Security Sector Focus Report

Protective Materials for Emergency Responders

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Executive summary

This report is focused on protective materials for emergency responders assessing both the technological developments and market applications in this sector. The technological and economic drivers and barriers are also identified and discussed.

The EU market for Personal Protective Equipment (PPE), which includes filtration apparatus in addition to protective textiles, is estimated at €9.5-10 billions. Protective textiles have been identified as one of six lead markets for Europe with technological and market developments offering the opportunity to renew a traditional industry. The sector is therefore enjoying considerable political support.

The protective materials market is driven by developing standards to improve the effectiveness of PPE in response to emerging security threats and challenges. One example is the increased threat of terrorism, which presents a need to protect emergency personnel responding to such events.

The technological assessment of nano-enabled technologies in the protective materials sector has been divided into four sub-sectors: detoxification and decontamination; protection from impact; fire resistance/retardency; and integration of ICT devices.

Technological developments are driven by functionality requirements such as lightweight protective clothing, fire resistance, non-toxicity, and information storage capabilities of integrated ICT devices. In all sub-sectors nano-enabled materials can potentially offer superior qualities over existing technologies. Examples include:

- Prototype protective vests made using carbon nanotube yarns and inorganic fullerenes with superior ballistic protection yet at a fraction of the thickness, and therefore weight, of current materials;
- Quantum Tunnelling Composites offering “smart” functionalities such as a flexible control interface allowing the user to illuminate sections of clothing for high visibility purposes;
- Magnesium oxide nanoparticles loaded into nanofibres providing effective detoxification and decontamination coupled with ability to be incorporated into cloths;
- Use of nanoparticles in shear thickening and electro-rheological fluids providing advanced ‘liquid’ armours changing their rigidity when required.

Despite considerable progress in utilising nanomaterials and nanotechnologies for security applications, the majority of experts involved in preparation of this report concurred that significant effort is still required for these results to become technically and commercially viable. One of the way to speed up the process seen by the experts is to join where possible this effort with the development of conventional materials and technologies.

Regulation and standardisation, and dual use applications are the main economic drivers in this sector; the European Commission Directive on PPE 89/686/EEC sets out a number of standards, thus creating a market for PPE to meet these requirements. Barriers to economic development include: the importance of public procurement, where in some markets the public sector is the sole purchaser; protection of intellectual property; and the perception of the sector as a declining, low tech industry.

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Introduction

Definition

It is important to firstly define the term ‘emergency responder’. For the purposes of this report this term has been favoured over ‘first responder’ to encompass all personnel potentially involved in critical incidents.

As an example, patrol police have little more access to protective equipment_than what they carry on their person. It should be noted that, in comparison to military personnel, a high level of fitness cannot be assumed for civil emergency services which reduces their loading capability. For such emergency responders protection must be light and able to be donned quickly to allow for rapid response to a critical incident.

In comparison, firefighters and specialist police teams can carry out some degree of risk assessment before entering the situation, and carry greater amounts of equipment. Therefore their requirements include more long lasting protection but with less need for highly portable equipment.

Therefore it is clear that the functionalities required by emergency responders cannot be described uniformly and instead will be evaluated according to essential, and desirable, requirements of specific groups of responders.

Keywords

textiles, vests, protective gear, ballistic projectiles, nanoparticles, nanomaterials, fibres, oxides, body armour, Kevlar, carbon nanotubes, fullerenes, dendrimers, polymer nanofibres, shield, ceramic composites, nano-layered double hydroxide, nanoclays, buckypaper, buckyball, sensing, processing, storage, memory, communication, information transfer, carbon nanotubes, graphene, nanowires, interconnects, transistors, power supply, semiconductors, value chain, regulations and standardisation, dual use applications, intellectual property, public procurement, functional requirements, boundary conditions.

Methodology

This report will cover technological developments and economic market analysis of the following protective materials sub-sectors:

- Detoxification and decontamination;
- Protection from impact such as knives, ballistic projectiles, and firearms;
- Protection, resistance and retardance, against fire; and
- Integration of electronics into emergency responder's protection.

This integrated analysis aims to bring together technology and economic assessment. The technological developments have been related to additional demands for research, critical functionalities, application perspectives, measurement of research and development, and the current situation in Europe. Our economic analysis provides generic market information, a view on the drivers and barriers, boundary conditions, economic factors, and profiles of selected companies and products.

The figure below details the methodology used in the preparation of this report indicating the importance of expert engagement throughout. An expert engagement workshop on the topic of this report took place in November 2009.

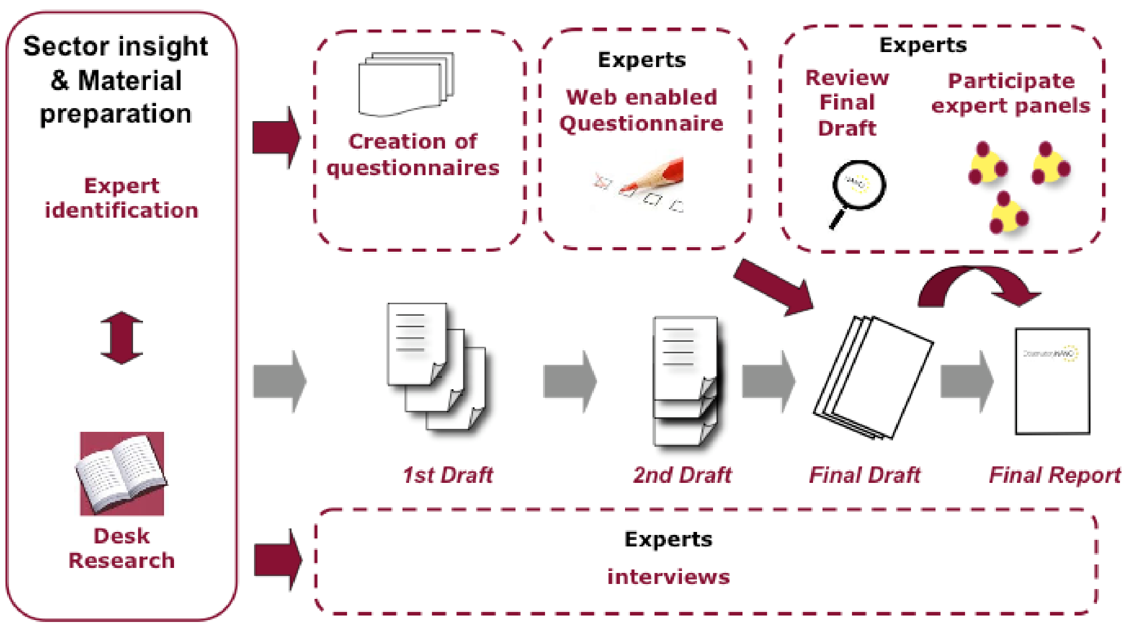

Figure 1: Flowchart detailing the project standard methodology utilised for the preparation of the ObservatoryNANO Focus Reports.

Science and Technology Aspects

State of R&D

Detoxification/Decontamination

Required functionality

In this area the 'perceived' increasing threat level of a chemical or biological attack is driving development even though wide scale experience of such incidents is somewhat limited.

Protective clothing is largely based on barrier materials, which are either full barrier impermeable suits or partially permeable adsorptive suits. Aerosol and gas protection is also a key area of concern, and is therefore driving development of breathing apparatus or hood type protection. The requirements for design of breathing protection are different from those for protective clothing due to a much higher flow of the agent through a protective layer, whereas in cloth the agent propagates as result of slow diffusion.

There is a clear difference between the functionality required by defence forces compared to civil security. While defence personnel could potentially be wearing protective equipment for a number of hours, civil security personnel would not be expected to be deployed in a hazardous situation for longer than around 1 hour. This means that less robust materials may be acceptable for use in civil security applications.

Existing technologies

Existing technologies such as functionalised activated charcoal and other carbon cloth based materials are used for adsorption. The key advantage of current solutions is low cost; however, disadvantages are heavy weight and high moisture retention[1].

Modern decontaminants such as the "German emulsion" normally consists of calcium hypochlorite, tetrachlorethylene, emulsifier ("phase transfer" catalyst) and water. Instead of tetrachlorethylene, the more environmentally harmless xylene is sometimes used. These decontaminants are, however, corrosive and release toxic by-products.

Nanotechnology developments

Research developments in decontamination and detoxification include metal oxide nanoparticles, such as magnesium oxide, which have been mixed with a range of polymer solutions to produce composite nanofibres to incorporate into membranes. The fabricated composite membrane (containing 5% MgO) was tested for chemical warfare agent stimulant, paraoxon, and found to be around 2 times more efficient (reactive) than currently used charcoal[2].

Nanofibres filled with metal oxide nanoparticles offer additional properties such as low fibre diameter, potential to include active chemistry, and high permeability[3] and, therefore, are capable to expand the range of existing decontaminant products. They can be incorporated into cloths which provide enhanced protection against aerosols. Additionally, the nanofibres also serve as carriers of active functionality that can detoxify the warfare agent without adding extra weight to the cloth. Functionalising the appropriate catalyst on the surface of the nanofibres has been indicated as a suitable approach to detoxification[4]. Polymer nanofibres membranes, produced using the electro spinning technique, were functionalised with activated granular carbon as a catalyst. The catalyst provided good performance for the paraoxon, an organophosphorus model for sarin, utilised in the study[5].

The use of dendrimers to detoxify the effects of mustard gas has been investigated by researchers at the Institute of Soldier Nanotechnologies at MIT and found to be effective.

In terms of respiratory protection for emergency responders nanoporous adsorbents, such as activated carbons, are well established; however, they currently do not provide universal protection. Therefore development is ongoing into a broad spectrum protection and low burden nanoporous adsorbent; an example is the FP7 FRESP project aiming to develop such an adsorbent for use in a hood-type protection, which may be quickly donned in an emergency situation. Such an easy-to-use application could also be used for the rapid protection of injured civilians in event of a terrorist attack.

Protection from Impact

Required functionality

Protective equipment is required to provide light weight gear allowing for extreme mobility and a high degree of protection, in addition to increased breathability and user comfort. Without such functionalities, unless regulations require it, emergency responders will be reluctant to utilise the equipment.

Existing technologies

Current technologies such as aramids (Kevlar), PBO (Zylon) and UHMWPE (Dyneema, Spectra) fibres and ceramics despite their extremely high theoretical strength do not provide sufficient impact resistance that is mainly governed by distribution of defects in bulk materials. For example, Zylon vests were used in the US in the late 1990's but experienced continued failures, ultimately resulting in the death of a police officer.

At present UHMWPE seems to take over a major part of the market currently covered by the aramid fibres. The experimental M5 fibre seems promising as well. Nevertheless, there is a market opportunity for new technologies to enhance performance of the existing solutions.

Nanotechnology developments

Inorganic fullerenes (IF) are providing promise in terms of shock absorbing protection; they are twice as strong as current materials, such as boron carbide and silicon carbide, and four to five times stronger than steel. An Israeli company, ApNano, commercialised the inorganic fullerene material technology and are thought to be developing a body armour application under the name 'NanoArmor'.

At the more fundamental stage of development, researchers in Australia have examined the theoretical potential of using carbon nanotubes against ballistic impact. They concluded that ballistic resistance capacity is greater when a bullet hits the centre of a single nanotube and that those with a larger radius can withstand a higher bullet speed. From these results they theorise that body armour of only 600µm in thickness, made from six layers of 100µm carbon nanotube yarns, may bounce off a bullet with muzzle energy of 320 J. Extending this theory they suggested that CNT body armour could have a constant ballistic resistance even when bullets strike at the same spot; the studied CNTs withstood a bullet at almost the same speed as the first impact after a short time interval[6]. Although these fundamental results show promise, they very much depend on multiple yarns containing many millions of CNTs behaving in the same way as a single nanotubes and may not be correct..

Yarns of multi-walled carbon nanotubes with promising mechanical properties have been recently produced at an experimental scale. These new materials can be used for making bullet proof vests as strong as existing products, in addition offering 48% reversible damping and much higher thermal, creep resistance, and chemical resistance.

Despite considerable concerns regarding practical implementation of CNT and IF ballistic and dynamic properties they appear to be the most promising materials for the future (at a timescale of 10 years or more). However, the introduction of new or improved conventional ballistic fibres and/or ceramic whiskers could lead to an important breakthrough in the field of ballistic protection on a much shorter timescale.

So-called 'liquid' armour that remains flexible until impact is highly desirable. Shear thickening fluids have been suggested as providing such functionality for low end of ballistic velocities required for applications such as protective helmets, boots/footwear, gloves and face protection (such as goggles, masks, and shields). In addition, the use of shear thickening fluids based on nanomaterials may provide greater spike protection (particularly important for prison guards). Commercialisation of this technology has been slow but dual use applications, such as impact protection for sports, are beginning to speed up development of these materials; an example being d3o technology. Electro-rheological fluids which change their rigidity in response to an electric charge have also been suggested for protection applications[7].

Fire resistance/retardancy

Required functionality

Any improvements on the current heavy and cumbersome fire resistant protective clothing would be greatly beneficial in terms of protecting firefighters, providing an increased level of comfort, and reducing the physical burden.

Existing technologies

Although halogenated fire resistant materials provide effective protection they contain bromine and, as such, will be phased out under Waste Electrical and Electronic Equipment *(*WEEE) and Restriction of Hazardous Substances (RoHS) Directives due to their health and environmental impacts. Personal Halon fire extinguishers for public order will be banned in 2013 and therefore there is an open market for technology to replace these. This is particularly important in the UK context due to less hard-line approach to public order incidents (less use of CS spray etc) than in other European countries.

Nanotechnology developments

The effects of nano-scaled layered double hydroxides (LDH) and nano-titanium dioxide in improving fire resistance and anti-aging properties of fire resistant coatings have been investigated; the addition of such nanoscale additives to coatings, even in very small amounts, has been shown to produce great improvements in properties[8].

Acrylic nanocomposites with nanoscale silicon dioxide enhance the anti-oxidation, char accumulation and char structure of flame retardant coatings. The fire protection properties of these acrylic nanocomposites are reported to be better than conventional acrylic resin[9].

With the addition of 1.5% of nanoclays, nanocomposite coatings have also demonstrated good fire resistance and aging[10]. A number of studies of the fire resistance of polymers filled with organoclays, polyhedral silsesquioxanes and carbon nanotubes established that good dispersion of fillers improves flame retarding ability. The best results were obtained using a combination of conventional flame retardants and nanofillers[11]. Studies of polymer and layered silicate nanocomposites have shown that indefinite protection against fire could not be achieved. A number of approaches were suggested for improving fire retardancy such as improving coupling of silicate layers in the char and incorporating additional additives as second layers of defence to improve their effectiveness[12].

The flame retardant properties of buckyball nanocomposites have been investigated. The presence of C_{60} resulted in a marked increase in the flame retardant properties of the nanocomposites. The flame retardancy was also found to increase with increasing loading of the C_{60} in the polymer matrix. A mechanism of the buckyballs for trapping the free radical has been proposed[13].

Buckypaper is another name for carbon nanotubes membrane, which is made up of tangled carbon nanotubes ropes. Buckypaper has been incorporated onto the surface of polyhedral oligomeric silsesquioxane and glass fibre composite to experimentally study fire resistance; it was shown to effectively reduce flammability for covering glass fibre composites. The advantages offered by the buckypaper are its thermal stability and ability to act as a barrier in reducing the material degradation, slowing the escape of the combustible products during burning.[14].

Integration of ICT devices

Required functionality

The integration of ICT devices into protective clothing offers many benefits to emergency responders such as sensors to monitor vital body signs such as heart rate, respiration, body temperature, and heart rate variability. Additionally, accelerometers could provide a remote indication of fall or collapse through measurement of limb movement and GPS units provide rapid locational information to remote locations (such as command centres). An energy supply, energy storage, data transmission and processing, and memory are all required for such functionality. Each of these elements is required to be;

- ***Lightweight*** – there is a considerable drive towards reducing the physical burden of emergency responders. Miniaturisation is therefore is an important focus of research.
- ***Flexible*** – in order for the protective clothing to be comfortable and easy-to-wear all components must be as flexible as possible.
- ***Robust*** – so that repeated use will not impair the function of the sensors.

- ***Durable*** – they must be durable to wear and tear conditions expected of the environment likely to be encountered.
- ***Low power consumption*** – due to the limitations on power generation on the scale required devices must be energy efficient.

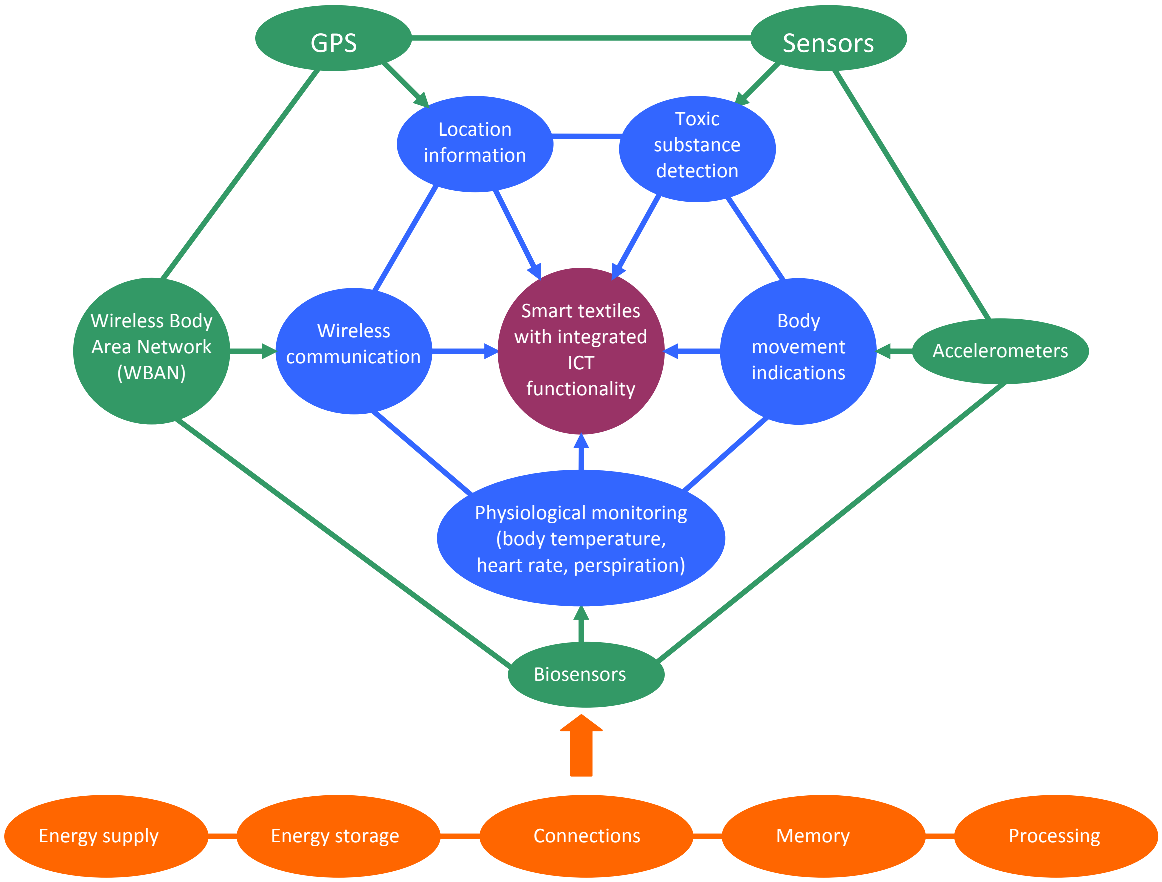

Figure 2: Flow chart showing the components required for the ideal smart textile for protective clothing showing functionality required (blue), components to provide such functionality (green), and the base components required (orange).

Through miniaturisation the described devices can be embedded on a textile substrate allowing for a multifunctional garment. However, a more challenging aim is the development of textiles which, themselves, act as sensors, batteries, or an energy supply.

Existing technologies

There are certainly existing technologies which meet many of the requirements in terms of function; however, their size is an issue when looking at integration of such devices into lightweight and effective protective clothing. Sensor technologies, in terms of both bio-monitoring and chemical and biological substance detection are becoming increasingly powerful and small in size. However, energy storage and supply technologies remain bulky and not sufficiently efficient.

Nanotechnology developments

Areas where nanotechnologies show potential towards improved performance of integrated ICT devices or novel multifunctional textiles include:

Biosensors: The INTELTEX FP6 project is utilising Conductive Polymer NanoComposites (CPC) integrated into textile fabrics. The electrical conductivity of CPC changes depending on external stresses such as temperature, strain and vapour atmosphere and therefore processing of CPC integrated textiles allow the fibres and textile to act as sensors.

Pressure sensors: Quantum tunnelling composite is an electrically conductive material made from metal filler nanoparticles with a binder such as silicone rubber developed by Peratech. QTC can be used as a switch; in the off position it is an insulator but then in the 'on' position it performs as a metal conductor. A QTC sensor may offer functionality such as a flexible control interface allowing the user to illuminate sections of his clothing for high visibility purposes; such functionality would be desirable for emergency responders working in areas of restricted light.

Energy storage: The use of nanocrystalline material and nanotubes has been suggested to improve power density, lifetime, and power charge/discharge rates of batteries. Nanotubes as a replacement in the graphite-lithium electrode of portable batteries can be expected to improve performance by increasing performance due to greater surface area. Nanocrystalline materials are a potential material for separator plates due to their foam-like structure which can hold more energy[15]. Other materials under consideration include transition metal oxides of cobalt, zinc, iron, and copper for electrodes in lithium ion batteries. The surface electrochemical reactivity is improved by nanoparticles, thereby improving the performance of lithium ion batteries[16]. Due to their high energy storage and power density super capacitors have been suggested as power units; carbon nanotubes increase the surface area of the capacitors exponentially and provide low electrical resistivity and high stability. They are therefore an ideal candidate electrode material for supercapacitors[17]. CNT can be also woven into textiles to provide electrical conductivity.

Smart textiles: It has been suggested that full integration of devices into textiles is very much at the basic research level; however, conducting fibres are being more widely utilised, integrated within fabrics, to provide connections between devices. In the PROeTEX FP7 project these take the form of either metal strands woven into the fibre or conductive polymers. Weaving of specific fibres for ECG analysis is also now commercially available.

Additional demand for research

Demand in this sector is largely driven by the threat level and operational requirements of the emergency responder to provide materials which are not only increasingly effective but within the cost restrains of civil security forces.

The following additional areas of demand for research have been identified through the literature review and expert engagement process:

- Catalysts functionalised on nanofibres membrane provide a means for detoxifying chemical warfare agents. Further development work has looked at brining the different nanofibre layers to form a woven textile as a protective garment. This is expected to offer additional comfort through exchange of moisture in comparison with charcoal impregnated suits [5].

- Further development of magnesium oxide nanoparticles based nanofibre membranes to degrade mustard agents and biological warfare agents have been anticipated[2].
- A research need for assessing the bullet impact of carbon nanotubes under different loading conditions application has been identified for applications such as bullet proof vests and explosion blankets [6].
- Further research and development in terms of operational effectiveness and capability of first responders for reducing injury and loss of life has been raised. Research areas include protective clothing for first responders, monitoring performance and health, integrating sensors and communication devices[18].
- Active decontamination materials to protect responders from threats[19] were raised as being an important area of development:
    1. Chemical - nano barrier materials that can be applied to textiles and do not require PPE suits;
    2. Biological - encapsulate to protect responders from contamination at the site of attack and prevent spread; and
    3. Radioactive - barriers that can be applied to reduce or eliminate exposure of responders and subsequent cleanup crews.

Applications and perspectives

During the expert engagement process of 2009/2010 the following factors were considered most important in driving nanotechnology developments in the Protective Materials sector;

- The perceived threat level and diversification of terrorist activities and attack type; there is very limited experience of chemical attack but it is seen as a potentially increasing risk.
- Current technologies in many areas have reached their limit; an example being police body armour where current technologies, such as aramids (Kevlar) and ceramics are still bulky and uncomfortable for users. Therefore there is a clear market space for nano-enabled developments in this sector if they can compete on an cost effective basis with existing technologies.
- Government defence funding priorities drive developments in the appropriate sectors; many countries are focusing on reducing the physical burden on military personnel and development made here would likely filter through.
- Dual use applications, such as protective clothing for extreme sports, provide an additional commercial driver for technology developments within the sector.
- A number of barriers to development of technology in this field were suggested:
- The emergency responder and dual application markets are fragmented; they are small and deployment times are very long.
- Despite the large potential market for body armour applications, outlined above, cost remains a critical factor which may prevent the most effective nano-enabled materials being widely adopted.

- There is an education issue in terms of procurement teams; those in larger forces are likely to have a higher level of training to assist them in the assessment of new technologies, smaller forces may be lacking these skills. This then represents a barrier to technologies being widely adopted.
- The threat of liability appears to be preventing the adoption of new technologies; by setting threat levels higher the costs are raised. If developments allow adverse conditions to be known (such as temperature stress of a fireman) or can provide protection then pressure will grow for civil protection authorities to provide this.

Technology Readiness Levels Assessment

This section provides an assessment of the research and development status of enabling nanotechnologies in the protective materials sector; a five step Technology Readiness Level (TRL) system utilised by ObservatoryNANO partners, VDI, has been adopted for all 2009/2010 reports (Fig. 3).

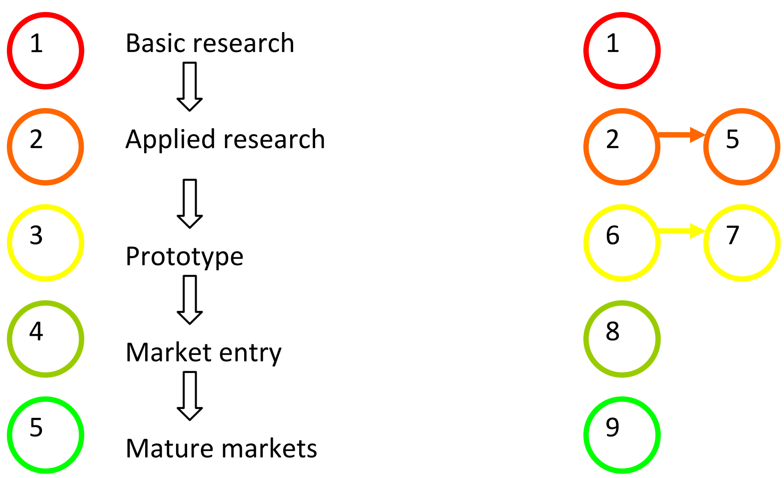

Figure 3: ObservatoryNano TRL scheme corresponding to the defence standard nine point scheme.

Application Area	Technology	Basic Research	Applied Research	Prototype	Market entry	Mature Market
Detoxification & Decontamination	Nanoparticles of magnesium oxide					
	Nanofibres					
	Dendrimers					
	Nanoporous adsorbents					
Impact Protection	Inorganic fullerenes					
	Shear thickening fluids					
	Electrorheological fluids					
	CNT for ballistic absorption					
Fire resistance	Nanoscale LDH					
	Nanoscale TiO_2					
	Nanoscale SiO_2					
	Nanoclay, buckyball and buckypaper nanocomposites					
ICT integration	Quantum Tunnelling Composite					
	Conductive polymer nanocomposites					
	Organic polymer PV					

Table 1: TRL assessment of research and development status for key protective materials technologies.

Current situation within the EU

The following Framework projects (FP6 & FP7) have been funded by the European Commission under the Security theme and are relevant to the protective materials sector:

- Identifying the needs of medical first responders in disasters the NMFRDISASTER project was completed in 2009; its aim was to identify the research needs of medical first responders. This relates to the use of protective equipment used in chemical and biological incidents[20].
- Advanced first response respiratory protection (FRESP) project was initiated in 2008. The aim of the project is to develop nanoporous adsorbent for respiratory protection of first responders. The research and development of protection would cover a wide range of toxic chemical and biological agents [21].
- PROeTex was funded as an integrated FP6 project focusing on micro-nanotechnologies for textile applications. The goal of the project was to develop smart and wearable micro-nano engineered applications embedded in textiles and fibres. The research and development in smart textiles is expected to be of benefit to first responders in emergency and disaster situations through continuous monitoring of life signs, wireless communication, temperature sensors, chemical detection and power generation[22].

A number of other projects are relevant to micro-nanotechnology applications for textiles:

- wearIT@work: IST Integrated project aimed for improving applicability of computer systems to work [23]
- MyHEART: IST Integrated project was focused on gaining knowledge of citizen's health by continuous monitoring of vital signals [24]
- WEALTHY: IST project was focused on embedding smart materials in textiles and yarns for collecting physiological data [25]
- BIOTEX: STREP project for biochemical sensing aimed at integration into textiles [26]
- STELLA: Project is focused on developing stretchable and soft touch substrate for monitoring functions of the human body and data related to activity [27]
- ConText: Project focused on contact-less sensors incorporated into textiles for continuous monitoring [28]
- OFSETH: Integrated project focused on researching optical fibres for health monitoring while being compatible with textile manufacturing [29]

The expert engagement process of 2009/2010 suggested that, in relation to US, for the protective materials sector, the EU was ahead in terms of fundamental and applied research. However, the opinion was that US excelled at commercialisation, technology transfer, routes to market, and 'supporting mechanisms' whereas the EU was mentioned as having weaknesses in these areas. Evidence for these opinions may be found from analysis of patent and publication data for the whole Security sector; the US accounts for only 22% of publications, compared to an EU-27 figure of 36%, but represents 46% of patent applications, compared to 26% attributable to EU-27.

Economic aspects

General market description

The market for protective textiles for emergency responders is part of a larger market for personal protective equipment (PPE). Approximately 200,000 jobs are thought to exist in production of PPE and related industries, including 35-40,000 employees in firms which provide related services. The EU market for PPE has been estimated to be worth €9.5-10 billion[30].

The importance of protective textiles is such that it has been identified as one of six lead markets for Europe.[31] The lead market initiative provides support for strategically important sectors by providing, in the case of protective textiles, SME involvement in standardisation, technical harmonisation, networking contracting authorities, and funding research projects[32]. One reason why there has been such political support for the protective textile industry is that technology and market developments offer the chance to renew a traditional industry. However, awareness of the lead market initiative amongst participants in the security workshop was low.

Consumers for PPE can be divided into five categories:

- Military and civil security personnel
- Emergency workers
- Professionals dealing with hazardous working environments
- Medical workers
- Professionals in working environments which are sensitive to contamination (such as integrated circuit manufacturing)

The focus of this report is on PPE for civil security personnel and emergency workers. This market is driven by developing standards to improve the effectiveness of PPE, and emerging security threats and challenges. One example is the increased threat of terrorism, which presents a need to protect first responders from chemical, biological and radiological agents.

New technologies are also providing an opportunity to better meet existing challenges. As an example, integrating sensing and communication capabilities within PPE would enable fire fighting teams to track each member's location when dealing with a building fire, improving communication and safety.

The value chain of protective textiles runs from fibre producers to garment manufactures, retail and services. This is shown in Figure 4. In terms of geographical distribution within Europe, fibre and yarn manufactures are located in Western Europe, and garment manufacturers in Southern and Eastern Europe.

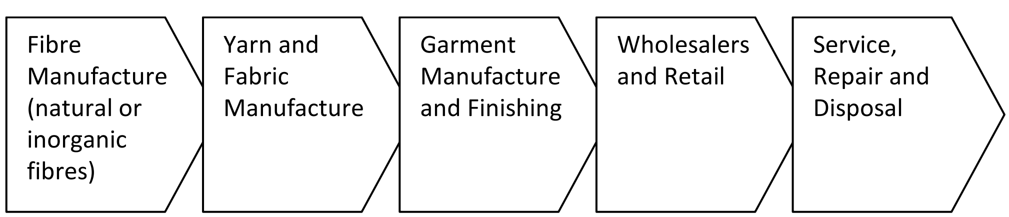

Figure 4: Protective textiles value chain

The type of fibre production process depends on whether the fibres are natural (such as cotton) or synthetic (such as nylon). Technological innovation is more likely to be found at the fibre production and garment manufacture points. One of the trends in recent years has also been a move away from buying products towards service contracts.

An important characteristic is the existence of spill over markets for the products created at each stage of the value chain. Synthetic fibres are also used to produce other materials, such as composite materials, rubber goods, or fibre reinforced concrete. Similarly, a protective textile material may also have wider applications, such as sportswear or coverings for furniture.

Economic drivers

New Threats and Challenges

Workshop participants, particularly from the public sector, identified a changing threat environment as an important driver for development (or more specifically, as a driver for changing regulations and standards). Examples of this include an increasing incidence of knife crime in the United Kingdom, requiring police officers to wear body armour – which on average saves the life of ten officers per year.

Regulation and Standardisation

The European Commission Directive on Personal Protective Equipment (PPE) 89/686/EEC sets out a number of standards, creating a market for PPE which satisfies these needs. There are also a number of more specific national, EU and international standards for specific applications of PPE, such as the EU standard EN 469:2005 for fire fighter equipment. European standards are often used as benchmarks for standardisation in other world regions, which has the benefit of supporting interoperability.

Emerging markets include countries which previously did not place great emphasis on protecting workers in hazardous environments, but which are now following, and enforcing, standards. In China, for example, "the Chinese Government is increasingly emphasizing working safety issues and strictly enforcing safety laws, compelling enterprises to offer PPE to their employees."[33]

Dual Use Applications

Another driver of technological innovation in PPE has been military research programmes – though this is truer of the United States than Europe. MIT's Institute for Soldier Nanotechnologies is funded by the US Army and much of its research is in the area of PPE, including lightweight multifunctional fibres and materials, battle suit medicine and blast and ballistic protection.

Materials developed for military use may then be transferred to first responders and later to the general public. This was the case with Kevlar, which was used as a material for soldier helmets, was then used in protective equipment for police and fire-fighters, and is now incorporated into protective gear for motorcyclists.

DuPont is currently developing a Selective Permeable Membrane (SPM) technology for the US Army which will enable the production of materials which offer a greater degree of protection against chemical and biological agents.

Economic barriers

Importance of public procurement

In some markets, particularly PPE for emergency responders, the public sector is the sole purchaser. This can lead to a situation in which demand is highly fragmented amongst a number of local authorities. In an effort to reduce complexity for both public buyers and suppliers, a number of demand aggregations schemes have been established, such as the UK's Firebuy procurement agency. Firebuy supplies procurement, contract management and testing services to individual fire and rescue authorities.

Public procurement can also lessen innovation by encouraging local authorities to purchase the least costly solution which meets certain standards and basic requirements. It is therefore not always possible for a company to obtain a price premium for supplying an innovative product. A more significant problem is the cost associated with tendering for work – a workshop participant reported having to produce 80 samples of a garment, at significant cost. Situations can also arise in which tenders are directed to specific technologies rather than the outcomes that need to be achieved, thus blocking novel solutions.

One of the remedies introduced by the lead market initiative is a network of public procurement agencies for PPE, which has received funding of one million Euros over three years.

Regulation

Regulation can also serve as a barrier to new entrants. To be accepted by buyers, a product will need to demonstration compliance with standards and become an approved supplier. In the case of equipment designed for CBRNE protection, the testing process is expensive and difficult due to lack of universal requirements across Europe.

Protection of Intellectual Property

One barrier to innovation in protective textiles is the challenge of protecting intellectual property, with trademark infringement in textiles being particularly common. The degree to which the threat of IP infringement disincentivises innovation depends on the extent to which that innovation can be copied. In this sense a material innovation should be more attractive to textile manufacturers, if it requires specialist equipment and knowledge to replicate.

Availability of Funding

Workshop participants reported that the availability of venture capital in this sector was very low. Whist there are a few defence-focused VCs, the long payback times and lack of trade sales as an exit route discourage investment.

The ObservatoryNano Year 1 report also identified barriers for R&D in 'Personnel Protection'. This were thought to include 'inadequately skilled personnel', 'health effect of nanoparticles', 'lack of research funding', and 'lack of integration of nanomaterials into products'.

Functional requirements and boundary conditions

Functional requirements of protective textiles depend on the use case, with specific requirements being set by local, national or regional bodies. ANNEX II of the Directive on Personal Protective Equipment[34] sets out a number of general requirements for all PPE:

- Design principles: PPE should be ergonomic, and should provide "the optimum level of protection … is that beyond which the constraints imposed by the wearing of the PPE would prevent its effective use during the period of exposure to the risk or normal performance of the activity."
- Innocuousness of PPE: PPE should not in itself produce risks, such as having rough or sharp surfaces in contact with the user.
- Comfort and Efficiency: the PPE should enable the user to be in a particular position without discomfort for a period of time; should be as light as possible, and be compatible with other PPE
- Information supplied by manufacturer: should include cleaning instructions, obsolescence deadlines, etc.

Annex II goes on to give a number of requirements for PPE that are subject to specific risks, including protection against mechanical impact, (static) compression of part of the body, physical injury (abrasion, perforation, cuts, bites).[35]

As referenced earlier, the functional requirements also depend on the definition of an emergency responder. Those who are likely to be first on the scene of an incident (such as police officers and paramedics) require protective equipment which can be carried with them at all times, and which provides up to 30 minutes of protection in a hazardous situation – by which time secondary responders with specialised equipment should have arrived.

The UK's Home Office mandates that police body armour should protect the wearer from handgun bullets (from 9mm and .357 magnum firearms), knives and spikes. Armed police require a higher level of protection from rifle rounds.

Additional requirements that may become more important for emergency responders are protection against chemical, biological and radioactive agents.

PPE standards also apply to emergency responders. The EN 469:2005 PPE standard specifies four requirements for fire fighter equipment, as well as the approved test methods to assess compliance with these requirements. These requirements have two classes, a lower specification for rescue work, and a more demanding specification for fire fighting within structures. For example, EN 469:2005 specifies that PPE for structural fire fighting must take longer than 18 seconds to allow a temperature rise of 24°C.[36]

Economic information and analysis

The total European market for PPE, according to EURATEX, is estimated to be €8 billion per annum for PPE products and €1.5-2 billion per annum for PPE services (distribution, rental, cleaning)

This is part of a larger market for industrial textiles, the size of which was estimated at 39.4 BEUR in 2006. Protective end uses are the second largest market segment with 20.2%, after transport (21.7%) and ahead of construction (15.8%), medical, pharma and health (8.3%) and wooden furniture (8.3%).

Exports of PPE accounted for 3 BEUR in 2006, an increase of 6.6% on the previous year. The annual growth rate for the world PPE market since 2000 has averaged over 3.5%, though reports indicate that the rate of market growth has accelerated recently (with higher growth rates in specific emerging PPE markets). These markets include Eastern Europe and Asia, though in the latter EU producers face competition from other Asian and US producers. However, this optimistic growth prediction dates from before the current financial crisis. Figures from Eurostat indicate a production drop in the textile industry of 23% in the first quarter of 2009. [37]

During the expert engagement process for the first year (2008/2009), qualitative suggestions for policy makers were made for the technology segment of Protection. They were as follows:

- Improving tax benefits for R&D for security applications.
- Enhancing academic focus on commercialisation in EU.
- Introducing a commercialisation performance metric for academics contributing to research ratings.
- Promoting scientific defence enterprise that promotes development and validation of concept.
- Specification generation through collaboration with security enterprise as a non-competitive activity.

Selected company profiles / products

This section profiles some of the companies working with nanotechnology for protective equipment. The chart in figure 4 plots the technology readiness level, adoption potential and relative number of companies for the most commercially relevant technology areas. Adoption potential is defined as the likelihood of each technology overcoming technology and economic barriers to be adopted by users, and is estimated using expert involvement at the workshop and desk research. The size of the bubble corresponds to the number of companies in each sector.

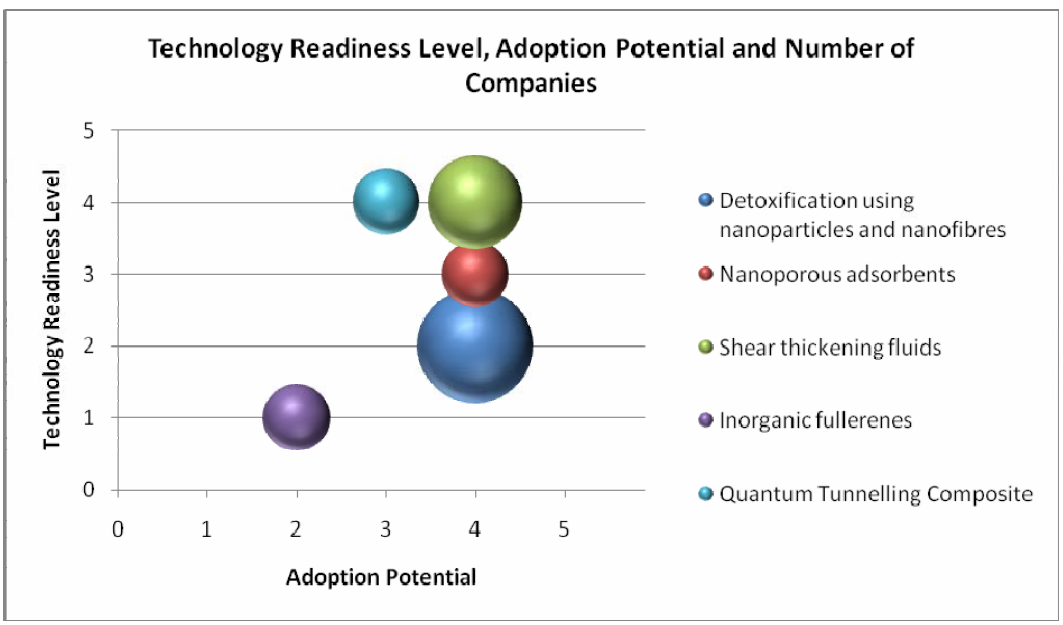

Figure 5: TRL and adoption potential of the key nanotechnology based applications

European Companies

Peratech develops Quantum Tunnelling Composite (QTC) materials -a material which is normally an insulator but becomes conductive when sufficient pressure is applied. The company has recently licensed its technology to Samsung Electro-mechanics to create pressure sensitive input devices for mobile phones. One application for PPE described by the company is a control interface for a high visibility uniform, allowing the wearer to control which part of the garment is illuminated.

d3o develops protective materials which employ shear-thickening fluids. The company produces protective padding, headgear and gloves for sports and motorcycling applications. In February 2009, the company was awarded a £100 000 contract to provide a helmet lining for the UK's Ministry of Defense.[38]

One business group of TenCate produces protective fabrics for industry, services, fire fighting and defence applications. Material brands include Tecashield, which provides flame and chemical protection. A subsidiary of Royal Ten Cate, Xennia, has developed technology which enables coating particles to be inkjetted onto textiles, resulting in enhanced functionalities. The first applications to be targeted by this technology are safety and protection.[39]

Elmarco develops electrospinning technology for the production of nanofibres. One application which the company is targeting is protective equipment such as face-masks, in which nanofibres form a barrier layer to protect against chemical and biological agents.

Company	URL	Country	Size	Technology
Elmarco	www.elmarco.com	Czech Rep.	Medium	Electrospinning nanofibres
d3o	www.d3olab.com	UK	Small	Shear thickening fluids
TenCate	www.tencate.com	Netherlands	Large	Textiles and materials
Peratech	www.peratech.com	UK	Small	Quantum Tunnelling Composites
Smartex	www.smartex.it/	Italy	Small	Smart materials for textiles. Proetex partner
Thuasne France	www.thuasne.com/	France	Large	Medical textiles. Proetex partner
Intelesens	www.intelesens.com	UK	Small	Non-invasive monitoring of vital signs. Proetex partner
Steiger	www.steiger-textil.ch	Switzerland	Large	Knitting machines (for technical textiles)
iXscient	www.ixscient.com	UK	Small	R&D Services (Proetex partner)
Nanocyl	www.nanocyl.com	Belgium	Small	CNT manufacturer (Inteltex partner)

Rest of the World Companies

Dow Corning is a supplier of silicones and silicone technology. The company is jointly owned by Dow Chemical and Corning, Inc. The company produces and sells a protective fabric under the brand name 'Active Protection System'. This material uses a silicone dilatant coating which acts as a sheer thickening fluid to provide impact protection.[40] The material is sold for sports applications and for personal protective equipment.

DuPont manufactures a number of synthetic fibres with applications in protective materials, such as Nomex, used in fire fighter uniforms for its heat resistant properties. DuPont is a founding member of the Institute for Soldier Nanotechnologies at MIT, and is focusing on the following PPE applications:[41]

- Energy dissipative systems for blast protection
- Chemical/Biological sensing
- Materials processing (such as selectively permeable membranes)

Radiation Shield Technologies (RST) produces radiation shielding material under the trade name Demron. According to the company's marketing material and patent portfolio, the radiation shielding functionality is provided by "a radiopaque polymeric mixture having a polymer and a radiopaque nano-material."[42]

ApNano Materials was established to commercialise inorganic nanostructures developed at the Weizmann Institute of Science, Israel. The company is headquartered in the United States, with research and development in Israel.

The company is investigating the use of tungsten disulfide fullerenes for impact resistant materials (under the trade name NanoArmor). The impact resistance properties of individual nanostructures have been observed, but the most recent references to this technology (2008) suggest that the company has not replicated these properties in a bulk material.[43]

Company	URL	Country	Size	Technology
ApNano Materials	www.apnano.com	US / Israel		Inorganic nanostructures
Radiation Shield Technologies	www.radshield.com	US		Radiation shielding nanomaterials
Dow Corning	www.dowcorning.com	US		Silicone producer
PBI Performance Products Inc.	www.pbigold.com/	US		Polybenzimidazole fibres
DuPont	www2.dupont.com	US	Large	Synthetic fibres
Lion Apparel	www.lionapparel.com	France	Large	Protective clothing (French subsidiary is Proetex partner)

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