Technical Information

NOMEX®
only by DuPont

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# Technical Guide for NOMEX® Brand Fiber

PERFORM WHEN THE HEAT'S ON

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## What Is NOMEX®?

NOMEX® is a DuPont registered trademark for its family of aromatic polyamide (aramid) fibers. This family consists of staple fibers, continuous filament yarns, paper, and spunlaced fabrics. Uses for staple, yarn, and spunlaced products include apparel fabrics to protect against flash fire and electric arc exposure; firefighter garments; fabrics and spun yarns for filtration applications; insulation in fire resistant thermal protective apparel; rubber reinforcement; and in transportation textiles such as aircraft carpeting. Some uses for the paper products include insulation in electric motors and transformers, wire wrapping, and honeycombed strength members in many aircraft. This technical guide focuses on products and end uses for the staple and yarn products. Information on other applications may be obtained from the Advanced Fibers Systems Customer Inquiry Center.

Unlike flame-retardant treated (FRT) materials, NOMEX® brand fibers are inherently flame resistant(FR): the flame resistance is an inherent property of the polymer chemistry. It will not diminish during the life of the fiber. The fiber's low stiffness and high elongation give it textile-like characteristics which allow processing on conventional textile equipment. These and other properties are discussed in detail in this guide.

In this guide FR will designate materials that are ***inherently*** flame-resistant, such as NOMEX® and KEVLAR®. FRT will designate materials that have been ***treated*** with a flame-retardant chemical to make them flame resistant, such as FRT cotton.

Since its introduction, the product lines of NOMEX® have been augmented to include a variety of natural and colored fibers and blends, each with unique properties designed to meet specific end-use requirements. The general classes of these products are discussed in the following section. Table I-1 on page 4 lists some specific commercial products and their end uses.

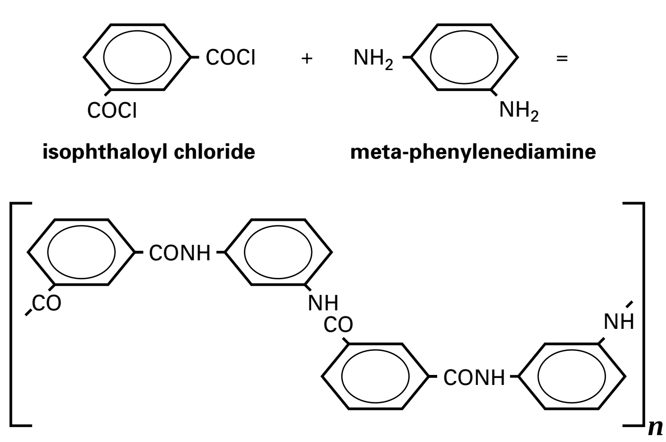
## Development and Molecular Structure of NOMEX® Brand Fiber

NOMEX® was developed by a DuPont research team seeking a fiber which would add thermal resistance to the physical properties of nylon. This research, begun in the late 1950's, led to subsequent laboratory production and extensive evaluation of a fiber originally called HT-1. Adoption of the trademark NOMEX® nylon was announced in 1963, when pilot plant facilities commenced operation. By 1967, NOMEX® was available commercially. In 1972 the tradename NOMEX® aramid was adopted.

NOMEX® meta-aramid, poly(meta-phenyleneisophthalamide), is prepared from meta-phenylenediamine and isophthaloyl chloride in an amide solvent. It is a long chain polyamide in which at least 85% of the amide linkages are attached directly to two aromatic rings. The meta oriented phenylene forms bends in the polymer chain, reducing chain rigidity as compared to the para orientation in the chemically similar KEVLAR® para-aramid chain. This flexible polymer chain gives NOMEX® more textile-like qualities while retaining high temperature properties similar to KEVLAR®.

The aromatic rings and the conjugated amide bonds that link them together are particularly strong and resistant to chemical attack. They also provide a high degree of heat resistance to the polymer backbone. As a result, NOMEX® does not melt and drip, and merely chars when exposed to high temperatures for prolonged periods.

**Figure 1.1 NOMEX® Meta-aramid Synthesis**




NOMEX® meta-aramid [poly(meta-phenyleneisophthalamide)]

## Products of NOMEX®

This guide contains technical information on continuous filament yarns and staple fibers of NOMEX®, including a listing of the products sold in North America. Outside North America, contact your local DuPont Representative, since product names and type designations may be different.

### Type 430 NOMEX®

A high crystalinity natural filament yarn of NOMEX® with higher strength and chemical resistance than staple spun yarns. Type 430 is used where the aesthetics and properties of a filament yarn are required. It is available in light deniers for textile applications or higher deniers for rubber hose reinforcement applications. Type 430 is used in firefighters' turnout gear shells and liners, coated fabrics, electrical insulation, radiator hoses, and industrial laundry press covers. Generally, it is used in its natural color because of difficulty in producing a uniformly dyed product.

### Type 450 NOMEX®

A natural staple fiber. It has higher crystallinity and strength than Type 455 and 462 fibers, and is sold as a 100% meta-aramid staple in various cut lengths. It is used in applications requiring high tensile properties, as well as chemical and thermal stability, such as in hot gas filtration fabrics, sewing threads, zipper tapes and firefighters turnout facing fabrics. It is also used in its natural color for knit products such as balaclavas and underwear. Although dyeable, it is less dyeable than the Type 455 and 462 staple products, and is not available as a dye merged staple.

### Type 455 NOMEX® (NOMEX® III)

Type 455 staple of NOMEX®, a patented blend of NOMEX® and KEVLAR® brand fibers, was introduced to fill the need for higher performance thermal protective apparel. Type 455 staple when converted to fabric is known commercially as NOMEX® III. It offers several improvements over yarns or fabrics produced from Type 450 staple. However, because of its lower crystallinity, it produces yarn and fabrics that are slightly lower in strength than those produced from Type 450 staple.

Advantages versus Type 450 include:

- *Increased resistance to break open under thermal load.* The presence of 5% KEVLAR® inhibits thermal shrinkage, thus reducing the probability of break-open and the subsequent loss of the protective barrier.
- *Easier dyeability.* Type 455 NOMEX® can be uniformly dyed in fabric or yarn form to the many colors required for civilian protective apparel. Type 455 NOMEX® is sold as a dye merged staple.
- *Fabric Appearance*. Crease retention and wrinkle resistance can be imparted to NOMEX® III or NOMEX® IIIA by autoclaving pressed garments at 30 psig steam pressure. Although not as strong as the memory of heat-set polyester, these memory forces provide significant advantages in appearance and ease of care vs. many competitive materials, or unautoclaved garments.

### Type 462 NOMEX® (NOMEX®IIIA)

Type 462 staple of NOMEX® is a blend of NOMEX® and KEVLAR® brand fibers and P-140, a proprietary static dissipative fiber. When converted to fabric it is known commercially as NOMEX® IIIA and is used for thermal protective apparel. It offers all the features of Type 455 staple plus a higher level of static dissipation in fabric form. The P-140 fiber dissipates static generated from fabric-to-fabric and fabric-to-surface rubbing, minimizes the contribution of clothing to static hazards and reduces apparent electric field strength and nuisance static. The staple is dye mergeable and can be package dyed as yarn for use in knit goods or sewing threads, or piece dyed as fabric for civilian protective apparel. Except for the static dissipative properties of NOMEX® IIIA, all other properties are essentially the same as for NOMEX® III. Properties reported in this guide should be considered applicable to both, unless a specific difference is noted in the text.

### Type N102 Texturized Filament Yarn

Producer colored texturized filament yarn is available in a range of colors on a 4.5 lb. package. Standard denier is 900, but other deniers may be available by special request.

### ■ ■ ■ Type N104 Dyeable Filament Yarn

A low crystalinity filament yarn available for applications where a dyed yarn is required. It dyes similar to Types 455 and 462 NOMEX®. Shrinkage of 7-8% may make package dying difficult.

### ■ ■ ■ NOMEX® Producer-Colored Fibers

Producer colored Type N300 Series staple and Type N101 filament yarn are available in a range of colors. These are used mainly for military protective apparel applications. However, colors are available for civilian protective apparel or other end uses. Custom colors can be produced with minimum volume restrictions. Staple blends similar to Type 455 and 462, and light denier yarns are commercially available. Staple blends with higher levels of KEVLAR® are available for improved thermal performance.

These staple and yarn fibers have high crystallinity similar to the Type 430 yarn and Type 450 staple fibers but with spun-in color. They have enhanced colorfastness and color uniformity, and higher yarn and fabric strength when compared to trade dyed products.

### ■ ■ ■ NOMEX CGF®** and NOMEX THERMACOLOR®† Brand Fiber

NOMEX CGF® is available in staple form in a broad range of producer colors, while NOMEX THERMACOLOR® is a natural staple product that enables trade-dyeing of yarn to exact color requirements, without the pressure and carriers typically used to dye aramid yarns and fabrics. DuPont developed these products to meet the needs of the transportation and hospitality markets for thermal-resistant furnishings with superior colorfastness. Both are made from NOMEX®, but differ from other products of NOMEX® in their higher denier per filament and improved lightfastness.

### ■ ■ ■ NOMEX OMEGA®

NOMEX OMEGA® is a total turnout system for firefighters. Components include an outer shell of DuPont™ Z200™ fiber, a moisture barrier, and a thermal liner of DuPont materials. The system is designed to minimize heat stress and maximize thermal performance and comfort.

### ■ ■ ■ Spunlaced Fabrics

Spunlaced fabrics of NOMEX® and KEVLAR® brand fibers are produced using our SONTARA® technologies. These fabrics are durable, soft, conformable, saturable and lightweight – a unique combination of properties. Fabric integrity is based on the hydraulic jet entanglement of 3/4" staple fibers. Resin binders which detract from the aramid thermal properties are not necessary, though they may be applied as a post treatment to impart stiffness or color. Fabrics offered in a variety of basis weights from 0.7 to 8.0 oz/yd$^2$. They may be patterned or plain. Converted widths match end use requirements, typically less than 75" wide. Composition may be 100% NOMEX®, 100% KEVLAR® or blends of the two. KEVLAR® in the blends provides resistance to flame breakopen. The formed fabrics are in some cases processed further to modify properties for specific applications. Product may be calendered to reduce thickness and increase modulus. Multiple layers of spunlace fabric are quilted with woven face fabric of NOMEX® to make durable conformable and lightweight fireblocking fabrics for transportation and thermal liners for fireservice garments.

Product descriptions and types follow:

| Composition | Application | Type | Description |
|---|---|---|---|
| 100% NOMEX® | Filtration; Apparel | E-88 | |
| | Business Machines | E-88C | Calendered |
| | Shielding Tapes; Electrical Insulation | E-140 | Calendered high density |
| NOMEX® and KEVLAR® blends | Apparel Liners; Moisture Barrier Substrate | E-89 | NOMEX® E-89™ |
| 100% KEVLAR® | Fireblocking; Calender Roll | Z-11 | Narrow width tapes. |
| Quilted Fabrics | Transportation Seat Fireblocking; Thermal Liners | E-92 | Multi-layer quilts with woven fabric facing. |

Table I-1 (on the following page) shows the product line by type. The "N" series number identifies a product or product composition while merge numbers identify the specific color. For inquiries about products other than those shown contact your DuPont representative for details.

** Registered trademark of E.I. du Pont de Nemours and Company for its color guard fibers.

† Registered trademark of E.I. du Pont de Nemours and Company for its easily dyeable fibers.

## Table I-1. NOMEX® Brand Fiber Products

| Fiber Type | Availability | Description | Primary End Uses |
|---|---|---|---|
| **■ Yarn** | | | |
| Natural Yarn | | | |
| 430 | 200 d, 100 filament<br>1200 d, 600 filament<br>1600 d, 800 filament<br>2400 d, 1200 filament | Natural bright luster, high crystalinity, low dyeability, continuous-filament yarn | Rubber reinforcement, sewing thread, filtration fabrics, protective apparel |
| N104 | 150 d, 100 filament<br>200 d, 100 filament | Natural bright luster, low crystalinity, dyeable, continuous-filament yarn | Protective apparel applications where a dyable yarn is required |
| Producer Colored Yarn | | | |
| N101 | 200 d, 100 filament | Continuous filament yarn in a range of colors | Protective apparel |
| N102 | 900 d, 400 filament | Texturized continuous filament yarn in a range of colors | Protective apparel |
| **■ Staple** | | | |
| Natural Staple | | | |
| 450 | 1.0, 1.5 or 2.0 dpf; 2 or 3 in.<br>5.5 dpf; 3 in. | Natural (bright luster) staple fiber | Filtration fabrics, sewing thread, knit fabrics for protective apparel, paper makers, laundry, business machine felts |
| E510 | 10.0 dpf, 3 in. | Natural (bright luster) staple fiber | Filtration fabrics, laundry felts |
| 455 (NOMEX® III) | 1.5 dpf, 1.5 or 2 in. | Dye merged, natural (bright luster) staple fiber containing 5% KEVLAR® | Woven fabrics for civilian protective apparel |
| 462 (NOMEX® IIIA) | 1.5 dpf, 1.5 or 2 in. | Dye merged, static dissipative, natural (bright luster) staple fiber containing 5% KEVLAR® and 2% static dissipative fiber | Fabrics for protective apparel requiring lowest potential for static discharge |
| N330 | 1.5 dpf, 2 in. | Dye merged, static dissipative, natural (bright luster) staple fiber containing 5% KEVLAR® and 3% static dissipative fiber | Fabrics for protective apparel requiring lowest potential for static discharge |
| E50ZT (NOMEX THERMACOLOR®) | 3 dpf; 2 in., 6 in. or varicut<br>7.0 dpf; 6 in. or varicut | Yarn-dyeable staple fiber | Aircraft and other transportation upholstery and floor coverings; contract furnishings for hospitals, day-care centers and nursing homes |
| Z200 | 1.5 dpf, 2 in. | Proprietary aramid fiber | Fire services protective apparel |
| Producer Colored Staple | | | |
| N301 | 1.5 dpf, 1.5 or 2 in. | Staple fiber in a range of colors containing 5% KEVLAR® | Protective apparel |
| N302 | 1.5 dpf, 2 in. | Staple fiber in a range of colors containing 5% KEVLAR®, 2% static dissipative fiber | Protective apparel |
| N303 | 1.5 dpf, 2 in. | Staple fiber in a range of colors containing 5% KEVLAR®, 3% static dissipative fiber | Military protective apparel |
| N305 | 1.5 dpf, 2 in. | Staple fiber in a range of colors containing 23% KEVLAR®, 2% static dissipative fiber ("Delta T" fabric in Europe) | Protective apparel |
| N307 | 1.3 dpf, 2 in. | Staple fiber in a range of colors containing 5% KEVLAR® and 2% static dissipative fiber ("Delta C" in Europe) | Protective apparel |
| N308 | 1.5 dpf, 2 in. | Staple fiber in a range of colors containing 60% KEVLAR®, 40% NOMEX® | Protective apparel |
| N310 | 1.5 dpf, 2 in. | Staple fiber in a range of colors containing 50% KEVLAR®, 50% NOMEX® | Protective apparel |
| E50 (NOMEX® CGF) | 7.0 dpf, 6 in. or varicut | Staple fiber in a range of colors | Aircraft and other transportation upholstery and floor coverings, contract furnishings for hospitals, day-care centers and nursing homes |

NOTES: d = denier, dpf = denier per filament

## SECTION II: PROPERTIES OF NOMEX®

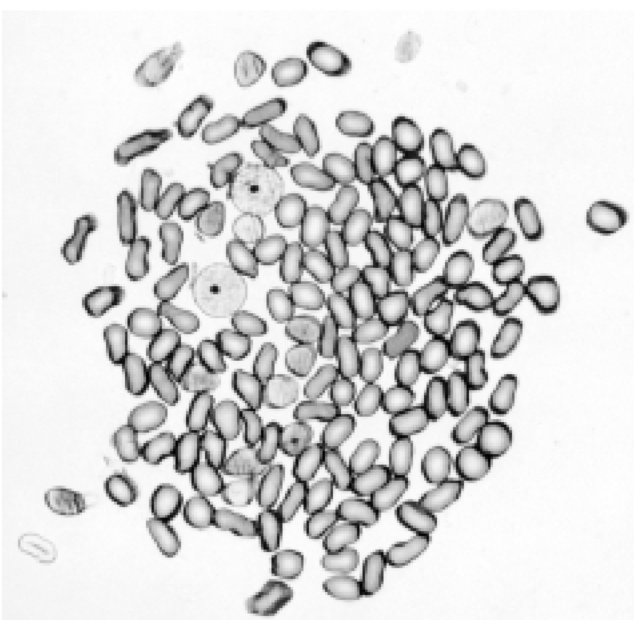
This section lists and describes the typical properties of NOMEX®. The data reported are those most often observed, and are representative of the particular denier and type indicated.

For information on safety and health, refer to the NOMEX® Material Safety Data Sheet.

### Fiber Properties

NOMEX® brand fiber, a member of the aramid family of fibers, offers excellent flame resistance, good textile properties, dimensional stability, and resistance to degradation by a wide range of chemicals and industrial solvents. Most varieties have an oval to dogbone fiber cross-section, as shown in Figure 2.1.

**Figure 2.1. Photomicrograph of a Typical Cross Section of Type 462 yarn**



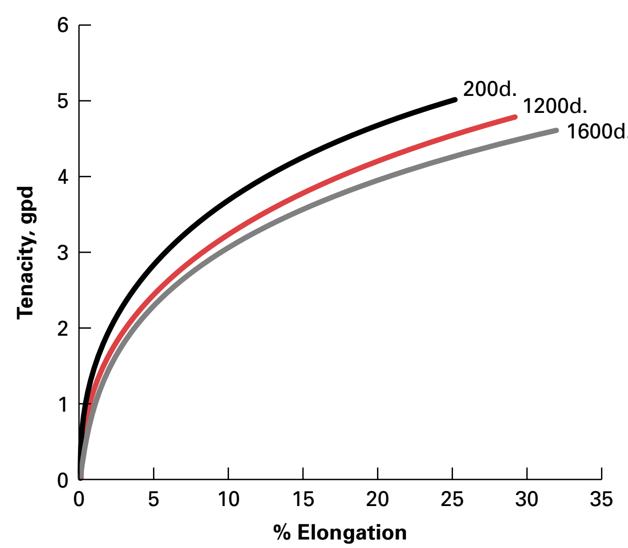
### Fiber and Fabric Test Methods

Included in this bulletin are many physical and chemical properties of staple fibers, filament yarns, fabrics, and garments. The results reported are those most often observed and are representative of particular samples. The tests are conducted using recognized standards, or in some cases, modifications of those, or methods developed by DuPont. Appendix I lists the properties reported, the reference standard used, and the general location within this bulletin. The properties listed should not be considered specifications. Contact your DuPont representative for copies of the most recent fiber specifications.

### Tensile and Thermal Properties

NOMEX® shows essentially no embrittlement or degradation at cryogenic conditions [temperatures as low as -320°F (196°C)]. At room temperature the tensile properties are in the same range as those of nylon and polyester, making it easily processable on standard textile equipment. Typical room temperature stress-strain curves are shown in Figure 2.2. A summary of the tensile and thermal properties is shown in Table II-1 on the following page.

**Figure 2.2 Typical Stress-Strain Curves for Type 430 Natural NOMEX® Yarn. (3 TPI, 10" gauge length, 12 in/minute extension rate)**



## Table II-1. Tensile and Thermal Properties of NOMEX® Brand Fibers

| | Type 430 | Type 430 | Type 450 | Type 455/462 | Type N301 |
|---|---|---|---|---|---|
| **Product Tested** | 1200 denier<br>2 dpf | 1600 denier<br>2 dpf | 1.5 dpf<br>32/2 CC | 1.5 dpf<br>32/2 CC | 1.5 dpf<br>22/1 CC |
| Density, gm/cm$^3$ | 1.38 | 1.38 | 1.37 | – | – |
| Moisture, % | | | | | |
| - As Shipped* | 4.0 | 4.0 | 8.2 | 8.3 | 8.3 |
| - Billed (Commercial, ASTM) | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| **Tensile Properties** | | | | | |
| Straight Test (1) | | | | | |
| Tenacity, gm/den. | 5.0 | 4.9 | 2.9 | 2.6 | 2.8 |
| Elongation, %(at break) | 30.5 | 31.0 | 22 | 21 | 19 |
| Initial Modulus, gm/den. | 94 | 85 | – | – | – |
| Loop Test | | | | | |
| Tenacity, gm/den. | 4.1 | 3.9 | – | – | – |
| **Thermal Properties** | | | | | |
| Heat of Combustion (2) | | | | | |
| BTU/LB | 12100 | _ | 12100 | 12100 | 12100 |
| Joule/kg | 28.1x$10^{6}$ | _ | 28.1x$10^{6}$ | 28.1x$10^{6}$ | 28.1x$10^{6}$ |
| Specific Heat (3) at 77°F (25°C), cal/gm°C | 0.30 | | 0.30 | 0.26 | 0.29 |
| Shrinkage in Water at 212°F (100°C), % | 1.3 | 1.1 | 4.0 max. | 0.5 | – |
| Shrinkage in Dry Air, 30 min. (4) | | | | | |
| at 545°F (285°C), % Aim | 1.5 | 1.2 | – | – | – |
| Max. | 4.0 | 4.0 | – | – | – |
| Thermal Conductivity (5) | | | | | |
| W/m•°K | 0.25 | – | – | – | – |
| [BTU-in/(h.ft$^2$.°F)] | 1.7 | – | – | – | – |
| Coefficient of Linear Expansion | | | | | |
| 78°F - 266°F (26°C - 130°C) | | | | | |
| cm/cm-°C | 1.8 x $10^{-5}$ | 1.8 x $10^{-5}$ | 1.8 x $10^{-5}$ | 1.8 x $10^{-5}$ | 1.8 x $10^{-5}$ |
| in/in°F | 1.0 x$10^{-5}$ | 1.0 x$10^{-5}$ | 1.0 x$10^{-5}$ | 1.0 x$10^{-5}$ | 1.0 x$10^{-5}$ |
| Filament Cross Section: | | | | | |
| Oval to Dog Bone Shaped | | | | | |
| Major Diameter, microns Avg. (Range) | 20 (17-22) | – | 17 (15-18) | 18 (15-20) | 18 (15-20) |
| Minor Diameter, microns Avg. (Range) | 11 (9-13) | – | 10 (8-12) | 10 (8-12) | 10 (8-12) |

* Typical moisture levels on fiber as shipped. Equilibrium moisture levels are dependent on humidity and processing conditions.

(1) Filament yarn tested at 3 TPI, 10" gauge length and 60%/minute extension rate. DuPont Test Method 12002.

(2) Per ASTM D2015, yarn dried in 90 TORR vacuum oven at 194°F (90°C) for 60 minutes before testing.

(3) TA Instruments Model 2920 modulated DSC, ASTM TM E1269.

(4) Yarn shrinkage per DuPont Test Method 12029.

(5) Per ASTM E1530-93 on 1.4 g/cc compressed paper; density equivalent to crystallized yarn.

**Note:** The data in this table are those most commonly observed and are representative of the particular denier and type indicated; they are not product specifications. Properties will vary with denier and type.

**Figure 2.3 Effect of Twist on 200 Denier NOMEX® Brand Yarn, (200-100-0 Type 430)**

10" gauge length, 120%/minute extension rate

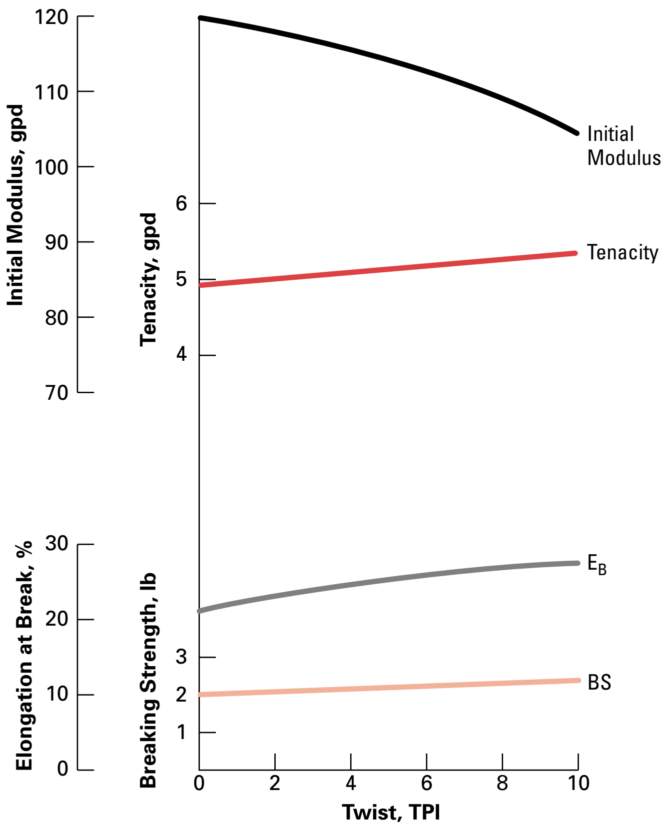
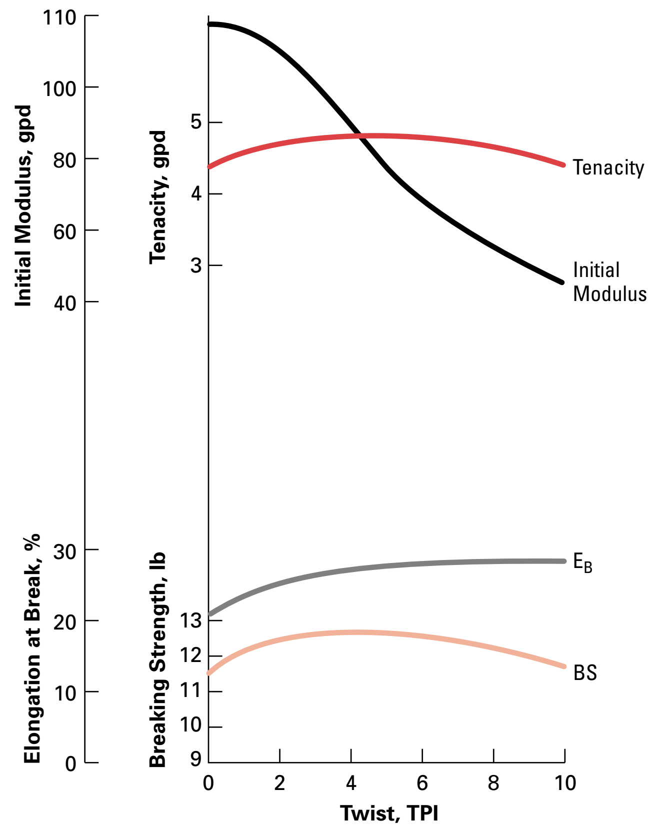



**Figure 2.4 Effect of Twist on 1200 Denier NOMEX® Brand Yarn, (1200-600-0 Type 430)**

10" gauge length, 120%/minute extension rate




***Effect of Yarn Twist***

Yarn twist has a significant influence on filament yarn properties, and benefits can be derived from using the optimum twist for all load-bearing yarns.

The influence of yarn twist on physical properties of NOMEX® filament yarns is shown for 200 denier and 1200 denier Type 430 in Figures 2.3 and 2.4 and is as follows:

Effect of Increasing Twist

- Elongation increases
- Initial modulus decreases sharply
- Tenacity increases as twist increases for 200 denier yarn
- Tenacity peaks at approximately 4 TPI then decreases with further twist for 1200 denier yarn

***Effect of Dry Heat***

Thermogravimetric analysis (TGA) of Type 455 NOMEX® (Figure 2.5) shows less than 10% fiber weight loss up to approximately 752°F (400°C) in air or nitrogen. Rapid weight loss is seen above ~801°F (~427°C). Thermal oxidation in air is time/temperature dependent. Fabric scorching or charring can occur in as little as 30 seconds at 662°F (350°C) in air. Increasing the temperature will decrease the time to form char.

NOMEX® does not melt or drip. A typical Differential Scanning Calorimeter (DSC) curve for Type 462 (Figure 2.6) shows the change in energy input vs. temperature. It does not show a defined melting point for NOMEX®. The inflection in the curve shown at 491.5°F (255.3°C) represents the melting point of the P140 static dissipative fiber in Type 462. The DSC curves for Type 450 and 455 NOMEX® will be similar, but without the P140 inflection at 491.5°F (255.3°C).

**Figure 2.5 Thermogravimetric Analysis of Type 455 NOMEX® in Nitrogen and air**

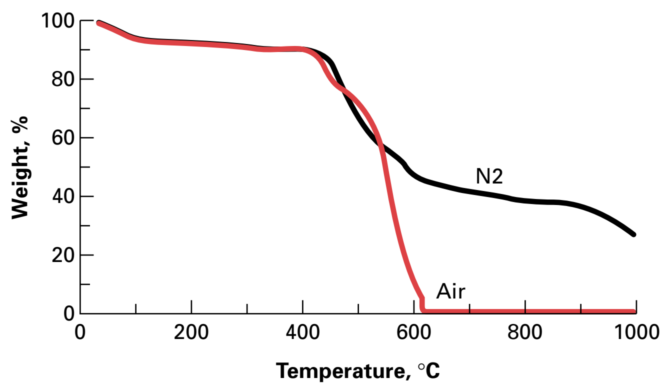
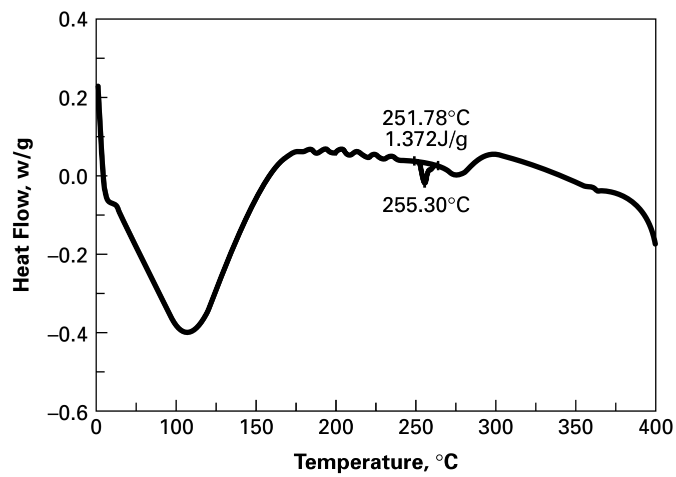



**Figure 2.6 Differential Scanning Calorimeter Curve of Type 462 NOMEX® in Nitrogen**




The strength retention of NOMEX® when exposed to heat is a function of time, temperature and environment. In applications such as hot gas filtration where exposures may be continuous for several months to years, and where fiber strength may impact filter bag life, a maximum continuous operating temperature of 400°F (204°C) is recommended. In applications such as firefighters' turnout gear where exposure temperatures may be much higher but of shorter duration, gear fabric may perform its intended function for many years and still exceed NFPA strength guidelines.

NOMEX® has good stress-strain properties at temperatures above the melting point of most other synthetic fibers. Increasing temperature reduces the tensile strength, modulus, and break elongation of yarns of NOMEX®. Yarns tested after exposure to various temperatures for 5 minutes in dry air give the stress-strain curves shown in Figure 2.7. The relationships between temperature and breaking tenacity, breaking elongation and initial modulus are shown under the same conditions in Figure 2.8. At 489°F (254°C), the approximate melting point of nylon and polyester fibers, NOMEX® has a breaking strength ~50% of that at room temperature.

After exposing fibers of NOMEX® to dry air at 500°F (260°C) for 1,000 hours and then returning them to room temperature, the breaking strength and toughness of NOMEX® is approximately 65% of that exhibited before exposure. The effect of prolonged exposure is shown in Figures 2.9 and 2.10.

**Figure 2.7. Stress-Strain Curve for 200 Denier Type 430 NOMEX® Tested at Various Temperatures after 5 Minute Exposure**

A 200-denier, 100-filament yarn with 3 TPI, 60%/minute extension rate.

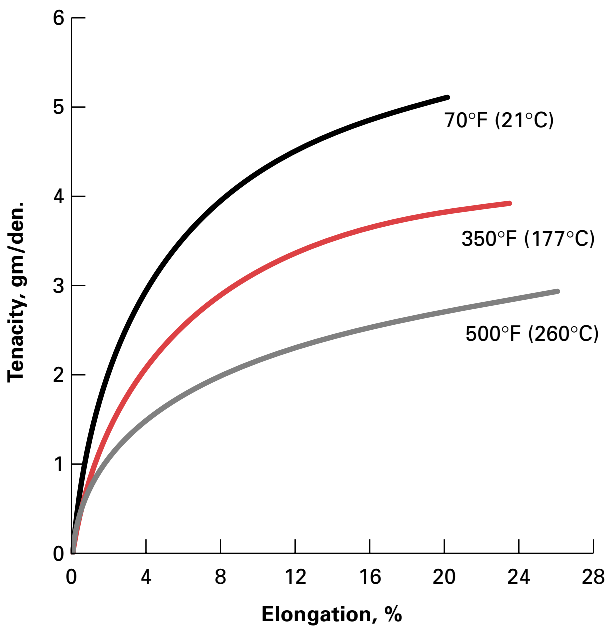



**Figure 2.8. Tensile Properties of Type 430 NOMEX® Tested at Various Temperatures After 5 Minute Exposure**

1200 and 1600 denier yarn, 3 TPI, 60%/minute extension rate

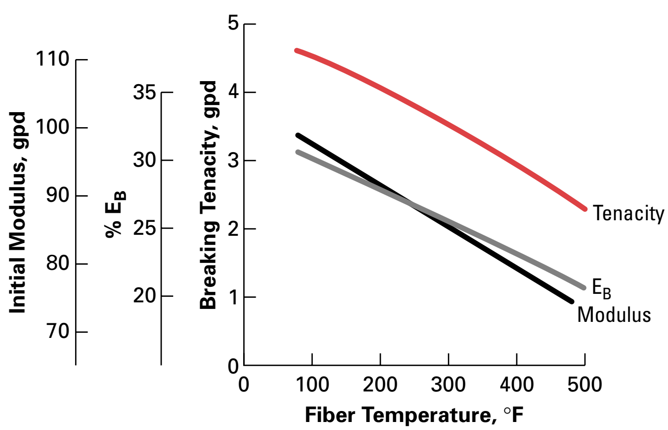



**Figure 2.9. Strength Retained by Type 430 NOMEX® After Prolonged Exposure to Hot, Dry Air**

Tested at 70°F (21°C), 65% RH, 3 TPI, 120%/min. extension rate.

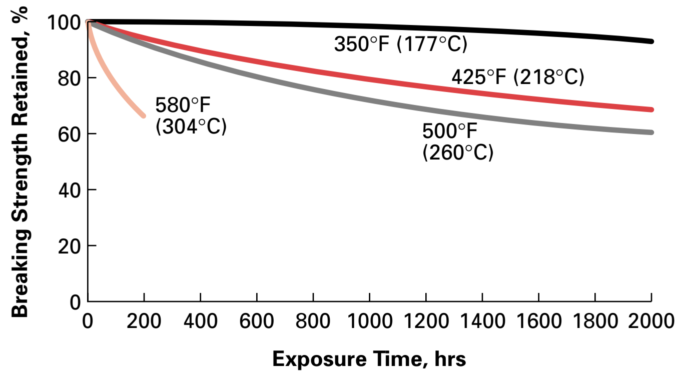
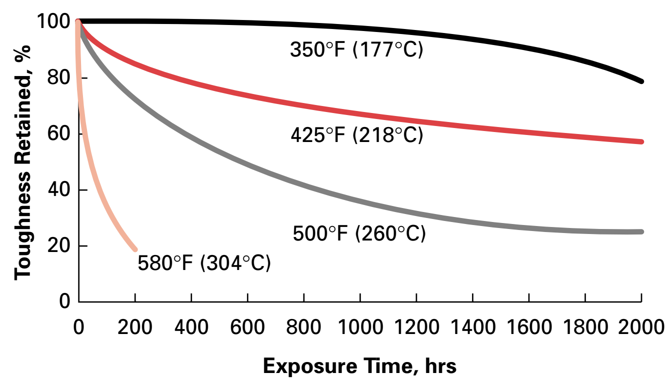



**Figure 2.10. Toughness retained by Type 430 NOMEX® after Prolonged Exposure to Hot Dry Air**

Tested at 70°F (21°C), 65% RH, 3 TPI, 120%/min. extension rate.



*Effect of Moisture*

The presence of small amounts of water vapor in air or other gases has no apparent effect on the strength properties of NOMEX®, even at elevated temperatures. Variations in relative humidity from 5% to 95% have virtually no measurable effect on the strength of NOMEX® at room temperature.

Tests have shown that thoroughly wet yarn of Type 430 NOMEX® is approximately 75% as strong as dry yarn at the same temperature. At elevated temperatures, NOMEX® fiber in intimate contact with water or saturated steam exhibits a progressive loss in strength. Sealed-tube tests have shown a strength loss of approximately 70% for NOMEX® fibers exposed for 1,000 hours at 300°F (149°C) in air saturated with water vapor. In contrast, nylon completely deteriorates in less than 100 hours under the same conditions.

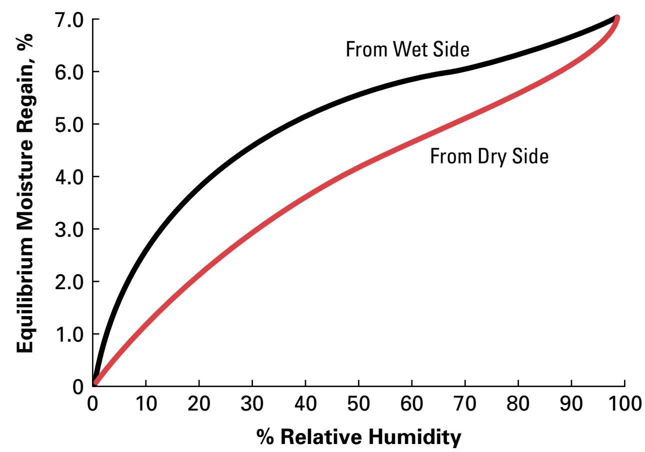
### ▪ ▪ ▪ Moisture Regain and Dimensional Stability

Moisture regain is the tendency of most fibers to pick up or give off ambient atmospheric moisture until an equilibrium moisture content is reached. Relative humidity has a significant effect on the rate of moisture absorption and equilibrium level. The higher the relative humidity, the faster NOMEX® absorbs moisture during the initial phase of moisture gain, and the higher the final equilibrium level. The effect of relative humidity on the moisture regain of Type 430 NOMEX® is shown in Figure 2.11. When tested in accordance with ASTM D-2654 at 70°F (21°C) at 65% RH, fabrics of NOMEX® IIIA contain 5% to 5.5% moisture at equilibrium levels. The moisture regain of NOMEX® is significantly greater than that of polyester, slightly higher than that of nylon, and less than that of cotton.

The longitudinal stability of NOMEX® brand fiber is virtually unaffected by changes in relative humidity. When exposed to dry air at 500°F (260°C), Type 430 NOMEX® shrinks approximately 1% in length within a few seconds. Additional shrinkage of approximately 0.7% occurs within the first 10 minutes of exposure. Longer exposures at this temperature have essentially no further effect on yarn length.

**Figure 2.11. Equilibrium Moisture Regain of Type 430 NOMEX® at 70°F (21°C)**

(Ref: "Absorption and Desorption of Water by Some Common Fibers", John F. Fuzek, Eastman Kodak Company, Kingsport, TN 37662)



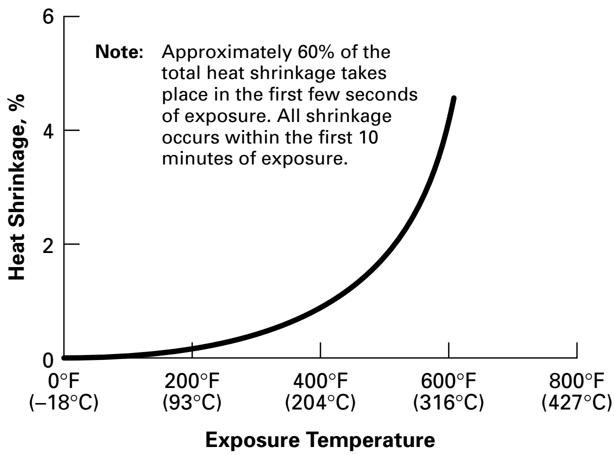

A combination of moisture and heat produces greater shrinkage of NOMEX® fiber than dry heat alone because it more fully releases internal fiber stresses. Boiling water, for example, produces an immediate shrinkage of approximately 1.3% in Type 430 NOMEX®. Repeated 5-minute exposures in boiling water result in progressively greater shrinkage, for a total of 3.8% after 100 exposures.

Due to high shrinkage, uncrystallized NOMEX® fibers, currently T455, T462 and N330 staple and N104 filament, require wider loom reed width than crystallized fibers to obtain desired fabric width after dyeing and/or finishing.

Woven fabrics of NOMEX® III, NOMEX® IIIA and producer-colored fibers exhibit a low level of shrinkage when laundered. In a laboratory test, fabrics of NOMEX® were commercially laundered at 160°F (71°C). After five launderings, both shirt-weight (4.5 oz/yd$^2$) and pant-weight (6.0 oz/yd$^2$) fabrics shrunk an average of 2% in both the warp and fill direction. No additional shrinkage was seen in 45 subsequent launderings.

Properly constructed filtration fabrics of NOMEX® will neither stretch nor shrink more than 1% when exposed to operating temperatures less than 400°F (204°C), nor will they change significantly in length with variations in relative humidity.

**Figure 2.12. Shrinkage of Type 430 NOMEX® Yarn in Hot, Dry Air After 10 Minutes at Test Temperature**




### Flammability, Smoke and Off-Gas Generation

The Limiting Oxygen Index (LOI) of NOMEX® is approximately 28. Thus, when exposed to flame at room temperature in a normal air environment, NOMEX® will not continue to burn when the flame is removed. At temperatures above approximately 800°F (427°C), NOMEX® carbonizes and forms a tough char.

The composition and quantity of off-gases varies widely depending on rate of heating, presence of oxygen and other factors. Burning NOMEX® brand fiber produces combustion products similar to those of wood, wool, cotton, polyester and acrylic. At combustion temperatures, NOMEX® releases carbon dioxide and carbon monoxide; and, sometimes traces of hydrogen cyanide and nitrogen oxides are detected. Under less stringent heating conditions, NOMEX® degrades very slowly, releasing small quantities of a wide variety of organic compounds. These may include carbon dioxide, acetone, acetamide, acetaldehyde, benzene, butane, toluene and many other compounds in trace amounts depending on exposure conditions.

## Resistance to Degradation

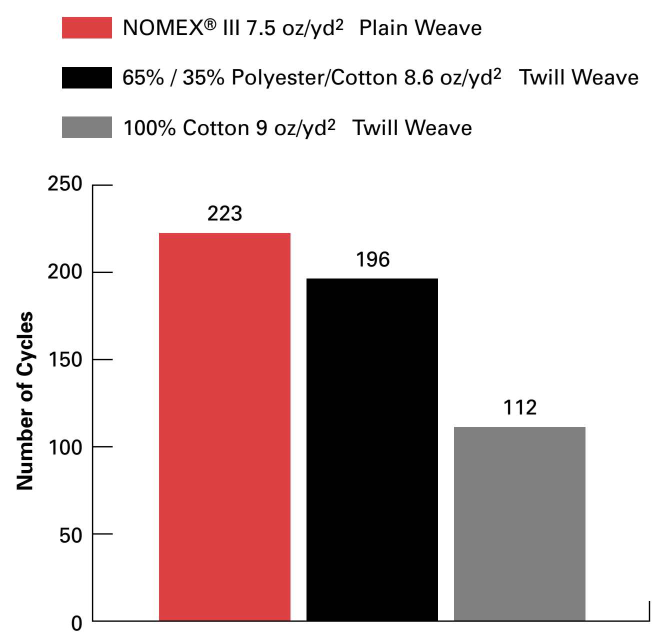
### Abrasion

Abrasion resistance is an important consideration in both protective apparel and filtration applications. Abrasion from wear and laundering is a primary cause of garment failure, while abrasion from dust exposure and cage wear often leads to filter bag failure.

Woven fabrics made from spun staple yarns of NOMEX® consistently exhibit abrasion resistance superior to comparable, or in some cases, even heavier constructions of polyester/cotton blends and 100% cotton (Figure 2.13). This advantage contributes to extended garment wear life (Table II-2).

**Figure 2.13. Modified Wyzenbeek Cycles to Failure for Protective Apparel Fabrics of NOMEX®III and Workwear Fabrics of Polyester/Cotton and Cotton**

All fabrics were made from spun yarn.



## ■ ■ ■ Laundering and Wear Life

NOMEX® used in protective apparel applications can be of several types, as described in Section I. NOMEX® III and NOMEX® IIIA are used in shirts, pants, and coveralls, and outerwear garments. The use of a static dissipative fiber in NOMEX® IIIA reduces nuisance static buildup and makes it the preferred product for most garments. NOMEX® III and NOMEX® IIIA perform similarly in laundering and chemical resistance such that the performance data is interchangeable.

Garments of NOMEX® brand fiber can be laundered or dry-cleaned by conventional home or industrial cleaning methods. Due to its superior abrasion and chemical resistance, little decrease in fabric strength is seen as a result of laundering. Colorfastness is best maintained through use of low alkalinity detergents and moderate 140°F wash water temperatures. Higher temperatures and alkalinity can be used, along with solvenated detergents if required, to remove heavy oily soil. See the Laundering Guide for NOMEX® Brand Fiber, available from the DuPont Advanced Fibers Systems Customer Inquiry Center. Call (800) 453-8527 to request a copy.

After 100 industrial laundry cycles, NOMEX® III tear strength decreases only 10-12% and after 200 cycles has only decreased 20-25%. After 100 industrial laundry cycles, the flex abrasion and tensile and tear strength of 4.5 oz/yd$^2$ NOMEX® III is still greater than new 7 oz./yd$^2$ FRT cotton (See Table II-2).

The tear strength of FRT cotton falls sharply after 25 industrial launderings. After 50 industrial launderings, its strength has decreased by ~50%. The average service life experience with FRT cotton garments is reported to be 25 to 40 wear/wash cycles[1]. Garments made of NOMEX® will retain the strength and durability to remain serviceable well beyond 100 wear/wash cycles, depending on the severity of service.

(1) Loftin, D.H., "The Durability of Flame Resistant Fabrics in an Industrial Laundry Environment", Performance of Protective Clothing: Fourth Volume, ASTM STP 133, James P. McBriarty and Norman W. Henry, Eds., American Society for Testing Materials, Philadelphia, 1992.

**Table II-2. Fabric Strength After Industrial Laundering****

| Fabric | No. IL* Cycles | Flex Abrasion Cycles | | Tensile kg/cm | | Tear g | |
|---|---|---|---|---|---|---|---|
| | | Warp | Fill | Warp | Fill | Warp | Fill |
| NOMEX® III 4.5 oz/yd$^2$ | NEW | 1725 | 1990 | 83.2 | 84.3 | 4676 | 4495 |
| | 25 | 862 | 856 | 82.6 | 81.0 | 4540 | 4540 |
| | 50 | 631 | 652 | 82.6 | 81.5 | 4404 | 4177 |
| | 75 | 636 | 721 | 79.4 | 77.7 | 4540 | 4358 |
| | 100 | 783 | 1086 | 79.9 | 78.8 | 4268 | 4767 |
| Indura® FRT Cotton 7.0 oz/yd$^2$ | NEW | 590 | 578 | 77.2 | 36.4 | 3632 | 2769 |
| | 25 | 133 | 249 | 75.0 | 37.5 | 2088 | 1725 |
| | 50 | 79 | 135 | 71.2 | 42.4 | 1816 | 1453 |
| | 75 | 64 | 109 | 57.1 | 33.7 | 1317 | 1135 |
| | 100 | 54 | 140 | 44.0 | 35.3 | 1090 | 1135 |

* Industrial laundry cycles, 165°F (74°C) wash temperature, pH 11.5 - 12.5, dried at 160°F (71°C) stack temperature for 20 minutes with 10 minute cool down.

** Taken from Table 3 "Fabric Strength and Durability", Loftin, D.H., "The Durability of Flame Resistant Fabrics in an Industrial Laundry Environment", Performance of Protective Clothing: Fourth Volume, ASTM STP 133, James P. McBriarty and Norman W. Henry, Eds., American Society for Testing Materials, Philadelphia, 1992.

## ■ ■ ■ Chemical Resistance

In general, NOMEX® fiber exhibits very good resistance to many chemicals. It is highly resistant to most hydrocarbons and organic solvents. Chemical resistance during exposure in use and to chemicals and solvents used in cleaning contributes to the excellent durability and wear life of garments of NOMEX®.

In addition, the resistance of NOMEX® to acid solutions is better than that of nylon, but not as good as that of polyester. However, at elevated temperatures, its resistance to acid vapors is better than that of polyester. NOMEX® shows excellent resistance to alkalis at room temperature, but is degraded by strong alkalis at high temperatures. Type 430 and Type 450 NOMEX® have excellent resistance to sodium hypochlorite bleach, but Type 455 NOMEX® and Type 462 NOMEX® exhibit moderate (35%) strength loss in this exposure. NOMEX® is resistant to degradation by fluorine-containing elastomers, resins and refrigerants at high temperatures. Additional information on the chemical resistance of Type 430 NOMEX® is shown in Table II-3.

Indura® is a registered trademark of Westex Inc.

## Table II-3. Chemical Resistance of Type 430* Filament Yarn of NOMEX®

| Chemical | Concentration, % | Temperature, °F (°C) | Time, hr | Effect on Breaking Strength** |
|---|---|---|---|---|
| **Strong Mineral Acids :** | | | | |
| Hydrochloric | 1 | 160 (71) | 10 | Slight |
| | 10 | 70 (21) | 1000 | Appreciable |
| | 10 | 160 (71) | 10 | Appreciable |
| | 37 | 160 (71) | 10 | Degraded |
| | 37 | 160 (71) | 100 | Degraded |
| Nitric | 1 | 70 (21) | 100 | Slight |
| | 10 | 70 (21) | 100 | Moderate |
| | 70 | 70 (21) | 100 | Appreciable |
| Sulfuric | 10 | 70 (21) | 100 | None |
| | 10 | 250 (121) | 100 | Appreciable |
| | 50 | 210 (99) | 10 | None |
| | 70 | 70 (21) | 100 | None |
| | 96 | 70 (21) | 100 | Degraded |
| Hydrobromic | 10 | 70 (21) | 1,000 | Moderate |
| Phosphoric | 10 | 70 (21 ) | 1,000 | None |
| | 10 | 210 (99) | 100 | Slight |
| | 70 | 210 (99) | 100 | Slight |
| | 70 | 210 (99) | 1000 | Degraded |
| Hydrofluoric | 10 | 70 (21) | 100 | None |
| | 10 | 210 (99) | 10 | Moderate |
| **Organic Acids:** | | | | |
| Acetic | 5 | 210 (99) | 1000 | None |
| | 100 | 70 (21) | 100 | None |
| | 100 | 210 (99) | 100 | None |
| Benzoic | 3 | 210 (99) | 100 | None |
| Formic | 40 | 70 (21) | 1000 | None |
| | 5 | 210 (99) | 1000 | Moderate |
| | 40 | 210 (99) | 100 | Moderate |
| | 90 | 70 (21) | 100 | None |
| | 90 | 210 (99) | 100 | Moderate |
| Oxalic | 10 | 210 (99) | 100 | Moderate |
| | 5 | 210 (99) | 1,000 | Appreciable |
| Chromic | 10 | 70 (21) | 1,000 | None |
| | 10 | 210 (99) | 100 | Degraded |
| | 30 | 210 (99) | 10 | Degraded |
| Salicylic | 3 | 210 (99) | 1,000 | Slight |

* Refer to text for a discussion of the effect of these chemicals on other products of NOMEX®. Type 430 NOMEX® is 1200-denier, 600-filament yarn.

** None ............................ 0 to 10% strength loss
Slight ........................... 11 to 20% strength loss
Moderate ...................... 21 to 40% strength loss
Appreciable .................. 41 to 80% strength loss
Degraded ...................... 81 to 100% strength loss

## Table II-3. Chemical Resistance of Type 430* Filament Yarn of NOMEX® (Continued)

| Chemical | Concentration, % | Temperature, °F (°C) | Time, hr | Effect on Breaking Strength** |
|---|---|---|---|---|
| **Strong Alkalis:** | | | | |
| Ammonium Hydroxide | 28 | 70 (21) | 1,000 | None |
| Sodium Hydroxide | 1 | 210 (99) | 1,000 | Moderate |
| | 1 | 250 (121) | 1000 | Degraded |
| | 10 | 70 (21) | 1,000 | None |
| | 10 | 210 (99) | 100 | Degraded |
| | 10 | 210 (99) | 10 | Moderate |
| | 40 | 70 (21) | 100 | None |
| | 40 | 70 (21) | 1,000 | Slight |
| | 40 | 250 (121) | 10 | Degraded |
| Tetramethyl Ammonium | 10 | 70 (21) | 1,000 | None |
| Hydroxide | 10 | 150 (66) | 100 | None |
| **Oxidizing and Reducing Agents:** | | | | |
| Peracetic Acid pH-4 | 2 | 70 (21) | 1,000 | None |
| | 2 | 210 (99) | 100 | Slight |
| | 0.2 | 210 (99) | 1,000 | Slight |
| Sodium Chlorite | 0.7 pH-4 | 210 (99) | 100 | Appreciable |
| | 0.7 pH-8 | 210 (99) | 100 | Appreciable |
| Sodium Hypochlorite | 0.01 pH-10 | 70 (21) | 1,000 | None |
| | 0.01 pH-10 | 160 (71) | 100 | Slight |
| | 0.4 pH-11 | 70 (21) | 1,000 | Slight |
| | 0.4 pH-11 | 160 (71) | 100 | Slight |
| Hydrogen Peroxide | 0.4 pH-7 | 70 (21) | 1,000 | None |
| | 0.4 pH-7 | 160 (71) | 100 | None |
| | 0.2 pH-11 | 70 (21) | 1,000 | None |
| | 0.2 pH-11 | 160 (71) | 100 | None |
| Sodium Perborate | 1 | 70 (21) | 1,000 | None |
| | 1 | 210 (99) | 100 | None |
| Sodium Hydrosulfite | 1 | 160 (71) | 100 | None |
| Sodium Sulfoxylate Formaldehyde | 1 pH-4 | 210 (99) | 100 | None |
| Sodium Bisulfite | 1 pH-4 | 210 (99) | 100 | None |
| **Organic Chemicals:** | | | | |
| Acetaldehyde (Water) | 10 | 70 (21) | 1,000 | None |
| Acetone | 100 | 70 (21) | 1,000 | None |
| | 100 | 133 (56) | 100 | Slight |
| Amyl Alcohol | 100 | 70 (21) | 1,000 | None |

* Refer to text for a discussion of the effect of these chemicals on other products of NOMEX®. Type 430 NOMEX® is 1200-denier, 600-filament yarn.

** None ............................ 0 to 10% strength loss
Slight ............................ 11 to 20% strength loss
Moderate ...................... 21 to 40% strength loss
Appreciable .................. 41 to 80% strength loss
Degraded ...................... 81 to 100% strength loss

## Table II-3. Chemical Resistance of Type 430* Filament Yarn of NOMEX® (Continued)

| Chemical | Concentration, % | Temperature, °F (°C) | Time, hr | Effect on Breaking Strength** |
|---|---|---|---|---|
| **Organic Chemicals (continued):** | | | | |
| Benzaldehyde | 100 | 70 (21) | 1,000 | None |
| Benzene | 100 | 70 (21) | 1,000 | None |
| Carbon Disulfide | 100 | 70 (21) | 1,000 | None |
| Carbon Tetrachloride | 100 | 171 (77) | 100 | None |
| | 100 | 70 (21) | 1,000 | None |
| Chloroform | 100 | 70 (21) | 1,000 | None |
| Cottonseed Oil | 100 | 70 (21) | 1,000 | None |
| Dimethyl Formamide | 100 | 70 (121) | 1,000 | None |
| Ether | 100 | 70 (21) | 1,000 | None |
| Ethyl Acetate | 100 | 70 (21) | 1,000 | None |
| Ethyl Alcohol | 100 | 70 (21) | 1,000 | None |
| | 100 | 170 (77) | 100 | None |
| Ethylene Glycol | 50 | 210 (99) | 1,000 | Slight |
| Formaldehyde (Water) | 10 | 70 (21) | 1,000 | None |
| FREON® 113 Refrigerant | 100 | 70 (21) | 1,000 | Appreciable |
| Gasoline (leaded) | 100 | 70 (21) | 1,000 | None |
| Glycerine | 100 | 210 (99) | 10 | None |
| Iodine in Ethyl Alcohol | 3.5 | 70 (21) | 10 | None |
| Lard | 100 | 70 (21) | 1,000 | None |
| Linseed Oil | 100 | 70 (21) | 1,000 | None |
| Methyl Alcohol | 100 | 70 (21) | 1,000 | None |
| Mineral Oil | 100 | 210 (99) | 10 | None |
| Nitrobenzene | 100 | 70 (21) | 10 | None |
| Perchloroethylene | 100 | 210 (99) | 10 | None |
| Phenol (Water) | 5 | 70 (21) | 10 | None |
| | 100 | 210 (99) | 1 | None |
| Resourcinol (Water) | 5 | 70 (21) | 10 | None |
| | 5 | 70 (21) | 100 | None |
| | 100 | 250 (121) | 10 | None |
| Stoddard Solvent | 100 | 160 (71) | 10 | None |
| Tetrachloroethane | 100 | 70 (21) | 1,000 | None |

Refer to text for a discussion of the effect of these chemicals on other products of NOMEX®. Type 430 NOMEX® is 1200-denier, 600-filament yarn.

** None ............................ 0 to 10% strength loss
Slight ........................... 11 to 20% strength loss
Moderate ...................... 21 to 40% strength loss
Appreciable .................. 41 to 80% strength loss
Degraded ...................... 81 to 100% strength loss

**Table II-3. Chemical Resistance of Type 430* Filament Yarn of NOMEX® (Continued)**

| Chemical | Concentration, % | Temperature, °F (°C) | Time, hr | Effect on Breaking Strength** |
|---|---|---|---|---|
| **Salt Solutions :** | | | | |
| Copper Sulfate | 3 | 70 (21) | 1,000 | None |
| | 3 | 210 (99) | 100 | None |
| Ferric Chloride | 3 | 210 (99) | 100 | Moderate |
| Sodium Carbonate | 5 | 250 (121) | 100 | Slight |
| Sodium Chloride | 3 | 70 (21) | 1,000 | None |
| | 3 | 210 (99) | 100 | None |
| | 10 | 70 (21) | 1,000 | None |
| | 10 | 210 (99) | 100 | None |
| | 10 | 250 (121) | 100 | Slight |
| Sodium Metasilicate | 10 | 210 (99) | 100 | Moderate |
| Sodium Phosphate | 5 | 210 (99) | 100 | None |
| Zinc Chloride | 3 | 210 (99) | 100 | None |

* Refer to text for a discussion of the effect of these chemicals on other products of NOMEX®. Type 430 NOMEX® is 1200-denier, 600-filament yarn.

** None ............................ 0 to 10% strength loss
Slight ........................... 11 to 20% strength loss
Moderate ...................... 21 to 40% strength loss
Appreciable .................. 41 to 80% strength loss
Degraded ...................... 81 to 100% strength loss

The effects of various chemicals on Type 430 filament yarn, and Type 450 and Type 455 spun yarns of NOMEX®, are shown in Table II-4. When exposed to chemicals that cause degradation, the more crystalline Type 430 and 450 yarns generally have higher resistance to degradation than spun yarns of Type 455 and Type 462. The spun yarns generally have lower chemical resistance than filament yarns.

It is particularly important to note that the chemical resistance discussed here is *the resistance of the fiber to degradation by specific chemicals, not the resistance of fabrics of* NOMEX® *to penetration by those chemicals*. Specially designed, laminated or coated fabrics of NOMEX® are available for use in protective apparel where barrier protection against hazardous chemical penetration is required.

**Table II-4. Comparative Chemical Resistance of Filament and Spun Yarns of NOMEX® Brand Fibers***

| Chemical | Concentration, % | Temperature, °F (°C) | Time, hr | pH | Strength Retained, % Filament Type 430* NOMEX® | Spun Type 450* NOMEX® | Spun Type 455* NOMEX® |
|---|---|---|---|---|---|---|---|
| **Organic Chemicals** | | | | | | | |
| Dimethyl Sulfoxide | 100 | 200 (93) | 10 | - | 82.5 | 69.9 | 8.9 |
| Formic Acid | 91 in $H_2O$ | 200 (93) | 10 | - | 95.8 | 92.8 | 78.6 |
| Butyrolactone | 100 | 200 (93) | 10 | - | 100 | 98.8 | 91.4 |
| Propylene Carbonate | 100 | 200 (93) | 10 | - | 99.2 | 94.0 | 92.9 |
| **Salt Solutions** | | | | | | | |
| Ferric Chloride | Saturated | 200 (93) | 10 | - | 62.5 | 55.4 | 37.1 |
| Sodium Thiocyanate | Saturated | 200 (93) | 10 | - | 100 | 100 | 85.7 |
| Silver Nitrate | Saturated | 200 (93) | 10 | - | 100 | 97.6 | 95.7 |
| **Oxidizing and Reducing Agents** | | | | | | | |
| Sodium Chlorite | 0.60 | 210 (99) | 10 | 4.5 | 95.0 | 85.5 | 72.9 |
| Peracetic Acid | 2.0 | 210 (99) | 10 | 6.0 | 67.5 | 49.4 | 22.9 |
| Sodium Hypochlorite | 0.30 | 160 (71) | 10 | 10.6 | 100 | 97.6 | 65.7 |
| Sodium Bisulfite | 3.0 | 210 (99) | 10 | 4.7 | 99.2 | 100 | 92.9 |
| Sodium Thiosulfate | 3.0 | 210 (99) | 10 | 8.3 | 100 | 100 | 88.6 |
| **Acids and Alkalis** | | | | | | | |
| Hydrochloric Acid | 10.0 | 160 (71) | 10 | - | 62.5 | 53.0 | 27.1 |
| Nitric Acid | 1.0 | 210 (99) | 10 | - | 75.0 | 69.9 | 50.0 |
| Sulfuric Acid | 10.0 | 210 (99) | 10 | - | 90.8 | 74.7 | 50.0 |
| Sodium Hydroxide | 10.0 | 210 (99) | 10 | - | 53.3 | 9.0 | Dissolved |
| **Distilled Water** | - | 210 (99) | 10 | 6.7 | 100 | 100 | 98.6 |

* Type 430 NOMEX® is 1200-denier, 600-filament yarn. Type 450 and Type 455 NOMEX® are 16/4 cotton count spun yarn (4 ply, each ply is 16 singles).

## ▪ ▪ ▪ Vapors

The resistance of NOMEX® to degradation by vapors is an important consideration in hot gas filtration applications (depending on their concentration in the gas stream). Acidic gases such as HCl, $SO_2$, and $NO_x$ can significantly reduce the service life of filter bags made of NOMEX®. Organic vapors generally have little effect on NOMEX®.

## ▪ ▪ ▪ UV Light

Like other natural and synthetic textile materials, most types of NOMEX® are impacted by prolonged exposure to ultraviolet (UV) radiation from both sunlight and artificial light sources. After prolonged exposure, unprotected natural yarn tends to discolor from its natural light tone to deep bronze. Similarly, dyestuffs, if present, also may change color or fade. Fabrics made from producer-colored fiber have better colorfastness than dyed fabrics, although dyeing technology has advanced to maximize the colorfastness of dyed fabrics. Thus, in applications where colorfastness is critical, special attention should be given to color selection.

Color change or fading is not necessarily indicative of fiber degradation. However, extended exposure to UV radiation can also cause loss of mechanical properties, depending on wavelength, exposure time, radiation intensity and product geometry.

Two conditions are necessary for light of a particular wavelength to cause fiber degradation. First, the light must be absorbed by the polymer. Second, sufficient energy must be present to break the chemical bonds.

The absorption spectrum of NOMEX® overlaps with the energy spectrum produced by natural sunlight in the near-UV and lower visible regions. NOMEX® absorbs its maximum energy at the high end of the UV spectrum (approximately 360 nanometers), where the relative intensity of the UV component of most light sources is greatest.

Exposing samples to a xenon arc light in a "Weather-Ometer" allows an accelerated product performance comparision to be made under laboratory UV light exposure conditions. Under these laboratory conditions, 200 denier Type 430 yarn of NOMEX® retains approximately 70% of its original strength after 40 hours of exposure, and approximately 55% after 80 hours of exposure (Figure 2.14). Fabric of NOMEX® III under the same conditions retains approximately 70% of its original strength after 40 hours exposure, and 50% after 80 hours exposure (Figure 2.15). Although the strength is reduced under these conditions, the inherent flame resistance is not impacted.

The rate of color fading of dyed fabric of NOMEX® III when exposed to UV light is dependent on the dyed color and dye concentration in the fabric. Darker colors with high dye concentrations generally have better resistance to fading than light colors. However, dyed fabric color (Figure 2.15) has no significant impact on fabric strength retention when exposed to UV light.

In the workplace, natural sunlight exposure time and intensity varies widely with job assignment and location. While xenon arc exposure in the laboratory attempts to simulate an accelerated natural sunlight exposure, it cannot duplicate the variety of exposure conditions experienced in the workplace. Thus, strength retention results from accelerated xenon arc exposure in the laboratory cannot be directly correlated to garment fabric strength retention in actual use. The laboratory results can only be used for comparing samples exposed to UV light under those specific laboratory conditions.

The strength loss that accompanies UV exposure has no effect on the inherent thermal properties of NOMEX®. Despite strength loss after UV exposure, the thermal protective performance (TPP rating) and vertical flammability (char length) of fabrics of NOMEX® III remain unaffected (Table II-5).

**Figure 2.14. Strength Retained by Untwisted 200 Denier NOMEX® Yarn After Xenon Arc-Light Exposure in a "Weather-Ometer"**

Specimens exposed per AATCC Standard Test Method 16E.

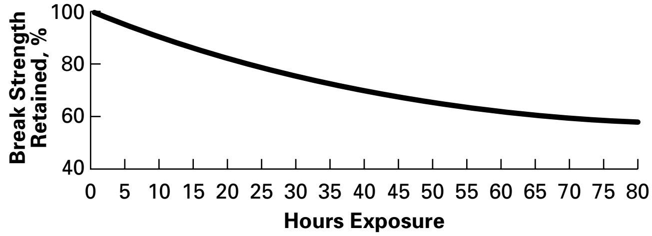
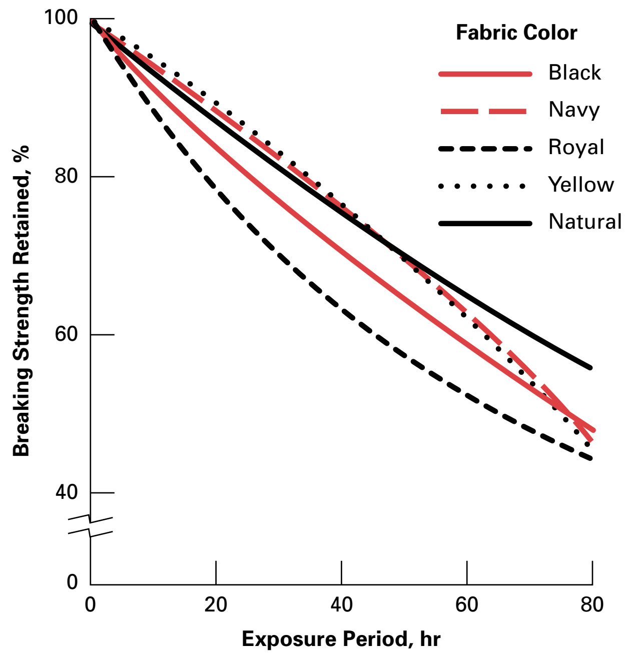



**Figure 2.15. Strength Retention by Fabric of NOMEX® III After Exposure in a "Weather-Ometer"**




Storage in a dark environment is recommended to minimize color change and strength loss. Garments or other articles of NOMEX® should never be stored in direct or indirect sunlight. Small amounts of UV light occur in artificial light sources, such as ordinary incandescent and fluorescent bulbs, or in sunlight filtered by window glass. Where indoor storage is used, incandescent lighting is preferable to fluorescent lighting because the UV component of incandescent light in the 360-nanometer range of the spectrum is significantly less intense. Storage near windows should be avoided because the 360-nanometer range of the spectrum exceeds the point at which common window glass absorbs most UV radiation.

**Table II-5. Strength Retention and Thermal Resistance of Fabrics of NOMEX® III After 80 Hours Xenon-Arc Exposure**

| | Original Weight, oz/yd[2] | Strength, % of Original | TPP Value,[1] % of Original | Vertical Flammability[2] Char Length, in. Original/After Exposure |
|---|---|---|---|---|
| Fabric Description | | | | |
| Natural | 5.8 | 55.2 | 105.0 | 2.8 / 3.3 |
| Yellow | 5.9 | 45.3 | 101.6 | 3.2 / 4.1 |
| Navy | 6.2 | 46.3 | 102.3 | 3.6 / 3.5 |
| Black | 6.3 | 47.6 | 103.1 | 3.7 / 4.0 |

[1]ASTM D-4108 with combined convective and radiant heat source, single-layer fabric configuration.
[2]Federal Test Standard 191A, Method 5903.1; average of warp and fill measurements.

## ■ ■ ■ Radiation

Nuclear power plants and other high-energy radiation operations often require the use of fiber products capable of withstanding the deteriorating effects of gamma and ultraviolet radiation. The outstanding resistance of NOMEX® to degradation by such radiation is illustrated by the data shown in Table II-6. NOMEX® does not, however, provide protection against radiation.

## ■ ■ ■ Insects and Fungi

NOMEX® is not digestible and is not attacked by insects. NOMEX® spunlace, consisting of the same polymer as fibers of NOMEX®, is resistant to fungi growth when tested per ASTM G 21-80, "Determining Resistance of Synthetic Polymeric Materials to Fungi".

**Table II-6. Resistance of Type 430 NOMEX® Filament Yarn to Radiation Degradation***

| | | Breaking Strength Retained, % | |
|---|---|---|---|
| Radiation Type | Level | NOMEX® | Nylon |
| As Received | – | 100 | 100 |
| Gamma | $1.72\times10^{8}$ rads | 100 | 30 |
| Ultraviolet | $6.04\times10^{-2}$ W/in$^2$ | 80 | 80 |
| Ultraviolet + Gamma | $4.07\times10^{-3}$ W/in$^2$<br>$6.88\times10^{6}$ rads | 105 | 70 |
| Ultraviolet + Gamma | $1.2\times10^{-2}$ W/in$^2$<br>$1.72\times10^{8}$ rads | 95 | 5 |

* G. Hargreaves and J. H. Bowen, Jr., Textile Research Journal, Vol. 43, p. 568, October 1973.

## Applications Overview

Because of its excellent physical and thermal properties, NOMEX® brand fiber is used in a wide variety of applications, including industrial coated fabrics, ironing- or pressing-machine covers, rubber hose reinforcement, felt scrims, and the three leading applications: thermal protective apparel, filtration and thermal-resistant furnishings.

## Thermal Protective Apparel

### Applications

Because of its unique combination of textile and thermal properties, NOMEX® is used in a broad range of thermal protective apparel applications wherever the risk of a fire or electric arc exposure is present. These include industrial workwear for petroleum, petrochemical and chemical operators, mechanics and electricians, as well as electrical utility employees. NOMEX® is also used by race car drivers, and their crews, the military, and NASA astronauts, space shuttle crew, and rocket fuel handlers. Further, NOMEX® is used when there is an expectation that the individual will be exposed to flames, e.g., in firefighter turnout coats and stationwear. Garments of NOMEX® may also be used for protection against molten metal splatter under certain circumstances.

#### *Industrial Applications*

Occupational Safety and Health Administration regulations, American Society for Testing and Materials standards and corporate safety guidelines drive adoption of flame-resistant clothing for worker protection where a flash fire or electric arc hazard is identified. Chemical, petrochemical, and utility workers wear clothing of NOMEX® Workwear and NOMEX® Comfortwear as a protective barrier against the intense heat from flash fires and electric arcs and to give the wearer a few seconds of escape time. In addition to shirts, pants and coveralls, sweatshirts, rainwear and cold weather coveralls and coats are available.

#### *Military Applications*

The U.S. Military began specifying NOMEX® in the mid-1960s. The military specifies producer-colored fibers, with colorants incorporated during the fiber-spinning process, for improved consistency in appearance and lightfastness. The largest application is the flight suit adopted by the four major services of the U.S. Military. Coveralls of NOMEX® are also used for combat vehicle crews and shipboard engineering crews. They are also used in selected applications in gloves, underwear, balaclava head coverings, and cold weather gear.

The National Aeronautics and Space Administration uses fabrics of NOMEX® for the outer layer of astronaut launch and re-entry suits and as a component of its extravehicular activity suits.

#### *Fire Fighting Applications*

Blends of NOMEX® and KEVLAR® are used in fire fighter protective apparel all over the world. These inherently flame-resistant materials provide thermal protection in turnout gear, station uniforms, wildland apparel, hoods, gloves and boots. NOMEX® and KEVLAR® also are used in sewing thread for these items.

Thin, lightweight, nonwoven spunlaced sheets of NOMEX® E89™, a blend of NOMEX® and KEVLAR®, are used as thermal liners and substrates for moisture barriers.

NOMEX® Preferred Turnout Systems provide high levels of thermal protection, comfort, and reduced heat stress. NOMEX® EMS Wear provides flash fire protection in addition to meeting NFPA 1999 standards. NOMEX® Stationwear offers the highest levels of durability and thermal protection.

#### *Race Car Driver and Support Personnel Applications*

Race car drivers and their crews wear clothing of NOMEX® to protect themselves from fires, which often accompany crashes on the track and in pit accidents. Race car drivers supplement their protective suits with underwear, socks and gloves of NOMEX®.

The outer shell of the uniforms may be woven spun yarns or knit filament yarns. These are backed with thermal batts of aramid fibers to provide extra insulation against flash fires resulting from fuel spills.

Support personnel, including the crew and standby firefighters are protected by flame-resistant apparel of NOMEX® in case of a pit fire.

***Molten Metal Applications***

Fabrics of NOMEX® III and NOMEX® IIIA provide thermal protection from molten metal splatter, where small drops of metal are generated during light welding or where portions of the conductor melt in an electric arc discharge. Fabrics of NOMEX® III and NOMEX® IIIA will develop small, charred holes where large drops of metal heat the fiber to its carbonation temperature, but these fabrics will not ignite and continue to burn or become a hazard to the wearer. Heavier fabrics of NOMEX® will provide greater thermal insulation and longer garment life. Wearing appropriate outer garments in welding applications, such as aprons or arm guards, will further increase thermal insulation and extend garment life.

Field experience has shown that fabrics of NOMEX® III and NOMEX® IIIA provide effective resistance to molten metal splash with low-temperature metals, such as lead, zinc, or pot metal. However, fabrics of NOMEX® III and NOMEX® IIIA are not recommended for protection from high-temperature metal splash, such as aluminum or steel, where the molten metal may have a temperature in excess of 1,000°F (538°C). Fabrics of a 50/50 blend of NOMEX®/KEVLAR®, 100% KEVLAR®, or FR rayon blends with KEVLAR® are commercially available for welding and molten metal splash protection.

To determine if fabrics of NOMEX® and KEVLAR® brand fibers meet your requirements, testing should be conducted under actual exposure conditions. Contact DuPont for further information on protective apparel in applications involving potential exposure to molten metals.

## ▪▪▪ Essential Characteristics

The flame resistance of NOMEX® is an essential characteristic that is inherent or built into the fiber. Thus, the actual chemical structure of the fiber itself is not flammable. Unlike natural fibers and most synthetic fibers, NOMEX® does not ignite and burn in air nor does NOMEX® melt and drip. Garments of NOMEX® act as a protective barrier and help reduce burn injury.

The high-temperature integrity of NOMEX® results from a unique mechanism in the fiber. When exposed to intense heat, the NOMEX® fiber carbonizes and becomes thicker, forming a protective barrier between the heat source and the skin. This protective barrier stays supple and flexible until it cools, giving the wearer extra seconds of protection for escape.

The NOMEX® fiber helps to reduce burn injury in three ways:

- The fiber itself absorbs heat energy during the carbonization process.
- The fiber swells and seals openings in the fabric, decreasing air movement and the associated convective heat transfer. Figure 3.1 shows a graphic representation of this fiber thickening under intense heat.
- Both the fiber and the fabric thicken, increasing the insulative barrier and reducing conductive heat transfer. Figure 3.2 shows carbonization and thickening of NOMEX® III fabric. Fabric of NOMEX® IIIA, which contains a static dissipative fiber, performs in a similar manner.

**Figure 3.1. Representation of Thickening of NOMEX® III When Exposed to Heat and Flame, in Accordance with ASTM D-4108 TPP Testing**

Thickness represents nominal overall thickness.

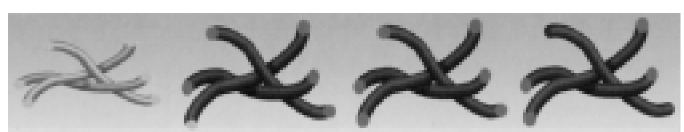


**Figure 3.2. Carbonization and Thickening of NOMEX® III When Exposed to Heat and Flame, in Accordance with ASTM D-4108 TPP Testing**

Thickness represents nominal overall thickness.

NOMEX® shares many of the same characteristics of KEVLAR®: excellent thermal stability, inherent flame resistance, and good chemical and corrosion resistance. However, NOMEX® fibers, because of their chemical bonding arrangement, are softer and more textile-like than fibers of KEVLAR®. Therefore, NOMEX® fibers are favored for use in apparel. Mechanical toughness of the fiber results in a much higher fabric strength and durability than cotton fabrics of greater weight. High resistance to tearing and abrasion result in a much longer useful garment life than obtained with FRT cotton fabrics.

Where flash-fire or electric arc exposure is a possibility, KEVLAR® is combined with fibers of NOMEX® to reduce flame shrinkage and fabric "break open" during flame exposure. This latter phenomenon can result in the loss of the barrier material and insulating air layer between the flame and the wearer, potentially increasing burn injury. In the case of electric arc exposure, multiple layers of NOMEX® III or NOMEX IIIA® may be needed. NOMEX® III, NOMEX® IIIA and NOMEX® fiber for military apparel are sold as a blend of NOMEX® and KEVLAR®. Only Type 450 NOMEX® and the filament yarns are sold as 100% meta-aramid fiber.

Like most synthetic fibers, NOMEX® is electrically non-conductive. As a result, static generated on the body or in garments through fabric-to-fabric or fabric-to-surface contact is not quickly dissipated. In such cases, it is theoretically possible for electrostatic discharge (ESD) to occur with sufficient intensity to cause ignition of some flammable gas/air mixtures. This possibility is of particular concern in the petroleum, petrochemical and chemical industries, where employees frequently work in areas where hazardous fuel/air mixtures may be present. However, neither DuPont nor the American Petroleum Institute knows of any instances where ESD from clothing has ignited a flash fire. Usually, greater electrostatic discharges are available from the human body, e.g. hands, than from clothing on the body due to the higher capacitance of the body.

NOMEX® IIIA incorporates P-140 to dissipate static generated from fabric-to-fabric and fabric-to-surface rubbing. This minimizes the contribution of clothing to static charge buildup on the human body, reduces the apparent electric field strength on the fabric, and reduces nuisance static, thus increasing garment comfort. P-140 filaments consist of a carbon core and insulating sheath, which through induction attracts static charges from the fabric until their intensity becomes sufficient to ionize the surrounding air molecules, thus reducing the accumulated static charge. Wearing garments of NOMEX® IIIA does not eliminate the need to follow proper electrostatic safety procedures, including grounding of personnel and equipment in hazardous areas where ignitable gases may be present, or where static may affect electronic instruments.

In high humidity conditions, conventional work clothing of polyester/cotton blends or 100% cotton depend on water absorption of cotton to provide limited anti-static performance. In low humidity conditions, the water content of the cotton fiber is no longer sufficient to provide anti-static performance. NOMEX® IIIA maintains its static dissipation qualities even in low humidity conditions.

## ■ ■ ■ Test Methods

Fabrics for thermal protective apparel are evaluated for physical, thermal, durability, comfort and wearability properties using a broad range of test methods based on industry standards. A summary of these tests, cross-referenced with where they are cited in this bulletin, is shown in Appendix I.

Four laboratory test procedures demonstrate the unique flame-resistant characteristics of NOMEX®, especially as they are used for protective apparel. These are the Vertical Flame Test, the Thermal Protective Performance Test, Instrumented Manikin Tests for Flash Fires, and Instrumented Mannequin and panel tests for Electric Arc exposure. A static charge decay test can also be used to demonstrate the reduction in nuisance static in fabrics of NOMEX® IIIA, and a range of other physical and chemical tests can be used to determine specific fabrics performance characteristics of interest.

***Vertical Flame Test (Flame Resistance or Flammability)***

This test (Federal Standard 191A, Method 5903.1) measures the relative flammability of a fabric specimen rigidly held in a three-sided frame. A methane burner provides a small igniting flame which is allowed to impinge on the bottom edge of the fabric for 12 seconds. The char length, afterflame (the amount of time flames continue on the fabric surface after the burner is turned off or removed), afterglow (the amount of time the fabric continues to glow after any afterflame stops) and relevant observations are recorded.

This test is a qualitative pass/fail indicator of fabric flammability and is important for protective apparel, because a fabric that ignites and burns can contribute to burn injury rather than reducing it. However, the vertical flame test does not measure thermal protective performance, and, consequently, is not an effective discriminator among flame-resistant materials. Table III-1 shows typical results of vertical flammability tests on fabrics of NOMEX® IIIA, 65%/35% polyester/cotton and 100% cotton.

**Table III-1. Vertical Flammability Test Results***

| Fabric | Weight ($oz/yd^2$) | Char Length (in) | Afterflame (sec) |
|---|---|---|---|
| NOMEX® IIIA | 4.5 | 3.3 | 0 |
| NOMEX® IIIA | 6.1 | 3.1 | 0 |
| 65%/35% Polyester/Cotton | 8.6 | 12.0 | 48.5 |
| 100% Cotton | 9.0 | 12.0 | 36.0 |

* Average of warp and fill determinations. Fabrics were home laundered prior to testing. Test utilizes a fabric specimen of 12 inches in length.

Everyday fabrics of polyester/cotton and 100% cotton ignite within a few seconds of exposure and continue to burn until the entire sample length (12 inches) is consumed. Fabrics from some synthetic fibers, such as polypropylene, polyester or nylon, can melt and drip and ignite. Fabric ignition, melting, and dripping in a garment can significantly increase the extent and severity of burn injury due to the added heat transfer to the wearer. In contrast, fabrics of NOMEX® do not ignite or continue to burn, nor do they melt and drip. Thus, they do not contribute to the hazard but instead provide a protective layer which can reduce burn injury.

Fabrics of NOMEX® pass industry vertical flammability standards that require a char length of no more than 4 or 6 inches and an afterflame time of no more than 2 seconds (Table III-2).

**Table III-2. Vertical Flammability Performance Requirements**

| Standards | Application | Maximum Char Length, (in) | Maximum Afterflame, (sec) | Maximum Afterglow, (sec) |
|---|---|---|---|---|
| American Society for Testing and Materials (ASTM) F1506-98 | Electrical workers exposed to momentary electric arc and related thermal hazards | 6.0 | 2.0 | – |
| NFPA 1971, 2000 Edition | Protective clothing for structural fire fighting | 4.0 | 2.0 | – |
| NFPA 1976, 2000 Edition | Protective ensemble for proximity fire fighting | 4.0 | 2.0 | – |
| NFPA 1977, 1998 Edition | Wildland firefighting | 4.0 | 2.0 | – |
| U.S. Military Specification MIL-C-83429B | Aviation, tank crews, shipboard engineering | 4.0 | 2.0 | 25.0 |

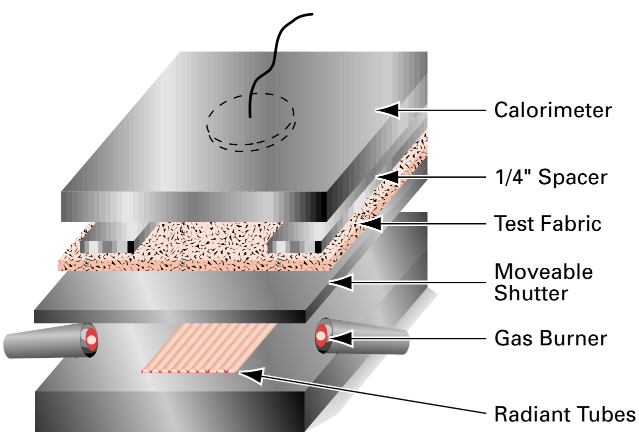
### *Thermal Protective Performance Test*

The thermal protective properties of fabrics and fabric systems can be demonstrated through the use of the Thermal Protective Performance (TPP) Test, as described in National Fire Protection Association Standard NFPA 1971 and American Society for Testing and Materials (ASTM) D-4108. This test also can be used to assess the integrity of fabrics under thermal load - an important consideration in protective apparel. The TPP test is not applicable to non flame-resistant fabrics.

The equipment required to perform the TPP test is shown in Figure 3.3. As normally practiced, a combined convective/radiant heat source with a heat flux of 2 cal/$cm^2$-sec is impinged on the outer surface of a 4-inch by 4-inch area of the fabric system, and the time required to reach the equivalent of a second-degree burn at the calorimeter on the other side of the fabric system is recorded. This time (in seconds), multiplied by the heat flux of the exposure, gives the TPP rating of the system. The higher the TPP value, the more protection a fabric or system provides the wearer.

**Figure 3.3. TPP Test Apparatus, ASTM D-4108 with Combined Convective and Radiant Heat Source as Specified in NFPA 1971**

Recommended configuration for single-layer fabrics.




ASTM D-4108 specifies two methods for TPP testing. When testing single-layer fabrics, a 1/4-inch spacer is placed between the fabric sample and the heat sensor to simulate the normal fit of protective clothing as well as to allow the fabric to reach as high a temperature as would occur in an actual flame exposure. TPP results for single-layer fabrics of NOMEX® IIIA are listed in Table III-3, which shows that for a specific material type the TPP value increases with increasing fabric weight. When testing multilayer fabrics or systems, such as firefighters' turnout coats, the ASTM standard specifies that the sample and heat sensor be in contact with the innermost fabric layer of the system. No spacer is used for multilayer fabric samples. The results of several such tests are shown in Table III-4. NFPA Standard 1971 (2000 Edition), requires that firefighters' turnout gear have a minimum TPP rating of 35.

**Table III-3. TPP Ratings of Single-Layer Fabrics, ASTM D-4108 with Combined Convective and Radiant Heat Source**

(Recommended Configuration for Single-Layer Fabrics)*

| Fabric | Actual Weight ($oz/yd^2$) | TPP ($cal/cm^2$) |
|---|---|---|
| NOMEX® IIIA | 4.5 | 11.8 |
| NOMEX® IIIA | 6.0 | 13.3 |
| NOMEX® IIIA | 7.5 | 15.3 |
| 65%/35% Polyester/Cotton | | N/A-Ignites |
| 100% Cotton | | N/A-Ignites |

* 2.0 $cal/cm^2$-sec heat flux. Fabrics were home laundered one time prior to testing. N/A Not Applicable.

**Table III-4. TPP Ratings* of Multiple-Layer Systems, NFPA 1971 2000 Edition with Combined Convective and Radiant Heat Source**

| Component | Fabric | System Weight ($oz/yd^2$) | TPP ($cal/cm^2$) |
|---|---|---|---|
| **NOMEX OMEGA®** | | | |
| Outer Shell | Fabric of Z-200™ fiber at 7.5 $oz/yd^2$ | 18.8–20.5 | 51.2–53.6 |
| Moisture Barrier | Breathable PTFE film on NOMEX® E89™ or NOMEX® pajama check | | |
| Thermal Liner | 3 layers of NOMEX® E89™ quilted to 2.2 $oz/yd^2$ fabric from NOMEX® filament yarn | | |
| **NOMEX® with KEVLAR®** | | | |
| Outer Shell | 60/40 KEVLAR®/NOMEX® blend at 7.0 $oz/yd^2$ | 18.9–20.1 | 43.7–44.8 |
| Moisture Barrier | Breathable PTFE film on NOMEX® E89™ or NOMEX® pajama check | | |
| Thermal Liner | 2 layers of NOMEX® E89™ quilted to 4.4 $oz/yd^2$ fabric from NOMEX® spun/filament yarns | | |
| **NOMEX®** | | | |
| Outer Shell | NOMEX® IIIA at 7.5 $oz/yd^2$ | 19.5–19.8 | 41.0–42.9 |
| Moisture Barrier | Breathable PTFE film on NOMEX® E89™ or NOMEX® pajama check | | |
| Thermal Liner | Aramid batt quilted to 3.2 $oz/yd^2$ fabric from NOMEX® spun yarn | | |

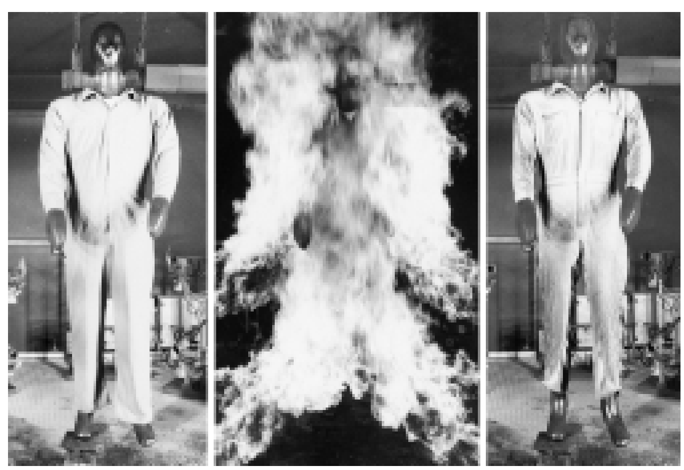
* 2.0 $cal/cm^2$-sec heat flux. Tested as received.
NOMEX® E-89™ is a trademark of E.I. du Pont de Nemours and Company for its spunlaced fabric made from a blend of NOMEX® and KEVLAR® fibers by the SONTARA® spunlace process.
SONTARA® is a registered trademark E.I. du Pont de Nemours and Company.

### *Instrumented Manikin Test (Flash Fire Simulation)*

DuPont's manikin system, THERMO-MAN®, is an instrumented laboratory manikin that utilizes skin model software to determine the predicted burn injury in a carefully controlled, reproducible laboratory flash fire that simulates actual flash-fire conditions (Figure 3.4). Data obtained from 122 heat sensors distributed over the 6-foot-1-inch manikin body are used to measure the heat transmitted from the fire through the test garment to the surface of the manikin. A sophisticated computer program then calculates the predicted percentage of second- and third-degree burns and indicates the burn injury locations for the selected simulated flash fire exposure conditions. THERMO-MAN® testing is conducted according to ASTM F 1930.

In one series of tests, THERMO-MAN® was dressed in a T-shirt and briefs of 100% cotton and industrial clothing made from different materials, all home laundered five times prior to testing. Each ensemble was then subjected to a propane gas flash fire of 3.5 seconds duration, with a heat flux of 2.0 $cal/cm^2$-sec.

**Figure 3.4. Simulated Flash-Fire Testing with THERMO-MAN®, an Instrumented Laboratory Manikin.**



Before Exposure During Exposure After Exposure

Under these conditions, garments made from 6.1 oz/yd$^2$ fabrics of inherently flame-resistant NOMEX® IIIA limited predicted second-degree plus third-degree body burns to less than 35%. In a similar test, garments made from untreated 100% cotton (6.5 oz/yd$^2$ shirt + 8.5 oz/yd$^2$ pants) or untreated 65%/35% polyester/cotton (7.5 oz/yd$^2$ coverall) exhibited predicted second- and third-degree burns ranging from 75 to 90% of the body. Data compiled by the American Burn Association* indicate that a 90% body burn level translates into less than a 30% chance of survival for the 20's and 30's age group and less than a 15% chance of survival for the 40's and 50's age group. In contrast, the chance of survival for a burn injury level of less than 40% of the body is greater than 80% for all age groups.

Manikin testing is used to compare the relative thermal protective performance of fabrics by exposing full-size garments to laboratory simulations of a flash fire. The results of these tests are only predictions of body burn injury under specific laboratory conditions. Because the dynamics of real flash fires vary greatly and can be more or less intense than the fire used in the manikin test, results do not duplicate or represent garment or fabric performance under actual flash-fire conditions.

***Electric Arc Testing using Mannequins and Instrumented Panels (Electric Arc Simulation)***

It is well recognized that exposure to electric arcs can cause electric shock injury as some or all of the arc current passes through or along the surface of the human body. It is not as well recognized that the intense radiant and convective energy from an electric arc and subsequent ignition of work clothing or other elements in the work environment can cause serious burn injury, even if there is no contact with the arc. These non-contact burn injuries make up the majority of the injuries resulting from electric arc accidents.

NFPA 70E, "Standard for Electrical Safety Requirements for Employee Workplaces", under Part II (Safety Related Work Practices), Chapter 2 (General Requirements for Electrical Work Practices), requires that Flame Resistant (FR) Clothing and Personal Protective Equipment (PPE) be used by employees within a flash boundary based upon the incident energy exposure associated with the task involved. The incident energy exposure can be determined by conducting a flash hazard analysis, or a Hazard Risk Category can be selected from a table in Chapter 3 (Personal and Other Protective Equipment) which defines Hazard Risk Category classifications by Task. Chapter 3 also defines five Hazard Risk Categories based on increasing incident energy exposure levels. Protective clothing fabric performance meeting these category requirements is determined by using ASTM test procedures.

The protective performance of various fabrics and/or systems in an electric arc exposure is determined using two procedures: **ASTM F 1958/F 1958M-99** is used for non-flame resistant materials on mannequins. This method determines the incident energy that causes ignition of the material, and the probability of ignition. Per NFPA 70E, Non-FR materials, such as cotton, may only be worn in Hazard Risk Category 0 (ATPV <5 cal/cm$^2$) areas. However, light weight clothing made of 4.5 oz/yd$^2$ NOMEX® IIIA also meets these requirements and gives the added benefit of flame resistance and increased durability. **ASTM F1959/F 1959M-99** is used for flame resistant materials and determines the incident energy which would predict the onset of a second degree burn injury from an electric arc. FR materials must be worn in Hazard Risk Category 1-4 areas. Conducting a Hazard Analysis is recommended to determine the best light weight system that is required to meet the hazard involved.

Copper calorimeters are used to measure temperature rise similar to the TPP test method described earlier. The temperature rise at each calorimeter can be compared to the Human Tissue Tolerance to Heat data. Second Degree Burn criteria is used to determine whether a burn would be predicted under the test conditions with the test fabric shielding the calorimeters. In addition, observations are made regarding fabric ignition, melting, dripping, shrinkage, brittleness, and weakness, as well as whether the fabric "breaks open" and consequently no longer provides a barrier against heat and flame.

The electric arc hazard and potential for burn injuries can be quantified in terms of the incident energy in cal/cm$^2$ that a worker would be exposed to under a specified set of arc parameters. The incident energy from an arc increases with arc current, arc duration and arc gap. The incident energy decreases approximately with the square

* J. R. Saffle, et al, J. Burn Care Rehabil 16:219-232 (1995).

of the distance from the arc. Incident energy can be calculated using available software programs or measured empirically in laboratory arc exposures. Generally, the incident energy from an arc exposure is greater than the heat energy due to a flash-fire exposure, even though the typical arc duration is less than a second and the flash-fire duration may be several seconds.

Some examples of protective clothing of NOMEX® that would comply with the NFPA 70E Hazard Risk Categories are shown in Table III-5. As can be seen from the table, the greater the hazard as measured by the incident energy, the heavier the fabric or multi-layer system is required.

**Table III-5. Some Examples of Protective Clothing of NOMEX® That Comply with NFPA 70E 2000 Edition Requirements**

| Hazard/Risk Category Number | Examples of Compliant Systems of DuPont™ NOMEX® |
|---|---|
| **0 ATPV or $E_{bt}$ rating < 5 cal/cm²** | |
| | Shirt or coverall of 4.5 oz/yd² or greater, plain or twill weave fabric of NOMEX® IIIA or NOMEX® Comfortwear provide a minimum ATPV of >4 cal/cm² |
| **1 Requires ATPV or $E_{bt}$ rating ≥ 5 cal/cm²** | |
| | Shirt of 4.5 oz/yd² or greater, plain or twill weave fabric of NOMEX® IIIA or NOMEX® Comfortwear, over 100% cotton knit (4.5 oz/yd²) with 6 oz/yd² or greater pants of NOMEX® IIIA<br>**or**<br>Coveralls of 6 oz/yd² or greater of NOMEX® IIIA or NOMEX® Comfortwear |
| **2 Requires ATPV or $E_{bt}$ rating ≥ 8 cal/cm²** | |
| | Shirt of 6.0 oz/yd² or greater, fabric of NOMEX® IIIA, over 100% cotton knit (4.5 oz/yd²) with 8.5 oz/yd² denim pants made of NOMEX® IIIA<br>**or**<br>7.6 oz/yd² polar fleece jacket made of NOMEX® IIIA with 8.5 oz/yd² denim pants made of NOMEX® IIIA<br>**or**<br>Rainwear of 8.0 oz/yd² NOMEX® trilaminate or 10.0 oz/yd² neoprene coated on pajama check of NOMEX® |
| **3 Requires ATPV or $E_{bt}$ rating ≥ 25 cal/cm²** | |
| | Jacket consisting of two layers of 7.5 oz/yd² NOMEX® IIIA worn over 100% cotton knit (4.5 oz/yd²) with insulated bib overalls with a facecloth of 6.0 oz/yd² NOMEX® IIIA, and a quilted liner consisting of a 7.5 oz/yd² batt of NOMEX® quilted to a 3.0 oz/yd² liner of NOMEX® worn over 100% cotton knit (4.5 oz/yd²) |
| **4 Requires ATPV or $E_{bt}$ rating ≥ 40 cal/cm²** | |
| | Insulated jacket and bib overalls made of a facecloth of 6.0 oz/yd² NOMEX® IIIA with a quilted liner consisting of a 7.5 oz/yd² batt of NOMEX® quilted to a 3.0 oz/yd² liner of NOMEX® over a 100% cotton knit (4.5 oz/yd²).<br>Jacket made of three layers of NOMEX® IIIA consisting of 2 each 6.0 oz/yd² or greater, and one 4.5 oz/yd² or greater fabric over a 100% cotton knit (4.5 oz/yd²) with insulated bib overalls as above. |

Note that the clothing cited are typical examples of fabric or multi-layer systems that have been tested but may or may not be commercially available from garment manufacturers.

The Arc Thermal Performance Value (ATPV) and Breakopen Threshold Energy ($E_{bt}$) are measured using fabric specimens on sensored panels according to the ASTM F 1959/F 1959M-99 arc test method. When ATPV cannot be determined due to fabric breakopen, the $E_{bt}$ value is reported.

Real electric arc exposures may be more or less severe than laboratory simulated arc exposures. Arc flash hazard analysis can determine the potential incident energy exposure of the worker and should be used to determine the Hazard Risk Category to be used in selecting personal protective clothing.

*Static Test (Static Dissipation)*

Static can be generated in fabric by sliding across a car seat or removing a jacket. The static dissipation performance of fabrics can be measured by a charge decay test. Fabrics such as NOMEX® IIIA which incorporate a static dissipative fiber show a very short charge decay time, or very good static dissipation.

Table III-6 shows the result of a series of charge decay tests on typical protective apparel and conventional work clothing fabrics. In this procedure (Federal Test Standard 191A, Method 5931), the fabric specimen is mounted between two electrodes and exposed to a 5-kV potential. To meet DuPont requirements for acceptable anti-static performance, the fabric must accept at least a 3 kV potential and must discharge to 10% of the accepted voltage within one-half second after grounding the electrodes. Fabrics are tested at 70°F (21°C) and 20% relative humidity.

**Table III-6. Charge Decay Test Results (70°F [21°C], 20% RH)***

| Fabric | Number of Launderings | kV Accepted | Seconds to Discharge to 10% of kV Accepted |
|---|---|---|---|
| NOMEX® IIIA | 0 | 3.95 | 0.01 |
| | 25 | 3.75 | 0.02 |
| | 50 | 3.45 | 0.01 |
| | 100 | 3.10 | 0.01 |
| NOMEX® III | 0 | 4.50 | 8.9 |
| | 25 | 1.35 | >10 |
| | 50 | 1.35 | >10 |
| | 100 | 1.35 | >10 |
| 100% Cotton | 0 | 3.82 | >10 |
| | 25 | 2.14 | >10 |
| | 50 | 2.03 | >10 |
| 65%/35% Polyester/Cotton | 0 | 4.90 | 4.3 |
| | 25 | 2.20 | >10 |
| | 50 | 2.25 | >10 |

* Federal Test Standard 191A, Method 5931.

The short staple fibers of P-140 do not provide a continuous conductive pathway throughout the fabric or garment. This feature eliminates the possibility of the garment creating a conductivity hazard, which is of particular concern to the electric utility industry.

Since the main hazard of ESD (Electro-Static Discharge) in potentially explosive environments is from ungrounded personnel, and not from the garments they wear, personnel grounding is always the first line of defense. Discharging static from the body before entering a potentially explosive atmosphere, wearing a wristlet connected to the ground and using conductive footwear and flooring are all recommended. Wearing of NOMEX® IIIA does not eliminate the need to follow proper safety procedures, including grounding of personnel and equipment.

### ▪ ▪ ▪ Cleaning

Flammable contaminants will reduce the thermal performance of any flame-resistant garment. Proper and periodic cleaning is essential to maintain thermal protective performance. Protective clothing of NOMEX® brand fiber can be cleaned by traditional methods, such as home laundering, commercial laundering or dry cleaning.

For maximum protection, new protective garments of NOMEX® should be cleaned prior to wearing to remove any processing aids or finishes from the manufacturing process that could adversely affect the performance of the fabric of NOMEX®. They should be cleaned frequently thereafter to ensure no greases, oily soils or other flammable contaminants are present when the garment is worn. Refer to the Laundering Guide for NOMEX® brand fiber for complete information on cleaning garments of NOMEX®. Call (800) 853-8527 to request a copy.

## ▪ ▪ ▪ Filtration

### ▪ ▪ ▪ Applications

Filter bags of NOMEX® are the industry leader in asphalt manufacturing facilities, as well as a variety of other applications. Filter bags of NOMEX® permit these facilities to operate at higher temperatures, which significantly improves capacity, lowers power costs and eliminates condensation.

### ▪▪▪ Temperature Resistance

Typically, filtration facilities operate in the range of 200°F (93°C) to 400°F (204°C). Maximum continuous operating temperatures for various filter bag fabrics are shown in Figure 3.5. Strength retention of filter bags of NOMEX® when exposed to heat is a function of time, temperature and environment. In most situations, the maximum continuous operating temperature recommended for NOMEX® is 400°F (204°C). If temperature surges above this limit are expected on a frequent basis, it may be necessary to adjust the average operating temperature downward to extend filter bag life.

Environment also affects the durability of filter bags of NOMEX®. In a highly acidic environment, it may be necessary to reduce the average operating temperature to extend filter bag life.

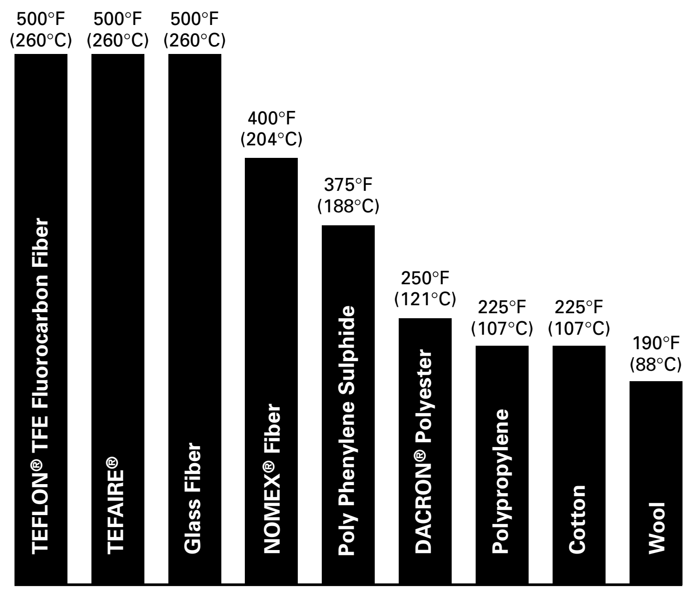
NOMEX® brand fiber is inherently flame resistant; however, if combustible materials are collected on filter media of NOMEX® and exposed to an ignition source, they can ignite and burn, resulting in destruction of the filter bag. In addition, the presence of certain non-combustible dusts, such as copper oxide, iron oxide and lead oxide can catalyze oxidative degradation of the filter bag and can even result in combustion in the presence of an ignition source.

Therefore, baghouses should be designed to prevent ignition from occurring. For example, all ignition sources should be kept from reaching the filter media through the use of suitable spark- and flame-arresting equipment. Where ignition sources are likely to be present, fire detection and extinguishing systems should be installed.

Baghouse maintenance operations involving high temperatures, flames or sparks, should be performed with the baghouse shut down. Even in these situations, proper precautions should be taken to isolate from ignition sources any bags coated with flammable dust.

**Figure 3.5. Maximum Recommended Operating Temperatures for Filter Fabrics Used in Continuous Service Systems**

Temperatures are generally accepted trade standards. Lower operating temperatures may be required for a particular baghouse installation.




### ▪▪▪ Acid Resistance

In hot gas filtration applications, low concentrations of hydrofluoric acid (up to approximately 0.05%) are often present in metallurgical and rock product fumes and do not significantly affect fabrics of NOMEX®. For example, dust bags of NOMEX® have demonstrated a service life in excess of four years in filter fumes from an electric steel furnace that was heavily fluxed with fluorspar.

Materials that do attack NOMEX® are strong acids, strong alkalis and/or strong oxidizing agents. Water vapor is also necessary for activation of the degrading reactions; thus, care must be used in estimating performance when the moisture level is unknown or uncontrolled. Severe attack may be encountered in startups and shutdowns, or if the filter operates for extended periods at temperatures below the dew point.

Frequently, reduced filter life occurs due to acid attack when gases containing sulfur dioxide or trioxide are filtered. If acid attack is a possibility, or flue gas components are unknown, filter bags of NOMEX® should be tested prior to installation.

The performance of NOMEX® vs. polyester felts when tested in a laboratory pulse-jet unit is shown in Figure 3.6. The data demonstrate the superior toughness of NOMEX® when compared to polyester under both acid and non-acid conditions, at temperatures ranging from 225°F (107°C) to 350°F (177°C). The data also show the damaging effect of acid attack on both NOMEX® and polyester and indicate the relative toughness lost due to acid attack. The acid conditions used for this test were typical of those arising from powerhouse operations burning 2% to 3% sulfur coal.

NOMEX® is not usually recommended for use where elemental halogens or their acids are present in high concentrations. In these cases, TEFLON®* TFE-fluorocarbon fiber or TEFAIRE®** are recommended.

An extensive computerized database on filter performance in a wide variety of laboratory tests and actual field trials has been developed for many exposure conditions. The DuPont™ FILTER ADVISOR™ uses this database to estimate important parameters such as bag life, pressure drop, and emissions. Felters, bagmakers, OEM's, and end-users of NOMEX®, TEFLON®, or TEFAIRE® filter media may request use of the FILTER ADVISOR™ program by contacting DuPont Marketing at (800) 453-8527, to develop a bag life estimate.

## ▪▪▪ Thermal-Resistant Furnishings

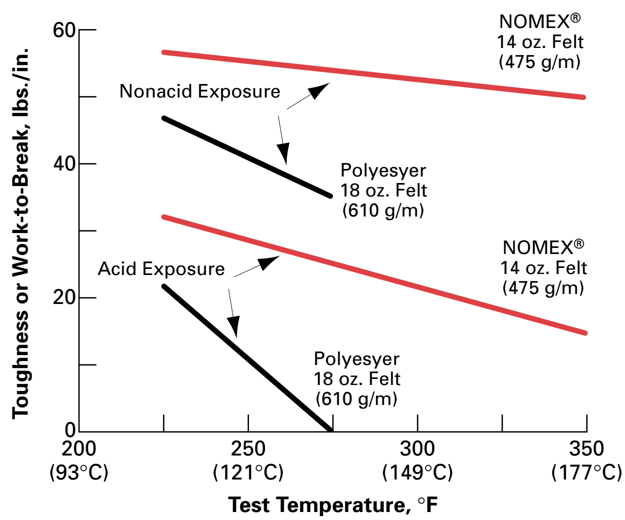
The superior performance and attractiveness of NOMEX CGF® and NOMEX THERMOCOLOR® enable these fibers to be used in a wide varity of applications. They allow creation of beautiful interiors while still meeting ever-changing fire regulations. Applications range from aircraft interior textiles including upholstery, floor covering, bulkheads, and wall coverings, to contract furnishings for hotels, offices, auditoriums, hospitals and day care centers.

Both NOMEX CGF® and NOMEX THERMOCOLOR® are inherently flame resistant, so they don't have topical treatments that will wear off over time or be washed out during cleaning. They are a superior choice for abrasion resistance and durability. They can be maintained easily by conventional methods without concern for fading, crocking or fiber degradation.

NOMEX CGF® is available in a wide range of standard colors as well as custom colors. Yarns made from NOMEX CGF® can be fabricated into a wide varity of constructions for use in loop pile carpets and woven tapestries. All of the various choices of NOMEX CGF® are colorfast so they typically won't fade or wash out, even over time.

NOMEX THERMOCOLOR® can be customed-dyed in the trade. This allows smaller quantities to be dyed, which provides the creative flexibility to customize virtually any color desired. It also can be dyed without the use of carriers typically used in the dyeing of aramid fibers. Therfore, NOMEX THERMOCOLOR® is carrier free, providing exceptional flammability protection.

**Figure 3.6. Accelerated Mini Baghouse Comparison of NOMEX® vs. Polyester in a Pulse Jet Unit.**




| Acid Condition | | Nonacid Condition | |
|---|---|---|---|
| 500 Hours Exposure | | 500 Hours Exposure | |
| $O_2$ | 5% | $O_2$ | 5% |
| $SO_2$ | 1500 ppm | $SO_2$ | 0 |
| $H_2O$ | 6% | $H_2O$ | 6% |
| A/C* | 10/1 | A/C* | 10/1 |
| Pulse | 2 cps (2 Hz) | Pulse | 2 cps (2 Hz) |
| Basic** | Powerhouse Dust | Basic** | Powerhouse Dust |

*Ratio of air to cloth **Alkaline

* TEFLON® is a registered trademark of E.I. du Pont de Nemours and Company for its fluorocarbon fiber.

** TEFAIRE® is a registered trademark of E.I. du Pont de Nemours and Company for its blends of TEFLON® and glass fibers, as well as felts incorporating these blends. Felts are produced under license from DuPont.

FILTER ADVISOR™ is a trademark of E.I. du Pont de Nemours and Company.

## Packaging

### Yarn Packages

Filament yarns of NOMEX® brand fiber are shipped on recyclable paper-tube cores (Figure 4.1). The sizes of the tube and yarn package are listed in Table IV-1.

A label inside each tube gives the yarn description and merge number. The package can be used directly for down-twisting or other processing.

**Figure 4.1. Filament Yarn Package of NOMEX® Brand Yarn**

**Table IV-1. Sizes of Tube and Yarn Package for NOMEX® Brand Fiber**

| | | |
|---|---|---|
| **Tube Core** | | |
| | Length | 6 l/2 in. (165 mm) |
| | Diameter (inside) | 2 in. (51 mm) |
| | Taper | None |
| **Yarn Package** | | |
| | Diameter (max.) | 7 l/8 in. (181 mm) |
| | Traverse of yarn | 5 l/2 in. (140 mm) |
| | Net weight (max.) | 7.5 lb (3.4 kg) |

### Shipping Containers

Filament yarns of NOMEX® are shipped in smooth-faced, corrugated cardboard cartons (Figure 4.2). Staple is shipped in bales wrapped with polypropylene (Figure 4.3). These containers are designed to prevent damage from normal shipping and handling procedures. Their capacities and approximate dimensions are given in Table IV-2 on the following page.

For information on recycling packaging materials, contact DuPont at 1-800-453-8527. Because package forms and shipping containers may vary outside the United States, please contact your local DuPont Representative for details.

**Figure 4.2. Shipping Carton for Filament Yarns of NOMEX® Brand Yarn**

**Figure 4.3. Bale of NOMEX® Brand Staple with Polypropylene Wrapping**

## Table IV-2. Details of Shipping Containers

| Putup | Outside Dimensions Length, in. (cm) | Width, in. (cm) | Height, in. (cm) | Weight Net, lb (kg) | Gross, lb (kg) |
|---|---|---|---|---|---|
| **Yarn Carton** | | | | | |
| 32 units/case | 22 3/4 (58) | 21 (53) | 27 3/4 (70) | 192 (87) | 217 (98) |
| 16 units/case | 22 3/4 (58) | 21 (53) | 14 1/2 (37) | 96 (44) | 110 (50) |
| 8 units/case | 23 (58) | 21 (53) | 7 1/8 (18) | 48 (22) | 54 (25) |
| **Staple Bale*** | | | | | |
| Type 450, 2 denier staple | 36 (91) | 30 (76) | 56 (142) | 650 (295)* | – |
| Type 450, 5.5 denier staple | 36 (91) | 30 (76) | 56 (142) | 450 (204)* | – |
| Type 455, 462 staple | 36 (91) | 30 (76) | 56 (142) | 600 (272)* | – |
| Producer colored staple | 36 (91) | 30 (76) | 56 (142) | 450 (204) or 600 (272)* | – |
| CGF® staple | 35 (89) | 27 (69) | 54 (137) | 450 (204)** | – |
| THERMACOLOR® staple | 35 (89) | 27 (69) | 54 (137) | 450 (204)** | – |

* +/- 50 lbs.
** +/- 50 lbs. for full size bales. Smaller bales are produced for less than full bale order quantities.

### ▪ ▪ ▪ Staple Bale Size and Compaction

Staple bale outside dimensions are similar regardless of net weight. The lighter weight bales are compacted less during the baling operation, resulting in a lower density bale which may have less bale bloom when the strapping is removed. The outside dimensions of the lighter weight bale may be one to three inches smaller in any dimension than the heavier weight bales.

## ■ ■ ■ Background

NOMEX® brand fiber has been manufactured and processed into useful products since the early 1960s without any identifiable adverse health effects. Finished products present no known adverse health or environmental effects.

NOMEX® brand fiber products are produced in two forms: staple and continuous filament. Three compositions of staple are produced: (1) 100% NOMEX®, (2) NOMEX®-KEVLAR® blends with up to 28% KEVLAR®, and (3) NOMEX®-KEVLAR® blends with static dissipative fibers. NOMEX® meta-aramid is composed principally of a solid organic polymer composed of carbon, oxygen, nitrogen and hydrogen. The fiber contains up to 12% moisture (depending upon storage and use conditions) and a small amount of residual dimethylacetamide (DMAC) from the manufacturing process. Surface coatings of lubricating and antistatic agents, and additives designed to enhance specific product performance, such as coloring agents and ultraviolet light blockers, may also be present. These additives are tightly bound within the substrate and do not present any known hazardous exposure in handling or use.

Many staple products contain KEVLAR® para-aramid fiber. KEVLAR® like NOMEX® is composed principally of a solid organic polymer consisting of carbon, oxygen, nitrogen and hydrogen.

Static dissipative fibers are sheath-core fibers. The ultrathin conductive core consists of carbon black enclosed in a polyethylene membrane. The protective sheath is nylon. The static dissipative fiber is blended with NOMEX® at low levels (less than 5%).

## ■ ■ ■ Toxicity

Based on more than 30 years of experience in commercial use and extensive toxicological testing, NOMEX® aramid fiber products present minimal risk to human health and the environment. When NOMEX® is subjected to flame or intense heat, it is converted to the usual combustion products for substances of the same elemental composition: carbon dioxide, water and oxides of nitrogen. However, carbon monoxide, small amounts of hydrogen cyanide and various other chemical residues (some possibly toxic or irritating) may be produced, depending on the conditions of burning. In small-scale evaluations, combustion products from NOMEX® appear to have similar toxicity as smoke from burning wood and other natural, combustible materials. For further information, refer to the Material Safety Data Sheet for NOMEX® fiber products.

NOMEX® III and NOMEX® IIIA contain KEVLAR® aramid fibers. During certain processing operations, such as staple carding, fibrillation of KEVLAR® can generate small quantities of airborne respirable fibers. Consult the Material Safety Data Sheet for KEVLAR® for more information.

## ■ ■ ■ Dermatology

As produced and shipped by DuPont, NOMEX® contains finish and moisture, and neither these components, nor the fiber itself, have been observed to cause sensitization in human skin tests. There is, however, potential for sensitization as a result of the application of other additives applied to fabrics or garments of NOMEX® during the manufacturing or laundering processes.

Infrequent cases of skin irritation have appeared in the initial wearings of garments of NOMEX®. The mechanical action of wearing a stiff, unwashed fabric can cause irritation in areas where there is restricted movement, such as at clothing binding points, thick seams and unfinished edges. DuPont recommends washing a garment at least once prior to wearing. This will remove stiffeners that are applied by fabric mills for ease of handling in garment manufacturing.

## Fiber and Fabric Test Method Descriptions and Bulletin References

| Test | Reference Test Method | Description | Bulletin References |
|---|---|---|---|
| General Test Methods and Specifications | ASTM F 1002<br>ASTM F 1506 | Standard performance specifications for protective apparel | — |
| | NFPA 1971<br>NFPA 1975 | Testing Methods and Standards for fire service structural firefighting protective clothing, and station and work uniforms | — |
| **Fabric Physical Properties:** | | | |
| Air Permeability | ASTM D 737 | Measures air flow through a fabric | — |
| Abrasion Resistance | ASTM D 3886-02 (Inflated Diaphram) | Measures resistance of knit and woven fabrics to abrasion when exposed to a rough surface | Fig. 2.13, Table II-2 |
| Basis Weight | FTMS 191A, 5041 | Weight of fabric per unit area, usually oz/yd$^2$ | Table III-1, Table III-3, Table III-4 |
| Bending Stiffness | ASTM D 1388 | Force required to bend fabric | — |
| Breaking Load | ASTM D 5034 Grab Test G | Load to break 1" wide section of 4" strip of fabric | — |
| Bursting Strength (Mullen Burst) | ASTM D 3786 | Measures force to rupture knit fabric with expandable diaphram | — |
| Fungal Resistance | ASTM G 21 | Measures resistance of synthetic materials to fungi | Section II |
| Pilling (Random Tumble) | ASTM D 3512 | Measures resistance to pilling by tumbling knit or woven fabric in a container with abrasive material | — |
| Seam Slippage | ASTM D 434 | Load required to separate a sewn seam as compared to unsewn fabric | — |
| Surface Appearance | AATCC 124 | Evaluates knit or woven fabric smoothness after repeated home launderings | — |
| Tear Resistance (Elmendorf) | ASTM D 1424 | Tear resistance of fabric using an Elmendorf apparatus | — |
| Denier (Yarn) | ASTM D 1907 | Weight in grams of 9000 meters of yarn | Tables I-1, II-1 |
| Denier Per Filament | ASTM D 1907 | Weight in grams of 9000 meters of a single filament | Tables I-1, II-1 |
| Density | ASTM D 1505 | Density of fiber as weight/unit volume | Table II-1 |
| Finish | ASTM D 2257 | Percentage by weight of added finish on fiber | — |
| Moisture | ASTM D 2654 | Moisture level based on dry fiber weight | Table II-1 |
| Staple Cut Length | ASTM D 1440 | Length of uncrimped staple fibers | Table I-1 |
| Tensile Properties:<br>– Elongation<br>– Modulus<br>– Tenacity | ASTM D 2101<br>ASTM D 2101<br>ASTM D 2101 | Tensile properties measured on yarn or staple tow prior to cutting | Table II-1 |

## Fiber and Fabric Test Method Descriptions and Bulletin References (continued)

| Test | Reference Test Method | Description | Bulletin References |
|---|---|---|---|
| **Colorfastness:** | | | |
| Lightfastness | AATCC 16 | Measures change in knit or woven fabric color after exposure to light from a xenon arc | Section II, Figure 2.15 |
| Shade Change (Laundering) | AATCC 61, IIA | Accelerated lab laundering at 120°F (49°C) with steel balls to test colorfastness of knit or woven fabrics | — |
| Shade Change (Dry Cleaning) | AATCC 132 | Laboratory dry cleaning to test colorfastness of knit or woven fabrics | — |
| **Dimensional Change:** | | | |
| Laundering | AATCC 135 | Measures shrinkage or stretching after laundering knit or woven fabrics | — |
| Dry Cleaning | AATCC 158 | Measures shrinkage or stretching after dry cleaning knit or woven fabrics | — |
| Also see Thermal Shrinkage Resistance | | | |
| **Electrical Properties:** | | | |
| Antistatic Performance | FTMS 191A-5931 (5 kV Imposed) | Measures time to dissipate electric charge on fabric | Table III-6 |
| **Moisture Charactertistics:** | | | |
| Commercial Moisture Regain | ASTM D 1909 | Commercially accepted moisture for billing purposes | Table II-1 |
| Moisture Regain | ASTM D 2054 | Moisture in fiber based on dry fiber weight | Table II-1, Fig. 2.11 |

## Fiber and Fabric Test Method Descriptions and Bulletin References (continued)

| Test | Reference Test Method | Description | Bulletin References |
|---|---|---|---|
| **Thermal Characteristics:** | | | |
| Arc Thermal Performance | ASTM F 1959/F 1959M-99 | Measures energy to cause second degree burn | Table III-5 |
| Coefficient of Liner Expansion | | Change in fiber length with change in temperature | Table II-1 |
| Differential Scanning Calorimeter | ASTM E 794 | Measures difference in energy inputs into a fiber and a reference material as a function of temperature. Shows melting or crystallization temperature | Fig. 2.6 |
| Flame Resistance | See Flammability | | |
| Flammability (Vertical Flame Test) | FTMS 191A, 5903.1 | Measures char length, afterflame and glow time on 3" x 12" fabric sample exposed to flame at lower edge for 12 seconds. Initial and after laundering or dry cleaning | Tables III-1, III-2 |
| Flash Fire Manikin Test for Predicted Body Burn Injury | ASTM F 1930 | Predicts second- and third-degree body burn injury for garments on an instrumented manikin in a controlled flash-fire exposure | Pages 25–26 |
| Heat Resistance | NFPA 1975 | Measures burning, melting, separation and ignition on knit or woven fabrics after 5 minute exposure to 500°F (260°C) | — |
| Ignitability of Flammable Fabrics by Electric Arc | ASTM F1958/F 1958M-99 | Measures energy required to ignite flammable fabrics (untreated cotton, etc.) | Page 26 |
| Limiting Oxygen Index (LOI) | ASTM D 2863 | Determines minimum oxygen content (%) in air that will sustain combustion of a material | Section II |
| Specific Heat | | Amount of heat required to raise fiber temperature | Table II-1 |
| Thermal Conductivity | ASTM E 1530 | Rate at which unit heat will flow through fiber polymer per unit temperature | Table II-1 |
| Thermal Protective Performance (TPP) | ASTM D 4108 with the heat source and exposure window modified for NFPA 1971. A spacer is used for single layer fabrics and no spacer for multilayer fabrics | A fabric specimen is exposed with a combination of radient and convective energy. The total energy required to cause second-degree burn injury to human tissue is determined based on heat transfer through the fabric specimen and the Stoll second-degree burn criteria. Single and multiple layer fabric specimens can be tested. | Fig. 3.1-3.3, Tables III-3, III-4 |
| Thermal Shrinkage Resistance | NFPA 1975 | Measures fabric shrinkage after 500°F (260°C) oven exposure for 5 minutes | — |
| Thermal Shrinkage<br>– In water<br>– In dry air | ASTM D 2259 | Fiber shrinkage when exposed to hot dry air or water | Table II-1, Fig. 2.12, |
| Thermogravimetric Analysis (TGA) | | Measures weight loss of fiber with increasing temperature | Fig. 2.5 |
| Vertical Flame | See Flammability | | |

NOMEX®
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