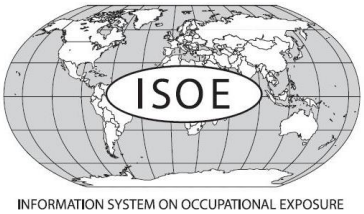
2021



[ISOE Country Reports]

NEA/ISOE(2022)5, Rev 7, 03/02/2023

Foreword

Throughout the world, occupational exposures at nuclear power plants have steadily decreased since the early 1990s. Regulatory pressures, technological advances, improved plant designs and operational procedures, as well as the "as low as reasonably achievable" (ALARA) culture and exchanges of experience have contributed to this downward trend. However, with the continued ageing and life extensions of nuclear power plants worldwide, ongoing economic pressures, regulatory, social and political evolutions, along with the potential of new nuclear build, the task of ensuring that occupational exposures are ALARA continues to present challenges to radiation protection professionals, in particular when taking into account operational costs and social factors.

Since 1992, the Information System on Occupational Exposure (ISOE), jointly administered by the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), has provided a forum for radiological protection professionals from nuclear power licensees and national regulatory authorities worldwide to discuss, promote and co-ordinate international co-operative undertakings for the radiological protection of workers at nuclear power plants. The objective of the ISOE is to improve the management of occupational exposures at nuclear power plants by exchanging broad and regularly updated information, data and experience on methods to optimise occupational radiation protection.

As a technical exchange initiative, the ISOE includes a global occupational exposure data collection and analysis programme, culminating in the world's largest occupational exposure database for nuclear power plants, and a network for sharing dose reduction information and experience. Since its launch, ISOE participants have used this system of databases and communications networks to exchange occupational exposure data and information for dose trend analyses, technique comparisons, and cost-benefit and other analyses promoting the application of the ALARA principle in local radiological protection programmes.

This special edition of country reports presents dose information and principal events of the year 2021 in 30 out of 31 ISOE countries and will be incorporated into the Thirty-First Annual Report of the ISOE programme.

Table of contents

Introduction

Since 1992, the Information System on Occupational Exposure (ISOE) has supported the optimisation of the radiological protection (RP) of workers in nuclear power plants through a worldwide information and experience exchange network for RP professionals at nuclear utilities and national regulatory authorities, as well as through the publication of relevant technical resources for as low as reasonably achievable (ALARA) management. This special edition of country reports presents dose information and principal events of the year 2021 from 30 out of 31 ISOE countries and will be incorporated into the Thirty-First Annual Report of the ISOE programme.

The ISOE is jointly administrated by the Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), and its membership is open to nuclear licensees and radiological protection regulatory authorities worldwide who accept the programme's terms and conditions. The ISOE terms and conditions for the period 2020-2023 came into force on 1 January 2020. As of 31 December 2021, the ISOE programme included 79 participating licensees (345 operating units, 77 shutdown units, 11 units under construction and/or commissioning) and 27 regulatory authorities in 31 countries.

In 2020, the world faced the worst global health crisis in decades as COVID-19 brought unprecedented challenges which continued well into 2021. Working effectively in the midst of a global pandemic was a matter of flexibility and adaptation. As the NEA Director-General, Mr William D. Magwood, IV stated: *"For nearly everyone, this has been a life-changing experience that will surely be remembered as one of the most impactful events of the 21st century. Many lessons have been learned in the course of this experience. We have learned about the reliance of our modern world on advanced information and communications technologies and on a stable, reliable, and cost-effective supply of electric energy. We have learned about the resilience of nuclear energy and its ability to serve our societies under even the most adverse conditions. We have also learned a great deal about ourselves"*.

Despite the restrictions presented by COVID-19, the ISOE was able to continue work with minimal distraction. Its face-to-face meetings may have been cancelled from March 2020 but its management board, bureau as well as working and task groups continued to interact via videoconferencing.

The ISOE Technical Centres hosted international and regional fora (teleconferences) which in 2021 included: ISOE North American virtual ALARA symposium organised by the North American Technical Centre (NATC) in January; ISOE symposium/webinar organised by the European Technical Centre (ETC) in June; and a series of NATC virtual ALARA workshops held from February to July. The ISOE international symposium, originally planned to be organised in-person by ETC in Tours (France) in June 2020, was postponed again until June 2022 due to the COVID-19 pandemic.

The ISOE Network website (www.isoe-network.net) continued to provide the ISOE membership with a comprehensive web-based information and experience exchange portal on dose reduction and ISOE ALARA resources.

This report illustrates how the ISOE participants and many of their activities adjusted to the new environment, and in many cases achieved progress beyond their original objectives.

Principal events in participating countries

Armenia

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE			
OPERATING REACTORS			
Reactor type	Number of reactors	Annual collective dose [person·mSv/unit]	
		Armenian Nuclear Power Plant personnel	Outside workers
VVER	1	1 192.36	1 030.859

MAXIMUM PERSONAL DOSES [mSv]			
External		Internal	
Armenian Nuclear Power Plant personnel	Outside workers	Armenian Nuclear Power Plant personnel	Outside workers
25.028	18.293	0	0

2) Principal events of the year 2021

Outage information

The main contributor to the collective dose in 2021 was the planned outage.

Collective doses during the 2021 outage

Outage number	Outage dates	External collective dose [person·mSv]		
		Armenian Nuclear Power Plant personnel		Outside workers
		Planned	Received	Received
2020	15.05.2021 – 17.10.2021	1 322.0	1 126.975	1 030.859

Organisational evolutions

With the purpose of further implementing the as low as reasonably achievable (ALARA) principle in the Armenian Nuclear Power Plant, the "Program of the Armenian Nuclear Power Plant radiation protection for 2021" was developed which sets the objectives and tasks to minimise the radiation impact and ensure the effective radiation protection for the Armenian Nuclear Power Plant Personnel.

The tasks were the following:

- annual personnel collective dose should not exceed 1 539 person·mSv;

- personnel collective dose during outage should not exceed 1 322 person·mSv;
- annual individual dose should not exceed 28 mSv.

3) Report from authority

A draft of the Atomic Law was developed with taking into account International Atomic Energy Agency (IAEA) recommendations, European Union (EU) directives and Integrated Regulatory Review Service (IRRS) mission recommendations and was still under review as of 31 December 2021.

New national Basic Safety Standards were in the process of development, taking into account IAEA recommendations, EU directives and IRRS mission recommendations, which will replace the following two existing documents:

- Decree № 1489-N as of 18.08.2006 on approval of radiation safety rules;
- Decree № 1219-N as of 18.08.2006 on approval of radiation safety norms.

Belgium

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Total annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**7**	**Data for calendar year 2021 (01/01/2021 – 31/12/2021):** **Doel 1-2: 422 person.mSv for reactors D1 and D2 combined** **Doel 3: 189 person.mSv** **Doel 4: 227 person.mSv** **Tihange 1: 20 person.mSv** **Tihange 2: 93 person.mSv** **Tihange 3: 28 person.mSv**

2) Principal events of the year 2021

Events influencing dosimetric trends

Outage information

Note that the information provided below is for outages which started in 2021.

Duration and total collective dose during outage:

- Doel 1: 05/2021 – 06/2021 (227 person·mSv);
- Doel 2: 03/2021 – 06/2021 (156 person·mSv);
- Doel 3: 08/2021 – 09/2021 (164 person·mSv);
- Doel 4: 10/2021 – 11/2021 (211 person·mSv);
- Tihange 1: no outage started in 2021;
- Tihange 2: no outage started in 2021;
- Tihange 3: no outage started in 2021.

Reactor specific (details are provided if collective dose objective has been exceeded):

- At Doel 1, the dose objective has been respected.
- At Doel 2, the dose objective has been respected.
- At Doel 3, the dose objective has been respected.
- At Doel 4, the dose objective has been respected.
- No outage started at Tihange 1 in 2021.
- No outage started at Tihange 2 in 2021.
- No outage started at Tihange 3 in 2021.

Component or system replacements

The radiation monitoring system (RMS) chains, which are of critical importance for the safe operation of nuclear power plants, suffer from obsolescence at both sites. Multiple projects are ongoing to address this problem at both sites, though the urgency and severity is higher at Tihange Nuclear Power Plant as compared to Doel Nuclear Power Plant.

Unexpected events/incidents

At Doel Nuclear Power Plant, several radiological events have been reported to the authorities (non-exhaustive):

- In March 2021, high dose rate resins were released from a demineralisation tank through a drain valve in the common auxiliary building of Doel 1 and Doel 2. The event likely resulted from a ruptured membrane or an insufficient tightening of a drain valve. Multiple radiological protection (RP) aspects went wrong as an individual did not react to a dose rate alarm caused by the irradiating resins, and RP was not notified. Hotspots with dose rates of 1.3 mSv/h were detected. The event was evaluated as INES Level 0.

- In July 2021, while transporting drums to another location, it was observed that several yellow 200 l drums did not have ID numbers and were not stored in the radioactive waste database. Multiple drums were also damaged. The transport activities were put on hold, and the nuclear safety department was contacted. Non-compliances in the framework of the WENRA Royal Decree of 30 November 2011 were thus detected. A reactive inspection by the safety authorities took place shortly after, during which two infractions were reported.

- In September 2021, six empty waste drums intended to store potentially contaminated chromated water were transported from the RCA of the waste treatment building (WAB) to a cold area at Doel 3 without having passed through the full release process. Measurements showed that two of the six drums were internally contaminated (drum 1: 2.4 Bq/cm² and 6 µSv/h in contact, drum 2: 1.4 Bq/cm² and 2 µSv/h in contact). The drums were transported back to the RCA.

- In September 2021, a worker purposely smuggled a FME bag past the RCA exit monitors at Doel 4. It was found later on that the FME bag was contaminated with an activity of 11 kBq. In theory, the bag never left the RCA as it had been identified at the level of the last detector right before the official exit from the RCA. The event was evaluated as INES Level 0.

- At the end of 2021, several primary and secondary calibrations took place, and a justification note was written as several renovated radiation monitoring chains at Doel 4 had shown secondary calibration results outside of the acceptance criteria [-20%...20%]. Following this, primary calibrations were performed on the new chains to determine the correct reference levels. Analysis revealed that the sensitivity factors of the old and new chains were comparable (indicating that the primary calibration was well performed), but that the reference levels of the secondary calibration sources were underestimated. Based on historical data, it was concluded that the acceptance criteria of these two had not been respected for several months to years. The causes were attributed to a lack of questioning attitude (the situation and assumptions were not properly challenged) and to the poor determination of the activity of two back-up sources (i.e. not considering uncertainty on the activity) which again can be linked to a lack of questioning attitude or competency. The event was evaluated as INES Level 0.

At Tihange Nuclear Power Plant, several radiological events have been reported to the Authorities as well (non-exhaustive):

- In January 2021, a leakage occurred at the sampling station of the pressuriser of Tihange 2. The leak (+/- 0.3 GBq/m³) occurred via a manometer and was collected in a non-watertight gutter (at the junction between the wall) which induced a spread of the contamination leak to the floor underneath. This event was evaluated as INES Level 0.

- In February 2021, surface contamination was detected in a radioactive sources cabinet during a periodic control performed by RP.

- In June 2021, an uncontrolled modification of the discrimination threshold of a gas line was observed at Tihange 2, which led to partial loss of the signal. A good interrogative attitude of the agents during the calibration highlighted the issue.

- In September 2021, a container without a valid IP-2 conformity certificate was found on an outside storage, constituting a non-conformity with applicable regulation.

- In October 2021, two radioactive spills leading to several contaminations occurred, the latter was declared to the Safety Authorities as this was a recurring event. The spill occurred at the same location two days apart, leading to an internal contamination of an agent. The event was evaluated as INES Level 0. Hundreds of liters of water with resins were recovered in drums and for treatment by the radioactive waste department.

New/experimental dose-reduction programmes

- In 2018, analysis by ENGIE Laborelec revealed that a ^{110}mAg contamination of the primary circuit at Tihange 1 and Tihange 2 was responsible for half of the dose rate contribution in some circuits linked to the primary circuits such as the reactor heat removal system. At Tihange, an inventory was made of all the components containing silver, mainly seals. Maintenance launched an inspection plan to identify any components causing the contamination that could be replaced. The inspection plan was carried out at Tihange 1, but no root cause could be identified. In 2020, ENGIE Laborelec attempted to identify the source of silver contamination using two distinct approaches. The first approach, which consisted of a morphological examination of silver particles in the reactor coolant of Tihange 1 and Tihange 2, showed to be unsuccessful. The second approach, which relied on an analysis of the reactor pressure vessel (RPV) head seal of Tihange 1, could not narrow down the exact cause of the silver contamination, either. Because of this, ENGIE Laborelec recommended to verify and evaluate the feasibility of replacing primary circuit seals and seals of the residual heat removal system (RHRS) valves containing silver. Both recommendations were considered as not feasible by Tihange Nuclear Power Plant. Tihange requested ENGIE Laborelec to perform the same RPV head seal analysis at Doel 1-2 as done at Tihange 1. If the same defects were observed, they could then be excluded as a potential source of Ag contamination in Tihange 1 because there was no problem in Doel 3 and it was the same seal as in Tihange 1 and 2. The analysis of the RPV head of Doel 3, however, did not show defects. Nevertheless, Doel Nuclear Power Plant informed Tihange that the clips maintaining the RPV head seal were not positioned in the same way as in Tihange Nuclear Power Plant. Tihange proposed to stop searching for the origin of the silver contamination and close the related action after verifying the position of the clips of the RPV head seal at Tihange. The comparison of the position of the clips on the RPV head seal between Doel and Tihange is still ongoing.

- A zinc injection program aiming at decreasing the dose rate in the primary circuit was implemented at Doel 3 in 2011. This injection program is still ongoing. The evolution of the dose rate is followed up by means of a radiation monitoring system. Over the past years, a decreasing trend was observed, indicating its usefulness and effectiveness. At the end of the outage at Doel 3 in 2020, however, an increase of the dose rate was observed. The increase started at the moment of chemical deaeration of the primary circuit with hydrazine (primary circuit going from an oxidising to a reducing environment). The chemistry department explained that the increase could be partly attributed to the presence of radionuclide Sb-124 which had been released from the demineralisers at start and was absorbed by the latter afterwards. A downwards trend was observed again shortly after. Also, during the last and final outage at Doel 3 in 2021, a steep increase of the dose rate was observed. This increase could again be related to the primary circuit transitioning from an oxidising to a reducing environment, thereby releasing Zn particles from ion exchangers.

Organisational evolutions

In 2021, ENGIE Electrabel analysed its operational free release and clearance processes to ensure full compliance with the updated legal framework[*], but also to identify where its operational practices could be optimised in view of future decommissioning activities. In this context, optimisation referred to the efficiency and flexibility of the processes, as well as to the volume and activity of (post-)operational and decommissioning radioactive waste. These optimisations were a clear indication of the organisation's ambition to smoothen the transition from the operational phase to the decommissioning phase. ENGIE Electrabel is well aware of the drastic transformations that decommissioning will evoke, impacting not only the technical free release and clearance processes but also the prevailing culture which translates itself in daily operations.

Besides this organisational shift in mindset and process related optimisations, several organisational changes took place (e.g. redefining functions/priorities) to better prepare a transition from the operational phase to the post-operational phase, which should start in October 2022 for Doel (Doel 3) and in February 2022 for Tihange (Tihange 2) Nuclear Power Plants.

Regulatory requirements

In 2021, the Belgian regulatory framework relative to radiation protection did not undergo major changes (as compared to 2020[†]). Nevertheless, two new technical regulations, one relative to industrial radiography[‡] and the other to the accreditation of anthropogammametry services, were issued by the Belgian safety authorities, which were evaluated to have a high impact on the operational practices adopted so far at Doel and Tihange Nuclear Power Plants.

[*] The revised Basic Safety Standards (Council Directive 2013/59/Euratom) were transposed in Belgian law and initiated the revision of the Belgian General Radiation Protection Decree (Royal Decree of 20/07/01).

[†] Reported in the 30th ISOE Annual Report (2020).

[‡] Only the draft version was received in 2021 – final publication is expected in 2022.

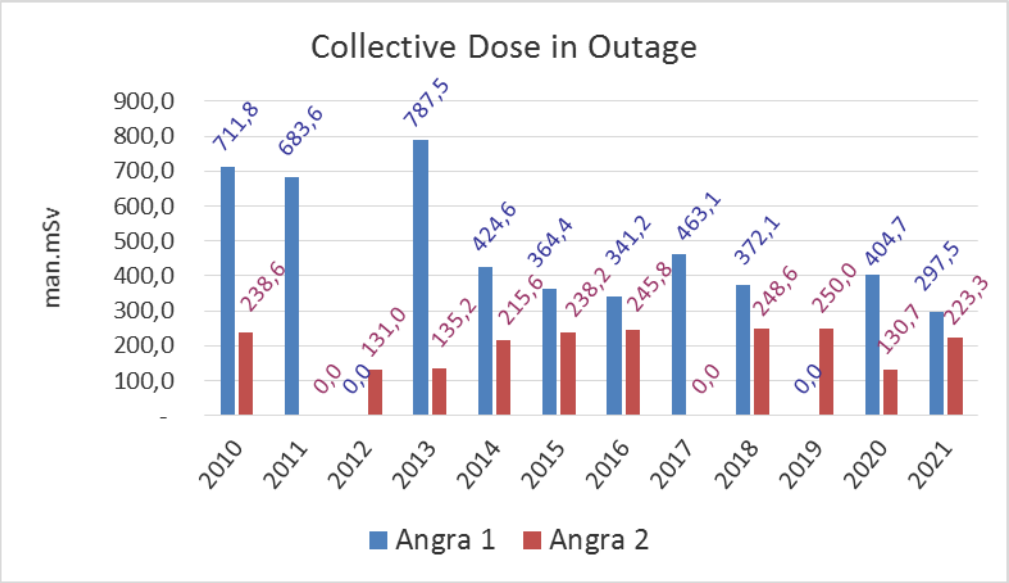
Brazil

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**2**	**332.78 (Angra 1: 347.125 + Angra 2: 318.432)**

2) Principal events of the year 2021

- Transfer of irradiated fuel elements from Angra 2 to UAS – Transfers 288 fuel elements in normal operation. Collective Dose: 72 855 person·mSv.



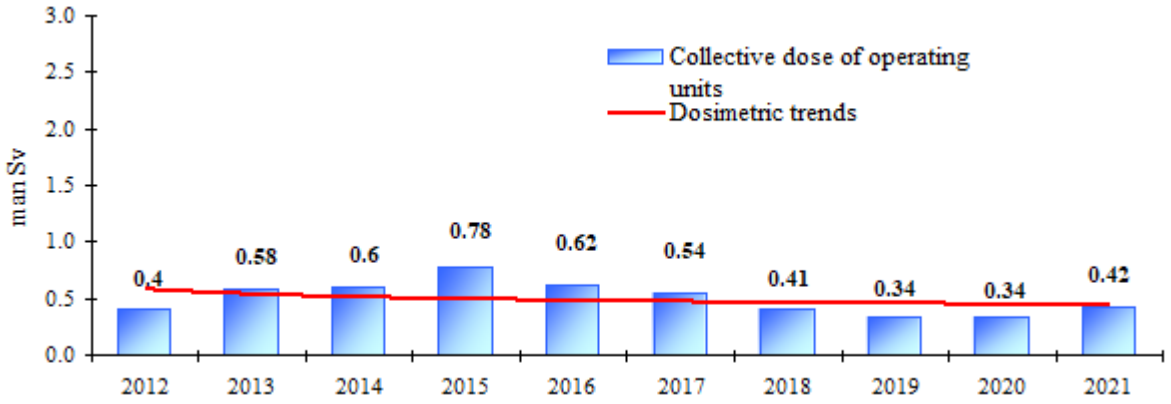
Unit	Days of outage	Outage information
Angra 1	32	Refuelling and maintenance activities
Angra 2	47	Refuelling and maintenance activities

Bulgaria

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
VVER-1000	**2**	**208**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
VVER-440	**4**	**10**

Summary of dosimetric trends



Unit No.	Outage duration, days	Outage information
Kozloduy Unit 5	42	Refuelling and maintenance activities
Kozloduy Unit 6	34	Refuelling and maintenance activities

2) Principal events of the year 2021

Events influencing dosimetric trends

The collective dose denotes the sum of the individual doses of all workers with measurable individual doses. The average collective dose is obtained by dividing the collective dose by the total number of the respective reactor units under consideration.

The average collective dose of reactors under decommissioning is calculated for four VVER-440 reactors. The change in the collective dose of the reactors under decommissioning is not significant. In general, for the time being, the doses associated with the decommissioning activities are kept low.

The average collective dose for the operating reactors is calculated on the base of two VVER-1000 reactors. The collective dose for the year 2021 increased about 20% in comparison to the year 2020, but despite the slight increase the trend of maintaining low levels of the collective dose at the operating reactors remains stable.

Operating reactors

The total amount of the collective dose of operating units is due to external exposure. In 2021, there were no doses imparted by internal exposure.

The main contributors to the collective dose were the works carried out during the outages. The outage activities resulted in about 89% of the total collective dose. Some of the maintenance works which have contributed to the radiation exposure are:

- maintenance works at the reactor vessel of Kozloduy unit 6;
- dismantling and assembling of the biological shield of the reactor vessel of Kozloduy unit 6;
- refurbishment of thermal control detectors of the reactor vessel of Kozloduy unit 5;
- refurbishment of non-return valves of safety systems of Kozloduy unit 5;
- utilisation of neutron in-core detectors of Kozloduy units 5 and 6;
- radiography and eddy current testing;
- thermal insulation replacement.

Works with higher radiation risk were performed under supplementary radiation protection measures.

Organisational evolutions

The process of radiation protection optimisation aimed at individual and collective dose reduction continued in 2021. Some new requirements aimed at a better radiation risk assessment were introduced and implemented in 2021.

A detailed revision of the existing requirements for the personal protective equipment used in the area of radiation protection was made. As a result, possibilities for their development and improvement were identified.

Regulatory requirements

The requirements, rules and restrictions in the field of radiation protection are defined in the following regulations:

- Regulation on the radiation protection (2018);
- Regulation for providing the safety of nuclear power plants;
- Regulation for the procedure of issuing licences and permits for safe use of nuclear energy;

- Regulation for emergency preparedness and response.

Detailed radiation protection programs and guides have been developed on the basis of regulatory requirements.

Canada

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PHWR (CANDU)	**17**	**1 081.9 (18 392 person·mSv / 17 units)**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PHWR (CANDU)	**1**	**7.3**
PHWR (CANDU)	**2**	**Dose associated with PNGS U2, U3 is negligible (< 1 person·mSv/unit) and included in PNGS operating dose**
REACTORS UNDER REFURBISHMENT		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PHWR (CANDU)	**2**	**8 800.4 (17 600.8 person·mSv / 2 units)**

Operating reactors – Reactors that have operated in the year 2021 including collective dose from all type of operations: normal operations, planned outage and forced outage. It excludes dose values from units that were under refurbishment or have been shut down.

Reactors definitively shut down or in decommissioning – Reactors that have been shut down through the year 2021. Pickering unit 2 and unit 3 are in safe storage. The dose associated with safe storage is negligible (< 1 person·mSv), any doses related to accessing safe storage units are included in Pickering Nuclear Generating Station (PNGS) operating reactor dose. The average dose in this category includes dose reported from Gentilly-2 only.

Reactors under refurbishment – Reactors that were in refurbishment through the year 2021. Bruce Power unit 6 and Darlington unit 3 were under refurbishment through the year 2021. Bruce Power unit 6 refurbishment dose is 7 228.5 person·mSv and Darlington unit 3 refurbishment dose is 10 372.3 person·mSv.

2) Principal events of the year 2021

2021 ANNUAL OPERATING REACTORS COLLECTIVE DOSE							
Nuclear station	**Number of reactors in operation**	**Number of reactors in refurbishment**	**Number of reactors in shutdown**	**Operating dose including outages [person·mSv]**	**Average operating dose [person·mSv/unit]**	**Refurbishment dose [person·mSv]**	**Average refurbishment dose [person·mSv/unit]**
Bruce A	4	0	0	8 417.8	2 104.45	0	0
Bruce B	3	1	0	2 747.9	916	7 228.5	7 228.5
Darlington	3	1	0	3 036.3	1 012.1	10 372.3	10 372.3
Gentilly-2	0	0	1	0	0	0	0
Pickering	6	0	2	3 902.6	650.4	0	0
Point Lepreau	1	0	0	287.4	287.4	0	0
Total	**17**	**2**	**3**	**18 392**	**1 081.9**	**17 600.8**	**8 800.4**

There are 22 units in total from all the CANDU nuclear stations combined. 17 of the reactors were in operation, 2 were in refurbishment, and 3 reactors were in the shutdown state during the year 2021. The above table's columns are organised accordingly. 2021 operating dose values include dose values from normal operations, planned outage and forced outages during the year. Refurbishment dose values are separated into their own category and stated accordingly.

Principal events in Canada:

2021 OPERATING REACTORS					
Nuclear power plant, unit	**Normal operations dose [person·mSv]**	**Planned outage dose [person·mSv]**	**Forced outage dose [person·mSv]**	**Outage ID: Outage information**	**Annual collective unit dose [person·mSv]**
Bruce A, U1	94.5	2 291.9	0	A2111 - Planned outage (68 days): Significant scope included primary vessel inspection and maintenance as well as reactor face inspections and maintenance.	2 386.4
Bruce A, U2	94.5	0	0	No outage dose.	94.5
Bruce A, U3	94.5	5 747.9	0	A2131 - Planned outage dose (198 days): Most significant contributing to A2131 CRE was the Extended West Shift Plus programme.	5 842.4
Bruce A, U4	94.5	0	0	No outage dose.	94.5
				Bruce Power Nuclear Generating Station A, units 1-4	**8 417.8**
Bruce B, U5	159.5	0	0	No outage dose.	159.5
Bruce B, U7	159.5	2 026.4	172.4	B2171 - Planned outage (57 days): Significant scope included primary vessel inspection and maintenance as well as reactor face inspections and maintenance. F2171- Forced outage (6 days): Unit 7 was removed from service for a 6-day forced outage to resolve a leak in the heat transport system.	2 358.3

Bruce B, U8	159.5	0	70.6	F2181 - Forced outage (57 days): Unit 8 was removed from service for a 13-day forced outage due to a boiler tube leak in boiler 3.	230.1
				Bruce Power Nuclear Generating Station B, units 5, 7 and 8	**2 747.9**
Darlington, U1	94.4	1 329.1	7.4	D2011 - Planned outage (77.93 days): Unit 1 major work scope included feeder inspection, fuel channel inspections and pressuriser heater replacement. D2112 - Forced outage (9.3 days): Unit 1 forced outage for troubleshooting a shutdown system detector.	1 430.9
Darlington, U2	89.1	0	13.4	D2021 - Forced outage (including portion from 2021) (8.01 days in 2021): Recovery of a fuelling machine stuck on channel with irradiated fuel on board.	102.5
Darlington, U4	89.9	1 413	0	D2141 - Planned outage (77.6 days): Major work scope included feeder inspections, fuel channel inspections, steam generator inspections.	1 502.9
				Darlington Nuclear Generating Station, units 1, 3 and 4	**3 036.3**
Pickering, U1	162.8	0	6.3	Forced outage (16 days): Unit 1 forced outage was for liquid zone troubleshooting.	169.1
Pickering, U4	162.8	0	6.8	Forced outage (4 days): Unit 4 forced outage was for fuelling machine repairs.	169.6
Pickering, U5	162.8	0	92.1	Forced outage (99 days combined): Unit 5 had two forced outages. Both unit 5 forced outages were for turbine troubleshooting/maintenance.	254.9
Pickering, U6	162.8	17.0	0	Planned outage (13 days): Pickering unit 6 had a planned outage from 1 to 13 January 2021.	179.8
Pickering, U7	162.8	1 111.8	0	Planned outage (140 days combined): Unit 7 had two planned outages: unbudgeted and planned. Unbudgeted outage from 19 February to 21 March 2021 accumulating a dose of 163.1 person·mSv, and planned outage from 10 September to 27 December 2021 accumulating a dose of 948.7 person·mSv.	1 274.6
Pickering, U8	162.8	1 691.7	0.1	Planned outage (155 days): Planned outage from 11 January to 14 June 2021. Forced outage (6 days): Unit 8 forced outage was for fuelling machine repairs and turbine issues.	1 854.6
				Pickering Nuclear Generating Station, units 1, 4-8	**3 902.6**
Point Lepreau	170.2	57.6	59.6	Planned outage (19 days): Planned outage from 12 to 30 November 2021 accumulating a dose of 57.6 person·mSv. Forced outage (58 days combined): Point Lepreau had 2 forced outages. Forced outages happened between 16 January to 28	287.4

				February 2021 (~43 days) and 17 to 30 April 2021 (~14 days).	
				Point Lepreau Nuclear Generating Station	**287.4**

2021 REACTORS UNDER REFURBISHMENT/REFURBISHED				
Nuclear power plant, refurbishment unit	Days in refurbishment (2021)	Internal dose [person·mSv]	External dose [person·mSv]	Annual collective unit dose [person·mSv]
Bruce, U6	365	96.4	7 132.1	7 228.5
Darlington, U3	365	72.1	10 300.2	10 372.3

Bruce A (BNGS-A)

In 2021, all four units were operational at Bruce A Nuclear Generating Station with unit 1 and unit 3 having planned outages. Bruce A, units 1-4 routine operations dose for 2021 was 378 person·mSv. The total outage dose was 8 039.8 person·mSv. The total collective dose for Bruce A units 1-4 was 8 417.8 person·mSv, which resulted in an average collective dose 2 104.45 person·mSv/unit.

Bruce B (BNGS-B)

In 2021, Bruce B, units 5, 7 and 8 were operational with unit 7 having a planned outage and a forced outage, and unit 8 having only a forced outage through the year. The routine operations dose for Bruce B for 2021 was 478.5 person·mSv. The outage dose was 2 269.4 person·mSv. The collective dose for Bruce B was 2 747.9 person·mSv, which resulted in an average collective dose of 916 person·mSv/unit. Refurbishment dose from unit 6 was excluded from collective dose and analysed separately.

Bruce B, unit 6 was in refurbishment for the whole year 2021. Unit 6 refurbishment dose for 2021 was 7 228.5 person·mSv.

Darlington (DNGS)

In 2021, Darlington units 1, 2 and 4 were operational. Unit 1 had a planned outage and a forced outage, unit 2 had a forced outage, and unit 4 had a planned outage through the year. The routine operations dose for Darlington was 273.4 person·mSv. The outage dose was 2 762.9 person·mSv. The collective dose for Darlington was 3 036.3 person·mSv, which resulted in an average collective dose of 1 012.1 person·mSv/unit. Refurbishment dose from unit 3 was excluded from collective dose and evaluated separately.

Darlington unit 3 was in refurbishment for the whole year 2021. Unit 3 refurbishment dose for 2021 was 10 372.3 person·mSv.

Pickering (PNGS)

In 2021, Pickering Nuclear Generating Station had six units in operation (units 1, 4-8). Units 1, 4 and 5 had only forced outages through the year. Units 6 and 7 had only planned outages through the year. Unit 8 had both forced and planned outages through the year. Units 2 and 3 continued to remain in a safe storage state, and doses associated with these units are included in routine operations. The routine operation collective dose for Pickering was 976.8 person·mSv. The outage dose was 2 925.8 person·mSv. The collective dose was 3 902.6 person·mSv, which resulted in an average collective dose of 650.4 person·mSv/unit.

Point Lepreau (PLNGS)

Point Lepreau Nuclear Generating Station (PLNGS) is a single unit station. During 2021, the station was operational. The station had both a planned outage and a forced outage through the year. The station had an operational dose of 170.2 person·mSv and outage dose of 117.2 person·mSv. The collective dose for the single-unit site was 287.4 person·mSv.

Gentilly-2

DECOMISSIONING REACTORS				
Nuclear power plant	Last day of operation	Internal dose [person·mSv]	External dose [person·mSv]	Annual collective unit dose [person·mSv]
Gentilly-2	28 December 2012	0.5	6.8	7.3

Gentilly-2 is a single unit CANDU station. In 2021, Gentilly-2 was in the storage phase of decommissioning. The reactor was shut down on 28 December 2012.

There was a decrease in the collective doses in 2021 at Gentilly-2 because most radiological work activities with the transition from an operational unit to a safe storage state occurred in 2014. The 2021 station collective dose is only attributed to safe storage transition activities.

The internal dose for the site was 0.5 person·mSv with an external dose of 6.8 person·mSv for the year. The annual collective unit dose for the site was 7.3 person·mSv.

Regulatory update highlights

The implementation of radiation protection programmes at Canadian nuclear power plants met all applicable regulatory requirements; doses to workers and members of the public were maintained below regulatory dose limits.

Safety-related issues

No safety-related issues were identified in 2021.

Decommissioning issues

Gentilly-2 continued in safe storage in 2021.

Pickering unit 2 continued in the safe storage/defuelled state in 2021.

Pickering unit 3 continued in the safe storage/defuelled state in 2021.

New plants under construction/plants shutdown

No units under construction in 2021.

Bruce unit 6 was in refurbishment in 2021.

Darlington unit 3 was in refurbishment in 2021.

Conclusions

The 2021 average collective dose per operating unit for the Canadian fleet was 1 081.9 person·mSv/unit. Various initiatives were implemented at Canadian units to keep doses ALARA. Bruce unit 6 and Darlington unit 3 were in refurbishment in 2021. Gentilly-2, Pickering unit 2 and Pickering unit 3 continued through the shutdown process through the year.

China

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**45**	**310.1**
VVER	**4**	**252.5**
PHWR	**2**	**444.5**
All types	**51**	**310.9**

2) Principal events of the year 2021

Summary of national dosimetric trends

- Two new PWR units (Tianwan 6, Hongyanhe 6) began commercial operation in 2021. For the 51 reactors, refuelling outages were performed for 32 of 45 PWR units, 1 of 2 PHWR units, and 4 of 4 VVER units in 2021.

- The total collective dose for the Chinese nuclear fleet (45 PWR units, 4 VVER units and 2 PHWR units) in 2021 was 15 855 person·mSv. The resulting average collective dose was 310.9 person·mSv/unit. No individuals received a dose higher than 15 mSv in 2021.

- In the operation of nuclear power plants, annual collective dose is mainly from outages. The ALARA programme is well implemented during the design and operation of all nuclear power plants. The average annual collective dose per unit of 310.9 person·mSv/unit is higher than in the year 2020 (274.1 person·mSv/unit).

- In 2021, there were no radiological events threatening the safety of people and the environment at the operational nuclear power plants. The monitoring index over the year showed that the integrity of three safety barriers was in sound status.

Regulatory requirements

- On 4 January, the *"Administrative Measures for the Safety Permit of Radioisotopes and Radiation Devices"* and *"Administrative Measures for the Safety Permit for the Transport of Radioactive Materials"* were issued (Order No. 20 of the Ministry of Ecology and Environment).

- On 26 March, Deputy Administrator of the National Nuclear Safety Administration and Director of the Department of Nuclear Power Safety Regulation TANG Bo virtually attended a special meeting of the policy group of the multinational design evaluation mechanism for nuclear power plants.

- On 18 May, HUANG Runqiu, Minister of Ecology and Environment, delivered a speech to the IAEA's *"Asia-Pacific Online Roundtable on Nuclear Technology Control of Plastic Pollution"* video, introducing the Chinese regulatory policies and achievements on the prevention and control of marine plastic waste and the use of nuclear technology.

Czech Republic

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
VVER	**6**	**141**

2) Principal events of the year 2021

The main contributors to the collective dose were six planned outages.

NPP, Unit	Outage information	Committed effective dose (CED) [person·mSv]
Temelin, unit 1	57 days, standard maintenance outage with refuelling	80
Temelin, unit 2	64 days, standard maintenance outage with refuelling	87
Dukovany, unit 1	42 days, standard maintenance outage with refuelling	24
Dukovany, unit 2	43 days, standard maintenance outage with refuelling	180
Dukovany, unit 3	45 days, standard maintenance outage with refuelling	183
Dukovany, unit 4	55 days, standard maintenance outage with refuelling	137

The 2021 annual collective dose was influenced by planned activities. The dominant activities were the ongoing non-destructive heterogenous weld testing and the replacement of feedwater inlet inside steam generators. The replacement had a common cause in the heterogenous welds and had to be done successively on all steam generators. A schedule for the following years was created based on the workforce capacity. The selected amount of steam generators was repaired in 2021. A long-term step-by-step replacement was chosen with respect to individual dose limits and ALARA principles.

ALARA principles were applied during the replacement of feedwater inlet.

Another activity which is worth mentioning is the mechanical cleaning and inspection of heat transfer tubes and bottom of one of the steam generators. This activity took place at the end of the year. Part of it was performed in the year 2022.

The outage of unit 1 at Dukovany NPP was performed at the turn of the years 2020 and 2021.

The outage of unit 2 at Dukovany NPP was performed at the turn of the years 2021 and 2022.

Outage and total effective doses were at low values. These results are based on a good primary chemistry water regime, a well-organized radiation protection structure and a strict implementation of ALARA principles during the activities related to the work with high radiation risk. All CED values are based on electronic personal dosimeter readings.

Regulatory requirements

Radiation protection status for the year 2021 has been evaluated in accordance with the new Czech legislation valid since 2016.

More information regarding the cleaning and inspection of heat transfer tubes and bottom of the steam generator

The collective effective dose received by the workers who performed activities inside the steam generator was at the level of approximately 70 mSv.

This activity was performed by the workers from the company Škoda JS and its subcontractors.

The cleaning was performed via a remotely controlled device designed by Framatom. It was the first time when a horizontal steam generator of VVER 440 was cleaned this way.

Dose reduction measures

- Training of workers at the Framatom headquarters in Germany.
- Flooding of the secondary side of the steam generator with water level checks prior to every entry.
- Use of shielding mats inside the steam generator.
- Radiation control of every item entering the steam generator to keep the secondary side of the steam generator uncontaminated.

Finland

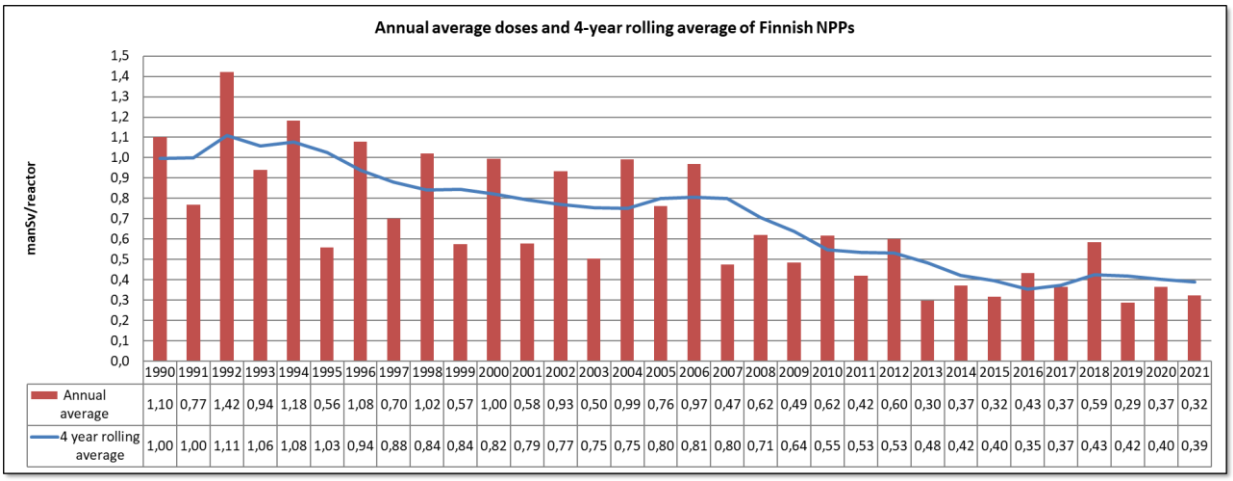
1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
VVER	2	153
BWR	2	492
EPR	1	0

2) Principal events of the year 2021

Summary of national dosimetric trends

The 4-year-rolling average of collective doses of the four operating reactors has decreased from the highest level of ca. 1 100 person·mSv in the early 1990's to a level of ca. 400 person·mSv per reactor unit.



Olkiluoto

The refuelling outage at Olkiluoto 1 (OL1) started in April, and the duration of the outage was 16 days. The length of the refuelling outage was longer than normally due to the primary circuit pressure test which required the reactor core to be defuelled. The total collective dose of the outage in OL1 was 284 person·mSv.

At the unit Olkiluoto 2 (OL2), the maintenance outage was in May-June. The duration of the outage was 32.5 days. The main task of the outage was the renewal of the shutdown reactor coolant system main pumps and related pipelines. The total collective dose of the outage in OL2 was 601 person·mSv.

The unit Olkiluoto 3 (OL3) was in the commissioning phase. The first criticality of the unit was achieved on 21 December 2021. The radiologically controlled area at full scale was taken into use in March 2021. Since then, all normal RCA radiation protection measures have been in use. The collective dose of OL3 was still 0 person·mSv.

The total collective dose of the Olkiluoto nuclear power plant was 985 person·mSv.

Loviisa

On both units, the 2021 outages were short refuelling outages with planned durations of 17 days per unit. On unit 2, a leaking fuel element was detected and removed from the reactor during refuelling. The outage at unit 2 was prolonged by ca 8 days. The main cause for the delay was that one primary coolant pump had to be replaced due to increased vibrations which had been noticed at the start-up after the outage.

The collective dose in 2021 was the lowest in Loviisa's operating history (306 person·mSv). The main contributors to the collective dose accumulation were reactor-related tasks (disassembly and assembly for refuelling), cleaning/decontamination and auxiliary work such as radiation protection and insulation.

Source term reduction:

- Primary coolant purification system was modified in 2019 on both units to enable coolant purification during outages. The new system was in operation during 2021 outages successfully.

- At unit 2, ^{110m}Ag on the primary system had been at a higher level for some years. The investigations continued with a specific sampling programme to identify the source on inactive silver. By the end of 2021, the source of ^{110m}Ag remained unknown.

3) Report from authority

The Ministry of Economic Affairs and Employment launched an assessment of the reform needs of the Nuclear Energy Act. The objective of the reform was to bring the regulation regarding the use of nuclear energy in nuclear facilities up-to-date, to make it clear and consistent as a whole. This regulatory work continued in 2021, and it will continue in the following years.

As of 2021, the operating licence for Lo1 was until the end of 2027, and for Lo2 – 2030. Fortum submitted applications for the renewal of the operating licence for its units in Loviisa until the end of 2050.

TVO has the licence to operate the units Olkiluoto 1 and Olkiluoto 2 until the end of 2038. For Olkiluoto 3, STUK granted the fuel loading permit at the end of March 2021. The first criticality took place in December 2021. According to the plant supplier schedule, regular electricity production is to start after the test period in December 2022.

A new NPP unit, Fennovoima Hanhikivi unit 1 (VVER type design in Pyhäjoki) was under the construction licence application review in 2021. However, the power company Fennovoima terminated the CLA process in April 2022.

Posiva, a joint company of Fortum and TVO, continued the construction of a spent nuclear fuel encapsulation plant and disposal facility at Olkiluoto site. Posiva applied for operating license for them in December 2021.

The only research reactor in Finland was in the decommissioning phase. The spent fuel was removed from the site.

France

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**58**	**710**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**1**	**79**
GCR	**6**	**37**
LWGR	**1**	**10**
FNR	**1**	**14**

2) Principal events of the year 2021

Summary of national dosimetric trends

For 2021, the average collective dose of the French nuclear fleet (58 PWRs) was 710 person·mSv/unit (as compared to the 2021 annual EDF objective of 760 person·mSv/unit). This objective was updated (730 person·mSv/unit) at mid-year due to the impact of the COVID-19 pandemic on the outage schedule. This collective dose is the average for the 58 PWR units in France. Though the two units of Fessenheim were definitely shut down in 2020, the 2021 average annual collective dose for the French operating reactors still includes them (a decommissioning licence for the two Fessenheim units shall only be issued in 2023).

The average collective dose for the 3-loop reactors (900 MWe – 34 reactors) was 910 person·mSv/unit, and the average collective dose for the 4-loop reactors (1 300 MWe and 1 450 MWe – 24 reactors) was 420 person·mSv/unit.

In 2021, the number of working hours in the RCA was 7 150 386 (+ 10% / 2020). The dose index was 5.76 µSv/h (+ 6% / 2020).

Type and number of outages

Type	Number
ASR – Short outage	**19**
VP – Standard outage	**17**
VD – Ten-year outage	**7**
No shutdown	**15**

Specific activities

Type	Number
SGR	**1**
RVHR	**0**

The outage collective dose represented 83 % of the total collective dose. The collective dose received when the reactor was in operation represented 17 % of the total collective dose. The collective dose due to neutron was 235 person·mSv; 64 % of which (151 person·mSv) was due to spent fuel transport.

Individual doses

In 2021, no worker received an individual dose higher than 16 mSv in 12 rolling months on the EDF fleet. Sixty-five per cent of the exposed workers received a cumulative dose lower than 1 mSv, and 99.6 % of the exposed workers received less than 10 mSv.

The main 2021 events with a dosimetric impact were the following:

- The main event of 2021, which occurred at the end of the year with a major impact on the French nuclear fleet, concerns the stress corrosion phenomenon detected on portions of pipes located in the safety injection system, an appendix to the primary circuit, which led to inspections of the molded elbows on 4-loop reactors (CIV, CHO and PEN1). The investigations will continue in 2022.

- The year 2021 was still impacted by the COVID-19 pandemic crisis, the impact being much lower than in 2020.

- The 2021 campaign was ultimately made up of 43 unit outages including 1 SGR (Gravelines 6). Only two outages were postponed to 2022. The actual collective dose for 2021 was 41 160 person·mSv, or 710 person·mSv/unit. The updated dose objective was respected.

3-loop reactors – 900 MWe

The 3-loop reactors outage programme was composed of 8 short outages, 14 standard outages and 4 ten-year outages.

- No outage for Chinon B4 and Cruas 4.
- Outages started in 2020 and finished in 2021: Bugey 2 (4th ten-year outage), Bugey 3 (short outage), Bugey 4 (4th ten-year outage), Gravelines 3 (standard outage).
- Outages started in 2021: Bugey 5 (4th ten-year outage), Dampierre 1 (4th ten-year outage), Gravelines 1 (4th ten-year outage), Gravelines 6 (short outage and SGR).

The lowest collective doses for the various outage types were:

- short outage: 188 person·mSv at Blayais 3;
- standard outage: 531 person·mSv at Cruas 2;
- ten-year outage: 2 371 person·mSv at Tricastin 2.

4-loop reactors – 1 300 MWe and 1 450 MWe

The 4-loop reactors outage programme was composed of 11 short outages, 3 standard outages and 3 ten-year outages. In 2021, five units had no outage.

- Outages started in 2020 and finished in 2021: Belleville 1 (3rd ten-year outage) and Paluel 2 (short outage).
- Outages started in 2021: Cattenom 2 (short outage), Penly 1 (3rd ten-year outage) and Civaux 1 (2nd ten-year outage).

The lowest collective doses for the various outage types for the 1 300 MWe were:

- short outage: 173 person·mSv at Saint-Alban 1;
- standard outage: 633 person·mSv at Golfech 2;
- ten-year outage: 1 566 person·mSv at Cattenom 3.

The lowest collective doses for the various outage types for the 1 450 MWe were:

- short outage: 204 person·mSv at Chooz 2;
- standard outage: 872 person·mSv at Civaux 1.

Main radiation protection significant events (ESR)

In 2021, five events were classified level 1 on the INES scale (eight in 2020). They all concerned skin doses.

- Saint-Laurent B Nuclear Power Plant

  One event at unit 1 in July: the skin dose was estimated to be higher than one quarter of the annual limit.

- Fessenheim Nuclear Power Plant

  One event at unit 3 in August: the skin dose was estimated to be higher than one quarter of the annual limit.

- Cattenom Nuclear Power Plant

  One event at unit 3 in August: the skin dose was estimated to be higher than one quarter of the annual limit.

- Cruas Nuclear Power Plant

  One event at unit 2 in August: the skin dose was estimated to be higher than one quarter of the annual limit.

- Gravelines Nuclear Power Plant

  One event at unit 1 in October: the skin dose was estimated to be higher than one quarter of the annual limit.

The analysis of the ESRs highlights the following preponderant causes:

- insufficient consideration of the risk of contamination in the preparation of activities;
- absence and non-mastery of radiological controls during the activities;
- non-compliance with the countermeasures provided for in the radiological work permit.

2022 goals

The collective dose objective for 2022 for the French nuclear fleet is set at 800 person·mSv/unit.

For the individual dose, the objectives are the same as in 2021 due to the outage programme. The objective of no worker with an individual dose > 18 mSv over 12 rolling months is maintained. The following indicators are used:

- number of workers > 10 mSv over 12 rolling months ≤ 200;
- number of workers > 14 mSv over 12 rolling months = 0.

In order to maintain the momentum on individual dosimetry of the most exposed workers, a monthly follow-up of companies with at least 5 workers > 10mSv over 12 rolling months is carried out.

A weekly watch is carried out on dose overruns in relation to the categories of workers (Non-exposed workers ≤ 1mSv; B workers ≤ 6mSv).

Future activities in 2022

For the individual dose: following the European Council Directive and the French decrees, a reclassification of EDF's workers is in progress (A to B for nuclear power plant workers, B to Non-exposed workers for other workers).

Collective dose: continuation of the activities initiated since 2012:

- source-term management (oxygenation and purification during shutdown, management and removal of hotspots, tests with the gamma camera);
- chemical decontamination of the most polluted circuits;
- optimisation of biological shielding (using CADOR software);
- use of the RMS.

The 2022 outage program consists of 41 outages, with 15 short outages, 20 standard outages, 7 ten-year outages and 1 SGR (Flamanville 1). Seven outages that began in 2021 are planned to end in 2022: the short outage at Cattenom 2 and Gravelines 6 (with SGR) and 5 ten-year outages at Bugey 5, Dampierre 1, Gravelines 1, Penly 1 and Civaux 1.

Blayais 1, Dampierre 2, Gravelines 3, Saint-Laurent B2 and Tricastin 3 (3-loop 900 MW) will carry out their 4th ten-year outage, and the phenomenon of stress corrosion detected on portions of pipes located in the safety injection system will be further taken care of, which will disrupt the 2022 outage campaign.

3) Report from authority

ASN assessment.

ASN carries out its oversight by using the regulatory framework and individual resolutions, inspections and, if necessary, enforcement measures and penalties, in a way that is complementary and tailored to each situation, to ensure optimal control of the risks nuclear activities pose for people and environment. ASN reports on its duties and produces an assessment of the actions of each licensee, in each activity sector.

ASN assessments per licensee – EDF.

Nuclear power plants in operation

For EDF, the year 2021 was particularly dense in terms of industrial activity, after 2020 which was disrupted by the COVID-19 pandemic. Progress was observed with regard to radiation protection after two years of regression. This should be confirmed in 2022.

- **Worker radiation protection and occupational safety.**

  In 2021, ASN found improvements in the handling of the issues related to worker radiation protection at several nuclear power plants, after deteriorations observed in 2019 and 2020. However, behavioural anomalies persist and the situation remains a subject of concern on certain sites. EDF must continue with the steps taken to improve the way in which radiation protection is handled.

- **Individual nuclear power plant assessments.**

  With regard to radiation protection, the nuclear power plants of Civaux, Paluel and Saint-Alban stood out positively. ASN considers that the nuclear power plants of Dampierre-en-Burly, Gravelines and, to a lesser extent, Cruas-Meysse underperformed.

Nuclear power plants being decommissioned and waste management facilities

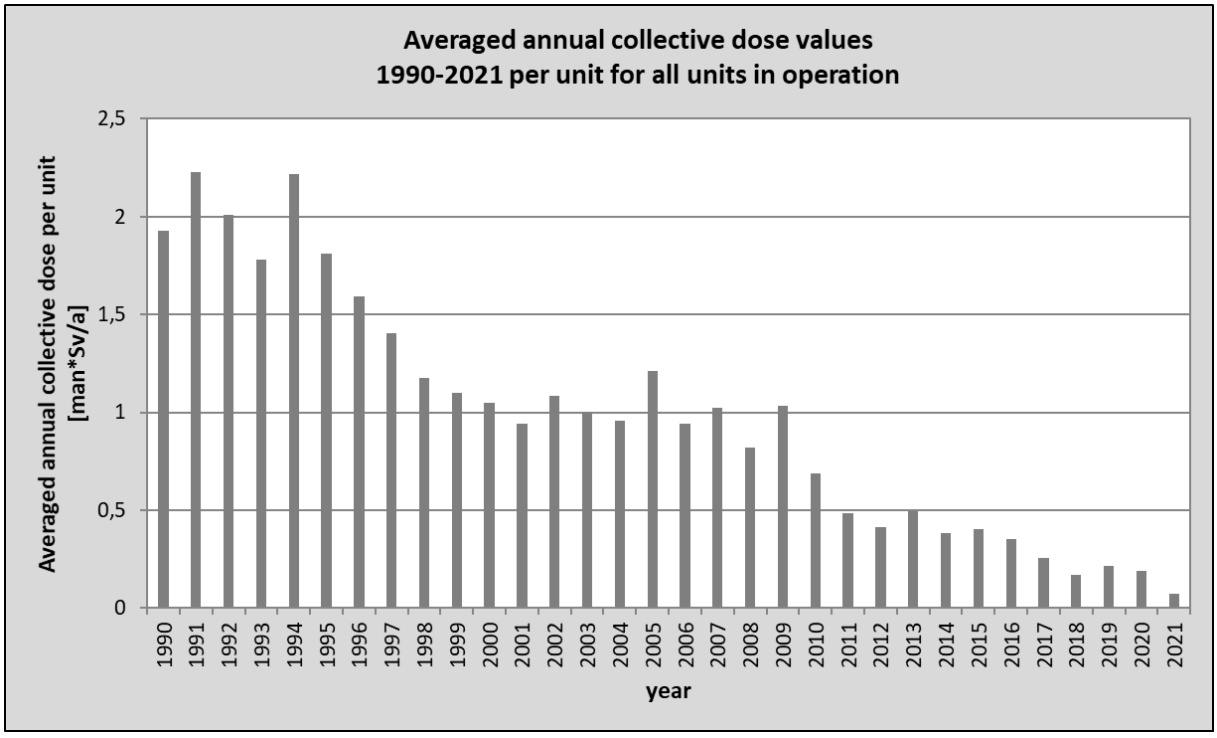
With regard to worker radiation protection, the “alpha” action plan implemented at the Chooz A installation in 2020 is resulting in a positive trend in the number of contaminations detected. Efforts in this field must however be continued on all the decommissioning worksites in order to confirm this trend over the course of 2022.

[ref] ASN Report on the state of nuclear safety and radiation protection in France in 2021.

Germany

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**5**	**-**
BWR	**1**	**-**
All types	**6**	**72.0**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**9**	**114.0**
BWR	**5**	**92.1**
All types	**14**	**100.0**

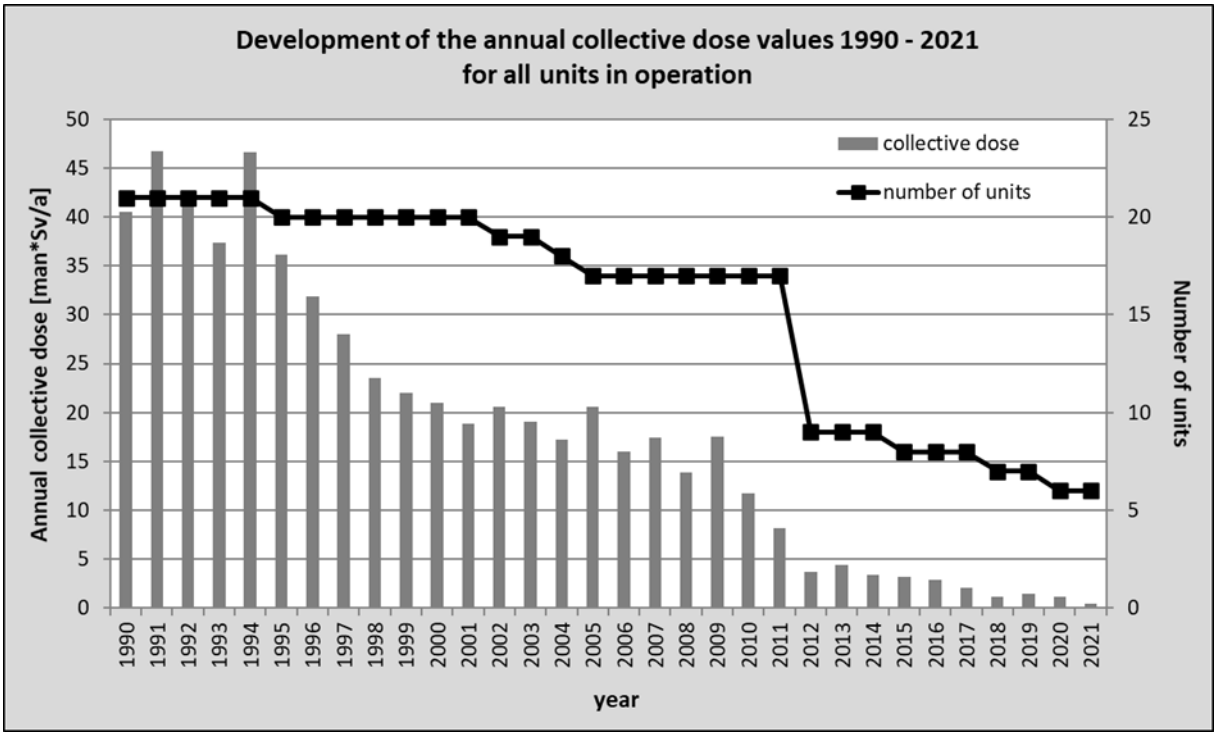


Summary of national dosimetric trends

After the accident at the Fukushima Nuclear Power Plant, Germany decided to terminate the use of nuclear power for the commercial generation of electricity. This was enforced by an amendment of the Atomic Energy Act on 6 August 2011, where further operation of eight nuclear power plants (Biblis A, Biblis B, Brunsbüttel, Isar 1, Krümmel, Neckarwestheim 1, Philippsburg 1 and Unterweser) was terminated. With this amendment, the remaining nine nuclear power plants in operation were/will be permanently shut down step by step by the end of the year 2022. In this course, the Grafenrheinfeld Nuclear Power Plant was finally shut down on 27 June 2015, Gundremmingen B on 31 December 2017, Philippsburg 2 on 31 December 2019, as well as Grohnde, Gundremmingen C and Brokdorf on 31 December 2021. Decommissioning of five of the switched off nuclear power plants started in 2017 (Biblis A, Biblis B, Isar 1, Neckarwestheim 1 and Philippsburg 1), of two in 2018 (Unterweser and Grafenrheinfeld), of two in 2019 (Gundremmingen B and Brunsbüttel), and of one in 2020 (Philippsburg 2). The remaining nuclear power plant, Krümmel, which was switched off, was in the post-operational phase; a decommissioning licence was not issued to Krümmel until the end of the year 2021.

The trend in the average annual collective dose for all units in operation from 1990 to 2021 is presented in the figure above. The decrease observed in the years 2011 and 2012 is based on the shutdown of the aforementioned eight nuclear power plants. These plants belong to older construction lines which generally showed a higher annual collective dose compared to later construction lines. In 2021, the average annual collective dose per unit in operation (5 PWR, 1 BWR) was 72 person·mSv. The reason for the significant decrease in 2021 as compared to the previous year (2020) is mainly due to the fact that no refuelling outages were carried out at Gundremmingen C and Brokdorf due to the shutdown at the end of the year. A similar trend is obtained for the total annual collective dose, which is presented in the figure below.

For the plants in decommissioning, the value of the average annual collective dose is slightly higher, at 100 person·mSv. In this, the one plant in the post-operational phase (Krümmel) and the thirteen nuclear power plants (Gundremmingen B, Brunsbüttel, Unterweser, Grafenrheinfeld, Biblis A, Biblis B, Isar 1, Neckarwestheim 1, Philippsburg 1, Philippsburg 2, Mülheim-Kärlich, Obrigheim and Stade) were taken into account.


Development of the annual collective dose values 1990 - 2021
for all units in operation
collective dose
number of units
Annual collective dose [man*Sv/a]
Number of units
year
0
5
10
15
20
25
30
35
40
45
50
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021

Hungary

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
VVER	**4**	**340 (with electronic dosimeters), 330 (with TLDs)**

2) Principal events of the year 2021

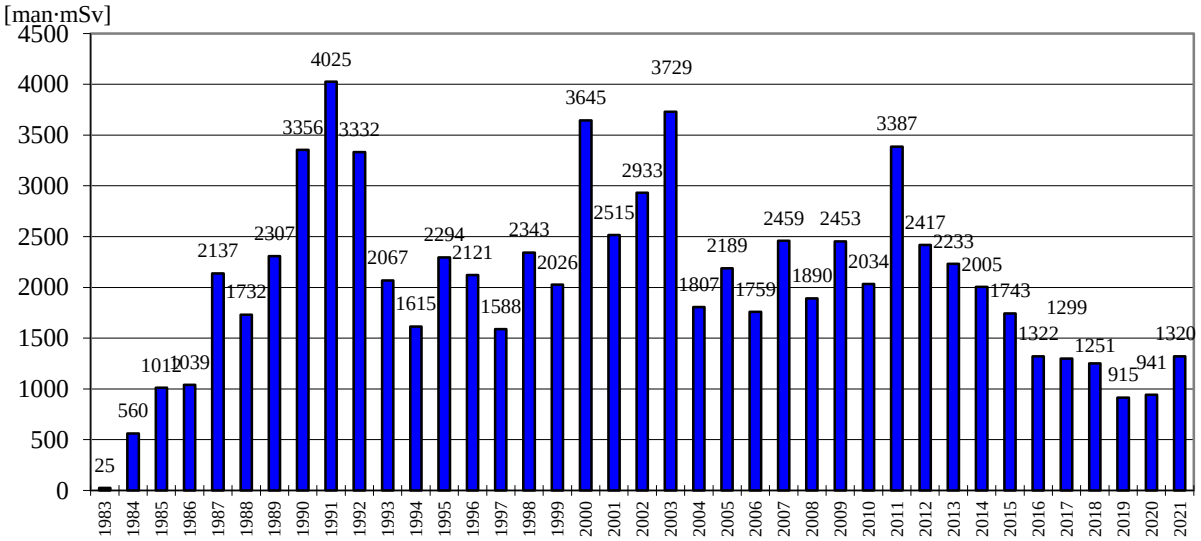
Summary of national dosimetric trends

Using the results of operational dosimetry, the collective radiation exposure was 1 359 person·mSv for 2021 at Paks Nuclear Power Plant (1 033 person·mSv with dosimetry work permit, and 326 person·mSv without dosimetry work permit). The highest individual radiation exposure was 8.8 mSv, which was well below the dose limit of 20 mSv/year, and the dose constraint of 12 mSv/year.

The collective dose was higher in comparison to the year 2020.

The electronic dosimetry data corresponded acceptable with thermoluminescent dosimeters (TLD) data in 2021.

Development of the annual collective dose values at Paks Nuclear Power Plant (upon the results of the TLD monitoring by the authorities)



From 2000, this data shall be quoted as individual dose equivalent /Hp(10)/

Events influencing dosimetric trends

There was one general overhaul (long maintenance outage) in 2021. The collective dose of the outage was 737 person·mSv at unit 2.

Duration and collective dose of outages

The durations of outages were 27 days at unit 1, 60 days at unit 2, and 30 days at unit 4. Unit 3 was not shut down for outage. The collective doses of outages were 110 person·mSv at unit 1, 737 person·mSv at unit 2, and 112 person·mSv at unit 4.

Italy

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**1**	**31.29 (1 unit – Trino Nuclear Power Plant)**
BWR	**2**	**25.3 (1 unit – Caorso Nuclear Power Plant [10.65] + 1 unit – Garigliano Nuclear Power Plant [39.95])**
GCR	**1**	**1.32 (1 unit – Latina Nuclear Power Plant)**

2) Principal events of the year 2021

Events influencing dosimetric trends

Trino Nuclear Power Plant: waste management, radiological characterisation, recovery of the activated chips of the biological shield and their transfer to the spent fuel pool (in bottles).

Garigliano Nuclear Power Plant: N/A.

Caorso Nuclear Power Plant: sludge and spent resin treatment activities (characterisation and handling and transportation activities).

Latina Nuclear Power Plant: routine activities.

Japan

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**10**	**213**
REACTORS OUT OF OPERATION		
PWR	**6**	**71**
BWR	**17**	**50**
All types	**23**	**56**
REACTORS IN DECOMMISSIONING		
PWR	**8**	**159**
BWR	**15**	**1 718**
GCR	**1**	**0**
LWCHWR	**1**	**230**

2) Principal events of the year 2021

Outline of national dosimetric trend

The average annual collective dose for operating reactors decreased from 350 peron·mSv/unit in the previous year (2020) to 213 person·mSv/unit in 2021. The average annual collective dose for reactors out of operation decreased from 104 person·mSv/unit in the previous year (2020) to 56 person·mSv/unit in 2021. The average annual collective dose for reactors in decommissioning (excluding Fukushima Daiichi Nuclear Power Plant) was 73 person·mSv/unit, and that of Fukushima Daiichi Nuclear Power Plant – 4 247 person·mSv/unit.

Operating status of nuclear power plants

In FY 2021, at most nine PWRs operated.

- From 1 April to 4 April, 2021: 4 units (Ohi 4, Genkai 3, Sendai 1, 2);
- From 5 April to 14 April, 2021: 5 units (Takahama 3, Ohi 4, Genkai 3, Sendai 1, 2);
- From 15 April to 12 May, 2021: 6 units (Takahama 3, Ohi 4, Genkai 3, 4, Sendai 1, 2);
- From 13 May to 26 July, 2021: 7 units (Takahama 3, 4, Ohi 4, Genkai 3, 4, Sendai 1, 2);

- From 27 July to 29 July, 2021: 8 units (Mihama 3, Takahama 3, 4, Ohi 4, Genkai 3, 4, Sendai 1, 2);
- From 30 July to 16 October, 2021: 9 units (Mihama 3, Takahama 3, 4, Ohi 3, 4, Genkai 3, 4, Sendai 1, 2);
- From 17 October to 22 October, 2021: 8 units (Mihama 3, Takahama 3, 4, Ohi 3, 4, Genkai 3, 4, Sendai 2);
- From 23 October, 2021 to 16 January, 2022: 7 units (Takahama 3, 4, Ohi 3, 4, Genkai 3, 4, Sendai 2);
- From 17 January to 20 January, 2022: 8 units (Takahama 3, 4, Ohi 3, 4, Genkai 3, 4, Sendai 1, 2);
- From 21 January to 23 January, 2022: 7 units (Takahama 3, 4, Ohi 3, 4, Genkai 4, Sendai 1, 2);
- From 24 January to 20 February, 2022: 8 units (Takahama 3, 4, Ohi 3, 4, Ikata 3, Genkai 4, Sendai 1, 2);
- From 21 February to 28 February, 2022: 7 units (Takahama 3, 4, Ohi 3, 4, Ikata 3, Genkai 4, Sendai 1);
- From 1 March to 10 March, 2022: 6 units (Takahama 4, Ohi 3, 4, Ikata 3, Genkai 4, Sendai 1);
- On 11 March, 2022: 5 units (Takahama 4, Ohi 3, Ikata 3, Genkai 4, Sendai 1).

Exposure dose distribution of workers at Fukushima Daiichi Nuclear Power Plant

Exposure dose distributions at Fukushima Daiichi Nuclear Power Plant for dose during FY 2021 are shown below.

Cumulative dose Classification (mSv)	Fiscal year 2021 (April 2021 – March 2022)		
	TEPCO	Contractor	Total
>50	0	0	0
20～50	0	0	0
10～20	7	836	843
5～10	59	925	984
1～5	209	2247	2456
≦1	1083	4771	5854
Total	1358	8779	10137
Max.(mSv)	13.10	17.46	17.46
Ave.(mSv)	0.85	2.77	2.51

* TEPCO uses the integrated value from the APD that is equipped every time when an individual enters the radiation controlled area of the facility.

*These data are sometimes replaced by monthly dose data measured by an integral dosimeter for the individual.

* There has been no significant internal radiation exposure reported since October 2011.

Regulatory requirements

The examination of the new safety standards began in July 2013. One BWR obtained approval in FY 2021.

3) Report from authority

- The revisions of regulations on the new dose limit of 50 mSv in a year and 100 mSv in 5 years for the lens of the eye was enforced in FY 2021.

- In addition, the Radiation Council, established under the Nuclear Regulation Authority (NRA), has requested the appropriate reports of relevant administrative bodies, relating to radiation workers at the TEPCO Fukushima Daiichi Nuclear Power Plant and in the medical area, regarding the status of Individual exposure dose control including the lens of the eye.

Korea

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**21**	**360**
PHWR	**3**	**433**
All types	**24**	**369**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**1**	**14.6**
PHWR	**1**	**31.7**

2) Principal events of the year 2021

Outline of national dosimetric trend

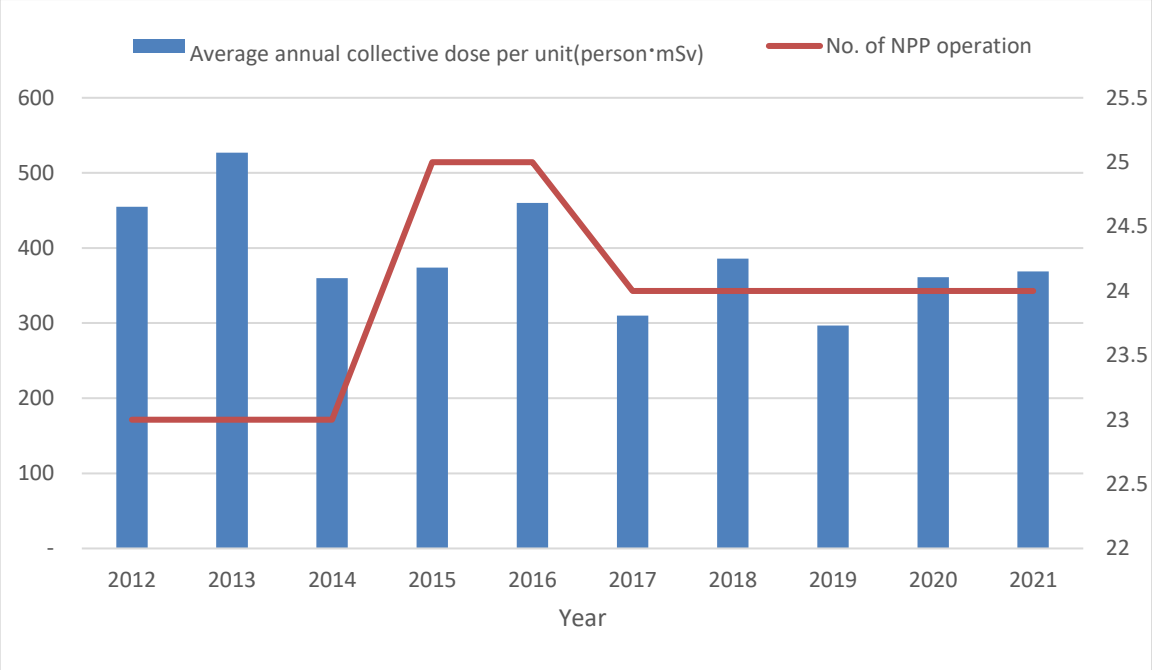
In 2021, the total number of operating nuclear power reactors was 24; including 21 PWRs and 3 PHWRs. In terms of nuclear power plant operation, the total number of 16 795 workers had access to the radiation controlled area and received a total amount of 8 906.71 person·mSv. The total number of workers decreased by 49 in 2021, and the total amount of collective dose increased by 176.84 (approximately 2.03%) compared to 8 729.87 person·mSv in the previous year 2020. Overall, the number of radiation works and the number of workers' input were similar compared to the previous year.

The average collective dose per unit in 2021 was 369 person·mSv based on the operation of 24 nuclear power reactors. The average individual dose in 2021 was 0.53 mSv. There was no individual whose dose exceeded 50 mSv. The maximum individual dose in 2021 was 14.88 mSv. The fractions of the number of individuals whose doses were less than 1 mSv to the total number of individuals were 86.52%. The radiation dose caused mainly by external exposure was approximately 97.70%, and internal exposure contributed to only 2.30% of the total amount of exposure. In PHWRs, the contribution of internal exposure was relatively higher (approximately 15.25%) than that (almost zero %) in PWRs due to tritium exposure.

Occupational dose distributions in nuclear power plants (Year 2021)

Year	Total number of individuals	Number of individuals in the dose ranges (mSv)								
		< 0.1	[0.1-1)	[1-2)	[2-3)	[3-5)	[5-10)	[10-15)	[15-20)	[20-)
2021	16 795	11 125	3 406	971	444	414	348	87	0	0

Average collective dose per NPP unit from 2012 to 2021



Lithuania

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
LWGR	**2**	**327**

2) Principal events of the year 2021

Events influencing dosimetric trends

In 2021, the collective dose for the Ignalina Nuclear Power Plant staff was 643 person·mSv (60% of planned dose), and 11 person·mSv (18% of planned dose) – for contractors' personnel. External dosimetry system used – thermoluminescent dosimeters (TLD).

The highest individual effective dose for the Ignalina nuclear power plant staff was 14.12 mSv, and for contractors' personnel – 1.00 mSv. The average effective individual dose for the Ignalina Nuclear Power Plant staff was 0.43 mSv, and for contractors' personnel – 0.02 mSv.

The main works that contributed to the collective dose during technical service and decommissioning of units 1 and 2 at Ignalina Nuclear Power Plant were dismantling of the equipment; CONSTOR®RBMK-1500/M2 containers treatment; fuel handling; repairing of the hot cell; modernisation and maintenance works at the spent fuel storage pool hall, reactor hall and reactor auxiliary buildings; waste and liquid waste handling; radiological monitoring of workplaces and radiological investigations.

In 2021, no component or system replacements were performed. In 2021, there were no unexpected events.

New/experimental dose-reduction programmes

The doses were reduced by employing up-to-date principles of organisation of work, by doing extensive work on the modernisation of plant equipment, and by using automated systems and continuously implementing programmes of introducing the ALARA principle during work activities. The evaluation and upgrade of the level of safety culture, extension and support to the effectiveness of the quality improvement system are very important.

Organisational evolutions

Every year the scope of dismantling works increases. In 2021, about 38% of the equipment (62.4 thousand tonnes of planned 166.9 thousand tonnes) was dismantled. About 47.9 thousand tonnes of dismantled equipment were decontaminated up to free release level. Dismantling of the equipment of the turbine hall of unit 1 was finished in 2019, dismantling of the equipment of the turbine hall of unit 2 was almost finished (about 98%) and will be completed in 2022. 84% of the dismantled equipment from unit 1 was decontaminated and can be used as secondary raw materials.

In 2021, the final stage of spent fuel management was reached, and the last container with damaged spent nuclear fuel was transported from unit 1. All damaged fuel management works are planned to be completed in October 2022.

Also, the building works of the Disposal Module of the LANDFILL Facility for Short-Lived Very Low Level Waste (B19-2 project) were finished. The first company of placing waste will start in 2022.

Ignalina Nuclear Power Plant must ensure the storage of radioactive waste according to the Nuclear and Radiation Safety Requirements by taking maximum measures to prevent radioactive contamination. Consequently, the construction of the Fuel Storage Facilities and Radioactive Waste Repositories is an aspect of the strategic importance of the activities performed at Ignalina Nuclear Power Plant.

The priority activities of Ignalina Nuclear Power Plant are nuclear and radiation safety, transparency and effectiveness of the activity, responsibility of staff and high professional quality of workers and social responsibility.

3) Report from Authority

In 2021, VATESI carried out radiation protection inspections at Ignalina Nuclear Power Plant in accordance with an approved inspection plan. Assessments were made regarding how radiation protection requirements were fulfilled in the following areas and activities: clearance of radioactive materials, monitoring of occupational exposure, inspection of radiation control systems at radioactive waste treatment facilities, work planning and use of mobile aerosol monitors as redundant equipment for the operational control of the release of radioactive materials and planning and control from the radiation protection point of view of the implementation of higher dose tasks.

In 2022, VATESI will continue supervision and control of nuclear safety of decommissioning of Ignalina nuclear power plant, giving more attention to radiation protection during dismantling and radioactive waste treatment activities. To enhance radiation protection level during decommissioning of Ignalina Nuclear Power Plant, VATESI will continue to review the radiation protection requirements established in legal documents.

Mexico

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
BWR	**2**	**1 159.21**

- Annual site collective dose: 2 318.42 person mSv.
- Operating reactors: Laguna Verde 1 and Laguna Verde 2.
- Reactor type: BWR/GE.
- Number of reactors: 2.
- Average annual collective dose per unit and reactor type: 1 159.21 person mSv/unit.

2) Principal events of the year 2021

The nuclear reactors existing in Mexico are two BWR/GE units at Laguna Verde Nuclear Power Station located in Laguna Verde, State of Veracruz, Mexico.

- Laguna Verde unit 1 did not have a scheduled refuelling outage in 2021. The normal operating dose for unit 1 was 1 279.32 person·mSv. The total collective dose for Unit 1 was 1 279.32 person·mSv.
- Laguna Verde unit 2 refuelling outage (17U2) started on 14 November 2020 and ended on 2 February 2021. The refuelling outage dose accumulated in 2021 was 558.42 person·mSv. The normal operating dose for unit 2 was 480.68 person·mSv. The total collective dose for unit 2 was 1 039.1 person·mSv.
- The total site dose in 2021 was 2 318.42 person·mSv.

Laguna Verde's historical collective dose both on-line and during refuelling outages is higher than the BWR average. On-line collective dose is high because of failures or shortcomings in equipment reliability. Some examples are steam leaks, reactor water clean-up system pumps failures, and radioactive waste treatment systems failures.

Events influencing dosimetric trends

a) Increase of radioactive source term

This factor was originated by the reactor water chemical instability induced in turn by the application of noble metals and hydrogen since 2006 to prevent the stress corrosion cracking of reactor internals. Radioactive source term is still strongly influencing dose rates at the plant and specifically in the drywell during refuelling outages. The drywell is where 70-80% of the refuelling dose is obtained.

During future planned refuelling outages, the station ALARA programme has the following challenges:

- Radiological ALARA objectives in drywell will be carried out with technicians and supervisors involved with the firm purpose of optimising the collective dose at Laguna Verde Nuclear Power Station. Steam tunnel activities are also carefully managed by RP to reduce worker dose.

- Likewise, the strategies implemented from previous refuelling will be maintained including:

  – installation of temporary shielding;
  –
  – installation of solid collector filter;
  –
  – use of selective Co-60 resin in the demineralisation filters implemented for the control and reduction of the source term.

b) Chemical decontamination

The main problem associated with the high collective dose at Laguna Verde Nuclear Power Station is the continued increase of the radioactive source term (insoluble cobalt deposited in internal surfaces of piping, valves). Chemical decontamination has been performed on the A/B loops of the recirculation system and on the G33 system in the drywell and reactor building.

The Laguna Verde units have experienced significant reduction in BRAC point dose rates by completing chemical decontamination and continued LT-ZiP's. Results observed in 2021 include the following:

1. 90% removal of activity on reactor recirculation piping (before: 690-1 000 mR/hr; after: 20-160 mR/hr with 61 Ci removed).

2. 95% removal of activity on RWCU piping (before: 600-6 000 mR/hr; after: 10-750 mR/hr with 53 Ci removed).

3. Continued feed of 2 ug/cm^2 Pt and 5 ug/cm^2 Zn deposited on RRC piping. Platinum is aimed at mitigating intergranular stress corrosion cracking: Zinc aimed at suppresses Co-60 deposition.

c) High efficiency ultrasonic cleaning

Unit 1 implemented high efficiency ultrasonic cleaning (HE-UFC) in the 2020 refuelling outage. Significant quantities of CRUD and activated debris were removed similar to US BWR experience. In 2021, a decrease in Co-60 colloids in reactor coolant was observed.

Netherlands

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR (Borssele Nuclear Power Plant)	**1**	**441 (99 person·mSv EPZ, 342 person·mSv contractors)**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
BWR	**1**	**0**

2) Principal events of the year 2021

- One regular outage in April (17 days) with 395 person·mSv, and one short unplanned outage in October (4 days) with 5 person·mSv.

- Maximum individual dose: 3.44 mSv (EPZ) and 4.01 mSv (contractors).

- 2 incidents during the regular outage:

    a) 40 m^3 of primary water in the containment due to a leakage of the reactor basin shutter;
    b) release of activity in the air of the containment due to an insufficient filtering of the air from the open steam generators (opened for inspection).

Both incidents led to an increased number of personnel contaminations inside the controlled area but had no significant consequences for the workers.

3) Report from authority

- In the 2021 maintenance outage of Borssele nuclear power plant, ANVS performed more inspections than in 2020 because the previously postponed maintenance and in-service inspection works

were required to be done in the 2021 outage due to the COVID-19 pandemic. This was also the reason for a higher collective dose in 2021 compared to previous years.

Despite the second year of the COVID-19 pandemic, ANVS was able to perform their inspections as planned, both physically and virtually.

- ANVS reviewed the base document for the 10-yearly periodic safety review (10EVA23) of Borssele Nuclear Power Plant, and EPZ (licensee of Borssele Nuclear Power Plant) started with the conduction of the periodic safety review.

- In the field of radiation protection, ANVS supervised the following situations at EPZ:
    - an incident in which radioactive material was found outside the controlled area;
    - a situation regarding unlicensed mobile X-ray devices;
    - replacement of a baggage scanner resulting in more shielding.

Pakistan

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**4**	**102.24**
PHWR	**1**	**1 407.06**
All types	**5**	**363.204**

2) Principal events of the year 2021

Events influencing dosimetric trends

TYPE	UNIT	OUTAGES (No.)	DURATION (Days)
PWR	C-1	03	50.4
	C-2	02	7.67
	C-3	02	4.64
	C-4	02	54.89
PHWR	K-1	05	269

Component or system replacements, Unexpected events/incidents

NIL

New reactors on line, Reactors definitively shutdown

NIL

New/experimental dose-reduction programmes

NIL

Organisational evolutions

NIL

Regulatory requirements

NIL

Romania

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PHWR	**2**	**186**

2) Principal events of the year 2021

Events influencing dosimetric trends

Normal operation of the plant (Cernavoda U1 & U2)

At the end of 2021:

- there were 104 employees with annual individual doses exceeding 1 mSv; 5 with individual doses exceeding 5 mSv; and none with individual dose over 10 mSv;
- the maximum individual dose for 2021 was 7.768 mSv;
- the contribution of internal dose due to tritium intake was 20%.

Planned outages

- A 39-day planned outage was done at unit 2 between 8 May and 15 June 2021. Activities with major contribution to the collective dose were as follows:
  - fuel channels fixed end changing;
  - fueling machine bridge components preventive maintenance;
  - feeder-yoke clearance measurements and correction;
  - inspection for tubing and supports damages in the feeder cabinets;
  - planned outages systematic inspections;
  - feeder thickness, feeder clearance and feeder-yoke measurements, elbow UT examination;
  - snubbers inspection;

- piping supports inspection;
- implementation of engineering changes.

The total collective dose at the end of the planned outage was 220.7 person·mSv (185.4 person·mSv external dose and 35.3 person·mSv internal dose due to tritium intakes).

Finally, this planned outage had a 59% contribution to the collective dose of 2021.

Unplanned outages

N/A.

New/experimental dose-reduction programmes

In order to decrease individual and collective doses during normal operation of the plant, an action plan was issued and implemented for the optimisation of the preventive maintenance programme.

Personnel response to contamination monitors alarms is one of the topics in the radiation protection (RP) staff observation and coaching programme. All RP personnel are already involved in the observation/ guidance programme, in order to identify and correct deficiencies in work practice, RP fundamentals, RP equipment and systems.

A special designed application was used for the first time during the 2018 planned outage for tracking the accumulated collective external dose for each job, in order to compare it with estimated collective dose and the execution status. This allowed quick identification of jobs needing dose re-evaluation.

The application is still used for monitoring dose progress of all radiation jobs.

Radiation work permits for jobs with the estimated collective dose ≥ 5 person·mSv and ALARA measures for optimisation of the exposures are analysed and approved by the ALARA Technical Committee.

RP supervisors attend all the high radiological work risk activities pre-job briefings. RP technicians act as RP assistants for high radiological work risk activities (including industrial radiographies).

Russia

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
VVER	**22**	**377.6**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
VVER	**3**	**86.8**

Collective doses

In 2021, the total effective annual collective dose of employees and contractors at 22 operating VVER-type reactors was 8 306 person·mSv. This value is 25 % less in comparison to 2020.

Average annual collective doses for the groups of VVER-440, VVER-1000 and VVER-1200 reactors in operation in 2021 were:

- 482.2 person·mSv/unit for a group of 5 operating VVER-440 reactors (Kola 1-4, Novovoronezh 4);
- 405.7 person·mSv/unit for a group of 13 operating VVER-1000 reactors (Balakovo 1-4, Kalinin 1-4, Novovoronezh 5, Rostov 1-4);
- 155.2 person·mSv/unit for a group of 4 operating VVER-1200 reactor (Novovoronezh II-1 and II-2, Leningrad II-1 and II-2).

These results show that average annual collective dose for the new VVER-1200 reactors is 2.9 times lower than the average values for the VVER-440 and VVER-1000.

Average annual collective dose for three reactors at the stage of decommissioning (Novovoronezh 1-3) in 2021 was 260.4 person·mSv.

The total planned outages collective dose of employees and contractors represents 75.7 % of the total collective dose.

Individual doses

In 2021, individual effective doses of employees and contractors did not exceed the control dose level of 18.0 mSv per year at any VVER-440, VVER-1000 or VVER-1200 reactor.

The maximum recorded individual dose was 13.4 mSv. This dose was gradually received over the full year by a representative of Kalinin Nuclear Power Plant (central maintenance department). The maximum annual effective individual doses at other nuclear plants with VVER-type reactors in 2021 varied from 4.8 mSv (Leningrad II Nuclear Power Plant) to 13.3 mSv (Balakovo Nuclear Power Plant). For reactors at the stage of decommissioning, the maximum recorded individual dose was 4.5 mSv (Experimental Demonstration Engineering Center, department of radioactive waste management).

Planned outages duration and collective doses (2021)

Reactor type	Reactor	Duration [days]	Collective dose [person·mSv]
VVER-440	Kola 1	52	383.2
	Kola 2	68	340.2
	Kola 3	63	304.9
	Kola 4	61	210.2
	Novovoronezh 4	34	574.0
VVER-1000	Balakovo 1	52	661.9
	Balakovo 2	37	318.6
	Balakovo 3	47	612.5
	Balakovo 4	20	105.0
	Kalinin 1	34	376.1
	Kalinin 2	—*	
	Kalinin 3	57	418.0
	Kalinin 4	—*	
	Novovoronezh 5	42	614.0
	Rostov 1	49	298.3
	Rostov 2	45	322.2
	Rostov 3	31	240.3
	Rostov 4	36	164.6
VVER-1200	Leningrad II-1	—*	
	Leningrad II-2		
	Novovoronezh II-1	64	31.4
	Novovoronezh II-2	71	318.1
* No outage.			

2) Principal events of the year 2021

Events influencing dosimetric trends

In 2021, the relatively elevated contribution in the "Rosenergoatom" collective dose was registered at four units. This is completely due to large scope of radiation works:

- Balakovo 1: long-term planned outage with modernization of equipment (662 person·mSv);
- Novovoronezh 5: medium planned outage, overhaul of 1 steam generator and 2 reactor coolant pumps (614 person·mSv);
- Balakovo 3: long-term planned outage, maintenance of 2 reactor coolant pumps (613 person·mSv);
- Novovoronezh 4: medium planned outage, different types of work on 6 steam generators and 3 reactor coolant pumps (574 person·mSv).

Leningrad II Nuclear Power Plant unit 2 (VVER-1200) was put into commercial operation in March 2021.

Optimisation of radiation protection of workers at nuclear power plants

"Rosenergoatom" has a programme for optimisation of occupational radiation protection at nuclear power plants (dose reduction plan). The programme sets targets for collective and individual doses for each nuclear power plant to be achieved by 2024.

Main actions under the programme are:

- organisational measures for improving radiation protection (dose planning and analysis, analysis of "unforeseen" personnel exposure, increasing the responsibility of nuclear power plant managers for dose reduction);
- decrease of radiation levels in nuclear power plant premises and equipment (identification and exclusion of stagnation areas, detection and elimination of high radiation areas, dose rate reduction in drains of special sewer system, minimising corrosion product activity in primary coolant during shutdown);
- reduction of exposure time (reduction of "transit doses", creation of low dose areas, use of mock-ups and practice areas).

Slovak Republic

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
VVER	**4**	**136.91**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
VVER	**2**	**Not included in ISOE**
GCR	**1**	**Not included in ISOE**

2) Principal events of the year 2020

Events influencing dosimetric trends

- Bohunice Nuclear Power Plant (2 units):

  The total annual effective dose at Bohunice Nuclear Power Plant in 2021, calculated from legal electonic dosimeters and E_{50}, was 265.94 person mSv (employees: 85.677 person·mSv; outside workers: 180.263 person·mSv). The maximum individual dose was 6.171 mSv (outside worker). There was no internal contamination. There were no anomalies in radiation conditions.

- Mochovce Nuclear Power Plant (2 units):

  The annual collective effective dose in Mochovce Nuclear Power Plant in 2021, evaluated from legal film dosimeters, neutron TLD dosimeters and E_{50} was 281.696 person·mSv (employees: 100.438 person·mSv; outside workers: 181.258 person·mSv). The maximum annual individual effective dose was 3.391 mSv.

  There was no worker's internal contamination. There were no anomalies in radiation conditions.

Outage information

- Bohunice Nuclear Power Plant:

Unit 3 – 18.9 days, standard maintenance outage. The collective exposure was 99.76 person·mSv from electronic operational dosimetry.

Unit 4 – 22.2 days, standard maintenance outage. The collective exposure was 131.364 person·mSv from electronic operational dosimetry.

- Mochovce Nuclear Power Plant:

Unit 1 – 28.2 days, standard maintenance outage. The collective exposure was 171.253 person·mSv from electronic operational dosimetry. The maximum individual dose was 2.073 mSv.

Unit 2 – 24.5 days, standard maintenance outage. The collective exposure was 103.503 person·mSv from electronic operational dosimetry. The maximum individual dose was 1.760 mSv.

New reactors on line

Mochovce Nuclear Power Plant, units 3 and 4 were under construction. Radiologically controlled area was created at unit 3 on 6 July 2021.

3) Report from authority

In 2021, the Slovak Radiation Regulatory Authority made inspections at both nuclear power plant facilities in operation concerning optimisation of radiation protection. The conclusions from the inspections are that the authority calls for more short- and long-term concrete and proactive goals for the optimisation of radiation protection.

The Slovak Radiation Regulatory Authority approved the using of electronic personal dosimeters DMC3000 as dosimeters of legal use for measurement of individual effective dose from gamma radiation and DIS-1 dosimeters for Hp(0,07) measurement at Bohunice Nuclear Power Plant.

The Slovak Radiation Regulatory Authority applied the regulations for radiation protection according to Council Directive 2013/59/EURATOM. The major change in this revision includes: (1) lowering the individual effective dose limit from the current value of 50 mSv/year to 20 mSv/year in alignment with the individual dose limits as published in Council Directive 2013/59/EURATOM; (2) lowering the current lens dose equivalent limit to 20 mSv/year in alignment with the lens dose limit as published in Council Directive 2013/59/EURATOM.

Slovenia

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR (Krško)	**1**	**925**

2) Principal events of the year 2021

- Normal operation and the plant outage during COVID-19 situation.
- The last part of the upgrade programme was completed at the end of 2021, and it included:
  - new shelter building for operative support centre;
  - bunkered building with safety injection pump and borated water tank;
  - auxiliary feedwater pump with condensate storage tank;
  - make-up possible from underground water source;
  - additional alternative RHR pump.
- Construction of the spent fuel dry storage was in progress and will be finished at the end of 2022 (the first filling of containers with spent fuel elements is planned in 2023).
- The Slovenian Nuclear Safety Administration approved changes to the safety report for another 20 years of plant operation, i.e. a total of 60 years, on the condition that periodic safety review is successfully completed every 10 years, the next one already in 2023.

3) Report from authority

The Slovenian Radiation Protection Administration and the Slovenian Nuclear Safety Administration continued inspection and surveillance of Krško Nuclear Power Plant in compliance with their respective competences. Special arrangements due to the COVID-19 pandemic were still in place in 2021; however, both institutions carried out their planned activities in full scope.

In 2021, Slovenia made extensive preparations for the IAEA Integrated Regulatory Review Service (IRRS) to be carried out in April 2022. Within the IRRS preparation process, both regulatory bodies

reviewed Slovenia's regulatory system in radiation protection and nuclear safety with respect to the IAEA standards. An action plan for improvements was prepared before the IRRS mission. In parallel, preparations for the Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation (ARTEMIS) were carried out.

South Africa

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**2**	**344.696**

2) Principal events of the year 2021

The 25th outage at Koeberg unit 1 was due to commence on 18 February 2021, however, due to a leak above the technical specifications limits, the unit was shut down on 2 January 2021, initiating the outage. The outage included significant testing of the steam generator tubes before reloading fuel, as well as nozzle lower level work on important valves.

Summary of national dosimetric trends

- Number of occupationally exposed persons for the year: 2 459.
- Total collective dose to the workforce for the year (person·mSv): 689.392 (TLD).
- Annual average dose to occupationally exposed persons (mSv): 0.280.
- At Koeberg Nuclear Power Station, during 2021:
    - 1 683 workers received a minimum dose of less than 0.1 mSv;
    - 772 workers received a dose between 0.1 mSv and 5.0 mSv;
    - 4 workers received a dose between 5 mSv and 10 mSv;
    - 0 workers received a dose between 10 mSv and above.

Events influencing dosimetric trends

The execution of a nozzle level outage compounded by the leaking steam generator resulted in a higher dose incurred for the outage than normally expected.

Major evolutions

Replacement of 3 steam generators is planned for the next maintenance outage scheduled for 2023 at Koeberg units 1 and 2.

Spain

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**6**	**348.91**
BWR	**1**	**1 664.66**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**1**	**9.13**
BWR	**1**	**7.77**

2) Principal events of the year 2021

PWR

Almaraz Nuclear Power Plant

- *Number and duration of outages*
  - 28th outage of Almaraz unit 1:
    - duration: 47 days;
    - beginning: 22 November 2021;
    - ending: 7 January 2022;
    - collective dose: 537.418 person·mSv;
    - maximum individual dose: 3.522 mSv.
- *Component or system replacements*
  - Design modification in the refuel reactor cavity for installation of a permanent cavity sealing ring at unit 1.
- *New/experimental dose-reduction programmes*
  - Improvement in the use of shielding:
    - tungsten shielding;
    - shielding for steam generator;

- racks of quick deployment;
- pipe shields;
- reactor head shielding.

- New equipment for monitoring radiation

  - Continuous airborne contamination monitoring;
  - spectrometry in hot spots;
  - spectrometry in filters and smears.

Ascó Nuclear Power Plant

- *Number and duration of outages*

  - 28th refuelling outage of Ascó 1:

    - duration: 46 days;
    - collective dose: 458.579 person·mSv;
    - maximum individual dose: 3.703 mSv.

    Relevant activities from RP point of view performed during the 28th refuelling outage of Ascó 1:

    - upper internals plate and control rod guide assembly tube welding inspection (6.279 person·mSv);
    - automatic steam generator hot legs welding inspection with track scanner equipment (8.494 person·mSv);
    - reactor vessel under-head shield disassembly and assembly due to penetrations inspection with the Visiotec equipment (17.981 person·mSv).

  - Interventions related to the solid waste system (6.023 person·mSv).

  - Realisation of four spent fuel transfer campaigns to the temporary repository on the Ascó site (6.668 person·mSv).

  - Increased scope of maintenance and inspections activities during the outage that were postponed in 2020 due to the impact of the COVID-19 pandemic.

Trillo nuclear power plant

- *Number and duration of outages*

  - 33rd outage of Trillo:

  - duration: 38 days;
  - beginning: 18 May 2021;
  - ending: 24 June 2021;
  - collective dose: 216.557 person·mSv;
  - maximum individual dose: 1.908 mSv.

- *New/experimental dose-reduction programmes*

  - Performed 3D scanning of controlled area for use in work planning and radiological information. The programme is ongoing.

Vandellós 2 Nuclear Power Plant

- *Number and duration of outages*

  - 24th refuelling outage of Vandellós 2:

    - duration: 39.4 days;
    - beginning: 15 May 2021;
    - ending: 22 June 2021;
    - collective dose: 583.03 person·mSv;
    - maximum individual dose: 3.826 mSv (operational).

  - Component or system replacements: none.
  - Safety related issues: none.
  - Unexpected events/incidents: none.
  - New reactors on line: none.
  - Reactors definitively shutdown: none.

- *New/experimental dose-reduction programmes*

  None.

- *Organisational evolutions*

  None.

- *Regulatory requirements*

  None.

Zorita 2 Nuclear Power Plant

- *Events influencing dosimetric trends*

- Number of outages: N/A.
- Component or system replacements: none.
- Safety related issues: none.
- Unexpected events/incidents: none.
- New reactors on line: none.
- Reactors definitively shutdown: none.

- *New/experimental dose-reduction programmes*

  None.

- *Organisational evolutions*

  None.

- *Regulatory requirements*

  None.

BWR

Cofrentes Nuclear Power Plant

- *Events influencing dosimetric trends*

  - During the 20th outage in 2015, a chemical decontamination of the systems of recirculation (B33) and of water clean-up of the reactor (G33) was performed. In relation with the evolution of the source term in the dry well, it was observed during the 23th outage (2021) that the dose rate values in the recirculation pipelines were stable with respect to the last outage (year 2019).

  - In relation to the reactor water clean-up system, the degree of recontamination was more pronounced than expected, so it became necessary to establish an action plan to compensate for this increase in the observed source term. The plan had specific follow-up through the different ALARA Committees carried out during the outage.

- *Number and duration of outages*

  - 23th outage.
  - Duration: 32 days.

  - There were two forced outages:

  - In the period from 9 to 12 September – by automatic action of the reactor protection system, due to work related to the condensate water purification system. Dose received: 9.89 person·mSv.

  - In the period from 15 to 16 December – in the start-up process after the 23rd outage, during the low-speed transfer manoeuvre of the recirculation pumps. Dose received: 9.19 person·mSv.

- *Component or system replacements*

  - The replacement of the loop A residual heat extraction system pump (E12C002A) was carried out during the outage.

- *Unexpected events/incidents*

  - There were no incidents.

- *New/experimental dose-reduction programmes*

  - During cycle 23 (2020-2021), the spent fuel dry storage casks were tested and subsequently loaded, generating 5 casks, which were stored in the temporary storage facility built at the site. With this action, 260 elements were removed from the fuel pools, with the consequent increase in their capacity.

  - Continuing with the programme for changing nuclear instrumentation dry tubes, 8 tubes were changed during the 23rd outage (2021).

  - Improvements were made in the installation process of the main steam nozzle plugs, so that they could be placed from a platform with a water level of 7 m instead of placing them from a cavity with a water level below the nozzles, which means a reduction in the dose rates in the area where this task is carried out.

  - As a relevant aspect to be highlighted and derived from the increase in the source term due to the recontamination of the G33 system (reactor water cleaning system), a series of actions were launched during the 23rd outage aimed at reducing the impact on the recharge work. The most significant actions were as follows:

    - the temporary shielding programme was reinforced;

    - reliability in the execution of works was marked as a priority, to avoid reworking;

    - the lamination of works that did not have an operational impact and that represented a radiological benefit in future decontamination was analysed.

  - Since the 19th outage (2013), the use of trinuke filters had increased, an auxiliary system that makes it possible to reinforce the cleaning of the water in the cavity, reactor and fuel pools. As an improvement in the auxiliary filtering systems, a pre-filtering stage was incorporated.

- The temporary and permanent shielding campaign continued, reinforcing the impact zones of the lines of the reactor water cleaning system (G33) due to recontamination of the system.

- Reduction of the increase factor associated with the direct reading dosimeter, applied in each entry-exit transaction of the controlled area (going from 15% to 8%). With this change, the capacity of the DLD dosimetry system is maintained to ensure compliance with the administrative and legal limits of the workers at Cofrentes Nuclear Power Plant, reducing the increase in the individual and collective operational dose.

- Training continued in scale models in the following jobs: LPRM's extraction and cut, CRD's change and cleaning of the PRM's conduit.

▪ *Organisational evolutions*

- There were no organisational changes.

a) Regulatory requirements

- There were no changes in the regulatory requirements.

Santa Maria de Garoña Nuclear Power Plant

▪ *Events influencing dosimetric trends*

Date	Event	Mean activity (if it exists)	Collective dose (person·mSv)*
2 January to 30 December	Waste processing (pressing, storage, transportation)	--	7.778

** Note that this is operational dose.*

▪ *New/experimental dose-reduction programmes*

None.

▪ *Organisational evolutions*

None.

▪ *Regulatory requirements*

None.

Sweden

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**2**	**211.8**
BWR	**4**	**385.5**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**1**	**142.7**
BWR	**5**	**128.7**

2) Principal events of the year 2021

Ringhals nuclear power plant

Ringhals two reactors were performing well during 2021 from a radiation protection point of view, which resulted in Ringhals lowest annual site collective dose (CRE), 712 person·mSv (incl. waste handling, workshop and decontamination facility). The forecast for 2022 is < 800 person·mSv (TLD).

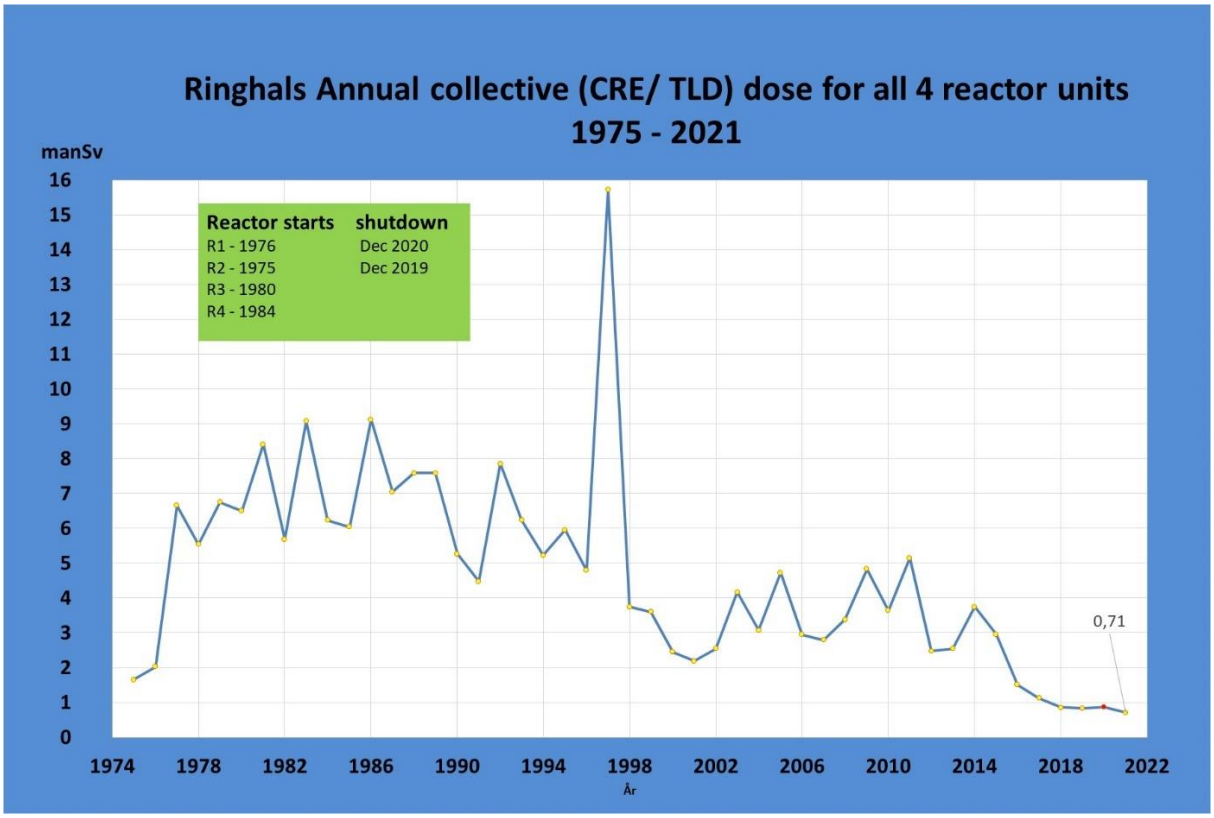
The continuous work on source term control and high dose/dose rate work are two main factors in dose reduction measures along with, what is believed to have a considerable effect, education and training SIP (Radiation Protection in practise), an increasing interest and effort from the entire organisation to implement ALARA on daily basis, and in projects for long-term ALARA investments.

The ALARA committee had five scheduled meetings, and the expansion of the Ringhals ALARA network is in progress.

An important tool to prevent unplanned radiation exposure, the RadPJB (Radiological Pre Job Briefing), was frequently used and implemented in daily RP planning and optimisation.

Furthermore, the fact that Ringhals unit 2 was taken to final shutdown in the end of 2019, and Ringhals unit 1 was to be permanently shut down in the end of 2020, has resulted in smaller amounts of maintenance needed in controlled area on systems with radioactive content, which decreased the total dose exposure at those units in service operation during 2021.

No internal contaminations resulting in an equivalent dose > 0.25 mSv were encountered during 2021.



The figure above shows the annual collective dose since mid-70's when Ringhals 2 went into operation.

Source term management is always in focus and long-term analysis has been made concerning origin of antimony sources to reduce outage doses on the PWR reactors (Ringhals 3 and 4). Exchange of material with high content of antimony will be planned for supportive and condition-based maintenance.

Another nuclide of interest is Ag-110m which is tracked during operation and refuelling, further steps are needed to predict refuelling source term and implement actions for dose optimisation.

An important part of source term reduction is online trending of nuclide specific build up in reactor system oxide layers. Implementation on units 3 and 4 is in a pre-project phase, the experience from Ringhals 1 OLA (OnLine nuclide specific Activity) and DOSOLA (DOS rate OnLine Activity) is carefully considered.

During 2021, three events were subject for INES classification. From a historical point of view, 12 events were INES evaluated from 2015 to 2021, with the maximum rating of INES 1 (4 events).

- The INES 1 (1 event in 2021) concerned fuel handling. A fuel assembly dropped when transported to fuel rack position in the fuel building. There was no release of fission gas.

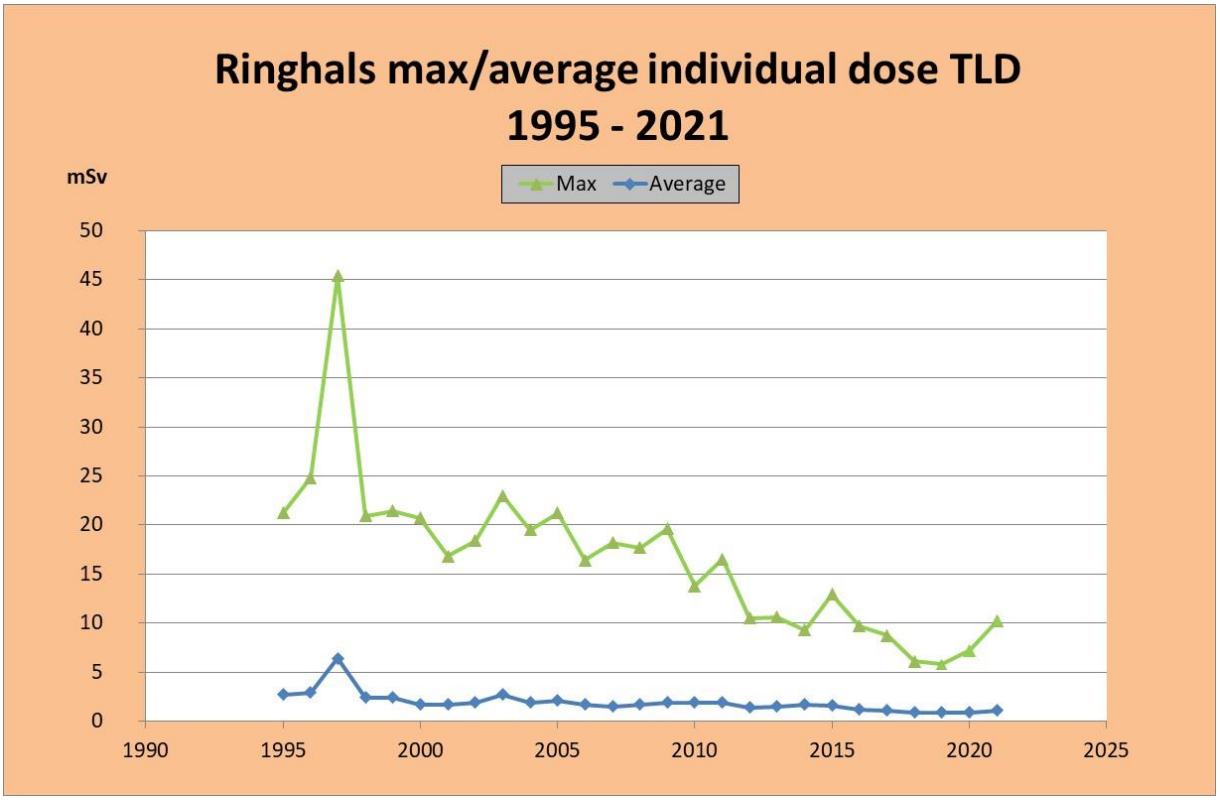
- The INES 0 events (2 events in 2021) involved alpha contamination during FSD at unit 2 and storage of ADR class 7 containers on uncontrolled area with deficiencies in barriers and signs regarding information about elevated radiation levels.

Furthermore, dosimetry system and logistics concerning dose to the eye lens was implemented a couple of years earlier, and e.g. from a PWR reactor perspective, focus is given to SG work and especially jumpers doing work inside SG channel head.

In general, Hp3 is on par with Hp10 doses, exposure situation with concerns for Hp3 were just a few during 2021.

Ringhals reactors have been operating over the last 25 years with less than a handful of fuel leaks and the latest in 2014.

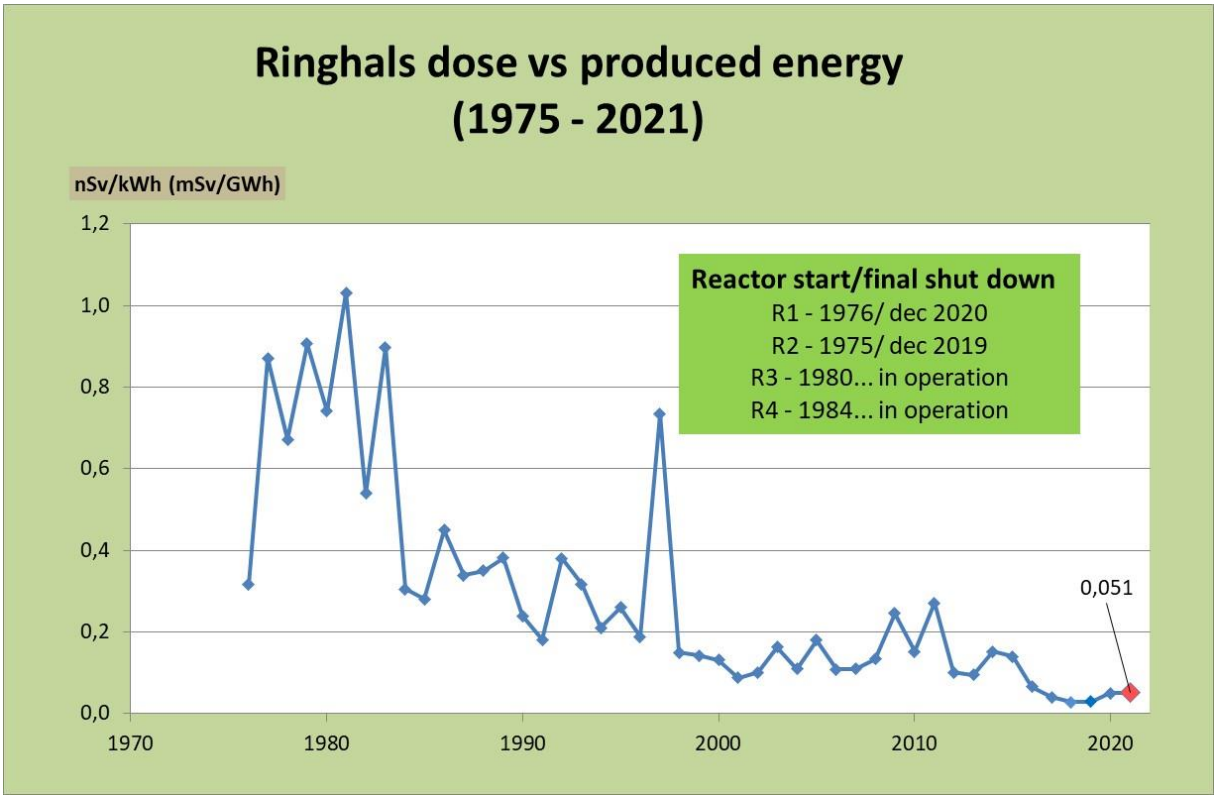
Ringhals unit 1 and 2 has been in service shutdown mode, preparing for decommissioning. Full System Decontamination (FSD) was performed at both reactors during 2021. The FSD at unit 1 obtained a satisfactory decontamination factor (Df 20 on average), while unit 2 had issues resulting in a low DF and remaining high levels of alpha contamination in the RC system.



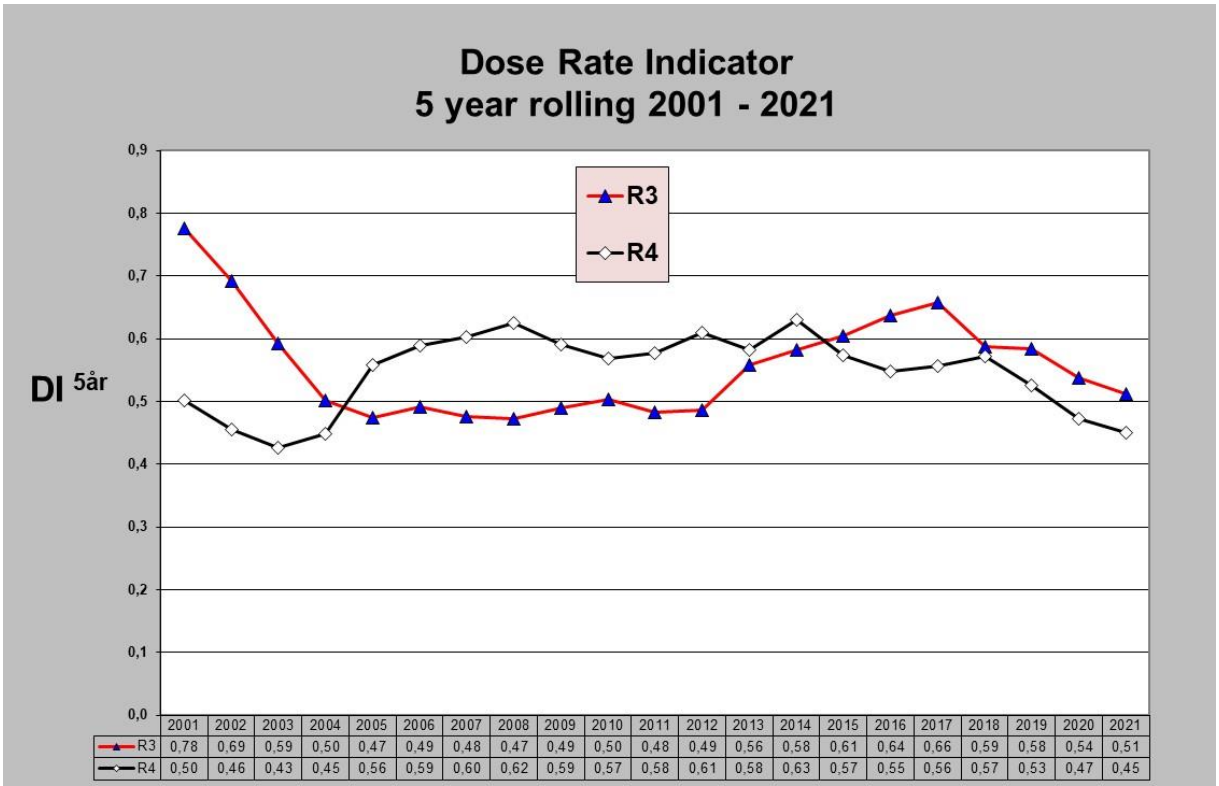
Since the mid-90s individual doses have decreased, and the company goal has been successively lowered, and the long-term goal for maximum entitled annual individual dose is < 6 mSv/ year for dose

received at Ringhals. Even if 5 individuals exceeded the 6 mSv check point in the year 2021, these were carefully pre-evaluated and justified regarding exceeding the 6 mSv dose check point.

The dose constraint will be set at 7 mSv with a check point at 5 mSv in 2022.



Ringhals availability on grid in relation to CRE is 50 µSv per produced GWh in 2021.



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
R3	0,78	0,69	0,59	0,50	0,47	0,49	0,48	0,47	0,49	0,50	0,48	0,49	0,56	0,58	0,61	0,64	0,66	0,59	0,58	0,54	0,51
R4	0,50	0,46	0,43	0,45	0,56	0,59	0,60	0,62	0,59	0,57	0,58	0,61	0,58	0,63	0,57	0,55	0,56	0,57	0,53	0,47	0,45

The graph above illustrates dose rate index per Ringhals reactor for 5 rolling years.

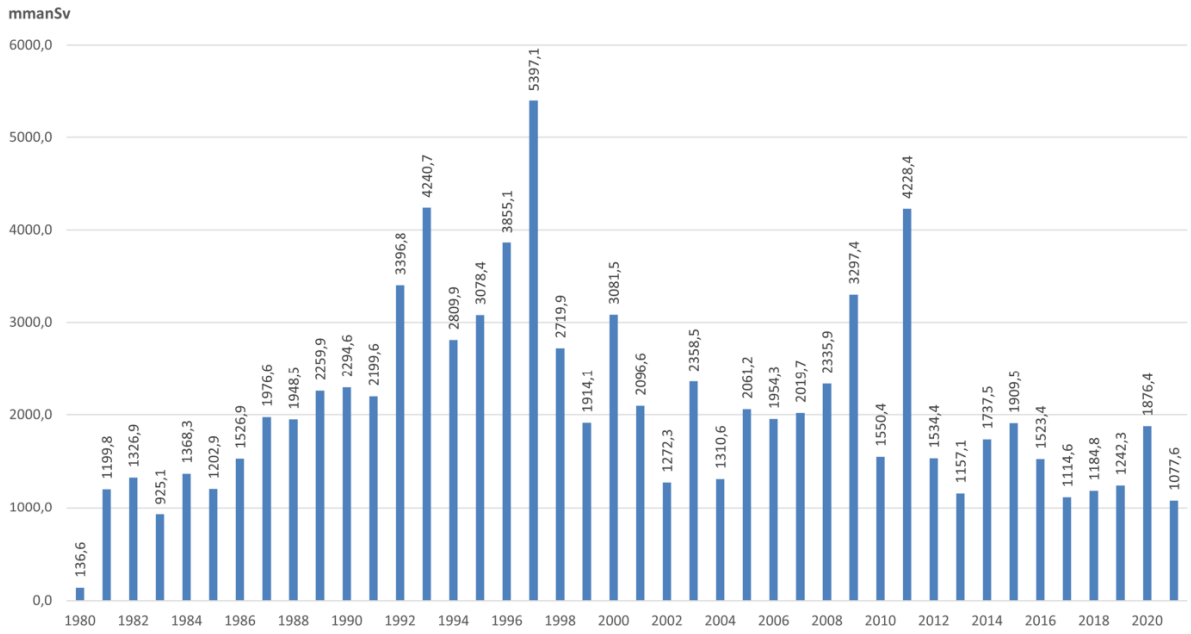
Based on the 2021 ALARA analysis and evaluation, the radiation protection work at Ringhals is generally considered to function satisfactorily. During 2021, several measures were started to develop and strengthen the ALARA business, which includes Alpha gap-analysis implementation, preparing for WANO and SOER reviews including gap analysis regarding the WANO PO&C, and review of the Alpha monetary value.

No spread of contamination has been detected in uncontrolled areas. In cases of contamination spread on the controlled side, the area has been limited and has not resulted in any significant intake resulting in unplanned dose to individuals; internal dose contribution has been well below reporting limit.

The dose outcome (CRE) 2021 is the lowest since Ringhals started, both from an individual and a collective dose perspective.

Forsmark nuclear power plant

The total dose for Forsmark was 1 077.6 person·mSv based on measurements with TL dosimeters, and there were 1 132 persons with a registered dose. The maximum individual dose was 7.5 mSv.



Forsmark annual collective dose (TLD) from 1980 to 2021

The collective dose (TLD) for 2021 is the lowest since all three reactors started operating (1985).

The regulatory body's safety evaluation of the FKA radiation protection work concludes that FKA have addressed many of the areas of improvements that were proposed in previous years.

Major refurbishment of the chemistry lab and the decontamination workshop at units 1 and 2 started during the fall of 2020, was finished during the spring of 2021, has greatly improved working environment and reduced dose.

All of the total 398 measurements to control internal intake did not show any internal intake that resulted in a mortgaged effective dose exceeding 0.25 mSv.

Forsmark 1

The planned outage was a short "maintenance outage", 19 days, with no major work performed, besides the changing of fuel.

The collective dose received was 198.2 person·mSv, in accordance with the dose projection.

Four radiological incidents occurred regarding, for example, personnel not wearing correct protection equipment, spread of contamination, high personnel contamination.

Both the highest individual and collective doses were received during work with Control Rod Drive Mechanism service (CRDMs).

The dose rates in the reactor systems are stable, dose rates in turbine systems show a slightly decreasing trend.

Forsmark 2

The planned outage was a “maintenance outage”, 28 days. Major work was performed on the high pressure turbine on both turbines. The collective dose received was 272.7 person·mSv, in accordance with the dose projection.

Three radiological incidents occurred, all regarding problems with dose rate instruments.

The dose rates in the reactor systems remain fairly stable, dose rates in turbine systems show a slightly decreasing trend.

The highest individual dose was received in connection with inspection and maintenance of valves in the reactor coolant system. The highest collective dose was received during work with Control Rod Drive Mechanism service (CRDMs).

Forsmark 3

The planned outage was a long “maintenance outage”, 40 days. Major work was performed with Control Rod Drive Mechanism service (CRDMs), besides the changing of fuel. The collective dose received was 499.7 person·mSv, much above the dose projection of 382.6 person·mSv. The main issues were additional work and prolonged work.

Two radiological incidents occurred regarding spread of contamination and lack of barrier to high dose rate area.

The dose rates in the reactor systems remain fairly stable, dose rates in turbine systems show a slightly increasing trend.

The highest individual dose was received in connection with inspection and maintenance of valves in the reactor coolant system. The highest collective dose was received during work with Control Rod Drive Mechanism service (CRDMs).

Oskarshamn nuclear power plant

The supervisory authority's radiation safety evaluation of OKG 2020-2021 was continued and overwhelmingly positive, and the authority has expressed satisfaction with OKG, which for the fourth year in a row received the best rating.

The total dose for OKG during 2021 was 839.3 person·mSv based on measurements with TL dosimeters for 813 individuals, with registered dose, and the maximum individual dose for one individual was 8.7 mSv.

A total of 209 measurements were performed to control internal intake, and these measures did not show any internal intake that resulted in a mortgaged effective dose exceeding 0.25 mSv.

Area monitoring and contamination control outside controlled area has been carried out at all facilities in accordance with regulatory requirements, and no increase above normal background was detected during the measurements carry-out during the year.

OKG has a continued high accuracy and quality in its work with dose forecasts and has a continued good collaboration across organisational boundaries, in planning measures and in implementation at the facility and with a clear understanding of personal responsibility for dose and the importance of co-operation and clear communication. The 2021 outage was extended due to shell valve leak and diesel generator replacement and ended in a 27-day outage shutdown. High dose rate and contamination levels were measured at the 2020 outage when valves in the system were opened, and the cause was linked to an increased amount of contamination from spreader material in the reactor water combined with a high moisture content in the main steam. During the outage of 2021, high dose rate and contamination levels continued when systems were opened.

The dose forecast for the outage shutdown 2021 at the O3 reactor was calculated to 322 person·mSv, and the outcome was 317 person·mSv, of which 45 person·mSv was additional. The largest exceedance can be found under the heading insulation works.

No deviation or exceedance regarding individual dose or internal contamination were noted.

During the year, extensive work was continued with the FME, with the main purpose is to keep down the number of fuel damages at the O3 reactor.

The decommissioning activities have been administered through sub-steps and with the help of developed work packages, which are reminiscent of corresponding planning for outages and with a process for optimisation of radiation protection, with regard to the operating system's governing documents and how these documents are linked.

During 2021, work packages with disassembly and demolition have been carried out at reactor facilities of O1 and O2, with disassembly and demolition of drives, disassembly and demolition of turbine with its inner and outer casing, generators, preheater, condenser, pumps and valves and dismantling and demolition in reactor containment and work with drilling into wet well.

During the year, continued preparation was carried out for intermediate storage areas linked to the ongoing decommissioning of the O1 and O2 reactors and the construction of a storage facility for waste. Also, work was performed to get the new free-release facility in operation.

The instruction for categorisation, classification and reporting of radiation protection incidents was widely used in the company, both in operating activities and for decommissioning. The instruction has been updated to take into account that radiation protection forms part of the concept of radiation safety, and the updated instruction addresses requirements for the preparation of documentation for radiation protection incidents for operational management meetings. However, the instruction is planned to be updated again with regard to revising the reporting and time criteria for reporting and linked to categories and classes of events as well as with regard to the implementation of radiation safety reviews and operational management's decisions on the matter. In addition, a linking instruction is drawn up that will provide guidelines for grading the level of causal analysis that each category and class of event must generate.

Barsebäck nuclear power plant

Barsebäck's two reactors have been permanently shut down, unit 1 since 1999 and unit two since 2005.

Nuclear decommissioning and dismantling started at Barsebäcksverket (BVT) in 2020.

The main projects during 2021 were WP1 (segmentation of RPV:s), WP2.2 (dismantling of the turbines), WP3 (dismantling of the condensers) and WP6.1-2 (dismantling of components inside the biological shield including pimary circuit pumps and the opening of transport ways into the containment).

The other project underway was Foct (reconditioning of low- and intermediate level waste).

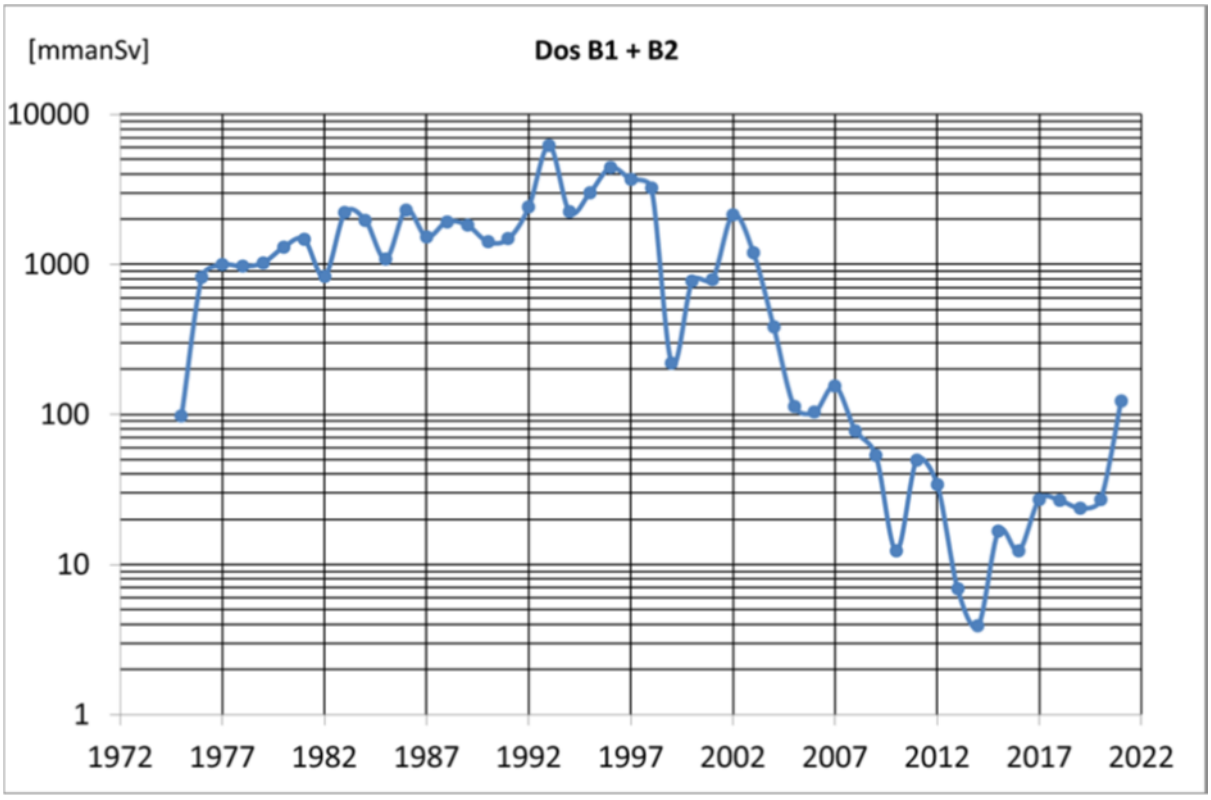
The annual collective dose received was 122.7 person·mSv (TLD). 110 individuals were registered.

The two largest dose contributors were project WP1 (108.2 person·mSv) and project WP6.1-2 (9.8 person·mSv).

The highest individual dose in 2021 was 5.6 mSv (TLD).

No internal contaminations giving and equivalent dose > 0.25 mSv were encountered during the year. A total of 115 measurements was performed.

BKAB notes an increase in radiation protection incidents in 2021. Reasons for the increase are partly due to increasing scope of work and an increased degree of reporting but also to inexperienced personnel in terms of working in controlled area, cultural differences and communication problems.



BKAB annual collective dose (TLD) 1975-2021

3) Report from Authority

SSM continues to actively follow the planning / work performance of the decommissioning of the six reactors that closed down (1999, 2005 and 2016-2020), but also normal supervision of the operating nuclear reactors has been conducted, due to the pandemic situation, mainly via telephone and video conferencing. However, in the fall of 2021, many of the restrictions were ended so site visits became possible. SSM have planned inspections for 2022 at the three operational nuclear power plants concerning the "occupational exposure". Minor inspections were carried during 2021 as a baseline on account of that upcoming inspection.

Some general comments from the outcome were that SSM had noted that the nuclear power plants became more experienced in classifying radiation protection events during the year. SSM also noted that there were challenges in getting hold of competent/experienced radiation protection staff due to retirement, which can become challenging in the long-term perspective.

Switzerland

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**3**	**233**
BWR	**1**	**3 596**
All types	**4**	**1 074**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
BWR	**1**	**332**

2) Principal events of the year 2021

- Leibstadt (KKL) conducted a major upgrade with a replacement of the reactor recirculation system and the main condenser in a 195-day outage. Details were presented at the 2022 NATC ALARA symposium. The KKL's outage dose greatly influences the average values of all reactors.

- Gösgen (KKG) performed a regular operating cycle and refuelling outage. Additionally, more than 3 tonnes of in-core material, including 49 control rods were disassembled and packed for disposal.

- Beznau (KKB) performed regular operating cycles and a refuelling outage in KKB-1, a maintenance outage in KKB-2. Slightly increasing dose rate levels at unit 1 steam generators hot and closure legs were under investigation.

- Mühleberg (KKM) performed decommissioning work, mainly in the secondary systems. However, the plant was not yet completely defuelled. Large amounts of material were released from the radiologically controlled area or shipped to the interim storage in case of radioactive waste. The so called "decay storage" was under consideration, in order to take advantage from the radioactive decay for decontamination purposes. Industrial safety regarding conventional hazards, like asbestos, reached a higher importance compared to radiation protection during decommissioning activities.

Ukraine

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
VVER	**15**	**529**

In 2021, across the "Energoatom" nuclear power plants, the metric that indicates the level of the collective radiation dose of personnel was 529 person·mSv per one power unit. Compared to 2020, the indicator has increased slightly.

The growth of this indicator in 2015-2019 was associated with a significant number of radiation-hazardous activities carried out in order to extend the life of nuclear power plant units beyond their initial design life. These activities involved significant number of third-party personnel conducting respective activities. This particular circumstance led to an increased level of the total collective radiation dose of personnel at the nuclear power plants.

However, all such works were completed by 2020. In addition, in 2021, at unit 1 of Zaporizhzhe Nuclear Power Plant and unit 1 of Khmelnitsky Nuclear Power Plant, scheduled preventive maintenance with the implementation of radiation hazardous works was not planned and not carried out. This fact has also decreased the level of collective radiation dose for personnel across "Energoatom".

As a result of the contributing factors above, the indicator of the dose level per unit in the year 2020 improved as compared to previous years.

In 2021, all 15 nuclear power plant units were in a state of scheduled repairs, of which RNPP unit 3 was in a state of overhaul which began in November 2020 and ended in March 2021. These circumstances contributed to a slight increase in the indicator "Average annual collective dose per unit and reactor type, person·mSv/unit" in 2021.

United Arab Emirates

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**1***	**3.61****

Notes
*Out of four.
**From 6 April to 31 December 2021.

2) Principal events of the year 2021

Events influencing dosimetric trends

Outage information

Barakah 1: no refueling outage in 2021.

Component or system replacements

None.

Unexpected events/incidents

None.

New reactors on line

Barakah 1 (April 2021).

Reactors definitely shutdown

None.

New/experimental dose-reduction programmes

Barakah 1 initiated new dose-reduction programme implementing a graded approach to radiological risk activities such as planning, implementing, oversight and identifying lessons learnt for the remaining Barakah units when they come on-line.

Organisational evolutions

In 2021, the Station 1 Radiation Safety Organisation was supplemented with personnel from Station 2; this provided an opportunity for personnel from the non-operational plant to obtain normal operations and check outage experience. The development of UAEA nationals was an integral part to the implementation of the radiation safety programme. Mentors were assigned to each shift to transfer knowledge during off-normal hours, first time evolutions, monitoring and catching to critical behavioral standards, and communicating effectively with various departments (i.e. Operations) and a multi-cultural workforce (i.e. radiation workers).

Regulatory requirements

In 2021, Barakah unit 1 commenced operation and demonstrated compliance with UAE regulations. The Regulator implemented an inspection plan reviewing various areas of radiation safety and radioactive waste management.

United Kingdom

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**1**	**373**
GCR	**14(1)**	**12**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
GCR	**20(2)**	**13**

Notes
(1) 14 Advanced Gas-Cooled Reactors.
(2) 20 Magnox Reactors.

2) Principal events of the year 2021

The impact of the COVID-19 pandemic continued to be felt for the majority of 2021. Sizewell B commenced its 17th refuelling outage with a reduced work scope, to limit the number of overseas contract workers needed. Unfortunately, early in the outage, following the initial lift of the reactor pressure vessel head (RPVH), one of the thermal sleeves from the RPVH was found to be resting on the upper internals. Subsequent inspections identified the need to replace fifteen thermal sleeves. This additional work resulted in an extension to the outage and additional radiation dose, due to the emergent work. The refuelling outage extended to a duration of 129 days, with a collective radiation exposure (CRE) of ~350 person·mSv. The thermal sleeve repairs and inspections contributed an emergent dose of ~135 person·mSv.

Of the Advanced Gas Cooled reactors (AGRs), Dungeness B remained in extended shutdown, with final permanent closure of both Dungeness reactors announced mid-way through the year. The two oldest AGRs, at Hinkley Point and Hunterston are due to be permanently shut down, definitively, in 2022. The reduced number and scope of AGR outages resulted in very low doses with the annual CRE ranging from ~ 5 person·mSv to ~32person·mSv per AGR site.

Decommissioning continued on the Magnox sites with the majority of the sites focus being on intermediate level waste retrieval and packaging. The annual CRE at decommissioning sites ranged from approximately 3 person·mSv to 63 person·mSv.

Construction of the Hinkley Point C twin EPRs continued with commissioning expected in 2026. EDF continued to progress plans for another twin EPR site at Sizewell C. The final investment decision is expected in 2022.

United States

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
OPERATING REACTORS		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**62**	**315.745 (19 576.16 / 62 units)**
BWR	**31**	**1 079.22 (33 455.82 / 31 units)**
All types	**93**	**570.236 (53 031.98 / 93 units)**
REACTORS DEFINITIVELY SHUTDOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**11**	**151.2 (1 663.2 / 11 units)**
BWR	**5**	**345.59 (1 727.96 / 5 units)**
FBR (Fermi 1)	**1**	**0.00**

2) Principal events of the year 2021

Summary of US occupational dose trends

The US PWR and BWR occupational dose averages for 2021 reflected a continued emphasis on dose reduction initiatives at the 93 operating commercial reactors. Also, two units transitioned to the decommissioning phase.

Reactor type	Number of units	Total collective dose	Average dose per reactor
PWR	62	19 576.16 person mSv	315.745 person mSv/unit
BWR	31	33 455.82 person mSv	1 079.22 person mSv/unit

The total collective dose for the 93 reactors in 2021 was 53 031.98 person mSv. The resulting average collective dose per reactor for US LWR was 570.236 person mSv/unit.

US PWRs

The total collective dose for US PWRs in 2021 was 19 576.16 person mSv for 62 operating PWR units. The 2021 average collective dose per reactor was 315.745 person mSv/PWR unit. US PWR units are generally on 18- or 24-month refuelling cycles. The US PWRs with the lowest annual doses in 2021 were Waterford (19.99 person·mSv), Callaway (33.2 person·mSv) and Davis Besse (78.1 person·mSv).

US BWRs

The total collective dose for US BWRs in 2021 was 33 455.82 person mSv for 31 operating BWR units. The 2021 average collective dose per reactor was 1 079.22 person·mSv/BWR unit. Most US BWR units are on 24-month refuelling cycles. This level of average collective dose is primarily due to power up-rates and water chemistry challenges at some US BWR units.

New plants on-line/plants shutdown

Southern Company is continuing the construction of two new PWRs at the Vogtle site in Georgia. Vogtle unit 3 is scheduled to commence commercial operations in 2023.

The University of Illinois is in the process of planning and licensing a new micro-reactor on campus to provide heat and electricity to the University.

Indian Point unit 3 ceased power generation on 30 April 2021. Indian Point unit 3 commenced commercial operations on 30 August 1976.

Palisades is scheduled to permanently shut down in May 2022. However, the Michigan Governor and US DOE are taking steps to support financially stressed US nuclear plants so they can continue to operate to meet carbon-free national electric generation goals. Electric grid storages in Texas and California during extreme weather conditions are prompting stronger support of safe and efficient nuclear plant operations. Diablo Canyon units 1 and 2 are scheduled to shut down in 2024 and 2025, respectively. However, state government and US DOE are evaluating new opportunities for the units including adding desalination and hydrogen production for California. Diablo Canyon Units 1 and 2 generate 9% of the state electricity.

Three US nuclear sites are transitioning to safe-store in 2021 including:

1.) Duane Arnold (BWR) shut down permanently on 10 August 2020, after high winds from storm derecho caused extensive damage to its cooling towers. The unit was scheduled to shut down for decommissioning later in August by owner NextEra.

2.) Indian Point unit 2 permanently shut down for decommissioning on 30 April 2020, after 59 years of operation supply electricity to New York City.

3.) Pilgrim Nuclear Power Station was shut down for decommissioning on 31 May 2019 by Entergy. Holtec International purchased Pilgrim site and started decommissioning activities in 2020.

Four US sites are fully decommissioned. These units report the number of badged workers and the annual dose for the interim spent fuel storage pad. In 2021, the following units were in this category:

Big Rock Point	BWR	24 badged workers	0.00 Person mSv;
Haddam Neck	PWR	42 badged workers	0.658 person mSv;
Maine Yankee	PWR	21 badged workers	0.013 person mSv;
Yankee-Rowe	PWR	46 badged workers	0.428 person mSv.

Some decommissioning sites are being considered for future micro-reactors or other new carbon-free electric generation.

Major evolutions

Turkey Point Nuclear Generation Plant units 3 and 4 were authorised a subsequent licence renewal by the US Nuclear Regulatory Commission (NRC) on 4 December 2019. This marked the first time a US reactor lifespan was extended from 60 years to 80 years. The two units were previously scheduled to shut down in 2032 and 2033. The NRC issued guidance to the 80-year reactor licensing renewal in July 2017. Turkey Point units 3 and 4 filed for the 80-year reactor lifespan extension in June 2018. Peach Bottom units 2 and 3 were also granted an 80-year operating license by the NRC. In 2021, additional documentation was requested by the US NRC to support the reactor life-extension licensing activities.

New/experimental dose-reduction programmes

Tennessee Valley Authority achieved the first drone entry to a BWR drywell at 100% power at the Browns Ferry BWR unit to look for unidentified steam leaks. No leaks were found and the unit continued 100% operation.

Nine Mile Point (US BWR) is also expanding the role of drone technology in their radiological surveillance programmes.

Seventy pixelated 3D CZT units are in use at Canadian and US nuclear plants. The CZT technology achieves individual isotopic identification using GPS to verify the adequacy of temporary shielding, contamination control and radioactive waste shipments dose rates.

Diablo Canyon has implemented a telemetry, real-time electronic dosimeter system to produce electronic RP dose surveys to save labour costs and improve accuracy.

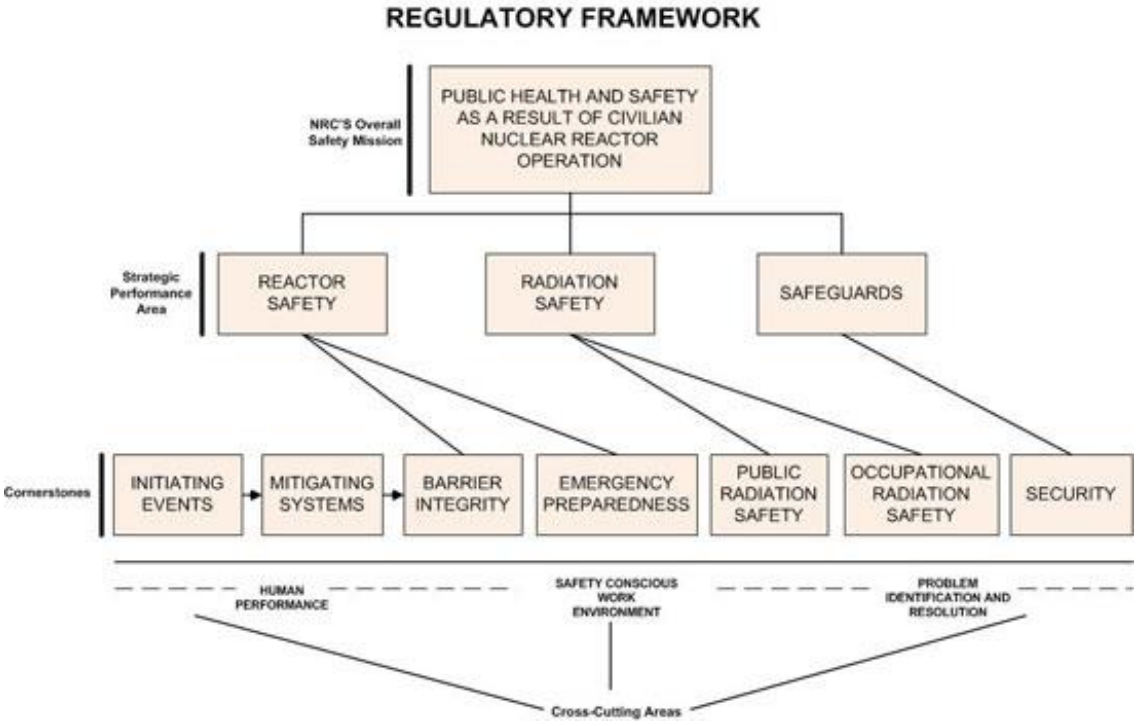
Technical plans for major work in 2021

LaSalle County (US BWR) has implement new technology that may become a “game-changer” for nuclear plant maintenance. The use of high efficiency ultrasonic CRUD cleaning and metal filter systems to preclude the need to cut out and replace highly contaminated plant piping and valves. US PWRs are replacing up to 800 baffle bolts on their core barrel due to foreign material exclusion (FME) and embrittlement issues. About 200 baffle bolts are being replaced per refuelling outage at PWRs classified as moderately susceptible by the NRC. Some PWRs are having Westinghouse complete an up-flow modification in the reactor vessel to preclude failed fuel episodes.

Regulatory plans for major work in 2021: NRC’s Reactor Oversight Programme – Regulatory Framework

The US NRC’s regulatory framework for reactor oversight is shown in the diagramme below. It is a risk-informed, tiered approach to ensuring plant safety. There are three key strategic performance areas: reactor safety, radiation safety, and safeguards. Within each strategic performance area are cornerstones that reflect the essential safety aspects of facility operation. Satisfactory licensee performance in the cornerstones provides reasonable assurance of safe facility operation and that the NRC's safety mission is being accomplished.

Within this framework, the NRC's operating reactor oversight process provides a means to collect information about licensee performance, assess the information for its safety significance, and provide for appropriate licensee and NRC response. The NRC evaluates plant performance by analysing two distinct inputs: inspection findings resulting from NRC's inspection programme and performance indicators (PIs) reported by the licensees.



Occupational radiation safety cornerstone and 2021 results

Occupational radiation safety – The objective of this cornerstone is to ensure adequate protection of worker health and safety from exposure to radiation from radioactive material during routine civilian nuclear reactor operation. This exposure could come from poorly controlled or uncontrolled radiation areas or radioactive material that unnecessarily exposes workers. Licensees can maintain occupational worker protection by meeting applicable regulatory limits and ALARA guidelines.

Inspection procedures – There are five attachments to the inspection procedure for the occupational radiation safety cornerstone:

IP	71124	Radiation Safety-Public and Occupational
IP	71124.01	Radiological Hazard Assessment and Exposure Controls
IP	71124.02	Occupational ALARA Planning and Controls *
IP	71124.03	In-Plant Airborne Radioactivity Control and Mitigation
IP	71124.04	Occupational Dose Assessment
IP	71124.05	Radiation Monitoring Instrumentation

Occupational exposure control effectiveness – The performance indicator for this cornerstone is the sum of the following:

- technical specification high radiation area occurrences;
- very high radiation area occurrences;
- unintended exposure occurrences.

Occupational Radiation Safety Indicator	**Thresholds**		
	(White) Increased Regulatory Response Band	(Yellow) Required Regulatory Response Band	(Red) Unacceptable Performance Band
Occupational Exposure Control Effectiveness	> 2	> 5	N/A

The latest ROP performance indicator findings can be consulted at

www.nrc.gov/NRR/OVERSIGHT/ASSESS/pi_summary.html.

Additional background information can be found on the detailed ROP description page at

www.nrc.gov/reactors/operating/oversight/rop-description.html.