Environmental Product Declaration of Electricity from Torness Nuclear Power Station

Technical Report

A study for
British Energy
undertaken by
AEA Technology Environment

May 2005

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British Energy

AEA TECHNOLOGY ENVIRONMENT

Key Findings

Key findings

AEA Technology has been commissioned by British Energy to develop an Environmental Product Declaration (EPD) for electricity from its nuclear power plant at Torness. The EPD quanitifies the life-cycle environmental impacts associated with generation of electricity at Torness, assessed over the entire fuel cycle.

- The mining and milling stage has the largest single contribution to the emission of greenhouse gases and acidifying pollutants. The variation in emissions between sites relates to the fossil fuels use at each site and the uranium content of the ore.

- The construction, operation and decommissioning of the power plant combined also make a strong contribution to the overall environmental impacts.

- The impacts of the conversion and fuel fabrication stages of the fuel cycle are generally small in comparison to the other stages.

- The reprocessing of spent fuel from Torness produces high level radioactive waste. The final route of disposal for high level radioactive waste in the UK is currently under consideration.

- The total emissions of CO_2 from electricity generated at Torness power station, calculated on a lifecycle basis, are estimated to be just over 5 g/kWh. This compares to emissions of CO_2 from a typical UK coal plant of around 900 g/kWh, based upon the operational stage alone. Typical CCGT CO_2 emissions are around 400 g/kWh.

- The emissions of acidifying pollutants from the fuel cycle relate closely to the use of fossil fuels. The total lifecycle emissions of NO_x and SO_2 from the Torness fuel cycle amount to 0.02 g/kWh, and 0.01 g/kWh, respectively.

- Radioactive substances are handled during the course of the normal operation of facilities in the nuclear fuel cycle. These substances emit ionizing radiation that may result in doses to the people working at the facility, and to people outside the facility. At all sites in the fuel cycle during the reference year, the occupational dose was within the respective national regulatory limits.

- The EPD also assesses land use, biodiversity, safety and security.

Introduction

1.1 The product

This constitutes the Environmental Product Declaration (EPD) of electricity from the nuclear power plant at Torness commissioned by British Energy. This report has been prepared by AEA Technology Environment on behalf of British Energy.

The declared product is 1 kWh (the functional unit) generated and thereafter distributed to the customer during the reference year 2002.

The nuclear power plant at Torness is a base-load plant of the UK electricity system, running at maximum power output throughout the year. A nuclear power plant is, however, unable to control its power output as flexibly as fossil plant.

1.2 The declaration and the system

As the concept of Life Cycle Assessments (LCA) evolves, certified EPDs have been established as a prime vehicle for industry in the communication of environmental impacts to professional procurers.

This EPD has been developed in accordance with the document "Product Specific Requirements (PSR) for preparing an environmental product declaration (EPD) for Electricity and District Heat Generation. PSR 2004:2". Building on work undertaken by Vattenfall in Sweden, this document provides the guidance, as accepted by the European section of GEDnet[1], for undertaking EPDs in the electricity sector within Europe. It describes the scope and goal of the underlying LCA for the EPD according to ISO14020 and 14040 life cycle assessments.

This EPD contains certifiable sections in accordance with rules and regulations. However, although verified, this EPD has not been formally certified. In addition a voluntary, partly qualitative, partly quantitative, and verifiable description of environmental impact is presented. The minimum basic parameters to be included within the EPD are defined in the PSR document, these are summarised in Table 1 below. In developing the EPD a series of data validation and verification procedures have been followed to check the data quality. These procedures are described further in Section 8.

There are also sections on land use, safety, barriers, risks, and radiation as well as precautions against proliferation of weapons grade material, all of which are areas that British Energy's customers consider important.

[1]GEDnet is a global network for Type III Environmental Product Declarations. Its purpose is to encourage information exchange between type III environmental product declarations system developers and to discuss key issues in development of systems.

Table 1. Overview of the environmental parameters captured by the EPD framework

Input parameters	Output parameters	Risk related issues
Extracted resources	*Impact*	*Impact*
• Non-renewable resources • Renewable resources • Water Use	• Air Emission • Water Emissions	• Radiology • Biodiversity • Safety and Security
Recycled resources	*Additional inventory data*	
• Recycled resources	• Hazardous waste • Nuclear waste • Other waste • Area of land use • Outputs subject to recycling	

1.3 British Energy, LCA, and environmental efforts

British Energy plc is the United Kingdom's largest generator, producing one fifth of the country's electricity, and employing approximately 5,200 staff in the UK. The Company owns and operates eight nuclear power stations in the UK with a combined capacity of approximately 9,600 MW. Seven stations have twinned advanced gas cooled reactors (AGR); the other station has one pressurised water reactor (PWR). British Energy also owns Eggborough, a 2,000 MW flexible coal fired plant, purchased in March 2000.

British Energy recognises that it has a duty to care for the environment. Its environmental policy is to seek continuous improvement in its environmental performance by:

- Reducing the environmental effect of its activities to a practicable minimum by the prevention of pollution, reduction of waste and efficient use of resources.
- Promoting the efficient use of energy.
- Continuing to develop a sense of environmental responsibility among staff and contractors.
- Openly reporting performance against environmental targets.

Environmental product declarations are fully consistent with this policy, and offer a number of additional benefits. Most significantly:

- By meeting the market demand for quantified environmental information. Many sectors in society want a systems approach by which it is possible to communicate relevant and credible information about environmental performance of products and services. EPDs can have an important role in meeting this requirement.

- It provides a basis for professional procurement, private as well as public sector, in permitting comparison of different power sources. This creates an incentive for electricity producers to reduce their use of resources and the impact on the environment caused by their systems.

- It is an effective instrument in the continuing environmental efforts within British Energy plc, the objective being constant improvement.

1.4 Procurement policy

British Energy's procurement policy places requirements in the area of environmental protection on those contacted to supply goods and services. It states that the Contractor and all persons (including sub-contractors) employed by him on the Contract works shall comply fully with all statutory health, safety and environmental requirements and all other relevant Regulations, Approved Codes of Practice, appropriate Guidance Notes and Standards, BE Safety Rules and Site Mandatory Procedures. The Contractor must comply with the British Energy environmental policy.

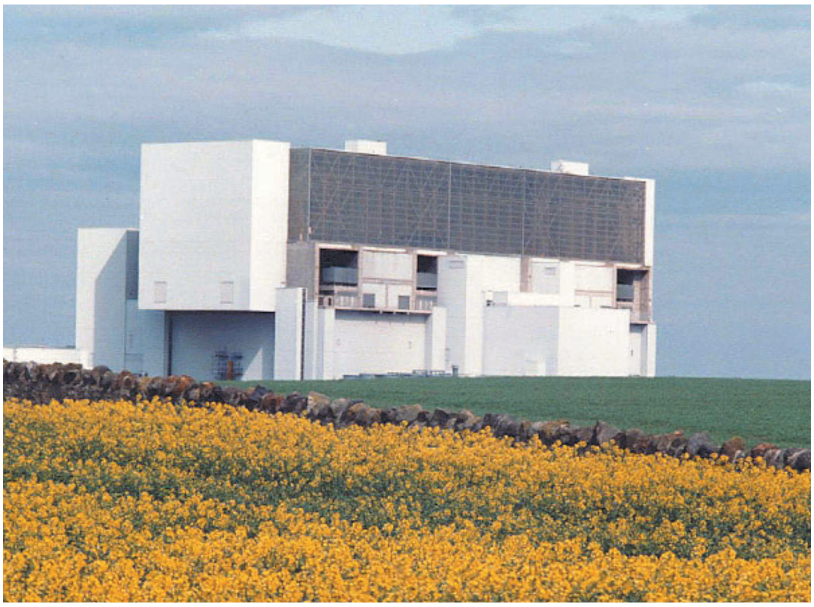
British Energy locations operate to ISO 14001 and contractors are required to conform to the requirements of the site environmental management system. Local requirements are also set out in the site environmental policy and objectives.

British Energy has a policy which excludes the purchase of products, equipment and plant containing and/or using Ozone Depleting Substances (ODS's). The Contractor shall ensure that they comply with this policy and provide an assurance in their tenders that ODS's are excluded in all goods and services that they may supply to British Energy.

Manufacturer and Product

2.1 Torness

The manufacturer of the product is Torness power station, part of British Energy Group Plc. The construction of Torness was completed in 1986 by the South of Scotland Electricity Board. In 1990 Torness came under the ownership of the newly created company Scottish Nuclear Ltd, where it resided until SNL was privatised in 1996 as part of the British Energy Group.



Torness is located on the East Lothian coast 35 miles from Edinburgh. The nuclear power plant comprises two Advanced Gas Cooled Reactors (AGR). The two reactors are practically identical. The combined net power output is 1250MW electricity, which represents around 12% of the current generation capacity in Scotland.

Torness's share of the Scottish production of electricity is approximately 15%. During 2001/2002 production from the Torness facility was 8.3 TWh.

The nuclear power plant at Torness

2.2 Environmental program/EMAS

British Energy implements an environmental management system at the Torness site, certified and registered according to ISO 14001. The environmental management system is an integral part of Torness's management system, which comprises the whole organization, planning, accountability, routines, and processes. The objective of the environmental management system is to ensure compliance with, and maintenance of, British Energy's environmental policy, and addresses radiological as well as conventional environmental issues.

2.3 The nuclear fuel cycle

The fuel cycle describes the various stages and activities that are involved, on a life-cycle basis, in the production of electricity from uranium. The flow chart above illustrates the AGR fuel cycle, step-by-step, from extraction to final disposal.

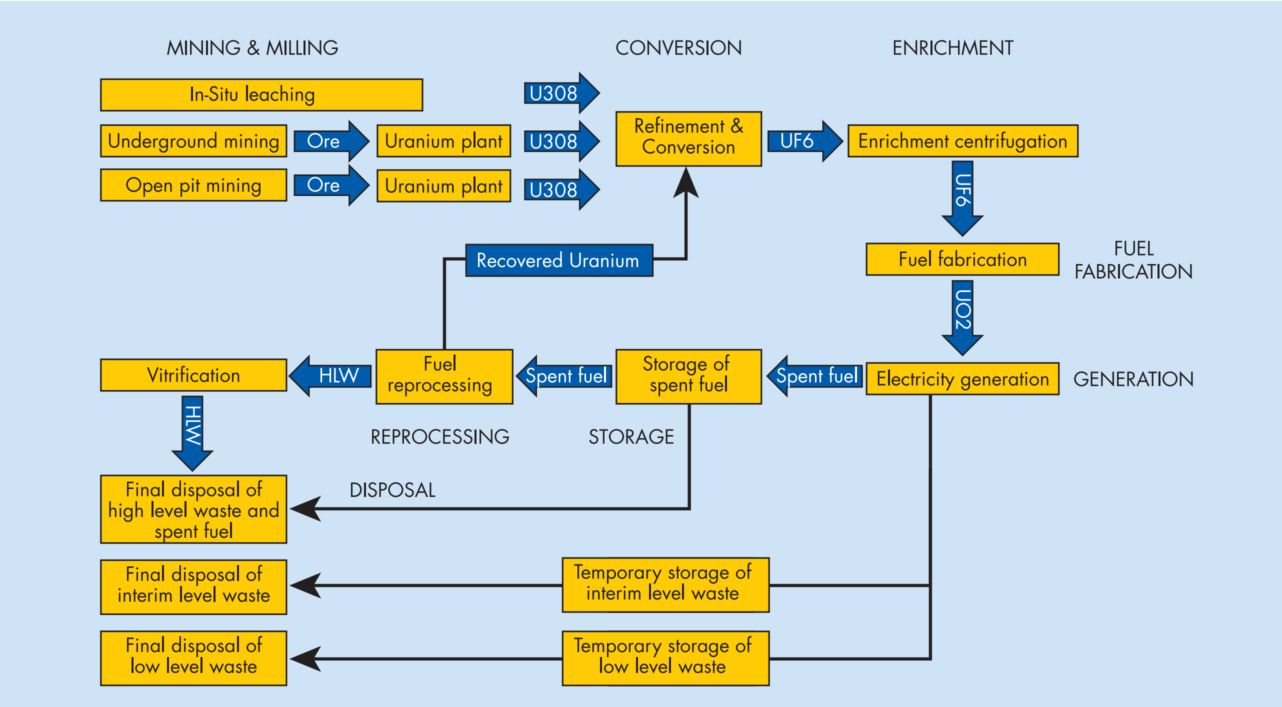


Figure 1. The nuclear fuel cycle

The nuclear fuel cycle differs from that of other power systems, in that:

- The nuclear fuel cycle and the technology are complex, and fuel is produced and refined in various locations;
- Radioactive substances are formed during the process;
- Ionizing radiation can neither be seen, heard nor felt;
- The general public worries about accidents, long-lived radioactive waste, and proliferation of nuclear weapons.

The facilities that are involved in the fuel cycle for Torness, and have been included in this EPD, are presented in Table 2 below. A representative facility has been identified and analysed for each of the stages in the fuel cycle. For the final disposal stage the analysis has been based upon a reference case scenario[2].

For certain facilities, and for certain stages within the fuel cycle, it is not practical to include all possible suppliers to British Energy. For example, uranium ore could be purchased from a wide range of global mine operators. The facilities selected for inclusion within this EPD are considered representative to the Torness fuel cycle, if not comprehensive.

[2] For the final disposal stage the analysis has been based upon a report prepared by Nirex, specifically for use within this EPD. Nirex Inputs to Environmental Product Declaration for Torness power station. 2005.

Table 2. Fuel cycle stages, and facilities captured within the EPD for Torness

Fuel cycle stage	Process	Facility, Location	Company
Mining and milling Mining and milling	Underground mine Uranium milling	McArthur River, Canada Key Lake, Canada	Cameco Corporation
Mining and milling	Underground mine and milling	Olympic Dam, Australia	WMC Ltd
Mining and milling	Underground mine and milling	McClean Lake, Canada	Cogema
Refinement and Conversion	Uranium refinery Conversion facility	Blind River, Canada Port Hope, Canada	Cameco Corporation
Enrichment	Gas centrifugation	Gronau, Germany	Urenco Ltd
Fuel Fabrication	Fabrication facility	Springfields, UK	BNFL Ltd
Electricity Generation	Nuclear power station	Torness, UK	British Energy
Fuel reprocessing and vitrification	Spent-fuel reprocessing and vitrification facility	Sellafield, UK	BNFL Ltd
Final Disposal	LLW/ILW repository HLW/SF repository	No location specified	Nirex

The route for final disposal of radioactive waste within the UK is currently under consideration. Therefore, an assessment of the impacts of the final disposal of radioactive waste in the UK has been based upon a reference scenario developed by Nirex[3]. This is based upon Nirex's Phased Geological Disposal concept for the UK's intermediate level waste, and certain low level solid radioactive wastes and its Reference Repository Concept for the deep geological disposal of high level waste and spent fuel[4]. In both instances the concepts are generic and could be applied to a wide range of sites in the UK.

The inventory data presented in later sections of this report has been based upon three extraction processes and for all other stages in the fuel cycle a single process site has been selected. In each case the uranium quantities from each process have been calculated according to the proportion of British Energy's combined purchases for the AGRs. The quantities used are Torness's requirements for generation during the financial year 2001/2002. For all other stages in the fuel cycle environmental data has been collected, where possible, for 2002. Assumptions regarding transportation of uranium are based on transportation routes during 2002. Due to limited data availability the refinement and conversion stage of the fuel cycle is based upon 1999 data. Elements of the fabrication and reprocessing stages are based upon 2003 data.

3 Nirex is a non-governmental public body whose role is to develop and advise on safe environmentally sound and publicly acceptable options for the long-term management of radioactive materials in the UK.

4 The development of these concepts, including supporting safety assessments, have been based upon wastes that are currently stored at, or are scheduled to arise at, the UK's nuclear facilities. The concepts represent robust solutions to the long-term management of these materials and have been developed to address a range of possible future waste arising scenarios (Nirex, 2005).

Environmental Performance

3.1 Background

The first LCA of nuclear power for EPD certification was conducted by Vattenfall in 1995, and has been updated in 1999 and 2004[5]. A similar methodology has been applied to Torness as a basis for this EPD. The base year is 2002 and the functional unit is 1kWh electricity generated and thereafter distributed to the customer. Extraction, fuel production, as well as the operation and maintenance of nuclear power plant, and reprocessing facilities are included in the assessment. Waste facilities have been assessed based upon a plausible reference scenario.

Resource use, emissions, and waste are distributed over 40 years, the assumed station life for the purposes of this study[6], in accordance with system recommendations.

3.2 System boundaries and representativeness

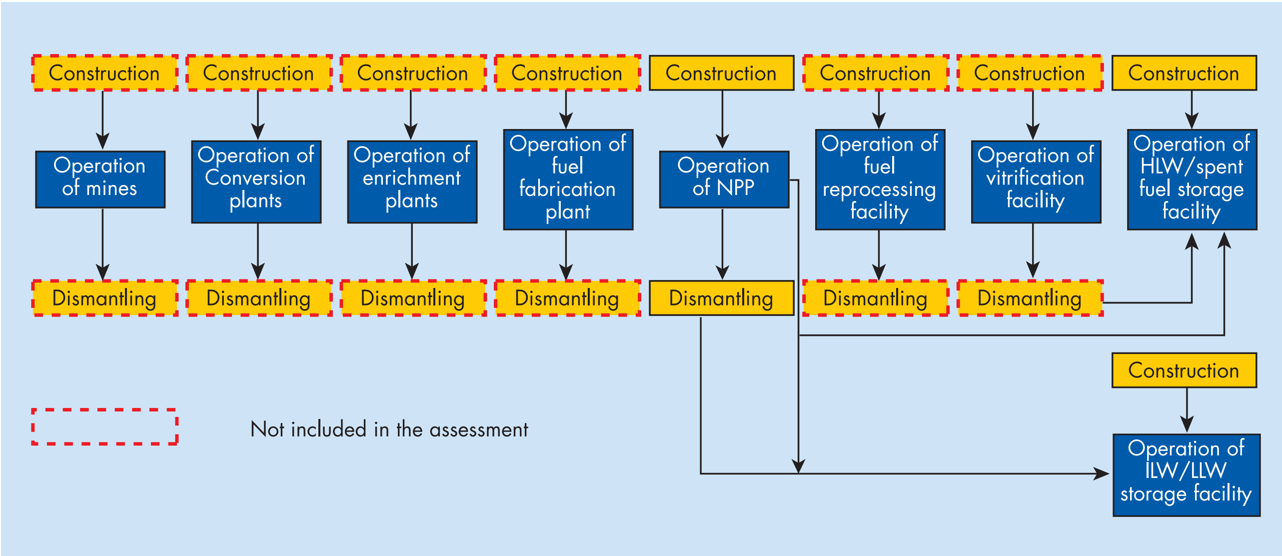
The PSR requires that the following processes are included within the boundary of the Life Cycle Analysis:

- Extraction of natural resources e.g. uranium mining
- Refining of raw materials e.g. refinement and conversion
- Refining of natural resources into energyware e.g. fabrication uranium fuel
- Conversion of energyware into heat e.g. nuclear power station
- All relevant transport e.g. transport of UF_6 from enrichment facility to fabrication facility
- Construction, operation and dismantling of energy conversion equipment e.g. construction and decommissioning of nuclear power station.
- Management of waste generated as outputs from the production phase e.g. radioactive waste

The process stages included within this EPD are described in the diagram below. In accordance with the PSR impacts have been captured for each of the stages in the fuel cycle. The PSR requires that the impacts of construction and dismantling only need to be included in the case of the energy conversion equipment (i.e. the nuclear power

[5] See: http://www.environdec.com/reg/026/
[6] The current declared accounting life for Torness is 35 years.

Figure 2. Process stages covered by the EPD



station) and fuel related waste facilities. The construction and dismantling impacts associated with the extraction, refinement, enrichment and fabrication facilities do not need to be considered under the PSR rules, and are not considered here.

It is important to be clear about those impacts and processes that are not covered by the EPD framework. In accordance with the PSR, the following processes have been excluded from the analysis:

- Impacts associated with prospecting
- Construction and dismantling of the extraction facilities
- Manufacturing and scraping of vehicles or construction of roads beyond the site
- Impacts caused by personnel

3.3 Uranium balance for chosen facilities in the nuclear fuel cycle

It is possible to track the transfer and conversion of uranium through each of the stages of the fuel cycle. The sites used within this EPD are representative of the uranium balance, and impacts associated with a unit of electricity from Torness power station, although the coverage of suppliers is not comprehensive. For the sites where data has been made available for use within this EPD, the tables below describe the assumed supply distribution between facilities. This represents the proportion of Torness annual requirements, at each stage in the fuel cycle, which is provided by each of the individual facilities.

Table 3: Fuel cycle facilities

Fuel cycle stage	Facility, Location	Proportion of Torness requirements
Mining and millinge Mining and milling	McArthur River, Canada Key Lake, Canada	40%
Mining and milling	Olympic Dam, Australia	40%
Mining and milling	McClean Lake, Canada	20%
Refinement and Conversion	Blind River, Canada Port Hope, Canada	100%
Enrichment	Gronau, Germany	100%
Fuel Fabrication	Springfields, UK	100%
Electricity Generation	Torness, UK	100%
Fuel reprocessing and vitrification	Sellafield, UK	100%
Final Disposal	No location specified	100%

When products other than uranium are involved in the process, allocations have been made, where possible, on a process basis i.e. the inclusion of the inputs and outputs that relate to the activities on site that are involved in the uranium cycle, and the exclusion of non-uranium process impacts. However, for certain sites it has not been possible to allocate life cycle components at this level of detail, so instead allocations have been based on the economic characteristics, which is the primary alternative in the PSR.

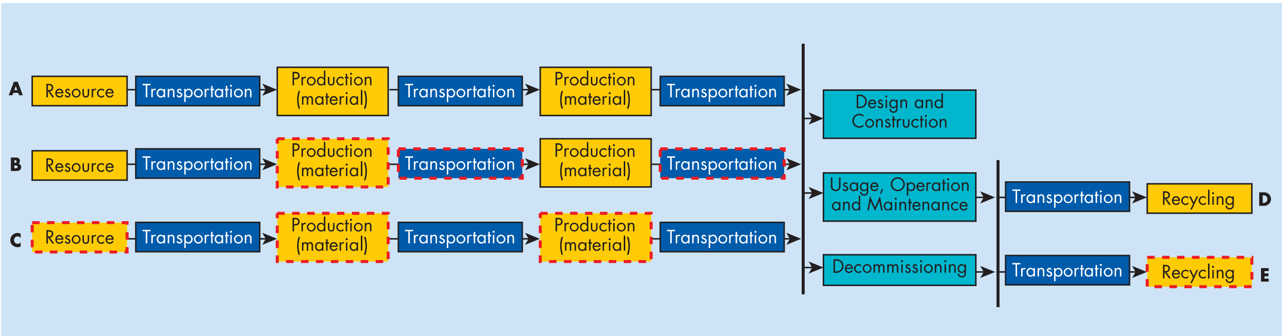
Torness is allocated its share of the total production of uranium and the same principle is applied regarding conversion, enrichment, and fuel fabrication. Construction and decommissioning of Torness Power station has been included. Due to limited data it has not been possible to consider the construction and decommissioning impacts associated with the Thorpe fuel reprocessing facility at Sellafield.

The assessment of the waste management stage of the fuel cycle has been based upon a reference scenario developed from data provided by Nirex. This is consistent with Nirex's Phased Geographical Repository concept for the storage and disposal of the UK's ILW (Intermediate Level Waste) and certain LLW (Low Level Waste), and its

Reference Repository concept for the deep geological disposal of HLW (High Level Waste) and spent fuel. This represents the best available evidence for assessing the impacts from waste management in the UK.

Flows of consumables and by-products in each phase of the nuclear fuel cycle are analysed to varying degrees "from cradle to grave". The figure below shows an example of flows where solid and dotted lines indicate included and excluded items respectively.

Figure 3: Example process flows



Typical process tree regarding construction and operation of nuclear power plants as well as examples of materials from each branch:

Inflow:

Full process	A Concrete
Partial process	B Steel
Transport only	C Gases

Outflows:

Full process	D Steel
Partial process	E Waste

3.4 Production phase

The assessment results are summarised in the following table. This shows the lifecycle inventory for Torness. It represents the inputs, outputs, impacts and wastes, across all of the fuel cycle facilities described in Table 2. Quantities are expressed per functional unit. i.e. 1kWh electricity.

Table 4. Assessment inputs and outputs

Category	Unit/kWh	Input	Output
Resource Use			
Non renewable resources			
Bauxite	g	$9.54x10^{-3}$	
Bentonite	g	$8.704x10^{-3}$	
Chromium in ore	g	$3.21x10^{-3}$	
Coal	g	1.39	
Copper in ore	g	$3.01x10^{-4}$	
Crude Oil	g	$9.55x10^{-2}$	
Gravel	g	2.43	
Gypsum	g	$6.77x10^{-2}$	
Iron in ore	g	$3.36x10^{-1}$	
Lignite	g	$3.35x10^{-1}$	
Limestone	g	$2.43x10^{-5}$	
Manganese in ore	g	$4.01x10^{-3}$	
Natural Gas	g	$4.78x10^{-1}$	
Nickel in ore	g	$3.01x10^{-6}$	
Platinum in ore	g	$6.99x10^{-12}$	
Sand	g	1.92	
Silver in ore	g	$1.23x10^{-7}$	
Tin in ore	g	$7.20x10^{-8}$	
Uranium in ore[7]	g	$2.99x10^{-2}$	
Renewable resources			
Wood	g	$1.35x10^{-2}$	
Pollutant Emissions			
Emissions of carbon dioxide	g		5.05
Emissions of sulphur dioxide	g		$9.99x10^{-3}$
Emissions of oxides of nitrogen	g		$1.91x10^{-2}$
Emissions of greenhouse gases	g GWP-equiv.[8] (100 year)		5.06
Emissions of atmospheric ozone-depleting gases	g CFC-11 equiv.[8] (20 year)		$3.26x10^{-6}$

[7] $2.71x10^{-2}$ g/kWh is used for fuel for Torness, the rest is used in other nuclear power plant supplying electricity elsewhere in the nuclear fuel cycle.
[8] GWP: Global Warming Potential, CFC: Chlorofluorocarbon.

Category	Unit/kWh	Input	Output
Emissions of acidifying gases	Mol H^{+}[9]		2.92×10^{-2}
Emissions of gases contributing to the formation of ground-level ozone	g NO_x VOC[9] and CO[9] as g ether-equiv		1.20×10^{-2}
Emissions of oxygen-consuming substances to water	g O_2		2.05×10^{-2}
Emissions of toxic substances			
• Arsenic	g		4.20×10^{-6}
• Cadmium	g		3.68×10^{-7}
• Lead	g		2.17×10^{-5}
• Mercury	g		1.35×10^{-7}
• PAHs	g		4.97×10^{-7}
Other Information			
Hazardous waste fuel related			
• High level radioactive waste	m^3		9.34×10^{-11}
• Spent fuel	m^3		2.15×10^{-9}
Intermediate level radioactive waste	m^3		1.55×10^{-8}
Low level radioactive waste	m^3		4.88×10^{-8}
Hazardous waste, non fuel-related	g		4.59×10^{-3}
Other waste, fuel-related			
• Uranium mine tailings	g		9.68
Other waste non fuel-related			
• Solid waste	g		4.49×10^{-2}
Recycled materials			
• Metals	g	1.79×10^{-1}	
• Waste Oil	g	6.64×10^{-5}	
• Rock/excavated material	g	4.58×10^{-5}	
• Paper	g	3.49×10^{-3}	
• Crushed concrete	g	2.24x10	
Water use	g	1.91×10^{1}	

[9] Mol: Moles of H^{+}, a measure of potential acidity; VOC; Volatile organic compounds; CO: Carbon monoxide.

EPD system requirements in the PSR impose restrictions on selections of data. Environmental impact must be distorted by less than 1% because of selections concerning the specified categories (such as e.g. greenhouse gases).

According to the PSR, generic data can be used when specific data is lacking and as a general rule, the sum of the contribution from processes described by generic data instead of specific data must not exceed 10% of the contribution to the separate impact categories. On account of suppliers' limited ability to provide adequate data this has been difficult to accomplish as well as to demonstrate.

The following data gaps have been identified:

- Construction and decommissioning of certain facilities in the nuclear fuel cycle, in relation to extraction, refining and fuel fabrication have been excluded. Estimates show that less than 1% of total environmental impacts in any category are thus omitted. (Vattenfall, 2001). Facilities that were used in the Vattenfall assessment are similar to those used by Torness. Construction and decommissioning impacts associated with the reprocessing stage were attempted, but have not been presented due to lack of reliable data.

- For certain sites the impacts associated with electricity use represent a significant proportion of the total environmental impacts. However, it has not always been possible to collect reliable life cycle data for the electricity mix at each of the sites. Instead, generic life cycle data has been applied to the local electricity supply mix at each site. This may lead to some inconsistency with local level emissions estimates.

- Individual companies involved in the fuel cycle seldom keep information on the location of their suppliers. Consequently, there is significant uncertainty in the transport impacts associated with the transport of inputs. Where transport impacts have been calculated a worst-case estimate has been used to avoid under allocation.

- For certain product impacts e.g. certain chemicals, it has not been possible to collect reliable life cycle data. This may lead to an underestimate in the total impacts, however, this is not thought to be significant for any of the sites.

These omissions and approximations are not considered to significantly affect the conclusions drawn from this study. Whilst the EPD has not been certified, a series of data validation and verification procedures have been carried out to ensure the quality of the data presented.

3.4.1 Resource use

Material resources are related to manufacturing of building materials and materials for operation of the power station and the site for final disposal of the radioactive waste. It also includes natural resources for energyware used in the manufacturing processes of materials for fuel fabrication, electricity generation, reprocessing, waste management, and transportation.

Required quantities of bauxite, copper ore, iron ore, limestone, wood, sand and gravel for the construction and operation of the nuclear power plant are accounted for. Resources for chemicals are included whenever data has been made available.

It has not been possible to follow the consumption of electricity to the cradle (i.e. to calculate the resource use associated with all electricity consumed as part of the fuel cycle) for each of the individual sites. Instead, the resource use has been estimated using generic resource use estimates for the different generation technologies.

Limitations in available data meant that the analysis has been unable to take account of the manufacturing of components (turbines, generators, etc) for the nuclear power plant and waste management facilities. These impacts are not expected to be significant.

3.4.2 Emissions, general

The calculation and categorization of life cycle emissions has been carried out in accordance with the PSR, as is the recommendation in the PSR. This outlines the specifications, including weighting factors, which must be applied to specific substances to yield the total environmental impact in regard to greenhouse gases, ozone depletion, acidification, ground-level ozone, and eutrophication. For example nitrogen oxide, NO_2 -values must be multiplied by 0.0217 before adding it to values of other acidifying substances, and by a factor 6 in regard to eutrophication (oxygen-consumption).

When evaluating different electricity generation technologies, environmental impacts are typically compared in terms of the emissions of CO_2, SO_2, and NO_x from the different technology types. These emissions are presented separately here for Torness. Emission of radioactive substances is treated in chapter 5 Safety and Radiation.

Figure 4. CO_2 emissions to air, total of 5.05 g/kWh

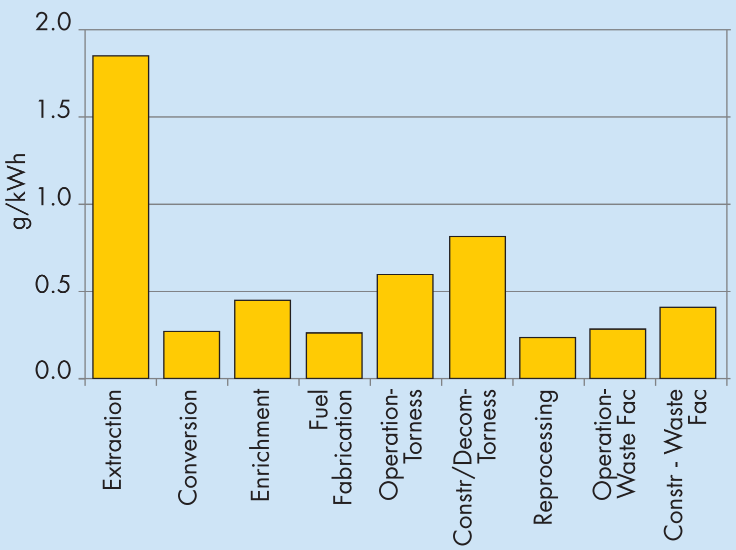


Figure 5. SO_2 emissions to air, total of 0.010 g/kWh

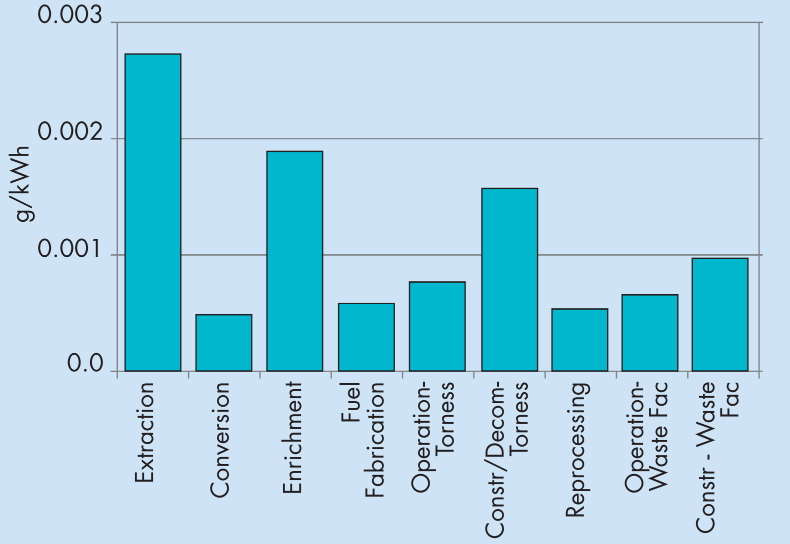
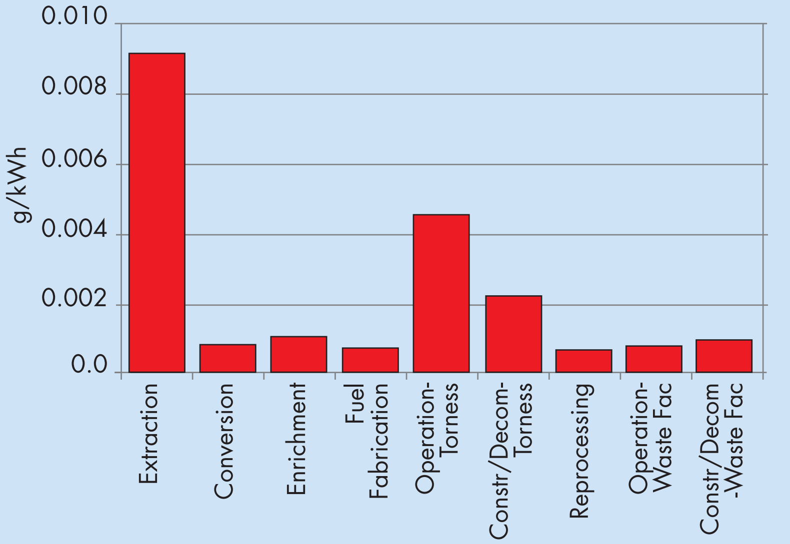


Figure 6. NO_x emissions to air, total of 0.019 g/kWh



3.4.3 Emission of greenhouse gases

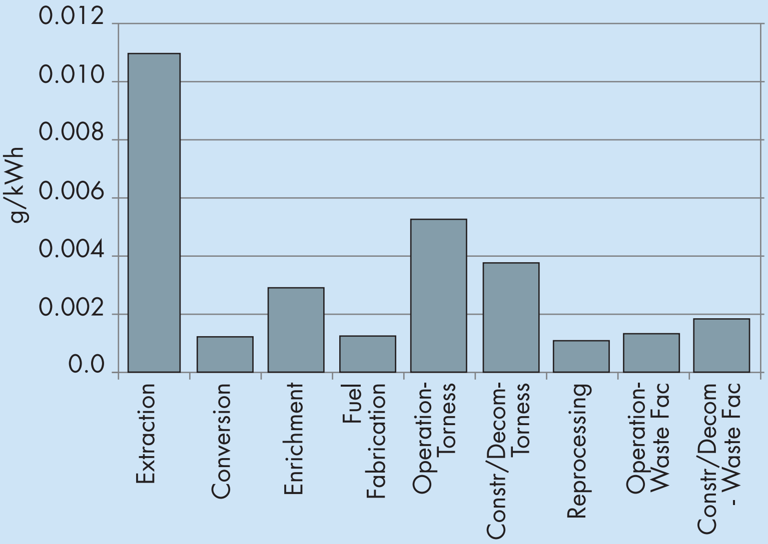
Total greenhouse gas emissions are 5.06g CO_2 equiv./kWh. Carbon dioxide is the dominant greenhouse gas contributing over 99% of emissions. The extraction phase contributes 37% of greenhouse gases. Uranium is extracted at three locations where different concentrations of uranium ore are mined. The underground mine in Australia generates proportionately more greenhouse gases per kg uranium extracted than the two underground mines in Canada. The main reason is the use of fossil fuel as the energy source for electricity generation and a low content of uranium in the ore.

3.4.4 Emission of atmospheric ozone depleting gases

Substances that contribute to ozone depleting are CFC-equivalents and numerous HCFC-substances.

The emissions of ozone depleting gases are very small from all facilities in the nuclear fuel cycle. Site specific emissions data were only available for the enrichment, fuel fabrication and reprocessing stages, and emissions for the construction stage were estimated based upon generic data.

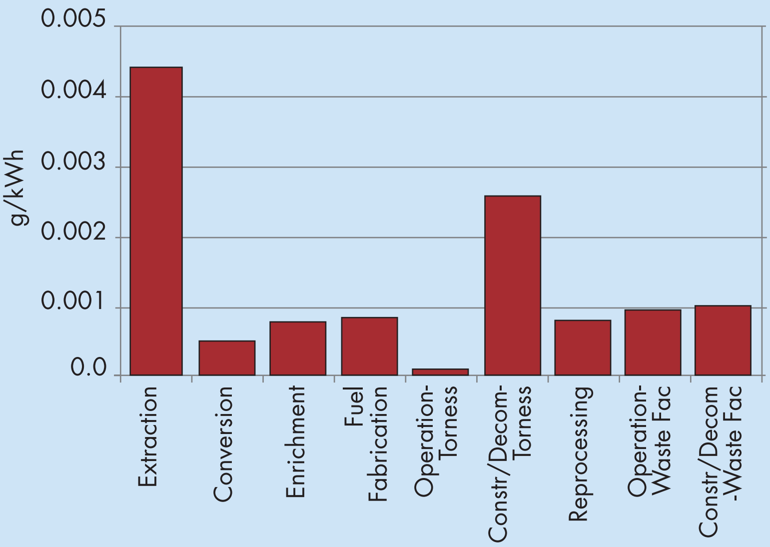
Figure 7. Acidifying gases (mol H+)



3.4.5 Emission of acidifying gases

Emissions of identified and quantified acidifying gases are almost totally dominated by SO_X and NO_X. The extraction phase is the most dominant source (38%) followed by the operation of Torness (18%). The main source of acidifying gases from the operation of Torness is from the combustion of fuel oil in the stand-by generators and the auxiliary boilers.

Figure 8. Ground level ozone (POCP)

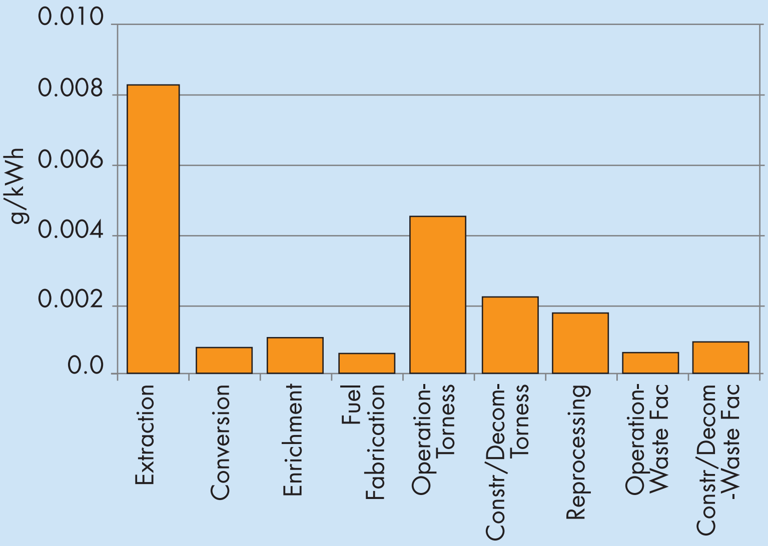


3.4.6 Emission of gases potentially contributing to ground-level ozone

Generation of ground-level ozone is dependent on several factors, e.g. climatic conditions (solar, wind), and NO_X in the air. The PSR states that NO_X is not to be reported under this heading. Hydrocarbons, ethene equivalents, and VOCs are reported. Hydrocarbon emissions results from incomplete combustion, and are thus related to combustion of energyware (e.g. transportation). Impacts are therefore strongly related to the assumptions that have been made with respect to transport distances and emission factors.

In the case of Torness, emissions of hydrocarbons and VOCs from the combustion of fuel oil in the stand-by generators and the auxiliary boilers are not monitored, and have not been included within the inventory. The impacts from the operation of Torness therefore likely to be larger than those indicated in the chart, although not of the magnitude of the emissions from the extraction phase.

Figure 9. Eutrophicating substances



3.4.7 Emission of substances potentially contributing to oxygen consumption

62% of substances contributing to eutrophication emanate from emission of NO_x. Emissions of eutrophicating substances in the nuclear fuel life cycle mostly emanate from the extraction phase (40%) and the operation of Torness (22%).

3.4.8 Emission of toxic substances

The processes and stages involved in the fuel cycle release a wide range of potentially toxic substances into the environment. However, at each individual point source the amounts of toxic substances are small. There are minute emissions of e.g. arsenic, poly-aromatic hydrocarbons, and heavy metals mainly emanating from mining of raw materials for construction of nuclear power plants and waste management facilities.

Emissions of particulate matter arise from the combustion of fossil fuels. The aggregate level of emissions is small, however, at a local level the human health impacts associated with the emissions could be more significant. Reporting of direct emissions of particulate matter by the facilities is limited, and this represents and areas where the lifecycle inventory could be improved.

3.4.9 Waste and recycled material

3.4.9.1 Hazardous waste

Hazardous waste is accounted in two categories, fuel-related and non fuel-related.

Fuel-related radioactive waste originates from the operation of the power station at Torness, but also from some of the other fuel chain facilities. Intermediate and low level waste is produced during the operation of Torness, and during the decommissioning of the Torness site. A proportion of Torness's spent fuel is sent for reprocessing[9] with the remainder in long-term storage prior to final disposal. Reprocessing of the spent fuel produces low and intermediate level radioactive waste, as well as some high level radioactive waste. The amount of direct radioactive waste arising from the operation of Torness is summarised in the table below. The values are expressed in terms of the volume of waste. This includes direct waste from the other facilities in the fuel chain, but excludes any indirect waste that results from the electricity used in the fuel chain.

Table 5. Life cycle radioactive waste and spent fuel

Category	Normalised value
• High level radioactive waste	$9.34x10^{-11}$ m^3/kWh
• Spent fuel	$2.15x10^{-9}$ m^3/kWh
• Intermediate level radioactive waste	$1.55x10^{-8}$ m^3/kWh
• Low level radioactive waste	$4.88x10^{-8}$ m^3/kWh

Indirect fuel related waste, associated with the electricity used in the fuel chain, amounts to some $3.65x10^{-14}$ m^3/kWh, equivalent to $3x10^{-4}m^3$/year assuming annual generation of 8.3 TWh.

Non fuel-related waste consists mainly of hazardous chemicals.

3.4.9.2 Other waste

The dominant non-hazardous waste produced as part of the Torness fuel cycle is the rock and mineral waste emanating mainly from the mining and milling activities. Non-recyclable waste material from the construction and decommissioning of Torness are also considered important.

3.4.10 Land use

The dominant stage of the fuel cycle, in terms of land area occupied, is the mining stage. A qualitative description of the land use impacts of the McArthur River and Olympic Dam mines is provided in the next section. A more detailed quantitative assessment of the land use impacts of the power station is also provided.

3.4.11 Electricity usage, net

Total consumption of electricity by machines and processes at Torness as well as at suppliers' sites: (see Table 6 over)

[9] Current estimates suggest that this will represent 45% of total spent fuel arising from Torness

Table 6. Energy use at Torness

Energy use	%
Electricity used in Torness, that was supplied by Torness itself	$9.5x10^{-2}$
Electricity used by suppliers to Torness, generated with the following energy ware	$3.6x10^{-3}$
Renewable Energyware	
Hydropower	$2.1x10^{-4}$
Other (non-hydro)	$3.6x10^{-5}$
Non-renewable Energyware	
Coal	$1.3x10^{-3}$
Lignite	$1.7x10^{-4}$
Natural Gas	$1.2x10^{-3}$
Nuclear	$6.8x10^{-4}$

3.4.12 Inputs - Outputs; areas from improvement

3.4.12.1 Inputs which have not been tracked to the cradle

A limitation in the availability of specific data has meant that not all input flows have been tracked to the cradle. These inputs consist of a material flows, which are either poorly defined or impossible to track to the cradle e.g. certain chemical inputs. Supplier data and/or general data either do not exist or are unavailable. Inputs, which have not been tracked to the cradle result in under-allocation of environmental impact because extraction, transportation, and production of these raw materials has not been accounted for. These inputs are considered to represent less than 1% of the total impacts, which is consistent with the general rules within the PSR guidelines.

3.4.12.2 Outputs which have not been tracked to the grave

For some of the process sites it has not been possible to derive detailed data on the output flows to the reuse, recycling or waste disposal sites. The greatest effort has been invested in collecting data on the most significant outputs (either in terms of mass e.g. mining tails, or burden e.g. radioactive waste).

Byproducts such as commercial fertilizers are not tracked to the grave. Since no allocation is made to these byproducts there is an over-allocation of environmental impact in this respect.

3.5 Impact from the various phases of the nuclear fuel cycle

3.5.1 Extraction of uranium

Extraction of uranium is the largest overall contributor of atmospheric emissions within the nuclear fuel cycle. The concentration of the uranium in the ore deposit has a large impact upon the associated environmental impacts. Lower concentration deposits require a proportionately higher amount of energy and resources, with associated emissions.

Mining and milling also generates a large amount of rock and mineral waste in the form of mill tailings.

3.5.2 Conversion

The process has two sub-processes, cleaning of extracted uranium dioxide and conversion to uranium hexafluoride. The environmental impact from conversion is small compared to other phases in the nuclear fuel cycle.

3.5.3 Enrichment

The enrichment processes that are relevant to the Torness fuel cycle are gas centrifuge[10]. Enrichment is an energy intensive process, and therefore the life cycle impacts are strongly dominated by the presiding energy mix of the location. The Gronau site is based in Germany, so the overall impacts constitute a mix of fossil, nuclear and renewable generation sources. This fuel mix represents a larger relative proportion of SO_x emissions per kWh of electricity supplied than at other sites in the fuel cycle.

3.5.4 Fuel fabrication

Fuel fabrication has small overall impact in comparison to the other stages in the fuel cycle. The only exception is with respect to the emissions of ozone depleting substances, where the emissions from Springfields are proportionately large in comparison to the other sites (60% of total contribution). This is mainly due to emission of HCFC-22.

3.5.5 Nuclear power plant

The construction and decommissioning of the nuclear power plant at Torness is a relatively large contributor to the environmental impact in the nuclear fuel cycle. The largest contribution to the environmental emissions from this stage is the production of the construction material. A feature of the Torness site that has increased the level of impact is the sea wall, which required additional construction materials.

[10] as opposed to gas diffusion, which typically requires over 95% more energy to enrich an equal amount of uranium

The operation of the Torness site also makes a strong contribution to the overall emissions. In particular, the combustion of fuel oil in the auxiliary boilers and stand-by generators contribute to the overall NO_x emissions from the fuel cycle.

The operation and decommissioning of the plant produces low and intermediate level radioactive waste, together with spent fuel, which requires storage, management and disposal.

3.5.6 Reprocessing facilities

The emissions associated with the reprocessing phase are generally small in comparison to the overall impacts of the fuel cycle. The largest relative contribution from the reprocessing stage to a particular emissions category is with respect to the emissions of oxygen consuming substances.

Reprocessing produces high level radioactive waste that requires storage and disposal.

3.5.7 Waste facilities

The most significant environmental impact from waste management comes from production of explosives and cement for the construction of waste facilities. Large quantities of copper are required for the encapsulation of spent fuel prior to deposition in deep repository.

3.5.8 Use phase

The use phase of electricity generation comprises the distribution chain, i.e. all processes from delivery to the grid to feed-in at the customer. The grid comprises transmission and distribution systems consisting of numerous lines, cables, transformers, and switchyards. Torness power station is attached to the high voltage grid system in Scotland, which is in turn linked to that of England and Wales via two interconnectors.

Losses associated with the use phase of electricity relate to both the transmissions and distribution of electricity. In 2002, 30,000 GWh of losses were identified across the UK network. Approximately 5,600 GWh ($1^1/_2$ per cent of electricity available) were lost from the high voltage transmission system of the National Grid and 22,500 GWh (6 per cent) between the grid supply points (the gateways to the public supply system's distribution network) and customers' meters. The balance (about $^1/_2$ per cent of electricity available) is accounted for by theft and meter fraud, accounting differences and calendar differences (DUKES, 2003).

Assuming the losses associated with electricity generated from Torness are consistent with the UK average then an extra 664 GWh of generation is required from Torness, to account for these transmission losses.

3.5.9 Dominance analysis and conclusions

Combustion of fossil fuels produces emissions of CO_2, NO_x, and SO_x in relatively stable proportions.

Energyware is required directly in nuclear fuel cycle facilities as well as during production of consumable raw materials. The environmental impact from emissions of NO_x and SO_x varies depending on local environmental conditions. Generation of ground-level ozone also depends strongly on local conditions.

CO_2 emissions have global consequences. Environmental impact occurs largely before electricity generation is started in the nuclear power plant, mainly during the mining and milling stage. The most substantial components of the impact are attributable to three factors, these are the low uranium content in the ore; economic allocation of electricity; fossil fuel based electricity.

One conclusion is that consumption of energyware has the single largest impact on the environment in the nuclear fuel cycle. Furthermore, the environmental impact depends strongly on the base for electricity (energyware) generation.

4 Land Use and Impact on Biodiversity

4.1 Background

The total area of the Torness site is 130 ha, of which around 30 ha is permanently used for operational activities. The quality of British Energy data enables the application of quantitative analysis of the land use impacts at the Torness site, whereas qualitative assessments are made regarding land use impacts from British Energy's suppliers.

Across the full fuel cycle the uranium extraction activities have the most significant impact upon land use (when measured in terms of land area), although only a proportion of the total site area will be developed at any one time. Using land area as an indicator may not necessarily reflect fully the impacts upon biodiversity, since it takes no consideration of the type and scarcity of the ecosystems affected. This is one component of the EPD that has scope for significant further development.

4.2 Land use classification for the Torness site

A classification has been made of the land use in and around the Torness site. Using aerial photographs of the site an estimate has been made of the land use classification in 1977, prior to the construction of the Torness facility. Comparing the land use classification pre-construction, to the current land use classification, provides an indication of the change in land use type that has occurred as a result of the Torness facility. Table 7 describes the change in land use types quantitatively, by total area. Figure 10 and Figure 11, respectively, describe in map form the location of the different land use types in and around the site prior to the generation plant's construction, and currently.

The major change in the classification has been due to an increase in the land area available due to the reclamation of land from the sea as part of the plant's construction. It has not been possible to quantify and changes in biodiversity that may have resulted from the land use changes. Instead a qualitative description of the biodiversity in and around the Torness site is provided in the following section.

Table 7. Land use at Torness

Land use classification	Areas in hectares		% change
	1977	2004	
Agriculture (Arable/Improved Grassland)	84.6	70.8	-16%
Semi-Improved Neutral Grassland	13.8	22.4	62%
Mixed Plantation Woodland	2.9	1.8	-38%
Coastal Grassland	2.0	2.4	20%
Dune Grassland	1.2	0.6	-50%
Scrub	0.4	0.1	-75%
Developed Land	0.0	1.8	-
BE Operational	0.0	29.2	-
Improved Amenity Grassland	0.0	0.9	-
Total	104.9	130.0	24%
Total land under BE Ownership	143.7	143.7	-

4.2.1 Description of the land use classification for the Torness site

East Lothian is bounded by the Firth of Forth merging into the North Sea to the north and east and by the Southern Uplands to the south and west. The low coastline is backed by the undulating lowlands incised by steep sided wooded valleys leading up to the steep upland moorlands of the Lammermuir Hills. The soils are among the most fertile in Scotland and the area has long been settled and farmed.

British Energy's Torness estate extends to some 144 ha and comprises mainly arable land, grassland and foreshore adjoining the operational site. Much of the foreshore and coastal fringe of British Energy's ownership forms part of the Barns Ness Coast Site of Special Scientific Interest (SSSI) which extends from Broxburn, just south of Dunbar in the north, to the Power Station breakwater at Torness Point in the south. The SSSI was notified in 1984 for the botanical and geological interests of its coastland habitat. The area is also a designated Geological Conservation Review (GCR) Site.

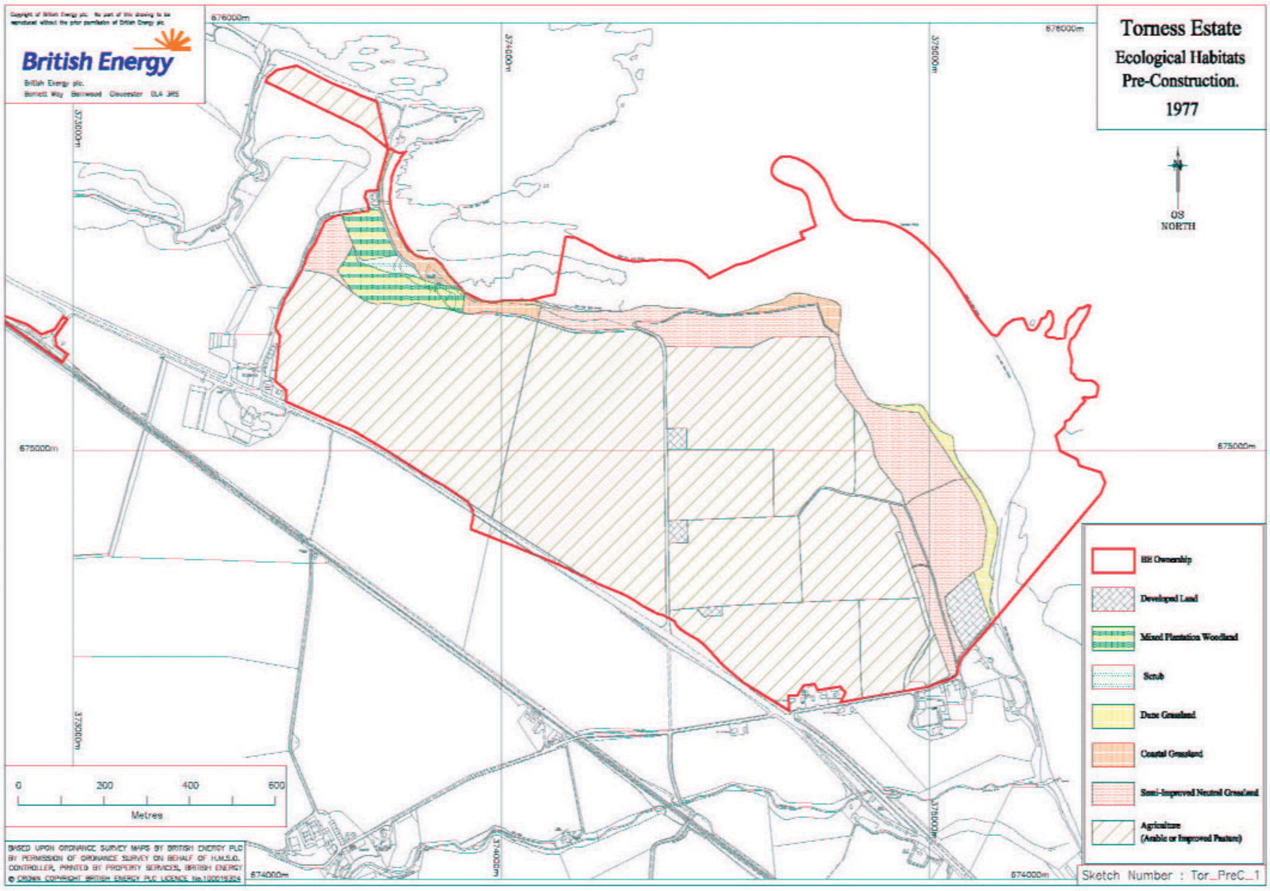


Figure 10. Land use classification of the Torness estate pre-construction (1977

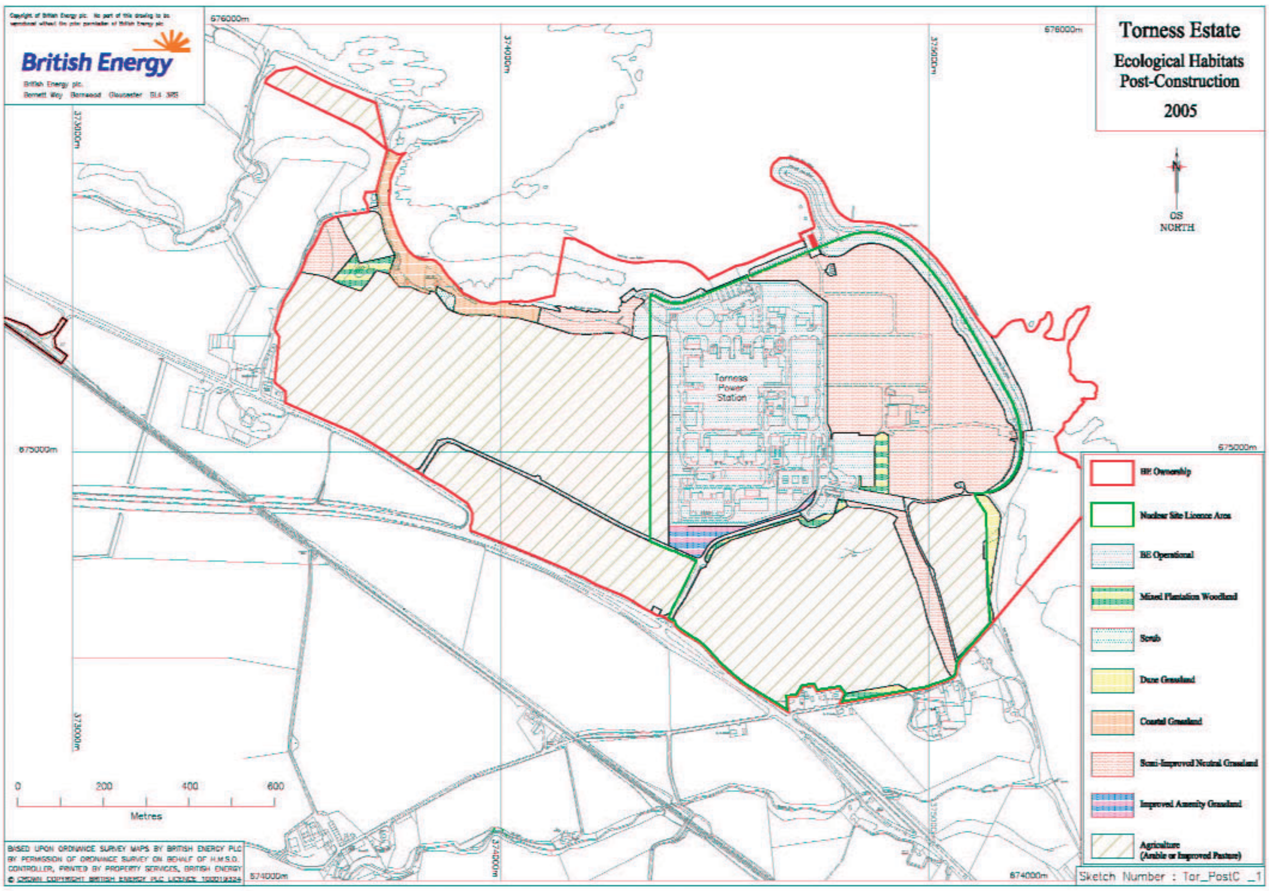


Figure 11. Land use classification of the Torness estate post-construction (2005)

To the north, the Firth of Forth is a Special Protection Area and Ramsar Site under the Birds Directive 1994 and the UK Habitat Regulations 1998. The area is an important wetland area which supports large numbers of wintering wildfowl and waders. To the north of Dunbar is the John Muir Country Park established in 1976 and encompassing 3 square miles of the coastline and important for wildfowl and wading birds. To the south is the St Abbs and Eyemouth Voluntary Marine Reserve covering 1030ha of coast between Pelticowick to Hairy Ness and offshore to the 50m depth contour. The Reserve is now part of the Berwickshire and North Northumberland Coast Special Area of Conservation (SAC). The Scottish Wildlife Trust has a nature reserve at Thornton Glen to the west and two wildlife sites along the length of the Dry Burn to the north and Thornton Burn to the south.

4.2.2 Biodiversity pre-construction

The habitats shown on the Pre-Construction Plan (Figure 1) have been identified so far as is possible, from a 1977 air photograph. This shows that the habitats appear to have changed little between 1977 and 2005. The foreshore was within the Barns Ness SSSI originally designated in 1952 and renotified in 1972. The majority of the land was in intensive arable use with some improved or semi-improved pasture. Along the coastline were narrow strips of slightly more diverse coastal and dune grassland.

4.2.3 Current biodiversity

The coastal margins of the Torness site form part of the Barns Ness SSSI important for its botanical and geological interest. The inter-tidal areas are feeding grounds for wading birds like oystercatchers, dunlin and curlew. They also feed and take refuge on inland fields at high tide. Flocks of eiders and small numbers of other sea ducks are seen regularly. Gannets come down from Bass Rock to feed. The area is especially important for passage migrants particularly in winter.

The majority of the landholding has been in intensive arable production following restoration of the land after station construction. Consequently much of the site is of low biodiversity interest. Small strips of coastal and dune grassland provide some diversity of grasses and other herbaceous species, e.g. restharrow, birds-foot-trefoil and scentless mayweed, attracting butterflies like small copper and small blue.

The small pockets of woodland and scrub give landfall shelter to migrant birds particularly in storm conditions.

19ha of land immediately to the east of the station were never restored and since clearance of all contractors' buildings has been left to naturally vegetate and has been largely unmanaged. Being predominantly concrete and other fill material, it is species poor dominated by clover and fescue grasses. It has provided suitable habitat for skylark and grey partridge to breed.

4.2.4 British Energy and biodiversity

British Energy's Biodiversity Action Plan identifies the priority habitats and species at each of British Energy's sites; sets and monitors biodiversity targets for British Energy and identifies ways in which staff and local communities can be involved through education, participation and partnership.

Maintaining this biodiversity requires continued active management and British Energy has developed Integrated Land Management Plans (ILMPs) for each of its power station sites including Torness, to ensure that this management is effective and sustainable. These plans set out objectives, prescriptions and targets for managing the land aimed at protecting and enhancing biodiversity, conserving the local landscape character and historical heritage, encouraging public recreation, education and community participation whilst at the same time meeting the needs of the business. Each ILMP is assessed against the core set of indicators of sustainable development set out in the Government's document "Quality of Life Counts" 1999.

After completion of the station construction, some woodland and shrub planting was undertaken at Thorntonloch and parallel to the main station access road. This continues to provide landfall shelter and a source of food for migrant birds particularly in autumn. In 2002 an additional 3000 native shrubs and trees were planted on the southern edge of the former contractors' area to provide additional feeding and shelter.

4.3 Description of land use at the extraction locations

The following section describes the land use at the McArthur River, Key Lake and McClean Lake sites in Canada, and the Olympic Dam site in Australia. Where possible quantitative estimates of the land are provided.

4.3.1 McArthur River and Key Lake facilities

The McArthur River underground mine site covers an area of 651 ha of which 113 ha has been exploited to date. Key Lake is the milling operation associated with the McArthur River mine. The site covers 3,476 ha of which 762 ha are currently exploited. A further 34 ha of previously exploited land have been restored, and 2,680 ha are permanently undisturbed.

The McArthur River and Key Lake facilities are situated in the northern region of Saskatchewan, Canada. The area is characterized by sub-arctic climate with long, very cold winters and short cool summers, and less than 100 days above freezing. Two thirds of annual precipitation comes as rain from July to September. The flora is relatively homogenous and meager, and dominated by evergreen coniferous trees. The geography is also characterized by an abundance of lakes and marshland. Lakeshore areas exhibit more plentiful flora including deciduous trees, e.g. birch and willows, and provide added opportunities for the fauna. Forest fires are very frequent and most forested areas are in various states of recovery. The fauna is typical of Boreal forests; mammals (e.g. moose, deer, bear, and wolf) subsist all year round, while birdlife is predominantly migratory. The region has one of the world's largest populations of breeding American bald eagle, a.k.a. white-faced sea eagle, (Vattenfall 2004).

4.3.2 McClean Lake

McClean Lake is also located in the Saskatchewan region of Canada. It cover an area of some 3677 ha, of which 3078 are permanently undisturbed.

4.3.3 Olympic Dam

Olympic dam covers an area of 29,600 ha in southern Australia. Currently, 1015 ha are exploited. The dominant local ecosystem is low density arid zone vegetation. No species recorded in the Project Area or region that are classified as rare or endangered under Australian or South Australian legislation.

The climate is of a desert-like inland type with summer temperatures reaching +35°C. Precipitation is irregular and small - approximately 160 mm annually. The area has been grazing grounds for animals since the middle of the 19th century. The settlers have influenced flora and fauna by introducing grazing animals and rabbits. The regional flora is characterized by sparse and arid-zone vegetation. Some areas, particularly dune fields, are host to Acacias and tall shrubs, and other areas to white cypress pines.

4.4 Description of land use at other locations in the fuel cycle

4.4.1 Fuel Fabrication - Springfields

Springfields is a site 63 ha in area of which approximately half is permanently developed. The site is surrounded by agricultural land. There is a SPA (Special Protection Area) within 5km of the site (the Ribble Estuary, Site Code UK9005101). The Ribble Estuary is also an SSSI, a National Nature Reserve and a RAMSAR site. There is also an SSSI (Newton Marsh) approximately 3km from the site along with 2 built heritage sites and 11 biological heritage sites within 3km of the site. There is also a 'blue bell wood' that is classified as ancient woodland and a colony of Great Crested Newts towards the north east corner of the site. The site has recently put in place a site-specific biodiversity plan. No adverse environmental affects have ever been recorded on either the woodland or newt colony due to the AGR production process and no complaints have been received regarding the SPA or other heritage sites outside the site perimeter.

4.4.2 Reprocessing - Sellafield

Sellafield is located within an area of some 3,545 ha of land. There are a large number of protected or designated sites in the area surrounding the site including sites that are of local, national and international interest. These include sites registered as County Wildlife Sites (CWS) by Cumbria Wildlife Trust. There is also an important breeding colony of Natterjack Toads in pools adjacent to the site boundary and railway. The British Herpetological Society oversees the management of this habitat.

Within close proximity to the site are Local Nature Reserves i.e. sites with wildlife or geological features that are of special interest locally and also Sites of Special Scientific Interest i.e. the country's best sites for wildlife and geology, and are protected under the Wildlife and Countryside Act 1981 and the Countryside and Rights of Way Act 2000. National Nature Reserves were established to protect the most important areas of wildlife habitat and geological formations in Britain, and are places for scientific research. A number of sites of this type are present in the area around the site.

Sellafield is situated on the eastern boundary of the Lake District National Park, which is also designated as an Environmentally Sensitive Area (ESA). The Habitats Directive includes lists of 169 habitat types and 623 species for which EU Member States must consider designation of SACs. There are a number of candidate SAC sites located close to the Sellafield site. Similarly, the EU Council Directive on the Conservation of Wild Birds provides for the protection, management and control of naturally occurring wild birds within the European Union through a network of SPAs. Member States are required to pay particular attention to the protection of wetlands, especially wetlands of international importance, and are obliged to take necessary steps to avoid deterioration of natural habitats and disturbance of the species. SPAs and SACs together form the European wide Natura 2000 network of sites.

The Convention on Wetlands of International Importance, Especially as Waterfowl Habitats (The Ramsar Convention) is an intergovernmental treaty that aims to stem the progressive encroachment on and loss of wetlands now and in the future. Wetlands are among the world's most productive environments. They are cradles of biological diversity, providing the water and primary productivity upon which large numbers of plant and animal species depend for survival. They are also important locations of plant genetic diversity and support large numbers of bird, mammal, reptile, amphibian, fish and invertebrate species. The nearest SPA and RAMSAR sites are a significant distance from the Sellafield site.

4.4.3 Final repository - location unspecified

The analysis of the impacts of final disposal has been based upon two repository concepts that are generic and could be applied to many sites in the UK. The estimated area of land at the surface required for both repositories on a possible brown field site would be 1,000,000 m^2. The underground area of potential hard crystalline rock required by the ILW/LLW and HLW/SF repository concept is estimated to be 1,200,000 m^2 and 3,000,000 m^2 respectively. Without a specific site it is impossible to estimate the impact that the construction of a repository would have on the biodiversity in the area.

Safety and Radiation

The main objective of safety systems and procedures at the nuclear power plant is to protect the employees, public and environment from the potential effects of all operations on that site. Safety is the top priority, and the design, operation and maintenance of the plant are all focused on this. Output production and economic factors are never permitted to jeopardize the safety of environment, personnel or facilities.

5.1 Safety

Fuel production and power plant operation have the potential for very low frequency but high consequence events. Accidents associated with the final waste repository would have relatively low consequences (compared with reactor faults).

The availability of data on the environmental risks associated with the different stages in the Torness fuel cycle is limited, at least in quantitative terms. The analysis has focused on the assessments for the operation of the power stations and the final waste disposal facilities, since these sites represent a nuclear safety risk and information on the management of risks has been made available.

5.1.1 Torness

5.1.1.1 Regulation

The activities at Torness nuclear power plant are governed by various Acts of Parliament. Of particular importance is the Nuclear Installations Act 1965 (as amended), which requires a licence to be granted to construct, operate and decommission a nuclear site. The site licence places conditions on the licencee to ensure the safe management of the site. The site nuclear operations are regulated by the Nuclear Installations Inspectorate (NII), a division of the Government Health and Safety Executive. In addition, environmental activities are regulated by the Scottish Environment Protection Agency (SEPA).

5.1.1.2 Nuclear safety

Design and operation of nuclear power plants incorporates protection against technical faults as well as hazards such as fire, flooding and earthquakes. These systems are intended to prevent the release of activity to the environment.

- **Prevention**

Safety was a key design criterion for the Torness plant. The credible fault scenarios have been identified and analyzed, and plant operating, maintenance and testing procedures are in place to avoid the occurrence of these faults.

- **Protection**

The plant is designed with protection against all credible faults. This protection provides all essential safety functions necessary to prevent a release of activity to the environment. The essential safety functions are for trip, shutdown, post trip cooling and monitoring of the reactor. The protection systems are designed with redundancy, diversity and separation, in order to minimise the risk of failure of these functions.

- **Mitigation**

In the unlikely event that main protections systems fail to avoid a release of activity, there are arrangements to minimize the risk of expose to the operator, public and environment. These include the instructions for the plant operator to carry out recovery actions and accident management, and also the provision of an emergency plan.

Torness has the following specific barriers against the release of radioactive emissions:

- The solid fuel itself provides containment. It is in the form of very stable and hard ceramic pellets that contain the fission products produced in the nuclear reaction.

- The fuel pellets are contained within a stainless steel cladding that is designed to be leak tight and resistant to damage by heat, corrosion and radiation.

- The steel-lined concrete pressure vessel provides overall containment of the reactor. Its walls are more than five and a half metres thick and are reinforced by thousands of steel cables -with a total length of more than 100 kilometres - woven through them. It also serves as a biological shield that reduces radiation emissions.

5.1.1.3 Nuclear safety risks at Torness

The risks due to operation at Torness are managed in such a way as to meet with the requirements of the UK Health and Safety Executive guidelines on Tolerability of Risk from Nuclear Power Stations. These guidelines were derived by considering societal attitudes to risk from a variety of sources, such as large industrial plant including nuclear power stations. They defined three levels of risk, according to the likelihood of an event causing the death of one or more members of the public. The first is a frequency cut-off above which it is not permissible to operate (the upper tolerable level). Below this is a region termed the Tolerable if ALARP region, where the ALARP (As Low as Reasonably Practicable) principle requires the licencee to do everything practicable to minimise risks. Lastly is the acceptable level of risk, for which the risk is sufficiently low that no further actions to reduce it are necessary (the broadly acceptable level).

In order to satisfy these requirements British Energy has adopted frequency limits for events of various consequences, ranging from minor releases to a significant release of activity, such as may result from core melt. The frequency limits for each category apply for all credible faults in that category. These consequences are defined according to the dose received by the worst individual (adult, child or infant) at the nearest habitation. The dose-frequency relationship is shown in the following table:

Table 8. Dose-frequency limits

Effective Dose (mSv)	Total Frequency (Per Year)	
	Broadly Acceptable	Upper Tolerable
0.1 – 1.0	10^{-2}	1
1.0 – 10	10^{-3}	10^{-1}
10 – 100	10^{-4}	10^{-2}
100 – 1000	10^{-5}	10^{-3}
>1000	10^{-6}	10^{-4}

In order to show that these frequency targets are met, all credible reactor faults are identified and analysed. A probabilistic risk assessment is used to calculate the actual risk in each category. In addition to this, deterministic rules are applied to ensure that for each fault the number of independent lines of protection is commensurate with the fault frequency.

5.1.1.4 Environmental safety at Torness

Environmental risks at Torness are managed in accordance with British Energy's Environmental policy. Briefly, the policy involves complying with relevant legislation and regulations, minimising environmental impact and waste, promoting energy efficiency, developing a sense of environmental responsibility among staff and openly reporting environmental performance. Torness has ISO 14001 accreditation.

A key part of Torness's environmental management is the systematic environmental risk reduction process continually employed on site. The process involves 1) identifying the most significant areas of environmental risk for further assessment; 2) carrying out an environmental impact assessment to identify recommended barriers to minimise or prevent the threats; 3) implementing the recommendations in order of significance. The process is reviewed annually. Whilst the process does not quantify risks in absolute terms it does subjectively take account of the frequency and consequences as part of the scoring system and then ranks them in order of their significance.

The most significant risks, identified and managed via the above process are listed below:

Table 9. Environmental risks

Priority	Description
=1	Oil Storage
=1	Dirty Drains Effluent via Interceptor
=3	Bulk Chemical Storage
=3	Bulk Oil Storage
=3	Contaminated Land
=6	Process Oil Coolers/Heat Exchanges
=7	Foul Drains
=8	AETP Active Liquid Waste Management and Disposal
=8	Water Treatment Plant Operations
=8	Low Level Waste

5.1.2 Final repository

5.1.2.1 Nuclear safety

The analysis presented in this section is based upon research undertaken by Nirex and relates to its Phased Geological Repository concept for ILW/LLW and its Reference HLW/SF concept[11]. The reference case is generic, in the sense that it could represent a range of potentially suitable sites. It is not based on a specific real site, but nevertheless, it is intended that the reference case is reasonably realistic, in that the values of parameters of the system are physically reasonable. It is intended that the levels of uncertainty in the parameters should be realistic, in that they should be of the level that might be expected after a suitable site investigation programme.

The development of the final disposal concepts has been undertaken in accordance with Nirex's Generic Operational Safety Assessment procedures. Its scope includes examination of the on-site transport of the waste packages, transfer of the waste packages below ground, emplacement of the waste packages in the vaults and other general associated activities, such as maintenance or cleaning of equipment, or the operation of the ventilation system. To identify the faults or hazards that could be associated with these different activities Nirex uses the HAZOP process.

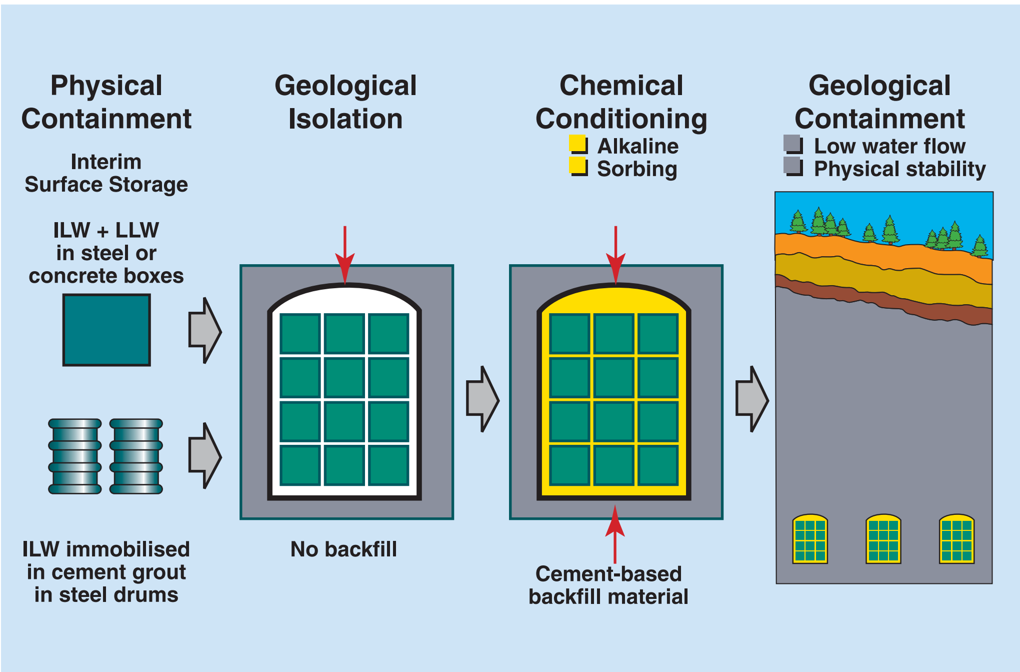
This EPD assumes waste will be disposed of in such facilities, although the final decision on the preferred waste option has yet to be made.

[11] See Nirex (2005) for further details

Effective barriers against radioactive emissions are a priority consideration in the design of the final disposal facilities. Successive phases of packaging, emplacement, backfilling and repository sealing and closure build up a multi-barrier disposal concept (Figure 3). These include:

- **Physical containment** by immobilisation and packaging of wastes in steel or concrete containers;
- **Geological isolation** by emplacement of the waste packages in vaults excavated deep underground within a suitable geological environment;
- **Chemical conditioning** by backfilling the vaults with a cement-based material (the Nirex Reference Vault Backfill) at a time determined by future generations;
- **Geological containment** achieved by the suitable geological environment, after final sealing and closure of the repository at a time determined by future generations.

Figure 12. The multi-barrier disposal concept (Nirex 2005)



Where faults and hazards cannot be eliminated they are subject to the following detailed assessments:

- A Design Basis Accident Analysis, to judge whether there are sufficient safety measures within the design and what safety status these features should be assigned. The higher the safety status, the more critical the system is to ensuring safety.

- A Probabilistic Safety Assessment (PSA) to determine the potential annual risk from operations at the facility to both workers and members of the public.

Events and accidents would include instances such as flooding, fire, adverse weather, rockfalls, seismic events etc. Nirex has undertaken work on seismic events and glaciation, primarily when investigations were still underway at Sellafield (these ceased in 1997). Assessments of how a repository may evolve in response to both seismicity and major disruptive events (e.g. glaciation) would be key considerations in a repository siting process. However, the effects of these and other natural disruptive events are highly site specific and are therefore not explicitly considered.

The overall outcome is an Operational Safety Assessment showing that the current limits stated in the Ionising Radiations Regulations can be met and that no significant challenges to the viability of the concept have been identified. Furthermore most of the activities planned for Phased Geological Repository Concept are comparable to those carried out on licenced nuclear sites in the UK, and other nuclear sites throughout the world.

5.1.2.2 Nuclear safety risks at the final waste repository

ILW/LLW repository

Three major pathways have been identified for the return of radionuclides to the environment:

- Groundwater (including natural discharge and abstraction from a domestic well);
- Gas;
- Human intrusion.

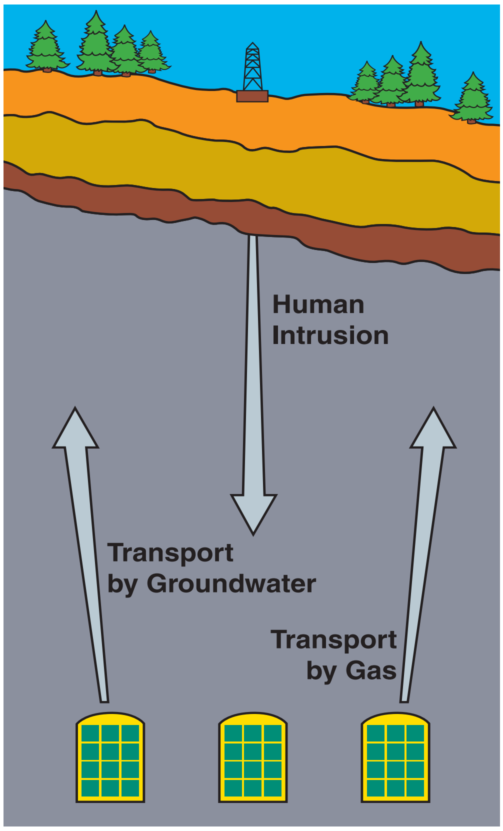


Figure 13. Schematic illustration of main assessment pathways (not to scale)

Groundwater Pathway

The reference case radiological risk versus time plot for the groundwater pathway, is shown in Figure 5. It also identifies the key radionuclides for this pathway. In accordance with the definition of the reference case, the total radiological risk remains below the broadly acceptable level of 10^{-6} per year at all times.

The results presented in Figure 5 are for the whole inventory of UK waste arisings. The specific contribution from the Torness Power Station waste will also be below the regulatory risk target.

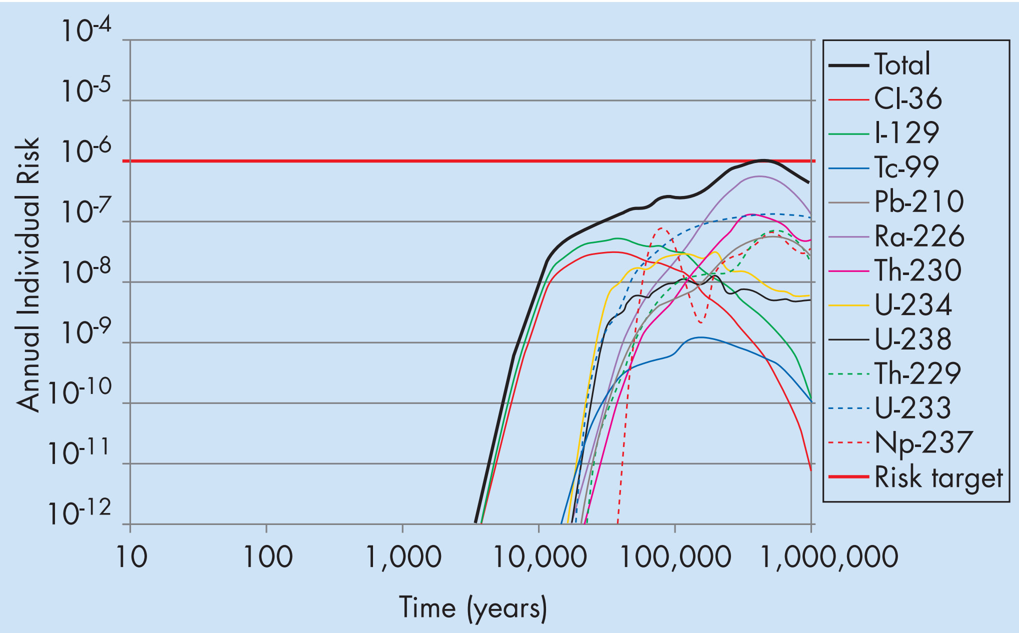


Figure 14. Reference case radiological risk against time

Gas Pathway

The radioactive gases of main concern in the assessment of the gas pathway are Carbon-14 bearing methane, radon and tritium. However, given the relatively short half-lives of radon (radon-222, the longest-lived radon isotope, has a half life of less than 4 days) and tritium (12 years), any significant delay in the transit of these radionuclides from a repository to the land surface would negate their radiological significance. The break through of gas at the surface is estimated to occur at around 6000 years after repository closure - the risk from repository-derived tritium and radon is therefore assessed to be insignificant.

Human Intrusion Pathway

Two human intrusion pathway scenarios are identified. In the first scenario (the 'geotechnical worker scenario'), core from exploratory drilling is subjected to laboratory analysis by a geotechnical worker. The second scenario (the 'site occupier scenario') concerns the distribution of spoil from the exploratory drilling operations onto the land surface in the vicinity of the borehole site. Some radionuclides would then remain in the soil in the vicinity of the site for considerable periods of time, affecting individuals who occupy the site after the end of drilling activities and make use of the land for growing food. The risks to individuals in these scenarios are not quantified but would depend upon the details of the event.

5.1.2.3 HLW/SF repository concept

As part of a collaborative project with SKB, Nirex has performed a preliminary post-closure safety assessment for the Reference HLW/SF Concept. Calculations have been carried out for the groundwater, gas and human intrusion pathways. The potential for a criticality has also been assessed. A probabilistic calculation of risk has been carried out using this model assuming one canister of each of PWR fuel, AGR fuel and HLW has a defect that ultimately results in failure.

A model has been developed for assessing the risk from the groundwater pathway which draws on a conceptual model and data developed by SKB for the SKB-3 concept, and uses the same geosphere and biosphere model as Nirex's Generic Performance Assessment (GPA03). The annual individual risk was found to be substantially below the acceptable risk target.

The conclusions of the assessment of the gas pathway are that radioactive gas generation from a failed canister of PWR fuel, AGR fuel or HLW is not significant, and does not pose an unacceptable radiological risk.

For the assessment of inadvertent human intrusion into a deep geological repository for the Reference HLW/SF Concept, annual individual radiological risks for the geotechnical worker scenario are calculated to be below the regulatory risk target. In the case of the site occupier scenario, the radiological risk from radon associated with the HLW/SF is lower than the radiological risk from naturally occurring radon by a factor of 40.

The potential for a criticality in the Reference HLW/SF Concept has been assessed, and shows there is no risk of criticality.

5.1.2.4 Nuclear safety risks from the transport of radioactive materials

Radioactive waste can be transported by road, rail or sea and must meet stringent international transport regulations. More hazardous waste will be transported inside robust containers designed to withstand the severe tests prescribed by the regulations i.e. a free fall from 9 meters onto a rigid surface, an 800°C fire for 30 minutes and a water immersion test equivalent to a water depth of 200m.

Probabilistic safety assessments of the proposed transport operation show the radiological accident risks to be very low and orders of magnitude less than the levels accepted by the HSE as “broadly acceptable”.

If waste transport operations begin for Torness, around 2040, about 1 train per week will be required until about 2090 to clear waste which arise from day to day power station operations. No further waste would be transported until 2109 when the power station will be decommissioned giving rise to about 300 packages (about 74 trains) over a 4 year period.

5.1.3 Environmental risks at other sites

Before it has served in a nuclear reactor uranium is only slightly radioactive and its chemical toxicity is more significant. Potential accidents with environmental impact in the extraction, milling, conversion, and enrichment phases are predominantly chemical, such as accidents during shipments of chemicals or minor leaks from tanks and waste depots. No probable scenarios with sizeable consequences have been identified in these phases.

British Energy’s policy is to seek confirmation from its long term uranics suppliers that they are compliant with the international environmental standard ISO 14001 in their operations. In accordance with the ISO 14001 procedures companies are required to identify their environmental aspects and to assess their significance in terms of risk.

Figure 6 describes a generic approach commonly applied for identifying the environmental risks at a site. These risks could be captured and managed as part of a risk matrix.

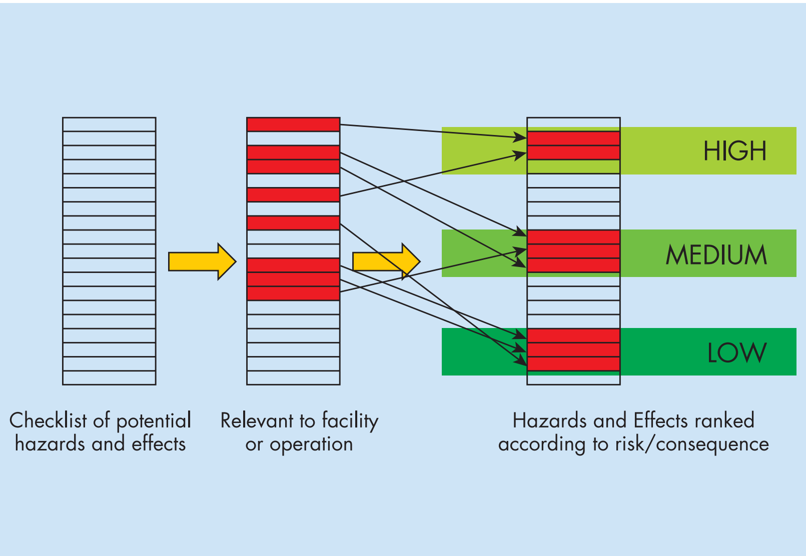


Figure 15. Generic hazard risk assessment

5.2 Ionizing radiation

Radioactive substances in various forms are handled in the course of normal operation of facilities in the nuclear fuel cycle. These substances emit ionizing radiation that may result in doses to the people working in the facility (dose-to-personnel), and to people outside the facility (dose-to-the public).

5.2.1 Dose-to-personnel

This section concerns dose-to-personnel for all facilities in the nuclear fuel cycle, based on measurements taken at the various facilities. The table below shows how much should be allocated to Torness's electricity in terms of average dose to an individual.

Table 10. Average annual dose-to-personnel at the facilities in the nuclear fuel cycle in 2002.

	Facility	Average annual individual dose-to-personnel at respective facility mSV in 2002	Allocated average dose dose-to-personnel mSv/kWh in 2002 WMC Ltd
Mining	McArthur River	1.4	$2.1x10^{-12}$
	Key Lake	1.0	$1.5x10^{-12}$
	Olympic Dam	2.6	$1.2x10^{-11}$
	McClean Lake	0.1	$2.6x10^{-13}$
Conversion	Blind River	1.3	$3.7x10^{-12}$
	Port Hope	0.9	$3.7x10^{-12}$
Enrichment	Capenhurst[12]	0.3	$3.1x10^{-12}$
Fuel Fabrication	Springfields	2.2	$4.3x10^{-11}$
Reprocessing	Sellafield	1.0	$1.9x10^{-11}$
Final Disposal	Undecided	- (see footnote 13)	-

In the UK, annual statutory dose limits for exposure to ionising radiation arising from sources other than medical and natural background are set at levels which ensure that the risk of harm to any person receiving such doses is low. The current annual statutory dose limit for classified workers is 20 mSv. However, UK legislation requires doses to workers to be as low as reasonably practicable and British Energy operates a policy of minimising risks according to this principle. It also operates to a more restrictive Company Dose Restriction Level of 10mSv.

12 In the absence of occupational does data for Gronau, data has instead been presented for URENCO's enrichment site at Capenhust, which employs an equivalent technology.

13 The scoping calculations and proposed modifications give confidence that the operational dose from the Generic Repository Design would better Nirex design targets, these are set at 10% of the limits stated in the Ionising Radiations Regulations.

5.2.2 Dose-to-third party

Doses to the public can arise by two possible means. Firstly, controlled release of radioactive substances to air and water within clearly regulated and safe limits is normal during operation of facilities in the nuclear fuel cycle. If this activity were to reach the food chain it could cause a dose to members of the public. Discharges from Torness are monitored and are subject to strict control by the Scottish Environment Protection Agency (SEPA), which issues authorizations specifying the maximum limits within which discharges should be kept. The annual discharge limits for Torness in 2002 are shown in the following table, along with values expressed per kWh. Note that actual discharges are less than these values.

Table 11. Discharge authorisation limits.

Discharge species	Annual authorisation limit	Equivalent value per kWh
Gaseous		
Tritium	20 TBq	2.4×10^{-9} TBq
Carbon - 14	3 TBq	3.6×10^{-10} TBq
Sulphur - 35	800 GBq	9.6×10^{-8} GBq
Argon - 41	220 TBq	2.7×10^{-8} TBq
Beta particulate	2 GBq	2.4×10^{-10} GBq
Liquid		
Tritium	800 TBq	9.6×10^{-8} TBq
Carbon - 14	10TBq	1.2×10^{-9} TBq
Cobalt - 60	30 GBq	3.6×10^{-9} GBq
Other beta	450 GBq	5.4×10^{-8} GBq
Total alpha	1 GBq	1.2×10^{-10} GBq

Note: 1Bq (1 Becquerel) equals one nuclear disintegration per second. Units are variously GBq (10^9) and TBq (10^{12}) and have been kept consistent in the table.

To determine the effect of these discharges on the general public SEPA carry out monitoring around the station. In general most of the activity entering the food chain is due to the effects of discharges at Sellafield (see below), weapons testing and Chernobyl fallout, and only a small fraction will be due to Torness. Nonetheless, the 2002 monitoring report showed the annual dose to fish and shellfish consumers (the critical group) to be 0.005mSv, and the dose to terrestrial food consumers to be 0.007mSv. These should be compared with public dose limits of 1mSv from artificial sources and typical natural exposures of 2.2mSv.

Other facilities operate to equivalent discharge authorisations were appropriate.

Facilities in the UK are monitored and reported in the same document described above. The main conclusions of these are summarised below:

Springfields.
The most important marine pathway is external exposure, due to adsorption of radioactivity on the muddy areas of river banks and in salt marshes. Four important groups were identified as receiving higher than background doses. These are: houseboat dwellers (0.12mSv); Anglers on the estuary bank (0.015mSv); Children playing in the area (<0.005mSv) and; Skin dose to fishermen handling nets (0.37mSv). The dose to the seafood consumption group was 0.017mSv and the dose to the critical group of terrestrial consumers was less than 0.005mSv. However, much of these were due to Sellafield discharges and Chernobyl fallout respectively.

Sellafield.
The dose to the local critical group of high-rate consumers of fish and shellfish was 0.19 mSv.

The second means by which the public could receive a dose due to operation of a nuclear power station is by direct irradiation, which is assumed to have the greatest effect on any members of the public at or near the site fence. The dose rates around Torness are generally too low to be distinguished from background radiation. However, measurements have been performed at the site fence, which shows a combined annual dose (of background plus that due to Torness) of 614μSv/yr. This corresponds to 7.4E-08 μSv/kWh.

For the final disposal of radioactive wastes, calculations by Nirex indicate that the final repository design could incorporate features that would ensure that the off-site dose would fall within Nirex design targets; these are set at 2% of the limits stated in the Ionising Radiations Regulations.

It has not been possible to estimate the doses to the public from the other nuclear fuel cycle facilities. Countries have different definitions of critical group (those that receive the greatest dose), which makes comparisons difficult.

Security and Anti-Proliferation Measures

6

The security position at civil nuclear sites in the UK is best described by reference to the Parliamentary Office of Science and Technology (POST) report: Assessing the risk of terrorist attacks on nuclear facilities[14], which states:

"Security at UK civilian nuclear facilities is based closely on international standards. The International Atomic Energy Agency (IAEA) is involved in setting these standards. International standards which affect the security of nuclear facilities fall broadly into two categories: those which specify acceptable security practices relating to physical protection of nuclear material and facilities, and those which specifically aim to combat nuclear proliferation."

In the UK security is regulated by the Office for Civil Nuclear Security (OCNS), an independent body responsible for setting the level of security on our sites. The Company takes the security of our sites extremely seriously. Security is regulated by the Office for Civil Nuclear Security (OCNS), an independent body responsible for setting the level of security on our sites. Following a decision by the OCNS we are putting in place arrangements to provide an on-site armed response capability as an additional precaution. These armed guards belong to the newly designated Civil Nuclear Constabulary and are a prudent enhancement to the measures already in place at our sites.

6.1 Security

The POST report states: "The physical protection of nuclear material in international transit is covered by the IAEA's Convention on the Physical Protection of Nuclear Material, which came into force in 1987. There are no binding international standards on the domestic use of such material, although some analysts argue that there should be. However the IAEA has issued guidelines on the Physical Protection of Nuclear Material and Nuclear Facilities which apply to domestic use. These guidelines set out general principles aimed at minimising the risk of theft or sabotage - for example through the use of physical barriers and guards, or through procedures such as access control and security vetting."

6.2 Non-proliferation

The UK is a signatory to the Nuclear non-Proliferation Treaty (NPT) and the EURATOM treaty and as such it has agreed to be bound by certain international agreements that involve the declaration of nuclear material stocks, transfers and

[14] July 2004, report number 222

transformations (i.e. the irradiation of reactor fuel and the consequential production of plutonium). UK is also a Nuclear Weapon State (NWS) and possesses, quite legally, nuclear materials intended for use in weapons. In order that the UK does not benefit commercially over non-nuclear Weapons States (NNWS), it has signed a 'voluntary offer' which essentially says that it will declare all non-weapons materials and will allow safeguards inspectors to visit non-weapons related facilities to verify the declarations.

In order to fulfil its obligations under these treaties, all member states must submit to international safeguards regimes. Safeguards are designed to ensure that nuclear material is not diverted away from its declared end use, into clandestine weapons programmes. They involve accounting for nuclear material (i.e. declaring stockpiles) as well as submitting to international inspections. Safeguards arrangements are not specifically designed to protect facilities against terrorist acts. However, in many cases, the security arrangements in place for safeguarded material provide additional defence against theft by terrorists. OCNS works closely with the UK safeguards office to maintain standards.

Suppliers' Environmental Performance

Torness complies with the international standard ISO 14001 regulations for environmental management, which requires knowledge of environmental performance of suppliers and contractors.

BE's policy is to seek confirmation from all our long term uranics suppliers that they are compliant with the international environmental standard ISO 14001 in their operations.

8

Data Verification

This EPD has been prepared in accordance with the PSR. To ensure the quality of the data presented a series data validation and verification procedures have been adopted as part of the EPD development. These procedures are outlined below:

- All data has been collected, where possible, directly from the suppliers;
- Site specific data has then been cross checked against generic data and/or other published sources;
- All calculations have undergone a sample checking process;
- Preliminary findings have been presented to internal and external stakeholders for comment;
- Preliminary results have been cross-checked against the results from other relevant EPDs.

Verification has found the EPD to be fit for purpose.

List of Acronyms

AETP	Active Effluent Treatment Plant
AGR	Advanced Gas-Cooled Reactor
ALARP	As Low As Reasonably Practicable
CFC	Chlorofluorocarbon
CO	Carbon Monoxide
CO2	Carbon Dioxide
CWS	County Wildlife Sites
EPD	Environmental Product Declaration
ESA	Environmentally Sensitive Area
GCR	Geological Conservation Review
GPA	Generic Performance Assessment
GWh	Gigawatt-hour
GWP	Global Warming Potential
HAZOP	Hazard and Operability study
HCFC	Hydro Chlorofluorocarbon
HLW	High Level Waste
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
ILMP	Integrated Land Management Plan
ILW	Intermediate Level Waste
LCA	Life Cycle Assessment
LLW	Low Level Waste
Mol	Molar [a measure of molecular concentration]
mSv	milli-Sievert
NII	Nuclear Installations Inspectorate
NNWS	Non-Nuclear Weapons State
NOx	Oxides of Nitrogen
NPT	Nuclear non-Proliferation Treaty
NWS	Nuclear Weapons State
OCNS	Office for Civil Nuclear Security
ODS	Ozone Depleting Substance
PAH	Polycyclic Aromatic Hydrocarbons
POCP	Photochemical Ozone Creation Potential
POST	Parliamentary Office of Science and Technology
PSA	Probabilistic Safety Assessment
PSR	Product Specific Requirements
PWR	Pressurised Water Reactor
SAC	Special Area of Conservation
SEPA	Scottish Environment Protection Agency
SF	Spent Fuel
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
TWh	Terawatt-hour
VOC	Volatile Organic Compounds

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British Energy

British Energy Group plc, 3rd Floor, 1 Sheldon Square, London W2 6TT.
Telephone: +44 (0)207 266 8300 Facsimile: +44 (0)207 266 8305
Website: www.british-energy.com Email: environment@british-energy.com

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