

Environmental Product Declaration

Beznau Nuclear Power Plant | Update 2011



Summary

Company

Axpo AG, a wholly owned subsidiary of the Axpo Holding AG, is the leading Swiss electricity producer. For more than 90 years Axpo AG has guaranteed a reliable supply of electricity. Nuclear and run-of-river power stations cover the base load. Fluctuating demand and peak loads are balanced through storage and pump storage plants.

Product and declared unit

The Beznau nuclear power plant (NPP), wholly-owned by Axpo AG, consists of two virtually identical, dual-loop, pressurised water reactor units. The combined net power output is 730 megawatt electrical (MWe) which represents an annual electricity production of approx. 6 terawatt hours (TWh). This corresponds to approx. 10% of total Swiss electricity consumption. Since 2001, Beznau NPP has operated with an environmental management system certified and registered according to ISO 14001.

The declared product is 1 kilowatt hour (kWh) net electricity generated in Beznau NPP and thereafter distributed to a customer connected to the Axpo AG distribution network during the reference year 2009/10.

The International EPD® System

The international EPD® system managed by the International EPD Cooperation (IEC) is a Type III environmental declaration programme according to ISO 14025. The relevant governing documents in hierarchical order are PCR-CPC 17, General Programme Instructions for environmental product declaration (EPD), ISO 14025 and ISO 14044. Electricity belongs to the product category UNCPC Code 17, Group 171 – Electrical energy.

Verification of the results presented

The complete material presented in this EPD® has been reviewed and certified by the accredited certification body Bureau Veritas Certification Sweden.

Environmental impact of electricity generation in Beznau NPP

The life cycle assessment methodology has been applied to quantify the environmental impact. It comprises the full nuclear fuel-cycle and associated processes. The reference time period is 2009/10, which covers one fuel cycle at Beznau NPP starting with the annual revision in 2009 (refuelling and outage) and ending before the subsequent revision in 2010. The main results of the life cycle assessment are summarized in the table below. Further results including resource depletion and radioactive emissions are shown in the EPD®.

Environmental impact	Unit	1 kWh net electricity at Beznau NPP (uncertainty range)	1 kWh net electricity at Axpo AG customer (uncertainty range)
Greenhouse gases	g CO ₂ -equivalents	3.54(3.16 to 4.26)	3.61 (3.29 to 4.36)
Ozone-depleting gases	g CFC-11-equivalents	4.75 · 10 ⁻⁷ (3.50 · 10 ⁻⁷ to 7.47 · 10 ⁻⁷)	4.78 · 10 ⁻⁷ (3.54 · 10 ⁻⁷ to 7.45 · 10 ⁻⁷)
Formation of ground-level ozone	g ethylene-equivalents	1.93 · 10 ⁻³ (1.66 · 10 ⁻³ to 2.58 · 10 ⁻³)	1.94 · 10 ⁻³ (1.68 · 10 ⁻³ to 2.59 · 10 ⁻³)
Acidifying substances	g SO ₂ -equivalents	1.34 · 10 ⁻² (1.17 · 10 ⁻² to 1.95 · 10 ⁻²)	1.35 · 10 ⁻² (1.18 · 10 ⁻² to 2.11 · 10 ⁻²)
Eutrophying substances	g PO ₄ ³⁻ -equivalents	3.39 · 10 ⁻³ (1.89 · 10 ⁻³ to 7.78 · 10 ⁻³)	3.41 · 10 ⁻³ (1.91 · 10 ⁻³ to 1.06 · 10 ⁻²)
Depletion of fossil resources	MJ-equivalents	5.40 · 10 ⁻² (4.63 · 10 ⁻² to 6.72 · 10 ⁻²)	5.45 · 10 ⁻² (4.78 · 10 ⁻² to 6.87 · 10 ⁻²)

Table of contents

1	Introduction	5
1.1	The declared product	5
1.2	The environmental declaration and the international EPD® system	5
1.3	Axpo AG, LCA and EPD®	5
2	Manufacturer and product	6
2.1	Axpo AG	6
2.2	Environmental management system	6
2.3	Product system description	6
2.3.1	Beznau nuclear power plant	6
2.3.2	The nuclear life cycle of Beznau NPP in 2009/10	6
3	Environmental impact declaration	10
3.1	The life cycle assessment methodology	10
3.2	System boundaries, allocations and data sources	10
3.2.1	Core processes	11
3.2.2	Upstream processes	11
3.2.3	Downstream processes	12
3.3	Ecoprofile of electricity generation	12
3.3.1	Resource use	17
3.3.2	Emission of pollutants	18
3.4	Uncertainty analysis	25
3.5	Dominance analysis and conclusions	26
3.6	Differences versus the earlier version of the Beznau NPP EPD®	27
4	Additional environmental information	28
4.1	Land use	28
4.2	Biodiversity	29
4.3	Radiation protection	31
4.3.1	Protection of the operating personnel	31
4.3.2	Protection of third parties	32
4.4	Risks	34
4.5	Electromagnetic fields	36
4.6	Noise	37
5	Certification body and mandatory statements	38
5.1	Information from the certification body	38
5.2	Mandatory statements	38
5.2.1	General statements	38
5.2.2	Omissions of life cycle stages	38
5.2.3	Means of obtaining explanatory materials	38
5.2.4	Information on verification	38
6	Links and references	39
7	Frequently used abbreviations	39

1 Introduction

1.1 The declared product

This document constitutes the certified Environmental Product Declaration EPD® of electricity from the Beznau NPP. Beznau NPP is operated by Axpo AG, which is fully owned by Axpo Holding AG.

The declared product is 1 kWh net electricity generated in Beznau NPP and thereafter distributed to a customer connected to the Axpo AG distribution network during the reference year 2009/10.

Beznau NPP is an important pillar in the electricity production of Axpo AG. It contributes significantly to the base-load supply. The plant is operated round the clock, except for a few weeks each year set aside for refuelling and maintenance. Planned maintenance usually occurs during the summer, when power demand is lower.

1.2 The environmental product declaration 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 so that they will be credible and understandable by:

- offering a complete programme for any interested organisation in any country to develop and communicate EPDs according to ISO 14025,
- supporting other EPD programmes (i.e. national, sectorial, etc.) in seeking cooperation and harmonisation and helping organisations to broaden the use of their EPDs advantageously on the international market.

This Environmental Product Declaration conforms to the standards of the International EPD Consortium (IEC), www.environdec.com. 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-CPC 17 (Product Category Rules for preparing an Environmental Product Declaration for Electricity, Steam, and Hot and Cold Water Generation and Distribution), Version 1.1
- 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 life cycle assessment. Additional environmental information is presented in accordance with the PCR:

- Information on land use based on a categorisation according to CORINE¹ Land Cover Classes.
- 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 that arise from the electricity generation in Beznau NPP.
- Information on noise that arises from the electricity generation in Beznau NPP.

1.3 Axpo AG, LCA and EPD®

There are many reasons to declare the environmental impact of electricity production. For Axpo AG, the decisive reasons are:

- Electricity generation is a fundamental component of modern society, as electricity is required for the production of most goods and the delivery of almost all services. Therefore, as the largest electricity producer in Switzerland, Axpo AG wants to take the initiative in communicating clearly and reliably.
- The scientific assessment and rigorous minimisation of environmental impact are core pillars of Axpo AG's sustainability strategy. Our main goal is to minimize green house gas production throughout the total life cycle. An EPD® environmental declaration is a reliable foundation for the quantitative presentation of the environmental impact using a number of environmental indicators and taking into account the total production cycle.

For questions concerning this EPD® contact Axpo AG Sustainability, sustainability@axpo.ch.

For additional information about Axpo AG, please visit our website at www.axpo.ch.

¹ CORINE: Coordination of information on the environment: <http://terrestrial.eionet.europa.eu/CLC2000/classes>

2 Manufacturer and product

2.1 Axpo AG

The Axpo AG is a wholly owned subsidiary of the Axpo Holding AG. The Axpo group is a leading Swiss energy company supplying electricity to about three million people.

Axpo AG uses nuclear and run-of-river power plants to cover the base load. Fluctuating demand and peak loads are balanced through storage and pumped storage systems. Key figures of the energy procurement of Axpo AG are summarized in the table below.

Energy procurement 2009/10	Axpo AG [GWh]
Nuclear power plants	16377
Hydroelectric plants	5565
New renewable energies	105
From third-parties and trading	9840
Total	31887

2.2 Environmental management system

Since 2001, Beznau NPP has implemented an environmental management system, certified and registered according to ISO 14001. The environmental management system is an integral part of the integrated management system (IMS) that further includes the quality management system ISO 9001 and occupational health measures OHSAS 18001. The IMS is a central management tool covering the whole organisation, planning, accountability, routines and processes. The objective of the IMS is to ensure full compliance with the IAEA Safety Series 50-C/SG-Q as well as with Axpo AG's own safety, quality and environmental policies.

pressurised water reactor units. In this study, the expression "Beznau NPP" always refers to both reactor units. The combined net power output is 730 MWe representing an annual electricity production of approx. 6 TWh. This corresponds to approx. 10 % of the total Swiss electricity consumption. In addition to the electricity production, thermal energy is fed into the local district heating system. The two reactor units are loaded with a total of approx. 80 tons of fuel (uranium and plutonium) of which approx. 13 tons are replaced during the summer maintenance work. The technical service life of Beznau NPP is estimated at 50 years. The plant is located on an artificial island in the river Aare. When both units are running at full load, 40 m³ per second of water is required for cooling, which can be provided by the river. No cooling tower is required.

2.3 Product system description

2.3.1 Beznau nuclear power plant

The Beznau nuclear power plant, wholly-owned by Axpo AG, consists of two virtually identical, dual-loop,

	Power output [MWe]	Electricity generation 2010 [GWh]	Heat fed into local district heating 2010 [GWh]	Load factor 2010 [%]	Average load factor of the last 3 years [%]	Commissioned [year]
Unit 1	365	2674	178	83.7%	90.8%	1969
Unit 2	365	2857	15	89.6%	90.8%	1971
Total	730	5531	193			

2.3.2 The nuclear life cycle of Beznau NPP in 2009/10

Core processes: energy conversion and radioactive waste disposal

The core processes comprise the operation of Beznau NPP, the interim storage of spent fuel, the treatment of low-level nuclear waste with subsequent interim storage

as well as the storage of nuclear waste in deep geological repositories.

The Nuclear Energy Act calls for submission to the federal authorities of a project demonstrating the feasibility of radioactive waste disposal. Those responsible for disposal have to show that potential sites can be found in Switzerland where repositories can be constructed and operated

using present-day technology; these have to fulfil the long-term safety requirements defined by the authorities. For spent fuel (SF), vitrified high-level waste (HLW) and long-lived intermediate-level waste (ILW), the National Cooperative for the Disposal of Radioactive Waste (Nagra) has demonstrated disposal feasibility for the example of the Opalinus Clay in the Zürcher Weinland. The reports documenting this study were submitted to the federal authorities in 2002. In June 2006, the Federal Council and its supporting authorities came to the overall conclusion that the legally required demonstration for these wastes was successful. This was not a siting decision, but only a demonstration of the feasibility in principle of constructing a geological repository in Switzerland, as required by the nuclear energy legislation. The demonstration of disposal feasibility for

low- and intermediate-level waste was approved by the Federal Council in 1988². In this study, two types of repository for the final disposal of nuclear waste were assumed according to scenarios presented by Nagra.

- A deep geological repository for the disposal of low- and intermediate-level waste (LLW).
- A deep geological repository for the disposal of spent fuel (SF), high-level waste (HLW) and long-lived intermediate-level waste (ILW). A facility for the encapsulation of spent fuel and vitrified waste from reprocessing is integrated into the reception of the deep repository.

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

Company	Facility, location	Operation
Axpo	Beznau NPP, Switzerland	Electricity generation
Axpo	Interim storage facility Beznau, Switzerland	Interim storage of spent fuel
ZWILAG	Interim storage facility Würenlingen, Switzerland	Treatment and interim storage of low-level waste from operation of Beznau NPP
Nagra	Encapsulation facility, location in Switzerland as yet undetermined	Encapsulation of spent fuel
Nagra	Deep geological repository for SF, HLW and ILW, location in Switzerland as yet undetermined	Storage of nuclear waste
Nagra	Deep geological repository for LLW, location in Switzerland as yet undetermined	Storage of nuclear waste

Upstream processes: fuel manufacturing

During the reference year 2009/10 three types of nuclear fuel were present in the reactor core of Beznau NPP. The production chains of the used fuel types are:

Conventional uranium fuel (UO₂ fuel)

The manufacturing of the UO₂ fuel comprises the uranium mining and refining, the conversion to UF₆, the enrichment and the fabrication of the fuel assembly.

The conventional uranium fuel used in Beznau NPP was purchased at the mid/end of the 90s. The uranium originates from various sources. As the UO₂ fuel elements

are loaded in the core intermittently, the detailed origin and its processing into fuel elements vary from year to year. The UO₂ fuel that was in the core in the reference year 2009/10 originates from Russian stockpiles and was mined at the Priargunsky mining site in Russia. The conversion was performed in a two-step process. The converted uranium was enriched in Russia as well using centrifugation. Which of the four available Russian enrichment plants was used cannot be determined.

Facilities that are involved in the UO₂ fuel fabrication process are presented in the table below:

Company	Facility, location	Operation
Rosatom	Priargunsky Mining Combine (PMC), Krasnokamensk, Russia	Uranium mining (underground)
Rosatom	Chepetsk Mechanical Plant (CMP), Glasov, Russia Angarsk Electrolyze Chemical Combine (AECC), Angarsk, Russia	Conversion first step in CMP (U ₃ O ₈ to UF ₄) Conversion second step in AECC (UF ₄ to UF ₆)
Rosatom	Ural Electrochemical Integrated Plant (UEIP), Novouralsk, Russia Siberian Chemical Combine (SCC), Seversk, Russia Electrochemical Plant (ECP), Zelenogorsk, Russia Angarsk Electrolyze Chemical Combine (AECC), Angarsk, Russia	Enrichment (centrifugation)
AREVA	Lingen, Germany	UO ₂ fuel assembly

² www.nagra.ch

2 Manufacturer and product

Mixed oxide fuel (MOX fuel)

The key production step in the manufacturing of MOX fuel used in Beznau NPP is the recycling of plutonium from spent nuclear fuel arising from Swiss NPPs. The fuel reprocessing includes the separation of uranium and plutonium from fission products. Vitrified high-level waste (HLW) and long-lived intermediate-level waste (ILW) that result from the reprocessing are transported back to Switzerland where they are stored in the interim

storage facility ZWILAG and will be disposed in the deep repository. The MOX fuel is produced by mixing together uranium oxide (UO₂) from depleted uranium arising from enrichment and recycled plutonium oxide (PuO₂) from reprocessing.

Facilities that are involved in the MOX fuel fabrication process are presented in the table below:

Company	Facility, location	Operation
AREVA	La Hague, France	Plutonium recycling from spent nuclear fuel (reprocessing)
Sellafield Ltd.	Sellafield, UK	Plutonium recycling from spent nuclear fuel (reprocessing)
AREVA	Dessel, Belgium	MOX fuel assembly
AREVA	Cadarache, France	MOX fuel assembly
Sellafield Ltd.	Sellafield SMP, UK	MOX fuel assembly
ZWILAG	Interim storage facility, Switzerland	Interim storage of vitrified high-level and long-lived intermediate-level waste from reprocessing
Nagra	Encapsulation facility, location in Switzerland as yet undetermined	Encapsulation of vitrified high-level waste from reprocessing
Nagra	Final repository for SF, HLW and ILW, location in Switzerland as yet undetermined	Storage of nuclear waste from reprocessing

Enriched reprocessed uranium fuel (ERU fuel)

Enriched reprocessed uranium fuel is a complex mixture of recycled uranium originating from various sources with different enrichment grades and isotopic compositions. The production of ERU fuel comprises the recycling of uranium from spent nuclear fuel of Beznau NPP or other western NPPs in the reprocessing facilities Sellafield and La Hague. As with MOX production, HLW and ILW originating from Swiss nuclear spent fuel reprocessing are returned to Switzerland and stored temporarily before final storage in the deep geological repository. The reprocessed uranium is transported to the Siberian Chemical Combine (SCC) in Seversk for enrichment with centrifuges.

Also at the SCC facility, reprocessed uranium from Russian industrial reactors is enriched using centrifugation. Industrial reactors were used for military purposes. Today these reactors are all shut down and in 2009 reprocessing at SCC was stopped as well. Large stockpiles of reprocessed uranium from industrial reactors still exist. That is why uranium from SCC can remain an important source for ERU fuel production in the future.

The enriched reprocessed uranium from SCC and Sellafield/La Hague is mixed³ and thereafter transported to Mashinostroitelny Zavod (MSZ) facility.

A further source that is used for ERU fuel production is reprocessed uranium from the facility Mayak Product Association (MPA). In MPA, spent nuclear fuel from naval sources (submarines, icebreakers), research and breeding reactors and civil Russian light-water reactors is reprocessed. MPA is an important facility to reduce the nuclear legacy from the days of the Cold War as it is the only place in Russia for the treatment of spent nuclear fuel from disused submarines. Some of the reprocessed uranium from MPA is transported to MSZ.

The ERU fuel is fabricated in MSZ. To this end, scrap pellets and powder from previous campaigns are recycled and blended with the reprocessed uranium from SCC and MPA. In the fuel assembly process, the previously blended uranium is processed and then sintered into pellets. These pellets are then loaded into fuel rods which are combined into fuel assemblies.

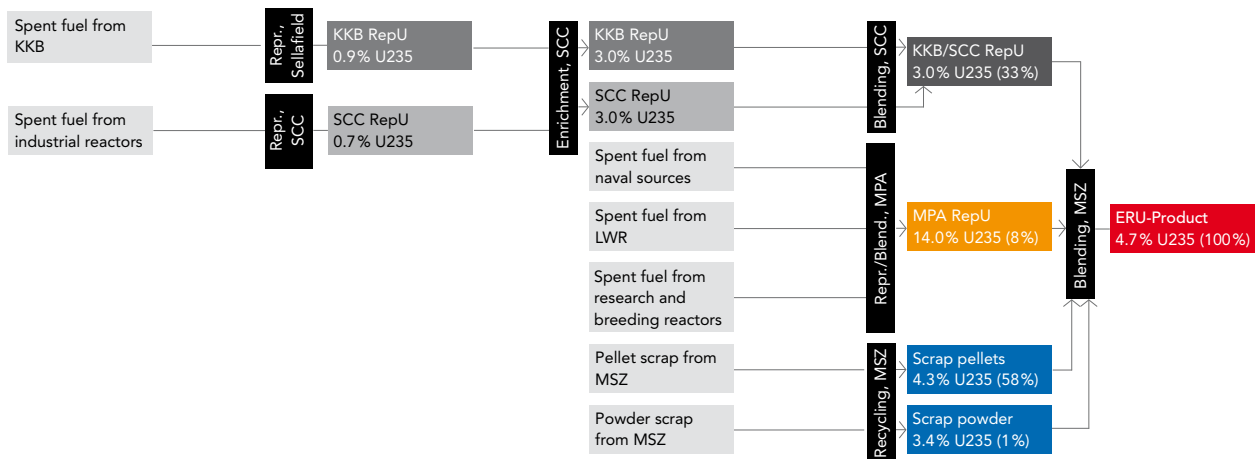
Facilities that are involved in the ERU fuel fabrication process are presented in the following table:

³ SCC has the technical abilities to mix the reprocessed uranium from the European facilities with the reprocessed uranium from SCC in a first step and to enrich the mixture in a subsequent production step. The sequence of the process steps does not influence the LCA results.

Company	Facility, location	Operation
AREVA	La Hague, France	Uranium recycling from spent nuclear fuel arising from Beznau NPP or other western NPPs (reprocessing)
Sellafield Ltd.	Sellafield, UK	Uranium recycling from spent nuclear fuel arising from Beznau NPP or other western NPPs (reprocessing)
Rosatom	Siberian Chemical Combine (SCC), Seversk, Russia	Uranium recycling from spent nuclear fuel from Russian industrial reactors (reprocessing) Enrichment of reprocessed uranium from Sellafield/La Hague Enrichment of reprocessed uranium from industrial reactors Mixing of reprocessed uranium from Sellafield/La Hague with reprocessed uranium from SCC
Rosatom	Mayak Product Association (MPA), Ozersk, Russia	Uranium recycling from spent naval fuel (submarines, icebreakers), spent fuel from research and breeding reactors and civil Russian light-water reactors (reprocessing)
Rosatom	Mashinostroitelny Zavod (MSZ), Elektrostal, Russia	Recycling of scrap pellets and powder Blending of recycled uranium from SCC and MPA with recycled scrap
Rosatom	Mashinostroitelny Zavod (MSZ), Elektrostal, Russia	ERU fuel assembly
ZWILAG	Interim storage facility, Switzerland	Interim storage of vitrified high-level and long-lived intermediate-level waste from reprocessing
Nagra	Encapsulation facility, location in Switzerland as yet undetermined	Encapsulation of vitrified high-level waste from reprocessing
Nagra	Final repository for SF, HLW and ILW, location in Switzerland as yet undetermined	Storage of nuclear waste from reprocessing

The diagram below shows the ERU fuel fabrication process schematically. In addition, the enrichment grade of uranium-235 is indicated for all intermediates and for

the final ERU product. The percentages written in brackets show fractions of uranium from various sources used to fabricate the ERU fuel in the reference year.



Abbreviations: Repr.: Reprocessing, RepU: Reprocessed uranium, LWR: civil light-water reactor, KKB: Beznau NPP

Downstream processes: electricity distribution within the Axpo AG network

It is not possible to determine exactly where electricity generated in Beznau NPP is ultimately used. This is because firstly, Beznau NPP is directly connected to the UCTE⁴ high voltage grid (220/380 kV). One cannot determine the end user of power fed to the UCTE grid. Secondly, electricity may also be distributed to local customers over the Axpo AG distribution network. In this study, only the latter option was taken into consideration.

Axpo AG operates a distribution network consisting of 2006 km of high voltage (110/50 kV) and 60 km of medium voltage (16 kV) current lines. Axpo AG customers are usually publicly owned electric utilities in Switzerland that further transform and distribute electricity. During the reference year 2009/10, 16.6 TWh electricity was distributed over the Axpo AG network. Total losses due to the distribution within the Axpo AG network amounted approximately to 130 gigawatt hours (GWh) in 2009/10, which corresponds to 0.8%.

⁴ UCTE: Union for the Coordination of Transmission of Electricity

3 Environmental impact declaration

3.1 The life cycle assessment methodology

The life cycle assessment (LCA) methodology was applied according to the ISO 14025 standard to quantify the environmental impact of the electricity generation in Beznau NPP and its subsequent distribution. LCA is a clearly structured framework based on international standards⁵ that facilitates the quantification and assessment of emissions to the environment and resource use along the entire electricity production chain. The LCA allows for comprehensive findings on overall energy, mass and emission flows, key processes that are involved and the quantification of important environmental impacts, such as greenhouse gas emissions.

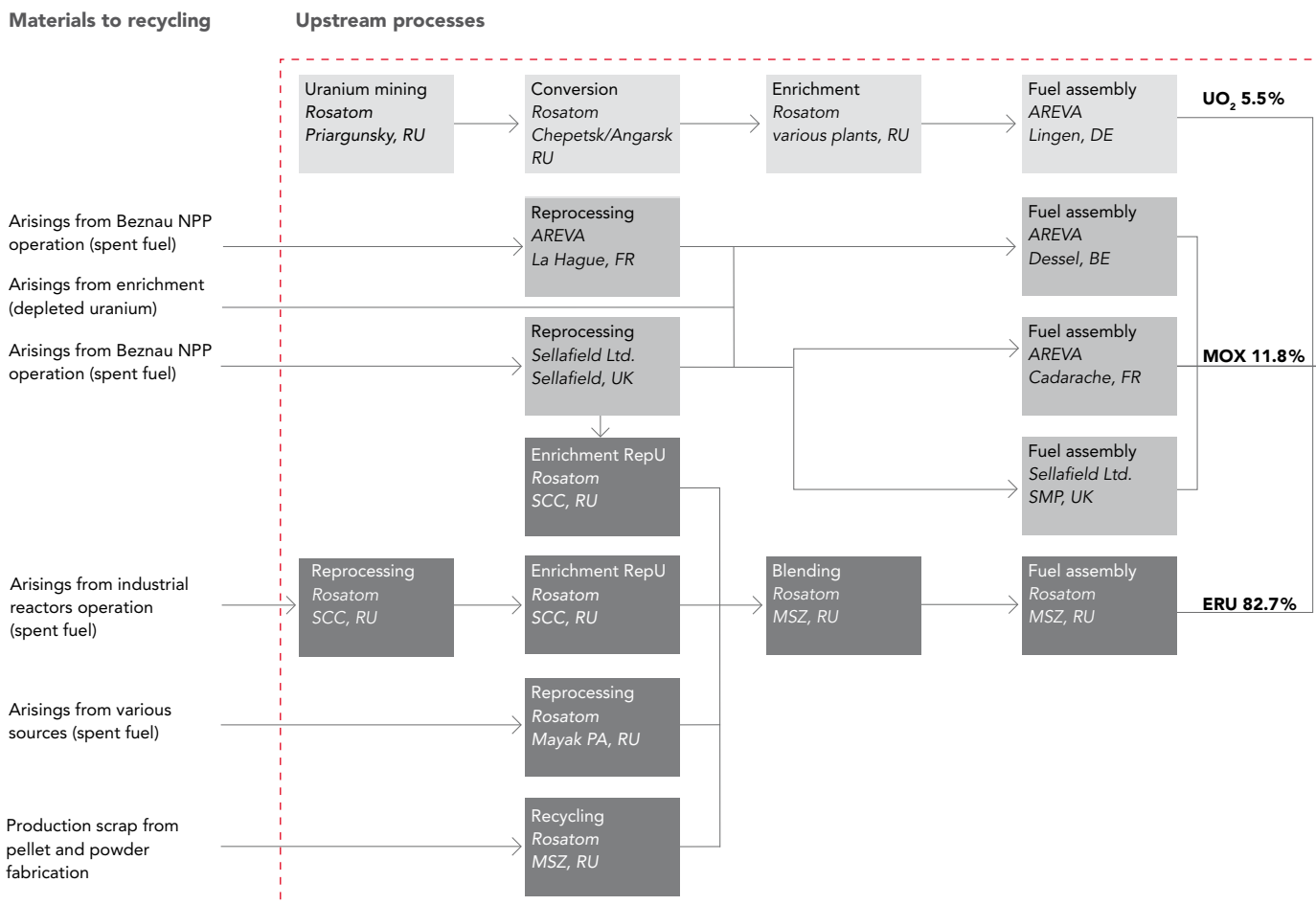
However, despite these advantages, there are also some issues beyond the scope of an LCA. For example, the LCA study only focuses on the normal operation of processes. Unusual process conditions or even accidents are not included. Additionally, due to the investigation of the full process chain, local effects on the environment may not be considered, such as the water quality of the river

Are in the ultimate vicinity of Beznau NPP for example. Finally, a LCA study only quantifies environmental impacts. No economic, social or ethical aspects are included.

3.2 System boundaries, allocations, and data sources

The life cycle assessment comprises the full nuclear fuel cycle and associated processes "from cradle to grave". The reference time period is 2009/10, which covers one fuel cycle at Beznau NPP starting with the annual revision in 2009 (refuelling and maintenance) and ending before the subsequent revision in 2010. The figure below is a simplified process chain with system boundaries for the LCA for electricity from Beznau NPP.

Data for all processes in the process chain presented below was gathered from the suppliers directly or from technical and environmental reports. These data provide an exceptionally good basis for an LCA study. For the calculation of the LCA results all available data were used without using a cut-off for supposedly unimport-



ant data. Data on material and energy supply (power mix, heat and process steam), building material supply (e.g. steel and concrete production) and transport services as well as on waste treatment processes (e.g. incineration, wastewater treatment) connected to the investigated process chain was taken from the ecoinvent database⁶. The ecoinvent database is a joint initiative of institutes and departments of the Swiss Federal Institute of Technology and provides consistent, transparent and quality-assured life cycle inventory (LCI) data.

3.2.1 Core processes

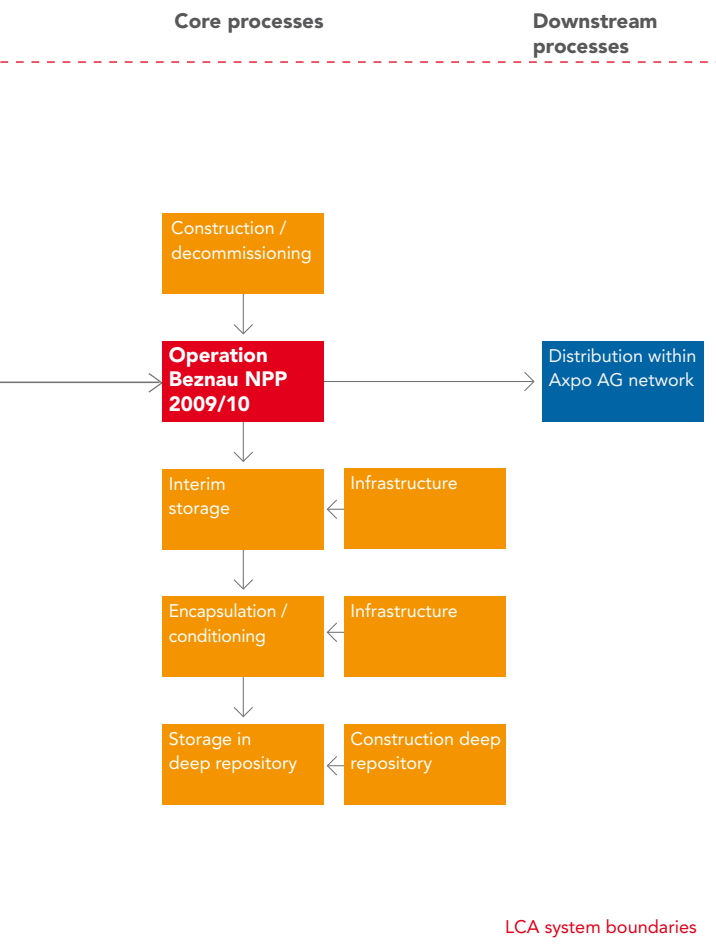
Comprehensive environmental data of the operation of Beznau NPP and the interim storage facility was taken from the environmental management system and other measurements. The data represent the operation from 2006 to 2010. The heat fed to the district heating system is considered a by-product and all environmental burdens are allocated to the electricity production. Infrastructure is considered for all facilities involved in the core processes. The infrastructure comprises the construction of all facilities and the decommissioning

of Beznau NPP, interim storage and encapsulation facility. Data on the construction and decommissioning of the nuclear power plant and the interim storage facility was obtained from decommissioning studies. With regard to Beznau NPP, a service lifetime of 50 years was assumed. In addition to these processes, the manufacturing of the transport and storage casks for spent nuclear fuel was taken into account. Data on the foreseen encapsulation facility and deep repositories were taken from reports of Nagra published 2002 as well as from LCA studies elaborated by the Paul Scherrer Institute (PSI) and published as part of the ecoinvent database. Generic transport distances for the consumption of auxiliary materials were assumed as used in the ecoinvent database.

3.2.2 Upstream processes

Analysis of the upstream processes is based on facility-specific environmental data available for the processes uranium mining, conversion, enrichment (AECC, UEIP, SCC), reprocessing (La Hague, Sellafield, Mayak PA, partly SCC), blending (MSZ) and fuel assembly (Lingen, Dessel). The data was obtained in the form of environmental reports, product data sheets from manufacturers, expert reports and personal communication with experts from the respective companies. On the other hand, no or only partly site-specific environmental data was available for the enrichment process in ECP and for the fuel assembly processes in MSZ, Sellafield SMP and Cadarache. Environmental data for these facilities were approximated with site-specific data of technically comparable facilities.

All data represent process conditions in the time period from 2004 to 2010. Regarding uranium mining some data were used that represent the time period of mid-90s. Generic transport distances for the consumption of auxiliary materials were used as applied in ecoinvent. Infrastructure of upstream processes is omitted, which is in accordance with the PCR guideline.



Simplified process scheme of the electricity production and distribution of Beznau NPP in the reference year 2009/10. The percentages indicate the contribution of the three fuel types to the energy production in the reference year.

⁵ ISO 14040 and ISO 14044 as well as Product Category Rules, PCR-CPC 17

⁶ ecoinvent database v2.2, Swiss Centre for Life Cycle inventories, www.ecoinvent.org

3 Environmental impact declaration

Allocation in recycling processes was made according to the "Polluter Pays (PP) allocation method" recommended in the General Programme Instructions of the international EPD® system. Thus, recycled materials enter a product system without adding the data about the environmental impact caused in earlier life cycles. Processes with input of recycled materials are fuel reprocessing (spent fuel is subject to recycling), MOX fuel assembly (depleted uranium is subject to recycling) and recycling of scrap pellets and powder. Allocation in multi-output processes was made according to the physical properties of the products: Environmental burdens arising from nuclear spent fuel reprocessing are allocated to the products uranium and plutonium based on the amount of fissionable material (U-235 and Pu-239).

3.2.3 Downstream processes

Comprehensive data on the operation of the Axpo AG distribution network was available, such as distribution losses or SF₆ emissions. Infrastructure of downstream processes was omitted in accordance with the PCR guidelines.

3.3 Ecoprofile of electricity generation

Results of the life cycle assessment are presented in the Ecoprofile tables below and commented in the sections 3.3.1, 3.3.2 and 3.5. More detailed LCA results were

available for the certifier. Quantities are expressed per declared unit 1 kWh generated electricity (net) at Beznau NPP during the reference year 2009/10 as well as 1 kWh electricity distributed to a customer connected to the Axpo AG distribution network.

The ecoprofile consists of various types of life cycle assessment results that can be summarized 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 CO₂ emissions or the consumption of freshwater.
- 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 CO₂).
- Material flows: Selected materials that are subject to waste treatment or recycling are presented in this category.

Ecoprofile – Resource use	Unit	per kWh net electricity at Beznau NPP	per kWh net electricity at customer of Axpo AG
Non-renewable material resources			
Gravel and sand	g	1.90	1.91
Calcite	g	$3.99 \cdot 10^{-1}$	$4.02 \cdot 10^{-1}$
Iron	g	$2.14 \cdot 10^{-1}$	$2.16 \cdot 10^{-1}$
Clay	g	$2.89 \cdot 10^{-1}$	$2.92 \cdot 10^{-1}$
Nickel	g	$4.89 \cdot 10^{-2}$	$4.93 \cdot 10^{-2}$
Chromium	g	$4.55 \cdot 10^{-2}$	$4.58 \cdot 10^{-2}$
Barite	g	$1.25 \cdot 10^{-3}$	$1.26 \cdot 10^{-3}$
Aluminium	g	$1.23 \cdot 10^{-2}$	$1.24 \cdot 10^{-2}$
Fluorite	g	$3.07 \cdot 10^{-9}$	$3.10 \cdot 10^{-9}$
Copper	g	$6.56 \cdot 10^{-3}$	$6.61 \cdot 10^{-3}$
Magnesite	g	$3.50 \cdot 10^{-3}$	$3.53 \cdot 10^{-3}$
Zinc	g	$1.86 \cdot 10^{-3}$	$1.88 \cdot 10^{-3}$
Kaolinite	g	$1.18 \cdot 10^{-3}$	$1.19 \cdot 10^{-3}$
Uranium	g	$1.24 \cdot 10^{-3}$	$1.25 \cdot 10^{-3}$
Zirconium	g	$9.77 \cdot 10^{-4}$	$9.85 \cdot 10^{-4}$
Renewable material resources			
Wood	m ³	$1.07 \cdot 10^{-7}$	$1.08 \cdot 10^{-7}$
Non-renewable fossil primary energy resources			
Hard coal	MJ-equivalents	$2.90 \cdot 10^{-2}$	$2.93 \cdot 10^{-2}$
Crude oil	MJ-equivalents	$8.96 \cdot 10^{-2}$	$9.04 \cdot 10^{-2}$
Natural gas	MJ-equivalents	$1.14 \cdot 10^{-2}$	$1.15 \cdot 10^{-2}$
Lignite	MJ-equivalents	$4.18 \cdot 10^{-3}$	$4.22 \cdot 10^{-3}$
Non-renewable nuclear primary energy resources			
Uranium	MJ-equivalents	$5.59 \cdot 10^{-1}$	$5.63 \cdot 10^{-1}$
Renewable primary energy resources⁷			
Energy, in biomass	MJ-equivalents (kWh)	$1.18 \cdot 10^{-3}$ ($3.27 \cdot 10^{-4}$)	$1.19 \cdot 10^{-3}$ ($3.30 \cdot 10^{-4}$)
Converted kinetic energy in wind power	MJ-equivalents (kWh)	$1.08 \cdot 10^{-4}$ ($2.99 \cdot 10^{-5}$)	$1.09 \cdot 10^{-4}$ ($3.02 \cdot 10^{-5}$)
Converted potential energy in hydropower	MJ-equivalents (kWh)	$4.25 \cdot 10^{-3}$ ($1.26 \cdot 10^{-3}$)	$4.55 \cdot 10^{-3}$ ($1.27 \cdot 10^{-3}$)
Converted solar energy	MJ-equivalents (kWh)	$3.35 \cdot 10^{-6}$ ($9.32 \cdot 10^{-7}$)	$3.38 \cdot 10^{-6}$ ($9.39 \cdot 10^{-7}$)
Electricity consumption in Beznau NPP			
	kWh	$4.23 \cdot 10^{-2}$	$4.27 \cdot 10^{-2}$
Use of recycled material			
Recycled uranium from nuclear fuel	g	$5.09 \cdot 10^{-3}$	$5.13 \cdot 10^{-3}$
Depleted uranium from enrichment	g	$2.55 \cdot 10^{-4}$	$2.57 \cdot 10^{-4}$
Aluminium scrap	g	$3.66 \cdot 10^{-3}$	$3.69 \cdot 10^{-3}$
Iron scrap	g	$1.35 \cdot 10^{-1}$	$1.36 \cdot 10^{-1}$
Copper scrap	g	$2.02 \cdot 10^{-3}$	$2.04 \cdot 10^{-3}$
Lead scrap	g	$8.90 \cdot 10^{-4}$	$8.98 \cdot 10^{-4}$
Other scrap from electronic devices	g	$1.14 \cdot 10^{-2}$	$1.14 \cdot 10^{-2}$
Other recycled metals	g	$1.67 \cdot 10^{-2}$	$1.68 \cdot 10^{-2}$
Water consumption			
Freshwater	g	$3.53 \cdot 10^4$	$3.55 \cdot 10^4$
Saltwater	g	2.95	2.98

⁷ According to the PCR, renewable primary energy resources should be presented in kWh. To compare these results with other primary energy resources numbers, are also presented in MJ-equivalents.

3 Environmental impact declaration

Ecoprofile – Pollutant emissions	Unit	per kWh net electricity at Beznau NPP	per kWh net electricity at customer of Axpo AG
Airborne emissions – impact assessment results			
Greenhouse gases (100 years)	g CO ₂ -equivalents	3.54	3.61
Ozone-depleting gases	g CFC-11-equivalents	$4.75 \cdot 10^{-7}$	$4.78 \cdot 10^{-7}$
Acidifying substances	g SO ₂ -equivalents	$1.34 \cdot 10^{-2}$	$1.35 \cdot 10^{-2}$
Formation of ground-level ozone	g ethylene-equivalents	$1.93 \cdot 10^{-3}$	$1.94 \cdot 10^{-3}$
Airborne emissions contributing to given impact assessment results			
Ammonia	g	$2.66 \cdot 10^{-4}$	$2.68 \cdot 10^{-4}$
Carbon dioxide, fossil	g	3.20	3.22
Carbon monoxide	g	$8.58 \cdot 10^{-3}$	$8.65 \cdot 10^{-3}$
Dinitrogen monoxide	g	$3.34 \cdot 10^{-4}$	$3.36 \cdot 10^{-4}$
Methane, tetrachloro-, CFC-10	g	$1.63 \cdot 10^{-7}$	$1.64 \cdot 10^{-7}$
Methane, bromochlorodifluoro-, Halon 1211	g	$1.55 \cdot 10^{-8}$	$1.56 \cdot 10^{-8}$
Methane, bromotrifluoro-, Halon 1301	g	$7.00 \cdot 10^{-9}$	$7.05 \cdot 10^{-9}$
Methane, biogenic	g	$9.05 \cdot 10^{-5}$	$9.12 \cdot 10^{-5}$
Methane, fossil	g	$8.76 \cdot 10^{-3}$	$8.83 \cdot 10^{-3}$
Nitrogen dioxide (NO ₂)	g	$1.78 \cdot 10^{-3}$	$1.79 \cdot 10^{-3}$
Nitrogen oxides (NO _x)	g	$6.25 \cdot 10^{-3}$	$6.30 \cdot 10^{-3}$
NMVOC, non-methane volatile organic compounds	g	$1.07 \cdot 10^{-3}$	$1.08 \cdot 10^{-3}$
Sulphur dioxide	g	$8.95 \cdot 10^{-3}$	$9.02 \cdot 10^{-3}$
Other relevant non-radioactive airborne emissions			
Carbon dioxide, biogenic	g	$8.09 \cdot 10^{-2}$	$8.16 \cdot 10^{-2}$
Particles, < 10 µm	g	$1.74 \cdot 10^{-3}$	$1.75 \cdot 10^{-3}$
Particles, < 2.5 µm	g	$2.21 \cdot 10^{-3}$	$2.23 \cdot 10^{-3}$
Particles, > 10 µm	g	$3.73 \cdot 10^{-3}$	$3.76 \cdot 10^{-3}$
Arsenic	g	$2.18 \cdot 10^{-6}$	$2.20 \cdot 10^{-6}$
Cadmium	g	$6.41 \cdot 10^{-7}$	$6.46 \cdot 10^{-7}$
Dioxins	g	$2.85 \cdot 10^{-12}$	$2.87 \cdot 10^{-12}$
PAH, polycyclic aromatic hydrocarbons	g	$1.11 \cdot 10^{-6}$	$1.11 \cdot 10^{-6}$
Radioactive airborne emissions			
Tritium H3	kBq	$1.59 \cdot 10^{-1}$	$1.60 \cdot 10^{-1}$
Carbon 14	kBq	$4.19 \cdot 10^{-2}$	$4.22 \cdot 10^{-2}$
Krypton (all isotopes)	kBq	$2.47 \cdot 10^2$	$2.49 \cdot 10^2$
Radon (all isotopes)	kBq	$2.18 \cdot 10^{-1}$	$2.20 \cdot 10^{-1}$
Xenon (all isotopes)	kBq	$8.41 \cdot 10^{-1}$	$8.48 \cdot 10^{-1}$
Argon 41	kBq	5.99	6.04
Noble gases, unspecified	kBq	$7.66 \cdot 10^{-1}$	$7.73 \cdot 10^{-1}$
Other radioactive isotopes	kBq	$5.74 \cdot 10^{-1}$	$5.78 \cdot 10^{-1}$
Radon (long-term emissions)	kBq	$3.65 \cdot 10^2$	$3.68 \cdot 10^2$
Waterborne emissions – impact assessment results			
Eutrophying substances	g PO ₄ ³⁻ - equivalents	$3.39 \cdot 10^{-3}$	$3.41 \cdot 10^{-3}$

Waterborne emissions contributing to given impact assessment results			
Nitrate	g	$3.01 \cdot 10^{-3}$	$3.04 \cdot 10^{-3}$
Phosphate	g	$1.80 \cdot 10^{-3}$	$1.81 \cdot 10^{-3}$
COD, Chemical Oxygen Demand	g	$2.76 \cdot 10^{-3}$	$2.78 \cdot 10^{-3}$
Ammonium, ion	g	$2.66 \cdot 10^{-5}$	$2.68 \cdot 10^{-5}$
Other relevant non-radioactive waterborne emissions			
Sulphate	g	$2.10 \cdot 10^{-2}$	$2.12 \cdot 10^{-2}$
Oil	g	$7.33 \cdot 10^{-4}$	$7.39 \cdot 10^{-4}$
Radioactive waterborne emissions			
Tritium H3	kBq	$1.63 \cdot 10^1$	$1.64 \cdot 10^1$
Carbon 14	kBq	$1.76 \cdot 10^{-2}$	$1.77 \cdot 10^{-2}$
Strontium (all isotopes)	kBq	$3.18 \cdot 10^2$	$3.21 \cdot 10^2$
Cesium (all isotopes)	kBq	$3.27 \cdot 10^2$	$3.30 \cdot 10^2$
Other actinides	kBq	$9.48 \cdot 10^{-3}$	$9.56 \cdot 10^{-3}$
Other radioactive isotopes	kBq	$3.84 \cdot 10^{-2}$	$3.87 \cdot 10^{-2}$
Other relevant non-radioactive emissions soil			
Oil	g	$6.99 \cdot 10^{-4}$	$7.05 \cdot 10^{-4}$

Ecoprofile – Waste and material subject to recycling	Unit	per kWh net electricity at Beznau NPP	per kWh net electricity at customer of Axpo AG
Core processes			
Spent fuel from NPP			
Spent fuel (incl. fuel assemblies)	g	$3.49 \cdot 10^{-3}$	$3.52 \cdot 10^{-3}$
Heavy metal in spent fuel (initial amount of uranium and plutonium in the fuel assemblies)	g	$2.33 \cdot 10^{-3}$	$2.34 \cdot 10^{-3}$
Hazardous waste – radioactive			
SF/HLW/ILW ⁸ in final repository	m ³	$6.66 \cdot 10^{-9}$	$6.71 \cdot 10^{-9}$
LLW ⁹ in final repository	m ³	$4.00 \cdot 10^{-8}$	$4.04 \cdot 10^{-8}$
Hazardous waste – non-radioactive			
Hazardous waste to incineration	g	$2.20 \cdot 10^{-2}$	$2.22 \cdot 10^{-2}$
Other waste			
Non-hazardous waste to landfill	g	3.10	3.13
Non-hazardous waste to recycling	g	1.04	1.05
Non-hazardous waste to incineration	g	$2.63 \cdot 10^{-2}$	$2.65 \cdot 10^{-2}$
Upstream processes			
Hazardous waste – radioactive			
SF/HLW/ILW in final repository	m ³	$4.15 \cdot 10^{-9}$	$4.18 \cdot 10^{-9}$
LLW in final repository	m ³	$9.58 \cdot 10^{-7}$	$9.66 \cdot 10^{-7}$
Hazardous waste – non-radioactive			
Depleted uranium from enrichment (tails) to recycling	g	$3.28 \cdot 10^{-3}$	$3.31 \cdot 10^{-3}$
Hazardous waste to incineration	g	$6.89 \cdot 10^{-3}$	$6.95 \cdot 10^{-3}$
Other waste			
Non-hazardous waste to landfill	g	$9.30 \cdot 10^{-1}$	$9.37 \cdot 10^{-1}$
Non-hazardous waste to recycling	g	$3.01 \cdot 10^{-2}$	$3.04 \cdot 10^{-2}$
Non-hazardous waste to incineration	g	$1.01 \cdot 10^{-2}$	$1.02 \cdot 10^{-2}$

⁸ SF/HLW/ILW: Spent fuel / High-level waste / Long-lived intermediate waste

⁹ LLW: Low- and intermediate-level waste

3 Environmental impact declaration

The contribution of the different life cycle stages to the overall results are shown in the figures below for all life cycle impact categories. The impacts are separated into the following categories:

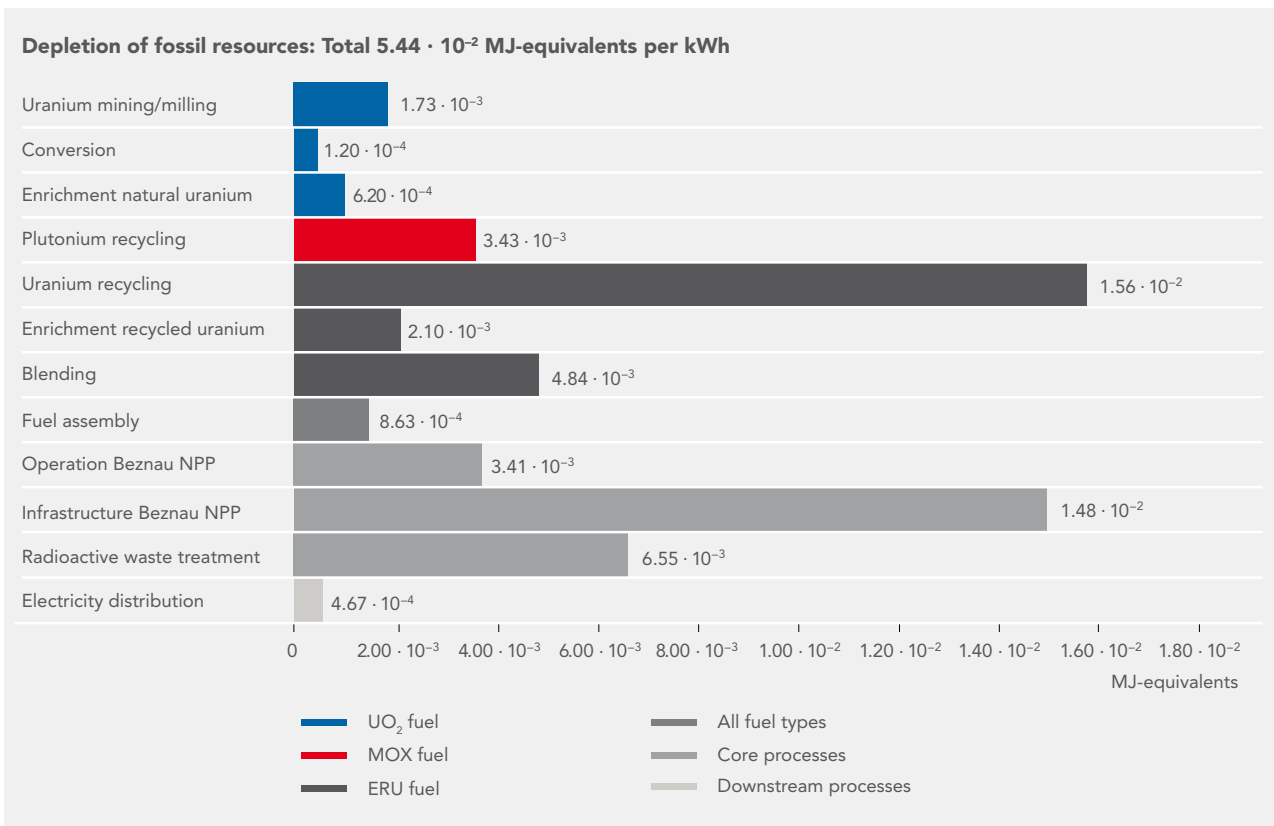
- Uranium mining and milling: Extraction of natural uranium (UO₂ fuel).
- Conversion: Conversion of natural uranium (UO₂ fuel).
- Enrichment: Enrichment of natural uranium (UO₂ fuel).
- Plutonium recycling: Reprocessing of spent nuclear fuel in the facilities Sellafield and La Hague for plutonium recovery (MOX fuel).
- Uranium recycling: Reprocessing of spent nuclear fuel in the facilities Sellafield, La Hague, SCC and MPA for uranium recovery (ERU fuel).
- Enrichment recycled uranium: Enrichment of reprocessed uranium from the facilities Sellafield/La Hague and SCC in Seversk (ERU fuel).
- Uranium blending: Recycling of scrap pellets and powder as well as blending of reprocessed and recycled uranium (ERU fuel).
- Fuel assembly: Assembly of fuel elements for all fuel types.
- Operation Beznau NPP: Operation of Beznau NPP as well as production of necessary auxiliary materials (chemicals, resins, etc.) and transport and storage casks for spent nuclear fuel.
- Infrastructure Beznau NPP: Construction and decommissioning of Beznau NPP.
- Radioactive waste treatment: Treatment of all radioactive waste in intermediate storage facilities as well as the construction and operation of planned final geological repositories.
- Electricity distribution: Transport of the electricity generated over the Axpo AG-owned distribution network.

3.3.1 Resource use

Use of fossil resources

Fossil resources are mainly used to generate process energy (steam, heat) and electricity. In the process chain of Beznau NPP, such fossil-based energy is either used directly as an energy supply for processes (e.g. reprocessing) or fossil-based energy was required for the manufacturing of materials essential to the process (e.g. steel, chemicals, cement). Resource use is expressed as gross calorific heating values.

The most important fossil resources used are coal (60%) and gas (20%). On the one hand, coal and gas are important energy resources to produce process energy in many Russian production facilities (MSZ, SCC, MPA and mining). On the other hand, coal is used for the energy-intensive production of materials like steel, cement and electronical equipment. Therefore, the infrastructure of Beznau NPP shows high contributions in this impact category.



All results are rounded

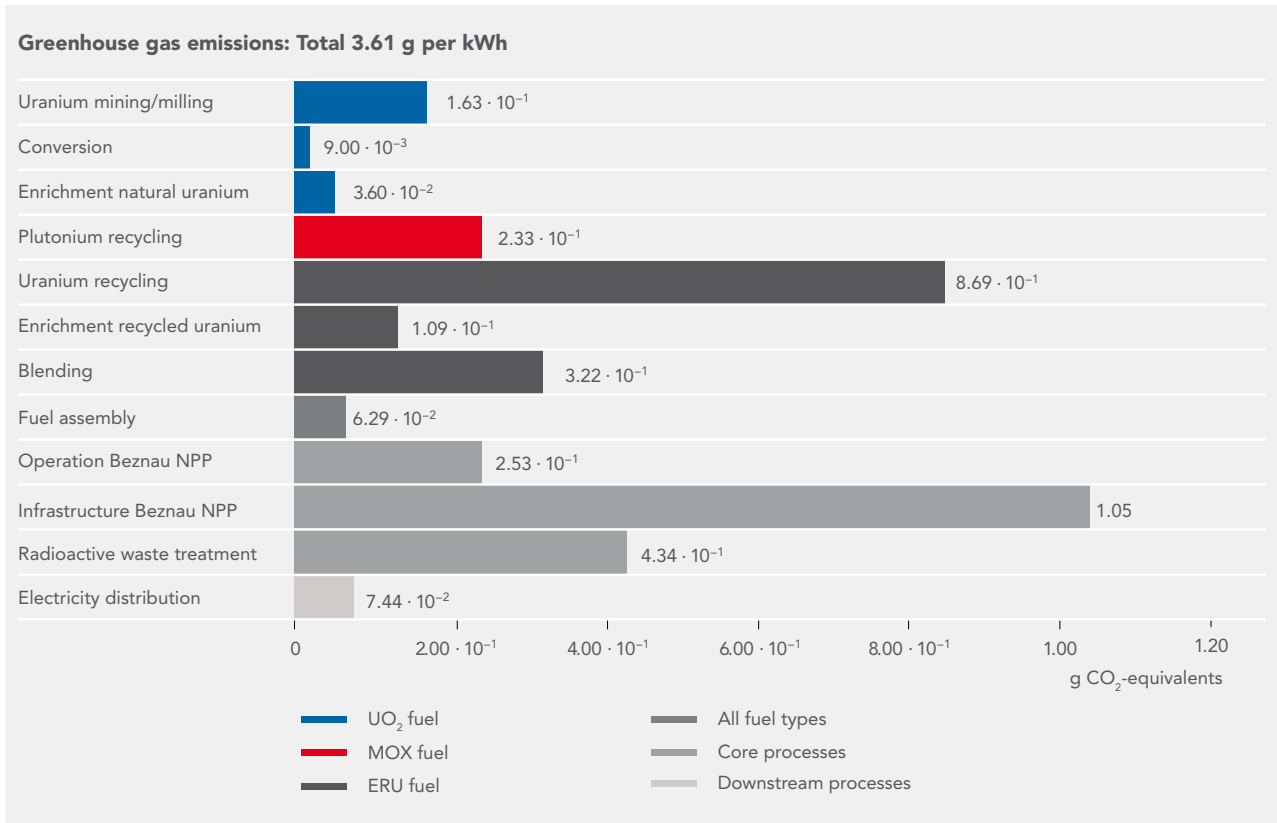
3 Environmental impact declaration

3.3.2 Emission of pollutants

Emission of greenhouse gases

Carbon dioxide is the dominating greenhouse gas, contributing 90%. In fuel manufacturing, greenhouse gas emissions arise from the energy-intensive reprocessing and recycling of scrap products and the blending

process. In addition, relatively high contributions from uranium mining occur because the process energy originates from the nearby lignite-fired power plant. Important sources of greenhouse gases in the NPP construction and waste disposal processes are the fabrication of steel, electronic components and cement.



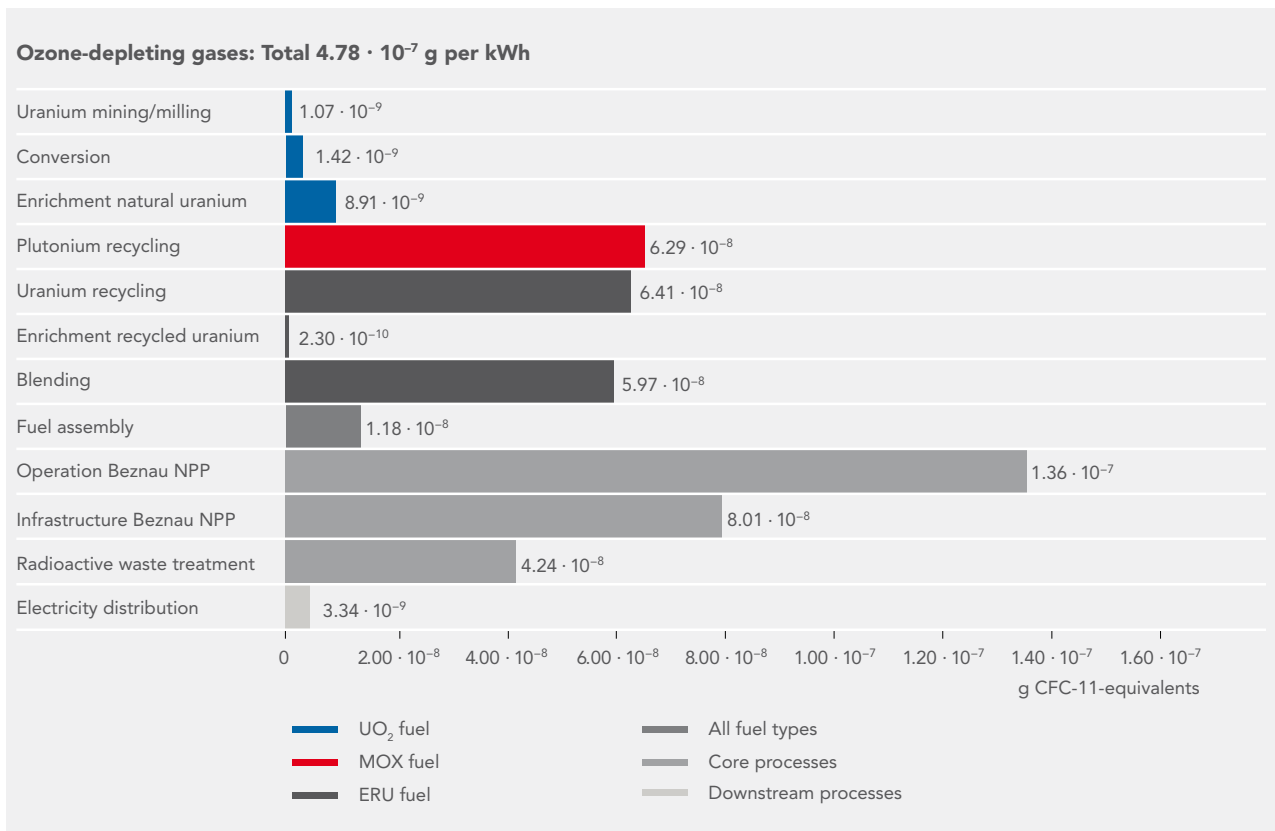
All results are rounded

Emission of ozone-depleting gases

Stratospheric ozone depletion is caused by the catalytic splitting of ozone by chlorine and bromine. The most significant sources of these halogen atoms in the stratosphere are the photodissociation of chlorofluorocarbons (CFCs) and of bromofluorocarbon compounds known as halons. These compounds rise up to the stratosphere after being emitted at the earth's surface.

In this study, the main substances contributing to ozone depletion are CFC-10 (42%), Halon 1211 (30%) and Halon 1301 (15%) emissions. Halon 1211 and Halon

1301 are important components in fire extinguishing systems installed in industrial production facilities such as reprocessing plants. These chemicals are also used in petrochemical production facilities. Therefore, energy intensive processes such as blending and the fabrication of steel, electronic components and cement contribute to Halon 1301 emissions. The relatively high contribution of the Beznau NPP operations to the overall ozone-depleting gases originates from CFC-10 emissions from the manufacturing of anionic resin and hypochloric acid as well as the use of refrigerants.



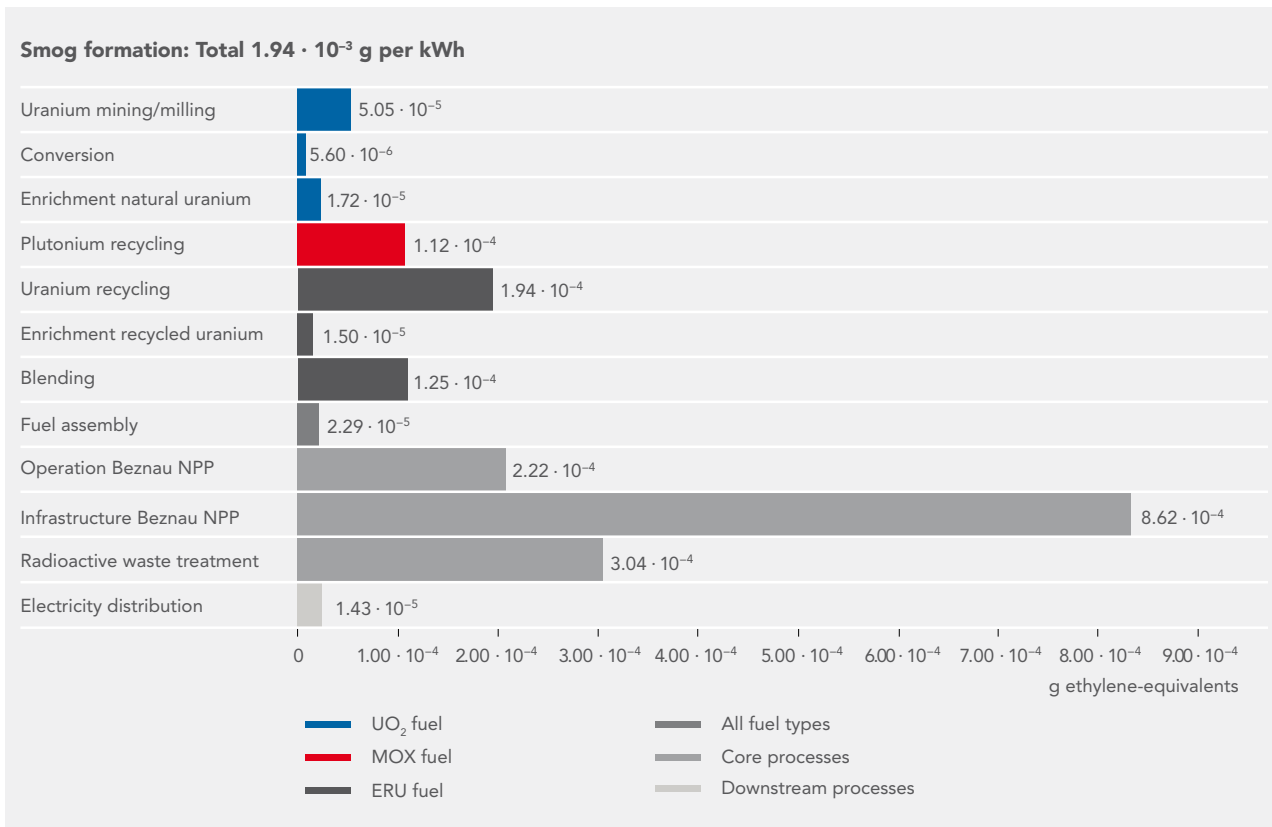
All results are rounded

3 Environmental impact declaration

Emission of substances contributing to formation of ground-level ozone (smog)

The combination of intensive solar irradiation, nitrogen oxides and various types of hydrocarbons and other chemicals in the air results in the formation of photochemical oxidants, mainly ground-level ozone. NMVOC emissions are the main contributor at 55%. Together with sulphur dioxide emissions (22%) and

carbon monoxide emissions (12%), these emissions account for to 90% of this impact category. The dominant sources are energy-intensive processes such as reprocessing and blending as well as the fabrication of steel, electronic compounds and cement. The operation of Beznau NPP shows relatively high contributions because the fabrication of transport and storage casks for spent nuclear fuel are included.

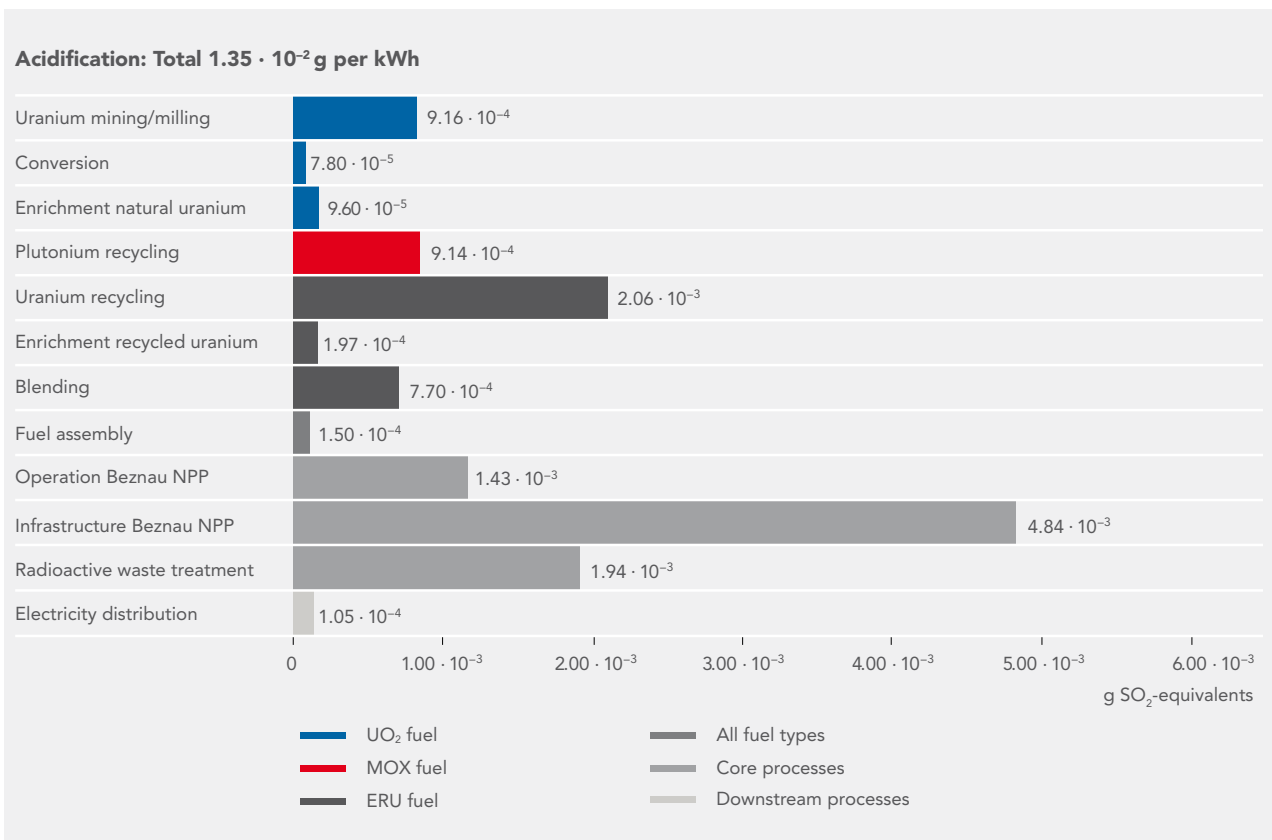


All results are rounded

Emission of acidifying substances

Acidification is understood as an increase in the concentration of H⁺ ions in the environment (soil, air and water). Sulphurous and nitrous compounds emitted by human activities oxidize in the air and produce sulphuric and nitric acid, which damage soil, water, organisms and buildings. In over-acidic soils, rainwater washes out nutrients more quickly (leaching) and toxic heavy metals are also more likely to be released from bedrock. The most important acidifying emissions in this study are sulphur dioxide (67%) and nitric oxides (23%). Regarding infrastructure the main sources of these emissions are the

production of clinker bricks and the consumption of diesel in construction machinery. Moreover, the combustion of coal leads to nitric oxide and sulphur dioxide emissions. Therefore, reprocessing in the Russian facilities SCC and MPA as well as uranium mining contribute to a large extent. Regarding uranium mining, large amounts of sulphuric acid are needed and its production causes sulphuric dioxide emissions.



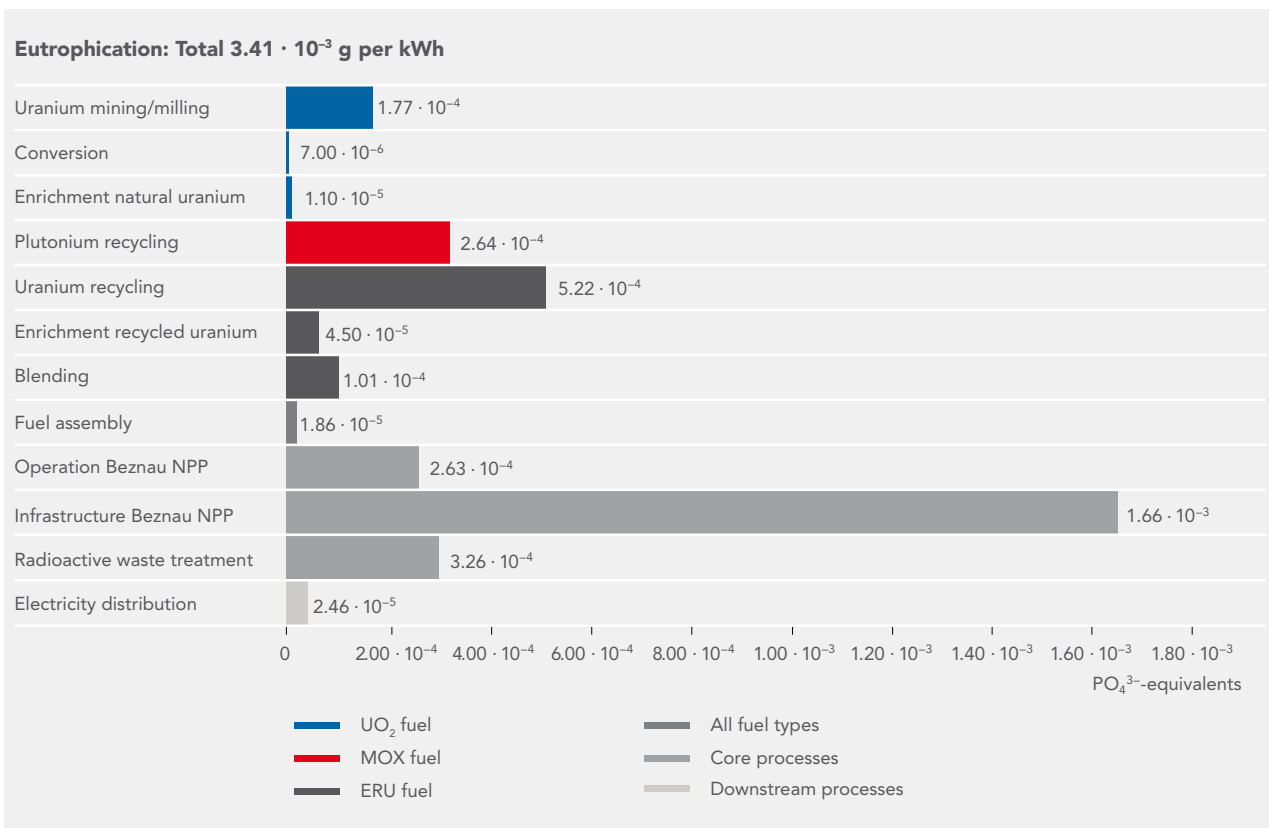
All results are rounded

3 Environmental impact declaration

Emission of eutrophying substances

Eutrophication is the name given to a process of over-fertilization of water bodies as a result of human activities. The release of phosphorous or nitrous compounds into natural waters results in a bloom of aquatic plant life. As the plants subsequently die, the oxygen supply in the water is used up in the process of decomposition creating anaerobic conditions that threaten fish populations.

The main eutrophying emissions in this study are phosphate emissions into water that contribute 53% to the total result. Airborne nitric oxide emissions are also important, contributing 30% to the total impact. On the one hand, these emissions originate from the combustion of fossil fuels. Therefore, the energy-intensive production of materials used for the construction of Beznau NPP dominates this impact category. On the other hand, such substances are also directly emitted, particularly from reprocessing facilities.

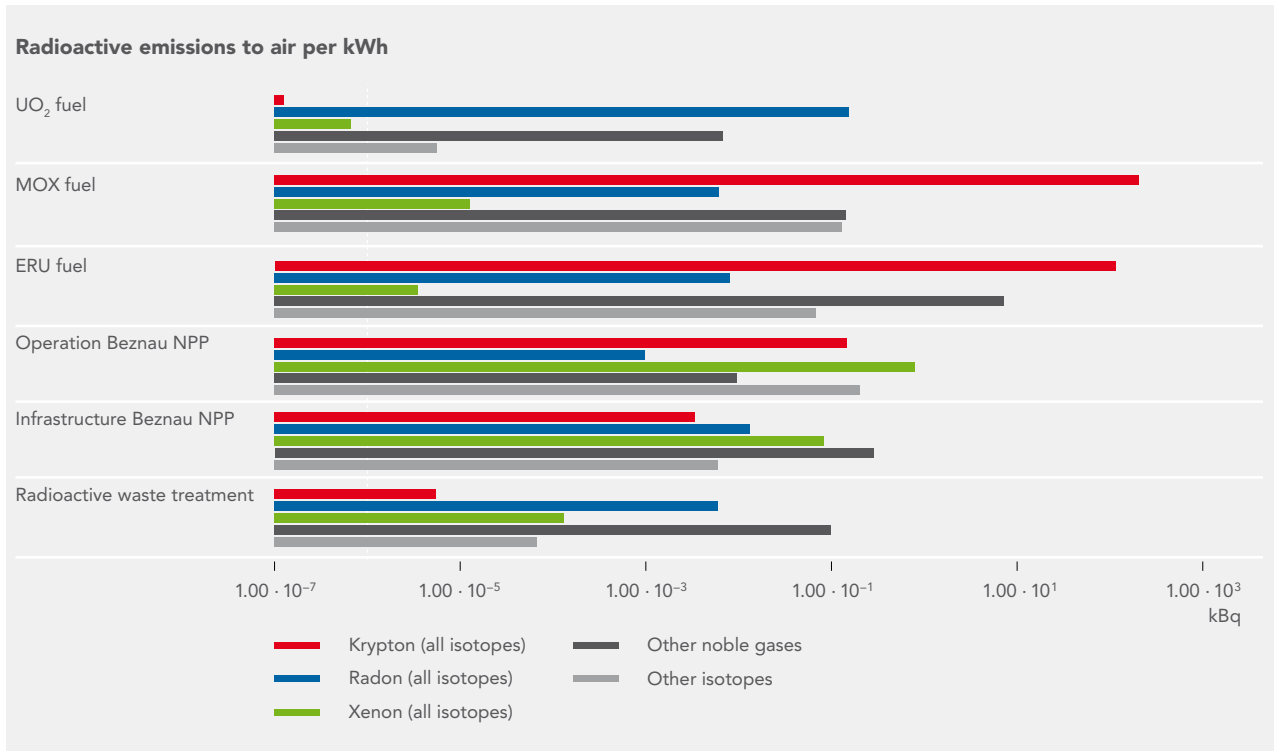


All results are rounded

Radioactive airborne emissions

The main source of radioactive airborne emissions are krypton or other noble gas emissions from reprocessing facilities. Reprocessing is an important production step for the fabrication of MOX and ERU fuel. Other radio-

active emissions arise to a lesser extent through Beznau NPP operation (xenon), uranium mining (radon) or electricity consumption in countries with nuclear power plants in the production mix.

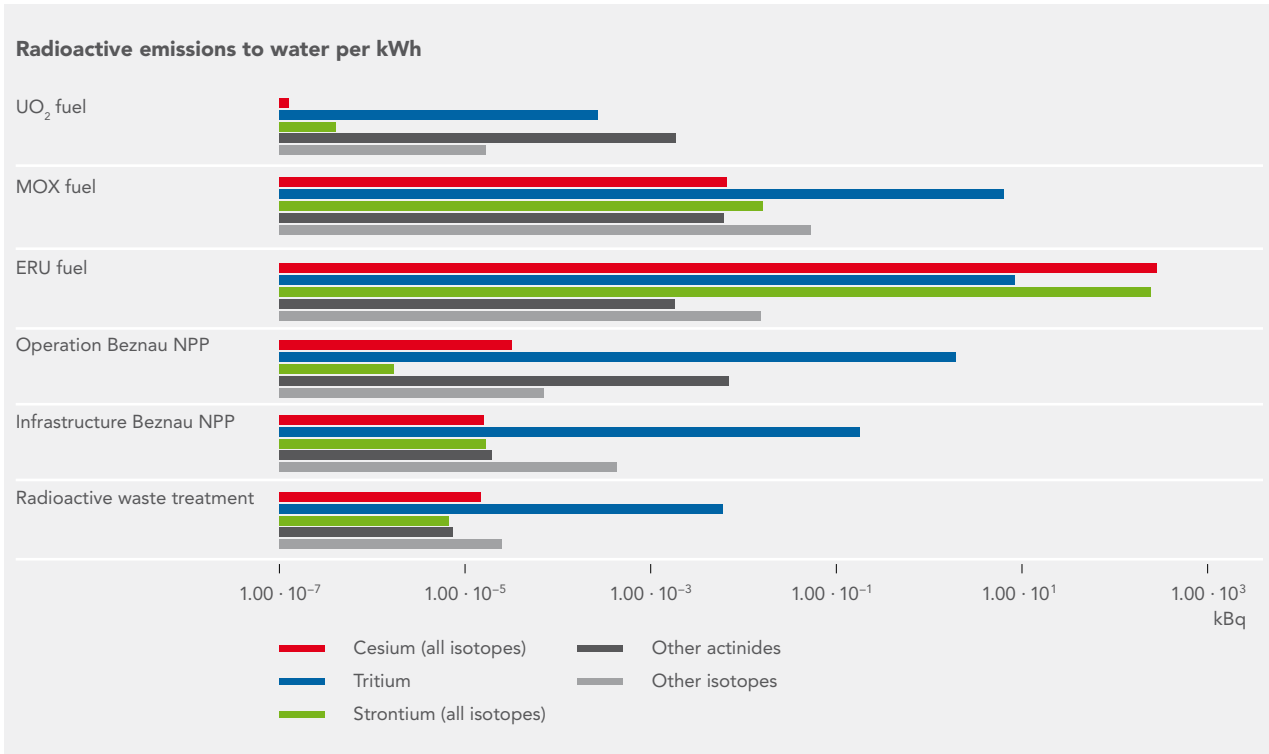


All results are rounded

3 Environmental impact declaration

Radioactive waterborne emissions

The main sources of radioactive waterborne emissions are strontium, cesium and tritium emissions from reprocessing facilities. Reprocessing is an important production step for the fabrication of MOX and ERU fuel.



All results are rounded

3.4 Uncertainty analysis

The purpose of the uncertainty analysis is to quantify the variability of the calculated life cycle assessment results. The variability results from the fact that the input and output parameters for the entire process chain (e.g. energy use, CO₂ emissions) are not precise values, but can fluctuate instead. To this end, probability distributions are assigned to the values of input and output parameters. Probability distributions were taken from the ETH ecoinvent database for all background processes¹⁰. Additional probability distributions were defined for the most important processes modeled in the present study. For example, the consumption of electricity and heat in the reprocessing facilities is dominant with regard to most of the life

cycle impact assessment categories. To define the variability of these parameters, data from all four reprocessing facilities involved in the reference year in the fuel cycle of Beznau NPP (Sellafeld, La Hague, SCC and MPA) were used.

In order to calculate the variability of the life cycle impact assessment results, repeated random sampling using a Monte Carlo algorithm was performed. The uncertainty range is defined in this study as the 95 % interval of the sampled distribution. Hence, the minimum value is determined as the 2.5th percentile and the maximum value as the 97.5th percentile. Results of the Monte Carlo analysis are given in the tables below.

1 kWh net electricity at Beznau NPP					
Environmental impact	Unit	Value calculated without uncertainty	Median (50 th percentile)	Minimum value (2.5 th percentile)	Maximum value (97.5 th percentile)
Greenhouse gases	g CO ₂ -equivalents	3.54	3.70	3.16	4.26
Ozone-depleting gases	g CFC-11-equivalents	4.75 · 10 ⁻⁷	4.97 · 10 ⁻⁷	3.50 · 10 ⁻⁷	7.47 · 10 ⁻⁷
Formation of ground-level ozone smog	g ethylene-equivalents	1.93 · 10 ⁻³	2.02 · 10 ⁻³	1.66 · 10 ⁻³	2.58 · 10 ⁻³
Acidifying substances	g SO ₂ -equivalents	1.34 · 10 ⁻²	1.43 · 10 ⁻²	1.17 · 10 ⁻²	1.95 · 10 ⁻²
Eutrophying substances	g PO ₄ ³⁻ -equivalents	3.39 · 10 ⁻³	3.31 · 10 ⁻³	1.89 · 10 ⁻³	7.78 · 10 ⁻³
Depletion of fossil resources	MJ-equivalents	5.40 · 10 ⁻²	5.62 · 10 ⁻²	4.63 · 10 ⁻²	6.72 · 10 ⁻²

All results are rounded

1 kWh net electricity at Axpo AG customer					
Environmental impact	Unit	Value calculated without uncertainty	Median (50 th percentile)	Minimum value (2.5 th percentile)	Maximum value (97.5 th percentile)
Greenhouse gases	g CO ₂ -equivalents	3.61	3.82	3.29	4.36
Ozone-depleting gases	g CFC-11-equivalents	4.78 · 10 ⁻⁷	5.02 · 10 ⁻⁷	3.54 · 10 ⁻⁷	7.45 · 10 ⁻⁷
Formation of ground-level ozone smog	g ethylene-equivalents	1.94 · 10 ⁻³	2.06 · 10 ⁻³	1.68 · 10 ⁻³	2.59 · 10 ⁻³
Acidifying substances	g SO ₂ -equivalents	1.35 · 10 ⁻²	1.47 · 10 ⁻²	1.18 · 10 ⁻²	2.11 · 10 ⁻²
Eutrophying substances	g PO ₄ ³⁻ -equivalents	3.41 · 10 ⁻³	3.62 · 10 ⁻³	1.91 · 10 ⁻³	1.06 · 10 ⁻²
Depletion of fossil resources	MJ-equivalents	5.45 · 10 ⁻²	5.75 · 10 ⁻²	4.78 · 10 ⁻²	6.87 · 10 ⁻²

All results are rounded

¹⁰ Ecoinvent report No 1, Overview and Methodology, published by the Swiss Centre for Life Cycle Inventories 2007

3 Environmental impact declaration

3.5 Dominance analysis and conclusions

Results of the various life cycle stages considering all environmental impact categories are shown in the table below:

Environmental impact category	Unit	Upstream processes			Core processes				Down-stream processes
		UO ₂ fuel	MOX fuel	ERU fuel	Operation NPP	Construction NPP	Dismantling NPP	Rad. waste treatment	Distr. in Axpo AG network
Greenhouse gases	CO ₂ -equivalents	5.9%	6.7%	37.4%	7.0%	22.6%	6.4%	12.0%	1.9%
Ozone-depleting gases	CFC-11-equivalents	2.4%	14.8%	28.0%	28.5%	13.3%	3.5%	8.9%	0.7%
Formation of ground-level ozone	ethylene-equivalents	3.8%	5.9%	18.2%	11.4%	35.3%	9.1%	15.6%	0.7%
Acidifying substances	SO ₂ -equivalents	8.2%	6.9%	23.3%	10.6%	29.1%	6.7%	14.4%	0.7%
Eutrophying substances	PO ₄ ³⁻ -equivalents	5.8%	7.8%	20.0%	7.7%	43.4%	5.1%	9.6%	0.7%
Depletion of fossil resources	MJ-equivalents	4.6%	6.5%	42.7%	6.1%	21.5%	5.7%	12.0%	0.9%

All results are rounded

The overall comparison of the life cycle stages shows that the environmental impacts of the production of ERU fuel, the construction of the NPP and the radioactive waste treatment dominate the results. These processes either require high amounts of electricity or thermal energy (reprocessing and blending) or materials are used that have an energyintensive production, such as electronic components or steel.

Furthermore, the following conclusions can be drawn from the dominance analysis:

- The operation of the Beznau NPP shows relatively high emissions of ozone-depleting substances due to the CFC-10 emissions from the manufacturing of anionic resin and hypochloric acid as well as the use of refrigerants.
- The production of MOX fuel shows a relatively high contribution with regard to ozone depletion. The reasons are direct emissions of halons at the relevant facilities.
- The use of fossil resources is particularly high for ERU fuel production. The reason is that coal is the most important energy source in Russian reprocessing facilities.
- The distribution of electricity has a low environmental impact as the transmission losses on a 110/50 kV network – as operated by Axpo AG – are low.

3.6 Differences versus the earlier version of the Beznau NPP EPD®

General changes:

Lower electricity production in the new reference year 2009/10

In the presented EPD® the reference time period is now defined as the year 2009/10. In the selected reference year the overall electricity production at Beznau NPP was lower due to an extended outage. This results in higher environmental impact allocated per kWh caused by infrastructure (construction and dismantling of Beznau NPP).

General changes:

Database update

A new version of the ETH ecoinvent database was used (version 2.2) for modelling background processes.

Changes in the UO₂ fuel fabrication process chain

The UO₂ natural uranium fuel used in Beznau NPP today was purchased at the mid/end of the 90s. The uranium originates from various sources. The origin of the UO₂ fuel relevant for this EPD® is different from the UO₂ fuel sources presented in the earlier version of the Beznau NPP EPD®. The natural uranium fuel, which was in the core in 2009/10, was purchased from Russian stockpiles. The uranium was extracted in the Russian Priargunsky mine and thereafter converted and enriched in Russian facilities. A detailed description of the current process chain is given in section 2.3.2.

Changes in the ERU fuel fabrication process chain

In-depth investigations in cooperation with suppliers and sub-suppliers have shown that the ERU fuel fabrication chain is more complex than presented in the earlier version of the Beznau NPP EPD®. Instead of blending the reprocessed uranium with highly enriched uranium arising from the disarmament of nuclear weapons, the new findings revealed that the required enrichment grade is achieved by enrichment of reprocessed uranium and blending with recycled scrap pellets and powder as well as with small quantities of medium-enriched, reprocessed uranium originating from various sources. A detailed description of the process chain is given in section 2.3.2.

4 Additional environmental information

4.1 Land use

The operation, construction and decommissioning of facilities involved in the electricity generation at Beznau NPP means it is not possible for the land to remain in its original natural state. In accordance with the PCR instructions, this land use is systematically classified and quantified using the land use classes (CLC) of the EU CORINE programme¹¹. The CORINE programme, launched by the European Commission in 1985, is the recording of land cover across Europe using a common nomenclature. The system has 44 classes and three hierarchical levels (e.g. use for industry, mining or forestry).

Land use is understood as a period of time for which the land is used in a particular category and is expressed as square metres multiplied by time (m²a). In the following tables the significant CLC classes are listed as well as the total land use for one year of electricity generation in Beznau NPP.

Considering the total land use, the construction and decommissioning (infrastructure) of Beznau NPP is the most important process, because during these processes the whole of the Beznau island became a construction site. Mining is the next most significant use of land because of the requirements for metals, gravel and sand used in construction. Forest area is also required because of the use of plywood in construction. The second most important land use process is the operation of the power plant, which requires the use of the island as an industrial area. The fuel manufacturing processes are of minor importance with regard to total land use.

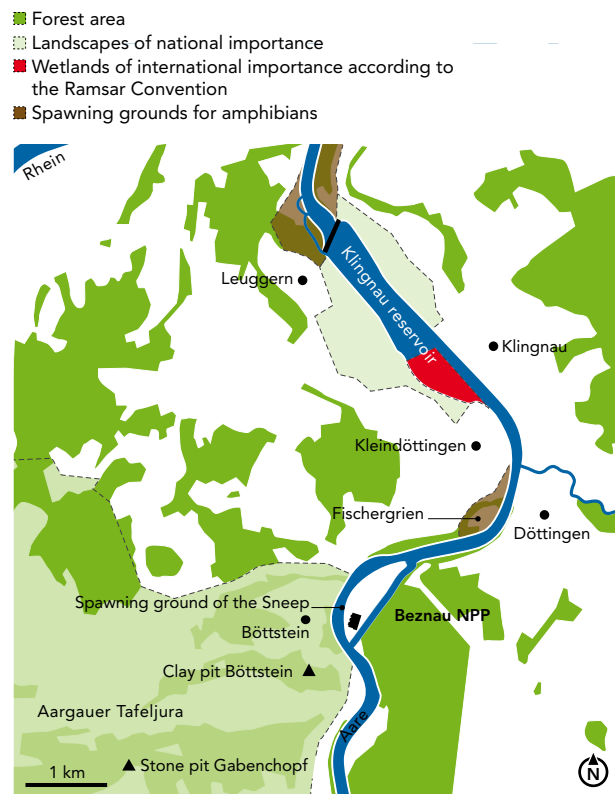
CLC Classes	Construction site		Industrial area		Forest area		Mineral extraction site		Water bodies		Other land types		Total land use	
CORINE-Code	133		121, 121a, 121b, 121c		31b, 31b1, 31b3		131		512a, 511a		211, 132, 132a, 222a, 333, 122			
Process	m ² a	%	m ² a	%	m ² a	%	m ² a	%	m ² a	%	m ² a	%	m ² a	%
UO ₂ fuel fabrication	4.9 · 10 ⁻⁹	0.0	6.2 · 10 ⁻⁷	1.0	1.1 · 10 ⁻⁶	0.4	3.5 · 10 ⁻⁶	40.7	3.6 · 10 ⁻⁷	4.4	1.9 · 10 ⁻⁵	47.4	2.4 · 10 ⁻⁵	5.8
MOX fuel fabrication	6.3 · 10 ⁻⁸	0.4	7.3 · 10 ⁻⁶	12.2	7.1 · 10 ⁻⁶	2.5	2.4 · 10 ⁻⁷	2.7	2.7 · 10 ⁻⁷	3.3	9.9 · 10 ⁻⁷	2.5	1.6 · 10 ⁻⁵	3.8
ERU fuel fabrication	1.1 · 10 ⁻⁷	0.7	8.2 · 10 ⁻⁶	13.6	3.8 · 10 ⁻⁵	13.2	3.2 · 10 ⁻⁷	3.7	1.5 · 10 ⁻⁶	18.5	4.8 · 10 ⁻⁶	12.0	5.3 · 10 ⁻⁵	12.6
Operation Beznau NPP	4.8 · 10 ⁻⁸	0.3	3.8 · 10 ⁻⁵	62.8	2.7 · 10 ⁻⁵	9.5	1.6 · 10 ⁻⁷	1.9	7.5 · 10 ⁻⁷	9.1	2.5 · 10 ⁻⁶	6.4	6.8 · 10 ⁻⁵	16.3
Infrastructure Beznau NPP	1.5 · 10 ⁻⁵	97.0	3.3 · 10 ⁻⁶	5.5	1.8 · 10 ⁻⁴	62.2	3.6 · 10 ⁻⁶	41.0	3.7 · 10 ⁻⁶	44.9	8.7 · 10 ⁻⁶	22.0	2.1 · 10 ⁻⁴	50.8
Radioactive waste treatment	1.2 · 10 ⁻⁷	0.8	2.3 · 10 ⁻⁶	3.9	3.3 · 10 ⁻⁵	11.4	8.0 · 10 ⁻⁷	9.2	1.6 · 10 ⁻⁶	19.0	3.5 · 10 ⁻⁶	8.9	4.1 · 10 ⁻⁵	9.8
Electricity distribution	1.2 · 10 ⁻⁷	0.8	4.8 · 10 ⁻⁷	0.8	2.3 · 10 ⁻⁶	0.8	6.9 · 10 ⁻⁸	0.8	6.5 · 10 ⁻⁸	0.8	3.1 · 10 ⁻⁷	0.8	3.3 · 10 ⁻⁶	0.8
Total per kWh at customer of Axpo AG	1.6 · 10 ⁻⁵	100	6.0 · 10 ⁻⁵	100	2.9 · 10 ⁻⁴	100	8.7 · 10 ⁻⁶	100	8.2 · 10 ⁻⁶	100	4.0 · 10 ⁻⁵	100	4.2 · 10 ⁻⁴	100

¹¹ CORINE: Coordination of information on the environment: <http://terrestrial.eionet.europa.eu/CLC2000/classes>

4.2 Biodiversity

Electricity generation has an impact on biodiversity due to the occupation of land and the associated habitat reduction (land use).

Beznau NPP is situated in the Aare valley, a rural region with a high percentage of forest areas, mainly beech grove forest. Several nature reserves of national and international importance are located in the immediate vicinity of the power plant. For example, there are spawning grounds for amphibians (a clay pit, a stone pit and a riverine zone¹²) flood plains¹³, landscapes of national importance¹⁴ and wetlands of international importance according to the "Ramsar" Convention¹⁵. An overview on the locations of those spots is given in the map on the right.



Nature reserves of national and international importance are located in the immediate vicinity of the power plant. Source: Swiss Federal Office for the Environment, www.ecogis.admin.ch

The island on which Beznau NPP is located is classified as an industrial zone. It is covered to a large extent by the power plant buildings and the transformer station. Before Beznau NPP was built, the island was used for agriculture. Only small areas of the original flood plains remain along the banks of the river and at the head of the water conduit channel. These areas still provide important habitats to insects, amphibians and birds, such as the endangered species Natterjack toad or Sandpiper. A further important habitat is a gravel land-fill located between the conduit channel and the railway tracks. This anthropogenic habitat shelters many vulnerable insects, particularly crickets and grasshoppers, such as the critically endangered Tuerk's Grasshopper. The course of the Aare river together with the artificial conduit channel as well as the adjacent forest present a multifaceted habitat for birds, particularly ducks, king-

fisher, falcons and woodpeckers. Regarding the fish fauna, 28 species were found in the area around the power plant (a total of 41 species are known to exist in Swiss central plateau rivers¹⁶). Of particular importance is the fact that the critically endangered Sneep uses the natural bed of the river Aare as spawning ground in the area where the cooling water from Beznau NPP is returned. The terrestrial and aquatic biodiversity in the above-mentioned habitats has been comprehensively investigated. The most important and valuable species found in the immediate vicinity of Beznau NPP are summarized in the table below. The risk of extinction of individual species is characterized based on the national Red Lists published by the Swiss Federal Office for the Environment¹⁷. Red Lists, which highlight the species in need of conservation action, are an important instrument in species and habitat protection efforts.

¹² Inventory of spawning grounds for amphibians of national importance (Bundesinventar der Amphibienlaichgebiete von nationaler Bedeutung), objects AG 120 (riverine zone "Fischergrien"), AG 117 (clay pit "Böttstein"), AG 830 (stone pit "Gabenchof")

¹³ Inventory of flood plain areas of national importance (Bundesinventar der Auengebiete von nationaler Bedeutung), object 36 ("Auenreste Klingnauer Stausee")

¹⁴ Inventory of landscapes and natural monuments of national importance (Bundesinventar der Landschaften und Naturdenkmäler von nationaler Bedeutung), objects 1108 ("Aargauer Tafeljura") and 1109 ("Aarelandschaft bei Klingnau")

¹⁵ "Klingnauer Stausee" added in 1991 to the list of wetlands of international importance according to the Ramsar Convention on Wetlands, <http://www.ramsar.org>

¹⁶ Swiss Federal Office for the Environment, Biodiversity Monitoring Switzerland, Species Diversity at National and Regional Level 2006, Indicator Z3, <http://www.biodiversitymonitoring.ch>

¹⁷ <http://www.bafu.admin.ch/artenvielfalt/>

4 Additional environmental information

Red Lists

- show which species are vulnerable, endangered or (presumed) extinct;
- document trends for species diversity in the wild (for this purpose, they are periodically revised);
- highlight species at particular risk, for which urgent action is required;
- also indicate conservation measures required to protect threatened species.

Group	Scientific name	English name	Red-list classification
Birds	<i>Mergus merganser</i>	Common Merganser	Vulnerable
	<i>Falco tinnunculus</i>	Common Kestrel	Potentially threatened
	<i>Falco subbuteo</i>	Eurasian Hobby	Potentially threatened
	<i>Falco peregrinus</i>	Peregrine Falcon	Vulnerable
	<i>Cuculus canorus</i>	Common Cuckoo	Potentially threatened
	<i>Picus canus</i>	Grey-headed Woodpecker	Vulnerable
	<i>Dendrocopos medius</i>	Middle Spotted Woodpecker	Vulnerable
	<i>Actitis hypoleucos</i>	Common Sandpiper	Endangered
	<i>Charadrius dubius</i>	Little Ringed Plover	Vulnerable
	<i>Bucephala clangula</i>	Common Goldeneye	Vulnerable
	<i>Aythya ferina</i>	Common Pochard	Vulnerable
	<i>Aythya fuligula</i>	Tufted Duck	Potentially threatened
	<i>Anas crecca</i>	Common Teal	Vulnerable
	<i>Alcedo atthis</i>	Common Kingfisher	Vulnerable
	Amphibians	<i>Hyla arborea</i>	Common Tree Frog
<i>Bufo calamita</i>		Natterjack	Endangered
<i>Triturus cristatus</i>		Warty Newt	Endangered
Insects	<i>Tetrix tuerki</i>	Tuerk's Grasshopper	Critically endangered
	<i>Chorthippus pullus</i>	Gravel Grasshopper	Potentially threatened
	<i>Phaneroptera falcata</i>	Sickle-bearing Bush-cricket	Vulnerable
	<i>Platycleis albopunctata</i>	Grey Bush-cricket	Potentially threatened
	<i>Metrioptera bicolor</i>	Two-coloured Bush-cricket	Vulnerable
	<i>Sphingonotus caeruleus</i>	Slender Blue-winged	Potentially threatened
Fish and cyclostomata	<i>Salmo trutta fario</i>	Brown Trout	Potentially threatened
	<i>Thymallus thymallus</i>	Grayling	Vulnerable
	<i>Coregonus</i> species	White Fish	Potentially threatened
	<i>Abramis bjoerkna</i>	White Bream	Potentially threatened
	<i>Chondrostoma nasus</i>	Sneep	Critically endangered
	<i>Alburnoides bipunctatus</i>	Riffle Minnow	Vulnerable
	<i>Anguilla anguilla</i>	European Eel	Vulnerable
	<i>Cottus gobio</i>	Bullhead	Potentially threatened
	<i>Gasterosteus aculeatus</i>	Stickleback	Potentially threatened

Critically endangered (CR)

A species is Critically Endangered when it is facing an extremely high risk of extinction in the wild within the next three generations.

Endangered (EN)

A species is Endangered when it is facing a very high risk of extinction in the wild.

Vulnerable (VU)

A species is Vulnerable when it is facing a high risk of extinction in the wild.

Near threatened (NT)

A species is Near threatened when it does not currently qualify for CR, EN or VU status, but is likely to qualify for a "threatened" category in the near future. Potentially threatened species are not included in the Red Lists.

4.3 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).

4.3.1 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 complete nuclear fuel cycle. For comparison, the maximum individual dose for individuals engaged in radiation work is 20 mSv per year according to the regulatory limit set in the Swiss radiation protection act (Strahlenschutzverordnung SR 814.501). All processes under study adhered to the relevant regulatory limits.

Step	Company, facility	Average annual individual dose to personnel ¹⁸ [mSv per year]	Year of data collection
Uranium mining	Rosatom, Priargunsky Mining Combine	ca. 10	2000–2010
Conversion	Rosatom, Chepetsk Mechanical Plant/Angarsk Electrolyze Chemical Combine (data from Malvési/Pierrelatte facilities)	0.6	2006
Enrichment	Rosatom, Ural Electrochemical Integrated Plant/Siberian Chemical Combine /Electrochemical Plant/Angarsk Electrolyze Chemical Combine	ca. 0.5	Several years of monitoring
Reprocessing	Cogema, La Hague	0.1	2008
	Sellafield Ltd., Sellafield	1.0	2003
	Rosatom, Siberian Chemical Combine	1–2	Several years of monitoring
	Rosatom, Mayak PA	2–3	Several years of monitoring
Uranium blending	Rosatom, Mashinostroitelny Zavod	1.7	2007
UO ₂ fuel assembly	AREVA, Lingen; MSZ, Elektrostal (data from Romans facility)	0.4	2005
MOX fuel assembly	AREVA, Dessel; AREVA, Cadarache; Sellafield Ltd., Sellafield SMP (data from Melox facility)	1.7	2005
Electricity generation	Axpo AG, Beznau NPP	0.5	2009
Waste treatment	ZWILAG, interim storage	0.2	2009
	Nagra, both types of deep repositories ¹⁹	< 0.1	1994

¹⁸ Data was obtained from environmental reports, radiation safety reports or expert presentations and judgements in case no published data was available. In absence of occupational doses data for some facilities, data from facilities that employ an equivalent technology has instead been presented.

¹⁹ Deep repositories are not yet built. The presented value was calculated by Nagra for the formerly planned LLW repository at "Wellenberg" site. A comparable dose is expected for a potential SF/HLW/ILW repository in the region of Zürcher Weinland with opalinus clay as host rock.

4 Additional environmental information

4.3.2 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. These emissions may influence in particular people living in the vicinity of the facilities (local effect). In Switzerland, the maximum individual dose for individuals not engaged in radiation work is 1 mSv per year²⁰. All the processes under study respected the relevant regulatory limits. The natural radiation in Switzerland leads to an average dose of about 4 mSv per person per year²¹.

Uranium mining

Uranium mining activities the environment. Such emissions may be a source of radiation exposure to members of the public when residents live in immediate vicinity of mining areas. Regarding the Priargunsky underground mine, main sources of radon emissions are the ventilation shafts on the surface. During recent years airborne radon emissions were within regulatory limits²².

Conversion, enrichment, UO₂ fuel assembly

The doses to third parties arising from conversion, enrichment and UO₂ fuel assembly facilities are negligible.

Reprocessing

The radiation exposure of members of the public living in the vicinity of the **Sellafield** site has been quantified for many years using a comprehensive monitoring system. All emissions were within regulatory limits²³.

The radiation exposure of members of the public living in the vicinity of the **La Hague** site has been quantified for many years using a comprehensive monitoring system. All emissions were within regulatory limits²⁴.

As at sites in the west, radiation exposure in the environs of the SCC facility in **Seversk** is permanently monitored. Emission data is available online²⁵. During recent years all emissions were within regulatory limits²⁶.

The surroundings of **Mayak PA in Ozersk** are also monitored using several hundred measuring points. Emission data is available online²⁵. The dose to the population inhabiting the monitored area of 1300 km² is reported to be between 0.07 to 0.22 mSv per year, which is below the regulatory limit of 1 mSv per year. The dose to the population living in the nearby city of Ozersk is 0.12 mSv per year.

Typically, over 95% of the radiation exposure originates from previous incidents – during normal operations and accidents – that took place between 1950 and 1970²⁷. During the Cold War, those working at Mayak PA were under considerable time pressure to produce weapons-grade plutonium. The last of the site's seven reactors was shut down in 1990.

Since 1970, several improvement measures have been implemented and regulatory limits have been set for the discharge of radioactive materials into the environment. Today, no radioactive materials are discharged into open waters anymore. Further measures for improvement and remediation of contaminated sites are implemented continuously. Funding of such measures comes from the facility's own financial resources, which are generated partly from transactions with foreign customers as well as from government programme focusing on remediation of nuclear legacy.

MOX fuel assembly

The doses to third parties arising from MOX fuel assembly facilities are negligible²⁸.

Uranium blending

The doses to third parties arising from uranium blending are negligible.

Beznau NPP

In 2009, the release of radioactive materials into the environment via waste water and exhaust air from Beznau NPP was considerably less than legal limits. The annual dose to individuals living in the immediate vicinity of Beznau NPP was calculated by the Swiss Federal Nuclear Safety Inspectorate (ENSI) using conservative, meaning unfavourable, assumptions. The calculated doses were 0.003 mSv for adults, 0.004 mSv for ten-year-old children and 0.006 mSv for small children. All values are significantly below the regulatory limit of 1 mSv per year²⁹.

Interim storage

ENSI calculated dose values for individuals living in the immediate vicinity of the interim storage facility (ZWILAG) using conservative, meaning unfavourable, assumptions. The values for adults, ten-year-old children and small children are all below 0.001 mSv²⁹.

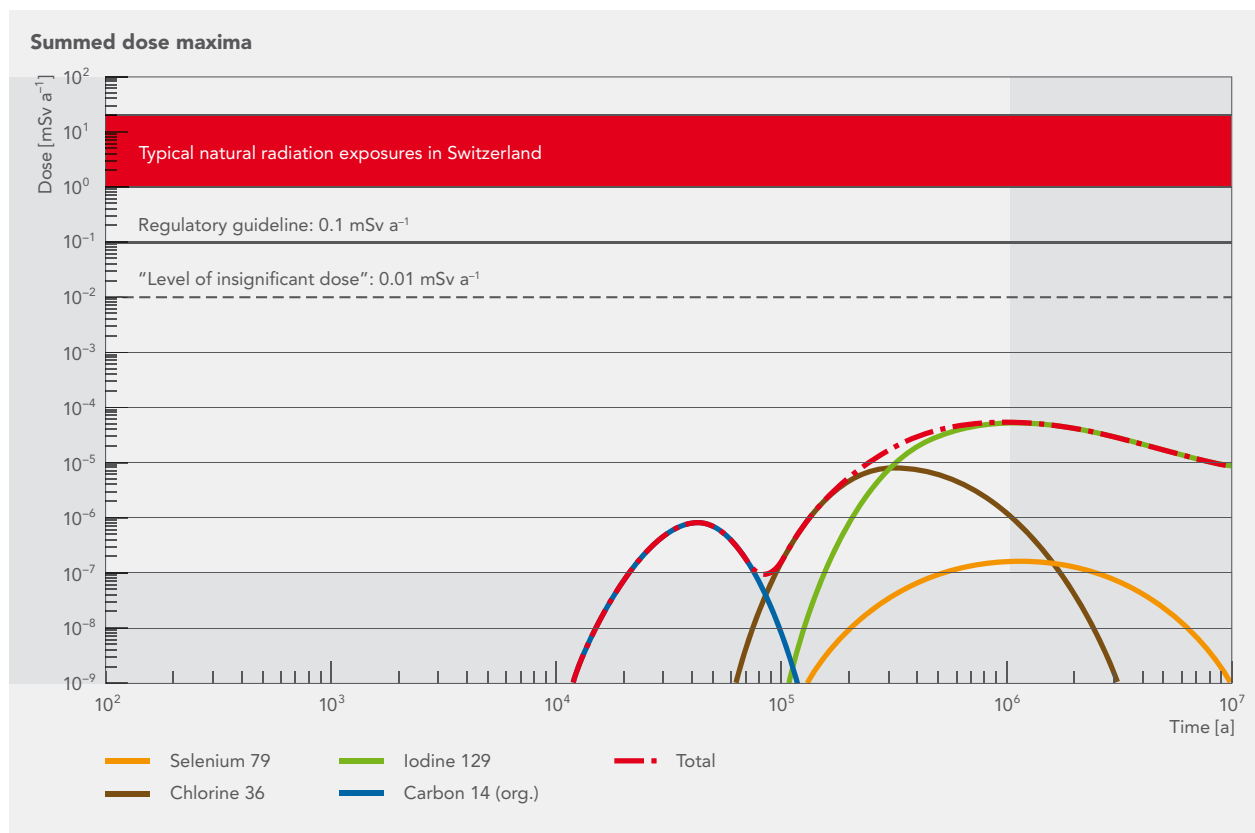
Deep repositories for nuclear waste

The Swiss regulatory guideline ENSI-R-21 stipulates that the release of radionuclides from a sealed repository subsequent upon processes and events reasonably

expected to happen shall at no time give rise to individual doses which exceed 0.1 mSv per year. This is even more restrictive than the general limit stipulated in the Swiss radiation protection act. For both repositories that are foreseen in Switzerland, Nagra calculated a Reference Case that represents future evolution of the repository system which is most consistent with the current understanding.

Results of the Reference Case calculated for the formerly planned LLW repository at "Wellenberg" site show a

maximum dose of $1.8 \cdot 10^{-3}$ mSv per year, which occurs at about a thousand years. The annual dose for the Reference Case of the proposed SF/HLW/ILW repository in the region of Zürcher Weinland, summed over all waste groups, is shown below. The maximum dose, which is due to Iodine 129 from spent fuel, is $4.8 \cdot 10^{-5}$ mSv per year. It occurs at about one million years and is more than three orders of magnitude below the Swiss regulatory guideline and more than two orders of magnitude below the "level of insignificant dose" set at 0.01 mSv per year by the IAEA³⁰.



Source: Nagra Safety Report Project Opalinus Clay (Nagra Technical Report NTB 02-05)

²⁰ Limit according to Swiss Radiation Protection Act

²¹ Report "Strahlenschutz und Überwachung der Radioaktivität in der Schweiz, Ergebnisse 2010", Swiss Federal Office of Public Health, www.bag.admin.ch

²² Rosatom, Env. report 2008 "Priargunsky Industrial Mining and Chemical Union" <http://rosatom.ru/wps/wcm/connect/rosatom/rosatomsite/partnership/environmentalmanagement/>. There is no confirmed information available about compliance with limit values during the operation in the 90s.

²³ Sellafeld Ltd., Env. report 2009, "Monitoring our Environment; Discharges and Monitoring in the United Kingdom."

²⁴ AREVA NC, Env. report La Hague 2008, "Rapport environnemental, social et sociétal"

²⁵ www.russianatom.ru

²⁶ Rosatom, Business report SCC 2009, www.atomsib.ru

²⁷ Rosatom, Env. report PA Mayak 2008, <http://rosatom.ru/wps/wcm/connect/rosatom/rosatomsite/partnership/environmentalmanagement/>

²⁸ AREVA, Env. report Melox 2005 "Rapport environnemental, social et sociétal"

²⁹ Source: ENSI, Aufsichtsbericht zur nuklearen Sicherheit in den Schweizer Kernanlagen 2009

³⁰ Nagra Technical Report 02-05, project Opalinus Clay, Safety Report (Entsorgungsnachweis), www.nagra.ch

4 Additional environmental information

4.4 Risks

Uranium mining

The main environmental risk from uranium mining is dam bursting of tailing ponds with subsequent uncontrolled leakage of chemically toxic and partly low-active liquids into the environment.

Conversion

The main risks of the conversion process arise due to the use of hazardous chemicals. In particular, hydrogen fluoride is highly toxic, volatile (risk of inhalation) and corrosive (R and S phrases: R26/27/28-35, S1/2-7/8-26-36/37-45). Furthermore, if hydrochloric acid comes into contact with ammonia, which is also used in the conversion process, toxic ammonium chloride can result.

Enrichment

The main risk of the enrichment process originates from the chemo-toxic properties of uranium hexafluoride (R and S phrases: R26/28-33-51/53 S1/2-20/21-36/37-45-61). The reaction of uranium hexafluoride with air humidity leads to corrosive hydrogen fluoride. Storage cylinders must therefore be hermetically sealed and regularly inspected for evidence of corrosion and leakage. To minimize risks during transport and storage, the cylinders are additionally kept under sub-atmospheric pressure in order to avoid the leakage of uranium hexafluoride. For storage, uranium hexafluoride is increasingly transferred to chemically stable forms (U_3O_8 or UO_3).

Reprocessing, fuel assembly and uranium blending

Risks associated with the reprocessing, fuel assembly and blending processes are the handling of radioactive materials and hazardous chemicals in terms of toxicity and flammability (solvents and reactive chemicals). The facilities therefore use multi-barrier systems to prevent the release of hazardous substances. The primary barriers include metal containers, gloveboxes/enclosures (reprocessing, MOX fuel assembly and blending process) and processing equipment (tanks and piping). The secondary barriers include the building structure and the heating, ventilation and cooling system. Filtration and scrubbing are used for exhausts from processes with potential for radionuclide releases. Additionally, exhaust air is permanently monitored.

Beznau NPP

Protection of the population, staff and the environment from ionizing radiation – and therefore the safety of the

nuclear installations – have absolute priority. The combination of technical safety barriers, redundancy of operational systems, safety culture and the permanent monitoring by authorities incorporates maximum protection against technical failures as well as external events such as fire, airplane crashes and earthquakes.

Technical safety barriers

Several technical barriers prevent the radioactivity produced by nuclear fission and the fission products from finding a path into the environment:

- The fuel: The fuel pellets are sintered to high chemical and mechanical stability with a melting point of 2800° C.
- Fuel tubes: The fuel pellets are encapsulated in gastight tubes of zirconium alloy, which are highly resistant to corrosion.
- Reactor pressure vessel: The fuel elements are sealed in the reactor pressure vessel made of steel.
- Biological shield: The shielding concrete with a thickness of 3 m prevents the escape of radioactive radiation.
- Containment: The primary systems are situated in double-walled containment buildings. They are surrounded by a gas-tight welded steel containment. It is 30 mm thick. The steel containment is completely enclosed by a concrete containment, which is 90 cm thick. The air from the cavity is sucked into the interior of the steel liner where a vacuum is created. This prevents air from accidentally escaping to the outside.

Operational safety

Particular attention is paid to operational safety – not only during normal operation, but especially if extraordinary events occur, such as unforeseeable defects in components of the plant. For this reason the vital components of the plant, such as control system or alarm devices, are provided in duplicate or in even higher numbers. Should any one of them fail, there is always a second or third available to take over its duties.

Ensure the cooling

In case the power plant is shut down or an incident occurs, the cooling of the reactor is essential to remove the decay heat. For the operation of the cooling systems primarily water and electricity to power the pumps in the cooling circuit system are needed. The following systems ensure the cooling in Beznau NPP:

- Beznau NPP has two identical, bunkered emergency buildings, which are protected against earthquakes,

sabotage, flooding and radiation. Each building includes an emergency control centre, which ensures the safe operation of the plant in the state of shut-down. In addition, the buildings are equipped with an emergency diesel, a feed pump and a bunkered groundwater well. The groundwater well provides water supply, even if the water of the river Aare is contaminated.

- Boric acid solution for the supply of the primary cooling system in order to stop the chain reaction in the reactor is stored in a bunkered bearing. It consists of two tanks, each with 1200 m³ boric acid solution.
- Reactor pressure vessel: The fuel elements are sealed in the reactor pressure vessel made of steel.
- Also in a bunkered building a tank filled with groundwater and a feed pump is installed to supply the secondary cooling system.
- In case of pressure rise in the containment, Beznau NPP is equipped with a filtered pressure relief system. The air is released directly into the environment.
- Catalytic H₂ recombiners are installed in the containment of Beznau NPP, which convert potentially explosive hydrogen into water. No electricity is needed for this operation.
- The cooling systems are equipped with numerous pre-installed fire nozzles. This allows in case of an incident the feeding of water using standard fire pumps.

Safety culture (Axpo Nuclear Safety Charter)

The Nuclear Safety Charter is a voluntary commitment by Axpo to continuous safety improvements through implementation of measures relating to the operation of nuclear installations and radiation protection. The starting point is compliance with the statutory requirements. The charter is the basis for all staff in the fulfilment of their daily tasks, including the company management. The Axpo Safety Charter can be accessed under <http://www.axpo.ch>.

Safety culture (Safety Controlling unit in Beznau NPP)

A special organisation unit, referred to as Safety Controlling, monitors and assesses nuclear safety in Beznau NPP, independent of the operational business and line organisations. The Safety Controlling unit directly reports to the plant manager and the Executive Board on the status of the safety systems and their assessment. In addition, the Safety Controlling unit is available to all staff as an ombudsman service for safety issues.

Third party verification

The nuclear power industry is closely regulated by several laws and guidelines. National and international authorities carry out nuclear safety checks on a regular basis. The most important national authority is the Swiss Federal Nuclear Safety Inspectorate (ENSI), which monitors ionizing radiation in the surroundings of Beznau NPP and legal compliance. On an international level, the operation of Beznau NPP complies with international nuclear safety standards specified by the IAEA Safety Convention. In addition, safety in Beznau NPP is analysed and appraised by WANO³¹ on a regular basis. WANO is a global association of nuclear power plant operators for mutual exchange of information as well as inspections.

Interim storage

Both the vitrified mass of highly active waste as well as spent fuel elements undergo interim storage in solid steel casks weighing up to 150 tonnes, which simultaneously serve as transportation casks. These casks protect the waste and fuel elements against all plausible types of damage such as aircraft crashes, earthquakes, fire and other ingressive events. Only those cask types licensed by the respective authorities may be used. The transportation and storage casks are monitored continuously for leaks. Additionally, the storage halls are checked continually for radioactivity.

Deep repositories for nuclear waste

The disposal system that is selected must ensure that the waste, including fissile materials, is secure and that human beings and the environment are protected from the hazardous effects of radiation. The safety concept consists of a barrier system that performs a number of functions relevant to long-term security and safety. These safety functions are described by Nagra as follows:

Isolation from the human environment

The safety and security of the waste, including fissile material, is ensured by placing it in a repository located deep underground, with all access routes backfilled and sealed, thus isolating it from the human environment and reducing the likelihood of any unwanted intrusion and misappropriation of the materials. Furthermore, these sites are chosen because there are no currently recognised and economically viable natural resources nor conceivable future infrastructure projects that might lead to inadvertent human intrusion into the site. Finally, appropriate siting ensures that the repository will not be prone to disruptive events or processes unfavourable to long-term stability.

³¹ WANO: World Association of Nuclear Operators. <http://www.wano.org>

4 Additional environmental information

Long-term confinement and radioactive decay within the disposal system

Much of the initial radioactivity decays while the waste is totally contained within the primary containers, particularly in the case of SF and HLW, for which the high-integrity steel canisters are expected to remain unbreached for at least 10000 years. Even in the case of canisters being breached, the stability of the SF and HLW waste forms in the expected environment, the slowness of groundwater flow and a range of geochemical immobilisation and retardation processes ensure that radionuclides continue to be largely confined within the engineered barrier system and the immediately surrounding rock, where further radioactive decay can take place safely.

More detailed information on the nuclear waste management in Switzerland is available at <http://www.nagra.ch>.

4.5 Electromagnetic fields

The term "electromagnetic field" (EMF) refers to the lower frequency range of the electromagnetic spectrum (0 to 300 GHz). 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. 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). The higher the current, the greater the strength of the magnetic field. One of the main characteristics of an EMF is its frequency or corresponding wavelength. Fields of different frequencies interact with the human body in different ways.

The main source of electromagnetic fields in Beznau NPP is the conversion of kinetic energy into electricity in the generator. The two generators running at 3000 rpm are mounted on the same shaft as the turbines. At this high speed their magnetic fields induce a voltage in the stator windings. The voltage generated is 15.5 kV and the current is approximately 8500 ampere (load-dependent) and a frequency of 50 Hertz (Hz). This frequency is classed as extremely low frequency (30 to 300 Hz) – the wavelengths in this band are over 100 km.

Various regulatory guidelines and recommendations for magnetic fields at 50 Hertz (Hz) frequency exist. The Swiss Protection Act on Non-Ionizing Radiation (NISV, SR 814.710) stipulates emission limits for the plant of 100 μT . General occupational limits of 400 μT are proposed by SUVA³². More specific recommendations for occupational limits are given in the DIN 0848 standard. This distinguishes between work areas where no specific electromagnetic fields are expected (limit of 424 μT) and work areas with identified, controlled and measured electromagnetic fields (limit of 1358 μT).

³² SUVA: The Swiss Accident Insurance Fund

Comprehensive measurements of magnetic fields have been taken to ensure the occupational safety in Beznau NPP. In most areas the magnetic fields are below 400 μT . In the immediate vicinity of the generator, however, a maximum magnetic field of 560 μT was measured. Given these results, SUVA and the Federal Inspectorate for Heavy Current Installations (ESTI) approval was obtained to clearly mark all areas of the plant with magnetic fields over 400 μT . A particular focus was put on employees with cardiac pacemakers. For all affected employees individual limits and working areas were defined in collaboration with the manufacturer of the specific cardiac pacemakers and SUVA.

4.6 Noise

The Beznau NPP island is categorized an industrial zone and the area on the opposite side of the river Aare is partly residential. According to the Swiss Federal Noise Protection Act (Lärmschutzverordnung SR 814.41) the limits for industrial areas are stipulated to be 70 dB(A) in the daytime and 60 dB(A) at night. For residential areas the limits are 60 dB(A) and 50 dB(A), respectively. During normal operation the noise immissions fall below these limits.

Noise exposure significantly increases during the start-up and shutdown of turbines. During these processes excess steam is released via pipelines located on turbine house roof. Measurements taken in 1994 showed that in the immediate vicinity of the steam pipelines emissions up to 116 dB(A) occurred, which led to a violation of the emission limit in the nearby residence area. As technical countermeasure, the orientation of the pipelines was changed in a way that noise is directed away from the residence area towards an industry area and thus, all emission limits are respected.

5 Certification body and mandatory statements

5.1 Information from the certification body

The certification of the environmental product declaration, EPD[®], of electricity from Beznau Nuclear Power Plant has been carried out by Bureau Veritas Certification, Sweden, which confirms that the product fulfils relevant process- and product-related laws and regulations. The EPD[®] has been made in accordance with General Programme Instructions for an environmental product declaration, EPD, published by International EPD Consortium (IEC) and PCR-CPC 17, Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD[®]) for Electricity, Steam, and Hot and Cold Water Generation and Distribution. Bureau Veritas Certification Sweden has been accredited by SWEDAC, the Swedish Board for Accreditation and Conformity Assessment, to certify Environmental Product Declarations, EPD[®]. This certification is valid until 19 October 2014. The registration number is S-P-00144.

5.2 Mandatory statements

5.2.1 General statements

Note that EPDs from different EPD programmes may not be comparable.

5.2.2 Omissions of life cycle stages

In accordance with the PCR, the use stage of produced electricity has been omitted since the use of electricity fulfils various functions in different contexts.

5.2.3 Means of obtaining explanatory materials

ISO 14025 prescribes that explanatory material must be available if the EPD is communicated to final consumers. This EPD is aimed at industrial customers and not meant for B2C (business-to-consumer) communication.

5.2.4 Information on verification

EPD programme

The international EPD[®] system, managed by the International EPD Consortium (IEC).
<http://www.environdec.com>

Product Category Rules

PCR-CPC 17, Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD[®]) for Electricity, Steam, and Hot and Cold Water Generation and Distribution. Electricity belongs to the product category UNCPC Code 17, Group 171 – Electrical energy.

PCR review

Sven-Olof Ryding, International EPD Consortium (IEC),
info@environdec.com

Independent verification

Independent verification of the declaration and data, according to ISO 14025: External, Bureau Veritas Certification, Sweden

6 Links and references

Further information on the company

<http://www.axpo.ch>

International EPD® programme information

<http://www.environdec.com>

Information on the International EPD Consortium (IEC), EPD®s and PCRs (PCR-CPC 17), and General Programme Instructions GPI, 2007

Background LCA data

<http://www.ecoinvent.org>

The ecoinvent database v2, Swiss Centre for Life Cycle Inventories

7 Frequently used abbreviations

AECC	Angarsk Electrolyze Chemical Combine, Angarsk, Russia
CMP	Chepetsk Mechanical Plant, Glasov, Russia
ECP	Electrochemical Plant, Zelenogorsk, Russia
ENSI	Swiss Federal Nuclear Safety Inspectorate
EPD	Environmental Product Declaration
ERU fuel	Enriched reprocessed uranium fuel (blending of recycled uranium from various sources)
HLW	High-level waste
ILW	Long-lived intermediate-level waste
IAEA	International Atomic Energy Agency
KKB	Beznau Nuclear Power Plant
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LEU	Low-enriched uranium
LLW	Low- and intermediate-level waste
MPA	Mayak Production Association, Ozersk, Russia
MSZ	Mashinostroitelny Zavod, Elektrostal, Russia
MOX fuel	Mixed oxide fuel
Nagra	National Cooperative for the Disposal of Radioactive Waste
NPP	Nuclear Power Plant
PCR	Product Category Rule
PMC	Priagunsky Mining Combine, Krasnokamensk, Russia
SCC	Siberian Chemical Combine, Seversk, Russia
SF	Spent nuclear fuel
UEIP	Ural Electrochemical Integrated Plant, Novouralsk, Russia
UO ₂ fuel	Uranium dioxide fuel

Axpo AG

Parkstrasse 23 | CH-5401 Baden
T +41 56 200 31 11 | F +41 56 200 37 55
www.axpo.ch