filter paper substrates will also have a low occurrence of smoldering on soft furnishings. However, results of portions of FLB on 10 layers of the ASTM E2187-04 filter paper substrate did not predict smoldering behavior on the mattress and mattress pad substrates tested here.
- ✓ The testing on mattress and mattress pad substrates showed a statistically significant difference in smoldering between the RIP Pall Mall and SRM 1196 cigarettes on three substrates and a difference between CP5 RIP and non-RIP on one substrate.
- ✓ The statistical model shows there is no statistically significant overall difference between RIP and non-RIP cigarettes' propensity to cause smoldering of the tested mattress/pad substrates, except for when the Pall Mall RIP/SRM1196 packagings are included in the model. This may be due to the inherent high ignition propensity of the Pall Mall cigarette.
- ✓ In addition to whether the cigarette is a RIP type, other variables play statistically significant roles, including: the packaging of the cigarette, the substrate, and the location of the cigarette on the substrate.

RIP and non-RIP cigarettes that produced FLBs did not always result in smoldering of the mattress and mattress pad substrates. Conversely, some RIP and non-RIP cigarettes caused smoldering of the substrates without producing FLBs. Therefore, staff concludes that for RIP cigarettes meeting the provisions of ASTM E2187-04 and sold in all 50 states, there are many factors that play a role in whether a RIP cigarette burns its full length, and whether a FLB results in smoldering of a mattress or mattress pad substrate.

The results of these CPSC investigations so far would suggest that:

- ✓ Testing of RIP cigarettes for percentage of FLBs per ASTM E2187-04 may not be predictive of RIP cigarette FLBs on soft furnishings.
- ✓ Percentage of FLBs per ASTM E2187-04 may not be predictive of smoldering on soft furnishings.
- ✓ It is premature to conclude that RIP cigarettes alone will greatly reduce the threat of unintentional cigarette-ignited fires involving soft furnishings.
- ✓ The type of cigarette packaging, type of substrate, and location of the cigarette have been shown to impact the likelihood that a mattress or mattress pad will smolder either by a RIP or non-RIP cigarette

While there may be some benefit made by the saturation of RIP cigarettes in the marketplace, the difference in ignition propensity between RIP and non-RIP cigarettes did not, in this study, demonstrate a change in the hazard that the CPSC standards address. Staff will consider the results of this study when recommending amendments to existing or proposed FFA rules for Commission consideration.

6. FUTURE WORK

The results of this study may warrant further investigation into the ignition propensity of SRM 1196/RIP Pall Mall cigarettes. Staff also plans to stay up-to-date on changes in RIP cigarette technology, voluntary standards development, and state legislation related to RIP cigarettes.

ATTACHED SUPPORTING DOCUMENTS

Supporting Document A: Mehta, S. "Literature Review of Reduced Ignition Cigarette Studies." Memorandum to J. Elder, May 31, 2007.

Supporting Document B: Smith, C. "Cigarette Market Information" Memorandum to S. Mehta, May 10, 2007.

Supporting Document C: Bhooshan, B., "Citric Acid Content in Cigarette Paper." Memorandum to S. Mehta, May 12, 2008.

Supporting Document D: Green, M., Andres, C., "Cigarette Ignition Risk Phase I: Analysis of Selected Reduced Ignition Propensity Cigarettes" Memorandum to S. Mehta, July 2008.

Supporting Document E: Mehta, S., "Cigarette Ignition Risk Phase II: Mattress and Mattress Pad Testing" September 2012.

Supporting Document F: Miller, D., Garland, S. "Cigarette Ignition Risk Phase II: Mattress and Mattress Pad Results Analysis" Memorandum to S. Mehta December, 2012.

Supporting Document G: Campbell, J. Mellish, R., "Characterization of Test Substrates Used in Cigarette Ignition Risk Project Testing" Memorandum to S. Mehta, August, 2012.

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
4330 EAST WEST HIGHWAY
BETHESDA, MD 20814

Memorandum

October 30, 2012

TO	:	J. DeWane Ray, Assistant Executive Director Hazard Identification and Reduction
THROUGH	:	George Borlase, Associate Executive Director Directorate for Engineering Sciences
		Patricia Adair, Division Director Division of Combustion and Fire Sciences
FROM	:	Shivani Mehta, Project Manger Division of Combustion and Fire Sciences
SUBJECT	:	Cigarette Ignition Risk: 2007 and 2008 Project Documents

The U.S. Consumer Product Safety Commission's (CPSC's) Cigarette Ignition Risk Project to evaluate Reduced Ignition Propensity (RIP) cigarettes began in 2007, and it continued through 2012, including a 2-year hiatus (from FY09 toFY10) during which staff was required to complete other work pursuant to the Consumer Product Safety Improvement Act of 2008. At the start of the project, research was conducted to formulate the project plan and to choose samples for testing and analysis.

There are four memoranda attached, which present the results of that initial research. The information in them was current as of their dates. Tab A provides a literature review of reduced ignition cigarette studies. CPSC staff conducted this review to determine what findings and research other parties had completed. Tab B provides information about the cigarette market in 2007, and Tab C discusses the results of a study to determine citric acid content of cigarette paper in RIP cigarettes, as well as in non-RIP cigarettes of the same brands. Tab D provides an initial data analysis of RIP cigarettes.

SUPPORTING DOCUMENT A: MEHTA, S. "LITERATURE REVIEW OF REDUCED IGNITION CIGARETTE STUDIES." MEMORANDUM TO J. ELDER, MAY 31, 2007.

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
4330 EAST WEST HIGHWAY
BETHESDA, MD 20814

Memorandum

Date: May 31, 2007

TO : Jacqueline Elder, Assistant Executive Director
EXHR

THROUGH: Hugh McLaurin, Associate Executive Director
Patricia Adair, Division Director
Division of Combustion and Fire Sciences
Directorate of Engineering Services

FROM : Shivani Mehta, Project Manager
Division of Combustion and Fire Sciences
Directorate for Engineering Sciences

SUBJECT : Literature Review of Reduced Ignition Cigarette Studies

1. INTRODUCTION

Cigarettes or other tobacco products provided the heat source for an estimated annual average (for the years 1999–2003) of 19,900 residential structure fires, resulting in 700 civilian deaths, 1,580 injuries, and $361.0 million in property losses.[1]

Currently, the federal standard for mattresses (16 CFR part 1632) includes a cigarette ignition test, and a potential standard for upholstered furniture uses a cigarette as a source of ignition. Cigarettes are used as the ignition source because the hazard data indicate that the majority of mattress and upholstered furniture fires are caused by smoldering cigarettes. The standard cigarette used in these regulations is an unfiltered Pall Mall.®

In 2004, New York State adopted a fire safety standard for cigarettes that requires all cigarettes sold in the state to be low-ignition strength, making them less likely to cause fires if left unattended. Currently, 14 states have passed legislation, and 16 states have filed legislation. As more states enact legislation to require these Reduced Ignition Propensity (RIP) cigarettes, the hazard of smoldering caused by cigarettes may change.

A review of literature was conducted to determine what other parties have learned about the behavior of cigarettes as ignition sources. This information will aid the project team in developing a test plan to determine the relative difference in hazard between the RIP and traditional cigarettes.

[1]Chowdhury, R., Greene, M., Miller, D., "1999−2003 Residential Fire Loss Estimates." October 2006.

2. LEGISLATION

2.1 Federal Legislation

In 1979, Rep. Joe Moakley (D-Mass.) and Sen. Alan Cranston (D-Calif.) introduced a bill requiring manufacturers of cigarettes and little cigars to comply with standard that would be developed by the U.S. Consumer Product Safety Commission (CPSC) to ensure that these products would stop burning within 5 minutes if they are not actively being smoked. However, the CPSC is not authorized by its statutes to regulate cigarettes.

In 1984, an amended Moakley-Cranston bill (The Federal Cigarette Safety Act of 1984) passed. The legislation called for the formation of a Technical Study Group to determine the technical and economic feasibility of making a fire-safe cigarette and the creation of an *Interagency Committee on Cigarette and Little Cigar Fire Safety*.

The Interagency Committee was chaired by the then-Chairman of CPSC and included 15 members from government agencies, the furniture industry, public health organizations, firefighters unions, fire safety organizations, and the cigarette industry. In 1987, the Interagency Committee completed its study, finding that it was technically, economically, and commercially feasible to develop a cigarette that would be less likely to cause fires. However, the Interagency Committee also recommended more research into the feasibility of manufacturing fire-safe cigarettes. Another two bills were then introduced in Congress: HR 293 by Rep. Moakley and HR 673 by Rep. Thomas J. Bliley, Jr. (R-VA) and Rep. Rick Boucher (D-VA). The Boucher-Bliley bill called for additional studies without setting a standard. HR 293 called for the CPSC to issue standards, complete any necessary research, and mandated that the tobacco companies produce fire-safe cigarettes.

In 1990, HR 293 was amended, suspending federal regulations mandating fire-safe cigarettes, but requiring the CPSC to develop a standard test for cigarette ignition propensity and to perform the research to develop a performance standard for fire-safe cigarettes. This bill was enacted as the Fire-Safe Cigarette Act of 1990 (Public Law No: 101-352).

The CPSC asked the National Institute for Standards and Technology (NIST) to conduct research in response to the Act, which led to the development of two methods for measuring the ignition propensity of cigarettes, the Mock-Up Ignition Method Extinguishment Test and the Extinguishment Test, both of which will be described in more detail below.

In 1993, the CPSC reported to Congress that a fire safety test had been developed. However, the CPSC Chairman asked Congress to appoint a more appropriate agency to develop a performance standard for fire-safe cigarettes because the CPSC does not have jurisdiction over cigarettes. Although NIST does not have authority over cigarettes either, NIST agreed to take on this task.

2.2 State Legislation

On December 31, 2003, New York State adopted legislation requiring all cigarettes sold in the state to be low-ignition strength, making them less likely to cause fires if left unattended. The law became effective on June 28, 2004. Fire-safe cigarettes are now the law in California, Illinois, Kentucky Massachusetts, New Hampshire, New York, Oregon, Vermont, Utah, and

Canada. As of April 26, 2007, when the literature review was conducted, 22 more states had filed fire-safe cigarette legislation.[2]

3. Test Methods

As a result of the work that NIST performed under the Fire Safe Cigarette Act of 1990, NIST developed the two methodologies previously mentioned for determining the ignition propensity of cigarettes.[1,2] The methods are designed as performance tests, independent of cigarette characteristics and intend to have links to real-world fire scenarios. During the development of the methodologies, NIST examined multiple standards and conducted extensive testing with experimental and commercially available cigarettes. An interlaboratory study was also completed to determine repeatability and reproducibility of the test methods following the ASTM Standard E 691, "Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method."

3.1 The Mock-Up Ignition Test Method

This test method determines whether a cigarette causes ignition by transferring enough heat to a fabric/foam combination representative of a piece of furniture. The fabrics are cotton duck materials of differing weights, the foam is polyurethane, and the fabric/foam combination is a polyethylene film between the duck and foam. The cotton duck was chosen because it possessed the properties of a control fabric, which includes a consistent fiber content, weight, and manufacturing process.

In the test, a lit cigarette is placed on one of three mock-ups. Each mock-up uses the fabric/foam combination described above, with the weight of the duck material being the only difference, *i.e.*, a different weight of cotton duck is used on each of the 3 mock-ups, with the polyurethane foam and the polyethylene (PE) film being the same on all 3. Ignition (*i.e.*, failure) is defined as char on the mock up that propagates more than 10 mm away from the burning tobacco column. A complete test series consists of 48 replicates of each cigarette on each of the three substrates for a total of 144 tests with each cigarette.

3.2 The Cigarette Extinction Test Method

The purpose of this test is to determine the ignition propensity of the cigarettes. A lit cigarette is placed on multiple layers of filter paper. The paper cannot ignite from a smoldering source but draws heat from the cigarette. The test determines whether the filter paper substrate absorbs enough heat to extinguish the cigarette. Because the filter paper is made consistently, the cigarette ignition propensities of multiple cigarettes can be compared without the confounding interaction of fabric-type substrates.

Once these two test methods were developed, various studies were undertaken to examine their sensitivity, and each will be discussed below.

[2] www.firesafecigarettes.org

3.3 The ASTM method

In 1995, a Task Group under ASTM Subcommittee E5.15 began developing a standard based on the Mock-up Ignition Test Method. However, the standard fabrics that originally had been specified in the methods were no longer in production. With state and federal legislation under development that required a test method document, an effort was begun to standardize the NIST Cigarette Extinction Method.

The original NIST method required additional detail to ensure a uniform implementation. The ASTM ballot process, during which committee members made changes to the proposed standard, resulted in the standard as it is seen in ASTM E-2187-04. Many of the modifications were clarifications of the NIST method. The test chamber, conditioning environment, and cigarette conditioning were unchanged from the original NIST method. The original method did not specify the ignition method and the number of tests per sample. There were only a few major changes to the original NIST standard[3]:

- The test metric, time to extinguishment, changed from an unspecified number of samples, to conducting 40 determinations and eliminating the reporting of the time.
- The test criterion changed from a measure of the consumed tobacco column, to a measure of the tobacco column up to the front plane of the tipping paper (or the metal pins for non-filtered cigarettes), *i.e.*, did the cigarette burn through the entire tobacco column?
- The ignition method was altered to ensure that the cigarette is ignited evenly about its cross-section.

As states have enacted legislation to require “fire safe” cigarettes, the current ASTM E 2187-04 standard is the test method to which the cigarettes are required to be tested.[4]

3.4 California Bureau of Home Furnishings and Thermal Insulation (CBHFTI)

Since 1975, upholstered furniture sold in California has been required to be flame retardant and cigarette ignition resistant. The California Bureau of Home Furnishings and Thermal Insulation (CBHFTI) developed two standards, Technical Bulletins 116 (small-scale) and 117 (full-scale) to test the fire retardancy of upholstered furniture. Unlike the NIST methods, which evaluate cigarette performance, these standards evaluate fabric performance. In developing the standards, the CBHFTI performed cigarette tests on the furniture to determine compliance with the requirements of TB 116.[5] Part of the CBHFTI study analyzed the effect of the type of upholstery cover fabrics on the cigarette ignition of the furniture tested. Although the cigarette ignition performance of upholstered furniture might be determined by the fabric/substrate combination, the results of this study indicated that the type of exterior cover fabric used on the furniture was probably the most significant factor for cigarette ignition. Test results indicated that furniture with an exterior cover fabric containing 80 percent or more of cellulosic fiber was unlikely to resist cigarette ignition.

A second study by CBHFTI tested more than 1,200 upholstered articles.[6] Test results showed that furniture covered by fabrics made with mainly cellulosic fibers was usually smolder prone, and that the probability of cigarette ignition increased as the weight of the fabric increased. The study concluded that the type of fibers used in the exterior cover fabric of the upholstered furniture is the key factor affecting the smoldering propensity of upholstered furniture.

4. CIGARETTE CHARACTERISTICS EXAMINED

There are many factors that affect the burning rates and temperatures of cigarettes. The circumference of the cigarette, regardless of whether there is a filter in place, the packing density of the tobacco, the length of the cigarette, and the chemicals added to the paper, as well as the permeability of the paper, may differ between cigarette brands. Studies were undertaken to examine the effects of some of these characteristics.

A part of the studies that NIST conducted to research the feasibility of reduced ignition cigarettes included examining the effect of cigarette characteristics on the ignition of furnishings.[7] Specifically, two variations of each of these characteristics, the tobacco packing density, cigarette circumference, paper permeability, paper citrate concentrations, and tobacco types, were evaluated. The NIST study found that low tobacco density, reduced circumference, and low paper permeability, *together* resulted in a considerable reduction in ignition propensity.

An industry group also investigated the effects of cigarette characteristics on the ignition propensity of various fabrics, including cotton duck, treated sail cloth, and commercial upholstery fabrics.[8] Twenty-five cigarette samples of varying tobacco packing density, cigarette circumference, paper porosity, and paper citrate levels were tested. The group performed a thorough statistical analysis of the data and showed the contradictory effects of duck fabrics and treated sail cloth. Reductions in packing density and circumference of the cigarettes reduced ignitions on duck fabrics but increased the ignition on treated sailcloth. The commercial fabrics showed mixed results; some showed similar results as the duck fabrics, and the others showed their ignition behaviors to be closer to the treated sail cloth.

4.1 Circumference

The tobacco industry conducted a study that examined only the effect of circumference on the ignition propensity of cigarettes.[9] For testing purposes, all other parameters were held constant in the range of commercial feasibility. Cigarettes with four different circumferences were examined: 21, 22, 22.5, and 27 mm. The original NIST study only evaluated 21 and 25 mm cigarettes and found that the larger-circumference cigarettes had a higher ignition propensity. With the exception of the differences in circumference, the cigarettes were of identical construction. The paper permeability, tobacco blends, packing density, filter, and cigarette lengths were identical. This study found that small circumference alone does not reduce the likelihood of ignition, and larger circumference, in and of itself, does not increase the likelihood of ignition.

4.2 Temperature

Some work has been conducted to attempt to characterize the temperature distribution within a burning cigarette. As part of the NIST method development, a mathematical model was developed to predict the burning characteristics of a burning cigarette.[10] One prediction for the peak temperature of the burning cigarettes is approximately 830ºC.

Because the cigarette has a small area of burning, measuring the temperature is often difficult. It has been shown that the measurement is sensitive to the size of the device used to measure it.[11] The burning temperature was measured with type K thermocouples of different sizes. The experiment indicated that if a large diameter thermocouple was used, the temperature was under-measured by about 70 percent; the range of temperature spanned 280ºC to 940ºC inside the cigarette, depending on the size of thermocouple used.

4.3 Foreign Cigarettes

Studies have shown that although the rates of injury and death from cigarette smoldering fires in foreign countries are lower, the cigarettes sold in those countries are not necessarily of a lower ignition propensity.[12,13,14] The characteristics of the best-selling cigarettes from seven countries were compared to the 10 best-selling brands from the United States. The differences are not significant enough to explain the discrepancy between the injury data in the United States versus other countries. The ability to ignite soft furnishings by the same brands of cigarettes was evaluated using the NIST mock-up method. The foreign cigarettes demonstrate a similar tendency to ignite the mock-ups in a lab environment. The authors of these studies conclude that much of the discrepancy can be explained by the cultures of these countries.

5. SMOLDERING IGNITION OF FABRICS

After NIST developed the test methods to quantify the propensity of cigarettes to ignite soft furnishings, many researchers evaluated the methods with alternate tests, fabrics, or cigarettes.

In order to determine the effects of fabric properties on the cigarettes' ignitability, Dwyer, et al., (1994) conducted a study using high ignition propensity cigarettes. [15] Five hundred upholstery fabric samples were collected and tested over a 25 mm thick polyurethane foam substrate under a Plexiglas box with a chimney. The authors found that high cellulose content in the fabric increased the possibility for a smoldering ignition. There was also a positive correlation between alkali metal ions (sodium and potassium) and smoldering ignitions. However, there was not a correlation between air permeability and smoldering ignitability for the fabrics.

The second part of the study was conducted with two high-ignition propensity and two lower-ignition propensity experimental cigarettes on 145 smolder-prone fabrics and 300 additional fabrics.[16] The testing indicated that the cotton duck fabrics used by the NIST mock-up method did not represent upholstery fabric properties. The results revealed that the fabric weight, cellulose content, and alkali metal ions are important fabric parameters that affect smoldering ignition behavior of the fabrics. Other cigarette design parameters, like paper porosity, circumference, tobacco packing density, and burn rate, did not have major impacts on the smoldering ignitions of upholstery fabrics.

A third party performed a statistical analysis of the data in the above two-part study to verify that the NIST mock-up test results were largely determined by the characteristics of the fabrics and not the cigarettes.[17] The mass burn rate and linear burn rate of the cigarettes can be used to characterize the ignition propensity of the cigarette. The rates appeared to depend on the fabric properties and the geometry of the test configuration, thus, also refuting the NIST methodology as the previous studies had.

The behavior of 50 upholstery fabrics, primarily smolder-prone cellulosic, was observed in another study when exposed to 11 commercial cigarette brands.[18] Six brands were designated by NIST as low-ignition propensity, and five were of high-ignition propensity. The group used the

NIST mock-up methodology, replacing the cotton duck with the chosen fabrics without a PE film in place but still keeping the foam in the substrate. The ignition responses of the fabrics to the different ignition propensity cigarettes were statistically similar. This result is contrary to NIST findings of cotton duck response to cigarettes of differing ignition propensities; on the cotton duck, a "low-"ignition propensity cigarette caused statistically fewer ignitions than the "high-"ignition propensity cigarettes. As in the previous two-part study, this study concluded that the ignition behavior of cigarettes is mainly controlled by fabric characteristics.

6. LIMITED STUDIES WITH THE REDUCED IGNITION STRENGTH CIGARETTES

Since the introduction of the New York version of the "Fire Safe" Cigarette in 2004, little work has been conducted to verify the effects of these cigarettes on ignition of soft furnishings. However, in the studies conducted by NIST, which led to the development of the ASTM standard, some brands were found to have lower ignition strength than others in the commercial market before 2005. Early studies that examined isolated characteristics with experimental cigarettes demonstrated that the combination of low tobacco content per unit length (small diameter and low packing tobacco density), lower paper porosity, and low citrate content did not ignite most substrates, including the NIST mock-ups.[19] Cigarettes with all of these characteristics were used as the "low-ignition propensity" cigarettes in test matrices until the "fire-safe" cigarette that is required by some states today came into existence.

A study was undertaken to examine the risk associated with low ignition propensity cigarettes in the UK.[20] The study assessed the risk in four parts: the risk of the ignition behavior of the cigarette; the cigarette interaction with upholstered furniture seating; the interaction with mattresses; and the interaction with bed assemblies. The author compared his results to the studies conducted by NIST, CPSC, and the Cigarette Ignition Propensity Joint Venture (CIPJV).[3]

The two methods developed by NIST, with minor modifications,[4] plus a section of BS 5852, were used to indicate the smoldering propensity of all cigarettes.[21] Commercial UK brands that represent the types of cigarettes that NIST found to be of low ignition propensity were tested. Additionally, untipped (unfiltered) cigarettes, which are unpopular, but are used as standard ignition sources in the UK and U.S. standards, were included in the test matrix.

The results were not consistent between the two NIST methods. When tested with the NIST Mock-Up Method, in no instance did progressive smoldering occur with the specified test material. Ten replicates gave a reasonably consistent result. The majority of the sample cigarettes have a low ignition propensity, according to this test. The cigarettes, which self-extinguished without significantly smoldering in this test, were tested to the NIST smoldering propensity test (ASTM E2187). These results showed that with a single exception, all of the cigarettes burned to completion using any thickness of filter paper. Limited replicates were carried out, but the results appeared to be repeatable.

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[3] Cigarette Ignition Propensity Joint Venture (CIPJV) was set up in 1990, by six U.S. domestic cigarette manufacturers.

[4] The NIST mock-up method has been criticized for not taking into consideration the effects of variations in the ignition source, the test specimens, and environmental conditions.

The next part of the study was to assess the role of the low ignition propensity cigarettes on upholstery composites using the British test method BS 5852. Composites that were likely to smolder were chosen and would not be expected to pass the UK 1988 regulations. Also, composites that were expected to smolder weakly and smolder strongly were included. The results indicated that while cigarettes of low ignition propensity caused a lower proportion of ignitions of the upholstery seating composites than the other filter-tipped and untipped cigarettes caused, all of the cigarettes caused ignition of at least some of the upholstered furniture composites.

Testing of mattress composites with cigarettes of differing ignition strength was conducted per test method EN 597-1.[22] Five mattress composites were selected for testing, but only one met current UK regulations. The specimens consisted of PU foam filling with a fabric surface and tape edges made up of several layers of the covering fabric. The results indicated that the low-ignition propensity cigarettes and regular-tipped cigarettes show relatively little difference for the surface ignition of mattresses. The untipped cigarettes caused significantly more smoldering results.

Finally, testing of bed assembly composites (which included blankets, sheets, pillows, duvets, and other bedding types) was conducted according to BS6807.[23] Combinations of composites included materials that varied in their smoldering potential. Tests were conducted over simulated mattresses and actual mattresses. The low-ignition propensity cigarettes caused fewer smoldering ignitions than the popular filter tip cigarettes. All of the cigarette-resistant mattresses resisted ignitions from all cigarettes.

Although the cigarettes that were classified as low ignition propensity, cigarettes exhibited a lower number of ignitions of mock- ups than the other popular filtered and unfiltered cigarettes, the UK regulations for upholstered furniture and mattress products provided greater protection at the time of the study.

In 2001, a test was conducted to assess the cigarette ignition performance of experimental, banded[5] cigarettes compared to controls using the NIST methods.[24] When the cigarettes were tested on the filter paper and cotton ducks, the experimental cigarettes demonstrated a significantly lower proportion of full-length burns than the control cigarette. In addition to the substrates in the NIST test methods, 34 “real-world” commercial fabrics were used to test the three cigarettes on both a flat surface and a crevice location. The experimental cigarettes produced significantly fewer ignitions of the commercial fabrics than the control on a flat surface, but they produced more ignitions on the commercial fabrics than on the NIST substrates. The experimental cigarettes did not produce statistically significantly fewer ignitions compared to control cigarettes when tested on the crevice configuration and when tested on the NIST substrates.

NIST conducted a study in 2001, at the request of the Federal Trade Commission (FTC), to determine whether a test market cigarette made with a slower burning paper would reduce the

[5] “Banded” cigarettes have an additional layer of paper around the circumference of the tobacco column, typically applied in two locations, each having a width less than 15mm.

risk that such a cigarette, if dropped or discarded, could start a fire.[25] These modified cigarettes are banded and similar to the current "fire-safe" cigarettes and were compared to experimental cigarettes provided to NIST as part of the work they conducted for the Fire Safe Cigarette Act of 1990. Both NIST test methods were used for the comparison.[6] The banded cigarettes produced significantly fewer ignitions on all the filter paper tests and on two weights of cotton duck in the mock-up method.

7. RIP Activities in Other Countries

In 2003, the Canadian Health Department initiated research to evaluate test methods that determine ignition strength of cigarettes. In 2005, Canada became the first country to implement a nationwide cigarette fire-safety standard for cigarettes. The UK and other EU countries are in the process of determining whether "fire-safer" cigarettes should replace traditional cigarettes in the market. In 2005, the UK government commissioned a study to determine the benefits of these "fire-safer" cigarettes. As of the date of this research, no regulation has been introduced into legislation.

7.1 Canada

The Canadian Health department (Health Canada) was interested in regulating the ignition propensity of cigarettes in order to reduce the ignitability of upholstered furniture by lit cigarettes. As part of its background research, Health Canada requested information on the ignition strength of at least 36 brands of Canadian cigarettes. In response to this need, the National Research Council (NRC) built a test facility in accordance with the ASTM E2187-02b standard test method and completed four experimental series to study the ignition strength of cigarettes.[26,27,28,29]

The Health Canada test facility included four test chambers and equipment for controlling and measuring temperature, humidity, and ventilation in the room. Each test chamber had a separate pipe to exhaust into the hood. The test areas also included heaters and humidifiers for conditioning the room, and a fan for air circulation.

The condition of the test room was monitored for stability for more than a week before starting the experimental series. Both the temperature and humidity were stabilized within required conditions (a relative humidity of 55% ± 5% and a temperature of 23°C ± 3°C). The exhaust and room ventilation were controlled and maintained at the level, such that air movement in the test chambers rose steadily with no turbulence. Calibration tests for 200 "standard" cigarettes were conducted to check and verify whether the NRC facility and operation would produce results consistent with those from NIST and other laboratories. Experimental variables, such as cigarette types, test chambers, and test samples were randomized for the experiment sequence in order to eliminate systematic errors.

Initially, 10 brands of Canadian cigarettes were examined and full-length burning was observed in 95 to 100 percent of the determinations on 15 layers of filter paper. These high percentages of full-length burns suggest that these cigarettes have a relatively high propensity to ignite

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[6] NIST had stored extra materials from the 1993 round of testing in a freezer that was used in the Mock-Up Test Method.

upholstered furniture if lit and dropped on soft furnishings, demonstrating the need to make these cigarettes less likely to cause a fire.

The second series of tests performed by Health Canada involved 54 brands of cigarettes; 52 were Canadian brands, and the remaining two brands were Philip Morris's Merit® cigarettes that are sold in the United States. Full-length burning of 90 to 100 percent was observed in 51 of the cigarette brands. The other three cigarettes demonstrated a low ignition propensity.

The third testing series was conducted to determine the ignition propensity of the low ignition propensity cigarettes identified in the previous series, as well as that of selected tobacco sticks (for a total of seven brands of cigarettes). Test results showed again that cigarettes exhibited the similar ignition propensity behavior as in series 2.

The fourth series of tests was performed on three more brands of Kreteks®, which are Canadian cigarettes. One of the brands was found to have a relatively low ignition propensity, while the other two were found to have a relatively high ignition propensity.

After these studies were completed, Health Canada proposed and passed a mandatory rule to require that cigarettes sold in Canada be of a reduced ignition propensity, effective October 1, 2005.

7.2 United Kingdom

In 2005, the UK Office of the Deputy Prime Minister commissioned a study to examine the ignition propensity of cigarettes.[30] The purpose of their project was to compare cigarette ignition propensity on a range of textiles and other materials at the lower end price of the UK market.

The materials that were used as the substrate to determine the ignition propensity were divided into three groups. All substrates were made with a significant portion of cellulosic material on which UK cigarettes will likely cause ignition. The first group represented materials from blankets and sheets. The second group represented materials that are used in combination with upholstery, mattresses, cushions, pillows, and duvet/quilt fillings. A few combinations that should not be on the UK market, due to their furniture regulations, were also chosen for the test series. The third group consisted of paper and newspapers. The upholstery materials were tested over non-fire-retardant foam, and all other substrates were tested over Rockwool, a mineral wool.

The test method was an adaptation of multiple standardized tests from British standards, European standards, the International Standards Organization, and the International Maritime Organization. Extensive testing with the UK cigarette was conducted to examine specimen composition, filling materials, cover materials, and the number of layers of materials. The final test series involved six upholstery-type materials of varying amounts of cotton, two throws, two 100 percent cotton sheets, one cotton/acrylic blanket, facial tissue, and a bed mattress filled with Kapok, a cotton-like substance. The test set up from BS 5852, the British upholstered furniture test standard, was used. In addition to examining substrate response to the cigarettes, the burning temperatures of the cigarettes were measured.

Each sample was subjected to one typical UK cigarette, a low-cost cigarette, and two New York State “fire safe” cigarettes (Brands: Camel® and Merit®). The two fire safe cigarettes represent high and low smoldering propensity extremes, respectively, among the New York State “fire safe” cigarettes.

The testing revealed that all the cigarettes tested can induce progressive smoldering in some materials when tested over foam, and all could induce flaming/smoldering combustion over Rockwool. Although the New York State cigarettes demonstrated a reduction in ignitions compared to the UK cigarette, the reduction between the two brands was distinctly different. The UK cigarette exhibited full-length burning in 91 percent of the trials; the banded Camels® exhibited a 69 percent full-length burning, and the Merits demonstrated full-length burning in 34 percent of the trials. These numbers do not represent the relative reduction in ignition propensity as compared to conventional versions of the cigarettes.

8. CONCLUSIONS

Much work has been conducted to evaluate the interaction of cigarettes with soft furnishings. The studies provide background information on the methods, explain the techniques, and describe weaknesses in the test methods. However, due to the recent introduction of reduced-ignition propensity cigarettes in the U.S. market, a comprehensive study to determine the change in hazard has not been completed. The conducted studies described in this memorandum benefit the project team’s goal to assess appropriately the fire hazard associated with the reduced ignition propensity cigarette as compared to traditional cigarettes sold in the United States.

REFERENCES

1. Jones-Smith, J.; Harwood, B. “Overview: Practicability of Developing a Performance Standard to Reduce Cigarette Ignition Propensity. Volume 1.” CPSC, Washington, DC. Vol. 1, August 1993.
2. Ohlemiller, T. J.; Villa, K. M.; Braun, E.; Eberhardt, K. R.; Harris, R. H., Jr.; Lawson, J. R.; Gann, R. G. “Test Methods for Quantifying the Propensity of Cigarettes to Ignite Soft Furnishings. Volume 2.” NIST SP 851, August 1993.
3. Gann, R. G.; Guthrie, W. F. “ Robustness of Measuring the Ignition Strength of Cigarettes With ASTM Method E2187-02b.” NIST TN 1454, July 2003.
4. ASTM E 2187 -04, “Standard Test Method for Measuring the Ignition Strength of Cigarettes.” ASTM International, 2004.
5. Damant, G. H.; Williams, S. S.; McCormack, J. A. “Role of Fabric in the Cigarette Ignition of Upholstered Furniture.” Journal of Fire Sciences, Vol. 1, Sep./Oct. 1983: 309–321.
6. Damant, G. H. “Cigarette Ignition of Upholstered Furniture.” Journal of Fire Sciences, Vol. 13, Sep./Oct. 1995: 337–349.
7. Gann, R., Harris, R., Krasny, J., Levine, R., Mitler, H., Ohlemiller, T. “The Effect of Cigarette Characteristics on the Ignition of Soft Furnishings.” NBS, October 1987.
8. Wanna, J. T.; Zelius, P. “Effect of Cigarette Variables on Ignition Propensity of Various Fabrics.” Journal of Fire Sciences, Vol. 19, Sep./Oct. 2001: 341–354.

9. Lewis, L. S.; Nestor, T. B.; Gee, J. W.; Morton, M. J.; Townsend, D. E. “Effects of Cigarette Circumference on Ignition Propensity.” Fire Safety '91 Conference. Volume 4. November 4–7, 1991: 352–366.
10. Mitler, H. E.; Walton, G. N. “Modeling the Ignition of Soft Furnishings by a Cigarette. Volume 3.” NIST SP 852; Vol. 3, August 1993.
11. Beland, B. “On the Measurement of Temperature.” Fire and Arson Investigator, Vol. 45, No. 1, 27, 30–31, 34–35, September 1994.
12. Lewis, L. S.; Townsend, D. E.; Robinson, A. L. “Comparative Ignition Propensity Study of Foreign and Domestic Cigarettes.” Journal of Fire Sciences, Vol. 8, July/Aug. 1990: 239–253.
13. Lewis, L. S.; Townsend, D. E.; Gee, J. W. “Comparative Ignition Propensity Study of Foreign Cigarettes: An Update.” Product Safety Corporation. International Conference on Fire Safety, 18th, 1993: 38–47.
14. Lewis, L. S.; Nestor, T. B.; Townsend, D. E. “Comparative Ignition Propensity Study of Foreign and U.S. Cigarettes Using the NIST Cotton Duck Mock-up Ignition Test Method.” Journal of Fire Sciences, Vol. 13, Sep./Oct. 1995: 386–398.
15. Dwyer, R. W.; Fournier, L. G.; Lewis, L. S.; Furin, D.; Ihrig, A. M.; Smith, S.; Hudson, W. Z.; Honeycutt, R. H.; Bunch, “The Effects of Upholstery Fabric Properties on Fabric Ignitabilities by Smoldering Cigarettes: Part 1.” Journal of Fire Sciences, Vol. 12, May/June 1994: 268–283.
16. Lewis, L. S.; Morton, M. J.; Norman, V.; Ihrig, A. M.; Rhyne, A. L., “The Effects of Upholstery Fabric Properties on Fabric Ignitibilities by Smoldering Cigarettes: Part II.” Journal of Fire Sciences, Vol. 13, Nov./Dec. 1995: 445–471.
17. Spears, A. W.; Rhyne, A. L.; Norman “Factors for Consideration in a Test for Cigarette Ignition. Propensity on Soft Furnishings.” Journal of Fire Sciences, Vol. 13, Jan./Feb. 1995: 59-84.
18. Greer, L. C.; Hudson, W. Z.; Jupe, R.; Pinion, D. O.; Wanna, J. T., “Ignition Responses of Fifty Upholstery Fabrics to Commercial Cigarettes.” Journal of Fire Sciences Vol. 14, Nov./Dec. 1996: 413–425.
19. Krasny, J., Harris, R., Levine, R., Gann, R. “Cigarettes with Low Propensity to Ignite Soft Furnishings.” Journal of Fire Sciences Vol. 7, July/Aug. 1989: 251–288.
20. Paul, K.T. “Assessment of Cigarettes of Reduced Ignition Power and Their Role to Reduce Fire Risks of Upholstered Furniture Seating, Mattresses, and Bed Assemblies.” Journal of Fire Sciences, Vol. 18, Jan./Feb. 2000: 28–73.
21. BS 5852 Part 1: 1979 Fire tests for Furniture, Part 1, “Methods of Test for Ignition of Smokers Materials of Upholstery Composites for Seating.”
22. BS EN 597-1: 1995, “Furniture – Assessment of the Ignitability of Mattresses and Upholstered Bed Bases, part 1, Ignition Source: Smoldering Cigarette.”
23. BS 6807, “Methods of test for assessment of the ignitability of mattresses, divans and bed bases with primary and secondary sources of ignition.” 1990.
24. Wanna, J.T., Chen, P.X., “Cigarette Ignition Performance.” Journal of Fire Sciences Vol. 19, Sep./Oct. 2001: 355–368.

25. Gann, R. G.; Steckler, K. D.; Ruitberg, S.; Guthrie, W. F.; Levenson, M. S. “Relative Ignition Propensity of Test Market Cigarettes.” National Institute of Standards and Technology, Gaithersburg, MD, January 2001.
26. Su, J.Z.; Lerous, P., Latour, J.C. “Cigarette Ignition Propensity Testing – First Series.” IRC-RR-142, November 2003.
27. Su, J.Z.; Lerous, P., Latour, J.C. “Cigarette Ignition Propensity Testing – Second Series.” IRC-RR-143, November 2003.
28. Su, J.Z.; Lerous, P., “Cigarette Ignition Propensity Testing – Third Series.” IRC-RR-164 March 31, 2004.
29. Su, J.Z.; Lerous, P., “Cigarette Ignition Propensity Testing – Three Brands of Kreteks.” IRC-RR-194 April 29, 2005.
30. Office of the Deputy Prime Minister. “Comparisons of the Propensity of Fire Safe Cigarettes and Conventional Cigarettes to Ignite Textile Materials Used in a Domestic Environment.” January 2006.

In addition to the references cited throughout the text, the following articles were reviewed.

- Baldry, P. J.; Cullis, C. F.; Goring, D.; Hirschler, M. M. “Combustion of Cigarette Paper.” Fire and Materials, Vol. 12, March 1988: 25–33.
- Eberhardt, K. R.; Levenson, M. S.; Gann, R. G. “Fabrics for Testing the Ignition Propensity of Cigarettes.” Fire and Materials, Vol. 21, Nov./Dec. 1997: 259–264.
- Gandhi, S.; Spivak, S. M.; Pourdeyhimi, B. “Study of Smoldering Conditions in Upholstery Fabrics Using Thermal Imaging.” Textile Research Journal, Vol. 68, 1998: 687–696.
- Gann, R. G.; Press, E.; Carey, C. M.; Charles, J. L.; Cullen, J. W.; Gerard, J. C.; Hoebel, J. F.; Leake, P. H.; McGibeny, M. D.; McGuire, A.; Poel, W. H.; Spears, A. W.; Tovey, H.; Townsend, D. E.; Wilkenfeld, J. “Toward a Less Fire-Prone Cigarette. Final Report of the Technical Study Group on Cigarette and Little Cigar Fire Safety. Technical Study Group Cigarette Safety Act of 1984.” Technical Study Group Cigarette Safety Act of 1984 Final Report; October 1987.
- Gann, R. G.; Harris, R. H., Jr.; Krasny, J. F.; Levine, R. S.; Mitler, H. E.; Ohlemiller, T. J. “Cigarette Ignition of Soft Furnishings.” International Association for Fire Safety Science. Fire Safety Science Proceedings. 2nd International Symposium. June 13–17, 1988.
- Harris, R. H., Jr.; Navarro, M.; Gann, R. G.; Eberhardt, K. R. “Reevaluation of Experimental Cigarettes Used in the Cigarette Safety Act of 1984. Report of Test.” NIST, Gaithersburg, MD and CPSC, Washington, DC. Report of Test FR 3984; May 1991.
- Hoebel, J. F.; Neily, M. L.; Ray, D. R.; Smith, L. E. “Role of the Consumer Product Safety Commission in Stimulating Development of More Fire-Safe Products.” CPSC, Washington, DC. International Conference on Fire Safety, 20th. Vol. 20, 1995: 13–20.
- Holleyhead, R. “Ignition of Solid Materials and Furniture by Lighted Cigarettes. A Review.” Science and Justice, Vol. 39, 1999:75–102.
- Ihrig, A. M.; Rhyne, A. L.; Norman, V.; Spears, A. W. “Factors Involved in the Ignition of Cellulosic Upholstery Fabrics by Cigarettes.” Journal of Fire Sciences, Vol. 4, July/Aug. 1986: 237–260.

- Ihrig, A. M.; Rhyne, A. L.; Spears, A. W. “Influence of Flexible Polyurethane Foams on Upholstery Fabric-Foam Mock-Ups Ignitions by Cigarettes.” Journal of Fire Sciences, Vol. 5, Nov./Dec. 1987: 392–415.
- McRae, D. D.; Kellogg, D. S.; Waymack, B. E.; Fournier, L. G.; Dwyer, R. W. “Modification of the NIST Test for Measuring the Ignition Propensity of Cigarettes.” Journal of Fire Sciences, Vol. 18, May/June 2000: 215–241.
- Mitler, H. E.; Davis, W. D. “Computer Model of a Smoldering Cigarette.” Combustion Institute/Eastern Section. Chemical and Physical Processes in Combustion. 20th Fall Technical Meeting and National Bureau of Standards/Center for Fire Research. Annual Conference on Fire Research. Combined Technical Meetings. November 2–5, 1987, Gaithersburg, MD, 1987.
- Ohlemiller, T. J. “Aspects of Smoldering Combustion.” R. J. Reynolds Tobacco Co. International Conference on the Physical and Chemical Processes Occurring in a Burning Cigarette. April 26–29, 1987, Winston-Salem, NC, 1987:246–354.
- Ohlemiller, T. J.; Villa, K. M.; Braun, E.; Eberhardt, K. R.; Harris, R. H., Jr.; Lawson, J. R.; Gann, R. G. “Quantifying the Ignition Propensity of Cigarettes.” Fire and Materials, Vol. 19, July/Aug. 1995: 155–169.
- Waymack, B.; Kellogg, D. “Ignition of Fabric by Cigarettes.” Textile Chemist and Colorist, Vol. 29, September 1994: 18.

SUPPORTING DOCUMENT B: SMITH, C. "CIGARETTE MARKET INFORMATION" MEMORANDUM TO S. MEHTA, MAY 10, 2007.

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
4330 EAST WEST HIGHWAY
BETHESDA, MD 20814

Memorandum

Date: May 10, 2007

TO : Shivani Mehta, Project Manager, Cigarette Ignition Risk Project

THROUGH : Gregory B. Rodgers, Ph.D., Associate Executive Director
Directorate for Economic Analysis

Deborah V. Aiken, Ph.D., Senior Staff Coordinator
Directorate for Economic Analysis

FROM: Charles L. Smith, Senior Economist, Directorate for Economic Analysis

SUBJECT: Cigarette Market Information

This memorandum provides information on the U.S. market for cigarettes in support of CPSC staff evaluations of the cigarette ignition risk.

Market Background

Annual cigarette consumption almost uniformly has fallen from year-to-year since consumption peaked at 640 billion cigarettes in 1981. Table 1 shows U.S. cigarette consumption for 1990–2006, as reported by the Economic Research Service of the U.S. Department of Agriculture. During that time, total cigarette consumption has fallen from 525 billion (in 1990) to 371 billion (estimated for 2006).[1]

In recent years, the U.S. cigarette market was dominated by what sometimes had been called the "Big Four." These firms were Philip Morris (the largest), RJ Reynolds, Brown & Williamson, and Lorillard. Although the Big Four reportedly held about 98 percent of the U.S. cigarette market in 1997, their combined share fell to less than 90 percent by 2003. In 2004, the Federal Trade Commission (FTC) approved a merger of RJ Reynolds and Brown & Williamson, citing the declining importance of Brown & Williamson in the market.[2] At the time of the merger approval, the next largest firms were said to be Commonwealth and Liggett, each with market shares of about 3 percent.

In November 1998, states' attorneys general and cigarette manufacturers signed an agreement (the Master Settlement Agreement), calling for tobacco manufacturers to reimburse the states for

[1] *Tobacco Yearbook, 2005.* Economic Research Service, U.S. Department of Agriculture.
[2] Statement of the Federal Trade Commission, RJ Reynolds Tobacco Holdings, Inc./British American Tobacco p.l.c., *File No. 041 0017,* Federal Trade Commission, June 22, 2004.

costs associated with the treatment of smoking-related illnesses and to reduce underage smoking. Cigarette manufacturers raised prices to cover the cost of the settlement.

Combined with increases in state taxes, the increased cost of cigarettes to consumers has contributed to decreased cigarette consumption. According to the FTC, the Master Settlement Agreement imposed substantially higher costs on the larger manufacturers, which provided a cost advantage for smaller firms selling discount cigarettes. This reportedly led the larger firms to place greater emphasis on the growth of a small number of premium brands, the market segment in which they face little direct competition from smaller firms, and they increased price promotions and stopped increasing wholesale prices for their premium brands.[3] This response of the leading manufacturers to the Master Settlement Agreement has reportedly contributed to an increase in the overall market share of premium brands at the expense of discount brands. Information on market shares held by major premium brands is provided on the following page.

Table 1.

U.S. Cigarette Consumption, 1990–2006

Year	Billions of Cigarettes
1990	525.0
1991	510.0
1992	500.0
1993	485.0
1994	486.0
1995	487.0
1996	487.0
1997	480.0
1998	465.0
1999	435.0
2000	430.0
2001	425.0
2002	415.0
2003	400.0
2004	388.0
2005	376.0
2006 (e)	371.0

Source: Economic Research Service, U.S. Department of Agriculture

[3] IBID.

Leading Cigarette Brands

Table 2 presents information on market shares of major cigarette brands, based on the most recent data (2005) from the National Survey on Drug Use and Health (NSDUH) and other market information, such as annual reports filed with the U.S. Securities and Exchange Commission. As shown in Table 2, the top 10 cigarette brands account for about 80 percent of the overall market share for cigarettes sold in the United States. The largest market share, by far, is held by the Marlboro brand, which is manufactured by Phillip Morris. Marlboro accounts for more than 40 percent of all cigarettes sold. The only other brand that holds more than a 10 percent market share is Newport, manufactured by Lorillard, with about 11 percent of the U.S. market.

Table 2.

Cigarette Brand Rankings and Market Shares

Rank	Brand	NSDUH ('05)	Market reports	Manufacturer
1	Marlboro	42.4%	40.6%	Philip Morris
2	Newport	11.3%	11.3%	Lorillard
3	Camel	7.5%	6.7%	R.J. Reynolds
4	Doral	3.1%	5.0%	R.J. Reynolds
5	Basic	4.2%	4.2%	Philip Morris
6	Winston	2.9%	4.2%	R.J. Reynolds
7	Kool	2.9%	3.0%	R.J. Reynolds
8	Salem	1.9%	2.6%	R.J. Reynolds
9	Parliament	2.0%	--	Philip Morris
9	USA Gold	1.9%	--	Commonwealth Brands
9	Virginia Slims	--	2.3%	Philip Morris
	Total Market Share for Brands Listed	80.1%	79.9%	

Cigarette Characteristics

The Economic Research Service of the U.S. Department of Agriculture compiles information on the characteristics of cigarettes that are produced, such as length and presence of filters. As shown in Table 3 below, nearly all manufactured cigarettes have filter tips, accounting for 99.2 percent of cigarettes made in the past 2 years. About 62 percent of filter-tipped cigarettes made from 2004 to 2006 were 80 mm or 85 mm in length, and most of the remainder were 100 mm in length.

Table 3.

Filter-Tipped and Non-filter Tipped Cigarettes by Length, 2004–2006

	Percent of Total Output		
Item	**2004**	**2005**	**2006 (e)**
Filter Tip:			
80 mm and 85 mm	61.8	62.0	61.7
100 mm	36.1	35.2	35.6
120 mm	1.0	2.1	1.9
Total	98.9	99.2	99.2
Nonfilter Tip:			
70 mm	0.6	0.5	0.4
85 mm	0.5	0.3	0.3
Total	1.1	0.8	0.8

Source: Economic Research Service, USDA, April 2007

Reduced Ignition Propensity Cigarettes

By a law that became effective on June 28, 2004, the State of New York has required that all cigarettes sold in the state have a reduced propensity to burn when left unattended. Since then, eight other states have adopted a similar law (California, Illinois, Kentucky, Massachusetts, New Hampshire, Oregon, Utah, and Vermont).[4] The laws are currently effective in California and Vermont. Legislation reportedly has been passed by the state legislatures of Iowa and Maryland and will become law upon signing by the governors of those states.

The State of New York requires that cigarette manufacturers certify brands that comply with the testing requirements of the law. The list of certified brands appears in Attachment A.

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[4] Based on information provided by the Coalition for Fire-Safe Cigarettes, www.firesafecigarettes.org.

Attachment A

Cigarette brands certified to be in compliance with the New York Fire-Safe Cigarette Law

(This entire section has been redacted)

SUPPORTING DOCUMENT C: BHOOSHAN, B., "CITRIC ACID CONTENT IN CIGARETTE PAPER." MEMORANDUM TO S. MEHTA, MAY 12, 2008

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
BETHESDA, MD 20814

DATE: July 16, 2008

TO: Shivani Mehta, Project Manager, Cigarette Ignition Risk Project
Directorate for Engineering Sciences
Division of Fire and Combustion Sciences

THROUGH: Andrew Stadnik, Associate Executive Director
Directorate for Laboratory Sciences (LS)
Joel Recht, Director,
Division of Chemistry (LSC)

FROM: Bharat Bhooshan, LSC

SUBJECT: Citric Acid Content in Cigarette Paper.

BACKGROUND

Recently, states have enacted legislation that requires cigarettes sold in the state to have reduced ignition propensity (RIP). Such cigarettes, also known as RIP cigarettes, are designed to self-extinguish if not actively smoked. Engineering Sciences (ES) is interested in evaluating the citric acid content of the rolling paper of cigarettes.[1] Citric acid can be used as a treatment of cigarette paper to control burning rate.[2] This report discusses the results of a study to determine citric acid content of cigarette paper in RIP cigarettes, as well as in non-RIP cigarettes of the same brands. No attempt was made in this study by the Division of Chemistry (LSC) to determine the presence or concentration of other potential flammability modifiers, such as calcium carbonate, aluminum trihydrate, or other constituents of cigarette paper.

EXPERIMENTAL

Two sets of cigarettes labeled A & B were received by LSC staff. Each package contained 13 packs of cigarettes of various packagings.[3] Each pack was marked by a code indicating the brand. Package A contained RIP cigarettes, and Package B contained non-RIP cigarettes of the same brands. These cigarettes were collected by the Division of Combustion and Fire Science (ESFS) under "Cigarette Ignition Risk Project," and the Division of Electrical Engineering (LSE) is the custodian of these cigarettes.

For this study, five cigarettes from each pack were randomly chosen. Each cigarette was cut along the cigarette length and the tobacco discarded. The cigarette paper was folded, weighed,

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[1] Mehta, Shivani, Personal Communication, July 16, 2007.
[2] Cohn, Charles C., U.S. Patent 4,453,553, June 12, 1984.
[3] A "packaging" indicates the brand, style, and size of the cigarette, *e.g.*, Marlboro Light 100's®.

and placed in a test tube. Cigarettes with filters were cut to remove the filter. Thus, there were five test tubes for each cigarette packaging and type (RIP or non-RIP for each brand). Because there were 13 packagings of cigarettes in each type, a total of 65 test tubes were used for each set, leading to a total of 130 test tubes for the study, where half were for RIP cigarettes and half were for non-RIP cigarettes.

In order to extract citric acid, two milliliters of deionized water at room temperature was added to each test tube, and the test tubes were placed in an Ultrasonic Bath for two 15-minute intervals, separated by 30 minutes of cooling at room temperature (the ultrasonic excitation of the liquid results in heating of the samples). Temperature was not monitored during this procedure. Next, the tubes were centrifuged at 5,000 rpm for 5 minutes, and the extract from each test tube was filtered through Whatman 2V Folded Filter Paper into a vial (1.5 ml) for analysis by HPLC (High Pressure Liquid Chromatography). Thus, extracts from all of the 130 test tubes were transferred to 130 vials.

The concentration of citric acid in each extract was determined by using an HPLC instrument made by Waters Corporation, Model Alliance 2695. The method for the quantitation of citric acid in aqueous solutions was retrieved from the website of Waters Corporation. The following conditions were used:

Autosuppressor	Alltech DS-Plus Autosuppressor
Detector	Waters 432 conductivity detector
Column	Allsep,A-2,Anion 7 µ, 100mm x 4.6 mm from Alltech, Part No. 51218
Eluent	10 mM Sodium carbonate
Flow	1.0 ml/minute
EMPOWER	software for data collection & processing

Standard solutions of citric acid at 50, 100, 250, and 500 ppm were prepared in deionized water and analyzed at the same time. Standard curves were prepared from the analysis of these standard solutions, and the concentration of citric acid in unknown solutions was calculated from this standard curve.

RESULTS & DISCUSSION

The citric acid content of cigarette paper in each pack or packaging of cigarette is calculated as weight percent. The data obtained from the analysis of the RIP cigarettes are shown in Table 1, while Table 2 shows data for the non-RIP cigarettes.

The concentration (weight percent) of citric acid in cigarette paper of the RIP cigarettes varies from 0.419 percent to 0.897 percent, with an average of 0.688 percent (S.D. 0.227). For the non-RIP cigarettes, the content varies from 0.348 percent to 0.797 percent, with an average of 0.522 percent (S.D. 0.129). Table 3 shows that seven of the 13 RIP cigarette packagings have a higher concentration of citric acid compared to the non-RIP cigarette of the same packaging; six cigarette packagings (CP3, CP5, CP8, CP9, CP10, and CP11) show no difference or only slight differences in average citric acid (less than 0.1 percent). The differences in averages between type for the remaining seven packagings can be categorized into two groups - high (CP1, CP6, CP7, and CP12), where the differences in averages are greater than 0.3 percent- and low (CP2, CP4 and CP13), where the differences between the average citric acid concentrations between types are greater than 0.1 percent but less than 0.2 percent.

CONCLUSION

A method was developed to determine citric acid concentration in cigarette paper. Thirteen different packagings of cigarettes were used to evaluate any differences in citric acid content of RIP cigarettes, compared to their non-RIP counterparts. Four cigarette packagings showed differences between cigarette type average citric acid that were greater than 0.3 percent; three cigarette packagings showed some differences; but six cigarette packagings showed differences in averages between types of less than 0.1 percent. In terms of citric acid concentration in cigarette paper, no consistent conclusion can be drawn from these data with respect to differences between RIP cigarettes and non-RIP cigarettes of the same packaging.

Table 1 – Citric Acid Content in RIP Cigarettes

Cigarette	**Cigarette**	**Cigarette**	**Citric Acid (as citrate)**	**Average**	**S.D.**
Name	**Paper**	**Paper**	**Content**	(%, w/w)	
	Weight	**Length**	(%, w/w)		
	(mg)	(cm)			
CP1 4	45.8	5.8	0.768	0.817	0.035
CP1 4	44.2	5.8	0.842		
CP1 4	44.7	5.8	0.819		
CP1 4	45.6	5.8	0.797		
CP1 4	42.4	5.8	0.856		
CP2 4	46.0	5.8	0.608	0.628	0.056
CP2 4	46.2	5.8	0.626		
CP2 4	44.6	5.8	0.638		
CP2 4	44.9	5.8	0.555		
CP2 4	44.9	5.8	0.711		
CP3 1	50.9	6.3	0.611	0.590	0.040
CP3 1	52.0	6.3	0.518		
CP3 1	50.3	6.3	0.608		
CP3 1	48.7	6.3	0.612		
CP3 1	49.8	6.3	0.600		
CP4 8	42.9	5.2	0.744	0.760	0.020
CP4 8	43.3	5.2	0.750		
CP4 8	41.8	5.2	0.768		
CP4 8	40.9	5.2	0.792		
CP4 8	42.8	5.2	0.747		
CP7 6	41.0	5.5	1.198	1.210	0.022
CP7 6	40.4	5.5	1.222		
CP7 6	41.5	5.5	1.184		
CP7 6	39.6	5.5	1.240		
CP7 6	41.0	5.5	1.206		
CP5 2	37.0	5.2	0.546	0.464	0.047
CP5 2	37.6	5.2	0.445		
CP5 2	38.2	5.2	0.428		
CP5 2	36.4	5.2	0.457		
CP5 2	36.8	5.2	0.445		
CP6 5	42.2	5.5	1.002	0.957	0.044
CP6 5	39.7	5.5	0.977		
CP6 5	40.1	5.5	0.981		
CP6 5	42.2	5.5	0.927		
CP6 5	44.7	5.5	0.896		

Table 1 (continued)

Cigarette	**Cigarette**	**Cigarette**	**Citric Acid (as citrate)**	**Average**	**S.D.**
Name	**Paper**	**Paper**	**Content**		
	Weight	Length	(%, w/w)		
	(mg)	(cm)			
CP9 3	61.6	8.4	0.417	0.419	0.010
CP9 3	63.1	8.4	0.428		
CP9 3	62.2	8.4	0.407		
CP9 3	65.1	8.4	0.430		
CP9 3	65.2	8.4	0.412		
CP8 5	35.3	4.8	0.461	0.444	0.014
CP8 5	37.1	4.8	0.429		
CP8 5	36.3	4.8	0.453		
CP8 5	36.7	4.8	0.431		
CP8 5	36.9	4.8	0.444		
CP10 5	44.7	5.2	0.591	0.577	0.060
CP10 5	44.5	5.2	0.609		
CP10 5	45.5	5.2	0.617		
CP10 5	45.6	5.2	0.595		
CP10 5	44.7	5.2	0.472		
CP11 4	68.2	8.4	0.673	0.667	0.015
CP11 4	66.2	8.4	0.641		
CP11 4	68.7	8.4	0.673		
CP11 4	69.3	8.4	0.667		
CP11 4	67.6	8.4	0.680		
CP12 8	60.5	8.4	0.908	0.897	0.022
CP12 8	60.3	8.4	0.880		
CP12 8	61.3	8.4	0.871		
CP12 8	60.0	8.4	0.925		
CP12 8	61.2	8.4	0.899		
CP13 6	40.3	5.8	0.508	0.510	0.011
CP13 6	40.2	5.8	0.498		
CP13 6	40.1	5.8	0.507		
CP13 6	40.9	5.8	0.510		
CP13 6	38.5	5.8	0.529		

Average 0.688% (w/w)
S.D. 0.227

Table 2 – Citric Acid Content in non-RIP Cigarettes

Cigarette Name	Cigarette Paper Weight (mg)	Cigarette Paper Length (cm)	Citric Acid (as citrate) Content (%, w/w)	Average (%, w/w)	S.D.
CP1 9	39.2	5.8	0.50	0.479	0.015
CP1 9	40.7	5.8	0.47		
CP1 9	41.5	5.8	0.46		
CP1 9	40.1	5.8	0.49		
CP1 9	40.7	5.8	0.48		
CP2 10	40.9	5.8	0.44	0.453	0.008
CP2 10	41.8	5.8	0.45		
CP2 10	41.7	5.8	0.45		
CP2 10	41.2	5.8	0.46		
CP2 10	39.7	5.8	0.45		
CP3 12	45.3	6.3	0.58	0.591	0.008
CP3 12	44.5	6.3	0.59		
CP3 12	45.8	6.3	0.59		
CP3 12	44.2	6.3	0.61		
CP3 12	44.5	6.3	0.59		
CP4 12	37.0	5.2	0.62	0.612	0.020
CP4 12	36.0	5.2	0.62		
CP4 12	38.5	5.2	0.58		
CP4 12	35.3	5.2	0.64		
CP4 12	36.8	5.2	0.60		
CP7 15	39.3	5.5	0.80	0.797	0.006
CP7 15	41.3	5.5	0.79		
CP7 15	40.0	5.5	0.80		
CP7 15	40.0	5.5	0.80		
CP7 15	40.4	5.5	0.79		
CP5 11	35.1	5.2	0.51	0.512	0.005
CP5 11	35.6	5.2	0.51		
CP5 11	36.2	5.2	0.51		
CP5 11	34.9	5.2	0.51		
CP5 11	36.0	5.2	0.52		
CP6 15	38.2	5.5	0.46	0.449	0.014
CP6 15	39.1	5.5	0.44		
CP6 15	37.1	5.5	0.46		
CP6 15	40.1	5.5	0.43		
CP6 15	38.4	5.5	0.45		

Table 2 (continued)

Cigarette Name	Cigarette Paper Weight (mg)	Cigarette Paper Length (cm)	Citric Acid (as citrate) Content (%, w/w)	Average	S.D.
CP9 12	58.9	8.4	0.43	0.441	0.01
CP9 12	58.4	8.4	0.43		
CP9 12	58.0	8.4	0.44		
CP9 12	57.7	8.4	0.45		
CP9 12	57.8	8.4	0.45		
CP8 16	33.3	4.8	0.39	0.379	0.02
CP8 16	33.4	4.8	0.38		
CP8 16	33.3	4.8	0.39		
CP8 16	32.8	4.8	0.39		
CP8 16	35.0	4.8	0.35		
CP10 10	34.7	5.2	0.57	0.553	0.01
CP10 10	34.6	5.2	0.56		
CP10 10	35.7	5.2	0.54		
CP10 10	36.3	5.2	0.55		
CP10 10	35.8	5.2	0.55		
CP11 13	58.7	8.4	0.73	0.733	0.00
CP11 13	57.6	8.4	0.74		
CP11 13	57.8	8.4	0.73		
CP11 13	56.0	8.4	0.73		
CP11 13	57.3	8.4	0.73		
CP12 15	54.2	8.4	0.43	0.436	0.03
CP12 15	54.3	8.4	0.44		
CP12 15	55.1	8.4	0.48		
CP12 15	55.0	8.4	0.40		
CP12 15	55.9	8.4	0.43		
CP13 11	41.5	5.8	0.35	0.348	0.00
CP13 11	38.4	5.8	0.35		
CP13 11	39.4	5.8	0.35		
CP13 11	40.7	5.8	0.34		
CP13 11	39.6	5.8	0.35		

Average 0.522% (w/w)
S.D. 0.129

Table 3 – Summary of Results

	RIP cigarette	non-RIP cigarette	
Name	**Citric Acid (as citrate)** Content	**Citric Acid (as citrate)** Content	Difference
	(%, w/w)	(%, w/w)	
CP1	0.817	0.479	0.338
CP2	0.628	0.453	0.175
CP3	0.590	0.591	-0.001
CP4	0.760	0.612	0.148
CP7	1.210	0.797	0.413
CP5	0.464	0.512	-0.048
CP6	0.957	0.449	0.508
CP9	0.419	0.441	-0.022
CP8	0.444	0.379	0.065
CP10	0.577	0.553	0.024
CP11	0.667	0.733	-0.066
CP12	0.897	0.436	0.461
CP13	0.510	0.348	0.162

SUPPORTING DOCUMENT D: GREEN, M., ANDRES, C., "CIGARETTE IGNITION RISK PHASE I: ANALYSIS OF SELECTED REDUCED IGNITION PROPENSITY CIGARETTES" MEMORANDUM TO S. MEHTA, JULY 2008

Cigarette Ignition Risk
Phase I

Analysis of Selected Reduced Ignition Propensity Cigarettes

July 2008

Craig D. Andres
Michael A. Greene
Division of Hazard Analysis
Directorate for Epidemiology
U.S. Consumer Product Safety Commission
Submitted by Steve Hanway, Director, Division of Hazard Analysis

EXECUTIVE SUMMARY

This report documents methods and presents findings from Phase I of a U.S. Consumer Product Safety Commission (CPSC) staff evaluation of selected Reduced Ignition Propensity (RIP) cigarettes. The overall objective of the evaluation is to determine if commercially available RIP and non-RIP cigarettes of the same brand packaging[1] (referred to here as packaging) perform differently with respect to ignition propensity on interior furnishings, including upholstered furniture and mattresses.

In this phase of the project, documented in this report, ignition propensity is measured as the proportion of cigarettes that achieve a full-length burn on filter paper in a laboratory setting. The test of ignition propensity in this paper follows the method in ASTM E2187-04. Later phases of this project will evaluate the cigarettes on full-size mattresses.

This report also presents a series of descriptive measurements of the differences between RIP and non-RIP cigarettes. The report also contains an analysis of the differences in the length of time that RIP and non-RIP cigarettes burn.

To summarize the most important findings: the 13 tested packagings clearly indicate that there are statistically significant differences between the proportion of RIP and non-RIP cigarettes of the same packaging that burn to full length. Also, there are statistically significant differences in the average burn times of RIP and non-RIP cigarettes of the same packaging. These findings support the continuation of the project into later phases, with simulated and real interior furnishings. Those phases will be useful to gain an understanding of the difference in actual residential fire risk between RIP and non-RIP cigarettes.

While the results and conclusions from Phase I do not project to all RIP and non-RIP cigarettes available in the United States, they do characterize some of the differences among 13 popular and available packagings.

Specific findings with respect to ignition propensity showed the following:

- The proportion of full-length burns for 12 of the 13 RIP packagings varied between 1.3 percent and 10 percent. One additional RIP packaging had 20 percent full-length burns. Non-RIP packagings varied between 95 percent and 100 percent full-length burns.
- In analysis of the effects of various factors on ignition propensity, whether a cigarette was RIP was the only statistically significant factor. No other factor, such as the region where the cigarette was purchased, the type of store where it was purchased, or the particular packaging (except for the RIP cigarette with 20 percent full-length burns) accounted for the variability in ignition propensity.
- The maximum burn temperature for each RIP and non-RIP packaging was recorded using samples of up to 18 cigarettes. Five of the 13 RIP cigarette packagings had higher

[1] A brand packaging denotes the brand and specific features of a particular package of the cigarette, *e.g.*, Marlboro® is the brand, and Marlboro 100s is the packaging.

maximum burn temperatures than non-RIP cigarettes of the same packaging. The difference in burn temperatures by packaging, were not statistically significant.

- The average burn time of RIP cigarettes was 30 percent to 61 percent lower than non-RIP cigarettes of the same packaging. On average, RIP cigarettes burned 6.2 minutes less (41 percent) than non-RIP cigarettes. Other factors determining the burn times for cigarettes included the length of the tobacco column of the cigarette and the packing density of the tobacco. Of the three effects, RIP versus non-RIP design, tobacco length, and tobacco density, the RIP design accounted for the largest difference in burn times.

- The burn times for the RIP cigarettes varied more than non-RIP cigarettes of the same packaging. This may be because the burn time is affected by the placement of the bands, which were shown to vary among cigarettes of the same packaging.

Findings with respect to physical characteristics include the following:

- Tobacco length and tobacco density had little variability within cigarette packaging and design.[2]

- For RIP cigarettes, the distance to the first band varied considerably within a particular packaging, but the distance between bands and the length of bands was consistent within a packaging.

It is important to understand that the analysis in this report cannot be used to assess the reduction in fire risk associated with RIP cigarettes. If the analysis did not show differences between RIP and non-RIP cigarettes in ignition propensity and burn times in a controlled laboratory setting, then there would be no reason to expect differences between designs of cigarettes for the fire risk of interior furnishings. The research described in this report did show such differences in ignition propensity and burn times. This supports continuing to investigate the properties of RIP cigarettes with ignition testing on simulated and real interior furnishings. In the next phase of this project, CPSC staff should be able to gain a better understanding of whether RIP cigarettes have the potential to reduce the risk of residential fires involving interior furnishings with specified materials, and if so, by how much.

[2] "Design" will be used throughout the document and refers to the dichotomy of a cigarette being RIP versus non-RIP.

INTRODUCTION

Cigarettes are most frequently cited as the heat source for upholstered furniture and mattress and bedding residential fires, deaths, and injuries. Smoking materials (primarily cigarettes, but also pipes, and cigars) were the heat source for an average of 310 deaths annually in upholstered furniture fires between 2003 and 2005, 330 injuries, and 2,200 fires. During the same period, smoking materials were the heat source for an average of 170 deaths annually in mattress and bedding fires, 380 injuries, and 2,500 fires.[3] Property damage in these furniture and bedding fires exceeded an average of more than $140 million per year.[4]

To reduce these fire losses, CPSC staff is comparing Reduced Ignition Propensity (RIP) cigarettes with conventional (non-RIP) cigarettes. The evaluation will take place in several phases. Phase I, the subject of this report, has tested the RIP and non-RIP packagings of 13 commercially available cigarette packagings. Testing was conducted according to ASTM E2187-04 on filter paper substrates in controlled laboratory chambers. The primary performance measure statistically analyzed was the proportion of full-length burns for the tested design of a cigarette packaging. Also measured and characterized were the average full-length burn times. Sources of statistically significant variation between RIP and non-RIP designs were determined, and descriptive statistics of a select set of physical characteristics are provided in this report. Staff will use the findings from Phase I as part of the design of the Phase II tests on mattresses and mattress pads.

The RIP cigarette design differs from the conventional (non-RIP) design in that a RIP cigarette is wrapped with two or three bands (see Figure 1) of less porous paper.
Conventional cigarettes have more porous paper and lack the bands. Air flow to the burning tobacco column is reduced when the heat reaches the bands in the RIP cigarette. If left unattended, the RIP cigarette should self-extinguish because of the reduced airflow. While the generic design of a RIP cigarette is consistent, placement, location, and the physical characteristics of the bands in RIP cigarettes may vary by packaging and may even vary within the same packaging.5

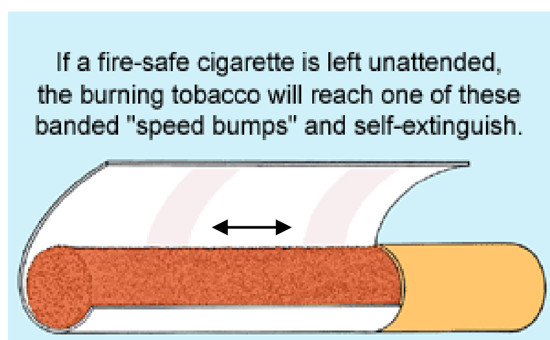

Figure 1

[3] The most recent 3-year averages from Miller (2012), "2008−2010 Residential Fire Loss Estimates" are 210 deaths, 270 injuries, and 1,400 upholstered furniture fires that had smoking materials as the heat source. Smoking materials were the heat source for 130 deaths, 320 injuries, and 1,600 mattress fires. Upholstered furniture and mattresses ignited by smoking materials accounted for combined property losses for an average of $125 million per year.

[4] Chowdhury R, Greene M and Miller D (2008), "2003–2005 Residential Fire Loss Estimates," U.S. Consumer Product Safety Commission, Washington, DC.

[5] Source: www.firesafecigarettes.org

As of September 2007, some 22 state legislatures had enacted standards regarding cigarette ignition propensity. New York was the first state with a standard (effective June 28, 2004), followed by Vermont (May 1, 2006), and California (January 1, 2007). The effective dates for the standards in the 19 remaining states with RIP legislation range from July 1, 2007 to January 1, 2010.[6] It is anticipated that the market share of RIP cigarettes will increase as the number of states with RIP standards increases.

This report documents the Phase I evaluation in three sections. The Methods section describes the collection and testing of the 13 packagings of commercially available RIP cigarettes. The Results and Findings section begins with a descriptive analysis of the different physical properties of RIP and non-RIP cigarettes. Results and a discussion of the findings regarding differences in the proportion of full-length burns, burn times, and burn temperatures appear in the third section of this report. A Conclusion section follows the Results section. The report also contains two appendices. Appendix A describes the method used for measuring burn temperature. Appendix B describes the statistical methods used for determining the statistical significance of the difference between the largest observations in two datasets.

METHODS

The section begins with a description of the sampling plan for obtaining RIP and non-RIP cigarettes. The second part of this section discusses the test methods used in the laboratory.

Sample Collection

Thirteen packagings of cigarettes, each with commercially available RIP and non-RIP designs were selected by CPSC staff in the Directorate for Engineering Sciences for Phase I testing. The packagings were selected to span a range of varieties of RIP and non-RIP cigarettes that were available in the United States, without regard to sales volume; but at least one packaging was chosen from each of the top 11 packagings sold in the United States.[7] Selected packagings differed with respect to length, width, and presence or absence of a filter. Physical properties of the different packagings are described later in this report.

Cigarettes packagings in this report are designated CP1–CP13.

Samples were collected by store type within different cities from one of two U. S. regions to control for the possible effects of different transporting, distribution, storing, and shelf life of cigarettes. Since RIP legislation was effective in New York in 2004, and in California in 2007, two major metropolitan areas were selected from each state (New York City and Buffalo; Los Angeles and San Diego) for obtaining samples of RIP designs of the 13 packagings. The conventional, non-RIP cigarettes of the same packaging were collected from four, large, metropolitan areas in the eastern and western United States (Cincinnati, Cleveland, Denver, and

[6] Legislation & Regulation: Reduced Cigarette Ignition Propensity. Available at: http://www.philipmorrisusa.com/en/legislation/reduced_ignition_propensity.asp.
[7] Market Sketch memo from ECON.

Phoenix). RIP cigarette legislation was not in force in Ohio, Colorado, and Phoenix at the time of the study.

To control for the possibility that storage and shelf life could affect test results, samples were collected from different store types as follows:

- Type A: Supermarkets or large retail stores
- Type B: Convenience stores and gas stations
- Type C: Drug stores
- Type D: Tobacco specialty stores.

CPSC field investigators were given a list of packagings to purchase and instructed to purchase one carton of each packaging of cigarettes from two store types selected from Type A, B, or C. Eight cartons were RIP cigarettes, and eight cartons were non-RIP of the same packaging. Across the 13 packagings that were evaluated in Phase I, a total of 208 cartons of cigarettes were collected for evaluation.

During the collection process, some field staff did not find the packagings in the stores specified in the sample design. Type D stores that carried a larger selection of cigarette packagings were usually substituted. In some cases, field investigators were asked to substitute Type A, B, or C for the type specified. The sample design and the modifications are shown in Table 1.

Store Type by Location and Packaging								
RIP Design					Standard (Non-RIP) Design			
Packaging	**San Diego**	**Los Angeles**	**Buffalo**	**NY City**	**Denver**	**Phoenix**	**Cleveland**	**Cincinnati**
CP1	D, D	B, C	A, C	A, B	A, B	A, A	A, A	B, B
CP2	C, C	A, B	A,C	A,B	A, B	A, C	B, C	A, B
CP3	A, D	B, C	A, B	A, C	B, C	A, D	A, B	A, B
CP4	A, D	A, B	B, C	C, D	A, D	B, C	C, D	A, B
CP5	A, B	B, C	A, C	A, D	A, C	A, B	B, C	A, B
CP6	A, C	A, C	B, C	A, D	A, C	A, B	B, C	A, B
CP7	D, D	B, C	A, B	A, C	B, D	A, C	A, B	B, C
CP8	A, D	B, C	A, B	A, C	A, B	A, B	A, C	A, B
CP9	D, D	A, A	A, B	A, D	A, C	A, D	D, D	B, C
CP10	A, D	B, A	A, C	C, D	A, C	B, D	B, D	B, B
CP11	D, C	A, A	B, B	D, D	A, A	D, D	D, D	A, A
CP12	A, D	B, C	A,C	A, C	D, D	A, C	A, C	A, B
CP13	D, C	A, B	A, B	A, C	A, D	B, C	A, D	A, B

Table 1: Store and city sample collection. Two cartons per packaging were purchased in each city, at the store type as designated above. Type A stores are supermarkets. Type B are convenience stores and gas stations. Type C are drug stores, and Type D are tobacco specialty stores. Type D represents purchases from substitute locations, different from A, B, and C store types. Note also that when the same store type is listed for a packaging and a city, the second store type is a substitution (*e.g*. Los Angeles, CP9, A, A). Substitute stores were used only when the packaging was not available in the originally designated store type. For cigarette packaging CP2, the Buffalo and New York City cigarettes were substituted with cigarettes from Los Angeles and San Diego from the same store type because that cigarette was unavailable in New York.

Tests and Test Method

Two packs of cigarettes were randomly selected from each collected carton per packaging and sent to a contractor for the ignition propensity testing. From each pack, the contractor then selected five cigarettes. Since each packaging was collected from two store types in each of four cities, a total of 80 cigarettes of each packaging design were tested.[8]

Ignition propensity of RIP and non-RIP designs was evaluated according to the procedure in ASTM E2187-04,[9] In accordance with the test method cigarettes were stored, conditioned, and tested under specified controlled conditions. The test provides a measure of the capability of an

[8] (5 cigarettes/pack)*(2 packs/carton)*(2 cartons/city)*(4 cities) = 80 cigarettes. With 13 RIP and 13 non-RIP designs, there were 13*2*80=2,080 cigarettes tested in Phase I.

[9] ASTM (2002), "Standard Test Method for Measuring the Ignition Strength of Cigarettes," ASTM International, West Conshohocken, PA.

unattended cigarette to generate sufficient heat to continue burning on 10 layers of filter paper in an environmentally controlled test chamber. If the cigarette burns the length of the tobacco column (*i.e*., from end to filter or end to end for non-filtered cigarettes), the outcome was recorded as a "full-length burn." The summary measure of the test is the proportion of full-length burns for a specific packaging and design.
The contractor was given a randomized schedule of the samples by pack to be tested to control for minor differences that might occur in the laboratory environment from day to day. Cigarettes were randomly assigned to one of four test chambers. Four cigarettes were tested at a time. The contractor used one test operator to perform all of the tests and make all of the measurements.

In addition to measuring the proportion of full-length burns, the contractor also measured how long the cigarettes burned until they extinguished. The time was recorded to the nearest minute. Also, in a separate experiment, six cigarettes of each packaging and design were burned suspended on three thermocouples. The maximum burn temperature was recorded for each packaging and cigarette design. The procedure for measuring temperature is found in Appendix A of this report.

Also, various physical measurements of the cigarettes were obtained. These included: tobacco density, tobacco column length, cross sectional area, and citric acid content. For RIP cigarettes, only measurements on band placement were made, distance to the first band, number of incomplete and complete bands in the RIP cigarette, distance between bands and band length. Permeability of the cigarette paper was also measured, but there was so much variability in the measurements within a packaging and design of cigarette that the measurements were not considered reliable and are not reported here. Most of these measurements were made by the contractor, but some were also made by the CPSC's Directorate for Laboratory Sciences.

Ignition propensity and mean burn time were modeled to determine their relationship to the physical properties and the packaging of cigarettes. Statistical modeling used the SAS® software system.[10] Physical measurements are reported first in the next section, followed by ignition propensity measurements, burn time and burn temperature, and the statistical analysis.

RESULTS AND FINDINGS

Statistical analyses are presented in two subsections in Results and Findings.

The first subsection, Physical Measurements, includes the length of the tobacco column and the density of the tobacco for all packagings in the study. Also in that subsection are measurements on RIP cigarettes, including the distance from the end of the cigarette to the first band, the number of bands, the distance between bands, and the band length.

The second subsection, Ignition Propensity, reports the analysis of ignition propensity variation, as measured by the proportion of full-length burns. Also included in this section is an analysis of the burn durations and the maximum burn temperature.

[10] SAS® is a service mark of the SAS Institute, Cary, NC.

Physical Measurements

This section includes several design characteristics of a cigarette that can influence ignition propensity.[11] All samples used for testing came from the same cartons used for the ignition propensity test. Three packs were randomly selected for each packaging and design of cigarette for measurements on tobacco length, tobacco mass, and cross-sectional area of cigarette. Other measurements were made on band distance and placement for RIP cigarettes. Note that the measurements in most cases involved destroying the cigarettes, so that the cigarettes involved were different specimens than those used in the ignition propensity testing.

Length of the Tobacco Column and Tobacco Density

The tobacco column length was shown in Table 2 to have very little variability within a particular packaging but substantial variability between packagings. The largest observed difference between RIP and non-RIP cigarettes of the same packaging was 0.9 mm for the CP9 cigarette, which is about 1 percent of the tobacco column length. The tobacco length varies greatly across packagings, ranging from 53.9 to 87.8 mm, due to packaging design differences.

[11] Research has shown that low tobacco density, reduced cigarette circumference, and low paper permeability are associated with lower ignition propensity.

Packaging	Cigarette Design	Tobacco Column Length (mm)			
		Mean	Standard Deviation	Minimum	Maximum
CP1	Non-RIP	62.0	0.4	61.5	62.5
CP1	RIP	62.0	0.0	62.0	62.0
CP2	Non-RIP	62.0	0.0	62.0	62.0
CP2	RIP	62.3	0.4	62.0	63.0
CP3	Non-RIP	66.9	0.2	66.5	67.0
CP3	RIP	66.6	0.4	66.0	67.0
CP4	Non-RIP	55.6	0.4	55.0	56.0
CP4	RIP	56.1	0.2	56.0	56.5
CP5	Non-RIP	56.0	0.0	56.0	56.0
CP5	RIP	56.0	0.0	56.0	56.0
CP6	Non-RIP	60.0	0.4	59.5	60.5
CP6	RIP	60.0	0.0	60.0	60.0
CP7	Non-RIP	58.6	0.2	58.5	59.0
CP7	RIP	58.7	0.3	58.5	59.0
CP8	Non-RIP	53.9	0.2	53.5	54.0
CP8	RIP	54.0	0.0	54.0	54.0
CP9	Non-RIP	83.0	0.0	83.0	83.0
CP9	RIP	83.9	0.2	83.5	84.0
CP10	Non-RIP	55.9	0.4	55.5	56.5
CP10	RIP	55.9	0.2	55.5	56.0
CP11	Non-RIP	82.9	0.2	82.5	83.0
CP11	RIP	83.0	0.0	83.0	83.0
CP12	Non-RIP	87.8	0.4	87.0	88.0
CP12	RIP	87.6	0.5	87.0	88.0
CP13	Non-RIP	62.0	0.0	62.0	62.0
CP13	RIP	62.1	0.2	62.0	62.5

Table 2: Tobacco Length by Packaging and Cigarette Design. All measurements based on five RIP and five non-RIP cigarettes of each packaging.

Table 3 shows measurements of tobacco density.

Packaging	Cigarette Design	Tobacco Density (g/cm^3) Mean	Standard Deviation	Minimum	Maximum
CP1	Non-RIP	0.23	0.01	0.22	0.24
CP1	RIP	0.22	0.01	0.21	0.23
CP2	Non-RIP	0.26	0.01	0.24	0.27
CP2	RIP	0.25	0.01	0.24	0.26
CP3	Non-RIP	0.23	0.01	0.22	0.25
CP3	RIP	0.24	0.01	0.23	0.25
CP4	Non-RIP	0.23	0.02	0.21	0.26
CP4	RIP	0.24	0.01	0.22	0.26
CP5	Non-RIP	0.24	0.01	0.23	0.25
CP5	RIP	0.25	0.01	0.24	0.25
CP6	Non-RIP	0.24	0.00	0.23	0.24
CP6	RIP	0.24	0.01	0.23	0.25
CP7	Non-RIP	0.24	0.01	0.23	0.25
CP7	RIP	0.23	0.01	0.22	0.24
CP8	Non-RIP	0.24	0.00	0.23	0.25
CP8	RIP	0.25	0.02	0.23	0.26
CP9	Non-RIP	0.25	0.00	0.24	0.25
CP9	RIP	0.24	0.00	0.23	0.24
CP10	Non-RIP	0.24	0.00	0.24	0.25
CP10	RIP	0.24	0.01	0.24	0.25
CP11	Non-RIP	0.21	0.01	0.19	0.22
CP11	RIP	0.21	0.01	0.20	0.22
CP12	Non-RIP	0.24	0.00	0.23	0.24
CP12	RIP	0.24	0.00	0.24	0.25
CP13	Non-RIP	0.23	0.01	0.22	0.24
CP13	RIP	0.24	0.01	0.22	0.25

Table 3: Tobacco Density by Packaging and Cigarette Design. All measurements based on five RIP and five non-RIP cigarettes of each packaging.

The "tobacco density" is defined as the mass divided by the volume (*i.e.*, $\rho = m/(\pi r^2 l)$ in g/cm^3). It was calculated from several measurements taken from each cigarette, which includes the length (in centimeters) of the tobacco section, the radius (which is one-half the measured diameter in centimeters) of the tobacco section, and the mass (in grams) of the tobacco contained. The standard deviation for each packaging and cigarette design of the calculated density is low (less than five percent of the density estimate). The tobacco density of the RIP cigarettes is about the same as the non-RIP cigarettes for each packaging. Across packagings, the average density of RIP cigarettes ranged from 0.21 to 0.25 g/cm^3, while the range for the standard (non-RIP) design was 0.21 to 0.26 g/cm^3. As this range and the estimated standard deviations suggest, very little variation in density was observed at this unit of measure between designs of the same packaging or across the 13 evaluated packagings.

Band Measurements

A banded region on a RIP cigarette may be complete or incomplete, where an incomplete band is less than full length because it is at the beginning or the end of the tobacco column. According to New York state legislation, RIP cigarettes that use a low permeability band design must have banded regions as follows:

- There must be at least two nominally identical bands on the paper surrounding the tobacco column.

- At least one complete band shall be located at least 15 mm from the lighting end of the cigarette and at least 10 mm from either the filter end or the end of the tobacco column for a non-filter cigarette. The standard allows for more bands, complete or incomplete, located closer to the lighting end.

The tables below are for RIP cigarettes. Table 4 shows statistics on the location of the first complete band relative to the lighting end of the cigarette. For most cigarette packagings, the standard deviation of the band distance is almost the same as the average distance. This shows that placement of the first complete band varies greatly within each packaging for all 13 packagings.

	Position of First Complete Band on an RIP Cigarette (mm)			
Packaging	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
CP1*	12.8	10.5	2.0	25.0
CP2	15.4	9.2	1.0	25.0
CP3	17.5	7.8	1.0	25.0
CP4	12.9	4.8	6.0	21.0
CP5*	12.5	9.3	0.0	22.0
CP6*	13.0	11.1	0.0	24.0
CP7	11.6	9.7	1.0	25.0
CP8*	8.1	6.4	1.0	18.0
CP9	13.9	9.5	1.0	28.0
CP10	10.9	6.6	0.5	20.0
CP11	18.8	7.8	2.5	27.0
CP12*	19.4	8.6	5.0	27.0
CP13	10.8	8.1	2.0	23.5

Table 4: First Position Distance by Packaging. Measurements with an asterisk(*) were done by the Directorate for Laboratory Sciences, with five samples per packaging. Other measurements were done by the contractor using 10 samples per packaging.

Tables 5 and 6 further show that the number of bands varies within packaging of cigarette. Table 5 describes the number of bands on the tobacco section of the cigarette and includes both complete and incomplete bands. For most packagings, there are between two and three, although several have more incomplete bands.

Table 6 describes the number of complete bands on the tobacco section of the cigarette within the burn area of the cigarette. (The burn area begins 5mm from the lighting end of the cigarette and ends where the tobacco section ends, and includes a pre-burn region on the tobacco section from 5mm to 15mm relative to the lighting end of the cigarette). In most cases, the average number of complete bands is between one-half and one band fewer than the total number of bands, and the minimum and maximum are almost always one fewer than the total number of bands.

	Number of Complete and Incomplete Bands per Cigarette			
Packaging	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
CP1*	2.2	0.45	2	3
CP2	2.6	0.52	2	3
CP3	2.5	0.53	2	3
CP4	2.2	0.42	2	3
CP5*	2.0	0.00	2	2
CP6*	2.2	0.45	2	3
CP7	2.6	0.52	2	3
CP8*	2.0	0.00	2	2
CP9	3.0	0.00	3	3
CP10	2.3	0.48	2	3
CP11	3.4	0.52	3	4
CP12*	3.2	0.45	3	4
CP13	2.3	0.48	2	3

Table 5: Number of Bands by Packaging. Measurements with an asterisk (*) were done by the Directorate for Laboratory Sciences, with five samples per packaging. Other measurements were done by the contractor using 10 samples per packaging.

Packaging	Number of Complete Bands per Cigarette			
	Mean	**Standard Deviation**	**Minimum**	**Maximum**
CP1*	1.6	0.55	1	2
CP2	1.7	0.48	1	2
CP3	2.0	0.00	2	2
CP4	1.8	0.42	1	2
CP5*	1.6	0.55	1	2
CP6*	1.2	0.45	1	2
CP7	1.6	0.52	1	2
CP8*	1.6	0.55	1	2
CP9	2.2	0.42	2	3
CP10	1.8	0.42	1	2
CP11	2.4	0.52	2	3
CP12*	2.6	0.55	2	3
CP13	1.5	0.53	1	2

Table 6: Number of Complete Bands by Packaging. Measurements with an asterisk (*) were done by the Directorate for Laboratory Sciences, with five samples per packaging. Other measurements were done by the contractor using 10 samples per packaging. Complete bands were at least 5 mm from the tip of the cigarette.

The distance between bands in Table 7 is fairly consistent within most packagings and is typically about 20 mm for the majority of packagings. Note that the CP9 packaging, the RIP packaging that had the highest full-length burn rate (shown in the next section), has a notably larger average distance between bands of 24 mm. The lengths of the bands are typically around 6 mm, as shown in Table 8, and these lengths do not vary much within any of the packagings.

Packaging	Number of Regions	Distance between Bands (mm)			
		Mean	Standard Deviation	Minimum	Maximum
CP1*	6	20.8	1.2	19.0	22.0
CP2	16	20.5	0.5	19.5	25.0
CP3	15	20.7	0.6	20.0	22.0
CP4	12	20.3	0.6	19.5	21.5
CP5*	5	19.2	1.9	16.0	21.0
CP6*	6	21.9	4.1	18.0	27.0
CP7	16	18.9	0.8	17.0	20.0
CP8*	5	21.9	3.2	19.0	27.0
CP9	20	24.0	0.6	23.0	25.0
CP10	13	17.7	0.3	17.0	18.0
CP11	25	20.4	0.5	19.5	21.5
CP12*	11	21.3	0.9	19.0	22.0
CP13	13	20.5	0.6	20.0	22.0

Table 7: **Descriptive Statistics of Distances between Bands by Packaging. Measurements are distances from the end point of one band to the beginning point of the next band. Measurements with an asterisk (*) were done by the Directorate for Laboratory Sciences, with five samples per packaging. Other measurements were done by the contractor using 10 samples per packaging.**

Packaging	Number of Regions	Band Length (mm)			
		Mean	Standard Deviation	Minimum	Maximum
CP1*	9	6.0	0.0	6.0	6.0
CP2	18	5.6	0.4	5.0	6.0
CP3	21	5.5	0.4	5.0	6.0
CP4	20	5.9	0.5	5.0	7.5
CP5*	8	5.8	0.5	5.0	6.0
CP6*	8	5.9	0.4	5.0	6.0
CP7	17	5.9	0.8	5.0	8.0
CP8*	9	5.9	0.3	5.0	6.0
CP9	25	6.0	0.4	5.0	7.0
CP10	20	6.2	0.4	5.5	7.0
CP11	25	6.6	0.4	6.0	7.0
CP12*	13	5.9	0.3	5.0	6.0
CP13	20	5.7	0.4	5.0	6.0

Table 8: Descriptive Statistics for Band Length Measurements by Packaging. Measurements with an asterisk (*) were done by the Directorate for Laboratory Sciences, with five samples per packaging. Other measurements were done by the contractor using 10 samples per packaging.

Citric Acid Content

The citric acid concentration of the cigarette paper was measured in the Directorate for Laboratory Sciences. Using measurements in percent by weight, RIP cigarettes averaged 0.688 percent (SD 0.227%), while non-RIP cigarettes averaged 0.522 percent (SD 0.129%). Seven packagings had an average difference between RIP and non-RIP cigarettes that exceeded 0.1 percent, while for the other six packagings, the difference was between -0.066 percent and 0.065 percent.

Additional details about the citric acid content of the cigarettes are in the memo provided by the Division of Chemistry, Directorate for Laboratory Sciences.[12] An analysis relating the citric acid content to the average burn time is found later in this report (see Figure 8).

Ignition Propensity

Percent of Full-Length Burns

Figure 2 illustrates the dramatic difference in the proportion of full-length burns between non-RIP and RIP cigarettes for all 13 selected packagings. The figure shows that almost all non-RIP cigarettes had full-length burns, while relatively few RIP cigarettes had full-length burns.

[12] Memo from Bharat Bhooshan to Shivani Mehta, “Citric Acid Content in Cigarette Paper,” May 12, 2008.

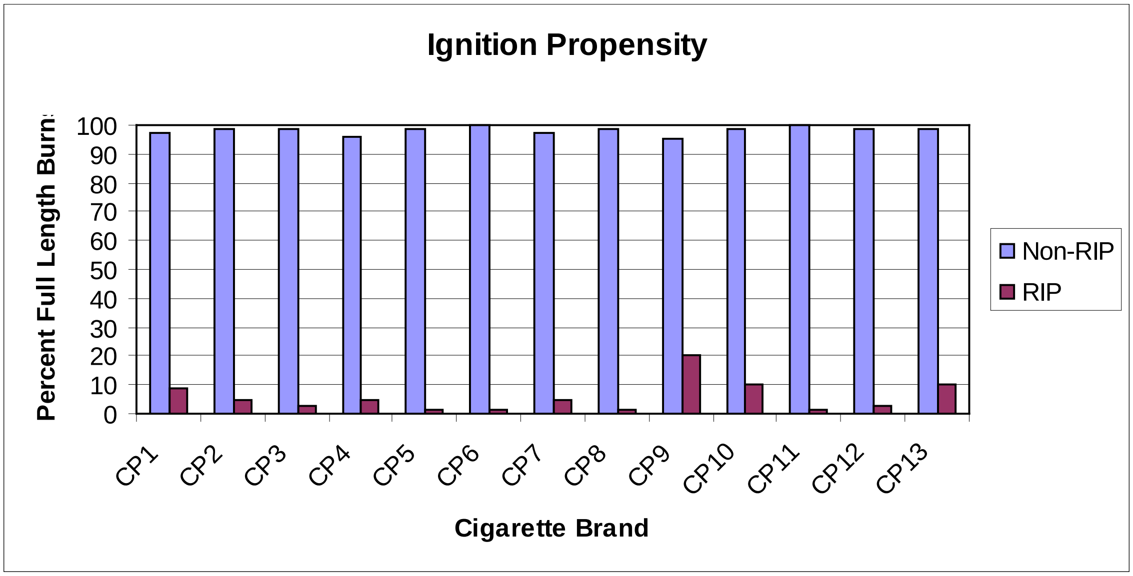

Figure 2: Observed Full-Length Burn proportions (n=80) for 13 cigarette packagings tested under ASTM E2187-04.

Table 9 shows additional detail on the proportion of full-length burns by cigarette packaging, the difference in proportions, and the 95 percent lower confidence limit on the difference.[13]

Packaging	Non-RIP Full Length Burns (n=80)		RIP Full Length Burns (n=80)		Difference in Proportions (%)	95% Lower Bound of Difference (%)
	Count	**Proportion (%)**	**Count**	**Proportion (%)**		
CP1	78	97.5	7	8.8	88.8	76.3
CP2	79	98.8	4	5.0	93.8	83.1
CP3	79	98.8	2	2.5	96.3	86.8
CP4	77	96.3	4	5.0	91.3	79.6
CP5	79	98.8	1	1.3	97.5	88.7
CP6	80	100.0	1	1.3	98.8	90.8
CP7	78	97.5	4	5.0	92.5	81.3
CP8	79	98.8	1	1.3	97.5	88.7
CP9	76	95.0	16	20.0	75.0	59.4
CP10	79	98.8	8	10.0	88.8	76.4
CP11	80	100.0	1	1.3	98.8	90.8
CP12	79	98.8	2	2.5	96.3	86.8
CP13	79	98.8	8	10.0	88.8	76.4

Table 9: Summary of Full-Length Burn test results for 13 cigarette packagings tested. Confidence limits are corrected for multiplicity.

Among non-RIP cigarettes, the percent of full-length burns varied between 95 percent and 100 percent, with the CP9 cigarette lowest at 95 percent and the CP6 and CP11 cigarettes at 100 percent. Full-length burn percentages varied between 1.3 percent and 20 percent with the CP5,

[13] Difference in proportions and confidence intervals computed using the method in Agresti A, Caffo B (2000), "Simple and Effective Confidence Intervals for Proportions and Differences of Proportions Result from Adding Two Successes and Two Failures," *The American Statistician*, 54, 4, pages 280–288.

CP6, CP8, and CP11 cigarettes, all 1.3 percent, and the CP9 cigarette at the higher end with 20 percent. The difference in proportions varied between RIP and non-RIP of the same packaging between 75 percent (CP9) to 98.8 percent (CP6 and CP11). The lowest 95 percent lower bound on the difference was 59.4 percent (CP9), indicating that in all packagings tested, the RIP packagings had significantly fewer cigarettes with full-length burns.

Further exploration of these data was undertaken to determine if other variables, such as store type, region, or test chamber had an effect on ignition propensity. Mixed model logistic regression was used to estimate the effects of these variables, along with design and packaging.[14] The use of this model necessitated changing the ignition probability for the two cigarette packagings with 100 percent full-length burns (see footnote 13). The analysis of variance table is shown below.

Effect Parameter	Numerator Degrees of Freedom	F Value	Pr > F
Design	1	502.54	<.0001
Packaging	12	0.50	0.9160
Packaging*Design	12	2.08	0.0156
Store-type	3	3.34	0.0185
Region	1	0.75	0.3855
Chamber	3	0.78	0.5064

Table 10: Analysis of Variance Table for Percent of Full-Length Burns. Output from PROC GLIMMAX in SAS. Model uses all 13 packagings. Denominator degrees of freedom is 2047 for all effect parameters. The *F Value* or F statistic is a measure of the statistical significance of the associated Effect. Pr > F is the probability that a larger *F* statistic would have been attained if the null hypothesis of no effect was true. This is usually referred to as the *p*-value. *P* -values less than 0.05 are usually taken as indicators of statistical significance.

The results show statistically significant effects for Design (RIP or non-RIP; p-*value* < 0.0001), the Packaging-Design interaction (p = 0.0156*)* and Store-type (p=0.0185). Of these, Design was expected to be significant, reflecting the differences in the percent of full-length burns between

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[14] PROC GLIMMIX in the SAS® statistical system was used. SAS Institute Inc. (2006) SAS/STAT®, Proc GLIMMIX User's Guide. Cary, NC: SAS Institute Inc. The model uses the log odds (log ($p/(1-p)$), where p is the proportion of ignitions) as the response variable. The odds are infinite when $p = 1$, which occurred with the CP6 and CP11 non-RIP packagings. The data must be modified in order to estimate the model. This was done by changing one full-length burn to a non-full length burn for one outcome in each CP6 and CP11 non-RIP packagings, essentially changing p, the proportion of full-length burns, from 1 to 0.988. The observations chosen for replacement were those with the longest burn times. This is conservative in the sense that if burn times and the proportion of full-length burns are correlated, then these observations are least likely to have the same characteristics as observations where full-lengths burns did not occur. Also the model was modified to treat the chamber as a fixed effect rather than a random effect. There was not enough variance in the data to estimate the separate chamber variance.

RIP and non-RIP cigarettes, as shown in Figure 2. That packaging was not significant, indicated that no particular packaging stood out as especially more likely or less likely to have a larger percent of full-length burns in *both* RIP and non-RIP cigarettes. The Packaging-Design interaction indicated that some packagings had a larger or smaller difference between RIP and non-RIP cigarettes than could be explained by either Packaging Effect or Design Effect by itself. Store-type was also significant.

Further exploration focused on the CP9 cigarette, the cigarette with the smallest difference between RIP and non-RIP percent of full-length burns. The data showed that a larger proportion of the CP9 cigarettes came from the D-type stores than the other cigarette packagings.[15] To determine the effect of the CP9 cigarette, it was removed from the data, and the data were analyzed again. The revised analysis of variance in Table 11 below shows that the Packaging-Design interaction and the Store Effect were no longer statistically significant and that only the Design variable remained statistically significant. Therefore, it seemed likely that the Store-type effect seen above was related to the disproportionate number of CP9 cigarettes from the D-type stores.

Effect Parameter	**Numerator Degrees of Freedom**	**F Value**	**Pr > F**
Design	1	463.93	<.0001
Packaging	11	0.50	0.9025
Packaging*Design	11	0.91	0.5301
Store-type	3	1.38	0.2465
Region	1	1.21	0.2708
Chamber	3	0.12	0.9483

Table 11: Analysis of Variance Table for Percent of Full-Length Burns. Model uses all 12 packagings, omitting CP9. The denominator degrees of freedom is 1889 for all effect parameters. See notes under Table 10 for description of the table headings.

To summarize the analysis, it should be pointed out that the statistical models indicate that there was no statistically significant store, region, or chamber effect on the percent of full-length burns. Moreover, except for the CP9 cigarette, there was no packaging-design interaction. Table 11 shows that RIP cigarettes have statistically significantly lower percentages of full-length burns than non-RIP cigarettes.

Other models were considered for the percent of full-length burns, including some models with physical properties, such as tobacco density, tobacco column length, and citric acid content; physical properties described earlier in this section. Because the physical properties were measured with different cigarettes than those used in the ignition propensity experiment, there was one measurement for each packaging and design of cigarette. This meant that the design

[15] For the CP9 cigarettes, 62.5 percent came from the A, B, and C store types, while 37.5 percent came from the D-type stores. For the other cigarettes, 82.3 percent of the RIP cigarettes came from the A, B, C store types, and 85.4 percent of the non-RIP cigarettes came from the A, B, C type stores.

and packaging variables could not be used in models with physical properties. None of the models with the physical properties (in place of the design and packaging variables) was an improvement over the model in Table 11.

Burn Temperature

To compare the burn temperatures of RIP cigarettes to non-RIP cigarettes, six cigarettes of each packaging and design were burned, suspended on three thin thermocouple sensors. One temperature measurement was made at each of three positions of the cigarette, giving a total of 18 measurements for each cigarette packaging and design.[16] The actual test procedure and apparatus are shown in Appendix A.

The values shown in Table 12 are the maximum burn temperatures of the 18 possible readings for non-RIP cigarettes and of up to 18 readings for RIP cigarettes. Some of the RIP cigarettes self-extinguished before reaching the second or third sensor, so that the measurement could not be made. As a result, there were 18 measurements for the non-RIP cigarettes and between 9 and 18 measurements for the RIP cigarettes. The number of temperature measurements is shown in the notes for Table 12.

	Maximum Burn Temperature (°F)			
Packaging	**Non-RIP**	**RIP**	**Difference between Maximum Temperatures**	**P-value**
CP1	1322	1339	-17	0.5502
CP2	1277	1261	16	0.4980
CP3	1279	1280	-1	0.5558
CP4	1340	1315	25	0.3961
CP5	1248	1186	62	0.0141
CP6	1257	1274	-17	0.3497
CP7	1245	1296	-51	0.2285
CP8	1278	1230	48	0.0986
CP9	1280	1334	-54	0.3915
CP10	1322	1247	75	0.0293
CP11	1270	1265	5	0.5122
CP12	1300	1269	31	0.3318
CP13	1236	1219	17	0.2175

[16] In the ignition propensity test, in contrast to the burn temperature test, cigarettes were burned on a standard substrate that provided a heat sink. With no adjacent heat sink, other than the thin sensors in the burn temperature test, the cigarettes in the burn temperature test were more likely to burn to full length than in the ignition propensity test.

Table 12: Maximum Burn Temperature by Packaging and Design. Number of observations for RIP cigarettes as follows: CP1 11, CP2 16, CP3 15, CP4 14, CP5 10, CP6 11, CP7 17, CP8 9, CP9 18, CP10 16, CP11 14, CP12 9, and CP13 11. Six cigarettes used per packaging and design with up to three measurements per cigarette. See text for details. The *P-value* is for the hypothesis test of equality of the difference using two tails. Test based on 10,000 bootstrap replications, as described in Appendix B. P-values are not corrected for multiplicity. Using the Bonferroni correction for multiplicity with 13 independent hypothesis tests, the *p-value* corresponding to a single test with α = 0.05 is (0.05/13=) 0.0038.

Table 12 shows that for five of the 13 packagings tested, the RIP cigarette had a higher maximum burn temperature than the non-RIP cigarettes, while for the other eight packagings the non-RIP cigarettes had the higher maximum burn temperature. After correcting the *p-values* for multiplicity, none of the differences in maximum burn temperature was statistically significant.

Burn Time

In addition to determining if cigarettes burned to full length, as described earlier in this report, how long a cigarette burns may be associated with fire risk. Measurements of burn time were made by noting the time of ignition and subsequent extinguishment, and then calculating burn time as the difference. Burn time was reported to the nearest minute.[17] These measurements were with the same cigarettes used in the ignition propensity study.

Descriptive statistics for burn times are reported in Table 13 below.

[17] Rounding the burn times to the nearest minute when reporting the data will make individual observations accurate only to plus or minus one-half minute. Averages should be more accurate to plus or minus one-half minute, divided by the square root of the number of measurements. For example, an average calculated from a sample of 80 should be accurate to plus or minus about 3 seconds.

Packaging	Non-RIP Mean Burn Time	Non-RIP Standard Deviation	Non-RIP CV	RIP Mean Burn Time	RIP Standard Deviation	RIP CV	Percent Decrease in Mean Burn Time
CP1	13.1	2.1	16.0	8.2	3.8	46.3	37.3
CP2	15.6	1.7	10.9	8.5	3.1	36.5	45.6
CP3	15.4	2.1	13.6	9.1	4.3	47.3	41.2
CP4	12.8	1.7	13.3	7.8	2.8	35.9	39.3
CP5	13.3	2.0	15.0	8.0	2.5	31.3	39.9
CP6	13.3	1.1	8.3	7.7	2.7	35.1	42.1
CP7	13.2	1.3	9.8	9.2	4.5	48.9	30.1
CP8	11.9	1.4	11.8	8.1	3.1	38.3	32.5
CP9	17.9	2.8	15.6	12.1	5.0	41.3	32.5
CP10	13.3	1.2	9.0	8.6	2.9	33.7	35.3
CP11	15.4	1.6	10.4	7.1	3.0	42.3	53.6
CP12	20.4	2.9	14.2	8.0	3.7	46.3	60.7
CP13	15.0	1.5	10.0	8.7	3.5	40.2	42.4
Average	**14.7**	**1.8**	**12.2**	**8.5**	**3.4**	**40.2**	**41.0**

Table 13: Burn Times for RIP and Non-RIP cigarettes. There were 80 Non-RIP and 80 RIP cigarettes tested for each packaging. The last row, labeled "Average," shows the average of the means, the standard deviations, and the coefficients of variation (CVs). The units are as follows: means and standard deviations in minutes; coefficients of variation (CV); and percent decrease in mean burn time in percentages.

In the experiment, observations on burn time were limited to 30 minutes. During the experiment, all cigarettes tested, except one of the 80 RIP CP7s, had stopped burning at or before 30 minutes. If the CP7 RIP cigarette had been allowed to burn until completion, there would have been a small increase in mean burn time and probably a small increase in the standard deviation for the CP7 RIP cigarette.

Table 13 shows that, on average, RIP cigarettes burn a shorter time than non-RIP cigarettes of the same packaging. The difference in average burn time collectively between RIP and non-RIP cigarettes was (14.7-8.5 =) 6.2 minutes. For each packaging, all mean burn times for RIP cigarettes are statistically significantly different from the mean burn times for the non-RIP cigarettes.[18]

Differences in the standard deviations as shown in Table 13 indicate that there was more variability in burn times between the packagings of the RIP design cigarettes than the non-RIP cigarettes. All variances of burn times (squares of standard deviations) for RIP cigarettes were

[18] Hypothesis tests calculated using PROC TTEST in SAS® Statistical System. SAS Institute Inc. (2004) SAS/STAT® 9.1 User's Guide, Cary, NC: SAS Institute Inc. Satterthwaite Method used for unequal variances. Bonferroni correction used for multiplicity (*i.e.*, 13 hypothesis tests), α=0.05, z=2.90 (two tails).

statistically significantly different from the variances in burn times for the non-RIP cigarettes, except for CP5 and CP12 packagings.[19]

To gain insight into what factors were associated with the differences in average burn times, it is useful to consider the physical properties of the cigarettes, such as tobacco length, mass (weight), density, cross-sectional area, and distance between bands, and permeability. Because it was necessary to destroy the cigarettes to obtain these measurements, the physical property measurements do not describe the same cigarettes that were tested for ignition propensity and burn times, but instead describe other cigarettes of the same design and packaging. This is of little consequence for measurements that did not vary much among cigarettes within a packaging, for example, tobacco length, mass (weight), density, and cross-sectional area. Distance from the end of the cigarette to the first band, on the other hand, was observed to vary considerably among samples of cigarettes of the same design and packaging. Band distance, therefore, because of this within-cigarette packaging variability, is not used in modeling burn time.

Graphs of tobacco length, tobacco density, store, region, and chamber with burn time are shown below to explore the relationship between these variables and burn times. Regression lines are shown on scatterplots.

[19] PROC TTEST in the SAS® system was used for the test for equality of variances. Bonferroni corrections made for multiplicity with 79 numerator and denominator degrees of freedom, $\alpha=0.05$, $F = 1.84$.

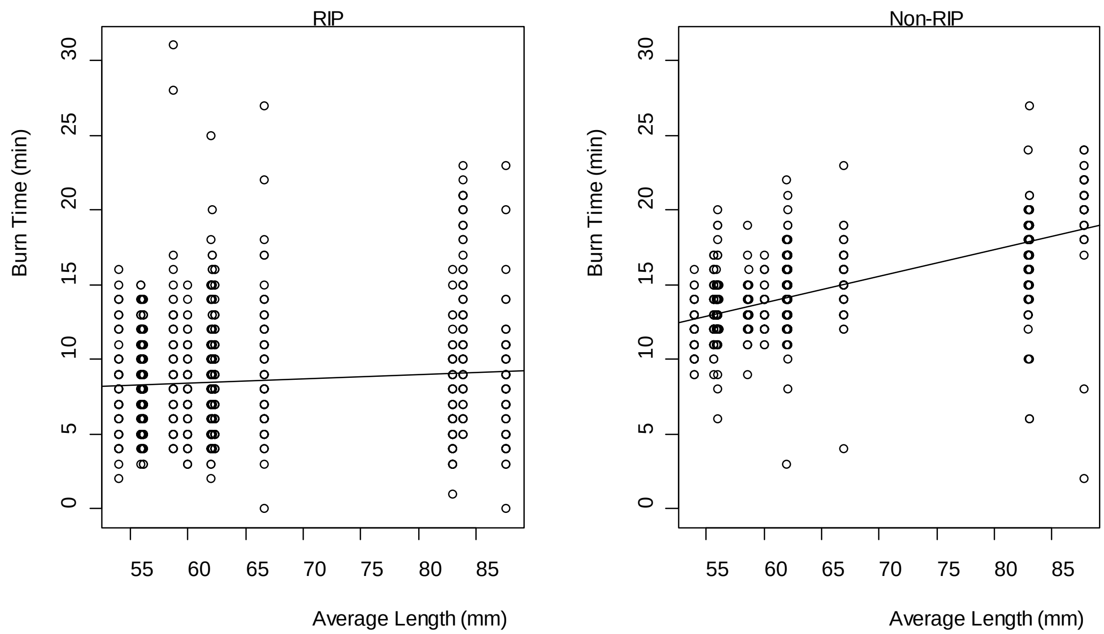


Figure 3: Average Cigarette Length vs. Burn Time for RIP and non-RIP cigarettes. To aid in visualizing the points, the values for length are jittered (slightly displaced by a random amount) in the horizontal direction. Based on n=2080 cigarettes (80 cigarettes per packaging and cigarette design). Regression statistics, RIP (slope =0.0287, p=0.0478), non-RIP (slope 0.1785, p<0.0001). Plots and regression were produced using R version 2.6.0 software. R is a product of the R Foundation for Statistical Computing.

Figure 3 shows the relationship between average tobacco length and burn time. The reason for the vertical clustering is that average length is used (*i.e.*, one measurement per cigarette packaging and design), but there are 80 measurements for burn time. Many of the points are on top of each other and not well shown in the graph. For example, there are nine distinct vertical clusters of points in each plot. Two clusters (at about 56 mm and 62 mm) in the left plot for the RIP cigarettes show a dark pattern that indicates overplotting of points, suggesting that two or more different cigarette packagings are plotted there. This would account for 11 of the 13 cigarette packagings. Overplotting can also be seen in the non-RIP plots.

Figure 3 illustrates the extent of the variability in burn time, which is not unexpected, considering the coefficients of variation (CVs) shown in Table 13. The regression line shows a positive relationship between cigarette length and burn time; cigarette packagings that have longer lengths tend to burn for a longer time than shorter cigarette packagings. Note that the slope is flatter for the RIP cigarettes, indicating that with the increasing length, the cigarettes' burn time does not increase as much as for the non-RIP cigarettes.

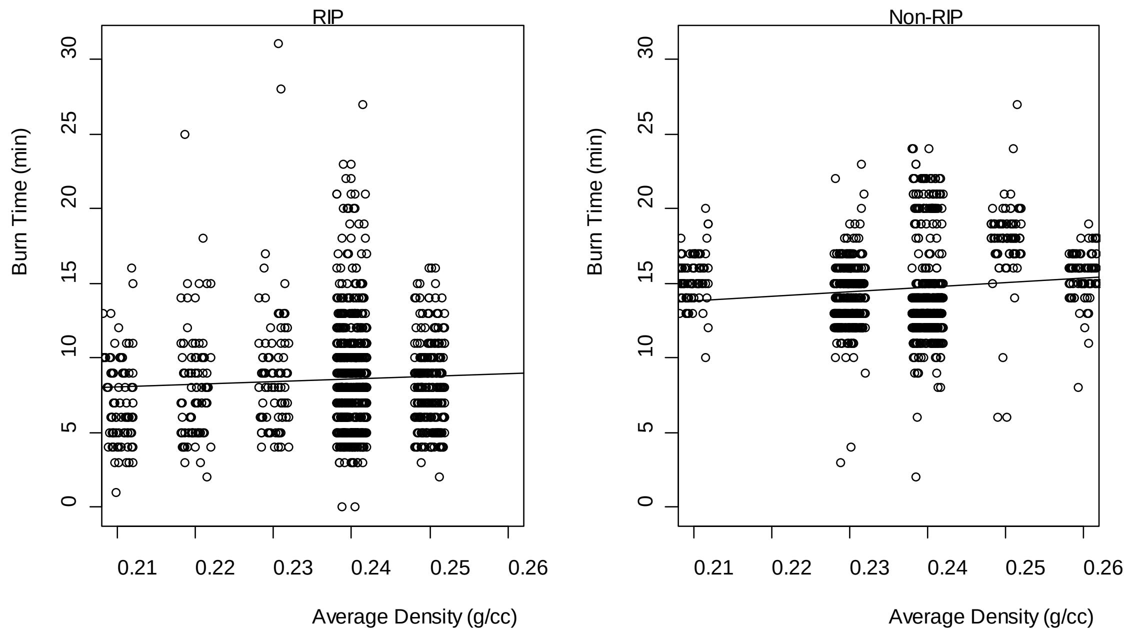


Figure 4: Average Tobacco Density vs. Burn Time for RIP and non-RIP cigarettes. Average Density is in grams per cubic centimeter. To aid in visualizing the points, the values for density are jittered (slightly displaced by a random amount) in the horizontal direction. Plots and regression were produced using R version 2.6.0 software. R is a product of the R Foundation for Statistical Computing.

Figure 4 shows the relationship between average tobacco density and burn time. The regression lines suggest that more densely packed cigarette packagings tend to burn longer than less densely packed packagings.

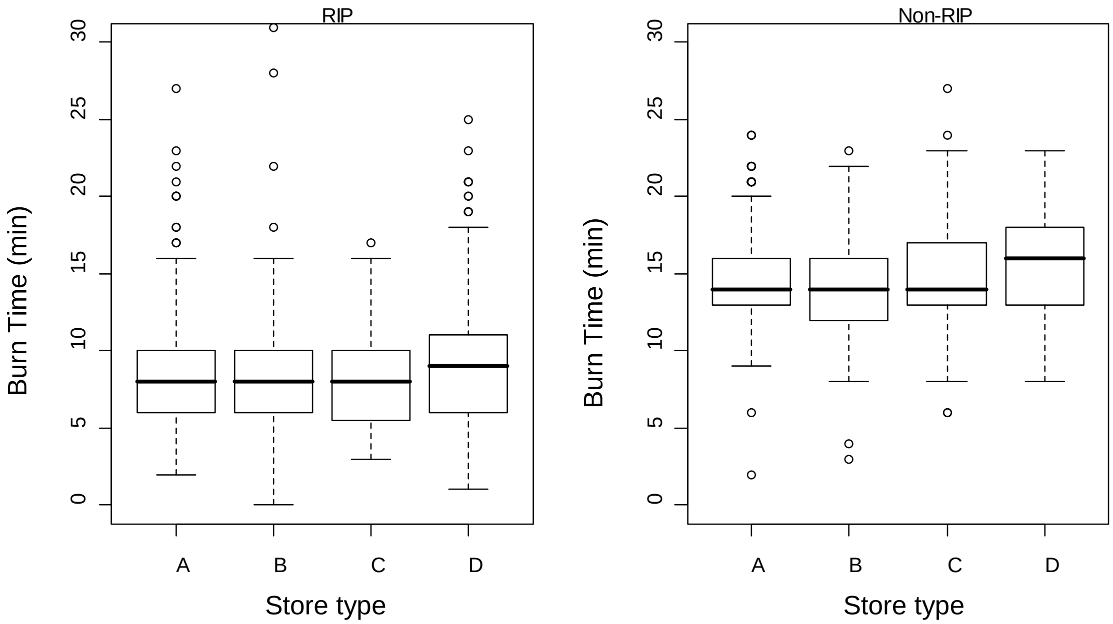


Figure 5: Store type vs. Burn Time for RIP and non-RIP cigarettes. Store type A are supermarkets; type B are convenience stores and gas stations; type C are drug stores; and D are other types of stores.

Figure 5 shows the relationship between store type and burn time for RIP and non-RIP cigarettes.[20] For each store type, the median burn time is higher for non-RIP cigarettes than RIP cigarettes. For the A, B, and C stores, the RIP cigarettes have a median burn time of 8 minutes, while the Non-RIP had a median burn time of 14 minutes. In the D stores, the median burn time for the RIP cigarette was 9 minutes and the non-RIP was 16 minutes. Recall from previous sections that the D-type stores had a larger proportion of the CP9 cigarette, which was shown to have the highest ignition propensity.

[20] To read the box plots, note that the center line of each box is the median burn time (50th percentile), the bottom of each box is the 25th percentile, and the top is the 75th percentile. The vertical lines or whiskers extend out from each box a distance of 1.5 interquartile ranges. An interquartile range is the difference between the values of the 75th percentile and the 25th percentile. For normally distributed data, the interquartile range is about 40 percent larger than the standard deviation. With normally distributed data, the whiskers typically enclose about 99 percent of the data. Points outside the whiskers are considered outliers.

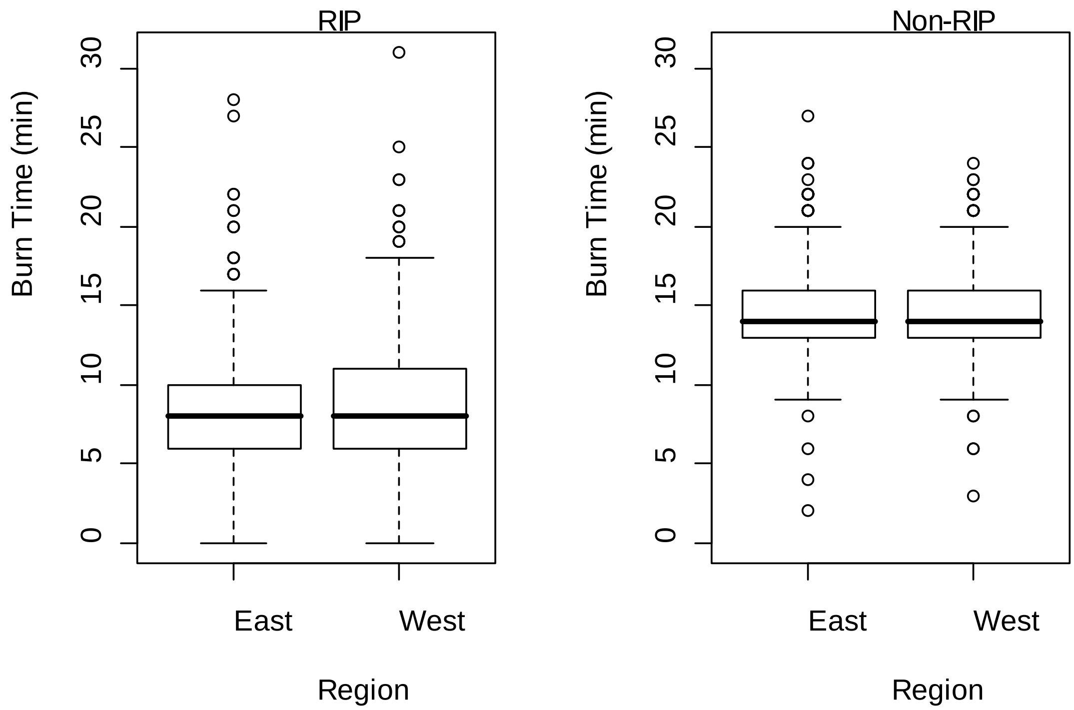


Figure 6: Region vs. Burn Time for RIP and non-RIP cigarettes.

Figure 6 shows almost no difference in burn time between geographical regions of the United States. Similar to the trend in other plots, the non-RIP cigarettes tend to burn longer than the RIP cigarettes.

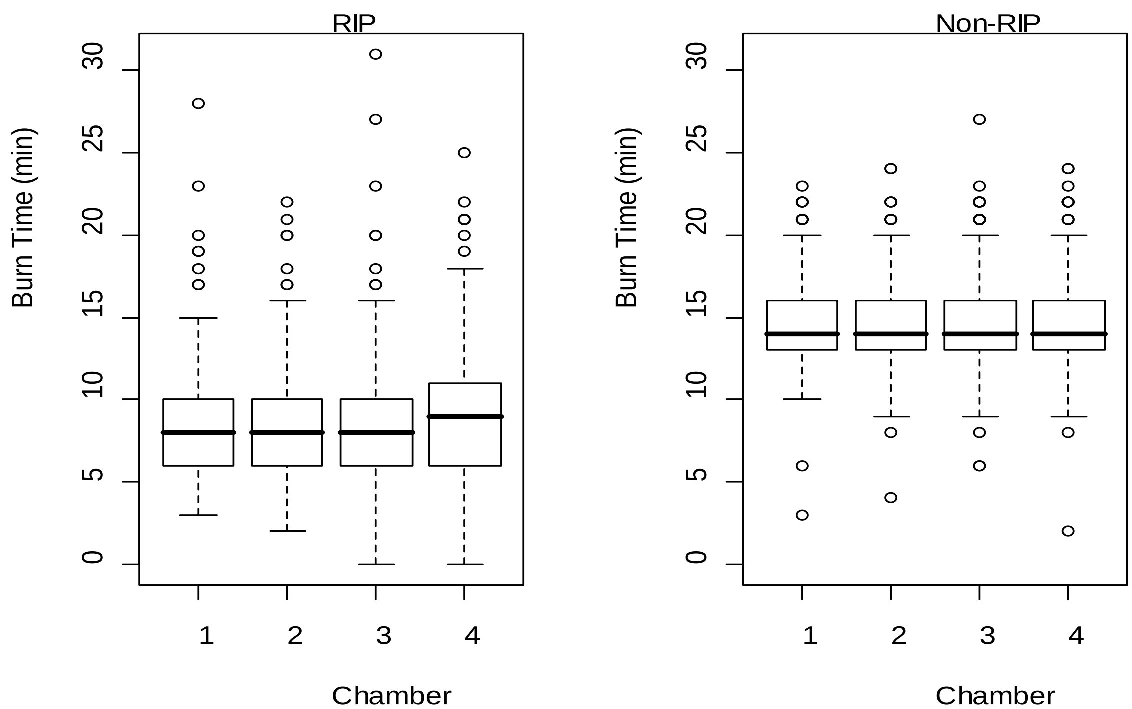


Figure 7: Chamber vs. Burn Time for RIP and non-RIP cigarettes.

Figure 7 shows almost no difference in burn times by chamber. This is a useful finding because chamber should not affect the burn time.

To identify the contribution of all of these factors simultaneously, a regression model was estimated, using PROC LIFEREG in SAS®, a procedure specifically designed for censored data.[21] The reason for employing the correction for censoring was the single observation on the burn time for the CP7 RIP cigarette that was recorded as 31 minutes, although the cigarette was still burning at the time. Also, in keeping with the previous section on the percent of full-length burns, data from packaging CP9 was excluded from the analysis.

The statistical model estimated was as follows:

$$\text{Burn Time} = b_0 + b_1\text{Design} + b_2\text{TobaccoLength} + b_3\text{TobaccoDensity} + b_4\text{StoreType} + b_5\text{Region} + b_6\text{Chamber}$$

where Design, Tobacco Length, and Tobacco Density were averages measured on different cigarettes of the same packaging. The quantities $b_{0,}$ b_1 …, b_6 are effect parameters to be estimated by the model.

Because each cigarette packaging and design had unique average tobacco length and average tobacco density values, it was not possible to add specific terms for each packaging (as for example was done in modeling ignition propensity). The results are shown in Table 14 below.

Effect Parameter	**Degrees of Freedom**	**Wald Chi-Square**	**Pr > ChiSq**
Design	1	2091.0802	<.0001
Tobacco Length	1	196.1494	<.0001
Tobacco Density	1	65.0017	<.0001
Store-type	3	14.0694	0.0028
Region	1	0.4172	0.5183
Chamber	3	5.3534	0.1477

Table 14: Analysis of Variance. The output is from PROC LIFEREG in SAS. Normal probability distribution specified for the residuals. Sample size n = 1920, excluding results from the CP9 cigarette. DF is degrees of freedom, equal to one less than the number of levels of the associated variable. Pr> ChiSq is the *p-value*.

Table 14 shows Design (RIP or non-RIP), tobacco length, density, and store type have statistically significant effects ($p < 0.05$) on burn time, while region and chamber were not significant. Effect parameter estimates are shown in Table 15 below.

[21] See PROC LIFEREG in SAS® Statistical System. SAS Institute Inc. (2004) SAS/STAT® 9.1 User's Guide, Cary, NC: SAS Institute Inc.

Effect Parameter		Degrees of Freedom	Estimate	Standard Error	Chi-square	Pr > ChiSq
Intercept		1	-10.19	1.82	31.33	<.0001
Design	Non-RIP	1	6.25	0.14	2091.08	<.0001
Tobacco Length		1	0.10	0.01	196.15	<.0001
Tobacco Density		1	54.02	6.70	65.00	<.0001
Store-type	A	1	-0.69	0.21	11.00	0.0009
Store-type	B	1	-0.72	0.22	10.56	0.0012
Store-type	C	1	-0.75	0.23	10.65	0.0011
Region	East	1	-0.09	0.14	0.42	0.5183
Chamber	1	1	-0.38	0.19	4.05	0.0442
Chamber	2	1	-0.35	0.19	3.43	0.0639
Chamber	3	1	-0.15	0.19	0.64	0.4251
Scale		1	2.94	0.04		

Table 15: Effect parameter estimates from the statistical model. See notes for Table 12. All units in the table are in minutes, except for tobacco length (minutes per millimeter and density (minutes per gram per cubic centimeter). Pr> ChiSq is the *p-value*.

Table 15 shows effect parameter estimates for all but one level of each variable. The reference levels, which are the omitted level in each variable, are RIP Design, Store-type D, West Region, and Chamber 4. The omitted effect parameter estimates shown are the difference between the reference level and the parameter estimate shown. For example, the difference between Non-RIP and RIP cigarettes is 6.25 minutes and between Store-type C and Store type D is -0.75 minutes (C has a shorter mean burn time than D).

Note that in Table 15, the parameter estimate for Non-RIP cigarettes has a positive sign, which indicates that everything else held constant. Non-RIP cigarettes burn longer than RIP cigarettes of the same design by an average of 6.25 minutes. Note that this is about the same as the differences in average burn times between RIP and Non-RIP cigarettes shown in Table 11.

Other findings from the regression model indicate that burn time also increases with increasing tobacco length and increasing density. Holding everything else constant, burn time would increase 1.0 minutes for every 10 mm increase in tobacco length. As the difference between shortest and longest cigarettes is about 30 mm, the longest cigarettes tested would account for about 3 minutes greater burn time than the shortest cigarettes. For tobacco density, an increase of one-twentieth of a gram per cubic centimeter, which is about the observed range of density, would be associated with an increase of (54.02/20=) 2.7 minutes in burn time.

Store type is also shown to be significant in Table 15. With all three stores-types, A, B, and C having negative signs, the reference, store type D, must then have an offsetting positive sign, indicating longer burn times from that store type. Cigarettes obtained from store-type D would burn 0.69 minutes longer than those from A, 0.72 minutes longer than those from B, and 0.75 minutes longer than from C. As mentioned previously, these differences may be associated with the difference in packagings that were purchased at each store type, or it may be associated with handling, cigarette sales turnover at stores, store inventory practices, or some other factor.

Neither chamber, nor region, is statistically significant, suggesting that neither variable has a strong effect on burn time.

We explored a variety of different models for burn time. When adding packaging and a design*packaging interaction, it is necessary to remove the physical measurements, as discussed previously. A model with packaging and design fit as well as the model above, but was obviously not as informative as the effects of physical measurements. As expected from the different packagings by store, the store effect is no longer significant, suggesting that the store effect in the model of Table 15 is probably associated with the differences in packagings. Another model variation that was explored involved adding a term for the citric acid concentration to the model with packagings and designs. That variable was not statistically significant. The reason for that can be seen in Figure 8.

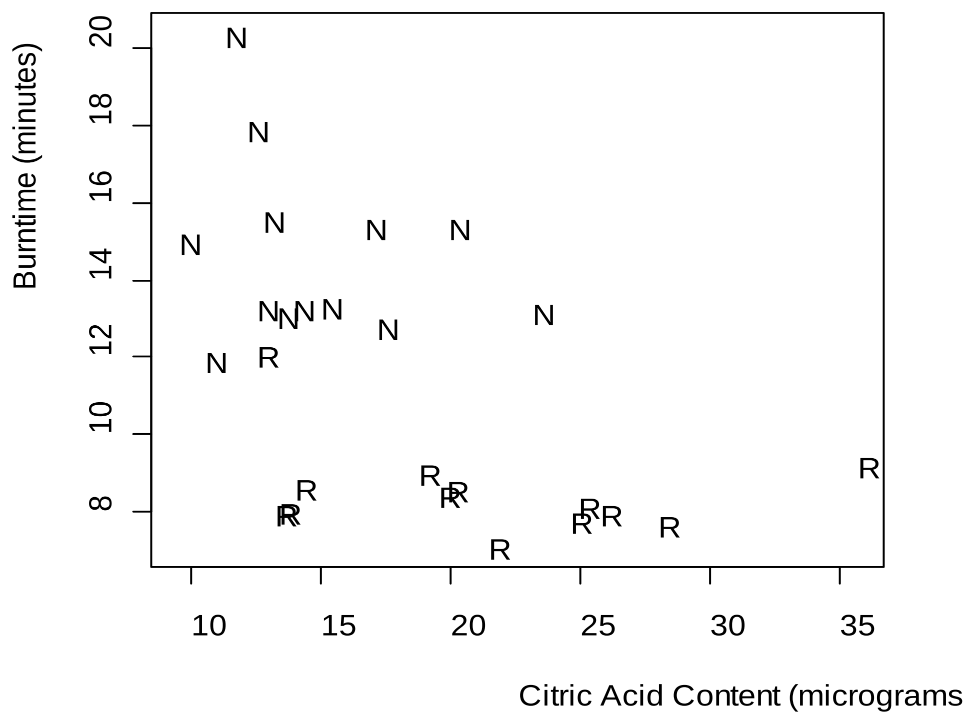


Figure 8: Burn time as related to Citric Acid Content. R denotes RIP and N denotes non-RIP cigarettes.

Figure 8 shows that there is substantial overlap between the average citric acid content of the RIP and non-RIP cigarettes, except for the few RIP cigarettes that have higher concentrations than most. Average burn time tends to decrease with increasing citric acid content, but the larger difference in burn time is related to whether the cigarette is RIP or non-RIP. For non-RIP cigarettes, there is a tendency toward decreasing average burn times with increasing citric acid content. That effect is much weaker for RIP cigarettes.   In fact, aside from the one RIP cigarette with the lowest citric acid measurement, the relationship with burn time is virtually flat. On the other hand, the strongest effect in Figure 8 is the design, *i.e.*, whether the cigarette is RIP or non-RIP. Thus, putting design into the model leaves little explanatory power for the citric acid content, which is why it is not a significant predictor of burn time.[22]

To conclude this section, both the graphical analyses and regression analyses show burn times increasing with tobacco length and density. More importantly, the results show that RIP cigarettes, at a given tobacco length and/or tobacco density, will burn on average at least 6 minutes less than non-RIP cigarettes. Chamber and region effects are not statistically significant, which increases the generality of the results (*i.e.*, there is no statistical evidence linking specific chambers or regions to burn time). Store type does have an effect, but that appears to be connected primarily with the difference in the cigarette packagings purchased at the D-type stores. However the average difference between the D stores and other stores is less than 1 minute and of much less importance than the other significant variables.

CONCLUSION

The most important finding of this research is that when tested in a laboratory setting on filter paper, the RIP cigarettes have a much lower proportion of full-length burns than non-RIP cigarettes of the same packaging. In modeling the proportion of full-length burns, the effects of store type—where the cigarette was purchased, region of the country where cigarette was purchased, and test chamber were not statistically significant. This suggests that the experimental results are repeatable with different test chambers and with cigarettes from different stores and different regions of the country. Only one RIP packaging was exceptional, the CP9, with 20 percent full-length burns. All the other RIP cigarettes had no more than 10 percent full-length burns, and there was no statistical evidence to distinguish between them. Non-RIP cigarettes ranged between 95.0 percent and 100 percent full-length burns, in contrast.

Unsurprisingly, if RIP cigarettes self-extinguished more frequently than non-RIP cigarettes, then RIP cigarettes would be expected to burn on average a shorter time than non-RIP cigarettes. The data show that RIP cigarettes burned on average 8.5 minutes, while the non-RIP cigarettes averaged 14.7 minutes, a difference of 6.2 minutes. When modeling burn time, as related to the physical properties of the cigarettes, whether the cigarette was RIP or non-RIP accounted for most of the variation in burn time. Tobacco column length and tobacco density also affected burn time.

The physical properties of the cigarettes, as measured in this study, indicated that tobacco column length and density varied little within a cigarette packaging and design. For RIP cigarettes, the distance to the first band varied considerably within each packaging, but the distance between bands was consistent. Citric acid content varied between packagings, but there was more variability between non-RIP packagings than between RIP packagings.

[22] Another way to see the effect between cigarette design, burn time, and citric acid content is to think about plotting a regression line on Figure 8. When using all the data points, the regression line would start in the upper left hand corner, with the N points, and it would be negatively sloped. On the other hand, if plotting two regression lines, one for the RIP cigarettes and the other for the non-RIP cigarettes, both lines would be flat.

The key question is whether RIP cigarettes have the possibility to reduce fire losses associated with interior furnishings. The analysis in this report does not answer that question because the tests in this report were in a laboratory setting using test chambers with the cigarettes on filter paper. If this research had shown that there were no difference in ignition propensity and burn times, there would be no reason to continue with simulated interior furnishings. However, the research showed significant differences between RIP and non-RIP cigarettes, and as a result, this experiment supports continuation of this research.

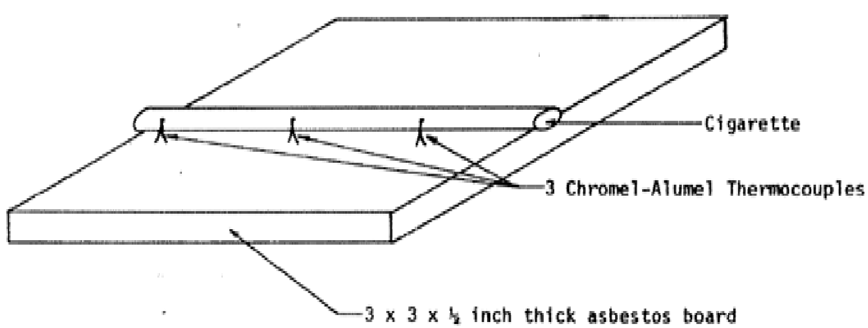
Appendix A
Burn Temperature Test Method

Source: Extract of scan from memo from Joseph J. Loftus, Chemist, Office of Flammable Fabrics, National Bureau of Standards to L. James Sharman, Chief Test Development Unit, Office of Flammable Fabrics, National Bureau of Standards, June 18, 1971.

Apparatus and Test Method

A 3 x 3 x ½ inch thick asbestos board (See Figure 1) was used to support three chromel and alumel 24 gauge (.020 inch) thermocouples. In a typical test the couples pierce the cigarette cylinder wall to one radius depth at three locations, 1/8 inch from the butt end, and at 1 and 2 inch distances from the butt thermocouple. Butt end here means measured from the point where the tobacco ends and not from the filter tip end. The cigarettes were tested in a horizontal position, were ignited (with the aid of a vacuum bulb) and allowed to burn their full length to extinguishment. Temperatures developed by the cigarettes on burning were recorded on a twelve point potentiometer recorder.

Figure 1 Temperature Measurements Made on Burning Cigarettes Test Apparatus



Appendix B

Testing the Difference between the Largest Observations from Two Distributions

This problem arose to determine if the maximum burn temperatures of the RIP and non-RIP cigarettes are statistically significantly different from each other.

The standard approach is to assume that the largest observations in both RIP and non-RIP cigarette designs come from a normal distribution, to estimate the standard errors, and then to look up the data in a table. Some simulations with the maximum of small samples from a normal distribution showed that the distribution of the maximum did not follow a normal distribution as tested using the Anderson-Darling test for normality.[23]

A bootstrap procedure was then created to test the significance of the distribution of the difference of the largest observations.[24] Define $x_1, x_2, x_3,\ldots, x_n$ as the burn temperatures of the n RIP cigarettes for a particular packaging and $y_1, y_2, y_3,\ldots, y_m$ as the burn temperatures of the m non-RIP cigarettes of that same packaging. Let $y_{(m)}$ and $x_{(n)}$ be the respective maximum burn temperatures from the RIP and non-RIP cigarettes tested. Let $d=y_{(m)}-x_{(n)}$. This is the observed difference in the maximum burn times.

The bootstrap procedure tests the null hypothesis that the difference (in maximum burn temperature is zero) against an alternative hypothesis that it is nonzero (i.e. $|d|>0$). Before beginning the bootstrap procedure, the data from the RIP and non-RIP cigarettes are collected into a single vector, v, of length $m+n$. The bootstrap procedure is as follows:

- Step 1. Randomly sample m observations from v (the pooled observations) and n observations from v. Sampling is with replacement consistent with bootstrap procedure. The two samples are bootstrap replications of the RIP and non-RIP burn temperatures under the assumptions of the null hypothesis that the samples are drawn from the same population (and therefore, would have the same maxima).
- Step 2. Find the maximum of the two samples.
- Step 3. Record the difference $d_{B.}*$

These three steps constitute a single bootstrap iteration. The process is then repeated 10,000 times, resulting in 10,000 values for $d_{B.}*$ This is the bootstrap distribution under the null hypothesis.

The bootstrap distribution is then compared with the observed difference *d*. The bootstrap *p* value is defined as the percent of the values of d_B* values of that are greater than d in absolute value. For example, suppose d is 15, 2 percent of the values of d_B* are greater than 15 and 1

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[23] The Anderson-Darling test is a standard test for the normal distribution. See Thode Jr., H.C. (2002): Testing for Normality. Marcel Dekker, New York. The *R* implementation of the Anderson-Darling Test (ad.test in the nortest package) was used. All simulations were in *R*.

[24] Efron, B. and Tibshirani, RJ (1993), *An Introduction to the Bootstrap*. Chapman & Hall, New York.

percent are less than -15 (the remaining 97 percent of the values between minus 15 and plus 15). Then the *p-value* is (2+1=) 3 percent.

SUPPORTING DOCUMENT E: MEHTA, S. , "CIGARETTE IGNITION RISK PHASE II: MATTRESS AND MATTRESS PAD TESTING," SEPTEMBER 2012

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
4330 EAST WEST HIGHWAY
BETHESDA, MD 20814

Memorandum

Date: October 18, 2012

TO : File

THROUGH: George A. Borlase, Ph.D., PE, Associate Executive Director
Directorate for Engineering Sciences

Patricia K. Adair, Director
Division of Combustion and Fire Sciences
Directorate for Engineering Sciences

FROM : Shivani Mehta, Project Manager,
Division of Combustion and Fire Sciences,
Directorate for Engineering Sciences

SUBJECT : Evaluation of Reduced Ignition Propensity (RIP) and Conventional (non-RIP) Cigarettes on Mattress and Mattress Pad Substrates.

1 INTRODUCTION

As of mid-2011, all 50 states have legislation in effect adopting a fire safety standard for cigarettes. As a result, all cigarettes are required to be of low ignition strength, *i.e.*, less likely to burn their entire length when unattended.[1] As a result, the ignition performance of Reduced Ignition Propensity (RIP) cigarettes may be different than conventional cigarettes (non-RIP) on soft furnishings, such as mattresses and mattress pads, and may warrant future consideration of revisions to existing and proposed flammability regulations, as well as voluntary standards.

The complete saturation of RIP cigarettes in the market prompted staff to evaluate the relative difference between the ignition propensity of conventional cigarettes and their RIP counterparts on mattresses and mattress pads. The cigarette smoldering ignition risk associated with mattresses and mattress pads is currently addressed in 16 CFR part 1632, *Standard for the Flammability of Mattresses and Mattress Pads*.

In 2008, CPSC staff undertook a multiphase project to evaluate the relative risk of smoldering ignition between RIP and non-RIP cigarettes. In Phase I, staff examined the relative ignition propensity of RIP and non-RIP cigarettes in accordance with the states' regulatory test. In Phase II, staff planned and performed tests to evaluate mattresses and mattress pads to observe any relative differences in flammability behavior when exposed to RIP and non-RIP cigarettes per the methodology in 16 CFR part 1632; these tests were not designed to determine if a mattress or pad passes or fails the standard. Based on the testing conducted in Phase I of the project,

[1] These cigarettes are commonly known as "fire safe" cigarettes, but the CPSC staff refers to them as Reduced Ignition Propensity (RIP) cigarettes so as not to imply that they do not present a fire risk.

cigarette packagings were "ranked,"[2] and four were chosen to be tested in this series. The testing was completed by an outside laboratory as part of a contract. The detailed test plan submitted to the contractor is in Appendix A.

This design of experiments is intended to examine the difference in smoldering behavior of RIP and non-RIP cigarettes within specific packaging and substrate types. The data presented here are specific to the items tested and do not necessarily represent the performance of all cigarettes.

2 TEST PROCEDURE

For the tests, lit cigarettes were placed on a mattress or mattress pad substrate (referred to here as substrate) and allowed to burn to completion or self-extinguishment. Each test consisted of 18 cigarettes (a mix of both RIP and non-RIP type) placed on the substrate with the cigarettes resting on one of the three substrate surface features, as applicable: on a smooth surface, in a tuft, or along the tape edge of the substrate area. The cigarettes were either sandwiched between two pieces of cotton sheeting fabric or placed directly onto the bare substrate.[3] Three cigarettes were placed in one of six evenly-spaced sections or blocks of the substrate. The test plan (Appendix A) details the locations and sheeting. Six video cameras were placed above the substrate and corresponded approximately to each block. Cigarette packagings were distributed among the substrate types so that the results were biased by the type of substrate. Each cigarette is considered a distinct evaluation.

All cigarette and substrate samples were conditioned at 70 ± 5ºF and 55 ± 5% relative humidity (RH) for 48 hours prior to testing. After conditioning, a sample substrate was placed on a frame for testing in a room that was also conditioned at 70 ± 5ºF and 50 ± 5%. If the room was not conditioned appropriately, at least one cigarette was to be placed on the substrate within 10 minutes of removal from the conditioning chamber, and all 18 cigarettes were to be placed within 30 minutes.

The cigarettes were lit and allowed to burn 10 mm before being placed by hand onto the substrate in a previously determined location. The cigarettes were observed during the test to determine if the cigarette self-extinguished, burned its full length, or whether any other notable event occurred.

The tests continued until all 18 cigarettes and substrates stopped smoldering, or at 60 minutes after the last cigarette was placed, whichever came first. Some tests were stopped early, due to the untenable conditions created in the lab from smoldering of the substrate. At the end of the test, any remaining cigarettes were collected, and the length of the unburned cigarette was measured.

3 DESCRIPTION OF TEST SAMPLES

The number of cigarettes and corresponding substrates was determined by a statistical plan developed by Directorate for Epidemiology staff. Forty-eight substrate samples were used to

[2] A "packaging" indicates the brand, style, and size of the cigarette, *e.g.*, Marlboro Light 100s.
[3] Section 4(a)(ii)(6) of 16 CFR 1632 calls for the use of cotton sheeting in cigarette ignition tests.

evaluate 863 cigarettes.[4] The substrates were chosen to distinguish between RIP and non-RIP cigarettes' ignition behavior.

3.1 Cigarettes

The four cigarette packagings were chosen based on a ranking of the cigarettes by their FLB portions on when tested per ASTM E2187-04 *Standard Test Method for Measuring the Ignition Strength of Cigarettes*, and band-to-band distance.[5] Cigarettes were purchased by CPSC field staff in 2008. One of the packagings selected was the unfiltered Pall Mall because it is the ignition source described by physical characteristics in mandatory and voluntary flammability standards, including the original 16 CFR part 1632. After the start of the project, 16 CFR part 1632 was amended to specify NIST Standard Reference Material (SRM) 1196 as the cigarette ignition source.[6] The SRM cigarette was designed to have the same ignition propensity as the non-RIP, unfiltered Pall Mall, and thus, the SRM 1196 was chosen to be the non-RIP counterpart of Pall Mall cigarettes.[7] Packs of the RIP Pall Mall and the other three packagings were selected randomly from the samples that CPSC Field staff collected in 2008. The cigarettes were stored in a freezer and delivered to the contractor in dry ice to maintain the conditions for storage until the time of testing. Once the contractor received the cigarettes, they were stored in a freezer until removed for conditioning for testing. Table lists the number of each cigarette packaging that was included in this test series.

Table 1. Cigarette Samples for Mattress and Mattress Pad Testing

Cigarette Packaging	RIP/non-RIP	Filter (Yes/No)	Approx. Tobacco Length (mm)	Number of cigarettes tested
CP5	Non-RIP	Yes	56	109
CP5	RIP	Yes	56	109
CP7	Non-RIP	Yes	58	107
CP7	RIP	Yes	58	105
CP9/SRM	Non-RIP	No	83	108
CP9 /PM	RIP	No	83	108
CP13	Non-RIP	Yes	62	108
CP13	RIP	Yes	62	109

The cigarettes were marked 10mm from the lighting end, as an indicator for the test operator to place the cigarette on the substrate for testing.

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[4] The test plan specified 864 cigarettes, but one cigarette was damaged during testing, resulting in only 863 cigarette evaluations.

[5] Green, M., Andres, C., "Cigarette Ignition Risk Phase I: Analysis of Selected Reduced Ignition Propensity Cigarettes" Memorandum to S. Mehta, U.S. Consumer Product Safety Commission. July 2008.

[6] 76 FR 59014, "16 CFR part 1632, Standard for the Flammability of Mattresses and Mattress Pads; Technical Amendment" September 23, 2011.

[7] Gann, R.T. "Technical Note 1627: Modification of ASTM E2187 for Measuring the Ignition Propensity of Conventional Cigarettes" NIST 2009.

3.2 Mattresses and Mattress Pads

Four test substrates specifically were chosen to provide a range of substrates that might encourage the possibility that a discernible difference could be found, if it existed, between the ignition propensity of RIP and non-RIP cigarettes. Preliminary tests at the CPSC were conducted to identify substrates likely to distinguish between RIP and non-RIP cigarette ignition behaviors. It is well known that certain cellulosic materials smolder more readily than others when exposed to cigarettes, so CPSC staff started with cotton rich, commercially available mattresses. Staff also procured mattress substrates that were specifically exempt from complying with 16 CFR part 1632, thus making them good candidates for evaluating cigarette ignition behavior. After testing, four substrates, described in Table 2, were chosen to continue the evaluation.

Table 2. Substrate Specifications

Substrate Code	Substrate Type	16 CFR 1632 Compliant	Ticking Type	Fiber Content of Ticking	Number of Substrates Tested	Evaluations (No. of cigarettes tested)
A	Mattress Pad	Yes	Woven Fabric, Sateen	Cotton	12	216
B	Mattress	Yes	Woven Fabric, Twill (Herringbone)	Cotton	12	216
C	Futon	No	Woven Fabric, Twill	Cotton	12	216
D	Mattress	No	Woven Fabric, Plain	Cotton	12	215

The contractor was directed to save a cross-section of each substrate sample so fiber content identification confirmations could be done later by CPSC staff. Examination of all 48 substrate pieces showed that all samples of the same substrate were identical to each other.[8]

Each of the 48 substrates test included 18 cigarettes, with packagings distributed as indicated in Table 3.

[8] Campbell, J. and Mellish, R. "Characterization of Test Substrates Used in Cigarette Ignition Risk Project Testing" Memorandum to S. Mehta, September 6, 2012.

Table 3. Breakdown of Cigarettes Evaluated by Substrate

Cigarette ID[9]	Substrate			
	A	B	C	D
CP5N	26	26	28	29
CP5R	24	27	28	30
CP7N	28	27	29	23
CP7R	28	26	26	25
CP9/SRM	21	28	24	35
CP9/PM	21	30	29	28
CP13N	33	27	27	21
CP13R	35	25	25	24

4 RESULTS

All tests were recorded with cameras placed directly above the substrate that captured the entire test. A plate with known dimensions was placed in the frame of the camera for each cigarette location to obtain dimensions in video processing. Observations on cigarette self-extinguishment, full-length burn (FLB), and continuous substrate smoldering were made from the videos. A complete record of data is presented in Appendix B. This section will analyze the results by separating the evaluations based on the incidence of substrate smoldering. The data will also be examined as a function of location and presence of sheeting. A statistical analysis was also conducted to characterize the observed differences in cigarette burning behavior.[10]

4.1 Evaluations in which substrates did not smolder

There were 429 evaluations in which smoldering of the substrate did not occur. This section will look at this set of data as a whole, and separately by cigarette full-length burns (FLB), as a function of substrate, location, and sheeting. Table 4 shows a summary of the evaluations that did not result in smoldering of the substrate. The results vary greatly depending on the type of substrate.

[9] To distinguish between results of RIP and non-RIP versions of each packaging in the data, the letter "N" is placed after the packaging designation for non-RIP cigarettes, and "R" is placed after the packaging designation for RIP cigarettes.

[10] Miller, D. and Garland, S. "Cigarette Ignition Risk Phase II: Mattress and Mattress Pad Testing Results and Analysis" Memorandum to S. Mehta, December 2012.

Table 4. Cigarettes that Did Not Cause Smoldering of Substrate

Cigarette ID	Substrate ID								
	A		B		C		D		
	Tests	% of Total	Tests	% of Total	Tests	% of Total	Tests	% of Total	Total
CP5N	21	81%	26	100%	10	36%	1	3%	58
CP5R	22	92%	26	96%	10	36%	8	27%	66
CP7N	15	54%	27	100%	2	7%	0	0%	44
CP7R	20	71%	25	96%	5	19%	0	0%	50
CP9/SRM	16	76%	24	86%	1	4%	0	0%	41
CP9 /PM	14	67%	27	90%	6	21%	0	0%	47
CP13N	31	94%	26	96%	5	19%	0	0%	62
CP13R	27	77%	23	92%	9	36%	2	8%	61
Total	**166**		**204**		**48**		**11**		**429**

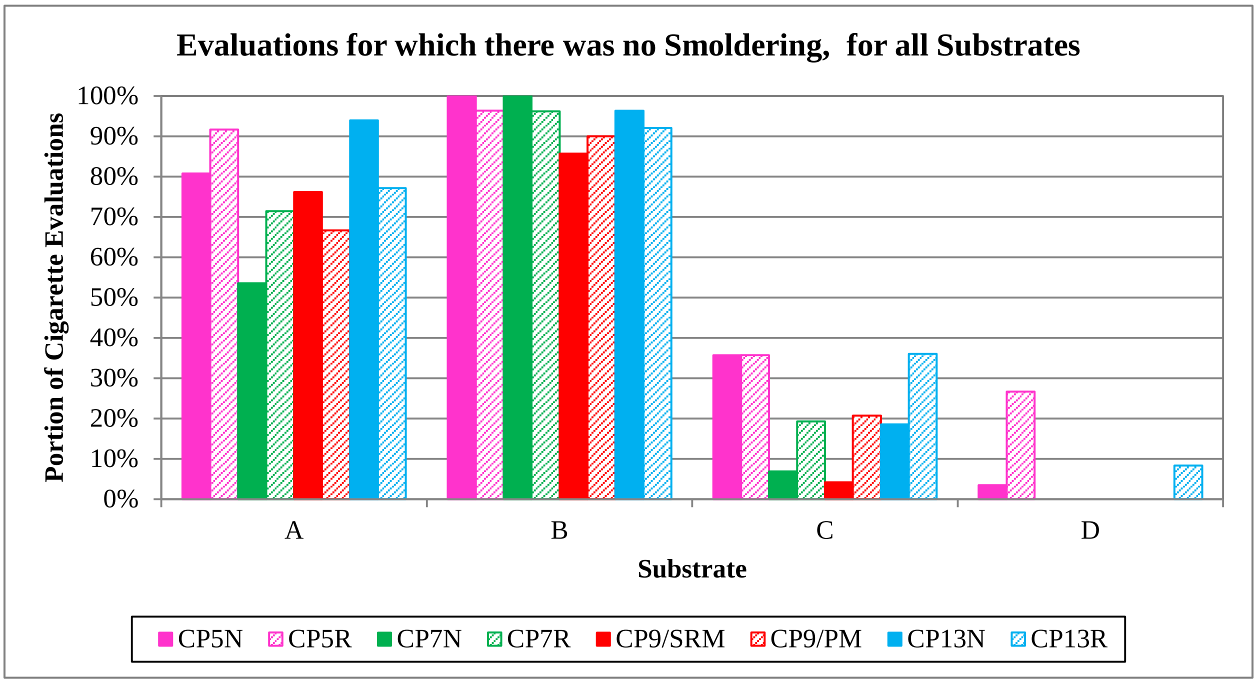

Figure 1. Portion of evaluations that did not result in smoldering of the substrate

In 16 CFR part 1632, all location types and sheeting presence are treated equally in describing the performance of the substrate. Therefore, the data in Table 4 are combined over these different locations. However, the data can be broken down to examine the locations more closely (see Appendix I for examples of location type). Figure 2 shows the portion of the evaluations in which no smoldering occurred for each location. (For example, the number of evaluations that did not result in smoldering and that were located on the edge of the substrate. Substrate C did not have an edge location, so no data were generated for this location type). Figure 2 shows no obvious location effect in this set of data.

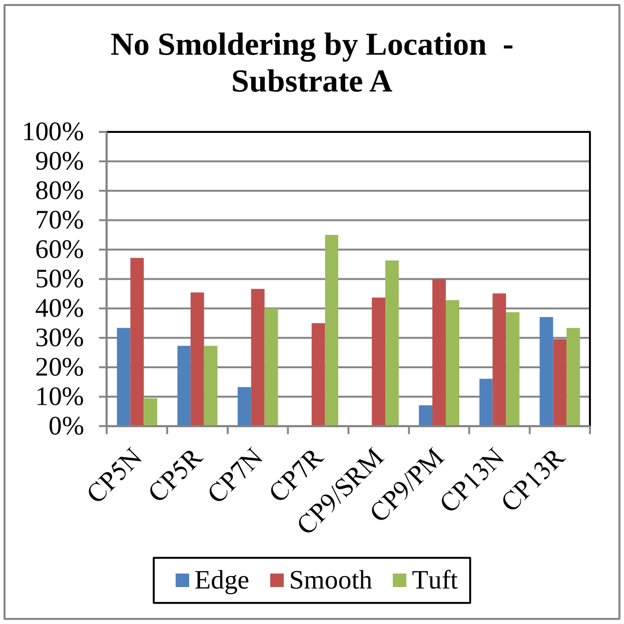

Figure 2a

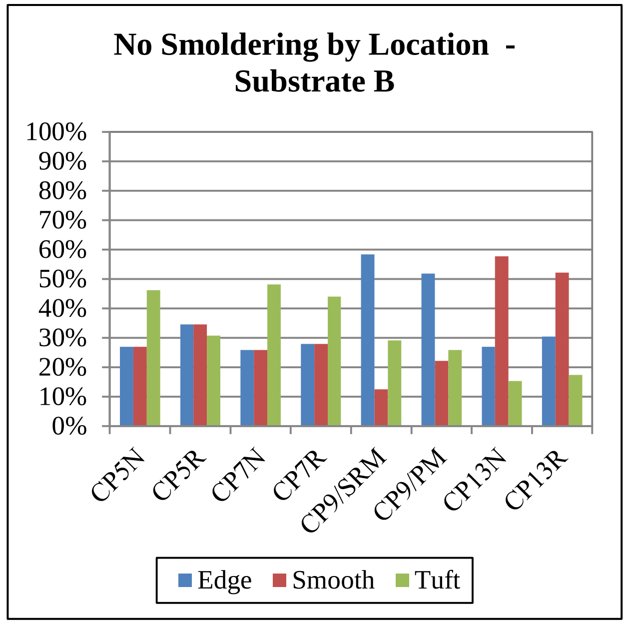

Figure 2b

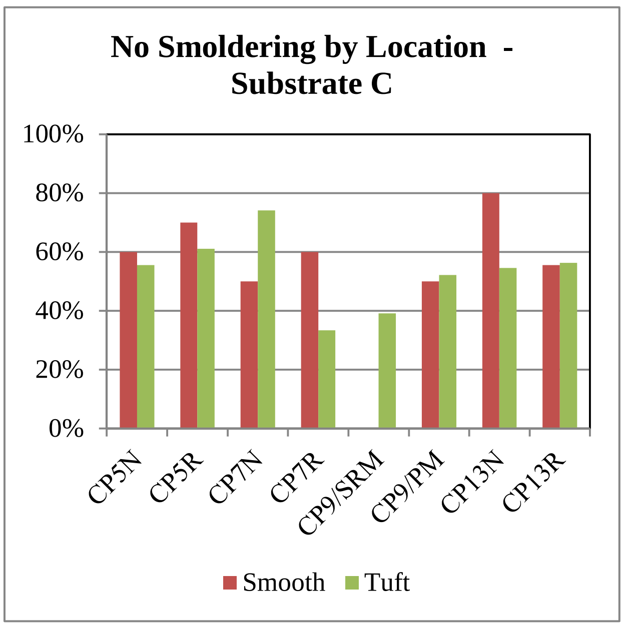

Figure 2c

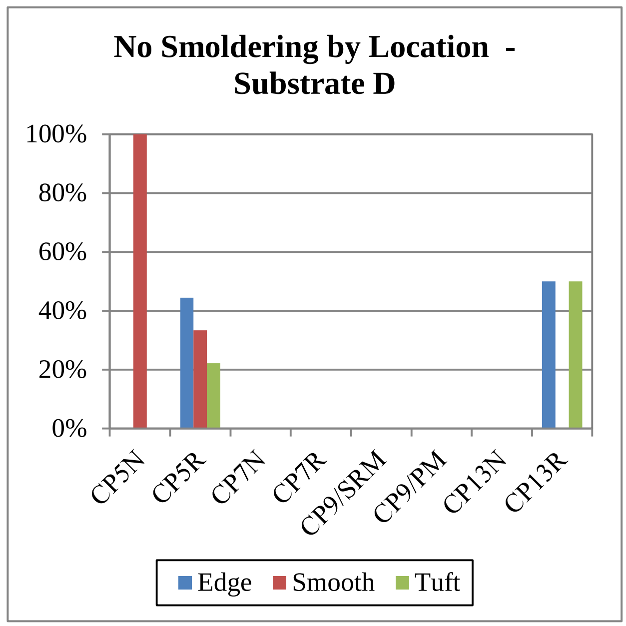

Figure 2d

Figure 2. Evaluations not resulting in smoldering, separated by location type for each substrate

Similarly, in 16 CFR part 1632, evaluations with and without sheeting are considered equal. The portion of evaluations that were located with sheeting and did not result in smoldering is shown in Figure 3 for each substrate and packaging. The results vary by substrate. For example, on substrate B, about half of the time there was no smoldering there was sheeting present.

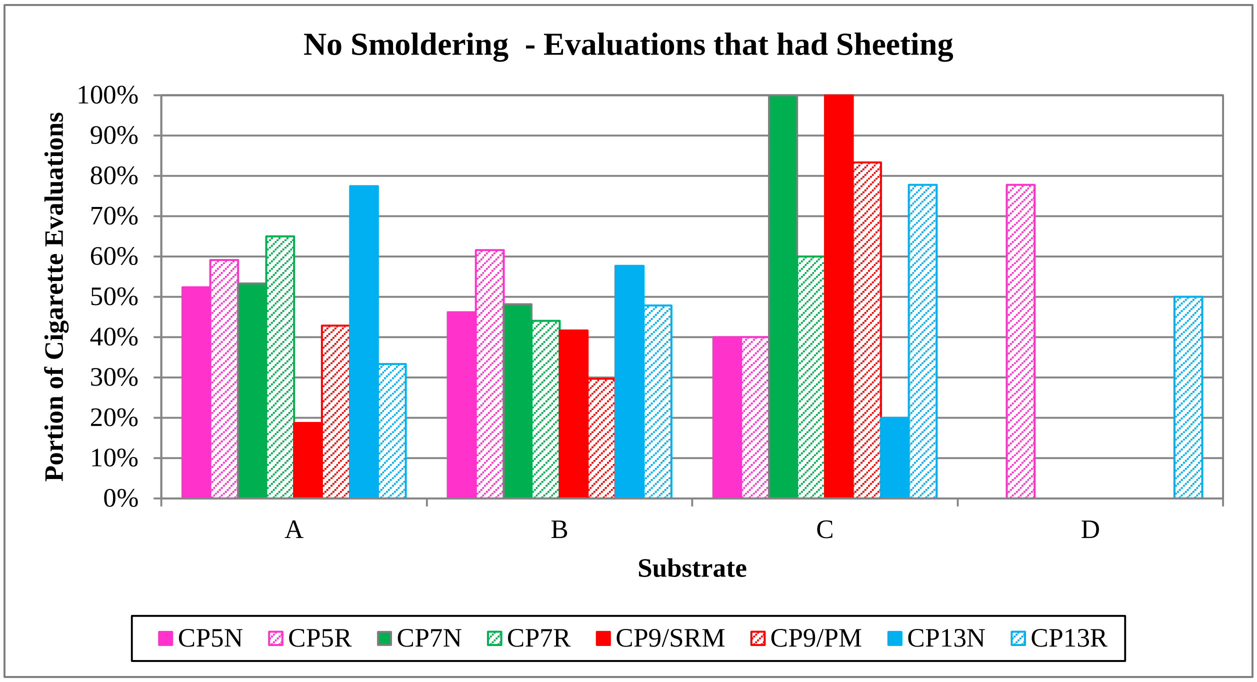

Figure 3. Sheeting for all evaluations that did not result in smoldering, total number of tests that did not smolder are listed in Table 4

4.1.1 Full-Length Burns and no Smoldering of the Substrate

The theory behind the RIP cigarette is that if it is left unattended, it will be more likely to self-extinguish prior to burning its full length, thus resulting in fewer fires. This theory is the reason why the ASTM E2187-04, Standard for the standard counts the number of cigarettes that burn their full length to ascertain a cigarette's ability to self-extinguish. In an effort to understand the difference between the RIP and non-RIP cigarettes on mattresses and mattress pads, the data also can be analyzed by the portion (or percentage) of full-length burns (FLB).

Of the 429 non-smolder-producing evaluations, the cigarette demonstrated a FLB 343 times. The number of full-length burns for each cigarette packaging and substrate is shown in Table 5. A cigarette was considered to burn its full length if the smolder front reached the end of the tobacco column. In the case of filtered cigarettes, this was at the location of the paper that covered the filter. The two unfiltered cigarette packagings' tobacco length was the entire length of the cigarette. Figure 4 shows the location considered to be full length burn on all the cigarette packagings.

Table 5. Number of Full-Length Burns, Where No Smoldering of Substrate Occurred

Cigarette ID	Substrate ID							
	A		B		C		D	
	Tests	% FLB	Tests	% FLB	Tests	% FLB	Tests	% FLB
CP5N	21	100	25	96	10	100	0	0
CP5R	13	59	15	58	4	40	0	0
CP7N	14	93	27	100	2	100	0	0
CP7R	19	95	17	68	4	80	0	0
CP9/SRM	16	100	24	100	1	100	0	0
CP9 /PM	13	93	15	56	6	100	0	0
CP13N	30	97	26	100	5	100	0	0
CP13R	20	74	11	48	5	56	0	0
Total	**146**		**160**		**37**		**0**	

Cigarette ID	Non-RIP		RIP	
	Without Sheeting	With Sheeting	Without Sheeting	With Sheeting
CP5				
CP7				
CP9				
CP13				

Figure 4. Example of Full Length Burns (FLB) for each packaging, with and without sheeting.

Figure 5 shows the portion of the cigarettes that burned their full lengths in evaluations where no smoldering of the substrate occurred. Substrate D was not included in this figure because no cigarettes showed a FLB in tests where the substrate did not smolder. These data show that although the substrate did not smolder, many cigarettes did burn their full lengths. For substrates A, B, and C, almost all non-RIP cigarettes burned their full lengths.

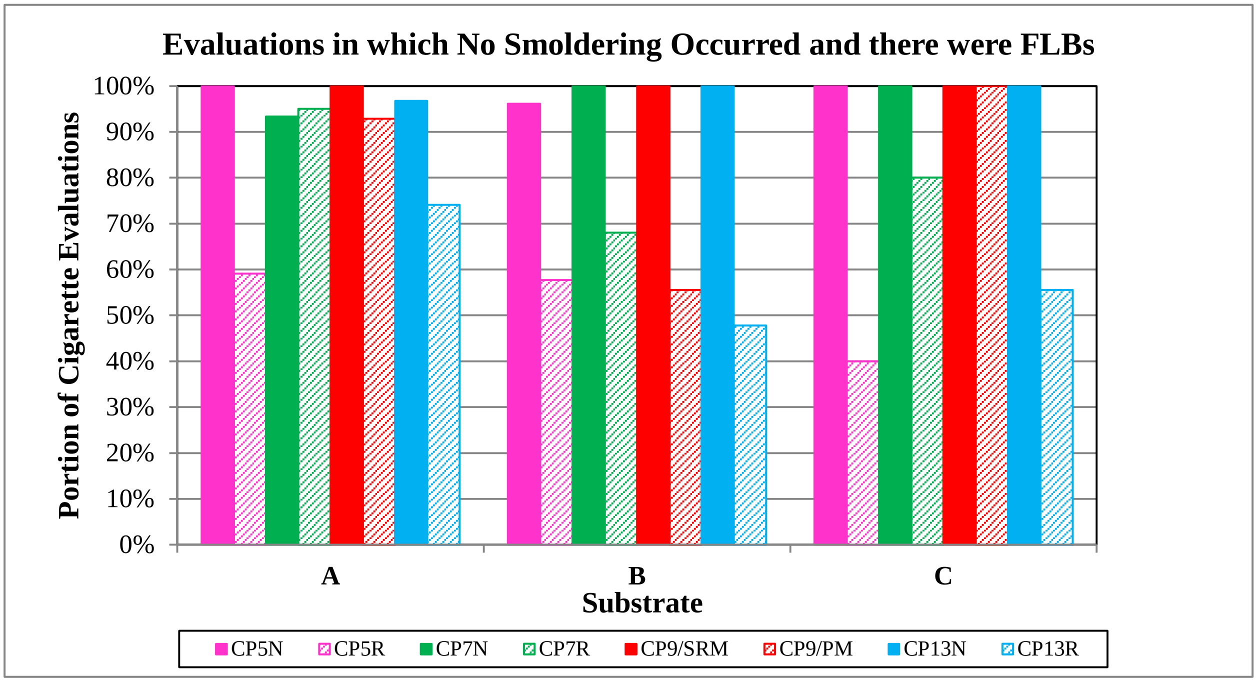

Figure 5. Portion of FLB for evaluations that did not result in smoldering of the substrate

As was done for the whole data set of non-smoldering evaluations, the data for FLB evaluations can be examined by location. The evaluations that resulted in full-length burns without substrate smoldering are separated by cigarette placement location in Figure 6. Again, substrate D is not shown because there were no evaluations in this category. As in the overall testing among cigarette packagings, there was no apparent location effect among the FLBs, resulting in no smoldering of the substrate.

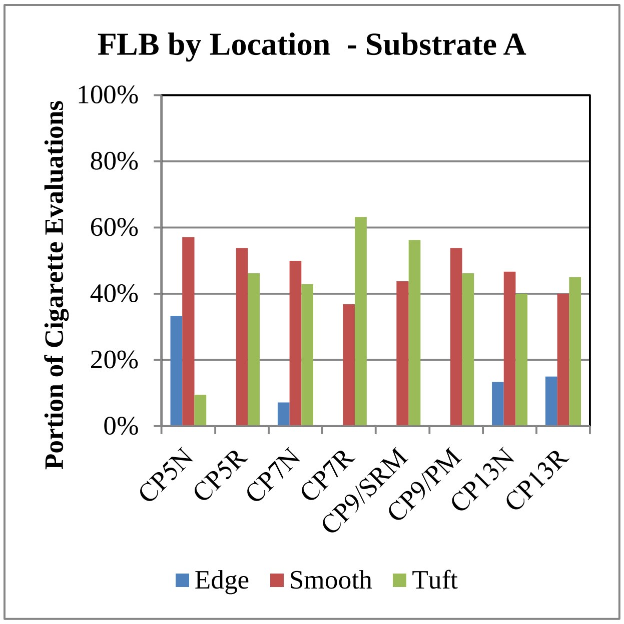

Figure 6a

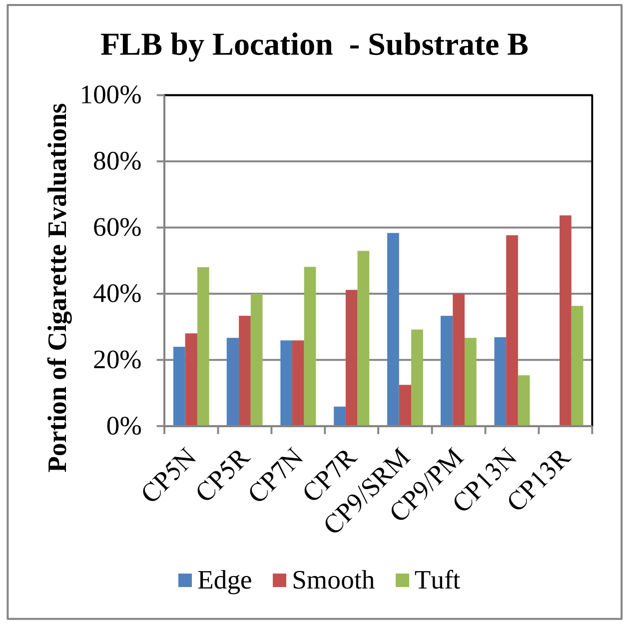

Figure 6b

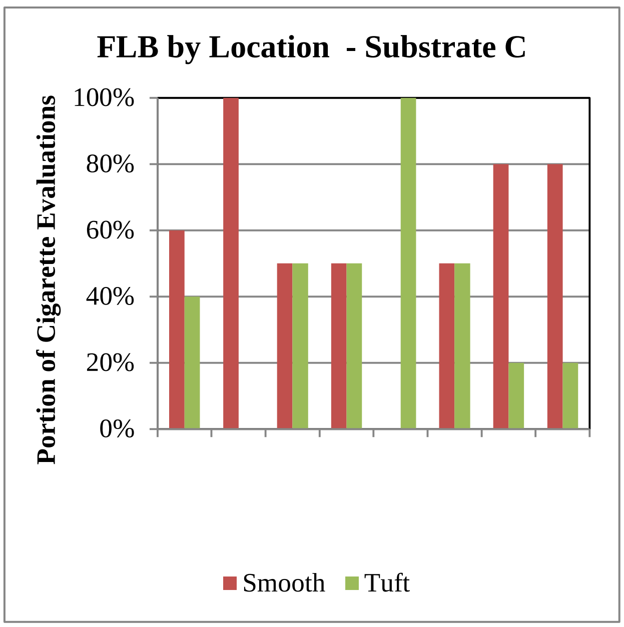

Figure 6c

Figure 6. FLB by location for non-smoldering evaluations

Similarly, the data can be broken down by the portion of FLBs that were in locations with sheeting. Figure 7 shows the portion of evaluations that resulted in a FLB and that was also in a sheeted location; substrate D is not shown because there were no evaluations in this category. It does not appear that sheeting presence influenced the likelihood of FLBs.

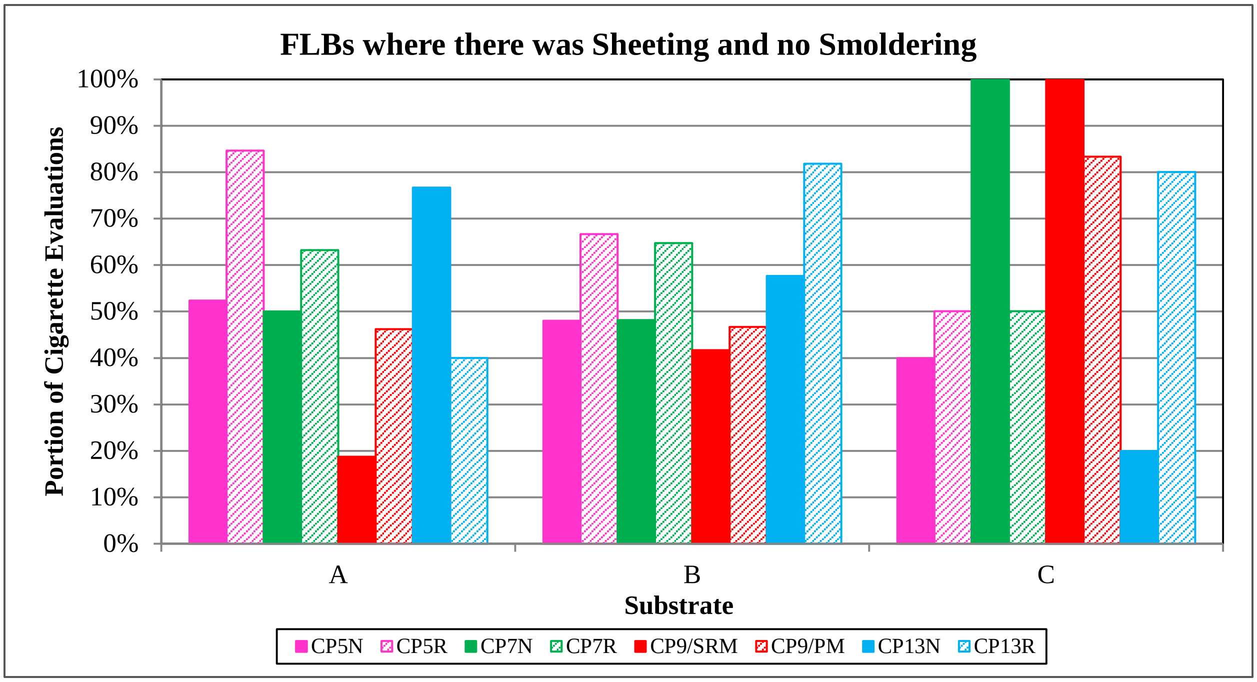

Figure 7. Effect of Sheeting on Portion of FLBs for non-smoldering substrates, Table 5 shows the total number of evaluations

4.2 Evaluations in which the Substrate Smoldered

A total of 863 cigarette evaluations were completed, of which 434 cigarettes caused smoldering of the substrate. "Smoldering" occurs when the char around the cigarette exceeds the footprint of the cigarette at any time during the test. The number of cigarettes that caused smoldering per substrate is shown in Table 6. The portion of cigarettes that caused smoldering by substrate is seen in Figure 4.

Table 6. Cigarettes that Caused Smoldering of Substrate

	Substrate ID								
Cigarette ID	A		B		C		D		Total
	Tests	% of Total	Tests	% of Total	Tests	% of Total	Tests	% of Total	
CP5N	5	19	0	0	18	64	28	97	51
CP5R	2	8	1	4	18	64	22	73	43
CP7N	13	46	0	0	27	93	23	100	63
CP7R	8	29	1	4	21	81	25	100	55
CP9/SRM	5	24	4	14	23	96	35	100	67
CP9 /PM	7	33	3	10	23	79	28	100	61
CP13N	2	6	1	4	22	81	21	100	46
CP13R	8	23	2	8	16	64	22	92	48
Total	**50**		**12**		**168**		**204**		**434**

As seen in the data, the incidence of smoldering varies between the substrates. The data show that more cigarettes resulted in smoldering of substrates C and D than on substrates A and B. This result was expected because substrates A and B are sold as 16 CFR part 1632 compliant. Of the 215 evaluations completed on substrate D, 204 resulted in smoldering of the substrate, indicating that the substrate is dominating the smoldering phenomena the cigarette's ignition strength.

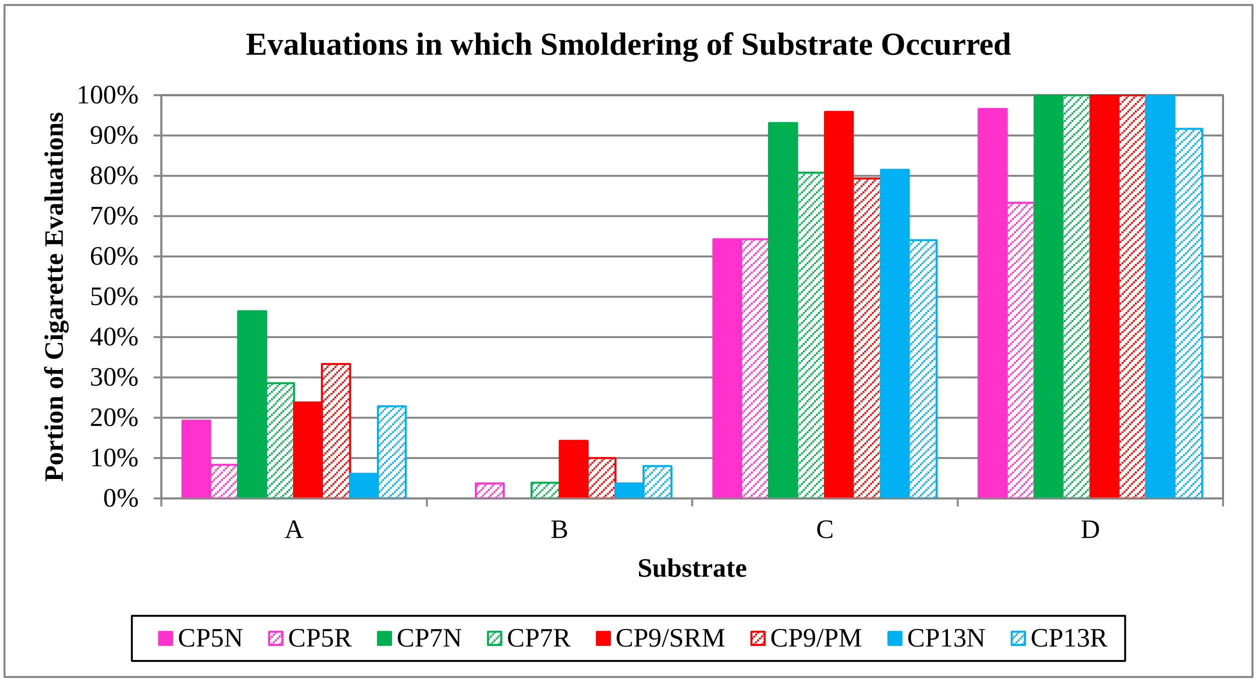

Figure 8. Portion of Cigarettes that Caused Smoldering

As explained above, the data for all locations are analyzed together, but the data can be explored further by location. Figure 9 shows results for all mattress substrates by location type. This is the portion of all evaluations that resulted in smoldering, not all tests per substrate. For substrate A, cigarettes placed in the edge location frequently resulted in smoldering of the substrate; no cigarettes placed in smooth locations caused smoldering. For substrate B, the edge location did not promote smoldering with any of the cigarettes tested. Substrate C does not have an edge location; thus, no data are generated for that location type. On substrate A, the majority of smoldering occurred at the edge locations. On substrate B, no smoldering was seen in the edge location, but the majority was in the tuft location. There weren't that many data points for substrates A and B, so these differences may be indiscriminate. The results are more evenly distributed for substrates C and D among the locations in which smoldering occurred.

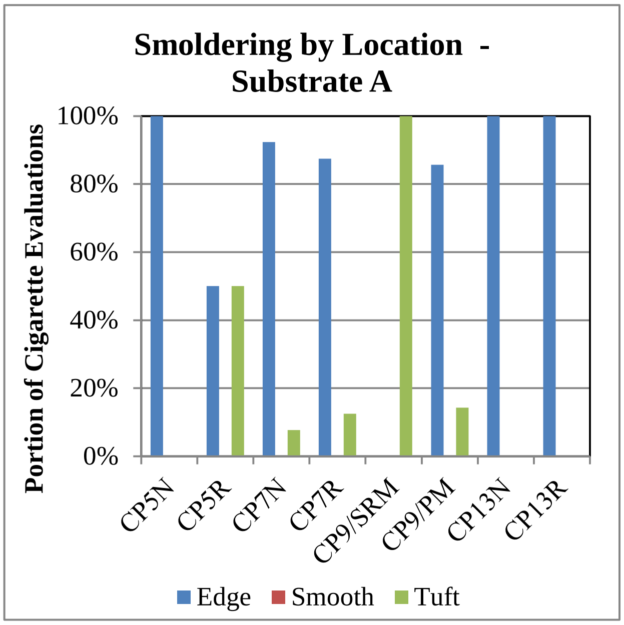

Figure 9a

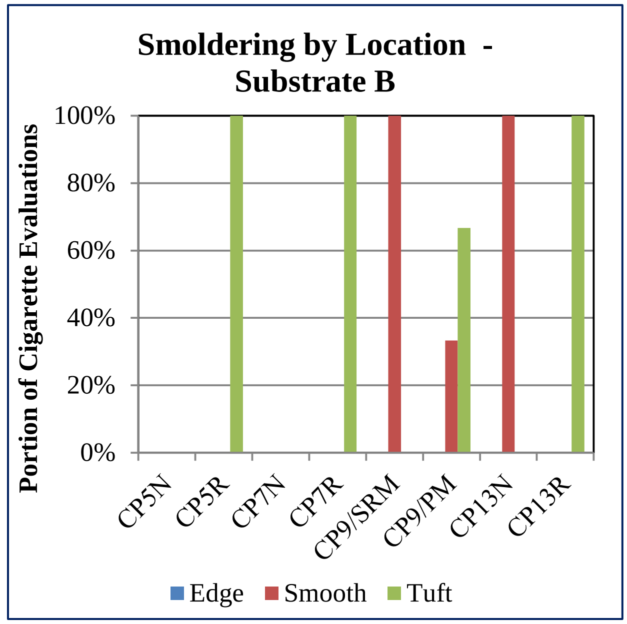

Figure 9b

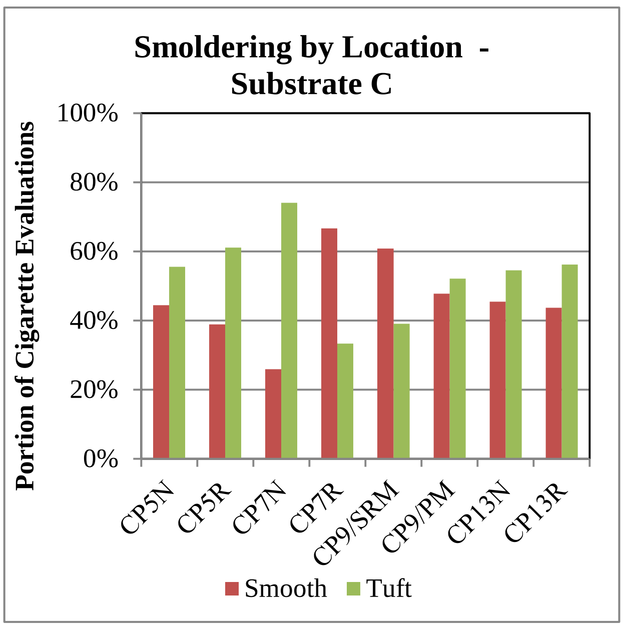

Figure 9c

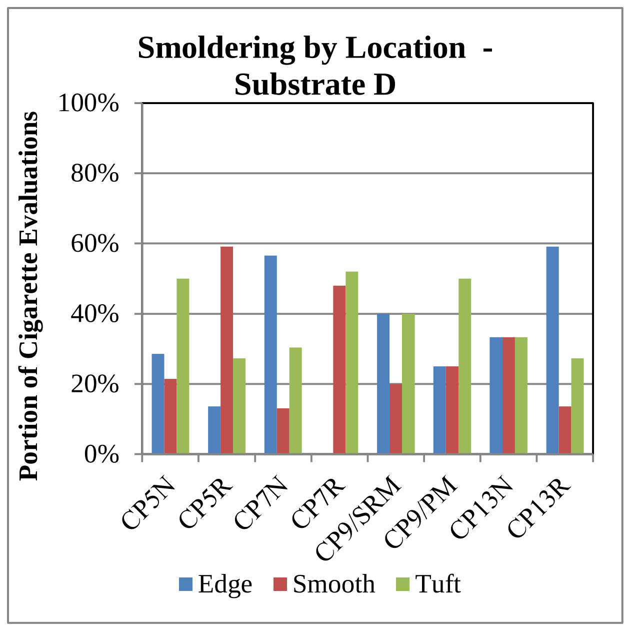

Figure 9d

Figure 9. Location in which smoldering occurred by cigarette packagings for each substrate

Similarly, Figure 10 presents the portion of evaluations that resulted in smoldering as shown by presence of sheeting. All evaluations that resulted in smoldering on Substrate B included sheeting. For the other substrates, the presence of sheeting has no apparent effect on smoldering.

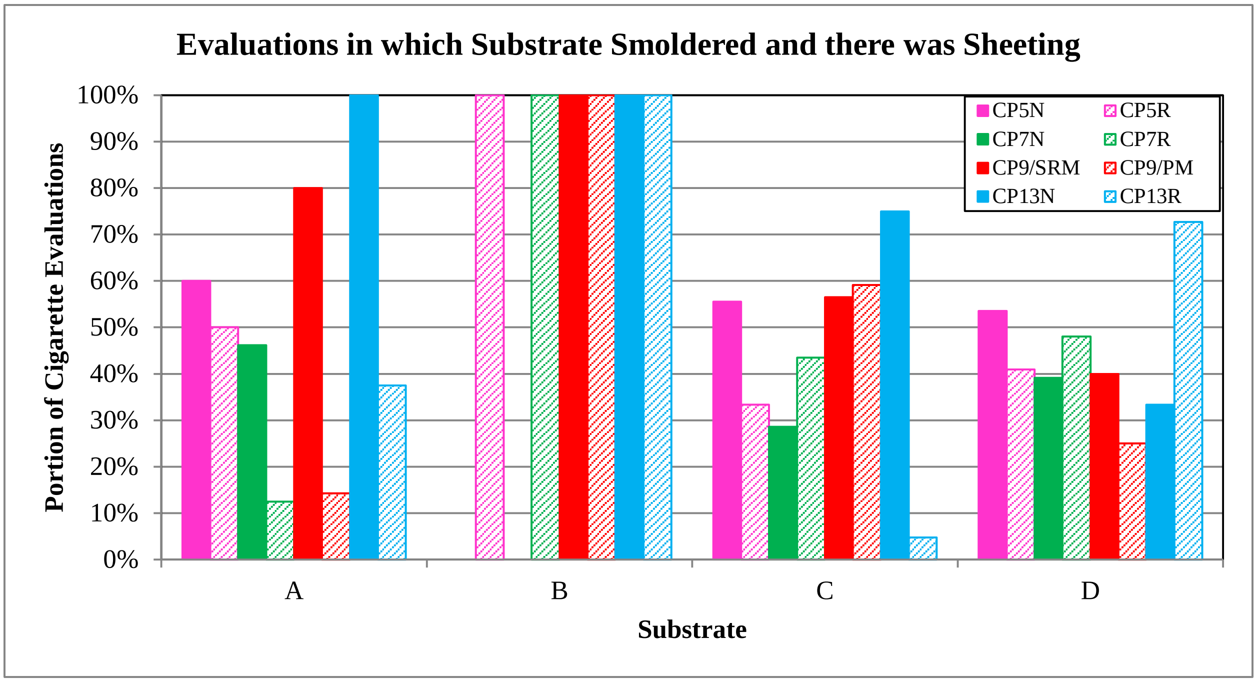

Figure 10. Presence of sheeting for smoldering evaluations by cigarette packaging for each substrate

4.1.2 Full-Length Burns and Smoldering of Substrate

For each of the 434 cigarettes that caused smoldering, it was difficult to ascertain whether the cigarette had self-extinguished or the heat from the substrate had forced the cigarette to continue burning. In the locations without sheeting, more information on the behavior of the cigarette could be ascertained from the videos and can be categorized into four categories:

- Sometimes it was clear that the cigarette burned its full length before the substrate smoldering started (Figure 11a). These evaluations were considered FLBs.
- Sometimes the smolder front of the cigarette and substrate were the same (Figure 11b). These evaluations were considered FLBs.
- Sometimes the cigarette appeared to stop burning on its own, but the mattress continued to burn (Figure 11c). These evaluations are coded as “No” for FLB. In these evaluations, the cigarettes eventually burned, most likely from the heat of the substrate, not of their own propensity to burn.
- In the remaining evaluations, smoldering became evident at some point as the cigarette was burning, but the location of the smoldering on the substrate was not in sync with the cigarette (Figure 11d). These evaluations were categorized as “unknown.” In contrast to the previous case, the cigarette did not show any cessation of burning during the test.

In tests with sheeting, however, it was more difficult to determine how the cigarette was burning. If there was not much smoldering of the sheeting, the progression of the cigarette could be monitored based on previous experience of the burning behavior of the sheeting. However, most cases were categorized together as “unknown” for whether the cigarette burned its full length.

Figure 11a. Mattress and cigarette smolder front simultaneously growing
FLB = Yes

Figure 11b. Cigarette burned its full length before mattress started to show char growth
FLB = Yes

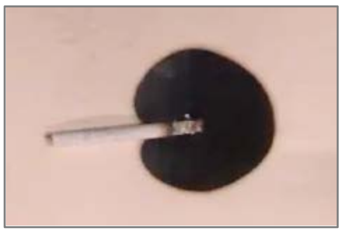

Figure 11c. Cigarette stopped burning but mattress continued
FLB = No

Figure 11d. Cigarette and mattress smolder fronts not synced
FLB = Unknown

Figure 11. Examples of FLB codes for substrates that resulted in smoldering

Table 7. FLB data for evaluations that resulted in smoldering

Cigarette ID	Substrate										
	A			B		C			D		
	FLB			FLB		FLB			FLB		
	Yes	No	NA	Yes	No	Yes	No	Na	Yes	No	NA
CP5N	3	0	2	0	0	12	2	4	3	13	12
CP5R	2	0	0	0	1	9	2	7	5	9	8
CP7N	11	0	2	0	0	22	0	5	9	6	8
CP7R	8	0	0	0	1	14	4	3	13	1	11
CP9/SRM	4	0	1	4	0	12	1	10	9	13	13
CP9 /PM	6	1	0	1	2	9	2	12	7	14	7
CP13N	1	0	1	1	0	15	0	7	1	14	6
CP13R	4	2	2	2	0	9	2	5	6	2	14
Total	**39**	**3**	**8**	**8**	**4**	**102**	**13**	**53**	**53**	**72**	**79**

Because there was much uncertainty, the results presented are limited. Table 7 shows the breakdown of FLB data for the evaluations where smoldering occurred. The plots in Figure 12 show the portions of FLB, no FLB, and unknowns for each substrate where smoldering occurred.

Substrate B did not have any smoldering evaluations for CP5R and CP7N; accordingly, there are no data for those cigarettes. CP7R is a RIP packaging and is expected to self-extinguish. However, as seen in Figure 12b, smoldering also occurred on the substrate, while CP13R (also RIP) did not self-extinguish and also caused smoldering to occur. Many evaluations on Substrate D were unknowns because the substrate smoldered heavily and soon after the start of the test.

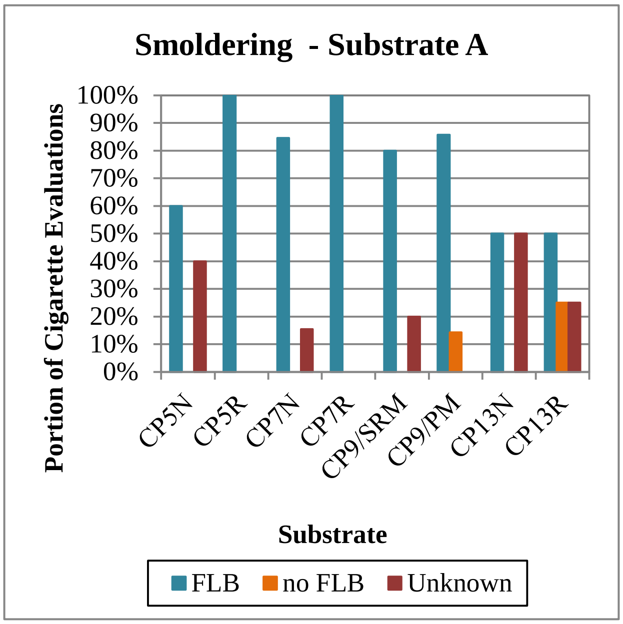

Figure 12a

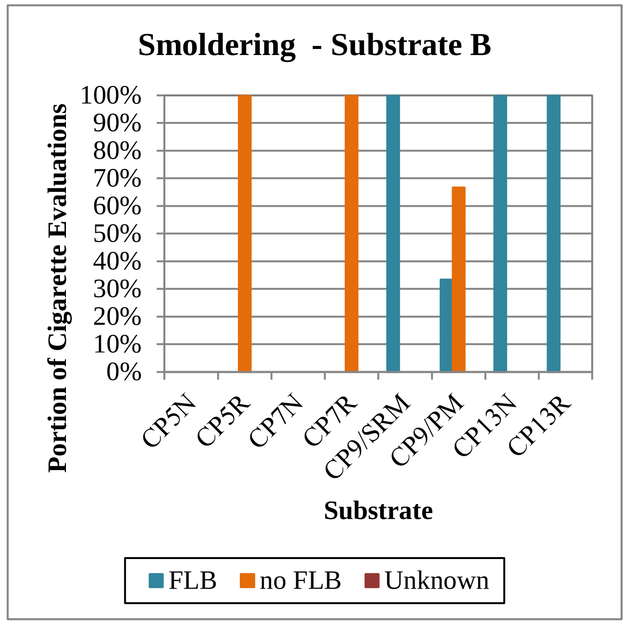

Figure 12b

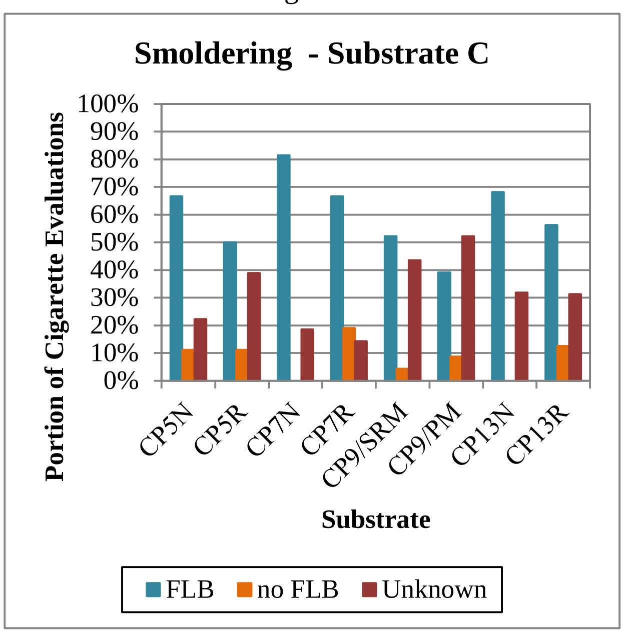

Figure 12c

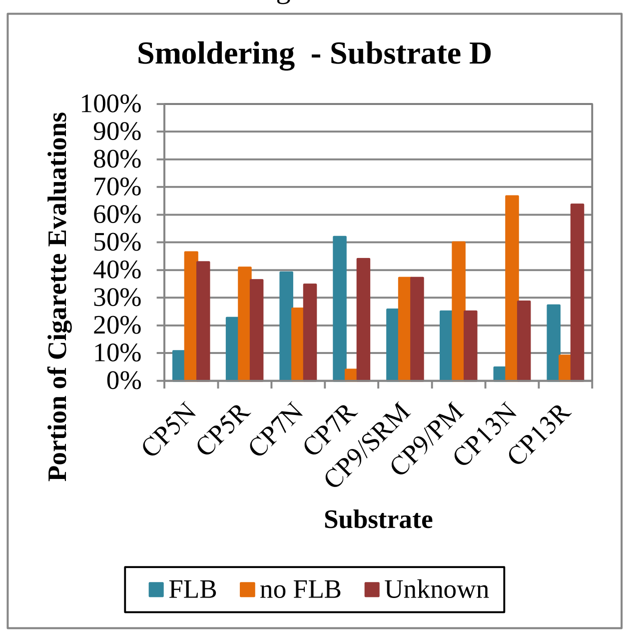

Figure 12d

Figure 12. FLB determinations for all evaluations where smoldering occurred

4.3 Full Length Burns, Overall

Combining the data for all 863 evaluations, the portion of FLB is shown in Figure 13. In this plot, the evaluations previously categorized as unknown FLB are not included. In substrates A, B, and C, the portion of FLB was very high for non-RIP cigarettes. As seen in Figure 12d, there were many unknowns for Substrate D, significantly limiting the number of evaluations considered for Figure 13. The number of evaluations considered for this figure is shown in Table 4.

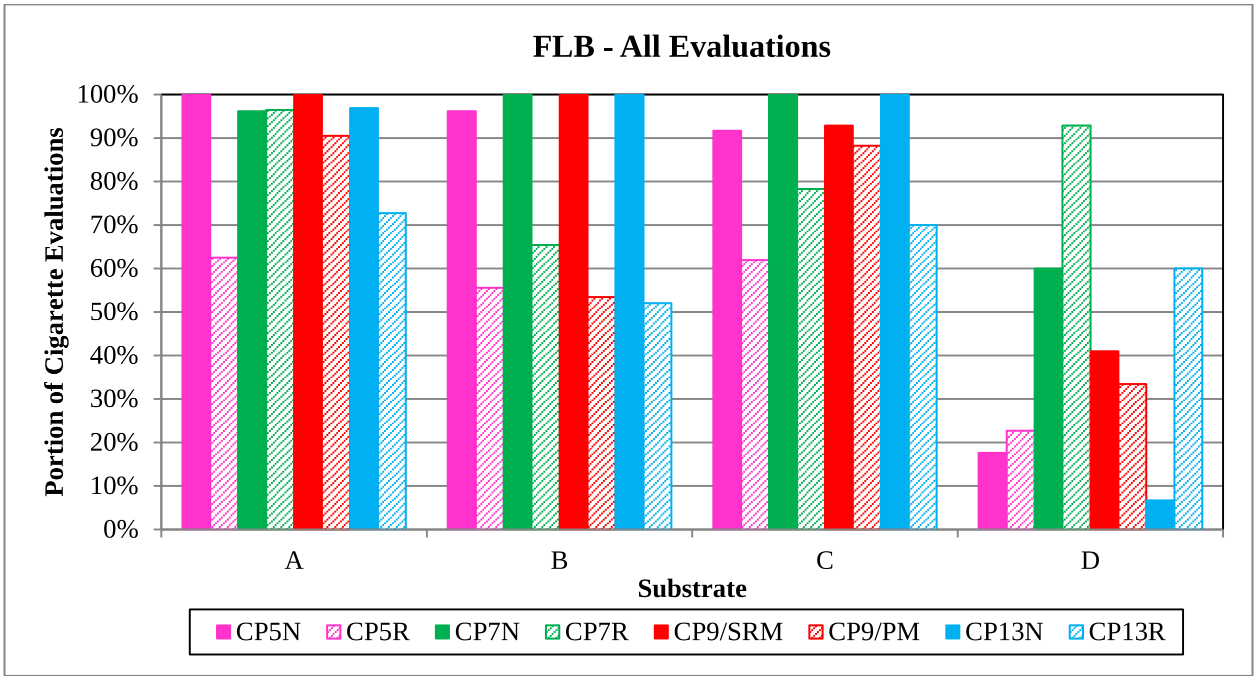

Figure 13. Portion of FLB for all evaluations, including smoldering and non-smoldering substrates

Table 8. Evaluations with FLB for both smoldering and non-smoldering results.

Cigarette ID	Substrate			
	A	B	C	D
CP5N	24	26	24	17
CP5R	24	27	21	22
CP7N	26	27	24	15
CP7R	28	26	23	14
CP9/SRM	20	28	14	22
CP9/PM	21	30	17	21
CP13N	32	27	20	15
CP13R	33	25	20	10

5 OBSERVATIONS

In addition to the results discussed above, many observations were made during the testing on the cigarette and substrate behaviors.

5.1 Char Areas

Staff used ProAnalyst® software to calculate the area of the char as smoldering progressed on the substrates. Typically, the char grows in a circular fashion from the initiation point of smoldering of the substrate. Figure 14 shows a typical progression of the char area as the substrate continues to smolder over time.

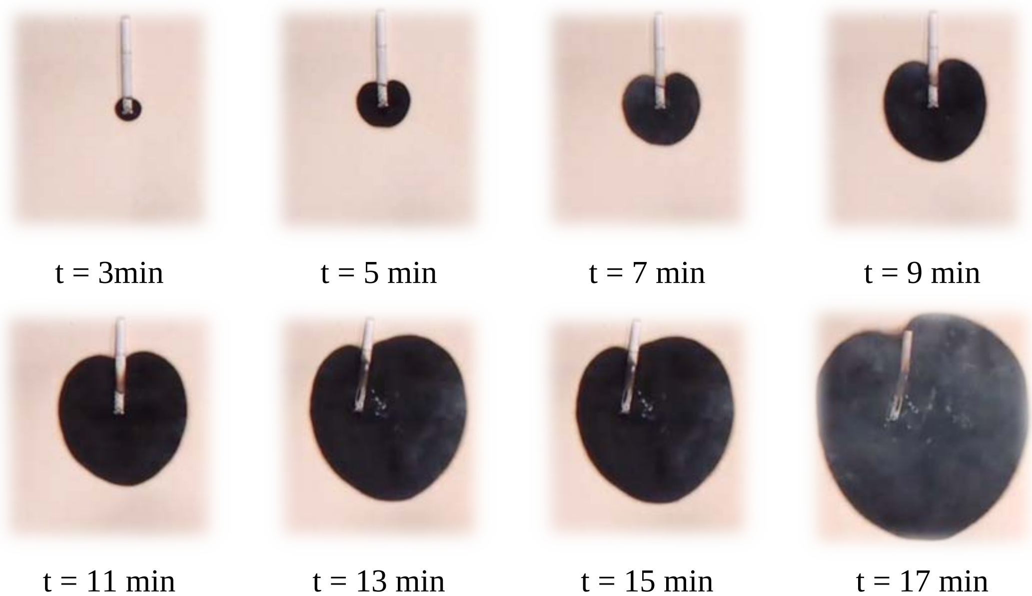

Figure 14. Typical pattern of char growth on a substrate; typically grows as a circle. The time is not typical for all substrates

Not all substrates char in this typical fashion. At the beginning of the smoldering, they often smolder at different rates. The char area data are not a comparable set within a substrate for cigarettes of the same packaging, due mainly to four factors:

- As described earlier, cigarettes were placed in edge locations of the substrates for three of the substrates. In these tests, the char area was only measured on the top surface of the substrate; and because it was on the edge, it did not grow in the same circular fashion; thus, it does not produce the same rate of area growth.
- For the locations where sheeting was present, the top sheet did not show the char area of the substrate directly, and the sheet puckered as it smoldered, showing a different pattern of the char area than what was really on the substrate.
- Sometimes the char area around one cigarette overlapped with the char area growing from another cigarette area on the substrate. When this occurred, the char areas could no longer be distinguished from one another.

- There were some instances when the char area grew out of the video camera frame, so the char growth could not be calculated for the entire test.

Even though these issues exist, observations could be made on the rates of char growth evaluations that were straightforward. Since the majority of evaluations that resulted in smoldering occurred on the edge location for substrate A, the average char growth rate at this location is shown in Figure 15.

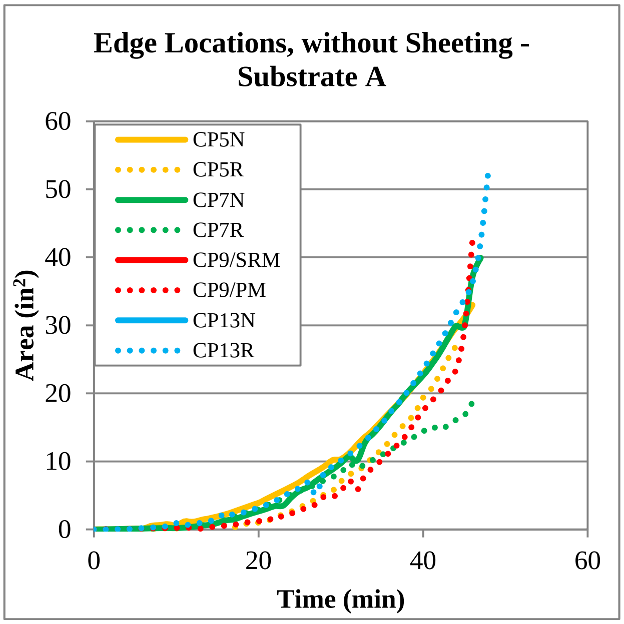

Figure 15a. Substrate A char growth on edge location, without sheeting.

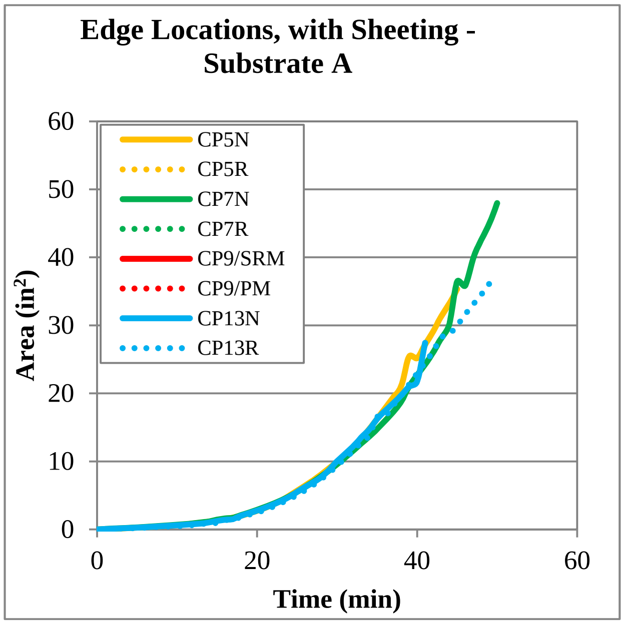

Figure 15a. Substrate A char growth on edge location, with sheeting.

Figure 15. Substrate A char area growth rate

All but one of the evaluations on substrate B that resulted in smoldering were located under sheeting. The average, or in some cases, the only, char area growth for each of the packagings is shown in Figure 16. Packagings CP5N and CP7N did not have any evaluations that resulted in smoldering on this substrate.

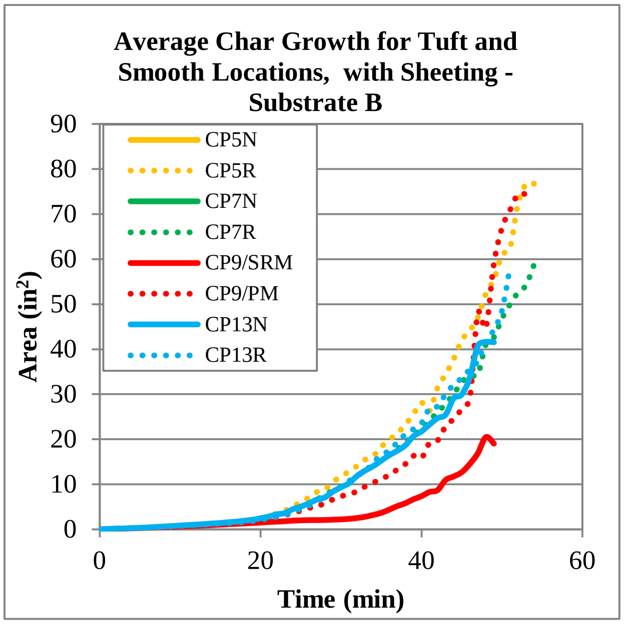

Figure 16. Substrate B char growth rate on tuft and smooth locations, with sheeting

Figure 17 shows the average char area growth for substrate C, which had no edge locations, so all the smoldering evaluations are included in these plots. The growth rates for the RIP and non-RIP types of the same packaging seem similar in the locations without sheeting. The growth rate of the RIP types seems a little slower with the sheeting present, although the growth rate was a little faster overall with sheeting present.

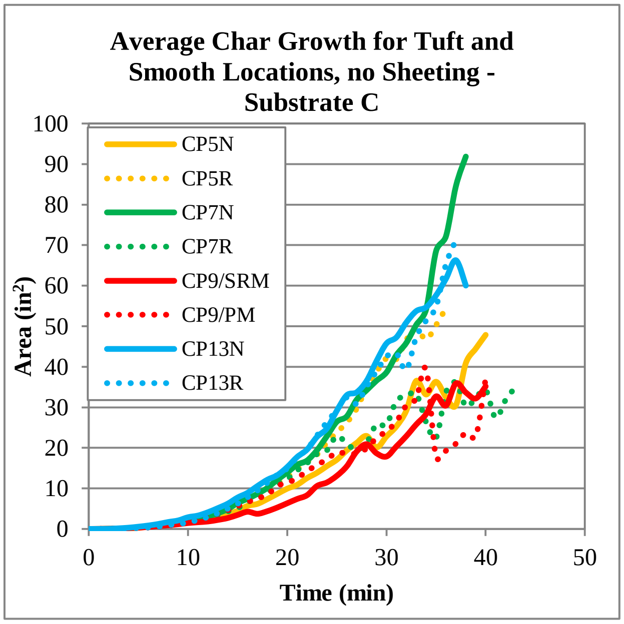

Figure 17a. Substrate C char growth rate on tuft and smooth locations, without sheeting.

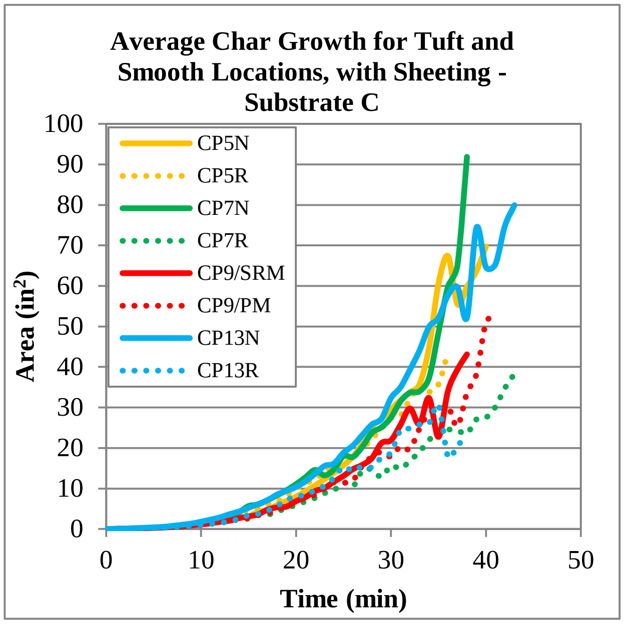

Figure 17b. Substrate C char growth rate on tuft and smooth locations, with sheeting.

Figure 17. Substrate C char area growth rate

Figure 18 shows the average char area growth for substrate D, in the tuft and smooth locations only. The rate of growth was slightly slower when sheeting was present, as expected, because the sheeting obscures the char initially. However, in the presence of sheeting, the rate of growth was very similar, not only for the RIP and non-RIP types of the same packagings, but also for all packagings. Because the presence of the sheeting affects the air flow around the cigarette, this may be more representative of the growth rate of the substrate than the non-sheeted locations.

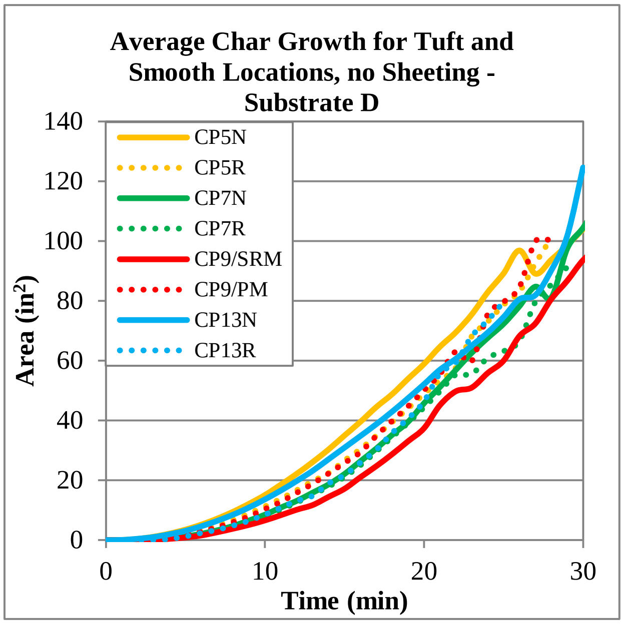

Figure 18a. Substrate D char growth rate on tuft and smooth locations, without sheeting

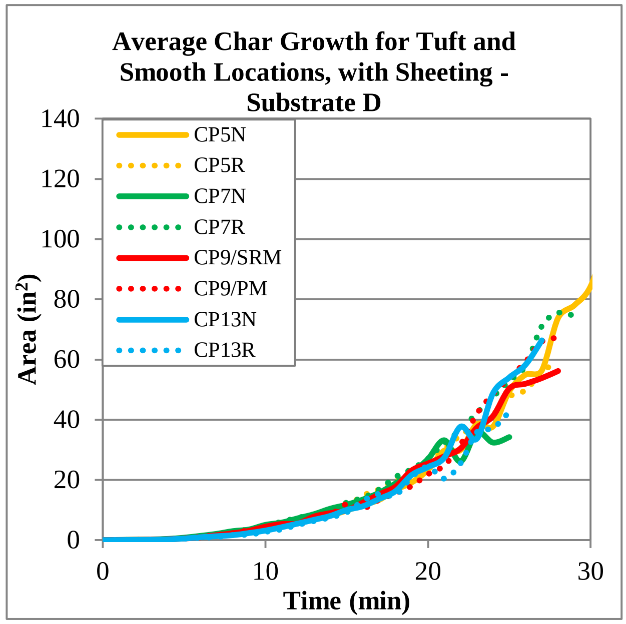

Figure 18b. Substrate D char growth rate on tuft and smooth locations, with sheeting

Figure 18. Substrate D char area growth rate

As would be expected, the observed char areas described above indicate that the substrates have differing rates of smolder. However, the growth rates on each of the substrates are similar between cigarettes, indicating that once the cigarette has initiated smoldering of the substrate, the substrate dominates the smoldering behavior.

5.2 RIP Cigarettes - Banding

The RIP technology currently used by cigarette manufacturers is to wrap cigarettes with two or three thin bands of less porous paper that act as “speed bumps” to slow down a burning cigarette’s smoldering front, see Figure 19.[11]

[11] Coalition for Fire Safe Cigarettes, www.firesafecigarette.org.

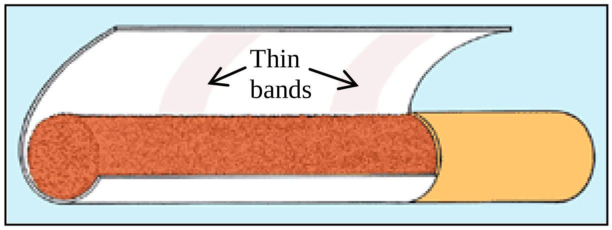

Figure 19. An illustration of a cigarette showing the banded paper

Often, as a RIP cigarette burned, there was a discoloration in the cigarette. The staff hypothesizes that this discoloration indicates a "band" on the RIP cigarette. Figure 20 shows examples of this discoloration for all of the packagings. Further, as the RIP cigarettes burned, sometimes the smoldering front of the cigarette could be seen slowing down over an area or the cigarette ash would break apart; this was probably also associated with the presence of a band.

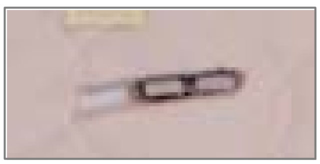

Figure 20a. CP5R

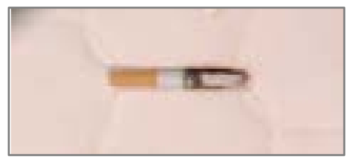

Figure 20b. CP7R

Figure 20c. CP9/PMR

Figure 20d. CP13R

Figure 20. Examples of discoloration at a band

The contractor was not able to see the bands on the RIP cigarettes before the cigarettes were tested; so no data are presented here for number or bands or band-to-band distance. Additionally, the contractor was unable to recover and measure all the cigarettes in which there was still a portion of the tobacco column unburned, so no data are presented on the measurements.

6 CONCLUSIONS

The testing completed in this series aimed to evaluate the relative difference between the RIP and non-RIP cigarettes of the same packaging on a set of specific mattress substrates. While the results are specific to the substrates and packagings tested, and they are not offered as a generalization on the behavior of all cigarettes, some conclusions can be made:

- ✓ There was significant variability in ignition propensity among both RIP and non-RIP cigarettes when allowed to burn on the different substrates tested here. The variability in full length burn portions was more pronounced on some substrates.

- ✓ In evaluations where smoldering did not occur, both non-RIP and RIP-types of the same packaging exhibited full length burns.

- ✓ The effect of sheeting on the incidence of smoldering varied between substrates. On substrate B, all of the evaluations where smoldering occurred had sheeting. However, for the other substrates, the presence of sheeting was not an obvious effect where smoldering occurred.

- ✓ There was no apparent consistent effect of location type on smoldering.

- ✓ On substrates that were expected to be more smolder-prone (*i.e.*, noncomplying with 16 CFR part 1632), both RIP and non-RIP cigarettes caused smoldering, indicating that once the cigarette initiated smoldering, the substrate dominated the continuation of smoldering. This also suggests that the RIP cigarettes did not have a desired effect on the substrates that would not be required to meet current standards.

- ✓ The portion of full length burn did not match the portion of cigarettes that caused smoldering to occur. Some cigarettes burned their full length but did not cause smoldering to occur; conversely, some cigarettes caused smoldering to occur before a full length burn. This lack of correlation indicates that the likelihood of a cigarette to have a full length burn, alone, is not sufficient to determine the ignition propensity of a cigarette.

- ✓ Based on these results, there is still uncertainty about the effectiveness of the RIP cigarette in reducing smoldering ignition on mattresses and mattress pads.

APPENDIX I. MATTRESS AND MATTRESS PAD TEST PLAN

Task 1
Cigarette Ignition Risk Project - Test Plan for Evaluating Cigarettes on Mattresses and Mattress Pads

1. SCOPE

The following task shall be completed per the Consumer Product Safety Commission (CPSC) Contract CPSC-D-11-0001. The purpose of this task is to evaluate the difference, if any, between conventional and Reduced Ignition Propensity (RIP) cigarettes on mattress and mattress pad substrates.

2. SUMMARY

In this test series, cigarettes will be placed on mattress or mattress pad substrates (herein referred to as "substrate") and allowed to burn to completion or self-extinguishment. Video cameras located above the substrate will record the burning behavior and char development around each cigarette. This test plan describes: the preparation of mattresses, mattress pads, and cigarette samples; cigarette lighting procedures; how and where to place cigarettes; and recordkeeping requirements.

Each test will consist of 18 cigarettes of both RIP and traditional type. The cigarettes will be placed in three locations (as available): on the smooth surface, in a tuft or on the tape edge of the substrate area. Each substrate will be visually divided into six sections or blocks for cigarette placement. The cameras that will be placed above the substrate should correspond approximately to each block, with overlaps. A schematic of the substrate blocking and camera placement is provided in Appendix B.

Below is the general test procedure. The attached sampling plans specify cigarettes and locations for each test.

3. GOVERNMENT FURNISHED MATERIALS.

A. All cigarette samples
B. Six video cameras with trigger mechanisms
C. Ten cigarette holders
D. Schematic for video camera placement
E. External hard drive for videos and photos
F. Sampling plans

4. CONTRACTOR FURNISHED MATERIALS.

A. All mattress and mattress pad samples. Contractor shall furnish the following mattress and mattress pad samples. All samples of each product should be ordered from the same vendor in one order.

Product	Brand	Size	Price[1]	#	Website/Contact
Mattress	[redacted] Quilted Organic Cotton Deluxe	Twin	$699	12	[redacted]
Mattress Pad	[redacted] Organic cotton mattress pad – double weight	Full	$259	12	[redacted]
Mattress	[redacted], All organic cotton mattress	Twin	$552	12	[redacted] (will require a letter from CPSC)
Mattress	[redacted] Futon	Twin	$530	12	[redacted] (will require a letter from CPSC)

5. TEST PLAN

A. Equipment List

- 6 Cameras
- Dry-erase board for identifying videos and photos
- 19 stop watches
- 10 cigarette holders
- Vacuum and hose
- Candle or alcohol burner or lamp to ignite cigarettes
- Temperature and humidity measuring device
- Anemometer
- Balance, with draft enclosure and a precision of 0.001g.
- Ruler, in mm.

B. Mattress/Pad Sample Preparation

1. Label mattresses and pads using the codes as assigned in Appendix A.
2. Launder mattress pad.[2] Mattresses require no laundering.
3. Condition mattress/pad and sheeting for 48 hours at 70 ± 5ºF and 55 ± 5% RH prior to testing.

C. Cigarette Preparation

1. Remove cigarettes from cartons per sampling plan, in Appendix G. Record carton and pack number.

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[1] Estimated cost; does not include shipping.
[2] Launder per 16 CFR §1632.5(b)(2).

2. Make a pencil mark on each cigarette 10 mm from the lighting end.
3. Condition cigarettes for 48 hours at 70 ± 5ºF and 55 ± 5% RH.
    a. After conditioning, mark cigarettes with pencil at 10mm from lighting tip.
    b. Measure the length [3]and mass of each cigarette. Record values on data sheet.
    c. Measure band width and distance between bands on RIP cigarettes, if possible (bands can often be seen on light tables). Record on data sheet.
4. If cigarettes were removed from conditioning chamber for measurement, re-condition the cigarettes for 48 hours at 70 ± 5ºF and 55 ± 5% RH prior to testing.
    a. Note: In-house testing showed that storing cigarettes in flat trays helped to organize the cigarettes. See Appendix D.

D. <u>Test Setup</u>

1. Set all stop watches to 00:00 (mm:ss)
2. Locate cameras so that there is one in the center of each block of the mattress. See Appendix B for placement.
3. Turn on cameras. The cameras need to be AC adaptor powered.
4. Place placard with test date, number and sample ID, for at least 5seconds in view of each camera for test identification.
5. Turn off cameras until ready to start test.
6. Record temperature and relative humidity in test area.
7. Record the air flow at sample surface, in all four cardinal directions.
8. Place sample mattress or mattress pad on fiberboard. Record time that sample was removed from conditioning.
9. Vacuum any debris or lint from the substrate surface.
10. Photograph any identifying tags or marks on the mattress or mattress pad sample. Make sure that the test number and sample ID are indicated in the photograph for recordkeeping purposes. Cut off any tags that may interfere with char formation. Save the tags for CPSC.
11. Place a label with test and cigarette number in the location where each cigarette will be placed. These labels will need to be in a contrasting color that can be seen in the videos. See Appendix C for instruction on how to place cigarettes in these locations for the different samples. Information on placement of cigarettes using the sheeting fabric is also included in the Appendix.

E. <u>Conduct Tests</u>

1. Turn on cameras. Set up so that the camera takes elapsed photos at 30 second intervals.
2. Light cigarettes with a vacuum hose and candle or other open flame source. Hold cigarette in vacuum hose stream until evenly lit. See Appendix D.
3. Place cigarettes in holders and allow to burn to 10 mm mark before placing on substrate.

[3] The length includes the filter, where applicable.

- To allow enough time between cigarettes for placement, it is recommended that cigarettes are lit 30 seconds apart.

4. Place cigarettes on specimen per sampling plan and previously located labels.
    - Ensure that the label near the cigarette for video identification, but not in the char area for identification in photos.
5. Record time that each cigarette was placed. See Appendix F for a sample data sheet.
6. If cigarette self-extinguishes within 60 seconds of placement, re-ignite the same cigarette and re-place.
7. Record time to full length burn of cigarette, if possible.
    - Note: Do not lift sheeting to determine full length burns.
    - For cigarettes with filters: note the time at which both the smoke has ceased and the cigarette has burned past the words/ colored paper over the filter. See Appendix E for more detail.
8. Record time of cigarette self-extinguishment, if possible.
    - Note: Record only in the case that the cigarette extinguishes before burning its full length.
    - Do not lift sheeting to determine self-extinguishment.
9. Record time of substrate self-extinguishment, if possible.
10. Record any excessive smoke or other unusual occurrence per cigarette.
11. Test for each cigarette will end when all cigarettes and substrate have stopped smoldering, or at 60 minutes after cigarette is placed, whichever comes first.

F. <u>Post-test:</u>

1. Turn off video cameras.
2. If it is safe to do so:
    a. Photograph each location, including the cigarette label and with a ruler in view, if possible.
    b. Measure the maximum char length in 4 directions from the cigarette, if possible. Record measurement on data sheet.
3. For each cigarette that did not burn its complete length[4]:
    a. Photograph with a ruler in the picture.
    b. Measure the mass of each cigarette, if possible. Lightly tap the cigarette to remove any loose ash prior to measurement. Record mass on the data sheet.
    c. Measure location of band from smoking end, if present. Record length on the data sheet.

6. Reporting Requirements

Per the Original Contract, section H, Reporting Requirements, the contractor will provide the following:

---

[4] If it looks like other areas on the substrate may cause extreme smoldering, it is recommended that self-extinguished cigarettes be removed before end of test to ensure that measurements can be made.

1. A bi-weekly status report during the task period, to be submitted to the CPSC project manager as below.

   a. Format – The report must be provided in either Microsoft Word or Adobe Acrobat format and must be e-mailed to the CPSC project manager at: SMehta@cpsc.gov.

   b. Content – The report must contain the following:
      - Status of project and new developments, e.g. how many tests have been completed
      - Problems and proposed solutions
      - Changes in schedule

2. All test results to the CPSC project manager at:
   Shivani Mehta
   U.S. Consumer Product Safety Commission
   5 Research Place
   Rockville, MD 20850

   a. Format – The data results of the Contractor testing will be provided in a Microsoft Excel spreadsheet format (1 electronic copy by email and 1 electronic copy on a CD). A sample data sheet is in Appendix F.

   b. Videos will be downloaded onto an external hard drive that will be provided by CPSC.

   c. Content – The results of the Contractor testing will include all data recorded and observations. Specifically, the following information will be provided for each cigarette tested:
      - Date of test
      - Beginning time of test
      - Operator ID (s)
      - Ambient humidity level (% R.H.) at beginning of test
      - Ambient temperature (ºF) at beginning of test
      - Air flow (ft/sec) in each of the cardinal directions at beginning of test
      - Cigarette brand (using CPSC identifier)
      - Type of cigarette (non-RIP, RIP)
      - Cigarette number
      - Carton and pack of cigarette
      - Mass and length of cigarette before test
      - Substrate (mattress or pad) tested
      - Location type (tuft, smooth, edge)
      - Cigarette burn to completion (yes/no)
      - Time for cigarette to burn to completion, if possible
      - Cigarette self – extinguishment (yes/no)
      - Time for cigarette self – extinguishment

- Substrate time to self – extinguishment
- End time of test
- Ambient humidity level (% R.H.) at end of test
- Ambient temperature (ºF) at end of test
- Mass and length of cigarette after test, if possible
- Photographs of the mattress with the cigarettes in place, before and after test.

7. OTHER REQUIREMENTS:
CPSC staff will visit the testing facility once materials are received and testing is in progress. The exact date and time will be determined based on contractor's estimated test schedule and will be discussed with the project officer.

8. DELIVERY INFORMATION
Testing shall be completed and data received at CPSC no later than 60 days after receipt of materials.

APPENDIX A. CODES FOR SUBSTRATE AND CIGARETTES

Substrates

Brand	Type	Size	Code	Quantity
[redacted]	Pad	Full	A	12
[redacted]	Mattress	Twin	B	12
[redacted]	Futon	Twin	C	12
[redacted]	Futon	Twin	D	12

Cigarettes

Brand	Code	RIP/Non	Quantity
[redacted]	[redacted]	Non	108
[redacted]	[redacted]	RIP	108
[redacted]	[redacted]	Non	108
[redacted]	[redacted]	RIP	108
[redacted]	[redacted]	Non	108
[redacted]	[redacted]	RIP	108
[redacted]	[redacted]	Non	108
[redacted]	[redacted]	RIP	108

APPENDIX B. SUBSTRATE BLOCKING AND CAMERA PLACEMENT

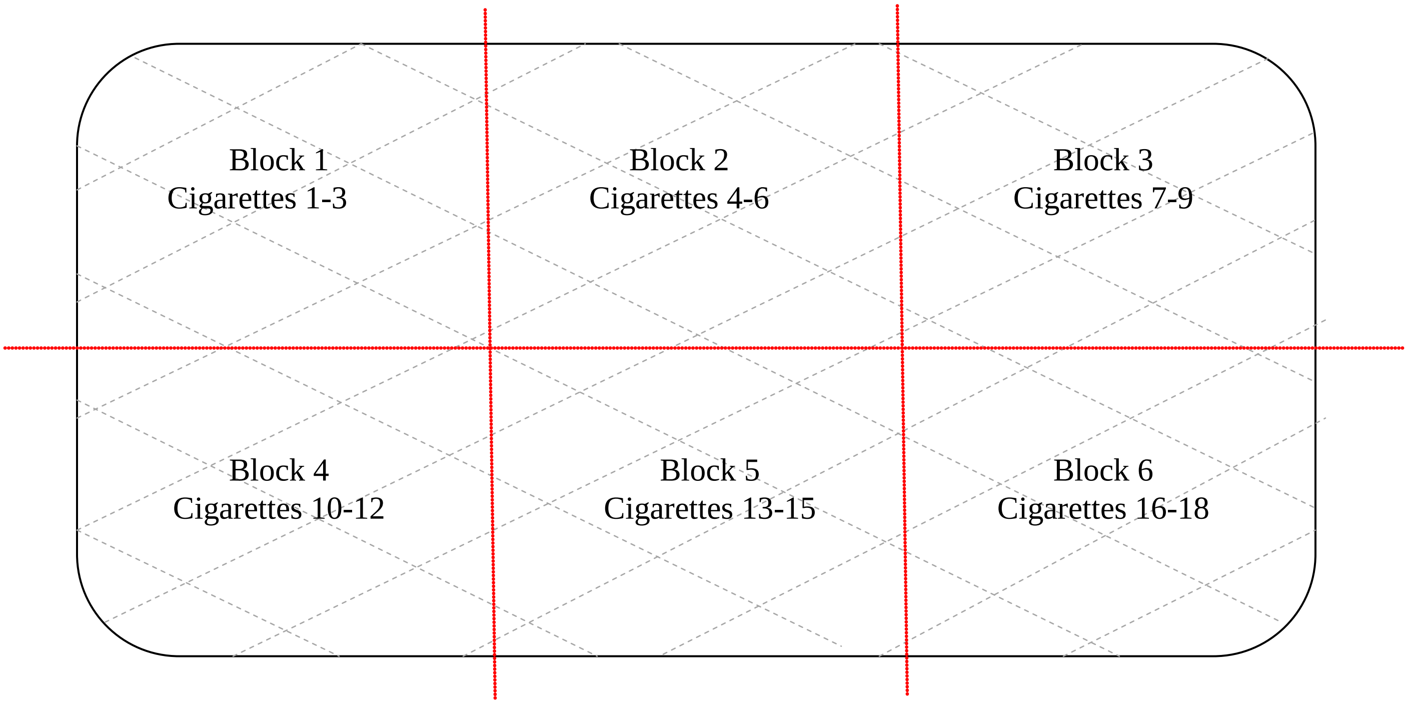
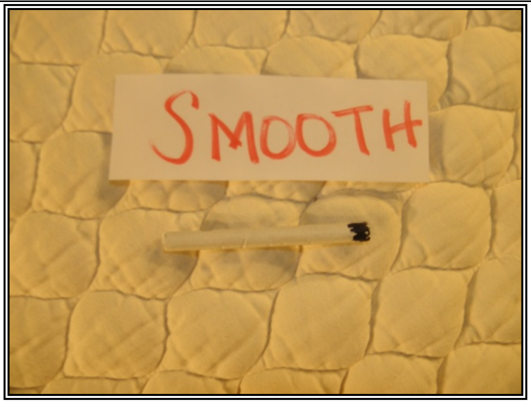
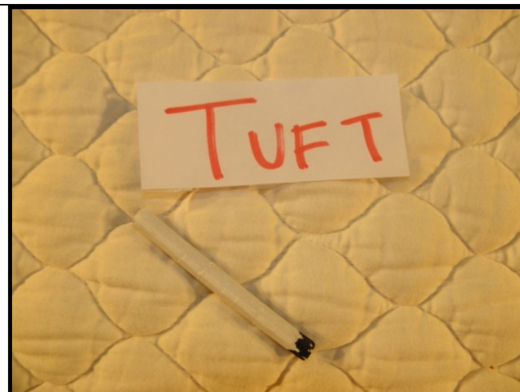
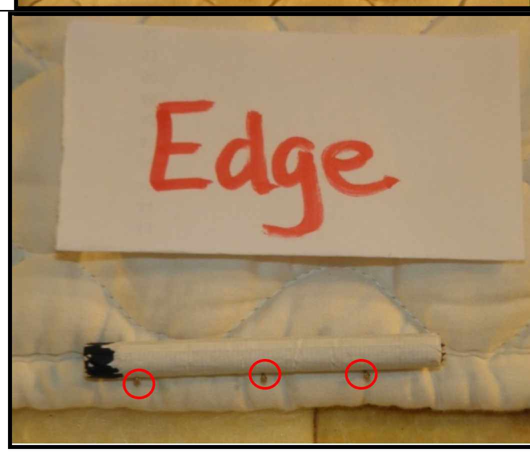


Figure 1. Substrate Blocking

APPENDIX C. PLACEMENT OF CIGARETTES FOR EACH SUBSTRATE BRAND

Placement for [redacted]

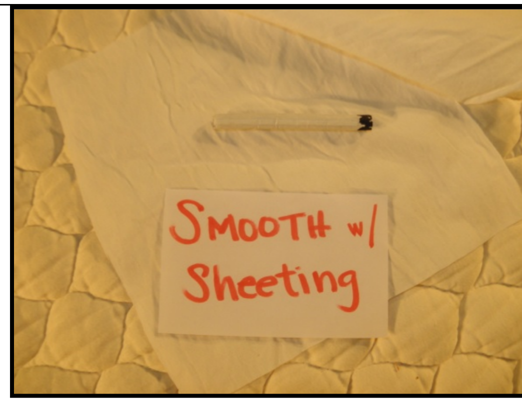
Sooth, No Sheeting The cigarette should start and end on the smooth surface. Cigarettes may also be placed perpendicular to what is shown in picture.	
Tuft, No Sheeting The cigarette should be placed in the crevice made by the quilting. Cigarettes may also be placed perpendicular to what is shown in picture.	
Edge, No Sheeting Cigarettes should be placed in the crevice made by the stitching on the edge. Pins should be used to hold the cigarette in place, as seen in the red circles. The pins should be little lower than the top of the cigarette.	

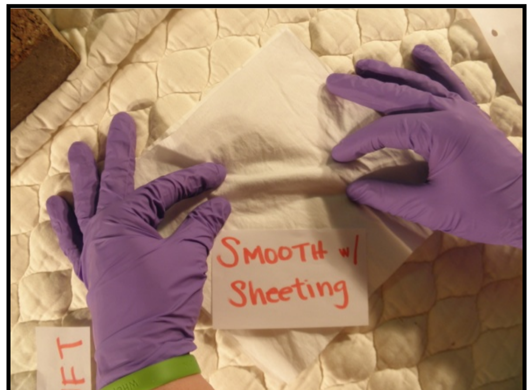
Smooth, with Sheeting

The cigarette should start and end on the smooth surface. It may be helpful to run a finger along the quilt lines to help define the smooth surface area through the sheeting fabric.

Once the cigarette is covered with the sheeting fabric, flatten the sheeting around the cigarette so that there is contact between the sheeting and cigarette. Be careful not to squeeze the cigarette or to cause the cigarette to move/shift locations.

Cigarettes may also be placed perpendicular to what is shown in picture.



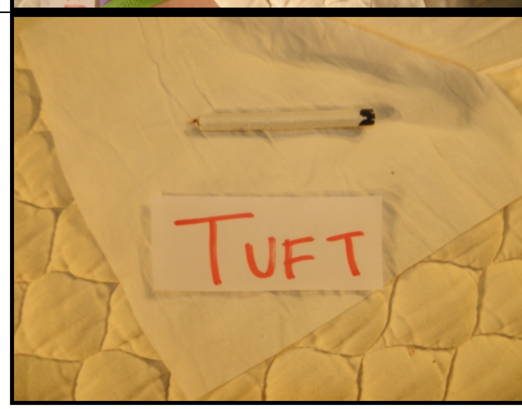


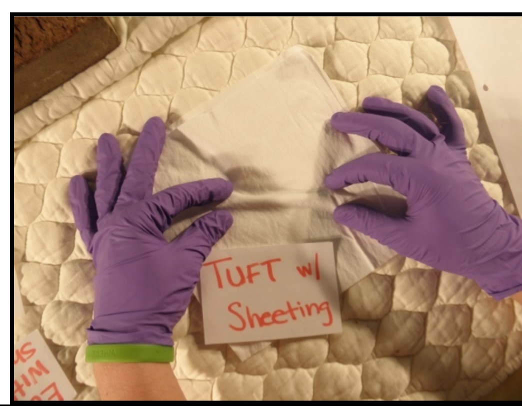
Placement on Tuft, with Sheeting

The cigarette should be placed in the crevice made by the quilting. It may be helpful to run your finger along the crevice so that it is clear where the tuft is under the sheeting for ease of placement.

Once the cigarette is covered with the sheeting fabric, flatten the sheeting around the cigarette so that there is contact between the sheeting and cigarette. Be careful not to squeeze the cigarette. Or to cause the cigarette to move/shift locations.

Cigarettes may also be placed perpendicular to what is shown in picture.

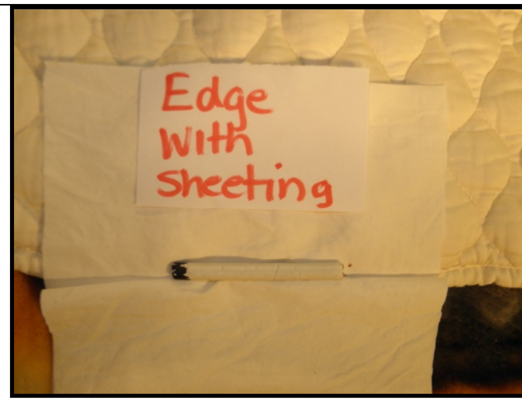


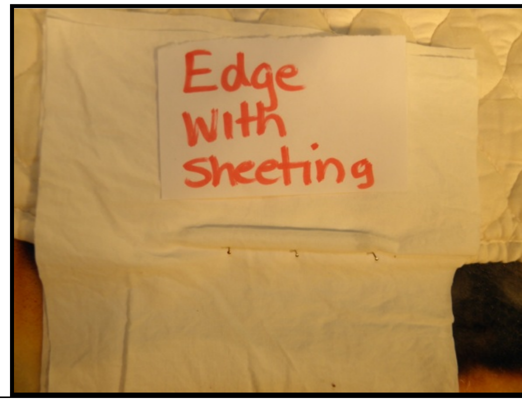


Placement on Edge, with Sheeting

Cigarettes should be placed in the crevice made by the stitching on the edge. Pins should be placed through both pieces of sheeting to hold the cigarette in place once the cigarette is covered. The pins should be little lower than the top of the cigarette. This can be done before the lit cigarette is placed on the test surface for ease of placement.

Once the cigarette is covered with the sheeting fabric, flatten the sheeting around the cigarette so that there is contact between the sheeting and cigarette. Be careful not to squeeze the cigarette. Or to cause the cigarette to move/shift locations.

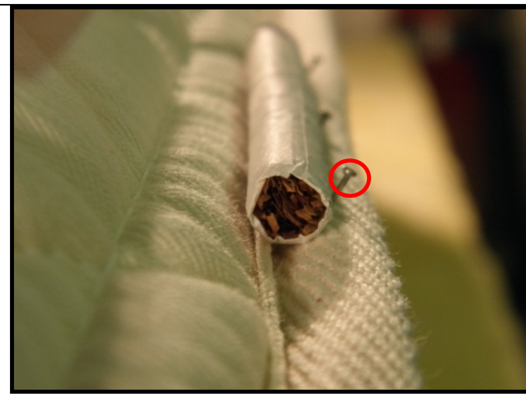
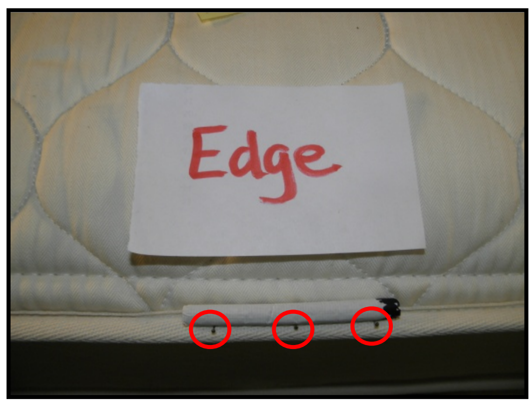


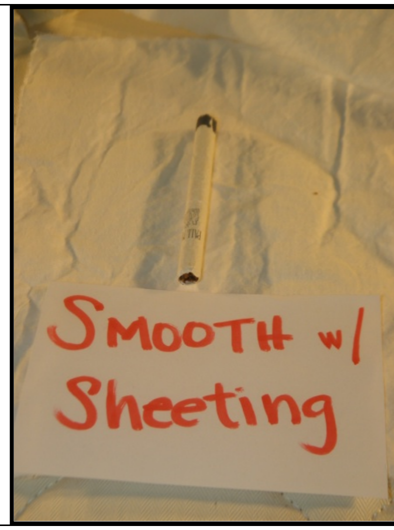


Placement for [redacted] Mattress

Smooth, No Sheeting

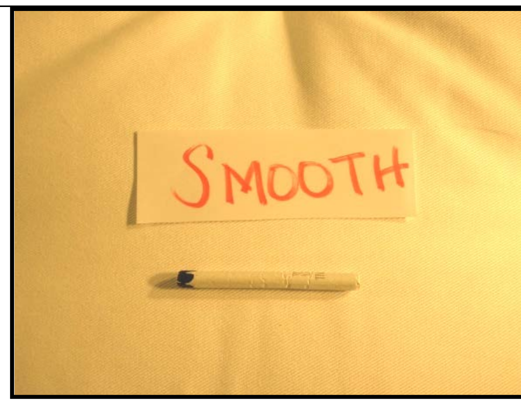
The cigarette should start and end on the smooth surface. Cigarettes may be placed in any direction as long as the entire cigarette in on the smooth surface.

Tuft, No Sheeting The cigarette should be placed in the crevice made by the quilting. The smoking end of the cigarette should terminate on the tuft line.	
Edge, No Sheeting Cigarettes should be placed in the crevice made by the tape edge. Pins should be used to hold the cigarette in place, as seen in the red circles. The pins should be little lower than the top of the cigarette.	 

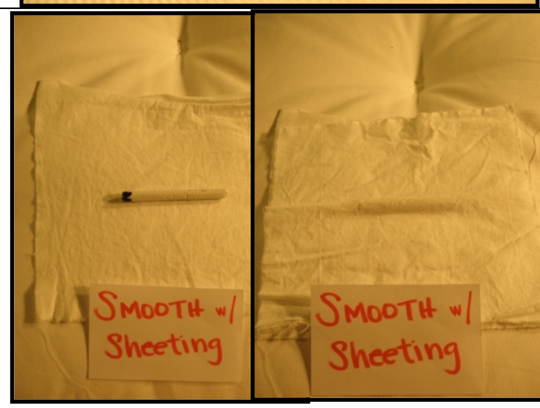
Smooth, with Sheeting The cigarette should start and end on the smooth surface. It may be helpful to run a finger along the quilt lines to help define the smooth surface area through the sheeting fabric. Once the cigarette is covered with the sheeting fabric, flatten the sheeting around the cigarette so that there is contact between the sheeting and cigarette. Be careful not to squeeze the cigarette or to cause the cigarette to move/shift locations.	
Placement on Tuft, with Sheeting The cigarette should be placed in the crevice made by the quilting. It may be helpful to run a finger along the crevice, through the sheeting fabric so that it is clear where the tuft is under the fabric for ease of placement. Once the cigarette is covered with the sheeting fabric, flatten the sheeting around the cigarette so that there is contact between the sheeting and cigarette. Be careful not to squeeze the cigarette, or to cause the cigarette to move/shift locations.	
Placement on Edge, with Sheeting Cigarettes should be placed in the crevice made by the tape edge. Pins should be placed through both pieces of sheeting to hold the cigarette in place once the cigarette is covered. The pins should be little lower than the top of the cigarette. This can be done before the lit cigarette is placed on the test surface for ease of placement. Once the cigarette is covered with the sheeting fabric, flatten the sheeting around the cigarette so that there is contact between the sheeting and cigarette. Be careful not to squeeze the cigarette, or to cause the cigarette to	

<table>
<tr><td>move/shift locations.</td><td>
</td></tr>
</table>

Placement for The [redacted] [redacted]

<table>
<tr><td>Smooth, No Sheeting
The cigarette should start and end on the smooth surface. Cigarettes may be placed in any direction as long as it stays in the center of the smooth surface.</td><td>
</td></tr>
<tr><td>Tuft, No Sheeting
The cigarette should be placed in the valley made by the tufts. Cigarettes may be placed in any direction out of the tuft. The lit end of the cigarette must be outside the valley, as shown in the picture.</td><td>
</td></tr>
</table>

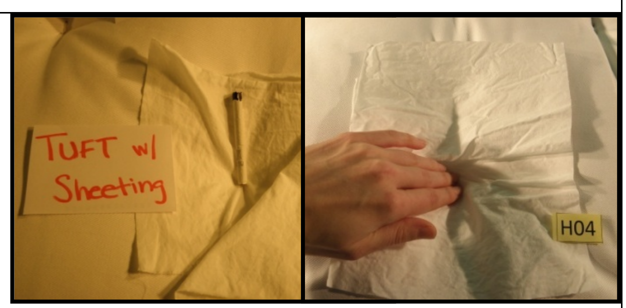
Smooth, with Sheeting
Once the cigarette is covered with the sheeting fabric, flatten the sheeting around the cigarette so that there is contact between the sheeting and cigarette. Be careful not to squeeze the cigarette. Or to cause the cigarette to move/shift locations.
Cigarettes may be placed in any direction as long as it stays in the center of the smooth surface.

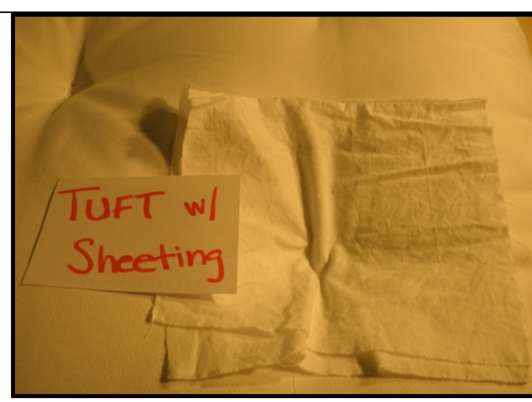


Placement on Tuft, with Sheeting
The cigarette should be placed in the crevice made by the tufting. Place a sheet centered over the tuft; place a finger into the valley so that the sheeting sits against the futon surface

Once the cigarette is covered with the sheeting fabric, flatten the sheeting around the cigarette so that there is contact between the sheeting and cigarette. Be careful not to squeeze the cigarette. Or to cause the cigarette to move/shift locations.

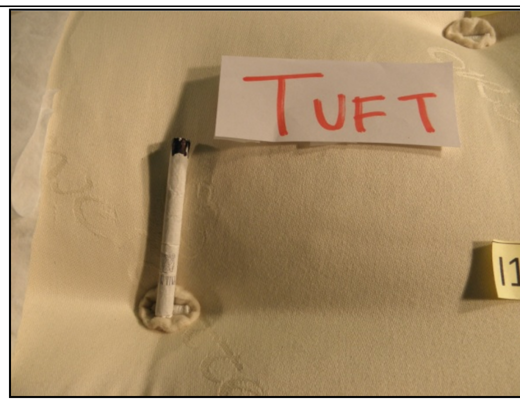
Cigarettes may be placed in any direction out of the tuft. The lit end of the cigarette must be outside the valley, as shown in the picture.

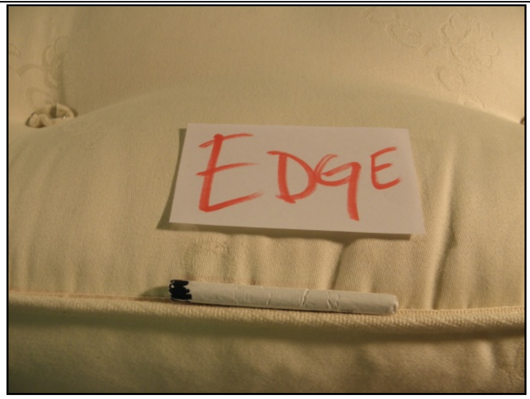
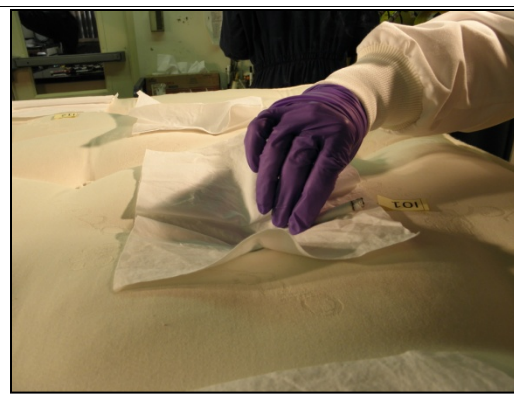




***Note**: If the tuft looks like it has been mistakenly punctured, as seen here, or the tuft area does not look like other tufts on the futon, do not use this tuft location.	

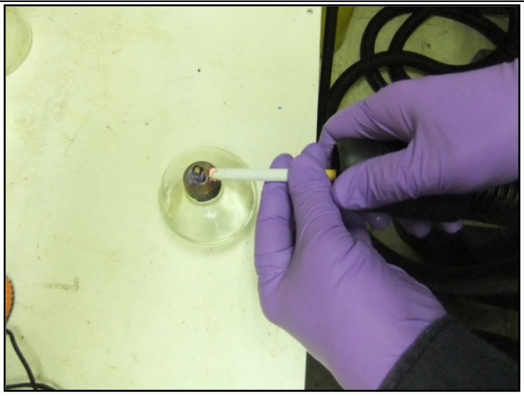
Placement for the [redacted] Mattress

Smooth, No Sheeting The cigarette should start and end on the smooth surface. Cigarettes may be placed in any direction as long as the entire cigarette in on the smooth surface.	
Tuft, No Sheeting The cigarette should be placed in the tuft. The lit end of the cigarette should be facing away from the tuft indentation.	

Edge, No Sheeting Cigarettes should be placed in the crevice made by the tape edge. Pins should be used to hold the cigarette in place, as seen in .	
Smooth, with Sheeting The cigarette should start and end on the smooth surface. It may be helpful to run a finger along the quilt lines to help define the smooth surface area through the sheeting fabric. Once the cigarette is covered with the sheeting fabric, flatten the sheeting around the cigarette so that there is contact between the sheeting and cigarette. Be careful not to squeeze the cigarette or to cause the cigarette to move/shift locations.	See Placement for The [redacted] Shop, Smooth, with Sheeting example
Placement on Tuft, with Sheeting The cigarette should be placed in the crevice made by the tufting. Place a sheet centered over the tuft; place a finger into the valley so that the sheeting sits against the futon surface Once the cigarette is covered with the sheeting fabric, flatten the sheeting around the cigarette so that there is contact between the sheeting and cigarette. Be careful not to squeeze the cigarette or to cause the cigarette to move/shift locations. Cigarettes may be placed in any direction out of the tuft. The lit end of the cigarette must be outside the valley, as shown in the picture.	 See **Placement for The** [redacted], Placement on Tuft with Sheeting for more detail.
Placement on Edge, with Sheeting Cigarettes should be placed in the crevice made by the tape edge. Pins	

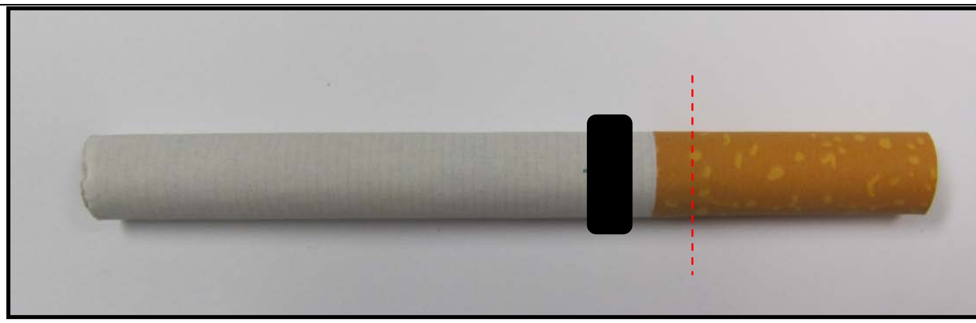
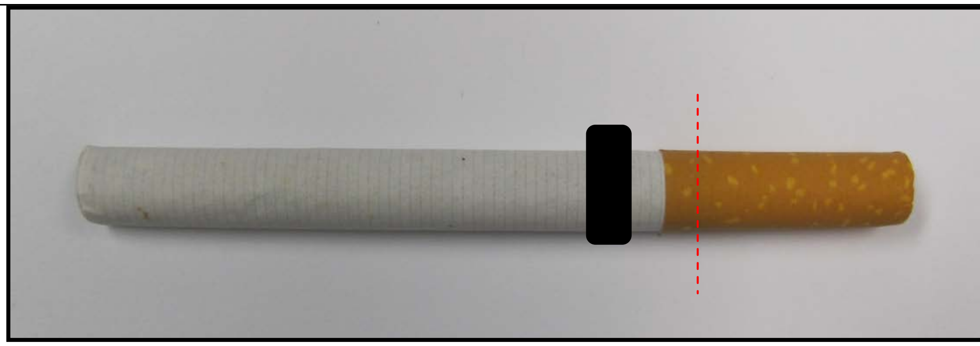
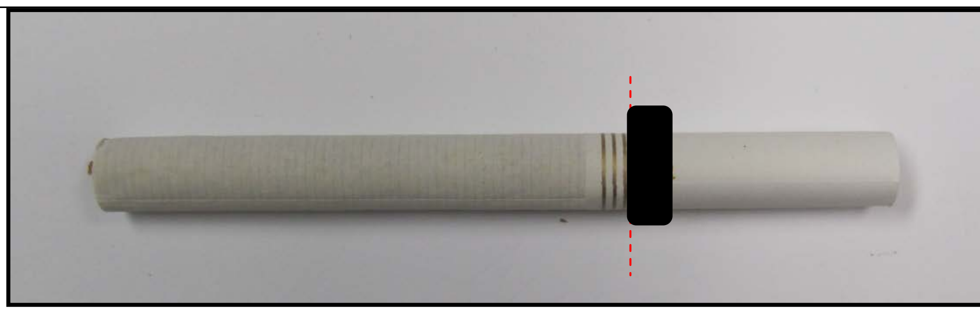
should be placed through both pieces of sheeting to hold the cigarette in place once the cigarette is covered. The pins should be little lower than the top of the cigarette. This can be done before the lit cigarette is placed on the test surface for ease of placement. Once the cigarette is covered with the sheeting fabric, flatten the sheeting around the cigarette so that there is contact between the sheeting and cigarette. Be careful not to squeeze the cigarette. Or to cause the cigarette to move/shift locations.	See **Placement for The** [redacted], Placement on Edge, with Sheeting for more detail.

APPENDIX D. CIGARETTE LIGHTING PROCEDURE.

Action	Photo/Description
Lay cigarettes out in tray	
• Start stopwatch • Ignite candle or lamp • Turn on vacuum hose	  
Hold cigarette with smoking end about a half inch into the hose and the lighting tip over the flame. Hold there until the cigarette is ignited.	

Place cigarette in holder.	
Wait 30 seconds until lighting next cigarette	

APPENDIX E. CIGARETTE FULL LENGTH BURN DESCRIPTIONS

[redacted]	
[redacted]	
[redacted]	

The red dashed lines indicate the approximate location of the filter end.

APPENDIX II. RESULTS FROM MATTRESS AND MATTRESS PAD TESTING

Test number	Substrate (A…D)	Cig ID[1]	Location (E,S,T[2])	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (Yes/No/NA)	Smolder (Y/N)
1	B	CP9N	E	N	NON	YES	N
1	B	CP7N	S	Y	NON	YES	N
1	B	CP7N	T	N	NON	YES	N
1	B	CP5R	T	Y	RIP	NO	Y
1	B	CP9R	T	N	RIP	YES	N
1	B	CP9R	T	Y	RIP	NO	Y
1	B	CP7N	S	Y	NON	YES	N
1	B	CP7R	T	N	RIP	YES	N
1	B	CP7N	E	N	NON	YES	N
1	B	CP9N	E	Y	NON	YES	N
1	B	CP7R	T	N	RIP	NO	N
1	B	CP13N	S	Y	NON	YES	Y
1	B	CP5R	T	N	RIP	NO	N
1	B	CP7N	S	Y	NON	YES	N
1	B	CP7R	E	N	RIP	NO	N
1	B	CP5N	T	N	NON	YES	N
1	B	CP13R	S	N	RIP	YES	N
1	B	CP13N	E	Y	NON	YES	N
2	B	CP9R	E	N	RIP	NO	N
2	B	CP7R	E	N	RIP	YES	N
2	B	CP9N	E	N	NON	YES	N
2	B	CP5R	S	N	RIP	NO	N
2	B	CP5N	T	N	NON	YES	N
2	B	CP7R	T	Y	RIP	NO	Y
2	B	CP9N	E	N	NON	YES	N
2	B	CP13N	S	N	NON	YES	N
2	B	CP9N	E	Y	NON	YES	N
2	B	CP5R	S	N	RIP	NO	N
2	B	CP13R	T	Y	RIP	YES	Y
2	B	CP7R	E	N	RIP	NO	N
2	B	CP13R	S	Y	RIP	YES	N
2	B	CP9R	E	N	RIP	NO	N
2	B	CP9R	E	N	RIP	NO	N
2	B	CP5R	E	N	RIP	NO	N

[1] CP9R is the Pall Mall RIP packaging or CP9/PMR, and CP9N is the SRM 1196 packaging or CP9/SRM.
[2] E = Tape Edge, S = Smooth surface, T = Tufted surface

Test number	**Substrate (A…D)**	**Cig ID**	**Location (E,S,T)**	**Sheeting (Y/N)**	**RIP/NON**	**Cigarette Full-Length Burn (YES/NO/NA)**	**Smolder (Y/N)**
2	B	CP9R	S	Y	RIP	NO	Y
2	B	CP5N	E	N	NON	YES	N
3	D	CP7R	T	N	RIP	YES	Y
3	D	CP13N	T	Y	NON	YES	Y
3	D	CP13N	E	N	NON	NO	Y
3	D	CP9R	S	N	RIP	NO	Y
3	D	CP5R	T	N	RIP	NO	N
3	D	CP5N	T	Y	NON	NA	Y
3	D	CP7R	S	Y	RIP	NA	Y
3	D	CP9N	T	Y	NON	NA	Y
3	D	CP7N	E	N	NON	NO	Y
3	D	CP7R	T	N	RIP	YES	Y
3	D	CP7R	S	Y	RIP	NA	Y
3	D	CP9N	T	N	NON	YES	Y
3	D	CP7N	E	Y	NON	NA	Y
3	D	CP5R	S	N	RIP	NO	Y
3	D	CP13R	E	Y	RIP	NA	Y
3	D	CP9R	T	Y	RIP	NA	Y
3	D	CP5N	E	N	NON	NO	Y
3	D	CP9N	T	Y	NON	NA	Y
4	B	CP5R	S	Y	RIP	YES	N
4	B	CP9N	E	N	NON	YES	N
4	B	CP5R	T	Y	RIP	YES	N
4	B	CP13N	S	Y	NON	YES	N
4	B	CP9N	E	Y	NON	YES	N
4	B	CP13N	T	N	NON	YES	N
4	B	CP9R	S	Y	RIP	YES	N
4	B	CP13N	E	Y	NON	YES	N
4	B	CP9R	T	N	RIP	YES	N
4	B	CP5N	T	Y	NON	YES	N
4	B	CP9R	S	Y	RIP	YES	N
4	B	CP9R	E	N	RIP	YES	N
4	B	CP9N	T	N	NON	YES	N
4	B	CP13N	S	Y	NON	YES	N
4	B	CP7R	T	Y	RIP	YES	N
4	B	CP9R	S	Y	RIP	YES	N
4	B	CP7N	E	N	NON	YES	N
4	B	CP13N	E	Y	NON	YES	N

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
5	A	CP7N	E	N	NON	YES	Y
5	A	CP13N	S	Y	NON	YES	N
5	A	CP13R	E	N	RIP	YES	N
5	A	CP13N	T	Y	NON	YES	N
5	A	CP5N	E	Y	NON	YES	N
5	A	CP5N	E	N	NON	YES	Y
5	A	CP7N	E	N	NON	YES	Y
5	A	CP9R	E	N	RIP	YES	Y
5	A	CP13N	S	Y	NON	YES	N
5	A	CP9R	S	N	RIP	YES	N
5	A	CP13N	S	Y	NON	YES	N
5	A	CP9R	S	N	RIP	YES	N
5	A	CP9N	T	N	NON	YES	N
5	A	CP13R	E	Y	RIP	NO	N
5	A	CP9R	T	Y	RIP	YES	N
5	A	CP13R	T	N	RIP	YES	N
5	A	CP7N	T	Y	NON	YES	N
5	A	CP13R	S	Y	RIP	YES	N
6	B	CP7R	S	Y	RIP	YES	N
6	B	CP5N	T	Y	NON	YES	N
6	B	CP13R	E	N	RIP	NO	N
6	B	CP13N	S	Y	NON	YES	N
6	B	CP5R	E	Y	RIP	NO	N
6	B	CP5N	T	N	NON	YES	N
6	B	CP13R	T	Y	RIP	YES	N
6	B	CP5N	T	N	NON	YES	N
6	B	CP5R	E	Y	RIP	YES	N
6	B	CP5R	S	Y	RIP	NO	N
6	B	CP5N	T	N	NON	YES	N
6	B	CP9N	E	Y	NON	YES	N
6	B	CP13R	S	Y	RIP	YES	N
6	B	CP13N	S	N	NON	YES	N
6	B	CP5N	E	N	NON	YES	N
6	B	CP5R	E	N	RIP	YES	N
6	B	CP5R	E	Y	RIP	YES	N
6	B	CP5N	S	Y	NON	YES	N
7	B	CP9R	T	N	RIP	NO	N
7	B	CP7N	S	Y	NON	YES	N

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO)	Smolder (Y/N)
7	B	CP5R	T	Y	RIP	YES	N
7	B	CP5R	S	N	RIP	YES	N
7	B	CP5N	T	Y	NON	YES	N
7	B	CP5R	T	Y	RIP	YES	N
7	B	CP7N	T	N	NON	YES	N
7	B	CP5R	E	Y	RIP	NO	N
7	B	CP9R	T	Y	RIP	NO	N
7	B	CP5R	S	N	RIP	YES	N
7	B	CP7R	T	N	RIP	YES	N
7	B	CP13N	S	Y	NON	YES	N
7	B	CP9N	T	N	NON	YES	N
7	B	CP5N	T	Y	NON	YES	N
7	B	CP5N	T	N	NON	YES	N
7	B	CP13N	E	Y	NON	YES	N
7	B	CP13R	T	Y	RIP	YES	Y
7	B	CP13R	E	N	RIP	NO	N
8	D	CP13N	E	N	NON	NO	Y
8	D	CP13N	E	N	NON	NO	Y
8	D	CP9N	T	N	NON	YES	Y
8	D	CP7N	E	Y	NON	NA	Y
8	D	CP7N	T	N	NON	YES	Y
8	D	CP7N	E	N	NON	NO	Y
8	D	CP13N	S	N	NON	NO	Y
8	D	CP9N	E	N	NON	NO	Y
8	D	CP5R	S	Y	RIP	NO	Y
8	D	CP5N	T	Y	NON	NA	Y
8	D	CP7N	E	N	NON	NO	Y
8	D	CP9R	T	N	RIP	YES	Y
8	D	CP5R	E	Y	RIP	NO	N
8	D	CP5N	E	N	NON	NO	Y
8	D	CP9N	S	Y	NON	NO	Y
8	D	CP9N	E	N	NON	NO	Y
8	D	CP9R	E	N	RIP	NO	Y
8	D	CP5N	T	Y	NON	NA	Y
9	B	CP13R	S	Y	RIP	YES	N
9	B	CP13N	S	N	NON	YES	N
9	B	CP9N	T	N	NON	YES	N
9	B	CP7N	T	Y	NON	YES	N

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
9	B	CP9R	E	N	RIP	NO	N
9	B	CP7N	T	N	NON	YES	N
9	B	CP13R	E	N	NON	NO	N
9	B	CP9R	E	N	RIP	YES	N
9	B	CP7N	T	N	NON	YES	N
9	B	CP5N	E	N	NON	YES	N
9	B	CP7R	S	Y	RIP	YES	N
9	B	CP9R	E	N	RIP	YES	N
9	B	CP7N	E	N	NON	YES	N
9	B	CP7R	S	Y	RIP	YES	N
9	B	CP7N	E	N	NON	YES	N
9	B	CP5R	T	Y	RIP	YES	N
9	B	CP5R	S	N	RIP	NO	N
9	B	CP7R	S	Y	RIP	YES	N
10	C	CP9R	T	N	RIP	YES	Y
10	C	CP5R	S	Y	RIP	YES	N
10	C	CP5R	S	Y	RIP	YES	Y
10	C	CP7R	S	Y	RIP	YES	Y
10	C	CP9N	S	N	NON	YES	Y
10	C	CP9N	T	Y	NON	YES	Y
10	C	CP13N	S	N	NON	YES	Y
10	C	CP5R	S	N	RIP	YES	Y
10	C	CP13N	T	Y	NON	YES	Y
10	C	CP13R	T	N	RIP	YES	Y
10	C	CP7R	T	Y	RIP	YES	Y
10	C	CP5N	T	N	NON	YES	Y
10	C	CP13N	T	Y	NON	YES	Y
10	C	CP7N	T	N	NON	YES	Y
10	C	CP7R	S	Y	RIP	YES	Y
10	C	CP9R	T	N	RIP	YES	Y
10	C	CP5R	T	N	RIP	NO	N
10	C	CP13N	S	Y	NON	YES	N
11	A	CP13N	S	N	NON	YES	N
11	A	CP7R	T	Y	RIP	NO	N
11	A	CP13R	T	Y	RIP	YES	N
11	A	CP13N	E	Y	NON	NA	Y
11	A	CP5R	S	Y	RIP	NO	N
11	A	CP5R	E	N	RIP	NO	N

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
11	A	CP13N	T	Y	NON	YES	N
11	A	CP7N	S	N	NON	YES	N
11	A	CP7N	E	Y	NON	YES	Y
11	A	CP7N	E	N	NON	YES	Y
11	A	CP5R	E	N	RIP	YES	Y
11	A	CP9R	E	N	RIP	NO	Y
11	A	CP13R	S	N	RIP	YES	N
11	A	CP5N	S	N	NON	YES	N
11	A	CP5N	T	N	NON	YES	N
11	A	CP13N	T	Y	NON	YES	N
11	A	CP5N	E	Y	NON	YES	Y
11	A	CP13R	S	N	RIP	YES	N
12	D	CP5N	T	Y	NON	YES	Y
12	D	CP7N	T	N	NON	YES	Y
12	D	CP9N	T	Y	NON	NO	Y
12	D	CP5N	T	Y	NON	NO	Y
12	D	CP9R	E	N	RIP	NO	Y
12	D	CP7R	S	Y	RIP	NO	Y
12	D	CP5R	T	N	RIP	YES	Y
12	D	CP9N	T	N	NON	YES	Y
12	D	CP5R	S	N	RIP	NO	Y
12	D	CP13R	T	N	RIP	YES	Y
12	D	CP13R	E	Y	RIP	YES	Y
12	D	CP7R	T	N	RIP	YES	Y
12	D	CP13R	T	N	RIP	NO	Y
12	D	CP9N	T	Y	NON	NA	Y
12	D	CP5N	T	Y	NON	NA	Y
12	D	CP7R	T	N	RIP	YES	Y
12	D	CP5R	S	Y	RIP	NA	Y
12	D	CP9N	T	N	NON	YES	Y
13	B	CP13R	S	N	RIP	NO	N
13	B	CP5N	T	Y	NON	YES	N
13	B	CP5R	T	Y	RIP	YES	N
13	B	CP9N	S	Y	NON	YES	N
13	B	CP7R	T	N	RIP	NO	N
13	B	CP13N	S	Y	NON	YES	N
13	B	CP7N	E	N	NON	YES	N
13	B	CP9R	S	Y	RIP	YES	N

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
13	B	CP5R	E	Y	RIP	NO	N
13	B	CP13R	E	N	RIP	NO	N
13	B	CP13R	S	N	RIP	NO	N
13	B	CP9N	E	Y	NON	YES	N
13	B	CP9N	E	N	NON	YES	N
13	B	CP5N	E	N	NON	NO	N
13	B	CP13R	T	Y	RIP	YES	N
13	B	CP9N	T	N	NON	YES	N
13	B	CP7R	S	Y	RIP	YES	N
13	B	CP5R	T	Y	RIP	NO	N
14	A	CP9N	T	N	NON	YES	N
14	A	CP5N	S	Y	NON	YES	N
14	A	CP13R	E	N	RIP	NO	N
14	A	CP5N	S	N	NON	YES	N
14	A	CP13R	E	Y	RIP	YES	Y
14	A	CP5R	T	Y	RIP	YES	N
14	A	CP5R	E	N	RIP	NO	N
14	A	CP5N	E	N	NON	YES	N
14	A	CP13N	T	N	NON	YES	N
14	A	CP13R	S	Y	RIP	YES	N
14	A	CP5N	E	Y	NON	YES	N
14	A	CP13N	E	N	NON	YES	N
14	A	CP7R	S	N	RIP	YES	N
14	A	CP5R	S	N	RIP	YES	N
14	A	CP7N	T	Y	NON	YES	N
14	A	CP9R	E	N	RIP	YES	Y
14	A	CP13N	S	Y	NON	YES	N
14	A	CP9N	S	N	NON	YES	N
15	D	CP5N	T	Y	NON	YES	Y
15	D	CP5N	E	N	NON	NO	Y
15	D	CP5R	E	Y	RIP	NO	N
15	D	CP9N	E	N	NON	NO	Y
15	D	CP5N	T	Y	NON	NA	Y
15	D	CP5R	S	N	RIP	NO	Y
15	D	CP7N	E	Y	NON	YES	Y
15	D	CP13N	S	N	NON	NO	Y
15	D	CP9R	S	N	RIP	NO	Y
15	D	CP13N	S	N	NON	NO	Y

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
15	D	CP5N	T	Y	NON	NA	Y
15	D	CP13N	T	Y	NON	NA	Y
15	D	CP5R	S	Y	RIP	NA	Y
15	D	CP5R	T	N	RIP	YES	Y
15	D	CP9N	E	N	NON	YES	Y
15	D	CP13R	E	Y	RIP	NA	Y
15	D	CP7R	T	N	RIP	YES	Y
15	D	CP9N	S	Y	NON	NA	Y
16	C	CP7R	S	Y	RIP	NO	N
16	C	CP7N	T	N	NON	YES	Y
16	C	CP9N	S	Y	NON	NO	Y
16	C	CP5N	T	Y	NON	YES	Y
16	C	CP13R	S	Y	RIP	YES	Y
16	C	CP7R	T	N	RIP	NO	Y
16	C	CP5N	T	N	NON	YES	N
16	C	CP7N	T	N	NON	YES	Y
16	C	CP13R	T	Y	RIP	NO	N
16	C	CP13R	T	Y	RIP	YES	Y
16	C	CP5R	S	Y	RIP	NA	Y
16	C	CP13R	T	N	RIP	NO	N
16	C	CP13N	S	Y	NON	YES	Y
16	C	CP5N	S	Y	NON	YES	Y
16	C	CP5N	S	Y	NON	YES	Y
16	C	CP7R	S	N	RIP	NO	Y
16	C	CP5R	T	N	RIP	NO	Y
16	C	CP13N	T	Y	NON	YES	Y
17	C	CP9R	T	Y	RIP	YES	N
17	C	CP13R	S	N	RIP	YES	N
17	C	CP7N	T	N	NON	YES	Y
17	C	CP7N	S	Y	NON	YES	Y
17	C	CP7N	T	N	NON	YES	Y
17	C	CP5N	S	N	NON	YES	N
17	C	CP7R	S	N	RIP	YES	N
17	C	CP13N	T	Y	NON	YES	Y
17	C	CP13R	S	Y	RIP	YES	N
17	C	CP7N	T	N	NON	YES	Y
17	C	CP5N	T	Y	NON	NA	Y
17	C	CP7N	S	Y	NON	NA	Y

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
17	C	CP13N	S	Y	NON	NA	Y
17	C	CP13R	S	N	RIP	NO	Y
17	C	CP7R	S	N	RIP	YES	Y
17	C	CP13N	T	N	NON	YES	Y
17	C	CP9R	S	N	RIP	NO	Y
17	C	CP9R	S	Y	RIP	NA	Y
18	D	CP9R	S	N	RIP	NO	Y
18	D	CP5R	E	Y	RIP	NA	Y
18	D	CP13N	S	N	NON	NO	Y
18	D	CP13N	E	N	NON	NO	Y
18	D	CP7N	T	N	NON	YES	Y
18	D	CP13R	T	N	RIP	NO	Y
18	D	CP9R	T	Y	RIP	NA	Y
18	D	CP7N	E	N	NON	NO	Y
18	D	CP9R	E	N	RIP	NO	Y
18	D	CP13R	E	Y	RIP	NA	Y
18	D	CP5R	S	N	RIP	NO	Y
18	D	CP9N	T	Y	NON	NA	Y
18	D	CP7R	T	N	RIP	YES	Y
18	D	CP13R	E	Y	RIP	NO	N
18	D	CP9N	E	N	NON	NO	Y
18	D	CP13R	E	Y	RIP	NA	Y
18	D	CP13R	T	N	RIP	YES	Y
18	D	CP5R	S	N	RIP	NO	Y
19	A	CP7R	S	N	RIP	YES	N
19	A	CP13R	T	Y	RIP	YES	N
19	A	CP7N	E	Y	NON	YES	Y
19	A	CP9N	T	Y	NON	YES	Y
19	A	CP13R	E	N	RIP	NO	N
19	A	CP5R	T	Y	RIP	YES	N
19	A	CP9N	T	Y	NON	YES	Y
19	A	CP13R	S	N	RIP	YES	N
19	A	CP5R	T	Y	RIP	YES	N
19	A	CP9N	T	Y	NON	YES	Y
19	A	CP9R	E	N	RIP	NO	N
19	A	CP9N	S	N	NON	YES	N
19	A	CP13N	S	N	NON	YES	N
19	A	CP7R	T	Y	RIP	YES	N

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
19	A	CP9R	E	N	RIP	YES	Y
19	A	CP5N	S	N	NON	YES	N
19	A	CP7R	T	Y	RIP	YES	Y
19	A	CP13N	E	Y	NON	YES	Y
20	C	CP5N	S	Y	NON	YES	N
20	C	CP9N	T	N	NON	YES	Y
20	C	CP7R	S	Y	RIP	YES	Y
20	C	CP9R	S	N	RIP	YES	N
20	C	CP9N	T	Y	NON	NA	Y
20	C	CP9R	T	Y	RIP	YES	Y
20	C	CP13N	S	N	NON	YES	Y
20	C	CP5N	S	N	NON	YES	N
20	C	CP13R	S	Y	RIP	YES	N
20	C	CP13N	S	N	NON	YES	N
20	C	CP13N	T	Y	NON	NA	Y
20	C	CP13R	S	Y	RIP	NA	Y
20	C	CP9N	T	Y	NON	NA	Y
20	C	CP9N	S	Y	NON	NA	Y
20	C	CP7R	S	N	RIP	YES	Y
20	C	CP5N	T	Y	NON	NA	Y
20	C	CP5N	S	Y	NON	YES	Y
20	C	CP7N	T	N	NON	YES	Y
21	C	CP13N	T	N	NON	YES	Y
21	C	CP9N	S	Y	NON	NA	Y
21	C	CP13N	S	N	NON	YES	N
21	C	CP5N	T	N	NON	YES	Y
21	C	CP9R	T	Y	RIP	YES	N
21	C	CP5R	T	Y	RIP	NO	N
21	C	CP7R	T	N	RIP	YES	Y
21	C	CP5R	T	N	RIP	YES	Y
21	C	CP13N	S	N	NON	YES	Y
21	C	CP7N	S	N	NON	YES	Y
21	C	CP7N	T	Y	NON	NA	Y
21	C	CP5N	T	N	NON	YES	Y
21	C	CP7R	S	N	RIP	YES	N
21	C	CP7N	T	N	NON	YES	Y
21	C	CP7R	S	Y	RIP	YES	Y
21	C	CP9N	S	N	NON	YES	Y

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
21	C	CP5R	T	Y	RIP	NA	Y
21	C	CP5N	T	N	NON	YES	N
22	D	CP9N	S	Y	NON	NA	Y
22	D	CP7N	T	N	NON	YES	Y
22	D	CP5R	E	Y	RIP	NO	N
22	D	CP13R	E	Y	RIP	NA	Y
22	D	CP5N	S	N	NON	NO	Y
22	D	CP5R	S	Y	RIP	NO	N
22	D	CP9N	E	N	NON	NO	Y
22	D	CP7R	S	Y	RIP	NA	Y
22	D	CP7R	S	Y	RIP	NA	Y
22	D	CP9R	T	Y	RIP	NA	Y
22	D	CP7N	E	N	NON	NO	Y
22	D	CP5N	T	Y	NON	NA	Y
22	D	CP13N	T	Y	NON	NA	Y
22	D	CP9R	T	N	RIP	YES	Y
22	D	CP5N	E	Y	NON	NA	Y
22	D	CP13N	S	N	NON	NO	Y
22	D	CP13N	T	Y	NON	NA	Y
22	D	CP13R	S	Y	RIP	NA	Y
23	A	CP5N	E	Y	NON	YES	N
23	A	CP7R	S	N	RIP	YES	N
23	A	CP13N	T	Y	NON	YES	N
23	A	CP5N	S	Y	NON	YES	N
23	A	CP7R	T	Y	RIP	YES	N
23	A	CP13R	T	N	RIP	YES	N
23	A	CP5R	S	Y	RIP	YES	N
23	A	CP13R	E	N	RIP	NO	Y
23	A	CP13N	S	Y	NON	YES	N
23	A	CP13N	E	Y	NON	YES	N
23	A	CP9R	S	N	RIP	YES	N
23	A	CP7R	S	N	RIP	YES	N
23	A	CP7N	T	Y	NON	YES	N
23	A	CP7R	T	Y	RIP	YES	N
23	A	CP13R	T	N	RIP	YES	N
23	A	CP9R	S	N	RIP	YES	N
23	A	CP9R	S	N	RIP	YES	N
23	A	CP5R	E	N	RIP	NO	N

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
24	D	CP7N	E	Y	NON	NA	Y
24	D	CP5R	T	N	RIP	NO	Y
24	D	CP13N	E	N	NON	NO	Y
24	D	CP5R	S	N	RIP	NO	Y
24	D	CP13R	T	N	RIP	YES	Y
24	D	CP5N	S	N	NON	YES	Y
24	D	CP9R	T	Y	RIP	NA	Y
24	D	CP9N	E	N	NON	NO	Y
24	D	CP9N	T	Y	NON	NA	Y
24	D	CP9N	E	N	NON	NO	Y
24	D	CP5N	S	N	NON	NO	Y
24	D	CP13N	T	Y	NON	NA	Y
24	D	CP9R	E	N	RIP	NO	Y
24	D	CP5N	T	Y	NON	NA	Y
24	D	CP5N	T	Y	NON	NA	Y
24	D	CP5R	T	N	RIP	YES	Y
24	D	CP13R	E	Y	RIP	NA	Y
24	D	CP5R	E	Y	RIP	NO	N
25	D	CP13R	S	Y	RIP	NA	Y
25	D	CP9N	S	Y	NON	NA	Y
25	D	CP7R	T	N	RIP	YES	Y
25	D	CP9R	T	Y	RIP	NA	Y
25	D	CP9R	S	N	RIP	NO	Y
25	D	CP13N	T	Y	NON	NA	Y
25	D	CP9R	T	N	RIP	YES	Y
25	D	CP7R	S	Y	RIP	NA	Y
25	D	CP9N	S	Y	NON	NA	Y
25	D	NMM	E	N	NON	YES	Y
25	D	CP5R	S	Y	RIP	NO	N
25	D	CP9R	S	N	RIP	NO	Y
25	D	CP5R	S	Y	RIP	NO	N
25	D	CP9R	T	N	RIP	YES	Y
25	D	CP13R	S	Y	RIP	NA	Y
25	D	CP9R	T	Y	RIP	NA	Y
25	D	CP7N	T	N	NON	YES	Y
25	D	CP9N	E	N	NON	NA	Y
26	D	CP13R	E	Y	RIP	NA	Y
26	D	CP9R	E	N	RIP	NO	Y

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
26	D	CP5N	S	N	NON	NO	Y
26	D	CP7N	E	N	NON	NO	Y
26	D	CP9R	T	N	RIP	YES	Y
26	D	CP9N	E	N	NON	NO	Y
26	D	CP5R	T	N	RIP	NA	N
26	D	CP13R	E	Y	RIP	YES	Y
26	D	CP5N	S	N	NON	NO	Y
26	D	CP9R	S	N	RIP	NO	Y
26	D	CP13R	E	Y	RIP	NA	Y
26	D	CP9R	E	N	RIP	NO	Y
26	D	CP7R	T	N	RIP	YES	Y
26	D	CP5N	E	N	NON	NO	Y
26	D	CP5R	E	Y	RIP	NA	Y
26	D	CP9R	E	N	RIP	NO	Y
26	D	CP5N	E	N	NON	NO	Y
26	D	CP5N	T	Y	NON	NA	Y
27	C	CP9N	S	N	NON	YES	Y
27	C	CP7R	T	Y	RIP	YES	N
27	C	CP5N	T	Y	NON	YES	Y
27	C	CP7N	S	Y	NON	YES	N
27	C	CP7N	T	N	NON	YES	Y
27	C	CP13N	S	Y	NON	NA	Y
27	C	CP5R	T	N	RIP	NO	N
27	C	CP13R	T	N	RIP	YES	Y
27	C	CP9N	S	Y	NON	NA	Y
27	C	CP5N	S	N	NON	NO	Y
27	C	CP5N	T	Y	NON	YES	N
27	C	CP13R	T	N	RIP	NO	Y
27	C	CP5N	S	Y	NON	YES	Y
27	C	CP7R	T	Y	RIP	YES	N
27	C	CP13N	T	N	NON	YES	Y
27	C	CP13R	T	N	RIP	YES	Y
27	C	CP9R	S	Y	RIP	NA	Y
27	C	CP5R	S	Y	RIP	NO	N
28	A	CP5N	S	Y	NON	YES	N
28	A	CP7N	E	N	NON	YES	Y
28	A	CP13R	E	Y	RIP	YES	Y
28	A	CP13N	S	Y	NON	YES	N

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
28	A	CP7N	S	N	NON	YES	N
28	A	CP13R	E	N	RIP	YES	Y
28	A	CP5N	S	N	NON	YES	N
28	A	CP5R	T	Y	RIP	YES	Y
28	A	CP13R	T	Y	RIP	YES	N
28	A	CP7R	T	Y	RIP	YES	N
28	A	CP13N	T	Y	NON	YES	N
28	A	CP5N	E	N	NON	YES	N
28	A	CP9R	S	N	RIP	YES	N
28	A	CP5R	T	Y	RIP	YES	N
28	A	CP7R	S	N	RIP	YES	N
28	A	CP5R	T	Y	RIP	YES	N
28	A	CP5R	S	N	RIP	NO	N
28	A	CP13N	T	Y	NON	YES	N
29	A	CP7R	T	Y	RIP	YES	N
29	A	CP5N	S	Y	NON	YES	N
29	A	CP13R	E	N	RIP	NA	Y
29	A	CP9N	T	N	NON	YES	N
29	A	CP9N	T	Y	NON	NA	Y
29	A	CP5N	T	N	NON	YES	N
29	A	CP7R	E	N	RIP	YES	Y
29	A	CP13R	E	Y	RIP	NA	Y
29	A	CP9N	T	Y	NON	YES	N
29	A	CP7R	S	N	RIP	YES	N
29	A	CP9N	T	Y	NON	YES	N
29	A	CP9N	T	N	NON	YES	N
29	A	CP7R	T	Y	RIP	YES	N
29	A	CP13N	S	Y	NON	YES	N
29	A	CP7R	E	N	RIP	YES	Y
29	A	CP7R	E	N	RIP	YES	Y
29	A	CP13N	S	N	NON	YES	N
29	A	CP7R	E	N	RIP	YES	Y
30	C	CP13R	T	Y	RIP	YES	N
30	C	CP9R	T	N	RIP	YES	Y
30	C	CP9N	S	Y	NON	NA	Y
30	C	CP9N	S	N	NON	YES	Y
30	C	CP5N	S	N	NON	YES	N
30	C	CP9N	S	Y	NON	NA	Y

Test number	**Substrate (A…D)**	**Cig ID**	**Location (E,S,T)**	**Sheeting (Y/N)**	**RIP/NON**	**Cigarette Full-Length Burn (YES/NO/NA)**	**Smolder (Y/N)**
30	C	CP5R	T	N	RIP	NO	Y
30	C	CP7R	S	Y	RIP	YES	Y
30	C	CP5R	T	Y	RIP	NA	Y
30	C	CP7N	T	N	NON	YES	Y
30	C	CP7R	S	Y	RIP	NA	Y
30	C	CP7N	T	Y	NON	YES	N
30	C	CP13R	T	N	RIP	YES	Y
30	C	CP13N	T	N	NON	YES	Y
30	C	CP9R	T	Y	RIP	NA	Y
30	C	CP13N	T	N	NON	YES	Y
30	C	CP5R	T	N	RIP	YES	Y
30	C	CP7R	S	Y	RIP	NA	Y
31	A	CP7R	T	Y	RIP	YES	N
31	A	CP13N	S	Y	NON	YES	N
31	A	CP7R	E	N	RIP	YES	Y
31	A	CP9N	T	N	NON	YES	N
31	A	CP9N	T	N	NON	YES	N
31	A	CP5N	E	Y	NON	NA	Y
31	A	CP9N	S	N	NON	YES	N
31	A	CP9R	S	N	RIP	YES	N
31	A	CP13R	E	N	RIP	NO	N
31	A	CP13R	E	N	RIP	NO	N
31	A	CP5R	S	Y	RIP	YES	N
31	A	CP13R	S	N	RIP	YES	N
31	A	CP13N	T	Y	NON	YES	N
31	A	CP13N	E	N	NON	YES	N
31	A	CP5N	S	Y	NON	YES	N
31	A	CP9N	S	N	NON	YES	N
31	A	CP5N	S	N	NON	YES	N
31	A	CP7N	S	N	NON	YES	N
32	B	CP13N	S	Y	NON	YES	N
32	B	CP9N	T	N	NON	YES	N
32	B	CP13N	S	N	NON	YES	N
32	B	CP9N	S	Y	NON	YES	Y
32	B	CP9N	E	N	NON	YES	N
32	B	CP13R	E	N	RIP	NO	N
32	B	CP9R	E	N	RIP	NO	N
32	B	CP9N	S	Y	NON	YES	Y

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
32	B	CP9N	S	Y	NON	YES	Y
32	B	CP5N	S	Y	NON	YES	N
32	B	CP9R	S	Y	RIP	YES	N
32	B	CP9R	E	N	RIP	YES	N
32	B	CP7R	E	N	RIP	NO	N
32	B	CP7N	S	Y	NON	YES	N
32	B	CP9N	E	Y	NON	YES	N
32	B	CP13R	T	Y	RIP	YES	N
32	B	CP9R	E	N	RIP	NO	N
32	B	CP13R	S	Y	RIP	NO	N
33	D	CP7R	S	Y	RIP	NA	Y
33	D	CP9N	E	N	NON	NO	Y
33	D	CP9N	T	Y	NON	NA	Y
33	D	CP5R	T	N	RIP	YES	Y
33	D	CP5N	S	N	NON	NO	N
33	D	CP7R	S	Y	RIP	NA	Y
33	D	CP5N	E	N	NON	NO	Y
33	D	CP13N	S	N	NON	NO	Y
33	D	CP7N	T	N	NON	YES	Y
33	D	CP7N	E	Y	NON	NA	Y
33	D	CP7R	T	N	RIP	YES	Y
33	D	CP5R	E	Y	RIP	NA	Y
33	D	CP9N	E	N	NON	YES	Y
33	D	CP9N	T	N	NON	YES	Y
33	D	CP7R	S	Y	RIP	NA	Y
33	D	CP7N	E	Y	NON	NA	Y
33	D	CP9N	T	N	NON	YES	Y
33	D	CP13R	E	Y	RIP	NA	Y
34	C	CP13N	S	Y	NON	NA	Y
34	C	CP9N	T	N	NON	YES	Y
34	C	CP5R	T	N	RIP	YES	Y
34	C	CP7N	T	Y	NON	NA	Y
34	C	CP7N	T	N	NON	YES	Y
34	C	CP9R	S	N	RIP	NO	Y
34	C	CP7N	T	N	NON	YES	Y
34	C	CP5R	S	N	RIP	YES	Y
34	C	CP7N	T	N	NON	YES	Y
34	C	CP9N	T	Y	NON	NA	Y

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
34	C	CP13R	T	N	RIP	YES	Y
34	C	CP5N	S	N	NON	NO	Y
34	C	CP9R	T	Y	RIP	NA	Y
34	C	CP13R	T	Y	RIP	NO	N
34	C	CP9R	S	N	RIP	YES	Y
34	C	CP5R	T	Y	RIP	NA	Y
34	C	CP7N	T	N	NON	YES	Y
34	C	CP7N	T	N	NON	YES	Y
35	D	CP7R	T	N	RIP	YES	Y
35	D	CP13N	E	N	NON	NO	Y
35	D	CP5N	T	Y	NON	NA	Y
35	D	CP9R	T	N	RIP	YES	Y
35	D	CP5R	S	Y	RIP	NA	Y
35	D	CP5R	S	Y	RIP	NA	Y
35	D	CP13N	E	N	NON	NO	Y
35	D	CP9N	E	N	NON	NO	Y
35	D	CP7R	S	Y	RIP	NA	Y
35	D	CP7R	T	N	RIP	YES	Y
35	D	CP5R	T	N	RIP	YES	Y
35	D	CP9N	S	Y	NON	NA	Y
35	D	CP13R	T	N	RIP	YES	Y
35	D	CP7R	S	Y	RIP	NA	Y
35	D	CP13N	S	N	NON	NO	Y
35	D	CP5N	S	N	NON	NO	Y
35	D	CP7N	T	N	NON	YES	Y
35	D	CP13N	T	Y	NON	NA	Y
36	A	CP9N	S	N	NON	YES	N
36	A	CP7N	T	Y	NON	YES	Y
36	A	CP7R	T	Y	RIP	YES	N
36	A	CP9R	T	Y	RIP	YES	N
36	A	CP13R	E	N	RIP	NO	N
36	A	CP7N	E	Y	NON	NA	Y
36	A	CP9N	S	N	NON	YES	N
36	A	CP7N	T	Y	NON	YES	N
36	A	CP7R	T	Y	RIP	YES	N
36	A	CP7N	T	Y	NON	YES	N
36	A	CP7N	E	N	NON	YES	Y
36	A	CP13N	S	Y	NON	YES	N

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
36	A	CP13R	S	Y	RIP	YES	N
36	A	CP7N	S	N	NON	YES	N
36	A	CP5R	S	Y	RIP	YES	N
36	A	CP5R	S	Y	RIP	NO	N
36	A	CP7R	E	N	RIP	YES	Y
36	A	CP7N	E	N	NON	YES	Y
37	B	CP9R	T	N	RIP	YES	N
37	B	CP13N	E	Y	NON	YES	N
37	B	CP5N	S	Y	NON	YES	N
37	B	CP9R	E	N	RIP	NO	N
37	B	CP13R	T	Y	RIP	YES	N
37	B	CP7R	E	N	RIP	NO	N
37	B	CP7N	T	N	NON	YES	N
37	B	CP13N	E	Y	NON	YES	N
37	B	CP5N	S	Y	NON	YES	N
37	B	CP5R	S	N	RIP	YES	N
37	B	CP7N	T	Y	NON	YES	N
37	B	CP13N	T	N	NON	YES	N
37	B	CP9R	E	N	RIP	NO	N
37	B	CP13N	S	Y	NON	YES	N
37	B	CP7R	T	N	RIP	YES	N
37	B	CP9R	T	N	RIP	NO	N
37	B	CP13R	E	N	RIP	NO	N
37	B	CP9R	T	Y	RIP	YES	Y
38	A	CP9R	E	N	RIP	YES	Y
38	A	CP7N	T	Y	NON	YES	N
38	A	CP5N	E	N	NON	YES	Y
38	A	CP5R	E	N	RIP	NO	N
38	A	CP5R	S	N	RIP	YES	N
38	A	CP9N	S	N	NON	YES	N
38	A	CP13R	T	N	RIP	YES	N
38	A	CP13N	T	N	NON	YES	N
38	A	CP13N	E	Y	NON	NO	N
38	A	CP13N	E	Y	NON	YES	N
38	A	CP7N	S	N	NON	YES	N
38	A	CP5N	E	Y	NON	YES	N
38	A	CP13R	E	N	RIP	YES	N
38	A	CP7N	E	N	NON	YES	Y

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
38	A	CP13R	T	N	RIP	YES	N
38	A	CP13R	E	N	RIP	NO	Y
38	A	CP5N	E	Y	NON	NA	Y
38	A	CP7R	T	Y	RIP	YES	N
39	B	CP7R	E	N	RIP	NO	N
39	B	CP5R	E	Y	RIP	NO	N
39	B	CP13R	S	Y	RIP	NO	N
39	B	CP7R	T	Y	RIP	YES	N
39	B	CP9R	E	N	RIP	NO	N
39	B	CP7N	T	Y	NON	YES	N
39	B	CP7R	T	N	RIP	YES	N
39	B	CP9N	E	Y	NON	YES	N
39	B	CP7N	S	Y	NON	YES	N
39	B	CP13R	S	Y	RIP	YES	N
39	B	CP7N	T	N	NON	YES	N
39	B	CP13N	E	Y	NON	YES	N
39	B	CP5N	E	N	NON	YES	N
39	B	CP9N	S	Y	NON	YES	Y
39	B	CP9N	S	Y	NON	YES	N
39	B	CP13R	S	N	RIP	NO	N
39	B	CP9N	S	Y	NON	YES	N
39	B	CP9R	T	Y	RIP	YES	N
40	B	CP7N	T	Y	NON	YES	N
40	B	CP7R	S	Y	RIP	YES	N
40	B	CP9R	E	N	RIP	YES	N
40	B	CP7N	E	N	NON	YES	N
40	B	CP9R	S	Y	RIP	YES	N
40	B	CP5N	S	Y	NON	YES	N
40	B	CP5N	E	N	NON	YES	N
40	B	CP7R	T	Y	RIP	YES	N
40	B	CP7N	E	N	NON	YES	N
40	B	CP5N	S	Y	NON	YES	N
40	B	CP5R	S	N	RIP	YES	N
40	B	CP13N	T	N	NON	YES	N
40	B	CP7R	S	Y	RIP	YES	N
40	B	CP13N	S	N	NON	YES	N
40	B	CP13N	S	N	NON	YES	N
40	B	CP9N	E	N	NON	YES	N

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
40	B	CP7N	T	Y	NON	YES	N
40	B	CP7N	S	Y	NON	YES	N
41	C	CP5R	T	Y	RIP	NA	Y
41	C	CP7N	T	Y	NON	NA	Y
41	C	CP5N	S	N	NON	YES	Y
41	C	CP13N	S	N	NON	YES	Y
41	C	CP13N	S	N	NON	YES	N
41	C	CP5R	T	Y	RIP	NA	Y
41	C	CP7N	S	N	NON	YES	Y
41	C	CP9R	S	Y	RIP	NA	Y
41	C	CP5N	T	N	NON	YES	Y
41	C	CP9R	S	N	RIP	YES	Y
41	C	CP5N	T	Y	NON	YES	N
41	C	CP13R	S	N	RIP	NA	Y
41	C	CP13R	S	Y	RIP	YES	N
41	C	CP5N	T	N	NON	YES	Y
41	C	CP7N	S	Y	NON	NA	Y
41	C	CP7R	T	N	RIP	YES	Y
41	C	CP5R	S	N	RIP	YES	N
41	C	CP5R	S	N	RIP	NO	N
42	A	CP9R	T	Y	RIP	YES	N
42	A	CP13N	T	Y	NON	YES	N
42	A	CP7R	E	N	RIP	YES	Y
42	A	CP13R	E	N	RIP	YES	Y
42	A	CP13N	S	Y	NON	YES	N
42	A	CP13R	T	Y	RIP	YES	N
42	A	CP7N	E	Y	NON	YES	Y
42	A	CP7N	S	N	NON	YES	N
42	A	CP9N	T	Y	NON	YES	N
42	A	CP9R	E	N	RIP	YES	Y
42	A	CP5N	S	Y	NON	YES	N
42	A	CP7N	E	Y	NON	NA	Y
42	A	CP13N	T	Y	NON	YES	N
42	A	CP5N	E	N	NON	YES	N
42	A	CP7R	T	Y	RIP	YES	N
42	A	CP13R	E	N	RIP	NO	N
42	A	CP9R	T	Y	RIP	YES	N
42	A	CP13R	E	Y	RIP	YES	N

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
43	D	CP9R	T	Y	RIP	NA	Y
43	D	CP9N	S	Y	NON	NA	Y
43	D	CP9N	E	N	NON	NO	Y
43	D	CP13R	E	Y	RIP	NA	Y
43	D	CP7R	S	Y	RIP	NA	Y
43	D	CP9R	T	N	RIP	YES	Y
43	D	CP7R	T	N	RIP	YES	Y
43	D	CP7N	S	Y	NON	NA	Y
43	D	CP13R	T	N	RIP	NO	N
43	D	CP9N	T	N	NON	YES	Y
43	D	CP9R	S	N	RIP	NO	Y
43	D	CP5N	E	N	NON	NO	Y
43	D	CP13R	E	Y	RIP	NA	Y
43	D	CP7N	S	Y	NON	NA	Y
43	D	CP7R	T	N	RIP	YES	Y
43	D	CP7N	S	Y	NON	NA	Y
43	D	CP5R	S	Y	RIP	NA	Y
43	D	CP5R	S	N	RIP	NO	Y
44	C	CP5N	T	Y	NON	NA	Y
44	C	CP9R	T	N	RIP	YES	Y
44	C	CP13R	S	Y	RIP	NO	N
44	C	CP9R	T	Y	RIP	NA	Y
44	C	CP9N	T	Y	NON	NA	Y
44	C	CP7N	S	N	NON	YES	Y
44	C	CP9R	T	Y	RIP	NA	Y
44	C	CP13N	S	Y	NON	NA	Y
44	C	CP9N	S	N	NON	YES	Y
44	C	CP9N	T	Y	NON	NA	Y
44	C	CP7N	S	N	NON	YES	Y
44	C	CP9R	S	Y	RIP	YES	N
44	C	CP9N	S	N	NON	YES	Y
44	C	CP9R	T	Y	RIP	NA	Y
44	C	CP5N	S	Y	NON	NA	Y
44	C	CP13R	T	Y	RIP	YES	Y
44	C	CP5R	S	Y	RIP	YES	Y
44	C	CP9N	T	N	NON	YES	Y
45	B	CP13R	S	Y	RIP	YES	N
45	B	CP5N	E	N	NON	YES	N

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
45	B	CP13N	S	Y	NON	YES	N
45	B	CP7N	T	N	NON	YES	N
45	B	CP5R	E	Y	RIP	YES	N
45	B	CP13N	T	N	NON	YES	N
45	B	CP13N	S	N	NON	YES	N
45	B	CP5N	S	Y	NON	YES	N
45	B	CP5R	T	Y	RIP	YES	N
45	B	CP7R	T	Y	RIP	YES	N
45	B	CP13R	E	N	RIP	NO	N
45	B	CP7R	E	N	RIP	NO	N
45	B	CP9N	T	N	NON	YES	N
45	B	CP9N	T	N	NON	YES	N
45	B	CP13R	S	N	RIP	YES	N
45	B	CP5N	T	N	NON	YES	N
45	B	CP7R	T	N	RIP	YES	N
45	B	CP7N	T	Y	NON	YES	N
46	A	CP7R	S	N	RIP	YES	N
46	A	CP9R	T	Y	RIP	YES	Y
46	A	CP13N	S	Y	NON	YES	N
46	A	CP9N	T	N	NON	YES	Y
46	A	CP5N	S	Y	NON	YES	N
46	A	CP9R	T	Y	RIP	YES	N
46	A	CP13N	T	Y	NON	YES	N
46	A	CP5R	S	Y	RIP	YES	N
46	A	CP5R	E	N	RIP	NO	N
46	A	CP5R	E	N	RIP	NO	N
46	A	CP7N	E	Y	NON	NO	N
46	A	CP5R	T	Y	RIP	YES	N
46	A	CP7N	E	Y	NON	YES	N
46	A	CP13R	S	N	RIP	YES	N
46	A	CP7R	T	Y	RIP	YES	N
46	A	CP7N	S	N	NON	YES	N
46	A	CP9R	T	Y	RIP	YES	N
46	A	CP5R	S	Y	RIP	YES	N
47	C	CP7R	S	N	RIP	YES	Y
47	C	CP7R	S	Y	RIP	YES	Y
47	C	CP13N	S	Y	NON	NA	Y
47	C	CP9R	T	N	RIP	YES	Y

Test number	Substrate (A…D)	Cig ID	Location (E,S,T)	Sheeting (Y/N)	RIP/NON	Cigarette Full-Length Burn (YES/NO/NA)	Smolder (Y/N)
47	C	CP5R	S	Y	RIP	YES	N
47	C	CP9R	S	Y	RIP	NA	Y
47	C	CP9R	S	Y	RIP	NA	Y
47	C	CP5N	S	N	NON	YES	N
47	C	CP9R	S	Y	RIP	NA	Y
47	C	CP9R	T	Y	RIP	YES	N
47	C	CP5R	S	N	RIP	NO	N
47	C	CP13N	T	Y	NON	NA	Y
47	C	CP13R	S	Y	RIP	YES	Y
47	C	CP9N	S	Y	NON	YES	Y
47	C	CP5R	S	N	RIP	YES	N
47	C	CP5N	S	Y	NON	YES	N
47	C	CP9N	T	Y	NON	YES	N
47	C	CP9N	S	N	NON	YES	Y
48	C	CP5R	T	Y	RIP	NA	Y
48	C	CP5R	S	N	RIP	YES	Y
48	C	CP5R	S	N	RIP	YES	Y
48	C	CP13R	S	Y	RIP	NA	Y
48	C	CP7N	T	N	NON	YES	Y
48	C	CP13R	T	Y	RIP	NA	Y
48	C	CP13N	T	N	NON	YES	N
48	C	CP7R	S	N	RIP	YES	Y
48	C	CP9R	T	N	RIP	YES	Y
48	C	CP7R	T	Y	RIP	NA	Y
48	C	CP7R	T	N	RIP	NO	Y
48	C	CP7R	S	N	RIP	YES	Y
48	C	CP7R	T	N	RIP	NO	Y
48	C	CP13R	S	Y	RIP	NA	Y
48	C	CP9R	S	Y	RIP	NA	Y
48	C	CP7N	T	N	NON	YES	Y
48	C	CP13N	T	N	NON	YES	Y
48	C	CP9R	S	Y	RIP	YES	N

SUPPORTING DOCUMENT F: MILLER, D., GARLAND, S. "CIGARETTE IGNITION RISK PHASE II: MATTRESS AND MATTRESS PAD RESULTS ANALYSIS" MEMORANDUM TO S. MEHTA. DECEMBER 2012.

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
BETHESDA, MD 20814

Memorandum

Date: December 21, 2012

TO: Shivani Mehta, Project Manager
Division of Combustion and Fire Sciences
Directorate for Engineering Sciences

THROUGH : Kathleen Stralka
Associate Executive Director
Directorate for Epidemiology

Stephen Hanway
Division Director
Division of Hazard Analysis

FROM: David Miller
Division of Hazard Analysis

Sarah Garland, Ph.D.
Division of Hazard Analysis

SUBJECT: Cigarette Ignition Risk Phase II: Mattress and Mattress Pad Testing Results and Analysis[1]

BACKGROUND

In 2004, New York became the first state to pass a law requiring lower ignition strength for cigarettes. Since then, all other states have passed similar laws making reduced ignition propensity (RIP) cigarettes a de facto national requirement. RIP cigarettes are designed to self-extinguish if left unattended. The law requires that at least 30 of 40 cigarettes tested should self-extinguish when lit and placed on 10 layers of filter paper.

The Consumer Product Safety Commission (CPSC) does not have regulatory authority over cigarettes, but it does regulate mattresses and other items frequently ignited by burning cigarettes. Mattresses or bedding were the item first ignited in an estimated annual average of 1,600 smoking material fires from 2008 to 2010, leading to an estimated annual average of 130 deaths and 320 injuries.[2] In 2007, CPSC staff undertook the Cigarette Ignition Risk (CIR) project to evaluate the effectiveness of RIP cigarettes. As part of that project, CPSC staff performed a study to compare the ignition propensity of RIP cigarettes with that of non-RIP cigarettes on mattresses and mattress pads substrates.

Four different cigarette packaging[3] pairs (RIP/non-RIP) were evaluated on four different substrates (mattress or mattress pad). The cigarette packaging pairs were selected, based on previous RIP versus non-RIP cigarette testing on filter paper, to be from a range of ignition strengths (one "most" ignition-

[1] This analysis was prepared by CPSC staff and has not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.
[2] Miller, D., "2008–2010 Residential Fire Loss Estimates," September 2012.
[3] A "packaging" indicates the brand, style, and size of the cigarette, *e.g.*, Marlboro Light 100's. ®

prone, one "least" ignition-prone, and two "mediums"). Preliminary tests were conducted at the CPSC to identify substrates that would be able to distinguish between cigarette behaviors.

DESIGN

CPSC staff designed an experiment to answer two main questions: (1) is there a difference between the full length performance of RIP and non-RIP cigarettes when tested on mattress and mattress pad substrates (and if so, how much)? and (2) for each packaging and substrate combination, is there a difference in the smoldering of the substrate beneath RIP and non-RIP cigarettes (and how much)? It was not known before testing began which dependent variables would be feasible to evaluate. Possibilities for dependent variables included: (1) whether a cigarette smoldered, (2) char length or area the cigarette produced, and (3) whether a cigarette burned its full length. Whether a cigarette caused smoldering of the substrate and whether it burned its full length are both binomial variables. Char length or char area are continuous variables.

The independent variables were all known in advance. They are (1) RIP/non-RIP, (2) substrate, (3) cigarette packaging, (4) location of cigarette on substrate, and (5) presence/absence of sheeting.[4] These are all categorical variables.

The four substrates selected will be referred to as Substrate A, Substrate B, Substrate C, and Substrate D. The four cigarette packagings will be referred to as CP5, CP7, CP9, and CP13.[5,6] For each substrate and packaging, there were both RIP and non-RIP cigarettes to be evaluated. A suffix is used to indicate whether a cigarette is RIP or non-RIP. For example, CP5R is a RIP cigarette and CP5N is a non-RIP cigarette. Neither the substrates, nor the cigarette packagings, were selected randomly. This means that the independent variables will be fixed effects in the model and conclusions drawn from the data should be restricted to the specific substrates and cigarettes tested. Three of the substrates had three locations: (1) smooth surface, (2) tuft, and (3) edge. One of the substrates had only two locations: (1) smooth surface and (2) tuft.

Testing was conducted per the methodology of 16 CFR part 1632, *Standard for the Flammability of Mattresses and Mattress Pads*, which requires 18 cigarettes to be tested at once, per substrate; however, unlike 16 CFR part 1632, char length was not measured, and test cigarettes that did not burn their full length were not replaced.[4] Staff wanted to identify whether: (1) a cigarette caused smoldering of the substrate, and (2) a cigarette burned its full length.

Staff selected a split-plot design with an individual substrate as the whole plot and the cigarette as the split plot.[7] This was done because the substrate is a difficult factor to vary, but the other variables can be varied for each cigarette. Therefore, randomization is restricted so that the first 18 cigarettes are tested on the same one-sample substrate, and the next 18 are tested on another sample substrate, and so forth. Staff selected a D-optimal split-plot design instead of a traditional split-plot design. With a D-optimal design,

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[4] 16 CFR part 1632 *Standard for the Flammability of Mattresses and Mattress Pads, Section* 3(b).

[5] Green, M., Andres, C., "Cigarette Ignition Risk Phase I: Analysis of Selected Reduced Ignition Propensity Cigarettes" Memorandum to S. Mehta, U.S. Consumer Product Safety Commission. July 2008.

[6] Mehta, S., "Cigarette Ignition Risk Project" U.S. Consumer Product Safety Commission. November 2012.

[7] A split-plot design is used when a multifactor design cannot be fully randomized (i.e., if one or more factors is either difficult or impossible to vary with other factors in the study). In the case of this study, substrates could not be fully randomized to burn one cigarette, in one location, with or without sheeting, then change out the substrate for the next cigarette combination. This would be an inefficient use of resources. Because each mattress can be used to burn up to 18 cigarettes, a group of fully randomized factor combinations of cigarette packagings, RIP/non-RIP type, sheeting, and location can be tested on one substrate (the whole plot). The fully randomizable factor combinations of cigarette packaging, RIP/non-RIP type, sheeting, and location are varied completely within the whole plot.

it is possible to estimate all of the effects of interest without testing every possible combination; this was important for purposes of cost and time, given that there are so many independent variables. This design also allows for the exclusion of certain factor combinations that are not possible to test. Not all substrates have all the possible locations; for example, it was necessary to exclude “the edge” as a possible location for one of the substrates.

When the dependent variable is a binomial variable, such as whether a cigarette produced smoldering of the substrate, a logistic regression model is used to analyze the data. However, because the design chosen is a D-optimal design, there is another consideration in the model. The model will be a mixed model, whether an ANOVA or logistic regression. That is, the model will have fixed effects and random effects. The fixed effects are the chosen design variables (substrate, cigarette packaging) and random effects relating to the split-plot nature of the design. Throughout this memo, the model will be called a logistic regression model for simplicity; however, it is a generalized linear mixed model. All analyses were performed using SAS® 9.2.

CPSC staff used SAS JMP® software to select the D-optimal split-plot design. Staff specified that the model should be able to include all two-way interactions of independent variables and one three-way interaction (RIP*substrate*cigarette packaging). SAS JMP® selected a D-optimal split-plot design capable of estimating all main effects, all two-way interactions, and this one three-way interaction. This design involved 96 total tests (cigarettes). CPSC staff decided to replicate this design seven times for a total of 672 cigarettes (or evaluations) in order for the analysis to have a high probability of finding statistically significant differences between RIP and non-RIP cigarette performances on mattress/mattress pad substrates. In a mixed model, it is not a straightforward calculation to obtain sample size. Thus, staff began with the sample size calculations for comparing two groups with a binomial response and found the number of tests required to find a difference larger than 30 percent. This was then applied to the generated design and it was replicated the needed number of times to have the approximate sample size in each cell. This number of replicates was used as the starting point in simulations designed to find the best number of replicates to detect differences in the model with the resources available. The resulting number of replicates of the design was seven.

The 672 cigarettes that were the seven replicates of the JMP® design were not evenly distributed among the four substrates. Because CPSC staff wanted the design to be distributed evenly among the four substrates, additional cigarettes were added to the design so that there were an equal number of cigarettes for each substrate. The final design called for 864 cigarettes, 216 for each substrate. Table 1 below gives the details of the design by substrate, cigarette packaging, and RIP/non-RIP.

Table 1. Number of Cigarettes to Be Tested by Substrate and Cigarette

	Substrate			
Packaging	**Substrate A**	**Substrate B**	**Substrate C**	**Substrate D**
CP5	50 (24 RIP, 26 NON)	53 (27 RIP, 26 NON)	56 (28 RIP, 28 NON)	60 (31 RIP, 29 NON)
CP7	56 (28 RIP, 28 NON)	53 (26 RIP, 27 NON)	55 (26 RIP, 29 NON)	48 (25 RIP, 23 NON)
CP9	42 (21 RIP, 21 NON)	58 (30 RIP, 28 NON)	53 (29 RIP, 24 NON)	63 (28 RIP, 35 NON)
CP13	68 (35 RIP, 33 NON)	52 (25 RIP, 27 NON)	52 (25 RIP, 27 NON)	45 (24 RIP, 21 NON)

Note that these cigarettes were tested at different locations and some were tested with sheeting, while others were tested without. Some combinations of substrate, cigarette, location, and sheeting did not have any cigarettes evaluated. The evaluations were not balanced across sheeting and location. This confounds simple comparisons between RIP and non-RIP cigarettes across the combinations of cigarette packaging and substrate. The main focus of the study is on smoldering propensity of different RIP and non-RIP cigarettes on different mattress and mattress pad substrates, not on locations and sheeting. The sampling plan is detailed in a Directorate for Engineering Sciences memo.[5]

RESULTS

Of the 864 cigarettes evaluated, 434 produced progressive and continuous smoldering, indicated by char, heat, and smoke, and 429 did not. During testing, one cigarette was not able to be used and has no results associated with it. Based on the theory behind and requirements of 16 CFR part 1632, the presence of char as evidence of continuous smoldering is the best dependent variable for assessing the difference between RIP and non-RIP cigarettes on substrates in this study. Therefore, the results and analysis related to this measure are considered the most important. It did not prove feasible to measure char length or area for all the cigarettes evaluated. Table 2 shows the results of the smoldering evaluations by cigarette packaging, RIP/non-RIP, and substrate.

Table 2. Smoldering Results by Cigarette and Substrate

Cigarette	Substrate A	Substrate B	Substrate C	Substrate D
CP5N	19% (5/26)	0% (0/26)	64% (18/28)	97% (28/29)
CP5R	8% (2/24)	4% (1/27)	64% (18/28)	73% (22/30[8])
CP7N	46% (13/28)	0% (0/27)	93% (27/29)	100% (23/23)
CP7R	29% (8/28)	4% (1/26)	81% (21/26)	100% (25/25)
CP9N	24% (5/21)	14% (4/28)	96% (23/24)	100% (35/35)
CP9R	33% (7/21)	10% (3/30)	79% (23/29)	100% (28/28)
CP13N	6% (2/33)	4% (1/27)	81% (22/27)	100% (21/21)
CP13R	23% (8/35)	8% (2/25)	64% (16/25)	92% (22/24)

Because a RIP cigarette is designed to self-extinguish prior to burning its full length, if left unattended, where possible, it was recorded when a cigarette demonstrated a full length burn (FLB). Results and analysis will also be given for this dependent variable. When a cigarette caused smoldering of the substrate, it was not always possible to tell if the cigarette burned its full length. Of the 429 cigarettes that did not produce smoldering, 343 were observed to have burned their full length and 86 did not burn their full length. Of the 434 cigarettes that did produce smoldering, 202 burned their full length, 92 did not burn their full length, and there were 140 where it could not be determined. Table 3 shows the results of the FLB evaluations.

Table 3. FLB Results by Cigarette and Substrate

Cigarette	Substrate A	Substrate B	Substrate C	Substrate D
CP5N	Y-24,N-0,?-2	Y-25,N-1,?-0	Y-22,N-2,?-4	Y-3,N-14,?-12
CP5R	Y-15,N-9,?-0	Y-15,N-12,?-0	Y-13,N-8,?-7	Y-5,N-17,?-9
CP7N	Y-25,N-1,?-2	Y-27,N-0,?-0	Y-24,N-0,?-5	Y-9,N-6,?-8
CP7R	Y-27,N-1,?-0	Y-17,N-9,?-0	Y-18,N-5,?-3	Y-13,N-1,?-11
CP9N	Y-20,N-0,?-1	Y-28,N-0,?-0	Y-13,N-1,?-10	Y-9,N-13,?-13
CP9R	Y-19,N-2,?-0	Y-16,N-14,?-0	Y-15,N-2,?-12	Y-7,N-14,?-7
CP13N	Y-31,N-1,?-1	Y-27,N-0,?-0	Y-20,N-0,?-7	Y-1,N-14,?-6
CP13R	Y-24,N-9,?-2	Y-13,N-12,?-0	Y-14,N-6,?-5	Y-6,N-4,?-14

Note: Y = burned its full length; N = did not burn its full length; ? = it could not be determined if it burned its full length.

[8] The one cigarette that was not able to be used was a CP5R cigarette on Substrate D. Thus, there are only 30 data points, instead of 31 for CP5R and Substrate D.

It did not prove feasible to measure char length or area for all of the cigarettes evaluated. Therefore, the analysis will focus first on the logistic regression model with whether a cigarette caused smoldering as the dependent variable and second on the logistic regression model with whether a cigarette burned its full length as the dependent variable.

Smoldering Model

Once the substrate starts to smolder, there is a possibility that it will transition to a flaming fire if left unattended so the smoldering model is very important. CPSC staff ran a stepwise logistic regression model, where the dependent variable was the result of smoldering (smoldering = 1, no smoldering = 0) and RIP/non-RIP, substrate, cigarette packaging, location, and sheeting were the independent variables. Interactions were removed from the model if the p-value was greater than 0.25. An interaction is where the effect of one variable in the model is dependent upon the level of another variable (or variables) in the model. An example would be if the effect of cigarette packaging were different depending on which mattress substrate the cigarette was placed. The model included all of the main effects and two-way interactions for substrate*RIP/non-RIP, substrate*sheeting, cigarette packaging*location, location*sheeting, cigarette packaging*RIP/non-RIP, and cigarette packaging*sheeting. Three of these interactions were significant. Table 4 gives details of statistically significant (throughout this memo, p-values below 0.05 are considered statistically significant) main effects and interactions in the model.

Table 4. Statistically Significant Main Effects and Interactions in the Smoldering Model

Effect	p-value
location	<0.0001
substrate	<0.0001
cigarette packaging	<0.0001
RIP/non-RIP	0.0163
substrate*sheeting	0.0090
location*sheeting	0.0002
cigarette packaging*sheeting	0.0176

The magnitude of test effects and the role played by interactions are discussed in detail in the next section of this memo. According to the model, the sheeting main effect is not significant but all three significant interactions involve the sheeting variable. This indicates that sheeting plays a role in conjunction with other variables in the model. The sign (positive/negative) and magnitude of the estimates in the model indicate that cigarettes placed on the edge of the mattress are most likely to cause smoldering of the substrate, and cigarettes in the smooth surface area are the least likely to cause smoldering of the substrate. Cigarettes on Substrate D were most likely to produce smoldering followed by cigarettes on Substrate C. Cigarettes on Substrates A and B were less likely to cause smoldering. The CP9 cigarettes were most likely to cause smoldering and CP5 were least likely. The CP7 and CP13 cigarettes were between the CP5 and CP9 cigarettes in terms of causing smoldering but not statistically significantly different from each other. Overall, RIP cigarettes were less likely to cause smoldering of the substrate than non-RIP cigarettes, although this differed, depending on things such as the mattress and cigarette packaging involved.

Smoldering Model Analysis

The logistic regression model with smoldering as the dependent variable (smoldering = 1, no smoldering = 0) has three statistically significant interactions, all involving the sheeting variable. The substrate*sheeting variable is statistically significant (p-value = 0.0090). Substrate A and Substrate B were more likely to smolder when cigarettes were placed between sheeting than when cigarettes were placed on the bare mattress.[9] For Substrate C and Substrate D, sheeting seems to make almost no difference.

The location*sheeting interaction is also statistically significant (p-value = 0.0002). Cigarettes placed on a bare mattress are much more likely to produce smoldering of the substrate than cigarettes placed between sheeting when cigarettes are placed on the edge[10] of a substrate.

The third statistically significant interaction is the cigarette packaging*sheeting interaction (p-value = 0.0176). The model predicts that CP7 and CP9 cigarettes are much more likely to cause smoldering of the substrate if they were placed on a bare mattress than if they are between sheeting. For CP5 and CP13 cigarettes, presence of sheeting appeared to make little difference.

In the model, sheeting was involved with three significant interactions. The other independent variables are all significant by themselves. The model shows the following:

- Location, substrate, and cigarette packaging are all significant with p-values below 0.0001.
- RIP/non-RIP is significant with a p-value of 0.0163.
- Cigarettes on the edge are more likely to cause smoldering than cigarettes on the smooth surface. Cigarettes in the tuft were between the edge and the smooth surface in terms of likelihood of causing smoldering.
- Cigarettes on Substrates C and D are more likely to cause smoldering of the substrate than cigarettes on Substrates A and B.
- CP9 cigarettes are more likely to cause smoldering of the substrate than CP5 cigarettes. CP7 and CP13 cigarettes were between the CP9 and CP5 cigarettes in terms of causing smoldering.

In logistic regression, the estimated coefficients are in log odds ratios. Exponentiating these estimates result in odds ratios. These ratios are relative odds with one level of the variable set as the default denominator level. The odds, in this case, are pr(smoldering)/(1-pr(smoldering)).[11] Table 5 below gives details of the estimates for the main effects for the smoldering model.

Table 5. Main Effects for Smoldering Model

Effect	**Level**	**Estimate**	**Odds Ratio**
Location	Edge	0.8566	2.3551
	smooth surface	-0.3314	0.7179
Substrate	substrate A	-3.8558	0.0212
	substrate B	-3.7343	0.0239
	substrate C	-1.0153	0.3623
Cigarette Packaging	CP5	-0.4563	0.6336
	CP7	-0.1720	0.8420
	CP9	0.3679	1.445
RIP/non-RIP	Non-RIP	2.1571	8.6460

Note: Odds ratios for location are relative to tuft; odds ratios for substrate are relative to substrate D; odds ratios for cigarette packaging are relative to CP13; and odds ratios for RIP/non-RIP are relative to RIP.

If the estimate of the log odds ratio is negative, then it is estimated that the odds are lower for that level than for the default level. If the estimate is positive, then the estimated odds are higher. A higher (more positive) estimate indicates a higher estimated likelihood of smoldering relative to the default level. For

[9] For example, the raw data for Substrate B shows none of the 108 cigarettes placed on the bare mattress result in smoldering of the substrate, but 12 of the 108 cigarettes placed between sheeting result in smoldering.

[10] Substrate C did not have an edge but the other three substrates did.

[11] Pr(smoldering) is the model's predicted probability of a cigarette causing smoldering of the substrate.

example, it is estimated that the odds of producing smoldering are 8.646 times higher for non-RIP cigarettes than for RIP cigarettes. This does not mean it is 8.646 times more likely to produce smoldering because the odds are not equal to the likelihood, but the odds are equal to the likelihood divided by one minus the likelihood [pr(smoldering)/(1-pr(smoldering))].

The odds are an increasing one-to-one function of the likelihood. Therefore, if the odds are higher, the likelihood is higher. A demonstration of the relationship between likelihood and odds is given below in Table 6. Unfortunately for those trying to interpret these ratios, it cannot be tied to a specific percentage difference in the likelihood of smoldering. The odds of producing smoldering for non-RIP cigarettes are an estimated 8.646 times higher than for RIP cigarettes, but this doesn't necessarily translate to 20% more likely, or 30% more likely, and so forth. To gain a sense of the difference that RIP cigarettes make, it is best to look at the predicted probability of smoldering plots on p. 9−12 (Figures 1−4).

Table 6. Odds as a Function of Likelihood

Likelihood	Odds
5%	0.053
10%	0.111
20%	0.25
30%	0.429
40%	0.667
50%	1
60%	1.5
70%	2.333
80%	4
90%	9
95%	19

A comparison was made of the odds for RIP versus non-RIP cigarettes on each of the 16 combinations of substrate and cigarette packaging. Before adjusting for multiple comparisons, it was found that four of these 16 comparisons are statistically significant (that the odds and therefore the likelihood of causing smoldering was higher for the non-RIP cigarette than for its RIP counterpart), three of which involved the CP9 cigarettes. The fourth involved the CP5 cigarette. After making adjustments to fix the experiment-wise error rate[12] to 0.05, two of these four comparisons remained statistically significant. Both of these comparisons that remained significant involved the CP9 cigarette. Table 7 gives details of these 16 RIP versus non-RIP comparisons. The statistically significant comparisons are in bold. The comparisons that are statistically significant, even after the multiple comparison adjustments are made, are in red.

[12] The Type 1 error rate for a given comparison is the likelihood that you find a difference if no difference exists. When making more than one comparison, not adjusting the chance of making a Type 1 error (alpha) for a given test causes the chance of making at least one such error in the group of tests to increase. Therefore, an adjustment is made to set the chance of making at least one type 1 error out of all the tests (in this case there were 16 tests) to alpha (for these tests alpha = 0.05). The Bonferroni-Holm method was used to make this adjustment.

Table 7. RIP Comparisons for each Substrate/Cigarette Combination - Smoldering Model

Comparison	Estimate	Odds Ratio	Odds Ratio CI	p-value	Adj. p-value
Substrate A – CP5 non vs. RIP	0.3039	1.3551	(0.3554, 5.1673)	0.6559	1.0000
Substrate A – CP7 non vs. RIP	-0.0092	0.9909	(0.1998, 4.9148)	0.9910	1.0000
Substrate A – CP9 non vs. RIP	**2.0158**	**7.5068**	**(1.5182, 37.1181)**	**0.0135**	**0.1892**
Substrate A – CP13 non vs. RIP	0.0340	1.0346	(0.3081, 3.4740)	0.9561	1.0000
Substrate B – CP5 non vs. RIP	-1.0326	0.3561	(0.06081, 2.0851)	0.2517	1.0000
Substrate B – CP7 non vs. RIP	-1.3457	0.2604	(0.03911, 1.7332)	0.1638	1.0000
Substrate B – CP9 non vs. RIP	0.6793	1.9726	(0.3874, 10.0434)	0.4128	1.0000
Substrate B – CP13 non vs. RIP	-1.3025	0.2718	(0.0512, 1.4435)	0.1260	1.0000
Substrate C – CP5 non vs. RIP	0.7889	2.2010	(0.8115, 5.9697)	0.1210	1.0000
Substrate C – CP7 non vs. RIP	0.4759	1.6094	(0.3930, 6.5913)	0.5077	1.0000
Substrate C – CP9 non vs. RIP	**2.5008**	**12.1928**	**(2.4581, 60.4792)**	**0.0023**	**0.0353**
Substrate C – CP13 non vs. RIP	0.5190	1.6804	(0.5946, 4.7488)	0.3270	1.0000
Substrate D – CP5 non vs. RIP	**2.4270**	**11.3247**	**(1.2463, 102.90)**	**0.0312**	**0.4052**
Substrate D – CP7 non vs. RIP	2.1139	8.2806	(0.6542, 104.82)	0.1025	1.0000
Substrate D – CP9 non vs. RIP	**4.1389**	**62.7339**	**(4.4543, 883.53)**	**0.0022**	**0.0353**
Substrate D – CP13 non vs. RIP	2.1571	8.6457	(0.8344, 89.5822)	0.0705	0.8462

The 16 comparisons are two-sided t-tests comparing the relative odds of smoldering resulting from RIP and non-RIP cigarettes for each of the 16 combinations of substrate and cigarette packaging. The numerator in the odds ratio is the non-RIP and the denominator is the RIP. Therefore, because the estimate is the natural log of the odds ratio, a positive estimate indicates that the non-RIP cigarette is estimated to be more likely to result in smoldering of the substrate. If the estimate is positive, the odds ratio is above one and if it is negative, the odds ratio is below one. The four combinations of substrate and cigarette packaging for which a statistically significant difference was found are bolded in Table 7. For these four combinations, the non-RIP cigarettes are estimated to be more likely to cause smoldering of the substrate than their RIP counterpart. Three of these four involve the CP9 cigarettes. When adjusting for multiple comparisons, by setting the experiment-wise error rate to 0.05, two of the four remain statistically significant. Both of these involve CP9 cigarettes.

Odds ratios can be difficult to interpret. It is helpful to look at plots of the model's predicted probabilities for RIP versus non-RIP. Figure 1 to Figure 4 give these plots for each of the 16 combinations of substrate and cigarette packaging. Each line in the plots is formed by two points – the predicted probability for the non-RIP version of the cigarette and the corresponding predicted probability for the RIP version. There are four lines for the plots involving Substrate C because it only has two locations (smooth surface and tuft) and two possibilities for sheeting (yes and no). The plots for the other three substrates have six lines because those substrates have a third location (edge) and still two possibilities for sheeting. In plots where the lines are fairly parallel, the location and sheeting are not making much of a difference in the smoldering. In the ones where the slopes differ, you can see the difference that the location and/or the sheeting are making in the likelihood of causing smoldering. If the lines slope downward (going from left to right), that means the model estimates the likelihood of smoldering is higher for the non-RIP cigarettes. If they slope upward, it is estimated that the RIP cigarettes are more likely to cause smoldering.

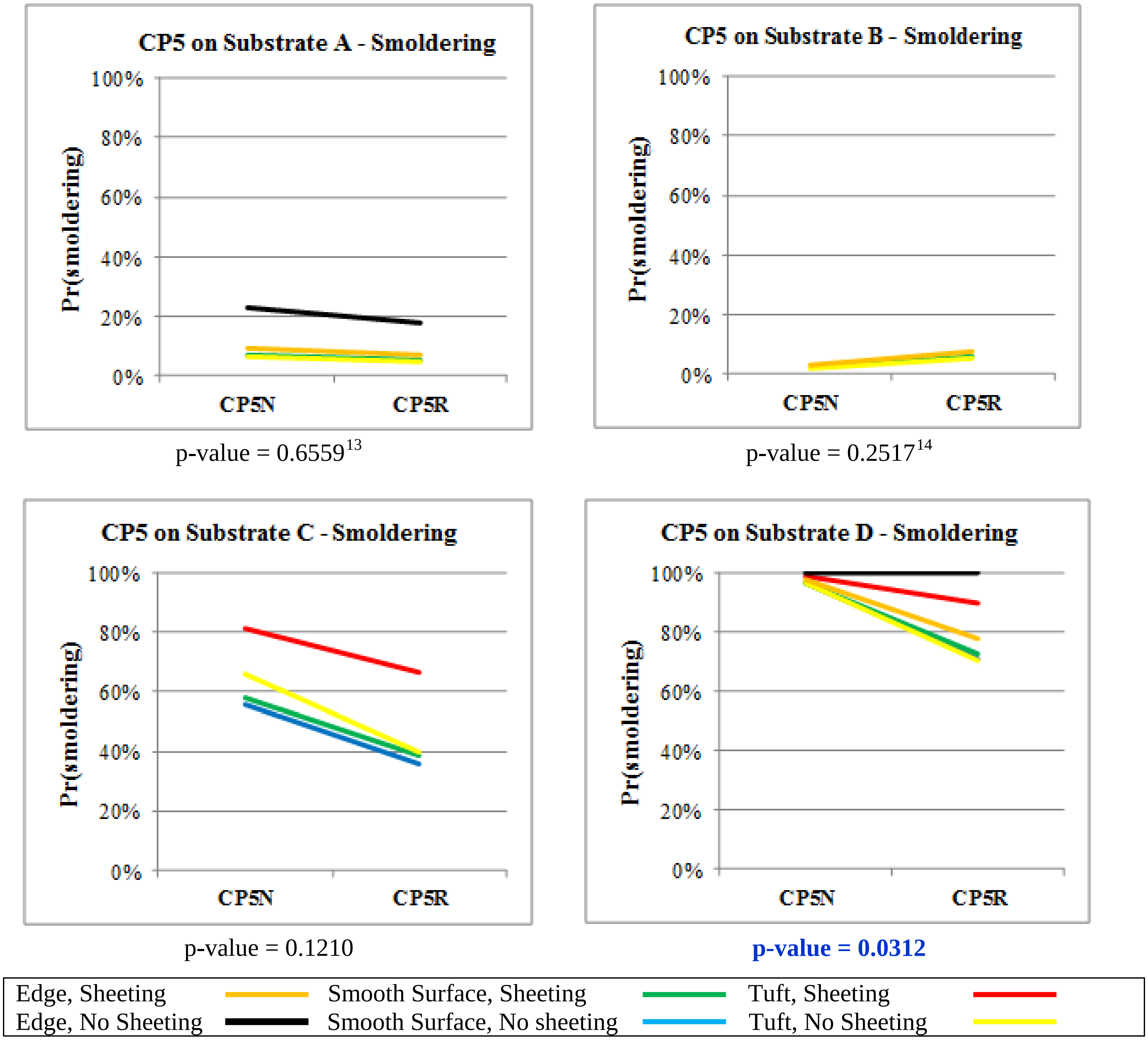


Figure 1. Predicted Probability of Smoldering Plots for CP5 Cigarettes

The plots for CP5 demonstrate the greater estimated likelihood of smoldering on substrates A and D than on substrates B and C. For substrates A, C, and D, the estimated likelihood of smoldering for RIP cigarettes is lower than for non-RIP. For substrate D, the RIP/non-RIP effect is statistically significant (p-value = 0.0312), but even for the RIP cigarettes on substrate D, all of the predicted probabilities of smoldering are greater than 70%. Cigarettes on the tuft and the edge tend to have higher probabilities of

[13] The line for "smooth surface, no sheeting" is hidden. The predicted probabilities of smoldering for this location/sheeting combination are 0% for both RIP and non-RIP cigarettes.

[14] The lines for "smooth surface, no sheeting" and "tuft, no sheeting" are hidden. The predicted probabilities of smoldering for these location/sheeting combinations are 0% for both RIP and non-RIP cigarettes.

smoldering than those on the substrate's smooth surface. The effect of sheeting varies from substrate to substrate and from location to location.

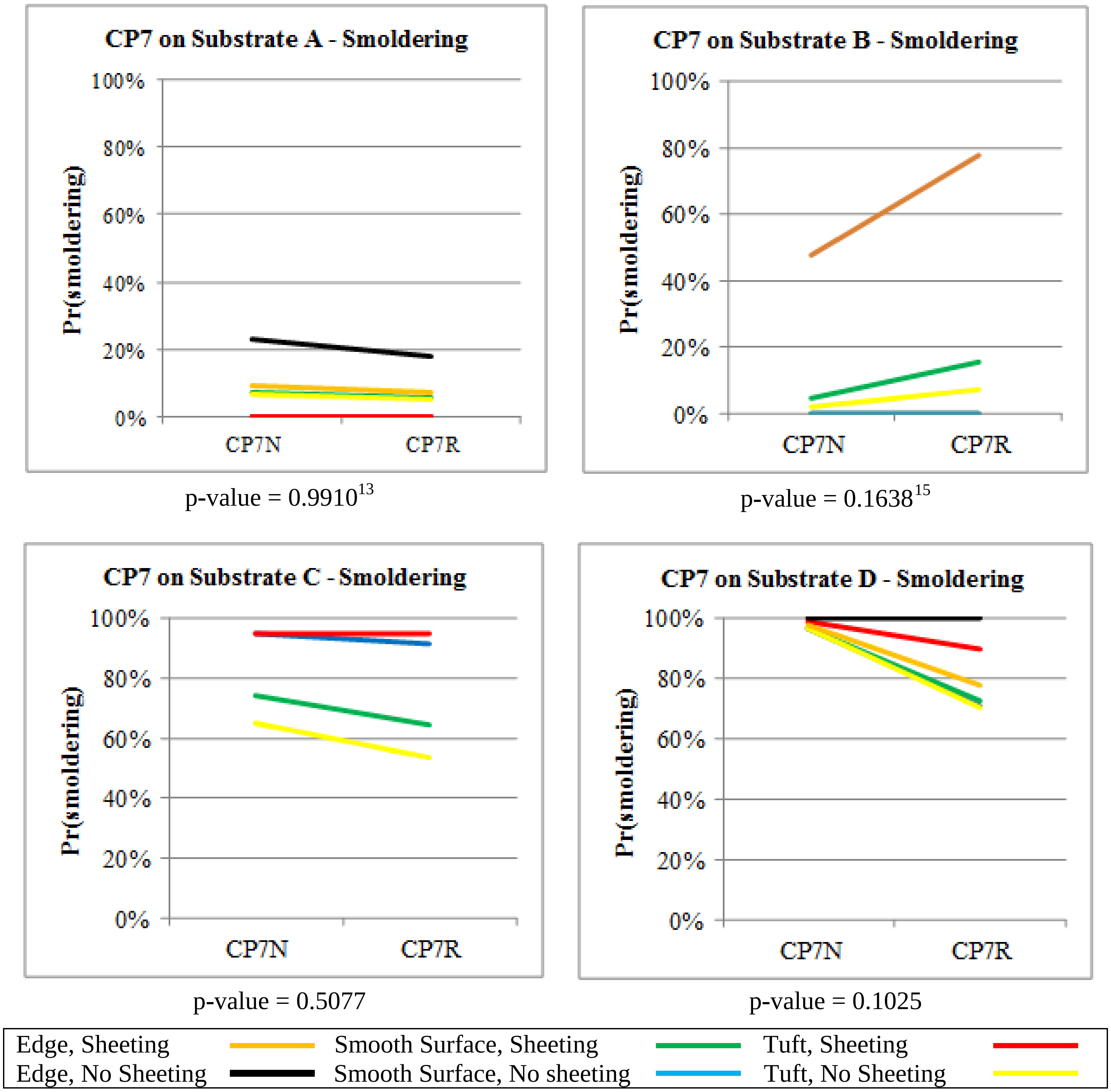


Figure 2. Predicted Probability of Smoldering Plots for CP7 Cigarettes

None of the RIP/non-RIP comparisons involving CP7 cigarettes are statistically significant. They show higher probabilities of smoldering for non-RIP cigarettes than their RIP counterparts on substrates A, C, D. Substrate B shows a higher probability of smoldering for the RIP cigarettes than the non-RIP. As with, CP5 cigarettes, CP7 cigarettes on substrate D all had predicted probabilities of smoldering greater

[15] The lines for "edge, no sheeting" and "tuft, no sheeting" are hidden. The predicted probabilities of smoldering for these location/sheeting combinations are 0% for both RIP and non-RIP cigarettes.

than 70%. CP7 cigarettes on the edge tend to have the highest predicted probabilities of smoldering. The effect of sheeting again appears to vary from substrate to substrate and location to location.

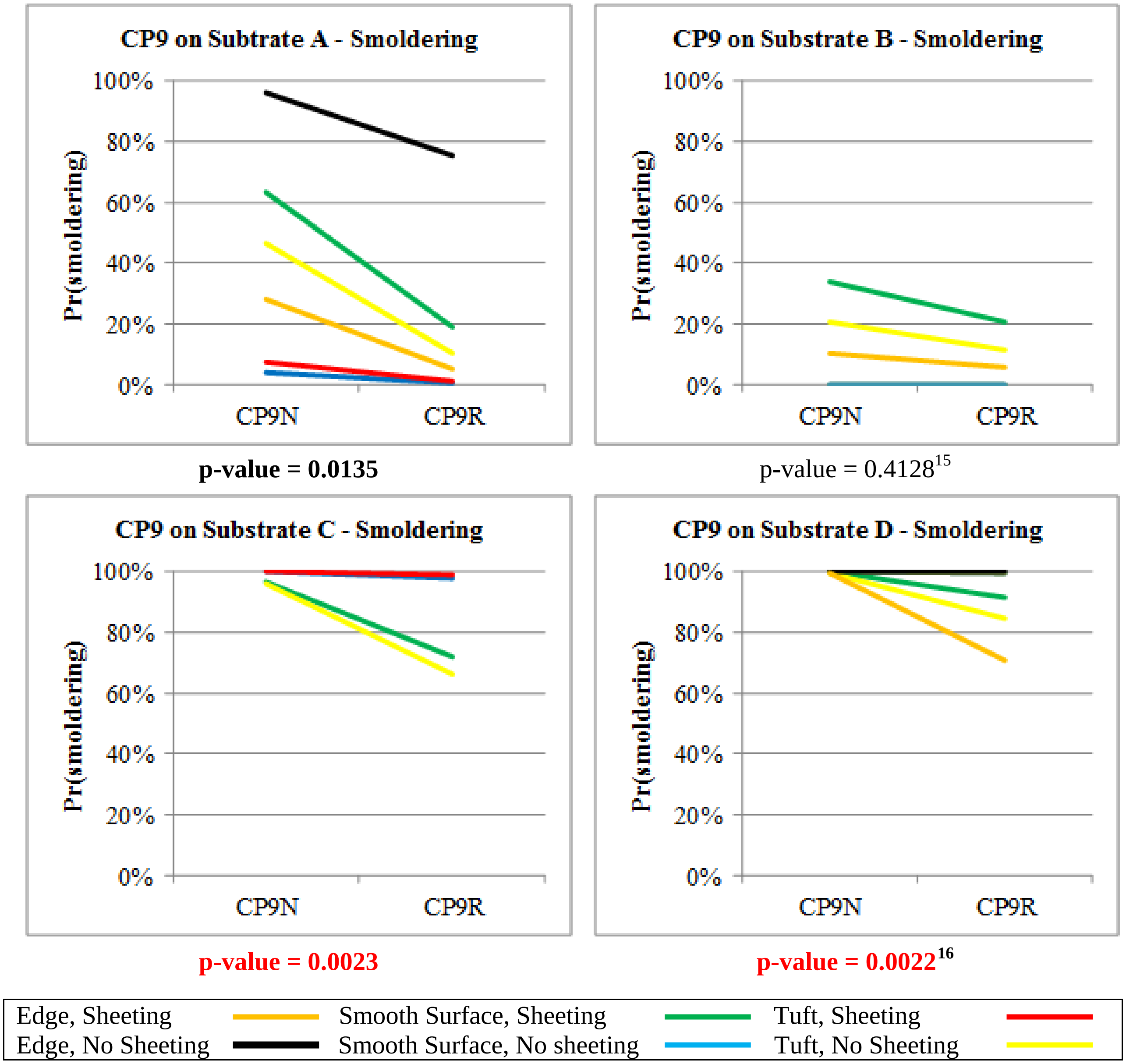
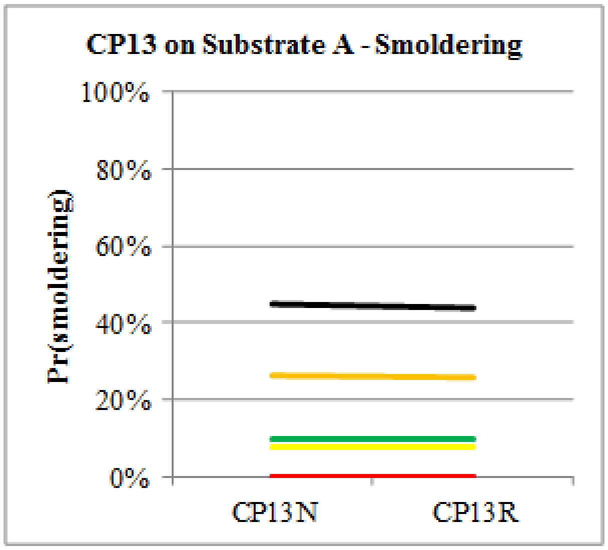


Figure 3. Predicted Probability of Smoldering Plots for CP9 Cigarettes

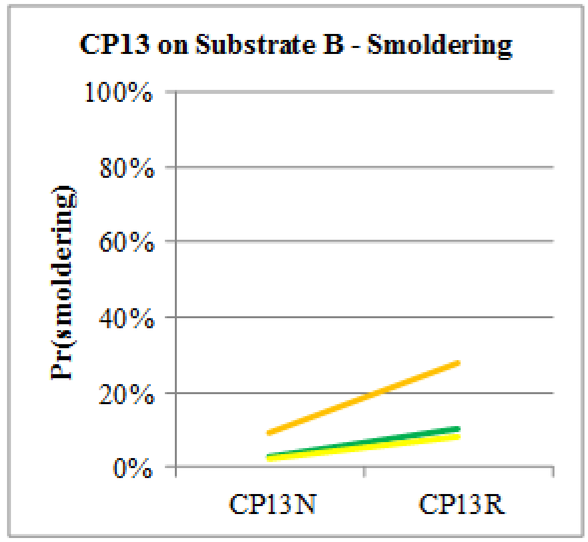
The RIP/non-RIP comparisons for cigarettes on substrates A, C, and D are statistically significant with the RIP cigarette having a lower predicted probability of causing smoldering than their non-RIP counterparts. For substrates C and D, the comparisons remain statistically significant after adjusting for multiple comparisons. Although the RIP-predicted probabilities of causing smoldering are significantly lower for substrates C and D, each one is still 66% or higher (71% for substrate D). On substrates C and D the presence of sheeting leads to lower predicted probabilities of smoldering for the RIP cigarettes, but

[16] The line for "tuft, no sheeting" is hidden. The predicted probabilities of smoldering for this location/sheeting combination are 100% for both RIP and non-RIP cigarettes.

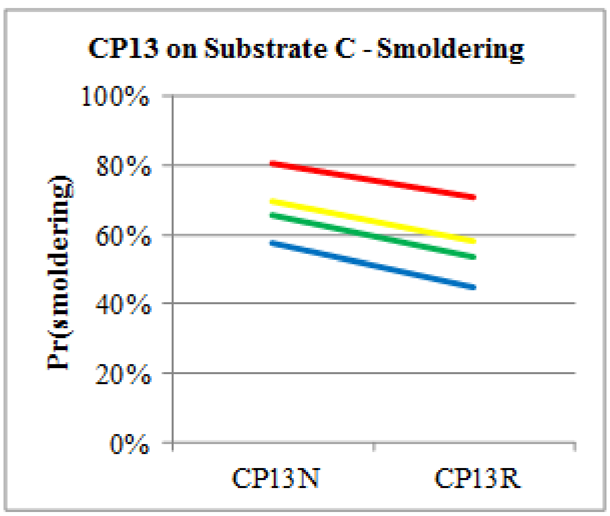
in most cases on substrates A and B, the presence of sheeting leads to higher predicted probabilities of smoldering.



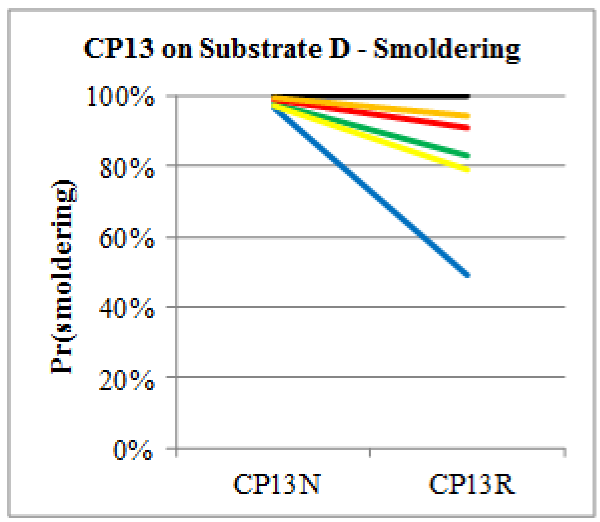
p-value = 0.9561[13]



p-value = 0.1260[15]



p-value = 0.3270



p-value = 0.0705

Edge, Sheeting	Smooth Surface, Sheeting	Tuft, Sheeting
Edge, No Sheeting	Smooth Surface, No sheeting	Tuft, No Sheeting

Figure 4. Predicted Probability of Smoldering Plots for CP13 Cigarettes

The predicted probabilities of causing smoldering for CP13 cigarettes were lower for the RIP cigarettes than the non-RIP on substrates C and D. The predicted probabilities were higher for the RIP than the non-RIP on substrate B and on substrate A they were nearly the same – thus, the very high p-value. The RIP/non-RIP effect was not statistically significant on any of the substrates for CP13 cigarettes although it was close on substrate D (p-value = 0.0705). On substrate D, the predicted probabilities for the RIP differed from the non-RIP much more on the smooth surface than on the other locations.

Three of the four statistically significant substrate/cigarette packaging combinations, and both of the combinations that remained significant after multiple comparison adjustments were made, involved the

CP9 cigarettes. This cigarette is known to be of high ignition propensity as compared to the other packagings on the market. Due to this difference between the other cigarettes and the appearance that these cigarettes are a large driver in the variability seen in the model, CPSC staff ran a logistic regression model with the CP9 cigarettes removed from the data.

Smoldering Model without CP9 Cigarettes

This is the same logistic regression smoldering model as described above with whether a cigarette caused smoldering of the substrate as the dependent variable (smoldering = 1, no smoldering = 0) and substrate, cigarette packaging, RIP/non-RIP, location, and sheeting as the independent variables; the only difference is that the CP9 cigarettes are removed. Once again, interactions were removed from the model if they had a p-value greater than 0.25. The resulting model is much different from the one where CP9 cigarettes were included. The interactions that remain in the model are substrate*cigarette packaging, substrate*RIP/non-RIP, cigarette packaging*location, RIP/non-RIP*location, and cigarette packaging*sheeting. The only interaction that is statistically significant is substrate*RIP/non-RIP, which has a p-value of 0.0129. This model predicts that for Substrate A and Substrate B, the RIP cigarettes have higher odds of causing smoldering, whereas for Substrate C and Substrate D, the non-RIP cigarettes have higher odds of causing smoldering.

In the full model (all cigarettes), all main effects were statistically significant with the exception of sheeting. In the model without the CP9 cigarettes, only location and substrate are statistically significant. Cigarettes placed on the edge have higher odds of producing smolder than cigarettes on the smooth surface, which is also true for the model with the CP9 cigarettes included. Cigarettes on Substrate C and Substrate D have higher odds of causing smoldering of the substrate than cigarettes on Substrate A or Substrate B. The RIP/non-RIP effect is not statistically significant in this model with a p-value of 0.5825. The only statistically significant role played by the RIP/non-RIP in this model is in the substrate*RIP/non-RIP interaction. Table 8 gives the details of the significant main effects from this model.

Table 8. Main Effects for Smoldering Model Without CP9 Cigarettes

Effect	Level	Estimate	Odds Ratio
location	edge	1.0598	2.8858
location	smooth surface	-0.6496	0.5223
substrate	substrate A	-4.2390	0.0144
substrate	substrate B	-4.5380	0.0107
substrate	substrate C	-1.0823	0.3388

Note: Odds ratios for location are relative to tuft and odds ratios for substrate are relative to substrate D.

Using the full model, RIP/non-RIP is statistically significant as is location, substrate, and cigarette packaging. Sheeting is not statistically significant by itself, but it is involved in three statistically significant two-way interactions. The RIP/non-RIP effect is of particular interest. In the full model, it appears that it is driven largely by the CP9 cigarettes. The CP9N is more likely to produce smoldering than the CP9R. The results of the model are very different when it is run without the CP9 cigarettes included. The RIP/non-RIP effect is no longer statistically significant and neither is the cigarette packaging. There is a statistically significant interaction for substrate*RIP/non-RIP. The model (with CP9 removed) predicts that the RIP cigarettes are more likely to cause smoldering than the non-RIP cigarettes on Substrate A and Substrate B but less likely to cause smoldering than the non-RIP on Substrate C and Substrate D.

Full Length Burn (FLB) Model: Results

The theory behind the RIP cigarette is that if it is left unattended, it will be more likely to self-extinguish prior to burning its full length, thus resulting in fewer fires. The states' regulations require that cigarettes be evaluated for the portion of FLBs on a filter paper substrate. In order to relate the data on mattresses and mattress pads to the states' regulations, it is important to analyze FLBs in this study. CPSC staff ran a stepwise logistic regression model, testing full length burn (FLB) as the dependent variable (FLB = 1, no FLB = 0, unknown FLB = 1) and RIP/non-RIP, substrate, cigarette packaging, location, and sheeting as the independent variables. An evaluation was coded "unknown" when it was not possible to determine whether the cigarette burned its full length independent of the substrate or it did not burn at the same rate as the substrate. All of these evaluations resulted in smoldering of the substrate and did not show any cessation of cigarette burning during the test. Therefore, it was decided to treat the cigarettes where it could not be determined if they burned their full length as FLBs. Interactions were removed from the model if they had a p-value greater than 0.25. This resulted in a model that included all main effects and two-way interactions for substrate*RIP/non-RIP, substrate*sheeting, cigarette packaging*location, RIP/non-RIP*location, location*sheeting, and RIP/non-RIP*sheeting. Four of these interactions were significant. Table 5 gives details of significant main effects and interactions in the FLB model.

Table 9. Statistically Significant Main Effects and Interactions in the FLB Model

Effect	p-value
location	<0.0001
substrate	<0.0001
cigarette packaging	<0.0001
RIP/non-RIP	<0.0001
substrate*RIP/non-RIP	<0.0001
substrate*sheeting	0.0496
location*RIP/non-RIP	0.0204
location*sheeting	0.0029

All of the main effects, except for sheeting, are highly statistically significant (p-value < 0.0001).

- The sign of the estimates indicates that cigarettes in the tuft are most likely to burn their full length and cigarettes on the edge are least likely to burn their full length. Cigarettes on the smooth surface are between the other two in their likelihood to burn their full length.

- Cigarettes on Substrate A are most likely to have full length burns and cigarettes on Substrate D are least likely. Cigarettes on Substrates B and C are between those on Substrates A and D in terms of their likelihood to burn their full length.

- CP13 cigarettes are estimated most likely to have full length burns and CP5 the least likely with CP7 and CP9 in the middle.

- RIP cigarettes are less likely to burn their full length than non-RIP cigarettes when tested on mattress and mattress pad substrates.

The estimate (log odds ratio) for the RIP/non-RIP effect in the model is 1.6850 and the estimated relative odds are 5.3925. This means that the model estimates the odds of a cigarette burning its full length are 5.3925 times higher for RIP cigarettes than non-RIP. This does not mean that non-RIP cigarettes are an estimated 5.3925 times more likely to burn their full length. Odds are a function of likelihood but they are not the same as likelihood. When this model is run with the CP9 cigarettes removed, the results are similar; all main effects are significant, except for sheeting, and the estimate for RIP/non-RIP in the model is 2.0933 (relative odds = 8.1116).

Table 10. Main Effects for Smoldering Model

Effect	Level	Estimate	Odds Ratio
Location	edge	-1.3623	0.2561
	smooth surface	-0.2230	0.8001
Substrate	substrate A	3.2275	25.2165
	substrate B	2.2440	9.4310
	substrate C	2.2431	9.4225
Cigarette Packaging	CP5	-0.6425	0.5260
	CP7	0.5372	1.7112
	CP9	0.6323	1.8819
RIP/non-RIP	Non-RIP	1.6850	5.3925

Note: Odds ratios for location are relative to tuft, odds ratios for substrate are relative to substrate D, odds ratios for cigarette packaging are relative to CP13, and odds ratios for RIP/non-RIP are relative to RIP.

A cigarette burning its full length does not necessarily correspond with producing smoldering and being likely to start a fire. This can be seen by the differences in the Smoldering and Full Length Burn models.

CONCLUSIONS

A model was developed to assess the difference in ignition behavior between RIP and non-RIP cigarettes of the same packaging when tested on mattress and mattress pad substrates. Staff is primarily interested in the smoldering of the substrate caused by the cigarettes as an indication of potential transition to a flaming fire. The cigarette's ability to burn its full length on the mattress or mattress pad substrate is also of interest because this is the performance metric used in states' regulations.

The model analyzing the smoldering results showed overall that RIP cigarettes had lower odds of causing smoldering of the substrate than non-RIP cigarettes when placed on a substrate and controlling for the other factors. There are different effects for RIP versus non-RIP cigarettes for each substrate as seen in the interaction terms. This can also be seen by the differences in the predicted probabilities of causing smoldering between the different Figures (1−4) for each combination of substrate and cigarette packaging. The differing slopes of the lines in Figures 1−4 demonstrate that the role the RIP cigarette plays in smoldering can vary with location of the cigarette and the presence of sheeting.

The CP9 cigarette plays a large role in this statistically significant RIP/non-RIP effect. When comparing odds of smoldering for the 16 combinations of substrate and cigarette packaging, there were four combinations that were statistically significant. Three of these four involved the CP9 cigarette.

How different interactions of factors play into the effect of smoldering between the RIP and non-RIP cigarettes is very important. The model shows that the RIP has smaller odds of causing smoldering than the non-RIP, but the interactions and the CP9 cigarettes' effect on the model must be considered in understanding how the RIP cigarettes are performing. Substrate, cigarette packaging, location, and sheeting (in combination with other variables) also played a statistically significant role in the likelihood that a cigarette would cause smoldering of the substrates.

When the model is run with the CP9 cigarettes removed, the RIP/non-RIP effect is not statistically significant. There is a statistically significant substrate*RIP/non-RIP interaction. It appears that the RIP cigarettes performed better at not causing smoldering on Substrate C and D, but the non-RIP actually performed better on Substrate A and B. When the CP9 cigarettes are removed from the data, the substrate and location variables are statistically significant in the model. It seems that the CP9R cigarette is effective in producing less smoldering than its non-RIP counterpart. Thus, there appears to be a statistically significant RIP effect that is dependent upon the CP9 cigarettes being part of the data. When the CP9 cigarettes are not part of the data, there is no statistically significant RIP effect.

The Full Length Burn model showed that all main effects, except for the sheeting effect, were very statistically significant. RIP cigarettes were less likely than non-RIP cigarettes to burn their full length. Unlike for the smoldering model, this remained true when the CP9 cigarettes were removed from the data.

It is important to point out that for certain combinations of substrate, cigarette packaging, location, and sheeting, the smoldering model predicts a high probability of smoldering of the substrates for both RIP and non-RIP cigarettes. The substrates and cigarette packagings tested were not selected randomly, so our conclusions are limited to these particular substrates and cigarettes.

Bibliography

Agresti, A. (2002). *Categorical Data Analysis*. Hoboken, NJ: John Wiley and Sons, Inc.

Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D., & Schabenberger, O. (2006). *SAS for Mixed Models* (2nd ed.). Cary, NC: SAS Institute, Inc.

Supporting Document G: Campbell, J. Mellish, R., "Characterization of Test Substrates Used in Cigarette Ignition Risk Project Testing" Memorandum to S. Mehta. August, 2012.

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
4330 EAST WEST HIGHWAY
BETHESDA, MD 20814

Memorandum

Date: September 6, 2012

TO : Shivani Mehta, Project Manager, Cigarette Ignition Risk Project
Directorate for Engineering Sciences
Division of Fire and Combustion Sciences

THROUGH: George A. Borlase, Ph.D., Associate Executive Director
Directorate for Engineering Sciences
Patricia K. Adair, Director
Directorate for Engineering Sciences
Division of Combustion and Fire Sciences

FROM : Jacqueline H. Campbell, Textile Technologist
Richard E. Mellish, Student Intern
Directorate for Engineering Sciences
Division of Combustion and Fire Sciences

SUBJECT : Characterization of Test Substrates Used in Cigarette Ignition Risk Project Testing

1. INTRODUCTION

Reduced Ignition Propensity (RIP) cigarettes are cigarettes that have been designed to self-extinguish when there is no interaction with a smoker. While the U.S. Consumer Product Safety Commission (CPSC) does not regulate cigarettes, cigarettes are identified as a possible ignition source for soft furnishings, such as mattresses, of which the flammability performance is regulated by the CPSC in 16 C.F.R. part 1632, *Standard for the Flammability of Mattresses and Mattress Pads*. CPSC staff conducted a study[1] to investigate the differences in burning behavior between RIP and non-RIP cigarettes on mattresses, futons, and mattress pads. Mattresses, futons, and mattress pads were sourced as test substrates to evaluate cigarette smoldering behavior. In this memorandum, CPSC staff characterized the test substrates in order to document their construction and confirm the reported material content.

2. BACKGROUND

Reduced Ignition Propensity cigarettes are designed to self-extinguish when not in use by a consumer. These cigarettes commonly are referred to as “fire safe” or “low ignition

[1] The results of this study will be addressed in a separate CPSC staff memorandum.

propensity" cigarettes. Since July 2011, all states have mandates that only RIP cigarettes may be introduced into commerce.

One of the CPSC mattress flammability standards, 16 C.F.R. part 1632, *Standard for the Flammability of Mattresses and Mattress Pads* (1632), requires the use of cigarettes as the test ignition source. The cigarette currently used as an ignition source when testing for 1632 is a standard reference material (SRM) cigarette that is a non-RIP design.[2] Because every state requires that all cigarettes sold to consumers are RIP cigarettes, the risk of smoldering ignition caused by cigarettes potentially could change and may warrant consideration of revisions of existing regulations and voluntary standards.

CPSC staff designed and conducted a study to observe the flammability performance of RIP and non-RIP cigarettes on mattresses, futons, and mattress pads, using a modified version of the 1632 test method. Four test substrates were selected to provide a range of flammability performance when subjected to the ignition source. The four test substrates subjected to testing were characterized using two methods. The first method was a visual inspection of the substrates, including a characterization of the basic construction (*e.g.*, weave, color, components) along with photomicrographs taken at 5X, 50X, and 500X magnification. The second method involved a composition analysis using Fourier Transform Infrared Spectroscopy (FT-IR) to confirm the fiber type of the component material. The following memorandum describes the process by which the test substrates were characterized and documents the results.

3. TEST MATERIALS

The four different test substrates consisted of a futon, two mattresses, and a mattress pad. The four substrates were commercially available products, identified as good candidates in initial testing conducted by CPSC staff. They were sourced not to contain flame-retardant treatments or inherently flame-retardant materials so that the substrates would be more likely to smolder, thereby showing the ignition propensity of the test cigarettes. The purpose of this testing was to examine the differences in mattress ignitions and smoldering, as a means of characterizing differences between non-RIP cigarettes and RIP cigarettes that are now in the marketplace. These four test substrates specifically were chosen to provide a range of substrates that might encourage the possibility that a discernible difference could be found, if it existed, between the flammability performance of RIP and non-RIP cigarettes. The results reported in this memorandum are not necessarily representative of all mattresses, futons, or mattress pads, but rather, provide documentation of the test materials used, and therefore, a baseline when evaluating the results of testing reported in a separate staff memorandum on RIP versus non-RIP cigarette flammability performance.

4. METHODS

The four different test substrates were characterized using two different methods. The first method was a physical examination of the basic construction of the substrates themselves. This method included a layer-by-layer assessment of the test substrates to catalogue the different

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[2] NIST SRM 1196, Standard Cigarette for Ignition Resistance Testing. www.nist.gov/ts/msd/srm.

components of the substrates and to determine that all specimens of a given substrate were the same. Using a microscope at 5X, 50X, and 500X magnification allowed for a more detailed look at the constructions, fabrics, and fibers of the substrate components. The resulting photomicrographs provide a visual documentation of the substrates for posterity. The second method used FT-IR to confirm the fiber types of the substrates.

- **Physical Examination of Construction**

The method used to characterize the basic construction of the test substrates was applied to a sample of each substrate. First, the general category of the substrate was identified (mattress, mattress pad, or futon). It was noted whether the substrate was labeled to meet any mattress flammability standards, such as 16 C.F.R. part 1633. Next, the construction of the substrate was characterized, starting from the outermost layer of construction, down to the innermost layer. The ticking was always the first component characterized. “Ticking” is the outermost fabric that is used in upholstering the mattress or mattress pad. The fiber type as reported on the product label, fabric type, color, weave, and any pattern sewn into the ticking were noted.

From there, the next layer was characterized. Usually, this layer was some sort of batting material. “Batting” is defined as fabric or fibers that are used for padding in filled bedding or mattresses. The characteristics that were examined in the batting were quality of batting (dirty/clean, containing few or many seed fragments or immature fibers), color of the materials, and thickness of the layer of material in relation to the other substrate components. Any remaining test substrate components were characterized, noting fabric type, color of the materials, similarities to any of the other layers of construction, and thickness of the layers of materials in relation to the other substrate components.

If the test substrate had a tape edge, that would be noted and characterized, including the type and color of yarn used in the stitching. “Tape edge” is defined as the outermost edge of a mattress or mattress pad that serves to bind together the ends of the ticking and internal components to stabilize the product construction. Typically, this edge is made from the same material as, or a slightly heavier fabric than, the ticking fabric. Finally, any other qualities that did not fit under any of the previous characterization categories were noted.

Photomicrographs were taken of each component layer of the test substrates. Small pieces were cut from the test substrate to make handling the materials easier. Materials are presented in this report from the outermost layer to the innermost layer. Photomicrographs were produced at a 5X magnification with a single focal point and at 50X and 500X magnification, using the three dimensional mode on the microscope software so that the entire field would be in focus. In order to produce the three dimensional photomicrograph, the software takes multiple photomicrographs in small increments, starting from the lowest to the highest focal points of the material and then renders the compilation of all the images, giving a clear and detailed picture with the entire subject material in focus.

- **Fourier Transform Infrared Spectroscopy (FT-IR)**

The FT-IR was used in conjunction with OMNIC® software to confirm the reported fiber types used in the construction of the substrate. The instrument model is a Nicolet 6700 FT-IR using OMNIC® software version 8.8.11.

This analytical technique is used frequently to provide a qualitative confirmation of chemical components. Infrared spectroscopy works by exposing light across the infrared spectrum to a sample liquid, solid, or gas. Each molecular bond has its own specific resonance frequency, which is detectable when the infrared light is at that particular wavelength, creating absorbance peaks in the resulting spectrum. These peaks on the spectrum represent a specific bond type (functional group). This method is fast to perform, does not require a highly skilled operator, and can be nondestructive. It is also important to note that asymmetrical molecules, such as water (HOH), are visible, whereas symmetrical molecules, such as nitrogen gas (N_2), will not be visible in infrared spectroscopy. This limitation is one disadvantage of this method. Other disadvantages include: error in identification if an operator is not trained to differentiate peaks in spectra and only accepts the software's match; quantitative analyses can be difficult to achieve accurately; and equipment is expensive and requires maintenance by skilled personnel.

For purposes of these analyses, the components of the test substrates were presented to the instrument in solid form under ambient conditions. When testing the components of the substrate, a scan was performed with no material in the machine in order to collect data on the background. These data were used to determine a baseline for the remainder of the measurements. Background scans were repeated at the start of every test series. After the background data were collected, the component sample was presented to the instrument detector, and the data were collected. For both the background data and the component sample data, eight scans were performed to determine each spectrum. For purposes of this experiment, this number of scans kept the time required to collect the data relatively low, but it also provided enough scans to lower the effect of noise in the resulting spectra. Once the sample had been measured, the OMNIC® software creates an absorption spectrum. Using this measured spectrum, the software can search the database to find the closest match. It is important to note that the amplitude of the different peaks on the spectra is not as important as the wavelength locations of the peaks of the different spectra. The search results give a list of the closest matches sorted by percentage match. For the results with low percentages or similar percentages to the closest match, it is important to consider the other spectra to make sure that the highest rated match, according to the software, is accurate. In most cases, cotton was identified easily by the software. In other cases, such as with the polypropylene components, it was not immediately obvious which type of polypropylene the material contained. However, for purposes of this investigation, the generic identification of the fiber type was sufficient. All of the FT-IR results were confirmed using microscopy.

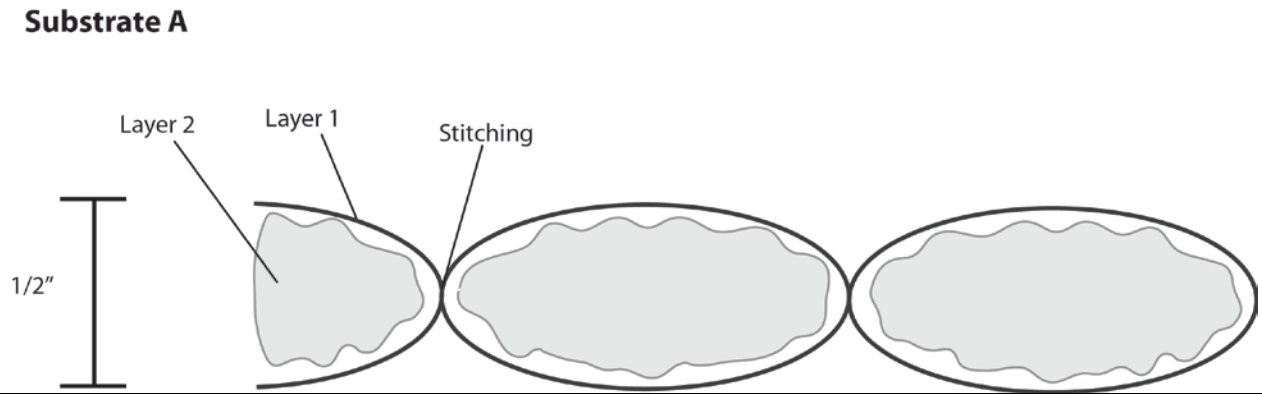
5. RESULTS

- **Test Substrate A**

Substrate A is a mattress pad. Layer 1, the ticking, is made of cotton sateen weave. It is labeled as containing 100 percent organic cotton and is cream colored. The pattern on the top of the ticking is a wavy diamond pattern that is stitched into the ticking from one side to the other. The diamond pattern repeat is 1.0 by 1.5 inches. Layer 2, the batting, is quilted inside of the mattress pad between the top and bottom ticking. A tape edge made from the same fabric as the ticking binds the two fabric layers and batting together at the edges of the mattress pad. The batting is off-white and neppy,[3] with seed fragments and leaf trash, and is approximately 0.5

[3] Contains immature fiber bundles.

inches thick. Off-white thread was used for both the quilting pattern and the tape edge. All specimens consisted of the same components.

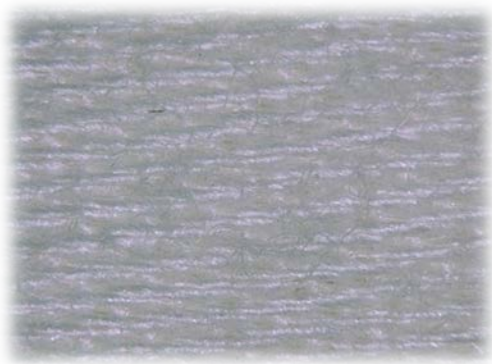


Substrate A	*Form*	*Type*	*Fiber Type*
Layer 1	Fabric	Woven, Sateen	Cotton
Layer 2	Fiber	Batting	Cotton

Figure 1. Substrate A, Construction and Characterization

The first two photomicrographs are of the ticking. The first photomicrograph shows the pattern of the stitching, and the second shows the weave of the ticking. The second row of photos shows the batting at two different magnifications. In the second column you can see the visible leaf trash in the batting.

Layer 1



Layer 2

Figure 2. Substrate A, Layers 1 and 2 at 5X and 50X magnification

Figure 3 shows the longitudinal view of the fibers from layers 1 and 2, respectively, at a magnification of 500X. The images are representative of cotton fibers with convolutions and the lumen channel present.

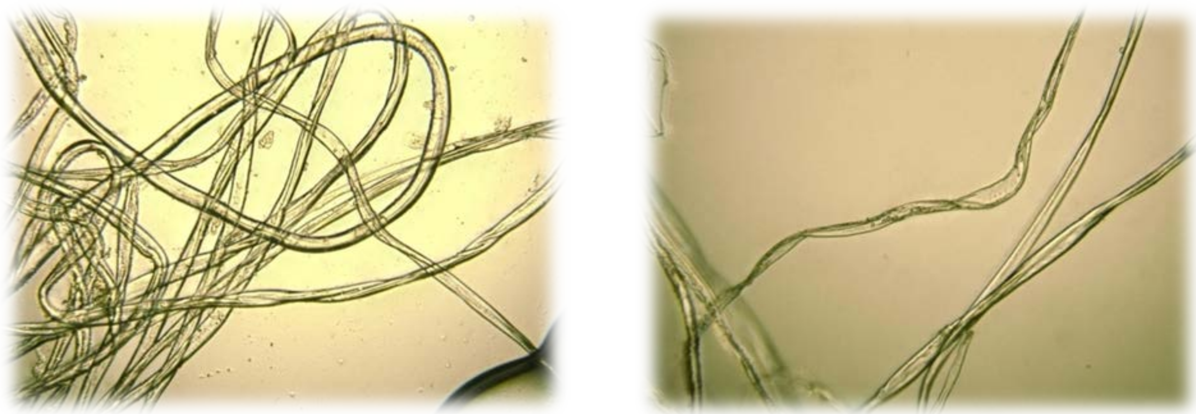
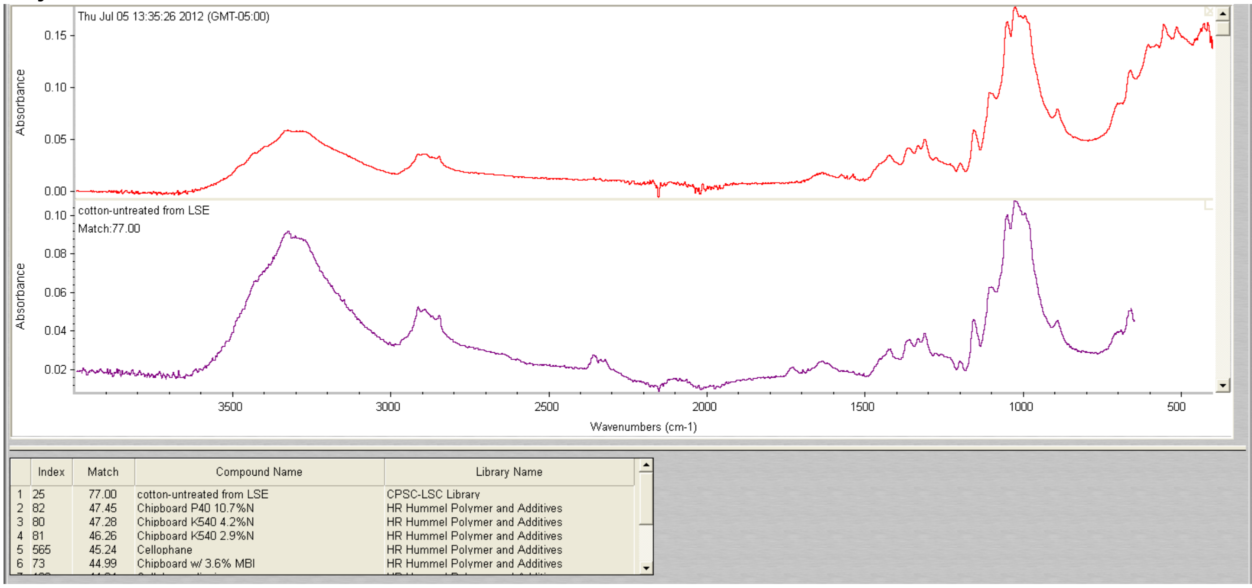


Figure 3. Substrate A, Layers 1 and 2 at 500X magnification

Below are the FT-IR spectra for Substrate A. The top spectrum is the ticking, and the bottom spectrum is the untreated cotton standard for comparison. The first set of spectra shows the verification that the ticking is composed of cotton. The second set of spectra confirms that the batting is cotton. The measured spectra show the same characteristic peaks as the standard.

Layer 1:



Layer 2:

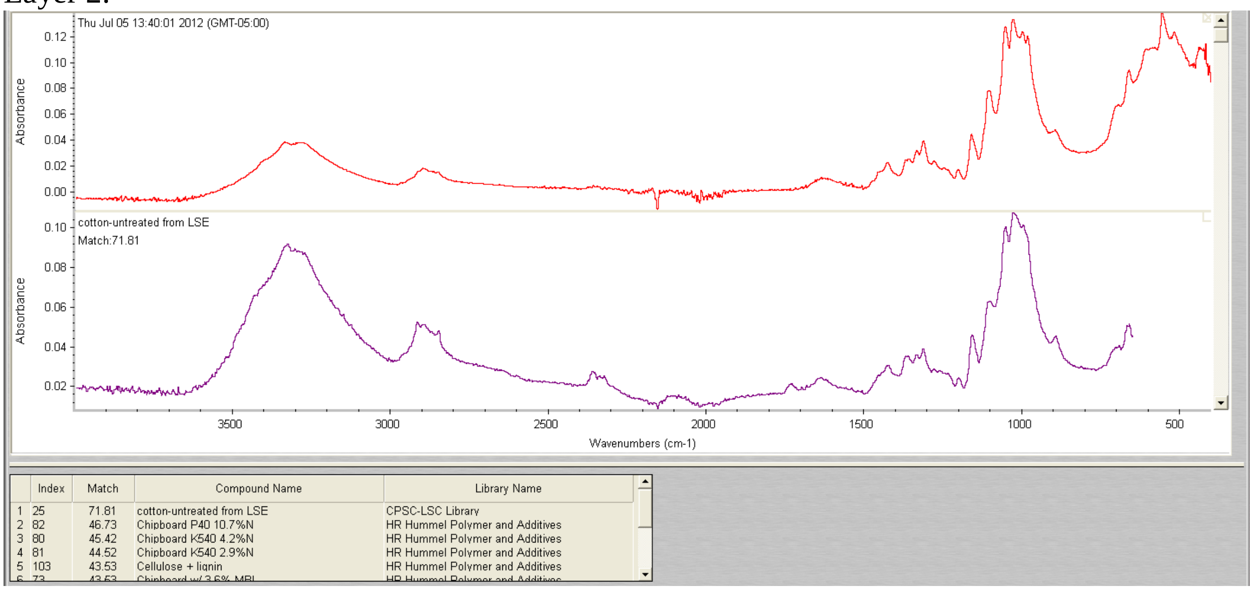
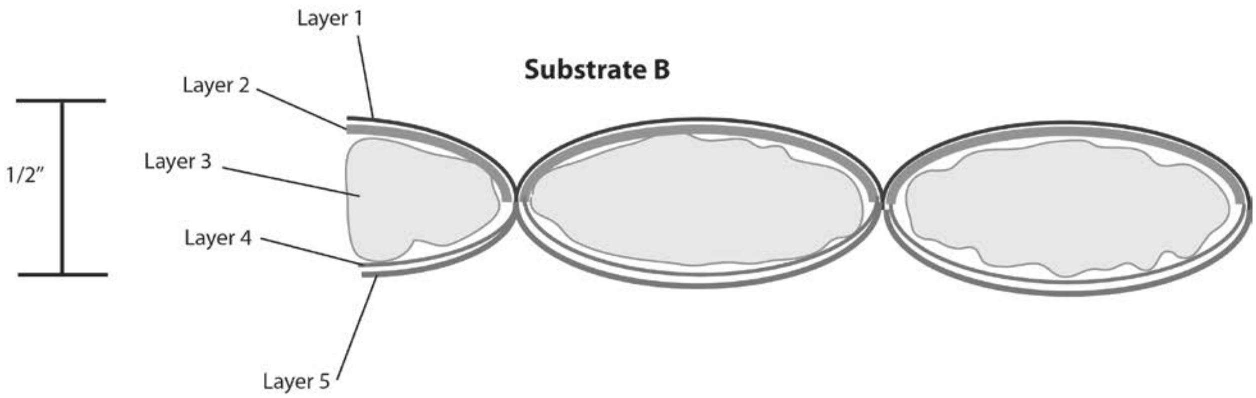


Figure 4. Substrate A, Layers 1 and 2 FT-IR Spectra

- **Test Substrate B**

Substrate B is a mattress. Layer 1, the ticking, is an off-white cotton twill weave fabric. Layer 3, the batting, is stuffed inside of the ticking, below layer 2, and above two layers of non-woven fabric (layers 4 and 5). The batting is neppy and contains some seed fragments and leaf trash, but it is relatively clean. Off-white thread was used for the stitching and tape edge. For this study, only the top layer of the mattress was characterized. All specimens consisted of the same components.



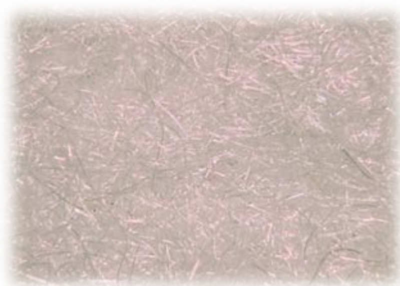
Substrate B	*Form*	*Type*	*Fiber Type*
Layer 1	Fabric	Woven, Herringbone twill	Cotton
Layer 2	Fabric	Non-woven, Needle punched	Polyester/Rayon
Layer 3	Fiber	Loose fiber	Cotton
Layer 4	Fabric	Non-woven, Calendered	Polyester
Layer 5	Fabric	Non-woven, Calendered	Polyester

Figure 5. Substrate B, Construction and Characterization

Below are the photomicrographs for the substrate. Each row shows a layer at 5X and 50X magnification, respectively.

Layer 1

Layer 2



Layer 3

Layer 4

Layer 5

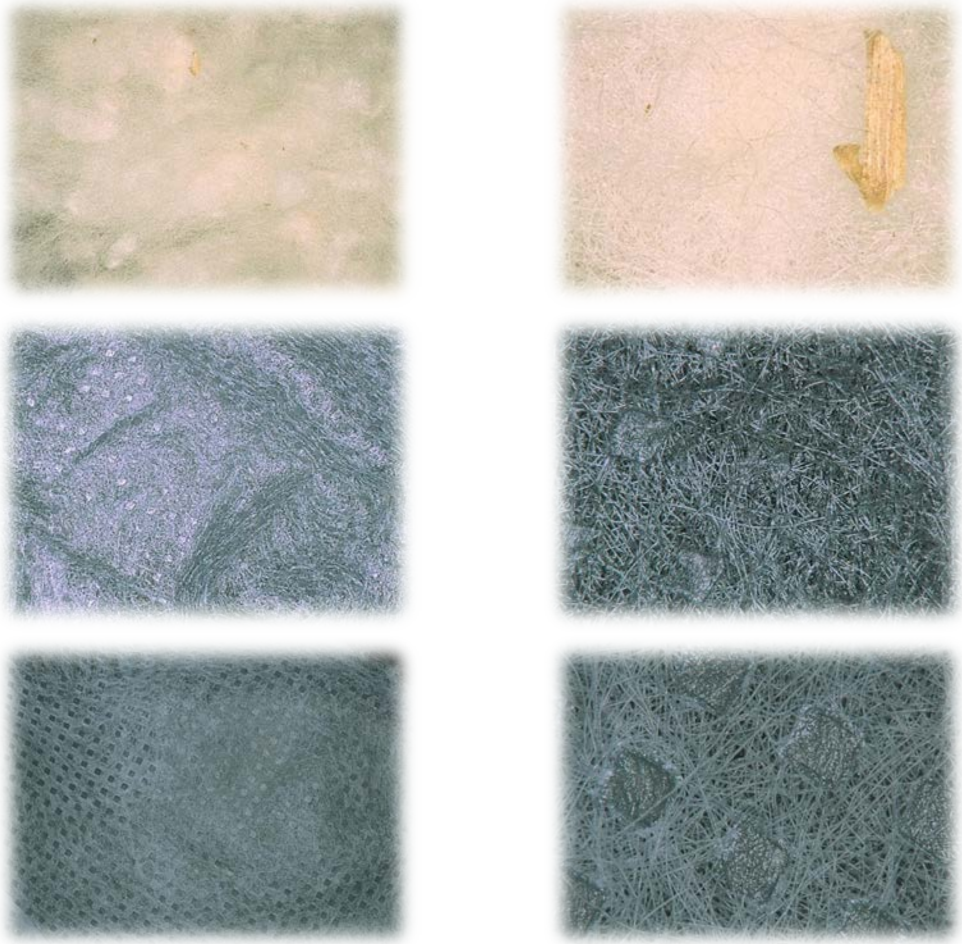


Figure 6. Substrate B, Layers 1, 2, 3, 4, and 5 at 5X and 50X magnification

Figure 7 shows the longitudinal view of the fibers from layers 1 through 5, respectively, at a magnification of 500X. Layers 1 and 3 are representative of cotton fibers with convolutions and the lumen channel present. Layer 2 appears to be a blend of a manmade fiber, identified by the smooth, cylindrical shape and black specs of delustering agent (FT-IR analysis indicates polyester), and a regenerated cellulose, identified by striations running the length of the fiber (probably rayon because FT-IR indicates the presence of a cellulosic fiber). Layers 4 and 5 are representative of manmade fibers with smooth, cylindrical shapes and the presence of a delustering agent.[4]

[4] The image for layer 4 appears to have a damaged fiber (the wide, flat object to the left) and a single strand of cotton fiber (the thin, translucent fiber in the bottom right corner of the image). Damaged fibers are not unusual to observe; however, the presence of the cotton fiber seems to be contamination from layer 3 because further examination did not indicate that there were enough cotton fibers present to constitute a blend in the fabric layer.

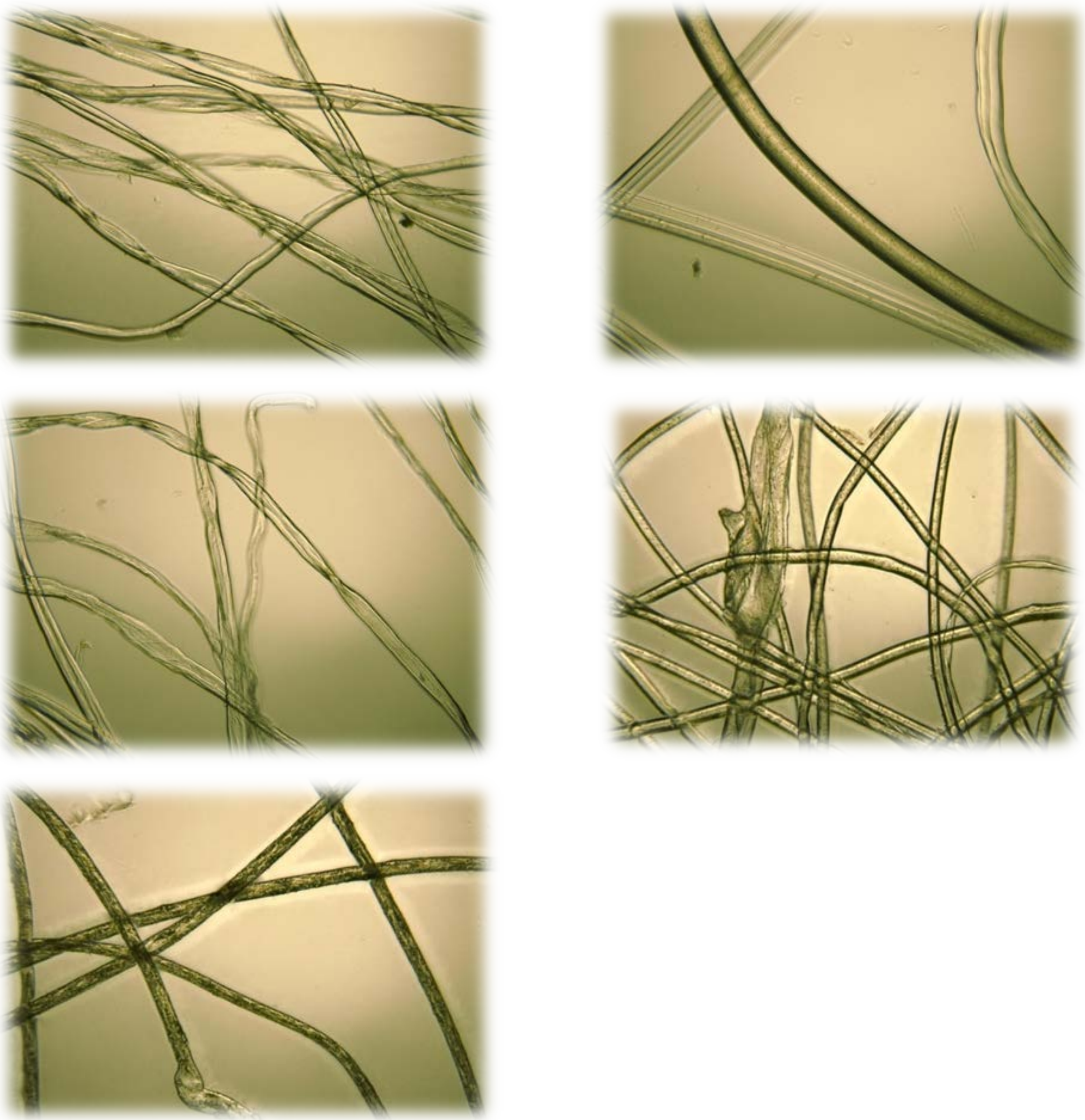
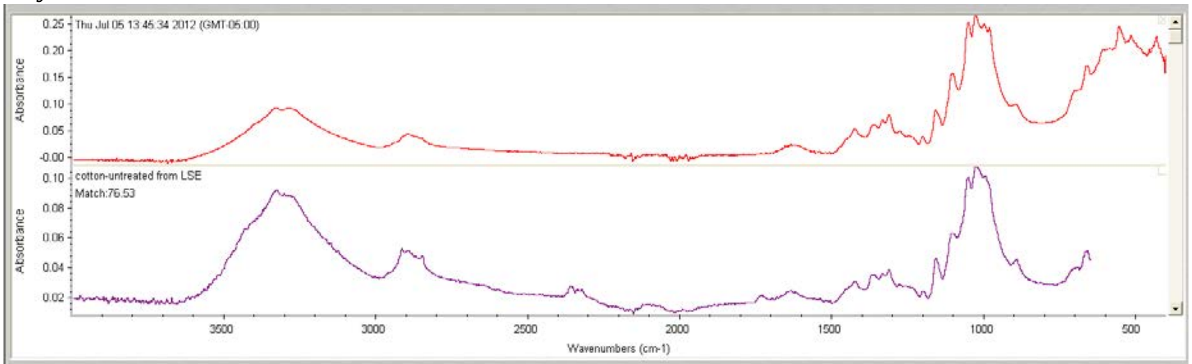


Figure 7. Substrate B, Layers 1 and 2 (row 1), Layers 3 and 4 (row 2), and Layer 5 (row 3) at 500X magnification

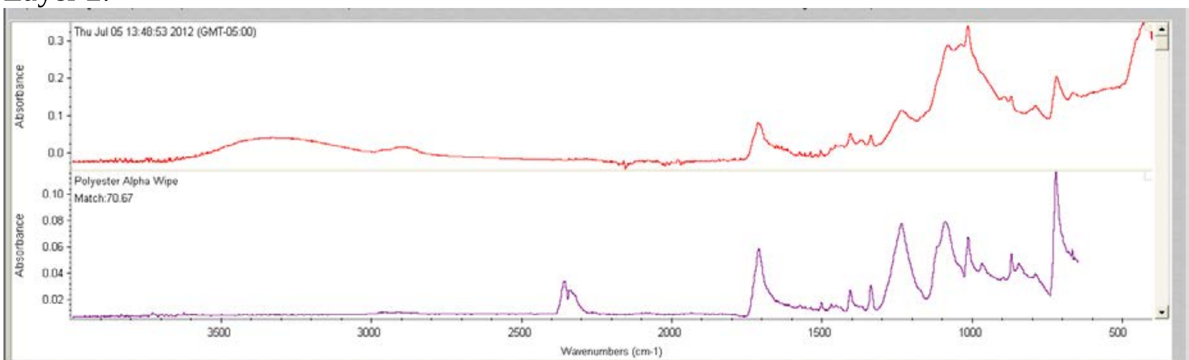
The FT-IR results below in Figure 8 are presented with the sample spectrum on the top half of the screen capture and the closest matching spectrum below it for comparison. Layers 1 and 3 (the ticking and batting) match the cotton reference spectrum. Layer 2 shows peaks for both cellulose and polyester (as seen in Figure 7, above). Layer 4 is identified as polyester, and layer 5 is identified as polypropylene.

Layer 1:



	Index	Match	Compound Name	Library Name
1	25	76.53	cotton-untreated from LSE	CPSC-LSC Library
2	82	48.12	Chipboard P40 10.7%N	HR Hummel Polymer and Additives
3	80	47.10	Chipboard K540 4.2%N	HR Hummel Polymer and Additives
4	81	46.34	Chipboard K540 2.9%N	HR Hummel Polymer and Additives
5	103	45.09	Cellulose + lignin	HR Hummel Polymer and Additives
6	73	44.80	Chipboard w/ 3.6% MBI	HR Hummel Polymer and Additives
7	68	44.05	Wood + melamine-formaldehyde resin	HR Hummel Polymer and Additives
8	74	41.58	Chipboard w/ 6.5% MBI	HR Hummel Polymer and Additives
9	565	40.81	Cellophane	HR Hummel Polymer and Additives
10	75	40.20	Chipboard w/ urea-formaldehyde cond	HR Hummel Polymer and Additives

Layer 2:

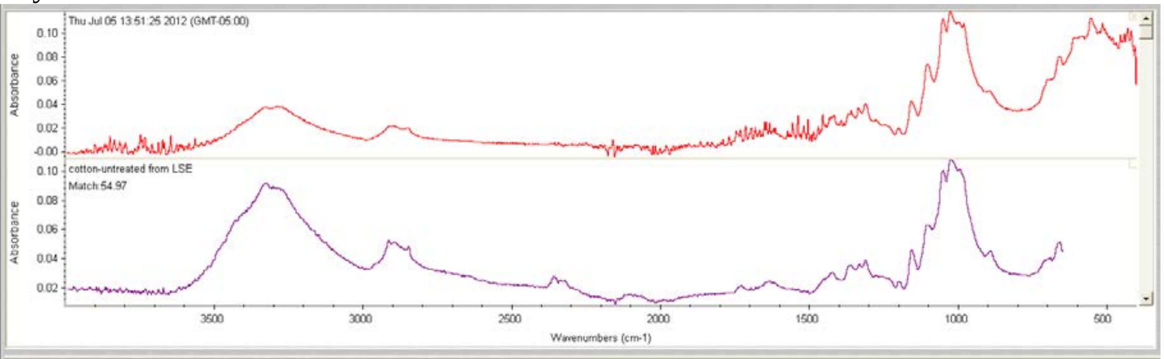


	Index	Match	Compound Name	Library Name
1	2	70.67	Polyester Alpha Wipe	CPSC-LSC Library
2	45	56.42	06-302-3088-01, larger grill, black paint losen by [	CPSC-LSC Library
3	543	50.74	Poly(ethylene terephthalate)	HR Hummel Polymer and Additives
4	32	46.13	Poly(1,4-butylene terephthalate)	HR Hummel Polymer and Additives
5	46	44.70	06-302-3087-01, black paint losen by DCM, dried	CPSC-LSC Library
6	23	42.94	Polyester, tere- & isophthalic acids	HR Hummel Polymer and Additives
7	25	42.85	Polyester, tere- & isophthalic acids	HR Hummel Polymer and Additives
8	1001	41.87	2,2,2-TRICHLOROETHANOL, 99+%	HR Aldrich FT-IR Collection Edition II
9	381	41.87	2,2,2-TRICHLOROETHANOL, 99+%	HR Aldrich Alcohols and Phenols
10	17812	41.84	POLY(1,4-BUTYLENE TEREPHTHALATE)	HR Aldrich FT-IR Collection Edition II

Region: 3998.68-649.90

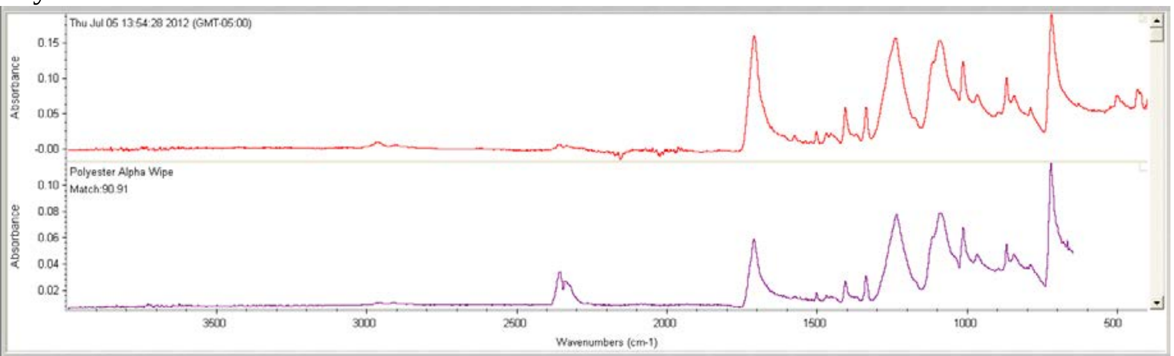
Overlay | Clipboard | Info... | Modify Display | Print | Help... | Close

Layer 3:



	Index	Match	Compound Name	Library Name
1	25	54.97	cotton-untreated from LSE	CPSC-LSC Library
2	1527	36.36	Zinc oxide	HR Hummel Polymer and Additives
3	1018	27.75	Poly(phenylene disulfide)	HR Hummel Polymer and Additives
4	73	26.99	Chipboard w/ 3.6% MBI	HR Hummel Polymer and Additives
5	41	26.93	calcium sulfate dihydrate, Fisher Scientific	CPSC-LSC Library
6	792	26.38	Canis Vulpes	HR Hummel Polymer and Additives
7	74	25.30	Chipboard w/ 6.5% MBI	HR Hummel Polymer and Additives
8	565	25.09	Cellophane	HR Hummel Polymer and Additives
9	80	24.34	Chipboard K540 4.2%N	HR Hummel Polymer and Additives
10	1126	24.14	Glucose	HR Hummel Polymer and Additives

Layer 4:



	Index	Match	Compound Name	Library Name
1	2	90.91	Polyester Alpha Wipe	CPSC-LSC Library
2	45	68.76	06-302-3088-01, larger grill, black paint losen by [	CPSC-LSC Library
3	543	65.60	Poly(ethylene terephthalate)	HR Hummel Polymer and Additives
4	32	57.01	Poly(1,4-butylene terephthalate)	HR Hummel Polymer and Additives
5	17812	56.03	POLY(1,4-BUTYLENE TEREPHTHALATE)	HR Aldrich FT-IR Collection Edition II
6	46	54.92	06-302-3087-01, black paint losen by DCM, dried	CPSC-LSC Library
7	23	53.94	Polyester, tere- & isophthalic acids	HR Hummel Polymer and Additives
8	25	53.45	Polyester, tere- & isophthalic acids	HR Hummel Polymer and Additives
9	19	53.20	Polyester, terephthalic acid	HR Hummel Polymer and Additives
10	24	50.89	Polyester, tere- & isophthalic acids	HR Hummel Polymer and Additives

Layer 5:

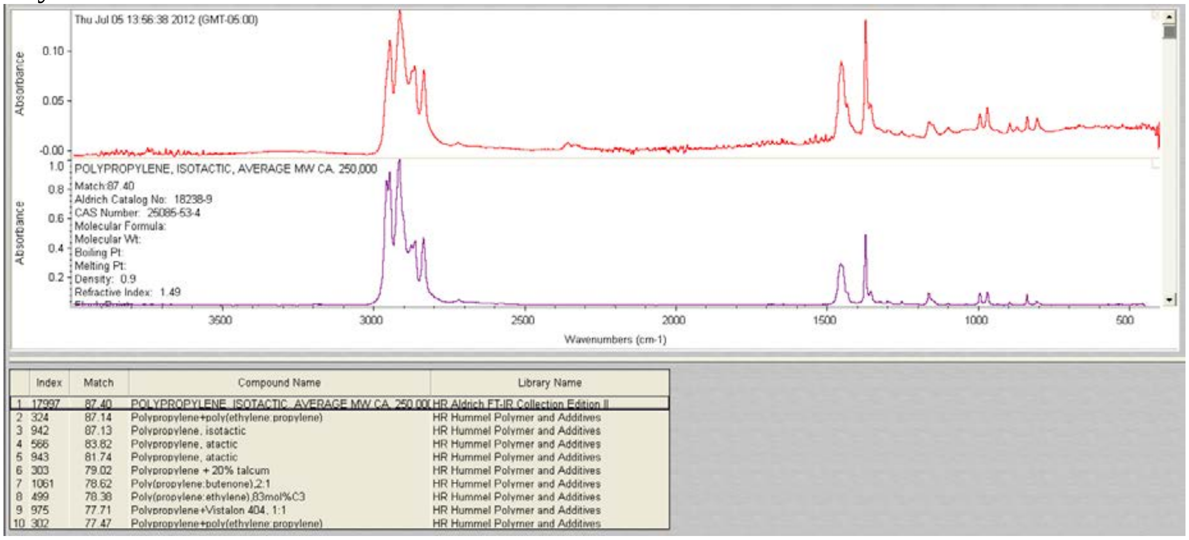
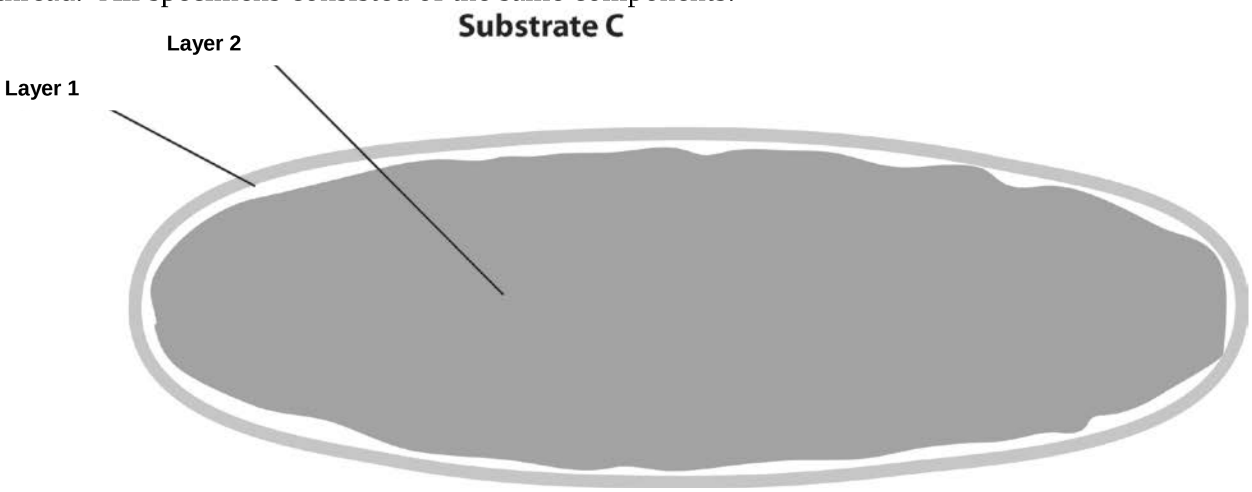


Figure 8. Substrate B, Layers 1 through 5 FT-IR Spectra

- **Test Substrate C**

Substrate C is a futon. Layer 1, the ticking, is a twill weave, off-white fabric. Layer 2 is off-white, neppy cotton batting with seed fragments and leaf trash. The stitching is off-white thread. All specimens consisted of the same components.



Substrate C	*Form*	*Type*	*Fiber Type*
Layer 1	Fabric	Woven, Twill	Cotton
Layer 2	Fiber	Loose fiber	Cotton

Figure 9. Substrate C, Construction and Characterization

Below are the photomicrographs for the substrate. The first row shows layer 1 at 5X and 50X magnification. In the 50X photomicrograph, the twill weave of the ticking is visible. The next row shows layer 2, the batting, with visible seed fragments and leaf trash.

Layer 1

Layer 2

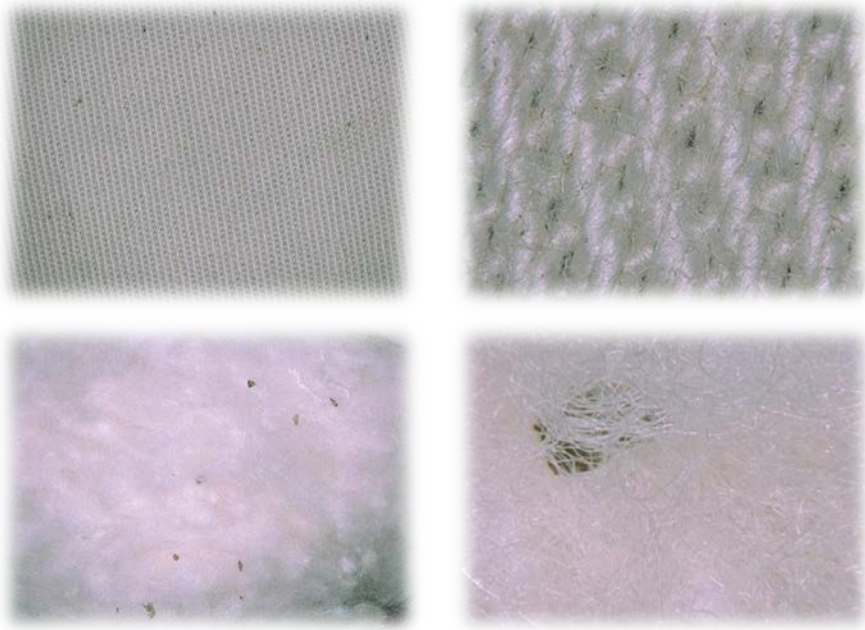


Figure 10. Substrate C, Layers 1 and 2 at 5X and 50X magnification

Figure 11 shows the longitudinal view of the fibers from layers 1 and 2, respectively, at a magnification of 500X. The images are representative of cotton fibers with convolutions and the lumen channel present.

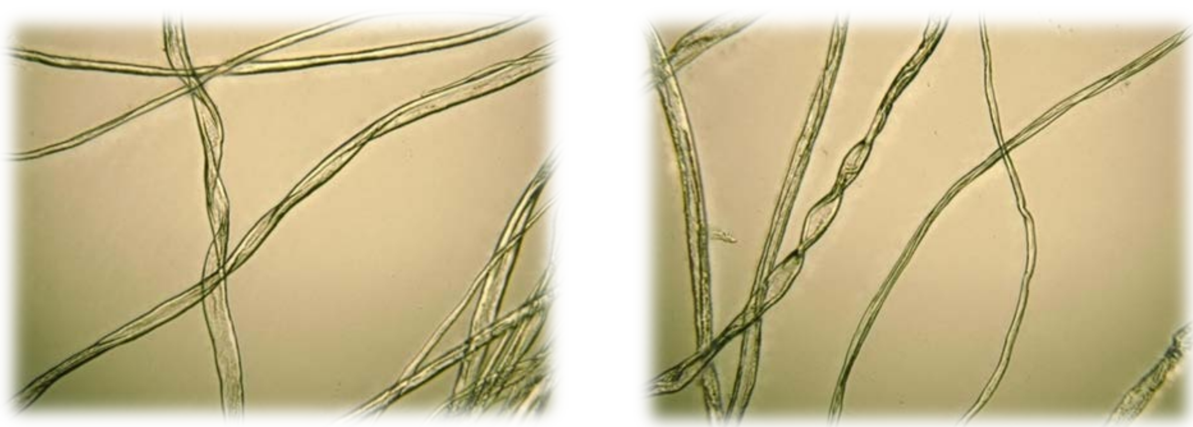
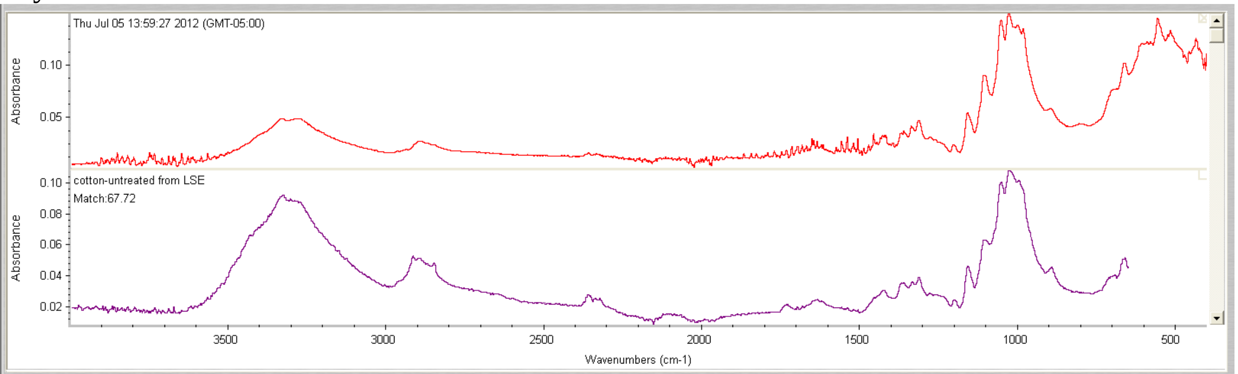


Figure 11. Substrate C, Layers 1 and 2 at 500X magnification

Below in Figure 12 are the FT-IR spectra for Substrate C. The first set of spectra shows the verification that layer 1 is composed of cotton. The top spectrum is the ticking, and the bottom spectrum is the untreated cotton standard, for comparison. The second set of spectra confirms that layer 2 is cotton.[5] The measured spectra show the same characteristic peaks as the standard.

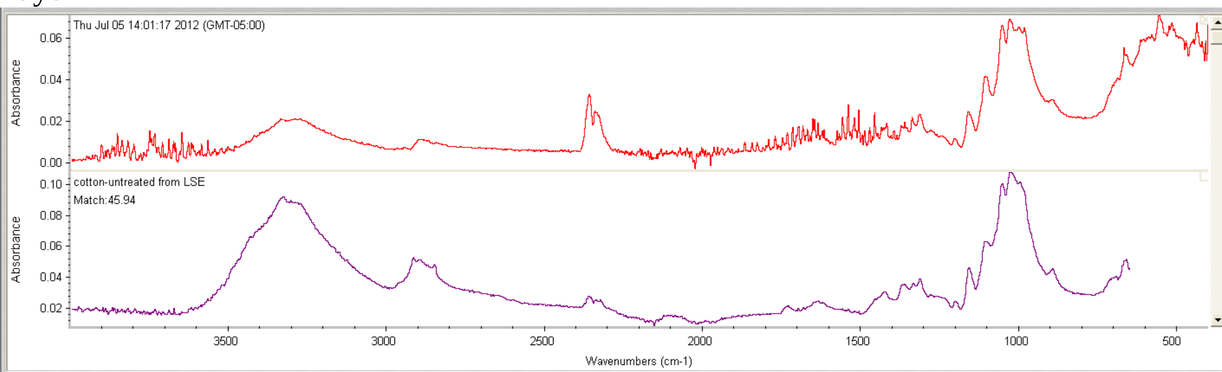
[5] The two peaks between 2300 and 2400 cm-1 are most likely due to noise.

Layer 1



	Index	Match	Compound Name	Library Name
1	25	67.72	cotton-untreated from LSE	CPSC-LSC Library
2	73	33.49	Chipboard w/ 3.6% MBI	HR Hummel Polymer and Additives
3	80	32.08	Chipboard K540 4.2%N	HR Hummel Polymer and Additives
4	1527	31.88	Zinc oxide	HR Hummel Polymer and Additives
5	82	31.78	Chipboard P40 10.7%N	HR Hummel Polymer and Additives
6	74	31.34	Chipboard w/ 6.5% MBI	HR Hummel Polymer and Additives
7	81	31.21	Chipboard K540 2.9%N	HR Hummel Polymer and Additives
8	103	31.15	Cellulose + lignin	HR Hummel Polymer and Additives
9	16606	31.03	(METHYL SULFOXIDE)-D6, 100.0 ATOM % D	HR Aldrich FT-IR Collection Edition II
10	1126	30.41	Glucose	HR Hummel Polymer and Additives

Layer 2

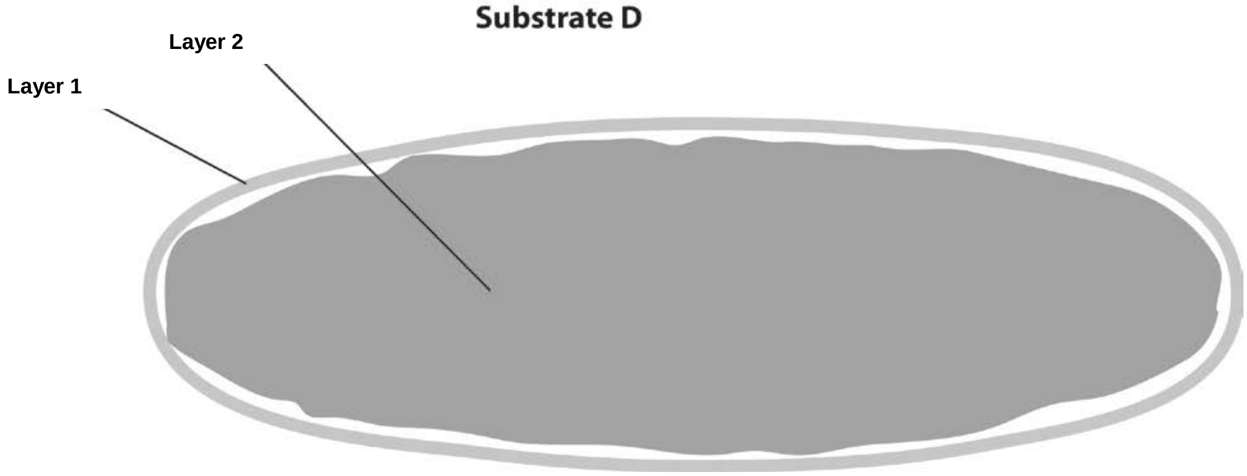


	Index	Match	Compound Name	Library Name
1	25	45.94	cotton-untreated from LSE	CPSC-LSC Library
2	1527	34.11	Zinc oxide	HR Hummel Polymer and Additives
3	1018	26.29	Poly(phenylene disulfide)	HR Hummel Polymer and Additives
4	41	25.43	calcium sulfate dihydrate, Fisher Scientific	CPSC-LSC Library
5	29	24.51	ethylene glycol, Fisher, 50%(w/w)	CPSC-LSC Library
6	1225	21.88	Methylamine	HR Hummel Polymer and Additives
7	290	21.36	Poly(amide-6,6:amide-6)	HR Hummel Polymer and Additives
8	792	19.09	Canis Vulpes	HR Hummel Polymer and Additives
9	221	18.99	Poly(butadiene:acrylonitrile)	HR Hummel Polymer and Additives
10	286	18.39	Polyamide-6 + polyamide-6,6	HR Hummel Polymer and Additives

Figure 12. Substrate C, Layers 1 and 2 FT-IR Spectra

- **Test Substrate D**

Substrate D is a mattress. Layer 1, the ticking, is off-white, plain woven fabric labeled as 100 percent organic cotton. The ticking has the words "Organic Cotton" woven into it. Layer 2, the batting, is off-white, loose fiber containing seed coats and leaf fragments. The tape edge is made of a heavier material than the ticking and is plain woven. The mattress is stitched with off-white thread. All specimens consisted of the same components.



Substrate D	*Form*	*Type*	*Fiber Type*
Layer 1	Fabric	Woven, Plain	Cotton
Layer 2	Fiber	Loose fiber	Cotton

Figure 13. Substrate D, Construction and Characterization

Below are the photomicrographs for the substrate. The first row shows layer 1 at 5X and 50X magnification. In the 50X photomicrograph, the plain weave of the ticking is visible. The next row shows layer 2, the batting, with visible seed coat fragments and leaf trash.

Layer 1

Layer 2

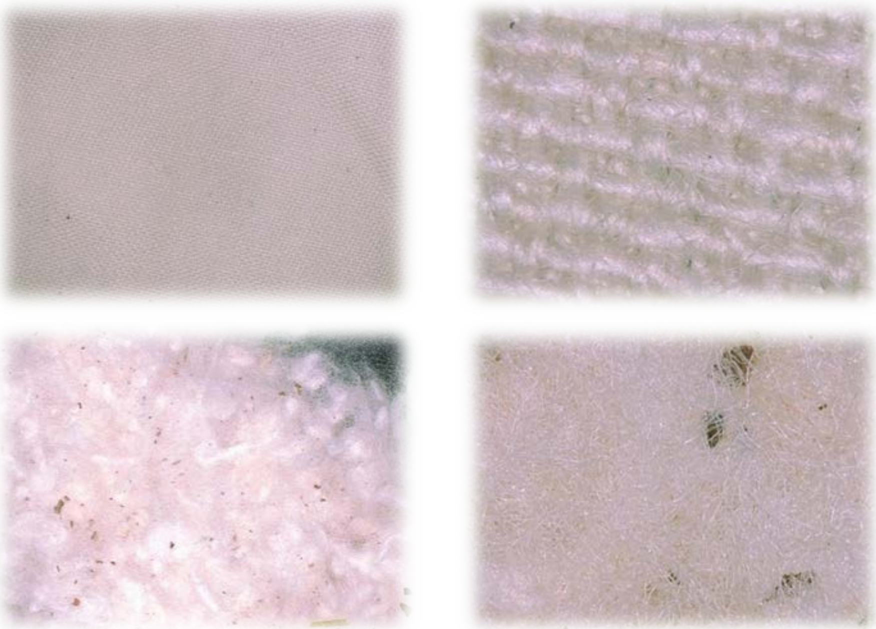


Figure 14. Substrate D, Layers 1 and 2 at 5X and 50X magnification

Figure 15 shows the longitudinal view of the fibers from layers 1 and 2, respectively, at a magnification of 500X. The images are representative of cotton fibers with convolutions and the lumen channel present.

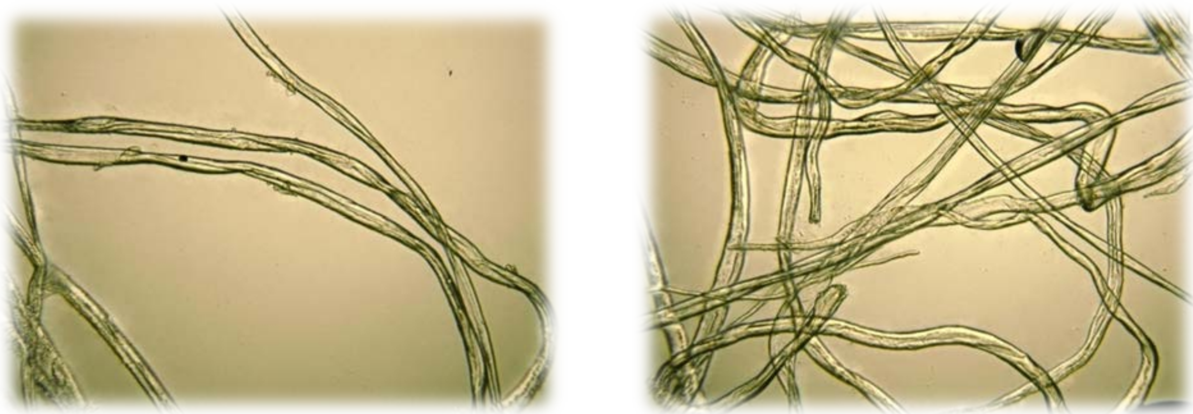
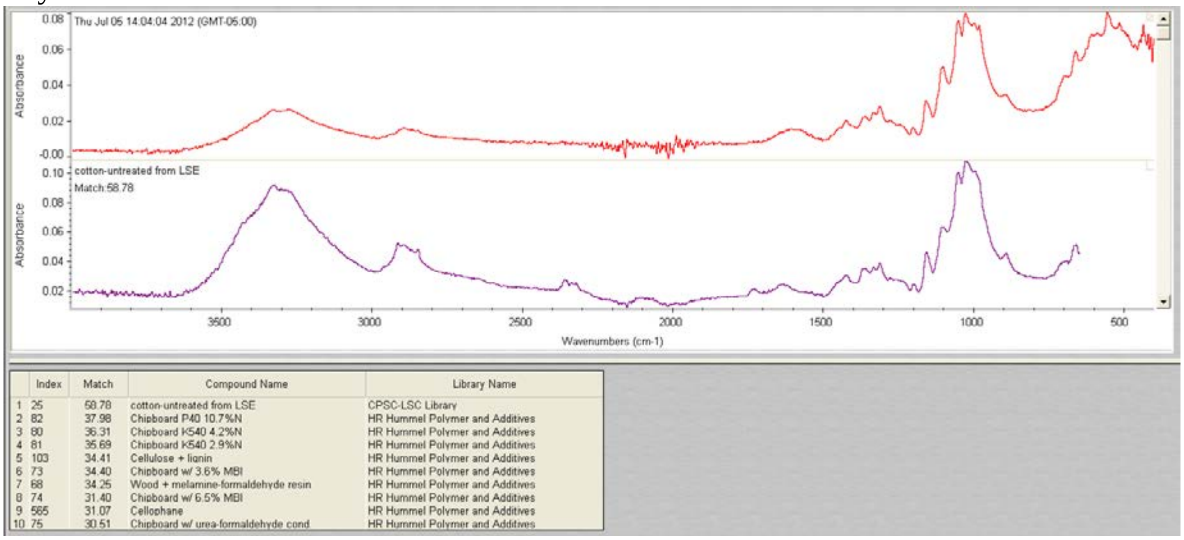


Figure 15. Substrate D, Layers 1 and 2 at 500X magnification

Below are the FT-IR spectra for Substrate D. Layers 1 and 2 are made out of cotton as confirmed by the FT-IR results below.

Layer 1



Layer 2

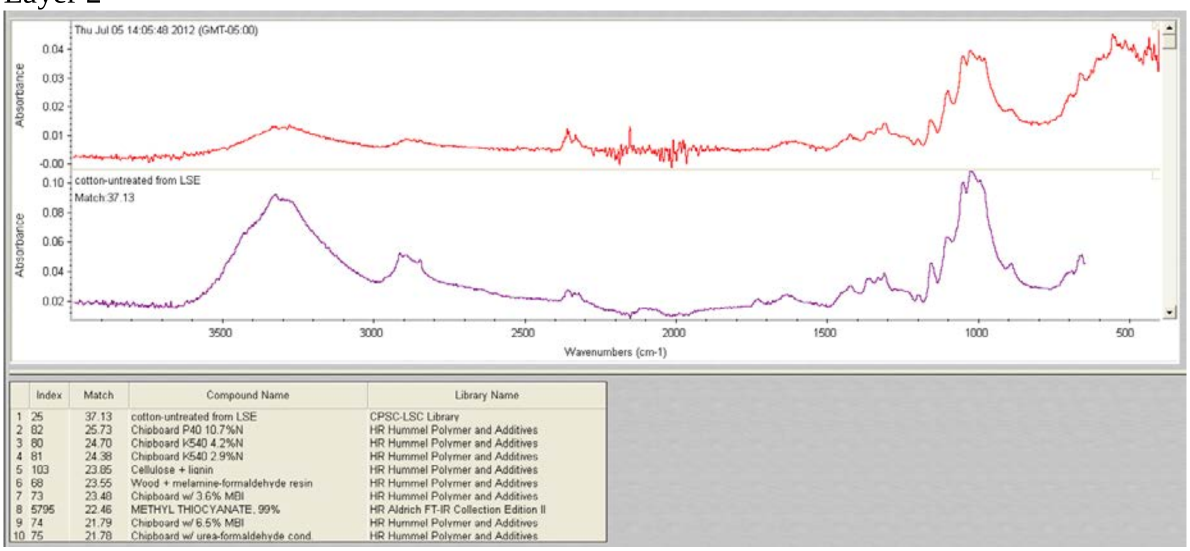


Figure 16. Substrate D, Layers 1 and 2 FT-IR Spectra

6. CONCLUSION

Reduced Ignition Propensity (RIP) cigarettes have been designed to self-extinguish when there is no interaction with a smoker. CPSC staff conducted a study to investigate the differences in burning behavior between RIP and non-RIP cigarettes on mattresses, futons, and mattress pads. For this testing, cellulose-based test substrates were chosen in order to provide a likely opportunity to observe smoldering behavior induced by the cigarettes tested. Characterization of the test substrates confirmed that the materials in contact with the test cigarettes were cotton or otherwise cellulose-rich,[6] and each specimen within a given substrate was consistent in terms of fiber content and construction.

[6] In the case of Substrate B, the layer just under the ticking (layer 2) was a rayon-polyester blend.