Environmental Product Declaration of electricity from Sizewell B nuclear power station

A study for EDF Energy undertaken by AEA

EDF ENERGY

Key findings

This document constitutes the Environmental Product Declaration (EPD) of electricity from the Sizewell B nuclear power station. The EPD has been prepared by AEA on behalf of EDF Energy.

The declared product is 1 kWh net[1] of electricity generated at Sizewell B and thereafter distributed to the customer during a reference period of 18 months during 2008/09.

The environmental impacts associated with the generation of electricity at Sizewell B have been assessed as part of a Life Cycle Assessment (LCA). LCA is a clearly structured framework based on international standards that facilitates the quantification and assessment of emissions and resource use along the entire electricity production chain. This includes impacts across all of the process stages in the nuclear fuel cycle, including uranium mining and milling, enrichment, fuel fabrication, power generation, and waste disposal.

The results of the analysis indicate that the environmental impacts associated with the mining and milling of the uranium fuel, the construction of the nuclear power station and the final disposal of the radioactive waste dominate the results.

The construction stage is a large contributor to the lifecycle CO_2 emissions, representing 42% of the total. These emissions are largely determined by the embodied energy associated with the construction material used (e.g. steel and concrete) and the electricity used during the commissioning of the plant. The construction stage is also an important source of ozone-depleting substances and acidifying gases.

The mining and milling stage is the second largest contributor to the emission of greenhouse gases and the largest contributor to emissions of acidifying gases. SO_2 emissions from the production of the sulphuric acid that is used in the uranium milling process are an important contributor to the latter impact category.

The environmental impacts associated with the conversion, enrichment and fuel fabrication stages are generally smaller in comparison to the other stages. The environmental impacts associated with the operation of the station, which includes the interim storage of spent fuel, are also of lesser significance.

The waste management stage includes the construction and operation of the waste facilities, as well as the conditioning and packaging of the radioactive waste. This stage has an important influence upon emissions of greenhouse gases, ozone depleting substances and acidifying gases. It is also the main source of eutrophicating substances. The latter impacts relate to the disposal of waste from copper production.

The total lifecycle greenhouse gas emissions per kWh of electricity generated at Sizewell B power station have been calculated to be 6.04 g CO_2e/kWh. This is a slightly larger value than the calculated carbon footprint for Sizewell B that was presented in the 2008 EPD. The increase reflects the inclusion of additional construction impacts from the planned dry fuel store in the current EPD, as well as changes in the operational performance of the plant, and changes in the supply chain.

Radioactive substances are handled during the course of the normal operation of the 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. The occupational dose at Sizewell B during the reference period was within the respective national regulatory limits.

[1] 1 kWh net means that electricity used within the power plant is subtracted from the amount of kWh generated in that plant.

Contents

1 Introduction

1.1 The declared product

This document constitutes the Environmental Product Declaration (EPD) of electricity from the Sizewell B nuclear power station. Sizewell B is operated by EDF Energy Nuclear Generation Limited, which is owned by EDF S.A (80% share) and Centrica. This is an update to the original Sizewell B EPD that was prepared in 2008. The EPD has been prepared by AEA on behalf of EDF Energy.

The declared product is 1 kWh net[2] of electricity generated at Sizewell B and thereafter distributed to the customer during a reference period of 18 months during 2008/09[3].

The nuclear power station at Sizewell B contributes significantly to the base-load supply of electricity to the United Kingdom. The station is operated round the clock, except for a few weeks every 18 months that are set aside for refuelling and maintenance.

1.2 The EPD and the international EPD system

The primary purpose of the international EPD® system is to support companies in the assessment and publication of the environmental performance of their products and services. EPD® is a system for the international application of Type III environmental declarations conforming to ISO 14025 standards. The international EPD® system and its applications are described in the general programme instructions.

The principal documents for the EPD® system are in order of hierarchical importance:

- Product Category Rules (PCR), PCR-CPC 171 & 173 (Product Category Rules for preparing an Environmental Product Declaration for Electricity, Steam, and Hot and Cold Water Generation and Distribution), Version 2.01
- General Programme Instructions for Environmental Product Declarations, EPD®, Version 1.0
- ISO 14025 on Type III environmental declarations
- ISO 14040 and ISO 14044 on Life Cycle Assessment (LCA).

This EPD® contains an environmental performance declaration based on LCA. Additional environmental information is presented in accordance with the PCR:

- information on land use
- information on biodiversity
- information on radiation during normal operation of the main facilities involved in the electricity production chain
- information on safety and risk-related issues
- information on electromagnetic fields
- information on noise.

2 1 kWh net means that electricity used within the power plant is subtracted from the amount of kWh generated in that plant.

3 This period was chosen to capture the complete impacts from the PWR fuel cycle, as a 12 month period does not capture all the stages of the cycle.

1.3 About EDF Energy

EDF Energy has an ambition to be a leader in sustainability. For us, sustainability is about balancing our social, environmental and economic resources to meet the needs of today without compromising the needs of tomorrow.

By delivering our mission of safe, reliable, generation over extended plant life, EDF Energy Nuclear Generation will continue to play a significant role in: providing a product vital to UK economic success; helping the UK meet its CO_2 emission reduction targets; and contributing to UK society through our skills, education and local community programmes.

We have developed a set of commitments in order to deliver our sustainability leadership ambition, one of which is to be open and transparent in our nuclear businesses. The publication of this Environmental Product Declaration is consistent with this commitment.

For more information about our sustainability programme please visit our website: http://www.edfenergy.com/sustainability/.

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2 Manufacturer and product

2.1 EDF Energy

EDF Energy is the UK's largest generator of low carbon electricity.

EDF Energy owns and operates eight nuclear power stations in the UK with a combined capacity of almost 9 Gigawatts (GW). Seven stations have twin Advanced Gas-Cooled Reactors (AGR) while the other station - and the focus of this EPD - Sizewell B, has one pressurised water reactor (PWR).

Station	Reactor type	NET capacity in Megawatts (MW)
Hunterston B	2 AGRs	890
Hinkley Point B	2 AGRs	870
Hartlepool	2 AGRs	1,190
Heysham 1	2 AGRs	1,160
Dungeness B	2 AGRs	1,040
Heysham 2	2 AGRs	1,210
Torness	2 AGRs	1,205
Sizewell B	1 PWR	1,191

Notes: Capacities are stated net of all power consumed for the stations' own use, including any power imported from the National electricity grid.

EDF Energy also operates gas and coal-fired power plants within the UK, three in total. These facilities have a total capacity of 4.8GW.

2.1.1 Environmental Management System

EDF Energy implements an Environmental Management System (EMS) at the Sizewell B site, certified and registered according to ISO 14001. The EMS is an integral part of Sizewell B's management system, and incorporates all the organisation, planning, accountability, routines, and processes. The objective of the EMS is to ensure compliance with, and maintenance of, EDF Energy's Environmental Policy, and address radiological as well as conventional environmental issues.

The Safety & Technical division internally regulates company safety and environmental performance and provides leadership, oversight and support for safety, workplace health & safety, environment, quality, nuclear fuel and liabilities, radioactive waste and sustainability.

2.2 Product system description

2.2.1 Sizewell B nuclear power station

Sizewell B is a Pressurised Water Reactor (PWR) with a net annual output of 1191 MW. It is capable of supplying just under 3% of the UK's current electricity needs.

The station has been designed to have an operational life of 40 years[4].

The key characteristics of the power station are summarised in the table below. The net electricity generation from the plant was 14 TWh, during the reference period 01/04/08 to 31/08/09 (Including 1 month for refuelling outage).

Table 2-1: Characteristics of the power station

Characteristic	Assumption
Reactor design	Pressurised Water Reactor (PWR)
Turbines	2 x 630 MWe unit
Fuel	4.5% enriched uranium oxide fuel
Fuel burn up	49 GWd/Te of uranium
Capacity factor (gross)	90% utilisation rate
Date commissioned	1995
Technical service life	40 years
Fuel cycle	Designed to operate at full power for a 'fuel cycle' of 18 months (Including 1 month for refuelling outage)
Location	Suffolk, United Kingdom
Transmission	Electricity is transmitted at 400 kV, and subsequently distributed to the majority of customers through lower voltage, and through more localised networks (from 132kV to 230V).

2.3 Nuclear fuel cycle of Sizewell B in 2008/09

The nuclear fuel cycle describes the various stages and activities that are involved, on a life-cycle basis, in the production of electricity from uranium. As shown in Figure 2-1, the generic nuclear fuel cycle consists of a series of steps including the extraction of the uranium ore, fuel production, the use of fuel in the nuclear power station and disposal of radioactive waste. All of these stages should be captured in the LCA.

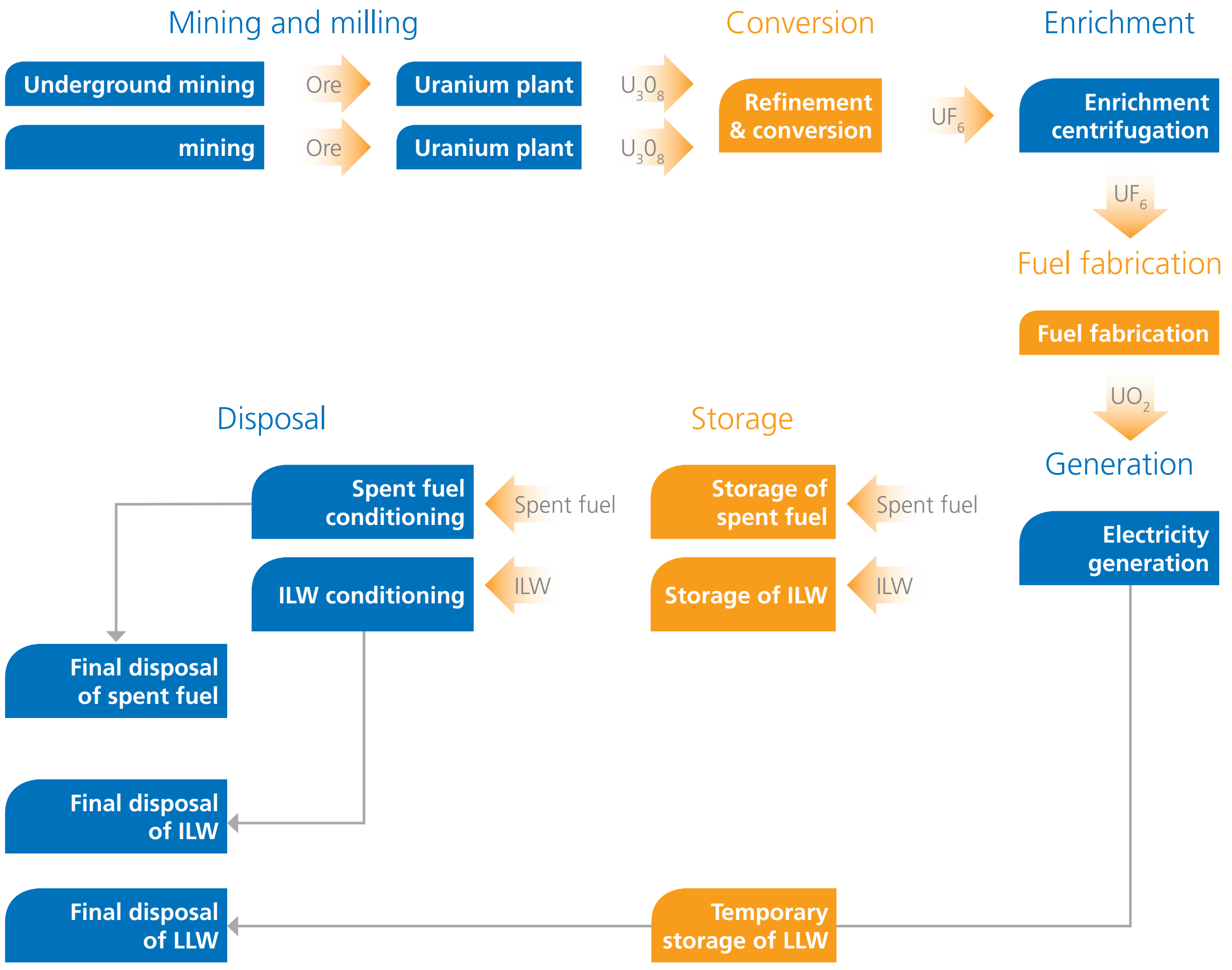
In practice, the nuclear fuel cycle for a specific generation facility may be more complex, and reflect a more diverse range of supplies from multiple locations. It may also include both virgin uranium from ore and uranium recycled from other uses. During the reference period the fuel supplied to Sizewell B originated from contracts that used reprocessed uranium. The enriched uranium was supplied from the Russian company MSZ Electrostal based in Moscow. As part of the arrangements EDF supply uranium recovered from the reprocessing of irradiated fuel from its AGR power stations, though MSZ are not obliged to use this specific material for the manufacture of Sizewell B fuel.

[4] One of EDF Energy's business imperatives is to focus on extending the life of its nuclear reactors. This will only be carried out when it is technically, economically and safe to do so.

In the absence of more detailed information on the exact source of the reprocessed uranium, a conservative approach has been used in the preparation of the EPD. This assumes that all of the uranium used in the fuel originated from virgin sources. It therefore includes the impacts associated with the mining and milling of the ore, and the subsequent processing. These impacts would not have been captured to the same extent if the fuel was assumed to have used reprocessed uranium. At the same time, impacts associated with the reprocessing and blending of the recycled uranium are excluded from the analysis. The extent of these omissions is uncertain. However any impacts associated with the use of reprocessed uranium to manufacture fuel are likely to be less than if the reprocessed uranium had instead to be disposed of as a waste.

As the basis for this modified fuel cycle, the suppliers for the mining of the virgin ore, its conversion and enrichment are based on facilities that EDF Energy Nuclear Generation used for its fleet of AGR reactors during the reference period. The supply chain is therefore representative of EDF Energy's wider portfolio of suppliers.

Figure 2-1: The nuclear fuel cycle



Key:

UF_6	Uranium hexafluoride	**U_3O_8**	Uranium oxide concentrate – also known as 'yellowcake'
Ore	Uranium ore	**UO_2**	Uranium dioxide – which form the reactor pellets in the fuel rods
ILW	Intermediate Level Waste	**LLW**	Low Level Waste

The different stages in the fuel cycle can be categorised into three basic modules, in accordance with the PCR. These are:

- **core module –** this includes processes and infrastructure associated with Sizewell B and radioactive waste disposal facility
- **upstream module –** this captured the activities in the fuel cycle prior to the electricity generation stage
- **downstream module –** this includes processes and infrastructure associated with the transmission and distribution of the electricity generated at the power station.

2.3.1 Core module

The core module of the EPD deals with the operation element of Sizewell B. It includes the construction, reinvestment and decommissioning of the station, plus other relevant facilities on site at Sizewell B.

The core module also includes the construction and operation of facilities for the interim storage of spent fuel and Intermediate Level Waste, the temporary storage of low-level nuclear waste, and the storage of nuclear waste in deep geological repositories.

At Sizewell B, the spent nuclear fuel is currently stored, on an interim basis, on site in a fuel pond which contains all of the spent fuel generated to date. However, the current safety arrangements in the UK mean that the fuel ponds cannot be filled to their maximum capacity with the result that the pond could be full by 2015. EDF Energy has therefore submitted an application to construct and operate a Dry Fuel Store (DFS) at Sizewell B. This is a building specifically designed for the storage of used nuclear fuel from the operation of Sizewell B. The environmental impacts associated with the construction and operation of the DFS have been estimated based on the information provided as part of the DFS planning documents.

The site and specific packaging arrangements for final disposal of ILW and spent fuel within the UK is not yet determined. Therefore, an assessment of the impacts of the final disposal of these types of waste has been based upon a reference scenario developed by Nirex (now the Nuclear Decommissioning Authority (NDA)). This is based upon Nirex's phased geological disposal concept for the UK's Intermediate Level Waste (ILW) and certain low level solid radioactive wastes (LLW), and its reference repository concept for the deep geological disposal of High Level Waste (HLW) and spent fuel. In both instances the concepts are generic and could be applied to a wide range of sites in the UK. The analysis is based on 2010 radioactive waste inventory, which includes the waste produced by the proposed nuclear new build fleet. This represents the best available evidence for assessing the impacts from ILW and spent fuel management in the UK.

Other types of LLW generated at Sizewell B are disposed of in the LLW repository near Drigg in Cumbria, and the Pyros incinerator in Hythe, Hampshire.

Facilities that are involved in the core processes are presented in the table below.

Table 2-2: Facilities involved in the core processes

Facility, location	Operation
Sizewell B, UK	Electricity generation
Dry storage facility, Sizewell B, UK	Interim storage of spent fuel
Pyros incinerator, Hythe, UK	LLW incineration
Drigg LLW storage facility, UK	LLW disposal
Encapsulation facility, location in the UK as yet undetermined	Encapsulation of spent fuel
Deep geological repository for ILW and LLW, location in the UK as yet undetermined	Storage of nuclear waste
Deep geological repository for HLW and SF, location in the UK as yet undetermined	Storage of nuclear waste

2.3.2 Upstream module

The upstream module includes the sites and facilities involved in the production and transportation of fuel and auxiliary substances that are inputs to the electricity generation process.

The manufacturing of the uranium oxide (UO_2) fuel comprises of the uranium mining and refining, the conversion to uranium hexafluoride (UF_6), the enrichment and the fabrication of the fuel assembly. The uranium originates from various sources. As the UO_2 fuel elements are loaded in the reactor intermittently, the origin of the uranium used in the fuel elements varies from year to year.

As described above the upstream module is based upon representative suppliers to EDF Energy for the reference period. The mining stage is based upon two extraction processes (open and underground mining), and two separate suppliers are assumed for the refinement and conversion stage. For all other stages in the fuel cycle a single process site has been selected.

The reference facilities are presented in Table 2-3 below.

Table 2-3: Fuel cycle stages, and facilities captured within the EPD for Sizewell B

Fuel cycle stage	Process	Facility, Location	Company
Mining and milling	Underground mine and milling	Olympic Dam, Australia	BHP Billiton
Mining and milling	Open pit mine and milling	Ranger Mine, Australia	ERA (Rio Tinto)
Refinement and conversion	Uranium refinery and conversion facility	Malvési, France Pierrelatte, France	AREVA NP
Refinement and conversion	Uranium refinery and conversion facility	Post Hope, United States Blind River, United States	Cameco
Enrichment	Gas centrifugation	Gronau, Germany	Urenco Ltd
Fuel Fabrication	Fabrication facility	Lingen, Germany	AREVA NP

For each stage in the fuel cycle the uranium quantities from each process have been calculated according to Sizewell B's requirements for generation, in accordance with the operational data for the reference period. Assumptions regarding transportation of uranium are based on transportation routes for the fuel cycle facilities in the reference fuel cycle. The data used for the stages, mining and milling, refinement and conversion, enrichment, and fuel fabrication is based on environmental reports for the respective facilities.

At the extraction phase, data was used from the Olympic Dam and Ranger mines in Australia. These are all relatively low grade ore mines, thus represent conservative estimates. Most uranium mines around the world have ore deposits in excess of 0.1% uranium and some Canadian mines contain ore which averages up to around 20% uranium. The grades of ore at the mines chosen in this study are 0.06% for Olympic Dam and 0.12% for Ranger (WNA, 2010)[5]. These mines are therefore at the low end of the scale in terms of ore grade and consequently it is less likely that the environmental impacts from this stage will be underestimated by selecting these sites for the present LCA.

The conversion stage assessment is based on environmental data from the Areva (Malvési, Pierrelatte) facilities in France, and the Cameco (Port Hope, Blind River) facilities in the United States.

For the enrichment stage Urenco's gas centrifuge facility at Gronau has been used as the reference facility. Gas centrifugation is one of two main enrichment technologies, and is more energy efficient than the main alternative (gas diffusion).

The fuel supplied to Sizewell B in the reference year was fabricated at Areva's facility in Lingen, Germany.

[5] Based on total reserves, including in-situ and underground resources. Source WNA, 2010, Australia's Uranium Mines.

2.3.3 Downstream module: electricity distribution within the UK network

The downstream module is concerned with the distribution of the product to the customer. It is not possible to determine exactly where electricity generated at Sizewell B is ultimately used. This is because the power station is attached to the high voltage grid system in England, which in turn is linked to Scotland and Wales via two interconnectors. The electricity could therefore be supplied to a wide range of end users.

The downstream module comprises of the distribution chain, i.e. all processes from delivery to the grid to its receipt by the customer. The grid is made up of transmission and distribution systems consisting of numerous lines, cables, transformers, and switchyards. Losses associated with the use phase of electricity relate to both the transmission and distribution of electricity.

Data on the downstream impacts of the electricity distribution network was drawn from the Ecoinvent database[6]. This is based on Swiss data for the construction and use of a high voltage, medium voltage and low voltage electricity transmission and distribution network.

The Digest of UK Energy Statistics reports 27,042 GWh of losses across the UK network in 2010. Approximately 5,949 GWh (1.6% of electricity available) were lost from the high voltage transmission system of the National Grid and 20,011 GWh (5.2%) between the grid supply points (the gateways to the public supply system's distribution network) and customers' meters. The balance (0.3% of electricity available) is accounted for by theft and meter fraud, accounting differences and calendar differences[7].

2.3.4 Uncertainties

The overall environmental impacts associated with a given stage in the nuclear fuel cycle are relatively well established. Data is available for a number of facilities, which allows the validation of results from individual sites. Therefore, while the impacts will vary from one site to the next, and also potentially over time, the overall magnitude of the impacts can be assessed with reasonable confidence.

However, the specific environmental performance of individual sites will relate to the processes and technologies that are employed. It was not possible to collect robust data on the fuel cycle for all facilities supplying to Sizewell B during the reference period. In particular, data on the environmental impacts associated with the reprocessing and blending of the recycled uranium from MSZ Electrostal in Russia was limited. It was therefore assumed that the uranium used in the fuel originated from virgin sources, with impacts associated with the reprocessing and blending omitted from the analysis, but impacts associated with mining, milling, conversion and refinement included. The influence of this change upon the overall environmental impact assessment is the largest uncertainty in the analysis.

6 The international Ecoinvent database is currently the world leading Life Cycle Inventory data source with more than 2500 users in more than 40 countries. The Life Cycle Inventory datasets are based on industrial data and have been compiled by internationally renowned research institutes and Life Cycle Assessment consultants.

7 Digest of United Kingdom Energy Statistics 2011.

3 Environmental performance

3.1 Life Cycle Assessment (LCA) methodology

The LCA methodology was applied according to the ISO 14025 standard to quantify the environmental impact of the electricity generation at Sizewell B and its subsequent distribution. LCA is a clearly structured framework based on international standards that facilitates the quantification and assessment of emissions to the environment and resource use along the entire electricity production chain.

There are generally two approaches that can be applied in the application of an LCA. The first method is Process Chain Analysis (PCA). PCA is a bottom up approach that requires the collection of data on the main production processes, or steps in the life cycle, which are then aggregated up in order to assess the impacts of the product as a whole. The second approach is Input-Output Analysis (IOA) which uses data that is already aggregated at a sectoral or sub-sectoral level and then uses expenditure data in order to estimate direct and indirect environmental impacts from different sectors.

The PCA method allows for a very detailed analysis but may suffer from truncation (i.e. incompleteness resulting from the omission of environmental loads associated with certain upstream processes). In contrast, the use of IOA allows a more complete analysis to be undertaken. However, its reliance on sector average emissions introduces uncertainties, particularly where the variation in environmental performance within a given sector is large.

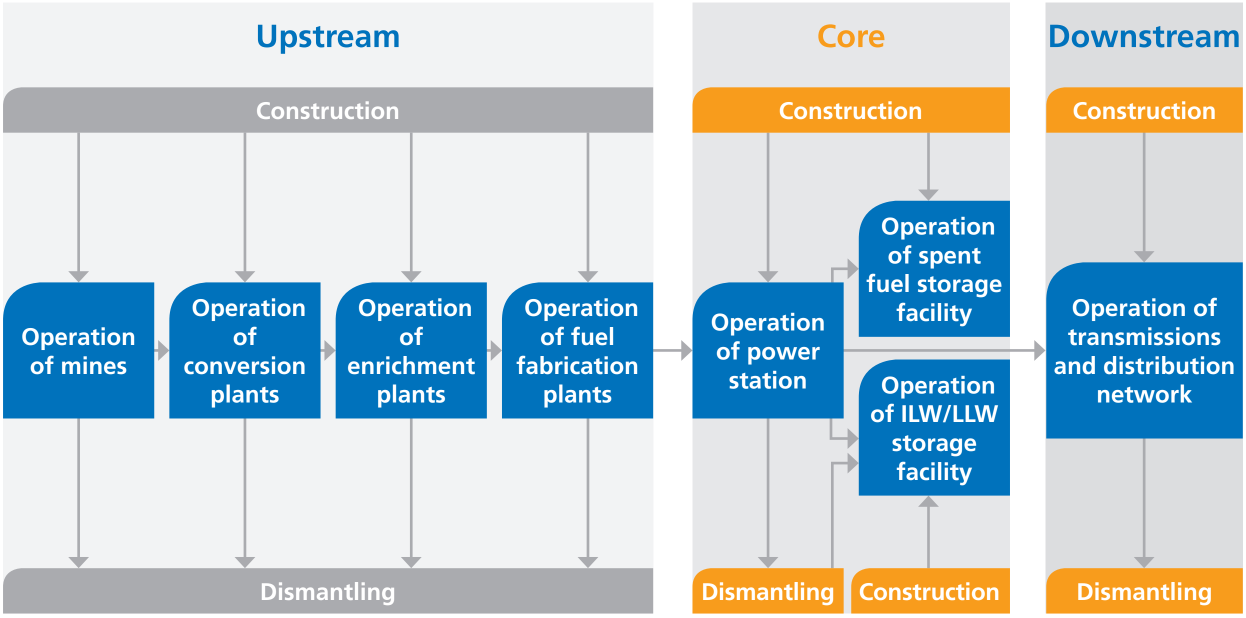
The approach used in the current study is a PCA approach. The analysis has drawn upon site specific data in order to reflect the impacts associated with specific facilities in the fuel cycle.

3.1.1 System boundary

The LCA captures the full nuclear fuel cycle and associated processes ‘from cradle to grave’. The reference time period is 18 months during 2008/09, which covers one fuel cycle at Sizewell B starting with the annual revision in 2008 (refuelling and maintenance) and ending before the subsequent revision in 2009.

The system boundary for Sizewell B has been defined in accordance with the specific PCR for preparing an EPD for electricity generation and distribution. The process stages included within the LCA are described in figure 3-1. In accordance with the PCR, impacts have been captured for each of the upstream, core and downstream modules.

Figure 3-1: Process stages covered by the EPD



Key:

LLW	Low Level Waste	**ILW**	Intermediate Level Waste

Not included in assessment | Included in assessment

In accordance with the PCR, the specific process and infrastructure elements that have been included within the system boundary are described below.

Fuel cycle stage	Included elements
Core module: processes	• Energy conversion process of plant(s). • Maintenance (for example lubrication but not reinvestment of components). • Reserve power and reserve heat including test operation. • Transportation of waste. • Handling/treatment/deposition of spent nuclear fuel and other radioactive waste. • Handling/treatment/deposition of other operational waste.
Core module: infrastructure	• Reactor building and other infrastructure including digging, foundations, roads etc. within the site, and respective construction processes. • Reactor, machinery, cables, tubes and other equipment for the conversion process and reserve power. • Power plant transformer. • Connection to the power network. • Transportation of inputs and outputs. • Facilities for handling of radioactive waste (on site and elsewhere) and facilities on site for handling of waste, residues and waste water. • Reinvestments of material and components during the estimated technical service life.

Fuel cycle stage	Included elements
Upstream module: fuel production	• Extraction of natural energy resources. • Processing of fuel. • Preparation of fuel. • Fuel storage process. • Transportation: extraction/cultivation → refinery → conversion plant.
Upstream module: production of auxiliary inputs	• Extraction of natural resources for auxiliary inputs (fuels and electricity used by suppliers, materials, chemicals). • Production of fuels and electricity used by suppliers producing auxiliary inputs. • Storage of auxiliary inputs at energy conversion site. • Transportation: extraction → processing → energy conversion plant.
Upstream module: upstream infrastructure	• Suppliers' factory buildings. • Suppliers' machines.
Downstream module: downstream processes	• Average transmission / distribution losses associated with the transmission and distribution of electricity to a consumer, defined with respect to connection voltage.
Downstream module: downstream infrastructure	• Infrastructure of the distribution system, construction, reinvestments and dismantling.

3.1.2 Core module

Comprehensive environmental data of the operation of Sizewell B was taken from the EMS and other measurements. The data represent the operation over an 18 month period in 2008 and 2009.

The PCR requires that impacts associated with infrastructure are considered for all facilities involved in the core processes. This includes impacts associated with the construction and decommissioning of Sizewell B, and the interim fuel storage facility.

Specific data on the material used in the construction of Sizewell B were obtained from engineering studies. For other construction related impacts e.g. vehicle movements and energy use during plant commissioning, generic data from the Ecoinvent database were used. A service lifetime of 40 years was assumed for the station. Data on the interim fuel storage facility was obtained from planning documents.

In addition to these processes, the manufacturing of the transport and storage casks for spent nuclear fuel was taken into account. Data on the deep repositories were taken from reports prepared by the NDA. Generic transport distances for the consumption of auxiliary materials were assumed as provided in the Ecoinvent database.

3.1.3 Upstream module

Analysis of the upstream processes is based on specific environmental data available for the facilities involved in the uranium mining, conversion, enrichment and fuel assembly. The data were obtained from environmental reports and data supplied directly by suppliers to EDF Energy.

All data represent process conditions in the time period from 2006 to 2010. Generic transport distances for the consumption of auxiliary materials were assumed as provided in the Ecoinvent database. Infrastructure of upstream processes is omitted, which is in accordance with the PCR.

Table 3-1 below describes the assumed supply distribution between facilities for the representative fuel supply chain for Sizewell B. This represents the assumed proportion of Sizewell B's requirements, during the reference period, that is assumed will be met by each facility in the fuel cycle.

Table 3-1 Facility locations and their relative proportion in Sizewell B's fuel cycle

Fuel cycle stage	Facility, Location	Proportion of Sizewell B requirement
Mining and milling	Ranger Mine, Australia	50%
	Olympic Dam, Australia	50%
Refinement and conversion	Malvési, France Pierrelatte, France	50%
	Post Hope, United States Blind River, United States	50%
Enrichment	Gronau, Germany	100%
Fuel fabrication	Lingen, Germany	100%

3.1.4 Downstream processes

Analysis of downstream processes associated with the operation of the UK electricity transmission and distribution network was based upon records within the Ecoinvent database. This included impacts associated with the construction of the network, as well as losses during the electricity transmission and distribution.

3.1.5 Allocation rules

Where possible, the allocation methodology recommended in the PCR is to gather data relating to each of the products and their associated emissions from the site directly i.e. based on physical relationships. This may involve looking at the on-site processes associated with each of the product types. Where this data is not available, the PCR recommends that emissions are split according to the value of the products produced.

The following technology specific allocations have been made, in accordance with the PCR:

- allocation of treatment/handling of spent fuel and residues follows the polluter pays allocation method. This means that the generator of the waste has to carry the full environmental impact until the point in the product´s life cycle where the waste is transported to a waste disposal site (i.e. final repository)
- at the Olympic Dam mine, products other than uranium are involved in the process. Therefore, the environmental impacts have been allocated on an economic basis i.e. on the basis of the market value of the different products during the reference year.

3.1.6 Boundaries towards risk assessment

Environmental impacts due to accidents and undesired events are not part of the LCA but part of the environmental risk assessment. However, environmental burdens occurring more than once in three years are considered normal operations, and were included in the LCA.

EDF Energy is currently working through systematic plans to address recurring risks associated with leakage from large refrigerant systems at Sizewell B.

3.1.7 Omitted or incomplete processes

Due to data limitations it has not been possible to capture all processes fully. The following processes have not been captured fully within the current analysis:

- impacts associated with the construction of the plant were based upon engineering data in relation to the main construction materials. The list of construction materials was incomplete, so may omit certain impacts associated with construction stage. Data was also unavailable on the resource use during the construction process and during the plant commissioning. To address this gap, generic data from the Ecoinvent database has been used
- impacts associated with the transmission and distribution of electricity are based upon generic data from the Ecoinvent database. It is unclear to what extent these estimates may reflect the UK grid. However, since these impacts are dominated by impacts associated with the infrastructure, the importance of these emissions may be less significant.

3.2 Ecoprofile of electricity generation

The assessment results are summarised[8] in Table 3-2. This shows the lifecycle inventory for Sizewell B. It represents the impacts and wastes, across all of the fuel cycle facilities described in. Results of the LCA are presented in the tables below and detailed in the sections that follow. Quantities are expressed per declared unit of 1 kWh generated electricity (net) at Sizewell B during a reference period of 18 months during 2008/09. In addition, the results are also expressed as 1 kWh electricity distributed to a customer connected to the electricity distribution network.

The ecoprofile consists of various types of LCA results that can be summarised in three categories:

- Life Cycle Inventory (LCI) results: Inventory results are direct emissions to and resource consumption from the environment. Examples of inventory results are CO_2 emissions or the consumption of fresh water
- Life Cycle Impact Assessment (LCIA) results: In the impact assessment, inventory results that contribute to the same environmental impact (e.g. climate change due to increasing greenhouse gas concentrations in the atmosphere) are grouped and their importance in relation to a specific basic substance is characterized with a factor (e.g. global warming potential of greenhouse gases in relation to CO_2)
- material flows: Selected materials that are subject to waste treatment or recycling are presented in this category.

[8] Note; the table is not exhaustive and presents only the most significant results. Impacts associated with other parameters are available in the underlying spreadsheets.

3.2.1 Use of resources

The resource use associated with the production of 1 kWh of electricity at Sizewell B is shown in table 3-2.

Table 3-2: Resource use per kWh

Resource Use	Unit	Per kWh net electricity at Sizewell B	Per kWh net electricity at customer on UK Grid
Non-renewable material use			
Gravel	kg	4.31E-03	4.61E-03
Calcite	kg	1.11E-03	1.18E-03
Iron	kg	4.05E-04	4.32E-04
Clay	kg	7.14E-04	7.62E-04
Nickel	kg	1.61E-05	1.72E-05
Chromium	kg	8.05E-06	8.60E-06
Barite	kg	1.21E-07	1.30E-07
Aluminium	kg	2.61E-06	2.79E-06
Fluorspar	kg	3.20E-05	3.45E-05
Copper	kg	4.92E-05	5.25E-05
Magnesite	kg	7.78E-06	8.31E-06
Zinc	kg	1.52E-08	1.62E-08
Kaolinite	kg	6.67E-07	7.13E-07
Uranium	kg	2.67E-05	2.85E-05
Zirconium	kg	1.01E-13	1.08E-13
Renewable material resources			
Wood	m^3	1.42E-07	1.52E-07
Non-renewable fossil primary energy resources			
Coal	kg	1.61E-03	1.72E-03
Crude Oil	kg	8.13E-04	8.68E-04
Natural Gas	m^3	3.53E-04	3.77E-04
Non-renewable nuclear primary energy resources			
Uranium	kg	2.67E-05	2.85E-05
Renewable primary energy resources			
Energy, in biomass	MJ	1.61E-03	1.72E-03
Converted kinetic energy in wind power	MJ	8.13E-04	8.68E-04
Converted potential energy in hydropower	MJ	3.53E-04	3.77E-04
Converted solar energy	MJ	1.61E-03	1.72E-03
Water consumption			
Freshwater	m^3	3.25E-03	3.47E-03
Seawater	m^3	8.75E-02	9.35E-02

3.2.1.1 Use of fossil resources

Fossil resources are used directly at the sites and facilities in the fuel supply chain, as well as indirectly through the embedded energy in products and materials consumed. This includes, for example, energy used in the production of the materials needed for the construction of the plant.

Direct fossil fuel use includes heating and cooling at the fuel cycle facilities, as well as process related energy use (steam, heat). In the supply chain fossil fuel is used directly as an energy supply for processes (e.g. enrichment) or in the manufacturing of materials essential to the process (e.g. steel, chemicals, cement).

Energy is also used in the production of electricity, which is then consumed as part of the fuel cycle. 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 in the fuel cycle. Instead, the resource use has been estimated using generic resource use estimates for each of the different generation technologies.

3.2.1.2 Use of other resources

Material resources are related to the manufacturing of building materials and materials for operation of the power station and the site for final disposal of the radioactive waste. This includes quantities of resources such as gravel for the construction of the nuclear power plant, and copper and iron ore, for use in the encapsulation of spent fuel.

3.2.2 Emissions of pollutants

The emissions of pollutants associated with the production of 1 kWh of electricity at Sizewell B is shown in table 3-3 below.

Impact assessment allows the effects of the resource use and emissions generated to be grouped and quantified into a limited number of impact categories which may then be weighted for importance. 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, oxides of nitrogen (NOx) 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).

Table 3-3: Pollutant emissions per kWh

Pollutant Emissions	Unit	Per kWh net electricity at Sizewell B	Per kWh net electricity at customer on UK Grid
Airborne emissions – impact assessment results			
Greenhouse gases (100 years)	kg CO_2 eq	6.04E-03	1.29E-02
Ozone-depleting gases	kg CFC-11 eq	5.42E-10	5.89E-10
Acidifying substances	kg SO_2 eq	6.05E-05	6.51E-05
Airborne emissions contributing to given impact assessment results			
Ammonia	kg	8.76E-07	9.36E-07
Carbon dioxide, fossil	kg	5.60E-03	5.99E-03
Carbon monoxide	kg	2.22E-05	2.37E-05
Dinitrogen monoxide	kg	4.19E-07	5.79E-06
Methane, tetrachloro-, CFC10	kg	2.16E-13	2.31E-13
Methane, bromochlorodifluoro-, Halon 1211	kg	1.04E-11	1.11E-11
Methane, bromotrifluoro-, Halon 1301	kg	2.82E-11	3.02E-11
Methane, biogenic	kg	1.55E-07	1.65E-07
Methane, fossil	kg	2.92E-13	3.12E-13

Pollutant Emissions	Unit	Per kWh net electricity at Sizewell B	Per kWh net electricity at customer on UK Grid
Airborne emissions contributing to given impact assessment results – continued			
Nitrogen dioxide (NO_2)	kg	0.00E+00	0.00E+00
Nitrogen oxides (NOx)	kg	2.41E-05	2.57E-05
NMVOC, non-methane volatile organic compounds	kg	6.09E-06	6.50E-06
Sulphur dioxide (SO_2)	kg	3.92E-05	4.19E-05
Other relevant non-radioactive airborne emissions			
Carbon dioxide, biogenic	kg	1.15E-04	1.23E-04
Particles, < 10 µm	kg	2.89E-05	3.08E-05
Particles, < 2.5 µm	kg	2.20E-05	2.35E-05
Particles, > 10 µm	kg	5.56E-05	5.94E-05
Arsenic g	kg	1.30E-07	1.39E-07
Cadmium g	kg	7.55E-09	8.06E-09
Dioxins g	kg	3.15E-18	3.37E-18
PAH, polycyclic aromatic hydrocarbons	kg	6.82E-10	7.28E-10
Radioactive airborne emissions			
Carbon-14	Bq	2.85E+01	3.04E+01
Krypton (all isotopes)	Bq	4.90E-01	5.24E-01
Radon (all isotopes)	Bq	8.65E+05	9.23E+05
Xenon (all isotopes)	Bq	5.25E-01	5.61E-01
Argon 41	Bq	3.43E-03	3.67E-03
Waterborne emissions – impact assessment results			
Eutrophying substances	kg PO4- eq	2.46E-05	2.65E-05
Waterborne emissions contributing to given impact assessment results			
Nitrate	kg	5.45E-06	5.82E-06
Phosphate	kg	1.90E-05	2.03E-05
Chemical Oxygen Demand (COD)	kg	1.36E-05	1.46E-05
Ammonium, ion	kg	2.84E-06	3.03E-06
Other relevant non-radioactive waterborne emissions			
Oils	kg	3.19E-06	3.41E-06
Radioactive waterborne emissions			
Strontium (all isotopes)	Bq	3.58E-02	3.82E-02
Cesium (all isotopes)	Bq	4.96E-01	5.29E-01
Other relevant non-radioactive emissions to soil			
Oil	kg	3.28E-06	3.50E-06

3.2.2.1 Greenhouse gas emissions

Emissions of CO_2 contribute over 93% of the Global Warming Potential (GWP) total for Sizewell B. The total greenhouse gas emissions per kWh of generation for Sizewell B have been calculated to be 6.04 g CO_2e/kWh. CO_2 emissions are dominated by the construction and mining and milling phases, which are responsible for 42% and 23% of all CO_2 emissions respectively. Emissions from waste disposal are also important.

At the construction phase, almost half of CO_2 emissions are associated with electricity used during the commissioning of the plant. In the absence of specific data for Sizewell B this is based upon data for a similar sized PWR plant from the Ecoinvent database. This assumes that 5.31 x 108 kWh of grid electricity were used during of the commissioning of Sizewell B. The greenhouse gas emissions associated with this electricity consumption have been estimated using data on the average UK electricity generation mix during the construction period (1989-1995), based upon data from the Digest of UK Energy Statistics.

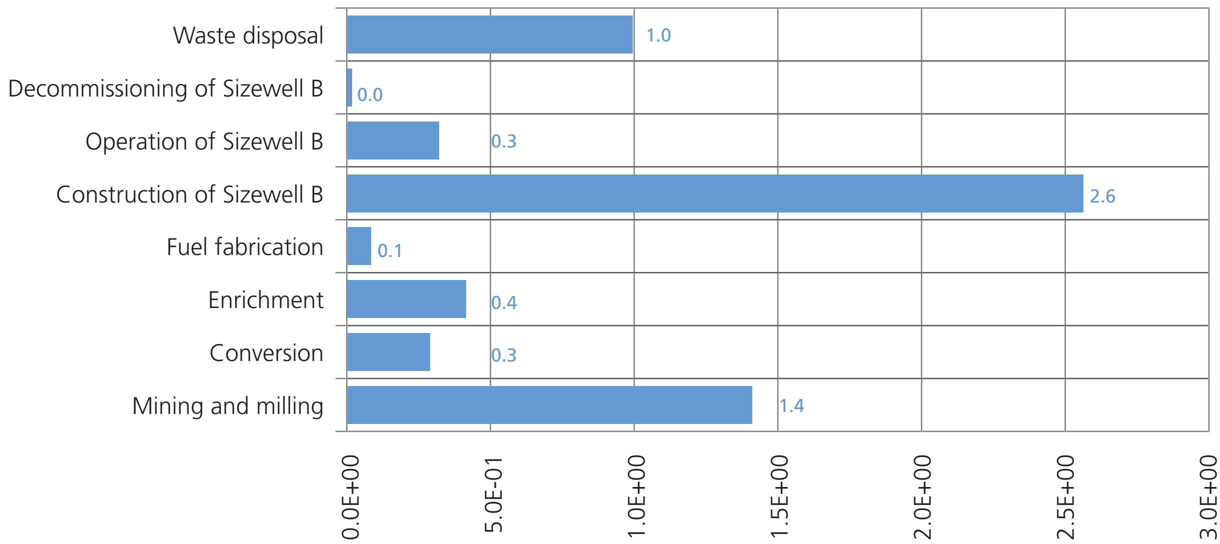
The remainder of the CO_2 emissions that are associated with the construction phase arise from the manufacture of reinforced steel and concrete, and to a lesser extent transport activities. One factor that has led to an increase in the estimated greenhouse gas emissions associated with the construction phase in the current EPD, as compared to the previous EPD published in 2008, is the inclusion of emissions associated with the construction of the planned dry fuel store.

A range of processes associated with the mining and milling phase are also a source of greenhouse gas emissions. Some emissions arise from direct combustion of fossil fuels at the mine sites, including vehicle movements. Other emissions are associated with the production of materials used in the mining and milling process, including certain chemicals.

As part of final disposal of radioactive waste, emissions of greenhouse gases are associated with materials used in the encapsulation of the waste in the final repository, including iron, bentonite and copper. In addition, emissions are associated with the electricity required as part of the on-going operation of the repository.

The relative importance of the difference stages in the fuel cycle on the overall greenhouse gas emissions are shown in the figure below.

Figure 3-2: Emissions of greenhouse gases to air (gCO_2e/kWh)[9]



[9] Emissions from the commissioning of the plant are included in the construction stage.

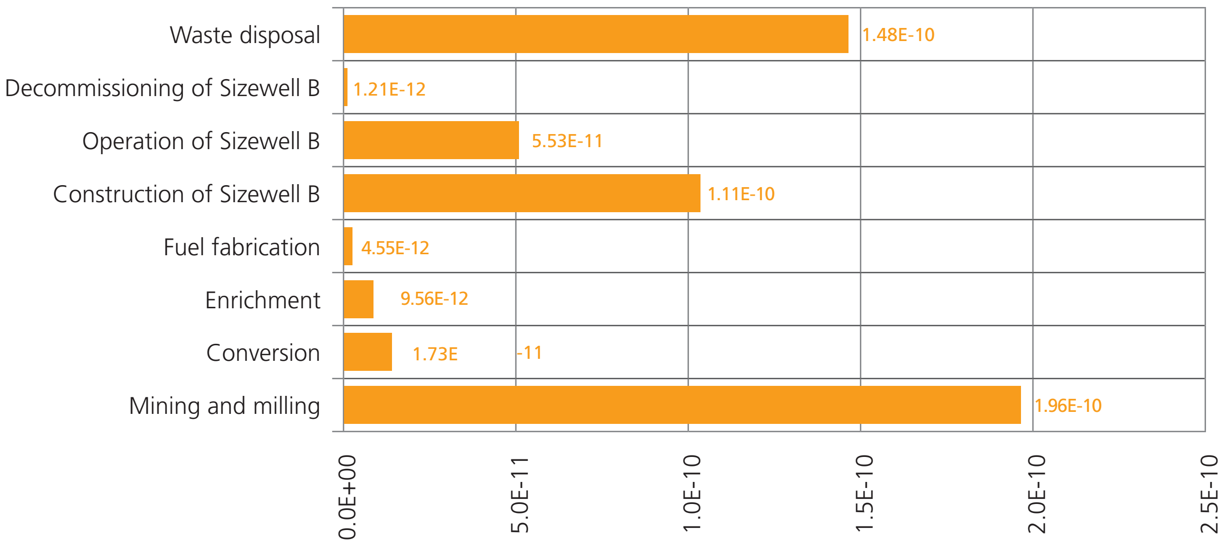
3.2.2.2 Emissions of ozone-depleting substances

Ozone-depleting substances (ODS) are man-made substances that cause damage to the stratospheric ozone layer and have contributed to the Ozone Hole over the Antarctic. Halons, hydrochlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs) are all types of ODS.

The main substances contributing to ozone depletion are Halon 1301 (61%), CFC-10 (22%) and Halon 1222 (10%). These emissions arise across all process stages, but in particular during the mining or the uranium, the construction of Sizewell B and the final disposal of the radioactive waste.

Emissions of ozone depleting substances at the construction and mining stages are dominated by releases further up the process chain. This includes emissions of Halon 1301 associated with the refinement of crude oil, and emissions of Halon 1211 and HCFC 22 associated with the transport of natural gas. Likewise, emissions of CFC-10 are associated with the production hydrochloric acid that is used in processing of bentonite which is associated with the waste disposal phase.

Figure 3-3: Emissions ozone depleting substances (kg CFC-11 equivalent/kWh)



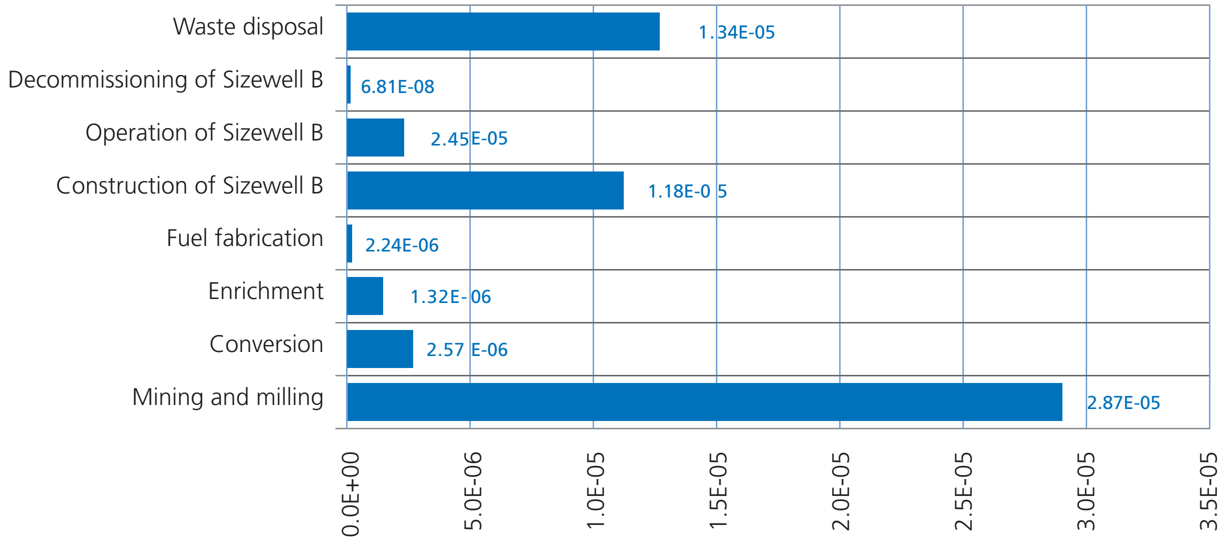
3.2.2.3 Emissions of acidifying gases

Sulphur dioxide (SO_2) and Nitrogen oxides (NO_x) cause over 98% of emissions of acidifying gases, with the remainder largely being made up of Ammonia (NH_3). During the Sizewell B fuel cycle, the mining and milling phase was the largest emitter of acidifying gases. This is again mainly associated with the emissions of SO_2, which are generated in the production of sulphuric acid, which is used as a leaching agent in the uranium milling process. A small amount of emissions NO_x also arise from chemicals used to make the explosives for blasting.

The construction and waste disposal phases are also important sources of acidifying gases. At the construction phase, over 50% of these emissions are associated with the combustion of fossil fuel to generate the electricity that is consumed during the commissioning of the plant. Fossil fuel consumption from steel production and during transportation is also important.

In relation to waste disposal, almost 79% of emissions are associated with the manufacture of copper that is used in the encapsulation of the radioactive waste.

Figure 3-4: Emissions of acidifying gases (kg SO_2 eq/kWh)



3.2.2.4 Emissions of gases potentially contributing to ground level ozone

Emissions of gases leading to the formation of ground level ozone are small across stages. The largest contributor is the extraction phase closely followed by the construction and operation phases. At the extraction and construction phases, ground level ozone is formed by emissions of a number of hydrocarbon gases, the most prominent being propene and pentane.

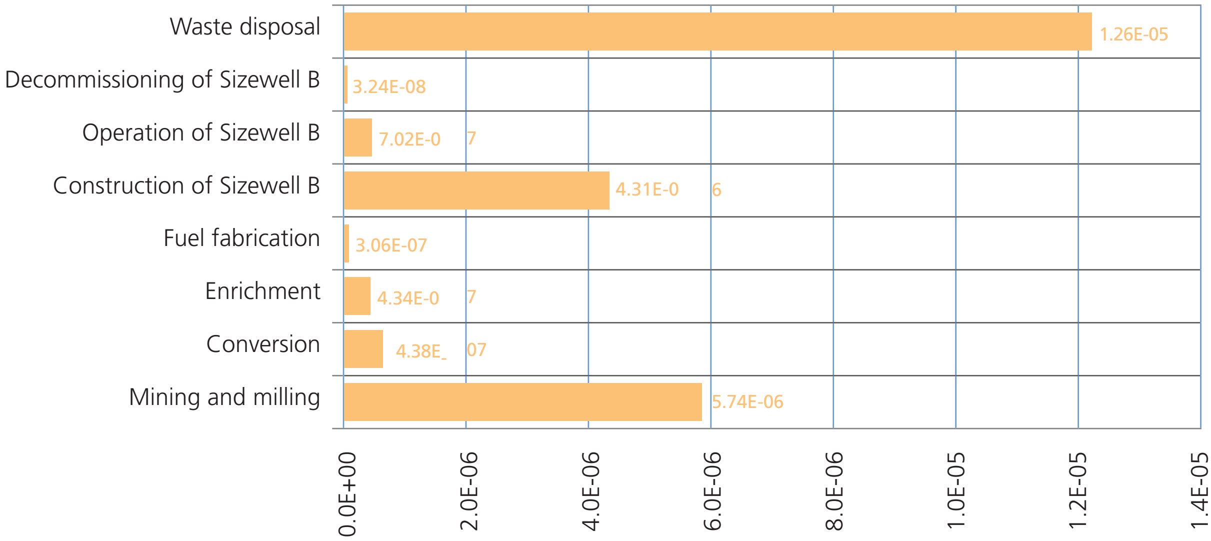
3.2.2.5 Emissions of substances potentially contributing to oxygen consumption

Eutrophication is the enrichment of water (lake or river) with nutrients, leading to the excessive growth of organisms and a lack of oxygen. The main eutrophying emissions relating to the production of electricity at Sizewell B are phosphate released into water which contributes 78% of the total impacts. Releases of nitrogen oxides are also important, and represent 13% of the total.

The waste disposal phase, the construction phase and the mining and milling phase are once again the main contributors to the overall impacts.

Impacts on eutrophication associated with waste disposal are dominated by disposal of waste from the copper production. At the construction phase emissions are associated with a variety of sub-processes including the combustion of fossil fuels during the production of electricity, copper and steel, and the disposal of spoil from coal mining. At the mining and milling phase, releases of phosphate associated with the disposal of the mine tailings are responsible for almost 50% of the emissions. Waste disposal associated with other primary fuels consumed as part of the construction phase are also sources of phosphate. NO_x emissions, largely associated with blasting, are a smaller source of emissions from this phase.

Figure 3-5: Eutrophicating substances (kg PO_4 eq/kWh)



3.2.2.6 Emissions of toxic substances

The processes and stages involved in the fuel cycle combined, release a wide range of potentially toxic substances into the environment. However, at each individual point source the amounts of toxic substances are small. For instance minute emissions of arsenic, cadmium and lead are associated with the treatment and disposal for radioactive waste. This is associated with the refining of copper which is used to encapsulate spent fuel. Likewise, at the construction phase, minute emissions of mercury and poly aromatic hydrocarbons occur, mainly from the generation of electricity and manufacture of reinforced steel.

Emissions of particulate matter arise from the incomplete combustion of fossil fuels, and also from mining activities such as the mechanical disturbance of rock. The mining and milling phase is the largest contributor of emissions of particulate matter.

3.2.2.7 Dominance analysis

The results of the various life cycle stages, considering each of the pollutant emissions described above, are shown in the table below.

Table 3-4: Relative contribution of each of the process phases to each of the impact categories

Impact category	Unit	Mining and milling	Refinement and conversion	Enrichment	Fabrication	Construction of Sizewell B	Operation of Sizewell B	Decommissioning of Sizewell B	Waste disposal
Acidification	kg SO_2 eq	47%	4%	2%	0%	20%	4%	0%	22%
Eutrophication	kg PO_4 eq	23%	2%	2%	1%	18%	3%	0%	51%
Global warming (GWP100)[10]	kg CO_2 eq	23%	5%	7%	1%	42%	5%	0%	17%
Ozone layer depletion (ODP)	kg CFC-11 eq	36%	3%	2%	1%	20%	10%	0%	27%
Photochemical oxidation	kg C_2H_4 eq	40%	11%	2%	0%	23%	4%	0%	20%

The overall comparison of the life cycle phases shows that the environmental impacts associated with the mining and milling of the uranium fuel, the construction of the nuclear power station and the final disposal of the radioactive waste dominate the results. These processes typically require large amounts of electricity or thermal energy, or use material that have an energy intensive production such as steel or copper.

Downstream impacts associated with the transmissions and distribution impacts have not been included in the analysis presented above. However, these impacts are important. In the table below a comparison of the relative contribution of the upstream (i.e. mining, conversion, enrichment), the core (construction, operation and decommission of the plant and waste repository) and the downstream (electricity transmissions and distribution) modules has been determined.

Table 3-5: Relative importance of the downstream module to the other environmental impacts

Impact category	Unit	Per kWh at consumer on UK Grid	Upstream	Core	Downstream
Abiotic depletion	kg Sb_2 eq	4.62E-05	34%	59%	7%
Acidification	kg SO^2 eq	6.51E-05	50%	43%	7%
Eutrophication	kg PO^4 eq	2.65E-05	26%	67%	7%
Global warming (GWP100)	kg CO^2 eq	1.29E-02	17%	30%	53%
Ozone layer depletion	kg CFC-11 eq	5.89E-10	39%	53%	8%
Photochemical oxidation	kg C_2H_4 eq	3.14E-06	49%	44%	7%

For most impact categories the relative impact of the downstream stage relates to the overall losses associated with the electricity transmission and distribution (c. 7%). However, there is a notable impact on global warming. This arises from the releases of sulphur hexafluoride associated with the transmission of the network. As described above, these emissions are based upon estimates within the Ecoinvent database.

[10] GWP100 – Global warming potential is a relative measure of how much heat a greenhouse gas traps in the atmosphere over a 100 year interval.

3.2.3 Waste

Fuel-related radioactive waste originates from the operation of Sizewell B, but also from some of the other fuel chain facilities. ILW and LLW is produced during the operation and decommissioning of the Sizewell site and spent fuel is produced as a by-product of electricity generation. At present no waste from Sizewell B is sent for reprocessing. LLW is either stored temporarily on site before being disposed of in the LLW repository near Drigg or sent for incineration at the Hythe Incinerator. All ILW and spent fuel is stored on site before final disposal in the future.

The amount of direct radioactive waste arising from the operation and decommissioning of Sizewell B is summarised in Table 3-6. The values are expressed in terms of the volume of packaged waste for disposal.

Table 3-6: Waste and spent fuel production (total lifetime volumes)

Type of waste	Quantity	Units
Spent fuel	1,049	tU
Operational Intermediate Level Waste (ILW)	820	m^3
Operational Low Level Waste (LLW)	3,454	m^3
Decommissioning ILW	2,443	m^3
Decommissioning LLW	9,975	m^3

Regarding non-radioactive waste, the main sources are the rock and mineral waste associated with the mining and milling activities, and the non-recyclable waste material from the construction and operation of Sizewell B.

4 Additional environmental information

This section provides additional environmental information that is not part of the LCA, but is considered an important environmental aspect of the production of electricity at Sizewell B.

4.1 Radiation protection

The handling of radioactive substances in various forms is part of the daily operations of facilities in the nuclear fuel cycle. The emission of ionizing radiation from these substances may result in doses to the people working in the facility (dose to personnel) as well as to people outside the facility (dose to third party).

4.1.1 Protection of the operating personnel

In all facilities involved in the investigated life cycle, regulations to protect working people are stipulated. A low level of radiation exposure, however, cannot be ruled out. In order to illustrate the radiation exposure, average individual doses are shown for all facilities representing the full nuclear fuel cycle.

For comparison, 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 millisieverts. However, UK legislation requires doses to workers to be as low as reasonably practicable and EDF Energy operates a policy of minimising risks according to this principle. It also operates to a more restrictive Company Dose Restriction Level of 10 mSv.

Table 4-1: Average annual dose to personnel at the facilities in the nuclear fuel cycle during the reference period

Fuel cycle stage	Facility, Location	Average annual individual dose to personnel (mSv per year)	Year of data collection
Mining and milling	Ranger Mine, Australia	1.3	2008
	Olympic Dam, Australia	3.6	2008
Refinement and Conversion	Malvési, France*	1.0	2009
	Pierrelatte, France		
	Port Hope, United States	2.2	2009
	Blind River, United States	3.4	
Enrichment	Gronau, Germany**	0.4	2007
Fuel Fabrication	Lingen, Germany*	1.0	2007
Generation	Sizewell B, United Kingdom	0.3	2011

Notes: * Based on data for all Areva sites - not site specific.
** Based on data for URENCO's Capenhust site in the UK which employs similar technology to the Gronau site.

4.1.2 Protection of third parties

The 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. In particular, these emissions may influence people living in the vicinity of the facilities (local effect).

4.1.2.1 Sizewell B

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. This results in a small dose to members of the public from consumption of local foods and exposure over intertidal sediments. Discharges from Sizewell B are monitored and are subject to strict control as required by the Environment Agency for England and Wales which issues permits specifying the maximum limits within which discharges should be kept. The annual discharge limits for Sizewell B are shown in table 4-2 below, along with the actual discharge values since 2008.

Table 4-2: Discharge authorisation limits

Discharge species	Annual limit	Annual discharges			Unit
		2008	2009	2010	
Gaseous releases					
Tritium	3	0.60	0.71	0.77	TBq
Carbon-14	500	330	300	150	GBq
Iodine-131	500	36	210	21	MBq
Noble Gases	30	2.9	3.9	3.0	TBq
Beta Particulate	100	7.2	4.7	5.1	MBq
Liquid releases					
Tritium	80	52	53	25	TBq
Caesium-137	20	4.5	4.8	5.7	GBq
Other Radionuclides	130	15	22	20	GBq

To determine the effect of these discharges on the general public the Environment Agency carry out monitoring around the station. Historically, most of the activity entering the local environment was due to Sizewell A (now decommissioning with much reduced discharges) weapons testing and Chernobyl fallout and only a small fraction will be due to Sizewell B. Local accumulation of radioactivity is still dominated by the historical discharges from Sizewell A. Doses to the most exposed members of the public in the vicinity of Sizewell B are summarised from the Environment Agency's monitoring reports in the table below. These should be compared with public dose limits of 1 mSv from artificial sources and typical natural exposures of 2.2 mSv.

Table 4-3: Dose to members of the public

Pathway	Dose, mSv/year		
	2008	2009	2010
Terrestrial food consumption	< 0.005	< 0.005	< 0.005
Seafood consumption	< 0.005	< 0.005	< 0.005
Exposure over sediments	< 0.005	< 0.005	0.005

4.2 Radiological safety and human health risks

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).

4.2.1 Sizewell B

4.2.1.1 Regulation

The activities at Sizewell B are governed by various Acts of Parliament. Of particular importance is the Nuclear Installations Act 1965 (as amended), which requires a license to be granted to construct, operate and decommission a nuclear site. The site license places conditions on the licensee to ensure the safe management of the site. The site nuclear operations are regulated by the Office for Nuclear Regulation (ONR). In addition, environmental activities are regulated by the Environment Agency (EA), chiefly under the Environment Permitting Regulations 2010.

4.2.1.2 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 Sizewell B. The credible fault scenarios have been identified and analysed, 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 exposure 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.

Sizewell B 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 main containment building is made from pre-stressed concrete and lined with steel. The use of a cylinder with a hemispherical dome provides a very strong configuration
- Sizewell B also has a second containment building made of reinforced concrete which encloses the first one.

4.2.1.3 Nuclear safety risks at Sizewell B

The risks due to operation at Sizewell B are managed in such a way as to meet with the requirements of the UK Office for Nuclear Regulation guidelines on Tolerability of Risk from Nuclear Power Stations. These guidelines we derived by considering societal attitudes to risk from a variety of sources, such as large industrial plant including operation. They define 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 licensee 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 EDF 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. In order to show that these frequency targets are met, all credible reactor faults are identified and analysed. These faults include failure of the shutdown systems as well as faults with the primary and secondary coolants. 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.

4.2.2 Final repository

4.2.2.1 Nuclear safety

The analysis presented in this section is based upon research undertaken by the NDA 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 NDA'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 NDA uses the HAZOP (Hazard and Operability) process.

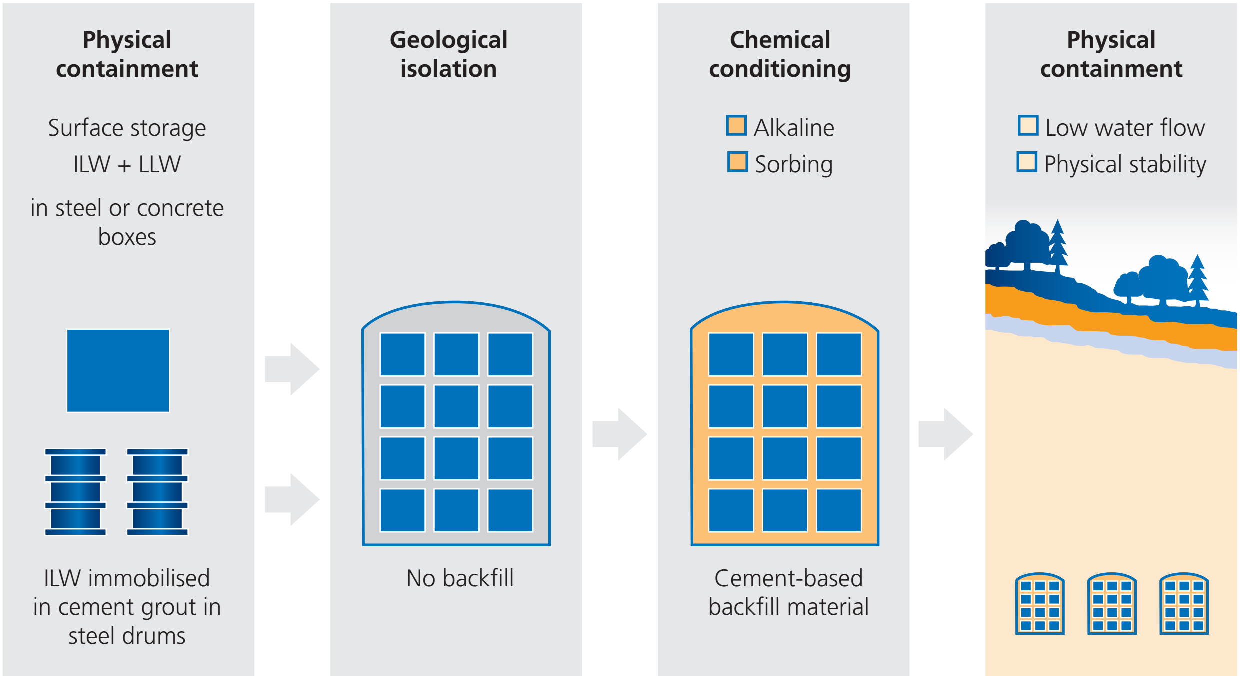
This EPD assumes waste will be disposed of in such facilities, although the final decision on the preferred waste option has yet to be made.

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 4-1). 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 NDA Reference Vault Backfill – NRVB) 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.

[11] See Nirex (2005) for further details.

Figure 4-1: The multi-barrier disposal concept (NDA 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, rock falls, seismic events etc. The NDA 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 licensed nuclear sites in the UK, and other nuclear sites throughout the world.

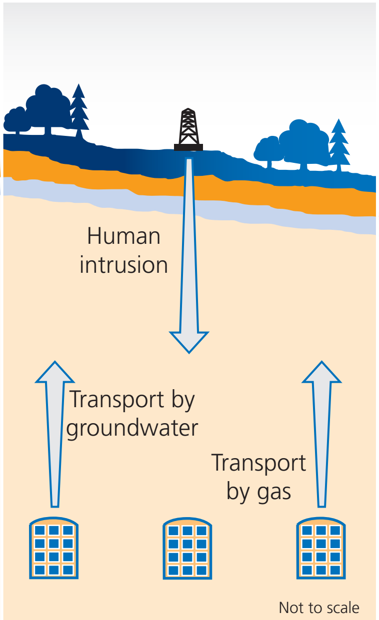
4.2.2.2 Nuclear safety risks at the final waste repository

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 4-2: Schematic illustration of main assessment pathways (not to scale)

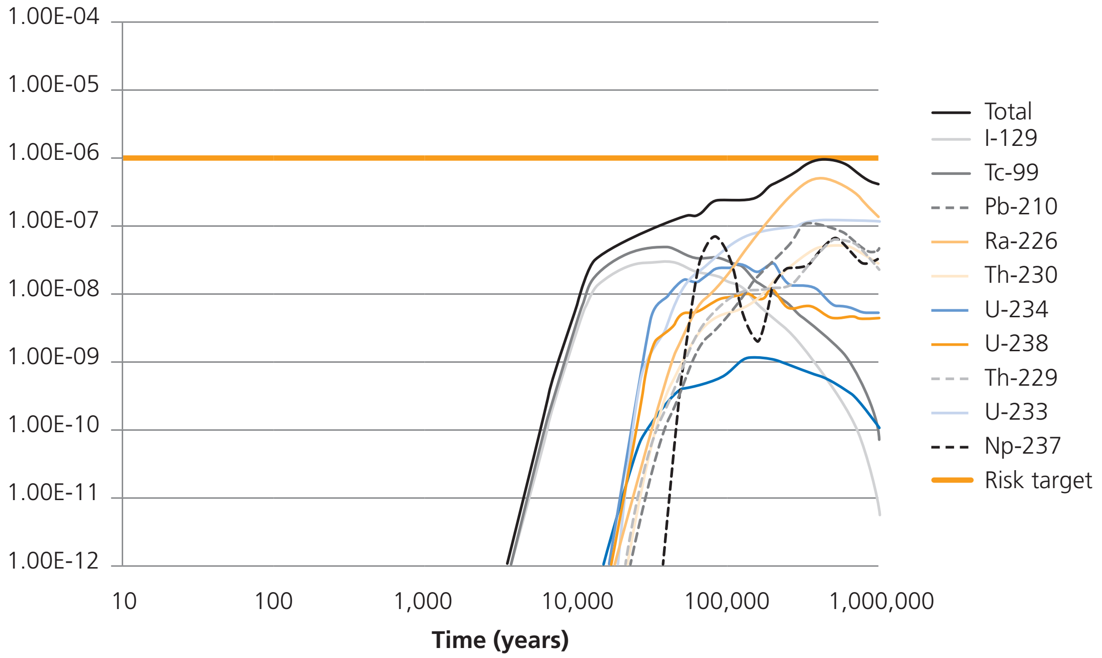


Groundwater pathway

The reference case radiological risk versus time plot for the groundwater pathway, is shown in Figure 4-3. 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 4-3 are for the whole inventory of UK waste arisings. The specific contribution from the Sizewell B power station waste will also be below the regulatory risk target.

Figure 4-3: 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 6,000 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.

4.2.2.3 HLW/SF Repository Concept

As part of a collaborative project with the Swedish Nuclear Fuel and Waste Management Company (SKB), the NDA has performed a preliminary post-closure safety assessment for the Reference HLW/spent fuel 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 KBS-3 concept, and uses the same geosphere and biosphere model as the NDA'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/spent fuel 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/spent fuel is lower than the radiological risk from naturally occurring radon by a factor of 40.

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

4.2.2.4 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^{o}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 Health and Safety Exectutive as "broadly acceptable".

4.3 Environmental risks

Environmental risks at Sizewell B are managed in accordance with EDF 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. Sizewell B's EMS is certified to the ISO 14001:2004 standard.

A key part of Sizewell B'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 in Table 4-4: below.

Table 4-4: Environmental risks

Priority	Description
1	Heating & Ventilation Refrigerant Management
2	Fuel Oil Supply to Combustion Plant
3	Active Drainage
4	HV Switchgear
5	Contaminated Ventilation
6	Radioactive Solid Low Level Waste Management
7	Transformer Oil Containment
8	Active Emissions
9	Management Control
10	Cooling Water Abstraction

4.4 Land use

The total area of the Sizewell B site is 623 ha, of which around 42 ha is permanently exploited for operational activities.

4.4.1.1 Land use classification for the Sizewell site

A classification has been made of the ecological habitats around the Sizewell B Power Station, within EDF Energy's current land ownership boundary. Using information and data collected by EDF Energy since its acquisition of the land, Figure 4-4 and Figure 4-5 overleaf provide a comparison of the ecological habitats prior to construction of the power station, with the habitats following both construction and the implementation of EDF Energy's Integrated Land Management Plan (ILMP) for the estate.

The maps, however, do not demonstrate the condition of the habitats. It is possible to say what habitat losses have occurred through direct land take for development. It has not been possible to fully quantify any possible changes in habitat condition or species populations that may have been indirectly due to the power station construction and operation. No complete comparable baseline data exists for pre construction. Also, the data is complex and subject to many influencing factors. However, regular monitoring from the year 2000 provides an indication of the success of the wider land management. A qualitative description of the habitat loss and habitat creation/enhancement is provided in the following section, together with a descriptive summary of the detailed monitoring results.

EDF Energy Nuclear New Build is proposing to construct a new nuclear power station on land immediately to the north of the Sizewell B. There will also be a new access road with temporary land take for contractors' areas. A full environmental impact assessment will be undertaken as part of the consent application but early mitigation planning has included the creation of semi-natural rough grassland on arable land on the Estate to facilitate future reptile translocation.

In 2010 Galloper Wind Farm leased land from EDF Energy near Sizewell Wents for construction of their sub-station.

These land use changes, which are not directly associated with the construction or operation of Sizewell B, have not been included within the figures.

The varied landscapes of the Suffolk Coast and Heaths Area of Outstanding Natural Beauty (AONB) provide a rich and diverse range of habitats including wetland, coast, lowland heath and woodland. The variety and proximity of these different habitats contribute to the area's high environmental value. Created over many centuries by the interaction of natural processes and human activity, the Suffolk Coast can be divided into three principal geological areas: the lowland heath separated by large tracts of arable land and coniferous forestry plantations on the higher ground of the Sandlings, the flat low lying marshes and reedbeds of the river valleys, and the coast which is deeply indented by the river estuaries and bounded by eroding cliffs and long shingle beaches. Each of these three geological areas and the diversity of ecological habitats associated with them can be found at Sizewell.

Figure 4-4: Sizewell estate – ecological habitat pre-construction

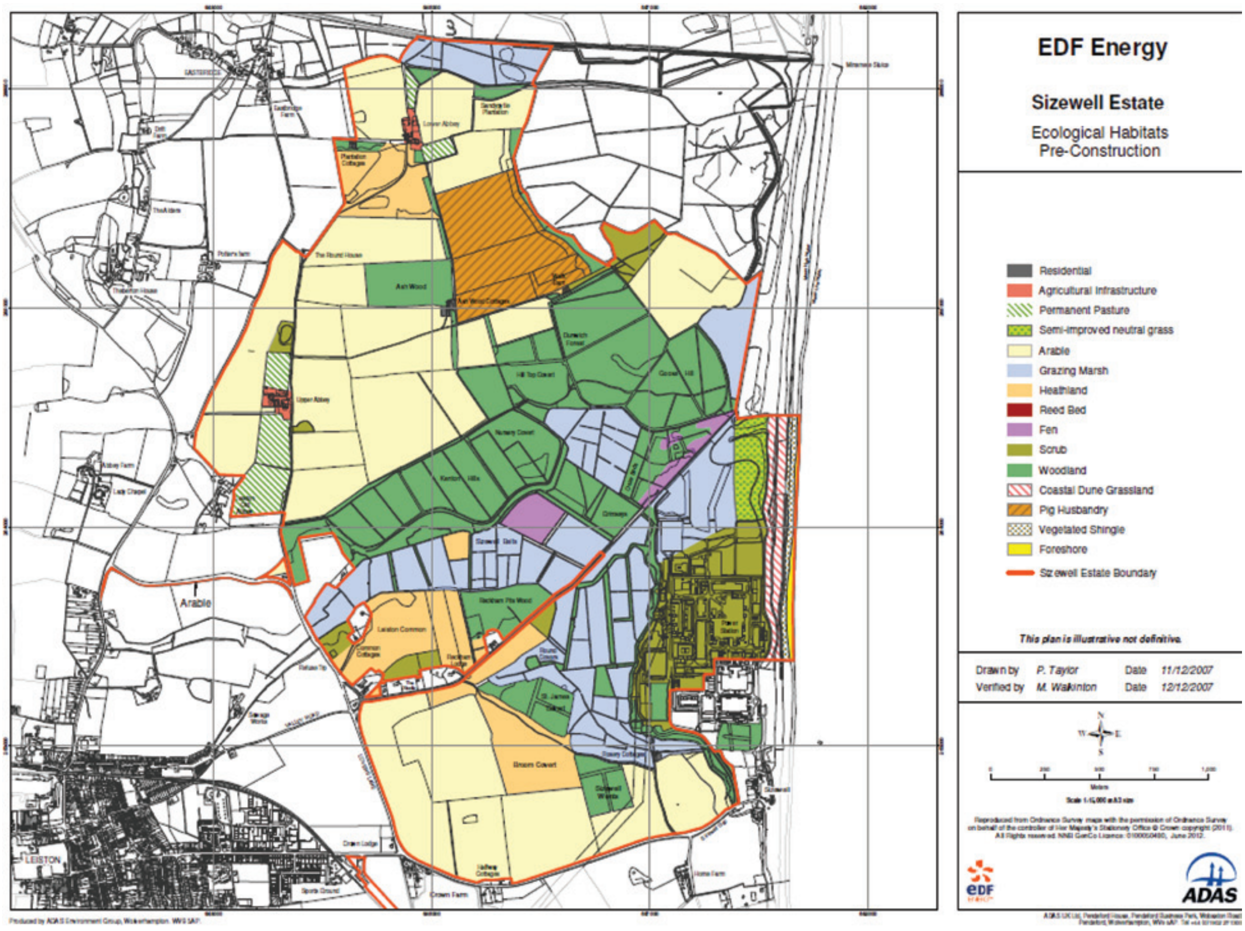
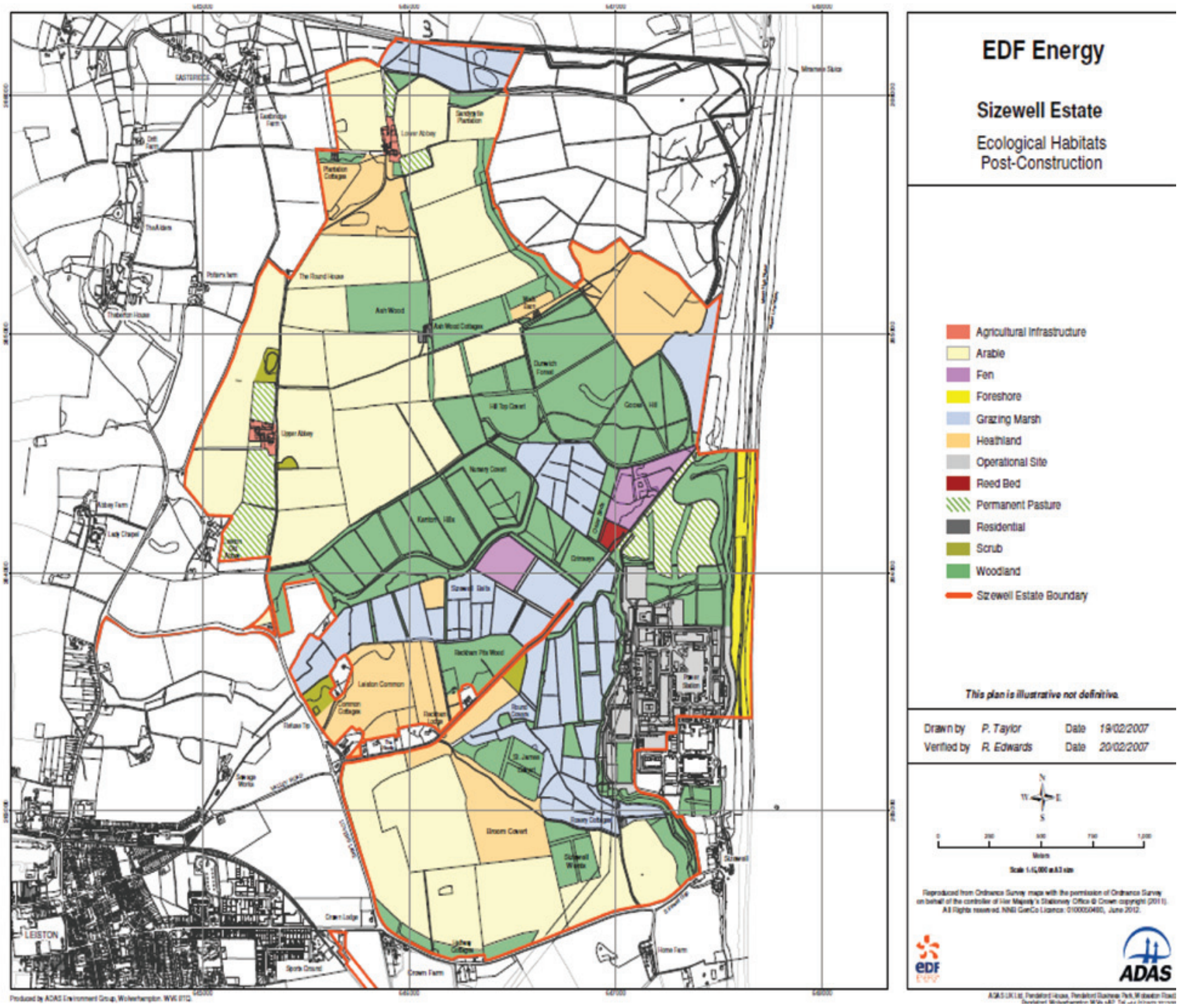


Figure 4-5: Sizewell estate – ecological habitat post-construction



4.4.2 Statutory designations

4.4.2.1 International

The Minsmere Walberswick Heath and Marshes Special Protection Area (SPA) and Special Area of Conservation (SAC) lies just to the north of Sizewell and comprises grazing marsh, extensive reedbeds, the estuary of the River Blyth and areas of lowland heath and woodland. It supports nationally important numbers of breeding and wintering birds. The site also qualifies as a Wetland of International Importance under the Ramsar Convention.

4.4.2.2 National

The Minsmere Walberswick Heaths and Marshes Sites of Special Scientific Interest (SSSI) contain a complex series of habitats, notably reedbeds and lowland heath which combine to create an area of exceptional interest especially for birds.

The 104.33ha Sizewell Marshes SSSI immediately to the west of the station are important for their large area of lowland, unimproved wet meadows which support outstanding assemblages of invertebrates and breeding birds. Several nationally scarce plants are also present.

The Leiston Aldeburgh SSSI, 3km to the south of Sizewell, contains a rich mosaic of habitats including acid grassland, heath, scrub, woodland, fen, open water and vegetated shingle. The variety of habitats supports a diverse and abundant community of breeding and overwintering birds, a high number of dragonfly species and many scarce plants.

4.4.2.3 Local

There are five County Wildlife Sites close to Sizewell: Leiston Common is an area of lowland heathland within EDF Energy's landholding to the west of the Sizewell Belts, and the beach and foreshore immediately to the east of the station comprises vegetated shingle and coastal dune grassland habitats. The Sizewell Rigs, the cooling water structure offshore from Sizewell A, supports a kittiwake colony of some 200 nests. The Sizewell Levels and Associated Areas includes the marshland, reedbeds and fen to the west of the power station almost all of which is also part of the Sizewell Marshes SSSI. Outside of the SSSI, the County Wildlife Site extends to the north encompassing the wet woodland at Leiston Carr, Fiscal Policy woodland, the Kenton and Goose Hills plantation and a small area of meadow adjacent to Leiston Common.

The Southern Minsmere Levels is directly adjacent to the Minsmere SPA, SAC and SSSI and is of interest for its breeding and wintering wildfowl and waders.

4.4.3 Biodiversity

The ecological habitats which existed at the Sizewell B site existed when the land was acquired for development are shown in table 4-5. This Sizewell B landholding has been assembled in parallel with the development of the power station which commenced construction in the mid 1980s. The present operational site was acquired by the Central Electricity Generation Board (CEGB) in 1960 in connection with the construction of Sizewell A. Kenton and Goose Hills to the north west of the site was planted by the Forestry Commission in 1958 and subsequently purchased in 1988 by CEGB. In 1992 the company purchased the Sizewell Belts marshes and some agricultural land to the west of the station. Gooderhams Fen, some 6ha, north east of the station was acquired in 1993. Finally, Abbey Farms was purchased in 1995 to provide land for future expansion of generation capacity.

The habitats when EDF Energy acquired the land were, in the main, degraded through intensive use of the more productive land for agriculture and forestry and a lack of management of the woodlands, marsh dykes and other marginal areas. The land developed for the B station was previously used as construction and contractors' areas during the building of Sizewell A and prior to development for Sizewell B was a mix of concrete hardstanding, grassland and scrub. To the north was an area of low lying grazing marshes of similar habitat quality to the marshes to the west which were designated SSSI in 1986. The eastern edge of the site comprised vegetated shingle and coastal dune grassland.

Table 4-5: Pre construction plan

Ecological habitats	Pre construction	Post construction	% change
	Area in hectares		
Arable, pig husbandry and permanent pasture	268.5	246.8	8.1%
Grazing marsh	105.6	90.6	14.2%
Heathland	50.1	73.3	+ 46.4%
Reedbed	0	1.1	
Fen	7.3	10.3	+ 45.6%
Scrub	47.0	4.4	90.6%
Woodland	156.0	185.9	+ 19.2%
Foreshore including coastal dune grassland and vegetated shingle	15.4	10.8	29.92%
Semi improved neutral grassland	6.98	0	-
Total	**656.82**	**623.30**	

4.4.3.1 Current biodiversity

The present station development occupies an area of former hardstanding, grassland and scrub which was obviously a loss of some 42ha habitat, most of which had probably naturally regenerated following use of the land in connection with the building of Sizewell A. To the north, the level of the 15ha of grazing marshes was raised during construction to allow use for contractors' laydown, spoil storage, etc. Subsequent restoration of the area has been to pasture and woodland/scrub of significantly lower ecological diversity than the original coastal grazing marsh habitat.

The shingle beach in front of the power station was extensively disturbed during construction. The area has been restored and replanted with plant communities taken from the site prior to construction, propagated and then replanted. No regular, comparable botanical monitoring has subsequently been undertaken so it is difficult to assess the success of the project and many factors may have influenced the plant communities which are now present.

4.4.3.2 EDF Energy and biodiversity

EDF Energy Nuclear Generation's Biodiversity Action Plan (BAP) identifies the priority habitats and species at each of the sites; sets and monitors targets and identifies ways in which staff and local communities can be involved through education, participation and partnership.

Maintaining this biodiversity requires continuing active management and EDF Energy Nuclear Generation has developed Integrated Land Management Plans (ILMS) for each of its power station sites including Sizewell B. The Sizewell B ILMP sets out objectives, policies and prescriptions for managing the land aimed at protecting and enhancing biodiversity, conserving the local landscape character and historical heritage, and encouraging public recreation, education and community participation whilst at the same time meeting the needs of the business.

In 1992 EDF Energy (formally British Energy) entered into a partnership with the Suffolk Wildlife Trust to manage the Sizewell estate. Since then, through the implementation of the ILMP in partnership with the Trust, substantive changes and improvements have been made to the variety of ecological habitats on the wider estate.

115ha of SSSI grazing marsh and fen have been restored under an ESA agreement through grazing, control of invasive scrub and water level management. A 1.14ha reedbed has been created. 76ha of heathland and acid grassland is being restored across the Estate including 15ha which is being reverted from arable.

In keeping with much of the Suffolk coast, a significant proportion of the Sandlings part of the estate is intensively cropped arable land. Field margins provide habitat for invertebrates and small mammals and act as wildlife corridors. The hedgerows on the estate were largely established as single species, usually hawthorn, during the period of enclosure. All of the estate's hedges have been managed under a Hedgerow Management Plan. Whilst some 3,000m of hedgerow have been restored by coppicing and restocking with native species.

Woodland on the Sandlings part of the estate is mainly coniferous plantation, the largest of these being Kenton and Goose Hills which occupies around 95ha of the central part of the estate. Small areas of lowland mixed deciduous woodland plantations are scattered throughout the estate. Prior to its acquisition, the woodlands had seen little recent management and were suffering windblow. Many of the woodland compartments were replanted after the storm of 1997. A total of 170,000 trees and shrubs have been planted since 1990 with 30ha of new woodland planted and other woods thinned and restocked. Rides have been cleared and widened with woody shrubs planted along ride edges.

Regular monitoring of habitats and species is undertaken at Sizewell B. Because of the complexity of factors influencing wildlife populations, many external to EDF Energy's landholding, it is difficult to precisely analyse the effects of the power station operation and the company's land management on the local wildlife. For example, the overall number of breeding bird territories on the Estate has increased since 1999 which probably points to a general improvement in the habitat across the Estate. However, eight breeding species have been lost and only two new species added. Overall these trends mirror national trends which suggest the declines are subject to external factors beyond the influence of local management. Overall the monitoring data does demonstrate that the wildlife populations have largely been sustained, and in some cases enhanced, by the pro active approach to land management.

In 2009 Sizewell B was awarded the Wildlife Trust's Biodiversity Benchmark for its land management.

4.4.3.3 Electromagnetic fields

The term "electromagnetic field" (EMF) refers to the lower frequency range of the electromagnetic spectrum (0 to 300 GHz). Fields of different frequencies interact with the body in different ways. EMFs are omnipresent in our environment – whether from natural or man-made sources, intended as in the case of radio signals or unintended as a by-product of power transmission or electrical appliances.

Electric fields are created by differences in voltage: the higher the voltage, the stronger will be the resultant field. The strength of the electric field is measured in volts per metre (V/m). Any electrical wire that is charged will produce an associated electric field. This field exists even when there is no current flowing. Electric fields are strongest close to a charge or charged conductor, and their strength rapidly diminishes with distance from it. Conductors such as metal shield them very effectively. Other materials, such as building materials and trees, provide some shielding capability. Therefore, the electric fields from power lines outside the house are reduced by walls, buildings, and trees. When power lines are buried in the ground, the electric fields at the surface are hardly detectable.

Magnetic fields are created when electric current flows: the greater the current, the stronger the magnetic field. The strength of the magnetic field is measured in amperes per metre (A/m). But more common is to specify to a related quantity, the flux density (in microtesla, μT). Magnetic fields are not blocked by common materials such as the walls of buildings.

The main source of electromagnetic fields in Sizewell B is the conversion of kinetic energy into electricity in the generator.

There is at present no UK legislation specific to EMFs. Control is exercised through the general duties in the Health and Safety at Work etc Act 1974, the Management of Health and Safety at Work Regulations 1999 and by reference to ICNIRP guidelines. ICNIRP are the International Commission on Non-Ionizing Radiation Protection. In 2010 they issued new guidelines for the frequency range 1 Hz to 100 kHz. These guidelines are currently used both by industry and HSE Inspectors when assessing risk from exposure to electromagnetic fields. For occupational exposure the limits set out in the ICNIRP guidelines are 1800 μT for magnetic fields and 46 kV/m for electric.

4.4.3.4 Noise

A noise measurement survey was carried out at the Sizewell B on the 8th and 9th of September 2009. The survey was used to inform the environmental impact assessment of the proposed future dry storage facility. Measurements were taken of the existing noise levels at 5 locations close to the site. The survey comprised 15-minute measurements during the day and evening and 5-minute measurements at night. Multiple measurements were taken at each location to ensure consistency of data gathered.

The survey found that at locations away from the road network the noise climate was generally steady and quiet, with contributions from vehicles on distant roads, faint noise from a nearby construction site and distant plant equipment noise emanating from the direction of Sizewell B. At roadside locations the dominant noise source was road traffic. During the night the noise levels dropped significantly. At one of the five locations the plant equipment noise from the direction of Sizewell B was more clearly audible at night than during the day.

During the construction of the dry storage facility some increased noise levels are expected. However, the general on-site construction activities are predicted to result in no noise impact at nearby residential properties. Noise impact from off-site construction traffic is predicted to be negligible, with regard to the typical and peak construction traffic flows. Potential vibration impacts associated with construction traffic are judged to be of minor significance.

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