NATIONAL BUREAU OF STANDARDS REPORT

10 107

FINAL REPORT

THE EVALUATION OF TEST METHODS FOR THE PREPARATION OF A STANDARD FOR THE FLAMMABILITY OF CHILDREN'S SLEEPWEAR

PROGRAM COMPLETION DATE AUGUST 1, 1969

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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by
Harvey W. Berger

NBS

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<u>Outline</u>

1. Introduction

The National Bureau of Standards has been assigned the task of preparing a standard for the flammability performance of children's sleepwear.

The need for strict standards is beyond question. The impact on society due to the pain, suffering and deaths of children injured in clothing fires must, by all humane criteria, supercede any economic, financial or profit-motivated considerations.

The are a number of test methods presently available for evaluating the flammability of fabrics. They all suffer, however, from a variety of technical insufficiencies. Nevertheless, if stringent requirements were to be set for the non-flammability of children's sleepwear, a method such as the Vertical Spread of Flame Test would be a satisfactory and reliable procedure upon which to base a standard.

The following report is a description of our experience with an Ignition Test, Vertical Spread of Flame Test and Fire Simulation during a four month assignment on test method development for the flammability of children's sleepwear.

2. Ignition Test

The assumption can be made that children's sleepwear will require fire retarding performance that exceeds that of other wearing apparel. If that is truly the case, the limits of performance will be set by those fabrics which have been treated in some manner to reduce flammability or have been constructed of those fibers or materials which are inherently of low flammability.

Children are exposed to greater hazards in a home environment than are adults. In the event of the ignition of a child's clothing, one would not expect the same reactions of the child as one would of an adult under the same conditions. The adult would be much more likely to take the correct action necessary to extinguish the fire. Therefore, the time at which protection for the child must come is at the time of ignition itself. A material that does not ignite, by definition, does not burn and, in general, materials that do not ignite easily will not burn easily. There are exceptions to the latter generalization but, nevertheless, the generalization is reasonable.

Children, when awake, are usually in constant motion and ignition of clothing most likely occurs during a transitory exposure to an open flame. If a child's clothing is such that it does not ignite and burst into flame during a relatively long exposure time, the major hazard will have been removed.

Performance criteria should be recommended on the basis of data accumulated for the ease of ignition of flammable and non-flammable children's sleepwear. As will be shown later on, there is a clear experimental distinction, between fabrics of high and low flammability, which can provide a definitive limit for performance.

3. Market Survey

An attempt was made in mid-May 1969, to purchase examples of non-flammable or flame retardant children's sleepwear. A total of twelve Washington, D.C. Metropolitan area stores listed in Table I were visited at that time but no such articles of clothing could be obtained. A selection of non-treated children's sleepwear representing eighteen different fabric types was purchased for flammability testing. In early June, however, and again in July, samples of treated, fire retardant, children's nightwear were finally obtained.

As a general observation, prices depend primarily on style and decorative treatment rather than fiber content. All of the stores visited carried items of $100% cotton, yet prices varied from $1.00 to $5.00. The most prevalent fiber types in each store were labeled as "permanent press". These fabrics ranged from 65% polyester, 35% cotton to 65% cotton, 35% polyester.

It would be unwise to draw conclusions on market availability on the basis of limited shopping experience. All of the stores have large and rapid turnovers which may bring in entirely different fiber types and styles and different prices along with them.

4. Measurement of Ease of Ignition

A final total of twenty-one different fabrics were evaluated for their ease of ignition using the technique and equipment developed by Joseph Loftus. Ignition time was measured with the fabrics mounted in three different positions as follows:

1. Fabric mounted horizontally with the flame impinging at an angle 45° to the horizontal.
2. Fabric mounted at a 45° angle with the flame impinging parallel to the test cabinet base i.e. 45° to the fabric.
3. Fabric mounted vertically with the flame impinging perpendicularly to the plane of the fabric.

Table II lists the averages of triplicate determinations of the minimum ignition times of the fabrics tested under ambient laboratory conditions (approximately 22 °C and 35% RH). The weights of the fabrics were obtained by weighing 25 cm^2 samples which had also been maintained at room conditions.

There are no general tendencies that can be observed for the ignition times as a function of the fabric mounting position. Two of the fabrics (Nos. 5 and 8) exhibit a significant decrease (0.3 seconds or more) in ignition time with increasing mounting angle. Fabrics No. 15 and 16 show an increase in ignition time with increasing mounting angle.

In order to demonstrate the effects of humidity or fabric water content on the ease of ignition, the fabrics were tested after conditioning at 105 °C for one-half hour followed by cooling in a desiccator for one-half hour. Table III shows a comparison of ignition times for conditioned and non-conditioned (ambient) fabrics mounted in the horizontal position.

Five of the fabrics listed in Table III showed a significant decrease (0.3 seconds or more) in ignition time, in the horizontal position, after they had been dried in the oven at 105 °C. Those fabrics (Nos. 2,8,9,10,17) are among the heaviest on the list, a fact which indicates that the thicker the fabric the more moisture it will hold and the longer it will take to ignite.

Figure I is a plot of minimum ignition time as a function of fabric weight. It appears that the ease of ignition for non-treated fabrics is generally related to the weight of the fabric. It is unfortunate that children's sleepwear constructed of winter weight fabrics were not available for testing during this program. It can be assumed that a selection of heavier fabrics would have expanded the data population at the less easily ignitable end of the flammability scale.

5. Vertical Spread of Flame

Table IV is a compilation of seven commonly used vertical test methods. There is a general uniformity among them but there are some variations that could drastically vary results from one technique to the other. Basically, however, a 2" x 12" specimen is suspended vertically in a test chamber which is 12" wide x 12" deep x 30" high. A flame ignition source is impinged at the bottom edge of the fabric for 12 seconds and the afterburn, afterglow and total char are measured. Pretreatment conditions range from four hours at 70 °F and 65% RH to accelerated laundering or dry cleaning followed by oven drying at 145 °F for 1-1/2 hours prior to testing.

The vertical test methods from ASTM; AATCC; NFPA and UL as well as Federal Test Method 5903 and British Standard 3119 are specifically designated as being designed for the evaluation of treated, inherently flame retardant or low flammability fabrics. Other flammability test methods based on 45 °, 30 ° or horizontal mounting of fabric specimens are designated as being for materials of moderate or high flammability.

5.1 Federal Test Method 5903

Federal Test Method 5903 of CCC-T-191b is for the most part, simular to the other methods listed in Table IV. On the basis of intuitive judgement, however, it appears that the test chamber described in this method provides an air flow pattern that is somewhat preferable to those described in the other methods. For this reason, and because of the lack of any other serious deviations from the other methods, Test Method 5903 was arbitrarily chosen for evaluation as a spread of flame test in the Children's Sleepwear Program.

It should be made clear at once that there are major weaknesses in Method 5903 which are shared by the other test methods. They are as follows:

a. The test is actually one of self-extinguishment. In order to perform satisfactorily,a fabric must self-extinguish in no more than two seconds after the removal of the 12 second ignition source.
b. There is no provision in the test for measurement of the ease of ignition. A 12 second ignition time is a forced ignition.
c. The flame source is poorly defined and difficult to control.
d. The end point of the test is poorly defined.
e. The free suspension of the fabric sample does not permit heat transfer between it and a solid body.
f. There is a lack of forced controlled air flow.
g. There is no means for obtaining a thermal profile for studying the propagation of the flame.
h. There is no provision for studying synergistic effects of fabrics or fabrics as part of a garment system.

In addition, prior conditioning of fabrics at 65% RH is an extremely lenient treatment. Relative humidities of 15 to 20% are quite common in homes heated by forced air systems.

In spite of these limitations and deficiencies Method 5903 can satisfactorily differentiate between flammable and non-flammable fabrics. This opinion is supported by the experience and data obtained in the testing of 21 different items of children's sleepwear.

5.1.1 Conditioning of Fabric Prior to Testing

Federal Test Method 5903 requires the pre-conditioning of fabrics for a minimum of four hours at 70° ± 2°F and 65 ± 2% relative humidity. These requirements necessitate the availability of a temperature and humidity controlled room or environmental chamber. These conditions are the least stringent of all of the seven test methods listed in Table IV.

Due to a lack of facilities, a study of the effect of conditioning at 70°F and 65% RH was not included in this program. Two other sets of conditions, however were evaluated for their effect on the vertical spread of flame; one, at room temperature and relative humidity for a time in excess of 24 hours and the other, drying in a convection oven for one-half hour at 105° followed by cooling in a desiccator for a minimum of one-half hour prior to testing.

5.1.2 Measurement of Vertical Spread of Flame

The complete series of fabrics previously described was tested for vertical spread of flame according to Federal Test Method 5903. Table V is a summary of the data obtained for triplicate determinations of, (a) the maximum burn, char or melt length for 12-inch specimens, (b) the time required to reach the maximum burn, char, or melt length for 12-inch specimens.

The general observation can be made that the fabrics which had been heated and desiccated required less time to burn than those fabrics which had been maintained at ambient conditions.

Federal Test Method 5903 does not provide performance criteria which can be used for the evaluation of fabrics. ASTM D626, NFPA 701 and U.L. 214-1969 are standards in which criteria for passing or failing a vertical spread of flame test are presented. Table VI is a summary of the performance of the twenty-one fabrics in terms of the requirements set by NFPA and U.L. Only three replicates were run, however, rather than the ten replicates required by the above standards.

In spite of their treatment to provide fire retarding properties, fabrics No. 19, 20 and 21 still do not pass the requirements set by NFPA and U.L. for non-flammability. If the criteria were to be raised to an average char length of 6-1/2 inches, however, those fabrics could be classified as non-flammable, which in fact they truly are.

Table VII shows an attempt to rank the performance of the test fabrics in terms of flammability. The first five fabrics are rated highest because of their failure to burn the full twelve-inches. The following sixteen fabrics are rated in order of decreasing time to burn the full length of the sample. The relation of flammability to fabric weight is shown clearly in the ranking of the last sixteen fabrics.

Referral to fabric composition indicates a general tendency for polyester blends to appear at the more flammable end of the list. Any conclusions based on this observation must take into account the fact that the average weight of the polyester blends is 9.44 mg/cm^2 whereas, the average weight of the fabrics not containing polyester is 12.93 mg/cm^2.

Table VIII is a demonstration of the consistency of the ignition and vertical spread of flame tests. The eleven highest rated fabrics, in the ignition test, are among the twelve highest rated in the vertical test.

5.1.3 Problems with Thermoplastics

Fabric No. 15, a 100% nylon, ignites in the ignition test but does not support combustion in the vertical test. This is not an indication of non-flammability because, under the proper conditions, this material can be demonstrated to be highly flammable. The difficulty arises from the fact that thermoplastic fibers such as nylon melt away from the igniting flame before ignition can actually take place. Attempts were made to support the melting nylon so that ignition could occur and some success was achieved by using glass marquisette but the results were not consistent. An approach that seemed to be quite promising was the use of a 100% cotton backing on the nylon. After the simultaneous ignition of both fabrics, the individual flammability of the nylon was quite obvious.

6. Laundering and Automatic Drying

A realistic evaluation of the flammability of fabrics must include a means of measuring the permanence of any fire retarding treatment. Some treatments are short-lived and lose their potency in the course of ordinary cleaning or laundering.

Three of the standard test methods listed in Table IV require dry cleaning or laundering prior to the final conditioning of fabrics being tested for flammability. NFPA Standard 701 and UL Standard 214-1969 have identical dry cleaning and laundering tests. They also have essentially the same scrubbing and water leaching tests. British Standard 3119 requires what is described as a "stringent washing" (BS 3121) which preceeds the flammability test.

Dry cleaning, water leaching and scrubbing are not pertinent to the evaluation of the flammability of children's sleepwear. It is common practice to launder such items in home laundries or in local self-service laundry establishments. The use of commercial laundering is limited by cost and the fact that such apparel is not usually purchased in large quantities for each child.

7. Heat Flow

The amount of heat energy transferred to a burn victim determines the amount of physiological damage incurred. The measurement of this parameter becomes, therefore, important in the overall evaluation of the burning characteristics of a fabric.

Heat flow is a complex physical process but a simple approximation of that function can be made by measuring the change in temperature occurring beneath a burning fabric. This can be accomplished by instrumentation of a backing upon which the fabric is placed and then burned.

8. Simulation of Real Burning

In an attempt to provide graphic demonstration of the flammability of some children's sleepwear, plastic dolls, approximately three feet tall, were dressed in actual articles of sleepwear and then set on fire.

It has become evident from our experience that the complex configuration and heat reflective properties of a life-like mannequin are valuable in studying the flammability of fabrics. The contribution of flammable garment decorations and patterns of flame spread have been demonstrated.

Initial work has been done on instrumentation of the mannequins for measurements of temperature and rates of flame spread. Preliminary control and monitoring of air flow patterns around the burning mannequin has been achieved and encouraging reproducibility in a series of experiments has been observed.

The use of identical mannequins and garments in the experiments permits the observation and thus the prediction of burning patterns. Thermocouples attached to the doll allow continuous recording of temperatures achieved in particular areas. Subsequent calculations of rate of flame spread from the time of ignition can then be made.

Motion pictures of the burning events were made simultaneously with the electronic measurement of temperatures. Such a photographic record is valuable as a demonstration tool as well as being a supplement to technical data.

9. Summary and Recommendations

9.1 Ignition Test

The ignition test as developed by Joseph Loftus is accurate and precise and meaningful as well. There are no trends observable in changing fabric mounting positions from the horizontal to 45° to the vertical. Dried and desiccated fabrics ignite more rapidly than those conditioned at room temperatures and humidities. Among non-treated fabrics the ignition time is proportional to the fabric weight. There is a sharp delineation between fabrics that are untreated and ignite in five seconds or less and those that are treated and do not ignite even in times exceeding one minute.

The standard should require an ignition time of not less than ten seconds.

9.2 Vertical Spread of Flame Test

Federal Method 5903 differentiates between fabrics that burn the full 12-inch sample length and those that do not. The latter are either treated for fire retardance or are thermoplastic and melt before they can burn. The rate of flame spread for those fabrics that burn readily can be measured with fair accuracy.

The standard should require an average char length of 6-1/2 - 7 inches and an after burn of no more than 2 seconds after forced ignition. The dripping of burning melted thermoplastic should constitute immediate failure.

The rate of spread of flame for non-treated flammable fabrics decreases with increasing fabric weight and with increasing water content.

9.3 Laundering

The standard Sears Roebuck Washing Machine and Dryer should be used for laundering the complete garment before sampling for testing. At least ten but no more than fifty cycles should be required in the standard and the AATCC standard detergent should be used.

9.4 Fire Simulation

The burning of whole garments on dolls gives a much more complete picture of flammability than an ignition or vertical test on a small strip of fabric.

The development of a standard mannequin and standard garment should be pursued. The measurements of ignition, spread of flame, temperature profile and heat transfer should and can be measured from such a simulator.

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TABLE I

Types of Stores Visited in Survey

a. Two department stores of nationwide chains with large catalog sales

b. Three department stores of nationwide chains

c. Three quality local department stores

d. Three specialty stores for children's and infant's wear

e. One local clothing store featuring economy merchandise

TABLE II

IGNITION TIME FOR CHILDREN'S SLEEPWEAR
AMBIENT CONDITIONING

Fabric No.	Fiber Composition Per Cent	Fabric Weight mg/cm^2	Ignition Time (Seconds) Horizontal	45°	Vertical
1	65-35 Polyester-Cotton	8.55	1.1	1.2	1.3
2	97-3 Cotton-Lycra	26.10	5.6	6.0	5.7
3	100 Cotton	8.66	1.2	1.2	1.2
4	Embossed Cotton Polyester	9.15	1.0	1.2	1.2
5	80-20 Acetate-Nylon	8.08	1.5	1.2	0.8
6	50-50 Cotton-Polyester	8.98	1.4	1.4	1.4
7	80-20 Cotton-Nylon	16.32	2.5	2.9	2.4
8	65-35 Cotton-Nylon	16.71	2.5	1.6	2.2
9	75-25 Cotton-Polyester	12.56	1.9	1.8	1.9
10	70-30 Nylon-Cotton	11.52	1.9	1.8	1.8
11	50-50 Polyester-Rayon	10.35	1.2	1.4	1.4
12	68-32 Cotton-Polyester	6.24	0.9	0.9	1.0
13	100 Acetate	9.98	1.2	1.0	1.0
14	80-20 Cotton-Polyester	9.33	1.1	1.3	1.3
15	100 Nylon	7.72	2.2	2.6	2.6
16	100 Cotton	10.34	1.1	1.4	1.4
17	100 Cotton Flannel	13.91	2.3	2.3	2.3
18	65-35 Cotton-Polyester	10.35	1.4	1.5	1.6
19	100 Cotton-fire retardant	14.29	DNI*	DNI	DNI
20	100 Cotton-fire retardant	14.77	DNI	DNI	DNI
21	100 Cotton-fire retardant	15.42	DNI	DNI	DNI

* Does not ignite (at least one minute exposure to igniting flame)

TABLE III

IGNITION TIME FOR CONDITIONED AND UNCONDITIONED CHILDREN'S SLEEPWEAR (HORIZONTAL MOUNTING)

Fabric No.	Ambient Conditions	Conditioned at 105°C
1	1.1	1.1
2	5.6	5.0
3	1.2	1.3
4	1.0	1.1
5	1.5	1.3
6	1.4	1.2
7	2.5	2.7
8	2.5	2.0
9	1.9	1.5
10	1.9	1.6
11	1.2	1.2
12	0.9	0.7
13	1.2	1.2
14	1.1	1.1
15	2.2	2.5
16	1.1	1.1
17	2.3	2.0
18	1.4	1.4
19	DNI	DNI
20	DNI	DNI
21	DNI	DNI

TABLE IV

Test Standard	Scope	Sample Size	No. of Samples	Conditioning	Test Chamber Geometry
ASTM D 626-55T	Treated textile fabrics	2" x 12-1/2"	10; 5 in each direction	16 hrs. at 70°F 65%	12"W x 12"D x 30"H open top 1 x 5 opening at bottom front
AATCC 34-1966	Treated fabrics and inherently flame retardant fibers	2-3/4" x 10"	6; 3 in each direction	8 hrs. at 70°F 65%	12"W x 12"D x 30"H 6" diam. hole w/ baffle on top 4 x 12 opening at bottom front
Fed. Spec. CCC-T-191b Method 5902	Flame proofed & fire retardant textiles	2-3/4" x 12"	Not specified implies one specimen	4 hrs. at 70°F 65%	12-14"W x 12-14"D x 30"H Baffled vent on top, baffled holes near bottom
Fed. Spec. CCC-T-191b Method 5903	As above	As above	As above	As above	As above
NFPA 701 Small scale	As above	2-3/4" x 10"	10; 5 in each direction	1 1-1/2 hrs. 140-145°F Dry cleaning Laundering	Same as ASTM
UL 214-1969	As above	As above	As above	As above	12 x 12 x 30 open top & bottom No side venting
B.S. 3119	Fabrics of low flammability	2 x 12	6	20°C, 65% RH Wash test BS 3121	Approximately as above

Ignition Source	Gas Composition	Ignition Time	Test Criteria
Bunsen or Tirrill 1-1/2" flame	Matheson Gas B	12 second	2 second duration of flame 3-1/2" avg. char length 4-1/2" max. char length
As above	As above or propane	As above	None
As above	Not Specified	As above	None
As above	Matheson Gas B	As above	As above
As above 25° tilt to burner	Not specified	As above	Same as ASTM
As above	800-1000 Btu/ft^3	As above	2 second duration of flame Same as ASTM
Not specified	Not specified	As above	8 second duration of flame 3-1/2" avg. char length 4-1/2 max. char length

TABLE V

Vertical Spread of Flame Test

for Children's Sleepwear

Federal Test Method 5903

Fabric No.	AMBIENT CONDITIONING: Burn, Char or Melt Length		AMBIENT CONDITIONING: Time to Reach Max. Length		CONDITIONING AT 105°C FOR 1/2 HR.: Burn, Char or Melt Length		CONDITIONING AT 105°C FOR 1/2 HR.: Time to Reach Max. Length		Δ Time
	Inches Avg.	σ	Seconds Avg.	σ	Inches Avg.	σ	Seconds Avg.	σ	
1	12	NA	6.0	0.3	12	NA	5.4	0.1	-0.6
2	12	NA	15.6	0.2	12	NA	15.2	0.5	-0.4
3	12	NA	6.4	0.2	12	NA	5.4	0.3	-1.0
4	12	NA	6.8	0.1	12	NA	6.5	0.2	-0.3
5	8.2	1.7	16.0	5.0	10.4	0.1	21.3	0.4	+5.3
6	12	NA	6.7	0.2	12	NA	6.0	0.7	-0.7
7	12	NA	13.9	0.6	12	NA	12.1	1.0	-1.8
8	12	NA	12.8	0.5	12	NA	12.1	0.4	-0.7
9	12	NA	8.6	0.3	12	NA	8.4	0.0	-0.2
10	12	NA	14.5	0.7	12	NA	12.8	0.5	-1.7
11	12	NA	7.5	0.2	12	NA	6.2	0.2	-1.3
12	12	NA	4.6	0.3	12	NA	4.1	0.3	-0.5
13	12	NA	14.1	3.7	12	NA	13.8	4.3	-0.3
14	12	NA	6.7	0.1	12	NA	6.2	0.1	-0.5
15	4.9	0.5	10.0	5.3	4.3	0.2	7.8	2.0	-2.2
16	12	NA	7.9	0.3	12	NA	6.9	0.2	-1.0
17	12	NA	9.7	0.6	12	NA	8.8	0.2	-0.9
18	12	NA	7.6	0.2	12	NA	7.9	0.2	+0.3
19	6.3	0.6	6.4	0.3	5.9	0.6	7.3	0.8	+0.9
20	5.4	0.5	7.4	0.8	6.1	0.3	6.9	0.8	-0.5
21	5.3	0.1	8.2	0.9	5.6	0.2	7.3	0.7	-0.9

TABLE VI

Performance of Fabrics Under Criteria Set by NFPA and U.L.

Fabric No.	Char Length Criteria [1/]		Afterburn Time Criteria [2/]	
	Ambient	105°C	Ambient	105°C
1	F	F	F	F
2	F	F	F	F
3	F	F	F	F
4	F	F	F	F
5	F	F	F	F
6	F	F	F	F
7	F	F	F	F
8	F	F	F	F
9	F	F	F	F
10	F	F	F	F
11	F	F	F	F
12	F	F	F	F
13	F	F	F	F
14	F	F	F	F
15	PASS	PASS	PASS	PASS
16	F	F	F	F
17	F	F	F	F
18	F	F	F	F
19	F	F	PASS	PASS
20	PASS	F	PASS	PASS
21	PASS	F	PASS	PASS

1/ For fabrics of 6 ozs. or less 5-1/2 inch average of 10 passes.

2/ Afterburn of less than 2 seconds after 12 second ignition time passes.

TABLE VII

Ranking of Fabrics in Vertical Test

Relation to Weight of Fabric

Ambient Conditioning		Conditioning at 105°C	
Rank (Lab. No.)	Fabric Weight mg/cm^2	Rank (Lab. No.)	Fabric Weight mg/cm^2
19	14.29	19	13.84
20	14.77	20	14.35
21	15.42	21	14.98
15	7.72	15	7.60
5	8.08	5	7.90
2	26.10	2	25.60
10	11.52	13	9.80
13	9.98	10	11.32
7	16.32	7	15.92
8	16.71	8	16.32
17	13.91	17	13.48
9	12.56	9	12.32
16	10.34	18	10.20
18	10.35	16	9.92
11	10.35	4	9.00
4	9.15	11	11.32
14	9.33	14	9.00
6	8.98	6	8.88
3	8.66	1	8.52
1	8.55	3	8.44
12	6.24	12	6.16

TABLE VIII

Comparison of Ranking for Flammability

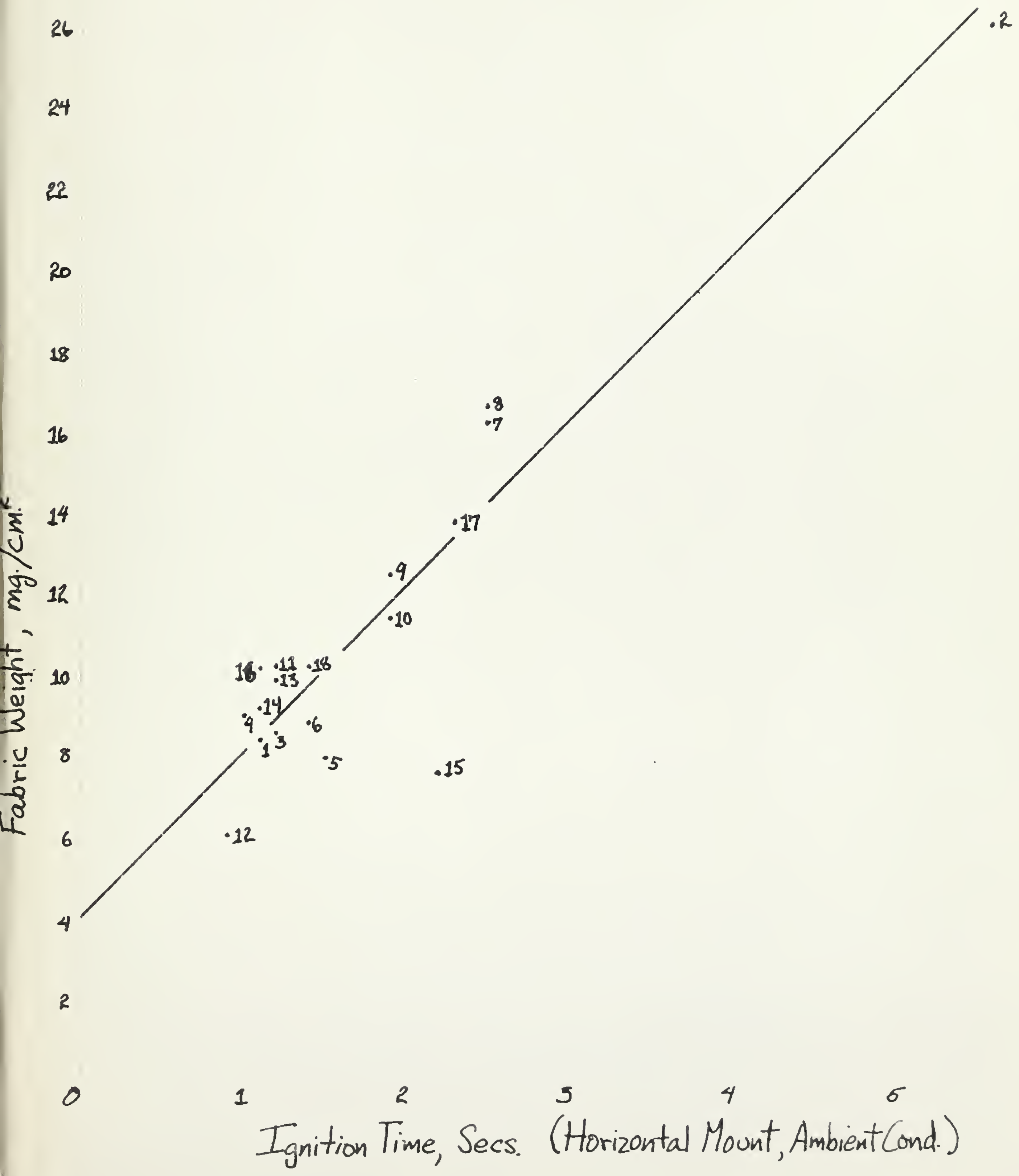
Vertical and Ignition Tests

Ambient Conditioning

Spread of Flame (Vertical) Ranking	Ease of Ignition (Horizontal) Ranking
19	19
20	20
21	21
15	2
5	7
2	8
10	17
13	15
7	9
8	10
17	5
9	6
16	18
18	3
11	11
4	13
14	1
6	14
3	16
1	4
12	12

Eleven highest ranked for difficult ignition are among the twelve highest ranked for lowest spread of flame.

Figure I
Relation of Fabric Weight to Ignition Time



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