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Documentation on Protective Textile: Existing Technical Textile Products & New Developments

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Abstract
This paper reviews a significant segment of the technical textile market is that of Protective Clothing (PC), which is receptive to new products and suppliers. Protective clothing can be divided into various groups, including, clothing against heat, flame, mechanical impacts, cold, chemical substances, radioactive contamination, and protective gloves against mechanical and thermal hazards. The focus of protective clothing is more on sophisticated needs, and in situations where the 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 hazardous situations. The Nuclear, Biological, and Chemical (NBC) lightweight over-boots provide more than twenty four protection against chemical warfare (CW) agents, and are fully antistatic. A common objective of the protective clothing industry is the creative and innovative application of available technology, and much of the technology involved is among the most sophisticated available, and the end uses being complex and of great value.

Keywords: Technical Textile, Protective Clothing, Ballistic protection, Chemical & Biological Protection, Military Protection, Industrial Equipment, UV, Heat & Thermal Protection, Hazards, Sensors, Actuators;

1. Introduction

Protective textiles are fiber-based materials designed to allow items to function effectively in dangerous environments. These fabrics have been utilized for human defense since ancient eras, mainly against cold and rain. As society progressed, wool felts and woven cotton textiles appeared. Intelligent fabrics can play a role in multiple areas, engaging with different factors such as absorbing or converting signals into understandable formats. These fabrics can serve as sensors or actuators, based on the interaction parameters

1.2 Technical Textiles for Protection: An Overview

Techtextiles are also known as technical textiles or industrial textiles, are specialized textiles or textile products manufactured primarily for their technical performance and functional properties rather than for aesthetics or decorative purposes Technical textile are defined as textile materials and product used primarily for their technical properties and functionality rather then aesthetic and decorative characteristics in 2010 [1]. They are composed of both rigid and compliant parts, and they are realized using techniques including stitching, lamination, and bonding. The market for protective textiles is incrementing at a rate of 6.6% per year, and worth around $2.5 billion. The primary objective of these materials is to enhance the safety of workers and the demand for these fabrics are growing as safety at work places are becoming more and more concern, world wide. ASTM, ISO and other organizations generate standards for these materials [2].

2. Fibres & Fabrics for Protective Textiles

Protective clothing or protective textiles are extensively used to shield human beings or environment from different natural or industrial hazards. There are some environmental hazards such as heat, cold, wind, ultraviolet radiations, snow, radioactive radiations, rain, abrasion, dust, microbes, static electricity etc. Some of the famous industrial or human hazards are fire, gases, bio-hazards, flash, projectiles, cutting by sharp etc. when we are near to these or one of them, then we shall need maximum protection from all these hazards. Enter protective textiles which are in place to protect us [3].

Figure 1: Protective Clothing Types

2.1 Review of fibre types:

A full classification of nearly 100 textile fibre types can be found in Textile terms and definitions, with a few exceptions, they can be roughly divided into six major categories in order of mechanical strength: 1.Highly extensible, elastomeric fibres, e.g. Lycra, 2.Very brittle fibres, e.g., rock wool, 3.Widely used, natural and regenerated fibres, e.g., cotton, wool, flax, rayon, 4.Tough fibres, moderately strong and extensible, e.g., silk, nylon, polyester · 5.Moderately strong, inextensible fibres, e.g., glass, ceramic fibres, 6.High- modulus, high-tenacity fibres, e.g., carbon, aramid, High Modulus Poly Ethylene (HMPE) [4].

2.2 High Performance Fibre:

High performance fibres are driven by special technical functions that require specific physical properties unique to these fibres. They usually have very high levels of at least one of the following properties: tensile strength, operating temperature, heat resistance, flame retardancy or chemical resistance. Applications include uses in the aerospace, biomedical, civil engineering, construction, protective apparel, geotextiles and electronic areas [5].

2.3 Fibres which used in Protective Clothing:

The fibres which are used in protective clothing have presented in the below table with their uses:

SL No.	Fibre	Uses
01	Meta-aramid fibre	Industrial **protective clothing**, Racing driver's suit, Filter bags for hot gas, Cargo covers, Boat covers.
02	Para aramid fibre	Tyre cords, Radiator hose and brake shoes of racing cars, Body armor, Reinforced composites for aircraft, High-speed boat components.
03	Carbon fibre	Aircraft and a Space shuttle, Automotive, Medical Implants, and Marine.
04	Glass fibre	Consumer goods, Roofing Tiles, Corrosion resistant products used in highway overlay, Aircraft, and aerospace.
05	Polypropylene fibre	Marine ropes and cables, Sailcloth, Protective clothing.
06	Spandex fibre	Foundation garments, Support hose, Sports and leisure garments.
07	PBI	Hot gas filtration, Thermal protective clothing, Racing driver's suit.
08	Tencel	Filtration media for the oil industry, Medical Textile, Industrial fabric.
09	Inorganic fibre	Aircraft, Automobile, Sport, Electrical Application and Military Application.
10	Fluorine-containing fibre	Filtration media for corrosive material, Refrigeration, Packing Material.

Table-1: Table of Pro-Tech fibres & their use

2.4 Fibres Used for High-Temperature Protective Textiles:

The following fibres are used in high-temperature protective clothing or protective textiles:

1. Aramid (Meta & Para),
2. Glass,
3. PAN or carbon,
4. Phenolic,
5. PTFE,
6. PBI,
7. Polyamide,
8. Melamine,
9. Poly-Acrylate.

2.5 Comparative fibre properties:

Where ranges are given for linear polymer fibres, high tenacity and modulus goes with low break extension [6].

Fibre	Density g/cm^3	Moisture 65% RH	Melting point ^{0}C	Tenacity N/tex	Modulus N/tex	Work to break J/g	Break ext %
Para Aramid	1.44	5	550	1.7	50-115	10-40	1.5-4.5
Meta Aramid	1.46	5	415	0.47	7.5	85	35
TLCP (vectran)	1.4	<0.1	330	2-2.5	45-60	15	3.5
HMPE	0.97	0	150	2.5-3.7	75-120	45-70	2.9-3.8
PBO	1.56	0	650	3.8-4.8	180	30-90	1.5-3.7
Carbon	1.8	0	>2500	0.4-3.9	20-370	4-70	0.2-3.1
Glass	2.5	0	1000-12000	1-2.5	50-60	10-70	1.8-5.4
Polypropylene	0.91	0	165	0.6	6	70	17
Ceramic	2.4	0	>1000	0.3-0.9	55-100	0.5 - 9	0.3-1.5

Table-2: Table of Comparative fibre properties

2.6 High Performance Fabrics for Protective textile:

Nonwovens:

The term Fliesstoffe with more positivity refers to nonwoven fabrics which can be made from staple fibers by laying, in-parallel or cross laying, depositing several layers of webs of fibers done in conventional textile carding where fibers are taken off a cylinder covered in a clothing of projecting wires. Bonded fibre fabrics are made by applying adhesive or thermally treating thermoplastic fibres. Alternatively, webs can be spread out by air streams or, for shorter fibres, from a dispersion in water. Continuous filaments can be laid from a bank of spinnerettes and spun into webs that are fed into bonding units to make spunlaid (spunbonded) fabrics. Flash-spun fabrics are produced by extruding polymer solutions to high temperatures where rapid evaporation takes place forming fine fibril webs; Tyvek is a well-known example. There are other types like melt-blown nonwovens. Fabrics made with needles and crosslaid webs are fed into banks of reciprocating needles which entangle the fibers creating an integrity. Airlaid webs can be spunlaced or hydroentangled by passing the webs under high-pressure water jets. Stitch-bonded fabrics are made by using yarns to stitch through webs in a warp-knitting operation [7].

Yarns:

Most textile fabrics are produced from the interlacing of yarns as explained below. As previously described, continuous filament yarns are made by extrusion. They can be rendered coherent by adding a twist, which can be low in degree, or nowadays more commonly by air-jet interlacing during the winding stage. Cords, which are more mechanically strong, are produced by twisting together singles yarns (plying). Ropes represent the ultimate one-dimensional utilization of a textile and are made by multi-level twisting of `textile yarn', rope yarn, strand, and rope; alternatively ropes can be produced by braiding or assembling yarns or sub-ropes enclosed in a jacket.

Different methods for producing yarns through twisting, interlacing, wrapping and bonding were developed in the second half of the 20th century, but the above ways are those of most current commercial importance. For some specially designed and harder to spin fibers, hollow-spindle spinning might work. A strand of fibers is placed within a tube that is continuously spun, allowing for the package of binder yarn to be spun around them. The specialty fibers are then held in the yarns by the wrapping. DuPont's presentation of Versaspun, an integrated process for making staple fibre yarns at ITMA 2003, showcased some potential for protective textiles. A continuous filament yarn is thickly wound, then stretches and breaks which produces long-staple fibers before moving to a spinning head for winding. One is clear economic advantage. Moving from extruded fibre to spun yarn in one step eliminates a lot of processing. More subtle is this. Fine aramid yarns are much more expensive to make than coarse yarns.The drafting, which occurs with Versaspun, offers a way of converting a cheaper coarse yarn into a fine yarn by an low-cost operation. Because of the length of filaments, the strength loss is small. Versaspun is also well modified to making blended yarns [8].

2.7 Fabrics Processing & Composites:

The finishing processes is perhaps more important with regard to technical fabrics. Stentering both control s the fabric dimensions and stabilises the fabric by heat setting. Chemical treatments, which operate on a molecular scale, can either modify or reinforce the fabric's structure. Calendering the fabric increases the thickness and alters its surface characteristics. Other treatments also change the nature of the physical surface. The chemical properties can be altered by adding surface treatments, the most straightforward example being water repellancy without compromising breathability. Finishing gives the fabric structure with just a slight reduction in weight. Coating adds a considerable quantity of a different material to the fabric for specific functional purposes. As previously discussed, foul weather garments are an obvious example but the greater protection comes at the cost of comfort [9].

Particularly in helmets for impact and ballistic protection, rigid composites—which may incorporate textile preforms—are employed for protective purposes. They are transformed into solid engineering materials by the matrix. Nonetheless, it is appropriate to bring up hot compaction as a method of creating innovative composites in the context of fiber. A tiny quantity of thermoplastic melts and joins the fibers when an assembly of thermoplastic fibers is compressed at a temperature slightly below the melting point. Although they are in physically different phases, the matrix and the reinforcing fibers are made of the same chemical substance. High-performance polyethylene fibers have benefited greatly from hot compaction. In one set of tests, the hot-compacted Dyneema's tensile strength was comparable to that of a traditional Dyneema composite; however, its modulus was a little lower, and its compressive strength was higher [10].

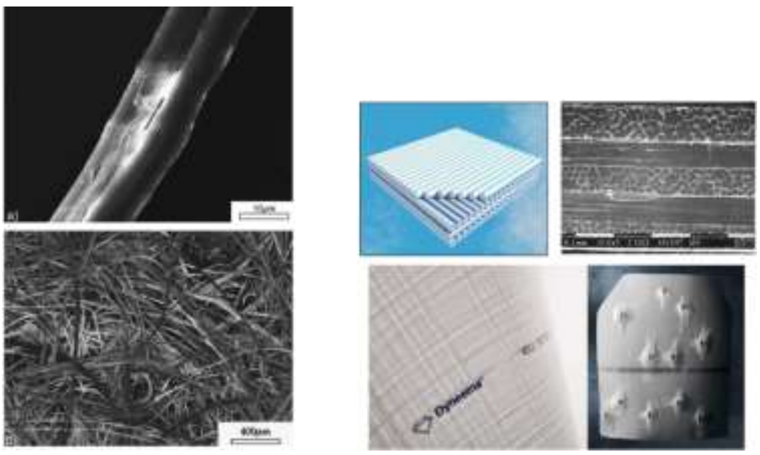


Figure 2: (a) Typical Dyneema SK75 bundle of two fibres. (b) Overall microstructure of the Fraglight NW201 nonwoven fabric. Fig: 5 Dyneema UD is a cross-ply laminate based on a unidirectional

polyethylene (PE) composite material and is available as UD-SB (soft ballistics) and UD-HB (hard ballistics) (DSM Dyneema, 2017) [11].

3. Protective Textiles Application in Different Fields

3.1 Properties of Protective Clothing or Protective Textiles:

There are some key characteristics of protective clothing which are listed in the following:

1. Lightweight and low bulk,
2. High durability and dimensional stability,
3. Good handle and drape property,
4. Low noise emission,
5. Water repellant,
6. Windproof and snow shedding,
7. Thermal insulating,
8. Ultra violate (UV) resistant,
9. Air permeability,
10. Flame retardant,
11. Heat and melt resistance or low smoke emission,
12. Safety from radar spectrum.

4. There are mainly 15 types of protective clothing used; those are listed in the following:

1. High-temperature protective textiles,
2. Chemical protective textiles,
3. Mechanical protective textiles,
4. Flame-resistant protective textiles,
5. Ultra Violet protection finish,
6. Metalized fabrics,
7. High visibility textiles,
8. Radiation protective textiles,
9. Protective health care garments,
10. Clean room technology,
11. Biological protective textiles,
12. Ballistic protective textiles,
13. Space suits,
14. Breathable fabrics,
15. Electrical protective textiles [12].

4.1 High Temperature Protective Textiles:

A very important concern for workers wearing thermal protective clothing is its often detrimental effect on the wearer's comfort. Besides being potentially cumbersome, in order to protect sufficiently, the material in a garment must be substantial and is likely to add to the worker's thermal load. And for steam and hot water protection, the material's breathability or water vapour diffusion is normally compromised. As noted above, fire fighters reported that their need for a high level of protection for some duties leaves them overprotected and uncomfortable for many others. Physical exertion combined with the temperatures from a structural fire can bring body temperature to a dangerously high level.

In order to develop thermal protective clothing, there is a need for high-performance fire-retardant/resistant textile fibres. There are, broadly speaking, two categories of fire- retardant/resistant fibres: (1) chemically modified fire-retardant fibres, and (2) inherently fire- resistant fibres. In the case of chemically modified fire-retardant fibres, flame-retardant materials are used as polymerization additives, spinning-dope additives, or finishing agents on commonly available natural or synthetic fibres (e.g. cotton, wool, polyester). The finishing technique can also be applied at the fabric stage. In this case, fabrics are first produced from natural or synthetic fibres and then the flame retardant finishes are applied to the fabrics. Furthermore, some synthetic fibres have such chemical structure that they can inherently resist the fires; these fibres are called inherently fire-resistant fibres. One of the criteria to evaluate the fire-retardant/resistant property of fibres is to evaluate the minimum amount of oxygen required to burn these fibres. This scale, mentioned earlier, is called the limiting oxygen index (LOI) and is expressed in terms of percentage (%) [13].

Example:
The Newtex Extreme Protective (NXP) line features high temperature protective clothing including high temperature gloves, proximity suits, fire entry suits, and aluminized clothing fabricated from the high temperature fabrics. High temperature protective clothing is commonly used in applications like industrial fire fighting, metalworking, and shipbuilding.
Manufactures: NewTex (United States) [14].
Material: Zetex®, ZetexPlus®, Z-Flex®, and Aramid fabrics to withstand heat up to 2000°F
/ 1095°C while providing outstanding comfort, thermal insulation, wear resistance, and protection from heat, flames, sparks, and molten metal splash.

Figure 3: NewTex Fire fighters' Aluminium-coated Cloth & Golves.

4.2 Chemical Protective Textiles:
On exposed skin, chemicals can have harmful effects that range from contact dermatitis to skin penetration and systemic toxic effects. Direct skin contact and contamination can be avoided with chemical protective apparel, which includes gloves, boots, suits, and other related items.

The Occupational Safety and Health Administration, or OSHA, states that "standard selection" of personal protective equipment (PPE) is based on a hazard assessment that establishes the necessity of necessary protections. Establishing the requirements that the equipment must fulfill is a major issue with PPE. Some tasks which may require PPE are (1) working with corrosive chemicals, (2) working with toxic chemicals, (3) working with dusts, (4) working in hot environments, (5) working in noisy environments, (6) welding, (7) fire fighting and (8) rescue.
Protective clothing should be regarded as a last line of defence. It is much preferable to remove or control the hazard, if this is practicable. Some of this type of protective clothing and equipment are (1) body clothing, (2) gloves, (3) helmets, (4) shoes, (5) eye protection and (6) ear protection [15].
Manufacturers: Honeywell (Europe), KCL, Tychem (DuPont). WeeSafe (France)

Applications:
- Petrochemical industries
- Industrial and tank cleaning
- Epidemic and viruses
- Remediation of polluted water
- Remediation of polluted sites
- Chemical industries
- Emergency services
- Offshore Maintenance
- Nuclear industry

Protection Standards:
EN ISO 14605 : Protection against saturation liquid of chemicals
EN ISO 13982-1 : Protection against hazardous dry particulates [16].

Figure 4: Materials of Chemical PPE

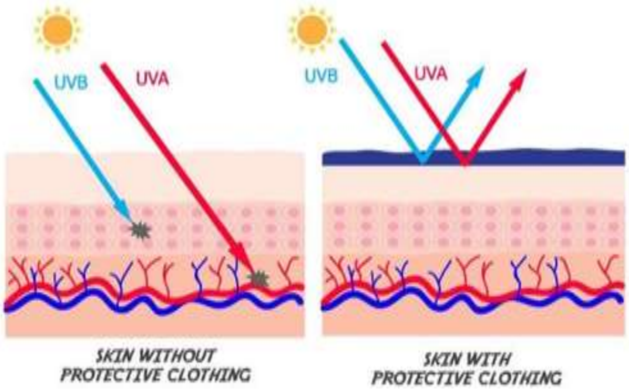
Merits & Demerits of materials used for Chemical PPE			
NO.	**Material**	**Merits**	**Demerits**
1	Butyl rubber	Protects well against other chemicals such as ketones, ester, inorganic salts & most acids & alkalis	Not resistant to oils, attacked by petroleum products, aromatic hydrocarbons & coal tars.
2	Natural rubber or latex	Good temperature resistant & tensile strength, good resistant to acids & alcohols	Moderate abrasion resistance.
3	Neoprene	Excellent resistant to strength chain hydrocarbons, aliphatic hydroxyl compounds, methanol, ethanol, ethylene, glycol, animal & vegetable fats, oils & fluorinated heat & ozone.	Not recommended for use with strong oxidizing agents, ketones & acetates.
4	Nitrile	Virtually unaffected by saturated & unsaturated aliphatic hydrocarbons, alkali solutions & saturated salt solutions.	Adversely affected by water
5	Polyvinyl Alcohol	Highly impermeable to gases & affords, excellent chemical resistance to aromatic & chlorinated solvents.	
6	Viton	Excellent resistance to petroleum products such as oils, fuels & lubricants & aliphatic, aromatic & chlorinated solvents.	
7	Polyethylene	Excellent abrasion characteristics & good resistance to cuts & tears.	

Table-3: Merits & Demerits of materials used for chemical PPE

Figure 5: DuPont Chemical PPE - TyChem 2000.

4.3 Ultra Violet protection finish:

Depletion of stratospheric ozone is one of the main causes of the rise in skin cancer incidence. Ozone is a very good UV absorber, so every 1% drop in ozone concentration is expected to raise the incidence of skin cancer by 2% to 5%. Operational Process: Laboratory testing in vivo or instrumental measurement in vitro are two methods that can be used to quantitatively evaluate a textile's UV protection. Consequently, two terms are used: ultraviolet protection factor (UPF) for instrumental evaluation in vitro and sun protection factor (SPF) for in vivo testing.



A broadband UV light source that has been filtered for UVR (Ultra Violate Radiation) is used in radiometric UV transmission techniques on a fabric sample. A radiometer measures the total amount of UV radiation that passes through a fabric. In the presence and absence of a textile material, the transmitted radiation was measured using a radiometer equipped with a diffuser. The textile material was wrapped around the detector to guarantee that the detector also measured the scattered light transmitted by the fabric. [17]

Standards for UV Protection: AS/NZS 4399 (Australia/New Zealand), American Association of Textile Chemists and Colorists (AATCC) Test Method 183 (USA), BS 7914 (British Standards Institution, Great Britain),29 and European standard EN 13758-130 are the standard test methods presently in use [18].

Fibre Chemistry & UV Protection: According to a study of thirty commercial summer textiles, viscose rayon, white cotton, and linen provided very little UV protection. Additionally, it was discovered that bleached cotton was transparent to UV light, most likely as a result of bleaching eliminating the lignins and natural pigments that can serve as UV absorbers. It was discovered that the UVR transmission of bleached silk fabrics was four times greater than that of comparable unbleached silk fabrics. In summary, it appears therefore that polyester and blends of polyester with other fibres may be the most suitable fabric in terms of UV protection particularly for white and un-dyed fabrics [19].

Fabric Construction & UV Protection: The three most crucial factors under the fabric construction category are porosity, weight, and thickness. Several studies have found that the best indicator of UVR transmission through white, uncolored fabrics with fiber chemistry is fabric porosity. A measure of weave tightness is fabric porosity, also known as fabric openness. When the yarns in a fabric are totally opaque to UVR and the pores or openings are small enough to prevent UV radiation from passing through, the fabric is considered utopian for sun protection. [20] [21].

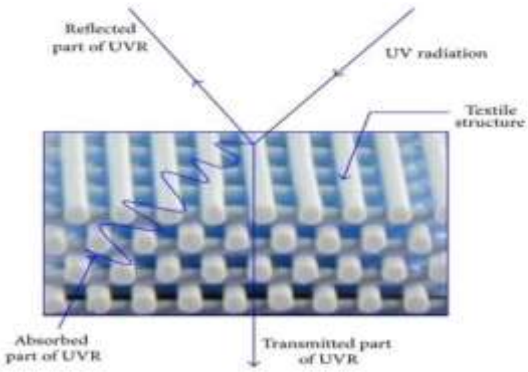


Figure 6: UV radiation and textile structure [22].

Manufacturers: Creora (Korea), KweHwa (Taiwan).

Fibres Used:

1. MIPAN® aqua-X dull for matte appeal with quick dry, moisture management and UV protection
2. MIPAN® regen™ recycled nylon and regen™ recycled polyester
3. askin® quick dry, UV protection polyester
4. cotna® cotton touch polyester
5. Polypropylene for super quick dry benefits
6. Cotton, seaweed and modal teamed with creora® ecosoft for beachwear apparel

Target Markets:

1. Performance surfwear
2. Fashion surfwear
3. Bikinis and rash guards

Figure 7: 3M developed – Vented, Hard, Breathable, comfortable UV Protection Helmet

Figure 8: Euronda (Italy) UV protection eyewear

Figure 9: Exo Tech® UV protected hooded shirt

4.3 High Visibility Textiles:

Safety apparel, also known as High Visibility Textiles (HVT), is essential for the construction and warehouse sectors. Among the many advantages of these vests are their low weight, high visibility, and portability. Because they are composed of intelligent materials and fluorescent colors, employees can be easily identified, as can their organization. According to health and safety regulations, high visibility vests are necessary in crowded areas with a lot of traffic, like construction sites, marshalling yards, and industrial buildings. Workers near entrances and exits must wear reflective jackets or over vests in large warehouses. In addition to offering advice to employers and company management, professional health and safety advisors can assist with local risk assessments. The chance of accidents and fatalities can be considerably decreased by donning a high visibility vest.

Figure 10: High-Vis Clothing

Certification/Standards: EN 20471

Performance Requirements: Color & Retro Reflection, Area of reflective material, position of reflective material. Fabric Color is measured by 'Spectrophotometer'

Material: Reflective Adhesive tape with fluorescent product is using for High Visibility clothing.

Working Procedure: Essentially, the Sun's ultraviolet rays react with the fluorescent colours of the material to create a glowing appearance. The effect of this glow is stronger at times of poor light, like dusk and dawn. However, it can also work using the ultraviolet light from other sources, such as car headlamps [23].

Manufacturers: TeraSafe(UK), Anshell, 3M (USA), HoneyWell(USA), Kermel.

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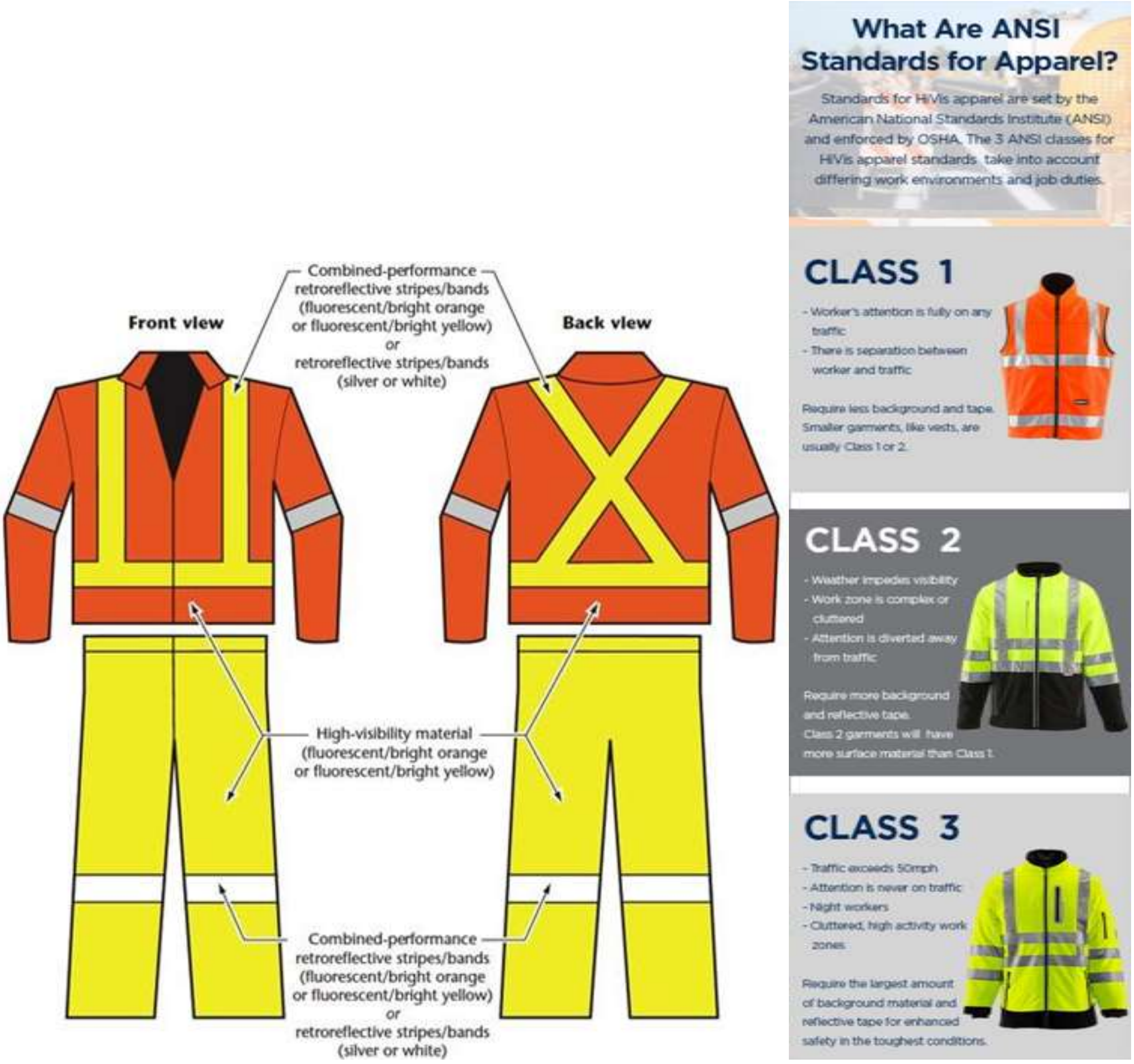

Figure 11: HiVis Clothing Type-2 (full body)

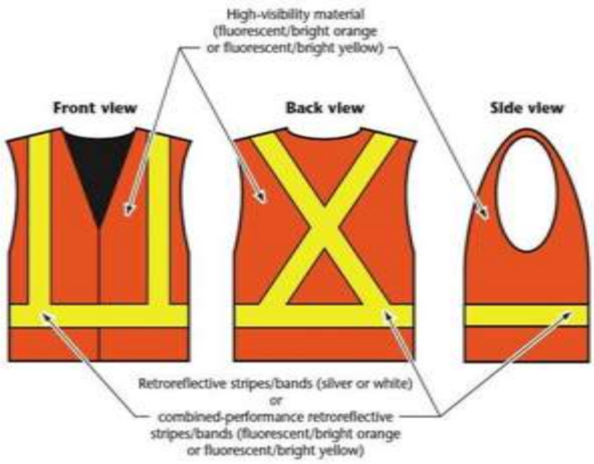

Figure 12: HiVis Clothing Type-1 (vest)

4.4. Ballistic Protective Clothing:

Warfare has been a continuous process since the beginning of humanity, with humans continuously deve loping weapons and armour to protect themselves. Ancient armour was made from animal skins, while medieval warriors covered their torsos in metal plates. Modern armour, such as projectile shielding, has seen technological rebirth in the 20th century, with experiments in World War I and World War II. Modern lightweight body armour, [24] such as ballistic nylon, was developed in the 1950s, and Kevlar 16, a new aramid fiber, improved performance. Hard body armour is made from hard ballistic materials, while soft body armour is made from polymeric lightweight fibrous materials. Textile armour materials include aramids, polyethylene, PBO, polyamide, and new polymeric fibres like PIPD [25].

Figure 13: picture (1) hard body armour & picture (2) soft body armour.

Material: Ballistic nylon is created using a very high-denier nylon thread—typically 1000d and above—though the defining feature of ballistic nylon is not the thread denier (and its accompanying weight), but rather the specific weave used to turn the thread into fabric.
A “ballistic weave” is a particularly tight and dense weave that maximizes the fabric’s durability and tear resistance. (The most common ballistic weave is a 2 x 2 basket weave, as pictured here.) This weave pattern provides exceptional tear resistance in all directions, while the large denier of the individual nylon threads effectively resists abrasion [26].

Figure 14: Close-up of a ballistic nylon 2 x 2 basket weave

Manufacturers: Cordura Fabrics.
Based on the original ballistic woven nylon developed for military body armour, dense, rugged CORDURA® Ballistic fabrics are made with high tenacity nylon 6,6 filament yarns and offer enhanced tear and abrasion resistance.

Characteristics:
Strong - Excellent resistance to tearing
Dense – tight woven fabric profile
Luster/Sheen - 100% high tenacity (> 420D) nylon 6,6 bright filament
Fabric type: Woven – minimum 2x2 basket weave. Can be coated or laminated. Ideal for use in luggage, bags, backpacks, equipment and accessories as well as footwear. Also used in motorcycle gear and apparel.

Manufacturer: Teijin (Australia)
Products: Conventional ballistic protective vests are heavy, uncomfortable and restrict movement. Vests based on Twaron® and Endumax® are different. Leveraging the superior strength, durability and low weight of our high performance aramid fibre, we've created materials with a unique soft textile-like texture. For wearers, it means maximum protection against hazards, but also freedom of movement. Lighter and more comfortable, Twaron®- and Endumax®-based vests allow users to move, work and perform as they need to – when it matters most [27].

Figure 15: (picture-1)Twaron® Platin PT900 is the best-in-class product for the strike face of hybrid ballistic packs. (Piture-2)The Endumax® SHIELD product family is based on Ultra High Molecular Weight Polyethylene (UHMWPE) cross ply sheets, developed for hard armoring, including inserts.

4.5 Spacesuit
A spacesuit is a protective garment used in outer space, vacuum, and temperature extremes, used for extravehicular activity, and is worn inside spacecraft for safety and extra-vehicular work.
Need of Space Suits: (1) We will become unconscious within 15 seconds because there is no oxygen (2) Our blood and body fluids will boil and then freeze because there is little or no air pressure (3) Our skin, heart, and other internal organs will expand because of the boiling fluids (4) We will be exposed to extreme changes in temperature: 248°F (120°C) in the sunlight and -148°F (-100°C) in the shade (5) We will be exposed to various types of radiation such as solar wind (charged particles emitted from the sun) and cosmic rays (6) Inside the spacecraft the atmosphere can be controlled so that special clothing is not

needed, (7) There is no atmospheric pressure and oxygen in space to sustain life so to explore and work in space human beings must take their environment with them,

A Space Suit provides: (1) Supply oxygen (2) Protection of the body from bombardment from micrometeoroids (3) Insulates the wearer from the temperature extremes of space (4) Removes heat and moisture generated by sweat (5) Protects the body from space radiation, (6) Be airtight and resistant to external influences (7) It allows as much unrestricted movement as possible (8) It has a large tensile strength because of the gas pressure inside the garment (9) Allows for communication in airless space (10) The radio communication gear allows the astronauts to keep in touch with each other and with the astronauts inside the space station (11) It also has a very sensitive alarm system in case a call for help is needed.

Materials: Nylon tricot, Spandex, Urethane-coated Nylon, Dacron, Neoprene-coated Nylon, Mylar, Gortex, Kevlar, Nomex etc.

Space Suits Components: (1) Gloves, helmet, torso assembly (2) Liquid Cooling and Ventilation garment (to remove excess body heat) (3) Communications Carrier Assembly (microphones and earphones) (4) Extravehicular Visor assembly (to protect from sunlight) (4) In-suit drink bag (5) Urine collection bag (6) Primary Life Support Subsystem (provides oxygen, removal of carbon dioxide, power, cooling water, radio equipment, and warning system).

Space Suits made of: The Apollo pressure space suit for EVA's consisted of many layers:

1. Three layers of nylon to hold the pressure,
2. Five layers of aluminized Mylar interwoven with Dacron and two layers of Kapton for heat protection.
3. Two layers of Teflon coated cloth (non-flammable) for protection from scrapes
4. The Extravehicular Mobility Unit (EMU) is used for space walking from the shuttle and the space station.
5. The EMU has 13 layers of material including an inner cooling garment, pressure garment, thermal micrometeoroid garment, and an outer cover.
6. The materials used are nylon tricot, Spandex, urethane-coated nylon, Dacron, neoprene- coated nylon, Mylar, Gortex, Kevlar, and Nomex The Spacesuit worn by Neil Armstrong on Apollo 11 mission (1969). [28]

Figure 16: The Spacesuit worn by Neil Armstrong on Apollo 11 mission (1969).

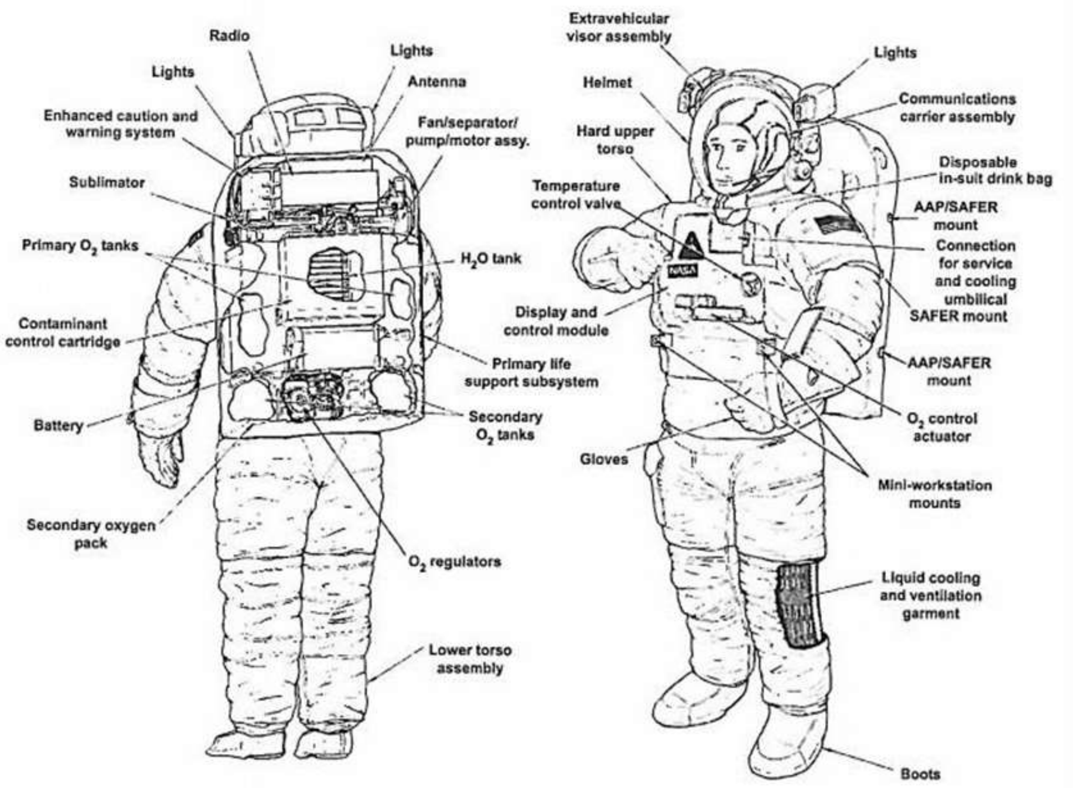

Figure 17: Space Suits All Components Provided by NASA.

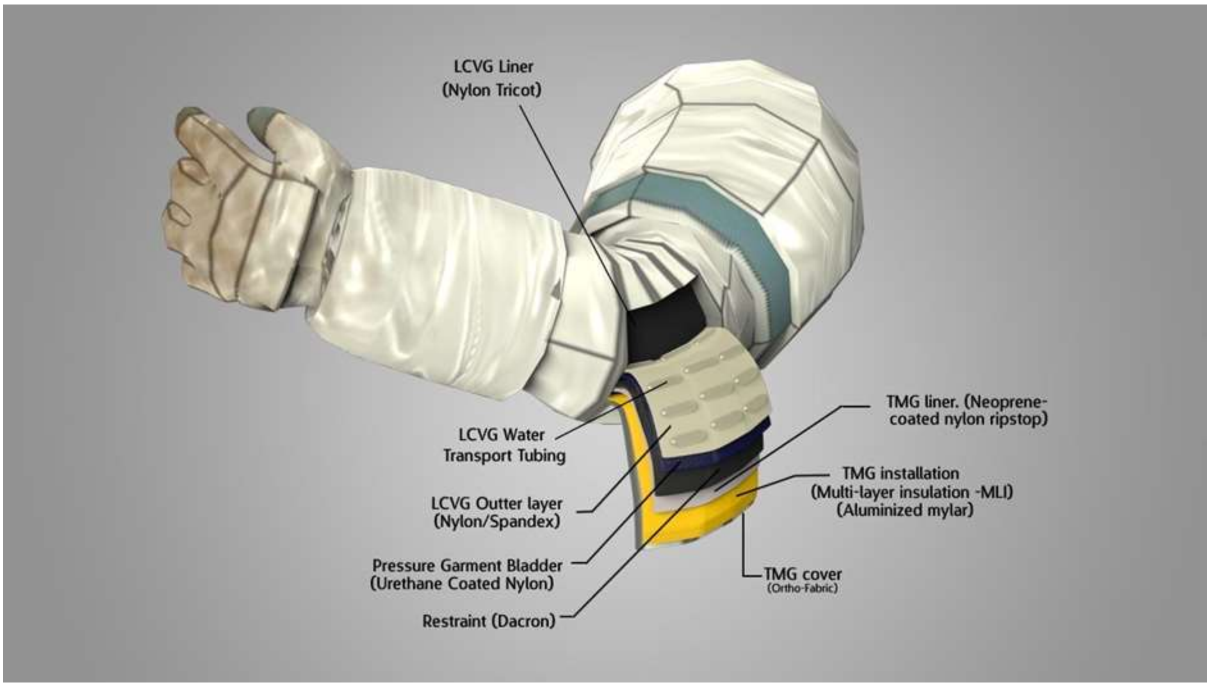

Figure 18: NASA Collaborates with Nanotex Corp for New Thermally Conductive Nano-textile for Use in Space Suit, Visual representation of the layers within the lining of an astronaut suit [29].

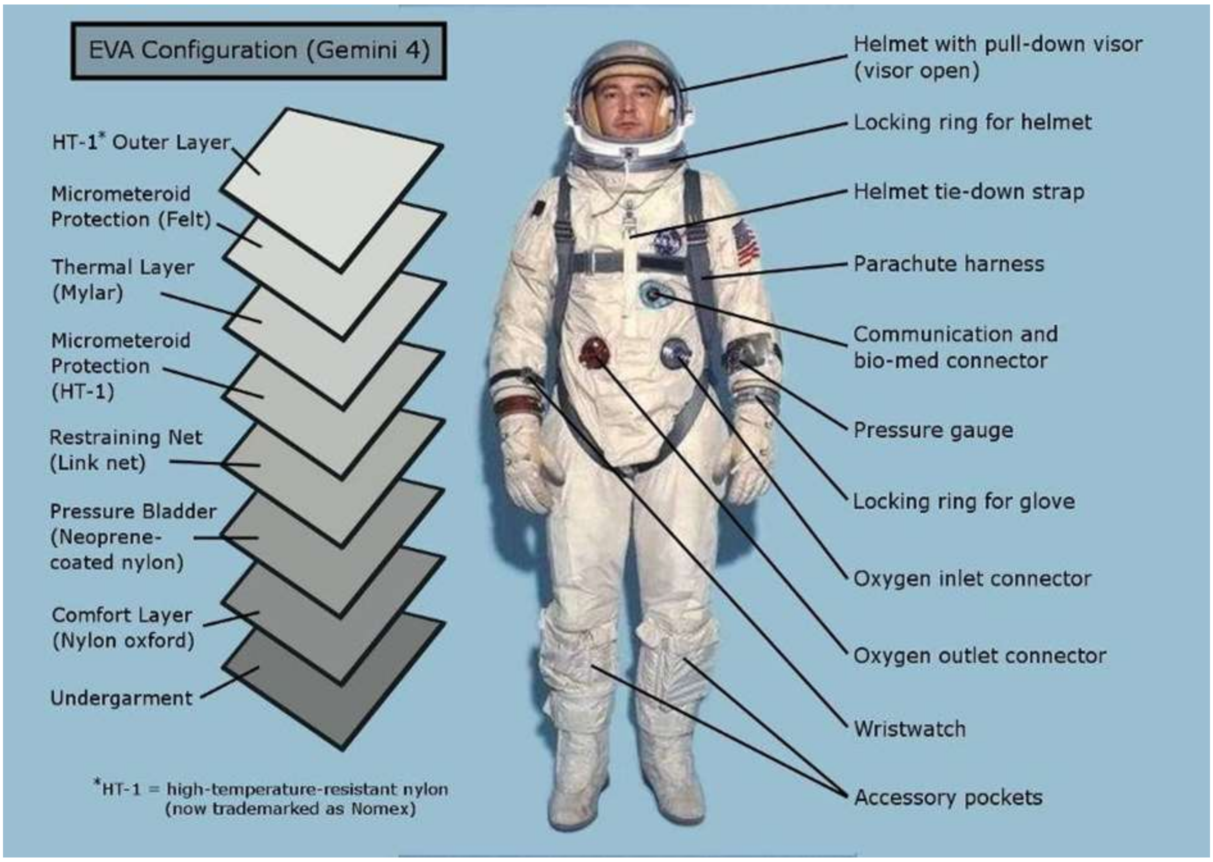

Figure 19: Different Layers of Space Suits for NASA's Gemini Project.

4.6 Electrical Protective Textiles

OSHA's Personal Protective Equipment (PPE) for electrical protection includes safety glasses, face shields, hard hats, safety shoes, insulating gloves, sleeves, and flame-resistant clothing. Additional PPE may be required for specific job tasks. Electric power workers also use Insulating Protective Equipment (IPE), such as line hoses, rubber hoods, and rubber blankets, but IPE is not considered PPE and is discussed separately [30].

Standards: 1.OSHA 29 CFR 1910 SUBPART, 2. NFPA 70-E, 3. National Electric Code 4.
IEEE Std 1584-2002.

Materials: 100% Cotton vs. FR Clothing - 100% cotton will catch on fire & burn, but won't melt to the burn making burn worse while FR will not support combustion, that is, it won't catch on fire and continue to burn. The fabric used in all of the Survive Arc clothing range is the ultra soft cotton/nylon blend. This is a premium fabric with many advantages over the synthetic / nomex/ modacrylics blends that other manufacturers use.

Figure 20: FR Clothing

Electrical PPE Requirements: Electrical PPE (rubber gloves, hard hat / arc face shield, cotton or FR clothing) is required for trouble shooting. After that, applying LOTO and testing dead. The line side terminal of the disconnecting device may still be energized. According to this standard if we are 'exposed' to energised part, electrical PPE is still required. "Exposed" means being within the Limited Approach Boundary, which is 1 ft, for circuits 120 – 480 V. We can "exposure and remove the PPE if you can "Insulate or "Isolate" yourself from the energized parts. Insulate by placing an insulating material over the part. Isolate by placing a rigid barrier over the part to prevent contact, or ensure your body and all conductive tools remain contact and all conductive tools remain > 1 ft. away PPE requirements based on your distance from "Exposed Energized Parts", not the equipment we're working on.

Manufacturers: HoneyWell, NexG Apparels, Unisex Blue, Unisex M.

Figure 21: Electrical Arc flash protective wear.

Electrical PPE Fabric Quality & Application:

APPLICATION	ULTRASOFT – COTTON/ NYLON BLENDS	SYNTHETIC / NOMEX MODACRYLICS BLENDS
Wear resistance	Excellent	Good
Washability	200 washes	130 washes
Comfort	Excellent cotton next to skin	Not skin friendly
Resistance to electric arc flash	Excellent HTN fibre/cotton form a “break open barrier” and the HTN increases ATPV of the fabric	It works
Length of life cycle	Longer life cycle	Shorter life cycle
Weight v protection	200 gm2 = 8.3 cal/cm2 (single layer)	Heavier
Cool to wear	Double Synthetic blends, moisture wicked away	No
Heat Attenuation Factor	High – heat blocked out by the fabric	Poor
Insulator	Cotton – good in winter	Poor
Shrunk	Fabric is double pre-shrunk	n/a

Table-4: Electrical PPE - Table of Application [31]

4.6 Protective Health Care Garments

The medical and healthcare industries are receiving more and more attention from the textile industry, which produces a variety of goods for safety, care, and hygiene. Nearly 12% of the global technical textiles market was expected to be made up of medical and hygiene textiles by 2005. These products fall into three categories: procedure-specific, general patient management, and patient-specific. Manufacturers are creating affordable solutions to shield patients and hospital employees from bodily fluid intrusions, viruses, and bacteria in operating rooms [32].

Figure 22: Medical Textile Products

Products - Medical and Pharmacy division: Adult Incontinence pads, Rectangular pads, shaped pads, urine collector and bag, feminine maternity pad, cotton mesh maternity pads, nursing wipes, gauze, wound dressing, surgical drapes, gowns, plaster, face mask, operation room table and tray covers, head wear, under pads, X ray gowns, scrub suits, barrier and isolation gowns, patient exam gowns, ostonomy bag, super absorbent fabrics, etc. are some products in this division [33].

Materials used: There are many applications for non woven textile products in the medical and healthcare sectors. Non woven have distinct advantages over more traditional forms of fabric formation as they can be manufactured directly from fibres at relatively lower cost. The non woven method is therefore suitable for the production of disposable products, which contribute greatly to the high levels of hygiene required in medical applications by limiting the incidence of cross infection. An extensive product line of disposable non woven is now available for products which require liquid barrier protection, absorbency, filtration efficiency, softness, etc. A dramatic increase in the rise of reusable linen products resulting from a rise in labour costs and a greater awareness of hygiene issues have increased the use of non woven disposable products. Adhesive bonded non woven fabrics are majorly used for hospital usage and sanitary applications, including nappy liners and complete throwaway items. It is these areas that disposables are established on the basis of practicality and hygiene. The development of low bulk density non-woven fabrics helps to achieve the cloth-like characteristics for surgical-care products, such as softness, opacity, substance, surface texture, absorbency, low static, comfort, acoustic deadness, porosity and improved liquid holding capacity, and fast drainage [34].

Product Application	Fibre Type	Manufacture System
Surgical clothing		
1. Gowns	Cotton, polyester, PP	Non woven, woven
2. Caps	Viscose	Non woven
3. Mask	Viscose, polyester, glass	Non woven
Surgical covers		
1. Drapes	Polyester, PE	Non woven, woven
2. cloths	Polyester, PE	Non woven, woven
Bedding		
1. Blankets	Cotton, Polyester	Woven, knitted
2. Sheets	Cotton	Woven
3. Pillow cases	Cotton	woven
Protective Clothing	Polyester, PP	Non woven
uniforms	Cotton, polyester	Woven
Wipes	Viscose	Non woven
Surgical hosiery	Polyamide, polyester	Knitted.

Table-5: Textile materials used in operation theatre [35]

Testing of healthcare garments: Laboratory tests include water repellency, launderability (if recyclable), burst strength and tear strength. The design of barrier fabrics is driven by the concern over HIV. Therefore for these fabrics test methods that would assist in the characterization of products as blood-resistant, blood proof or viral proof. These methods have been established as ASTM 1670-95 and 1671-97. The demand wettability method of measuring the absorbency characteristics of fabrics have been described by Lichstein. This technique measures both capacity and absorption rate simultaneously at zero hydrostatic head. It is applicable to different absorbents, wicking fluids and multiple-ply structures with the absorbent at any angle to the fluid and under different pressures. Other textile products used in hospitals include bedding, clothing, shoe covers, mattress covers, etc.

Sterilization Stability: Sterilization is the process used to inactivate microbiological contaminants and thereby transform the non sterile items into sterile ones. It is essential for hospital applications that sterile products are employed, and there are various techniques by which this can be achieved. Sterilization by steam, dry heat, ethylene oxide, and irradiation process are used depending on the product type and fibre characteristics. A sterilization process can bring about changes in properties as strength, absorbency and appearance.

Many hospitals have added peroxide plasma systems, such as STERRAD, to their standard steam autoclaves and ethylene oxide chambers in the Central Supply Room. When designing fabrics for sterilization it is essential to understand the impact of sterilization procedures on fabric performance features. In the U.S., steam autoclaves generally operate at 250-2700 (121-1320C). In Europe, flash sterilization temperatures up to 1380C have been proposed in respect to concerns about Jakob-Crueze Disease. The polymer selection must be made with this type of temperature exposure in mind.

Antimicrobial textiles: Treated textile articles can include medical textiles such as pads, face masks, surgical gowns, ambulance blankets, stretchers, filter materials and diapers.

Antimicrobial fibres: High performance fibres have been developed which prevent hazardous bacteria from build up and will find applications in the fields of personal hygiene where build up of dangerous bacteria can be hazardous to health: the fibre basically contains a combination of antimicrobial compounds, based on metallic salts which ultimately controls bacteria and fungi. The compounds are embedded in the matrix of fibres which renders it impervious to washing and wear.

Figure 23: Medi-Tech used in OT

4.8 Radiation Protective Textile

Radiation protection, also known as radiological protection, is the protection of people from harmful effects of exposure to ionizing radiation. Exposure can be from external sources or internal irradiation caused by radioactive contamination. Ionizing radiation can cause significant health hazards, including "tissue" effects and "stochastic effects" in low-level exposures. To protect, measures such as time, distance, and shielding should be used. The International Commission on Radiation Protection and International Commission on Radiation Units and Measurements publish recommendations and data to calculate the biological effects of certain levels of radiation and advise acceptable dose uptake limits [36].

1. **Internal Contamination Protective Equipment**: Internal contamination protection equipment (RPE) protects against the inhalation and ingestion of radioactive material. Internal deposition of radioactive material result in direct exposure of radiation to organs and tissues inside the body. The respiratory protective equipment described below are designed to minimize the possibility of such material being inhaled or ingested as emergency workers are exposed to potentially radioactive environments.

Reusable Air Purifying Respirators (APR): Elastic face piece worn over the mouth and nose, Contains filters, cartridges, and canisters to provide increased protection and better filtration.

Powered Air-Purifying Respirator (PAPR): Battery powered blower forces contamination through air purifying filters, Purified air delivered under positive pressure to face piece.

Supplied-Air Respirator (SAR): Compressed air delivered from a stationary source to the face piece,

Auxiliary Escape Respirator: Protects wearer from breathing harmful gases, vapors, fumes, and dust, Can be designed as an air-purifying escape respirator (APER) or a self-contained breathing apparatus (SCBA) type respirator.

Self Contained Breathing Apparatus (SCBA): Provides very pure, dry compressed air to full face-piece mask via a hose.

2. External Contamination Protective Equipment:

External contamination protection equipment provides a barrier to shield radioactive material from being deposited externally on the body or clothes. The dermal protective equipment described below acts as a barrier to block radioactive material from physically touching the skin, but does not protect against externally penetrating high energy radiation.

Chemical- Resistant Inner Suit:

- Porous overall suit- Dermal protection from aerosols, dry particles, and non hazardous liquids.
- Non-porous overall suit to provide dermal protection from:
- Dry powders and solids
- Blood-borne pathogens and bio-hazards
- Chemical splashes and inorganic acid/base aerosols
- Mild liquid chemical splashes from toxics and corrosives
- Toxic industrial chemicals and materials

Manufacturers: DuPont Tyvek® 500 Xpert, Tyvek® 600 Plus, DuPont Tychem® 2000 C Standard, as well as Tychem® 6000 F Standard garments are tested according to EN 1073-2 as protective clothing against radioactive contamination.

Others are 3M (USA), Sanyuan (China), W-Boat (China).

Figure 24: Nuclear Radiation Protective Clothing

5. Further Developments According Protective Textile

5.1 Teijinconex neo, a new meta-aramid fibre:

Teijin is planning to launch Teijinconex neo, a new type of meta-aramid fibre, offering unsurpassed heat resistance, as well as excellent dyeability, according to the manufacturer. Production at a new Teijin facility in Ayutthaya, Thailand, which is expected to nearly double the annual capacity of Teijin's global meta-aramid fibre production, is scheduled to start in mid-2015.

Figure 25: Teijinconex a new type of meta aramid fibre & fabric

This will provide customers with highly diversified solutions for the design and manufacturing of protective apparel, a feature that is not yet available or offered in the market, the company believes. In addition, Teijin’s new production technologies ensure a compliance with REACH and other environmental regulations without additional treatment. Teijinconex neo is expected to further strengthen Teijin’s position and competitiveness in the emerging economies of Asia and other regions, where the demand for heat-proof and flame- retardant high-performance materials is growing due to increasing safety awareness and regulations [38].

Omega Systèmes, a Web Industries company, is responding to needs for personal protective equipment (PPE) in the Pays de la Loire region of France by producing and delivering 60,000 single-use, disposable aprons per day to local hospitals. Single-use aprons are among the most needed PPE items in

Figure 26: Single-use aprons

France, along with face masks and gowns. When Omega Systèmes was contacted by Nantes University Hospital in mid-April 2020 with a request for aprons, the company responded quickly. Omega currently has material to manufacture one million single-use aprons. With their materials supply chain and high-speed precision formatting equipment, they can quickly meet apron needs for hospitals and care facilities throughout France and other European countries. The polyethylene aprons are worn by nurses, doctors, medics and caretakers who meet with patients to examine and carry out treatments, such as taking temperatures or changing an IV line. They are delivered in protective plastic sheaths that meet Nantes University Hospital's strict sanitary requirements [37].

5.2 New TenCate materials for protective clothing:

TenCate Protective Fabrics will launch two new protective products in the TenCate Tecasafe in Dusseldorf, Germany in 2013. Protective knits for company polo shirts and T-shirts are said to be extremely comfortable to wear and also wash well in industrial laundries.
A new protective fabric with a laminate will also be launched for use in flame-resistant industrial outdoor clothing. This fabric is designed to offer optimal protection against rain, wind and other adverse conditions, as well as to provide a high degree of wearer comfort and excellent moisture- regulating characteristics.

Figure 27: TenCate Tensafe Plus

5.3 Merino Wool – New man-made fibre for Protective Clothing:

Armadillo Merino uses superfine wool from hardy, merino sheep in its next to skin protective clothing range to provide professional risk takers including the military, police, fire, ambulance service and heav y industries with superior protection, performance and comfort.

According to Armadillo, merino wool harnesses its unique characteristics to deliver high quality safety workwear garments that are both soft and very strong which when combined with contoured styling provides a superior next- to-skin fit. Armadillo says merino sheep are renowned throughout the world for their fine, soft wool and their ability to thrive in extreme conditions and despite huge technological advances in synthetic fibres, wool is still the world's most technical performance fibre with its complex protein structure giving it unique qualities that are

Figure 28: Merino woollen glove

unsurpassed by manmade materials. Armadillo Merino says it recognises the heritage of merino wool and harnesses its natural advantages to create modern day performance fabrics for the ultimate in enhanced protection, performance and comfort in demanding environments. Using different grades of merino wool combined with technical knit structures, the company has developed a new generation of personal protective clothing.

5.4 Antistatic and flame retardant combination fabrics:

Argar's Tes-firESD range of knitted fabrics is the result of intensive research and development activity where antistatic features combined with flame retardant capabilities give the product what Argar calls an absolutely "irreplaceable protection performance", even in the most risky conditions. The antistatic and flame retardant features of Tes-firESD knitted fabrics fully comply with EN1149, EN11612 and Oeko-Tex Standard 100 Class II Certifications rules [39].

Argar has also partnered with Lenzing FR, the leading producer of flame resistant cellulosic fibres, to manufacture high performance protective knitted fabrics with antistatic and flame retardant features. The first Lenzing FR based knitted fabric in regular production is Fleece E910 which is certified EN1149, EN11612, EN14116 (protection of Workers against occasional and brief contact with small igniting flames), EN61482 (specific certification for Protection of Workers exposed to Electric Arc) and Oeko-Tex Standard 100 Class II Certifications rules.

Figure 29: Antistatic+flamer-etardent combination fabric

5.5 Rare UV-C Light Rays Remove Deadly viruses From Cloth Surfaces:

The deep ultraviolet color of rare UV-C light rays may soon be seen cleaning surfaces, as well as air and water, contaminated with the novel coronavirus that causes the disease. It was discovered on April 23, 2020, that UV-C light destroys viruses from cloth surfaces, including the deadly COVID-19.

The University of California Santa Barbara Solid State Lighting & Energy Electronics Center, SSLEEC, and member companies are conducting research to rapidly bring highly effective UV-C light-emitting diodes, or LEDs, to market. One significant use is in medical settings, where the materials are used to disinfect PPE, floors, surfaces, and HVAC systems. Christian Zollner is a researcher who focuses on the use of deep ultraviolet light LED technology for purification and sanitation. Since the protective suit also protects against UV-C radiation, there is no danger to people. To make the invisible UV-C radiation visible, the headpiece of the protective equipment is coated with a fluorescent paint that glows as the emitters are activated [40].

Figure 30: UV-C proof clothing

5.6 NBC Lightweight Overboot (2019):

It provides more than 24hr protection against chemical warfare agents. It can be fully decontaminated due to its smooth all butyl surface. Boot ensures excellent thermal isolation provided by double liner system, using a quarter inch pp-foam-polyester/viscose inner liner with a 3/8 in pp- wool / radiantex outer liner. Lighter then all existing ECW boots within its category, the boot has a polyester shell with a moisture vapour permeable (MVP) barrier layer, assuring water resistance, good breathability and dryness in all weather conditions [41].

5.7 Nomex® Comfort (2018):

Nomex® Comfort (in fig-31) is a fabric innovation that directly addresses the need for proven fire resistant protection with a comfortable, breathable technology. For over 50 years, garments made with Nomex® fibers have been advancing the performance of protective FR PPE. When it comes to serious hazards in the oil & gas, petrochemical, and general manufacturing industries, wearing the right FR PPE could be the difference between life and death in a workplace fire. The National Fire Protection Agency (NFPA) develops and publishes codes/standards for FR PPE intended to prevent

Figure 31: NBC overboots

injury and death due to fire and electrical hazards. While the Nomex® Comfort material is the lightest weight Flame-Resistant Personal Protective Equipment (FR PPE) fabric, it continues to meet NFPA 2112 and NFPA 70E standards, and provides enhanced inherent heat and flame protection [42].

Figure 32: Nomex FR PPE

5.7 Corsair's FEAM (Fiber Energy Absorbing Material) technology (2019):

With hundreds of uses, Corsair's FEAM (Fiber Energy Absorbing Material) technology is a revolutionary impact energy material made entirely of textile. FEAM is more pliable, breathable, and comfortable than the foams that are currently in use. Its fit and impact attenuation can be altered. It can be made into more effective fire-resistant protective padding and will either replace or supplement currently used foams. Military armor vests, sports protection padding, and sport and military helmets can all use FEAM. It was created by UMass Dartmouth, who found a creative application for the flocking production process. The flock fibers from FEAM create an area that is primarily air-filled, which improves breathability and comfort. Rotational forces can be effectively mitigated by FEAM fibers. FEAM can utilize woven fabrics, stretch fabrics, nonwovens, foams, and plastics in a sheets or rolls format. When applied to fabrics it can be sewn, laminated, welded, or assembled into a finished good [42].

5.8 Nullarbor Fibre:

A sustainable substitute for plant-based fibers that can have a big impact on the environment, like viscose, is Nullarbor Fibre. The Nullarbor Fibre is a tree-free rayon fiber made from organic liquid waste and was developed by Nanollose Ltd., an R&D company based in Australia that specializes in developing plant-free cellulose technologies. Since the fiber was spun into yarn, turned into fabric, and then manufactured into the garment using already-existing industrial equipment, the company has produced a sweater as evidence that Nullarbor can be used within the current industrial protocol. Compared to other fiber production methods used today, the 18-day process to create Nullarbor uses less energy, water, and land. The process of biomaterial technology turns the natural microbe-fermenting liquid food waste into cellulose, which is subsequently changed into a fiber material that resembles cotton, called Nullarbor. In order to greatly increase the production of new fiber by the middle of 2019, the company is currently building a supply chain within the Indonesian coconut industry. [42].

Figure 33: Totally Anti-microbial protective wear

5.8 Future of Space Suits:

A trip to Mars will require more thought than a trip to the space station -

1. Unlike Earth, Mars does not have a magnetosphere to protect astronauts from radiation and micro meteors.
2. We would also be exposed to sand storms and a hyper-cold environment
3. The space suit would also need to be light enough to move around and explore in Martian gravity.
4. Future space explorers on the Moon and Mars could be outfitted in lightweight, high- tech spacesuits that offer far more flexibility than the bulky suits that have been used since the 1960's.

Research is underway at MIT on a Bio-Suit system designed for travel to Mars:

1. It looks like a spandex leotard made out of a stretchy, skinlike polymer that encases the body in a flexible shrink-wrap that prevents the wearer from exploding in the vacuum of space.
2. The Bio-Suit is not only much lighter than conventional spacesuits but it can be outfitted with chemical sensors, wearable computers, and thermal threads for controlling body temperature.
3. NASA is developing "hard suits" that are more flexible, more durable, lighter weight, and easier to put on than current space suits [43].

Figure 34: The SpaceX designed pressure suits are more form fitting and maneuverable than the Space Shuttle's orange suits, Astronauts Bob Behnken and Doug Hurley assigned to first SpaceX crewed launch test out their new space suits. (NASA) above picture.

Figure 35: Upcoming New designated SpaceX Spacesuits.

6. Conclusion

The Protective textile market is respective 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. The market is quite small but exhibits moderately strong growth and produces are generally of high unit values. Due to increasing health and safety issues at work this may be an increasingly attractive segment. 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 products to market. The truth is, we can not afford not to have the ideas and products.

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