

Milliken®

Amplitude®

Flame Resistant Fabric

WHITEPAPER

Amplitude® Cotton/Nylon Protective Apparel Fabrics for NFPA 70E and NFPA 2112 Compliance

OBJECTIVE:

This white paper is intended to educate the reader regarding Milliken's flame resistant cotton/nylon-blended Amplitude fabrics. It will also address key factors that are important to consider when selecting FR fabrics for flame-resistance and arc protection.

2011



Please Note: Amplitude fabrics are innovative, high-tech, flame resistant materials intended to be used in garments that supplement personal protective equipment that reduce the flammability risks of momentary exposure to electric arc flash and flash fire hazards. They may be used as a layer of, but are not intended for use as the primary protection in fire fighting garments or other products subject to repeated or extended exposure to heat or flame except for Amplitude fabrics that are explicitly certified in writing to meet NFPA 1977 for use in wildland fire fighting garments. Use caution near sources of flame or intense heat and do not launder with bleach or fabric softeners. Amplitude flame resistant fabrics technology is left for the life of the garment when washed according to care instructions. As each customer's use of our product may be different, information we provide, including without limitation, recommendations, test results, samples, care/labeling/processing instructions or marketing advice, is provided in good faith but without warranty and without accepting any responsibility/liability. Each customer must test and be responsible for its own specific use, further processing, labeling, marketing, etc. All sales are exclusively subject to our standard terms of sale posted at www.milliken.com/terms (all additional/different terms are rejected) unless explicitly agreed otherwise in a signed writing.

TABLE OF CONTENTS

Executive Summary	3
Introduction	4
FR Regulations and Standards	4
Technology and the Marketplace	5
Amplitude — a Milliken FR Technology	5
Amplitude Basics	6
Why Not Ammonia Cure?.....	6
Testing and Certifications.....	7
Key Performance Drivers for an FR Fabric Manufacturer	7
Quality Control.....	7
Proprietary FR Finishing.....	8
Designed Comfort.....	8
Safety: The Milliken Safety Story	10
Environmental	10
Summary	10
About the Authors	11
About Milliken & Company	11

EXECUTIVE SUMMARY

Worker safety is a top priority for employers. Personal Protective Equipment (PPE) including safety apparel is the “life-saving device” worn every day for Flame Resistant (FR) protection. FR apparel is worn in manufacturing, maintenance, electrical, utility, oil and petrochemical, chemical, and other work environments to reduce the flammability risks of exposure to electric arc flash and flash fire hazards. These hazards can cause severe or fatal burns that can often be reduced or prevented through the proper use of flame resistant PPE.

Milliken introduces Amplitude, a new line of crossover FR fabrics that meets the market needs for both NFPA 70E arc flash and NFPA 2112 flash fire compliance.

Milliken & Company® entered the protective workwear fabrics market in 2003 with the launch of CXP®, a uniquely comfortable inherent FR fabric for the NFPA 2112 flash fire market. Recently, Milliken launched a line of fabrics that serve as crossover products, meeting the market needs for both NFPA 70E arc flash and NFPA 2112 flash fire compliance. Milliken is promoting this new line of fabrics under the Amplitude brand name.

Milliken’s new FR process is a proprietary ammonia-free process that offers unique product advantages.

Milliken is recognized as a leading producer of U.S. Military FR fabrics and FR bedding for the consumer market under the Paladin™ brand. This, coupled with the fact that Milliken is also widely recognized as the U.S. manufacturer of choice for high-quality workwear fabrics, positions Milliken to become a leader in the FR workwear market.

Milliken is a vertical manufacturer that has a team of more than 40 research scientists and engineers and more than 70 research technical associates who support the development of innovative, consistent high-quality products. Fabric engineering, chemical and process technology, and manufacturing process control are important drivers that help determine FR performance, fabric comfort, durability and the total cost of garment ownership. Milliken’s new FR process is a proprietary ammonia-free process that offers unique product advantages.



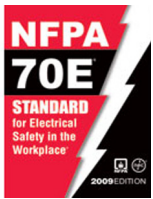
INTRODUCTION

For the last 25 years, government and industry safety leaders have recognized the importance of flame-resistant protective apparel. These groups have developed standards that help drive awareness of the importance of FR protection against burns when workers are exposed to electrical arc and flash fire hazards. Textile and apparel companies have addressed the need for FR protective apparel in several ways:

1. Use of inherent flame-resistant materials (e.g. meta-aramids)
2. Blends of inherent fibers with cellulose
3. Durable chemical treatments of cotton rich fabrics



A study of fabrics used for NFPA 2112 compliance in the U.S. conducted by Milliken demonstrates that inherent FR fabrics have the largest market share, but that this market share is declining. Additionally, NFPA 70E compliance is most often attained by using cotton-rich fabric blends that have been chemically treated. Performance to industry standards, comfort, cost and durability must be considered for each specific garment end use. Milliken has bridged the gap with the launch of Amplitude, offering the wearer comfort and NFPA 70E and NFPA 2112 compliance.



FR REGULATIONS AND STANDARDS

Section 5(a)(1) of the Occupational Safety and Health Act (OSHA), also known as the General Duty Clause, addresses situations where individuals are exposed to hazards on the job. According to the regulation, “Where a recognized hazard exists, such as exposure to electrical arc or flash fire, the employer must take reasonable measures to mitigate that risk.” Further, OSHA standards set forth in 29 CFR part 1910 subpart S specifically relate to electrical hazards and safeguards for personnel protection (1910.335).

OSHA recommends that consensus standards such as NFPA 70E-2009 be used as guides in hazard analysis and selecting control measures. The NFPA 70E-2009 standard addresses electrical safety in the workplace and states that “employees shall wear FR clothing wherever there is possible exposure to an electric arc flash above the threshold incident level for a second degree burn.” The standard also refers to ASTM F1506-10a regarding apparel which specifies vertical burn and electric arc testing.

Another consensus standard, NFPA 2112-2012, outlines the testing required for FR garments used in flash fire protection including vertical burn, thermal protective performance, thermal shrinkage resistance, heat resistance and flash fire manikin testing.

TECHNOLOGY AND THE MARKETPLACE

Today the flame-resistant market is largely divided between inherently FR products, such as those containing meta-aramid fibers like Nomex® by DuPont, and cotton/nylon durable treated FR products. Inherent FR products are often suitable for flash fire exposure, while cotton/nylon durable treated FR products make up the majority of sales and rentals in the electric arc exposure category. They are also gaining share as protective apparel for the NFPA 2112 compliance. While there have been several new cotton/nylon FR fabric manufacturers who have entered the

market in recent years, the last significant introduction was the FR treated ammonia-cured 88 percent/12 percent cotton/nylon blend pioneered by ITEX in 1994 (ref U.S. patent #5,468,545). Other subsequent 88/12 products have been introduced since 1994. Milliken entered the marketplace in 2008 with an internally developed, non-ammoniated, consistently durable FR technology for cotton/nylon and 100 percent cotton that is differentiated from the ammonia-cure process used by other manufacturers.

Recently, several different blends of inherent fibers and modacrylics have entered the market, but have been slow to gain significant market share. These products have been known to require higher initial upfront investments. As a result, industry leaders are looking for a cost-effective solution that offers high performance in both electric arc and flash fire protection, while delivering comfort and durability.

AMPLITUDE—A MILLIKEN FR TECHNOLOGY

Milliken entered the marketplace with an internally developed, non-ammoniated, consistently durable FR technology for cotton/nylon and 100 percent cotton that is differentiated from the ammonia-cure process used by other manufacturers.



External lab testing for arc flash conducted at Kinetics in Ontario, Canada.

Milliken Research Corporation has been the growth engine of innovation and new technologies for the company. Milliken has accumulated over 2,200 issued patents through 2010. The technology behind Amplitude originated from scientists at Milliken Research Corporation who recognized the variability of the ammonia treatment process and developed a proprietary technology and processes that provide a better product. Today, Milliken Research Corporation continues that commitment to innovation and, by all accounts, is the largest textile research center in the world.

Associate talent and experience make up the foundation of Milliken’s research leadership. Milliken Research Corporation has more than 40 research scientists and engineers, including a large number of Ph.D. scientists from top universities. The scientists and engineers are experts in chemistry and physical testing and are equipped with high-tech analytical equipment.

Milliken’s state-of-the-art laboratories are more sophisticated than traditional textile testing lab setups. The Environmental Scanning Electron Microscope, for example, allows examination of textile materials under different environmental conditions (such as relative humidity and temperature) at very high magnifications. This is important for understanding fibers and fabrics on a molecular level and has enabled Milliken to design a fabric substrate that readily accepts and binds Milliken’s proprietary FR chemistry through 100 industrial washings. Gas Chromatography-Mass Spectrometry (GC-MS), Inductively Coupled Plasma (ICP), Nuclear Magnetic Resonance (NMR), Infra-red Spectroscopy (IR), and Thermal Gravimetric Analysis (TGA) technologies allow Milliken scientists to study and understand different chemical processes at the molecular level. These scientific tools have been instrumental in developing FR and textile chemicals for highly desired FR fabrics.



State-of-the art analytical testing equipment at Milliken's research laboratories.

These scientific tools have been instrumental in developing FR and textile chemicals for highly desired FR fabrics.



Developing fabrics for flame resistance and fire protection have been key research initiatives at Milliken for a number of years. Milliken developed unique Nomex flash fire protection uniform fabrics under the brand name CXP. Additionally, Milliken provides the U.S. Armed Forces with fabrics that require stringent FR testing. Milliken has also become the leader in flame retardant bedding textiles (Paladin) for consumer markets in the U.S. With a rich history of commitment and success in FR innovation in other markets, developing workwear fabrics for the NFPA 70E and NFPA 2112 markets is a natural evolution of Milliken's FR research and expertise.

AMPLITUDE BASICS

Amplitude is a patented line of premium, high-performance flame resistant fabrics engineered for comfort in industrial workwear and public safety applications. The proprietary fabrics are processed with a patented, environmentally friendly, ammonia-free technology that resists fading and offers increased air permeability. The softness-enhanced fabrics are constructed of a cotton/nylon blend designed to help prevent potential injuries due to fire, electric arc and flash fire exposure, while providing enhanced durability and comfort. The combination of these capabilities makes it an ideal fabric for workwear occupations in public safety, manufacturing, utilities, electrical maintenance, petrochemical, welding and steel.

Milliken's six ounce Amplitude product is the lightest weight treated HRC 2 fabric on the market. The fabric doesn't only provide premium FR protection, but it also offers enhanced softness and improved breathability, which makes it more pleasant to wear.

Because Amplitude fabrics are processed without ammonia and with ultra-low formaldehyde content, they are less likely to irritate the skin while providing lasting protection for the life of the garment when washed or laundered according to care instructions. Instrumented manikin tests performed according to ASTM F1930-2011 show that Amplitude fabrics produce lower body burn percentages as compared with competitive cotton/nylon market products of equal weight. Evaluation for electric arc protection by test method ASTM F1959/F1959M-06a shows that Amplitude fabrics outperform current market products of equal weight with regard to Arc Thermal Performance Value.

There is a great complexity to achieving an optimum balance between FR performance, durability and comfort. The balance was achieved with Milliken's lightweight and comfortable six ounce Amplitude fabric.

Why Not Ammonia Cure?

As with any new market introduction, purchasers of new products look for a supplier who brings integrity and knowledge to the marketplace. However, any new product must be understood and put through the rigors of testing. This is especially important for products with such importance as personal protective equipment against electric arc and flash fire hazards.

In the beginning stages of Amplitude development, the widely used ammonia-cure process was analyzed and considered. In this particular process, it is critical to maintain a controlled fabric moisture level as fabric enters the ammonia chamber. This critical step is difficult to measure and control because there is no feedback on the degree of reaction inside the ammonia chamber. The reaction releases heat causing fabric temperature to rise, potentially affecting the fixation of the chemistry. Uniformity of ammonia gas penetration into the fabric is also difficult to achieve in a

reliable and consistent manner. For these and others reasons, Milliken developed a new technology minimizing these deficiencies through the design and engineering of Amplitude fabrics.

What resulted from the concentrated efforts of the research and development team is a unique ammonia-free process which uses Milliken-developed chemistry and proprietary processes. Amplitude fabrics are engineered with a cotton/nylon blend in multiple weights from 5 ounces per square yard to 14 ounces per square yard, with the addition of FR, comfort and laundry performance advantages. The market can expect to see more from Milliken’s FR team as additional Amplitude fabrics enter the late phases of development.

Testing and Certifications

Safety products such as flame-resistant, arc-rated fabrics for protective apparel should be rigorously testing to ensure that these products perform as designed when a person’s safety is at stake. Milliken tests Amplitude products extensively at our ISO 9001 certified testing labs and also at industry standard third-party test facilities. Instrumented manikin flash fire testing according to ASTM F1930-2011 takes place at the Textile Protection and Comfort Center at North Carolina State University as well as at the Protective Clothing and Equipment Research Facility at the University of Alberta in Canada. Determination of arc rating for Amplitude fabrics according to ASTM F1959/ F1959M-06a occurs regularly at Kinectrics, Inc. High Current facility in Toronto, Ontario, Canada. Milliken can provide test reports from these facilities on Amplitude products to customers.

In many cases, third-party certification of a product to the relevant standard(s) is required for market entry. Milliken has many fabrics certified as recognized components to safety standards by Underwriters Laboratories and these certificates are provided upon request. A standard certification means that the certifying organization has done independent testing of the product and recognizes the manufacturing facility’s quality process as being capable of reliably producing the product. Furthermore, the product from the manufacturer is sampled randomly throughout the year and is subjected to additional testing in order for the product to keep its certification.



Cutting edge equipment at Milliken’s manufacturing locations.

The Six Sigma methodology ensures high-quality products through controlled, repeatable, development processes.

KEY PERFORMANCE DRIVERS FOR AN FR FABRIC MANUFACTURER

For years Milliken has been dedicated to eliminating process variation and delivering superior textile products to the market. State-of-the-art process control systems and automation allow Milliken to continuously collect process data. The use of advanced statistical analysis tools allow Milliken to analyze all aspects of process variation and the impact it has on product performance. The use of Six Sigma methodology helps Milliken to optimize manufacturing and reduce variation in the end product. This is vital for consistent fabric strength, shade control and flame-resistant finishing. Over time, Milliken has demonstrated delivery of the lowest defect point counts in the workwear market.

Quality Control

Milliken’s dedication to quality has garnered many prestigious awards worldwide. Milliken is one of the only companies in the United States to achieve both the Malcolm Baldrige National Quality Award and the Japan Institute of Plant Maintenance (JIPM) TPM Excellence Award, an esteemed award for Total Productive Maintenance. Milliken has been awarded the Canadian Quality Award for achieving outstanding quality in physical, safety and social measures. Milliken has 54 separate

facilities that have received JIPM awards for TPM excellence and consistency, a sign of the company's operational excellence.

Quality-control procedures are critical when it comes to FR fabric manufacturing. Developing and maintaining specific and consistent production procedures is essential. Milliken's quality-control team is experienced in the physical testing and the evaluation of FR performance for fabrics. Milliken is a vertical textile manufacturer, producing its own specially-engineered yarns and base

fabrics for internal dyeing, FR chemistry application and testing.

In addition to FR protection, there are several key performance metrics where quality control is of utmost importance for protective garments. Shrinkage control and physical properties such as tear strength and the feel of the fabric are extremely important. These factors are created and controlled along multiple touch points throughout the manufacturing process. During carding, drawing and spinning to make the yarn, the effective use of statistical process control tools is essential

to engineer a consistent, high-strength yarn and fabric. The base fabric has been designed in such a way as to maximize both fabric strength and shrinkage reduction. Through the use of statistical process controls and defect root cause analysis, Milliken has engineered a base fabric with a consistently high level of quality. Once the fabric has been woven, it is ready for fabric preparation, dyeing, and FR finishing processes. Milliken has a unique product routing process through its manufacturing plants which imparts the characteristics of unparalleled performance in a cotton/nylon blended fabric.



NFPA 70E compliance end-use application for Milliken Amplitude.

Proprietary FR Finishing

Because the flame-resistant treatment is the most important step of an FR-treated cotton rich product, Milliken developed and patented (US PAT #7,713,891) its own proprietary process for imparting this property to the fabric. The deep science of our research group combined with Milliken's innovative culture resulted in a chemistry and process that finds a better way to achieve flame-resistance and produces a better, more reliable product. This step in the process is also the one that most affects the final product's strength, durability and comfort.

Because a controlled, repeatable process is vital, Milliken research scientists developed the patented Amplitude treatment using Six Sigma methodology to refine all aspects of this process. And because we developed the process, we are able to constantly work toward refinements that will enhance the protection and features of Amplitude.

Designed Comfort

Protective apparel works great when it is worn properly. However, accident investigations reveal that some injuries occur because the protective apparel was not worn properly or at all even when it was available. Workers are tempted to compromise safety when their safety gear is cumbersome or uncomfortable.

Comfort factors can also play a significant role in avoiding adverse health effects such as heat stress. The body produces heat by metabolic activity. When working, metabolic activity increases greatly. Some energy is liberated outside the body as work, but most is released into the muscles as heat. Fortunately, heat loss can help balance this thermal load. Heat loss occurs mostly by convection—when air flowing across the skin removes heat—and by evaporation of sweat, also known as evaporative cooling. When

the rate of heat production of the body exceeds the rate of heat loss, the body stores heat and body temperature rises above normal.

Clothing functions as a barrier to heat and moisture transfer between skin and the environment. It can protect against extreme heat and cold conditions, but at the same time it hampers the loss of extra heat during physical effort. For workers in hot, humid environments, the effect of clothing can have adverse effects on the body's ability to lose heat, making the wearer uncomfortable and possibly contributing to heat-related illness. Air movement in the work environment is normal and is typically generated by the wind or by the wearer moving around. Depending on the breathability of the fabrics, air pumps in and out as the person

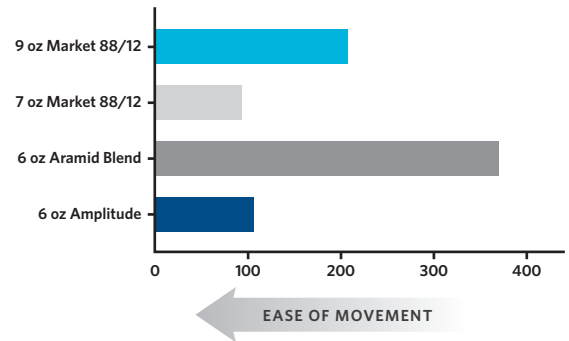
works, forcing exchange between the skin and the environment and helping to cool the skin to balance heat production and heat loss. The combination of these factors can be selected to develop protective clothing with optimal comfort.

Milliken designed Amplitude fabrics not only with softness and drape for ease of movement, but with much greater levels of air permeability to aid in the cooling of workers. Combined with lower available weight while maintaining flame resistant performance, Amplitude fabrics yield a comfort advantage that provides workers with protective apparel they can wear daily.

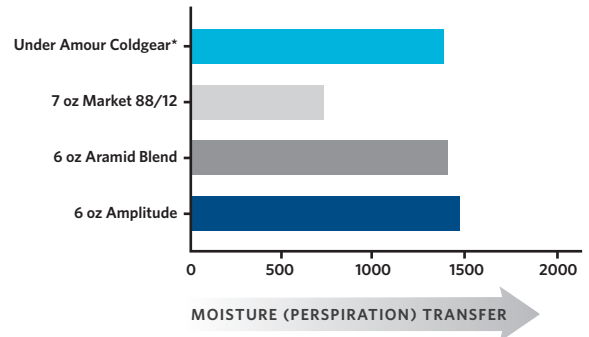
It is beneficial when evaluating potential protective garment fabrics to look at several factors including tests that indicate ease of movement and how well the fabric exchanges moisture and air with the environment.

Some examples of test results are shown below:

SOFTNESS AND MOBILITY: Measures the combination of surface friction and bending resistance of a fabric and can indicate ease of movement for activities, such as swinging arms and bending elbows. Grams of force: ASTM D2923.

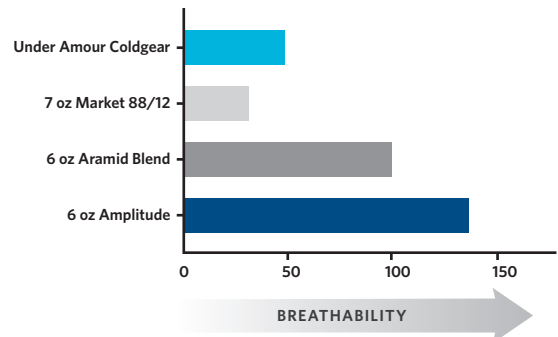


BREATHABILITY/MVTR: Ability of the fabric to transmit moisture vapor (perspiration) through the fabric. More vapor transmission can keep your skin cooler and drier. Grams per square meter per 24 hours: ASTM E96.



*6.8oz/yd² performance knit base layer. Under Armour and Coldgear are registered trademarks of Under Armour.

BREATHABILITY/AIR PERMEABILITY: Ability of the fabric to allow air movement through the fabric. Higher airflow can keep you cooler. Cubic feet per minute: ASTM D737.



SAFETY

The Milliken Safety Story

With safety as Milliken’s number one core value, Milliken has 51 OSHA certified Volunteer Protection Program STAR sites, the third largest in the nation. Qualification for the Voluntary Protection Program is not an easy task. An applicant must demonstrate management commitment to safety, assess hazards that may be present within their workplaces, maintain a system for hazard correction and control, provide associates with Safety & Health training, and assure their participation in the Safety & Health program. Milliken teams have also been recognized by leading manufacturing and associations for their safety process and for the involvement of its associates in the safety process, including the National Safety Council, Chamber of Commerce and the American Private Trucking Association.

The safety and health of Milliken’s employees is a true corporate value that is owned by each and every Milliken associate. Milliken was recently named one of the 17 Safest Companies in America by *Occupational Hazards Magazine*. For years, Milliken benchmarked the safety leaders in the industry. Today, those same companies now benchmark Milliken. In 2007, Milliken launched a safety consulting business providing training services to companies, showing how to develop a culture that centers around associate safety. The Milliken Safety Process has two basic cornerstones: team development of an uncompromising safe environment, and the ingrained belief that all safety incidents can be prevented.

ENVIRONMENTAL

Milliken is committed to operating its plants and facilities in complete compliance with all applicable environmental regulations and to operating in a manner that protects the quality of the environment and the health and safety of Milliken associates and the public. It is committed to the elimination rather than reduction of all solid waste, hazardous wastes and emissions to all media including land, air and water. This goal guides the conduct of Milliken’s manufacturing operations, the development of new products and the company’s interaction with suppliers and customers. Recycling of materials is an integral part of this on going effort. Milliken has been named Environmental Champion by the U.S. Environmental Protection Agency. In 2007 Milliken became certified as Carbon Negative by the Leonardo Academy—meaning as a corporate entity, it removes more carbon dioxide from the air in total than it produces. Milliken strives to create products that “do good” including our FR products that are manufactured without the harmful effects of ammonia. This type of product engineering supports Milliken’s belief that a truly good steward of the planet requires that you leave the world in a better condition than you found it.

SUMMARY

Milliken, a company that takes great pride in its safety performance and performance products, has developed a proprietary technology to produce high-performance, durable fabrics for NFPA 70E and NFPA 2112 compliance. The new cotton/nylon fabrics, Amplitude, were launched commercially in 2008. Creating a superior FR fabric starts by having strong internal research and technical expertise targeted to solve the unfulfilled quality, comfort, laundering and FR performance needs of the market. Choosing the right FR fabric is a critical factor in determining the level of protection provided to the garment wearer. It is imperative that companies and organizations fully understand the fabric options that are available today before selecting the best FR protection for their associates.

Milliken, being a vertical manufacturer, has extensive experience developing, spinning, weaving, dyeing and finishing flame-resistant fabrics. This experience has been instrumental in Milliken’s efforts to create a new cotton/nylon fabric with superior performance, quality, and comfort characteristics. Amplitude fabrics meet all tests outlined in NFPA 70E and NFPA 2112.



ABOUT THE AUTHORS

JAMES CLIVER joined Milliken & Company in 1992 after receiving a Bachelor of Science degree in Textile Chemistry from Clemson University. James spent several years in Milliken’s Dyeing and Finishing plants as a Process Improvement leader in color matching, shade control and testing before joining the Apparel & Specialty Fabrics Division’s New Concept Team for leading-edge research. James is currently focused on FR workwear fabric innovations and has two issued U.S. patents, including Milliken’s Ensist™ technology. Member of ASTM (American Society for Testing Materials International) and F18 Committee on Electrical Protective Equipment for Workers.



DR. SHULONG LI received his Ph.D. in Materials Science and Chemical Engineering from the University of Minnesota. He worked as a Postdoctoral Research Associate at the National Renewable Energy Laboratory. After joining Milliken & Company in 1994, Dr. Li has invented many successful new products and technologies, including Antimicrobial textiles and Digital Printing Technologies, and currently serves as an Innovation Lead in Milliken Research Corporation. Dr. Li has published seven articles and has 33 issued U.S. patents. Member of F23 Committee on Personal Protective Clothing and Equipment.



J. TRAVIS GREER is the Development Manager for the Workwear Fabrics Business at Milliken & Company. Travis graduated Summa Cum Laude with a Bachelor of Science in Mechanical Engineering from Tennessee Technological University with emphasis in Thermodynamics and Environmental Engineering. A 17-year veteran at Milliken with a focus on its protective markets, he is responsible for developing Milliken’s StainSmart™, BioSmart™, and the Amplitude™ line of flame resistant fabrics. The author and/or co-author of 15 U.S. patents/patents pending, Travis is a frequent speaker on protective fabrics and flame resistant technologies. Member of ASTM and F23 Committee on Personal Protective Clothing and Equipment.

ABOUT MILLIKEN & COMPANY

Combining expertise in both science and design, Milliken creates innovative solutions that touch the lives of people every day in multiple ways. With unwavering integrity and commitment to creative problem solving, Milliken takes on the issues of the world, however big, however small, across markets and across the world—and has been doing so since 1865. There are approximately 7,000 Milliken associates in 6 countries working every day to make the world safer, cleaner and a little more beautiful.

For more information about Milliken Flame Resistant Fabrics, contact Ricky Norris at 800-828-3034. www.MillikenFR.com