Implementation report on OSPAR Recommendation 18/01 on radioactive discharges by Switzerland

OSPAR: nuclear installations

2016 - 2019

Radioactive Substances Series

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8th Implementation Report of OSPAR Recommendation 18/01 on Radioactive Discharges

Presented by Switzerland

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.

Acknowledgement

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Summary

The purpose of OSPAR Recommendation 18/01 on Radioactive Discharges is to prevent and eliminate pollution caused by radioactive discharges from nuclear industries and their associated radioactive waste treatment facilities and decommissioning activities, by applying the best available techniques (BAT) and the best environmental practice (BEP) in accordance with Appendices 1 and 2 of the OSPAR Convention.

According to the Recommendation 18/01 Contracting Parties shall report on the implementation of this recommendation every six years in accordance with the Guidelines for the submission of Information about, and Assessment of, the Application of BAT and BEP in Nuclear Facilities (OSPAR Agreement 2018-01) using the format as set out in Appendix 1 to the Recommendation 18/01 as far as possible.

So far, Switzerland has reported compliance with PARCOM Recommendation 91/4 (now superseded by OSPAR recommendation 18/01) in all seven previous implementation rounds of reporting.

The current report represents the eighth round of reporting. It concerns the implementation of BAT and BEP in the nuclear facilities situated in Switzerland in accordance with OSPAR Recommendation 18/01.

From the evaluations of the BAT/BEP indicators for discharges, environmental impact and radiation doses to the public it is concluded that BAT and BEP have been applied at all Swiss nuclear facilities during the time period covered by this report.

1 Introduction

The OSPAR Recommendation 18/01 concerns the application of best available techniques (BAT) and best environmental practice (BEP) in accordance with Appendices 1 and 2 of the Convention to prevent and eliminate pollution caused by radioactive discharges from all nuclear industries, including nuclear power plants, reprocessing facilities, fuel fabrication facilities, research reactors, and their associated radioactive waste treatment facilities and decommissioning activities. After 2019 Contracting Parties should report every six years on the implementation of this Recommendation in accordance with the guidelines.

The OSPAR Recommendation 18/01 supersedes the PARCOM Recommendation 91/4. Switzerland has reported compliance with PARCOM Recommendation 91/4 during the seven previous implementation rounds. The seventh reporting was submitted in 2018 and concerned the time period from 2012 to 2017.

This report is the first according to the OSPAR Recommendation 18/01. It concerns the eighth round of reporting on the implementation of BAT and BEP at the four Swiss nuclear power plants, the waste treatment and interim storage facility ZWILAG and the Paul Scherrer Institute research facilities. Following the guidelines from Recommendation 18/01, the report covers a time period of six years, from 2015 to 2020.

2 General Information

2.1 Relevant national authorities and responsibilities

The Federal Council (Swiss government) is the general licensing authority for nuclear facilities. The construction or operation of a nuclear facility underlies a licensing from the Federal Department of Environment, Transport, Energy and Communications (DETEC). The decommissioning of nuclear installations is regulated by decommissioning orders by DETEC, which specify the activities requiring a permit to be granted by the supervisory authorities.

Switzerland has decided to phase out from nuclear energy and the law has been changed accordingly; the granting of general licences for new nuclear power plants is currently prohibited (Art. 12a NEA).

The Federal Office of Public Health (FOPH) is the licensing and supervisory authority for medical and non-nuclear research facilities. It is also responsible for the environmental radiation supervision in Switzerland.

The Swiss Federal Nuclear Safety Inspectorate (ENSI) is the supervisory authority for nuclear facilities. As such, it supervises the emissions and discharges of radioactivity from nuclear facilities into air and water. In addition, ENSI monitors the ionising radiation levels in the vicinity of nuclear installations.

2.2 National legislation

The Radiological Protection Act (RPA, 814.50) and the Radiological Protection Ordinance (RPO, 814.501) form the legal basis for radiation protection. They aim at protecting human health and the environment against ionising radiation and are based on the recommendations of the International Commission on Radiological Protection (ICRP). They implement the internationally agreed principles of justification of a practice, optimisation of radiation exposure and dose limitation. With the full revision of the Radiation Protection Ordinance and further underlying ordinances (which entered into force on January, 1st 2018), the legislation became compatible with the 2013/53/Euratom directive and the IAEA International Basic Safety Standard GSR Part 3 from July 2014.

As far as nuclear facilities are concerned, the Nuclear Energy Act (NEA 732.1) and Ordinance (NEO, 732.11) do also apply. More detailed requirements for nuclear facilities are defined in guidelines issued by ENSI. Further specific conditions and obligations are defined in the operating licence for each nuclear facility as well as in the corresponding orders issued by ENSI.

2.2.1 Application of BAT/BEP in domestic legislation

Under the Ordinance on the approval of international decisions and recommendations (814.201.81), which came into force in 2000, the competent Swiss authorities are recommended to consider the PARCOM-recommendation 91/4 (and subsequently the current OSPAR recommendation 18/01) when enforcing environmental protection legislation and regulations.

The Radiation Protection Act stipulates that measures shall be taken to limit the generation of radioactive waste and the emissions of radioactive substances as far as possible and reasonable, taking into account existing technical knowledge. In the nuclear sector specifically, Art. 30 NEA requires a minimization of the radioactive waste produced by nuclear facilities as well.

The NEO requires a periodic safety review to be performed by the licensee of nuclear power plants every ten years. In the framework of these periodic safety reviews the licensee has to assess the liquid and gaseous discharges and to benchmark them against the corresponding discharges from similar European reactors. In case of own discharges in excess of the benchmark, the licensee has to analyse the causes and suggest proportionate means of reduction. As nuclear regulatory body, ENSI performs a safety evaluation of the licensee's periodic safety reviews and addresses the adequacy of the adopted measures.

2.2.2 Dose limit, constraints and rationale for setting discharge limit

The Ordinance on Radiological Protection sets the dose limit for members of the public at 1 mSv in terms of annual effective dose. The sum of the doses due to radioactive emissions into the atmosphere, discharges into water and direct radiation from any nuclear site shall not exceed a source-related dose constraint, which has been defined in the guideline ENSI-G15 at 0.3 mSv per year and person. The dose guide value for direct radiation has been set at 0.1 mSv per year and person in the same guideline.

With regards to design basis accidents (potential exposure situations), the Swiss legislation (RPO and NEO) sets a series of dose criteria for the public. In particular the licensee shall demonstrate by means of accident analyses with dispersion calculation in the environment, that for failures with an occurrence probability greater than 1E-2 per year the maximal dose to the public does not exceed 0.3 mSv per year, for failures with an occurrence probability greater than 1E-4 per year (but less than 1E-2 per year) the maximal dose to the public does not exceed 1 mSv per year, for failures with an occurrence probability greater than 1E-6 per year (but less than 1E-4 per year) the maximal dose to the public does not exceed 100 mSv per year.

The discharge limits are fixed in the operating license of each facility; they correspond to the source-related dose constraint of 0.3 mSv per year and person. The concentration of radioactive substances (in terms of a nuclide specific weighted sum) within discharges into water are further constrained with reference to immission limits set in the RPO.

2.2.3 Regulation, surveillance and monitoring

Based on RPO, the licensing authority decides whether source-related dose constraints are required and shall specify these in the operating licence. For nuclear facilities with already existing operating licences by the time this regulatory aspect has been introduced, a source-related dose constraint may be specified within facility-specific regulations issued by the supervisory authority (ENSI). Within these the allowed rate and concentration are set for each facility specifically, according to the defined source-related dose constraint and the immission limits. Furthermore, the monitoring of emissions is specified and a mandatory reporting is defined. The regulations also define an environmental surveillance programme to be performed by the licensee.

The licensing authority may request an annual determination of the dose received by the most exposed members of the public (virtual person of the critical group, please refer to Chapter 2.2.5) and specify the requirements for the determination of radiation doses. For nuclear facilities, the specifications for the determination of radiation doses are issued in guideline ENSI-G14.

2.2.4 Environmental monitoring programmes

FOPH monitors ionising radiation and radioactivity in the environment by means of measurements in appropriate sampling media such as airborne particles, water intended for human consumption and foodstuffs. To this end, it may collaborate with the cantons (local authorities). Additionally, ionising radiation and radioactivity in the vicinity of nuclear installations are monitored by ENSI.

An automatic measuring network is operated by FOPH for the general monitoring of radioactivity (air, water) in the environment. Additionally, automatic dose rate measuring networks are operated by ENSI in the vicinity of nuclear facilities and by the National Emergency Operations Centre (NEOC) over the whole country.

A sampling and measurement programme for planned and for existing exposure situation is drawn up by FOPH, in cooperation with ENSI, NEOC and the cantons. It comprises the measurements of dose rate and integral dose as well as the measurement of air, drinking water, rainwater, river water, river sediments, soil, plants and food samples. The programme is reviewed annually and modified as necessary. On the basis of the collected data, FOPH evaluates the radiological situation and the dose to the public. It reports on it yearly.

ENSI has issued facility-specific discharge and environment monitoring regulations. These regulations define the control of emissions and discharges as well as a complete programme on environmental monitoring of radioactivity and direct radiation in the vicinity of the facility to be undertaken by the licensee. The location, frequency and methods of sampling and measurement, as well as the responsibility for conducting these, are determined within these regulations. In addition, abatement systems and environmental surveillance (sampling, measurement laboratories and equipment, data records, quality assurance and reporting) are inspected by ENSI on a regular basis. In this framework, environmental sampling and measurements are cross-checked by FOPH and further authorities several times every year.

2.2.5 Radiation dose assessment methods

The compliance with the dose constraint is assessed using a calculation model for a representative virtual person of the critical group in the vicinity of a nuclear facility. The dose calculation model is defined in the guideline ENSI-G14.

2.2.6 Environmental norms and standards

The Radiological Protection Ordinance defines immission limits on the allowed concentration of radioactive substances released into the atmosphere and water. The nuclide specific immission limits correspond to an annual inhalation and immersion dose (releases into the atmosphere) and an annual ingestion dose (discharges into water) of 0.3 mSv per year, respectively.

The Swiss Ordinance on Contaminants (SR 817.022.15) defines the maximum concentration values for radionuclides in food after a nuclear accident or other radiological emergency as an additional restriction. The maximum concentration values are based on the EURATOM 2016/52 regulation. For drinking water, the maximum concentration is defined in the Ordinance on Drinking Water and Water in Publicly Accessible Bathrooms and Shower Facilities (SR 817.022.11), which is based on the EURATOM 2013/51 directive.

2.2.7 Quality assurance

According to guideline ENSI-G07, the licensee of a nuclear facility is required to establish a quality management system for safety relevant processes. The laboratories involved in assessing radioactive environmental discharges are required by guideline ENSI-G13 to take part in proficiency tests. For the purpose of cross-examining the assessment of environmental probes, ENSI operates its own laboratory, which is accredited in accordance with SN EN ISO 17025 for the measurement of radioactivity and dose rate.

2.3 Swiss nuclear facilities

Switzerland has eight nuclear facilities: four NPPs, a waste treatment and interim storage facility, as well as three research and educational nuclear facilities. All but one discharge into the catchment area of the river Rhine (figure 1), the exception being a nuclear facility for educational purposes (EPFL) with no relevant discharges.

2.3.1 Nuclear Power Plants

The Swiss NPPs are of four different reactor designs by three different reactor suppliers. The main characteristics of the NPPs are compiled in table 1, the annual net electrical output in table 2.

In the time period covered by the current implementation report, the following key events have to be noted: Mühleberg NPP has definitely ceased power operation in December 2019, while decommissioning has started in September 2020. Unit 1 of Beznau NPP has been out of operation between March 2015 and March 2018 due to ultrasonic findings, subsequent investigations and safety assessments on the material of the reactor pressure vessel.

Figure 1: Location of the Swiss nuclear facilities, with four NPPs (triangles), a nuclear waste treatment and interim storage facility (square) and three research and educational facilities (stars). Major cities are shown by dots.

Table 1: Main characteristics of the Swiss NPPs

Name of site	Beznau 1	Beznau 2	Mühleberg	Gösgen	Leibstadt
Receiving waters	river Aare	river Aare	river Aare	river Aare, wet cooling tower	river Rhine, wet cooling tower
Licensed thermal power (MW_{th})	1130	1130	1097	3002	3600
Nominal net electrical power (MW_{el})	365	365	373	1010	1220
Reactor type[1] / supplier[2]	PWR / W	PWR / W	BWR / GE	PWR / KWU	BWR / GE
Site Licence	1964	1967	1965	1972	1969
Construction Licence	1964	1967	1967	1973	1975
Commercial operation	1969	1971	1972	1979	1984
End of power operation			2019		
Start of decommissioning			2020		
	First generation			Second generation	

[1] BWR: Boiling Water Reactor; PWR: Pressurised Water Reactor

[2] W: Westinghouse; GE: General Electric (now Global Nuclear Fuel); KWU: Kraftwerk-Union (now Framatome ANP)

Table 2: Annual net electrical output in [GW_{el} h]

	2015	2016	2017	2018	2019	2020
Beznau 1	*620.9*	*0.0*	*0.0*	*2'481.0*	*2'854.8*	*2'784,7*
Beznau 2	*2'021.5*	*3'048.4*	*2'813.6*	*3'057.4*	*2'827.3*	*2'956,0*
Beznau total	2'642.4	3'048.4	2'813.6	5'538.4	5'682.1	5'740,7
Gösgen	7'971.2	8'167.3	8'084.3	8'246.7	7'820.2	8'332.3
Leibstadt	8'589.5	6'075.4	5'618.8	7'799.2	8'819.5	9'050.4
Mühleberg	2'939.9	2'946.2	2'998.2	2'953.7	3'093.2	-

2.3.2 Waste treatment and interim storage facility

The ZWILAG facility in Würenlingen has been constructed for the treatment and the interim storage of waste from nuclear facilities. It consists mainly of an interim storage facility (in operation since 2001) and an incineration and melting plant. The latter started operation with low-level radioactive waste in 2004. Since 2008, close to all burnable and an important part of the meltable waste from all Swiss nuclear facilities are processed at the plant. In the initial years, discharges into the atmosphere and into the river Aare (which belongs to the catchment area of the Rhine) were very low and therefore not reported to OSPAR. Switzerland started reporting on discharges from ZWILAG in 2005.

2.3.3 Research facilities and facilities for nuclear education

The Paul Scherrer Institute (PSI) is part of the Domain of the Swiss Federal Institutes of Technology (ETH Domain) and is located between the villages of Villigen and Würenlingen. PSI is a multidisciplinary research institute for natural sciences and engineering, with various laboratories handling radioactive materials. PSI operates a Hotlab with hot cells for sample preparation techniques and microstructural characterisation of highly radioactive materials. The institute hosts a federal radioactive waste treatment plant and the federal interim storage facility for radioactive waste resulting from industry, medicine and research. The treated waste waters of the Institute are discharged into the river Aare, which belongs to the catchment area of the Rhine. Three former research reactors and the Institute's experimental incineration plant are in decommissioning.

The facilities with educational purpose at the University of Basel (for which the decommissioning progress has allowed for the clearance of the building structures in 2020) and at the Ecole Polytechnique Fédérale de Lausanne (EPFL) have no relevant discharges and therefore not part of this report.

3 Site-specific information

3.1 Beznau NPP (KKB)

The Beznau nuclear power plant (KKB) is owned by AXPO Power AG and consists of two virtually identical dual-loop pressurized water reactor units (KKB 1 and KKB 2). Each unit has a thermal power of 1130 MW_{th}. As a result of different backfitting measures, the electrical power of both units has increased through the years and since August 2005, the net electrical output is 365 MW_{el} for each unit.

KKB is located in Döttingen in the canton Aargau in the North of Switzerland. Water from the river Aare is used for cooling; liquid discharges are released into the same river, which belongs to the catchment area of the Rhine.

3.1.1 BAT/BEP systems

The waste water is collected and treated in batches. The radioactivity in the waste water is reduced by centrifugation and, since 2007, cross-flow-nanofiltration and/or, if necessary, by chemical precipitation. Samples of the cleaned waste water are measured and, if the concentration criteria are fulfilled, the batch is discharged. The activity concentration is additionally monitored by a total gamma counting system with an integrated automatic shut-off function. The radioactive waste by-products are dried and solidified in the radioactive waste treatment system of the plant.

3.1.2 Efficiency of abatement systems

The chemical precipitation system reduces the concentration of radioactivity in the discharged water by a factor of up to 1000. With the cross-flow-nanofiltration system, the concentration is reduced further by a factor of up to 100. The abatement system has however no effects on the level of tritium discharges.

3.1.3 Discharges and trends

Activities in liquid discharges are determined batch-wise using gamma spectrometry. Tritium is also determined in each batch. Sr-90 and alpha-emitters are monitored by analysing monthly resp. quarterly aggregate samples.

Discharge data has been reported to the OSPAR Commission and is available through the Odims database: https://odims.ospar.org. The discharges of radioactive substances without tritium are plotted in figure 2 (see section 3.7) as a function of time: a downward trend can be observed, including a downward step after the introduction of cross-flow-nanofiltration in 2007. As for tritium in the liquid discharges, no upward or downward trend can be observed.

3.1.3.1 Site-specific target value

A site-specific target for liquid discharge (excl. tritium) for Beznau NPP has been introduced in 2004 by the licensing authority. It requested the operator to pursue the reduction of liquid discharges (excl. tritium) down to the level of the median value of discharges (excl. tritium) from European Pressurised Water Reactors (hence 1 GBq/a), by 2007. The liquid discharges (excl. tritium) have been below the target value for the duration of the reporting period.

3.1.3.2 Normalised data

For the sake of comparison with facilities of a similar kind, the liquid discharges of Beznau NPP have been normalised with regard to net electrical output on an annual basis and compared to the global mean value from the UNSCEAR 2016 report (see figure 3 and 4, section 3.7). The normalised discharges of radioactive substances without tritium from Beznau NPP have remained stable, below the UNSCEAR mean global value for "other nuclides" over the reporting period. The normalised tritium discharges are at a comparable level as the relevant UNSCEAR mean global value.

3.1.4 Emission to air

The emissions of C-14 and tritium from KKB into the atmosphere are shown in table 3. The discharges from KKB into air have been stable on a low level for the duration of the reporting period. Following the recommendations from the German Nuclear Safety Standards Commission Programme of Standards KTA 1503.1, measurements of actual releases of I-129 into the air are not requested by the supervisory authority.

Table 3: C-14 and tritium emission into the atmosphere from KKB, in TBq

	2015	**2016**	**2017**	**2018**	**2019**	**2020**
C-14 (CO_2)	2.4E-02	1.8E-02	1.8E-02	1.3E-02	3.6E-02	2.6E-02
Tritium	2.9E-01	3.1E-01	3.1E-01	5.7E-01	5.9E-01	7.4E-01

3.1.5 Quality assurance – discharges

The data management system of KKB is certified in accordance with ISO 9001 and ISO 14001.

3.1.6 Other relevant information

KKB unit 1 has been out of operation between March 2015 and March 2018 due to ultrasonic findings, subsequent investigations and safety assessments on the material of the reactor pressure vessel.

3.1.7 Data completeness and compliance

Data submitted have been complete in all relevant aspects.

3.2 Gösgen NPP (KKG)

The Gösgen nuclear power plant (KKG) is owned by the Kernkraftwerk Gösgen-Däniken AG and consists of a 3-loop pressurized water reactor, built by Kraftwerk Union AG (KWU, now Framatome). KKG started commercial operation in 1979. It has a thermal power of 3002 MW_{th} and a net electrical output of 1010 MW_{el}.

KKG is located in Däniken in the canton Solothurn in the North of Switzerland. The plant has a wet cooling tower and releases its liquid discharges into the river Aare, which belongs to the catchment area of the river Rhine.

3.2.1 BAT/BEP systems

The waste water is collected and treated in batches. The radioactivity in the waste water is reduced by evaporation. Samples of the distillate are measured and, if the concentration criteria are fulfilled, the batch is discharged. The activity concentration is additionally monitored by a total gamma counting system with an integrated automatic shut-off function. The radioactive waste by-products are conditioned with bitumen in the radioactive waste treatment system of the plant.

3.2.2 Efficiency of abatement systems

The water evaporation reduces the concentration of radioactivity in the discharged water by a factor between 100 and up to 10'000. The abatement system has however no effects on the level of tritium discharges.

3.2.3 Discharges and trends

Activities in liquid discharges are determined batch-wise using gamma spectrometry. Tritium, Sr-90 and alpha-emitters are monitored by analysing monthly aggregate samples.

Discharge data has been reported to the OSPAR Commission and is available through the Odims database: https://odims.ospar.org. The discharges of radioactive substances without tritium are plotted in figure 2 (see section 3.7) as a function of time. The discharges of radioactive substances (excl. tritium) are among the lowest of the European pressurized water reactors. As for tritium in the liquid discharges, no upward or downward trend can be observed.

3.2.3.1 Site-specific target value

KKG has formulated an internal goal of keeping the environmental impact from discharges below 0.01 mSv per year for a member of the public, using the calculation methods of guideline ENSI-G14.

3.2.3.2 Normalised data

For the sake of comparison with facilities of a similar kind, the liquid discharges of Gösgen NPP have been normalised with regard to net electrical output on an annual basis and compared to the global mean value from the UNSCEAR 2016 report (see figure 3 and 4, section 3.7). The normalised discharges of radioactive substances without tritium from Gösgen NPP have remained stable, well below the UNSCEAR mean global value for “other nuclides” over the reporting period. The normalised tritium discharges are at a comparable level as the relevant UNSCEAR mean global value.

3.2.4 Emission to air

The emissions of C-14 and tritium from KKG into the atmosphere are shown in table 4. The discharges from KKG into air have been stable on a low level for the duration of the reporting period. Following the recommendations from the German Nuclear Safety Standards Commission Programme of Standards KTA 1503.1, measurements of actual releases of I-129 into the air are not requested by the supervisory authority.

Table 4: C-14 and tritium emission into the atmosphere from KKG, in TBq

	2015	**2016**	**2017**	**2018**	**2019**	**2020**
C-14 (CO_2)	4.6E-02	5.2E-02	4.4E-02	2.7E-02	6.8E-02	5.8E-02
Tritium	4.8E-01	4.4E-01	5.9E-01	5.7E-01	6.1E-01	6.0E-01

3.2.5 Quality assurance – discharges

The data management system of KKG is certified in accordance with ISO 9001, ISO 14001 and ISO 45001.

3.2.6 Other relevant information

There is no other relevant information.

3.2.7 Data completeness and compliance

Data submitted have been complete in all relevant aspects.

3.3 Leibstadt NPP (KKL)

The Leibstadt nuclear power plant (KKL) is owned by the Kernkraftwerk Leibstadt AG and consists of a boiling water reactor (BWR) of an General Electric design. KKL has a thermal power of 3600 MW_{th} and a net electrical output of 1220 MW_{el}. It started commercial operation in 1984.

KKL is located near the village of Leibstadt, in the canton Aargau, situated in the North of Switzerland on the border to Germany. The plant has a wet cooling tower and releases its liquid discharges into the river Rhine.

3.3.1 BAT/BEP systems

The waste water is collected and treated in batches. The radioactivity in the waste water is reduced by centrifugation and evaporation. Samples of the distillate are measured and, if the concentration criteria are fulfilled, the batch is discharged. The activity concentration is additionally monitored by a total gamma counting system with an integrated automatic shut-off function. The radioactive waste by-products are treated in the radioactive waste treatment system of the plant.

3.3.2 Efficiency of abatement systems

The centrifugation and the evaporation systems reduce the concentration of radioactivity in the discharged water by a factor of at least 100 and up to 10’000. The abatement system has however no effects on the level of tritium discharges.

3.3.3 Discharges and trends

Activities in liquid discharges are determined batch-wise using gamma spectrometry. Tritium, Sr-90 and alpha-emitters are monitored by analysing quarterly aggregate samples.

Discharge data has been reported to the OSPAR Commission and is available through the Odims database: https://odims.ospar.org. The discharges of radioactive substances without tritium are plotted in figure 2 (see section 3.7) as a function of time: a downward trend can be observed over time. As for tritium in the liquid discharges, no upward or downward trend can be observed.

3.3.3.1 Site-specific target value

KKL has defined the following internal target values for liquid discharges: 1 TBq for tritium, 1 GBq for all other liquid discharges.

3.3.3.2 Normalised data

For the sake of comparison with facilities of a similar kind, the liquid discharges of Leibstadt NPP have been normalised with regard to net electrical output on an annual basis and compared to the global mean value from the UNSCEAR 2016 report (see figure 3 and 4, section 3.7). The normalised discharges of radioactive substances without tritium from Leibstadt NPP have remained stable, below the UNSCEAR mean global value for “other nuclides” over the reporting period. The normalised tritium discharges are at a comparable level as the relevant UNSCEAR mean global value.

3.3.4 Emission to air

The emissions of C-14 and tritium from KKL into the atmosphere are shown in table 5. The discharges from KKL into air have been stable for the duration of the reporting period. Following the recommendations from the German Nuclear Safety Standards Commission Programme of Standards KTA 1503.1, measurements of actual releases of I-129 into the air are not requested by the supervisory authority.

Table 5: C-14 and tritium emission into the atmosphere from KKL, in TBq

	2015	**2016**	**2017**	**2018**	**2019**	**2020**
C-14 (CO_2)	4.2E-01	3.6E-01	2.8E-01	4.8E-01	4.1E-01	5.8E-01
Tritium	6.9E-01	4.4E-01	3.2E-01	4.2E-01	5.3E-01	4.9E-01

3.3.5 Quality assurance – discharges

The data management system of KKL is certified in accordance with ISO 9001.

3.3.6 Other relevant information

The years 2016 and 2017 were marked by the discovery of CRUD depositions on the rod claddings of specific fuel assemblies. Even though, as it turned out, the fuel rod integrity has never been affected, it resulted in outage periods for extended fuel assembly inspections, as well as extended periods of operation with reduced reactor power.

3.3.7 Data completeness and compliance

Data submitted have been complete in all relevant aspects.

3.4 Mühleberg NPP (KKM)

The Mühleberg nuclear power plant (KKM) is owned by BKW Energie AG and consisted of a boiling water reactor of an General Electric design. It started commercial operation in 1972. Mühleberg NPP has definitely ceased power operation in December 2019, while decommissioning has started in September 2020. KKM had a thermal capacity of 1'097 MW_{th} and a net electrical output of 373 MW_{el}.

KKM is located close to the village of Mühleberg in the canton Bern on the central Swiss Plateau. Water from the river Aare was used for cooling; liquid discharges are released into the same river, which belongs to the catchment area of the Rhine.

3.4.1 BAT/BEP systems

The waste water is collected and treated in batches. The radioactivity in the waste water is reduced by centrifugation, ion exchange and, since 2015, evaporation. Samples of the cleaned waste water are measured and, if the concentration criteria are fulfilled, the batch is discharged. The activity concentration is additionally monitored by a total gamma counting system with an integrated automatic shut-off function. The radioactive waste by-products are solidified in the radioactive waste treatment system of the plant.

3.4.2 Efficiency of abatement systems

The centrifugation, ion exchange and evaporation systems reduce the concentration of radioactivity in the discharged water by a factor at least 100 and up to 10'000. The abatement system has however no effects on the level of tritium discharges.

3.4.3 Discharges and trends

Activities in liquid discharges are determined batch-wise using gamma spectrometry. Tritium is monitored by analysing monthly aggregate samples, Sr-90 and alpha-emitters are monitored by analysing quarterly aggregate samples.

Discharge data has been reported to the OSPAR Commission and is available through the Odims database: https://odims.ospar.org. The discharges of radioactive substances without tritium are plotted in figure 2 (see section 3.7) as a function of time: a steady downward trend can be observed up to the last year of reporting (2020): the last datapoint is mainly linked to the discharges of water from the torus, in the framework of decommissioning work. As for tritium in the liquid discharges, no upward or downward trend can be observed.

3.4.3.1 Site-specific target value

As a consequence of the periodical safety review performed by the licensee in 2005, the supervisory authority requested a reduction of the activities (excl. tritium) in the liquid discharges to a target value of 1 GBq/a (the median value of discharges excl. tritium from European Pressurised Water Reactors) by 2010. The liquid discharges (excl. tritium) have been below this target value since 2016.

The target value of 1 GBq/a has been maintained for the decommissioning work.

3.4.3.2 Normalised data

For the sake of comparison with facilities of a similar kind, the liquid discharges of Mühleberg NPP have been normalised with regard to net electrical output on an annual basis and compared to the global mean value from the UNSCEAR 2016 report (see figure 3 and 4, section 3.7). The normalised discharges of radioactive substances without tritium from Mühleberg NPP are showing a downward trend and have stayed below the UNSCEAR mean global values for “other nuclides” since 2016. The normalised tritium discharges show a downward trend as well and are at a comparable level as the relevant UNSCEAR mean global value. No normalised datapoint is shown after the definitive end-of-power-operation in December 2019.

3.4.4 Emission to air

The emissions of C-14 and tritium from KKM into the atmosphere are shown in table 6. The discharges from KKM into air have been stable for the duration of the reporting period; a sharp decrease in C-14 emission can be observed after the end of operation (December 2019). Following the recommendations from the German Nuclear Safety Standards Commission Programme of Standards KTA 1503.1, measurements of actual releases of I-129 into the air are not requested by the supervisory authority.

Table 6: C-14 and tritium emission into the atmosphere from KKM, in TBq

	2015	**2016**	**2017**	**2018**	**2019**	**2020**
C-14 (CO_2)	3.3E-01	3.8E-01	3.6E-01	3.5E-01	4.0E-01	2.8E-02
Tritium	3.9E-02	2.3E-02	3.4E-02	2.7E-02	4.3E-02	2.4E-02

3.4.5 Quality assurance – discharges

The data management system of KKM is certified in accordance with ISO 9001 and ISO 14001 and OHSAS 18001.

3.4.6 Other relevant information

With the start of decommissioning, the limits on liquid discharge activities, formerly set in the operating license, have been reduced by a factor of 10 and newly defined within the decommissioning order issued by DETEC on June 20th, 2018.

3.4.7 Data completeness and compliance

Data submitted have been complete in all relevant aspects.

3.5 Waste treatment and interim storage facility (ZWILAG)

The ZWILAG waste treatment and interim storage facility is a limited company. The shareholders are the owners of the four Swiss nuclear power plants. Low and medium-level radioactive waste, originating from the Swiss nuclear power plants as well as from medicine, industry and research, is being processed at ZWILAG in a conditioning facility and an incineration and melting plant. The site also provides an interim storage for radioactive waste and spent fuel assemblies from Swiss nuclear power plants.

The stepwise commissioning of ZWILAG started with the interim storage facility in 2001, followed by the incineration and melting plant in 2004, after several inactive tests. The reporting to OSPAR of the discharges from ZWILAG has subsequently started in 2005.

The ZWILAG is located near the village of Würenlingen in the canton Aargau, in the immediate vicinity of the Paul Scherer Institute (PSI). It releases its liquid discharges into the river Aare, which belongs to the catchment area of the Rhine.

3.5.1 BAT/BEP systems

The waste water is collected and treated in batches. The radioactivity in the waste water is reduced by precipitation/filtration, centrifugation and/or, if necessary, element specific sorption on an inorganic ion exchange powder. Samples of the cleaned waste water are measured and, if the concentration criteria are fulfilled, the batch is discharged. The activity concentration is additionally monitored by a total gamma counting system with an integrated automatic shut-off function. The radioactive waste by-products are solidified in the radioactive waste treatment system of the facility.

3.5.2 Efficiency of abatement systems

The precipitation/filtration system reduces the concentration of radioactivity in the discharged water by a factor of at least 100 and up to 10'000. Aimed specifically at the Cs-137 content (in the chemical form of caesium chloride formed in the flue gas cleaning system of the incineration and melting facility) in the liquid discharges, a reduction by a factor of at least 10 and up to 100 can be achieved through sorption on an inorganic ion exchange powder. The abatement systems have however no effects on the level of tritium discharges.

3.5.3 Discharges and trends

Activities in liquid discharges are determined batch-wise using gamma spectrometry. Tritium, Sr-90 and alpha-emitters are monitored by analysing quarterly aggregate samples.

Discharge data has been reported to the OSPAR Commission and is available through the Odims database: https://odims.ospar.org. The discharges of radioactive substances without tritium are plotted in figure 2 (see section 3.7) as a function of time: no upward or downward trend can be observed over the reporting period, neither in the total activities (excl. tritium), nor for tritium in the liquid discharges.

3.5.3.1 Site-specific target value

Due to the immediate vicinity of the Paul Scherrer Institute and the ZWILAG facilities, the source-related dose constraint has been split by the regulators to the values of 0.15 mSv for PSI and 0.05 mSv per year for ZWILAG for discharges through air and water.

In view of the increasing radioactivity in the liquid discharges after the commissioning of the incineration and melting plant (culminating in 3.5 GBq in the year 2009), the supervisory authority convinced the licensee to carry out investigations into possible technical measures and suggested, as for KKB and KKM, the median value of discharges (excl. tritium) from European Pressurised Water Reactors (1 GBq/a) as a target value. ZWILAG introduced an abatement system based on sorption in an inorganic ion exchange powder to reduce the content of caesium chloride in the discharges as a consequence. The liquid discharges (excl. tritium) have been below the target value for the duration of the reporting period.

3.5.4 Emission to air

The emissions of C-14 and tritium from ZWILAG into the atmosphere are shown in table 7. The discharges from ZWILAG into air have been stable on a low level for the duration of the reporting period. Following the recommendations from the German Nuclear Safety Standards Commission Programme of Standards KTA 1503.1, measurements of actual releases of I-129 into the air are not requested by the supervisory authority.

Table 7: C-14 and tritium emission into the atmosphere from ZWILAG, in TBq

	2015	2016	2017	2018	2019	2020
C-14 (CO_2)		4.7E-05	2.0E-04	1.2E-04	4.8E-04	7.3E-04
Tritium	7.9E-04	1.8E-02	4.2E-02	1.3E-02	1.9E-03	6.2E-03

3.5.5 Quality assurance – discharges

The data management system of ZWILAG is certified in accordance with ISO 9001.

3.5.6 Other relevant information

There is no other relevant information.

3.5.7 Data completeness and compliance

Data submitted have been complete in all relevant aspects.

3.6 Paul Scherrer Institute (PSI) research facilities

The Paul Scherrer Institute, founded in 1988, is the largest research centre for natural and engineering sciences within Switzerland. The research activities are concentrated on three main subject areas: *Matter and Materials*, *Energy and the Environment* and *Human Health*. The institute's facilities include laboratories, facilities for the medical application of radiation, a proton accelerator with a spallation neutron source (SINQ), a free-electron X-ray laser (SwissFEL) and a synchrotron light source (SLS). The following facilities are subject to the nuclear energy legislation: the HOTLAB with its laboratories and hot cells, the waste treatment facilities, the federal interim storage facility BZL, as well as three former research reactors and a former experimental incineration plant for radioactive waste, currently all four in decommissioning.

PSI is located between the villages of Villigen and Würenlingen in the canton Aargau, in the immediate vicinity of the ZWILAG waste treatment and interim storage facility. Liquid discharges are released into the river Aare, which belongs to the catchment area of the Rhine.

3.6.1 BAT/BEP systems

The waste water is collected and treated in batches. The radioactivity in the waste water is reduced in ultrafiltration systems by diffusion through membranes. Samples of the cleaned waste water are measured and, if the concentration criteria are fulfilled, the batch is discharged. The activity concentration is additionally monitored by a total gamma counting system with an integrated automatic shut-off function. The radioactive waste by-products are solidified in the radioactive waste treatment system of the institute.

3.6.2 Efficiency of abatement systems

The described system reduces the concentration of the radioactivity in the discharged water at least by a factor of 1'000. The abatement systems have however no effects on the level of tritium discharges.

3.6.3 Discharges and trends

Activities in liquid discharges are determined batch-wise using gamma spectrometry. Tritium, Sr-90 and alpha-emitters are monitored by analysing quarterly aggregate samples.

Discharge data has been reported to the OSPAR Commission and is available through the Odims database: https://odims.ospar.org. The discharges of radioactive substances without tritium are plotted in figure 2 (see section 3.7) as a function of time: no upward or downward trend can be observed over the reporting period, neither in the total activities (excl. tritium), nor for tritium in the liquid discharges.

3.6.3.1 Site-specific target value

Due to the immediate vicinity of the Paul Scherrer Institute and the ZWILAG facilities, the source-related dose constraint has been split by the regulators to the values of 0.15 mSv for PSI and 0.05 mSv per year for ZWILAG for discharges through air and water.

No site-specific target value has been defined by or for PSI.

3.6.4 Emission to air

The emissions of C-14 and tritium from PSI into the atmosphere are shown in table 8. The C-14 emitted into the air by the waste treatment facilities and the federal interim storage facility are being monitored since 2016 following a requirement issued by ENSI. The discharges from PSI into air have been stable on a low level for the duration of the reporting period. The emissions of I-129 into air are not monitored.

Airborne positron emitters (O-15, C-11, N-13, etc.), associated to the high intensity proton accelerator facility (which is not classified as a nuclear installation) are the main contribution to the dose due to emissions from PSI (see section 5.1). With a short half-life well below the 30-day-criterion for reporting, these have a negligible impact on fluvial and marine environment.

Table 8: C-14 and tritium emission into the atmosphere from PSI, in TBq

	2015	**2016**	**2017**	**2018**	**2019**	**2020**
C-14 (CO_2)		2.2E-04	1.5E-04	5.7E-05	1.9E-04	9.5E-05
Tritium	1.1E+00	1.5E+00	2.5E+00	8.2E-01	3.1E+00	1.8E+00

3.6.5 Quality assurance – discharges

The data management system of PSI is accredited in accordance with ISO 17025.

3.6.6 Other relevant information

There is no other relevant information.

3.6.7 Data completeness and compliance

Data submitted have been complete in all relevant aspects.

3.7 Summary evaluation discharges

Detailed site-specific information and data on each of the Swiss nuclear facilities are given in the section 3.1 to 3.6 according to the OSPAR guidelines. Figure 2 summarises the yearly discharges of radioactive substances (excl. tritium) from the nuclear facilities in Switzerland. The total sum of the discharges from all nuclear facilities shows a downward trend over the last two decades.

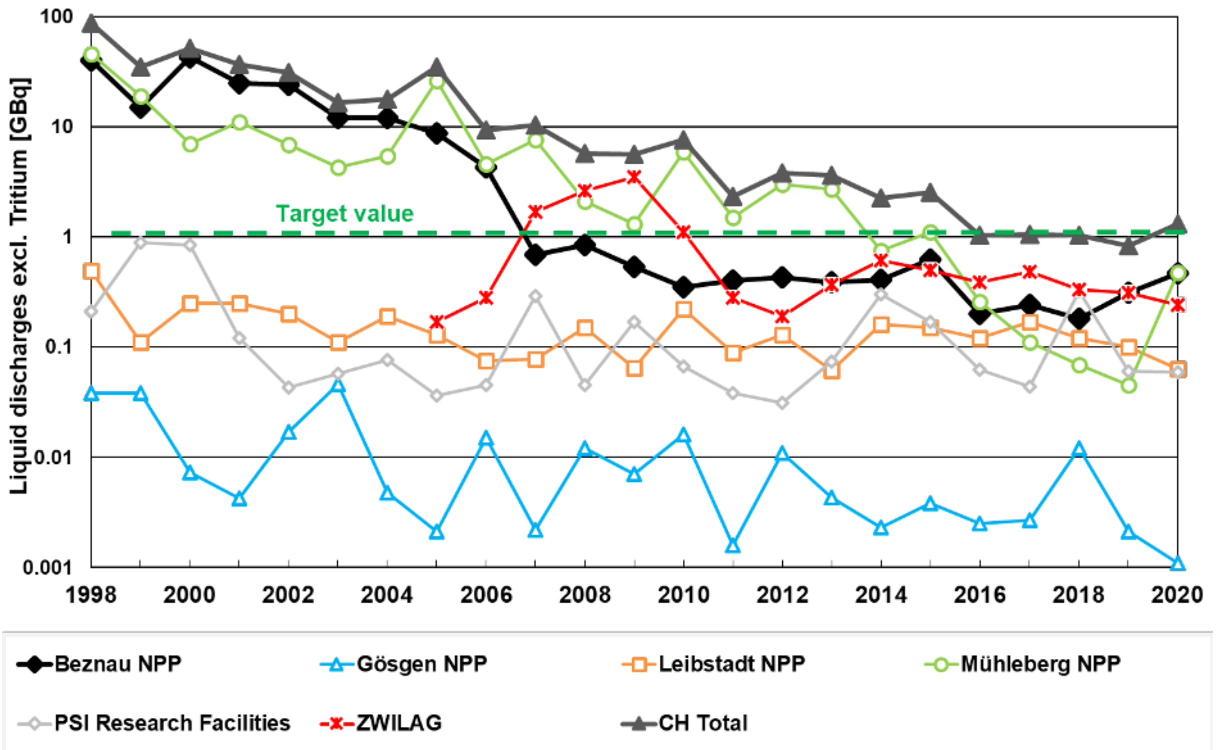

Figure 2: Yearly liquid discharges of radioactive substances by the Swiss nuclear facilities and total sum from 1994 to 2020. The site-specific target value of 1 GBq per year set for KKB, KKM and ZWILAG is shown for comparison.

By way of normalisation, the discharges can be compared to sources of a similar kind. For nuclear power plants, the discharge data are normalised with regard to net electrical output on an annual basis. These normalised discharges can then be compared with the mean global value for all reactors of the same type based on data published by UNSCEAR (table 9).

Table 9: Global mean values for annual discharges of tritium and "other radionuclides" from BWRs and PWRs, taken from the UNSCEAR 2016 report.

Reactor type	UNSCEAR 2016 global mean value	
	Tritium [TBq / GW_{el} a]	Other radionuclides [TBq / GW_{el} a]
BWR	0.82	0.0021
PWR	18	0.0038

The discharges from all Swiss nuclear power plants have been normalised (in [TBq / GW_{el} a]) and compared with the global mean values from the UNSCEAR 2016 report (figure 3 and 4). In this comparison, the normalised total beta discharges (as defined in the OSPAR context) are compared to the UNSCEAR global mean value for "other radionuclides".

Table 10 summarises the evaluation concerning BAT/BEP indicators on discharges from all Swiss nuclear facilities.

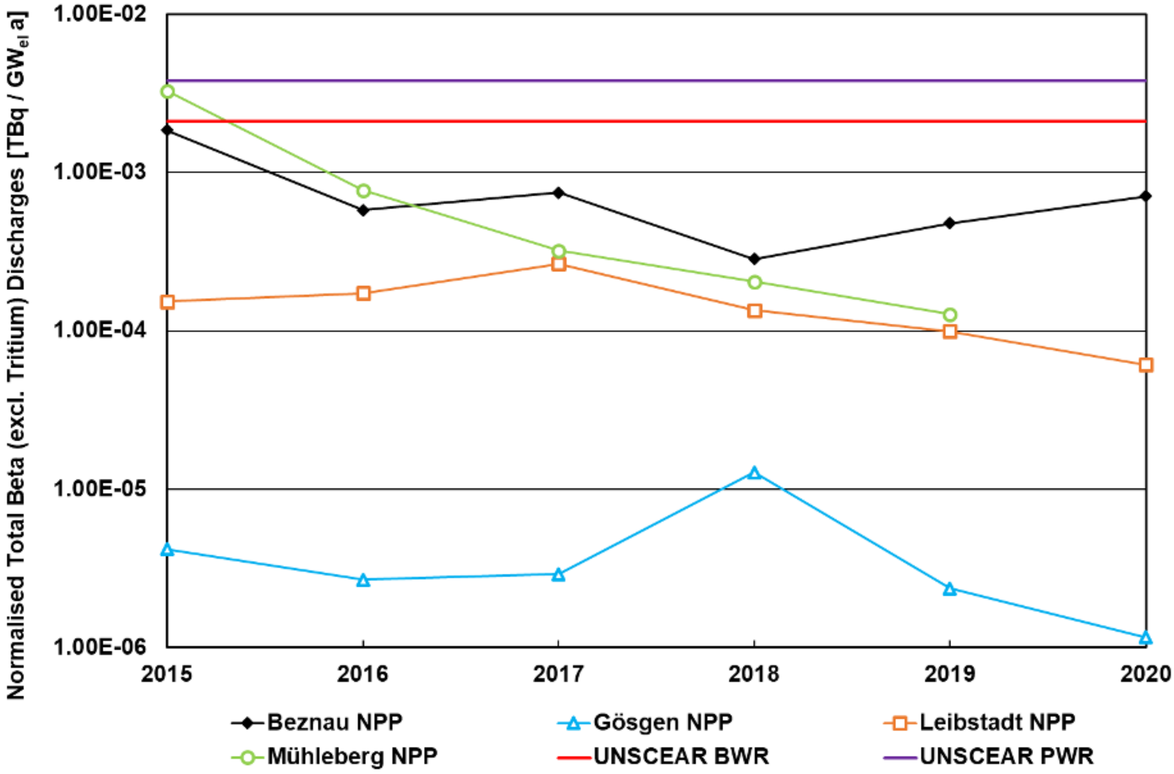

Figure 3: Normalised discharges from Swiss NPPs for total beta (excl. tritium, in [TBq / GW$_{el}$ a]), compared with the global mean value from the UNSCEAR 2016 report ("other" radionuclides). Beznau and Gösgen NPP are PWRs, while Leibstadt and Mühlberg are BWRs, respectively.

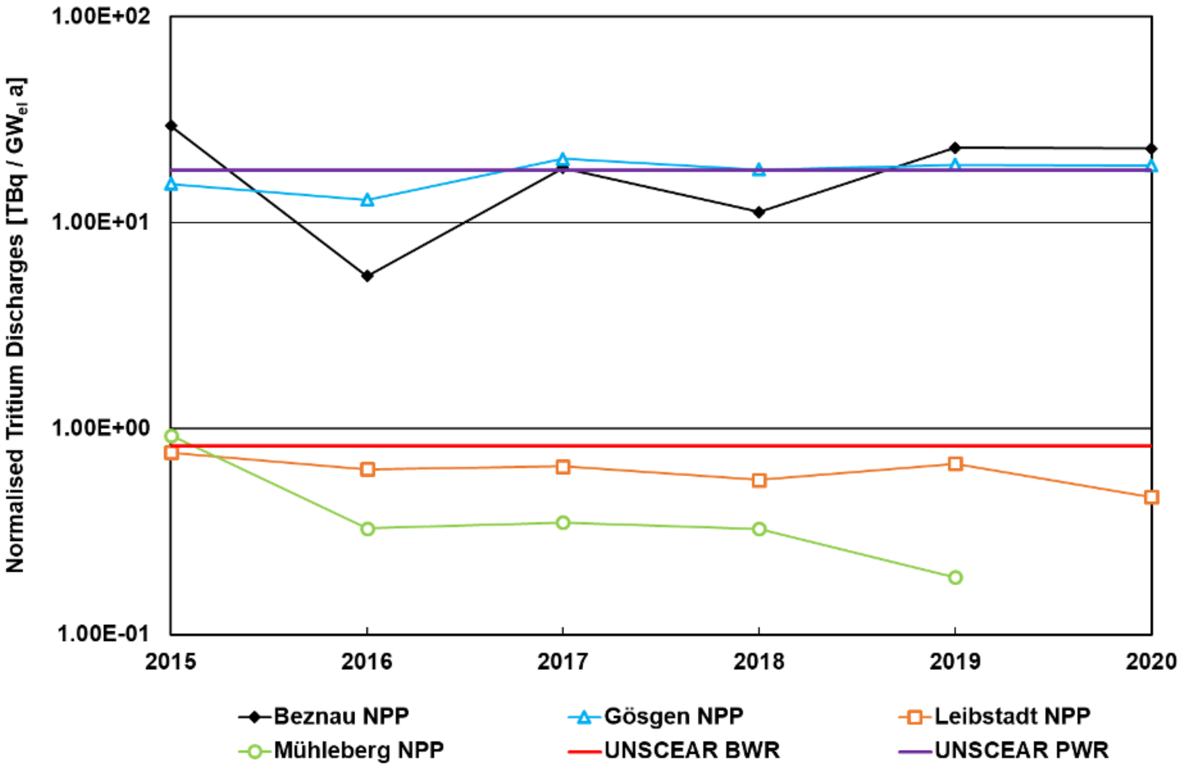

Figure 4: Normalised discharges from Swiss NPPs for tritium (in [TBq / GW$_{el}$ a]) with the global mean value from the UNSCEAR 2016 report.

Table 10: Summary evaluation of discharges

Criteria	Evaluation
The BAT/BEP indicators:	
• Relevant systems in place	Yes
• Abatement factor	According to present state of the art
• Downward trend in discharges	Low and stable or decreasing
• Downward trend in normalised discharges	Low and stable or decreasing
• Comparison with UNSCEAR data	Within or below the mean global value of available UNSCEAR data
• Downward trend in emission	Low and stable
• Relevant and reliable quality assurance	Yes
• Relevant site-specific discharge target values	Yes
Data completeness	Yes
Cause for deviations from indicators	No deviations
Other information	None other than site-specifically indicated

4 Environmental impact

All relevant Swiss nuclear facilities release their liquid discharges into the Rhine catchment area. Three of the nuclear power plants, the ZWILAG waste treatment and interim storage facility and the Paul Scherrer Institute research facilities are located on the river Aare, which flows into the river Rhine. The remaining NPP (Leibstadt) is located on the river Rhine. As a consequence, the environmental monitoring data on fluvial water can only partially be traced back to a specific discharge source.

4.1 Environmental monitoring programme

Samples of river water and sediments are continuously taken at three locations downstream of NPPs:

- On the Hagneck dam, on the river Aare, downstream of Mühleberg NPP
- On the Klingnau dam, on the river Aare, downstream of nearby Beznau NPP, the PSI research facilities and the ZWILAG facility. Further upstream lies Gösgen NPP (with however so small discharges levels, that its contribution to the measured activities is negligible) and Mühleberg NPP (however more than 100 km away).
- In Pratteln near Basel, on the river Rhine and hence downstream of all Swiss nuclear facilities, including Leibstadt NPP.

An overview of the sampling location is shown in figure 5. The samples are analysed in the laboratories of the Swiss Federal Institute of Aquatic Science and Technology (EAWAG) on a monthly basis.

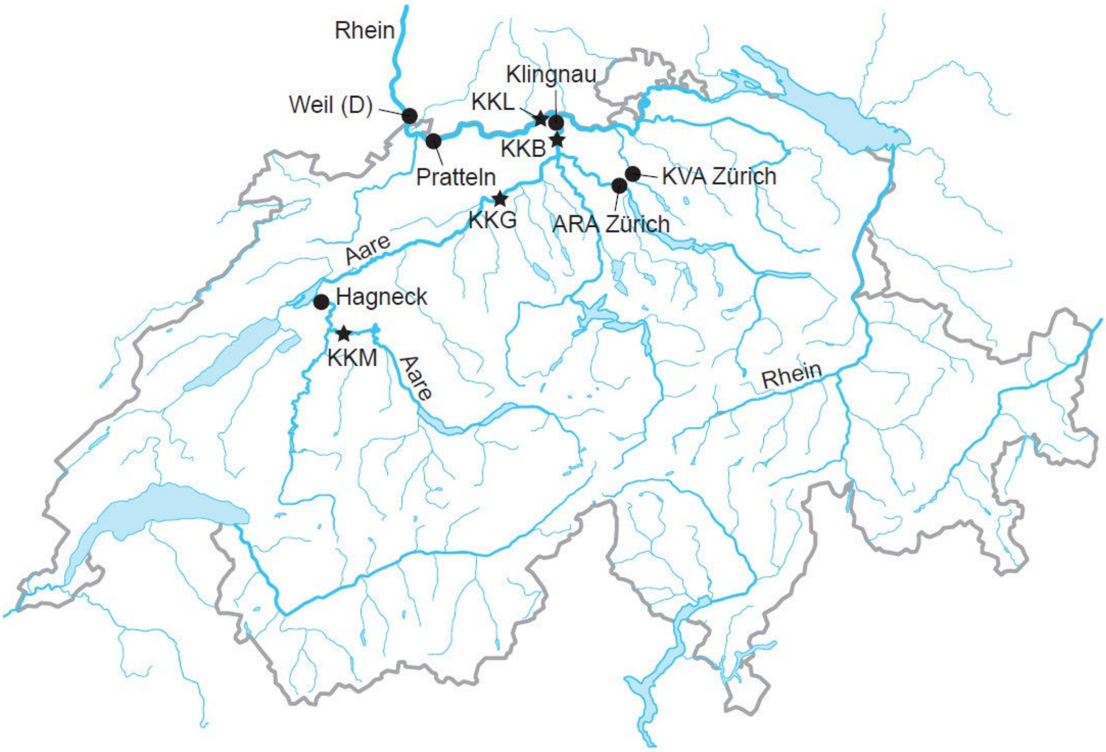

Figure 5: Overview of water and river sediment sampling locations (Source: EAWAG)

The results from the gamma spectroscopy measurements of the sediments from the Pratteln sampling location are shown in figure 6 for the period from 2005 to 2020. The sediments are sampled in traps over a 4-week period. Radionuclides originating from nuclear facilities, such as for instance Cs-137, Co-58, Co-60 and Mn-54, were observed only in traces. In the current reporting period, the highest concentration values were observed for Cs-137 (up to 8 Bq/kg) which is predominantly due to historical fallout.

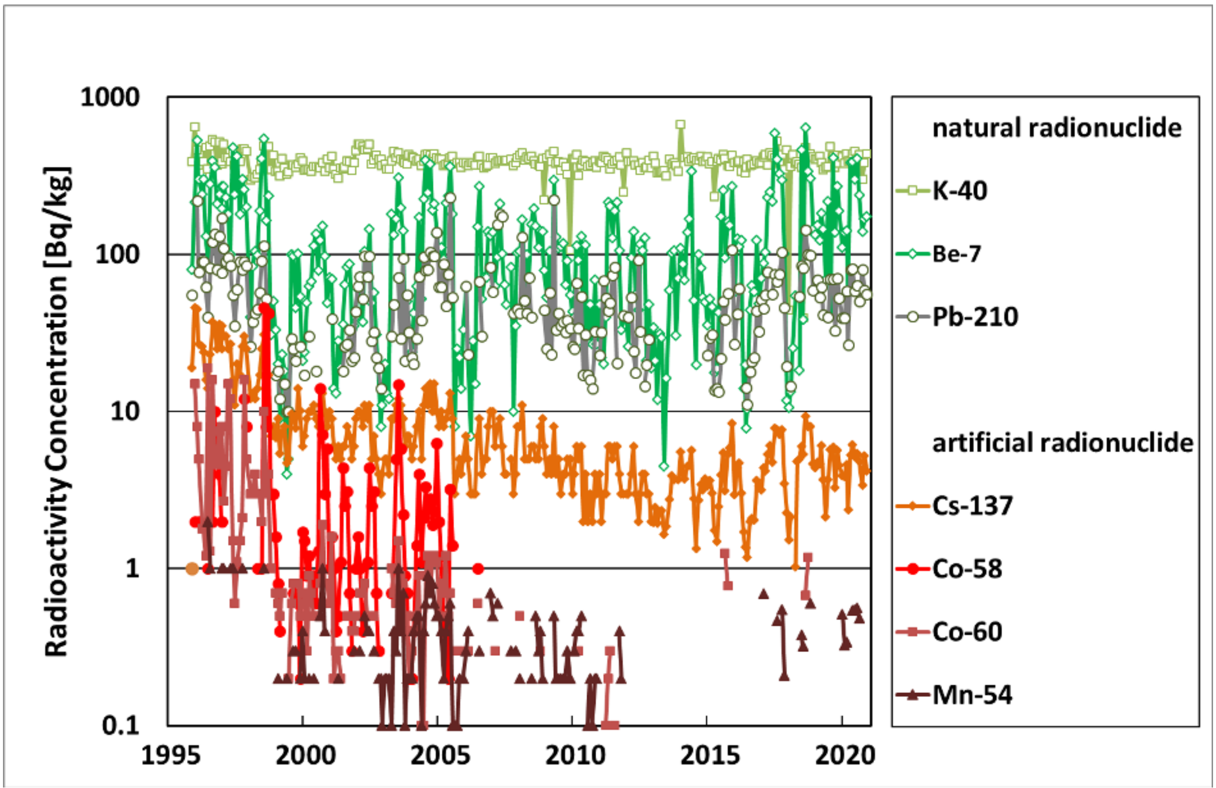

Figure 6: Radioactivity concentration in the sediment of the river Rhine at Pratteln, near Basel. For readability, values below the detection limit are not shown.

Since 2015, a continuous and automatic water monitoring system, based on NaI-detectors and delivering data every 10 minutes, is being operated by FOPH. Data are available online (https://www.radenviro.ch).

4.1.1 Quality assurance – environmental monitoring

The testing laboratory of FOPH is accredited for analyses in the field of environmental radioactivity, the testing laboratory of ENSI is accredited for radioactivity and dose rate measurements, both in accordance with ISO/IEC 17025.

4.1.2 Other relevant information

There is no other relevant information.

4.1.3 Data completeness and compliance

Data submitted have been complete in all relevant aspects.

4.2 Summary evaluation environmental impact

The environmental monitoring is aimed at judging long-term trends and compliance with environmental goals. The data indicate low environmental concentrations of key nuclides and do not reveal increasing trends. Although there are no systems in place to measure impact on non-human biota, present knowledge indicates that the discharges from the Swiss nuclear facilities cause no harm to the fluvial and marine ecosystems.

Table 11 summarises the evaluation concerning BAT/BEP indicators on the environmental impact from discharges from the Swiss nuclear facilities.

Table 11: Summary evaluation of environmental impact.

Criteria	**Evaluation**
The BAT/BEP indicators:	
• Downward trends in concentration	Low and stable or decreasing concentrations
• Relevant environmental programme	Yes
• Relevant quality assurance programme	Yes
Data completeness	Yes
Cause for deviations from indicators	No deviations
Other information	None

5 Radiation doses to the public

5.1 Average annual effective dose to individuals in the critical group

The yearly effective doses due to both liquid and airborne discharges, evaluated for individual members of the population (virtual person of the critical group, see Chapter 2.2.5) in the vicinity of the Swiss nuclear facilities as defined in the guideline ENSI-G14, are shown in table 12. For the nuclear power plants and ZWILAG, the doses are predominately due to the C-14 airborne emission. The doses reported for PSI are mainly associated to the emission of short-lived airborne positron emitters from the accelerator facility (see section 3.6), which is not classified as a nuclear installation. The reported values lie well below the source-related dose constraint of 0.3 mSv per year.

The annual effective doses due to liquid discharges have remained well below 1 microSv per year and person for the reporting period.

Table 12: Total effective dose (including doses from historic emissions) for a virtual person of the reference group living in the vicinity of a Swiss nuclear facility in microSv per year and person, as evaluated using the models from the guideline ENSI-G14

	2015	2016	2017	2018	2019	2020
Beznau NPP	< 2	< 1	< 1	< 1	< 2	< 2
Gösgen NPP	< 1	< 1	< 1	< 1	< 1	< 1
Leibstadt NPP	< 4	< 4	< 3	< 5	< 4	< 5
Mühleberg NPP	< 5	< 5	< 5	< 5	< 5	< 3
PSI	< 7	< 7	< 7	< 7	< 10	< 7
ZWILAG	< 1	< 1	< 1	< 1	< 1	< 1

According to Article 195 of the Swiss Radiation Protection Ordinance, if activity concentrations of artificial radionuclides are detected in the environment leading to an effective dose of more than 10 microSv per year for an exposure pathway and for members of the public, optimisation measures are required to reduce the discharges. Consequently, since the discharges are leading to calculated doses lower than 10 microSv, there is no legal requirement for additional efforts to reduce the level of radioactive releases and the resulting doses for the population any further.

5.2 Assessment methodology

The methodology to estimate the dose is laid down in the guideline ENSI-G14. The models and parameters used in this guideline are taken or derived from international guidelines (e.g. IAEA, ICRP) or regulations from neighbouring countries (e.g. the German administrative regulation “Allgemeine Verwaltungsvorschrift”).

The dose calculations are performed for a virtual individual who is living and working at the place with the highest total dose resulting from the considered pathways. The following pathways are considered: immersion from the plume, inhalation, ground radiation and ingestion of fruits, vegetables, milk, meat, fish as well as drinking water from the river downstream of the facility. It is assumed that the consumed food (fruits, vegetables, milk and meat) is produced locally. It is further assumed, that the fish and all the drinking water is taken from the river downstream of the given facility.

5.3 Site-specific factors

The dispersion factor for the emissions into the air has been determined site-specifically by a statistical analysis of the weather parameters measured near the facility. For liquid discharges, the mean value of the river flow is relevant.

5.3.1 Site-specific target annual effective dose

The source-related dose constraint for a nuclear site has been set at 0.3 mSv per year and person in the guideline ENSI-G15. In case of relevant superposition of the immission from facilities owned by different licensees, the source-related dose constraint is split. This has been applied for the PSI and ZWILAG facilities: concerning discharges through air and water, a source-related dose constraint of 0.15 mSv for PSI, resp. of 0.05 mSv per year for ZWILAG has been defined. The source-related dose constraint for direct radiation has been set at 0.1 mSv per year for both licensees.

5.3.2 Other relevant information

There is no other relevant information.

5.3.3 Data completeness and compliance

Data submitted have been complete in all relevant aspects.

5.4 Summary evaluation radiation doses to the public

Table 13 summarizes the evaluation concerning BAT/BEP indicators of the site-specific information on Radiation Doses to the Public from Swiss nuclear facilities. The methods for estimating doses are relevant for judging exposure of the population and compliance with dose limits and constraints. Doses to the public are well below any dose limits or dose constraints and are stable or declining due to the managerial and technical improvements made at the facility.

Table 13: Summary evaluation of radiation doses to the public

Criteria	**Evaluation**
The BAT/BEP indicators:	
• Downward trend in radiation dose	Low and stable
• Relevant critical group/representative person	Yes
• Reliable and sufficiently realistic dose estimates	Yes
• Relevance of target annual dose	Yes
• Relevant quality assurance systems	Yes
Data completeness	Yes
Cause for deviations from indicators	No deviations
Other information	None

6 Conclusions

From the evaluations of the BAT/BEP indicators for discharges, environmental impact and radiation doses to the public it is concluded that BAT and BEP have been applied at all Swiss nuclear facilities during the time period covered by this report.

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