Saxion Research Centre for Design & Technology

Textiles for protection at the workplace;

developments in textiles for a safer working environment

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Safety at Work (in Dutch Veiligheid op de werkvloer) is an initiative of the Saxion Research Centre for Design & Technology. The project focuses on how to achieve safety in working environments by using ambient technology. These include personal safety, a safe environment and safe behaviour. The project started on 1 January 2011 and will run for four years. The consortium members are Saxion, University of Twente, Novay, Thales Netherlands, Norma MPM, PANalytical, TenCate Protective Fabrics, Alten PTS and Noldus Information Technology. Also, there is a changing group of participating companies which occasionally participate in the program team. The project is funded by the Stichting Kennisontwikkeling HBO (SKO) under registration RAAK PRO-2-013.

Management summary

This report was produced within the framework of the RAAK PRP project 'Veiligheid op de werkvloer'.

Personal protective equipment (PPE) is used on a daily basis by millions of people all over the EU, voluntarily or as a result of EU legislation.

In this report we deal specifically with the textile/garment aspects of PPE. In this context we must consider the fact that PPE encompasses a huge area with hundreds of different applications of materials and systems tuned to specific needs; from a materials point of view it represents a complex area due to the large diversity of labour conditions.

Textiles and clothing represent an area whre PPE is an important area of attention. On a global scale it is an area of much research. Safety and comfort are becoming more and more important and these aspects must be in balance. Uncomfortable systems will not be used and put safe working at risk. Thus there is a continuous need for technological innovation to improve the effectiveness of PPE systems. Specialization and specific combinations aimed at use under well-defined conditions contributes to finding a good balance between comfort and safety. The design of products, taking into account the individual needs represent an area of intensive research: Safety directed 'fashion design'.

The ultimate goal is the development of proactive systems by which workers (but capital goods as well) are optimally prot ected. There is also a lot of attention for maintenance and cleaning since protective functions may deteriorate as a result of cleaning processes. Another important point is standardization because producers need directions for product development and supply of goods.

In our overview we make a distinction between static and dynamic systems. Static systems provide passive protection, simply by being a part of an equipment that separates the worker from the danger zone. Dynamic systems are more 'intelligent' because these can react to stimuli and subsequently can take action. These dynamic systems use sensors, communication technology and actuators.

From this research the following may be concluded:

1. Safety is obtained by choice of materials for a textile construction, including the use of coatings with special properties, application of specific additives and he use of special designed fibre shapes.
2. The architecture and ultimate construction and the combinations with other materials result in products that respond adequately. This is of great importance because of the balance comfort – safety. But a lot can be improved in this respect.

3. Insight in human behaviour, ambient intelligence and systems technology will lead to new routes for product development and a more active approach and higher levels of safety on the work floor.

Consequently there is a lot of research going on that is aimed at improved materials and systems. Also due to the enormous research area of smart textiles a lot of development is aimed at the integration of new technology for application in PPE. This results in complex products that enhance both passive and active safety.

Especially the commissioners, government and industry, must pay a lot of attention to specifying the required properties that a product should meet under the specific conditions. This has a cost aspect as well because production volumes are usually not that large if for small groups of products specific demands are defined. We expect that through the technology that is being developed in the scope of mass customization production technologies will be developed that allows production at acceptable cost, but still aimed at products that have specific properties for unique application areas.

Purchasing is now being practiced through large procurements. We must than consider the fact that specification takes place on the basis of functionality. In that case we should move away from the current cost focus but the attention should shift towards the life cycle cost. Purchase officials could than follow the so called pre commercial buying strategy whereby in collaboration with industry and scientists the needed products can be developed and produced. This means that buyers must innovate as well and enter into a constructive dialogue with producers and researchers to bring safety to the required level with optimal comfort for the users. This is the subject of the European ENPROTEX project that aims to play a significant role in overcoming the current barriers that exist to innovation within the European public procurement arena in the field of protective textiles. The results are expected by 2012.

Management samenvatting (in Dutch)

Dit rapport werd samengesteld in het kader van het RAAK-project Veiligheid op de werkvloer. Persoonlijke beschermingsmiddelen worden door miljoenen mensen dagelijks gedragen over de gehele EU, vrijwillig of als gevolg van EU regelgeving.

In dit rapport wordt specifiek ingegaan op de textiel/kledingaspecten van persoonlijke bescherming. Hierbij moet bedacht worden dat persoonlijke bescherming een enorm gebied omvat met honderden verschillende toeppassingen van materialen en systemen, afgestemd op een specifieke toepassing; vanuit materialenstandpunt bezien is het een complex gebied door de grote verscheidenheid in arbeidsomstandigheden.

Textiel en kleding is een gebied waarin beschermende kleding een belangrijk aandachtsgebied is. Er vindt wereldwijd veel onderzoek plaats op dit terrein. Veiligheid en comfort worden steeds belangrijker, omdat deze met elkaar in balans moeten zijn. Niet comfortabele systemen worden niet gebruikt, waardoor de veiligheid in het geding komt. Er is dan ook een voordurende behoefte aan technologische vernieuwing om de effectiviteit van beschermende systemen te verbeteren. Specialisatie en specifieke combinaties toegespitst op gebruik onder goed gedefinieerde omstandigheden draagt bij aan het vinden van een goed evenwicht tussen comfort en veiligheid. Het ontwerp van een product, rekening houdend met individuele behoeftes is een gebied waarop veel onderzoek plaatsvindt: op veiligheid gerichte 'fashion design'.

Het uiteindelijke doel is de ontwikkeling van proactieve systemen waarin de werker (maar ook kapitaalsgoederen) optimaal wordt beschermd. Veel aandacht is er ook voor onderhoud en reiniging omdat door reinigingsprocessen bijvoorbeeld beschermende functies kunnen afnemen.

Een verder belangrijk punt is standaardisatie omdat producenten richtlijnen nodig hebben om van uit te kunnen gaan bij productontwikkeling en levering van goederen.

In dit overzicht maken we onderscheid tussen statische en dynamische systemen. Statische systemen leveren passieve bescherming simpelweg doordat ze deel uitmaken van de uitrusting, waarbij de werker van de gevarenzone wordt gescheiden. Dynamische systemen zijn "intelligenter" doordat ze kunnen reageren op prikkels en vervolgens actie kunnen ondernemen. Deze systemen maken gebruik van sensoren, communicatie technologie en actuatoren.

Uit dit onderzoek kan het volgende geconcludeerd worden:

1. Veiligheid wordt verkregen door de keuze van materialen voor een textiel-

constructie, inclusief het gebruik van coatings met speciale eigenschappen, het toepassen van speciale additieven en het gebruik van speciaal vormgegeven vezels.

2. De architectuur en uiteindelijke opbouw en de combinatie met andere materialen levert producten die adequaat functioneren. Deze aspecten zijn van groot belang in verband met de balans veiligheid en comfort. Hier kan nog veel aan verbeterd worden.
3. Inzichten uit de gedragswetenschappen, ambient intelligence en systeemtechnologie zullen leiden tot nieuwe productontwikkelingen en zullen veiligheid op de werkvloer op een hoger niveau brengen.

Onderzoek of R&D richt zich vooral op verbeterde materialen en systemen. Als gevolg van het enorme onderzoeksterrein ‘smart textiles’ is er veel onderzoek naar nieuwe technologie om toe te passen in producten voor de persoonlijke bescherming. Dit leidt tot complexere producten die de passieve en de actieve veiligheid vergroten.

Speciaal de opdrachtgevers, overheden en bedrijfsleven, moeten dan veel aandacht schenken aan het specificeren van de gewenste eigenschappen waar een product onder de voorkomende gevallen aan moet voldoen. Dit heeft een kostenaspect omdat de productievolumes meestal niet erg groot zijn als er voor elk geval speciale eisen worden gesteld. We verwachten dat door de technologie die ontstaat als gevolg van mass customization productie technologie ontwikkeld wordt waardoor tegen acceptabele kosten speciale op elk geval toegespitste eisen veilige producten geproduceerd kunnen worden.

Inkoop geschiedt nu veelal door grote aanbestedingen. Hierbij moet bedacht worden dat er functioneel gespecificeerd wordt. Ook moet er niet alleen aan de kosten voor ontwikkeling en eenmalige productie gedacht worden (zoals nu!) maar moet er veel meer aandacht komen voor de kosten over de gehele levenscyclus van een product. Inkopers kunnen dan een zgn. precommerciële inkoopstrategie volgen waarbij samen met de industrie en onderzoekers de gewenste producten ontwikkeld en geproduceerd worden. Dus ook de inkoop moet innoveren en een constructieve dialoog aangaan met producenten en onderzoekers om de gewenste veiligheid op een goed niveau te brengen met optimaal comfort voor de gebruikers. Dit is het onderwerp van het EU-project ENPROTEX, met als doel het overwinnen van de obstakels waar innovatie vandaag de dag mee te kampen heeft als het gaat om Europese Openbare aanbestedingen in de sector van de beschermkledij.

Contents

1. Introduction

This work was executed within the framework of the RAAK project 'Veiligheid op de werkvloer'. The more specific aspects of working environments are described and studied in other work packages of this research project. Here we want to discuss some general facts that relate to clothing. Personal protection materials, and other personal protection matters.

Personal protection spans a vast area of hundreds of different applications of materials and systems applied and tuned to specific working conditions. From a materials and systems point of view, it represents an area of enormous complexity because of the many differences between the various working conditions.

If we consider the position of a person in a working environment we can distinguish some typical characteristics or interactions where protective materials or systems interfere:

1. Interaction with the machine or object that is being used or worked upon.
2. Interaction with the working environment.
3. Interaction between co-workers/colleagues.

In all of these interactions materials are being applied to perform certain tasks. Just to get an idea below a few examples:

- Gloves that protect the worker against sharp cutting tools, but also gloves that protect against dangerous chemicals or microorganisms.
- Protective gear that fire-fighters use: complex high tech suits, multilayer, fire resistant, and nowadays fitted with built-in communication systems. Comfort has become a major issue.
- Nurse uniforms: hygiene is an issue, but fashionable looks and comfort are key.
- In building and construction: think of the huge tent-like structures that cover whole facades to protect builders from weather.
- Goggles are being used in machining and welding. A wide range of specific materials and systems are being used.
- Separation of areas is done by flexible screens or curtains to prevent cutting particles, sparks or other unwanted effects to spread into the environment.
- Furnace operators' aprons to protect against hot metal splash.
- Fire entry suits.
- Racing car drivers' suits.

In all these solutions to specific problems materials, and in many cases textiles, play a dominant role. Thus we may conclude that functional textiles offer solutions for protective clothing for work wear, hazardous industrial occupations and extreme hazard protection.

Advances in clothing technology are continuous. Much research is aimed at the development of multifunctional protective clothing. The issue is to maintain a good balance between protection and comfort. Another trend is the use of protective clothing for specific groups of workers. We also see the emergence of smart systems or intelligent systems focus on task analysis and data interpretation. This development may lead to proactive systems that actively remove a person away form an endangered area.
Care and maintenance of textiles used in protective applications are always key issues since cleaning can destroy the protective functionality.

Standardization is of utmost importance since producers need to have guidelines for their product specs and users have a guarantee that the system works as may be expected (liability, peace of mind, protection).
There is a continuous need for advances in technology to improve the effectiveness of protective systems.

In the following text we will discuss the developments in this area in more depth with a focus on functional textiles. But before that we have to look at laws and legislation since protective textiles are subject of strict standards and rules.

2. Law and legislation: the rules and standards

PPE (personal protective equipment) is worn by millions of workers in the EU on a voluntary base or due to EU regulations. In principle the employer is responsible for supplying the right PPE tot their workers. The specifications of the PPE are regulated by EU-directives. Many of these directives have been transferred into product standards (EN). When a product complies to the standard, it automatically fulfils the demands from the directive. However, it is important to notice that the directives are the governing body and not the EN-standards. This is important due to the facts that standardization committees very often are dominated by suppliers. Therefore an EN-standard often reflects the commercial interests of suppliers and they are not always based on scientific research or daily experience. An example of an EN-standard is EN 469, which describes fire fighting gear. This standard is continuously under review. From a scientific point of view and from daily experience, ergonomic properties have to be part of EN469. However this is blocked by some participants in the EN 469 norm committee as it may compromise their materials used in fire fighting gear.

For many activities employers are required to provide their workers with the necessary protective clothing and protective equipment (helmets, gloves, safety boots, eye protection, hearing protection, falling prevention). This is governed by the occupational health and safety regulations (in NL: Arbo-wetgeving). For an optimal functioning of a PPE-assembly, the providers of the PPE are responsible for the complementarities of the different items. The protective wear has to cover and protect during all activities and movements.

With courtesy to Jan Heukelom, LFR, NL

3. Technology and developments

In this chapter we distinguish static systems from dynamic systems. Static systems provide passive protection simply by being part of the wearers outfit or separating the "danger area" form the worker. Dynamic systems are more intelligent, use sensors, communication technology and actuators as part of the textiles.

Static systems and technology: Materials technology

Table 1: static protective materials

The table below summarizes static systems.

Heat/flame protection Technologies: Additives and coatings, inherent inflammable materials	Heat/ Extreme cold resistant* Insulation	**Choice of materials**: 3 approaches to insulate the surface or wearer: 1. Materials with heat resistant additives, chemical treatment or finishing of conventional fibres, 2. Materials that are heat resistant by use of inherently flame retardant fibres, chemical structure and material properties: aramides 3. Combination of layers ▪ the application of a surface coating, Aluminium layers ▪ Thermal inertia and insulating character are both related to fabric weight and area density, however heavier fabrics become more uncomfortable in hot environments 4. 3D textile constructions designed to contain phase change materials 5. Polyester hollow fibres or polyolefin micro-fibres 6. Inflated tubing 7. Electrical heating
	Flame proof	1. Choice of materials ▪ Flame retardant finishes based on chloride or bromide, Aluminium hydroxide and Magnesium hydroxide fillers 2. Flame retardant coatings: additives that act as flame retardants. 3. Foam technology: material that burn to a carbon layer that protects from further burning. Blending of flame retardant and non-flame retardant fibres

Mechanical protection Technologies: Shear thickening fluids for instantaneous reaction to applied forces like impact Nano particles and fibres for reduced weight and stronger composite materials 3D constructions	Cut and Stab resistance and protection	1. Choice of materials: based on use of high modulus fibres that act as a mechanical barrier: aramides, (Kevlar, Twaron, Technora) 2. Structure of materials. 3D textile constructions designed to contain and retain shape memory materials 3. Highly oriented ultra high molecular weight polyethylene (e.g., Spectra, Dyneema), 4. PBO (e.g. Zylon) is p-phenylene-2-6-benzobisoxazole, 5. polyamide (e.g. Nylon) 6. PIPD (Polypyridobisimidazole) with high compressive strength (M5, under development)
	Impact protection	1. Polycarbonates in goggles and screens 2. Polyetylene, but also polyester wovens used in curtains to separate dangerous spots 3. 3D structures, knittings and wovens to protect the wearer from mechanical impact (TU Dresden, RWTH Aachen)
CBRN-protection Atmospheric Technologies: Fully encapsulating ensembles made from air impermeable materials with proper closures provide the highest levels of protection (but lowest levels of comfort)	Chemical protection	1. Chemical inert impermeable barriers (e.g. PTFE, PVC, neoprene) 2. Adsorptive barriers (e.g. active carbon) Micro-porous films can be combined with adsorbent-based materials to provide a film with liquid chemical resistance that adsorbs large molecular weight chemical vapours. 3. Soil release finishes (plasma, grafting, resin) 4. coated fabrics Breathable coatings: Microporous membranes and coatings waterproof coated fabrics based upon PVC, rubber, or polyurethane 5. visors or face shields
		As for chemical resistance 1. Materials/layers that reflect radiant thermal energy: heat reflective

surface activation and modification: plasma treatment, vapour deposition UV treatment Grafting chemicals on activated sites	Surface Radiation protection	treatments such as aluminium layers are used effectively 2. UV protection: Porosity, colour, weight, and thickness. Additives like Ti02, UV Absorbers. Stretch and moisture increase UV transparency
	Biological protection	As for chemical resistance 1. Antimicrobial fibres (chemical, nano-silver) 2. Protection against microorganisms and enzymes 3. Soil release surface
Electrostatic protection	Electrostatic discharges (ESD) are ignition source for gases, vapours, or powders	1. Conductive yarns like carbon yarns, copper yarns woven in the outer layer of the garment 2. Conductive finishes (PEO, grafting, corona/plasma treatment)
Generic technology		Electro-spun nanofiber-based membranes for lighter weight clothing
Comfort enhancing materials	Temperature regulating materials	1. Phase change materials: salts or waxes that reduce extreme temperature effects. 2. Luxicool is a light elastic monofilament which can be used in all standard textile technologies such as weaving, knitting and braiding. Its cooling efficiency issaid to be generated by a dual effect - the thermal conductivity of the polymer itself and the accelerated evaporation of moisture due to the specific polymer construction. It is probably the only filament that evaporates and cools and really cools (www.innovationintextiles.com)
	Insect repellants	Microcapsules can be coated of bound to fibre surfaces, use of nanocomposites attached to fibers (TU Dresden, RWTH Aachen)

Notes

Thermal Conductivity

- *Thermal conductivity is one of the important thermal properties of a fabric. This can be thought of as how well a fabric "breathes". A fabric that has a high thermal conductivity easily lets heat pass from a hot side (say the body of the wearer) to a cooler side (the air on the other side of the shirt). For clothing, especially clothing that's meant to protect against heat, thermal conductivity is a very important factor.*

Heat Resistance

- *Another factor, one which is the inverse (opposite) of thermal conductivity, is the fabric's heat resistance. As it might imply, a fabric's heat resistance is how much it resists heat being transferred through it. So if a fire fighter's jacket has a high heat resistance, then it will not only keep in the heat from his body temperature, but it will also stop the heat from the flames in a building from getting through his coat to burn his skin.*

Thermal Resistance

- *While it might seem similar to heat resistance, a fabric's thermal resistance refers to the fabric's thickness. Even fabrics with a high thermal conductivity like cotton may have a higher thermal resistance if that cotton is put in many layers to increase its thickness. So a fabric's thermal resistance is how long it actually takes a heat transfer to occur as heat moves through the fabric in one direction at the speed given by that fabric's heat conductivity.*

Conclusion on static systems

1. Looking at the overview it can be concluded that safety is obtained primarily by choice of materials of the construction: Aramides, Kevlar, Dyneema, polycarbonate, and the like.
2. The secondary option is the use of coatings. A broad selection of coatings is available: PVC, Polyurethane, and ceramics. Nanocoatings offer specific benefits in soil and water repellence. More advanced coating and the incorporation of new functionalities is discussed in the next chapter.
3. The third option is the use of additives to obtain specific properties: flame retardants are a good example, but also UV absorbents to protect the worker from UV radiation, carbon fillers to reduce electrostatic charging.
4. The shape/geometry of the fibres are also critical, we see the development of hollow fibres and fibres with surface structures to enhance comfort properties like moisture transport or cooling effects. In addition the use of conductive yarns, carbon, and copper, to avoid electrical charging is widely applied.

5. The architecture of the textile is of great importance. Knittings and woven textiles are used for the greater part. Non wovens are being applied to obtain 2D stability as interlinings or between layers for comfort reasons, the relatively new 3D wovens and knit ware are areas of further improvement: thickness can be tuned to specific needs. They provide comfort enhancing effects, impact benefits and allow for the incorporation of e.g. shear thickening materials in impact protection.
6. The final assembly of the gear or professional clothing, combining it with specific utensils is an area where many improvements find their way to the market. Fire fighters uniforms for example are continuously being improved, new materials and new insights form research into cause – effect studies lead to new and improved uniforms. This will be discussed in more detail in chapter 5.

Overall: a lot of progress has been made in the area of static protection. Direct protection and more indirect improved comfort immediately contribute to better safety for the workers. This is an area of continuing research since obviously it leads to direct improvement of the workers safety.

Dynamic systems

These systems are more complex. Use is being made of materials that contain built in intelligence: smart materials. In addition use is being made of combinations of textiles with electronics: wearable electronics. Examples are sensors, communication technology, and actuators like displays, alarming systems or even control of exoskeletons that move a person away from a dangerous spot. In the table below we summarize these (edition.cnn.com/2010/TECH/innovation).

Table 2: dynamic systems

Passive or active control* Smart functions Change of properties (insulation, permeability) by external trigger	Sensors: Soft sensors, fibre like sensors Interconnections between textiles and electronics Care and maintenance – durability Interoperability – standard protocols Reliability sensors (esp. under harsh conditions)	Sensing and data-acquisition of motion, radiation (IR, UV, visible light), electro-magnetic signals, mechanical parameters, Chemicals, temperature sensors, gas sensors, piezoelectric Films, switches. • Touch pads or handwriting recognition • Sensors for temperature, pressure, accelerator • GPS-modules for navigation • Acoustic sensor (e. g. microphones) • Simple transponder sensor and smart labels
System components and infrastructure	Data processing and decision algorithms needed for right interpretation of the signals	Data-storage and communication systems. Reliability data-transmission is essential. Context awareness to improve interpretation of signals / data is a need. Example: chain saw sensor built into trousers for the protection of forestry workers (Hohenstein, avantex 2011)
	Conductive yarns	Use of conductive yarns to build a conductive infrastructure in the knitting or wovens (special care for knitting or weaving technology). Copper, conductive polymers like PANI, acetates, carbon fibres (Dalsgaard) Plasma metalcoated fibres: Cu, Ti, Ag UV PU coated metalized PES, PA fibres (Ganu et al, Kluge et al), Ge nanowires, Si nanowires (Buyle et al, Korgel)
	LEDs, sensors	Yarns with built in sensors and LED's (Dias) Polymer optical fibres of PMMA, Polycarbonate (Xiaoming Tao, Ali Harlin, et al)

	MEMS	MEMS for Drug delivery, mechanical action, lighting. Sensors for Danger warning. Workwear heatingsuite, high visibility, gas sensing,temperature sensing, movement sensing, alarm sounder (Dr Steve Beeby)
Energy systems	Energy supply / power management / Electro-active polymers	Power generation by deformation (piezo-electric films) or movement and body heat. Piezoelectric Films are being used. Energy storage: Li ion packs, alkaline and Ni-MH primary and rechargeable power units • Commonly known round and small Li-ion batteries • Thin flexible Li-ion accumulators with no limitation as togeometrical dimension • Solar generators based on miscellaneous technologiessuch as crystalline silicon, amorphous silicon or on aflexible basis Power generators using the magnetic dynamic effect • Power generators using the piezo dynamic effect • New kinds of micro fuel cells (in development) • Power generators using electromagnetic waves
actuators	Actuators: response on impulse from sensor	Mechanical (tactile), noise, light, … Artificial muscle structures to support/ take over body motion Switches Miniaturized loud speakers • Several kinds of device-human interfaces like opticaldisplays (passive LCD and active TFT, organic LED, bistablecholesteric LCD) or virtual displays with specialglasses • Smart phone networksfor telecommunicationapplications or health care • Touch pads or handwriting recognition • Sensors for temperature, pressure, accelerator • GPS-modules for navigation • Acoustic sensor (e.g. microphones) • Simple transponder sensor and smart labels

	Light emitting textiles	Built in LEDs for alarming directing, crowd control, (many researchers work on this area)
Controlled release systems	Controlled / triggered release of chemicals	Application of nanotechnology Microencapsulation of functional products to allow protective effects to activate at the critical juncture and also to hold concentrated forms of protective products
smart material properties	Shear thickening fluids for instantaneous reaction to applied forces like impact	3D structures Nanostructures that harden upon impact
	Shape memory materials	Self healing materials Artificial muscles (onlinelibrary.wiley.com)
	Smart coatings and dyes	See list below
Combinations with electronics, wearable electronics, systems	Clothing that is combined with electronic systems to alarm, sens, act	Combining headset/helmets with control switches in the coat (www.texsys.de)

Smart protective suits will detect a risk and will react to it. The textile clothing or garments should try to prevent the impact or event, for instance by warning the person to move, or by moving the person by using the built-in muscle-like fibres. Alternatively, the necessary parts of the suit must transform into protective zones, for instance by built-in air bags or by local thickening and hardening (flexible nano-armour). The textile or other materials provide an adequate reaction, such as fixing ruptures (self healing systems), providing medication (triggered release), calling for help (sensing, data transmission, data processing, actuating) should this be necessary.

R&D is focussed on the embedding of electrical functions directly into textiles using conductive polymer yams or metal coated yams. Soft textiles sensors and actuators are required to provide functionality and monitoring. For future systems this also requires conductive circuits printed onto textiles, and optical fibres and photonics into woven structures with potential to change colour or act as a flexible display. The key factor to be resolved is the robustness of the systems, before ubiquitous applications can be developed.

The current trends are that there is a shift from mass production to mass customization and personalization. Fashion is increasingly playing an important role in achieving acceptance of personal protective clothing.
Development trends for innovation and technology are in the areas that follow:
Polymer technology: research into new fibre materials, composites and coatings is going on a global scale. The embedding of functional properties both in the fibres and in coating is subject of intensive research.
A lot of research is aimed at the incorporation of smart of intelligent/electronic components into the fibres. See research at FhG-IZM,Philips, and Hueck where LED's, chips, and quantum dots are combined with fibres to achieve miniaturised smart systems that can resist repetitive laundering.

All these innovative research programs lead to polymer and systems technology that lead to variable shaping, low weight, flexible, properties adaptable by chemical modifications, affordable technologies, and applicable for processing.
These developments lead to possible application of flexible substrates and complex integration of functions. The objective is to develop and introduce really small ("invisible") and smart systems, that means high performance by small dimensions. Also required are stable and sup-

ported interconnecting and communication platform as e.g. USB, Bluetooth, WLAN or Zigbee.
The integration of new parts must not be complicated. The prices have to be user friendly! This holds for the components as well as the services based upon them.

Adapted solutions with integrated electronics are already on the market. One can buy jackets with mobile phones and/or MP3 player from Levi's / Philips and Infineon / Rosner. The Wearable Electronics Project by Philips resulted in a Sweatshirt with Camera. Often those products are intended for use in rescue or outdoor activities.

Developments in dynamic systems

Functional clothing may well be the next platform for the protective garment industry value growth. Functional clothing provides professionals and consumers with customised properties to support their specific activities(medical staff, lab personnel, security forces, sportsmen, elderly and other dedicated target groups. The topics discussed also create new opportunities for textiles and garments. Below a few examples:

- Recently the textile research chair of the University of Twente reported on the digital application of b-cyclodextrine on textiles. The importance is:
  1. Digital printing of micro drop opens the possibility to precisely place functionalities where you want them according to a predetermined pattern. If necessary in more than one layer.
  2. It creates the possibility to precisely deposit functional compounds that are included in the micro particles, like controlled release compounds such as antibacterial compounds, UV protective agents or to achieve color effects.
  3. ß-cyclodextrine was chosen as a model compound. It was also shown that the ß-cyclodextrine can be chemically bound to the fiber (Agrawal, Warmoeskerken).

- This Group also studies hydrogels for fiber modification. These can also be used to act as depot compounds for controlled release. Another benefit may be moisture control and better wear properties (Tourrette et al).

- Light emitting textiles is a research work which focuses on the integration of optical fibers into textile structures. The aim is to create textile light designs which offer big light surfaces that have an even all over and strong light effect. Finally they could be used as big movable light screens in a space either private or public Optical fibers withstand the weaving process and the samples are able to light up.
  Optical fibers have been tested both in the weft and warp system. The longest length of light shining through optical fibers in one piece in the weft insertion reached up to 1,60m (maximum machine width). The light in the warp system passed until circa seven meters by eight meter warp length. From the weaving production point of view, after one year of tests on machines it can be recorded that suitable weave structures and material combinations have been found to permit the production of self-emitting textiles based on the integration of optical fibers into woven structures (www.fibre2fashion.com).

In order to really make progress in the area of dynamic textiles and to make the addition of functionalities possible we need a breakthrough in enabling or production technology. Design of multilayer functional structures is complex and design methods need to adapt to this rapid changing field as well. Hybrid and composite structures need a different approach both from design and from a production point of view. The addition of nanotechnology components, encapsulation of active principles, and incorporation of electronic circuits in textiles or fibers require the possibility to produce with digital printing on a large scale. Manufacturing of resilient ballistic structures and the use of composites moldable at low temperatures needs advanced assembly technology.
Structures with micro- and nanofibers and the handling of extra-high tenacity woven structures require production systems capable of handling these materials.
Self-cleaning covering materials and other advanced coatings can only be done if coating technology moves to higher levels of processing.

Conclusions for dynamic systems

1. This is an area of tremendous complexity and huge research efforts.
2. If combined with a diverse area of protective textiles one can easily see that the real challenge is the "art of specification". This specification must be based on a real end user need.
3. One of the major hurdles is the diversity of the protective clothing market. Volumes are of a relative small size and consequently the required business cases are not strong enough to carry the relative heavy investments required for production equipment.
4. Many of the developments discussed here are at a technology readiness level of 4 to 6. That means that it will take 3 to 5 years before these products can be introduced into the market.
5. If we combine point 3 and 4 it can be concluded that real end user needs are the only guarantee for speedy market introductions.

Coatings, static and dynamic

Coatings are a separate area of development. The use of membranes like Goretex or Sympatex, thin coated membranes that transport vapour (sweat), but stop water are in use in many applications. Comfort is greatly enhanced by these materials. In combination with specific fibre geometries comfort is greatly enhanced. The combination with Coolmax fibres or other fibres extent the comfort factor.

In this respect self healing materials are of importance. If coatings can repair themselves are being damaged that would be a great improvement.

Coatings are also combined with other functionalities. Such as:

1. Breathing
2. Skin-friendliness
3. Non-allergenic
4. Soil/stain repellent
5. Fluid repellent
6. Anti-microbial
7. Hygiene
8. Anti insect/mosquito
9. Mothproof
10. Flame retardant
11. Flame shielding/ heat reflection
12. Heat protection
13. Anti-static
14. Anti-abrasion
15. Impact protection
16. Tear resistant
17. Wrinkle free
18. UV protection
19. Radiation protection (x-ray, electrons, radio-activity)
20. Light reflection (gloss and matting)
21. Color fastness/ anti fading
22. Colour control /warning
23. Tracking and tracing
24. Communication
25. Positioning
26. History tracking
27. Conductivity
28. Shine
29. Wind proof
30. Anti fibrillation
31. Shrink resistant.

In conclusion: for protective clothing, or more in general protective textiles, developments in this area must be followed with close attention. Many applications are already possible. Care and maintenance are key issues since at the laundering process these functionalities tend to disappear. For that reason the EU project "Wash and Load" is important for Protective textiles.

4. Clothing aspects

The degree of comfort of personal protective equipment (PPE) was investigated in an automobile encapsulating plant. Up to 96.2% of employees used one or a combination of PPE. Only 8% of the workers felt their respirators were comfortable, 30% tolerated their respirators, and 62% rated them as uncomfortable. The percentage of employees who rated their PPE (other than a respirator) as comfortable ranged from 32 to 52%. For comfort factor, coveralls/aprons rated 52%, safety glasses 51%, rubber gloves 42%, and hearing protectors 36%. PPE was tolerable (just acceptable) for about 30% of the employees (www.ncbi.nlm.nih.gov).

To increase the effectiveness and safety of PPE, the human-factor aspects of PPE design should be emphasized more and quality improvement should cover the wear ability of PPE.Something funny is going on in the world of protective clothing. Where traditionally design of personal protective equipment (PPE) was driven by functionality and comfort, manufacturers are now increasingly offering products styled with more than a nod to high- street fashion. So what is driving some eye-protection makers to adapt their ranges to mimic snowboarding chic or safety footwear manufacturers to produce lines influenced by the latest trainer styles or weekend walking boots?

Examples of the new breed of PPE include Peltor's "sports style" Fuel spectacles, whose wraparound shape and mirror lenses make them look like they belong on a ski-slope, but which conform to the EN 166 1.F and EN 172 standards for impact resistance and ultraviolet light filtration. Or Pulsafe'sMetalite model, aimed at construction and manufacturing workers and also certified to EN 166, but described as "straight from the fashion catwalk". Timberland Pro emphasizes that its range of safety footwear and clothing comes with "designer desirability" and Jallatte promotes footwear which "draws inspiration from the latest trends and fashions".

A skeptic might argue these new fashion-conscious lines are just another way for a lucrative industry to persuade customers who cannot choose to do without their products (without compromising their duty of care to employees) to spend more. But the makers argue that if protective gear is less clumpy and more attractive, more like leisure clothes, then employees are more likely to put it on and keep it on and may even be pleased to be seen in it (www.healthandsafetyatwork.com).

Employees who believe PPE is not necessary for their work or who consider it too uncomfortable to wear run the risk of leaving themselves unprotected and vulnerable to occupational injuries. According to a new survey from Kimberly-Clark

Professional, this happens all too often.
Kimberly-Clark Professional conducted an online survey of 119 EHS professionals on their work force PPE compliance. The results reveal that 89 percent of safety professionals observed workers not wearing PPE when it was needed, with 29 percent claiming they had noted this unsafe behavior on multiple occasions. Gina Tsiropoulos, manufacturing segment marketing manager for Kimberly-Clark Professional, said this rate of noncompliance poses "a serious threat to worker health and safety."
"While the reasons for noncompliance are varied, the threat to workers is clear-cut," said Tsiropoulos. "Without the proper use of PPE, they are at risk of serious injury or even death."
The most common reason for PPE non-compliance (at 69 percent) was the belief that PPE was not necessary. But workers also opted out of donning PPE if they believed it to be uncomfortable, too hot, a poor fit, not available near the work task or unattractive.
According to 24 percent of survey respondents, eye protection proved to be the "most challenging" category in terms of PPE compliance, followed by hearing protection (18 percent), respiratory protection/masks (17 percent), protective apparel (16 percent), gloves (14 percent) and head protection (4 percent).
Bureau of Labor Statistics (BLS) data show that of the workers who sustained a variety of on-the-job injuries, the vast majority were not wearing PPE. EHS professionals who responded to the survey understand the severity of the situation – 78 percent said workplace accidents and injuries were the concerns most likely to keep them up at night.
These professionals also revealed their two top strategies for encouraging PPE compliance: improving education and training programs (61 percent) and increased monitoring of employees (48 percent). Other strategies included purchasing more comfortable PPE; tying compliance to individual performance evaluations; purchasing more stylish PPE; and developing incentive programs.
Of the 119 participants Kimberly-Clark surveyed online from June 10 through July 1, 63 percent were safety directors or managers, while the other 37 percent were industrial hygienists, facilities or general managers, environmental managers or held other positions. All survey respondents said they were responsible for purchasing, selecting or influencing the purchase or selection of PPE (ehstoday.com/ppe).

The following trends are found in the European market for PPE's:

- The number of employees in industrial production is decreasing.
- Protection for employees in industrial production is increasing.
- The import of PPE's from non-European countries is increasing however, these products are often of pour quality.
- People and companies are more and more conscious regarding to PPE's.
- Fashionability is an increasing factor for PPE's.
- Companies are strengthening their corporate identity with PPE's.
- There is a growing demand for PPE's with multiple functional properties.
- Standards for PPE's will keep developing because of practical experience and evolution in industrial processes.

Noticeable differences are shown between European countries and the PPE market. There are even differences between sectors and companies for example because of traditions, climate, culture or local law. In most of the European countries, the PPE market is stable. The decrease of industrial employees is not noticeable yet in the newest EU-countries however the protection of employees is an increasing attention. In these countries the increase of market volume is noticeable.
PPE's aren't just developed for their protective properties; they are also part of the social climate in several companies. PPE textiles that are pretty, comfortable and of good quality are worn with more pleasure and regularity than an old fashioned, boring outfit that is not comfortable. PPE's are becoming more fashionable every year and this is an important factor for employees to bind and keep their employees. Integrating fashionability and safety are also a great opportunity for producers in ways of innovation and versatility. Corporate identity is a marketing tool that companies want to strengthen by developing unique PPE's for their employees.
Another trend is a growing demand for "Multi-standard" PPE's. These are PPE's which are used for several conditions and against multiple risks. The importance in this product is that all employees in a company can be dressed equally no matter what their function or task implies. For producers, it means that they have to combine different types of protection in clothing with an optimal comfort for the carrier. The comfort in these "Multi-standard" PPE's is very important, because when a PPE isn't comfortable there is a good change it will hardly be worn by employees (safety & fashion at work).

In conclusion obviously the issue of textile design in relation with comfort and willingness of workers to wear the products is a great area of development. Scientific studies are going on toestablish design guidelines for textile products with optimal protection but keeping comfort as a key design issue at the highest level of priorities. Thermo physiology is the science area that will lead to new breakthroughs in this area (extensive list of work of prof. Hein Daanen).

5. Procurement

As shown in the previous chapters of this document, there are many developments in protective textiles and protective clothing (PPE). However, most of these new developments will only enter the market in a very slow pace, due to risks of bringing innovative products on the market. The EU has recognized this situation and is looking for methods in order to speed up the market introduction of innovative products.

With regards to PPE a number of measures have been taken in the last 5 years to stimulate the development and uptake of innovative products. The European Technology Platform for Textiles and Clothing has taken the initiative to start a Lead Market initiative on protective textile, to stimulate research, development and market uptake of products from innovative protective textiles. The main idea to stimulate market uptake is through (public) procurement. Procurers are seen as the representatives of the end-users of those products, but also as a specifier for future R&D-projects in which the needs of the end-users are fully reflected.

In words of the EU: By acting as technologically demanding first buyers, public procurers can drive innovation from the demand side. In addition to improving the quality and effectiveness of public services, this can help create opportunities for European companies to take international leadership in new markets (ec.europa.eu/information_society)

Enprotex (www.enptrotex.eu) is a pilot project in which 3 public procurement organizations from UK, Belgium and The Netherlands are working together to set up an ad hoc of public procurement organizations, who will buy innovative PPE. Therefore new procedures are under development in order to maximize the chances for the procurement of innovative products without conflicting with EU-procurement rules.

In the procurement of innovative products a few items are very important:

1. The products to be procured should be specified in a functional way and not in a technical (descriptive) way. As an example: smart specified products ask for a water tightness of 1m water column; technical specifications will be that the product has to be water tight through the use of a (Goretex) membrane. This leaves no opening for the use of innovative finishes or coatings to reach this goal.
2. Procurement should not only take the first investment as an important criterion for buying a product but focus should be more on life time costing. This might also include environmental cost (e.g. what is needed to maintain the product in terms of water, chemi-

cals and energy) and social cost (by whom and where is the product produced).

3. When demanded innovative products are not yet commercially available, a Pre Commercial Procurement (PCP) strategy might be started. Procurement organizations together with industry organize the last step in the development of the product. The required knowledge may come from EU co-funded projects, in which knowledge and technology are developed on a basic level (TRL 3-5), but not ready for industrial applications (TRL 8-9). The procurement organization commits itself to act as the launching customer when the product is ready for entering the market. In this way the risks of production and product development (to bridge the gap between TRL 5 and TRL 8) for the industry is reduced.
4. In a Forward Committed Procurement (FCP) a need for a certain product is identified but such a product is not available. A public procurement organization might invite parties to develop such a product. FCP offers a step-by-step approach to working with the supply chain. It provides the incentive, confidence and momentum for suppliers to invest and deliver innovative solutions. It also provides a way to manage the risk of innovation, for both the purchaser and the supply chain (www.bis.gov.uk/assets). Normally they are paid for this R&D, and the intellectual knowledge is transferred to the Procurement organization. Funding of such research and development is done in many countries under the SBIR (Small Business innovation).

It is envisaged that this kind of innovative procurement and the new role of procurement organizations as smart specifiers will be one of the cornerstones of the 8th Framework program of the EU in order to make R&D more effective, to stimulate the industry to adopt new production technology to produce innovative products and to provide the end-user with the best but affordable end-products. Therefore it is needed that a constructive dialogue between protective textile producers and public procurement organizations will be established.

6. Cases and examples

Industrial safety

Many professional workers are confronted more or less daily with extreme dangers in the workplace, both outdoors and indoors. Textils producers are supplying garment makers with an extensive range of top-quality and technologically advanced fabrics that form the basis for protective clothing. Important is that clothing does not hinder but facilitates their tasks. Those fabrics must be safe, but also flexible and comfortable, because professional workers must not have their freedom of movement restricted. That is why the current textile producers collaborate closely with fibre manufacturers, chemicals suppliers, laboratories, governments, garment makers, laundries and end users. The fabrics must provide protection against a multitude of dangers. From heat, flame, drops of molten metal and splashes of liquid chemicals, to electrical arc, static electricity and poor visibility. The fabrics must also offer other properties essential to a worker's daily tasks: comfort, breathability and moisture-regulating capacities, a durable character and industrial or domestic washing convenience.

The risks are sometimes so great that optimal protection is only possible by combining the fabrics and materials with a multi-layer solution. This leads to the development and market introduction of systems, with each protective layer having been developed for specific functionalities.

Utility workers

Utility workers work in an industry supplying gas, heat and electricity. Allthrough high-grade distribution grids. Energy suppliers provide numerous services and products that involve a multitude of risks.

Tasks differ greatly: checking the electricity meter, laying a main underground, or checking the power lines at great hight. They operate in a range of different working and weather conditions. Outdoor working conditions require durable fabrics, fabrics that also provide protection against a range of risks. Poor visibility at the roadside demands fluorescent clothing. Furthermore, a worker's movements can generate a static electric load in the clothing, sometimes to extremely high voltages. This static load must be discharged from the clothing in a controlled manner. Failure to do this creates a major risk in an explosive environment. In addition, employees in the energy sector can also be confronted with heat and flame, electrical arc, welding sparks, chemical splashes and foul weather conditions. The safety garments are produced from

protective fabrics that offer multi-risk protection.
A typical, high quality product will be made of a blend of Flame retardant plasma polymerized acrylonitrile/cotton/para-aramid/polyamide, which is an Inherently flame-resistant material with good comfort properties (Cool and breathable) strong thanks to para-aramid and polyamide.

Chemical industry workers

The chemical industry exposes workers to numerous risks that demand protective solutions. The level of protection and the clothing requirements are defined by the working conditions and the chemicals present. Protection against the release of explosive substances, working with flammable chemicals, and toxic chemicals. This work involves lots of movement.
Friction generates a static electric load in the clothing, sometimes to extremely high voltages. If this static load discharges the clothing in an uncontrolled manner, then it can create an explosion due to sparks in an explosive atmosphere. There are also production processes with flammable raw materials. Or pyrophorous substances are handled that ignite spontaneously on contact with air or water. This demands wearing clothing that is exceptionally heat- and flame-resistant. But that can also repel chemical splashes. Moreover, various production processes take place in plants that expose workers to extremely high or low temperatures. Their clothing must regulate moisture effectively to prevent heat stress. Typical an overall in these conditions is made of 93/5/2% meta-aramid/para-aramid/carbon fibre (for release of static electricity). In addition these workers wear helmets (made of polyethylene/PVC, or Acrylonitril-butadieen-styreen (ABS), could be glass fibre reinforced), gloves, goggles and boots.

Fire fighters

Firefighters across the globe are protected by unique fabrics and are composed of multi-protective layers required for firefighting garments. Life-threatening situations often start with a simple frying-pan fire. The flame in the pan spreads to the rest of the dwelling, resulting in excessive smoke, fire and high temperatures. This can lead to very dangerous flashovers. Firefighters are exposed on a daily basis to extreme risks to their personal safety. This requires the ultimate protection against huge seas of flame and intense heat. But also against splashes of water or chemicals. Those trying to save lives under such extreme conditions also require

protection against heat stress resulting from excessive perspiration.
Sweatladen clothing can be heated to life-threatening temperatures. Firefighters turnout gear must be comfortable, lightweight, easy to clean and exceptionally heat- and flame-resistant and must also regulate moisture very effectively.
Protective fabrics for firefighters are multilayers made of:
Layer 1: 59/39/2% para-aramid/PBO/carbon fbre for static electricity control (PBO =poly(*p*-phenylene-2,6-benzobisoxazole, Zylon) which is extremely strong.
Layer 2: Thermal moisture barrier, 3D spunlace non-woven (meta-aramid/para-aramid) with an ePTFE/PU BI membrane.
Layer 3: Thermal liner, e.g. a patterned meta-aramid (spun and filament).
In addition these workers wear helmets (made of polyethylene/PVC, or Acrylonitril-butadieen-styreen (ABS), could be glass fibre reinforced), gloves, goggles and boots.

Hygiene: hospital, food industry workers

The garments that these workers wear are obviously heavy duty, but must be comfortable and laundry resistant. The garments are made of cotton and/or Polyester, but mostly made of Polyester/cotton blends. These can also be personalized or show signs of corporate images, which means that they are suitable for dyeing or printing. Comfort is important thus moisture uptake and transport are key issues. Research is aimed at hygienic protection: built in hygiene indicators of functions that kill microorganisms are being developed.

7. Outlook

Advances in clothing technology are continuous. Much research is aimed at the development of multifunctional protective clothing. A lot of progress has been made in the area of static protection. Direct protection and more indirect improved comfort immediately contribute to better safety for the workers. This is an area of continuing research since obviously it leads to direct improvement of the workers safety. From the foregoing text it can be concluded that many developments are going on the level of research and development.

In table 3 below we present an overview of relevant development against a time axis. The table uses the concept of Technology Readiness levels, a measure for the state of development of a particular technology.

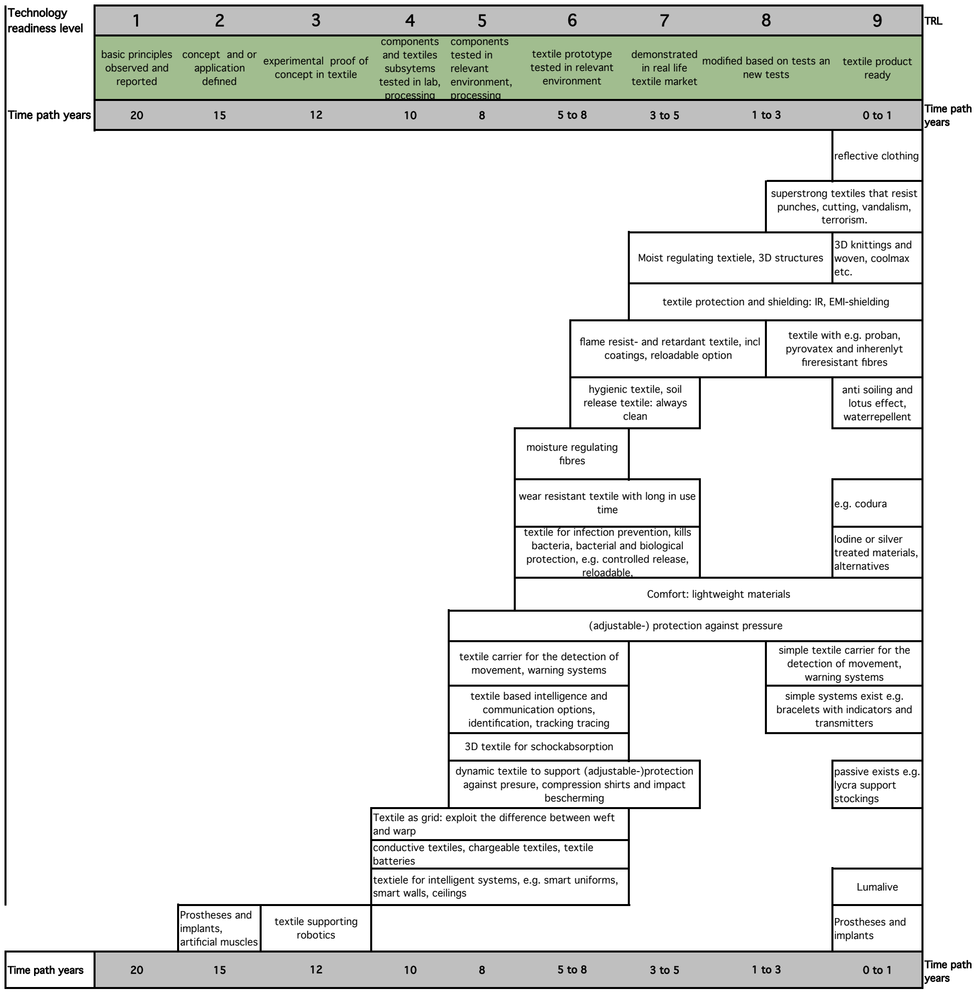
From this research the following may be concluded:

1. Safety is obtained by choice of materials for a textile construction, including the use of coatings with special properties, application of specific additives and he use of special designed fibre shapes.
2. The architecture and ultimate construction, and the combinations with other materials result in products that respond adequately. This is of great importance because of the balance comfort – safety. But a lot can be improved in this respect.
3. Insight in human behaviour, ambient intelligence and systems technology will lead to new routes for product development and a more active approach and higher levels of safety on the workfloor.

Consequently there is a lot of research going on that is aimed at improved materials and systems. Also due to the enormous research area of smart textiles a lot of development is aimed at the integration of new technology for application in PPE. This results in complex products that enhance both passive and active safety.

Especially the commissioners, government and industry, must pay a lot of attention to specifying the required properties that a product should meet under the specific conditions.

Table 3: roadmap and outlook



8. References

1. http://www.innovationintextiles.com/articles/905.php.
2. TU Dresden, RWTH Aachen, Avantex 2011.
3. A whole series of presentations at the Avantex symposium 2011.
4. http://edition.cnn.com/2010/TECH/innovation/11/11/iron.man.suit/index.html.
5. Hohenstein, avantex 2011, Sensorbasierte persönliche Schutzausrichtung bei der Forstarbeit mit gefährlichen Maschinen und Geräten (Motorsägen).
6. Dalsgaard Ohmatex, Smart Fabrics Conference 2011, London.
7. Kluge et al, Technische universitatDresen, Avantex 2011.
8. Ganu et al, EMPA, Avantex 2011.
9. Korgel, univ of Texas, avantex 2011.
10. Buyle et al Centexbel, avantex 2011.
11. Dias, university of Nottingham.
12. Ali Harlin, et al, TAMPERE UNIVERSITY OF TECHNOLOGY.
13. Xiaoming Tao, Smart fibres, fabrics and clothing.
14. Dr Steve Beeby, ESD Research Group, Smart Fabrics 2011,5th April 2011.
15. many researchers work on this area, e.g: aetske et al, EttlinPlesec, school of arts Berlin/TITV/Koen van Os et al, Philips.
16. http://onlinelibrary.wiley.com/doi/10.1002/adma.201090102/abstract.
17. http://www.texsys.de/
18. P.B. Agrawal and M.M.C.G. Warmoeskerken; -CYCLODEXTRIN BASED SLOW AND CONTROLLED REALEASE SYSTEM FOR DIGITAL FINISHING OF COTTON. Autex conference 2008, Biella, Italy. Engineering of Fibrous Smart Materials, Department of Engineering Technology, University of Twente.
19. Ref: A. Tourrette, P. Glampedaki, M.M.C.G. Warmoeskerken and D. Jocic.
20. SURFACE MODIFICATION OF TEXTILE MATERIAL WITH BIOPOLYMER-BASED MICRO- AND NANO-HYDROGELS; Autex conference 2008, Biella, Italy.
21. Engineering of Fibrous Smart Materials (EFSM), Faculty of Engineering Technology (CTW),
22. University of Twente.
23. http://www.fibre2fashion.com/industry-article/17/1677/light-textiles2.asp.
24. http://ehstoday.com/ppe/news/ppe-noncompliance-serious-threat-worker-safety-0728/
25. safety & fashion @work 1 maart 2009.

26. http://www.ncbi.nlm.nih.gov/pubmed/15677018
27. http://www.healthandsafetyatwork.com/hsw/content/fashionable-ppe-effective.
28. see the extensive list of work of prof. Hein Daanen, VU, TNO in this area.
29. http://ec.europa.eu/information_society/tl/research/priv_invest/pcp/index_en.htm
30. www.enptrotex.eu
31. http://www.bis.gov.uk/assets/biscore/innovation/docs/c/11-996-case%20study-fcp-in-practice.pdf

Photos

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