OSPAR COMMISSION

Protecting and conserving the North-East Atlantic and its resources

Belgian seventh round report on the implementation of PARCOM Recommendation 91/4 on radioactive discharges to the OSPAR Commission on the application of Best Available Technology in nuclear facilities

Radioactive Substances Series

2020

PARCOM Recommendation 91/4
on Radioactive discharges

Seventh Belgian implementation Report

January 2020

OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. The Contracting Parties are Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Convention OSPAR

La Convention pour la protection du milieu marin de l'Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d'Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. Les Parties contractantes sont l'Allemagne, la Belgique, le Danemark, l'Espagne, la Finlande, la France, l'Irlande, l'Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d'Irlande du Nord, la Suède, la Suisse et l'Union européenne.

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Contents

GENERAL INFORMATION

At its 2010 meeting in Stockholm, Sweden, the OSPAR Radioactive Substances Committee established, on a trial basis, revised "Guidelines for the submission of information on the assessment of the application of Best Available Technology (BAT) in nuclear facilities". In this report the requested information for Belgian nuclear installations is given. The report covers the five-year period 2014-2018 (including 2019 for some parts).

Implementation of BAT/BET in terms of the OSPAR Convention in Belgian legislation and regulation

The first law concerning protection of the population from ionising radiation dated from March 29th, 1958. The legislation with respect to radiological protection was based on the Royal Decree of February the 28th 1963. After some modifications by the Royal Decrees of May 17th 1966, May 22nd 1967, December 23rd 1970, May 23rd 1972, May 24th 1977, March 12th 1984, August 21st 1985 the legislation was thoroughly adapted by the Royal Decrees of January 16th and February 11th 1987 when the ICRP-26 and 30 (regarding the methodology for calculation internal radiation dose) were taken into account. Other modifications were made by the Royal Decrees of February 12th and September 6th 1991, June 17th 1992, September 7th 1993, October 2nd 1997 and May 3rd 1999.

The Federal Agency for Nuclear Control (FANC) was established by law of April 15th 1994 and according to its position it has a great independency, necessary to take up his responsibility to the society in an impartial way. It is lead by a board of directors and the daily management is observed by a General-Director.

A new legislation was created by the Royal Decree of July 20th 2001 *(General Regulations for the Protection of the population, workers and the environment against the dangers of Ionising Radiation - GRPIR*), which was necessary to harmonise the Belgian legislation with the European Directives (that take into account some recommendations of the ICRP-60). This Royal Decree attributes to the FANC the objectives of "protection of the population, workers and the environment against the dangers of ionising radiation" that consist to:

- propose, apply and improve law and regulations;
- control human (and non-human) activities responsible for exposure of man to radioactivity;
- ensure the surveillance of radioactivity on the territory (telerad automatic network - Radiological Surveillance Monitoring programme);
- co-operation to nuclear emergency plans;
- distribute neutral and objective information.

Law of August 5th, 2006 that gives right to the public in accessing information with regard to the environment, which transposes the EU directive 2003/4/CE of the European Parliament and council of January 28th, 2003 regarding the public access to information related to the environment, led to the diffusion of a note from the Belgian Safety Authority that regulates the periodical reporting of radioactive releases from nuclear installations (see §2.9).

Basis for national legislation/regulation:

The Belgian policy is based on EC Directives, on international conventions and on recommendations of appropriate international bodies like the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA). The major principles in these regulations are:

- justification of exposure: exposure to radiation is only allowed if the advantage is larger than the possible risk and damage of the exposure;
- optimisation: known as the alara-principle (As Low As Reasonably Achievable), exposure has to be as low as possible, taking social and economic factors into account;

- dose limits: exposure of individuals as result of the combination of different exposures, has to be subject to limits to prevent unacceptable risks.

Dose constraints/limits for nuclear installations

The limits, which are given by the Belgian regulation *General Regulations for the Protection of the population, workers and the environment against the dangers of Ionising Radiation* (GRPIR), are the following.

Dose	Public	Workers	apprentices and students	
			≥ 18 years	16≤ <18 years
	art. 20.1.4	art. 20.1.3	art. 20.1.5	art. 20.1.5
Effective (whole body)	1 mSv/a	20 mSv/a *	20 mSv/a *	6 mSv/a
Equivalent for any individual organ or tissue	-	500 mSv/a *	500 mSv/a *	-
Equivalent for lens of the eye	15 mSv/a	150 mSv/a *	150 mSv/a *	50 mSv/a
Equivalent for skin **	50 mSv/a	500 mSv/a *	500 mSv/a *	150 mSv/a
Equivalent for hands, arms, feet and ankles	-	500 mSv/a *	500 mSv/a *	150 mSv/a

* for 12 consecutive months.

** average dose for each area of 1 cm² of skin

Remark: the above limits do not take into account medical exposure

Nuclear installations apply for their workers a dose constraint of 10 mSv/a.

Discharge limits

The annual limits for discharges and emissions are specified for a nuclear facility in such a way that the resulting doses to the population shall not exceed 1 mSv per year for all pathways combined (art. 20 of the Royal Decree of July 20th 2001).

The Royal Decree introduces also a notion of dose constraint (optimisation principle-ALARA): the discharge limits have to be based on a fraction of the public annual limit of 1 mSv. Dose constraints have been discussed with the FANC: the following table shows the dose constraint used by the nuclear sites.

	Dose constraint (mSv/a)			Evaluation of real committed dose (average over the last 10 years) (mSv/a)			Reduction Yes / No
	Atmospheric discharge	Liquid discharges	Total	Atmospheric discharge	Liquid discharges	Total**	
Belgoprocess (Site of Mol)	0.3	0.25	0.55	$60\ 10^{-6}$	$625\ 10^{-6}$	$685\ 10^{-6}$	Y
NPP Tihange	0.19	0.08	0.21	$47\ 10^{-3}$	$2.5\ 10^{-3}$	$49\ 10^{-3}$	N
NPP Doel	0.18	0.23*	0.37	$18\ 10^{-3}$	$2.3\ 10^{-3}$	$19\ 10^{-3}$	N

* take into account a specific critical group

** maximum dose does not necessary correspond to the sum of doses due to atmospheric or liquid releases: the critical individual, even localised at the same place, is not always in the same age category

The model used to estimate the radiation exposure for a critical group caused by radioactive effluents of nuclear power plants was based on the NUclear REgulatory Guide (NUREG) 1.109 rev. 1, USNRC. Some conservative adaptations have been made by taking into account:

- Dose conversion factors (RD of July 20th 2001) based on the icrp 72;
- 6 classes of age (RD of July 20th 2001) : ≤ 1y, 1-2y, 2-7y, 7-12y, 12-17y and > 17y;
- Eventual adaptation of some parameters (e.g. consumption habit,…).

The dose is calculated at the most unfavourable receiving points, taking into account the relevant exposure pathways and living habits, e.g. the consumption rates of different foodstuffs. On the basis of these assumptions and parameters used in the models, the radiation exposure to individuals cannot be underestimated.

Monitoring programmes of discharges and environmental concentrations of radionuclides

Under the Royal Decree, the Federal Agency for Nuclear Control (FANC) is charged in particular with *monitoring the radioactivity of the territory and the doses received by the population* (Article 70) as well as organising the *monitoring of the population as a whole* (Article 71). It should also be noted that the Franco-Belgian co-operation agreement of September 8th 1998, relates to the Chooz nuclear power station situated on the Meuse in France close to the border with Belgium. This agreement ensures the full monitoring on Belgian territory of all radioactivity transfers around the nuclear site as well as the periodic exchange of results between states.

The Agency reviews its entire sampling and measurement programme each 4-years in order to stay harmonised with international requirements such as EURATOM.

Finally, the OSPAR Convention (OSlo-PARis Convention, 1998 – ratified by Belgium) on the protection of the marine environment of the North Sea and North-East Atlantic makes the development of monitoring and research programmes concerning the impact of radioactive discharges on the marine environment mandatory.

The programme for the radiological monitoring of the territory currently (2017-2018) relies on about 4,350 samples annually, which are subjected to almost 20,500 alpha, beta and gamma radioactivity analyses. This radiological monitoring programme includes radioactivity measurements carried out in:

- the Meuse and Sambre basins;
- the Scheldt and Nete basins;
- the marine zone;
- a reference zone (Brussels Capital region).

for the major parts of the biosphere (air, soil, water and biocenosis) as well as in the main constituents of the food chain, supplemented by the follow-up of the atmospheric and liquid discharges of the main nuclear sites and through dose rate measurements around these facilities.

Wastes releases from hospital will be also controlled in sewage purification plants by using submersible automatic gamma spectrometry probes. The goal is to qualify and quantify if possible the radioactivity that enters the environment at the outlet of the sewage plants. The in situ controls of the hospital practices conducted by nuclear inspectors will be also linked with the obtained results. The final aim being to minimize the radioactivity levels of the hospital releases.

The discharges and environmental impact of some NORM and legacy sites are also monitored. This monitoring occurs either periodically or in the framework of a specific measurements campaign. These NORM sites belong to the phosphate and to the titanium dioxide production sectors. An environmental follow up of a legacy site related to a former radium extraction facility is also performed.

Environmental norms and standards

The art. 34 of the RD of July 20th 2001 defines that liquid discharges in surface waters or sewer canalisations are forbidden when concentration in radionuclides, expressed in Bq/litre, exceeds one thousandth of the annual limit of intake by ingestion for an adult (annexe III D of the RD).

National authority responsible for supervision of discharges

All licensing and supervision activities concerning construction and operation of nuclear facilities is carried out by the regulatory authority of the federal state (FANC) with the co-operation of authorized inspection and controlling bodies (Bel V, Controlatom, …). This is also the case for authorisation of radioactive discharges to the environment. FANC is under the authority of the Ministry of Interior.

Nature of inspection and surveillance programmes

The nuclear installations are inspected several times each year by the federal authorities (FANC and authorised inspection and controlling bodies). The environmental monitoring programme is undertaken by special authorised laboratories under the co-ordination and the responsibility of the federal authority (FANC). Laboratories undertake analyses in accordance with internal Quality Control procedures also involving regular calibration of detectors and yearly comparison exercises. Therefore, the quality of environmental and discharge sample measurements, and the assessment of impact of discharges and emissions on members of the general public, is based on an independent national system of governmental bodies and experts.

The TELERAD network - automatic remote radioactivity measuring network in Belgium - has been modernised in during 2010. The network now comprises 245 stations, which constantly measure the radioactivity of the ambient air, river waters. The stations are distributed throughout the entire country for nationwide monitoring, in rings around the nuclear sites at Tihange, Doel, Mol, Fleurus and Chooz to monitor the installations, as well as in the urban areas close to these installations.

In addition, in selected sewage purification plants the radioactivity of waters are controlled in situ with automatic (submerged) gamma spectrometry probes (see also 2.6).

The modernisation – which started in 2010 - comprised the replacement of all stations by stations with a new generation of modern data communication links. To improve the nuclear sites surveillance, the ring stations (situated around the sites on the fence) have been equipped with a gamma spectrometry detectors to assure a quick identification of nuclides present in the ambient air. In addition, existing river stations are also modified and are now equipped with a gamma spectrometry detectors with identification of present nuclides. Finally, new automatic gamma spectrometry probes are implemented upstream and downstream of the Doel NPP on the Scheldt river. The surveillance of the aquatic releases from NPPs are now directly done by automatic gamma spectrometry probes placed at the outlet of the release channels of the NPPs (Tihange and Doel).

All stations are linked to a centralised system that is automatically alerted when detecting any abnormal rise in radioactivity levels or a nuclide is detected above a preset threshold on the ring stations. The central systems has a full redundant set-up at a disaster recovery site.

Reporting

The results of discharge measurements performed by operators are reported monthly to the federal authority (FANC) and are also available through annual reports. Moreover, a note from the FANC concerning the periodical reporting of radioactive releases (gas and liquid) is applicable since January 2011. the note transposes the requirements of the EU recommendation 2004/2/Euratom.

Belgium reports annually on the FANC website all the results obtained from the radiological surveillance programme of the territory (including TELERAD, foodchain, nuclear sites discharges, NORM and legacy sites…).

Belgium reports discharge data from nuclear installations annually to EURATOM (art. 35&36 of the treaty) and to the OSPAR secretariat.

Belgium also reports hourly the dose rate data from the TELERAD network to the European Commission (EURDEP).

SITE -SPECIFIC INFORMATION

Nuclear Power Plants (NPP) general information

Nuclear power currently accounts for about 58 % of Belgian's electric energy production in 2017[1] and about 34 % in 2018[2]. The low value in 2018 is due to the many unavailabilities of the Belgian's nuclear power plants during that year. The nuclear power stations are located near Doel and Tihange. There are 7 operational pressurised water power reactors (3 at Tihange and 4 at Doel). Discharge data are given for reactor sites. The activity concentrations of radionuclides in non-human biota of river water are so low that it is generally not possible to detect them.

Information to be submitted in accordance with the BAT Guidelines is given in Annex 1 referring to nuclear power plants for the period between 1998 and 2018.

For each installation, the information as defined in BAT Guidelines is given in tabular form:

- Name of facility;
- Type of facility;
- Date commissioned;
- Location;
- Installed electrical generation capacity;
- Electricity generation;
- Shut-down year;
- Annual emissions and discharges, absolute and normalised according to actual output as compared to the UNSCEAR ranges;
- Individual dose as compared to the national dose limits;
- Waste treatment.

The determination of individual dose covers all radionuclides discharged to the environment.

Other nuclear sites general information

There are two other nuclear sites in Belgium: the Fleurus site (IRE-National Institute of Radioelements and MDS-Nordion) in Wallonia and the Mol-Dessel site (the Nuclear Research Centre SCK●CEN / Belgoprocess sites 1&2 (BP) / Belgonucléaire (stopped in August 2006, dismantling started in 2009 and to be completed in 2019) / FBFC International - Franco-Belge de Fabrication de Combustibles International (in dismantling)/ JRC-GEEL – European Commission's Joint Research Centre for developing new measurement methods and tools, formerly known as IRMM) in Flanders. The facilities at these sites carry out scientific, technical and commercial programmes in the nuclear field.

For the Fleurus site there are no liquid discharges: all liquid wastes are sent to the Belgoprocess site 1 for treatment. After treatment, eventual liquid discharges are released by the Belgoprocess site 2. All the liquid discharges produced by the Mol-Dessel site are also managed by the Belgoprocess facilities.

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[1] Centrale nucléaire de Tihange – déclaration environnementale 2018, Engie Electrabel, 65 pages, mai 2019

[2] Elia présente ses chiffres concernant le mix énergétique belge en 2018, La Chronique, 04/02/2019 (Elia - figures on the Belgian energy mix in 2018, La Chronique, 04/02/2019)

For **Belgoprocess site 2** the information, as defined in BAT Guidelines, is given in tabular form (annex 2):

- Name of facility;
- Type of facility;
- Location;
- Annual emissions and discharges;
- Individual dose as compared to the national dose limits;
- Waste treatment.

The determination of individual doses covers all radionuclides discharged to the environment.

1. SITE CHARACTERISTICS

1.1 Tihange Nuclear Power Plant

1.1.1 Tihange

Tihange nuclear power station Belgium © Shutterstock

1.1.2 Type of facility (see Annex 1)

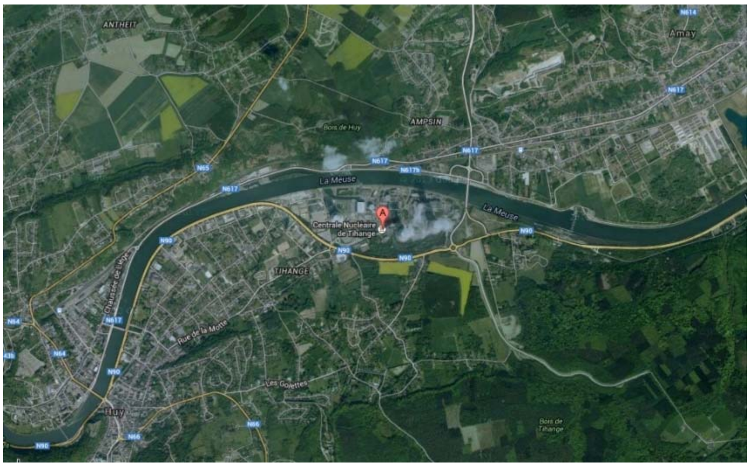
Three PWR.

1.1.3 Year for commissioning/licensing/decommissioning

- Tihange 1 : 1975/2015 => 2025;
- Tihange 2 : 1983/2023;
- Tihange 3 : 1985/2025.

1.1.4 Location

The site is situated on the right Meuse river side near of Huy and Tihange cities.



1.1.5 Receiving waters and catchment area, including, where relevant, information on water flow of receiving rivers

Meuse river.

1.1.6 Production

See "Tihange" tables in the annex 1.

1.2 Doel Nuclear Power Plant

1.2.1 Doel

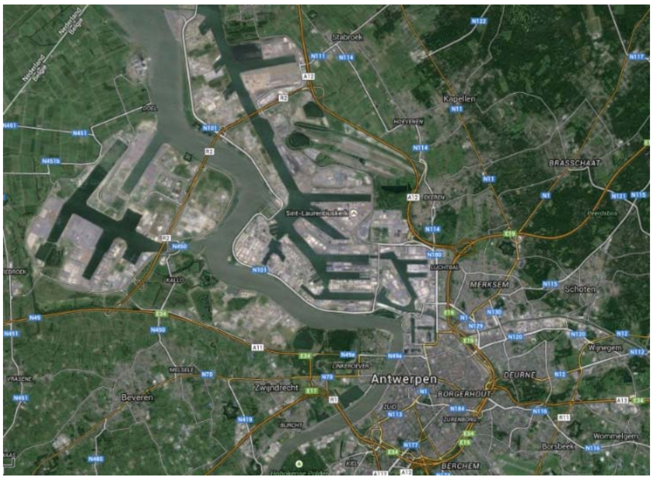
Nuclear power plant Doel near Antwerp, Belgium © Shutterstock

1.2.2 Type of facility (see Annex 1)

Four PWR.

1.2.3 Year for commissioning/licensing/decommissioning

- Doel 1 : 1975/2015=>2025;
- Doel 2 : 1975/2015=>2025;
- Doel 3 : 1982/2022;
- Doel 4 : 1985/2025



1.2.4 Location

The site is situated on the left Scheldt river side near Antwerpen city.

1.2.5 Receiving waters and catchment area, including, where relevant, information on water flow of receiving rivers

Scheldt river.

1.2.6 Production

See "Doel" tables in the annex 1.

1.3 Other Nuclear Sites

1.3.1 Belgoprocess (BP)

Belgoprocess site 1

Belgoprocess site 2 (liquid waste treatment and releases)

1.3.2 Type of facility (see Annex 1)

Waste treatment and storage facility.

1.3.3 Year for commissioning/licensing/decommissioning

1984/-

1.3.4 Location

The site is situated in the Mol-Dessel region and liquid releases are discharged in the Molse Nete river by an underground pipe of 10 km long.

1.3.5 Receiving waters and catchment area, including, where relevant, information on water flow of receiving rivers

Molse Nete river.

1.3.6 Production

NA.

2. DISCHARGES

2.1 Tihange NPP

The radionuclides to be monitored are stipulated in the “licence to operate” of the NPP reactors under the responsibility of the federal authority (FANC).

2.1.1 System(s) in place to reduce, prevent or eliminate discharges of radioactive substances

Origin: there are 3 reactors and for each reactor building there are 2 main categories of liquid wastes:

- Recyclable waste waters (primary waters known as hydrogenous waters) and;
- Non-recyclable waste waters (aerated primary water, drain floors, laundry, chemical such as lab decontamination components, resins regeneration solutions, and so on …).

Treatment:

- Ion-exchange resins, filtration, degassing and evaporation of waste waters (in degassers and evaporators, the tritium remains in the condensed distillate and released as a tritiated water).
- The concentrate phase is conditioned with cement in the NPP itself as solid concrete waste.

Waste management:

Recycle effluents

- Are collected in their respective units (Tihange 1, 2 or 3) and then pumped to unit 2 where they are filtered (1 or 5 µm filters), demineralised (anionic, cationic and mixed bed resins), degassed (fission gas and hydrogen) and evaporated.
- The distillate (boric acid solution) is recovered, the distillate (containing tritium) is sent to one of the available RAR tanks (storage tanks before release to river, two tanks /unit).

Non-recyclable effluents

- Are identically collected in their respective units and are also pumped to unit 2. If the radioactivity is low, treatment will be conducted by filtration. If the radioactivity is higher, the effluents will be treated by evaporation only.
- The distillate (evaporation) is treated as a low level activity effluent, analysed and repumped to one of the available RAR tanks (storage tanks before release to river, 2 tanks/unit).
- In either case, solid residues (concentrate or filter) are treated as solid waste according to ONDRAF/NIRAS[3] procedures.

All effluents from the RAR are analysed both chemically and radio-chemically prior to their release. In order to dilute the effluents, they are mixed first with waters from raw water cooling system before being released to the Meuse river. All the radioactive liquid releases into the river are under the approval of a Health Physician from the NPP .

In 2009, Tihange NPP decided to lower the limit for treatment of liquid effluents at ~1 MBq/m^3 (gross gamma counting).

2.1.2 Systems abatement efficiency

Abatement systems and management (according to 2.1.1 and 2.1.2).

[3] National Agency for Radioactive Waste and enriched Fissile Material.

Abatement system/ Management	Into operation (Year)		Efficiency of abatement system		Comments
	Existing	Planned	Decontamination Factor	Other measure of efficiency	
Discharges:					
delay tank(s**)** **Liquid** : storage tanks prior to release in the river Meuse) 2tanks /reactor **Gas** : on each unit , several gas tanks of different capacities and design pressures	**Liquid** **Ti 1**: 1986 **Ti 2**:1982 **Ti 3:** 1985 **Gas**: **Ti 1** 1975 (part of original design) and ca.1980 (two additional tanks) **Ti2 and Ti3:** part of original design of the plants		**Liquid** :See Ion exchange for typical figure **Gas** : delay policy is used on a regular basis in order to avoid short lived gas species releases (Xe-133) . gas release are mandatory filtered on PRE, HEPA and Active carbon filters		**Ti 1** : the 2 release tanks for liquid were added during the first 10 -years outage. **Ti 2 and Ti 3** : part of the basic design Discrepancies in storage capacities exist according to different ages and design
chemical precipitation	In operation in the late years 1980		Typical figures were poor (FD = about 20 but needed multi-step precipitation)	Gross gamma counting	One floculator (30 m³) in CNT2 Given up according to poor DF
centrifuging	NO	NO			
Hydro-cyclone	NO	NO			
cross-flow filtration					
ion exchange (with pre and post filtrations, coupled with thermal degasser and evaporator) for primary (recyclable) liquids , boric acid liquors are recycled , tritiated distillate are stored prior to release Evaporator alone : for non-recyclable liquids	Classical Filter/Ion exchange/ Filter /degasser/ evaporator process or evaporator only		Typical figures are … > 95 … 99 % for the whole treatment process of the primary effluents	Efficiencies of the ion exchange resins are checked by gross gamma counting / spec gamma, Efficiency of the single evaporation is measured by checking the distillate gross gamma activity	

osmosis	One semi-industrial unit in operation in TI3 in the mid-1990		DF measured by IN and OUT effluents activities	Gross gamma and spectro gamma counting's	Fused for Boraflex issue only , given up after the removal and the replacement of the Boraflex
ultrafiltration	NO	NO			
Emissions:					
electrostatic precipitation	NO	NO			
cyclone scrubbing	NO	NO			
chemical adsorption	NO	NO			
HEPA filtration	YES, part of the basic design of the 3 units		> 99 % (measured according to the technical specifications for classified filters or on a voluntary basis for the unclassified ones)		Discrepancies exist because the 3 unite are of different ages and designs
cryogenics	NO	NO			
Active carbon filter	See HEPA		> 95 % classified filter > 90 % for un-classified items		See HEPA

2.1.3 Annual liquid discharges

For tritium, the range for normalized liquid discharges for the whole period is 8.6 to 20.0 TBq/GWa, with an average of 14.8 TBq/GWa. No clear trend is discernible.

For beta/gamma emitters excluding tritium, the range since 1998 is 2.0 - 20.7 GBq/GWa and between 2.0 - 7.5 GBq/GWa during the period 2014-2018 with a mean value of 4.6 GBq/GWa.

Comparisons with UNSCEAR ranges show that:

- Tritium discharges are **near the lower end limit** of the range;
- Non-tritium discharges into water are always **below** the level of the range since 2007;

See annex 1 part 2 and trends graphs.

2.1.4 Emissions to air of concern for the marine environment

See annex 1 part 3 and trends graphs.

Note that Tihange NPP air emissions doesn't concern the marine environment, the data are mentioned for information only.

Origin:

1) Space between the reactor building itself and the second containment ("inter-space"), fuel building (spent-fuel pool), nuclear auxiliaries building (ventilation, machinery rooms, laundry building, deminerali sation building, decontamination building, …);
2) Gaseous effluents from hydrogenous circuits (primary circuit, chemical and volumetric conditioning circuits); 3) atmosphere of each reactor building itself (70,000 m^3).

Treatment:

- All gas releases from 1) are continuously monitored, can be filtered (HEPA and charcoal) and released at rates from 150,000 to 250,000 m^3/h.
- Gas releases from 2) are sent to storage / decay tanks. Venting of the atmosphere of the reactor building is done after monitoring and filtration (charcoal) if necessary.

Waste management:

- Releases from 2) for each reactor (Tihange 1, Tihange 2 & Tihange 3) are sent to primary storage tanks. Once the radioactivity of a full storage tank has sufficiently decreased, effluents are released through the chimney at a maximum rate of 75 m^3/h (presence of filters and continuous monitoring).
- All gas (mostly Xe-133 and spurs of Kr 85 and other short lived species) from 1) are continuously released through stacks and monitored by on-line detectors. When "action" levels are exceeded, gas releases are by-passed through HEPA filters (High Efficiency Particulate Air filters) and active carbon filters. Filters and active carbon cartridges samples - trapping iodine and airborne (except for laundry and decontamination buildings) - are analysed weekly (determination of iodine concentrations by gamma spectrometry). Tritium is determined by calculation taking into account flow rate and concentration.

2.1.5 Quality assurance

Tihange NPP AQ system is based on the IAEA Safety Standards for protecting people and environment (DS338, Draft 10, 1st December 2005). AQ system also integrate recommendations of the international standards ISO-14001 (environment), EMAS, OHSAS-18001 (safety) and WANO. System for quality assurance is defined in two internal QA procedures : SUR/00/040, SUR/00/041.

All liquid waste management and treatments are audited according to EMAS (*Eco-Management and Audit Scheme*) and ISO 14001 certifications.

2.1.6 Site specific target values

Liquid releases

- Beta –gamma emitters : 14.5 GBq (authorized limit : 888 GBq).

Gas releases

- Noble gas : 8.88 TBq (authorized limit : 2220 TBq);
- Aerosols : 500 MBq (authorized limit : 111 GBq);
- Iodine : 14.8 MBq (authorized limit : 14.8 GBq).

2.1.7 Any other relevant information

See 2.3.

2.1.8 Explanations for lack of data or failure to meet BAT/BEP indicators

Tritium gas releases are calculated for the 3 units but also measured on units 2 (since January 2019) and 3 (since May 2015).

The carbon-14 gas emissions are also calculated for the 3 units and measured on units 2 (since January 2019) and 3 (since October 2018).

There is no measuring system for tritium and carbon-14 gas emissions on unit 1 because of the design of the isokinetic sampling line on the stack.

2.1.9 Summary evaluation

Total releases in Tihange NPP are equivalent to the average release between 2008 and 2018.

During 2018, we notice that:

- Releases of tritium (air) decreased compared to 2017. This is explained by low electricity production in 2018, so there is little tritium in the primary circuit.
- Aerosol releases decreased compared to 2017 while iodine releases increased due to 3 unit shutdowns in 2018.
- Releases of Co-60 (liquid) increased since 2014. This is likely due to the higher use of filtration to decontaminate wastewater effluents rich in boron and low in activity, instead of producing evaporator concentrates.

Moreover, the installation of the measurements system at units 2 and 3 will allow to compare the recorded values with the calculated ones that are used in the determination of the releases in tritium en C-14.

2.2 Doel NPP

The radionuclides to be monitored are stipulated in the “licence to operate” of the NPP reactors under the responsibility of the federal authority (FANC).

2.2.1 System(s) in place to reduce, prevent or eliminate discharges of radioactive substances

Origin:

- There are 4 units at NPP Doel.
- The industrial waste waters of those units consist of: liquid effluents from controlled areas (‘GZ’; floor, laundry, lavatory, chemical drains, …) and liquid effluents from non-controlled areas (‘SEK’; floor, regeneration effluents from machinery, blow down of the steam generators).

Treatment:

- Ion-exchange procedures, filtration and evaporation of waste waters (in evaporators, tritium from the distillate is condensed and released as a liquid fraction).
- The concentrate phase is conditioned in the NPP itself as solid concrete waste.

Waste management:

- The GZ are always sent to the WAB (water and waste treatment building). Depending on their activity, the SEK will be treated in the WAB, directly sent via the GSL (building of secondary discharges) to the ELK (unique release collector to the Scheldt after dilution) or directly sent to the ELK. In WAB, all the liquid effluents are stored in tanks for intermittent release.
- All (treated) liquid effluents flow through the "L-Building" where an activity measurement may interrupt the discharge before going to the "Discharge Pavilion"where it is sent to the Scheldt. In the "Discharge Pavilion", the industrial water (GZ or SEK) is mixed with tertiary cooling waters before being effectively released into the river Scheldt. An instantaneous limit of 0.1 MBq/m³ drink water equivalent is applied for all liquids released through the discharge pavilion into the Scheldt.

2.2.2 Systems abatement efficiency

All liquid waste management and treatments are audited according to EMAS (*Eco-Management and Audit Scheme*) and ISO 14001 certifications.

For the 2001-2018(2019) period, following factors have influenced the reduction of radioactive liquid releases:

- more liquid waste is evaporated to solid waste instead of being released into the Scheldt river;
- replacement of the steam generators of reactor 2 (2004) allowed to recover the "blow-down" waters which induced a significant decrease of liquid releases;
- Steam Generators and power uprate of reactor 1: by the replacement of the steam generators (2009) the risk of leaks form the primary to the secondary circuit has decreased. Due to the power increase, the inventory of radioactive products present in the reactor core as in the primary circuit can raise to reach a possible maximum level proportional to the power increase factor. This doesn't necessary mean that releases towards the environment will rise and this is due to the dependence of plenty of other factors such as for example pH and mainly of the degree of leak tightness of all different barriers between the source of activity and its surroundings. Nevertheless, after the implementation, control and surveillance showed that the actual discharge limits - according to the Technical Specifications which remained the same as before – are still well respected and likewise amply meets the appropriate dose limits for the population.
- improvement projects of the evaporators in the WAB;

Abatement systems and management (according to 2.2.1 and 2.2.2).

Abatement system/ Management	Into operation (Year)		Efficiency of abatement system		Comments
	Existing	Planned	Decontamination Factor	Other measure of efficiency	
Discharges:					
Delay tank(s): ▪ Liquid: o the liquid effluents coming from the controlled areas (GZ) of the 4 reactor units are stored in 2 storage tanks in the WAB prior to release in the river Scheldt o the liquid effluents from the machinery buildings are stored in the GSL prior to release in the river Scheldt ▪ Gas: on each unit, several gas tanks of different capacities and design pressures	Liquid: 1982 Gas: D12: 3 tanks are part of original design, 2 additional tanks in place since end '80's D3, D4: part of original design of the plants		Gas: delay policy is used to avoid short lived gas species releases.		WAB = water and waste treatment building D12: prior to the startup of the WAB in 1982, liquid releases were handled by D12. Since 1982 all liquid releases from controlled areas are handled by the WAB.
chemical precipitation	NO				
centrifuging	NO				
hydrocyclone	NO				
cross-flow filtration	NO				

ion exchange: with pre and post filtrations, coupled with thermal degazifier and evaporator for primary (recyclable) liquids , boric acid liquors are recycled, tritiated distillates are stored prior to release. Evaporator alone: for non-recyclable liquids.				Efficiency of the ion exchange resins is checked by gross gamma counting / spec gamma. Efficiency of the single evaporation is measured by checking the distillate gross gamma activity.	
osmosis	NO				
ultrafiltration	NO				
candle filters for the laundry water	Yes				
Emissions:					
electrostatic precipitation	NO				
cyclone scrubbing	NO				
chemical adsorption	NO				
HEPA filtration	Yes, part of the basic design of the units.			>99,95%	
cryogenics	NO				
active carbon filtration	Yes, part of the basic design of the units.			Efficiency according to the Technical Specifications	
Bag filtration on the shredder	Beginning of 90's				

2.2.3 Annual liquid discharges

For tritium, the range for normalised liquid discharges for the whole period is 9.9 to 19.0 TBq/GWa with an average value of 14.5 TBq/GWa. No clear trend is discernible.

For beta/gamma emitters excluding tritium, the range since 2000 is 0.6 - 10.2 GBq/GWa, 0.6 – 1.0 during the period 2014 to 2018 with a mean value of 0.8 GBq/GWa. Since 2004, normalized discharges are very low.

Comparisons with UNSCEAR ranges show that:

- Tritium discharges are **near the lower end limit** of the range;
- Non-tritium discharges into water are always **below** the level of the range since 2000.

See annex 1 part 2 and trends graphs.

2.2.4 Emissions to air of concern for the marine environment

See annex 1 part 3 and trends graphs.

Origin: reactor building, annular space between the reactor building itself and the second containment, fuel building, nuclear auxiliaries building.

Treatment:

- All gas releases from hydrogenous circuits of the four reactors (degasification of primary circuit, …) or the WAB are sent to storage decay tanks.
- All gases from other sources (leakages, airy ventilation of the nuclear buildings, non-condensable gas, …) are continuously released and monitored.

Waste management:

- Once the radioactivity of a full storage tank has sufficiently decreased, effluents are released through the chimney (continuous monitoring). All gas from other sources are continuously released and monitored. When "action" levels are exceeded, gas releases are by-passed through HEPA filters (High Efficiency Particulate Air filters) and/or active carbon filters (trapping iodine).
- The particulate filters and active carbon cartridges are analysed weekly (determination of iodine concentration and gamma spectrometry). Using monthly aliquots, beta and alpha measurements are conducted on filters; ^{85}Kr is determined on gas; tritium is determined on condensed gas, gamma spectrometry on noble gases.

2.2.5 Quality assurance

The Nuclear Power Plants of Engie Electrabel have an integrated management system, called Nuclear Generation Management System (NGMS), which includes policies for the Care Systems. These concern Nuclear Safety, Health & Safety, Environment, Site Security and Fire Protection. The management system is in accordance with general safety requirements published by the IAEA GS-R-3 (Nuclear Safety) and with international standards ISO-14001 (environment), OHSAS-18001 (safety).

Nuclear safety performance is monitored by several internal monitoring mechanisms:

- Supervision within each team (Quality Control 1);
- Independent controls by the Care Department (Quality Control 2);
- Independent nuclear safety monitoring by the Electrabel Corporate Nuclear Safety Department (Quality Control 3) and;
- internal audits by the Quality Assurance section from the PPM Department.

All our processes are documented and activities are supported by operational procedures, instructions, support documents and witness documents. Document & Data management is one of these processes.

The operational procedure PREV/55 describes the management of radiological water discharge and atmospheric emissions.

All liquid waste management and treatments are audited according to EMAS (*Eco-Management and Audit Scheme*) and ISO 14001 certifications.

2.2.6 Site specific target values

NA.

2.2.7 Any other relevant information

See 2.3.

2.2.8 Explanations for lack of data or failure to meet BAT/BEP indicators

Tritium releases are calculated based on a monthly measurement of the tritium concentration in every operating stack and the monthly discharge volume through that stack.

The carbon-14 gas emissions are calculated in a conservative way.

2.2.9 Summary evaluation

Total releases in Doel NPP are lower than the average release between 2008 and 2018 for most isotopes. We notice that liquid releases remain very low since 2004.

2.3 Other relevant information concerning the Belgian nuclear sites (Tihange and Doel NPP)

2.3.1 Flaw indications in reactor pressure vessel of Doel 3 and Tihange 2

During the 2012 outages of the Doel 3 and Tihange 2 nuclear reactors, specific ultrasonic in-service inspections (UT) revealed the presence of a large number of quasi-laminar flaw indications in the lower and upper core shells of both RPVs. It was decided that both reactors would remain shut down until ENGIE Electrabel could demonstrate to the FANC that the newly discovered flaw indications did not affect the safety of both reactors.

After several safety evaluations conducted both by ENGIE Electrabel and independently by the regulatory body, the FANC authorized the Doel 3 and Tihange 2 reactor units to resume operation until they reach the age of 40 years. After an extended shutdown of 20 months, Tihange 2 and Doel 3 units were put back into operation in December 2015 and January 2016 respectively.

The reports have been published on the FANC web site: https://afcn.fgov.be/fr/dossiers-dinformation/centrales-nucleaires-en-belgique/actualite/indications-de-defauts-dans-les

The FANC required ENGIE Electrabel to perform follow-up UT-inspections using the qualified procedure on the RPV core shells at the end of the next cycle of Doel 3 and Tihange 2, and thereafter at least every three years.

Consequently, a new UT inspection of the RPV of Doel 3 was done in October 2016 and an inspection of the RPV of Tihange 2 was done in April 2017. Both inspections used the same qualified method as the one used in 2014. The results of those inspections showed that there was no evolution in the population of the indications. Some indications, close to the rejection thresholds, appeared during the new inspection but it was shown that they were already present during the inspection of 2014 and that the fluctuation in the reporting was due to a measurement threshold effect; other indications followed the inverse path: they were reported in 2014 but were below the rejection threshold in 2016/2017. For conservative reasons, it was decided to take into consideration in the Structural Integrity Assessment (SIA) all the flakes once reported and never removing them of the SIA analysis. The FANC has validated the conclusion of ENGIE Electrabel that the population of the indications is stable, does not evolve in any sense and that the operation of the plants may be pursued in accordance with the conclusions of the Safety Case of 2015.

The reports have been published on the FANC web site.

All other Belgian RPVs (of Doel 1, Doel 2, Doel 4, Tihange 1 and Tihange 3) have been screened for hydrogen flakes. No indication of hydrogen flakes was reported in any plant.

2.3.2 Jet Grouting and soil problems at Tihange 1

In order to create a dry work area for the construction of an underground gallery in the framework of the "Long Term Operation of Tihange 1" project, ENGIE Electrabel was performing jet grouting activities close to an existing building ("W building": housing - among others - the steam generator auxiliary feedwater turbo pump).

On September 7th, 2016, ENGIE Electrabel observed several damages at the ground floor of the W building: cracks and displacements of the ground floor and foundation slabs supporting the turbo pump, and its piping.

Electrabel decided to bring the unit to safe shutdown, to stop the jet grouting activities and to directly carry out investigations regarding the records from the jet grouting activities, the structural damages, the equipment damages and the characterization of the ground under the W building.

The results of the investigations showed that the event was caused by a progressive rise of pressure in the ground caused by the combination of several non-conformities from the company in charge of the jet grouting activities with a mischaracterization of the soil.

Some preliminary characterization tests of the ground under the W building revealed the presence of a less compacted soil layer located between 6m and 7m depth. Additional investigations of the ground under different buildings of the concerned unit revealed that the ground characteristics of a large zone around the reactor building are not consistent with the ground characterization referred to in the Safety Report of the unit. The soils used in the 70's to refill the foundations of the buildings around the reactor did not fulfil the design technical requirements.

ENGIE Electrabel therefore reinforced the ground directly under the concrete foundation slab that had risen during the incident. After analysis of ENGIE Electrabel and assessment by the regulatory body of the impact of this non-conformity on the seismic resistance of this building, the regulatory body asked ENGIE Electrabel to reinforce the ground under the foundations of this building before considering restart of the reactor. ENGIE Electrabel completed this soil consolidation at the end of April 2017. The analysis of the results, conducted during the first half of May 2017, showed the structural solidity of the building in the event of an earthquake.

Other buildings of Tihange 1 NPP were inspected simultaneously. Soil inspections and assessments concluded that these other buildings did not require soil consolidation and that their capability to withstand the design basis earthquake was confirmed.

The FANC eventually authorized the restart of the Tihange 1 unit on May 15th, 2017.

2.3.3 Extended shutdown of NPPs for concrete repair

Inspections during the planned outage of Doel 3 in October 2017 discovered concrete degradation on the bottom of the bunker building roof plate. These bunker buildings house the "second level" protection systems such as emergency diesel generators and emergency pumps to inject water into the primary circuit and the steam generators, designed specifically to be used in case of external initiating events. This building is designed to withstand the impact of extreme external events such as an airplane crash and this degradation could have impaired this design capability. Following the detection of this degradation, inspections were also carried out on the other Belgian units having an equivalent design, i.e. Tihange 3, Tihange 2 and Doel 4. During these inspections, the same type of degradation, however with variable severity, was also found.

The degradation results from a specific function of this part of the bunker buildings. If steam flow from the steam generators cannot be discharged into the main condenser, it is discharged through the steam generator's relief and safety valves into the rooms beneath these roof plates. The latter protecting them from external events and direct release to the atmosphere. This steam flow - exposing the bottom of the roof plates to high temperature and humidity - is the cause of the degradation.

While uncovering the degraded parts of the concrete of the bunker building roof plates, anomalies were found in the reinforcement of the concrete, more precisely mispositioning of some of these reinforcements during the initial construction of the buildings on one hand and corrosion of the lower reinforcement on the other hand.

The extent of the issues discovered led to the need to reconfirm the ability of these buildings to withstand to the initiating events postulated at the initial design, and particularly to an air plane crash.

In October 2018, the FANC decided to classify these anomalies as an overall INES 1 event for the concerned units: Doel 3, Doel 4, Tihange 2 and Tihange 3.

On the ENGIE Electrabel side, the Independent Nuclear Safety Oversight (INSO) department, supported by external independent experts in civil engineering, challenged the inspections, the repairs and the calculations performed by the engineering department of the operating organization.

FANC and its technical subsidiary Bel V closely followed all repair works, both through examination and evaluation of documents, quality plans and test results, as through inspections on site with support of civil works experts.

<u>Doel 3:</u>
At Doel 3, the degradation of the existing roof plate has been repaired and a new additional roof plate was built. These works were conducted under supervision of the INSO, the FANC and Bel V. On the basis of these works and calculations, the initial air plane crash resistance has been restored and - after the positive advice from the INSO and review by Bel V - the FANC approved restart of the reactor in July 2018.

<u>Tihange 3:</u>
At Tihange 3, less severe degradation was discovered during the planned outage in April 2018. However, when uncovering the degraded parts of the concrete, anomalies were found in the positioning of the steel reinforcements. At the end of December 2018, the repair works of the bunker roof plate had progressed sufficiently and, after the positive advice from the INSO and review by Bel V, the FANC authorized restart of the unit. In order to further increase the safety margins, ENGIE Electrabel has committed itself to construct an additional roof plate during the planned outage in the summer of 2020.

<u>Tihange 2:</u>
Inspections and subsequent repair work started in the planned outage of July 2018. The works and calculations necessary to demonstrate that the air plane crash resistance has been restored have been performed under supervision of the INSO, FANC and its technical subsidiary Bel V. An additional roof plate has been constructed to further increase the safety margins. FANC has approved restart of the reactor in June 2019.

<u>Doel 4:</u>
Inspections and subsequent repair work started in August 2018. Degradation as well as anomalies in the reinforcements were less severe and it could be confirmed that the initial air plane crash resistance was restored after repair works, without an additional roof plate. The reactor was restarted in December 2018, after positive advice by the INSO, review by Bel V and approval by the FANC.

2.3.4 Leak in an Upper Plenum Injection line of Doel 1 NPP

In April 2018, during full power operation of the Doel 1 nuclear power plant, a primary leak of around 4 to 5 L/min occurred and the reactor was consequently stopped and brought to cold shutdown. Investigations showed the leak to be situated in a part of one of the Upper Plenum Injection (UPI) lines, non-isolable from the reactor.

The 4” Stainless Steel 316 UPI lines are part of the Safety Injection system and are typical for the Westinghouse 2-loop design. They enable safety injection to be applied directly in the upper plenum of the reactor vessel, in addition to cold leg injection.

After the leak location was found in the UPI-A line, an extensive non-destructive inspection campaign was started on all UPI-lines (A and B) of both Doel 1 and Doel 2. These inspections revealed that the corresponding UPI-A line of Doel 2 also showed similar degradation in the same area. As a result, all pipe sections with reportable indications have been cut and replaced.

The inspections and repairs were performed in difficult technical and logistical circumstances (difficult accessibility, lack of space and high radiation dose) as the affected UPI pipelines are located in the cavity near the reactor vessel.

The removed pipes, containing the leak or indications, were examined in two independent laboratories. All examinations identified low-stress high-cycle fatigue to be the damage mechanism, the crack initiation and propagation showing to be a slow, multi-annual process.

The root cause analysis concluded that thermal fatigue is responsible for the observed cracking: temperature fluctuations in the quasi-horizontal stagnant branch, perturbed by instabilities, have led to cyclic thermal stresses.

Exploratory calculations show that thermal stress cycles in the UPI-B lines, which are shorter and have a different geometry, appear to be more limited, explaining the absence of degradation in these lines.

An extensive inspection of all other possibly susceptible non-isolable reactor coolant circuit branch lines, going beyond the recommendations of applicable EPRI guideline, was performed and revealed no reportable indications.

A comprehensive temperature, displacement and vibration monitoring has been installed on the UPI-lines of both units, in order to guarantee a close follow-up of the thermal and mechanical behaviour of the lines during all operational modes. Re-inspection of the areas of concern is foreseen during the next outages.

The understanding of the initiation and propagation of the damage phenomenon, the successful repair and the risk mitigating measures taken, allowed ENGIE Electrabel to introduce a safety file stating that both units can be operated in a safe manner and justifying start up. This safety file was analysed and approved by the regulatory body.

Based on the understanding of the damage phenomenon, the successful repair and all risk mitigating measures taken, the FANC authorized Doel 2 and Doel 1 to resume operation in January 2019 and in February 2019 respectively.

2.3.5 Completion of the Stress Tests Action plan "BEST"

As member of the European Union, Belgium participated in the "Stress Tests" programme initiated by the European Commission after the Fukushima-Daiichi accident. The main milestones of the "Stress Tests" programme developed by ENSREG are listed below:

- Technical definition of the "Stress Tests" by WENRA: May 2011;
- Stress Tests report by the licensee: October 2011;
- National Stress Test report: December 2011;
- Peer review organized by ENSREG of the Stress Tests report: April 2012;
- ENSREG action plan: August 2012;
- Publication of the National action plans: December 2012.

The various reports that have been issued by or for Belgium are available on the following ENSREG website: http://www.ensreg.eu/EU-Stress-Tests/Country-Specific-Reports/EU-Member-States/Belgium (in English) and on the FANC website : https://fanc.fgov.be/nl/informatiedossiers/kerncentrales-belgie/nucleaire-stresstests/verslagen (in Dutch and French).

As a result of the Stress Tests, the ENSREG action plan and peer review and the findings of the extraordinary meeting of the CNS in 2012, a Belgian national Action Plan (called "BEST") was issued in December 2012. More than 300 individual actions have been identified.

The current status (end 2018) of the Belgian National Action plan and other related reports are available on the same FANC web page (in English).

By the end of 2018, ENGIE Electrabel finalized more than 99% (i.e. 362/365 actions) of the stress-tests action plan. Two additional assessments and the construction of a new emergency response facility (backup to the current site operation center) in Tihange should be finalized in 2019.

Since 2011, the sites of Doel and Tihange have witnessed several main achievements: reinforcement of structures, systems and components to face severe earthquakes, construction of protections against flooding and additional mobile means, such as mobile pumps and mobile diesels. Both sites are now adequately protected against natural hazards, such as flooding and earthquakes.

By the end of 2017, the strategy for complete station black-out and for loss of the ultimate heat sink is well-defined on both sites and the related works were finalized.

The construction of filtered venting systems on all reactor buildings at Doel and Tihange were finalized in 2017 (except for Doel 1 and Doel 2, where filtered venting systems belong to the LTO action plan and are scheduled to be operational in 2020).

2.3.6 Long Term Operation of Tihange 1, Doel 1 & 2 Action plan

ENGIE Electrabel established action plans both for Tihange 1 and for Doel 1 & 2, which were assessed and approved by the FANC. The first part of these action plans was completed before the first restart of the reactors after the initially foreseen legal shutdown dates. The second part of these actions plans consisted of additional modifications related to ageing and more significant design improvements. The FANC made use of article 13 of the GRR-2001 (the "General Regulations regarding the protection of the public, the workers and the environment against the hazards of ionizing radiation") to propose licence amendments to enforce these action plans.

The execution of the Tihange 1 action plan is on track. However, the remaining actions, which are planned to be executed during a long outage planned from December 2019 until June 2020, are challenging. The main challenge is the commissioning of the "SUR-E = Système d'Ultime Repli Etendu" or "Ultimate Extended Backup System". This SUR-E is an important design improvement and is designed to be an independent backup system that can bring the reactor to a safe cold shutdown state. It includes the necessary instrumentation and control systems as well as independent power supply systems. An important event, linked to the execution of the action plan, was the jet-grouting incident in September 2016, detailed in section I.C.4.a).

The execution of the Doel 1 & 2 action plan is also in progress with the remaining actions to be executed during a long outage planned from October 2019 until April 2020.

The outages of 2018 were scheduled for about 3 months, but eventually the outages of the units Doel 1 and 2, started in May 2018, were extended until the beginning of February 2019 (Doel 2) and March 2019 (Doel 1). This delay was caused on one side by the different actions linked to a primary leak (UPI lines) that appeared end April 2018 at Doel 1 and that led to an early shutdown of the unit. The second major cause of the delay was an underestimation of the workload for the implementation of the LTO action plan and the execution of the associated requalification program of the new and modified equipment.

2.3.7 Quantity of liquid and solid waste generated by nuclear power stations (chart below).

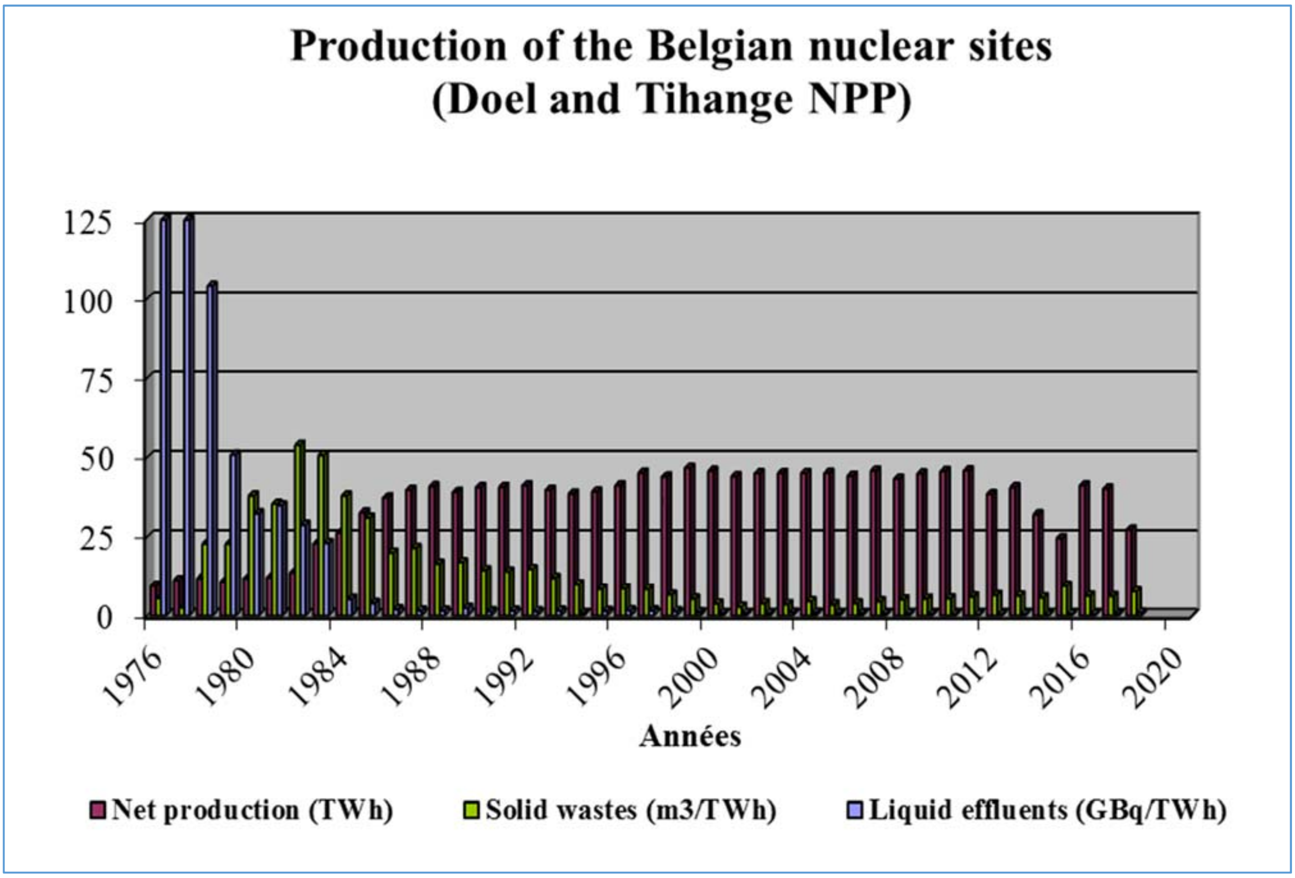
Another interesting point to note concerns the quantity of liquid and solid waste (removed for treatment by the ONDRAF/NIRAS - National Organisation for Radioactive Waste and Enriched Fissile materials) generated by nuclear power stations.

The total production of electricity is in general around 40 to 45 TWh. In 2014, 2015 and 2018 production dropped to a minimum of 25 to 30 TWh due to a long-term stop of some reactors.

The quantity of the radioactivity discharged in the liquid effluents dropped progressively from 1.0 tot 1.8 GBq/TWh (60 tot 70 GBq/y) in the 90's to about 0.3 to 0.4 GBq/TWh (15 to 17 GBq/y) in the period of 2010-2014. In the period of 2015-2017 it increased again to about 0.5 GBq/TWh (4 to 5 GBq/y) to reach almost 1.0 GBq/TWh (~ 8.5 GBq/y) in 2018. The increase last couple of years is mainly due to long term shut-down of multiple reactors.

This observation is even more amplified by the volume of solid waste generated per TWh removed for treatment by the ONDRAF/NIRAS: current volumes remain low and stable around 6 m³/TWh from 2012 to 2014, they increased to about 9,5 m³/TWh in 2015, decreased in 2016 to about 6.3 m³/TWh, to 6,2 m³/TWh in 2017 and to 7.8 m³/TWh in 2018.

This shows the efforts made by Belgian NPP's to reconcile the objectives of optimising industrial operations, notably in reducing the volumes of waste produced and the related costs while, on the other hand, "reducing" the discharge of effluents as far as possible. These elements of assessment clearly demonstrate the application of the B.A.T. – "Best Available Technology" – concept with regard to liquid and solid waste.



2.4 Belgoprocess nuclear site

The radioactive liquid effluents are generated by the waste treatment unit of Belgoprocess 2. Liquid discharges are operated in the Molse Nete river with a limit set at 25 GBq/month and a maximum of 150 GBq/year according to the following weighting formulae:

2,5 [α total] + 0.4 [^{90}Sr-^{90}Y] + 2.5 10^{-5} [^{3}H] + [^{60}Co] + 1.5 [^{134}Cs] + 1.5 [^{137}Cs] + 0.1 [β] $\leq$ 25 GBq/month (150 GBq/year maximum with a concentration limit of 15 MBq/m^3) in the river Molse Nete.

with [β] = [β total] – ([^{90}Sr-^{90}Y] + [^{60}Co] + [^{134}Cs] + [^{137}Cs])

The discharges from the site into the Molse Nete adequately comply with the limit set, even though they are not negligible. The principal radionuclides arising in liquid waste are tritium and, to a much lesser degree, activation and fission products. See Annex 2.

2.4.1 System(s) in place to reduce, prevent or eliminate discharges of radioactive substances

Origin:

- Liquid wastes treated by BP are mainly produced by SCK•CEN and Belgoprocess installations.
- Besides that, there are also effluents coming from Doel and Tihange NPPs, Belgonuclaire (dismantled now), FBFC International (dismantled now), IRE, JRC-GEEL (formerly known as IRMM, production of calibrated/reference sources, cyclotron) sites and finally hospitals and research centres (universities, …).

Kind of effluents:

Relatively low activity effluents:

- *Suspicious* effluents where activity is < 400 kBq/m^3 for beta/gamma emitters and < 40 kBq/m^3 for alpha emitters;
- *Contaminated* effluents where activity is < 400 MBq/m^3 for beta/gamma emitters and < 800 kBq/m^3 for alpha emitters;
- *Higher radioactive* effluents where activity is < 40 GBq/m^3 for beta/gamma emitters and < 80 MBq/m^3 for alpha emitters.

Medium activity effluents:

- With activity < 40 TBq/m^3 for beta/gamma emitters (i.e. liquid wastes of medium activity from the IRE site).

Treatment:

- Effluents are treated by coagulation/flocculation followed by sedimentation in settling tanks, the phase above is sent over an ultrafiltration unit before collected in a storage tank prior to disposal.
- Depending on the radioactivity levels, the effluents can be evaporated by BP.

Waste management:

- Residues or solid phases are conditioned by BP cementation before storage (since 2005 bitumisation is no longer applied). Up to 1992, high activity wastes - coming from the former Eurochemic plant (dismantled now) - were vitrified and stored. Now these processes are stopped.
- Before liquid effluents are released into the Molse Nete river, the following limits have to be respected: concentration < 15 MBq/m^3 and < 25 GBq/month or 150 GBq/a according to the weighting formulae described in 2.4.

The radionuclides to be monitored are stipulated in the licences of the nuclear sites under the responsibility of the FANC federal authority.

2.4.2 Systems abatement efficiency

Abatement systems and management (according to 2.4.1 and 2.4.2).

Abatement system/ Management	Into operation (Year)		Efficiency of abatement system		Comments
	Existing	Planned	Decontamination Factor	Other measure of efficiency	
Discharges:					
delay tank(s) **Liquid** : storage tanks prior to release in the river Molse Nete) 5 tanks (3 with volume of 400 m³ and 2 with volume 250 m³. **Ventilation Air and process gases** : Emissions consist of ventilation air, each installation is equipped with a discharge point with stack release after filtration.	**Liquid** : < 1960 **Ventilated Air** : <1970 part of the original design since 1960. Also for recent installations		**Liquid** : see precipitation and ultra-filtration **Ventilated air and process gases**: release are mandatory filtered on PRE, HEPA filters See HEPA	Gamma spectroscopy and alpha/ beta counting	Ventilation air to keep installations in under pressure. Process gases mainly coming from the extraction of the incinerator and extraction of the tank ventilations.
chemical precipitation	In operation in the late years 1960		Typical figures 95% Coagulation/flocculation for both radiological and chemical contaminants and sedimentation	Gross alpha, beta counting and gamma spectroscopy	4 reception tanks of 100 m³ each, 2 decanters of 100 m³ 'Cold' LW is treated in online system. LLW is treated batchwise
centrifuging	NO	NO			
hydrocyclone	NO	NO			
cross-flow filtration	NO	NO			
osmosis		NO			

Ultrafiltration: of the chemical components in the discharge liquid	Installation in operation since 2014		Removal of chemical parameters Hg, Ag, Co, U and Be to meet discharge norms	ICP analyses	2 separate treatment lines with a total capacity of 15 m^3/h
Evaporation: Liquid with higher activity contents, medium -level aqueous waste water is concentrated by evaporation	Installation in operation since < 1970		Distillates are further treated by flocculation. Concentrates are stored awaiting cementation.	Gamma spectroscopy and alpha/ beta counting	Treatment of MLW
Emissions:					
electrostatic precipitation	NO	NO			
cyclone scrubbing: extracted ventilation air from process installations passes a wet scrubber cyclone filter	Part of the original design		Washing and neutralization of acid gases before they reach the HEPA filtration. 90%		Neutralization of acid
chemical adsorption	NO	NO			
HEPA filtration	part of the basic design of each installation		> 99 % (measured according to the technical specifications for classified filters)		Intervention area's with high alpha contamination are equipped with double HEPA filters
cryogenics	NO	NO			
Active carbon filter	NO	NO			

2.4.3 Annual liquid discharges

The total alpha en the total beta liquid discharges have been more or less constant since 2004.

For tritium, since 2009, releases are decreasing. These releases are almost entirely due to the operation of the BR2 research reactor (MTR) situated on the SCK•CEN site. Observed fluctuations are linked to the number of working days during a considered year. Since the power of this reactor is small (125 MWth), produced quantities of tritium are also limited.

For beta emitters excluding tritium, releases are around 0,05 – 0,2 GBq per year. For alpha emitters, releases have increased to a maximum of 85,5 MBq in 2015 and 62.8 MBq in 2016 and then remain lower (25.55 MBq in 2017 and 20.7 MBq in 2018).

See annex 1 part 2 and trends graphs.

2.4.4 Emissions to air of concern for the marine environment

Origin: at Belgoprocess, gaseous wastes can be produced by burning solid and liquid wastes, by the gaseous and liquid waste treatments, by building ventilations,… The other nuclear installations also produce atmospheric wastes but will not be further discussed in this report.

Treatment: filtration by HEPA filters before releases in the chimneys.

Waste management: after filtration, releases are continuously monitored and sampled.

See annex 1 part 3 and trends graphs.

Note that Belgoprocess air emissions doesn't concern the marine environment, the data are mentioned for information only.

2.4.5 Quality assurance

Belgoprocess has a quality, safety and environmental policy. In order to implement this policy Belgoprocess has an integrated management system in accordance with the international standards ISO-9001 (quality), ISO-14001 (environment), ISO-45001 (safety) and ISO-17025 (lab). All the processes and activities are written down in process descriptions, instructions, forms and other matters.

Instruction-522 describes the control of discharge of waste water.

The monitoring and measurement of the atmospheric emissions are written down in instruction-751.

Data management occurs in order with these instructions and with the ISO-standards (records and records management is one of the requirements of the ISO–standards).

2.4.6 Site specific target values

Belgoprocess's aim is to perform all her activities with full consideration for the environment and the safety of its employees and of the population by reducing the effects of its operations to as low as reasonably achievable (ALARA). The discharge of radioactive effluents in the water (Nete at Mol) and emissions to the air are reduced and minimised by implementing the ALARA-policy. All the activities are carried out in accordance with the legislation and licenses and within its own requirements.

Specific target for radioactive liquid discharge:

Belgoprocess total discharged weighted radioactivity for 2018 was 0,288 GBq or just 0,2% of the permitted value (150 GBq/year). The specific site target is to emit not more than 2% (= 0,50 GBq/month) of the maximum month limit (25 GBq/month).

Specific target for radioactive atmospheric discharge:

The chimneys of the nuclear installations are continuously monitored and sampled after filtration (preliminary filters and high efficiency particulate air filters) so that a total overview is obtained of global alpha- and beta-emissions. The various chimneys on Belgoprocess sites 1 and 2 only emitted in 2018 a minimal fraction (maximum 0,5%) of the relevant authorised limits (N4).

The radon emissions from the waste stored at the Solarium are not included (emitted via the chimney 280X). The specific site target is to emit not more than 10% of the authorised limit (N4) or N3 (= N4/10) by each chimney.

Relevance of target and closeness to target value

Closeness to target value for radioactive liquid discharge:

The specific site target is to emit not more than 2% (= 0,50 GBq/month) of the maximum month limit (25 GBq/month).

The liquid discharge results for 2018 show that only a minimal fraction (maximum 16%) of the specific site target (= 0,50 GBq/month) is emitted in 2018.

Closeness to target value for radioactive atmospheric discharge:

The specific site target is to emit not more than 10% of the year limit (N4) or N3 (N4/10).

The atmospheric discharge results for 2018 for all chimneys show that only a minimal fraction (maximum 5%) of the specific site target (N3) is emitted in 2018 (except for radon chimney 280X).

2.4.7 Any other relevant information

NA.

2.4.8 Explanations for lack of data or failure to meet BAT/BEP indicators

NA.

2.4.9 Summary evaluation

Liquid and atmospheric releases remain very low since 2004 where the latter decreased significantly since 2013. The Belgoprocess releases are very low compared to their autorisation limits.

3. ENVIRONMENTAL IMPACT

3.1 Concentrations of radionuclides of concern in representative samples of water, sediment and fish

The environmental surveillance programme in the vicinity of nuclear power stations is performed by the FANC radiological monitoring programme. The analyses of environmental samples (sediment & water in rivers and north-sea, fauna & flora in freshwater and marine water, soil, air, rain, milk, foodchain, drinking water) show that there are no detectable α- and β-activity concentrations (excluding tritium) referring to radioactive discharges from NPP. Tritium discharges from pressurised water reactors can increase the tritium concentrations in surface water of rivers by 10 to 30 Bq/l (e.g. river Meuse).

In 2018 and 2019 (as previously) several sampling points have been chosen off the Belgian coast where sampling of sea water, sediments and fish living on the bottom is organised 4 times a year by the oceanographic vessel, the “Belgica” (photo on the right taken from the site of the North Sea Mathematical Model Management Unit). Sixteen samplings are carried out in a belt of 5 to 25 km offshore from the towns of Coxyde, Newport, Ostend and Blankenberge (one point is located 37 km directly below Wenduine near Blankenberge). The measurements taken relate to monitoring the levels of alpha, beta and gamma emitting radioactive nuclides, as well as ^{40}K as far as natural radioactivity is concerned.

On the coast, because of their accumulation and concentration capacity, samples are essentially taken of seaweed, fish, molluscs and crustaceans to measure the main fission and activation products as well as Th, Pu and U.

The compartments monitored are:

- Atmosphere compartment: dust samples from the air (filters) near Coxyde;
- Land compartment: taking of soil samples (meadows) near Coxyde;
- Marine compartment: water sediments and samples of fauna (crustaceans, bivalves, fish) and flora (seaweed).

Generally: The results obtained clearly show that the radiological situation of the maritime area does not give rise to any particular comments and does not require any action. Indeed, only natural radioactivity is measured (^{40}K). Although traces of artificial radioactivity (^{137}Cs and transuraniums in fish) are sometimes detected (at the level of the detection limits of the measuring equipment), they remain entirely negligible.

Sixteen sampling points are visited quarterly by the oceanographic vessel, the “Belgica”. They are situated in a band of 5 to 25 km off the towns of Coxyde, Newport, Ostend and Blankenberge (one point is situated 37 km offshore from Wenduine near Blankenberge). Samples of algae (Fucus vesiculosus) are taken on a pier in Ostend, shrimps (*Crangon sp.*) and mussels (*Mytilus edulis*) are also sampled.

The measurements taken relate to monitoring the levels of alpha, beta and gamma emitting radioactive nuclides, as well as ^{40}K as far as natural radioactivity is concerned.

Samples of sea water are taken with the help of "Niskin" bottles.

The sediments are brought to the surface using a "Van Veen" scoop (photo on the left), a sort of grapnel with an open jaw lowered to the sea bottom at the end of a steel cable.

As soon as the jaws touch the bottom, the spring which keeps the jaws open is released. Before returning to the surface, the jaws close and trap a quantity of sand or sediment from the sea bed.

Samples of the fauna (fish) are collected for subsequent radioactivity analyses using a trawl net (photos to the right).

The results obtained confirm the absence of any problem concerning the radiological state of the marine environment. The following table summarises the results obtained.

In greater detail:

- The results obtained show that the presence of natural radioactivity (^{40}K) is detected on a regular basis;
- Traces of artificial radioactivity (^{137}Cs) are revealed in the marine sediments and the fish (barely significant);
- No artificial radioactivity is demonstrated in fish.

Radioactivity measurements for the marine environment: waters and sediments

	Waters (Bq/L)		Sediments (Bq/kg dry)	
	measurement	DL	measurement	DL
γ	NM	~ 0.1 to 0.2	NM	0.6 to 2.1
^{137}Cs	traces (1.1 to 3.0) 10^{-3}	~ 2.1 10^{-3}	NM to 2	~ 0.7
^{60}Co	NM	0.1	NM	~ 0.7
total β	~ 11			
^{40}K	~ 10.5		200 to 320	
α total	NM	~ 0.3		
$^{226,228}Ra$	NM	0.2 to 0.4	6 to 13.5	~ 5
$^{238,(239+240)}Pu$	NM	~ 10^{-4}	NM to 0.9	~ 0.3

NM: non-measurable, measurement less than or equal to the detection limits (DL)

Radioactivity measurements for the marine environment: flora and fauna

	Flora (seaweeds) (Bq/kg dry)		Fauna (mussels and shrimps) (Bq/kg dry)		Fauna (flat fish) (Bq/kg dry)	
	measurement	DL	measurement	DL	measurement	DL
γ	NM	< 1.5	NM	< 2.6	NM	< 5.0
^{137}Cs	NM	~ 1.0	NM	~ 1.0	NM	~ 1.8
^{60}Co	NM	~ 1.2	NM	~ 1.0	NM	~ 1.9
^{131}I	NM to 25	~ 20	NM	14 to 18	NM	~ 52
^{90}Sr	NM	~ 6.0	NM	~ 3.5	NM	~ 5.9
^{40}K	880 to 970		180 to 240 (mussels) 180 to 210 (shrimps)		390 to 470	
^{3}H	NM	~ 14	NM	~ 13	NM	~ 15
^{99}Tc	NM	~ 45.0			traces	~ 6.5
$^{226,228}Ra$	NM to 9	4 to 9	NM	2 to 5	NM to 11	3.7 to 7.4
$^{238,(239+240)}Pu$	NM	~ 0.035	NM	0.036 to 0.070	NM	~ 0.05
^{241}Am	NM to 0.06	~ 0.04	NM	0.046 to 0.060	NM	~ 0.05

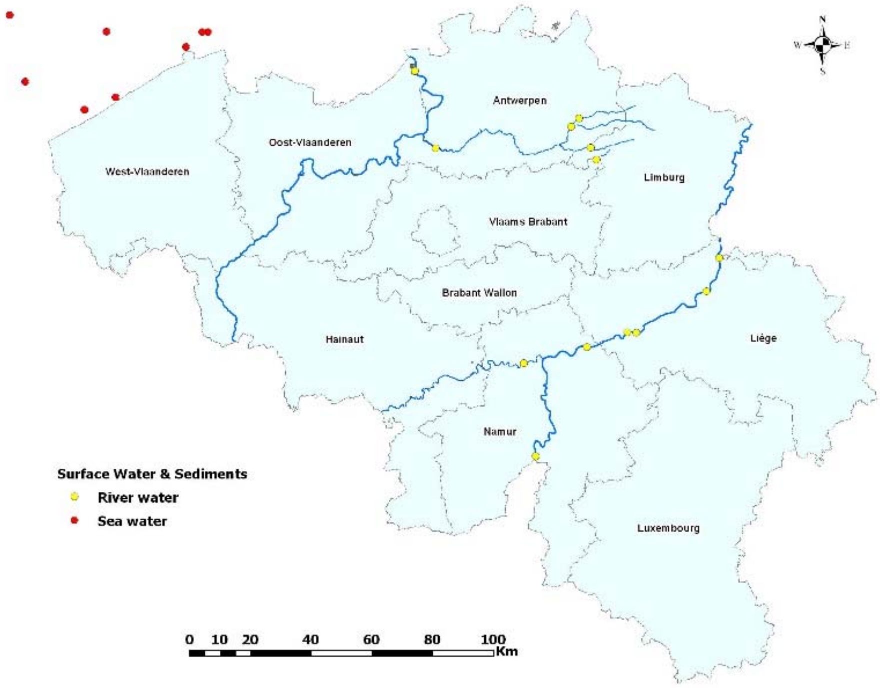
NM: non-measurable, measurement less than or equal to the detection limits (DL)

Summary:

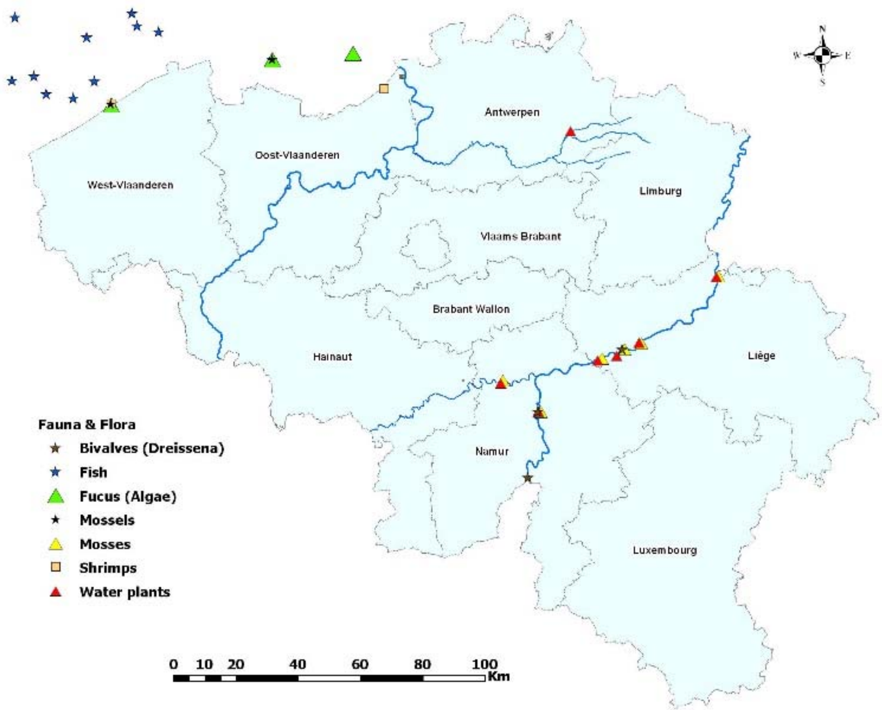
- Natural radioactivity (^{40}K) is mainly responsible for the radioactivity of the different sections of the marine environment;
- ^{137}Cs, $^{238,(239+240)}Pu$ and ^{241}Am, transuranic nuclides of artificial origin (produced and discharged by the nuclear power plants and discharged by the reprocessing industry of used fuel – reprocessing plants of the Hague in France and Sellafield in the United Kingdom) are not detectable: all the levels are of the order of the detection limits.

3.2 Environmental monitoring programme, frequency of sampling, organisms and or other types of environmental samples considered

Monitoring <u>surface water</u> and <u>sediments</u> in fresh – rivers (Sambre, Meuse, Grote Laak, Winterbeek, Grote Nete, Molse Nete and Scheldt) and marine water – North Sea;



Monitoring the <u>living environment</u> by searching for radioactivity in fauna in fresh and salt water (molluscs from fresh and salt water, shrimps and fishes) and in flora in fresh water (aquatic plants and mosses) and seawater (algae) who are <u>bio-indicators</u> of the presence of radioactivity;



Radiological monitoring programme for the maritime zone (North Sea and Scheldt estuary)

Zone		Location of sampling points	Type of measurement	Frequency of sampling
North Sea	water	off the coast (Belgica campaign), 16 locations	Spectrometry γ: $^{134-137}Cs$, $^{57-58-60}Co$, ^{54}Mn ^{40}K Spectrometry β total & α total Spectrometry α: $^{238-(239+240)}Pu$	quarterly
	sediments	off the coast (Belgica campaign), 16 locations	Spectrometry γ: ^{7}Be, $^{134-137}Cs$, $^{(57)-58-60}Co$, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}Ra$, ^{228}Th Spectrometry α: $^{238-(239+240)}Pu$	quarterly
	seaweeds	Ostende – Belgian coast	Spectrometry γ: ^{7}Be, $^{134-137}Cs$, $^{(57)-58-60}Co$, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}Ra$, ^{228}Th ^{90}Sr, $^{238-(239+240)}Pu$, ^{241}Am, ^{3}H organic, ^{99}Tc	quarterly
	mussels & shrimps	Ostende – Belgian coast	Spectrometry γ: ^{7}Be, $^{134-137}Cs$, $^{(57)-58-60}Co$, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}Ra$, ^{228}Th ^{90}Sr, $^{238-(239+240)}Pu$, ^{241}Am, ^{3}H organic	quarterly
	fish	off the coast (Belgica campaign), 16 locations	Spectrometry γ: ^{7}Be, $^{134-137}Cs$, $^{(57)-58-60}Co$, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}Ra$, ^{228}Th ^{90}Sr, $^{238-(239+240)}Pu$, ^{241}Am, ^{3}H organic, ^{99}Tc	quarterly
Scheldt	shrimps bivalves, seaweeds	estuary downstream from Doel (Kieldrecht) estuary/North Sea (Hoofdplaat & Kloosterzande)	Spectrometry γ: ^{7}Be, $^{134-137}Cs$, $^{(57)-58-60}Co$, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}Ra$, ^{228}Th ^{90}Sr, $^{238-(239+240)}Pu$, ^{241}Am, ^{3}H organic, (^{99}Tc for seaweed)	quarterly

3.3 Systems for quality assurance of environmental monitoring

ISO 5667: Water quality - Sampling - Preservation and handling of water samples.

ISO 18589: Measurement of radioactivity in the environment - Soil - Sampling strategy, sampling and pre-treatment of samples.

3.4 Any other relevant information

The TELERAD network is the automatic remote radioactivity measuring network in Belgium. It comprises 245 radioactivity measuring stations, which constantly measure the radioactivity of the air and river waters. The measuring stations are distributed throughout the entire country, around the Tihange, Doel, Mol and Fleurus, as well as in the urban areas close to these installations and in those around the Chooz nuclear installations. These measuring stations are linked to a centralised system which they alert automatically if they detect any abnormal rise in radioactivity levels.

The TELERAD network is a measuring and early warning network and, as such, pursues the following two major objectives:

- The continuous recording of measurements to provide all necessary statistical information on the level of radiation found in the country;
- The setting off, without delay, of an alarm to signal the exceeding of a warning threshold.

TELERAD is thus an alarm network that enables the real-time detection of any abnormal situation, which may lead at its highest level of severity to the launching of the Emergency Plan for Nuclear Risks.

In the event of a nuclear accident, TELERAD will play an important role in the taking of decisions, optimising interventions and countermeasures implemented by the relevant authorities as well as keeping the country's citizens informed on an ongoing basis.

The measuring stations used in the TELERAD network for measuring radioactivity in the air are of four types:

The **dosimetry stations** (Geiger Müller detector type) for measuring the ambient gamma radioactivity, of which there are 159 on the territory (including those around the boot of Givet for monitoring the Chooz nuclear site).

Each measuring station is equipped with a rain detector which provides information about the presence and duration of rainy periods. Following photographs show a station in the environment with a view on its electronics.

The **gamma spectrometry stations** (NaI detector) for measuring the ambient gamma radioactivity and the gamma radioactivity of some radionuclides (10 predefined nuclides), of which 67 were localized on the fences around nuclear sites of SCK•CEN, nuclear power stations of Tihange and Doel as IRE. Photographs show a station in its environment. In 2019, a reorganization of the gamma spectrometry stations was carried out: half of the spectrometry stations located on the fences of the nuclear sites were moved to the surrounding agglomeration and replaced by regular dosimetry stations. This gives the advantage of having spectrometric information on atmospheric releases in a larger area up to about 5 km around each site.

Three spectrometric stations have been added around the BELGOPROCESS site in 2018. These stations have the particularity of being powered by solar panels and can be moved by means of a trailer.

The **aerosol stations** (ZnS detector), of which there are 7 for measuring the radioactivity of dusts suspended in the air (aerosols and fine particles), which determine the total alpha and total beta radioactivity.

The photograph on the left shows the alpha/beta measuring unit with a view of the unreeling filter tape which collects the dusts and particles impacted when the air is pumped.

These stations are supplemented by a unit measuring radioactive iodine on the aerosols and the air particles when a pre-determined threshold of beta radioactivity is exceeded (7 units in total coupled with alpha/beta measurement). The photograph on the right shows the detector in its casing (cylinder) and the parallelepipedal tube containing the active charcoal cartridges (on the right).

If the warning thresholds are exceeded, active carbon cartridges, intended to trap the radioactive iodine, are automatically measured after pumping the outside air in order to determine the level of radioactivity.

TELERAD also has 8 **river stations** which continuously measure the gamma radioactivity of river waters. These stations are of two types:

Retrofit : this type of station (6) is installed close to the three rivers receiving discharges from nuclear sites and waste water from major urban centres (combining research centres, universities and hospitals): the Meuse, the Sambre and the Nete.

These stations are large containers from which two inlet and outlet pipes allow river water to be pumped to the detector and returned after radioactivity has been measured – photograph on the right.

On the far left of the photograph, a programmable automatic sampler (Buhler type PP MOS) enables water to be pumped into flasks for gamma, alpha and beta spectrometry (for the programme for the radiological monitoring of the territory).

Inside is the gamma spectrometry unit ($LaBr_3$ crystal coupled to multi-channel analyser) housed in its own tank, surrounded by a strong lead screen protected by a stainless steel casing in which the water pumped from the river enters and leaves – photograph on the left. Ten radionuclides are defined in the recognition software.

The photograph here below shows the inside of the PP MOS with the pumping instruments in its upper section and all the 2.9-litre flasks (12 in all) at the bottom base.

This fully programmable unit enables pre-determined volumes of water to be collected over a fixed time period and frequency.

Above the PP MOS are the counting unit and the high voltage supply of the river station detector.

To the left of the gamma spectrometry unit is a large volume water sampler (SwedMeter type) which enables a sample of the water in the pipe to be taken automatically as soon as an alarm level is exceeded. This water is stored in a 25-litre flask for the purpose of subsequent gamma (and beta) spectrometry analyses in the laboratory.

BCI : these stations have their probe directly immersed in river water. They are two in number located in the Scheldt downstream and upstream of the Doel nuclear power plant.

TELERAD also has 4 stations (BCI) in the release channels of the nuclear power plants which continuously measure the gamma radioactivity of the releases: one in the release channel of the nuclear power plant of Doel and three in the release channels of the nuclear power plant of Tihange. These stations allow to monitor the liquid discharges from the electricity producers with close attention.

These stations also have a $LaBr_3$ detector which is coupled to a multichannel detector. Ten radionuclides are defined in the recognition software.

3.5 Explanations for lack of data or failure to meet BAT/BEP indicators

NA.

3.6 Summary evaluation

The Agency reviews its entire sampling and measurement programme each 4-years in order to stay harmonised with international requirements (European Commission, OSPAR, …).

The actual programme (2017-2020) – with more than 4,350 samples giving rise to almost 20,500 radioactivity measurements – enables better monitoring of the different regions of the country while taking account of their specific nature. Comparisons between sections of each region and between regions themselves have been made easier.

The radiological situation is generally excellent:

The radiological monitoring of the territory, which makes it possible to obtain an accurate picture of environmental radioactivity in Belgium and the risks to the population, does not reveal any major problems. Most of the time, the radioactivity of artificial origin is considerably lower than radioactivity of natural origin, if it can be measured at all in the samples taken.

The radiological monitoring of the territory also clearly shows that the dose rate (ambient radioactivity) particularly depends on the nature of the soil: the rocky soil in the south of the country emits more radon (natural radioactive gas) than that in the north of the country (sandy soil). It is for this reason, for example, that the dose rate measured in Wallonia is greater than that measured in the vicinity of the Doel nuclear power station, which itself has a negligible impact on the environment.

Nuclear power stations, in particular, have a negligible or even undetectable radiological impact on the environment. Of course, any anomaly detected by the agency or brought to its attention is examined and dealt with in the appropriate manner.

Particular attention is required:

The radiological situation of the Belgian territory is perfectly satisfactory; however, one basin, i.e. the entire Laak-Winterbeek-Nete-Scheldt hydrographic network, still arouses attention on account of its abnormally high charge of both artificial and natural radioactivity (^{226}Ra). This concerns the entire Laak-Winterbeek-Nete-Scheldt hydrographic network.

Certain nuclear facilities in the Mol-Dessel region have a measurable, though small, radiological impact on the environment. It was also the case for the non-nuclear industry producing feed phosphates in the region of Tessenderlo (stopped in 2013, dismantled in 2017), with historical discharges of ^{226}Ra. On the other hand, the – measurable – radiological impact of these installations in the north-east of the country has declined sharply in recent years.

4. RADIATION DOSES TO THE PUBLIC

4.1 Nuclear Power Stations : Tihange and Doel

4.1.1 Average annual effective dose to individuals within the critical group(s) via the marine exposure pathway(s), and caused by current discharges

For both nuclear power stations, calculations made for liquid and atmospheric discharges under conservative assumptions show that the maximum effective doses to the population in the vicinity of the NPP's are well below the national limits of 1 mSv/y (maximum limit including all atmospheric and liquid contributions).

See annex 1 part 4 and annex 3: trend line figures.

4.1.2 Total exposures (i.e. including those from emissions and historic discharges/emissions)

The total dose due to releases in 2018 for the most critical person[4] (children 1-2 years) is 0.0692 mSv, far below the legal limit of 1 mSv/y. It is always the C-14 and to a lesser extent Tritium which are major contributors to the dose to the individual person.

Liquid discharges: for the period 2009 to 2018, the total exposure represents 0.12 to 0.23% for Tihange and 0.05 to 0.08% for Doel of the annual dose limit (1 mSv/y). If we take into account the dose constraint (see page 4 - Discharge limits), calculations show that effective doses represent 1.48 to 2.83% for Tihange and 0.2 to 0.36% for Doel of the dose constraint (0.08 and 0.23 mSv/y for Tihange and Doel respectively).

Atmospheric discharges: for the periode 2000 – 2018, the exposure represents around 2.27% for Tihange and between 0.9 – 1.0% for Doel of the annual maximum dose limit of 1 mSv/y. If we take into account the dose constraint (see page 4 - Discharge limits), calculations show that effective doses represent ~ 14% for Tihange and ~5% for Doel of the dose constraint (0.19 and 0.18 mSv/y for Tihange and Doel respectively).

See annex 1 part 4 and annex 3: trend line figures.

4.1.3 The definition of the critical group(s), including information on age distribution, size and other relevant information, and on whether the critical group is real (identified) or hypothetical

Following the calculation of the radiological consequences in the EURATOM Article 37 Dossier, the principle of the "most vulnerable person" is implemented for all calculations; this most vulnerable person is part of different critical groups (by age category) in order to determine which individual in a specific age category is the most vulnerable. It means a person located at the place with the highest radionuclides concentration resulting from the dispersion of the releases in the air. Similar conservative assumptions are considered for the liquid releases. Information on nearby population was gathered for the Article 37 dossier.

The assumption of the most exposed person is conservative as regards exposure to releases (= exposed continuously at the point of maximum exposure). Critical person is an extremely pessimistic situation: it is a person living permanently near the nuclear power plant, eating food exlusively produced around the plant, swimming and practicing water sports in the river who's receiving these liquid discharges. Different age classes are taking into account : baby, child (1-2 years, 2-7 years, 7-12 years), teenager, adult.

Local meteorological conditions are taken into account in the meteorological model (Art. 37 §3.4.1) that was developed in the years 1968-1971 for the plant licensing studies.

[4] The critical Person is an extremely pessimistic situation: it is a Person living permanently near the nuclear power plant, eating food exclusively produced around the plant, swiming and practicing water sports in the river where the liquid effluents are discharged into.

Local habits were taken into account by age category (as defined in NUREG 1.109 and applicable ICRP publications) in the definition of the exposure pathways that are locally significant. Conservative assumptions are taken into account (such as no dilution of the liquid releases in the river, use of underground water coming from undiluted water from the river with a transfer period of 82 days…).

This approach is consistent with the US 10CFR50 which is an important regulatory basis for the Belgian NPPs.

4.1.4 Information on exposure pathway(s) considered, and whether these are treated individually or collectively

Total dose to the most vulnerable person is calculated for atmospheric and liquid pathways.

Dose from atmospheric releases:

- direct exposure to the noble gas cloud;
- contamination due to iodine releases, aerosols, gaseous tritium and C-14:
    - air inhalation;
    - body exposure to deposition on the surface/ground;
    - contamination by ingestion of contaminated food (milk, meat, vegetables, fresh vegetables).

Dose due to liquid effluent discharges:

- By ingestion:
    - drinking water;
    - fish;
    - aquatic food other than fish;
    - milk and meat from contaminated domestic animals by water watering;
    - Food contaminated by irrigation water.
- external irradiation:
    - swimming;
    - water sports;
    - professional navigation;
    - stay on the banks;
    - stay on dredging sludge/mud.

4.1.5 Basis for methodology to estimate doses (models, actual measurements, and verification of data, as appropriate)

The calculation method is identical to the one used during the design of the units, the hypotheses are similar. This method is described in §3 and §4 of the Euratom Article 37 notification file for the nuclear power plant sites. The calculation method is based on NUREG 1.109. The calculation method used, was drafted in the framework of the Euratom Article 37 notification file.

In 2002, a re-evaluation of the dose calculation was made, taking into account new parameters (e.g. new dose conversion factors, respiration rate, etc.) by the applicable ICRP publications. This document takes into account 6 age categories (instead of the 4 age categories used in NUREG 1.109[5]). The re-evaluation of the

[5] Calculation of annual doses to man from routine releases of reactor effluents for the purpose of evaluating compliance with 10 CFR part 50, Appendix I, Regulatory Guide 1.109 rev.1, USNRC-October 1977.

dose calculation was made in the framework of Council Directive 96/29/Euratom of the European Commission.

In the framework of the PSR, an actualisation of the impact study for radiological consequences is performed every ten years.

4.1.6 Site-specific factors for significant nuclides, used to estimate the dose to critical group members from discharge values

The C-14 discharge is only measured since respectively January 2019 and October 2018 at units 2 and 3 of Tihange NPP. For Tihange NPP unit 1 and all Doel NPP units, the activity is determined conservatively, based on scientific literature and the Safety Analysis Reports of the units.

4.1.7 Site specific target annual effective dose

The legal effective dose limit is 1 mSv/year.

The estimated effective dose limit taking into account the discharge limits for the different nuclides, as defined in the Technical Specifications of the Safety Analysis Report, is 354 µSv.

The legal limit is determined in Article 20.1.4 of the Royal Decree of 2001: “General regulations for the protection of the public, workers and the environment against the dangers of ionizing radiation”.

The effective dose is calculated each year. The average effective dose for the years 2014 – 2018 was less than 2% of the legal limit and less than about 5% of the TechSpec limit, despite being calculated in a conservative manner.

Tihange Nuclear Power Plant doesn’t define a site specific target for annual effective dose. Objectives are fixed only on gaseous and liquid releases (see 2.1.6).

Effective dose constraint is fixed to 0.21 mSv/y for Tihange NPP and to 0.37 mSv/y for Doel NPP by technical specifications (FANC).

4.1.8 Systems for quality assurance of processes involved in dose estimates

Quality Assurance is made of several steps:

- At the time of dose estimation, the applicable referential is assessed, meaning that up-to-date reference documents (regulatory, standards and guides) are used; a regulatory watch is conducted on legislative texts, regulations, standards and guides and their impact on the dose assessment process is checked regularly;
- Dose estimates are made by use of internationally approved methods (US Regulatory Guides, ICRP publications…). The ensuing calculation results are then compared for consistency with expert judgement and results on similar contexts;
- Use of a Quality Management System based on ISO-9001 for the overall process.

Dose estimates are produced every year for the actual routine releases and averaged on the last 10 years period. This is based among others on the NUREG 1.109 and applicable ICRP publications.

In the framework of the Periodic Safety Review, an actualisation of the dose estimation for routine releases is underway. It intends to use state of the art modelling tools together with recent meteorological data and actualised local habits.

Similarly, dose estimates are reviewed at the light of recent knowledge in accident conditions. This process is driven by both the Corporate Nuclear Safety Department of the operator and the Safety Authorities.

4.1.9 Any relevant information not covered by the requirements specified above

NA.

4.1.10 Explanations for lack of data or failure to meet BAT/BEP indicators, as well as, when appropriate, a description of on-going or planned activities

In the framework of the Periodic Safety Review, an actualisation of the dose estimation for routine releases is being made every ten years, following the SSG-25.

4.1.11 Summary evaluation

The method for estimating the dose to the public caused by routine discharges, being based on requirements of Article 37 of the Euratom Treaty, is relevant and reliable. The calculations are performed in a conservative mannerand the method is kept up to date, e.g. in the framework of new directives, decennial revision, etc.

Total releases in Tihange and Doel Nuclear Power Plants are equivalent to the average releases between 2014 and 2018.

In 2018, total doses to the most critical person due to those releases (1-2 years children) is 0.049 mSv for Tihange and 0.020 mSv for Doel NPP. This value is largely below the legal limit (1 mSv/y) and the value given in the technical specifications (0.21 mSv/y for Tihange and 0.37 mSv/y for Doel).

4.2 Belgoprocess nuclear site

4.2.1 Average annual effective dose to individuals within the critical group(s) via the marine exposure pathway(s), and caused by current discharges

See annex 1 part 4, annex 2 part 3 and annex 3: trend line figures.

4.2.2 Total exposures (i.e. including those from emissions and historic discharges/emissions)

Liquid discharges: for the period 2014 to 2018, the total exposures represents between 0.0025 to 0.0044% of the dose limit (1 mSv/y). If we take into account the dose constraint (see page 4 - Discharge limits), calculations show that effective doses represent 0.01 to 0.018% of the dose constraint (0.25 mSv/y).

Atmospheric discharges: for the period 2014 - 2018, the total exposures represents 0.75 to 1.2% of the dose limit (1 mSv/y). If we take into account the dose constraint (see page 4 - Discharge limits), calculations show that effective doses represent 2.5 to 4% of the dose constraint (being 0.3 mSv/y).

See annex 2 part 3 and annex 3: trend line figures.

4.2.3 The definition of the critical group(s), including information on age distribution, size and other relevant information, and on whether the critical group is real (identified) or hypothetical

Dose impact of liquid waste discharge

Two categories of potentially exposed people are considered in the assessment. Both categories consists of local people, that is, people living sufficiently close to the river that they could be potentially exposed either directly to radionuclides in the river or indirectly. A second group is defined as people who are more intensive exposed due to special activities like fishing, swimming, farming, … Within the two categories of people two age groups are considered, 20 year old adults and 10 year old children, they cover the range of exposures.

Dose impact atmospheric

The calculation method bases on the IFDM model uses 6 age groups of exposed people with age distribution from baby to adults. Reference is the NUREG 1.109.

Dose conversion factors and the 6 age groups are included in the national legislation "*General regulations for the protection of the population, workers and the environment against the dangers of ionising radiation (GRPIR)*".

4.2.4 Information on exposure pathway(s) considered, and whether these are treated individually or collectively

Exposure pathway liquid discharge

The calculated dose is based on a calculation model from NRPB for the representative local people near the river Molse Nete.

It consists of 22 exposure pathways from which 19 have to do with internal contamination due to inhalation of contaminated dust particles and the ingestion of food that possibly could have come in contact with water from the river the other 3 pathways comprise the direct external radiation from the waste water and the sediment of the river. It is assumed the mean exposed group near the river spend 50 h/year near the riverside, swims 10 h in the river and spend 300 h/ year on area that contains sediment from the river. It is also assumed that the local habitat consumes 10% of the vegetables that has grown nearby the river.

Currently, the existing model is under revision. The preliminary results and dose calculations from the new model are about 20 times higher then those arising from the NRPB model.

Exposure pathway atmospheric discharge

Exposure pathways are inhalation, ingestion and external exposure.

The most critical person is an adult who stays permanently near the fence of the site border. Additionally this person consumes vegetables, meat and milk from cows near the site border.

This model is currently also under revision.

4.2.5 Basis for methodology to estimate doses (models, actual measurements, and verification of data, as appropriate)

For Belgoprocess nuclear site: adult, water pathway calculated by NRPB-231 (1990) and air pathway calculated by NUREG 1.109, DCF ICRP-72 (from 2002).

Model liquid discharge

Based on a mathematical model developed by NRPB. The doses calculated are the sum of the effective dose equivalent due to external radiation received in a year and the committed effective dose equivalent due to intakes of radionuclides in the same year.

Model atmospheric discharge

Calculation with the mathematical model IFDM (Immission Frequenty Distribution Model). Model developed by SCK•CEN and is an calculation of the dispersion of a pollution with a bi Gaussius dispersion model based on the NUREG 1.109.

4.2.6 Site-specific factors for significant nuclides, used to estimate the dose to critical group members from discharge values

NA.

4.2.7 Site specific target annual effective dose

Site constraint dose of 300 µSv per year due to atmospheric discharges and of 250 µSv per year due to liquid discharges.

The effective doses to the representative persons are assessed every year.

4.2.8 Systems for quality assurance of processes involved in dose estimates

The processes involved in dose assessment comply with the ISO 9001 quality standards and as part of the integrated certification management system ISO 14001, ISO 9001, OHSAS 18001 and ISO 17025 (lab). That is to say that they are traceable and subject to verifications conducted by independent Q&A organisms.

4.2.9 Any relevant information not covered by the requirements specified above

NA.

4.2.10 Explanations for lack of data or failure to meet BAT/BEP indicators, as well as, when appropriate, a description of on-going or planned activities

NA.

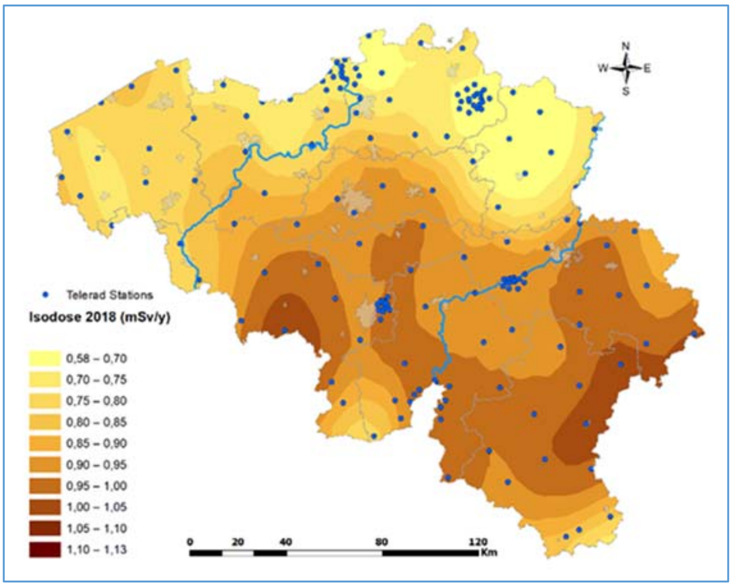
4.2.11 Summary evaluation

It can also be concluded that based on the evaluation of the BAT/BEP indicators for discharges from the Belgoprocess site that relevant and reliable management and technical systems are in place. Discharges are constant or in a downward trend.

The methods for estimating the doses (currently under revision for the Belgoprocess site) are relevant for the assessment of the exposure of the population and to check the compliance with dose limits and constraints.

It can be concluded that based on the BAT/BEP indicators for discharge, environmental impact and radiation doses to the public that the BAT have been applied at Belgoprocess site during the time period covered by this report.

4.3 TELERAD: instrument for calculating the external exposure dose rate

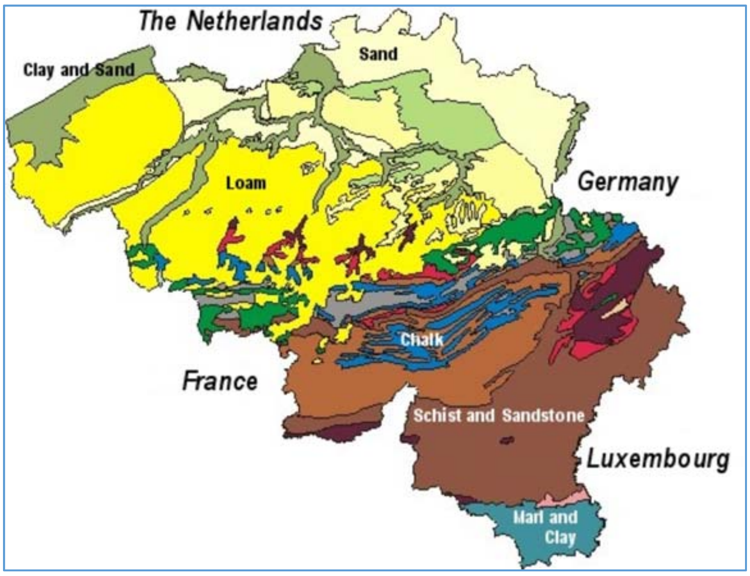


Since the TELERAD network measures a dose rate (µSv/h) continuously, it is possible to calculate the annual gamma exposure dose on a station-by-station basis. A group of values – only slightly different in value - can be brought together under the same colour by aid of a mathematical interpolation, enabling zones or surfaces where measurements are in a same value range to be represented on a map.

The map on the left shows the outcome of such processing which results in the construction of an illustrative map (because build up on basis of relatively limited detectors) of the natural background radiation due to gamma radioactivity. This background noise represents the annual exposure expressed in mSv (external gamma exposure dose) to which the territory is subjected.

An analysis of the exposure map shows that the average gamma exposure dose in Belgium is 1 mSv/year; it increases from 0.7 mSv/year in the north to about 0.8 - 0.9 mSv/year overall in Flanders until 1.1 mSv/year in Wallonia and, more particularly, in the Ardennes.

The exposure varies according to the nature of the soil. The doses are, indeed, generally higher in old terrains made up of rock such as chalkstone, schist, psammite and mixed sands with chalk etc. which is the case for Belgium in the Ardennes and Condroz area – see the geological map opposite. In Flanders, where the soil is predominantly made up of sedimentary terrains (sand, alluvium and clay), the doses are lower. It is noted that, in the south of the country, i.e. a marly, clayey region with sandy-silty layers over a chalk sub-stratum, the dose declines to reach values comparable to those in the north of the country.



The limit for the dose of ionizing radiation in the population, set at 1 mSv/year, does not take account of the natural radiation linked to cosmic radiation or the radiation of the soil and subsoil or the radiations used for medical purposes. Consequently, it does not apply in this case (natural ambient background noise).

ANNEX 1

NPPs

Tihange NPP

1. Site Characteristics		By:	
Name of facility	NPP Tihange		Claes Jurgen, ir
Type of facility	PWR		Hermans Audrey, ir
Date commissioned	1975-1982-1985		
date of shut-down	2025-2022-2025		
Location	Belgium (Tihange)		
Receiving water	Meuse		

Installed capacity	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
MW[e]	2973	2973	2973	2973	2985	2985	2985	2985	2985	2985	2985

Electricity generation (net)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
GWh	~23000				23186	23141	23495	23183	22597	23097	22740

2. Discharge and emission data

annual liquid discharges, Bq/a

Radionuclide (TBq/a)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Co-58	8,46E-03	6,21E-03	8,34E-03	2,06E-02	1,46E-02	1,37E-02	1,07E-02	8,40E-03	7,63E-03	4,55E-03	6,78E-03
Co-60	4,60E-03	3,84E-03	3,78E-03	5,30E-03	5,32E-03	5,07E-03	8,33E-03	5,22E-03	1,02E-02	6,10E-03	6,90E-03
Zn-65	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,42E-05	1,80E-05
Sr-90	2,10E-05	5,75E-06	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Zr/Nb-95	1,59E-04	2,20E-04	2,35E-04	1,02E-03	6,93E-05	3,00E-04	5,28E-04	2,62E-04	2,00E-04	7,15E-04	6,74E-04
Ru-106	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,25E-04	2,47E-05	0,00E+00	0,00E+00
Ag-110m	1,87E-03	3,59E-04	8,40E-04	3,57E-04	8,27E-04	1,48E-03	1,44E-03	7,16E-04	7,85E-04	4,32E-04	7,33E-04
Sb-125	1,58E-03	4,02E-04	2,70E-04	4,47E-04	1,02E-03	8,48E-04	1,95E-03	8,43E-04	6,71E-04	1,26E-04	6,75E-05
Cs-134	2,47E-04	9,05E-05	5,10E-05	9,62E-05	2,99E-04	1,17E-03	2,08E-03	7,89E-04	1,05E-03	4,51E-04	1,97E-04
Cs-137	1,05E-03	2,88E-04	3,50E-04	4,22E-04	5,36E-04	1,15E-03	2,10E-03	1,27E-03	2,02E-03	1,01E-03	4,83E-04
Ce-144	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,50E-06	9,00E-06	2,91E-05	4,27E-06	0,00E+00
Total-Beta*	2,00E-02	1,27E-02	1,57E-02	3,32E-02	2,66E-02	2,66E-02	3,13E-02	1,90E-02	2,41E-02	1,66E-02	1,77E-02
Total activity excluding H-3	3,80E-02	2,41E-02	2,96E-02	6,15E-02	4,93E-02	5,03E-02	5,84E-02	3,66E-02	4,67E-02	3,00E-02	3,36E-02
H-3	3,29E+01	6,66E+01	3,31E+01	4,10E+01	5,96E+01	4,35E+01	4,55E+01	4,60E+01	4,41E+01	5,71E+01	3,37E+01
Total-Alpha	9,00E-07	9,00E-07	7,10E-07	1,20E-07	0,00E+00	9,10E-10	5,13E-09	2,11E-09	1,73E-09	2,52E-09	1,36E-09

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total activity excluding H-3 (TBq/a)	3,80E-02	2,41E-02	2,96E-02	6,15E-02	4,93E-02	5,03E-02	5,84E-02	3,66E-02	4,67E-02	3,00E-02	3,36E-02
Annual limit (TBq/a)	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01
% of annual limit	4,3	2,7	3,3	6,9	5,5	5,7	6,6	4,1	5,3	3,4	3,8
Normalised to capacity (GBq/GWa)	12,8	8,1	9,9	20,7	16,5	16,9	19,6	12,3	15,6	10,1	11,2
UNSCEAR ranges (GBq/GWa)	14 - 140										
H-3 (TBq/a)	3,29E+01	6,66E+01	3,31E+01	4,10E+01	5,96E+01	4,35E+01	4,55E+01	4,60E+01	4,41E+01	5,71E+01	3,37E+01
Annual limit (TBq/a)	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02
% of annual limit	22,3	45,1	22,4	27,8	40,4	29,5	30,8	31,2	29,9	38,7	22,8
Normalised to capacity (TBq/GWa)	11,1	22,4	11,1	13,8	20,0	14,6	15,2	15,4	14,8	19,1	11,3
UNSCEAR ranges (TBq/GWa)	7,9 - 80										

3. Annual aerial emissions (Bq/a)

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
H-3 (TBq/a)	6,35	7,32	7,56	5,65	5,26	5,66	6,75	6,51	5,66	6,26	6,68
H-3 Normalised to capacity (TBq/GWa)	2,14	2,46	2,54	1,90	1,76	1,90	2,26	2,18	1,90	2,10	2,24
Total B-G (TBq/a)	2,87E-05	1,38E-05	4,03E-06	2,66E-05	7,81E-05	6,00E-05	4,75E-07	3,22E-05	1,53E-05	1,05E-05	8,47E-06
Total B-G Norm. To capacity (TBq/GWa)	9,65E-06	4,64E-06	1,36E-06	8,95E-06	2,62E-05	2,01E-05	1,59E-07	1,08E-05	5,13E-06	3,52E-06	2,84E-06
Iodine (TBq/a)	4,61E-06	5,87E-06	6,35E-07	7,72E-06	7,60E-07	4,47E-04	6,94E-05	5,33E-05	6,70E-05	1,29E-04	2,75E-05
Iodine (Norm. To capacity TBq/Gwa)	1,55E-06	1,974E-06	2,136E-07	2,597E-06	2,546E-07	0,0001497	2,325E-05	1,786E-05	2,245E-05	4,322E-05	9,213E-06
Noble Gases (TBq/a)	8,04E+00	4,32E+00	3,52E+00	4,65E+00	8,46E+00	3,24E+01	1,84E+01	1,40E+01	1,81E+01	3,35E+01	2,88E+01
Noble Gases (Norm. to capacity TBq/GWa)	2,70E+00	1,45E+00	1,18E+00	1,56E+00	2,83E+00	1,09E+01	6,16E+00	4,69E+00	6,06E+00	1,12E+01	9,65E+00

C-14 is not measured and estimated to 5,55E+02 GBq/a (according to literature** that mentions 5 Ci/a (18.5 GBq/a) for 1000 MWe installed)

4. Radiation doses to the public

Effective Dose (mSv/a)***	1992 to 1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Water pathway	0,0024	0,0024	0,0024	0,0025	0,00226	0,00295	0,00213	0,0028	0,00237	0,00182
% of dose limit (1 mSv/a)	0,24	0,24	0,24	0,25	0,226	0,295	0,213	0,28	0,237	0,182
Air pathway	0,0225	0,0225	0,0225	0,0224	0,0228	0,0227	0,0226	0,0226	0,0238	0,023
% of dose limit (1 mSv/a)	2,25	2,25	2,25	2,24	2,28	2,27	2,26	2,26	2,38	2,3

* Value of "other radionuclides" (= total Beta-Gamma) reported as mentioned in the 'instructions for the reporting format for liquid discharges of radioactive substances from nuclear installations' (point 8)

** Investigations into the emission of C-14 compounds from nuclear facilities,
J. Schwibach, H. Riedel und J. Bretschneider, november 1978, Commission of the European Communities

*** given for an adult. Calculated by NUREG 1.109, DCF ICRP-72 (2002)

Tihange NPP (continued)

1. Site Characteristics		By:	Claes Jurgen, ir
Name of facility	NPP Tihange		Hermans Audrey, ir
Type of facility	PWR		
Date commissioned	1975-1982-1985		
date of shut-down	2025-2022-2025		
Location	Belgium (Tihange)		
Receiving water	Meuse		

Installed capacity	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
MW[e]	3011	3022	3016	3016	3016	3016	3016	3016	3016	3016

Electricity generation (net)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
GWh	23674	23656	23086	20068	19912	18050	13524	19215	19408	15203

2. Discharge and emission data

annual liquid discharges, Bq/a

Radionuclide (TBq/a)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Co-58	9,10E-04	6,07E-04	1,45E-03	1,09E-03	1,70E-04	3,04E-04	7,12E-04	8,37E-04	6,23E-04	8,70E-04
Co-60	3,48E-03	2,39E-03	4,29E-03	4,62E-03	3,13E-03	2,45E-03	4,59E-03	5,66E-03	6,72E-03	1,03E-02
Zn-65	0,00E+00	0,00E+00	0,00E+00	8,50E-05	5,98E-05	4,45E-05	5,63E-05	6,80E-05	4,58E-05	6,37E-05
Sr-90	0,00E+00	0,00E+00	0,00E+00	1,65E-05	1,46E-05	1,01E-05	7,47E-06	1,02E-05	1,00E-05	6,62E-06
Zr/Nb-95	7,00E-05	7,56E-05	1,51E-04	3,39E-04	8,23E-05	5,88E-05	1,26E-04	1,66E-04	6,68E-05	2,62E-04
Ru-106	0,00E+00	0,00E+00	4,85E-05	3,48E-04	1,43E-04	1,36E-04	1,73E-04	2,20E-04	1,52E-04	1,97E-04
Ag-110m	2,57E-04	1,23E-03	6,99E-04	3,74E-04	4,52E-04	3,04E-04	4,28E-04	1,55E-03	1,05E-03	1,53E-03
Sb-125	4,19E-06	4,49E-05	3,09E-04	1,83E-04	1,36E-04	1,51E-04	2,73E-04	2,24E-04	2,77E-04	4,59E-04
Cs-134	1,06E-04	1,56E-04	1,18E-04	2,28E-04	8,90E-05	5,54E-05	3,67E-05	3,98E-05	2,63E-05	2,35E-05
Cs-137	3,09E-04	3,20E-04	5,90E-04	8,69E-04	7,32E-04	5,05E-04	3,73E-04	5,21E-04	5,02E-04	3,31E-04
Ce-144	0,00E+00	0,00E+00	0,00E+00	1,23E-04	6,09E-05	5,48E-05	6,55E-05	8,33E-05	5,31E-05	6,83E-05
Total-Beta*	5,53E-03	5,10E-03	8,26E-03	1,36E-02	6,58E-03	2,06E-03	3,83E-03	4,68E-03	5,61E-03	8,55E-03
Total activity excluding H-3	1,07E-02	9,93E-03	1,59E-02	2,19E-02	1,16E-02	6,14E-03	1,07E-02	1,41E-02	1,51E-02	2,27E-02
H-3	5,34E+01	5,50E+01	3,93E+01	5,26E+01	4,24E+01	4,43E+01	2,60E+01	4,06E+01	2,83E+01	4,57E+01
Total-Alpha	1,27E-09	1,09E-09	8,70E-10	2,66E-06	2,02E-06	1,36E-06	1,64E-06	2,46E-06	2,21E-06	3,48E-06

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Total activity excluding H-3 (TBq/a)	1,07E-02	9,93E-03	1,59E-02	2,19E-02	1,16E-02	6,14E-03	1,07E-02	1,41E-02	1,51E-02	2,27E-02
Annual limit (TBq/a)	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01	8,88E-01
% of annual limit	1,2	1,1	1,8	2,5	1,3	0,7	1,2	1,6	1,7	2,6
Normalised to capacity (GBq/GWa)	3,5	3,3	5,3	7,3	3,9	2,0	3,5	4,7	5,0	7,5
UNSCEAR ranges (GBq/GWa)	14 - 140									
H-3 (TBq/a)	5,34E+01	5,50E+01	3,93E+01	5,26E+01	4,24E+01	4,43E+01	2,60E+01	4,06E+01	2,83E+01	4,57E+01
Annual limit (TBq/a)	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02	1,48E+02
% of annual limit	36,2	37,3	26,6	35,6	28,8	30,0	17,6	27,5	19,2	31,0
Normalised to capacity (TBq/GWa)	17,7	18,2	13,0	17,4	14,1	14,7	8,6	13,5	9,4	15,2
UNSCEAR ranges (TBq/GWa)	7,9 - 80									

3. Annual aerial emissions (Bq/a)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
H-3 (TBq/a)	7,49	7,35	6,84	7,05	7,06	7,59	6,66	7,40	8,94	7,83
H-3 Normalised to capacity (TBq/GWa)	2,49	2,43	2,27	2,34	2,34	2,52	2,21	2,45	2,96	2,60
Total B-G (TBq/a)	1,22E-06	0,00E+00	2,74E-06	2,66E-04	2,25E-04	2,51E-04	2,50E-04	3,20E-04	2,69E-04	2,21E-04
Total B-G Norm. To capacity (TBq/GWa)	4,05E-07	0,00E+00	9,09E-07	8,82E-05	7,46E-05	8,31E-05	8,28E-05	1,06E-04	8,93E-05	7,34E-05
Iodine (TBq/a)	3,00E-05	1,05E-05	6,62E-06	3,29E-05	5,91E-06	8,27E-06	7,83E-06	8,46E-06	7,78E-06	1,10E-05
Iodine (Norm. To capacity TBq/Gwa)	9,965E-06	3,474E-06	2,195E-06	1,091E-05	1,96E-06	2,742E-06	2,596E-06	2,804E-06	2,581E-06	3,659E-06
Noble Gases (TBq/a)	1,25E+01	5,01E+00	6,67E+00	8,15E+00	4,91E+00	5,63E+00	4,74E+00	4,91E+00	5,14E+00	5,07E+00
Noble Gases (Norm. to capacity TBq/GWa)	4,15E+00	1,66E+00	2,21E+00	2,70E+00	1,63E+00	1,87E+00	1,57E+00	1,63E+00	1,71E+00	1,68E+00

C-14 is not measured and estimated to 5,55E+02 GBq/a (according to literature** that mentions 5 Ci/a (18.5 GBq/a) for 1000 MWe installed)

4. Radiation doses to the public

Effective Dose (mSv/a)***	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Water pathway	0,00165	0,00159	0,00153	0,00192	0,00145	0,00135	0,00118	0,00168	0,00148	0,00226
% of dose limit (1 mSv/a)	0,165	0,159	0,153	0,192	0,145	0,135	0,118	0,168	0,148	0,226
Air pathway	0,0227	0,0226	0,0228	0,0228	0,0227	0,0228	0,0226	0,0228	0,023	0,0228
% of dose limit (1 mSv/a)	2,27	2,26	2,28	2,28	2,27	2,28	2,26	2,28	2,3	2,28

* Value of "other radionuclides" (= total Beta-Gamma) reported as mentioned in the 'instructions for the reporting format for liquid discharges of radioactive substances from nuclear installations' (point 8)

** Investigations into the emission of C-14 compounds from nuclear facilities,

*** given for an adult. Calculated by NUREG 1.109, DCF ICRP-72 (2002)

Doel NPP

1. Site Characteristics		By:	Claes Jurgen, ir
Name of facility	NPP Doel		Hermans Audrey, ir
Type of facility	PWR		
Date commissioned	1975-1975-1982-1985		
date of shut-down	2025-2025-2022-2025		
Location	Belgium (Doel)		
Receiving water	Scheldt		

Installed capacity	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
MW[e]	2776	2776	2776	2776	2776	2776	2817	2817	2840	2840	2840

Electricity generation (net)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
GWh	21800				21801	21780	21404	21886	21627	22669	20500

2. Discharge and emission data

annual liquid discharges, Bq/a

Radionuclide (TBq/a)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Co-58	2,91E-03	9,32E-03	5,15E-03	8,43E-04	2,29E-03	5,09E-04	3,85E-04	0,00E+00	0,00E+00	7,24E-04	3,92E-04
Co-60	5,30E-04	2,43E-03	1,37E-03	9,50E-04	1,21E-03	1,05E-04	2,17E-04	3,09E-04	2,84E-04	3,82E-04	5,54E-04
Zn-65	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,20E-06	3,00E-07	3,00E-07
Sr-90	2,20E-05	2,13E-04	1,33E-04	2,31E-05	9,20E-06	1,00E-06	0,00E+00	3,70E-06	6,60E-06	0,00E+00	0,00E+00
Zr/Nb-95	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,59E-05	4,19E-05	3,33E-05	1,11E-04
Ru-106	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,57E-05	2,29E-05	1,20E-04
Ag-110m	1,80E-04	4,30E-05	5,18E-04	6,32E-05	3,68E-05	5,23E-04	1,31E-03	2,76E-04	1,78E-04	3,31E-04	6,56E-04
Sb-125	1,94E-03	2,25E-03	2,13E-03	2,11E-03	1,98E-03	2,54E-03	1,14E-03	2,16E-03	4,19E-04	4,56E-04	4,11E-04
Cs-134	3,08E-03	3,54E-03	6,57E-04	0,00E+00	2,50E-04	6,00E-05	5,80E-05	3,67E-05	8,60E-06	9,80E-06	1,74E-05
Cs-137	6,67E-03	9,42E-03	3,49E-03	2,73E-03	3,62E-03	3,49E-03	1,40E-03	5,81E-04	1,01E-06	2,62E-04	2,64E-04
Ce-144	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Total-Beta*	1,60E-02	2,78E-02	1,50E-02	6,70E-03	1,17E-02	8,41E-03	5,22E-03	4,52E-03	1,71E-03	2,54E-03	3,10E-03
Total activity excluding H-3	3,13E-02	5,50E-02	2,84E-02	1,34E-02	2,11E-02	1,56E-02	9,73E-03	7,92E-03	2,69E-03	4,76E-03	5,63E-03
H-3	4,71E+01	4,84E+01	3,09E+01	3,80E+01	2,75E+01	3,43E+01	4,21E+01	3,99E+01	4,61E+01	5,37E+01	4,17E+01
Total-Alpha	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,20E-06	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total activity excluding H-3	3,13E-02	5,50E-02	2,84E-02	1,34E-02	2,11E-02	1,56E-02	9,73E-03	7,92E-03	2,69E-03	4,76E-03	5,63E-03
Annual limit (TBq/a)	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00
% of annual limit	2,1	3,7	1,9	0,9	1,4	1,1	0,7	0,5	0,2	0,3	0,4
Normalised to capacity (GBq/GWa)	11,3	19,8	10,2	4,8	7,6	5,6	3,5	2,8	0,9	1,7	2,0
UNSCEAR ranges (GBq/GWa)	14 - 140										
H-3	4,71E+01	4,84E+01	3,09E+01	3,80E+01	2,75E+01	3,43E+01	4,21E+01	3,99E+01	4,61E+01	5,37E+01	4,17E+01
Annual limit (TBq/a)	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02
% of annual limit	45,5	46,7	29,8	36,7	26,5	33,1	40,6	38,5	44,5	51,8	40,3
Normalised to capacity (TBq/GWa)	17,0	17,4	11,1	13,7	9,9	12,4	14,9	14,2	16,2	18,9	14,7
UNSCEAR ranges (TBq/GWa)	7,9 - 80										

3. Annual aerial emissions (Bq/a)

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
H-3 (TBq/a)	0,052	5,665	0,017	0,326	1,026	0,710	0,030	0,476	1,975	2,927	2,609
H-3 Normalised to capacity (TBq/GWa)	0,019	2,041	0,006	0,117	0,370	0,256	0,010	0,169	0,696	1,031	0,919
Total B-G (TBq/a)	2,40E-06	0	0	1,40E-06	5,00E-06	1,03E-05	7,00E-07	6,00E-07	5,19E-05	4,00E-06	3,30E-06
Total B-G Norm. To capacity (TBq/GWa)	8,65E-07	0	0	5,043E-07	1,801E-06	3,71E-06	2,485E-07	2,13E-07	1,828E-05	1,409E-06	1,162E-06
Iodine (TBq/a)	1,37E-05	3,10E-06	8,52E-06	4,10E-06	9,40E-06	2,80E-06	5,50E-06	1,84E-05	3,63E-05	3,36E-05	5,91E-05
Iodine (Norm. To capacity TBq/Gwa)	4,94E-06	1,117E-06	3,069E-06	1,477E-06	3,386E-06	1,009E-06	1,952E-06	6,532E-06	1,278E-05	1,183E-05	2,081E-05
Noble Gases (TBq/a)	3,31E+00	2,66E+00	9,54E-02	2,60E-02	3,31E-01	7,75E-01	2,54E-02	7,07E-02	1,15E-01	1,35E-02	1,70E-02
Noble Gases (Norm. to capacity TBq/GWa)	1,19E+00	9,58E-01	3,44E-02	9,37E-03	1,19E-01	2,79E-01	9,02E-03	2,51E-02	4,05E-02	4,75E-03	5,99E-03

C-14 is not measured and estimated to 5,55E+02 GBq/a (according to literature** that mentions 5 Ci/a (18.5 GBq/a) for 1000 MWe installed)

4. Radiation doses to the public

Effective Dose (mSv/a)***	1992 to 1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Water pathway	0,0023	2,34E-03	2,34E-03	1,30E-03	1,00E-03	7,00E-04	6,00E-04	1,00E-03	1,00E-03	9,46E-04
% of dose limit (1 mSv/a)	0,23	0,23	0,23	0,13	0,10	0,07	0,06	0,10	0,10	0,09
Air pathway	0,0087	8,70E-03	8,70E-03	8,70E-03	8,60E-03	8,50E-03	8,60E-03	9,00E-03	9,00E-03	9,00E-03
% of dose limit (1 mSv/a)	0,87	0,87	0,87	0,87	0,86	0,85	0,86	0,90	0,90	0,90

* Value of "other radionuclides" (= total Beta-Gamma) reported as mentioned in the 'instructions for the reporting format for liquid discharges of radioactive substances from nuclear installations' (point 8)

** Investigations into the emission of C-14 compounds from nuclear facilities,
J. Schwibach, H. Riedel und J. Bretschneider, november 1978, Commission of the European Communities

*** given for an adult. Calculated by NUREG 1.109, DCF ICRP-72 (2002)

Doel NPP (continued)

1. Site Characteristics

Name of facility	NPP Doel	By:	Claes Jurgen, ir
Type of facility	PWR		Hermans Audrey, ir
Date commissioned	1975-1975-1982-1985		
date of shut-down	2025-2025-2022-2025		
Location	Belgium (Doel)		
Receiving water	Scheldt		

Installed capacity	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
MW[e]	2845	2911	2911	2911	2911	2911	2911	2911	2911	2911

Electricity generation (net)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
GWh	21167	21890	22741	18123	20720	14044	11048	22068	20623	11793

2. Discharge and emission data

annual liquid discharges, Bq/a

Radionuclide (TBq/a)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Co-58	5,69E-04	7,33E-04	1,36E-03	4,65E-04	1,11E-04	3,81E-04	4,39E-04	3,59E-04	2,62E-04	3,71E-04
Co-60	8,63E-04	7,31E-04	1,68E-03	7,56E-04	2,88E-04	2,51E-04	4,16E-04	5,43E-04	3,85E-04	3,57E-04
Zn-65	4,60E-06	1,20E-06	6,88E-05	4,11E-05	2,84E-05	2,79E-05	2,91E-05	4,75E-05	5,01E-05	4,78E-05
Sr-90	0,00E+00	7,00E-08	4,27E-06	3,50E-06	2,10E-06	1,58E-06	5,65E-06	2,34E-06	2,48E-06	3,43E-06
Zr/Nb-95	9,89E-05	3,94E-05	2,82E-04	1,50E-04	6,74E-05	1,20E-04	7,07E-05	1,49E-04	1,07E-04	6,50E-05
Ru-106	3,22E-05	1,99E-05	2,80E-04	2,10E-04	1,23E-04	1,28E-05	1,32E-05	2,17E-05	2,27E-05	2,18E-05
Ag-110m	4,95E-04	3,66E-04	5,93E-04	4,11E-04	1,03E-04	5,23E-04	1,37E-04	9,49E-05	2,12E-04	1,98E-04
Sb-125	4,04E-04	1,44E-03	1,58E-03	6,70E-04	4,05E-04	6,13E-05	2,84E-04	4,69E-04	1,18E-03	8,27E-04
Cs-134	2,10E-06	2,40E-06	3,80E-05	9,47E-05	3,63E-05	1,38E-05	1,39E-05	2,36E-05	2,45E-05	2,29E-05
Cs-137	3,59E-04	1,28E-04	2,88E-04	8,83E-04	1,46E-03	3,38E-05	1,32E-04	2,51E-04	2,58E-04	2,41E-04
Ce-144	0,00E+00	6,00E-07	1,74E-04	1,19E-04	8,22E-05	7,74E-05	7,75E-05	1,32E-04	1,38E-04	1,33E-04
Total-Beta*	3,53E-03	3,94E-03	8,67E-03	5,12E-03	3,23E-03	2,13E-04	3,55E-04	4,59E-04	3,27E-04	3,04E-04
Total activity excluding H-3	6,36E-03	7,40E-03	1,50E-02	8,92E-03	5,94E-03	1,72E-03	1,97E-03	2,55E-03	2,97E-03	2,59E-03
H-3	5,31E+01	5,18E+01	5,52E+01	4,76E+01	3,66E+01	3,67E+01	2,04E+01	4,18E+01	3,79E+01	3,51E+01
Total-Alpha	0,00E+00	0,00E+00	6,90E-06	1,41E-05	6,50E-06	6,31E-06	4,01E-06	5,75E-06	3,37E-06	4,05E-06

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Total activity excluding H-3	6,36E-03	7,40E-03	1,50E-02	8,92E-03	5,94E-03	1,72E-03	1,97E-03	2,55E-03	2,97E-03	2,59E-03
Annual limit (TBq/a)	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00	1,48E+00
% of annual limit	0,4	0,5	1,0	0,6	0,4	0,1	0,1	0,2	0,2	0,2
Normalised to capacity (GBq/GWa)	2,2	2,5	5,2	3,1	2,0	0,6	0,7	0,9	1,0	0,9
UNSCEAR ranges (GBq/GWa)	14 - 140									
H-3	5,31E+01	5,18E+01	5,52E+01	4,76E+01	3,66E+01	3,67E+01	2,04E+01	4,18E+01	3,79E+01	3,51E+01
Annual limit (TBq/a)	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02	1,04E+02
% of annual limit	51,3	50,0	53,3	45,9	35,3	35,4	19,7	40,4	36,6	33,9
Normalised to capacity (TBq/GWa)	18,7	17,8	19,0	16,4	12,6	12,6	7,0	14,4	13,0	12,1
UNSCEAR ranges (TBq/GWa)	7,9 - 80									

3. Annual aerial emissions (Bq/a)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
H-3 (TBq/a)	2,939	2,449	2,935	3,250	2,393	2,651	3,312	4,453	2,165	3,635
H-3 Normalised to capacity (TBq/GWa)	1,033	0,841	1,008	1,116	0,822	0,911	1,138	1,530	0,744	1,249
Total B-G (TBq/a)	8,50E-06	6,50E-06	1,32E-04	8,43E-05	8,42E-05	8,87E-05	9,28E-05	8,41E-05	5,92E-05	4,12E-05
Total B-G Norm. To capacity (TBq/GWa)	2,988E-06	2,233E-06	4,535E-05	2,896E-05	2,89E-05	3,05E-05	3,19E-05	2,89E-05	2,03E-05	1,42E-05
Iodine (TBq/a)	6,19E-05	6,64E-05	1,06E-04	3,63E-05	3,19E-05	3,17E-05	5,68E-05	2,65E-05	6,29E-06	2,31E-05
Iodine (Norm. To capacity TBq/Gwa)	2,176E-05	2,281E-05	3,641E-05	1,247E-05	1,10E-05	1,09E-05	1,95E-05	9,10E-06	2,16E-06	7,93E-06
Noble Gases (TBq/a)	1,58E-02	4,35E-02	3,65E+01	3,58E+01	2,92E+01	3,01E+01	5,63E+01	4,82E+01	2,74E+01	5,51E+01
Noble Gases (Norm. to capacity TBq/GWa)	5,55E-03	1,49E-02	1,25E+01	1,23E+01	1,00E+01	1,04E+01	1,93E+01	1,66E+01	9,41E+00	1,89E+01

C-14 is not measured and estimated to 5,55E+02 GBq/a (according to literature** that mentions 5 Ci/a (18.5 GBq/a) for 1000 MWe installed)

4. Radiation doses to the public

Effective Dose (mSv/a)***	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Water pathway	9,08E-04	9,07E-04	1,56E-03	1,08E-03	7,68E-04	5,64E-04	4,60E-04	8,39E-04	8,20E-04	7,22E-04
% of dose limit (1 mSv/a)	0,09	0,09	0,16	0,11	0,08	0,06	0,05	0,08	0,08	0,07
Air pathway	9,08E-03	8,90E-03	9,80E-03	9,93E-03	9,52E-03	9,43E-03	9,93E-03	9,97E-03	9,29E-03	9,96E-03
% of dose limit (1 mSv/a)	0,91	0,89	0,98	0,99	0,95	0,94	0,99	1,00	0,93	1,00

* Value of "other radionuclides" (= total Beta-Gamma) reported as mentioned in the 'instructions for the reporting format for liquid discharges of radioactive substances from nuclear installations' (point 8)

** Investigations into the emission of C-14 compounds from nuclear facilities,

*** given for an adult. Calculated by NUREG 1.109, DCF ICRP-72 (2002)

ANNEX 2

Other Nuclear Sites (BP)

Belgoprocess

1. Site Characteristics		By:	Claes Jurgen Hermans Audrey
Name of facility	Belgoprocess (BP)		
Type of facility	Wastes treatment and storage centre		
Location	Belgium (Mol-Dessel)		
Receiving water	Molse Nete		

2. Discharge and emission data
annual liquid discharges, MBq/a

Year		1998	1999	2000	2001	2002	2003 **[7]**	2003 **[8]**	2003 **[9]**
Tritium	**[1]** MBq	1,30E+06	3,34E+06	2,34E+06	2,29E+06	2,16E+06	4,95E+05	1,52E+06	2,01E+06
	[2] MBq	1,30E+03	3,34E+03	2,34E+03	2,29E+03	2,16E+03	4,95E+02	3,79E+01	
Total-α	**[1]** MBq	33,6	21,3	80,8	98,7	83,2	5,9	53,6	59,5
	[2] MBq	168,2	106,5	404,1	493,4	416,0	29,5	134,0	
Total-β	**[1]** MBq	2316,3	1430,0	2438,1	2110,4	1373,1	233,6	281,8	515,4
	[2] MBq	2316,3	1430,0	2438,1	2110,4	1373,1	233,6	28,2	
Co 60	**[1]** MBq							43,0	43,0
	[2] MBq							43,0	
Sr/Y 90	**[1]** MBq	178,7	149,9	108,6	111,6	63,0	18,4	73,9	92,3
	[2] MBq	1340,3	1124,3	814,5	837,0	472,5	138,0	29,6	
I 131	**[1]** MBq	3,5	5,1	8,0	3,3	4,2	1,7		1,7
	[2] MBq	10,6	15,2	23,9	10,0	12,5	5,0		
Cs 134	**[1]** MBq							18,0	18,0
	[2] MBq							27,0	
Cs 137	**[1]** MBq							383,0	383,0
	[2] MBq							574,5	
Ra 226	**[1]** MBq	0,030	0,032	0,032	0,032	0,033	0,011		0,011
	[2] MBq	8,9	9,5	9,7	9,5	9,9	3,4		
GBq released	per annum **[3]**	1,30E+03	3,35E+03	2,34E+03	2,29E+03	2,16E+03	4,95E+02	1,52E+03	2,01E+03
TBq released	per annum **[4]**	5,144	6,029	6,032	5,748	4,446	0,904	0,874	1,778
		[5]	**[5]**	**[5]**	**[5]**	**[5]**	**[5]**	**[6]**	**[5] + [6]**

Year		2004	2005	2006	2007	2008	2009	2010	2011
Tritium	**[1]** MBq	2,20E+06	2,37E+06	2,49E+06	1,89E+06	2,70E+06	2,29E+06	2,22E+06	2,02E+06
	[2] MBq	5,51E+01	5,93E+01	6,23E+01	4,72E+01	6,75E+01	5,73E+01	5,55E+01	5,05E+01
Total-α	**[1]** MBq	46,4	41,5	8,6	11,1	14,5	16,0	15,8	29,6
	[2] MBq	116,0	103,7	21,6	27,6	36,2	40,0	39,5	74,0
Total-β	**[1]** MBq	281,8	213,9	129,4	155,1	151,4	187,9	197,0	148,1
	[2] MBq	28,2	21,4	12,9	15,5	15,1	18,8	19,7	14,8
Co 60	**[1]** MBq	63,0	109,0	26,0	99,0	4,0	9,0	8,0	21,8
	[2] MBq	63,0	109,0	26,0	99,0	4,0	9,0	8,0	21,8
Sr/Y 90	**[1]** MBq	117,6	69,1	57,1	65,6	33,8	20,5	24,5	30,8
	[2] MBq	47,0	27,6	22,8	26,2	13,5	8,2	9,8	12,3
I 131	**[1]** MBq								
	[2] MBq								
Cs 134	**[1]** MBq	19,0	56,0	15,0	0,0	0,0	0,0	0,0	11,1
	[2] MBq	28,5	84,0	22,5	0,0	0,0	0,0	0,0	16,7
Cs 137	**[1]** MBq	324,0	315,0	80,0	96,0	144,0	96,0	109,0	146,3
	[2] MBq	486,0	472,5	120,0	144,0	216,0	144,0	163,5	219,5
Ra 226	**[1]** MBq								
	[2] MBq								
GBq released	per annum **[3]**	2,20E+03	2,37E+03	2,49E+03	1,89E+03	2,70E+03	2,29E+03	2,22E+03	2,02E+03
GBq released	per annum **[4]**	0,824	0,878	0,288	0,360	0,352	0,277	0,296	0,410
		[6]	**[6]**	**[6]**	**[6]**	**[6]**	**[6]**	**[6]**	**[6]**

Belgoprocess (continued)

1. Site Characteristics By: Claes Jurgen, Hermans Audrey

Name of facility	Belgoprocess (BP)
Type of facility	Wastes treatment and storage centre
Location	Belgium (Mol-Dessel)
Receiving water	Molse Nete

2. Discharge and emission data
annual liquid discharges, MBq/a

Year		2012	2013	2014	2015	2016	2017	2018
Tritium	**[1]** MBq	1,34E+06	1,84E+06	1,74E+06	1,22E+06	9,09E+05	1,15E+06	8,11E+05
	[2] MBq	3,34E+01	4,61E+01	4,34E+01	3,05E+01	2,27E+01	2,88E+01	2,03E+01
Total-α	**[1]** MBq	45,2	5,4	22,2	85,5	62,8	25,5	20,7
	[2] MBq	113,0	13,6	55,6	213,8	156,9	63,7	51,7
Total-β	**[1]** MBq	187,3	129,4	117,9	141,1	119,1	124,0	40,9
	[2] MBq	18,7	12,9	11,8	14,1	11,9	12,4	4,1
Co 60	**[1]** MBq	12,6	13,1	24,1	28,4	32,3	18,1	8,4
	[2] MBq	12,6	13,1	24,1	28,4	32,3	18,1	8,4
Sr/Y 90	**[1]** MBq	16,9	12,7	33,5	39,1	207,1	113,4	62,3
	[2] MBq	6,8	5,1	13,4	15,6	82,8	45,3	24,9
I 131	**[1]** MBq							
	[2] MBq							
Cs 134	**[1]** MBq	7,1	7,6	10,5	7,0	9,8	9,8	8,2
	[2] MBq	10,7	11,4	15,8	10,5	14,7	14,7	12,4
Cs 137	**[1]** MBq	230,5	24,6	145,1	537,2	359,2	157,0	130,4
	[2] MBq	345,7	36,9	217,6	805,8	538,9	235,5	195,6
Ra 226	**[1]** MBq							
	[2] MBq							
GBq released	per annum **[3]**	1,34E+03	1,84E+03	1,74E+03	1,22E+03	9,10E+02	1,15E+03	8,11E+02
GBq released	per annum **[4]**	0,541	0,139	0,382	1,119	0,860	0,418	0,317
		[6]	**[6]**	**[6]**	**[6]**	**[6]**	**[6]**	**[6]**

[1]	Amount of the radionuclide in MBq
[2]	Weighted Amount of the radionuclide in MBq being [1] multiplied by its weighting coefficient
[3]	Being the total amount of activity in TBq released
[4]	Being the total amount of ponderated activity in TBq released
[5]	Total Weighted Amount in TBq according former formula 0,001[H3] + 5[α] + 1[β] + 7,5[Sr90] + 3[I131] + 300[Ra226]
	applicable until March 2003
[6]	Total Weighted Amount in TBq according actual formula 2,5E-05[H3] + 2,5[α] + 0,1[b] + 1[Co60] + 0,4[Sr/Y90] + 1,5[Cs134] + 1,5[Cs137]
	with [b] = total beta ([β]) activity - [[Sr/Y90] + [Co60] + [Cs134] + [Cs137]]
	applicable from April 2003
[7]	Activity values for the months January, February and March calculated according formula [5].
[8]	Activity values for the months April until December calculated according formula [6].
[9]	Sum of the activities [7] and [8], being the amount for the whole year 2003.

Belgoprocess (continued)

1. Site Characteristics

By: Claes Jurgen, ir
Hermans Audrey, ir

Name of facility	Belgoprocess (BP)
Type of facility	Wastes treatment and storage centre
Location	Belgium (Mol-Dessel)
Receiving water	Molse Nete

3. Discharge and emission data
annual gaseous discharges, Bq/a

Releasepoint		Altitude Chimney (m)	2003		2004		2005		2006	
			alpha	beta	alpha	beta	alpha	beta	alpha	beta
BP site 1	Building 120	80	1,71E+06	1,41E+06	5,34E+06	1,15E+06	2,93E+06	6,26E+05	2,08E+06	9,72E+05
	Building 110	17	9,43E+03	3,16E+04	9,97E+03	3,28E+04	1,37E+04	4,61E+04	1,13E+04	3,94E+04
	Building 137	-	3,29E+04	2,41E+05	4,46E+04	4,87E+05	6,21E+04	1,07E+06	4,13E+04	1,54E+06
	Building 155	30					7,73E+03	3,94E+04	1,05E+04	1,30E+05
	Building 131	-								
BP site 2	Gen. Services	15	3,11E+04	5,15E+04	3,92E+04	7,59E+04	3,11E+04	6,00E+04	2,66E+04	3,47E+04
	FLK	19	2,58E+04	4,64E+04	4,27E+04	7,53E+05	1,91E+04	2,85E+04	1,51E+04	2,65E+04
	BRE	19	2,65E+03	6,14E+03	3,02E+03	4,90E+03	1,21E+03	7,26E+03	1,54E+03	5,91E+03
	280	30	1,56E+04	1,38E+04	1,92E+04	4,21E+04	1,52E+04	1,02E+05	1,31E+04	7,96E+04
BP Total		-	1,83E+06	1,80E+06	5,50E+06	2,55E+06	3,08E+06	1,98E+06	2,20E+06	2,83E+06

Releasepoint		Altitude Chimney (m)	2007		2008		2009		2010	
			alpha	beta	alpha	beta	alpha	beta	alpha	beta
BP site 1	Building 120	80	1,44E+06	4,02E+05	1,46E+06	9,42E+05	6,41E+05	1,11E+06	5,51E+05	6,51E+05
	Building 110	17	1,11E+04	3,73E+04	1,17E+04	3,95E+04	1,15E+04	3,96E+04	9,94E+03	3,50E+04
	Building 137	-	4,97E+04	3,42E+05	7,29E+04	1,33E+06	3,52E+04	2,43E+06	3,07E+04	5,89E+05
	Building 155	30	1,24E+04	1,04E+05	8,94E+03	4,11E+04	8,59E+03	5,13E+04	7,30E+03	4,38E+04
	Building 131	-	6,30E+03	2,26E+04	8,37E+03	2,84E+04	5,74E+03	1,77E+04	5,92E+03	1,98E+04
BP site 2	Gen. Services	15	2,10E+04	3,31E+04	2,76E+04	4,44E+04	2,83E+04	6,01E+04	2,70E+04	5,18E+04
	FLK	19	8,50E+03	3,33E+04	1,37E+04	3,37E+04	1,54E+04	5,82E+04	1,43E+04	9,84E+04
	BRE	19	1,91E+03	1,20E+04	3,31E+03	7,48E+03	5,30E+03	1,01E+04	2,57E+03	1,27E+04
	280	30	9,16E+03	4,82E+04	1,34E+04	7,27E+04	1,25E+04	6,07E+04	1,58E+04	5,92E+04
BP Total		-	1,56E+06	1,03E+06	1,62E+06	2,54E+06	7,64E+05	3,84E+06	6,65E+05	1,56E+06

Releasepoint		Altitude Chimney (m)	2011		2012		2013		2014	
			alpha	beta	alpha	beta	alpha	beta	alpha	beta
BP site 1	Building 120	80	1,10E+06	6,17E+05	1,53E+06	6,99E+05	3,22E+05	7,72E+05	2,63E+05	2,89E+05
	Building 110	17	2,65E+03	8,57E+03	3,02E+03	2,19E+04	2,17E+03	1,80E+04	2,32E+03	1,71E+04
	Building 137	-	1,29E+04	8,31E+05	1,10E+04	1,94E+06	9,18E+03	2,59E+06	7,07E+03	7,84E+05
	Building 155	30	2,19E+03	4,21E+04	3,01E+03	3,70E+04	2,32E+03	2,26E+04	2,28E+03	3,38E+04
	Building 131	-	1,50E+03	5,14E+03	1,56E+03	5,45E+03	1,30E+03	4,32E+03	1,41E+03	4,65E+03
BP site 2	Gen. Services	15	5,60E+03	2,24E+04	7,64E+03	1,74E+04	4,76E+03	1,41E+04	4,19E+03	1,42E+04
	FLK	19	2,25E+03	1,34E+04	2,44E+03	9,01E+03	2,58E+03	9,44E+03	2,43E+03	8,93E+03
	BRE	19	7,27E+02	3,14E+03	7,84E+02	2,66E+03	8,31E+02	1,52E+03	5,46E+02	9,06E+02
	280	30	4,46E+03	9,43E+03	3,91E+03	5,75E+03	8,05E+03	4,01E+04	4,15E+03	6,81E+03
BP Total		-	1,13E+06	1,55E+06	1,56E+06	2,74E+06	3,53E+05	3,47E+06	2,88E+05	1,16E+06

Releasepoint		Altitude Chimney (m)	2015		2016		2017		2018	
			alpha	beta	alpha	beta	alpha	beta	alpha	beta
BP site 1	Building 120	80	1,66E+05	7,66E+05	1,48E+05	1,26E+05	2,37E+05	3,30E+05	2,69E+05	2,52E+05
	Building 110	17	2,63E+03	1,66E+04	3,33E+03	1,09E+04	4,09E+03	1,06E+04	4,79E+03	1,01E+04
	Building 137	-	7,31E+03	9,03E+04	1,22E+04	2,52E+05	8,34E+03	1,75E+05	6,58E+03	4,41E+04
	Building 155	30	3,21E+03	3,50E+04	3,43E+03	1,86E+04	2,66E+03	6,35E+03	2,77E+03	1,34E+04
	Building 131	-	1,49E+03	5,22E+03	1,64E+03	5,10E+03	3,81E+03	1,27E+04	5,30E+03	1,91E+04
BP site 2	Gen. Services	15	4,58E+03	1,58E+04	5,52E+03	1,74E+04	7,75E+03	1,96E+04	6,62E+03	1,74E+04
	FLK	19	2,24E+03	7,80E+03	3,08E+03	9,85E+03	3,73E+03	1,31E+04	3,05E+03	1,39E+04
	BRE	19	6,74E+02	5,02E+03	6,18E+02	3,00E+03	7,87E+02	6,17E+03	7,08E+02	6,32E+03
	280	30	3,00E+03	9,79E+03	2,95E+03	1,63E+04	3,54E+03	3,31E+04	7,06E+03	4,88E+04
BP Total		-	1,91E+05	9,52E+05	1,81E+05	4,59E+05	2,72E+05	6,06E+05	3,06E+05	4,25E+05

Belgoprocess (continued)

1. Site Characteristics		By:	Claes Jurgen, ir
			Hermans Audrey, ir

Name of facility	Belgoprocess (BP)
Type of facility	Wastes treatment and storage centre
Location	Belgium (Mol-Dessel)
Receiving water	Molse Nete

4. Radiation doses to the public

Effective Dose (mSv/a)	2001	2002	2003	2004	2005	2006
Water pathway*	8,75E-05	6,83E-05	6,32E-05	6,16E-05	6,71E-05	5,68E-05
% of dose limit (1 mSv/a)	0,00875	0,00683	0,00632	0,00616	0,00671	0,00568
Air pathway**	1,00E-03	1,20E-02	1,30E-02	2,50E-02	9,10E-03	9,10E-03
% of dose limit (1 mSv/a)	0,10	1,20	1,30	2,50	0,91	0,91

Effective Dose (mSv/a)	2007	2008	2009	2010	2011	2012
Water pathway*	4,74E-05	6,11E-05	5,19E-05	5,00E-05	4,90E-05	3,70E-05
% of dose limit (1 mSv/a)	0,00474	0,00611	0,00519	0,005	0,0049	0,0037
Air pathway**	7,80E-03	8,30E-03	8,00E-03	7,50E-03	8,00E-03	9,70E-03
% of dose limit (1 mSv/a)	0,78	0,83	0,80	0,75	0,80	0,97

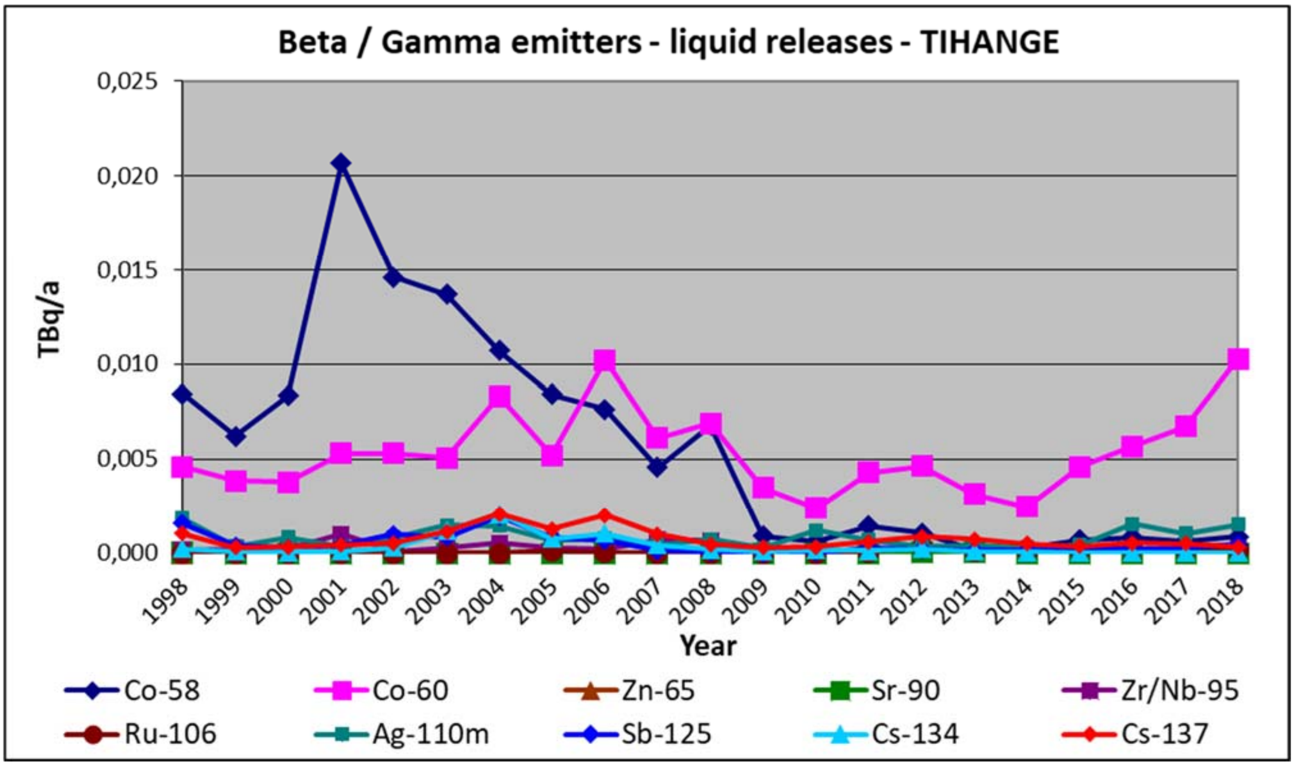
Effective Dose (mSv/a)	2013	2014	2015	2016	2017	2018
Water pathway*	4,10E-05	4,30E-05	4,40E-05	3,40E-05	3,10E-05	2,50E-05
% of dose limit (1 mSv/a)	0,0041	0,0043	0,0044	0,0034	0,0031	0,0025
Air pathway**	9,50E-03	7,50E-03	8,00E-03	8,00E-03	8,00E-03	7,80E-03
% of dose limit (1 mSv/a)	0,95	0,75	0,80	0,80	0,80	0,78

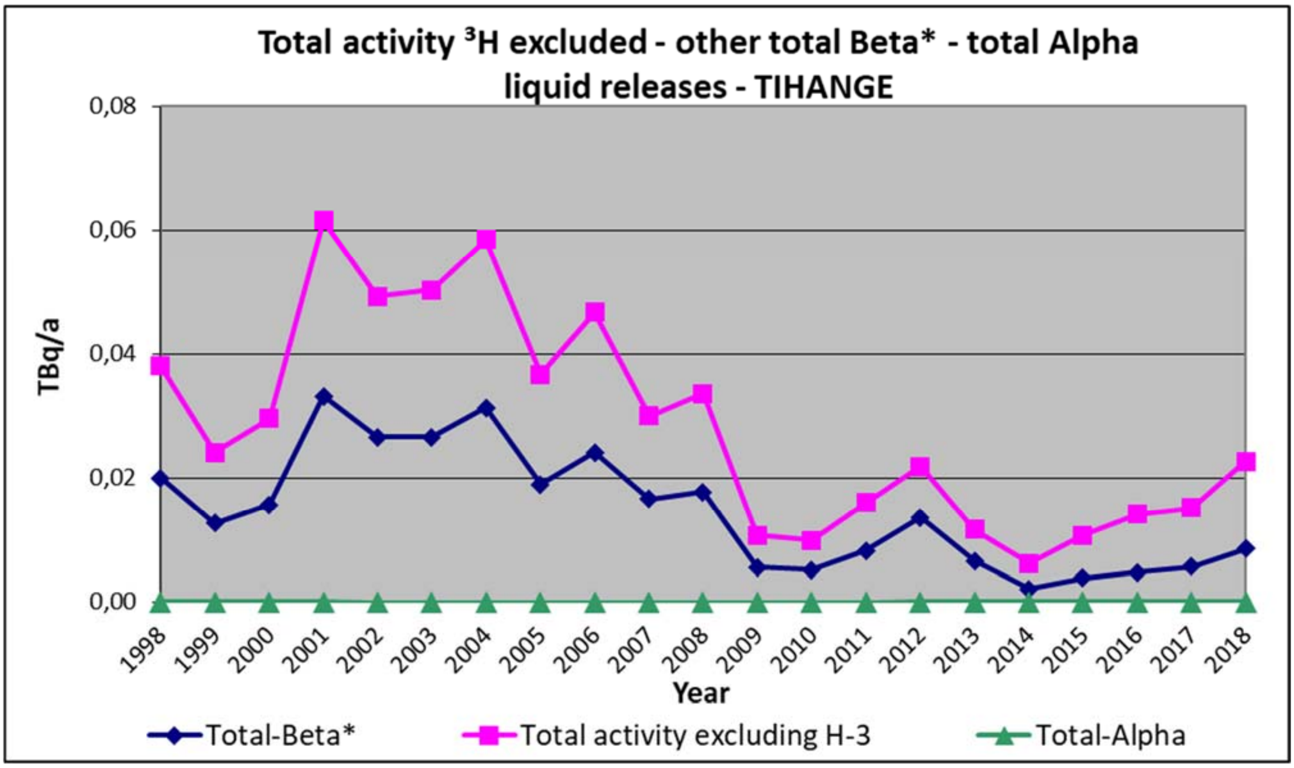
* given for an adult. Calculated by NRPB-231 (1990)
** given for an adult. Calculated by NUREG 1.109, DCF ICRP-72 (2002)
for the total site Mol-Dessel (Belgoprocess, SCK•CEN, FBFC, Belgonucléaire, IRMM)

ANNEX 3

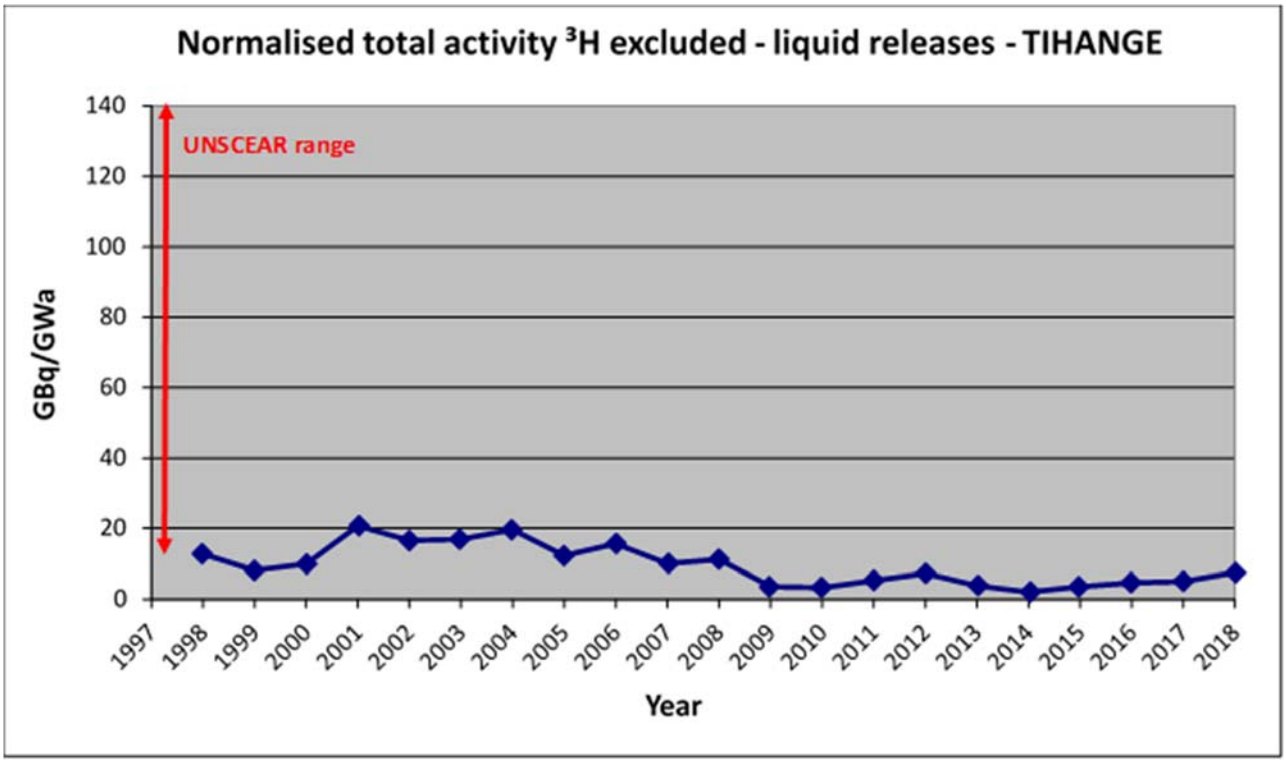
Trend line figures

Tihange NPP

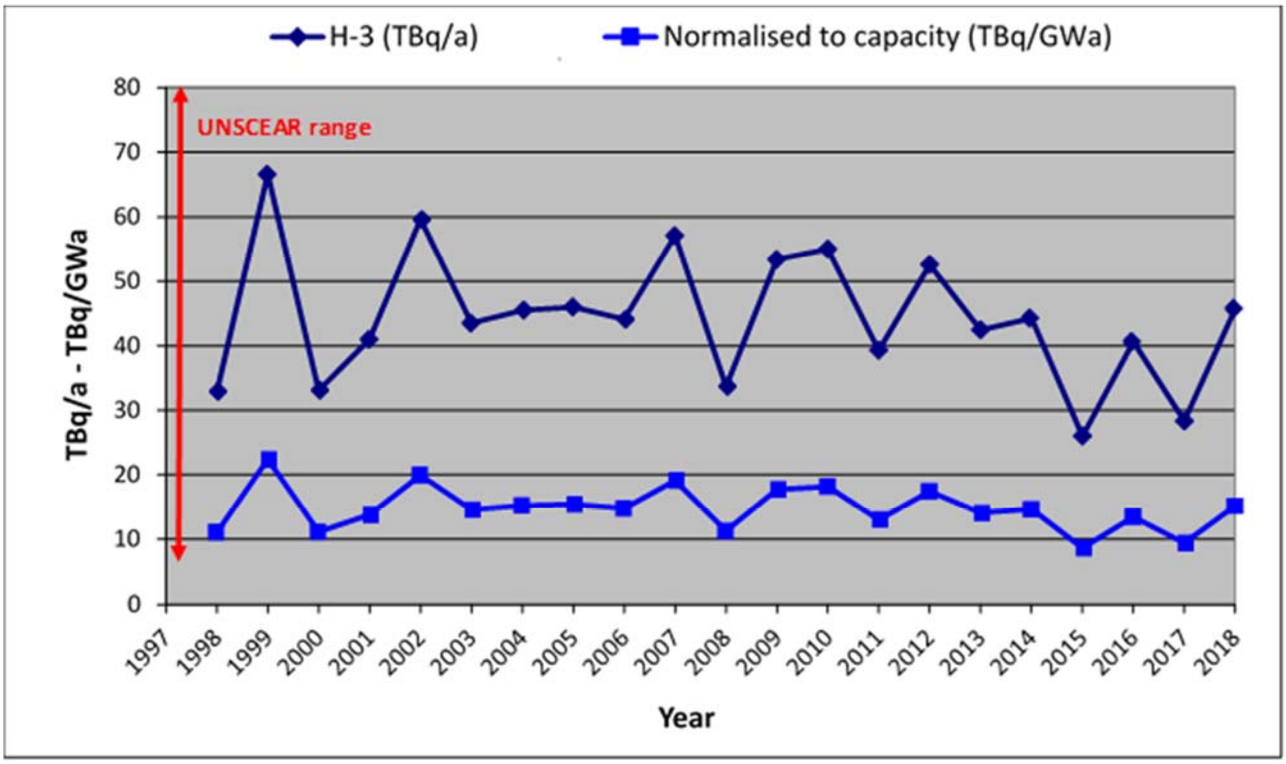




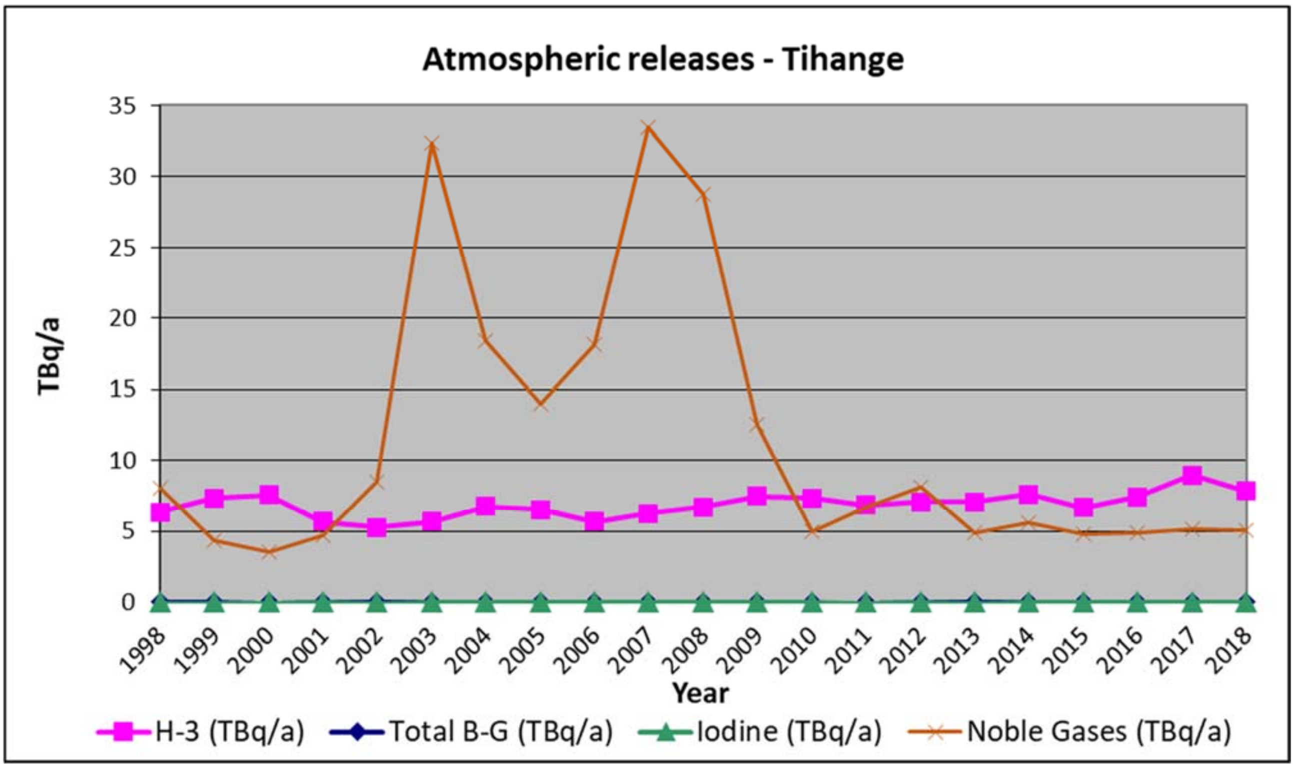
Note: The increase of activity (such as for Co-60) in some effluents is due to non-cleaning operations of a few discharge storage tanks and by preferring filtration over evaporation of effluents rich in bore and low in activity to limit the production of volumes of non-recyclable boron concentrates.

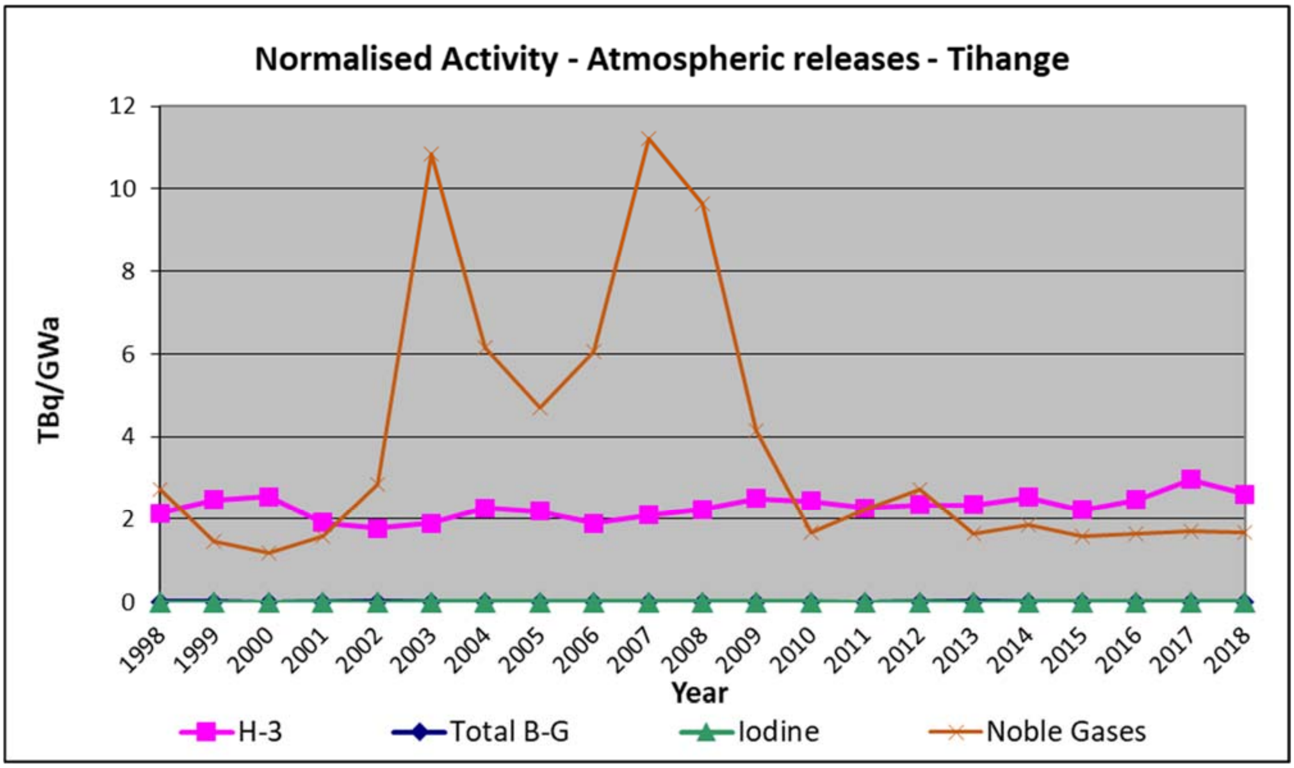


Normalised total activity ³H excluded - liquid releases - TIHANGE
UNSCEAR range
GBq/GWa
140
120
100
80
60
40
20
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year

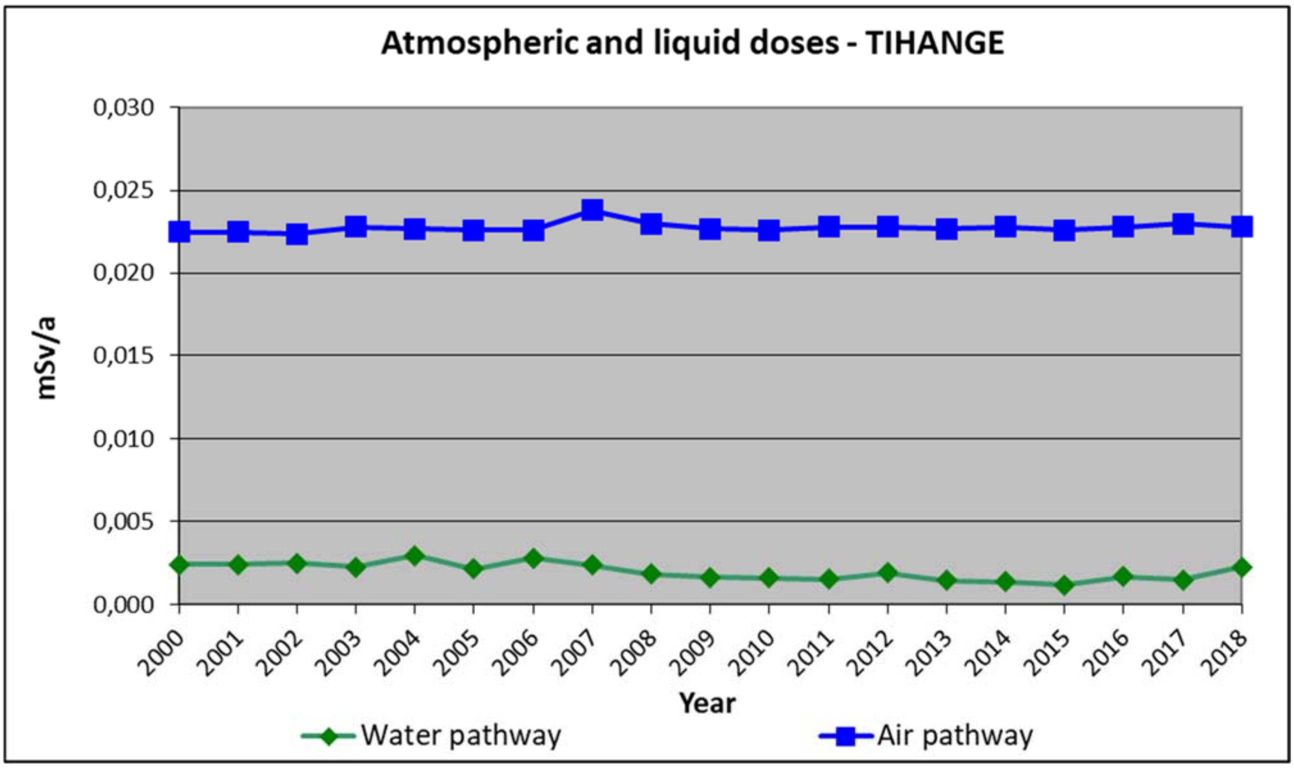


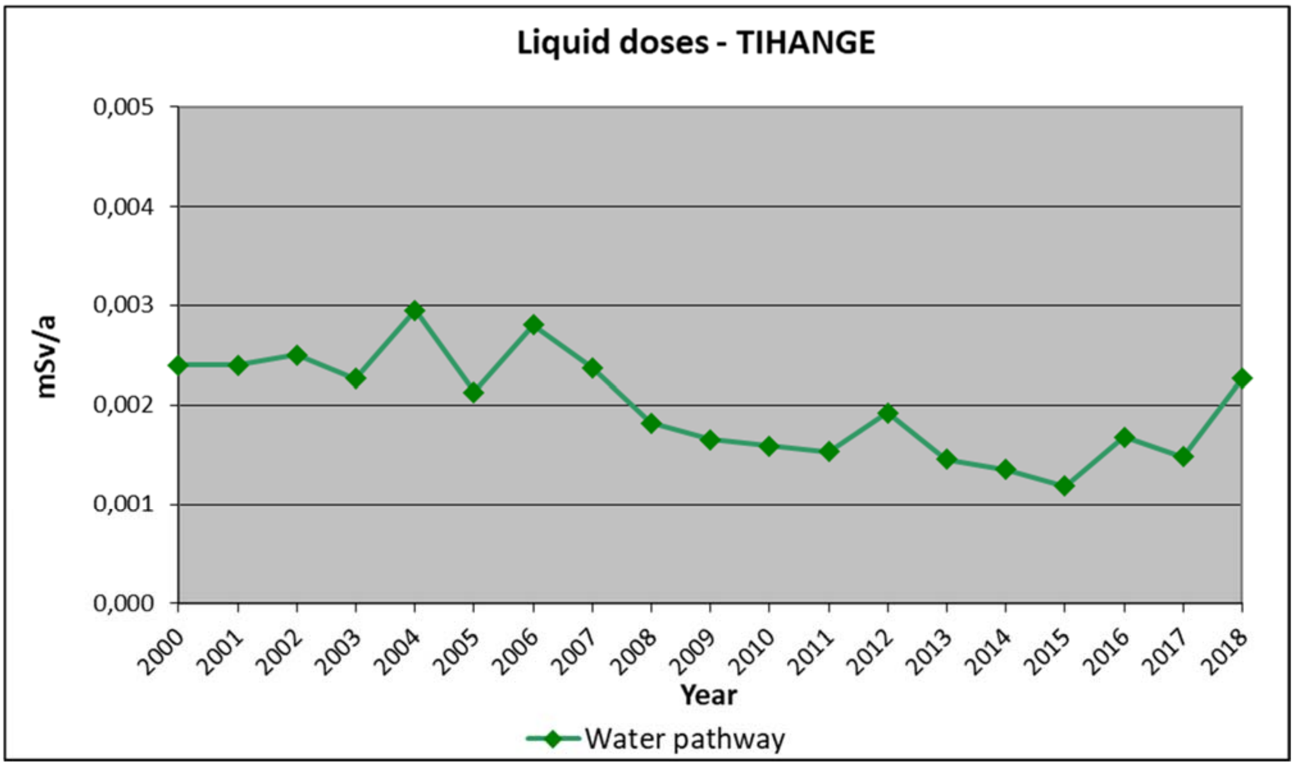
H-3 (TBq/a)
Normalised to capacity (TBq/GWa)
UNSCEAR range
TBq/a - TBq/GWa
80
70
60
50
40
30
20
10
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year



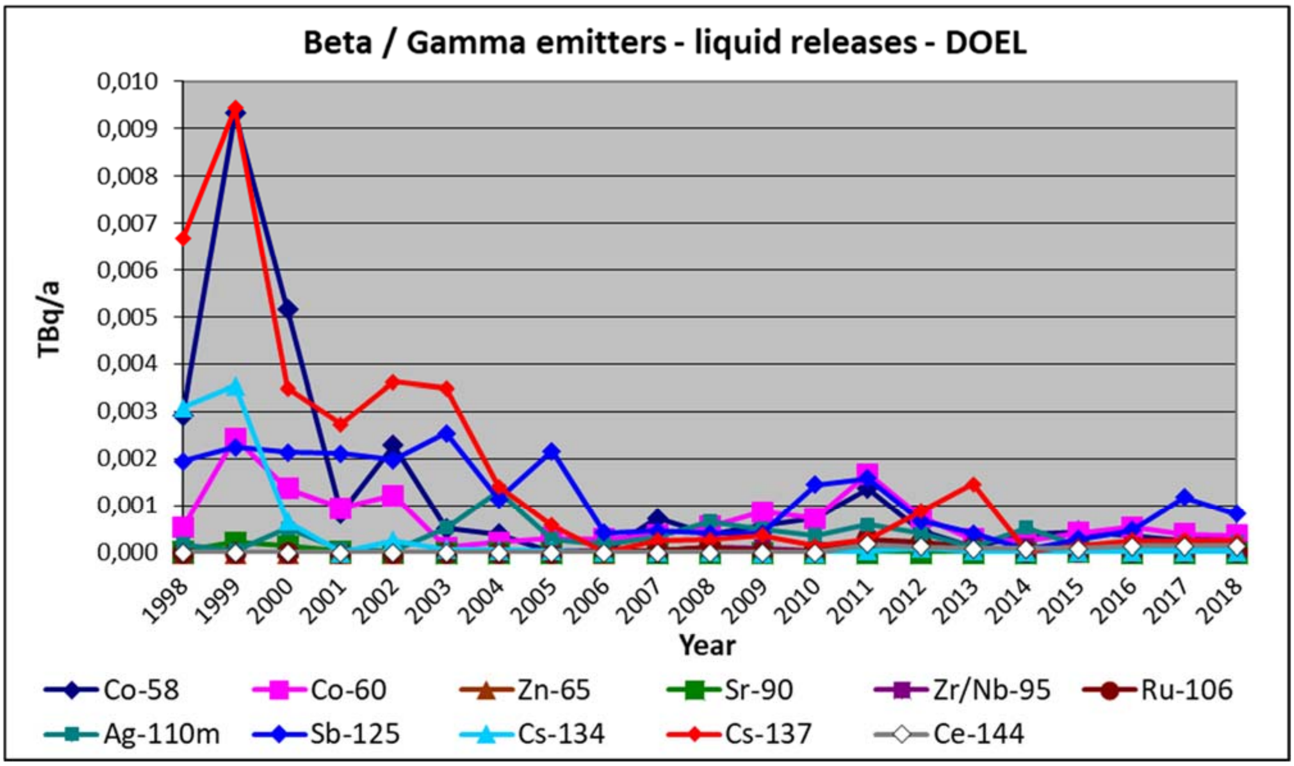


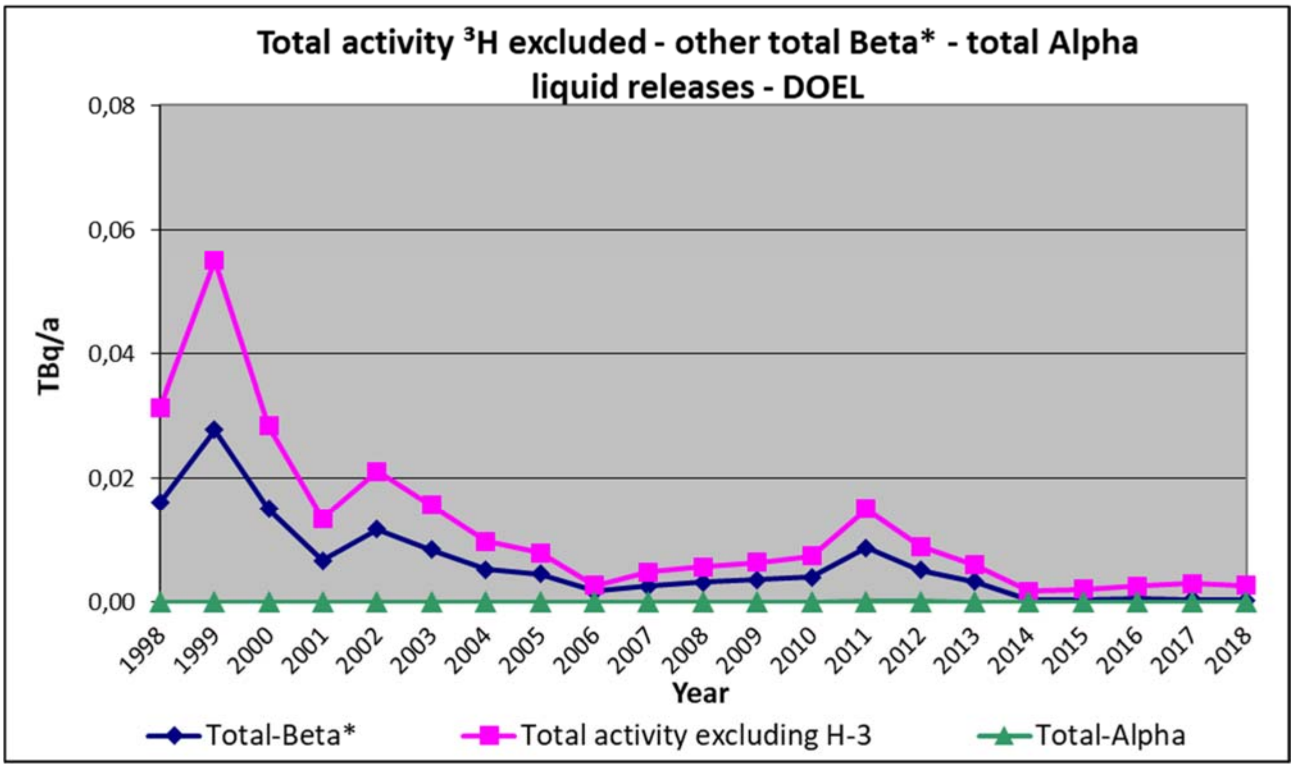
Note: Peaks 2003 and 2007 were caused by minor fuel assemblies defects (Tihange 1 and 3). Leaking fuel elements were detected by means of wet sipping tests when removed during outages and replaced by tight ones Full leakages mean also the possible releases of small amounts of fissile material. It needs some more cycles to remove all the "free" uranium from the reactor vessel and the primary circuits by means of RCVS (very low mesh filter cartridges and ion exchange mixed bed resins.


Atmospheric and liquid doses - TIHANGE
0,030
0,025
0,020
0,015
0,010
0,005
0,000
mSv/a
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year
Water pathway
Air pathway

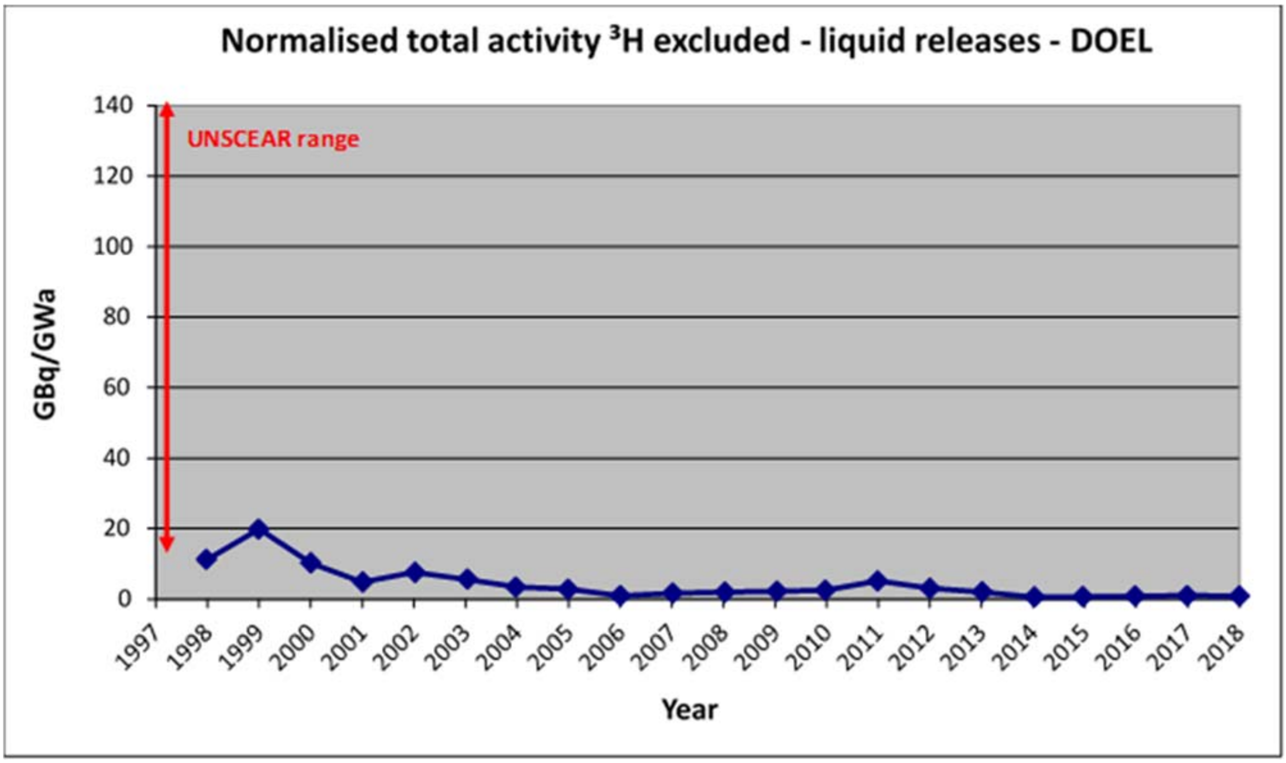

Liquid doses - TIHANGE
0,005
0,004
0,003
0,002
0,001
0,000
mSv/a
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year
Water pathway

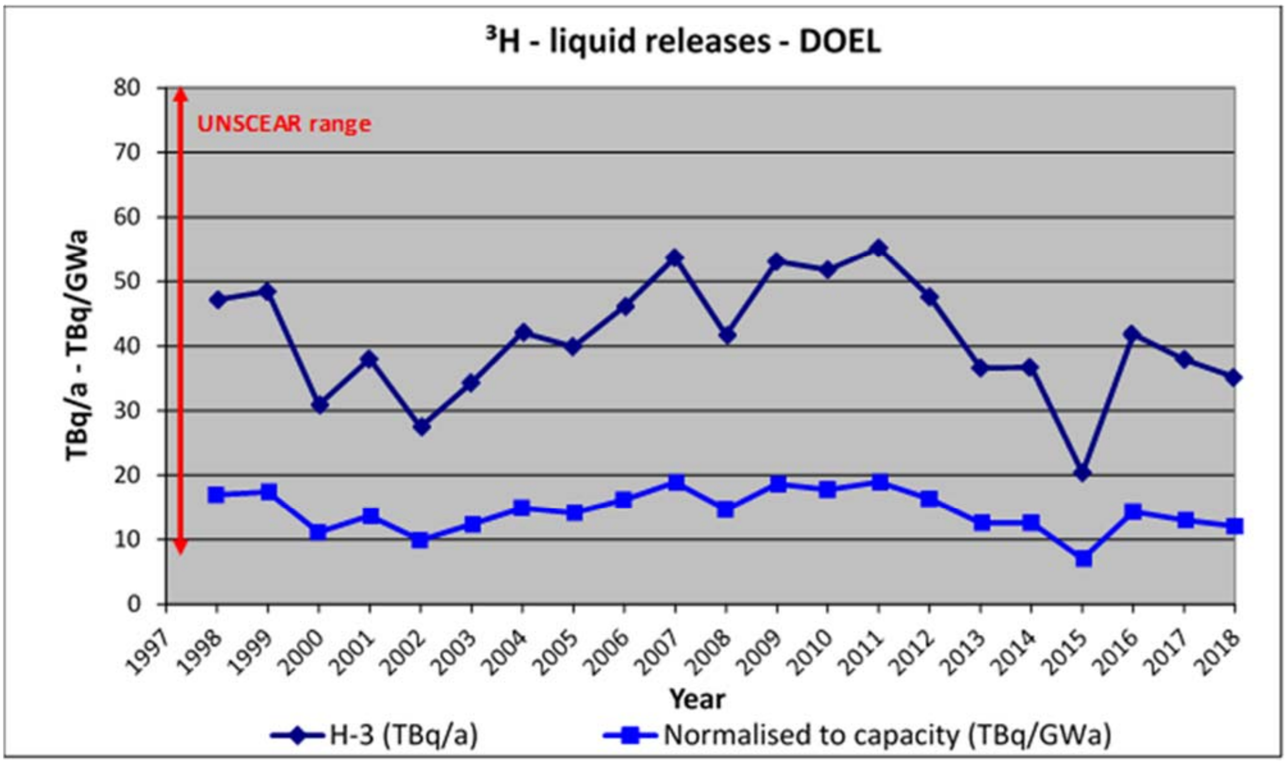
Doel NPP

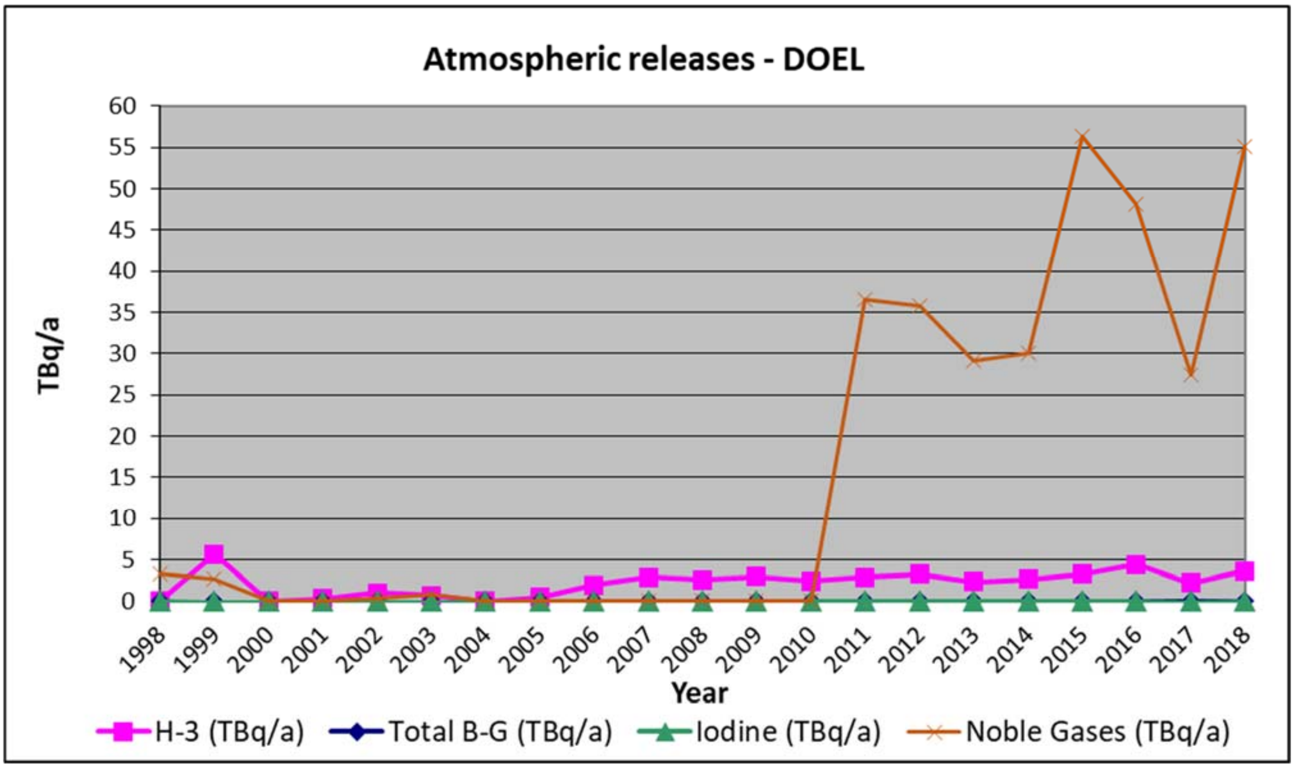


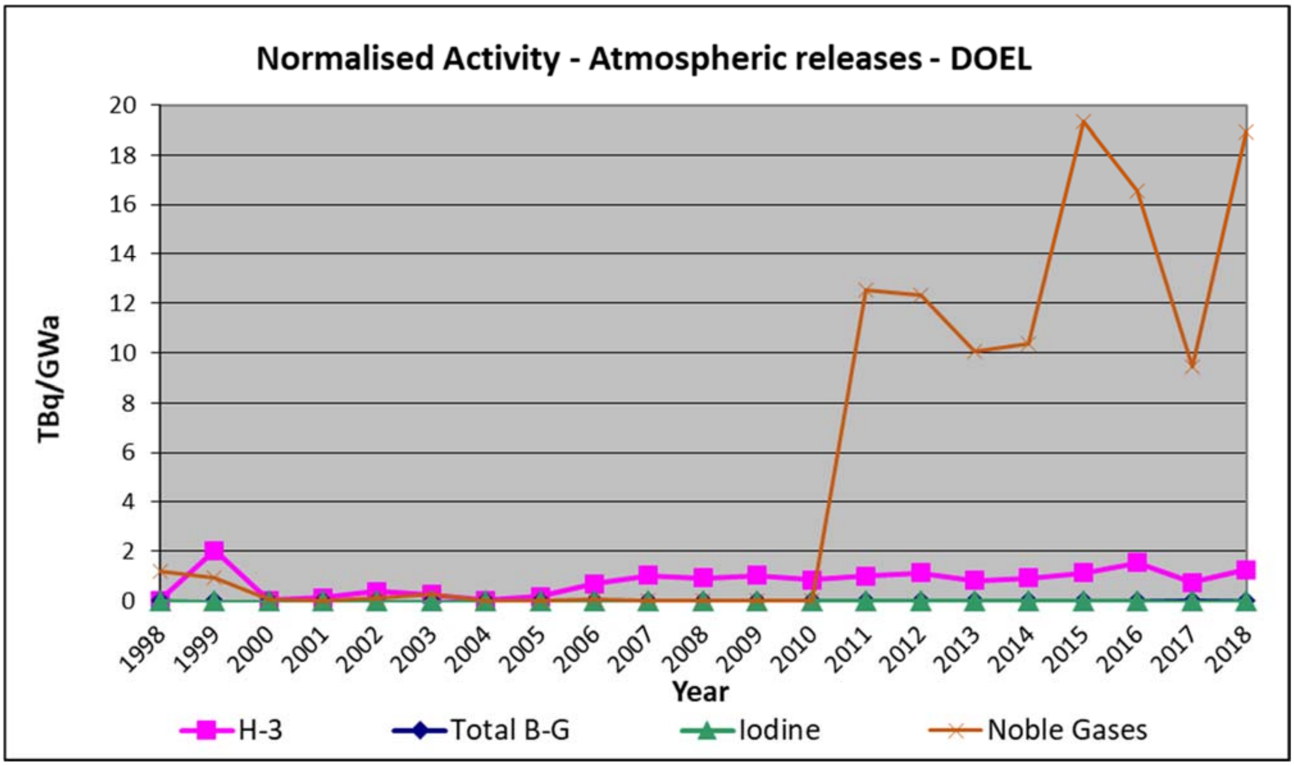


Note: The increase in liquid released activity (excluding tritium) is caused by frequent occuring technical problems with the evaporators in the WAB (water and waste treatment facility). Problems were solved in 2012/2013 with improvement and corrective projects.


Normalised total activity ³H excluded - liquid releases - DOEL
UNSCEAR range
GBq/GWa
140
120
100
80
60
40
20
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year

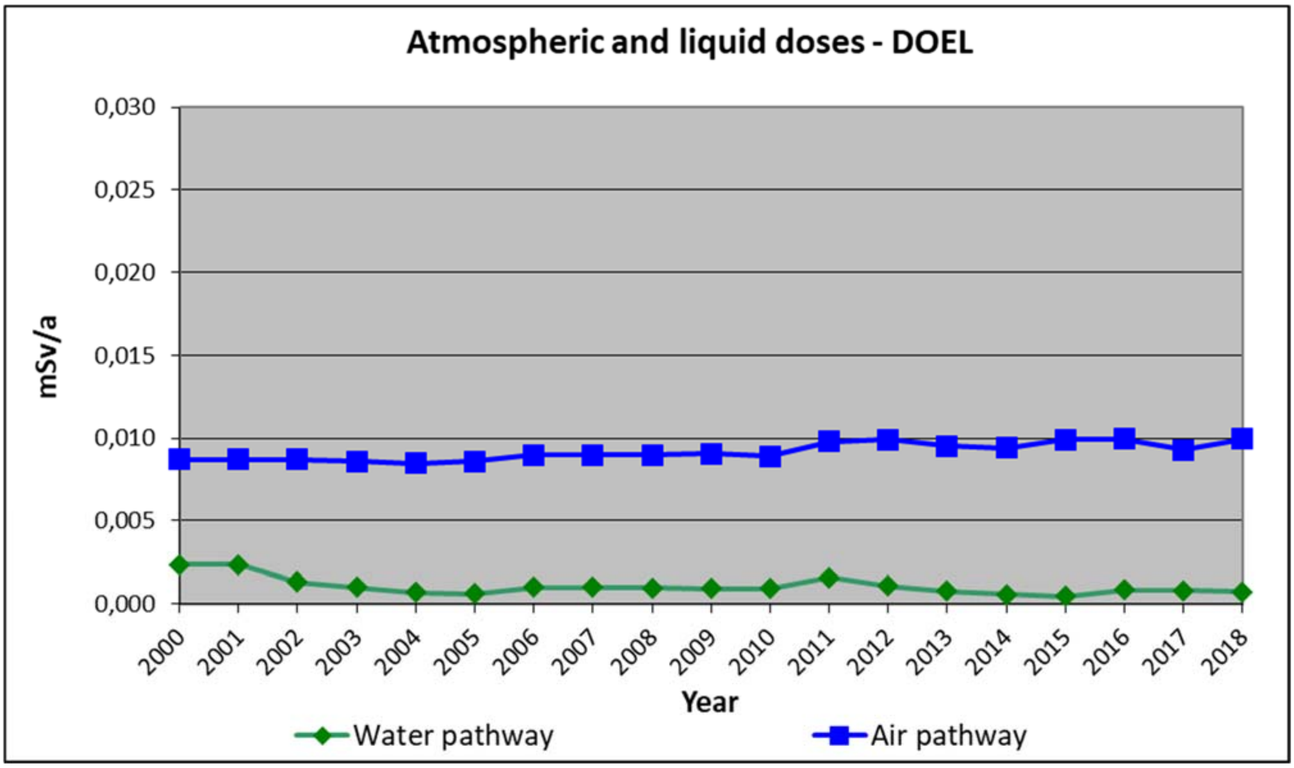

³H - liquid releases - DOEL
UNSCEAR range
TBq/a - TBq/GWa
80
70
60
50
40
30
20
10
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year
H-3 (TBq/a)
Normalised to capacity (TBq/GWa)



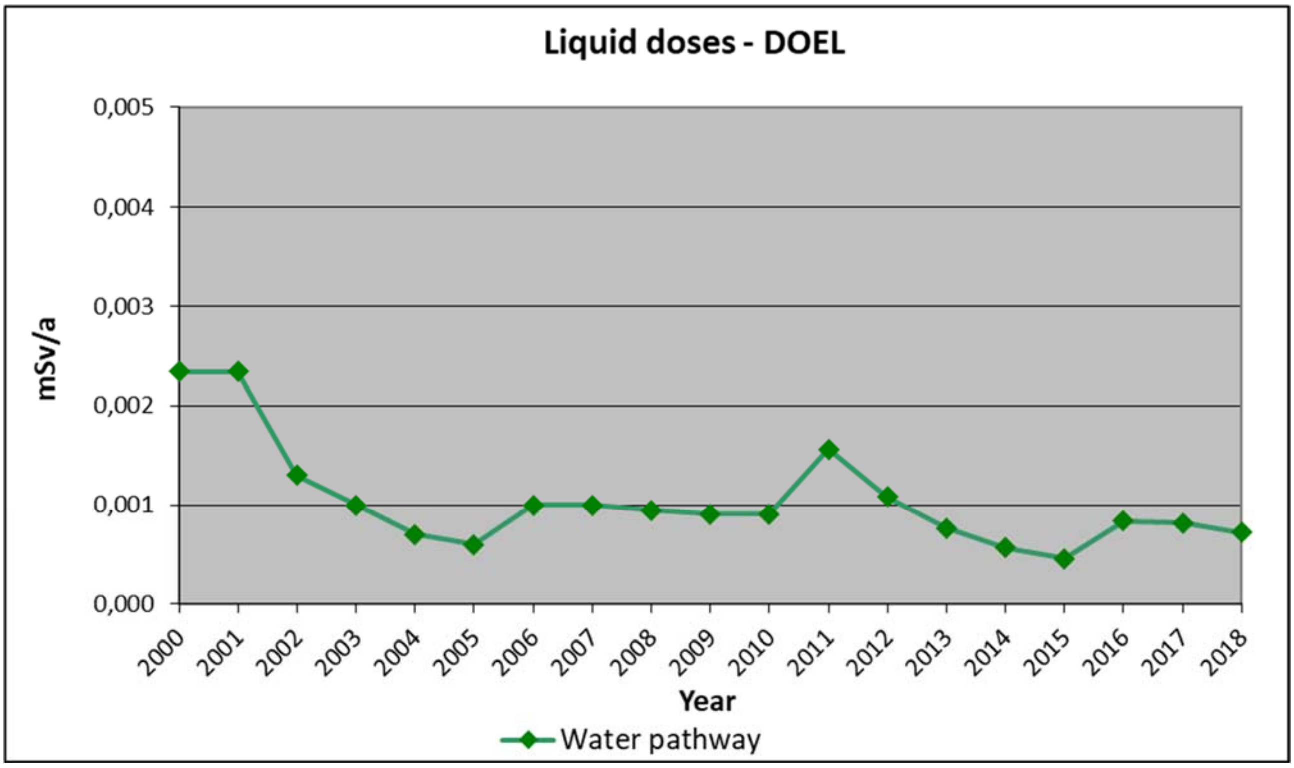


Note: The increase of the released (reported) activity in atmospheric discharges (noble gasses and aerosols) in 2011 is due to the new autorisation license/method of reporting which incorporates the EC Recommandations. Before, measurements below detection limit were reported as "zero", now they are reported as 1/4 of the DL. This new method has a great impact, especially for the noble gasses (factor 1000). In 2012-2013 the confidence interval of the spectrometric analyses was adapted to bring it in line with the current ISO standard. The increase of iodine activity in 2011 is due to additional filter tests and the fuelrod leakage of Doel 4.

Note: The peak in 2016 is due to a conservative calculation because of an erronous measurement. The increase in 2018 is due to the long shutdown of the reactor due to bunker problems (concrete degradation). This results in continuous ventilation of the reactor building and consequently an increase in atmospheric emissions.

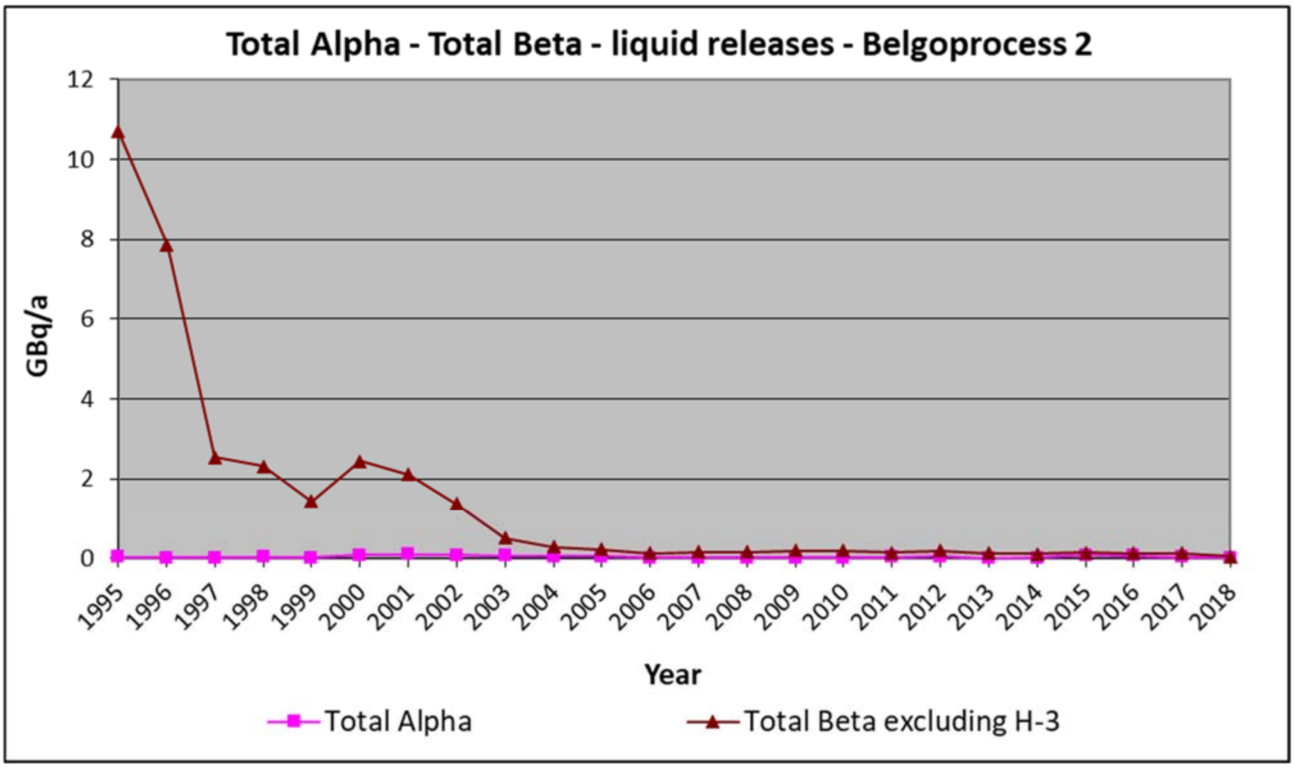


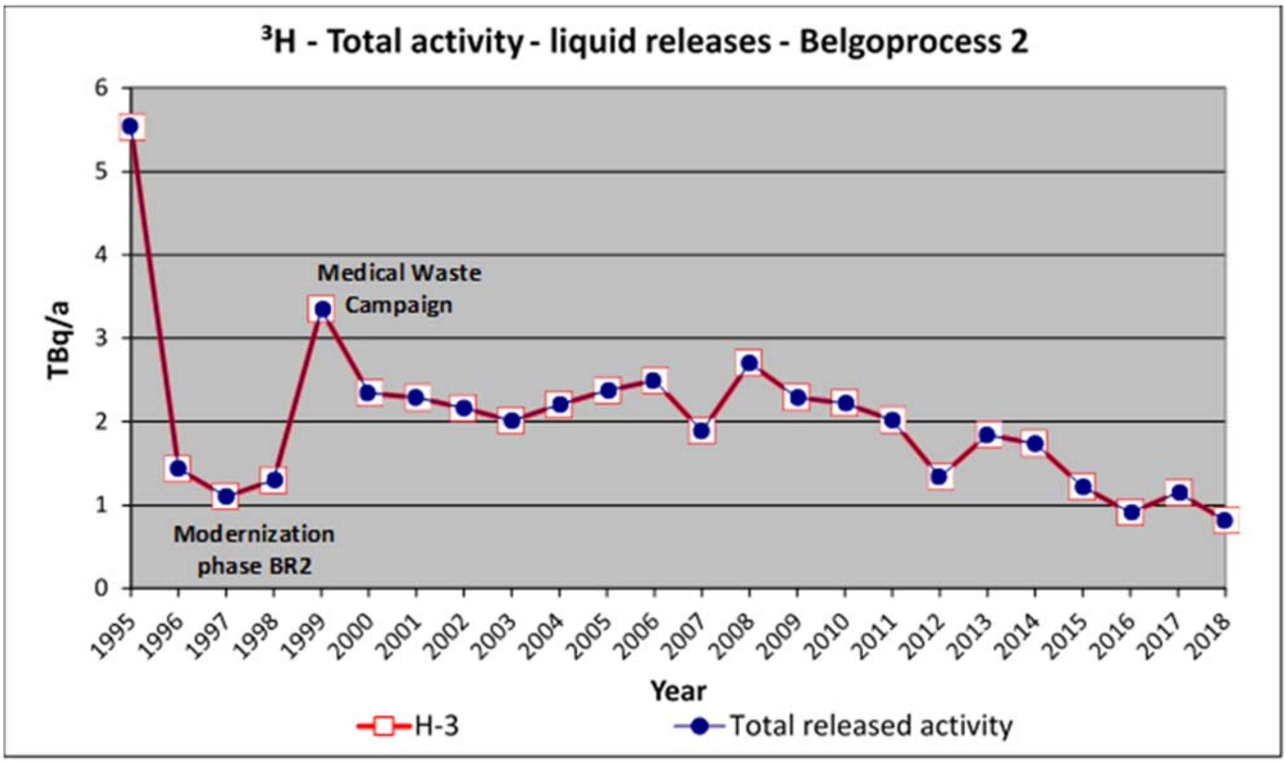
Atmospheric and liquid doses - DOEL
0,030
0,025
0,020
0,015
0,010
0,005
0,000
mSv/a
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year
Water pathway
Air pathway

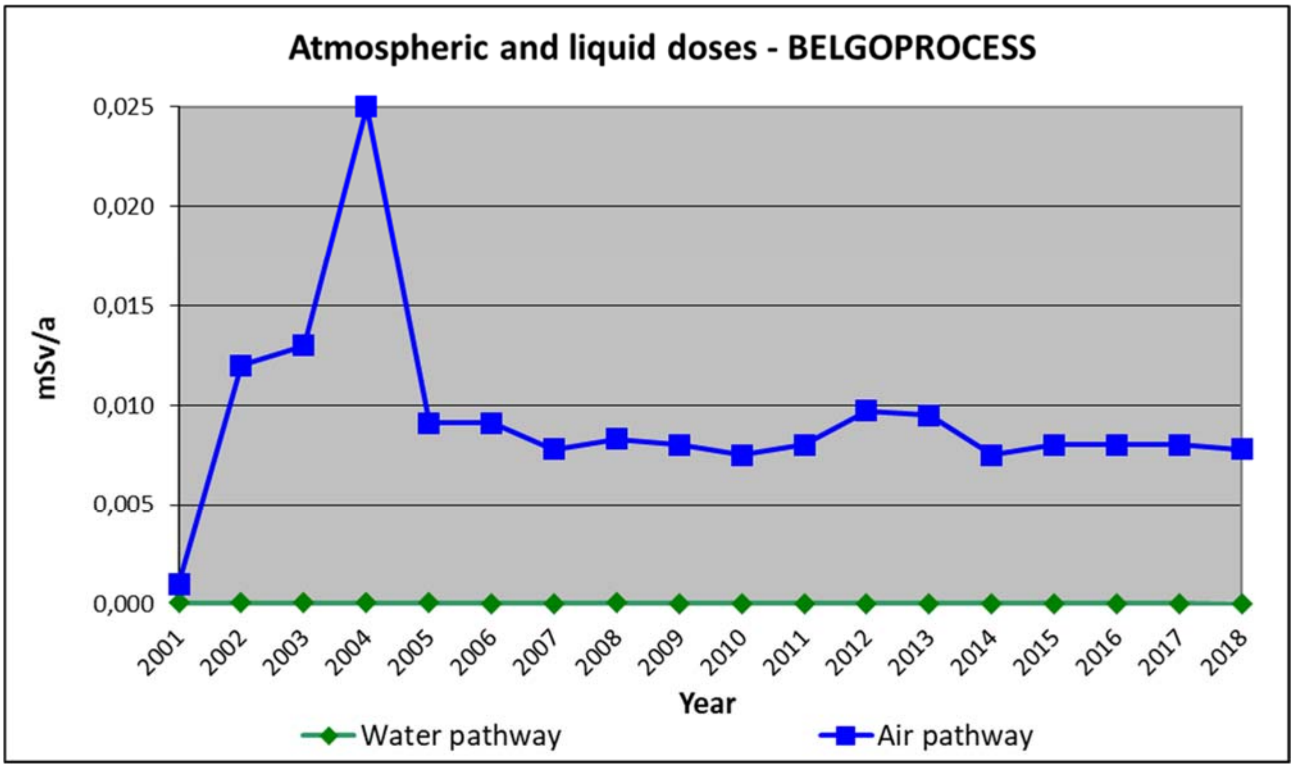


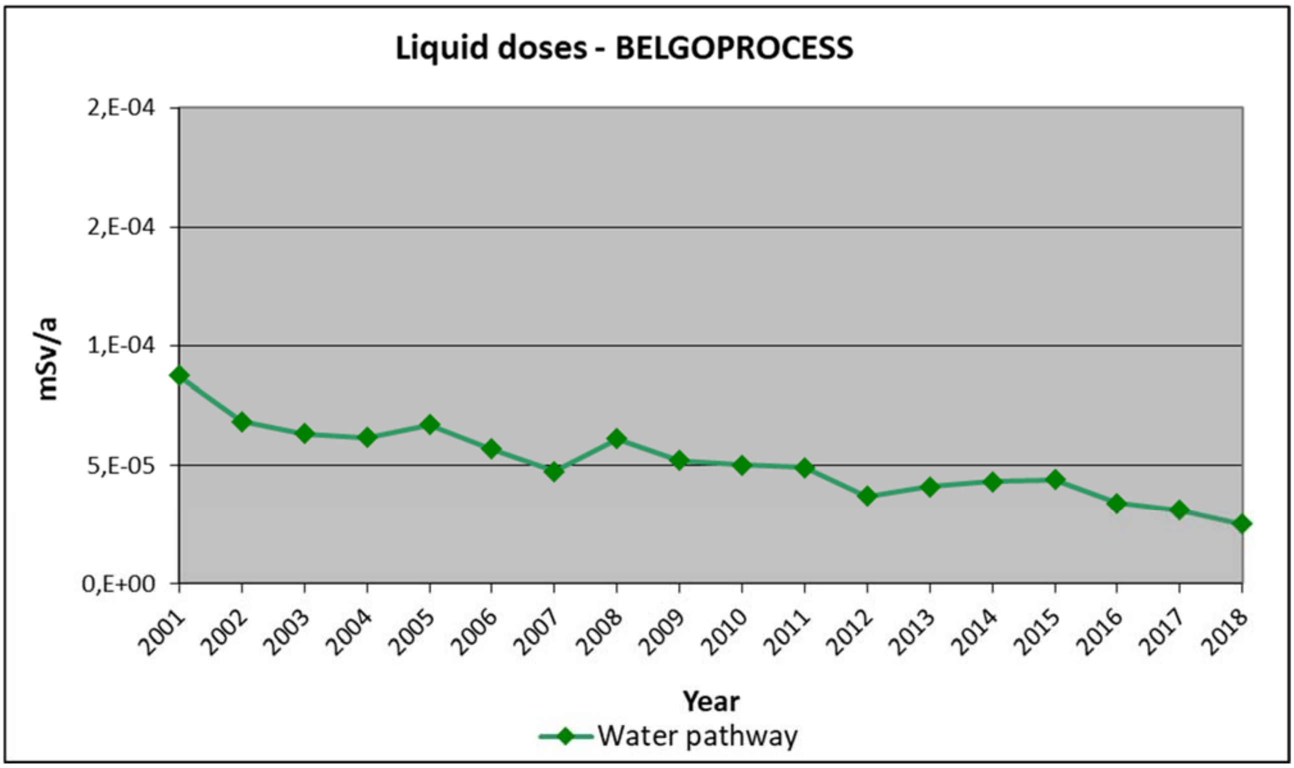
Liquid doses - DOEL
0,005
0,004
0,003
0,002
0,001
0,000
mSv/a
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year
Water pathway

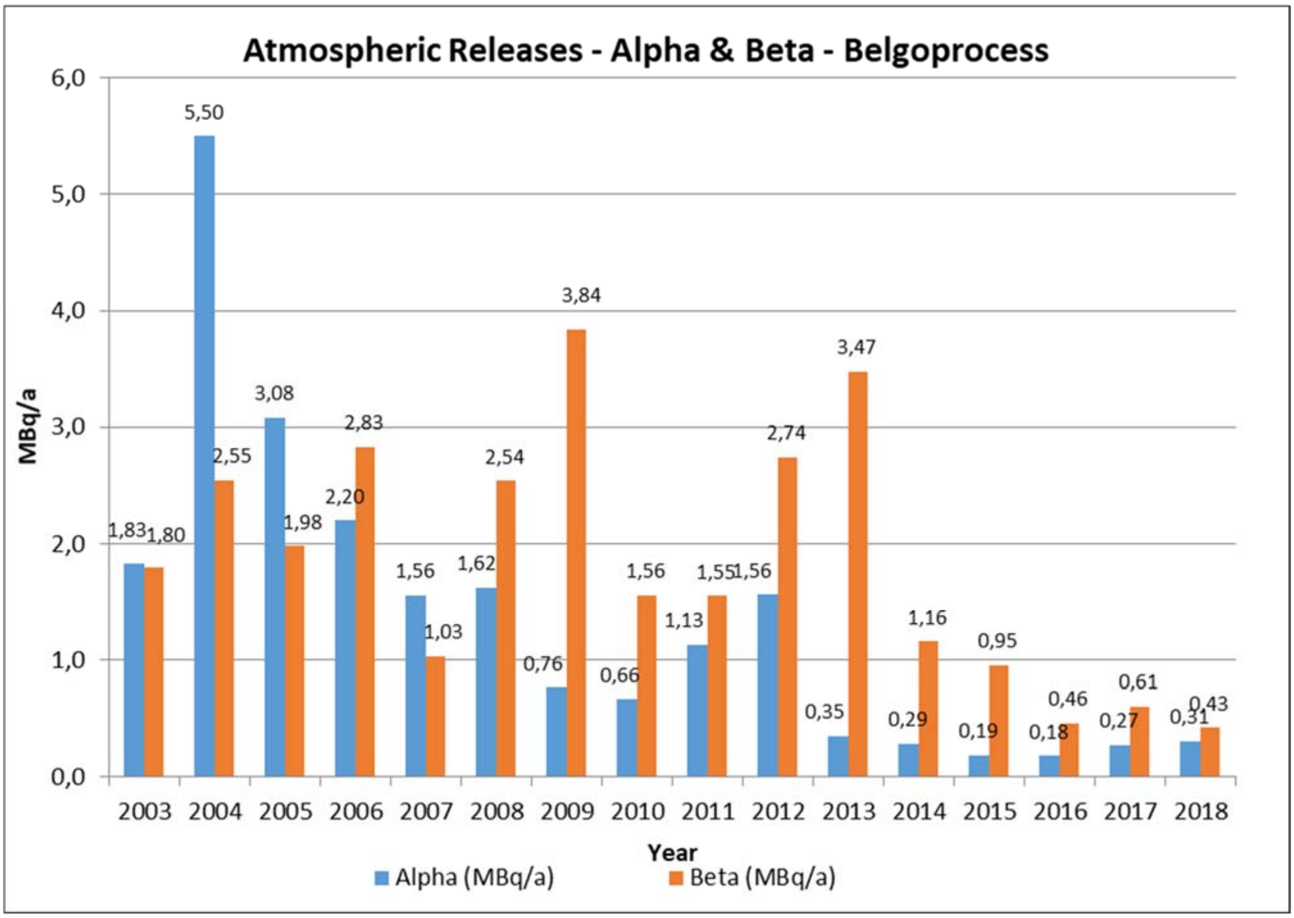
Belgoprocess 2 Nuclear Site






Atmospheric and liquid doses - BELGOPROCESS
mSv/a
0,025
0,020
0,015
0,010
0,005
0,000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year
Water pathway
Air pathway


Liquid doses - BELGOPROCESS
mSv/a
2,E-04
2,E-04
1,E-04
5,E-05
0,E+00
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year
Water pathway



Atmospheric Releases - Alpha & Beta - Belgoprocess
MBq/a
6,0
5,0
4,0
3,0
2,0
1,0
0,0
5,50
3,84
3,47
3,08
2,83
2,74
2,55
2,54
2,20
1,83
1,80
1,98
1,56
1,62
1,56
1,55
1,56
1,03
1,13
1,16
0,95
0,76
0,66
0,35
0,29
0,19
0,18
0,46
0,27
0,61
0,31
0,43
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Year
Alpha (MBq/a)
Beta (MBq/a)

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OSPAR's vision is of a clean, healthy and biologically diverse North-East Atlantic used sustainably

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