AN OVERVIEW OF PROTECTIVE CLOTHING - MARKETS, MATERIALS, NEEDS

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I. INTRODUCTION

One of the more interesting segments of the technical textile market is that of protective clothing (PC). A market that is receptive to new products and suppliers, and abounding with niche markets, the PC market may be attractive to companies wishing to diversify.

Many of the "high-tech" fibers and products, such as Kevlar®, Nomex® (DuPont), and Twaron® (Acordis) aramids, Spectra® (Allied) HDPE fibers, PBI, Kermel® (Rhone-Poulenc), P84® (Inspec), carbon impregnated fibers, aramid spunlace materials, fiberglass, even steel, copper, and other metal fibers have applications in the protective clothing areas. Conventional materials such as nylon and polyester, cotton and wool, are also used and provide satisfactory protection in certain applications - depending on the hazard or exposure. When new fibers with unique properties are being developed, they are often considered for protective clothing.

The PC market is representative of the *evolutionary* nature of technical textiles. As a market evolves, and many of the most pressing problems are solved, work is then expended on refining and solving problems more effectively. A common development thread is the creative and innovative applications of available technology toward solving market needs. Much creativity and innovation goes into PC.

The PC field is diverse and involves many areas, each having its own requirements and special materials. Much of the technology involved is among the most sophisticated available, and the end uses complex and of great value. While effective PC may help save lives, the use of PC *often allows us to work in and around hostile environments and to accomplish useful tasks.*

II. DEFINITION

Protective clothing does not mean the same to all people. As in most discussions of technical products, we must first define our subject.

While all clothing is protective to some degree, our concern is not with routine needs, such as clothing for warmth, rainwear, or routine work clothing. Our focus is on more sophisticated needs, protection in situations where hazards or risks are present that have the potential to be life threatening or pose considerable potential for injury or damage to the person working in and around the hazard. In some cases, such as clean rooms, we may be equally concerned about protecting the product we are working with as well as the worker.

So then, our definition involves ***garments, or textile related products that are worn, that prevents a person (or product) from coming into contact with, that protects from, and/or reduces the risk of exposure to hostile elements or environments***.

III. PROTECTIVE CLOTHING CONTINUUM

One method of looking at the risk level encountered when designing and/or choosing protective clothing is with a continuum similar to the one shown in Figure A (rear). George Kappler of Kappler Safety Group, developed the chart to graphically demonstrate the range of chemical protective clothing needs. Such a continuum categorizes the protection needs and their ranges from least-to-greatest depending on the risk/danger involved, and outlines the various products used or suitable for those applications. At the lower levels, protective clothing is worn to avoid the "dirty" aspects of a job – this conference is note concerned with these. At higher levels, where extreme danger exists, more sophisticated protective clothing is chosen. Most needs fall in between, and there is overlap.

Though Kappler's continuum represents chemical, materials, and particulate protection, similar continuums could be drawn for any PC field (figure B - firefighters level of exposure and risk). Showing varying levels of protection needs, it also presents a "good, better, best" approach to selecting PC – useful when budgets are of concern or the risk of exposure is slight or highly likely.

Another aspect to consider in selecting the PC is the ***fit for use*** standard: provide protection adequate for the risk involved, but avoid “overkill,” for both cost and functional considerations. Most PC are developed with this in mind.

IV. MARKET SIZE

The size of the market is a frequently asked question. The answer is difficult due to industry fragmentation, but any estimate of size has to be qualified by defining what one includes as protective clothing. The industry is somewhat secretive and hard to accurately assess, since the identical item may be used for image reasons, to prevent clothing from getting dirty, as well as a truly protective end use. Some general information can be shared as relative guidelines.

A recent Industrial Fabric Association International (IFAI) report puts the protective clothing market in the US at over 200 Million square yards, *exclusive of medical apparel and work gloves*. That is likely a conservative figure depending on ones point of view. The figures included material for abrasion and cut resistance products, extreme heat (fire), toxic spill control, asbestos abatement, and other, miscellaneous uses. One source feels that 65% of the market involves non-woven fabrics (mostly spunbond fabrics such as Tyvek and "plain vanilla" spunbond products, though some needled felts and high-lofts are used), 30% woven, and 5% knit. The nonwoven segment is growing at a much more rapid rate than other materials – mostly due to versatility and cost.

One recent study (LMRA) indicates that for Protective Apparel such as made from FR cotton and the high temperature fibers such as Nomex, PBI and others, accounted for 24.5 million yds^2 in 1995, with projections for 32.5 million yds^2 by 1996. While there was indeed a slowdown in 1998, ITA believes there was a market in the range of 34-35 million yds^2 for 1998. Of course, it all depends on what one counts.

Nonwovens consultant John Starr, estimated that in the medical area, nonwoven fabrics alone account for 1,300 million yds^2, with a value of $300 million for roll goods and $800 million in end-use converted products. Not all, of course, fits our definition of PC. For nonwovens in protective apparel, Starr estimates
$100 million value on 360 million yds^2 and $300 million value for the converted goods. Though a couple years old, they are likely much higher today, it provides a relative value and size of the market.

Most experts agree that the industry has been growing at an annual growth rate in the range of 6%/yr. Some niche areas, or specialized sub-categories, are reported to be growing up to 30% +/year, though such high growth is an anomaly and usually specific to newly mandated areas

A new Frost and Sullivan report says " total market revenues only grew only 3.4% (to $578.2 billion) in 1998, a significantly lower than the 6.4% ($559.1 billion) revenue growth rate in 1997. Although the overall market is growing slowly, the report predicts the market's growth rate to top out at 4.2% in 1999, then begin to slowly decrease to 2% in 2005. The report goes on to say that high levels of competition are preventing companies from boosting profits through price increases. Research and development and technology transfer, coupled with value added products, perhaps even acquisition will be the key to growth in the future. Many companies, it says, are indeed coping with slow growth through the acquisition route, ***and by finding market niches!*** While competition is indeed aggressive, all realize the demand will continue and offer opportunity.

The author's own proprietary work leads to general agreement with the above figures. Variances don't mean the figures are incorrect; *it depends on what is counted*. With differing definitions, and with many products used extensively in non-protective applications, *the given figures should be considered as relative and used as a guide only as to the general size and importance of the market*. Worldwide, it is an important market and one worthy of further study.

One must be wary of reliance on sheer numbers. It is a given that the overall market is large and that there are many niches. If you are interested in a particular segment, the concern is whether the market is large enough for you, both in terms of volume, market share, and profit potential. To more accurately determine this, further study may be required.

V. PROTECTIVE CLOTHING CATEGORIES

Over the years, ITA has divided the market for PC into the following segments. This has since become, in general, how the industry as a whole looks at the market.

- Protection from extreme cold
- Ballistic and mechanical protection
- Protection from radiation
- Protection from harmful particulate matter
- Bacterial/Viral protection
- Clean room - Protecting delicate items in manufacture
- Protection from harmful chemicals
- Protection from extreme heat and/or fire

There are other areas, high pressure for instance, but the above list covers most of those concerns where products have been, or are being developed. We'll look at each segment individually.

VI. EXTREME COLD

Cold protection requires products with high degrees of insulation, the least bulk, good/relative comfort, and still allowing good dexterity for doing useful work.

Still air is a poor conductor of heat, so insulation requires a layer of still air between the skin and the source of the heat or cold. The best insulation has always come from down, the fine underside and neck of goose or other fowl feathers. Industry has attempted to emulate the insulating characteristics of down, with varying degrees of success, using all types of fiber-fill, high-loft, high bulk products to create still air insulating space.

Among the most successful products are those that include blends of coarse and very fine microdenier fibers. 3M's Thinsulate® and Albany International's Primaloft® are examples of products that use combinations of microfine and "regular" sized fibers to create many air holding cells. The fibers absorb less than 1% of their weight in moisture, making the products, in this regard, superior to down where dampness is present. Used in combination with other "hi-tech" materials, good insulation with lower bulk and weight can be achieved in extreme situations.

A study, reported on to this conference a few years ago by Jack Sawicki, then of Arthur D. Little, Inc., involved the designing of clothing for use in Antarctica, *for everyday use* by those in long-term base camps, resulted in a multi-layered "Integrated Clothing Ensemble." This ICE consisted of hydrophilic-finish polyester fleece underwear, a brushed polyester fleece mid-wear layer, an insulation layer using multiple denier high-loft, and a water/wind-proof outer shell of an aramid knit laminated to microporous PTFE film. Garments utilizing down or even materials such as Thinsulate provided excellent protection, but did not stand up to the rigorous, everyday laundering/cleaning methods used by the permanently based crews. One must not lose sight of the fact how garments are used in the everyday world and compensate.

As is common in designing protective clothing, the cold weather ensemble represented a compromise. The chosen combination was not necessarily the ***best*** possible ensemble, but considering all factors, the ensemble represented a workable, effective compromise. Given the variables, high-tech materials are not always the best solution – a fresh approach may be needed to better use conventional materials.

VII. BALLISTIC/MECHANICAL

This area includes soft body-armor, various cut and/or slash hazards, such as chain saws, sheet metal, glass, knives or other sharp edges, and stab and puncture resistant materials.

The most significant advance in the ballistic area has been the development and use of para-aramids, such as DuPont's Kevlar, to replace nylon as a ballistic barrier. This very high strength fiber, the same as used in tire cord, composites, and the like, is used in soft body armor by loosely stacking layers (16+) of (usually) filament aramid fabric, each providing coverage and progressive resistance to bullet or fragment penetration. Similar technology with rigid composites result in superior lightweight "hard" armor as well, for uses such as helmets and replacement of heavier steel armor plate areas such as vehicle and aircraft armor.

A recent development, SpectraShield® (AlliedSignal) involves the use of Spectra®, Allied's high strength HDPE fiber. A warp beam containing parallel multifilament yarns is drawn through a thermoplastic polymer and laid side by side, in sheet form, atop a similar bundle of yarns at a 90^0 angle. Yarn layers can be stacked and cured for semi-rigid and rigid armor. With many yarns and virtually no voids or openings, as may be present at the interstices (crossing points) of a woven fabric, the matrix provides high levels of protection, including to angular penetration.

Lighter weight, up to 1/3 less than Kevlar, reportedly allows a 23 layer matrix to offer protection equal to 30+ layers of Kevlar, a significant advance in body armor. Less stress on the wearer results in greater comfort and a better chance that the garment will be worn. Spectra and SpectraShield is limited to uses with lower temperature expectations, <200'F, but many/most uses do not involve high temperatures. The material is also ideally suited for thermally forming into special shapes as required.

Similar laid yarn assemblies are also made of para-aramids such as Kevlar or Twaron. Many garments are now made with combinations of material, including Spectra and para-aramids.

The non-armor mechanical/cut-slash protection area is a growing one that includes needled felt and non-wovens as well as woven and knit fabrics of spun, filament and combination yarns. These include protective gloves, aprons, sleeves, felt inserts for chain saw cut protection, pads to protect from abrasion, protection from cuts while working with sheet metal, glass, meat cutting, etc.

Para-aramid knit gloves and sleeves, 100% or blended with other fibers, are used when handling sharp edges such as sheet metal, glass, saw blades, knives, etc. Users of such gloves and sleeves, such as the automotive and sheet metal industries, have dramatically reduced cut-related hand injuries, resulting in less lost time and lower medical costs. Combined with other materials, such as fine stainless steel yarns, cut resistant gloves are produced for such areas as meat cutters, carpet installers, etc.

Chaps, loose leg coverings used by those working with chainsaws, are used to help prevent serious injuries. Such chaps use para-aramids or heavy industrial nylon yarns and fibers, needled felts or woven fabric combinations, to entangle the turning chain and stop it before significant damage occurs. Aramids permit lighter, more comfortable chaps. This isn't a large market, perhaps 300,000 yards per in the US (IFAI), but a good example of a specialized niche.

Another area of concern involves stab and puncture resistant materials. Those working in law enforcement, such as prison guards, have a greater problem with puncture and stabbing incidents than with ballistic and cut/slash protection. Interesting new combinations of materials, including extremely tight sail cloth type weaves utilizing materials such as Kevlar and Vectran® (Celanese) are being developed for these areas. Stab and puncture resistant materials are also useful for emergency workers, forestry workers and hunters (snake bite resistant), among others. Other approaches are also being developed.

VIII. RADIATION

Concern in this area involves protection from radioactive particulate matter or fall-out protection. Most garments used are impermeable to particulates to prevent ingestion and/or skin contact and absorption into the body tissues. The penetration and permeation protection is offered by special co-polymer coatings or laminates with broad spectrum chemical resistance. The base fabric acts as carrier and/or a strength member to provides durability consistent with the use and the coating. Typical would be polyethylene coated fabrics onto Tyvek or other non-wovens such as polyester or olefin.

The US's Savannah River Site plutonium plant uses a suit made of such special coated fabric for tritium protection. The encapsulating suit is made of polyester fabric laminated on each side with layers of film consisting of co-polymer extrusions of CPE/EVA/PVDC (Saran)/EVA. Other suits of Saran/CPE supported with nonwoven or unsupported are also used.

Since most areas of nuclear facilities do not involve protection from radioactive hazards, lower level protective clothing is usually used for coveralls, aprons, smocks, etc.. Standard cotton or polyester and cotton blends and Tyvek or other non-wovens are used. These fall more in the category of work clothing but provide some protection from accidental particulate exposure. Power companies usually have specific ensembles to be used in various conditions in a nuclear plant, depending on the risk or exposure.

Work is being conducted to provide better radiation protection for those working with X-Ray equipment. Lead shields are most often used but are heavy and cumbersome. Some time ago, it was reported that the Japanese had developed a polyethylene and condensed boron fiber for protection against certain levels of radioactivity, and a lead impregnated fiber suitable for providing increased protection for those working around X-Ray equipment and cancer treating materials on a daily basis. Little has subsequently been heard about these products, but that concept provides some of the thinking in the area. Such materials could be fabricated into garments of reasonable comfort for continuous wear.

Non-ionizing radiation, as may be found around microwave relay towers or high voltage transmission lines, and even around electronic equipment (low level electromagnetic radiation from CRT's and other equipment), are also areas of interest. The dangers of these exposures are not fully accepted but recent studies indicate the danger has been overstated. Electromagnetic shielding using conductive and dissipative metal bonded to fibers and fabrics are being developed for use in these areas and offer great potential. But these are only for those who must work in direct contact with such hazards. Special conductive topical finishes are also being developed to dissipate static charges. Similar materials have found a home in the shielding of electronic equipment, both from interference and from electronic eavesdropping.

IX. PARTICULATE MATTER

Particulate protection refers to the hazards typified by those involved with asbestos or lead abatement, a large volume but relatively low dollar/unit application. US usage figures peaked in excess of 90 million yards[2], with declines seen as buildings were cleaned and/or reduction or delays in enforcement were encountered. Recent studies have even questioned whether the danger is as great as previously thought, even in schools. *Lead abatement and paint particulate protection has taken up some slack.*

The asbestos abatement market is a finite one since asbestos production has essentially stopped in the US and all asbestos to be removed from existing buildings, in the US at least, will be done within the next 4-5 years. At one time, it was estimated that we would spend 25 ***dollars*** to remove what it cost 25 ***cents*** to put in. A Fortune magazine article a few years ago estimated that as much as $100 billion would be spent in the US over the next 20 years to remove asbestos in schools and other public buildings; probably a high figure, but a lot of contractors jumped in the business. Rethinking the actual or real danger, and what exactly we should do about removing it, has lessened the amounts spent, but large amounts were and are involved.

Garments are mostly made from non-woven fabrics, though some woven polyester/cotton or 100% cotton garments and some coated fabric materials are used. The standard garments are usually one of three types: 1) uncoated Tyvek, 2) Kimberly Clark's 3-layer SMS (Spunbond, Meltblown, Spunbond) olefin fabric KleenGuard, and 3) miscellaneous non-woven materials such as spunbonded olefins. Many spunbond *garments* are in the third category, imported at very low prices and usually adequate, though there are honest disagreements about what level of particulate hold-out is safe.

Tyvek offers excellent barrier protection for sub-micron particles, with up to 99% holdout of < 0.5 micron particles. The basic garments are inexpensive with typical costs in the $3-5 range.

Kimberly Clark’s Kleenguard® three layer SMS nonwoven composite, structure is said to offer adequate protection from asbestos fiber penetration (70-80% holdout) while providing greater breathability, and a slightly more comfortable garment. This allows workers 10- 15 minutes more working time between changes, a 10-15% increase in productivity in this stress producing cleanup environment.

With cost concerns a major factor, plain spunbonded nonwoven olefins are increasingly being used, many of imported garments, and may now be the most widely used product. Though offering only about 40% holdout of the submicron asbestos particles, many contractors feel that this is sufficient when combined with adequate clean-up and other safeguards. Critics claim that if clean-up and safeguards are inadequate, the asbestos particulate on the body and inner clothing can be carried home by the worker where it can be mixed with other clothing and/or released into the air.

Similar garments are worn by those working around lead dust, painting, and similar hazardous environments containing dangerous fine particulate matter.

New products often are not cost or performance competitive – they don’t provide any greater benefits to justify the higher costs. Workers use the suit only once and may go through 3 or 4 suits a day. Worker turnover is extremely high due to the high heat stress factors involved.

As with most protective clothing, breathability and "comfort" in use are major concerns. The body tries to maintain its internal temperature during exertion by perspiring and evaporative cooling. If the moisture cannot evaporate, the body temperature rises and "heat stress" causes shut down, or at the very least the user is uncomfortable. Successful garments must allow the transmission of moisture vapor while still providing protection. Researchers are studying the effects of heat stress in PC applications, including asbestos abatement, in an effort to develop materials and construction techniques for effective, less stressful protection.

X. BACTERIAL/VIRAL

The PC area of medical textiles, as per our definition, has been fueled by the concerns related to the AIDS virus, hepatitis, and other life threatening transmittable diseases. Barrier fabrics, laminated or coated woven and non-woven fabrics with sophisticated co-polymer extrusion coatings, are being developed, along with anti-bacterial finishes for use by hospital and medical personnel, emergency responders such as ambulances, firemen, and police. A good example of the work being done in this area is DuPont's Biowear® materials for protection against bloodborne pathogens.

Anti-bacterial fabrics are of interest in this area. Most finishes are topical, with varying degrees of longevity. A Japanese product, Bactekiller® (Kanebo), has a bactericide built into the *polyester* fiber at the extrusion process. The bacteria killing agent, based on zeolite salts, stays in the fiber, even when dyed, processed, or washed. A unique feature is that the nature of the bactericide medium (sodium aluminosihcate) makes it applicable where dehumidifying, deodorant, and absorbent properties are important. Other products are also available.

Several producers are developing fibers with built-in bactericide. Celanese Acetate has a microbial acetate based on Microban® that may be applicable for some areas, though such products are usually limited as to its effectiveness on most areas of PC concern – they are mostly for odor control, like in socks. Other work is being done – for hospital upholstery, drapes, and other applications, using other methods, so look for extensive development of this type technology. It would appear, given the current press releases and literature, that many new products are being developed utilizing this technique. *While many will be effective in certain areas, for the most part, we must not think they are suitable for all hazards and must look at the claims with an inquiring, even skeptical mind*. More effective and less costly biocides would be a major advance.

Anti-odor products also show promise in the PC field. Molecular sieve products have been developed that are effective in combating odors in the medical field. This and similar technology under development, using encapsulated finish materials designed to release under predetermined conditions, could be used in fiber or fabric form to provide better bacterial/viral protective clothing-

Increased use of laser surgery creates a demand for nonflammable materials for use in garments and curtains normally found in the operating room. Opportunities exist for new inexpensive flame resistant materials in the medical area.

As in other areas newer non-woven meltblown products of microfine fibers are being developed to provide effective barrier materials with superior comfort levels. Improved coating and laminates are also being developed.

XI. CLEAN ROOM

The human body emits over 250,000 submicron particles (<.05 microns) every minute. In the clean room area, goal is to keep these particles from escaping and contaminating the product or environment in which one is working as well as prevent contamination of the worker in areas where harmful chemicals are present. Areas may include the manufacturing of electronics, pharmaceuticals, special medical or laboratory environments, etc.

Four major types of fabrics are used in this area: 1) continuous multifilament fabrics of nylon and polyester, 2) spunbonded olefins, such as Tyvek, 3) inherently antistatic fabrics, and 4) polymeric films (including the microporous PTFE laminates).

Filament polyester is the most versatile fiber for clean room garments since it is lint free and can withstand chemicals such as peroxide and strong acids, and it can be sterilized with gamma radiation (the olefins such as Tyvek break down). Woven and knitted garments are durable and reusable and are often enhanced with conductive materials incorporated into the fibers, fabrics, or garments. Non-wovens offer lower cost and disposability and offer good barrier properties and can be treated to provide antistatic properties. Barrier films offer the greatest protection but also suffer from the same comfort problems as other barrier materials used in protective clothing. Garments with breathable membrane films or coatings are used, or being evaluated, to help with this problem.

New developments in this area include microfine fibers, to 0. 1 denier per filament, produced by the Japanese for impermeable, yet breathable, fabrics; some with bactericides and/or antistatic properties built into the fiber. Fiber producers in the US and Europe are also working with microfine fibers, but most are expensive, demanding high value added products to make them worthwhile. Newly developed lyocell cellulosic fibers (made from environmentally friendly solvent spinning techniques, from Lenzing and Courtaulds), for instance, have a tendency to fibrillate under stress, creating microfine fibers. Filament versions are being developed which may be applicable in these areas.

The Japanese are also utilizing electret meltblown fabrics. Electrets are non-conductive polymeric materials which maintain long-lived electrostatic forces. The filtration characteristics of the charged electret fibrous materials are especially effective against fine submicron particles, making this product ideal for certain clean room applications.

Another development is that of barrier fabrics utilizing a close weave and unique multifilament polyester yarns with a carbon core, which permits full laundering with permanent anti-stat properties.

Concerns with clean room garments include the absence of lint, cleanability, breathability, ability to be disinfected or sterilized (by chemical and radiation means), permeability, antistatic and conductive (in many cases), barrier protection level, and chemical resistance, among others.

XII. CHEMICAL

Protective clothing used for chemical protection is categorized from high to low, Level A-D. Level A garments provides total encapsulation, with sealed seams, negative pressure, and with self contained breathing apparatus for protection from chemicals, gases and vapors**.** Level-B, for highly toxic chemical splash, is similar to Level-A except that the seams are may not be sealed and the garment is not intended for vapor protection. Permeation and penetration protection must be offered from a wide range of chemicals. Level-C provides significant splash penetration protection and may or may not use a respirator. Level-D, the least protection, is not much more than coveralls and boots to provide splash and dirt protection.

The most common type of garment used in the chemical area is made of Tyvek spunbonded nonwoven olefin fabric, plain or coated. In its uncoated state, it is used in particulate protection and relatively low levels of splash, non-hazardous chemical protection areas. For higher levels, Tyvek is coated with polyethylene or other polymers and used in splash suits for protection against many dangerous liquids.

Even higher protection Is offered by Tyvek laminated with Saranex 23P® from Dow Chemical. Saranex multi-layered barrier film has a low density polyethylene outer layer bonded to a layer of resin, a copolymer of vinylidine chloride (Saran) and an exposed layer of ethylene vinyl acetate (EVA) which acts as an adhesive to bond Saranex to the Tyvek. Properly constructed and sealed garments offer high degrees of protection over a wide range of chemicals. DuPont has added to their line of Tyvek materials to include several lower cost coatings for specific applications.

Fueled by a one-time shortage of Tyvek and a desire to have a proprietary product offering a wide range of protection at lower costs, several manufacturers developed special barrier coatings or laminations onto a variety of substrates, including polyester and olefin dry-laid, spunbonded, or meltblown non-wovens. Coatings/laminations may range from polyethylene coated olefins to exotic copolymers which offer a wide range of permeation and penetration protection. Most of these garments are inexpensive, well under $1000, compared to upwards of $3-5000 for the more durable coated fabric garments, Teflon coatings, etc.. But even the most effective Teflon coated limited use garments can cost over $3000.

The durable garments are of nylon or polyester, or poly/cotton blend fabrics, coated with chemically resistant polymers such as Teflon® (DuPont) PTFE, butyl, EDPM, Viton® (DuPont), and the like. These are sealed Level-A garments that use self-contained breathing apparatus. After use, they are often decontaminated and reused. While the lighter garments may offer similar chemical protection, the durable garments usually hold up better with heavy-duty use.

The growth segment in the US appears to be those using the lighter, lower cost, limited-use (rather than disposable) materials. Many feature improved, even superior, performance properties, lighter weight, effective seams, and the lower costs which will invite more widespread use. Due to the nature of the protection required, few, if any, of these materials are comfortable to wear, a major concern in this field often addressed with cooling vests, external cooling devices, etc.

These new products may open the doors to new coatings and substrates for the chemical protection field, but there is a down side. As far as the industry is concerned, they introduce a degree of claims and confusion as to which is best and which to use. The NFPA (National Fire Protection Association) and others are developing performance tests, and requiring third party certification for permeation and penetration by a wide variety of aggressive chemicals, there is no history as how well they will *perform in use*. The substrate does make a major contribution to the final product. Change the substrate and the permeation and penetration tests may no longer be valid. Extensive testing must be performed. This takes time and is expensive, a drawback in designing for or trying to penetrate this field.

XIII. THERMAL

Protection from fire and extreme heat, and the need to work around fire and heat, has long provided a need for protective clothing. Our primary concern has been to protect the fireman, those working in primary metal industries with molten metal, and similar areas involving high heats such as welding, foundries, ceramics manufacture, etc.

The development of the high heat resistant fibers such as Nomex, Kevlar, PBI, FR Rayon, Kermel, P84, and pre-oxidized PAN based fibers, among others, as well as better FR finishes for cotton and new blends of fibers have made possible far more effective garments. Many of these fibers were developed as asbestos substitutes for high heat areas. The thermal protection is a starting point for development of many of the new high temperature fibers; new ones are being introduced.

The fireman's multi-layered outfit, or turnout coat and pants, is generating fiber, fabric, and garment development. The outer shell is usually a Nomex, Kevlar, or Kevlar/PBI blend woven into a 7.5 oz/yd^2 twill fabric. This shell provides the primary protection from fire and offers good abrasion resistance. It usually contains light reflective strips for visibility and identification. A vapor barrier under the shell prevents water from entering and creating hot steam inside the garment when near a fire. It is made of a low-cost neoprene coated fabric for impermeability or, increasingly, a PTFE breathable membrane laminate which allows for moisture vapor transmission from the body to reduce heat stress.

Beyond the vapor barrier is a thermal liner to provide increased still air space, adding to the multi-layer insulating properties of the garment. The material most often used is a needled Nomex batting or high loft material often of reprocessed fiber, quilted and faced with woven Nomex fabric. A secondary thermal liner vest may also be worn for added protection. Thermal liner material is also used in the pants and other gear. In a complete garment, FR underwear is used, often of an inherently FR fiber such as Nomex. The ensemble is completed with suitable FR gloves, boots, helmet, etc.

Firemen's station wear uniforms are usually composed of shirts and pants of FR treated cotton or poly/cotton materials or of 4.5 and 6.0 oz/yd 2 Nomex III aramid. Springfield's FireWear® is making progress in this area as well. FireWear is made of a special acrylic and cotton blend, the acrylic containing a built-in vapor phase fire retardant released on exposure to high heat – ***an example of innovative thinking***.

DuPont produces hydroentangled spunlace non-woven Sontara®, of Nomex and Kevlar which is used extensively in thermal protection. These products are used turnout coats as thermal layers where fire resistance and thermal insulation is needed. Increases in thermal protection per unit of weight can be 50-100% over the same weight woven fabric, due to the bulking and still air insulating characteristics, resulting in equal or higher performance levels at a lower weight. They are also used in fire barriers on aircraft, and similar uses.

Responding to a fire, and to a chemical spill, requires a high degree of sophistication in protective clothing. A fire response or a chemical spill emergency response may involve flammable chemicals. Though moderately FR, few, if any, chemical response garments provide significant fire resistance or protection, and fire response garments provide only minimal chemical splash protection. Various and complex risk factors are involved that may require different types or combinations of garments depending on the type of fire and heat involved, and the exact nature of the chemical and characteristics of the spill. An ideal garment would provide both high levels of fire *and* chemical protection, yet remain light weight and comfortable.

The NFPA has developed standards for hazardous material (hazmat) suits that allow useful thermal protection as well as high levels of chemical resistance, usually an outer garment of thermally resistant material worn **over** the chemical suit.

The fire entry suit, for actually going ***into*** the flaming inferno, as in a gas or oil fire, is a small but important segment. Protection from extremely high heat levels (over 1000^{o} F) for as long as possible is essential. These garments are extremely bulky due to their many multilayers of insulation and reflectorized or silica compound coatings onto glass or high heat resistant fabrics. Working times may only be 2-5 minutes, but can provide enough working time to turn off a valve, lift an obstruction, or effect rescue.

The familiar metallized proximity suit is made of an aluminized film laminated to a high temperature fabric. The garment allows the firefighter to get closer to the fire with the aluminized surface of the material reflecting up to 90% of the radiant heat. Such garments are mandatory at airports and fire departments and for working around high radiant heat sources such as molten metal or metal castings.

Another major market involves protection from accidental molten metal splash while allowing workers to be in close proximity to the high heats and perform useful work. Most of these products are still of FR treated woven cotton, though fabrics of high temperature fibers such as Nomex, Kevlar, PBI, etc. are being developed for use 'm specific areas. FR treated cotton is still the mainstay in this area, especially for non-metallized garments in the ferrous metal industry, since the treated cotton allows the molten metal to roll off the garment, rather than stick (as is likely with many of the high performance fibers), reducing the exposure and risk of injury. FR treated wool is also used in several thermal protection fields, especially in foundries. Needled felts of Nomex and Kevlar used with woven fabric covers or quilting and/or laminated with heat reflective aluminized films offer superior insulation, reflective, and thermal insulation properties.

Heat stress is a major concern in the high-energy activity field of fire-fighting. More firemen die each year due to heat stress induced problems, such as heart attacks, than are killed by fire. As in other PC areas, the ability of the ensemble to permit high moisture vapor transmission, but still offer high levels of thermal insulation, is a desirable feature. New methods of cooling the wearer are being developed.

Testing and determination of effectiveness of various materials is crucial to predicting their performance in use. This is an area of concern since companies and various standards organizations worldwide have different, and often non-comparative, tests procedures. Many new tests and standards are being developed by trade groups, unions, insurance companies, and the like, in order to adequately test and/or predict the performance standards, at least on a comparative basis, of different materials. And now that labs with instrumented manikins at the university and government level open to industry, the ability to do the necessary testing is much more available

XIV. NEEDS

Perhaps the biggest need in the protective clothing market, aside from better base materials, is a better understanding of the problem, and have more universally ***accepted*** and ***followed*** standards and specifications. In many cases, the problem is not well studied, tested, understood. and defined.

Often we have no real basis for comparing different materials. Many claims don't hold up; many tests are "in-house," using specified equipment or methods not easily duplicated. Standard-setting groups don't necessarily have comparable methods. Many US, European, or Japanese standards are not comparable.

A point should be made here about the dynamics of constructing protective clothing. Tests concerning the effectiveness of fibers or fabrics are only relative guidelines as to how one fabric may perform compared to another. ***Such tests should be considered as starting points***. Many things may affect test results including moisture, thickness, airspace, etc. The insulation value of a fabric or garment changes dramatically when the body bends, twists, sweats, and does work. The use of and results of the manikin test in bum evaluations is a case in point. While manikin testing may be meaningful as a basis of comparison, few people have access to manikins, though more are available, so comparative testing is difficult. Even so, the test is a ***static*** one and disagreement exists on the procedures and validity of testing.

The most important consideration is the effectiveness of the ***entire ensemble*** in use, how the total package performs under actual work conditions.

Fortunately, this situation ***is*** being addressed. A lot of progress has been made since we first started this conference in 1987. Many associations and groups (NFPA, ASTM, ANSI, EPA in the US, and ISO and other international groups) are trying to develop ***meaningful*** standards, but much work needs to be done. Agreement is not easy. With increasing globalization of markets, tests ***must*** be developed which are meaningful realistic, easily performed by a number of people, cost effective, and comparable.

Testing, whether chemical, fire resistance, or particulate or other holdout can cost several thousands of dollars for a few basic tests to hundreds of thousands for a full complement of extensive tests. Therefore, many products get to market because the group of materials or chemicals may have been tested on similar products so, the reasoning goes, they should be comparable on the new product. This may not be the case. Testing should be low cost, consistent, comparable, and meaningful to encourage widespread use. Third-party certification is helping in this area, but development of low cost testing is a priority.

Other needs include more effective materials, materials that provider greater protection over a longer period of time over a broader range of hazards. Needed are materials with greater Thermal Protection Performance (TPP) properties, chemical resistance over a broader range, both fabrics alone and/or with coatings or other treatments, and garments with greater comfort that provide longer working time with less stress on the wearer. And, of course, all this at a lower cost.

It is important to remember that ***PROTECTIVE CLOTHING DESIGN ALWAYS REPRESENTS A COMPROMISE!***

When designing materials and garments, it is often difficult to get all concerns in balance and satisfied. Better often means greater cost, though the end user, with some exceptions, may not be able or willing to pay the higher cost. A product with the highest levels of protection consistent with cost, comfort, and other parameters is most often the item chosen.

XV. CONCLUSION

The protective clothing market is receptive to innovative new products. There is opportunity and need for functional, cost-effective materials. But the market is fragmented and complex. Development and lead times are often long and expensive. Anyone contemplating entering the business must be prepared to spend significant sums on development and proving the products if they are to be accepted and widely used. But new needs are constantly emerging and the rewards often worth the risk.

A plea and a word of caution **-** ***the homework must be done!*** The standards are not as tight as perhaps they should be, but they are a start. That should not be considered an invitation to produce marginal products that meet the letter but not the spirit of the requirements. We must remember that many situations requiring protective clothing are life threatening. Good products are needed and they must work well. It is a market that offers opportunity, but also one that ***demands*** that much development and testing be done prior to adopting new products.

There may be long lead times, much resistance to things new, and much expense involved in bringing new products to market. ***The truth is, we cannot afford not to have the new ideas and products***.

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