Radiological Protection and Public Health
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Occupational Exposures at Nuclear Power Plants

Thirty-First Annual Report of the ISOE Programme, 2021

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Radiological Protection

Occupational Exposures at Nuclear Power Plants

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NEA No. 7692

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 34 countries: Argentina, Australia, Austria, Belgium, Bulgaria, Canada, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Romania, Russia (suspended), the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Türkiye, the United Kingdom and the United States. The European Commission and the International Atomic Energy Agency also take part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for the safe, environmentally sound and economical use of nuclear energy for peaceful purposes.
- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of NEA competence include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

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Foreword

Throughout the world, occupational exposure at nuclear power plants has steadily decreased since the early 1990s. Contributing to this downward trend are effective “as low as reasonably achievable” (ALARA) regulations, new technologies, plant design modifications, improved water chemistry and operational ALARA awareness, as well as senior plant management support of a strong ALARA culture and global exchange of ALARA experiences. However, with the continued ageing and life extensions of nuclear power plants worldwide, ongoing economic pressures, regulatory, social and political changes, along with the potential of new nuclear build, including small modular reactors (SMRs), the task of ensuring that occupational exposures are ALARA continues to present challenges to radiological 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 Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), has provided a forum for radiological protection professionals from nuclear 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 radiological protection and ALARA lessons learnt.

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 an information network for sharing dose-reduction data 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 plant radiological protection programmes.

With new nuclear power plants commencing commercial operation, and some others transitioning into the decommissioning phase, the ISOE programme continues to evolve to embrace the ALARA information sharing of global nuclear power to ensure safe and efficient electric generation.

This 31st Annual Report presents the status of the ISOE programme for the calendar year 2021.

"… the exchange and analysis of information and data on ALARA experience, dose-reduction techniques, and individual and collective radiation doses to the personnel of nuclear installations and to the employees of contractors are essential to implement effective dose management programmes and to apply the ALARA principle." (ISOE Terms and Conditions, 2020-2023).

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Ag	Argentum
AGR	Advanced gas-cooled reactors
ALARA	As low as reasonably achievable
ANRA	Armenian Nuclear Regulatory Authority
ANVS	Authority for Nuclear Safety and Radiation Protection (Netherlands)
ASN	Nuclear Safety Authority (France)
ATC	Asian Technical Centre
BNGS	Bruce Nuclear Generating Station (Canada)
Bq	Becquerel
BWR	Boiling water reactor
CADOR	Code d’aide à la décision pour l’optimisation de la radioprotection (Code to Assist Decision-Making for Optimisation in Radiological Protection) (France)
CANDU	Canada Deuterium Uranium (a Canadian PHWR design)
CDLM	NEA Committee on Decommissioning of Nuclear Installations and Legacy Management
CEPN	Centre d'étude sur l'évaluation de la protection dans le domaine nucléaire (France)
ČEZ	české Energetické Závody (Czechia)
CGN	China General Nuclear Power Group
CJSC	Closed Joint Stock Company
CNCAN	National Commission for Nuclear Activities Control (Romania)
CNEN	Brazilian Nuclear Energy Commission
CNNC	China National Nuclear Corporation
CNNP	China National Nuclear Power
CNSC	Canadian Nuclear Safety Commission
Co-60	Cobalt-60
COVID-19	Coronavirus disease 2019
CRDM	Control Rod Drive Mechanism
CRE	Collective radiation exposure
CRUD	Fuel corrosion product deposits
CSN	Consejo de Seguridad Nuclear (Spain)
DDS	ISOE WGDECOM Decom Database Subgroup
DNGS	Darlington Nuclear Generating Station (Canada)
EC	European Commission

EDF	Électricité de France
ENSI	Swiss Federal Nuclear Safety Inspectorate
EPR	European pressurised reactor/Evolutionary power reactor
EPZ	Elektriciteits Produktiemaatschappij Zuid (the Netherlands)
ESR	Evènement Significatif en RP (Radiation protection significant event) (France)
ETC	European Technical Centre
EU	European Union
FANC	Federal Agency for Nuclear Control (Belgium)
FANR	Federal Authority for Nuclear Regulation (United Arab Emirates)
FENOC	FirstEnergy Nuclear Operating Co. (United States)
FKA	Forsmarks Kraftgrupp AB (Sweden)
FME	Foreign material exclusion
FNR	Fast neutron reactor
FSD	Full system decontamination
FY	Financial year
g	Gram
GCR	Gas-cooled reactor
GE	General Electric
GWh	Gigawatt hour
h	Hour
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
INES	International Nuclear Event Scale
IP	Inspection procedure
IRRS	Integrated Regulatory Review Service
ISOE	Information System on Occupational Exposure
LWCHWR	Light water-cooled heavy water reactor
LWGR	Light water graphite reactor
MB	Management Board
mSv	Millisievert
MWe	Megawatts electric
NATC	North American Technical Centre
NEA	Nuclear Energy Agency
NNR	National Nuclear Regulator (South Africa)
NPRE	Nuclear, Plasma & Radiological Engineering
NRC	Nuclear Regulatory Commission (United States)
OE	Operational experience
OECD	Organisation for Economic Co-operation and Development
OKG	Oskarshamn Kraftgrupp (Sweden)

ONR	Office for Nuclear Regulation (United Kingdom)
PAEC	Pakistan Atomic Energy Commission
PHWR	Pressurised heavy water reactor
PLNGS	Point Lepreau Nuclear Generating Station (Canada)
PNGS	Pickering Nuclear Generating Station (Canada)
PoW	Programme of Work
PWR	Pressurised water reactor
RAB	Ringhals AB (Sweden)
RCA	Radiologically controlled area
ROP	Reactor oversight process
RP	Radiological protection
RPM	Radiological protection manager
RPV	Reactor pressure vessel
RWMD	Division of Radioactive Waste Management and Decommissioning (NEA)
Sb-124	Antimony-124
SBPR	Sociedade Brasileira de Proteção Radiologica (Brazil)
SNRIU	State Nuclear Regulatory Inspectorate of Ukraine
SNSA	Slovenian Nuclear Safety Administration
SOER	Significant Operating Experience Report (WANO)
SSM	Swedish Radiation Safety Authority
STUK	Radiation and Nuclear Safety Authority (Finland)
Sv	Sievert
TC	Technical Centre
TCA	Technical Co-operation Agreement
TLD	Thermoluminescent dosimeter
TVA	Tennessee Valley Authority (United States)
TVO	Teollisuuden Voima Oyj (Finland)
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UVZSR	Public Health Authority of the Slovak Republic
VATESI	State Nuclear Power Safety Inspectorate (Lithuania)
VVER	Vodo-vodyanoy (water-water) energy reactor
WAB	Waste treatment building (Belgium)
WANO	World Association of Nuclear Operators
WENRA	Western European Nuclear Regulators Association
WGDECOM	Working Group on Radiological Protection Aspects of Decommissioning Activities at Nuclear Power Plants (NEA)

Executive summary

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 for national regulatory authorities, as well as through the publication of relevant technical resources for as low as reasonably achievable (ALARA) management. This 31st Annual Report presents the status of the ISOE programme for the calendar year 2021.

In 2020, the world faced the worst global health crisis in decades as COVID-19 brought extreme challenges that 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 learnt in the course of this experience. We have learnt about the reliance of our modern world on advanced information and communication technologies and on a stable, reliable, and cost-effective supply of electric energy. We have learnt about the resilience of nuclear energy and its ability to serve our societies under even the most adverse conditions. We have also learnt 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 is jointly administered 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 of 2020-2023 came into force on 1 January 2020. As of 31 December 2021, the ISOE programme included 79 participating nuclear licensees (with 345 operating units, 9 units under construction and/or commissioning, and 77 shut down units) and 27 regulatory authorities in 31 countries

The ISOE database contained occupational exposure information for 504 units[1], covering over 86% of the world's operating commercial power reactors. Four ISOE Technical Centres (Asia, Europe, North America and the IAEA) managed the programme's day-to-day technical operations.

Based on the occupational exposure data supplied by the ISOE members for operating power reactors, the 2021 average annual collective doses per reactor and three-year rolling averages per reactor (2019-2021) were:

	2021 average annual collective dose (person·Sv/reactor)	**Three-year rolling average for 2019-2021 (person·Sv/reactor)**
Pressurised water reactors (PWRs)	0.41	0.39
Pressurised water reactors (VVERs)	0.39	0.41
Boiling water reactors (BWRs)	0.75	0.80
Pressurised heavy water reactors (PHWRs)	1.49	1.14

1. All reactors ever included in the ISOE Programme (both in 2021 and in past years).

In addition to information from operating reactors, the ISOE database contained dose data from 123 reactors[2] that were shut down or in some stage of decommissioning. As these reactor units are generally of different types and sizes, and at different phases of their decommissioning programmes, it is difficult to identify clear dose trends. However, work continued in 2021 to improve the data collection for such reactors to facilitate better benchmarking. Details on occupational dose trends for operating reactors and for reactors undergoing decommissioning are provided in Chapter 2 of this report.

While the ISOE is well known for its occupational exposure data and analyses, the programme's strength comes from its objective to share such information broadly among its participants. In 2021, the ISOE network website (www.isoe-network.net) continued to supply the ISOE membership with comprehensive web-based information and an experience exchange portal on dose reduction and ISOE ALARA resources.

The annual ISOE ALARA symposia on occupational exposure management at nuclear power plants continued to provide an important forum for ISOE participants and for vendors to exchange practical information, experience and management approaches on occupational exposure issues. In 2021, the fora included: the ISOE North American online ALARA symposium organised by the North American Technical Centre (NATC) in January; the ISOE symposium/webinar organised by the European Technical Centre (ETC) in June; and a series of NATC online 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 combination of ISOE symposia and technical visits (and/or information exchange webinars) provided a means for radiological protection professionals to meet, share information and build links within and between ISOE regions to develop a global approach to occupational exposure management.

The ISOE Working Group on Radiological Protection Aspects of Decommissioning Activities at Nuclear Power Plants (WGDECOM) continued to develop a process to better share operational radiological protection data and experience for nuclear power plants at some stage of decommissioning or in preparation for decommissioning.

The principal events in 30 ISOE participating countries are summarised in Chapter 3 of this report.

2. ISOE participants (77) and non-participants (46).

1. Status of participation in the Information System on Occupational Exposure (ISOE)

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 licensees and for national regulatory authorities, as well as through the publication of relevant technical resources for as low as reasonably achievable (ALARA) management. The ISOE includes a global occupational exposure data collection and analysis programme, culminating in the world's largest database on occupational exposures at nuclear power plants, and a communications network for sharing dose-reduction information and experience. Since the launch of the ISOE, its participants have used these resources 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, and the sharing of experience globally.

ISOE participants include nuclear licensees (public and private), national regulatory authorities (or institutions representing them) and ISOE Technical Centres that have agreed to participate in the operation of the ISOE under its terms and conditions. Four ISOE Technical Centres (Asia, Europe, North America and the International Atomic Energy Agency [IAEA]) manage the day-to-day technical operations in support of the membership in the four ISOE regions (see Annex 3 for the technical centre affiliations of countries). The objective of the ISOE is to make available to the participants:

- broad and regularly updated information on methods to improve the protection of workers and on occupational exposures in nuclear power plants;
- a mechanism for dissemination of information on these issues, including evaluation and analysis of the data assembled, as a contribution to the optimisation of radiological protection.

As of 31 December 2021, the ISOE programme included 79 participating licensees (covering 345 operating units, 9 units under construction and/or commissioning, and 77 shut down units) and 27 regulatory authorities in 31 countries. Table 1.1 summarises total participation by country, type of reactor and reactor status as of 31 December 2021. A complete list of reactors, nuclear licensees and regulatory authorities officially participating in the ISOE as of 31 December 2021 appears in Annex 1.

In addition to exposure data provided annually by participating licensees, participating authorities may also contribute with official national data in cases where some of their licensees are not ISOE members.

In total, as of 31 December 2021, the ISOE database included occupational exposure data and information on 504 reactor units in 31 countries including both participating and non-participating reactors (372 operating, 123 in shutdown or in some stage of decommissioning, and 9 under construction and/or commissioning). The ISOE database is made available to all ISOE members, according to their status as a participating nuclear licensee or authority, through the ISOE network website.

Table 1.1. The official ISOE participants and the ISOE database (as of 31 December 2021)

Note: The complete list of official ISOE participants as of 31 December 2021 is provided in Annex 1.

Operating reactors: ISOE participants							
Country	**PWR**	**VVER**	**BWR**	**PHWR**	**GCR**	**LWGR**	**Total**
Armenia	–	1	–	–	–	–	1
Belgium	7	–	–	–	–	–	7
Brazil	2	–	–	–	–	–	2
Bulgaria	–	2	–	–	–	–	2
Canada	–	–	–	19	–	–	19
China	24	2	–	2	–	–	28
Czechia	–	6	–	–	–	–	6
Finland	–	2	2	–	–	–	4
France	56	–	–	–	–	–	56
Hungary	–	4	–	–	–	–	4
Japan	16	–	17	–	–	–	33
Korea	21	–	–	3	–	–	24
Mexico	–	–	2	–	–	–	2
Netherlands	1	–	–	–	–	–	1
Pakistan	5	–	–	–	–	–	5
Romania	–	–	–	2	–	–	2
Russia	–	22	–	–	–	–	22
Slovak Republic	–	4	–	–	–	–	4
Slovenia	1	–	–	–	–	–	1
South Africa	2	–	–	–	–	–	2
Spain	6	–	1	–	–	–	7
Sweden	2	–	4	–	–	–	6
Switzerland	3	–	1	–	–	–	4
Ukraine	–	15	–	–	–	–	15
United Arab Emirates	1	–	–	–	–	–	1
United Kingdom	1	–	–	–	–	–	1
United States	58	–	28	–	–	–	86
Total	**206**	**58**	**55**	**26**	**0**	**0**	**345**
Operating reactors: not participating in the ISOE but included in the ISOE database							
Country	**PWR**	**VVER**	**BWR**	**PHWR**	**GCR**	**LWGR**	**Total**
Germany	5	–	1	–	–	–	6
United Kingdom	–	–	–	–	14	–	14
United States	4	–	3	–	–	–	7
Total	**9**	**0**	**4**	**0**	**14**	**0**	**27**
Total number of operating reactors included in the ISOE database							
	PWR	**VVER**	**BWR**	**PHWR**	**GCR**	**LWGR**	**Total**
Total	**215**	**58**	**59**	**26**	**14**	**0**	**372**

Note: PWR is pressurised water reactor; VVER is vodo-vodyanoy energy reactor; BWR is boiling water reactor; PHWR is pressurised heavy water reactor; GCR is gas-cooled reactor; LWGR is light water graphite reactor.

Table 1.1. The official ISOE participants and the ISOE database (as of 31 December 2021)

(Cont'd)

Permanently shut down reactors: ISOE participants								
Country	**PWR**	**VVER**	**BWR**	**PHWR**	**GCR**	**LWGR**	**Other**	**Total**
Armenia	–	1	–	–	–	–	–	1
Bulgaria	–	4	–	–	–	–	–	4
Canada	–	–	–	3	–	–	–	3
France	3	–	–	–	6	–	–	9
Italy	1	–	2	–	1	–	–	4
Japan	8	–	15	–	1	–	1	25
Korea	1	–	–	1	–	–	–	2
Lithuania	–	–	–	–	–	2	–	2
Pakistan	–	–	–	1	–	–	–	1
Russia	–	3	–	–	–	–	–	3
Spain	–	–	1	–	–	–	–	1
Sweden	1	–	5	–	–	–	–	6
Switzerland	–	–	1	–	–	–	–	1
United States	10	–	5	–	–	–	–	15
Total	**24**	**8**	**29**	**5**	**8**	**2**	**1**	**77**
Permanently shut down reactors: not participating in the ISOE but included in the ISOE database								
Country	**PWR**	**VVER**	**BWR**	**PHWR**	**GCR**	**LWGR**	**Other**	**Total**
Canada	–	–	–	3	–	–	–	3
Germany	9	–	6	–	–	–	–	15
Netherlands	–	–	1	–	–	–	–	1
Spain	1	–	–	–	1	–	–	2
United Kingdom	–	–	–	–	20	–	–	20
United States	3	–	2	–	–	–	–	5
Total	**13**	**0**	**9**	**3**	**21**	**0**	**0**	**46**
Total number of permanently shut down reactors included in the ISOE database								
	PWR	**VVER**	**BWR**	**PHWR**	**GCR**	**LWGR**	**Other**	**Total**
Total	**37**	**8**	**38**	**8**	**29**	**2**	**1**	**123**

Reactors under construction and/or commissioning: ISOE participants								
	PWR	**VVER**	**BWR**	**PHWR**	**GCR**	**LWGR**	**Other**	**Total**
China	1	–	–	–	–	–	–	1
Finland	1	1	–	–	–	–	–	2
France	1	–	–	–	–	–	–	1
United Arab Emirates	3	–	–	–	–	–	–	3
United States	2	–	–	–	–	–	–	2
Total	**8**	**1**	**0**	**0**	**0**	**0**	**0**	**9**

Total number of reactors: participating in ISOE and/or included in the ISOE database								
	PWR	**VVER**	**BWR**	**PHWR**	**GCR**	**LWGR**	**Other**	**Total**
Total	**260**	**67**	**97**	**34**	**43**	**2**	**1**	**504**

Number of participating countries	**31**
Number of participating licensees	**79**
Number of participating authorities*	**27**

* Two countries participate with two authorities. Note: PWR is pressurised water reactor; VVER is vodo-vodyanoy energy reactor; BWR is boiling water reactor; PHWR is pressurised heavy water reactor; GCR is gas-cooled reactor; LWGR is light water graphite reactor.

2. Occupational exposure trends

A key element of the ISOE is the tracking of occupational exposure trends from nuclear power facilities worldwide for benchmarking purposes, comparative analysis and for the exchange of experience among ISOE members. This information is maintained in the ISOE Occupational Exposure Database, which contains annual occupational exposure data supplied by participating licensees (generally based on operational dosimetry systems).

The ISOE database incorporates dosimetric information from commercial nuclear power plants in operation, shutdown or at some stage of decommissioning, including:

- annual collective dose for normal operation;
- maintenance/refuelling outages;
- unplanned outage periods;
- annual collective dose for certain tasks and worker categories.

Using the ISOE database, ISOE members can perform various benchmarking and trend analyses by country, by reactor type or by other criteria such as sister unit grouping. The summary below provides highlights of the general trends in occupational doses at nuclear power plants.

Note: A bias has been identified in the previous ISOE Annual Reports in the calculation of the global average collective dose by reactor type and by year and in the calculation of the three-year rolling average collective dose per country:

- The global annual collective dose average by reactor type per year (last row of Table 2.1) was calculated as an average of the country annual collective dose averages per reactor instead of using the whole data set of individual annual collective doses per reactor to calculate this global average.
- It is the same for the three-year rolling average per country (Table 2.2), which was calculated as an average of three annual averages for each country instead of using the whole data set of individual annual collective doses per reactor for each country.

The calculation of all averages has been corrected in the ISOE Annual Report for 2019 and in this report. The impact on the final values is very small as the difference was in most cases not more than one or two percent for each figure.

This new (and correct) calculation method will be used for future ISOE Annual Reports.

2.1 Occupational exposure trends: Operating reactors

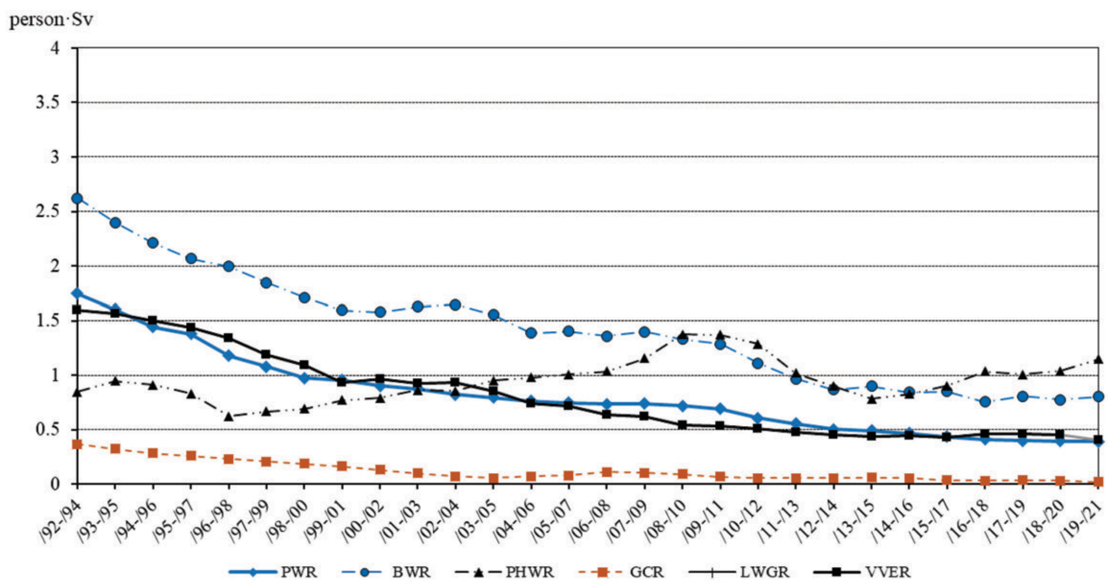
a) Global trends by reactor type

Figure 2.1 shows the trend in three-year rolling average collective dose per reactor, by reactor type, for 1992-2021. In spite of some yearly variations, a clear downward dose trend in most reactors has continued, with the exception of pressurised heavy water reactors (PHWRs), which have shown a slight increasing trend since the lows achieved in the 1996-1998 period.

PHWRs had an increasing trend in three-year rolling average collective dose from 2013 to 2015, which was a reflection of major refurbishment activities conducted at CANDU nuclear power plants (Point Lepreau, Bruce A units 1 and 2, and Wolsong) and a return to service of Bruce units 3 and 4. The increasing trend starting in 2016 is largely attributed to Darlington unit 2 refurbishment work and in particular the high dose work associated with removal of reactor internals (960 feeder pipes, 960 end-fittings, 480 pressure tubes, 480 calandria tubes, replacing horizontal and vertical flux detectors, cleaning steam generators, rehabilitating moderator valves, overhauling heat exchangers and pumps, reactor face work). While Darlington unit 2 refurbishment work was completed, and the unit returned to service in June 2020, the refurbishment of the Darlington reactors continued with unit 3 refurbishment starting in July 2020 and continuing through 2021. Additionally, Bruce unit 6 refurbishment began in January 2020 and continued throughout 2021. While all four Bruce A units were operational in 2021, unit 1 and 3 underwent planed outages. Similarly, in Bruce B, unit 7 and 8 had planned and/or forced outages. In Darlington, unit 1, 2 and 4 had planned and/or forced outages. In Pickering, unit 1, 4, 5 and 6 had planned and/or forced outage. The above-mentioned maintenance activities, when combined, resulted in the high average collective dose for PHWRs during 2021.

The average annual collective dose per reactor by country and reactor type for the period 2019-2021 and the three-year rolling average annual collective dose per reactor, by country and reactor type for the period of 2017-2019 to 2019-2021, are given in Tables 2.1 and 2.2, respectively. These results are based primarily on data reported and recorded in the ISOE database during 2021, supplemented by the individual country reports (Chapter 3) as required. Figures 2.2 to 2.5 provide information on average collective dose per reactor by country for pressurised water reactors (PWRs), vodo-vodyanoy energy reactors (VVERs), boiling water reactors (BWRs) and PHWRs. In all figures, the "number of units" refers to the number of reactor units for which data has been reported for 2021.

Figure 2.1. Three-year rolling average collective dose per reactor for all operating reactors included in ISOE by reactor type, 1992-2021 (person·Sv/reactor)



Note: PWR is pressurised water reactor; VVER is vodo-vodyanoy energy reactor; BWR is boiling water reactor; PHWR is pressurised heavy water reactor; GCR is gas-cooled reactor; LWGR is light water graphite reactor (operation terminated in 2011).

b) Average annual collective dose trends by country

Table 2.1 provides information on average annual collective dose per reactor by country and reactor type for the last three years. Most countries have maintained a relatively stable average collective dose over this period, allowing for some annual fluctuation that normally accompanies periodic tasks.

Figures 2.2 to 2.5 show this tabular data from Table 2.1 in a bar-chart format, for 2021 only, ranked from highest to lowest average dose. Please note that because of the complex parameters driving the collective doses and the variety of contributing plants, conclusions cannot be drawn on the quality of radiological protection performance in the countries addressed.

Table 2.1. Average annual collective dose per reactor, by country and reactor type, 2019-2021 (person·Sv/reactor)

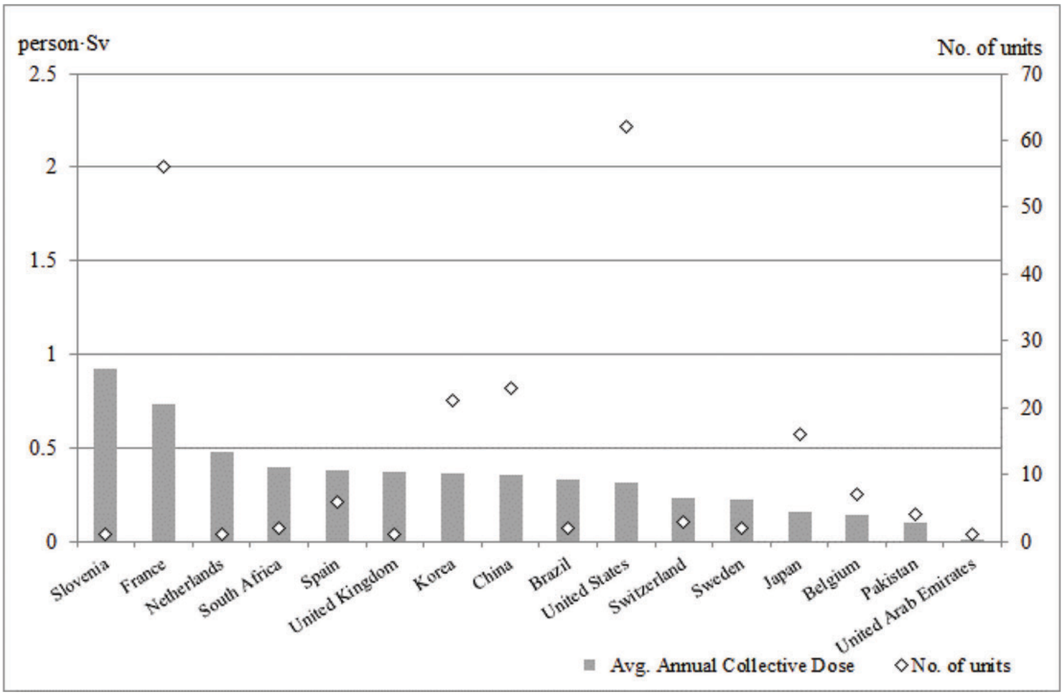
	PWR			VVER			BWR		
	2019	2020	2021	2019	2020	2021	2019	2020	2021
Armenia				1.62	0.70	2.22			
Belgium*	0.19	0.38	0.14						
Brazil	0.15	0.29	0.33						
Bulgaria				0.17	0.18	0.21			
China	0.35	0.27	0.36	0.15	0.16	0.34			
Czechia				0.14	0.17	0.14			
Finland				0.25	0.45	0.15	0.32	0.28	0.49
France	0.74	0.61	0.73						
Germany	0.12	0.11	0.06				0.79	0.56	0.14
Hungary				0.17	0.18	0.28			
Japan*	0.30	0.26	0.16				0.06	0.09	0.05
Korea*	0.27	0.35	0.36						
Mexico							6.80	6.30	1.16
Netherlands	0.26	0.09	0.48						
Pakistan	0.24	0.18	0.10						
Russia				0.58	0.52	0.38			
Slovak Republic				0.13	0.12	0.16			
Slovenia	0.67	0.13	0.93						
South Africa	0.27	0.33	0.40						
Spain	0.29	0.21	0.38				1.92	0.15	1.66
Sweden	0.19	0.26	0.22				0.39	0.65	0.39
Switzerland	0.28	0.16	0.23				0.76	1.26	3.60
Ukraine				0.58	0.44	0.53			
United Arab Emirates			0.004						
United Kingdom	0.26	0.04	0.37						
United States	0.27	0.31	0.32				1.07	0.93	1.08
Average	**0.40**	**0.37**	**0.41**	**0.45**	**0.39**	**0.39**	**0.84**	**0.81**	**0.75**

	PHWR			GCR		
	2019	2020	2021	2019	2020	2021
Canada	1.07	1.47	1.90			
China	0.34	0.27	0.44			
Korea*	0.29	0.42	0.43			
Pakistan	0.22	0.14	1.41			
Romania	0.22	0.36	0.19			
United Kingdom				0.03	0.01	0.01
Average	**0.82**	**1.13**	**1.49**	**0.03**	**0.01**	**0.01**

* Data provided directly from country reports, rather than calculated from the ISOE database: Belgium (2021); Korea (2020, 2021).

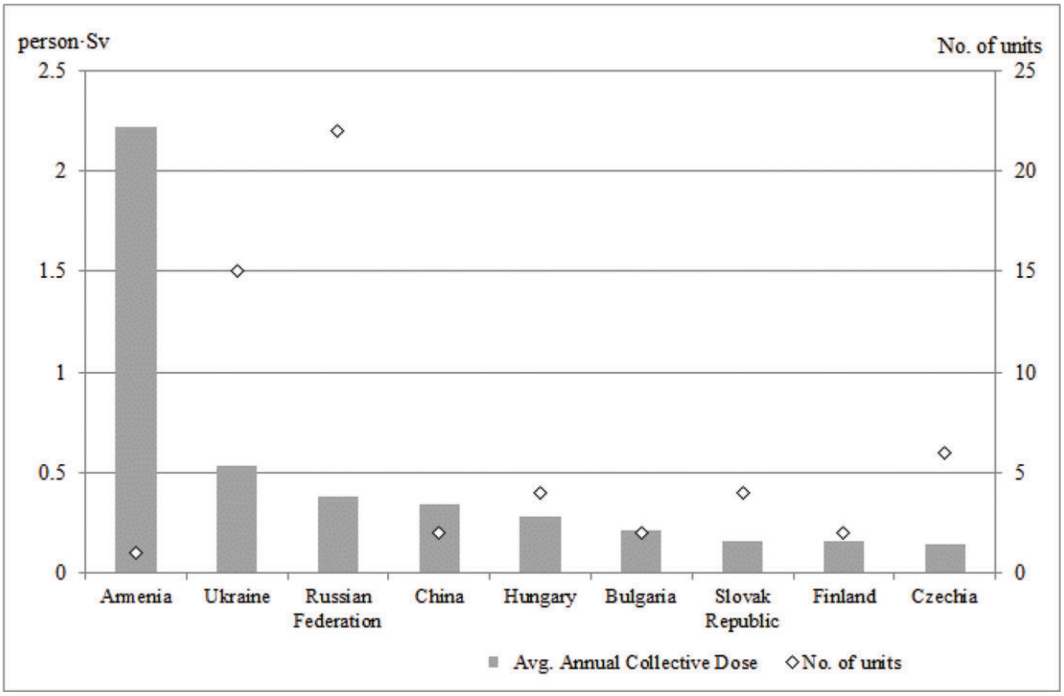
	2019	2020	2021
Global Average	0.48	0.47	0.51

Figure 2.2. 2021 PWR average collective dose per reactor by country (person·Sv/reactor)



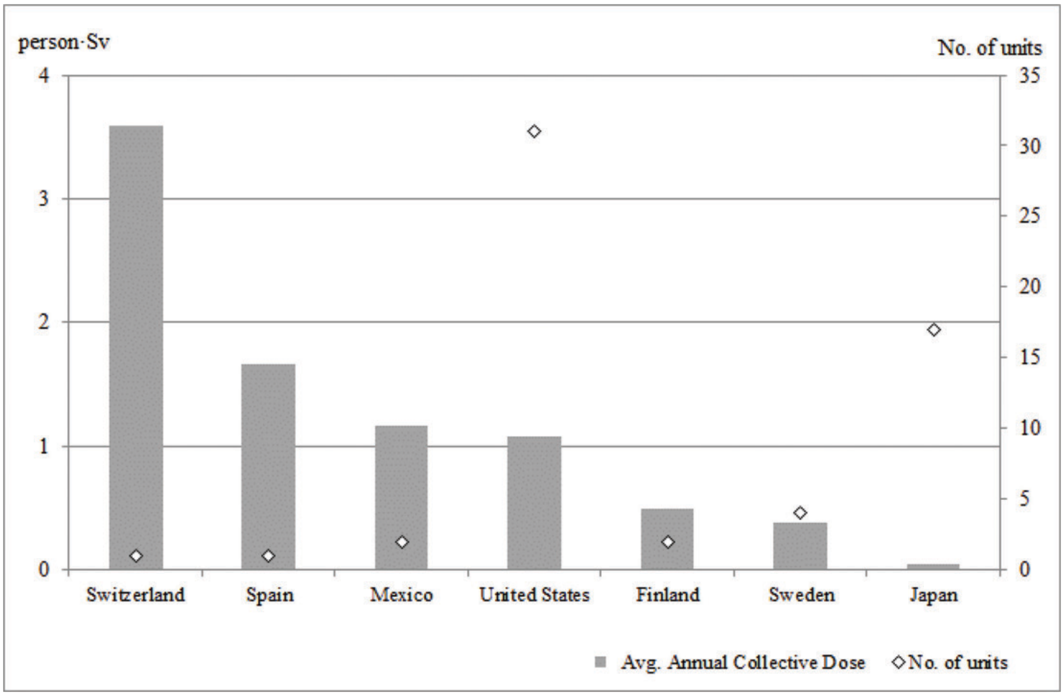
Note: See Chapter 3 for a discussion of the contribution to each country's average collective dose.

Figure 2.3. 2021 VVER average collective dose per reactor by country (person·Sv/reactor)



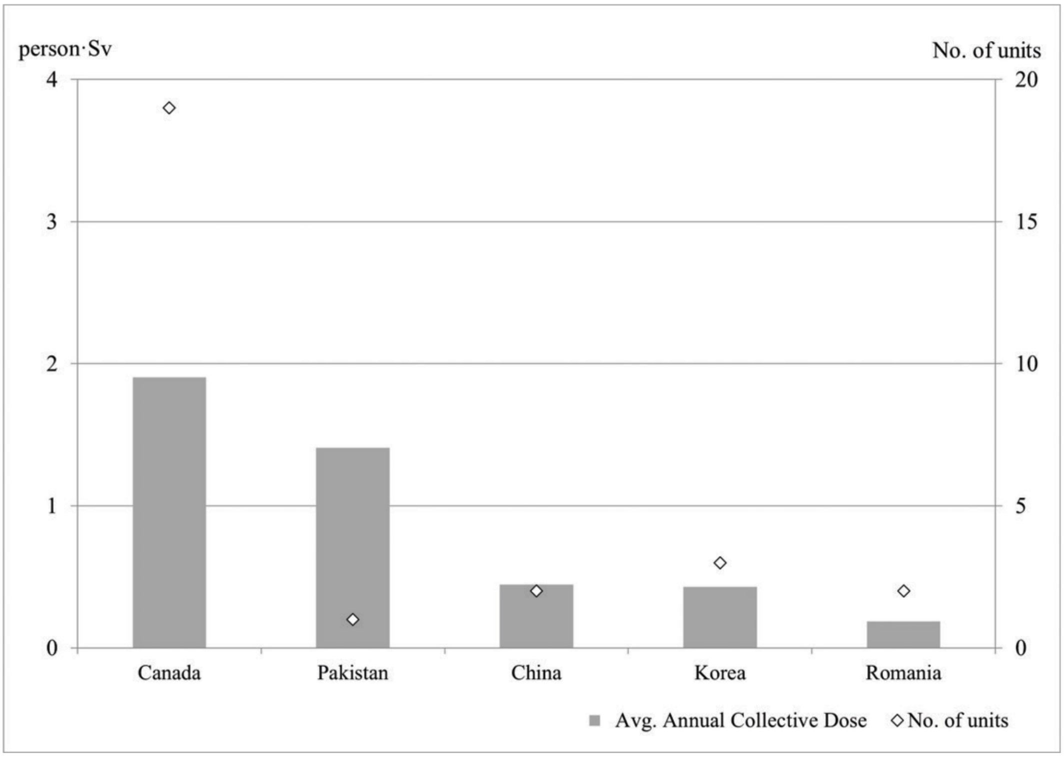
Note: See Chapter 3 for a discussion of the contribution to each country's average collective dose.

Figure 2.4. 2021 BWR average collective dose per reactor by country (person·Sv/reactor)



Note: See Chapter 3 for a discussion of the contribution to each country's average collective dose.

Figure 2.5. 2021 PHWR average collective dose per reactor by country (person·Sv/reactor)



Note: See Chapter 3 for a discussion of the contribution to each country's average collective dose.

c) Three-year rolling average collective dose trends by country

Table 2.2 provides information on the three-year rolling average annual collective dose per reactor, by country and reactor type, for the period of 2017-2019 to 2019-2021. Figures 2.6 to 2.14 present the three-year rolling average annual collective dose from 2008 to 2021 in different countries by taking into account the reactor types, including PWR, VVER, BWR and PHWR.

Table 2.2. Three-year rolling average annual collective dose per reactor, by country and reactor type, 2017-2019 to 2019-2021 (person·Sv/reactor)

	PWR			VVER			BWR		
	/17-/19	/18-/20	/19-/21	/17-/19	/18-/20	/19-/21	/17-/19	/18-/20	/19-/21
Armenia				1.28	1.12	1.52			
Belgium	0.28	0.30	0.24						
Brazil	0.24	0.26	0.26						
Bulgaria				0.21	0.18	0.19			
Canada									
China	0.37	0.33	0.32	0.20	0.20	0.22			
Czechia				0.15	0.15	0.15			
Finland				0.38	0.44	0.29	0.45	0.39	0.37
France	0.67	0.67	0.69						
Germany	0.12	0.11	0.10				0.65	0.64	0.50
Hungary				0.20	0.18	0.21			
Japan	0.22	0.26	0.24				0.10	0.08	0.06
Korea	0.31	0.33	0.33						
Mexico							4.48	4.61	4.75
Netherlands	0.42	0.24	0.27						
Pakistan	0.20	0.22	0.17						
Russia				0.61	0.61	0.49			
Slovak Republic				0.15	0.14	0.14			
Slovenia	0.50	0.53	0.57						
South Africa	0.49	0.51	0.33						
Spain	0.32	0.30	0.29				1.54	0.81	1.25
Sweden	0.21	0.22	0.22				0.42	0.46	0.48
Switzerland	0.22	0.20	0.23				1.05	0.95	1.59
Ukraine				0.57	0.54	0.52			
United Kingdom	0.22	0.13	0.22						
United States	0.33	0.30	0.30				1.12	1.04	1.03
Average	**0.40**	**0.39**	**0.39**	**0.46**	**0.45**	**0.41**	**0.81**	**0.77**	**0.80**

	PHWR			GCR		
	/17-/19	/18-/20	/19-/21	/17-/19	/18-/20	/19-/21
Canada	1.23	1.30	1.48			
China	0.39	0.35	0.35			
Korea	0.37	0.36	0.37			
Pakistan	1.75	1.40	0.59			
Romania	0.24	0.27	0.25			
United Kingdom				0.03	0.03	0.02
Average	**1.01**	**1.04**	**1.14**	**0.03**	**0.03**	**0.02**

	/17-/19	/18-/20	/19-/21
Global Average	**0.49**	**0.48**	**0.49**

Note: Calculated from the ISOE database, supplemented by data provided directly by the country.

Figure 2.6. Three-year rolling average collective dose by country from 2008 to 2021 for PWRs (1)

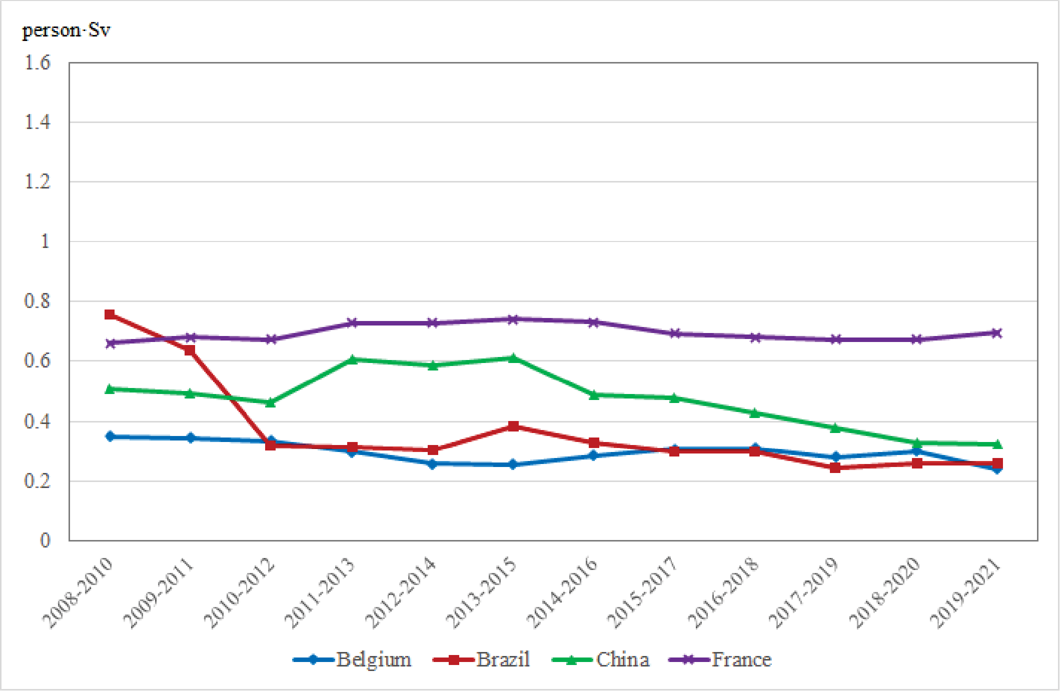


Figure 2.7. Three-year rolling average collective dose by country from 2008 to 2021 for PWRs (2)

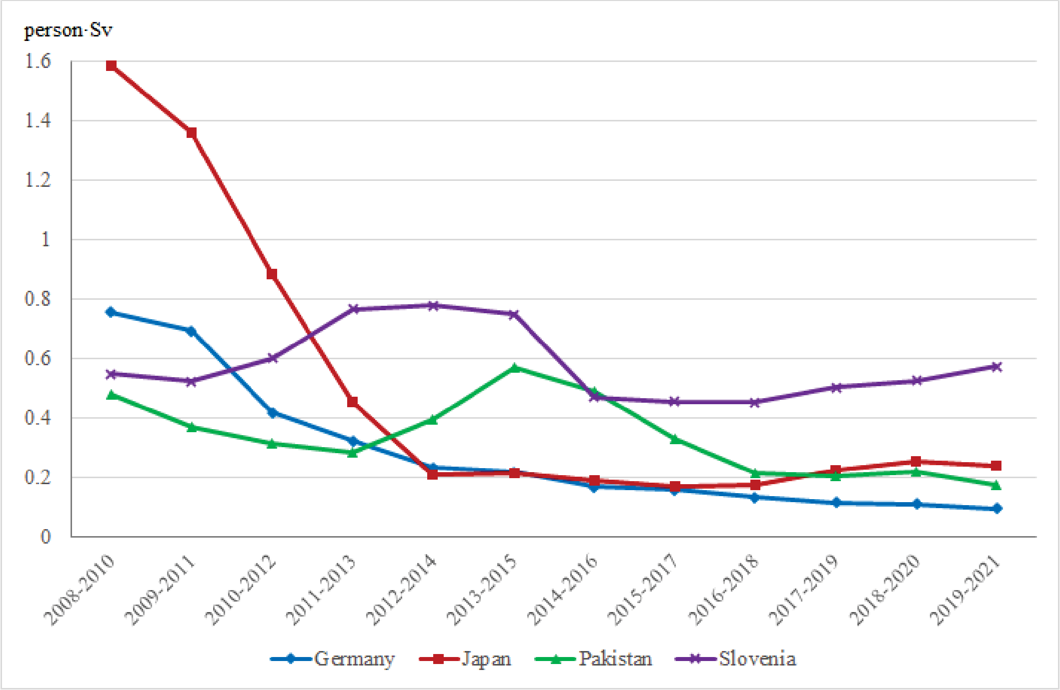


Figure 2.8. Three-year rolling average collective dose by country from 2008 to 2021 for PWRs (3)

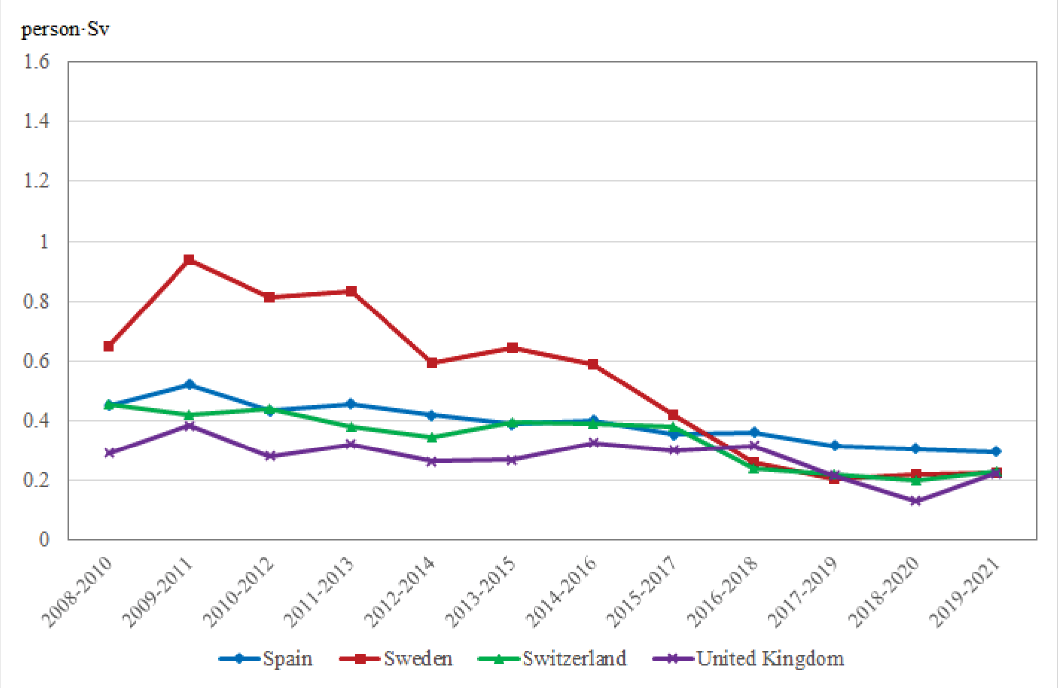


Figure 2.9. Three-year rolling average collective dose by country from 2008 to 2021 for PWRs (4)

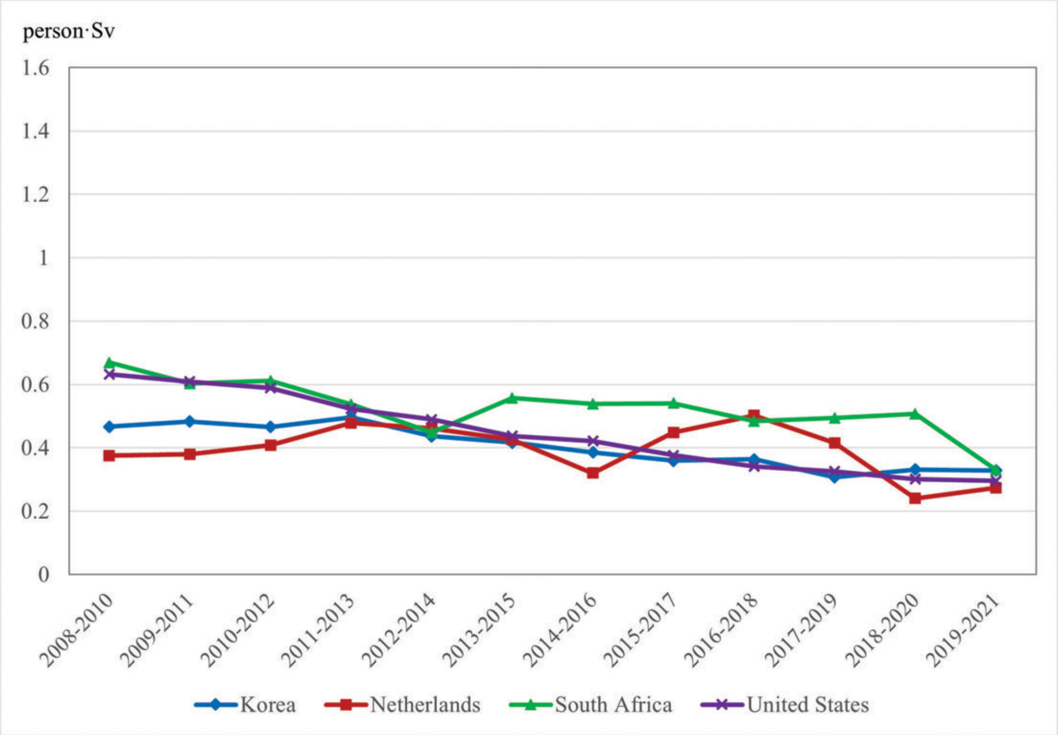


Figure 2.10. Three-year rolling average collective dose by country from 2008 to 2021 for VVERs (1)

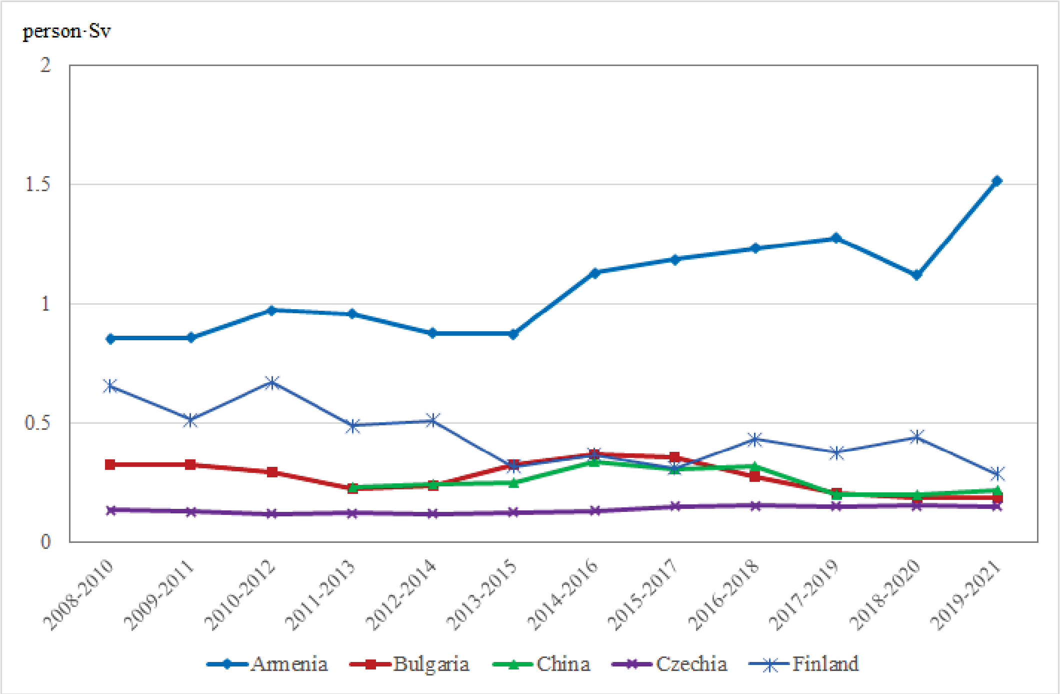


Figure 2.11. Three-year rolling average collective dose by country from 2008 to 2021 for VVERs (2)

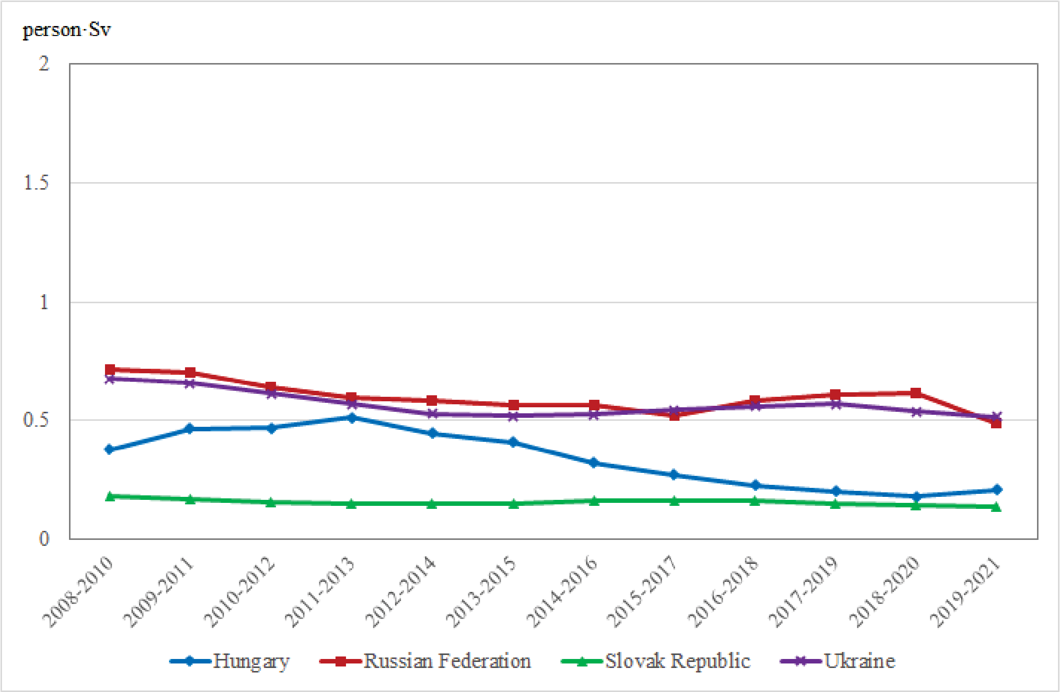


Figure 2.12. Three-year rolling average collective dose by country from 2008 to 2021 for BWRs (1)

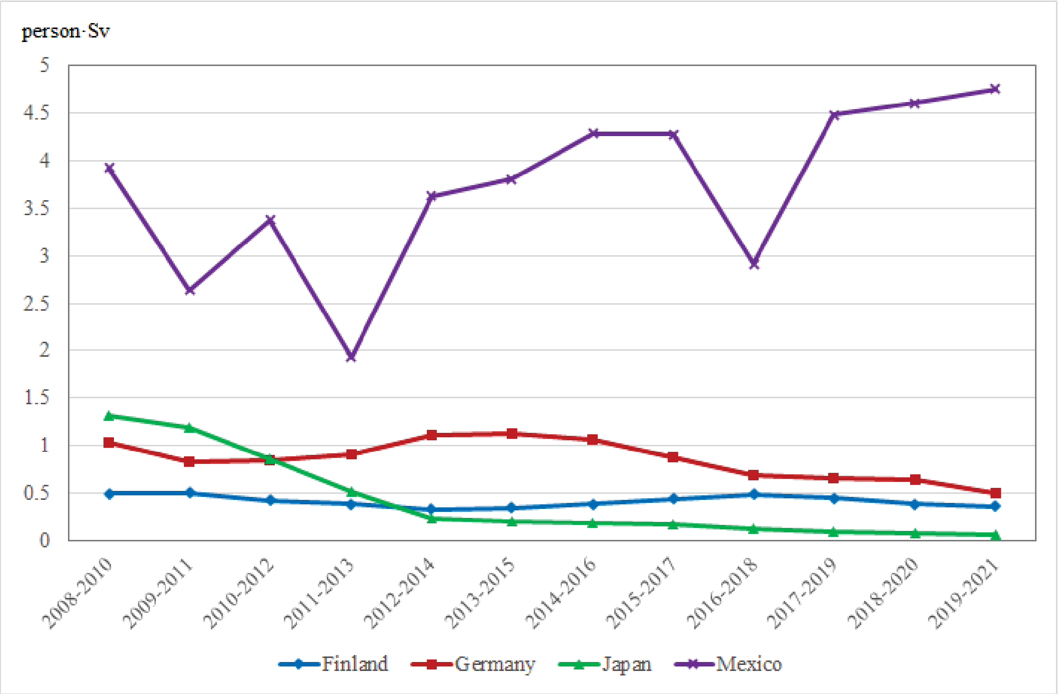


Figure 2.13. Three-year rolling average collective dose by country from 2008 to 2021 for BWRs (2)

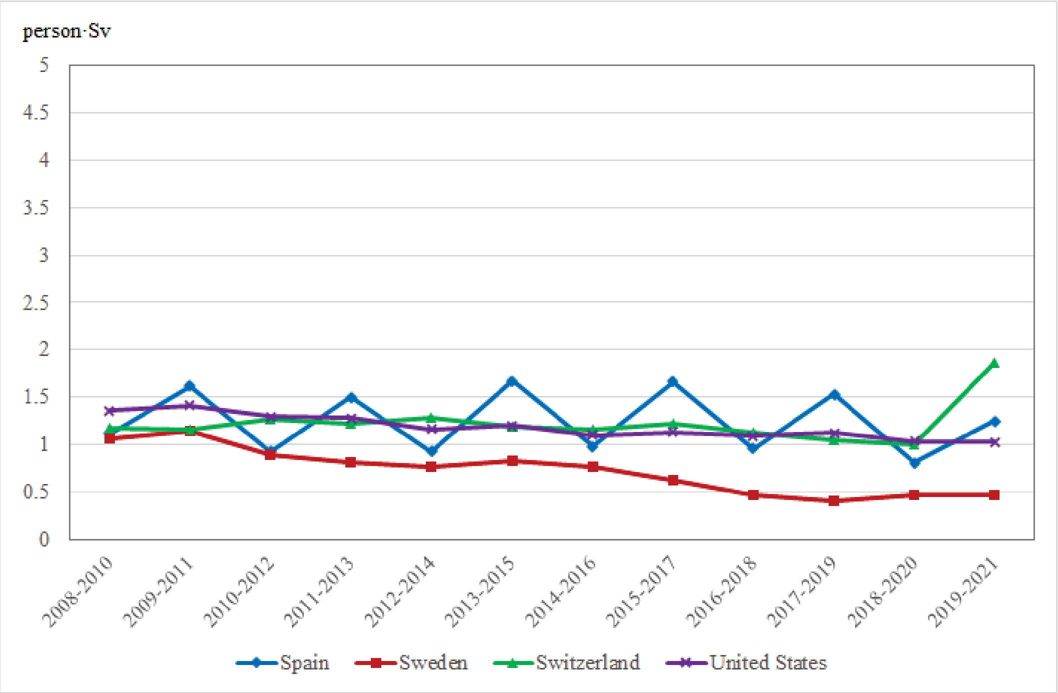
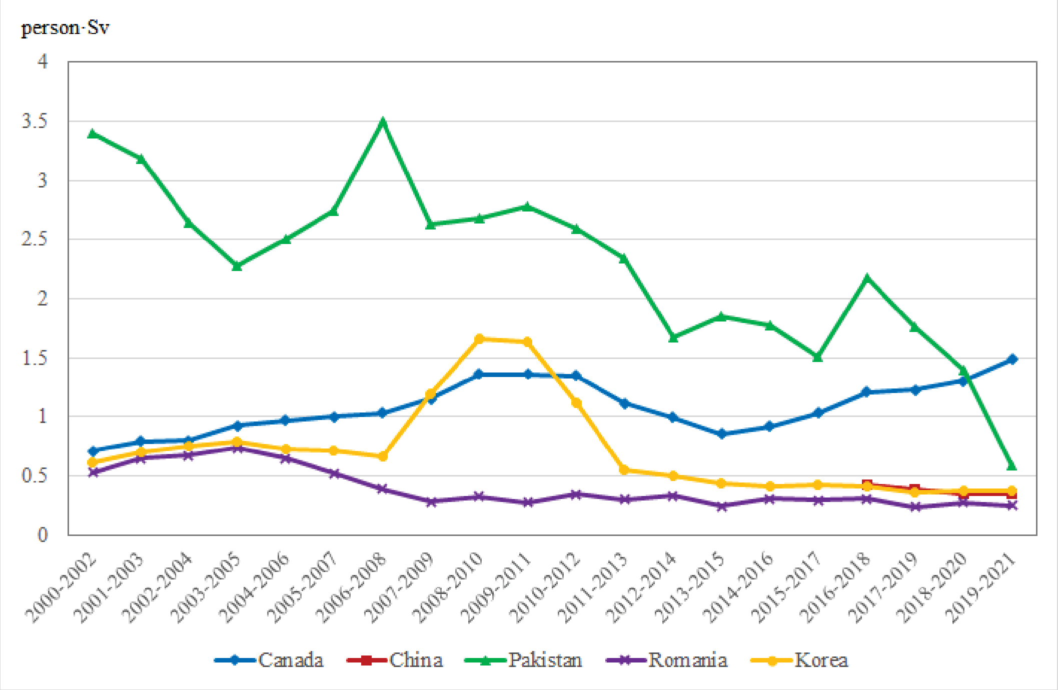


Figure 2.14. Three-year rolling average collective dose by country from 2008 to 2021 for PHWRs



2.2 Occupational exposure trends: Permanently shut down reactors

In addition to information from operating reactors, as of 31 December 2021, the ISOE database contained dose data from 123 reactors that were shut down or at some stage of decommissioning. This section provides a summary of the dose trends for those reactors reported during the 2019-2021 period. These reactor units are generally of different type and size, at different phases of their decommissioning programmes, and the supply data are at various levels of detail. For these reasons, it seems that definitive conclusions for comparative analyses of dose trends are uncertain.

Table 2.3 provides average annual collective doses per unit for permanently shut down reactors by country and reactor type for 2019-2021, based on data recorded in the ISOE database, supplemented by the individual country reports (Chapter 3) as required. Figures 2.15 to 2.19 present the average annual collective dose by country for permanently shut down reactors for the 2017-2021 period by reactor type (PWR, VVER, BWR, GCR, PHWR, LWGR, LWCHWR). In all figures, the "number of units" refers to the number of units for which data has been reported for the year in question.

Table 2.3. Number of units and average annual dose per reactor by country and reactor type for permanently shut down reactors, 2019-2021 (person·mSv/reactor)

		2019		2020		2021	
		No.	**Dose**	**No.**	**Dose**	**No.**	**Dose**
PWR	France	1	59.9	1	29.8	3	277.4
	Germany	8	73.7	9	90.8	9	92.1
	Italy	1	23.2	1	28.7	1	31.3
	Japan*	6	248.3	8	211.7	8	157.8
	Korea	1	109.5	1	12.8	1	14.6
	Spain	1	19.8	1	7.6	1	9.1
	Sweden	-		1	88.6	1	142.7
	United States	9	34.8	11	48.6	13	127.9
	Average	27	96.5	33	97.3	37	129.3
VVER	Bulgaria	4	5.4	4	8.0	4	10.0
	Russia	3	161.1	3	143.6	3	86.8
	Average	7	72.1	7	66.1	7	42.9
BWR	Germany	5	117.7	5	96.1	5	114.0
	Italy	2	18.7	2	25.0	2	25.3
	Japan*	4	63.2	9	65.7	9	37.9
	Netherlands	1	0.0	1	0.0	1	0.0
	Spain	1	68.6	1	22.1	1	7.8
	Sweden	4	68.0	4	79.1	5	128.7
	Switzerland	-		1	457.7	1	332.2
	United States	5	81.9	6	229.8	7	246.9
	Average	22	74.0	29	113.7	31	118.5
GCR	France	6	3.9	6	4.2	6	6.1
	Germany	1	0.0	1	0.0	1	0.0
	Italy	1	7.8	1	2.1	1	1.3
	Japan	1	10.0	1	0.0	1	0.0
	Spain	-		-		-	
	United Kingdom**	20	20.3	20	7.0	20	13.0
	Average	29	16.0	29	5.8	29	10.3
PHWR	Canada***	1	8.5	1	5.7	1	7.3
	Korea	-		1	43.3	1	31.7
	Average	1	8.5	2	24.5	2	19.5
LWGR	Lithuania	2	343.6	2	320.7	2	345.3
LWCHWR	Japan	1	103.7	1	166.6	1	227.3

* Without data on the Fukushima Daiichi Nuclear Power Plant.

** Data provided directly from country reports, rather than calculated from the ISOE database (2019, 2020, 2021).

*** Includes only the shut down reactor that reports occupational dose separate from operating reactor units or other licensed activities, i.e. Gentilly-2. The remaining two shut down units (Pickering 2, 3) report the dose together with the operating Pickering units (units 1, 4-8).

Figure 2.15. Average annual collective dose from 2017 to 2021 for shut down PWRs

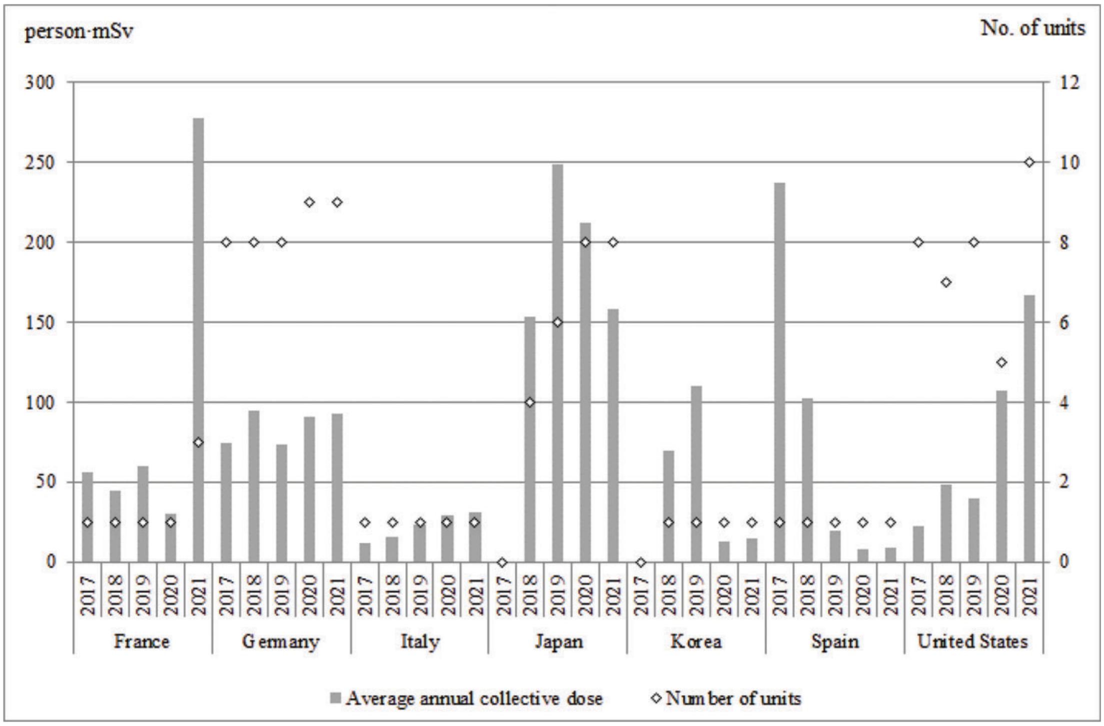


Figure 2.16. Average annual collective dose from 2017 to 2021 for shut down VVERs

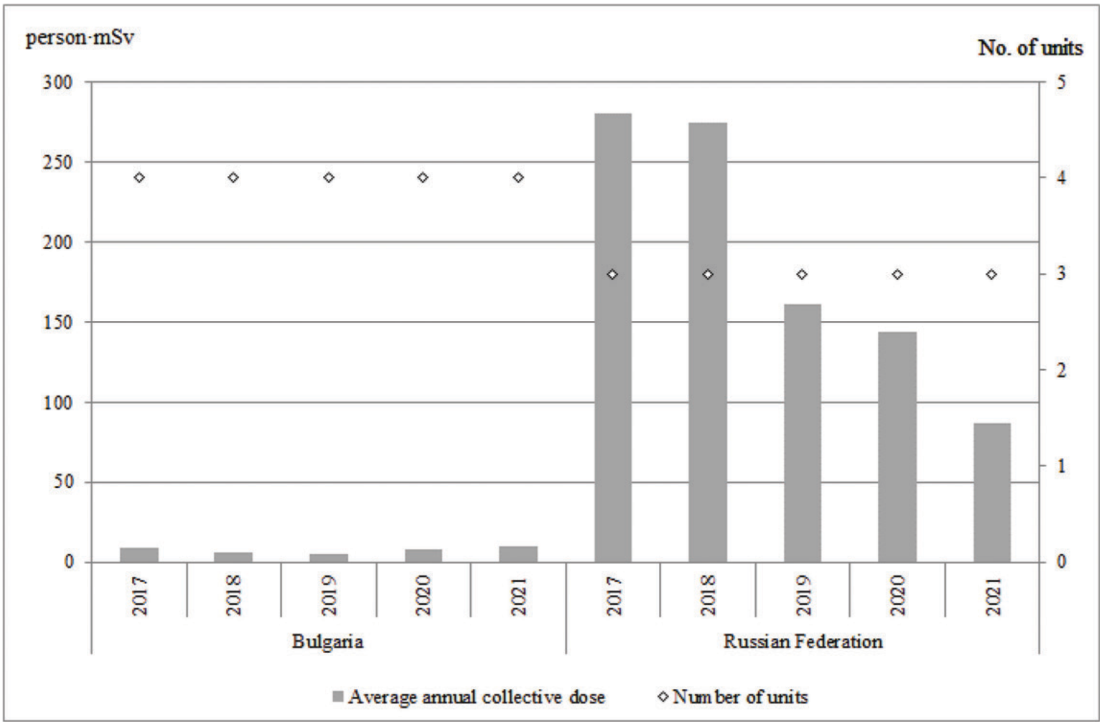


Figure 2.17. Average annual collective dose from 2017 to 2021 for shut down BWRs

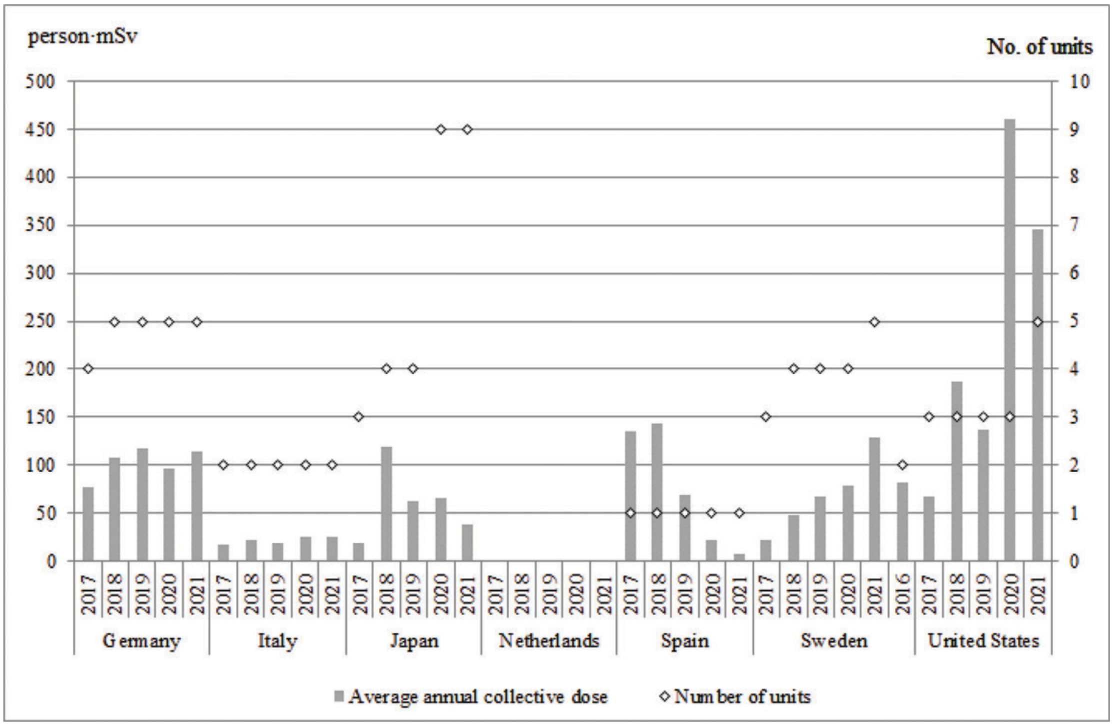


Figure 2.18. Average annual collective dose by country from 2017 to 2021 for shut down GCRs

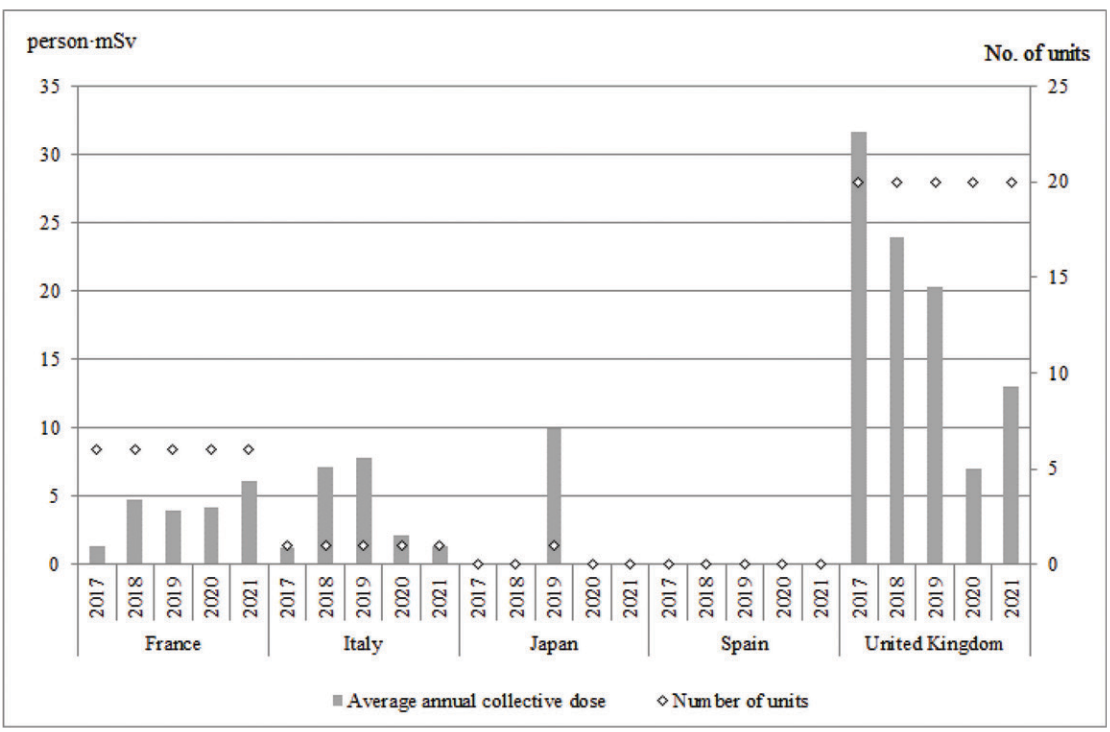
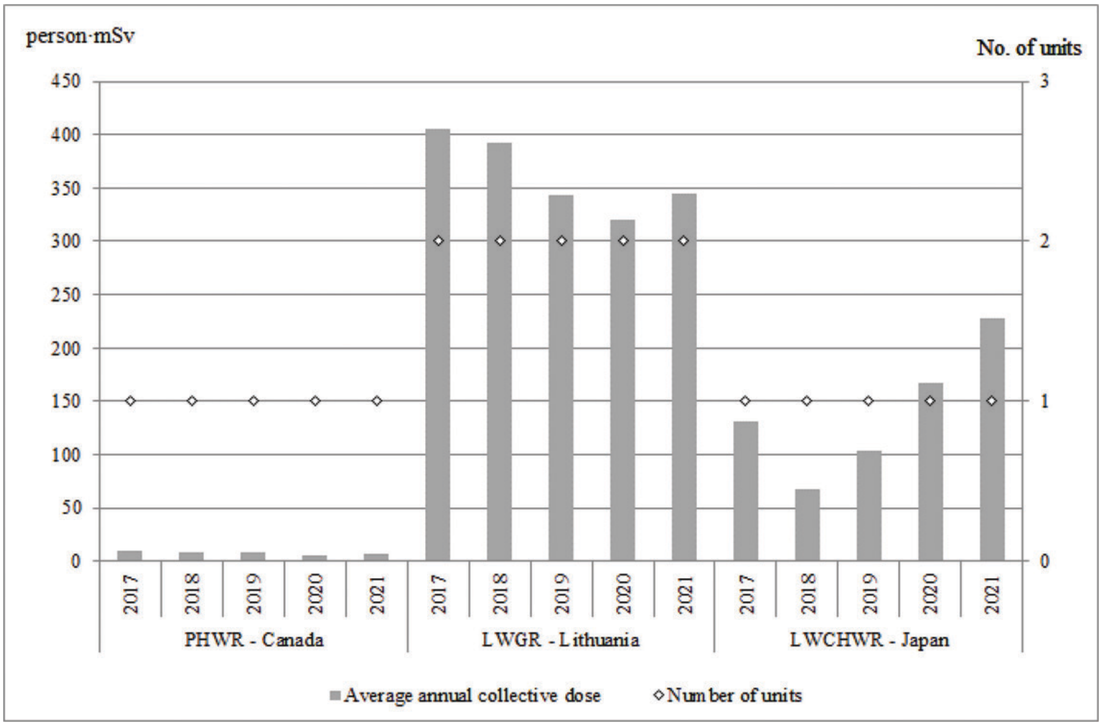


Figure 2.19. Average annual collective dose by country from 2017 to 2021 for shut down PHWRs, LWGRs and LWCHWRs



3. Principal events in participating countries

As with any summary data, the information presented in “Chapter 2: Occupational exposure trends” provides only a general overview of average numerical results from the year 2021. Such information serves to identify broad trends and helps to highlight specific areas where further study might reveal relevant experiences or lessons. However, to help enhance this numerical data, Chapter 3 lists the important events that took place in the ISOE participating countries during 2021 and may have influenced the occupational exposure trends. These are presented as reported by the individual countries.[5] It is noted that the national reports contained in this chapter may include occupational collective dose data arising from a mix of operational and/or reference dosimetry systems.

5. Due to various national reporting approaches, dose units used by each country have not been standardised.

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
2021	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 at the Armenian Nuclear Power Plant, the “Programme of the Armenian Nuclear Power Plant radiation protection for 2021” was developed. The programme sets objectives and tasks to minimise the impact of radiation and ensure effective radiation protection for the Armenian Nuclear Power Plant personnel.

The programme stipulates that:

- the annual personnel collective dose should not exceed 1 539 person·mSv;
- the personnel collective dose during outage should not exceed 1 322 person·mSv;
- the annual individual dose should not exceed 28 mSv.

3) Report from authority

A draft of the Atomic Law was developed 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 (for D1 and D2 combined)** **Doel 3: 189** **Doel 4: 227** **Tihange 1: 20** **Tihange 2: 93** **Tihange 3: 28**

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 has been exceeded):

- At Doel 1, the dose objective was respected;
- At Doel 2, the dose objective was respected;
- At Doel 3, the dose objective was respected;
- At Doel 4, the dose objective was respected;
- At Tihange 1, no outage started in 2021;
- At Tihange 2, no outage started in 2021;
- At Tihange 3, no outage started 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, though the urgency and severity is higher at Tihange Nuclear Power Plant compared to Doel Nuclear Power Plant.

Unexpected events/incidents

At Doel Nuclear Power Plant, several radiological events were 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 International Nuclear Event Scale (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/cm^2 and 6 µSv/h in contact, drum 2: 1.4 Bq/cm^2 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), while 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 backup 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 were reported to the authorities (non-exhaustive):

- In January 2021, a leakage occurred at the sampling station of the pressuriser of Tihange 2. The leak (+/- 0.3 GBq/m^3) 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 occurred, leading to several contaminations. The spills were declared to the safety authorities after the second instance, as it became 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 litres 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 ^{110m}Ag 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 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, was 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 verifying and evaluating the feasibility of replacing the seals of the primary circuit and of the residual heat removal system (RHRS) valves containing silver. Both recommendations were considered as not feasible by Tihange Nuclear Power Plant. Tihange requested that ENGIE Laborelec perform the same RPV head seal analysis at Doel 1-2 as performed at Tihange 1: if the same defects are observed, these defects could be excluded as a potential source of silver 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 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 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 was ongoing in 2021.
- A zinc injection programme aimed at decreasing the dose rate in the primary circuit was implemented at Doel 3 in 2011. This injection programme was ongoing in 2021. The evolution of the dose rate is followed up by means of a radiation monitoring system. Over the past years, a decreasing trend has been 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 de-aeration of the primary circuit with hydrasine (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 the radionuclide Sb-124, which is released from the demineralisers at the start and is absorbed by the latter afterwards. A downward trend was observed again shortly thereafter. Also, during the last and final outage at Doel 3 in 2021, a steep increase in 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[1], 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[2]). Nevertheless, two new technical regulations, one relative to industrial radiography[3] 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.

1. 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).
2. Reported in the 30th ISOE Annual Report (2020).
3. Only the draft version was received in 2021 – final publication is expected in 2022.

Brazil

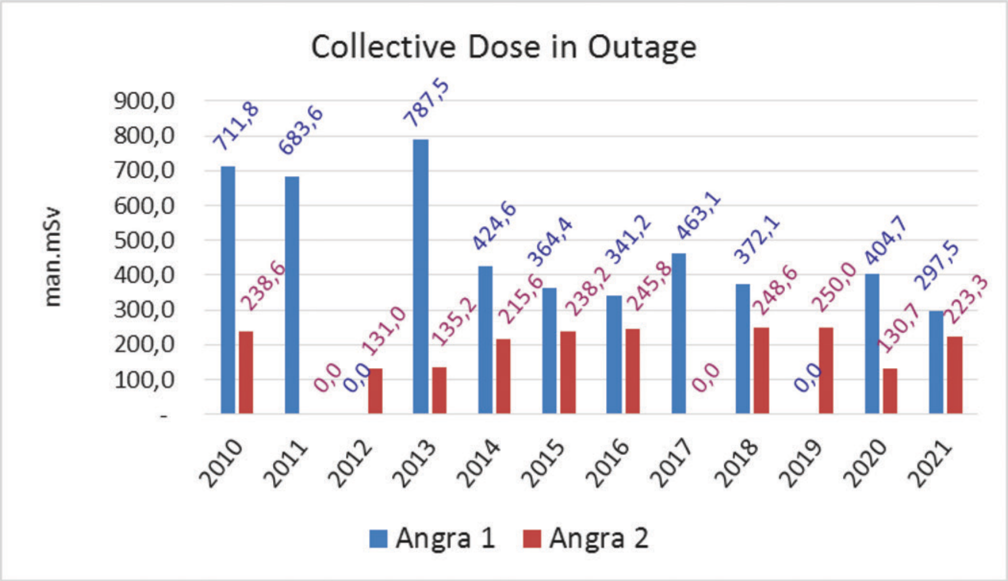
1) Dose information for the year 2021

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

Events influencing dosimetric trends

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



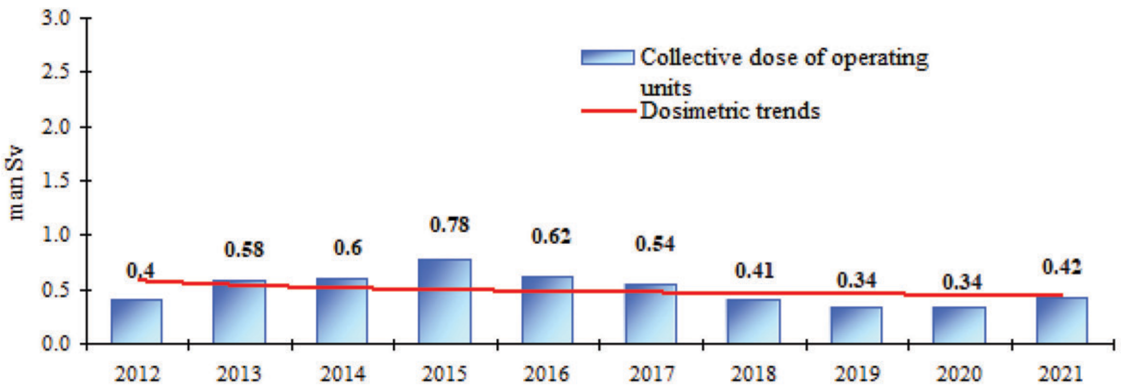
Unit	Days of outage	Outage information
Angra 1	32	Refuelling and maintenance activities
Angra 2	47	Refuelling and maintenance activities

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 SHUT DOWN 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 statistically significant. In general, for the time being, the doses associated with the decommissioning activities were kept low.

The average collective dose of operating reactors is calculated for two VVER-1000 reactors. The collective dose for 2021 increased about 20% in comparison to 2020 but despite the slight increase, there continued to be low levels of collective dose at the operating reactors.

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 contributor to the collective dose was work carried out during the outages. The outage activities resulted in about 89% of the total collective dose. The maintenance work that contributed to the radiation exposure included:

- maintenance work at the reactor vessel of Kozloduy unit 6;
- dismantling and assembling of the biological shield of the reactor vessel of Kozloduy unit 5;
- 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.

Work with higher radiation risk was performed under supplementary radiation protection (RP) 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 regulations:

- on radiation protection (2018);
- to ensure the safety of nuclear power plants;
- on the procedure of issuing licences and permits for the safe use of nuclear energy;
- for emergency preparedness and response.

Detailed radiation protection programmes 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 SHUT DOWN 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) 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 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 during 2021. Pickering unit 2 and unit 3 are in safe storage. The dose associated with safe storage is negligible (i.e. <1 person·mSv). Any dose related to accessing safe storage units is 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 2021. The refurbishment dose of Bruce Power unit 6 is 7 228.5 person·mSv and that of Darlington unit 3 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 power plants combined. Seventeen of the reactors were in operation, two were in refurbishment, and three were in the shutdown state during 2021. The above table's columns are organised accordingly. The 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 shut down 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 February 2021 (~43 days) and 17 to 30 April 2021 (~14 days).	287.4
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. The routine operations dose for Bruce A, units 1-4 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 of 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. The refurbishment dose from unit 6 was excluded from the collective dose and analysed separately.

Bruce B unit 6 was in refurbishment for the whole year 2021. The 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. The refurbishment dose from unit 3 was excluded from the collective dose and evaluated separately.

Darlington unit 3 was in refurbishment for the whole year 2021. The 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, while unit 8 had both forced and planned outages. 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 during the year. The station had an operational dose of 170.2 person·mSv and an outage dose of 117.2 person·mSv. The collective dose for the single-unit site was 287.4 person·mSv.

Gentilly-2

DECOMMISSIONING REACTORS				
Nuclear power plant, unit	**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 shut down

- No units were under construction in 2021.
- Bruce unit 6 was in refurbishment in 2021.
- Darlington unit 3 was in refurbishment in 2021.

Conclusions

No units were under construction in 2021.

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 and 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, the 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 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.

Czechia

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

Events influencing dosimetric trends

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

Nuclear power plant, unit	Outage information	Committed effective dose [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 annual collective dose in the year 2021 was influenced by planned activities, of which the main ones were the ongoing non-destructive heterogeneous weld testing and the replacement of the feedwater inlets inside the steam generators. The replacement had a common cause in heterogeneous welds and had thus to be carried out successively on almost 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 diligently during the replacement of feedwater inlets.

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

The outage of unit 1 at Dukovany Nuclear Power Plant took place at the turn of the years 2020 and 2021.

The outage of unit 2 at Dukovany Nuclear Power Plant took place 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-organised radiation protection structure and a strict implementation of ALARA principles during the activities related to work with high radiation risk. All CED values are based on electronic personal dosimeter readings.

Regulatory requirements

The radiation protection status for the year 2021 was 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 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 Framatome. It was the first time the horizontal steam generator of a VVER 440 was cleaned this way.

The dose reduction measures comprised:

- Training of workers at the Framatome 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 non-contaminated.

Finland

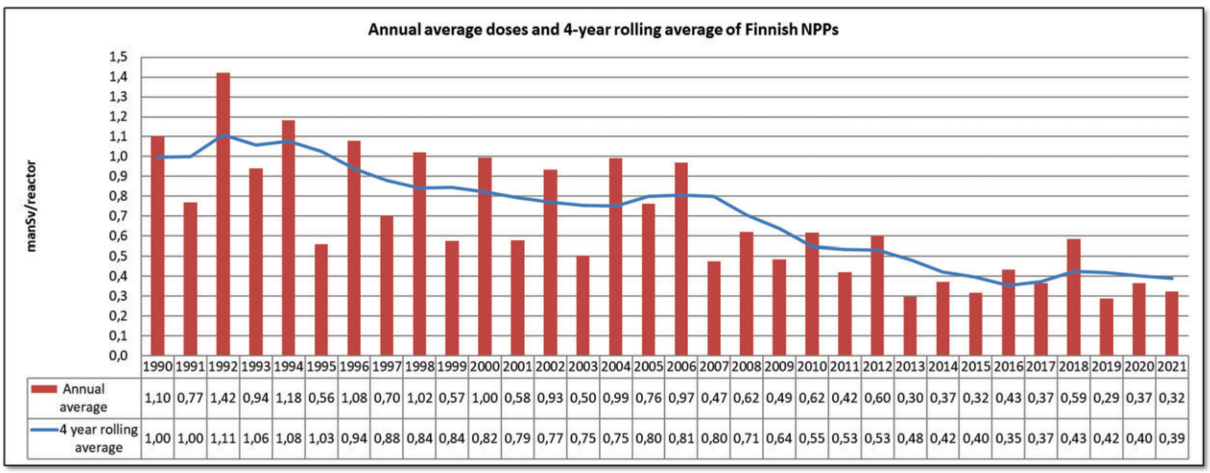
1) Dose information for the year 2021

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 four-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 1990s to a level of ca. 400 person·mSv per reactor unit.



Olkiluoto

The refuelling outage at Olkiluoto unit 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 Olkiluoto unit 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 shut down reactor coolant system main pumps and related pipelines. The total collective dose of the outage in OL2 was 601 person·mSv.

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

The total collective dose at Olkiluoto Nuclear Power Plant was 985 person·mSv.

Loviisa

On both units, the 2021 outages were short refuelling outages with a planned duration of 17 days per unit. At unit 2, a leaking fuel element was detected and removed from the reactor during refuelling. The outage at unit 2 was prolonged by about 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 startup after the outage.

The collective dose in 2021 was the lowest in Loviisa's operation 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 management:

- The primary coolant purification system was modified in 2019 on both units to enable coolant purification during outages. The new system was in operation during the 2021 outages.
- At unit 2, ^{110m}Ag on the primary system had been at a higher level for several years. The investigations continued with a specific sampling programme to identify the source of the 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 Loviisa unit 1 was until the end of 2027, and for unit 2 it was 2030. Fortum submitted applications for the renewal of the operating licence for its units in Loviisa until the end of 2050.

TVO has licence to operate Olkiluoto units 1 and 2 until the end of 2038. For Olkiluoto unit 3, STUK granted a 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.

One new unit, Fennovoima Hanhikivi unit 1 (a VVER type design in Pyhäjoki) was under the construction licence application (CLA) 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 fuel encapsulation plant and disposal facility at the Olkiluoto site. Posiva applied for an operating licence for them in December 2021.

The only research reactor in Finland was in the decommissioning phase. The spent nuclear 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 SHUT DOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
PWR	**1**	**79**
PHWR	**6**	**37**
GCR	**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 outage	15

Specific activities

Type	Number
SGR	1
RVHR	0

ASR = Arrêt simple pour rechargement (outage for refuelling); VP = Visite partielle (standard outage); VD = Visite décennale (ten-year outage); SGR = Steam generator replacement; RVHR = Reactor vessel head replacement.

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 from neutrons 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 are listed below.

- The main event of 2021, which occurred at the end of the year and had 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, 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 outages.

- 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 having no worker with an individual dose above 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 > 10 mSv 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 ≤ 1 mSv; B workers ≤ 6 mSv).

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 radiation monitoring system (RMS).

The 2022 outage programme 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 was disrupted by the COVID-19 pandemic. Progress was observed in 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 deterioration was 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.

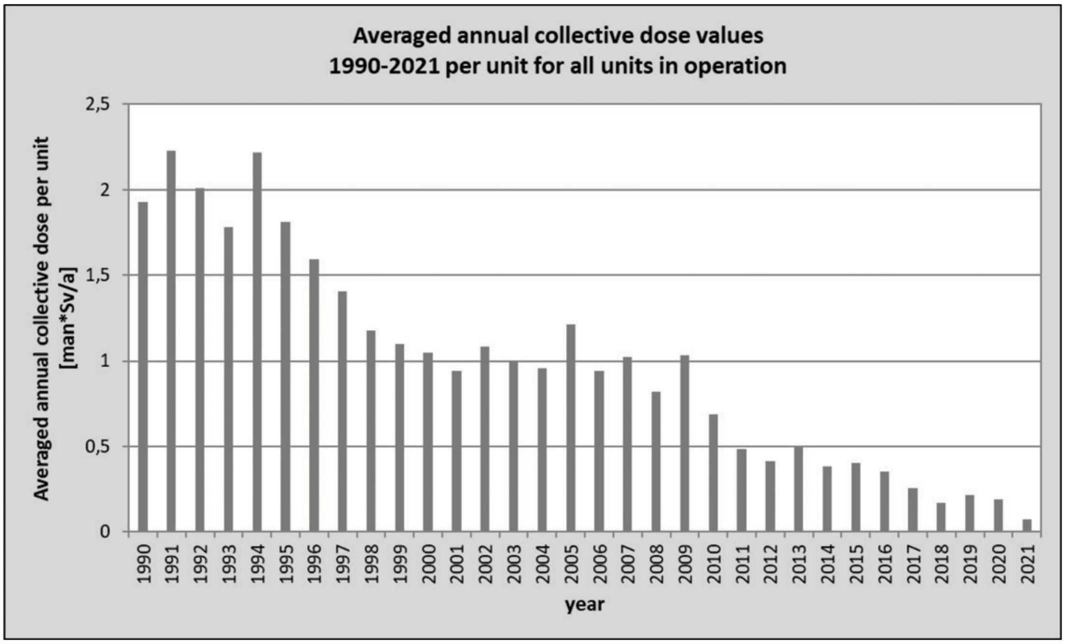
Nuclear power plants being decommissioned and waste management facilities

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 to confirm this trend over the course of 2022.

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 SHUT DOWN 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**

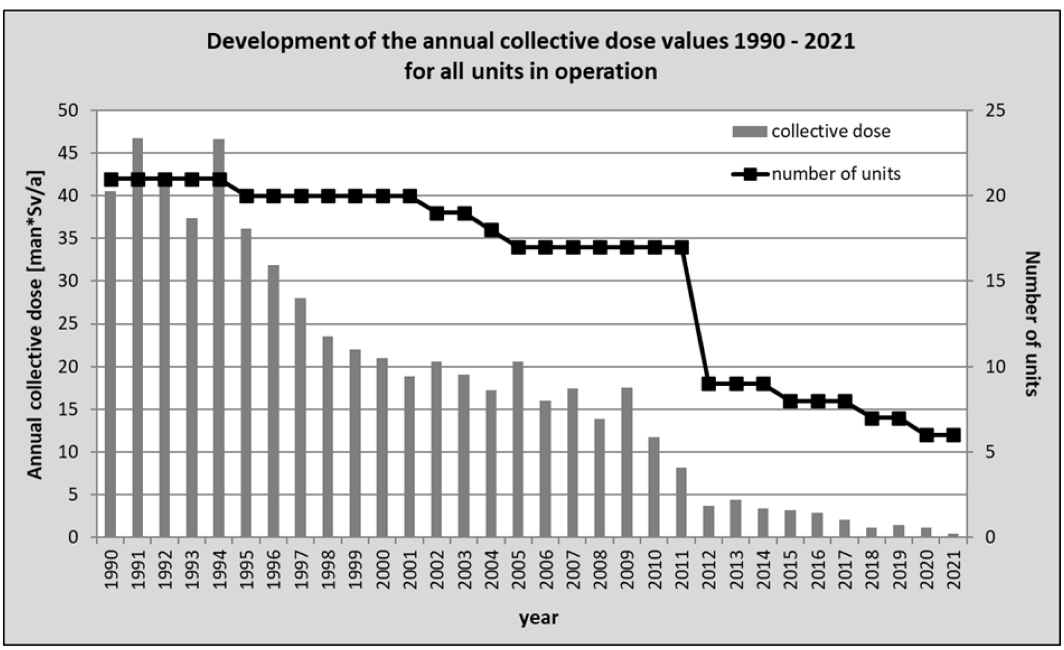


Summary of national dosimetric trends

After the Fukushima Daiichi accident, 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 2022. In this course, the nuclear power plant Grafenrheinfeld was finally shut down on 27 June 2015, Gundremmingen B on 31 December 2017, Philippsburg 2 on 31 December 2019 and 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, is in the post-operational phase; a decommissioning licence was not issued for Krümmel until the end of 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 abovementioned 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 man·mSv. The significant decrease in 2021 compared to the previous year 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 man·mSv. For this figure, the one plant in the post-operational phase (Krümmel) and the 13 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.



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

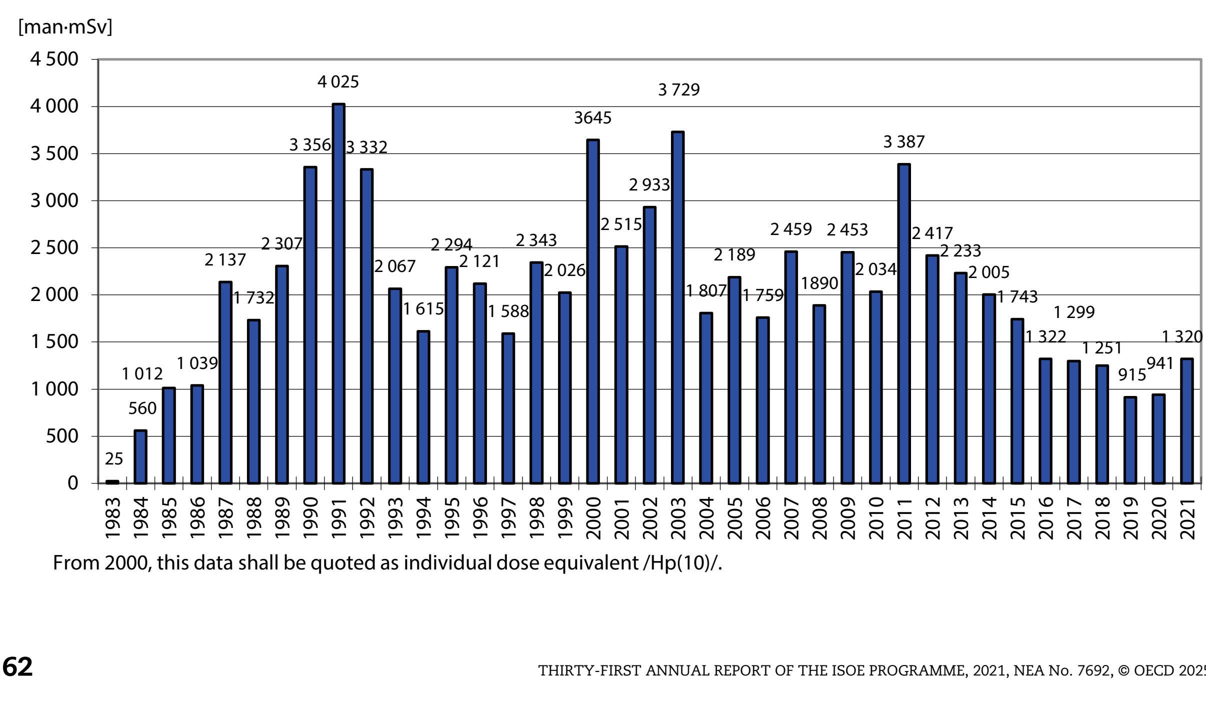
Summary of national dosimetric trends

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 2020.

Data were collected with electronic dosimeters as well as with thermoluminescent dosimeters (TLD) 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.

Number and duration 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 SHUT DOWN 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 [7.11] + 1 unit Garigliano Nuclear Power Plant [42.84])**
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 person·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 for the Fukushima Daiichi Nuclear Power Plant was 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 the 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	2 247	2 456
≦1	1 083	4 771	5 854
Total	1 358	8 779	1 0137
Max.(mSv)	13.10	17.46	17.46
Ave.(mSv)	0.85	2.77	2.51

TEPCO uses the integrated value from the avalanche photodiodes (APD) that is equipped every time 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. Internal exposure doses may be revised when the reconfirmation is made.

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 revision 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.
- The Radiation Council, established under the Nuclear Regulation Authority (NRA), has requested reports from administrative bodies relating to radiation workers at the TEPCO Fukushima Daiichi Nuclear Power Plant and, in the medical area, relating to the status of individual exposure dose control, including for 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 SHUT DOWN 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 trends

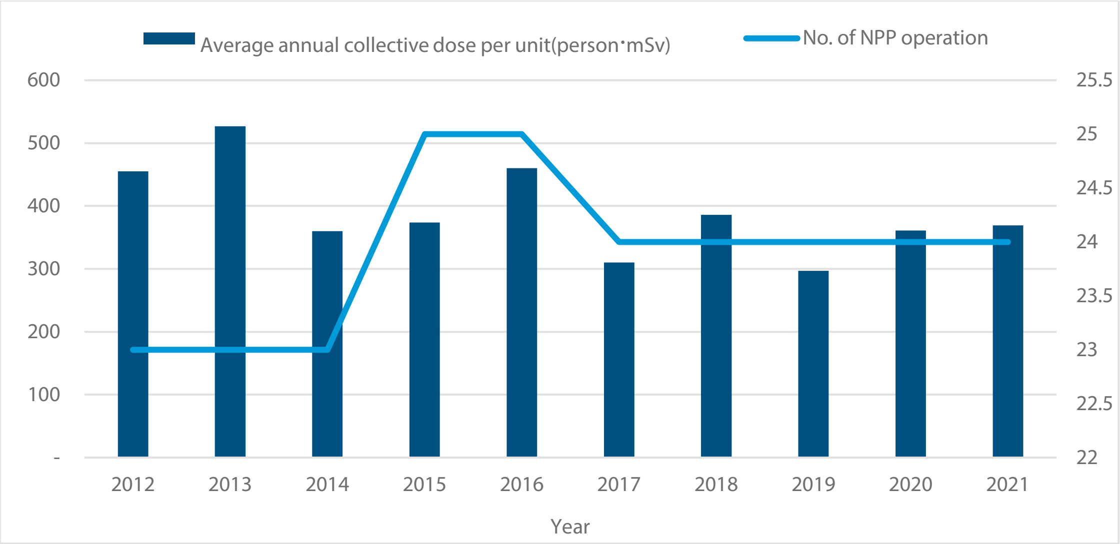
In 2021, the total number of operating nuclear power reactors was 24; including 21 PWRs and 3 PHWRs. In terms of nuclear power plant operation, a total of 16 795 workers had access to the radiation-controlled areas and received a total amount of 8 906.71 person·mSv. The total number of workers decreased by 49 in 2021, and the total amount of collective dose increased by 176.84 person·mSv (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 worker inputs were similar 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. In all, 86.52% of the total number of individuals had doses less than 1 mSv. 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 somewhat higher (approximately 15.25%) than that (almost zero %) in PWRs due to tritium exposure.

Occupational dose distributions in nuclear power plants in Korea (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 nuclear power plant unit from 2012 to 2021 in Korea



Lithuania

1) Dose information for the year 2021

ANNUAL COLLECTIVE DOSE		
REACTORS DEFINITIVELY SHUT DOWN 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). It was 11 person·mSv (18% of planned dose) for contractor personnel. Thermoluminescent dosimeters (TLD) were used for the external dosimetry.

The highest individual effective dose for the Ignalina Nuclear Power Plant staff was 14.12 mSv, and for contractors' personnel it was 1.00 mSv. The average effective individual dose for the Ignalina Nuclear Power Plant staff was 0.43 mSv; for contractor personnel it was 0.02 mSv.

The main work that contributed to the collective dose during technical service and decommissioning of units 1 and 2 at Ignalina Nuclear Power Plant was the dismantling of the equipment; treatment of CONSTOR®RBMK-1500/M2 containers; fuel handling; repairs to the hot cell; modernisation and maintenance work at the spent fuel storage pool hall, reactor hall and reactor auxiliary buildings; waste and liquid waste handling; and 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 work organisation, by doing extensive work on the modernisation of plant equipment, and by using automated systems and continuously implementing programmes to introduce 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 the dismantling work 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, and dismantling of the equipment of the turbine hall of unit 2 was almost finished (about 98%) and will be completed in 2022. Eight-four per cent 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 work is 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 radiological contamination. Consequently, the construction of the Fuel Storage Facilities and Radioactive Waste Repositories is a strategically important part of the activities performed at Ignalina Nuclear Power Plant.

The priorities of Ignalina Nuclear Power Plant are nuclear and radiation safety, the transparency and effectiveness of its activities, ensuring the responsibility of staff, having high-quality professional staff 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 during the 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

Mexico has two BWR/GE nuclear reactor units at the Laguna Verde Nuclear Power Station in Laguna Verde, State of Veracruz.

- 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.
- The 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 online and during refuelling outages is higher than the BWR average. The online collective dose is high because of failures or shortcomings in equipment reliability. Some examples are steam leaks, reactor water clean-up system pump failures, and radioactive waste treatment system failures.

Events influencing dosimetric trends

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. This factor is still strongly influencing dose rates at the plant and specifically in the drywell during refuelling outages. Indeed, this is the working area where between 70 and 80% of the collective dose of the refuelling 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.

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 (BWR Radiation Level Assessment and Control) point dose rates by completing chemical decontamination and continued low temperature zinc and platinum deposition. 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 is aimed at suppressing Co-60 deposition.

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, similarly to the US BWR experience. In 2021, a decrease in Co-60 colloids in the 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	**1**	**441 (99 person·mSv EPZ, 342 person·mSv contractors)**
REACTORS DEFINITIVELY SHUT DOWN 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 (contractor)
- Two incidents during the regular outage:
  1. 40 m^3 of primary water in the containment due to a leakage of the reactor basin shutter;
  2. 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 COVID-19 pandemic had caused maintenance and in-service inspection work to be postponed in 2020. This was also the reason for a higher collective dose in 2021 compared to previous years.

Despite a second year of the COVID-19 pandemic, ANVS was able to perform its 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 to conduct the periodic safety review.
- In the field of radiation protection, ANVS supervised the following situations at EPZ:
  a. an incident in which radioactive material was found outside the controlled area;
  b. a situation regarding unlicensed mobile X-ray devices;
  c. 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 (outage information – number and duration)

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

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 and 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 doses over 10 mSv;
- the maximum individual dose for 2021 was 7.768 mSv;
- the contribution to the internal dose from tritium intake was 20%.

Planned outages

- A 39-day planned outage was carried out at unit 2 between 8 May and 15 June 2021. Activities with major contributions to the collective dose were as follows:
  - changing of fuel channel fixed ends;
  - preventive maintenance of fuelling machine bridge components;
  - measurement and correction of feeder-yoke clearance;
  - inspection for tubing and supports damage in the feeder cabinets;
  - systematic inspections during planned outages;
  - examination of feeder thickness, feeder clearance and feeder-yoke measurements, elbow UT;
  - inspection of snubbers;
  - inspection of piping supports;
  - 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

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

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

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 pre-job briefings for high radiological risk activities. RP technicians act as RP assistants for high radiological 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 SHUT DOWN OR IN DECOMMISSIONING		
Reactor type	**Number of reactors**	**Average annual collective dose per unit and reactor type [person·mSv/unit]**
VVER	**3**	**86.8**

Summary of national dosimetric trends

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 with respect to the group of five operating VVER-440 reactors (Kola 1-4, Novovoronezh 4);
- 405.7 person·mSv/unit with respect to the group of 13 operating VVER-1000 reactors (Balakovo 1-4, Kalinin 1-4, Novovoronezh 5, Rostov 1-4);
- 155.2 person·mSv/unit with respect to the group of three operating VVER-1200 reactors (Novovoronezh II-1 and II-2, Leningrad II-1).

These results show that the average annual collective dose for the new VVER-1200 reactors is 1.5 times lower than the average values for the VVER-440 and VVER-1000.

The 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 and 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 Novovoronezh 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 for nuclear power plants in Russia (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 entirely due to the large scope of radiation works:

- Balakovo 1: long-term planned outage with modernisation 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.

The 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 the drains of special sewer systems, minimising corrosion product activity in the 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 SHUT DOWN 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 2021

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 electronic 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 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 online

At Mochovce Nuclear Power Plant, units 3 and 4 were under construction. A 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	1	925

2) Principal events of the year 2021

Events influencing dosimetric trends

- Normal operation during the COVID-19 pandemic.
- The last part of the upgrade programme was completed at the end of 2021, and it included:
  - new shelter building for an operative support centre;
  - bunkered building with safety injection pump and borated water tank;
  - auxiliary feedwater pump with condensate storage tank;
  - make-up possible from an underground water source;
  - additional alternative residual heat removal (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 safety reviews are 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

The 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 SHUT DOWN 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
  - 28^{th} 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.
- 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 an 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 inspection activities during the outage after some were postponed in 2020 due to 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

- Events influencing dosimetric trends
  - 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 online: none.
  - Reactors definitively shut down: 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 online: none;
  - reactors definitively shut down: 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 23rd 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
  - 23rd 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 startup 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), there has been an increase in the use of trinuke filters, 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.
- There has been a reduction in 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.

▪ 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 SHUT DOWN 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 having its 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).

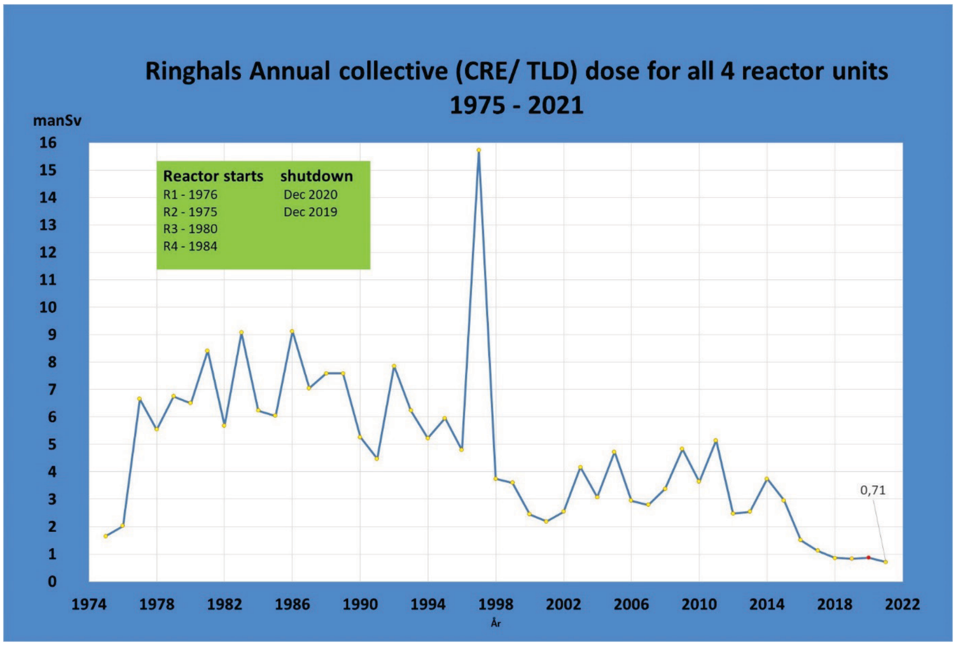
The continuous work on source term control and high dose/dose rate work is key to the dose reduction measures along with other actions that are believed to have a considerable effect, including education and training SIP (Radiation Protection in Practice) and increased interest and effort from the entire 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 at the end of 2019, and Ringhals unit 1 was to be permanently shut down at 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 the 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 buildup in reactor system oxide layers. Implementation on units 3 and 4 is in a pre-project phase, with the experience from Ringhals 1 OLA (OnLine nuclide specific Activity) and DOSOLA (DOS rate OnLine Activity) being 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 a fuel rack position in the fuel building. There was no release of fission gas.

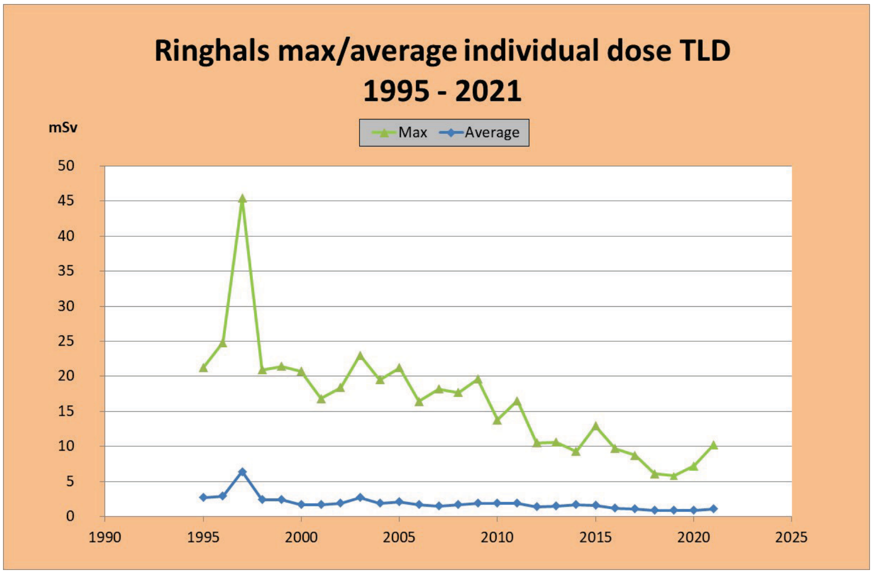
The INES 0 events (2 events in 2021) involved alpha contamination during FSD at unit 2 and storage of ADR class 7 containers on uncontrolled area with deficiencies in barriers and signs regarding information about elevated radiation levels.

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

In general, Hp3 is on par with Hp10 doses, and there were only a few exposure situations of concern for Hp3 during 2021.

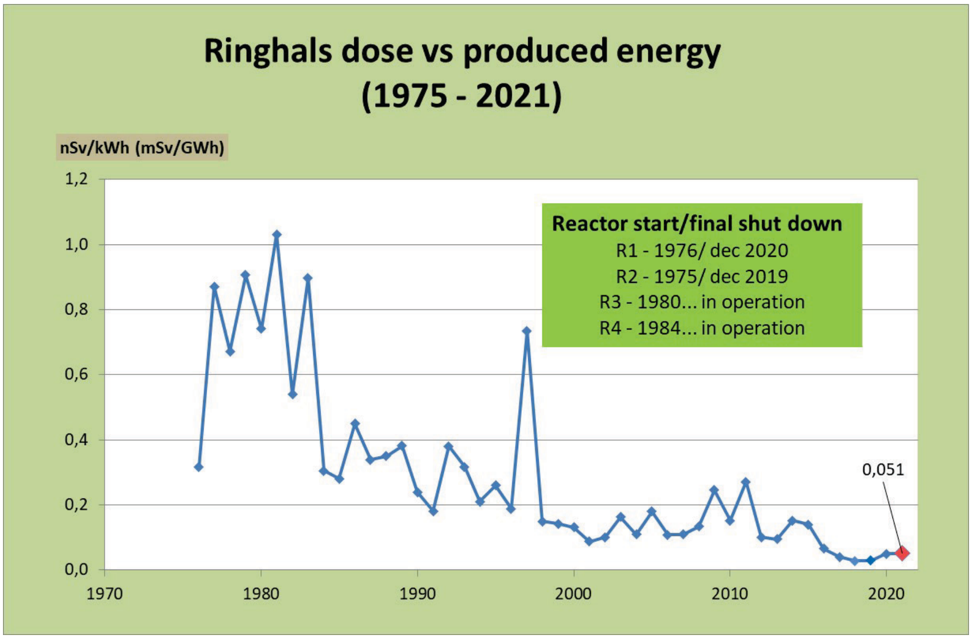
Ringhals reactors have been operating over the last 25 years with less than a handful of fuel leaks, the latest occurring in 2014.

Ringhals units 1 and 2 have 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 reactor coolant (RC) system.

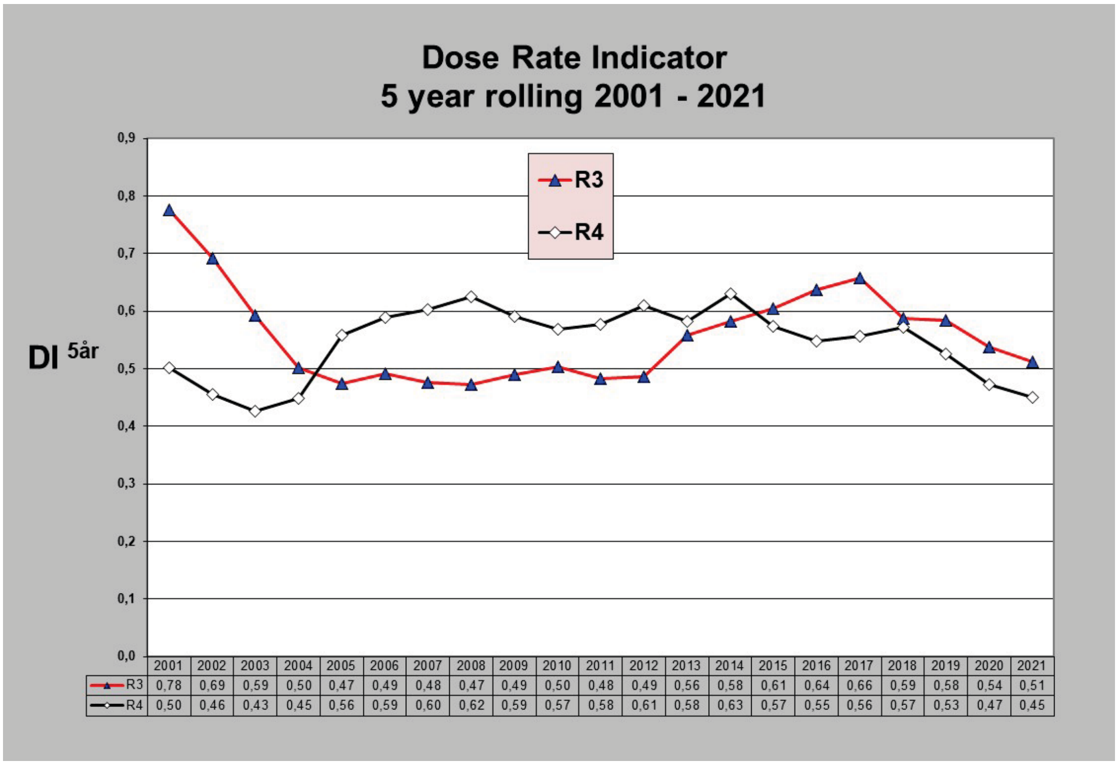


Since the mid-90s, individual doses have decreased. The company goal for doses has been successively lowered, and the long-term goal for the maximum entitled annual individual dose is < 6 mSv/ year for doses received at Ringhals. Even if 5 individuals exceeded the 6 mSv check point in the year 2021, these were carefully pre-evaluated and justified for 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.



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

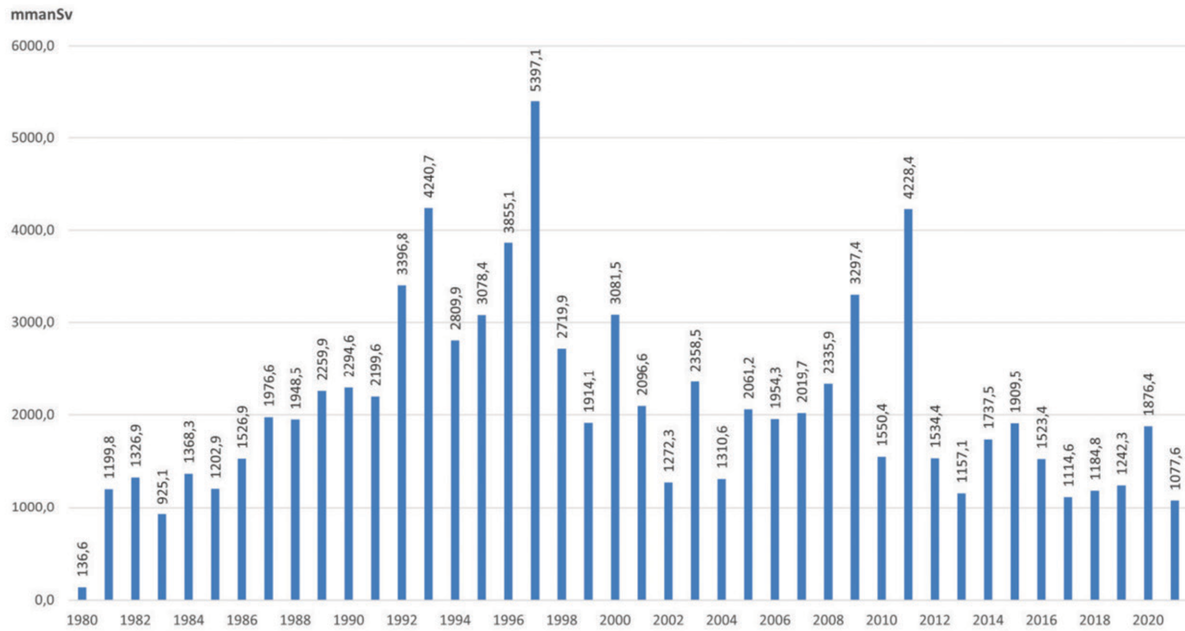
Based on the 2021 ALARA analysis and evaluation, the radiation protection work at Ringhals is generally considered to be satisfactory. During 2021, several measures were started to develop and strengthen the ALARA business, which includes alpha gap-analysis implementation, preparing for WANO and SOER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

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

The dose outcome (CRE) in 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 TLD, 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 of the decontamination workshop at units 1 and 2, started during the fall of 2020 and completed 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", of 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, the spread of contamination, and 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; the dose rates in the turbine systems show a slightly decreasing trend.

- Forsmark 2

The planned outage was a maintenance outage of 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, while the dose rates in the 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 CRDMs.

- Forsmark 3

The planned outage was a long maintenance outage of 40 days. Major work was performed with 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 the spread of contamination and lack of a barrier to the high dose rate area.

The dose rates in the reactor systems remain fairly stable, while the dose rates in the 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 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 TLD 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 measurements did not show any internal intake that resulted in a mortgaged effective dose exceeding 0.25 mSv.

Area monitoring and contamination control outside the controlled area has been carried out at all facilities in accordance with regulatory requirements, and no increase above the normal background level was detected 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 and implementing measures at the facility, and has a clear understanding of personal responsibility for dose and the importance of co-operation and clear communication. The 2021 outage was extended due to a shell valve leak and diesel generator replacement and ended in a 27-day outage shutdown. High dose rate and contamination levels were measured during the 2020 outage, when valves in the system were opened; 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 at 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 deviations or exceedance regarding individual dose or internal contamination were noted.

During the year, extensive work was continued with the FME, with the main purpose of keeping 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 were carried out at reactor facilities of O1 and O2, with the disassembly and demolition of drives; the disassembly and demolition of a turbine, with its inner and outer casing, generators, preheater, condenser, pumps and valves; and the dismantling and demolition of the reactor containment, including work involving drilling into the wet well.

During the year, preparations were 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 RPVs), WP2.2 (dismantling of the turbines), WP3 (dismantling of the condensers) and WP6.1-2 (dismantling of components inside the biological shield including primary circuit pumps and the opening of transport ways into the containment).

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

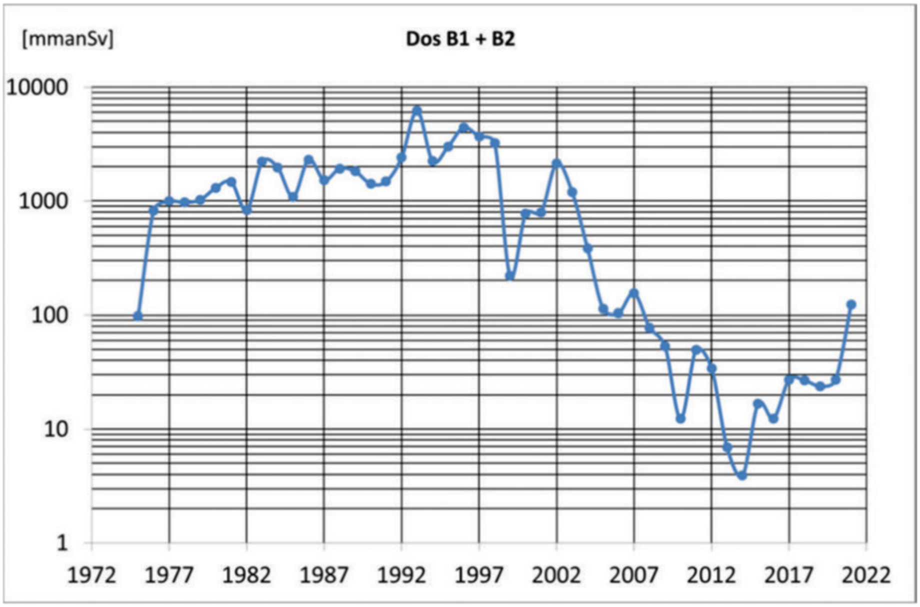
The annual collective dose received was 122.7 person·mSv (TLD). In all, 110 individuals were registered.

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 an equivalent dose > 0.25 mSv were encountered during the year. A total of 115 measurements was performed.

BKAB noted 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 areas, cultural differences and communication problems.



BKAB annual collective dose (TLD) 1975-2021

3) Report from authority

SSM continues to actively follow the planning and work performance of the decommissioning of the six reactors that have closed down (1999, 2005 and 2016-2020), but also conducts normal supervision of the operating nuclear reactors which, due to the pandemic situation, occurred mainly via telephone and video conferencing. However, in the fall of 2021, many of the pandemic-related restrictions were ended, making site visits possible. SSM has planned inspections for 2022 at the three operational nuclear power plants concerning 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, an issue that can become a challenge 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 SHUT DOWN 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, as well as a maintenance outage in KKB-2. Slightly increasing dose rate levels at the 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 of 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 a significant number of third-party personnel conducting respective activities. This led to an increased level of the total collective radiation dose of personnel at the nuclear power plants.

However, all such work was completed by 2020. In addition, in 2021, at unit 1 of Zaporizhzhia Nuclear Power Plant and unit 1 of Khmelnitsky Nuclear Power Plant, scheduled preventive maintenance with the implementation of radiation hazardous work 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 mentioned above, the indicator of the dose level per unit in 2020 improved as compared to previous years.

In 2021, all 15 nuclear power plant units were in a state of scheduled repairs, with Rivne Nuclear Power Plant unit 3 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 refuelling outage in 2021.
- Component or system replacements: none.
- Unexpected events/incidents: none.
- New reactors online: Barakah 1 (April 2021).
- Reactors definitely shut down: none.

New/experimental dose-reduction programmes

Barakah 1 initiated a 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 online.

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 impart knowledge during non-working hours about first-time evolutions, monitoring and catching critical behavioural standards, and communicating effectively with various departments (i.e. operations) and multicultural employees (i.e. radiological workers).

Regulatory requirements

In 2021, Barakah unit 1 began 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 SHUT DOWN 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 began 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 15 thermal sleeves. This additional work resulted in an extension to the outage and additional radiation dose. The refuelling outage lasted 129 days, with a collective radiation exposure (CRE) of about 350 person·mSv. The thermal sleeve repairs and inspections contributed an emergent dose of about 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 in 2022. The reduced number and scope of AGR outages resulted in very low doses, with the annual CRE ranging from about 5 person·mSv to about 32 person·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 SHUT DOWN 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	64	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 uprates and water chemistry challenges at some US BWR units.

New plants online/plants shut down

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 power 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 for safe and efficient nuclear plant operations. Diablo Canyon units 1 and 2 are scheduled to shut down in 2024 and 2025, respectively. However, the 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 a derecho storm 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 supplying electricity to New York City.
3) Pilgrim Nuclear Power Station was shut down for decommissioning on 31 May 2019 by Entergy. Holtec International purchased the 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 for 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 for 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 licence 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 its 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.

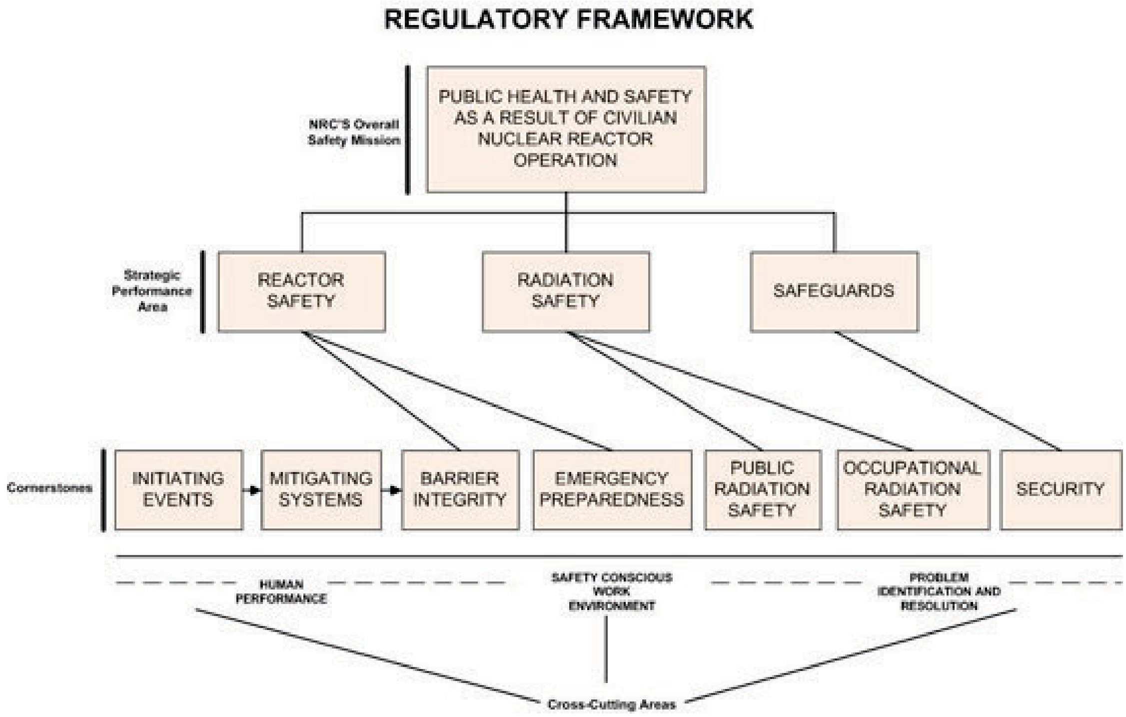
Technical plans for major work in 2021

LaSalle County (US BWR) has implemented new technology that may become a game-changer for nuclear plant maintenance. It involves 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 Program – 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.

4. ISOE experience exchange activities

While the Information System on Occupational Exposure (ISOE) is well known for its occupational exposure data and analyses, the programme's strength comes from its efforts to share such information broadly among its participants. The combination of the ISOE symposia, network and technical visits provides a means for radiological protection professionals to meet, share information and build links between the ISOE regions to develop a global approach to occupational exposure management. This section provides input on the main information and experience exchange activities within the ISOE during 2021.

4.1. ISOE symposia and other events

ISOE North American Symposium organised by NATC

Since 1997, the annual North American ISOE ALARA Symposium has steadily grown, with utility radiation protection (RP) managers attending from Canada, Mexico and the United States.

The 2021 North American ALARA Symposium was held on 4-6 January 2021 using a virtual format due to the COVID-19 pandemic. This was the first online meeting for the event. The symposium was sponsored by the North American Technical Centre (NATC) of the ISOE and supported by the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA).

The 2021 symposium meetings lasted three days, after which a fourth day was dedicated to meetings of Region III and IV radiation protection managers (RPM), with invited guests.

The primary goal of the 2021 symposium was to provide a forum for utility and regulatory RPMs and health physics professionals to exchange views on the latest good practices and lessons learnt from the execution of planned outages and from the implementation of new technologies and ALARA initiatives.

The themes of the 2021 symposium were RPM experience with ageing plant conditions and the RPM challenges in managing the COVID-19 pandemic while maintaining effective RP controls.

The symposium featured technical papers on the latest approaches in work management, dose control, CZT technology, remote monitoring, source term reduction and dose rate measurements. As per past practice, the symposium was held early in the calendar year at the suggestion of utility RPMs to assist individual plants in setting annual and refuelling outage ALARA dose goals/targets. Good ideas on successful refuelling and maintenance ALARA outage initiatives are the major focus of the ALARA symposium.

ISOE International Symposium organised by ETC

In response to the COVID-19 pandemic and the global cancellation of international travel, the 2020 ISOE International Symposium on Occupational Exposure Management at Nuclear Facilities, which had originally been planned for June 2020 in Tours, France, and had been postponed to 2021, was further postponed to June 2022.

Other events and activities

- ETC: ISOE ETC Symposium – webinar, 1-3 June 2021.
- NATC: Virtual ALARA Workshops 29 June and 6 July 2021.
- ETC: Publication of results of the 2020 "Survey on the precautionary measures implemented by the nuclear utilities to reduce the risk of transmission of COVID-19 and their impact on radiation protection management and practices".
- "ISOE User's Guide" (still under review, to be published for all the ISOE database users).

4.2 ISOE website (www.isoe-network.net)

The ISOE network is a comprehensive information exchange website on dose reduction and ALARA for ISOE participants, providing rapid and integrated access to ISOE resources through a simple web browser interface.

The network, containing both public and members-only sections, provides participants with access to a broad and growing range of ALARA resources, including ISOE publications, reports and symposia proceedings, web fora for real-time communications among participants, member address books and online access to the ISOE Occupational Exposure Database.

In 2021, the number of officially registered users of the ISOE network website reached 858.

ISOE Occupational Exposure Database

To increase user access to the data within the ISOE, the ISOE Occupational Exposure Database has been made accessible to ISOE participants through the ISOE network.

Since 2005, the database statistical analysis module, known as MADRAS, has been available on the network. Major categories of predefined analyses include:

- benchmarking at unit level;
- total annual collective dose;
- average annual collective dose per reactor;
- rolling average annual collective dose per reactor;
- average annual collective dose per energy produced;
- plant unit rankings;
- quartile rankings;
- total outage collective dose;
- average outage collective dose per reactor;
- dose index (outage collective dose/outage person-hours);
- job collective dose;
- occupational categories collective dose;
- dose rates;
- miscellaneous queries.

Outputs from these analyses are presented in graphical and tabular format, and can be printed or saved locally by the user for further use or reference.

Radiological protection (RP) library

The RP library, one of the most used website features, provides ISOE members with a comprehensive catalogue of ISOE and ALARA resources to assist radiological protection professionals in the management of occupational exposures. The RP library includes a broad range of general and technical ISOE publications, reports, presentations and proceedings. In 2021, the following types of documents were available:

- COVID-19 survey results;
- benchmarking visit reports;
- RP experience reports;
- ISOE information sheets on dose trend studies;
- RP management documents;
- plant information;
- ISOE-2 questionnaires;
- operating experience reports;
- RP forum syntheses;
- severe accident management documents;
- RP events.

RP forum

Registered ISOE users can access the RP forum to submit a question, comment or other information relating to occupational radiological protection to other users of the network. In addition to a common user group for all members, the forum contains a dedicated regulators group and a common utilities group. All questions and answers entered in the RP forum are searchable using the website search engine, increasing the potential audience of any entered information.

Two fora dedicated to RP operating experience (OE) have been in use at the ISOE website since their opening in 2018. These fora are intended for the exchange of information on events with radiological impact and other OE among the members.

4.3 ISOE benchmarking visits

To facilitate the direct exchange of radiological protection practice and experience, the ISOE programme supports voluntary site benchmarking visits among the participating licensees in the four Technical Centre regions. These visits are organised at the request of licensees with Technical Centre assistance. While both the request for and the hosting of such visits under the ISOE are voluntary on the part of the licensees and the Technical Centres, post-visit reports are made available to the ISOE members (according to their status as licensee or authority member) through the ISOE network website.

Due to the COVID-19 pandemic, no in-person benchmarking visits were held during 2021.

4.4 ISOE management

ISOE management and programme activities

As part of the overall operations of the ISOE programme, ongoing technical and management meetings (videoconferences) were held throughout 2021, including:

ISOE meetings (videoconferences)	Date
11th meeting of the ISOE Working Group on Radiological Protection Aspects of Decommissioning Activities at Nuclear Power Plants (WGDECOM)	25-26 November
31st ISOE Management Board	1-3 December

ISOE Working Group on Radiological Protection Aspects of Decommissioning Activities at Nuclear Power Plants (WGDECOM)

The 11th meeting of WGDECOM was held online on 25-26 November 2021. The participants emphasised that while in-person technical meetings and benchmarking visits to decommissioning sites should continue to be the core activity of WGDECOM, in the current pandemic situation, various IT tools (such as webinars, teleconferences, online meetings with particular organisations) were to be widely used.

The participants reviewed and agreed on the item-by-item draft of the "WGDECOM Programme of Work for 2020-2023". Subject to agreement by all the WGDECOM members at a later stage, the document was to be presented by the WGDECOM Chair for approval to the 31st meeting of the ISOE Management Board on 1-3 December 2021.

Other highlights of the 11th meeting of WGDECOM included:

- The case studies Excel template in its current state and form, as developed by the DDS, is detailed enough to be presented for the approval of the ISOE Management Board as a living document.
- A request should be prepared and submitted to the MB to approve the continuation of the DDS in 2022, at the very least, and the ISOE National Coordinators should be instructed to assist in the completion of the filled-in Excel templates for their country organisations or plants.
- Regarding items 9.1, 9.2 and 9.3 of the WGDECOM PoW 2020-2023, it was suggested to finalise and communicate the operational experience (OE) collection procedure to decommissioning operators by the end of 2021 and start the OE collection in 2022, with the aim of presenting the first synthesis at the 12th WGDECOM meeting.
- Subject to agreement from the ISOE Management Board, WGDECOM shall make efforts necessary to initiate co-operation with institutions having research reactors under decommissioning.
- The ISOE Secretariat made efforts to contact the NEA RWMD division to explore a possibility of establishing co-operation between CDLM and WGDECOM in the areas of radiological protection. The results should be reported by the NEA Secretariat to WGDECOM at its next meeting in 2022.

ISOE Management Board

Due to the COVID-19 pandemic and subsequent global travelling restrictions, the ISOE Management Board (MB) held its 31st annual meeting online, on 1-3 December 2021.

The ISOE Management Board continued to manage the ISOE programme, reviewing the progress made in 2021 and discussing the Programme of Work for 2022 and beyond.

(1) The performance indicators of the ISOE Technical Centres in 2021 showed significantly good overall rates of return in different areas. It was greatly appreciated by the ISOE Chair that people took time and effort to engage with ISOE by providing the responses that had been requested because ISOE was built upon information, and without information its participants could not perform effectively.

(2) Follow-up NATC issue the ISOE Secretariat proposed an alternative action plan. It was suggested to suspend the survey for one year and discuss the situation of NATC at NPRE, University of Illinois once again, at the next MB meeting. Meanwhile, the ISOE Secretariat would closely monitor and track the data delivery and the performance evolution of the current NATC on the basis of their regular reports to the ISOE Secretariat throughout 2021, according to a roadmap to be prepared by the ISOE Secretariat in collaboration with NATC and to be agreed with the ISOE participants. The suggested approach was to allow the current NATC to demonstrate the sustainability and effectiveness of its proposal on the basis of the roadmap to ensure its compliance with all obligations under the ISOE terms and conditions and to improve the decision-making process. The action plan proposed by the ISOE Secretariat was approved by the MB in March 2021. The MB supported the ISOE Chair's proposal and agreed to keep the ISOE North American Technical Centre in the structure and under the oversight of the University of Illinois.

(3) The financial report of the ISOE TCs and the NEA Secretariat, giving an overview of the resources needed to implement the ISOE Programme in 2021-2022, was approved by the MB. Seizing the occasion, the ISOE Chair emphasised that the ISOE membership had always been and continued to remain cost-effective.

(4) Ten country reports for 2021 were presented by the national co-ordinators from Canada, Finland, France, Germany, Japan, the Netherlands, Slovenia, Sweden, the United Kingdom and the United States. The presentations included various important topics like the nuclear power plant profile; collective, individual and exposure doses; national dosimetric trends for operational and shut down reactors; the timing of outages; RP significant events and activities; safety upgrade programmes; and oversight projects.

(5) The WGDECOM Programme of Work for 2020-2023, as agreed with the group members and presented by the WGDECOM Chair, was approved.

(6) The ISOE Programme of Work for 2022 was presented by the ETC on behalf of the ISOE Bureau and Technical Centres. The ISOE Chair emphasised that there was still the intention to hold a strategic planning meeting where participants would brainstorm to develop a new strategic plan, get new ideas and make progress within ISOE.

(7) As follow-up to the ISOE election process, the ISOE MB chairmanship for 2021-2022 moved to the current Chair-Elect (Bradley Boyer, Tennessee Valley Authority Radiation Protection Fleet Manager, United States) representing the North American ISOE RPM members. The ISOE Vice-Chair (Mr Hussain Alkatheeri, United Arab Emirates), whose two-year term had expired in December 2020, agreed to the offer to continue in the role for the next two-year period until December 2022. His second election as Vice-Chairperson of the ISOE Management Board was formally approved in mid-April 2021. Mr Chuan Wang (China) was elected the ISOE Chairperson-Elect and took up his new position on 1 June 2021.

Technical Co-operation Agreements (TCAs)

The TCA between the ISOE Management Board and Sociedade Brasileira de Proteção Radiológica (Brazilian Radiological Protection Society, SBPR) expired on 1 December 2021.

The only active TCA of ISOE as of 31 December 2021 was that with Oak Ridge Associated Universities (ORAU), United States (valid until 10 January 2022).

The "Framework for co-operation between the Secretariat of the UNSCEAR and the Management Board of the Information System on Occupational Exposure (ISOE) to co-ordinate practical arrangements for periodic collection and exchange of data on occupational radiation exposure" was signed by Guy Renn, the ISOE Chair on 6 January 2020 and remained in-force throughout 2021.

Possessing a Special Liaison Organisation (SLO) status, the ISOE continued to maintain formal relations with the International Commission on Radiological Protection (ICRP) on the issues relevant to the ICRP's mandate.

To maintain active engagement with organisations in formal relations with the ICRP, specific sessions are arranged at each ICRP symposium to discuss concrete and timely topics with representatives of such organisations. In addition, opportunities are provided for representatives of organisations in formal relations with the ICRP to meet with ICRP Main Commission members to discuss progress in areas of co-operation and mutual interest. Representatives from organisations in formal relations with the ICRP, such as ISOE, may be invited to provide expertise in specific ICRP Committee sessions. Representatives may also be invited to participate as members of ICRP Task Groups where their expertise is central to the objectives of the group. In addition to ad-hoc bilateral interactions and other activities, the ICRP holds annual meetings with senior representatives of all organisations in formal relations to discuss strategic questions relating to radiological protection at the international level.

Due to the COVID-19 pandemic, no such meetings were held by the ICRP in 2021.

Annex 1

Status of ISOE participation under the ISOE terms and conditions (2020-2023)

Note: This annex provides the status of ISOE official participation as of 31 December 2021.

Officially participating licensees (79)

Operating reactors (345)

Country	Licensee	Plant	
Armenia	Closed Joint Stock Company (CJSC) Armenian Nuclear Power Plant	Medzamor 2	
Belgium	ENGIE Electrabel	Doel 1, 2, 3, 4	Tihange 1, 2, 3
Brazil	Electrobras Eletronuclear S.A.	Angra 1, 2	
Bulgaria	Kozloduy Nuclear Power Plant Plc.	Kozloduy 5, 6	
Canada	Bruce Power	Bruce A1, A2, A3, A4	Bruce B5, B6, B7, B8
	New Brunswick Electric Power Commission	Point Lepreau	
	Ontario Power Generation	Darlington 1, 2, 3, 4 Pickering 1, 4	Pickering 5, 6, 7, 8
China	China General Nuclear Power Group (CGN)	Daya Bay 1, 2	Ling Ao 1, 2, 3, 4
	CNNP Sanmen Nuclear Power Company	Sanmen 1, 2	
	CNNC Qinshan Nuclear Power Company, Ltd	Qinshan 1 Qinshan II 1, 2, 3, 4	Qinshan III 1, 2 Fangjiashan 1, 2
	Fujian Ningde Nuclear Power Co., Ltd	Ningde 1, 2, 3, 4	
	Fujian Fuqing Nuclear Power Co., Ltd	Fuqing 1, 2, 3, 4, 5	
	Jiangsu Nuclear Power Corporation	Tianwan 1, 2	
Czechia	ČEZ, a. s.	Dukovany 1, 2, 3, 4	Temelin 1, 2
Finland	Fortum Power and Heat Oy	Loviisa 1, 2	
	Teollisuuden Voima Oyj (TVO)	Olkiluoto 1, 2	
France	Électricité de France (EDF)	Belleville 1, 2 Blayais 1, 2, 3, 4 Bugey 2, 3, 4, 5 Cattenom 1, 2, 3, 4 Chinon B1, B2, B3, B4 Chooz B1, B2 Civaux 1, 2 Cruas 1, 2, 3, 4 Dampierre 1, 2, 3, 4	Flamanville 1, 2 Golfech 1, 2 Gravelines 1, 2, 3, 4, 5, 6 Nogent 1, 2 Paluel 1, 2, 3, 4 Penly 1, 2 Saint-Alban 1, 2 Saint-Laurent B1, B2 Tricastin 1, 2, 3, 4
Hungary	Magyar Villamos Művek Zrt	Paks 1, 2, 3, 4	

Country	Licensee	Plant	
Japan	Chubu Electric Power Co., Inc.	Hamaoka 3, 4, 5	
	Chugoku Electric Power Co., Inc.	Shimane 2	
	Hokkaido Electric Power Co., Inc.	Tomari 1, 2, 3	
	Hokuriku Electric Power Co.	Shika 1, 2	
	Japan Atomic Power Co.	Tokai 2	Tsuruga 2
	Kansai Electric Power Co., Inc.	Mihama 3 Ohi 3, 4	Takahama 1, 2, 3, 4
	Kyushu Electric Power Co., Inc.	Genkai 3, 4	Sendai 1, 2
	Shikoku Electric Power Co., Inc.	Ikata 3	
	Tohoku Electric Power Co., Inc.	Higashidori 1	Onagawa 2, 3
	Tokyo Electric Power Co.	Kashiwazaki Kariwa 1, 2, 3, 4, 5, 6, 7	
Korea	Korea Hydro and Nuclear Power Co., Ltd (KHNP)	Hanbit 1, 2, 3, 4, 5, 6 Hanul 1, 2, 3, 4, 5, 6 Kori 2, 3, 4	Shin Kori 1, 2, 3, 4 Shin Wolsong 1, 2 Wolsong 2, 3, 4
Mexico	Comisión Federal de Electricidad	Laguna Verde 1, 2	
Netherlands	E.P.Z.	Borssele	
Pakistan	Pakistan Atomic Energy Commission (PAEC)	Chasnupp 1, 2, 3, 4	Kanupp 2
Romania	Societatea Nationala "Nuclearelectrica" S.A.	Cernavoda 1, 2	
Russia	Rosenergoatom JSC	Balakovo 1, 2, 3, 4 Kalinin 1, 2, 3, 4 Kola 1, 2, 3, 4 Leningrad II 1, 2	Novovoronezh 4, 5 Novovoronezh II 1, 2 Rostov 1, 2, 3, 4
Slovak Republic	Slovenské elektrárne, a.s.	Bohunice 3, 4	Mochovce 1, 2
Slovenia	Nuklearna Elektrarna Krško (NEK)	Krško 1	
South Africa	ESKOM	Koeberg 1, 2	
Spain	Asociación Nuclear Ascó-Vandellòs II, A.I.E. (ANAV)	Ascó 1, 2	Vandellós 2
	Centrales Nucleares Almaraz-Trillo (CNAT)	Almaraz 1, 2	Trillo 1
	Iberdrola, S.A.	Cofrentes	
Sweden	Forsmarks Kraftgrupp AB (FKA)	Forsmark 1, 2, 3	
	OKG Aktiebolag (OKG)	Oskarshamn 3	
	Ringhals AB (RAB)	Ringhals 3, 4	
Switzerland	Axpo AG	Beznau 1, 2	
	Kernkraftwerk Gösgen-Däniken AG	Gösgen	
	Kernkraftwerk Leibstadt AG	Leibstadt	
Ukraine	National Nuclear Energy Generating Company "Energoatom"	Khmelnitsky 1, 2 Rivne 1, 2, 3, 4	South Ukraine 1, 2, 3 Zaporizhzhya 1, 2, 3, 4, 5, 6
United Arab Emirates	Nawah Energy Company	Barakah 1	
United Kingdom	EDF Energy	Sizewell B	

Country	Licensee	Plant
United States	American Electric Power Co.	D.C. Cook 1, 2
	Arizona Public Service Co.	Palo Verde 1, 2, 3
	Detroit Edison Co.	Fermi 2
	Dominion Generation	Millstone 2, 3 North Anna 1, 2 Surry 1, 2
	Duke Energy Corp.	Brunswick 1, 2 Catwaba 1, 2 Harris 1 McGuire 1, 2 Oconee 1, 2, 3 Robinson 2
	Energy Northwest	Columbia
	Entergy Nuclear Operations, Inc.	Arkansas One 1, 2 Palisades
	Exelon Generation Co., LLC	Braidwood 1, 2 Byron 1, 2 Calvert Cliffs 1, 2 Clinton 1 Dresden 2, 3 Fitzpatrick 1 Ginna 1 LaSalle County 1, 2 Limerick 1, 2 Nine Mile Point 1, 2 Peach Bottom 2, 3 Quad Cities 1, 2
	FirstEnergy Nuclear Operating Co. (FENOC)	Beaver Valley 1, 2 Davis Besse 1 Perry 1
	Luminant Generation Company, Llc.	Comanche Peak 1, 2
	NextEra Energy Resources, Llc.	Point Beach 1, 2 Seabrook 1 Turkey Point 3, 4
	Pacific Gas & Electric Company	Diablo Canyon 1, 2
	Public Service Electric & Gas Co.	Hope Creek 1 Salem 1, 2
	South Carolina Electric & Gas Co.	Virgil C. Summer 1
	South Texas Project Nuclear Operating Co.	South Texas 1, 2
	Southern Nuclear Operating Co.	Farley 1, 2 Hatch 1, 2 Vogtle 1, 2
	Talen Energy	Susquehanna 1, 2
	Tennessee Valley Authority (TVA)	Browns Ferry 1, 2, 3 Sequoyah 1, 2 Watts Bar 1, 2
	Wolf Creek Nuclear Operation Corp.	Wolf Creek
	Xcel Energy	Monticello Prairie Island 1, 2

Reactors under construction and/or commissioning (9)

Country	Licensee	Plant
China	Fujian Fuqing Nuclear Power Co., Ltd	Fuqing 6
Finland	Fennovoima Oy	Hanhikivi 1
	Teollisuuden Voima Oyj (TVO)	Olkiluoto 3
France	Électricité de France (EDF)	Flamanville 3
United Arab Emirates	Nawah Energy Company	Barakah 2, 3, 4
United States	Southern Nuclear Operating Co.	Vogtle 3, 4

Permanently shut down reactors (77)

Country	Licensee	Plant	
Armenia	Closed Joint Stock Company (CJSC) Armenian Nuclear Power Plant	Medzamor 1	
Bulgaria	Kozloduy Nuclear Power Plant Plc.	Kozloduy 1, 2, 3, 4	
Canada	Hydro Quebec	Gentilly 2	
	Ontario Power Generation	Pickering 2, 3	
France	Électricité de France (EDF)	Bugey 1 Chinon A1, A2, A3 Chooz A	Fessenheim 1, 2 St. Laurent A1, A2
Italy	SOGIN SpA	Caorso Garigliano	Latina Trino
Japan	Chubu Electric Power Co., Inc.	Hamaoka 1, 2	
	Chugoku Electric Power Co., Inc.	Shimane 1	
	Japan Atomic Energy Agency	Fugen	
	Japan Atomic Power Co.	Tokai 1	Tsuruga 1
	Kansai Electric Power Co., Inc.	Mihama 1, 2	Ohi 1, 2
	Kyushu Electric Power Co., Inc.	Genkai 1, 2	
	Shikoku Electric Power Co., Inc.	Ikata 1, 2	
	Tohoku Electric Power Co., Inc.	Onagawa 1	
	Tokyo Electric Power Co.	Fukushima Daiichi 1, 2, 3, 4, 5, 6 Fukushima Daini 1, 2, 3, 4	
Korea	Korea Hydro and Nuclear Power Co., Ltd (KHNP)	Kori 1	Wolsong 1
Lithuania	Ignalina Nuclear Power Plant	Ignalina 1, 2	
Pakistan	Pakistan Atomic Energy Commission (PAEC)	Kanupp 1	
Russia	Rosenergoatom JSC	Novovoronezh 1, 2, 3	
Spain	Centrales Nucleares del Norte, S.A. (NUCLENOR)	Santa María de Garoña	
Sweden	Barsebäck Kraft AB (BKAB)	Barsebäck 1, 2	
	OKG Aktiebolag (OKG)	Oskarshamn 1, 2	
	Ringhals AB (RAB)	Ringhals 1, 2	
Switzerland	BKW Energie AG	Mühleberg	

Country	Licensee	Plant	
United States	Dominion Generation	Kewaunee	Millstone 1
	Duke Energy Corp.	Crystal River 3	
	Exelon Generation Co., LLC	Dresden 1 Oyster Creek 1	TMI 1 Zion 1, 2
	FirstEnergy Nuclear Operating Co. (FENOC)	TMI 2	
	NextEra Energy Resources, Llc.	Duane Arnold 1	
	Omaha Public Power District	Fort Calhoun 1	
	Pacific Gas & Electric Company	Humboldt Bay 3	
	Southern California Edison Co.	San Onofre 1, 2, 3	

Total reactors: 431

Participating regulatory authorities (27)

Country	Authority
Armenia	Armenian Nuclear Regulatory Authority (ANRA)
Belarus	Scientific Practical Centre of Hygiene, Ministry of Health
Belgium	Federal Agency for Nuclear Control (FANC)
Brazil	Brazilian Nuclear Energy Commission (CNEN)
Bulgaria	Bulgarian Nuclear Regulatory Agency (NRA)
Canada	Canadian Nuclear Safety Commission (CNSC)
China	Nuclear and Radiation Safety Centre (NSC)
Finland	Radiation and Nuclear Safety Authority (STUK)
France	Autorité de Sûreté Nucléaire (ASN) Direction Générale du Travail (DGT) du Ministère de l'emploi, de la cohésion sociale et du logement, represented by Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
Germany	Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz (BMUV), represented by Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH
Japan	Nuclear Regulation Authority (NRA)
Korea	Korea Foundation of Nuclear Safety (KoFONS)
Lithuania	State Nuclear Power Safety Inspectorate (VATESI)
Netherlands	Authority for Nuclear Safety and Radiation Protection (ANVS)
Romania	National Commission for Nuclear Activities Control (CNCAN)
Slovak Republic	Public Health Authority of the Slovak Republic (UVZSR)
Slovenia	Slovenian Radiation Protection Administration (SRPA), Ministry of Health Slovenian Nuclear Safety Administration (SNSA)
South Africa	National Nuclear Regulator (NNR)
Spain	Consejo de Seguridad Nuclear (CSN)
Sweden	Swedish Radiation Safety Authority (SSM)
Switzerland	Swiss Federal Nuclear Safety Inspectorate (ENSI)
Ukraine	State Nuclear Regulatory Inspectorate of Ukraine (SNRIU)
United Arab Emirates	Federal Authority for Nuclear Regulation (FANR)
United Kingdom	Office for Nuclear Regulation (ONR)
United States	US Nuclear Regulatory Commission (US NRC)

Country – Technical Centre affiliations

Country	Technical centre*	Country	Technical centre
Armenia	IAEATC	Mexico	NATC
Belarus	IAEATC	Netherlands	ETC
Belgium	ETC	Pakistan	IAEATC
Brazil	IAEATC	Romania	ETC
Bulgaria	ETC	Russia	ETC
Canada	NATC	Slovak Republic	ETC
China	IAEATC	Slovenia	ETC
Czechia	ETC	South Africa	IAEATC
Finland	ETC	Spain	ETC
France	ETC	Sweden	ETC
Germany	ETC	Switzerland	ETC
Hungary	ETC	Ukraine	IAEATC
Italy	ETC	United Arab Emirates	IAEATC
Japan	ATC	United Kingdom	ETC
Korea	ATC	United States	NATC
Lithuania	IAEATC		

* Note: ATC: Asian Technical Centre, IAEATC: IAEA Technical Centre, ETC: European Technical Centre, NATC: North American Technical Centre.

ISOE network and Technical Centre information

ISOE network web portal	
ISOE network	www.isoe-network.net
ISOE Technical Centres	
European region (ETC)	Centre d'étude sur l'évaluation de la protection dans le domaine nucléaire (CEPN) Fontenay-aux-Roses, France www.isoe-network.net
Asian region (ATC)	Nuclear Safety Research Association (NSRA) Tokyo, Japan https://isoeatc.jp/english/
IAEA region (IAEATC)	International Atomic Energy Agency (IAEA), Vienna, Austria Agence Internationale de l'Energie Atomique (AIEA), Vienne, Autriche www-ns.iaea.org/tech-areas/rw-ppss/isoe-iaea-tech-centre.asp
North American region (NATC)	Department of Nuclear, Plasma & Radiological Engineering, The Grainger College of Engineering, University of Illinois Champagne-Urbana, Illinois, United States
Joint Secretariat	
NEA (Paris)	www.oecd-nea.org/jcms/pl_24986/information-system-on-occupational-exposure-isoe-project
IAEA (Vienna)	www-ns.iaea.org/tech-areas/rw-ppss/isoe-iaea-tech-centre.asp

International co-operation

- European Commission (EC).
- International Commission on Radiological Protection (IRPA), status of ISOE as Special Liaison Organisation.
- United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Framework for co-operation to co-ordinate practical arrangements for periodic collection and exchange of data on occupational radiation exposure, signed by UNSCEAR on 18 October 2019, and by ISOE on 6 January 2020.

Technical co-operation agreements

- Sociedade Brasileira de Proteção Radiológica (SBPR), 1 December 2016 – 1 December 2021.
- Oak Ridge Associated Universities (ORAU), 10 January 2017 – 10 January 2022.

Annex 2

ISOE Bureau, Secretariat and Technical Centres

Bureau of the ISOE Management Board

	2017	2018	2019	2020	2021	2022
Chairperson (Licensees)	DO AMARAL, Marcus Antônio Angra Nuclear Power Plant (retired) Brazil		RENN, Guy Sizewell B Nuclear Power Station United Kingdom		BOYER, Bradley R. Tennessee Valley Authority (TVA) United States	
Chairperson Elect (Licensees)	RENN, Guy Sizewell B Nuclear Power Station United Kingdom		BOYER, Bradley R. Watts Bar Nuclear Power Plant United States		WANG, Chuan Nuclear Power Operations Research Institute (CNNC) China	
Vice-Chairperson (Authorities)	INGHAM, Grant Office for Nuclear Regulation (ONR) United Kingdom		AL KATHEERI, Hussain Federal Authority for Nuclear Regulation (FANR) United Arab Emirates		AL KATHEERI, Hussain Federal Authority for Nuclear Regulation (FANR) United Arab Emirates	
Past Chairperson (Licensees)	HWANG, Tae-Won Korea Hydro and Nuclear Power Co., Ltd (KHNP) Korea		DO AMARAL, Marcus Antônio Angra Nuclear Power Plant (retired) Brazil		RENN, Guy Sizewell B Nuclear Power Station United Kingdom	

ISOE Joint Secretariat

Nuclear Energy Agency (NEA)	
LI, Hua Nuclear Energy Agency Division of Radiological Protection and Human Aspects of Nuclear Safety 46, quai Alphonse Le Gallo 92100 Boulogne-Billancourt, France	Tel.: +33 1 73212944 Email: Hua.LI@oecd-nea.org
RAKHUBA, Aleksandr Nuclear Energy Agency Division of Radiological Protection and Human Aspects of Nuclear Safety 46, quai Alphonse Le Gallo 92100 Boulogne-Billancourt, France	Tel.: +33 1 73212936 Email: Aleksandr.RAKHUBA@oecd-nea.org
International Atomic Energy Agency (IAEA)	
MA, Jizeng Radiation Safety and Monitoring Section Division of Radiation, Transport and Waste Safety International Atomic Energy Agency P.O. Box 100, 1400 Vienna, Austria	Tel.: +43 1 2600 26173 Email: J.Ma@iaea.org

ISOE Technical Centres

Asian Technical Centre (ATC)	
YONEHARA, Hidenori Nuclear Safety Research Association (NSRA) 5-18-1, Shinbashi, Minato-ku Tokyo 105-0004, Japan	Tel.: +81 3 5470 1985 Email: isoeatc@nsra.or.jp
European Technical Centre (ETC)	
SCHIEBER, Caroline Centre d'étude sur l'évaluation de la protection dans le domaine nucléaire (CEPN) 28, rue de la Redoute 92260 Fontenay-aux-Roses, France	Tel.: +33 1 55 52 19 39 Email: caroline.schieber@cepn.asso.fr
IAEA Technical Centre (IAEATC)	
MA, Jizeng Radiation Safety and Monitoring Section Division of Radiation, Transport and Waste Safety International Atomic Energy Agency P.O. Box 100, 1400 Vienna, Austria	Tel.: +43 1 2600 26173 Email: J.Ma@iaea.org
North American Technical Centre (NATC)	
MILLER, David W. Department of Nuclear, Plasma & Radiological Engineering The Grainger College of Engineering University of Illinois Faculty Office 100B 216 Talbot Laboratory, MC-234 104 South Wright Street Urbana, Illinois 62801, United States	Tel.: +1 217 855 3238 Email: dmiller@illinois.edu

Annex 3

ISOE Management Board and national co-ordinators (2021)

Note: ISOE national co-ordinators are identified in **bold**.

ARMENIA	
POGHOSYAN, Lusine	Armenian Nuclear Regulatory Authority (ANRA)
PYUSKYULYAN, Konstantin	Medzamor 2 Nuclear Power Plant
BELARUS	
NIKALAYENKA, Alena	Republican Unitary Enterprise "Scientific Practical Centre of Hygiene", Ministry of Health
BELGIUM	
GACKOWSKI, Joris	ENGIE Electrabel
LEMAHIEU, Nathan	Federal Agency for Nuclear Control (FANC)
BRAZIL	
DO AMARAL, Marcos Antônio	Angra Nuclear Power Plant (retired)
(TBD)	Brazilian Nuclear Energy Commission (CNEN)
BULGARIA	
KATZARSKA, Lidia	Bulgarian Nuclear Regulatory Agency
NIKOLOV, Atanas	Kozloduy Nuclear Power Plant
CANADA	
ALLEN, Jennifer	Point Lepreau, Énergie NB Power
CHUI, Benjamin	Darlington Nuclear Generating Station, Ontario Power Generation (OPG)
ELLASCHUK, Bernard	Canadian Nuclear Safety Commission (CNSC)
CHINA	
JIANG, Jianqi	Qinshan Nuclear Power Plant
WANG, Chuan	Nuclear Power Operations Research Institute (CNNC)
YANG, Duanjie	Nuclear and Radiation Safety Centre (MEP)
CZECHIA	
FÁRNÍKOVÁ, Monika	Temelin Nuclear Power Plant, ČEZ a.s.
FINLAND	
KONTIO, Timo	Loviisa Nuclear Power Plant
RIIHILUOMA, Veli	Radiation and Nuclear Safety Authority (STUK)

FRANCE	
DESCAMPS, Xavier	Électricité de France (EDF)
GUENAULT, Charlotte	Autorité de Sûreté Nucléaire (ASN)
WEICKERT, Philippe	Électricité de France (EDF)
GERMANY	
STAHL, Thorsten	Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH
HUNGARY	
BUJTAS, Tibor	Paks Nuclear Power Plant
ITALY	
MANCINI, Francesco	SOGIN SpA
JAPAN	
HIROSE, Tomonori	Kyushu Electric Power Co., Inc.
MIYAZAWA, Akira	Tokyo Electric Power Co. Holdings, Inc.
SUZUKI, Akiko	Nuclear Regulation Authority (NRA)
KOREA	
JU, Sun-Dong	Korea Foundation Nuclear Safety (KOFONS)
KIM, Sungjun	Korea Hydro and Nuclear Power Co., Ltd (KHNP)
ROH, Hyun Suk	Korea Hydro and Nuclear Power Co., Ltd (KHNP)
LITHUANIA	
RAUBA, Kestutis	Ignalina Nuclear Power Plant
TUMOSIENĖ, Kristina	State Nuclear Power Safety Inspectorate (VATESI)
MEXICO	
GIRON PEDROZA, Juan Jesus	Laguna Verde Nuclear Power Plant
NETHERLANDS	
ARENDS, Patrick	Authority for Nuclear Safety and Radiation Protection (ANVS)
MEIJER, Hans	Borssele Nuclear Power Plant, E.P.Z
PAKISTAN	
AHMAD, Rana Iftikhar	Chashma Nuclear Power Plant
ROMANIA	
DOGARU, Daniela	National Commission for Nuclear Activities Control (CNCAN)
NEDELCU, Alexandru	Cernavoda Nuclear Power Plant
RUSSIA	
DOLJENKOV, Igor	Rosenergoatom JSC
SEMENOVYKH, Anton	All-Russia Research Institute for Nuclear Power Plant Operation (VNIIAES), Rosenergoatom JSC
SLOVAK REPUBLIC	
DRÁBOVÁ, Veronika	Public Health Authority of the Slovak Republic (UVZSR)
REMENEC, Boris	Bohunice Nuclear Power Plant

SLOVENIA	
BREZNIK, Borut	Krško Nuclear Power Plant
JUG, Nina	Slovenian Radiation Protection Administration, Ministry of Health
SOUTH AFRICA (REPUBLIC OF)	
MAREE, Marc	Koeberg Nuclear Power Plant
MPETE, Louisa	National Nuclear Regulator (NNR)
SPAIN	
DÍAZ AROCAS, Paloma	Consejo de Seguridad Nuclear (CSN)
GUILLÉN, Nicolás	Almaraz Nuclear Power Plant
SWEDEN	
HANSSON, Petra	Swedish Radiation Safety Authority (SSM)
ISOKIVELÄ, Johannes	Forsmark Nuclear Power Plant
SWITZERLAND	
JAHN, Swen-Gunnar	Swiss Federal Nuclear Safety Inspectorate (ENSI)
RITTER, Andreas	Leibstadt Nuclear Power Plant
UKRAINE	
BEREZHNAYA, Tatyana	National Nuclear Energy Generation Company "Energoatom"
CHEPURNYI, Yurii	State Nuclear Regulatory Inspectorate
UNITED ARAB EMIRATES	
AL KATHEERI, Hussain	Federal Authority for Nuclear Regulation (FANR)
AL NAQBI, Khalifa Abdulla	Nawah Energy Company
UNITED KINGDOM	
REES, Vaughan	Office for Nuclear Regulation (ONR)
RENN, Guy	Sizewell B Nuclear Power Plant
UNITED STATES	
BOYER, Bradley R.	Watts Bar Nuclear Power Plant, Tennessee Valley Authority
SUN, Casper	US Nuclear Regulatory Commission
HOGUE, Nathan	Palo Verde Generating Station, Arizona Public Service

Participation in the ISOE MB meetings in an advisory capacity

Technical Centre representatives

ATC	
NAKAGAWA, Saki	NSRA, Japan
NOMURA, Tomoyuki	NSRA, Japan
YONEHARA, Hidenori	NSRA, Japan
ETC	
BELTRAMI, Laure-Anne	CEPN, France
D'ASCENZO, Lucie	CEPN, France
SCHIEBER, Caroline	CEPN, France
IAEATC	
MA, Jizeng	IAEA, Austria
NATC	
DOTY, Richard	University of Illinois, United States
MILLER, David W.	University of Illinois, United States

Chairs of ISOE working groups

WGDECOM	
RANCHOUX, Gilles	Électricité de France (EDF)

Annex 4

ISOE Working and Task Groups (2021)

Working Group on Radiological Protection Aspects of Decommissioning Activities at Nuclear Power Plants (WGDECOM)

Chair: RANCHOUX, Gilles (France) **Vice-Chair: BELTRAMI, Laure-Anne (France)**

BELGIUM		
	GACKOWSKI, Joris	ENGIE Electrabel
BRAZIL		
	ESTANQUEIRA PINHO, Bruno	Angra Nuclear Power Plant
FRANCE		
	ARIES NASSER, Marie-Eve	Autorité de Sûreté Nucléaire (ASN)
	BELTRAMI, Laure-Anne	European Technical Centre (ETC), CEPN
	BOUSSETTA, Benjamin	EDF – DIPDE
	COUASNON, Olivier	Institut de Radioprotection et de Sûreté Nucléaire (IRSN)
	RANCHOUX, Gilles	EDF – DP2D
	VAILLANT, Ludovic	European Technical Centre (ETC), CEPN
GERMANY		
	DEWALD, Matthias	Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH
ITALY		
	CALDARELLA, Massimiliano	Sogin SpA
KOREA		
	KIM, Minchul	Korean Hydro & Nuclear Power (KHNP)
RUSSIA		
	SHAROV, Dmitrij	VNIIAES, Rosenergoatom JSC
SPAIN		
	DÍAZ AROCAS, Paloma	Consejo de Seguridad Nuclear (CSN)
SWEDEN		
	HANSSON, Petra	Swedish Radiation Safety Authority (SSM)
	LEISVIK, Mathias	BUND (Business Unit Nuclear Decommissioning), Vattenfall
	LJUNGBERG, Annika	Ringhals Nuclear Power Plant, Vattenfall
SWITZERLAND		
	NEUKÄTER, Erwin	Mühleberg Nuclear Power Plant
UNITED STATES		
	MILLER, David W.	North American Technical Centre (NATC), University of Illinois
	SHANNON, Daniel J.	Kewaunee Nuclear Power Station, Dominion Energy

JOINT SECRETARIAT

MA, Jizeng	International Atomic Energy Agency (IAEA)
RAKHUBA, Aleksandr	Nuclear Energy Agency (NEA)
ZHANG,Ye (Author, since 2022)	Nuclear Energy Agency (NEA)

Annex 5

ISOE Publications and International and Regional Symposia

Reports

NEA (2023), *Occupational Exposures at Nuclear Power Plants: Thirtieth Annual Report of the ISOE Programme, 2020*, OECD Publishing, Paris, NEA No. 7659.

NEA (2022), *Occupational Exposures at Nuclear Power Plants: Twenty-Ninth Annual Report of the ISOE Programme, 2019*, OECD Publishing, Paris, NEA No. 7620.

NEA (2021), *Occupational Exposures at Nuclear Power Plants: Twenty-Eights Annual Report of the ISOE Programme, 2018*, OECD Publishing, Paris, NEA No. 7536.

NEA (2020), *Occupational Exposures at Nuclear Power Plants: Twenty-Seventh Annual Report of the ISOE Programme, 2017*, OECD Publishing, Paris, NEA No. 7510.

NEA (2019), *Occupational Exposures at Nuclear Power Plants: Twenty-Sixth Annual Report of the ISOE Programme, 2016*, OECD Publishing, Paris, NEA No. 7453.

NEA (2017), *Occupational Exposures at Nuclear Power Plants: Twenty-Fifth Annual Report of the ISOE Programme, 2015*, OECD Publishing, Paris, NEA/ISOE(2017)20.

NEA (2017), *Occupational Exposures at Nuclear Power Plants: Twenty-Fourth Annual Report of the ISOE Programme, 2014*, OECD Publishing, Paris.

NEA (2017), *Occupational Exposures at Nuclear Power Plants: Twenty-Third Annual Report of the ISOE Programme, 2013*, OECD Publishing, Paris.

NEA (2015), "Occupational Radiation Protection in Severe Accident Management (EG-SAM) Report", NEA/CRPPH/R(2014)5.

NEA (2014), "Radiation Protection Aspects of Primary Water Chemistry and Source-Term Management Report", NEA/CRPPH/R(2014)2.

NEA (2013), "The International System on Occupational Exposure: An ALARA Success Story Relying on Strong Individual Commitments, Effective International Feedback and Exchanges, and a Robust Database", NEA/CRPPH/R(2013)6.

NEA (2012), *Occupational Exposures at Nuclear Power Plants: Twenty-Second Annual Report of the ISOE Programme, 2012*, OECD Publishing, Paris, NEA/CRPPH/ISOE(2012)8.

NEA (2011), *Occupational Exposures at Nuclear Power Plants: Twenty-First Annual Report of the ISOE Programme, 2011*, OECD Publishing, Paris, NEA/CRPPH/ISOE(2011)11.

NEA (2011), *Occupational Exposures at Nuclear Power Plants: Nineteenth Annual Report of the ISOE Programme, 2009*, OECD Publishing, Paris, NEA/CRPPH/R(2011)4.

NEA (2010), *Occupational Exposures at Nuclear Power Plants: Twentieth Annual Report of the ISOE Programme, 2010*, OECD Publishing, Paris, NEA/CRPPH/ISOE(2010)5.

NEA (2010), *L'organisation du travail pour optimiser la radioprotection professionnelle dans les centrales nucléaires*, OECD Publishing, Paris, NEA No. 6400.

NEA (2010), *Occupational Exposures at Nuclear Power Plants: Eighteenth Annual Report of the ISOE Programme, 2008*, OECD Publishing, Paris, NEA No. 6826.

NEA (2009), *Work Management to Optimise Occupational Radiological Protection at Nuclear Power Plants*, OECD Publishing, Paris, NEA No. 6399.

NEA (2009), *Occupational Exposures at Nuclear Power Plants: Seventeenth Annual Report of the ISOE Programme, 2007*, OECD Publishing, Paris, NEA No. 6386.

NEA (2008), *Occupational Exposures at Nuclear Power Plants: Sixteenth Annual Report of the ISOE Programme, 2006*, OECD Publishing, Paris, NEA No. 6318.

NEA (2007), *Occupational Exposures at Nuclear Power Plants: Fifteenth Annual Report of the ISOE Programme, 2005*, OECD Publishing, Paris, NEA No. 6317.

NEA (2006), *Occupational Exposures at Nuclear Power Plants: Fourteenth Annual Report of the ISOE Programme, 2004*, OECD Publishing, Paris, NEA No. 6164.

NEA (2005), *Occupational Exposures at Nuclear Power Plants: Thirteenth Annual Report of the ISOE Programme, 2003*, OECD Publishing, Paris, NEA No. 5414.

NEA (2005), *Optimisation in Operational Radiation Protection*, OECD Publishing, Paris, NEA No. 5411.

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NEA (2002), *Occupational Exposures at Nuclear Power Plants: Eleventh Annual Report of the ISOE Programme, 2001*, OECD Publishing, Paris.

NEA (2002), *ISOE – Information System on Occupational Exposure, Ten Years of Experience*, OECD Publishing, Paris.

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ISOE News

2016	No. 24 (October)
2015	No. 23 (November)
2014	No. 22 (March)
2013	No. 20 (July), No. 21 (December)
2012	No. 19 (July)
2011	No. 17 (September), No. 18 (December)
2010	No. 15 (March), No. 16 (December)
2009	No. 13 (January), No. 14 (July)
2008	No. 12 (October)
2007	No. 10 (July); No. 11 (December)
2006	No. 9 (March)
2005	No. 5 (April); No. 6 (June); No. 7 (October); No. 8 (December)
2004	No. 2 (March); No. 3 (July); No. 4 (December)
2003	No. 1 (December)

ISOE Information Sheets

Asian Technical Centre

No. 45: Nov. 2017	Japanese dosimetric results: FY 2016 data and trends
No. 44: Nov. 2016	Republic of Korea: Summary of national dosimetric trends
No. 43: Nov. 2016	Japanese dosimetric results: FY 2015 data and trends
No. 42: Nov. 2015	Republic of Korea: Summary of National Dosimetric Trends
No. 41: Nov. 2015	Japanese Dosimetric Results: FY 2014 data and trends
No. 40: Nov. 2014	Republic of Korea: Summary of National Dosimetric Trends
No. 39: Oct. 2014	Japanese Dosimetric Results: FY 2013 data and trends
No. 38: Nov. 2013	Republic of Korea: Summary of National Dosimetric Trends
No. 37: Nov. 2013	Japanese Dosimetric Results: FY 2012 data and trends
No. 36: Dec. 2012	Japanese Dosimetric Results: FY 2011 data and trends
No. 35: Nov. 2011	Japanese Dosimetric Results: FY 2010 data and trends
No. 34: Oct. 2009	Republic of Korea: Summary of National Dosimetric Trends
No. 33: Oct. 2009	Japanese Dosimetric Results: FY 2008 data and trends
No. 32: Jan. 2009	Japanese Dosimetric Results: FY 2007 data and trends
No. 31: Nov. 2007	Republic of Korea: Summary of National Dosimetric Trends
No. 30: Oct. 2007	Japanese dosimetric results: FY 2006 data and trends
No. 29: Nov. 2006	Japanese Dosimetric Results : FY 2005 Data and Trends
No. 28: Nov. 2005	Japanese Dosimetric Results : FY 2004 Data and Trends
No. 27: Nov. 2004	Achievements and Issues in Radiation Protection in the Republic of Korea

No. 26: Nov. 2004	Japanese occupational exposure during periodic inspection at PWRs and BWRs ended in FY 2003
No. 25: Nov. 2004	Japanese dosimetric results: FY2003 data and trends
No. 24: Oct. 2003	Japanese Occupational Exposure of Shroud Replacements
No. 23: Oct. 2003	Japanese Occupational Exposure of Steam Generator Replacements
No. 22: Oct. 2003	Korea, Republic of; Summary of National Dosimetric Trends
No. 21: Oct. 2003	Japanese occupational exposure during periodic inspection at PWRs and BWRs ended in FY 2002
No. 20: Oct. 2003	Japanese dosimetric results: FY2002 data and trends
No. 19: Oct. 2002	Korea, Republic of; Summary of National Dosimetric Trends
No. 18: Oct. 2002	Japanese occupational exposure during periodic inspection at PWRs and BWRs ended in FY 2001
No. 17: Oct. 2002	Japanese dosimetric results: FY2001 data and trends
No. 16: Oct. 2001	Japanese occupational exposure during periodical inspection at PWRs and BWRs ended in FY 2000
No. 15: Oct. 2001	Japanese Dosimetric results: FY 2000 data and trends
No. 14: Sept. 2000	Japanese Occupational Exposure During Periodical Inspection at LWRs Ended in FY 1999
No. 13: Sept. 2000	Japanese Dosimetric Results: FY 1999 Data and Trends
No. 12: Oct. 1999	Japanese Occupational Exposure During Periodical Inspection at LWRs Ended in FY 1998
No. 11: Oct. 1999	Japanese Dosimetric Results: FY 1998 Data and Trends
No. 10: Nov. 1999	Experience of 1st Annual Inspection Outage in an ABWR
No. 9: Oct. 1999	Replacement of Reactor Internals and Full System Decontamination at a Japanese BWR
No. 8: Oct. 1998	Japanese Occupational Exposure During Periodical Inspection at LWRs Ended in FY 1997
No. 7: Oct. 1998	Japanese Dosimetric Results: FY 1997 data
No. 6: Sept. 1997	Japanese Occupational Exposure during Periodical Inspection at LWRs ended in FY 1996
No. 5: Sept. 1997	Japanese Dosimetric Results: FY 1996 data
No. 4: July 1996	Japanese Occupational Exposure during Periodical Inspection at LWRs ended in FY 1995
No. 3: July 1996	Japanese Dosimetric Results: FY 1995 data
No. 2: Oct. 1995	Japanese Occupational Exposure during Periodical Inspection at LWRs ended in FY 1994
No. 1: Oct. 1995	Japanese Dosimetric Results: FY 1994 data

European Technical Centre

No. 62: Feb. 2019	Survey on reactor coolant pumps strategies (2018)
No. 61: Mar. 2018	Survey on the values and uses of the monetary of the man·Sievert (in 2017)
No. 60: Nov. 2016	European dosimetric results for 2015
No. 59: Jul. 2016	European dosimetric results for 2014
No. 58: Oct. 2015	European dosimetric results for 2013
No. 57: Sep. 2015	European dosimetric results for 2012
No. 56: Dec. 2012	European dosimetric results for 2011
No. 55: Nov. 2012	Man-Sievert Monetary Value Survey (2012 Update)
No. 54: Feb. 2012	European dosimetric results for 2010
No. 53: Feb. 2011	European dosimetric results for 2009
No. 52: Apr. 2010	PWR Outage Collective Dose: Analysis per sister unit group for the 2002-2007 period
No. 51: Dec. 2009	European dosimetric results for 2008
No. 50: Sep. 2009	Outage duration and outage collective dose between 1996 – 2006 for VVERs
No. 49: Sep. 2009	Outage duration and outage collective dose between 1996 – 2006 for BWRs
No. 48: Sep. 2009	Outage duration and outage collective dose between 1996 – 2006 for PWRs
No. 47: Feb. 2009	European dosimetric results for 2007
No. 46: Oct. 2007	European dosimetric results for 2006
No. 44: July 2006	Preliminary European dosimetric results for 2005
No. 43: May 2006	Conclusions and recommendations from the Essen Symposium
No. 42: Nov. 2005	Self-employed Workers in Europe
No. 41: Oct. 2005	Update of the annual outage duration and doses in European reactors (1994-2004)
No. 40: Aug. 2005	Workers internal contamination practices survey
No. 39: July 2005	Preliminary European dosimetric results for 2004
No. 38: Nov. 2004	Update of the annual outage duration and doses in European reactors (1993-2003)
No. 37: July 2004	Conclusions and recommendations from the 4th European ISOE workshop on occupational exposure management at NPPs
No. 36: Oct. 2003	Update of the annual outage duration and doses in European reactors (1993-2002)
No. 35: July 2003	Preliminary European dosimetric results for 2002
No. 34: July 2003	Man-Sievert monetary value survey (2002 update)
No. 33: March 2003	Update of the annual outage duration and doses in European reactors (1993-2001)
No. 32: Nov. 2002	Conclusions and Recommendations from the 3rd European ISOE Workshop on Occupational Exposure Management at Nuclear Power Plants
No. 31: July 2002	Preliminary European Dosimetric Results for the year 2001
No. 30: April 2002	Occupational exposure and steam generator replacements – update

No. 29: April 2002	Implementation of Basic Safety Standards in the regulations of European countries
No. 28: Dec. 2001	Trends in collective doses per job from 1995 to 2000
No. 27: Oct. 2001	Annual outage duration and doses in European reactors
No. 26: July 2001	Preliminary European Dosimetric Results for the year 2000
No. 25: June 2000	Conclusions and recommendations from the 2nd EC/ISOE workshop on occupational exposure management at nuclear power plants
No. 24: June 2000	List of BWR and CANDU sister unit groups
No. 23: June 2000	Preliminary European Dosimetric Results 1999
No. 22: May 2000	Analysis of the evolution of collective dose related to insulation jobs in some European PWRs
No. 21: May 2000	Investigation on access and dosimetric follow-up rules in NPPs for foreign workers
No. 20: April 1999	Preliminary European Dosimetric Results 1998
No. 19: Oct. 1998	ISOE 3 data base – New ISOE 3 Questionnaires received (since Sept 1998)
No. 18: Sept. 1998	The Use of the man-Sievert monetary value in 1997
No. 17: Dec. 1998	Occupational Exposure and Steam Generator Replacements, update
No. 16: July 1998	Preliminary European Dosimetric Results for 1997
No. 15: Sept. 1998	PWR collective dose per job 1994-1995-1996 data
No. 14: July 1998	PWR collective dose per job 1994-1995-1996 data
No. 12: Sept. 1997	Occupational exposure and reactor vessel annealing
No. 11: Sept. 1997	Annual individual doses distributions: data available and statistical biases
No. 10: June 1997	Preliminary European Dosimetric Results for 1996
No. 9: Dec. 1996	Reactor Vessel Closure Head Replacement
No. 7: June 1996	Preliminary European Dosimetric Results for 1995
No. 6: April 1996	Overview of the first three Full System Decontamination
No. 4: June 1995	Preliminary European Dosimetric Results for 1994
No. 3: June 1994	First European Dosimetric Results: 1993 data
No. 2: May 1994	The influence of reactor age and installed power on collective dose: 1992 data
No. 1: April 1994	Occupational Exposure and Steam Generator Replacement

IAEA Technical Centre

No. 9: Aug. 2003	Preliminary dosimetric results for 2002
No. 8: Nov. 2002	Conclusions and Recommendations from the 3rd European ISOE Workshop on Occupational Exposure Management at Nuclear Power Plants
No. 7: Oct. 2002	Information on exposure data collected for the year 2001
No. 6: June 2001	Preliminary dosimetric results for 2000
No. 5: Sept. 2000	Preliminary dosimetric results for 1999

No. 4: April 1999	IAEA Workshop on implementation and management of the ALARA principle in nuclear power plant operations, Vienna 22-23 April 1998
No. 3: April 1999	IAEA technical co-operation projects on improving occupational radiation protection in nuclear power plants
No. 2: April 1999	IAEA Publications on occupational radiation protection
No. 1: Oct. 1995	ISOE Expert meeting

North American Technical Centre

2021-30: Aug. 2021	NATC NPRE: BWR Refueling Outage Work Scope Deferral Due to Global COVID-19 Pandemic
Jan. 2021	NATC ISOE Newsletter No. 10
2020-21: May 2020	NATC Major Task Analysis Series for ALARA Planners: Braidwood 1, 2 PWR 4-Loop Rx Coolant Pump Motor Replacement Task Dose Analysis, Good Practices and Lessons Learned
2020-13: May 2020	NATC Major Task Analysis Series for ALARA Planners: Cook Units 1, 2 Westinghouse PWR 4-Loop Reactor Dis/Reassembly Task Dose Analysis, Good Practices and Lessons Learned
2020-12: May 2020	NATC Major Task Analysis Series for ALARA Planners: Watts Bar Units 1, 2 Westinghouse PWR 4-Loop Reactor Dis/Reassembly Task Dose Analysis, Good Practices and Lessons Learned
2020-11: May 2020	NATC Major Task Analysis Series for ALARA Planners: Braidwood units 1, 2 Westinghouse PWR 4-Loop Reactor Dis/Reassembly Task Dose Analysis, Good Practices and Lessons Learned
2020-3: May 2020	2019 Annual Dose Comparisons Canada Reactors (CANDU) 2019 Occupational Dose Benchmarking Charts
2019-3: May 2020	2018 Annual Dose Comparisons Canada Reactors (CANDU) 2018 Occupational Dose Benchmarking Charts
2018-1: Jun. 2018	3-Year Rolling Average Annual Dose Comparisons Canada Reactors (CANDU) 2015-2017 Occupational Dose Benchmarking Charts
2017-5: Jun. 2017	3-Year Rolling Average Annual Dose Comparisons Canada Reactors (CANDU) 2014-2016 Occupational Dose Benchmarking Charts
2017-4: Sept. 2017	North American Boiling Water Reactor (BWR) 2016 Occupational Dose Benchmarking Charts
2017-3: Sept. 2017	North American Pressurized Water Reactor (PWR) 2016 Occupational Dose Benchmarking Charts
2017-2: Sept. 2017	North American Boiling Water Reactor (BWR) 2015 Occupational Dose Benchmarking Charts
2017-1: Sept. 2017	North American Pressurized Water Reactor (PWR) 2015 Occupational Dose Benchmarking Charts
2016-1: Jun 2016	3-Year Rolling Average Annual Dose Comparisons Canada Reactors (CANDU) 2013-2015 Occupational Dose Benchmarking Charts
2015-1: Jun. 2015	3-Year Rolling Average Annual Dose Comparisons Canada Reactors (CANDU) 2012-2014 Occupational Dose Benchmarking Charts

2014-3: Jun. 2014	3-Year Rolling Average Annual Dose Comparisons Canada Reactors (CANDU) 2011-2013 Occupational Dose Benchmarking Charts
2014-2: Aug. 2014	Kewaunee PWR Low Dose Outage Worker Study
2014-1: July 2014	North American Pressurized Water Reactor (PWR) 2013 Occupational Dose Benchmarking Charts
2012-13: Sept. 2012	2011 CANDU Occupational Dose Benchmarking Charts
2012-12: July 2012	North American Boiling Water Reactor (BWR) 2008 Occupational Dose Benchmarking Charts
2012-11: July 2012	North American Pressurized Water Reactor (PWR) 2008 Occupational Dose Benchmarking Charts
2012-10: July 2012	North American Boiling Water Reactor (BWR) 2007 Occupational Dose Benchmarking Charts
2012-9: July 2012	North American Pressurized Water Reactor (PWR) 2007 Occupational Dose Benchmarking Charts
2012-8: Sept. 2012	North American Boiling Water Reactor (BWR) 2011 Occupational Dose Benchmarking Charts
2012-7: Sept. 2012	North American Pressurized Water Reactor (PWR) 2011 Occupational Dose Benchmarking Charts
2012-6: Sept. 2012	North American Pressurized Water Reactor (PWR) 2011 Occupational Dose Benchmarking Charts
2012-5: July 2012	North American Pressurized Water Reactor (PWR) 2010 Occupational Dose Benchmarking Charts
2012-4: July 2012	North American Boiling Water Reactor (BWR) 2009 Occupational Dose Benchmarking Charts
2012-3: July 2012	North American Pressurized Water Reactor (PWR) 2009 Occupational Dose Benchmarking Charts
2012-2: July 2012	North American Boiling Water Reactor (BWR) 2006 Occupational Dose Benchmarking Charts
2012-1: July 2012	North American Pressurized Water Reactor (PWR) 2006 Occupational Dose Benchmarking Charts
2010-14: June 2010	NATC Analysis of Teledosimetry Data from Multiple PWR Unit Outage CRUD Bursts
2003-8: Aug. 2003	US PWR – Reactor Head Replacement Dose Benchmarking Study
2003-5: July 2003	North American BWR – 2002 Occupational Dose Benchmarking Charts
2003-4: July 2003	U.S. PWR – 2002 Occupational Dose Benchmarking Chart
2003-2: July 2003	3-Year rolling average annual dose comparisons – US BWR 2000-2002 Occupational Dose Benchmarking Charts
2003-1: July 2003	3-Year rolling average annual dose comparisons – US PWR 2000-2002 Occupational Dose Benchmarking Charts
2002-5: July 2002	US BWR – 2001 Occupational Dose Benchmarking Chart
2002-4: July 2002	US PWR – 2001Occupational Dose Benchmarking Chart
2002-2: July 2002	3-Year rolling average annual dose comparisons – US BWR 1999-2001 Occupational Dose Benchmarking Charts

2002-1: Nov. 2002	3-Year rolling average annual dose comparisons – US PWR 1999-2001 Occupational Dose Benchmarking Charts
2001-7: Nov. 2001	US PWR 5-Year Dose Reduction Plan: Donald C. Cook Nuclear Power Plant
2001-5: Dec. 2001	US BWR – 2000 Occupational Dose Benchmarking Chart
2001-4: Dec. 2001	US PWR – 2000 Occupational Dose Benchmarking Chart
2001-3: Nov. 2001	3-Year rolling average annual dose comparisons – Canada reactors (CANDU) 1998-2000 Occupational Dose Benchmarking Charts
2001-2: July 2001	3-Year rolling average annual dose comparisons – US BWR 1998-2000 Occupational Dose Benchmarking Charts
2001-1: July 2001	3-Year rolling average annual dose comparisons – US PWR 1998-2000 Occupational Dose Benchmarking Charts

ISOE International and Regional Symposia

Asian Technical Centre

Sep. 2019 (Ehime, Japan)	2018 ISOE ATC Benchmarking
Oct. 2018 (Kyoto, Japan)	2018 ISOE International Symposium
Sep. 2016 (Fukushima, Japan)	2016 ISOE Asian ALARA Symposium
Sep. 2015 (Tokyo, Japan)	2015 ISOE Asian ALARA Symposium
Sep. 2014 (Gyeongju, Korea)	2014 ISOE Asian ALARA Symposium
Aug. 2013 (Tokyo, Japan)	2013 ISOE International ALARA Symposium
Sep. 2012 (Tokyo, Japan)	2012 ISOE Asian ALARA Symposium
Aug. 2010 (Gyeongju, Korea)	2010 ISOE Asian ALARA Symposium
Sep. 2009 (Aomori, Japan)	2009 ISOE Asian ALARA Symposium
Nov. 2008 (Tsuruga, Japan)	2008 ISOE International ALARA Symposium
Sep. 2007 (Seoul, Korea)	2007 ISOE Asian Regional ALARA Symposium
Oct. 2006 (Yuzawa, Japan)	2006 ISOE Asian Regional ALARA Symposium
Nov. 2005 (Hamaoka, Japan)	First Asian ALARA Symposium

European Technical Centre

Jun. 2021 (Virtual)	2021 ISOE European Symposium – Webinar
Jun. 2018 (Uppsala, Sweden)	2018 ISOE European Symposium
Jun. 2016 (Brussels, Belgium)	2016 ISOE International ALARA Symposium
Apr. 2014 (Bern, Switzerland)	2014 ISOE European ALARA Symposium
Jun. 2012 (Prague, Czechia)	2012 ISOE European Regional ALARA Symposium
Nov. 2010 (Cambridge, UK)	2010 ISOE International ALARA Symposium
Jun. 2008 (Turku, Finland)	2008 ISOE European Regional ALARA Symposium
Mar. 2006 (Essen, Germany)	2006 ISOE International ALARA Symposium
Mar. 2004 (Lyon, France)	Fourth ISOE European Workshop on Occupational Exposure Management at Nuclear Power Plants

Apr. 2002 (Portoroz, Slovenia)	Third ISOE European Workshop on Occupational Exposure Management at Nuclear Power Plants
Apr. 2000 (Tarragona, Spain)	Second EC/ISOE Workshop on Occupational Exposure Management at Nuclear Power Plants
Sep. 1998 (Malmö, Sweden)	First EC/ISOE Workshop on Occupational Exposure Management at Nuclear Power Plants

IAEA Technical Centre

Oct. 2019 (Beijing, People's Republic of China)	2019 ISOE International ALARA Symposium
May 2015 (Rio de Janeiro, Brazil)	2015 ISOE International ALARA Symposium
Oct. 2009 (Vienna, Austria)	2009 ISOE International ALARA Symposium

North American Technical Centre

Jan. 2021 (Virtual)	2021 ISOE North American ALARA Symposium
Jan. 2020 (Key West, FL, US)	2020 ISOE North American ALARA Symposium
Jan. 2019 (Key West, FL, US)	2019 ISOE North American ALARA Symposium
Jan. 2018 (Ft. Lauderdale, FL, US)	2018 ISOE North American ALARA Symposium
Jan. 2017 (Ft. Lauderdale, FL, US)	2017 ISOE International ALARA Symposium
Jan. 2016 (Ft. Lauderdale, FL, US)	2016 ISOE North American ALARA Symposium
Jan. 2015 (Ft. Lauderdale, FL, US)	2015 ISOE North American ALARA Symposium
Jan. 2014 (Ft. Lauderdale, FL, US)	2014 ISOE North American ALARA Symposium
Jan. 2013 (Ft. Lauderdale, FL, US)	2013 ISOE North American ALARA Symposium
Jan. 2012 (Ft. Lauderdale, FL, US)	2012 ISOE International ALARA Symposium
Jan. 2011 (Ft. Lauderdale, FL, US)	2011 ISOE North American ALARA Symposium
Jan. 2010 (Ft. Lauderdale, FL, US)	2010 ISOE North American ALARA Symposium
Jan. 2009 (Ft. Lauderdale, FL, US)	2009 ISOE North American ALARA Symposium
Jan. 2008 (Ft. Lauderdale, FL, US)	2008 ISOE North American ALARA Symposium
Jan. 2007 (Ft. Lauderdale, FL, US)	2007 ISOE International ALARA Symposium
Jan. 2006 (Ft. Lauderdale, FL, US)	2006 ISOE North American ALARA Symposium
Jan. 2005 (Ft. Lauderdale, FL, US)	2005 ISOE International ALARA Symposium
Jan. 2004 (Ft. Lauderdale, FL, US)	2004 North American ALARA Symposium
Jan. 2003 (Orlando, FL, US)	2003 International ALARA Symposium
Feb. 2002 (Orlando, FL, US)	North American National ALARA Symposium
Feb. 2001 (Orlando, FL, US)	2001 International ALARA Symposium
Jan. 2000 (Orlando, FL, US)	North American National ALARA Symposium
Jan. 1999 (Orlando, FL, US)	Second International ALARA Symposium
Mar. 1997 (Orlando, FL, US)	First International ALARA Symposium

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Occupational Exposures at Nuclear Power Plants

This 31th Annual Report of the International System on Occupational Exposure (ISOE) presents the status of the programme for the year 2021. As of 31 December 2021, the ISOE programme included 79 participating licensees (covering 345 operating units, 9 units under construction and/or commissioning, and 77 shut down units) and 27 regulatory authorities in 31 countries. The ISOE database contained occupational exposure information for 514 units, covering over 86% of the world's operating commercial power reactors. This report includes global occupational exposure data and analyses, information on the overall programme status and achievements, as well as the principal events in participating countries in the year 2021.

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