Report

Final

Document Reference: ENE/0068-US/AP/03

Quantifying the Carbon Footprint associated with OREX® and Textile Garment use in the USA

To: John Steward
Eastern Technologies Inc.
215 Second Avenue
P.O. Box 409
Ashford, Alabama (AL) USA 36312

Date: 27th August 2012

From: Dr Adrian Punt
Eden Nuclear and Environment

Dr Bryony Cunningham
SKM Enviros

Eden Nuclear and Environment Ltd
www.eden-ne.co.uk

SKM Enviros
www.enviros.com

DOCUMENT ISSUE RECORD

Document Title:	Quantifying the Carbon Footprint associated with OREX and Textile Garment use in the USA		
Project Reference:	ENE/0068-US/AP	**Document Ref:**	ENE/0068-US/AP/03
Project Manager	Adrian Punt, Eden Nuclear and Environment		

Issue	Description	Author (s)	Checker & Approver	Date
01	Draft for initial comment	Adrian Punt Bryony Cunningham	Duncan Jackson	22 Jun 12
02	Final Draft for review	Adrian Punt Bryony Cunningham	Duncan Jackson	7 August 12
03	Final	Adrian Punt Bryony Cunningham	Duncan Jackson	27 August 12
Final	Verified by: Jordan Johnston Engineering Vice President		Authorized by: John Steward Chief Executive Officer	27 August 12

Total number of pages:	Exec Sum.:	1	Text	21	Tables	3	Figures	4	Appendices	2

Previous issues of this document shall be destroyed or marked **SUPERSEDED**

Distribution: John Steward, Eastern Technologies Inc.

Executive Summary

The decisive move over the last decade by the US nuclear industry from the use of launderable garments to specialized single use OREX garments has been primarily driven by the fact that launderable garments are woven and inherently contain thousands of “holes” in the weave per square inch of fabric. Holes that on average are much larger than the mean diameter of the radioactive particulate the garment is intended to protect against. With each washing these holes get larger, and more numerous, thus increasing the risk of radioactive particulate penetration. This report further supports the move away from launderable garments by considering the environmental sustainability (in terms of the life cycle carbon footprint) of protective garment use in the US nuclear industry by comparing specialized single use OREX garments against the historical approach of use of launderable textiles.

This assessment has been based on a detailed understanding of the supply and processing of OREX® garments from Eastern Technologies Inc. (ETI) who have created and supply the only single use protective clothing that is specifically tested and certified to offer radiological protection. The OREX garments and paired processing technology provides both superior performance for the wearer and virtual elimination of solid waste. The garment uses a polyvinyl alcohol (PVA) polymer, a dissolvable material, and has set a new standard for radiation protection clothing within the US nuclear industry. Single use OREX garments have been shown to offer numerous benefits, not just in terms of radiological protection, but also in terms of cost, comfort and hygiene perception, and supply logistics and waste minimization; this report also demonstrates that under the full range of credible launderable garment use, OREX offers a more environmentally sustainable option than a multi-use launderable one.

This assessment has considered the full life cycle of the garments from production and distribution, processing (including, in the case of textiles, laundering after each use), transportation and ultimately waste disposal needs. The report identifies that previous work on this subject has not provided a fully comparative analysis between specialized single use and launderable textiles. Key aspects such as transportation and waste disposal requirements have previously been omitted and the technical operating aspects of the specialized single use garments have not been accurately reflected in calculations.

The inputs, boundaries, assumptions and calculations associated with the assessment process have been explained fully with the reporting unit of the study set as kg CO_2 per garment per use. It has been completed following US and international guidance and has used well established and robust data sets to assess the life cycle carbon footprint. This analysis allows for the manufacture, distribution and final disposal impacts of a garment to be allocated to either the single use of an OREX garment, or spread throughout the lifetime of multiple uses of a textile garment. A point for debate within the report is the number of times that the launderable garment could be used prior to final disposal. Although the maximum theoretical use / wash cycle number may be 100 times, this is virtually never achieved in operational practice. Evidence collected associated with this report would suggest that issues such as rejection due to residual contamination means the re-use value is more likely to be between 25 to 50 times for launderable garments. To ensure completeness in the approach the carbon footprint has been considered on a per use basis, and the assessment has considered a range of reuse cycles for a launderable textile.

The results show that the carbon footprint, whether for a single use OREX garment, or a multiple use nylon one, given on a per use basis, are not significantly different. In fact, up

to 80 to 90 uses, the carbon footprint of a single use garment offers better environmental performance compared to a nylon one.

CONTENTS

1 Introduction

This report considers the environmental sustainability (in terms of the life cycle carbon footprint) of protective garment use in the US nuclear industry. It focuses on the intercomparison of the carbon footprint of single use OREX garments, versus the historic approach of the use of textile garments and their respective laundry and final disposal needs.

Although a preliminary assessment of the life cycle carbon footprint of single use OREX garments verses a typical textile one has been made (see Chapter 2), this is subject to a number of uncertainties. Addressing these uncertainties is a key aspect of the work reported here.

This programme of work has been undertaken by the specialist nuclear industry consultancy Eden Nuclear and Environment (Eden NE) in collaboration with the global leader in environmental consultancy assessments and specialist in carbon footprint analysis, Sinclair Knight Merz (SKM Enviros). Details of Eden NE and SKM Enviros and the key authors of this report are provided in Appendix 1.

1.1 Background

Over the last decade there has been a paradigm shift in the US with a decisive move away from launderable garments to specialized single use garments. The main driver is that launderable garments are woven and inherently contain thousands of “holes” in the weave per square inch of fabric. Holes that on average are much larger than the mean diameter of the radioactive particulate the garment is intended to protect against. With each washing, these holes get larger, and more numerous, thus increasing the risk of radioactive particulate penetration. Although commercial nuclear laundry operators are capable of ‘decontaminating’ used protective clothing, not all the contamination is removed from the fabric. Some level of residual contamination will remain in the garment and will be present during any subsequent use by another worker. During heavy work conditions at many plants, perspiration can ‘wick’ residual contamination from the garments resulting in contamination of the skin of the wearer. Textile garments that cannot be appropriately cleaned to some predetermined activity level have to be rejected and dispositioned as radioactive waste.

Eastern Technologies Inc. (ETI) has created and supplies the only single use protective clothing technology that offers proven radiological protection. The technology carries the trademark OREX®. The OREX garments and paired processing technology (see Chapter 3) provides both superior performance for the wearer and virtual elimination of solid waste. This ‘Certified Soluble®’ technology, which uses a polyvinyl alcohol (PVA) polymer, a dissolvable material, has set a new standard for radiation protection clothing within the US nuclear industry while also significantly reducing the solid radioactive waste that has to be disposed of.

Although single use OREX garments have been shown to offer numerous benefits, not just in terms of radiological protection, but also in terms of cost, comfort and hygiene perception, and supply logistics and waste minimization; the question remains as to whether a single use garment represents a more environmentally sustainable option than a multi-use launderable one.

With the international concern over global warming, a valuable metric to measure environmental sustainability, is the carbon footprint of a particular product. For any such assessment to be robust, it needs to consider the full life cycle of that product from production and distribution, through processing (including, in the case of textiles, laundering following each use), and ultimately waste disposal needs. Such assessments need to include respective transportation impacts, and how the carbon implications of manufacture, processing and final waste disposal are attributed to the number of times that particular product is used. Most importantly any intercomparison needs to be undertaken on a like for like basis, while also ensuring that key process differences are accounted for.

1.2 Aim and Objectives

To date, there has been limited reporting of carbon footprint comparisons between single use OREX garments and launderable textiles (see Chapter 2 for details). The aim of this study is to therefore provide an underpinned and robust comparison of the carbon footprint of single use OREX garments versus those of launderable textiles. The specific objectives are to ensure that the full life cycle of each product is addressed – from manufacture through to final waste disposal, using robust input data and ensuring the process is reported in a clear and auditable way. This will be undertaken in a number of core steps:

- Step One: Define the goal of the study and build the process description of the product's life cycle, from raw materials to disposal, including material and energy use;
- Step Two: Confirm boundaries and perform high-level footprint calculations to help prioritize efforts (at this point the process description completed in Step One is updated with new information);
- Step Three: Collect data on material amounts, activities, and emission factors across all life cycle stages; and,
- Step Four: Calculate the product footprint and report in a clear and informative way.

1.3 Structure of this Report

The following sections of this report describe the carbon footprint assessment undertaken and results of this study, specifically:

- Chapter 2 summarizes previous work and identifies data gaps;
- The life cycle, in terms of energy and material use of an OREX garment compared to a textile one, is discussed in Chapter 3;
- Background to carbon footprint life cycle assessment and the approach adopted here is discussed in Chapter 4 along with input parameters and assumptions made.
- Chapter 5 sets out the results of this study and summary and conclusions are given in Chapter 6.

In addition, details of the authors of this report and of the Eden NE and SKM Enviros organizations are provided in Appendix 1.

2 Review of Previous Work

As noted in Chapter 1, there has to date been limited comparison of the carbon footprint of OREX garments compared to textile ones. Some previous work was undertaken by Exponent on behalf of UniTech Services laundry group to produce a life cycle inventory (LCI) comparison of radiological protective garments (2010)[1]. A review of this study is described below.

A review of the Exponent work by Cournoyer, Wannigman and Dodge (2011) "Pollution Prevention Benefits of Dissolvable Protective Clothing"[2] observed that, although the Exponent report includes energy use associated with OREX processing, it then assumed that the end-of-life final waste disposal needs of OREX and textile garments were the same. Hence it failed to recognize that after OREX processing, the volume of secondary waste associated with a single use garment is significantly less than a launderable, in fact it is virtually zero, and hence the transport and final waste disposal needs for an OREX garment are many times lower than that of a textile garment. Overall, Cournoyer described the Exponent report as "...*incomplete and inconclusive*". Further review points assessed by the expert authors of this report are described below.

The Exponent study was based on the use of launderable nylon garments that are relatively lightweight (c. 0.4 kg per coverall). It was assumed that an OREX garment weighs 35% less than a launderable textile garment. However, Cournoyer points out that in comparison to a heavier, poly-cotton garment (c. 1 kg per coverall), OREX garments weigh around 70% less than a launderable textile (a typical OREX coverall weights 0.25 kg). However, the Exponent work does make the reasonable assumption that the most typical coverall used in the US is nylon and this approach has been adopted in this report.

In addition, the Exponent report has not included transportation elements within their calculation. The transport to and from laundry operations or for secondary waste management and disposal have the potential to be substantial and would appear to be a critical factor that was not addressed. It is also important to note that not only are OREX garments lighter, but when packaged are smaller and can be transported more efficiently. During outage, nuclear power stations that have transitioned to OREX report over a 90% reduction in transport needs compared to the transportation requirements for reusable garments since such clothing must be shipped for laundering and returned multiple times during outage periods. This was not considered in the Exponent report.

Exponent based their assessment on the assumption that a textile garment can be used and laundered 100 times. This number may be a theoretical maximum quoted by the manufacturer, but in reality the number of uses will be significantly less (prospectively between 25 to 50 times), particularly where textile garments are rejected due to residual contamination and subsequently dispositioned as waste. Under any typical regime of use the Exponent study will therefore underestimate the carbon impact per wear per textile garment. It is interesting to note

---

[1] Exponent (2010) "Life Cycle Inventory Comparison of Radiological Protective Garments" prepared for UniTech Services Group Limited, available at: http://www.arta1.com/cms/uploads/UniTech%20Shares%20Life%20Cycle%20Evaluation%20of%20Reusable%20Protective%20Work%20Wear.2010.pdf

[2] Cournoyer, M.E.; Wanningman, D.L. and Dodge, R.L. (2011) "Pollution Benefits of Dissolvable Protective Clothing" in Proceedings of the ASME 2011 14th International Conference on Environmental Remediation and Radioactive Waste Management ICEM2011 September 25-29, 2011, Reims, France

that the Exponent study used a report by Franklin Associates, 1993[3] that quoted a figure of 40 uses (for a woman's blouse) and 75 uses (for a hospital garment). They then assumed 100 wears for a protective coverall. It must also be noted that a number of sources of data in the Franklin Associates report date back to the 1970s and may no longer be valid.

It is important to note that the source data employed by Exponent in their study to calculate the impact of OREX material production was based on polyethylene terephthalate (PET) data from the Franklin report and polypropylene (PPE) data from work by Ponder and Overcash (2007)[4] and Ponder (2009)[5]. However, the OREX 'Certified Soluble®' technology uses the PVA polymer, rather than PET or PPE, with a seemingly lower carbon impact for material production compared to these.

Exponent assumed that each batch of OREX garments processed only treated 240 garments. However, the MB-600 processor developed by OREX at their Alabama, USA, facility operates on a batch basis with each batch consisting of 600 lbs (c. 270 kg), dry weight, of OREX material. Based on a typical coverall weight of 0.25 kg each, this equates to approximately 1,000 OREX garments that can be processed in a single batch. It is therefore likely that Exponent have overestimated the energy use of OREX processing (on a per garment basis) by a factor of four. Although Exponent quoted totals for energy use associated with manufacture and processing / laundering of both OREX and textile garments, it is not clear how these values have been derived and further review is therefore difficult.

The Exponent work provides a useful starting point, but as discussed above does not provide a fully comparative analysis between OREX and launderable textiles. It also omits key aspects of the life cycle assessment, such as transportation and lacks the detailed understanding of the specialized OREX technology and subsequent waste disposal requirements needed for a proper assessment.

[3] Franklin Associates, 1993, file available at: http://www.fibersource.com/f-tutor/lca-page.htm Life Cycle Analysis (LCA): Woman's knit polyester blouse. Resource and environmental profile analysis of a manufactured apparel product. Final report. Prepared for American Fiber Manufacturers Association

[4] Ponder C.S. and Overcash N. (2007) LCA of healthcare garments. Presented at In LCA/LCM2007, Portland, Oregon, October 4 http://lcacenter.org/inlca2007/presentations/75.pdf

[5] Ponder, C.S. (2009) Life cycle inventory analysis of medical textiles and their prevention of nosocomial infections. Dissertation. North Carolina State University, 2009-08-11. Reference is unavailable, but content is expected to be the same as the 2007 presentation referenced above.

3 OREX and Textile Garment Life Cycles

The process descriptions given in this chapter aim to describe the key stages in the life cycle of both a single use OREX garment and a multi-use textile (nylon) garment and provide a more definitive description of the OREX process than considered in earlier studies.

3.1 OREX Garment Manufacture, Transport, Processing and Disposal

The range of OREX protective clothing has been designed specifically for the nuclear industry in the USA and globally. The innovative nature of the OREX technology has meant that the company has grown rapidly, with 70% of the US commercial nuclear fleet making the transition away from reusable garments to OREX protective clothing in the last six years with significant company growth each year since its establishment in 2001. Details of OREX garment manufacture and distribution, processing and final waste disposal are discussed below.

All OREX products are single use, and as noted before, are based on a PVA polymer, although a small proportion of elastic, hook and loop closure and zipper material is present (typically about 15 g per garment, around 6% in terms of mass). An OREX Original coverall weights 0.25 kg and a full dress-out about 0.3 kg.

The PVA material and the garments are produced in China and shipped from Shanghai to the USA, a sea freight distance of just over 10,000 nautical miles. 41,000 OREX garments are packaged within a single 40 ft ocean freight container and typically 7,000 containers are transported per ship. Freight containers are then transported by highway an additional 300 miles to the OREX distribution warehouse. The average distance between the distribution warehouse and nuclear facilities using OREX is currently approximately 800 miles.

Used OREX garments are then transported by road to the processing facility in Ashford, Alabama (an average road distance of about 835 miles). A key point to note is that used OREX garments can be easily compressed and return shipments can achieve a high packaging efficiency (typically 20,000 garments per sealand container. Unlike textile garments that need to be laundered and then returned to service promptly, used OREX can be stored on site until a container is full. This means that used OREX shipping movements off-site can be 10% or less than that associated with a site using launderable garments (which needs much more regular shipments to maintain sufficient garment stocks).

At Ashford, ETI currently operates two MB-600 processors for the dissolution of OREX. OREX is processed on a batch basis, with each batch consisting of 270 kg of OREX (dry weight), where a batch is equivalent to just over 1,000 coveralls. Both processors operate at full capacity and the dissolution process takes about 5 to 6 hours.

Each MB-600 processor batch uses 5,300 litres of water where the water is heated to and then maintained at between 100 and 120ºC under a pressure of around 1.05 kg cm^2 to convert the PVA items to liquid form. The MB-600 uses a gas-powered pre-heater (energy use equivalent to 4 hours of power consumption at 30 kW) followed by an 80 kW final heat-up phase (which is three to four hours long). When not in heat up mode (for the last two hours), power consumption is around 6 kW. The typical energy requirement to process each coverall as assessed here is just over 600 kJ.

The effluent generated from the dissolution phase is initially a 5% solution of PVA. The second step of the treatment process chemically converts the PVA solution to a more suitable form for subsequent biodegradation within the local municipal waste water treatment works. The process solubilises the PVA materials and subsequently converts the materials to a dilute solution of organic constituents through a Fenton oxidation reaction. This step uses a catalyst with heat to produce a dilute solution of weak organic acids, mostly acetic and formic acids. This effluent is then neutralised, tested, filtered and then discharged to the local municipal waste water treatment works (equivalent to about 5 litres per garment).

All PVA material is 100% dissolved in this process. Some limited components of the protective clothing, as noted above, are made of non-PVA materials that contribute to solid secondary waste products. These components, which for a typical coverall equate to about 6% of the original garment mass, are contained at the bottom of the processor (94% mass reduction). This secondary waste is further volume-reduced (at a separate authorized facility 450 miles away from Ashford) through a high-temperature thermal treatment (pyrolysis) process which achieves an approximate 98% mass reduction of this residual material. The final waste, at less than 0.01% of the original mass is then transported an additional 1,900 miles (by road) for landfill disposal in Clive, Utah.

Based on an annual throughput of in excess of 300,000 kg of OREX material, the Ashford facility generates about 5,000 spent polyester yarn effluent filter cartridges (around 2,000 kg). These are compacted and then dispositioned to landfill in Utah. Once compacted the annual volume disposed is around 2 m^3. On a per garment basis, the secondary filter waste generated is very small (about 1 g of spent filter cartridge per garment) and transportation and disposal needs are minimal.

3.2 Textile Garment Manufacture, Transport, Laundry and Disposal

Although heavier poly-cotton coveralls may be used, this study focuses on the more typical nylon coverall used in the USA. As part of this study we have weighed a US size 2X (median size) nylon coverall which gave a result of 0.56 kg (slightly heavier than the Exponent results of 0.41 kg). However, to try and ensure, where appropriate, consistency with early studies, the lighter 0.41 kg weight of a nylon coverall has been used (which will slightly under predict the carbon emissions from the nylon garment with respect to a median sized garment).

Unlike OREX garments, where there is a single manufacturing point and distribution route, nylon coveralls may be manufactured in a variety of countries and enter the USA via a number of different routes, hence a greater number of assumptions have to be made here. Based on shipping documents obtained, we have assumed manufacture near Shanghai, China and sea freight to the USA via the Dominican Republic, a sea freight distance of just under 11,000 nautical miles. As with OREX distribution we have assumed 7,000 freight containers per ship; however, due to the greater bulk of textile garments compared to OREX garments, we have assumed that 20,000 textile garments (as opposed to 41,000 OREX garments) are included within any one 40 ft freight container.

To ensure consistency wherever possible, we have assumed the same road transport distances from port of entry to distribution warehouse and from this to sites, noting though that each road shipment of textile garments includes about half the number of garments compared to that of OREX.

It is important to note that there are multiple commercial laundry sites servicing the US nuclear industry, our assessment has therefore assumed that the median distance (one way) from a site to a laundry is 350 miles. This will obviously vary on a site by site basis, but typically ranges from 10 to 800 miles. However, to maintain an operational stock of textile garments, laundry shipments have to be made on a much more frequent basis compared to the occasional shipments of used OREX garments for processing. Based on common industry knowledge, this equates to around 10 times the transport needs compared to OREX where a typical shipment for laundering only carries around 2,000 garments.

Based on the energy use of textile laundry operations that are maintained at the Ashford facility for clients that have not yet fully transitioned to OREX, a value of 700 kJ per garment per wash and about 1,100 kJ per dry cycle (about 1,800 kJ total per garment) has been derived with about 7.5 litres of waste laundry water per kg of garment laundered discharged to the municipal water treatment system. No allowance has been made for laundry detergent use in our assessment. Although waste water treatment filters (and other secondary waste, for example from lint accumulation from the dryers) will be generated, these have been assumed to be trivial on a per garment per wash basis and have not been considered further.

A small number of garments may retain residual levels of activity after washing and hence may need to be rewashed and again dried. We have assumed that 5% of garments go through the wash-dry cycle twice before being returned to a site for use[6].

At the end of a textile garment's life, whether dispositioned from a site, or from a laundry, we have assumed landfill disposal comparable to that for the final waste residues from the OREX process, with a median road transport distance of again 1,400 miles (assuming 5,000 trashed garments per container). No processes of volume reduction, whether via compaction or thermal processes, have been considered prior to disposal of textile garments.

A big question remains as to the number of uses that can be reasonably achieved with a textile garment (particularly a relatively light weight nylon one). Although the maximum theoretical use / wash cycle number may be 100 times, this is virtually never achieved in operational practice. Garment damage and issues of residual contamination mean that the typical number of uses may be as little as a quarter of this. To avoid any basis in our assessment from a presumed number of uses, we have performed calculations based on a wide number of uses. This approach is described further in the next chapter.

3.3 Summary Comparison

A summary comparison of the similarities and differences between OREX and textile garments pertinent to this carbon footprint assessment is given below:

- **Material and Mass –** OREX material is a PVA polymer, textiles coveralls are typically nylon. A median sized OREX Original weigh 0.25 kg. An equivalent nylon one weighs at least 0.4 kg (a 2X size was weighed at 0.56 kg).

- **Point of Manufacture and Distribution –** OREX PVA material and garments are manufactured in China and shipped by sea to the US and then by road to a distribution center and from here to user sites. Transport distances for textile garments are probably similar (although more variable). However, due to the packaged size and weight of an OREX garment, approximately twice the number of new OREX garments can be shipped per container compared to nylon ones.

- **Transport for Processing and Laundry –** OREX garments are used once then consigned for processing. Currently there is one OREX processing site in the USA, located in Ashford, Alabama, and the average transport distance from sites using OREX

[6] Based on laundry data from 7 nuclear power plants prior to transition to OREX, the percentage of garments requiring two washes typically ranged from 4 to 5%, but in one instance was over 14% (mean of 5.7%). A value of 5% was therefore taken as realistic estimated for rewash requirement.

to this facility is 835 miles. Laundry facilities can be closer (we have assumed 350 miles); however, used OREX can be stored on site while launderables have to be shipped and returned for reuse on a much more regular basis. As a result, off-site shipments of OREX can be as low as 10% of that of launderables.

- **Processing and Laundry** – OREX processing requires about 600 kJ of energy per coverall. Laundry and drying of a 0.4 kg nylon garment requires about 1,800 kJ energy (three times the amount). OREX processing achieves around a 94% reduction in garment mass, the residual (non-dissolvable components) then becomes secondary waste and hence this significantly reduces onward transport and disposal needs compared to rejected, damaged or worn out textile garments.

- **Secondary Waste Transport, Treatment and Disposal** – Secondary waste from OREX processing is then further volume reduced (by thermal treatment) to achieve a subsequent reduction in secondary waste mass of an additional 98% such that the final waste form is of the order of 1:10,000 of the original garment mass (that is, disposal of one nylon coverall is equivalent to that of over 15,000 OREX garments post processing). Hence, although additional energy and transport needs arise with OREX secondary waste processing, significantly reduced volumes of waste are transported and finally disposed (to landfill) on a "per use" basis.

4 Life Cycle Assessment Methodology

The assessment approach adopted in this work is described in this chapter and the results of the study provided in Chapter 5.

4.1 Background to Carbon Footprinting

Life Cycle Assessment (LCA) is used to evaluate the environmental impact from products, using a life cycle perspective. The ongoing discussion about carbon labeling has resulted in the development of specialized standards and guidelines, specifically designed for calculating the carbon footprint of products. The World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD) have created what is considered today as the *de-facto* standard for disclosing carbon footprints[7].

In the US, the Energy Information Administration (EIA)[8] and the Environmental Protection Agency (EPA)[9] have both produced a set of guidelines and tools. In addition, the US Department of Energy (DoE) is supporting the voluntary disclosure of carbon emissions via their 1605(b) Program[10].

In the UK, PAS2050[11] (2011) is a specification developed for assessing the life cycle greenhouse gas (GHG) emissions (such as carbon dioxide, CO_2) of goods and services. The PAS2050 is to a large extent based on the LCA standards[12], but in some areas it is more specific in how to calculate the carbon footprint.

To ensure conformity with the standards and guidelines in the US (and drawing on additional guidelines from the UK); a review of applicable guidelines and standards highlighted that the assessment should demonstrate the following:

- **Relevance**: select GHG sources, carbon storage, data and methods appropriate to the assessment of the GHG emissions arising from products;
- **Completeness**: include all specified GHG emissions and storage that provide a material contribution to the assessment of GHG emissions arising from products;
- **Consistency**: enable meaningful comparisons in GHG-related information; and,
- **Accuracy**: Reduce bias and uncertainties as far as practicable; and where the results of life cycle GHG emissions assessment are carried out in accordance with relevant guidance and communicated to third parties; the organization communicating the results shall disclose GHG emissions-related information sufficient to allow such third parties to make associated decisions with confidence.

---

7 See: http://www.ghgprotocol.org/ for details
8 See: http://www.eia.gov/oiaf/1605/reporting_tools.html for further details
9 See: http://www.epa.gov/ttn/chief/efpac/abefpac.html for further details
10 See: http://energy.gov/articles/doe-strengthens-public-registry-track-greenhouse-gas-emissions for further details
11 British Standards Institute, PAS2050:2011, Specification for the measurement of the embodied green house gas emissions in products and services, (updated from a 2008 version) available at: http://www.bsigroup.com/upload/Standards%20&%20Publications/Energy/PAS2050.pdf
12 British Standards Institute, BS EN ISO 14040: 2006, Environmental Management – Life cycle assessment – requirements and guidelines, 2006.

4.2 Assessment Approach and Input Parameters

The assessment approach set out below describes how the study has defined the reporting unit and boundaries of the assessment and the calculation method used. To provide a readily accessible assessment, the approach documented here is limited to standard coveralls equivalent to an OREX Original and a nylon textile one. However, the results can be directly scaled to a full dress-out.

4.2.1 Reporting Unit

The reporting unit of this study is kg CO_2 per garment per use. This approach allows for the manufacture, distribution and final disposal impacts of a garment to be allocated to either the single use of an OREX garment, or spread throughout the lifetime of multiple uses of a textile garment (noting that the number of uses achieved can be debated). With the addition of energy requirements for OREX processing, or of laundering a textile garment, a direct comparison, on a per use per garment basis, is therefore possible (noting that this needs to consider a range of use / laundry cycles for a textile garment).

4.2.2 Establishing the Boundaries of the Footprint

This study has been completed within the context of protective garment use within the USA nuclear industry and considers raw materials, garment manufacture, transportation loads and distances, laundering and treatment requirements and end of life waste disposal. A key factor in this comparison is the number of times that a textile garment is laundered and reused. The impact of manufacturing the garment (and final disposal) can then be divided by the number of garment uses; whereas for a single use garment (whether OREX material or other disposable) the carbon footprint of manufacture and disposal are borne by that single use of the garment. The number of times that a launderable garment is reused is not a definitive amount and will vary based on activities during each use and the potential for residual contamination where the garment has to be rejected and dispositioned as waste. Our approach here has therefore considered the carbon footprint on a per use basis, where the assessment considers a range of reuse cycles for a launderable textile.

As noted in Chapter 2, transportation was omitted from previous studies. Transportation includes not only distribution from the country of manufacture to the USA, but also the distribution to the user facility or site. It also needs to consider distance between the site and the laundry facility or OREX processing facility and finally, transportation and any processing of secondary waste prior to final disposal. These metrics can vary on a site by site basis and for this reason average values that are likely to be indicative of actual US Nuclear Power Plants experiences have been used.

The carbon footprint guidance discussed previously highlights the need to make clear which materials and which processes are included within any analysis (as not all inputs will be relevant or available). This process of definition is referred to as the “system boundary”. The selection of the system boundary must be consistent with the goal of the study. Table 1 below shows the data that was included and excluded in the analysis undertaken here based on the process descriptions given in Chapter 3. Assumptions and input parameters are then discussed in Section 4.3.

Table 1: System Boundary

Garment	Data Included	Data Excluded
OREX Garment	▪ Garment manufacture (includes raw material manufacture of PVA) ▪ Transportation from country of manufacture to distribution; distribution to sites; sites to OREX processor; secondary waste from processor for onward treatment and disposal ▪ Treatment process (including energy, water use and treatment; and filter use associated with the process) ▪ Secondary waste disposal with volume reduction via thermal treatment and landfill disposal of the thermally treated residue ▪ Treatment chemicals and neutralization acids used during OREX processing	▪ Land transportation from place of manufacture to distribution port ▪ PE film packaging for each garment (when new) – primary packaging ▪ Cardboard carton / secondary packaging of garments ▪ Wood pallets used during transport ▪ Impact from manufacture, maintenance and disposal of OREX processing equipment ▪ Fire retardant or other specialized coatings
Textile Garment	▪ Garment manufacture (includes raw material manufacture of nylon) ▪ Transportation from country of manufacture to distribution; distribution to sites; sites to laundry (and back); and for final waste disposal ▪ Textile laundering (including washing and drying assuming a 2% need to re-wash and dry in instances where a single wash fails to achieve a “radiologically clean” garment); ▪ Trashed and rejected garment disposal to landfill	▪ Land transportation from place of manufacture to distribution port ▪ PE film packaging for each garment – primary packaging ▪ Cardboard carton / secondary packaging of garments ▪ Wood pallets used during transport ▪ Washing agents used in the laundry process ▪ Lint collected from drying process, filters and secondary waste disposal needs ▪ Impact from manufacture, maintenance and disposal of washing and drying machines ▪ Fire retardant of other specialized coatings

4.2.3 Calculations

As recommended by guidance described in Section 4.1, the carbon footprint for materials and energy use has been completed using the Intergovernmental Panel on Climate Change (IPCC) 2007 carbon impacts based on a 100 year time frame that present the resulting data as kg CO_2 equivalent. The analysis has been completed within a bespoke MS Excel sheet with the primary data as described in Section 4.3.1. The emission factors used have been obtained from a variety of sources, but principally from the EcoInvent database (Version 2.2)[13]. The

[13] See: http://www.ecoinvent.org/home/ EcoInvent database – the world’s leading database with consistent and transparent, up-to-date LCI data. With more than 4,000 LCI datasets in the areas of agriculture, energy supply, transport, biofuels and biomaterials, bulk and speciality chemicals, construction materials, packaging materials, basic and precious metals, metals processing, Information Communication Technology and electronics as well as waste treatment, it is one of the most comprehensive international LCI databases. The high-quality generic LCI datasets are based on

emission factors have been used to reflect USA operating requirements (for example, emission factors for electricity have been taken to suit the USA infrastructure impacts) and are given in Section 4.3.2. SimaPro (Version 7)[14] (the most widely used life cycle assessment software) was then used to obtain the emission factors[15] and used to double check the calculations completed in the bespoke MS Excel sheet to ensure accuracy.

The input data that was collected has then been adjusted to a per garment basis, based on understanding the number of garments involved within each process stage (for example the number (or mass) of garments in a transportation container, or the number (or mass) laundered per cycle or OREX processed per batch). The material / energy use input data has then been multiplied by the emission factors that were identified. The relative areas of the output (for example production and final waste disposal) have then been divided by the number of uses applicable to the garment type (multiple use for launderable garments and single use for an OREX garment) to give the carbon (C) impact per garment per use as follows:

$$C\ per\ garment\ per\ wear = \frac{C\ M\&D}{No.} + C\ L\&P + \frac{C\ P\&D}{No.}$$

Where:

C M&D	= carbon impact of manufacture and distribution (including transportation);
C L&P	= carbon impact of laundering a textile garment or processing an OREX garment (including transportation);
C P&D	= carbon impact of secondary waste processing and disposal (including transportation);
No.	= number of uses (noting that for an OREX garment this is always one use).

Considering the uncertainty associated with the number of times a textile garment is used, these calculations have been repeated assuming that the number of uses of a textile garment varies from between 1 and 100 times. It is not suggested that either of these two extremes is likely (as stated the most likely range of number of uses of a textile garment is from 25 to 50 times). Nevertheless, this approach accounts for the uncertainty in number of textile garment uses and identifies the point (in terms of number of uses) where the per use life cycle carbon emissions of a textile garment exceed that of a single use OREX garment. This comparison is plotted graphically and discussed in Chapter 5.

4.3 Assumptions and Input Values

Detailed discussions and data gathering has been undertaken by the authors of this report with support from ETI with input from large-scale, non-nuclear industrial laundering organizations and input from nuclear site laundry facilities to quantify the input data needed. The material and energy needs and associated assumptions and rationale associated with OREX and textile garments are given in Table 2. As noted above, the final carbon impact results, when given on a per use basis, are clearly governed by the number of uses considered. The input

industrial data and have been compiled by internationally renowned research institutes and LCA consultants.

[14] See: http://www.pre-sustainability.com/content/simapro-lca-software

[15] Measure of the average amount of a specific pollutant or material discharged into the atmosphere by a specific process, fuel, equipment, or source. It is expressed as number of pounds (or kilograms) of particulate per ton (or metric ton) of the material or fuel.

data provided in Table 2 is therefore limited to a 'per garment' basis and the results 'per use' are described in Chapter 5.

Table 2: Life cycle input Parameters for an OREX and a textile coverall

Garment	OREX Coverall	Textile Coverall
1. Number of uses	▪ One	▪ Assessed from 1 to 100 times, noting that this is most typically between 25 and 50 times
2. Material and weight	▪ 0.25 kg consisting of a PVA polymer material (OREX Original)	▪ 0.411 kg consisting of nylon material (larger garments will weigh more, for example a 2X size weighs 0.56 kg)
3. Place of manufacture	▪ China	▪ China
4. Transportation associated with distribution	▪ Sea freight distance of 10,350 Nautical Miles (assessed as one way) – 19,714 km ▪ 41,000 OREX garments per 40 ft container and 7,000 containers per ship ▪ Road transport (40ft container) distance from port to distribution warehouse of 300 miles (483 km) and from here to user sites of 800 miles (1,288 km). Assumes return trip of truck without load).	▪ Sea freight distance of 10,645 Nautical Miles (transport via Dominican Republic) (assessed as one way) – 18,840 km ▪ 20,000 nylon garments per 40 ft container and 7,000 containers per ship ▪ Road transport (40ft container) distance from port to distribution warehouse of 300 miles (483 km) and from here to user sites of 800 miles (1,288 km). Assumes return trip of truck without load).
5. Transportation needs associated with OREX processing and textile laundering	▪ Assumes 20,000 OREX coveralls per shipment ▪ Road transport distance of 835 miles to Ashford processor (1,345 km). Assumes return trip of truck without load.	▪ Assumes 2,000 nylon coveralls per shipment ▪ Road transport distance of 350 miles (800 km) to a laundry. Assumes return trip of truck with laundered garment load.
6. Energy requirements associated with OREX processing and textile laundering	▪ 600 kJ energy requirement per garment associated with OREX dissolution ▪ 5 liters of waste water per garment discharged to municipal waste water treatment works ▪ Treatment chemicals used (100-150 kg per load) ▪ 94% mass reduction achieved, 6% (15 g) on non-dissolvable components become secondary waste ▪ 1 g of polyester yarn filter generated per garment processed	▪ 700 kJ per wash and 1,800 kJ per dry cycle per garment associated with laundry ▪ 3 liters of waste water per garment discharged to municipal waste water treatment works

Garment	OREX Coverall	Textile Coverall
7. Transportation of OREX secondary waste for treatment (thermal treatment)	▪ Road transportation distance from Ashford, AL, of 450 miles (723 km) for thermal treatment (assumes return trip of truck without load). ▪ Assumes residuals from 10 times the original number of garments stated in Point 4 per shipment	▪ Not applicable
8. Energy requirements for secondary waste treatment	▪ Based on energy use of incineration ▪ Assumes 98% mass reduction achieved	▪ Not applicable
9. Transportation for final disposal	▪ Road transportation (40ft container) from secondary waste treatment site to Utah for disposal of 1,875 miles (3,018 km). Assumes return trip of truck without load.	▪ Road transportation (40ft container) from sites to Utah for disposal of 1,400 miles (2,254 km). Assumes return trip of truck without load.
10. Energy requirements for final disposal	▪ Based on landfill, but accounting for the massive volume reduction achieved value per garment (or rather remains of) disposed	▪ Based on landfill, but assuming no volume reduction per garment disposed

As stated in Section 4.2.3 the carbon footprint for materials and energy use has been completed using the Intergovernmental Panel on Climate Change (IPCC) 2007[16] carbon impacts based on a 100 year time frame that present the resulting data as a kg CO_2 equivalent[17]. For the majority of inputs this was possible (used for all materials and activities apart from PVA) using the EcoInvent database.

There is some research available on the carbon emissions from the production of PVA that has been consulted, however as noted above, there are not definitive values given in the EcoInvent database, therefore some uncertainty associated with the emission factor associated with the manufacture of the OREX material is unavoidable. However, PVA is a water-soluble polymer made by hydrolysis of a polyvinyl ester (such as polyvinyl acetate) for which data is available. Dissertations and publications were therefore researched to identify likely emission factors applicable to PVA. One dissertation from Utrecht University (Netherlands) was identified detailing gross energy requirements and gross CO_2 emissions for products from the organic chemical industry[18]. This paper gives the carbon emission factor for polyvinyl acetate (one process down from PVA) as 2,060 kg CO_2 per metric tonne (1,000 kg) of product, which equates to 2.06 kg CO_2 per kg of material. This figure was benchmarked against other polyvinyl products (such as polyvinyl chloride) contained within EcoInvent databases in SimaPro, which gave a comparable or lower level of emission. An additional

---

16 http://www.ipcc.ch/index.htm

17 Global-warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. CO_2 equivalent is a measure for describing how much global warming a given type and amount of greenhouse gas may cause, using the functionally equivalent amount or concentration of carbon dioxide (CO2) as the reference.

18 Jochem, E Fraunhofer for Systems and Innovation Research, available at: http://igitur-archive.library.uu.nl/dissertations/1894529/c4.pdf

source of information, *Environmental Assessment of Bio-Based Polymers and Natural Fibers*[19] provided an emission factor of 1,730 kg CO_2 per metric tonne of PVA product, which equates to 1.73 kg CO_2 per kg of material. However, the “bio-based” nature of the material used in this analysis would suggest that this would likely be an underestimation, so despite it being an appropriate material it was not used and the more conservative (worst-case) value of 2.06 kg CO_2 per kg was seen as more representative (and was larger than the other values identified in the EcoInvent databases by about 0.05 kg CO_2 per kg or more).

As noted other carbon equivalent emission factors have been derived from the well-established EcoInvent database within SimaPro software. The values used in this assessment are given in Table 3 below:

Table 3: Carbon Equivalent Emission factors

Garment	Carbon Equivalent Emission Factors (kg CO_2)	
	OREX Coverall	Textile Coverall
Material	▪ 2.06 per kg PVA	▪ 9.22 per kg nylon
Road transportation (per shipment)	▪ 1.12 per km for 20-28 tonne truck with load ▪ 0.74 per km for 20-28 tonne truck without load	
Sea freight (per ship)	▪ 10.7 per km	
Washing and drying process	▪ Not applicable	▪ 0.000206 per kJ electricity used
OREX processing	▪ 0.000206 per kJ electricity used ▪ 1 to 1.5 per kg treatment chemicals	▪ Not applicable
Waste water treatment	▪ 0.000324 per litre discharged	
Filter use	▪ 19.6 per kg	▪ Not applicable
Secondary waste (thermal treatment)	▪ 1.4 per kg	▪ Not applicable
Disposal to landfill	▪ 0.000557 per kg disposed to landfill	

4.4 Summary Impacts

Production of nylon has a carbon footprint of around 4.5 times that of PVA per unit weight, and at a minimum a nylon garment weighs over 1.6 times that of an OREX garment. As a consequence the carbon footprint of producing a nylon garment is therefore over 7 times that of an OREX garment.

Our assessment has assumed that transportation distances from the place of manufacture to site of use are broadly similar, but that twice the number of OREX garments can be transported per freight container compared to nylon garments. On a per garment basis, the carbon footprint of transporting a new nylon garment is therefore about twice that of a new OREX one.

[19] Patel, M; Bastioli, C; Marini, L; Wurdinger, E Encyclopedia “Biopolymers”, 2003 Vol.10, pp. 409-452.

The energy requirements associated with processing an OREX garment are about one-third of that of washing and drying a textile garment (which is incurred on a per use basis). However, a key point is that transportation needs can be ten times lower when using OREX garments.

OREX processing achieves a 94% reduction in mass, thermal treatment achieves a 98% reduction in mass of the remaining residuals. As a consequence, final transportation and waste disposal requirements of OREX garments are significantly less (0.01%) than that of launderable garments.

5 Carbon Footprint Results

Carbon footprint results (kg CO_2) determined in this study are presented in this chapter and are given on a per garment per use basis.

5.1 OREX Garment Carbon Footprint

The carbon footprint results for a single use OREX coverall are given in Figure 1.

Figure 1 Carbon Footprint Breakdown for an OREX Garment

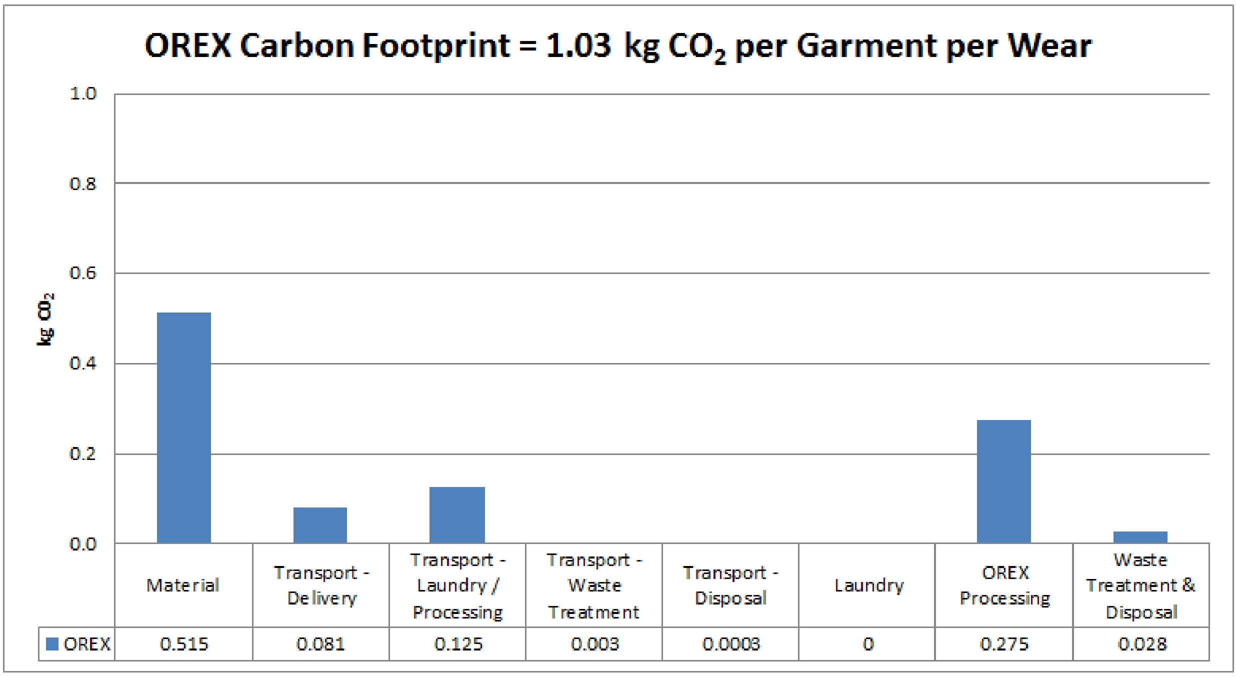


Figure 1 shows that lifecycle carbon footprint of an OREX garment expressed per garment per wear is around 1 kg CO_2. Of this, production of the PVA material accounts for 0.52 kg CO_2 (50%), OREX processing 0.28 kg CO_2 (27%), delivery transportation 0.08 kg CO_2 (8%), and transportation of used OREX to Ashford, AL, for processing of 0.13 kg CO_2 (12%). Transportation associated with secondary waste treatment, OREX processing and final waste disposal was 0.03 kg CO_2 (3%).

5.2 Textile Garment Carbon Footprint

The carbon footprint results for a nylon coverall are given in the following figures based on a realistic range of 25 uses (Figure 2), and 50 uses (Figure 3).

Figure 2 shows that lifecycle carbon footprint of a nylon garment expressed per garment per wear (assuming 25 wears) is 1.16 kg CO_2. Of this, production of the nylon material accounts for 0.15 kg CO_2 (13%), transportation for laundering 0.59 kg CO_2 (51%), laundry processing 0.38 kg CO_2 (33%) and transportation for disposal 0.03 kg CO_2 (3%).

Based on a prospective 25 uses, the carbon footprint of a nylon garment, per garment, per use is 1.16 kg CO_2, just over 0.26 kg CO_2 (29%) more than an OREX garment. This is primarily due to the per use transportation requirements associated with launderable garments.

Figure 2 Carbon Footprint Breakdown for a Nylon Garment (25 uses)

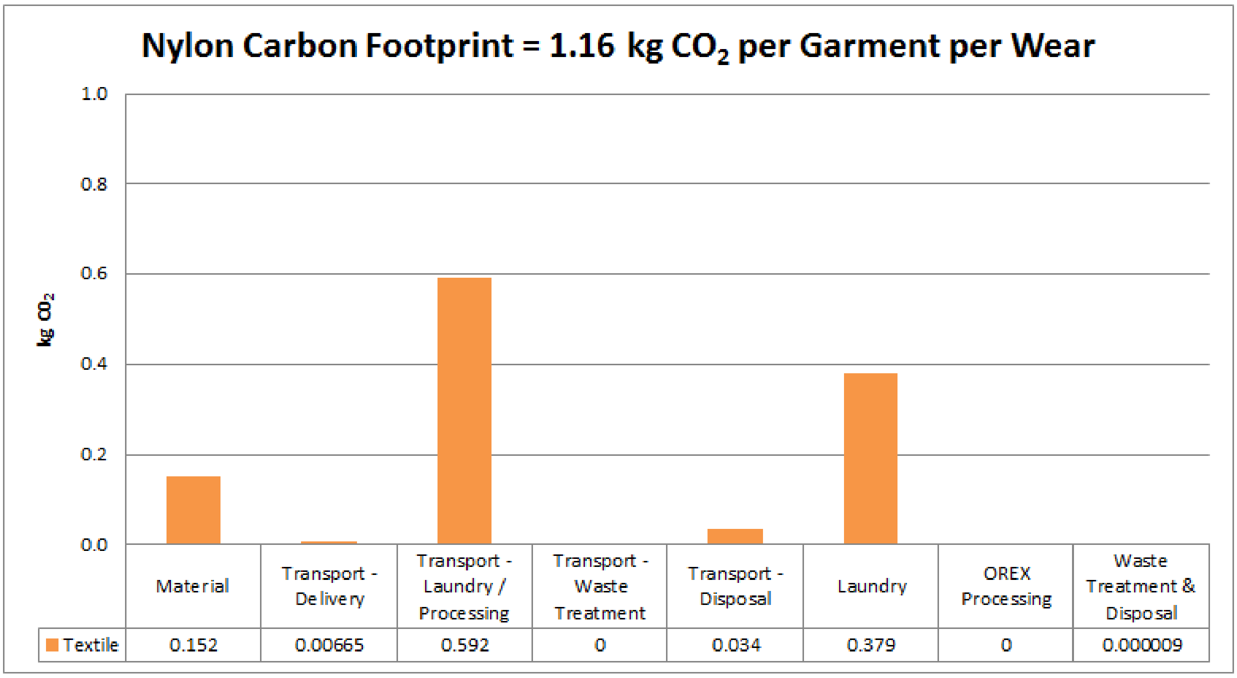
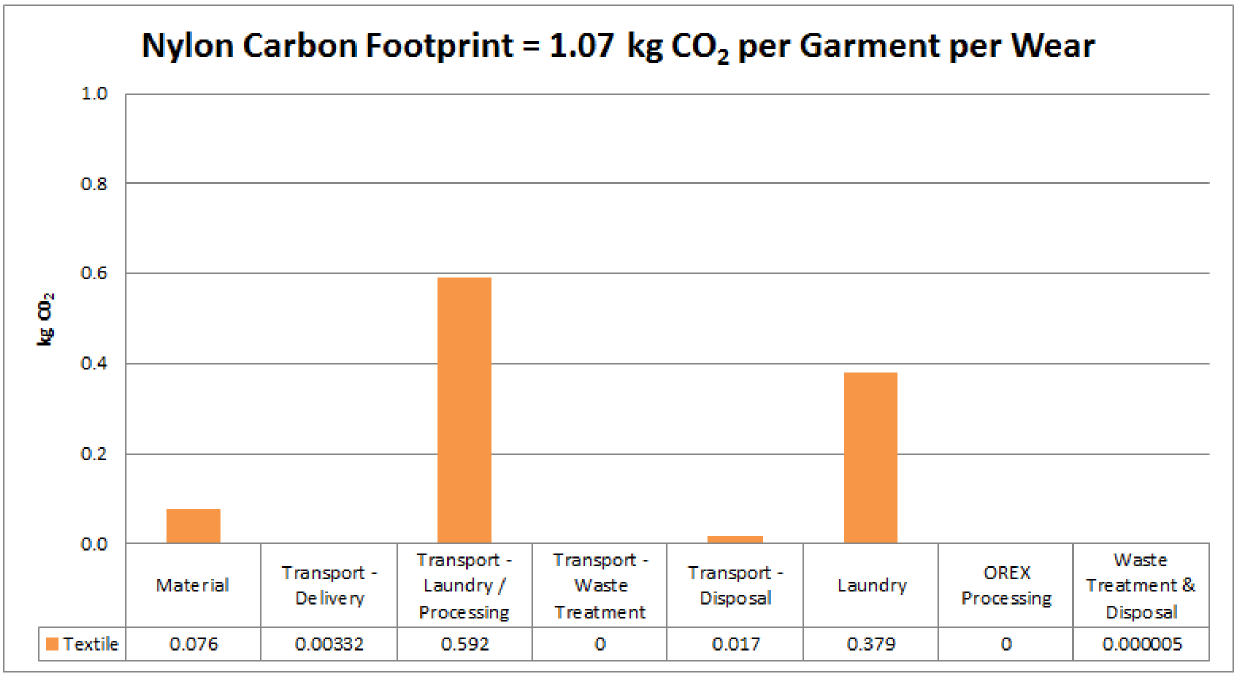


Figure 3 shows that lifecycle carbon footprint of a nylon garment expressed per garment per wear (assuming 50 wears) is 1.07 kg CO_2. Of this the contribution from the production of the nylon material has halved (twice the number of uses) to 0.076 kg CO_2 (7%), while transportation for laundering, which is assessed on a per use basis, remains constant at 0.59 kg CO_2 (but now 55% of the total per wear) and that for actual laundry processing remains constant at 0.38 kg CO_2 (but now 33% of the total per wear).

Figure 3 Carbon Footprint Breakdown for a Nylon Garment (50 uses)

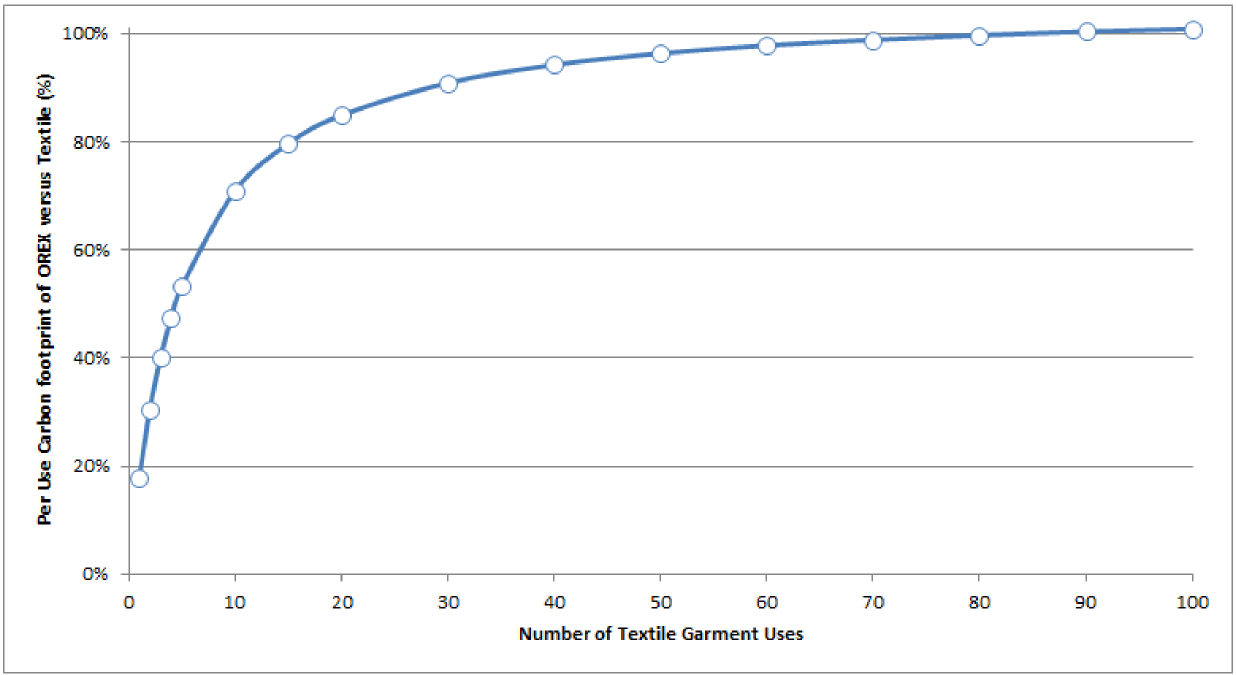


5.3 OREX and Textile Comparison

As shown above and discussed previously the relative carbon footprint performance of an OREX garment compared to a nylon one depends, in part, upon the number of uses of that nylon garment.

The assessment of the carbon footprint given in section 5.2 has therefore been repeated on an iterative basis from 1 to 100 uses of a nylon garment. The carbon footprint per use of an OREX garment compared to the per use carbon footprint of a nylon garment, expressed as percentage, is shown in Figure 4. This shows that, on a per use basis, OREX consistently offers a lower carbon footprint than textiles up to around 80 to 90 uses of a nylon garment. Although a nylon garment could theoretically be used and laundered up to 100 times, achieving such a number of uses from a launderable garment is very unlikely and would also significantly increase the chance of personal contamination events.

Figure 4 Carbon footprint comparison based on number of uses



6 Summary and Conclusions

A detailed carbon footprint assessment of OREX and nylon protective garments used in the US nuclear industry has been undertaken and has been reported here.

This study has followed US and international guidance and has used well established and robust data sets to assess the life cycle carbon footprint, expressed on a per use basis for OREX and nylon garments. The study has responded to critical review of previous work and has included manufacture and distribution, transportation, processing and laundering, secondary waste treatment and final waste disposition. Results have then been presented to account for the uncertainty in the number of prospective uses of a textile garment.

Overall the results show that the carbon footprint, whether for a single use OREX garment, or a multiple use nylon one, given on a per use basis, are not significantly different. In fact, the carbon footprint of a single use OREX garment offers better environmental performance compared to a nylon one up to 80 to 90 uses. Where nylon garments can be maintained in service beyond this number of uses, they may offer, in terms of carbon footprint per wear, better environmental performance, but even at 100 wears this the carbon footprint on a per use basis is virtually indistinguishable from that of an OREX garment. This study has not accounted for the use of detergents and possible water conditioners in the carbon footprint for launderable garments, hence the carbon footprint of their use will be higher than assessed here. It is also important to note that although the garment manufacturers may quote a theoretical number of uses of 100 times, in practical terms this is unlikely to be achieved due to garment damage and issues of residual contamination. As noted in the introduction to this report, launderable garments are woven and inherently contain thousands of “holes” in the weave per square inch of fabric and where, with each washing, these holes get larger and more numerous. Hence the radiological protection of worker can be compromised where garments are used many times.

The results of this assessment are very different to the preliminary study discussed in Chapter 2 which declared that one use of a PVA garment releases almost 18 times more greenhouse gas equivalents than one use of a reusable nylon garment. However, as noted in Chapter 2 key aspects of both garment life cycles were excluded in this preliminary study (particularly transportation and waste disposal and the respective requirements of both) and the emissions from PVA production were based on higher values from polyester type substances. Therefore the results of the two studies are not comparable.

Based on the preliminary study discussed in Chapter 2, Exponent multiplied the per garment per use carbon footprint of OREX and nylon garments to give an indication of absolute differences in carbon emissions. Following the USA and typical site use metrics they give, we have recalculated values based on the more comprehensive approach taken here. A calculation such as this needs to make an assumption on the realistic number of uses of a textile garment. For the purpose of this calculation we have used an optimistic value of 50 uses of a nylon garment. If OREX garment supply to the US nuclear industry over the last ten years is considered, a US industry use of 30,000,000 OREX garments, this would imply a total carbon footprint saving to the industry of over a 1,000 metric tonnes of CO_2 emissions.

Any assessment such as this, which includes factors such as transportation distance, particularly within country, road transportation is clearly influenced by the assumed distances and by quantities per shipment. Nonetheless, we have tried to use reasonable average values applicable to a broad number of user sites.

Although not assessed here, sustainability is not just about carbon footprint, in its broadest sense it also needs to consider worker protection, cost to the industry and availability of waste disposition routes. These are all areas where OREX garments may offer enhanced performance compared to the historic use of textiles.

Appendix 1 – Report Authors

This report has been produced by a partnership between Eden Nuclear and Environment (Eden NE) and SKM Enviros. Dr Adrian Punt (Eden NE) and Dr Bryony Cunningham (SKM Enviros) are the prime authors of this report.

Eden NE is accredited to ISO 9001:2008 for the provision of consultancy services to the nuclear industry and specializes in nuclear industry waste management, radiation protection and environmental sustainability and safety assessments. Eden NE are based in Great Britain, but support an international client base that includes organizations like the Electric Power Research Institute (EPRI) in the USA, the Nuclear Waste Management Organisation (NWMO) of Canada, fuel production, reprocessing and nuclear power plant operators in Great Britain and radioactive waste management organisations throughout Europe and in Asia. For more information and for contact details please visit www.eden-ne.co.uk.

Sinclair Knight Merz (SKM) is a leading projects firm, with global capability in strategic consulting, engineering and project delivery. It operates in three regions: Asia Pacific, the Americas and EMEA (Europe, Middle East & Africa), deploying some 7,000 people from more than 40 offices while serving the Buildings and Infrastructure, Mining and Metals, Power and Energy and Water and Environment sectors.

SKM Enviros works extensively with national and international organizations to calculate and report their carbon footprints. These clients range from public sector organizations such as local and national government authorities, higher education establishments, to private sector organizations like Coca-Cola and Nestle. These assignments involve the development of assessment tools and models to calculate carbon emissions to ensure that clients are able to report robust and technically underpin assessments of the carbon footprint of their operations. These studies are based on a detailed appraisal of life cycle impacts (as well as modeling end-of-life scenarios). For more information and for contact details please visit www.skmenviros.com.

Author - Dr Adrian Punt – PhD, MSc, BSc (Hons), CRadP

Dr Punt, Associate Director, Eden NE is an environmental and waste management expert with over 20 years' experience and is a Chartered Radiation Protection Professional (CRadP). Dr Punt has worked with a diverse range of operational and decommissioning nuclear facilities in areas of radiation and environmental protection, waste management and sustainability assessments. This experience covers the development of carbon footprints for radioactive waste management and options assessments and optimisation programmes to minimise the environmental impact of waste management. He is an expert in the development of integrated waste management strategies that provide a holistic and optimized approach to life cycle waste management and the hazardous and radiological impacts of gaseous, aqueous and solid waste disposal needs. Dr Punt has been the primary author for a number of key reports written on behalf of the environmental regulators in Great Britain, particularly the Environment Agency of England and Wales and the Scottish Environment Protection Agency. He has also provided specialist advisory services to the British Government and to the European Commission and has presented his work at international conferences such as Waste Management in Phoenix and for the International Atomic Energy Agency (IAEA) in Vienna.

Author – Dr Bryony Cunningham – EngD, MSc, BSc (Hons), AIEMA

Dr Bryony Cunningham, Principal Consultant, SKM Enviros is an environmental expert with 14 years experience with posts in industry, academia, government and consultancy, experience with a specific focus on life cycle carbon assessment and its application to environmental decision making. Dr Cunningham has both a Bachelor and Masters degree in environmental impact assessment. She was awarded an Engineering PhD Doctorate (EngD) whilst working for Shell in the UK, where her research studies focused on elements of life cycle assessment (LCA) techniques and the establishment of bespoke environmental and carbon modeling tools for the oil and gas sector. She has then gone on to manage a range of LCA and carbon footprinting projects for a range of subjects for national and international clients, including analysis of packaging, fuels, agricultural products, foodstuffs and waste treatment techniques for companies including Tata and Cadbury's (now part of Nestle group). This work includes the carbon footprint analysis for a nuclear industry client assessing the carbon impact of radioactive contaminated oil incineration, radioactive contaminated metal recycling and solid radioactive waste disposal. She has also been part of a small team that worked to produce UK government guidance on LCA and carbon footprinting for the waste sector, 'Carbon Sense for Better Waste Management'[20]. She is an expert user of SimaPro (utilising the EcoInvent database) and an Associate Member of the UK Institute of Environmental Management and Assessment (AIEMA).

[20] Available at: http://www.adeptnet.org.uk/assets/userfiles/documents/000101.pdf

Eden Nuclear and Environment Ltd registered address:
Eden Conference Barn
Low Moor, Penrith, Cumbria
CA10 1XQ

Company No 6314579, registered in England and Wales