National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Environmental radioactivity in the Netherlands

Results in 2018

National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Environmental radioactivity in the Netherlands

Results in 2018

RIVM report 2019-0216

Colophon

DOI 10.21945/RIVM-2019-0216

C.P. Tanzi (editor), RIVM

Contact:
Cristina Tanzi
Centre for Environmental Safety and Security
cristina.tanzi@rivm.nl

National Institute for Public Health and the Environment
Ministry of Health, Welfare and Sport

Rijkswaterstaat
Ministry of Infrastructure and Water Management

Netherlands Food and Consumer Product Safety Authority
Ministry of Agriculture, Nature and Food Quality

RIKILT
WAGENINGEN UR

EPZ N.V. Elektriciteits-Produktiemaatschappij Zuid-Nederland EPZ

This investigation has been performed by order and for the account of the Authority for Nuclear Safety and Radiation Protection, within the framework of Project 390120: environmental monitoring of radioactivity and radiation.

Published by:
National Institute for Public Health and the Environment, RIVM
P.O. Box 1 | 3720 BA Bilthoven
The Netherlands
www.rivm.nl/en

Synopsis

Environmental radioactivity in the Netherlands
Results in 2018

In 2018, the Netherlands fulfilled its annual European obligation to measure how much radioactivity is present in the environment and in food. All countries of the European Union are required to perform these measurements each year under the terms of the Euratom Treaty of 1957. The Netherlands performs these measurements following the guidance issued in 2000. The measurements represent the background values for radioactivity that are present under normal circumstances. They can be used as reference values, for instance, during a nuclear emergency. The results on radioactivity in the environment are reported to the European Commission by the National Institute for Public Health and the Environment (RIVM) on behalf of the competent authority in the Netherlands.

Radioactivity in air, food, milk, grass and feed
Radioactivity levels in the air were normal and similar to previous years. Radioactivity levels in food and milk were below the European export and consumption limits. The radioactivity levels in grass and feed were also normal, as in previous years.

Radioactivity in surface water, seawater and drinking water
Radioactivity levels in surface water and seawater were similar to previous years. The levels of radioactivity in most of the samples (more than 97 percent) of untreated water for drinking water production were well below the so-called screening levels: above these levels further investigation should be carried out. The levels of a small number of samples were slightly above the screening level. These measured radioactivity levels do not pose a threat to health. Further investigation revealed that radioactivity levels in associated finished drinking water were well below the screening levels.

Keywords: radioactivity, environment, airborne particles, water, food, milk

Publiekssamenvatting

Radioactiviteit in het Nederlandse milieu
Resultaten in 2018

In 2018 voldeed Nederland aan de Europese verplichting om elk jaar te meten hoeveel radioactiviteit in het milieu en in voeding zit. Alle landen van de Europese Unie zijn volgens het Euratom-verdrag uit 1957 verplicht om dat te doen. Nederland volgt daarbij de aanbevelingen op uit 2000 om de metingen op een bepaalde manier uit te voeren. De metingen leveren achtergrondwaarden op, ofwel radioactiviteitsniveaus die er onder normale omstandigheden zijn. Deze waarden kunnen bij bijvoorbeeld calamiteiten of rampen als referentie dienen. Het RIVM brengt namens Nederland verslag uit aan de Europese Unie over radioactiviteit in het milieu.

Radioactiviteit in lucht, voedsel, melk, gras en veevoer
De radioactiviteitsniveaus in lucht laten een normaal beeld zien, net als in eerdere jaren. De radioactiviteitsniveaus in voedsel en melk liggen net als in vorige jaren onder de Europese limieten voor consumptie en export. Ook de radioactiviteitsniveaus in gras en veevoer laten een normaal beeld zien, net als de jaren ervoor.

Radioactiviteit in oppervlaktewater, zeewater en drinkwater
De radioactiviteitsniveaus in oppervlaktewater en zeewater zijn vergelijkbaar met die van eerdere jaren. De niveaus van het merendeel van de monsters (meer dan 97 procent) van ongezuiverd water voor de drinkwaterproductie liggen onder de zogeheten referentiewaarde; boven deze waarde moet verder onderzoek worden uitgevoerd. De niveaus van een klein aantal monsters ongezuiverd water zaten daar licht boven. Deze verhogingen zijn zo klein dat ze niet schadelijk zijn voor de gezondheid. Het vervolgonderzoek liet ziet dat de niveaus in het gezuiverde drinkwater ruim onder de referentiewaarden lagen.

Kernwoorden: radioactiviteit, milieu, luchtstof, water, voedsel, melk

Acknowledgements

The following institutions contributed to this report:

The National Institute for Public Health and the Environment
Rijksinstituut voor Volksgezondheid en Milieu (RIVM)
Data on air dust, deposition, ambient dose rates and drinking water.
Dr. C.P. Tanzi (editor), ing. G.J. Knetsch, ing. R.B. Tax, ing. M. Boshuis, dr. H.H.J. Dik

Rijkswaterstaat (RWS)
Data on seawater and surface water from the main inland water bodies.
C. Engeler, A. Baak

The Netherlands Food and Consumer Product Safety Authority
Nederlandse Voedsel en Waren Autoriteit (NVWA)
Data on foodstuffs.
E. Laurensse

RIKILT Wageningen UR
Data on milk and foodstuffs.
ir. S.T. van Tuinen, C. Onstenk, ing. A. Vos van Avezathe

N.V. Elektriciteits-Produktiemaatschappij Zuid-Nederland (EPZ)
Data on environmental samples taken near the Borssele nuclear power plant, measured by the Nuclear Research & Consultancy Group (NRG).
D.A. de Schipper

Contents

Summary

The Dutch government is obliged to establish the necessary arrangements to carry out continuous monitoring of the level of radioactivity in air, water and soil under the terms of the Euratom Treaty of 1957. In 2000, the European Commission issued recommendations stipulating the matrices to be measured (air dust, ambient dose rate, surface water, drinking water, milk and food) and stipulating the frequency of the measurements. The results shall be reported to the European Commission annually.

In 2018, the Netherlands complied with the Euratom recommendations on annually measuring radioactivity in the environment and in food. The measurements were carried out by RIVM, RWS, RIKILT, NVWA and, commissioned by N.V. EPZ, NRG. This report presents the results of radioactivity measurements performed in the Dutch environment in 2018.

Yearly average activity concentrations in air dust were determined for gross α, gross β, ^{7}Be, ^{137}Cs and ^{210}Pb. The yearly total activity in deposition was determined for gross α, gross β, ^{3}H, ^{7}Be, ^{137}Cs, ^{210}Pb and ^{210}Po. Gross α and gross β are the total activity of radionuclides emitting α and β radiation, respectively. The results, which are presented in Table S1 below, are within the range of those presented in previous years.

The National Radioactivity Monitoring Network (NMR) was also used to determine the activity concentrations of gross α and artificial β (β radiation emitted by man-made radionuclides) in air dust. There is a difference between the NMR data and the gross α and gross β data mentioned above, which is due to the contribution of short-lived natural radionuclides (radon daughters) to the NMR data. The yearly average gross α activity concentration in air dust was 4.1 Bq·m^{-3}. This level was higher than in previous years and is attributed to a long period with little precipitation. The yearly average of the artificial β activity concentration did not deviate significantly from zero. The NMR was also used to determine the ambient dose equivalent rate: the yearly average was 82 nSv·h^{-1}.

In surface water, the yearly average activity concentrations of gross α, residual β (gross β minus naturally occurring ^{40}K), ^{3}H, ^{90}Sr and ^{226}Ra were determined. The yearly average activity concentrations of ^{60}Co, ^{131}I, ^{137}Cs and ^{210}Pb in suspended solids in surface water were also determined. In seawater, the yearly average activity concentrations were determined for gross α, residual β, ^{3}H and ^{90}Sr. The yearly average activity concentrations of ^{137}Cs and ^{210}Pb in suspended solids in seawater were also determined. The results are presented in Table S1.

The yearly average gross α, residual β, ^{3}H, ^{90}Sr and ^{226}Ra activity concentrations in surface water were within the range of those found in previous years**.** The yearly average ^{60}Co, ^{131}I, ^{137}Cs and ^{210}Pb activity concentrations in suspended solids in surface water were within the range of those found in previous years.

The yearly average gross α, residual β, ^{3}H and ^{90}Sr activity concentrations in seawater were within the range of those found in previous years. The yearly average ^{137}Cs and ^{210}Pb activity concentrations in suspended solids in seawater were within the range of those found in previous years.

Typical activities found in water used for drinking water production (untreated as well as treated) are presented in Table S1. There is little potassium (and thus ^{40}K) present in this water. The gross α activity concentration in untreated water used to produce drinking water, averaged per production station, exceeded the screening level (0.1 $Bq \cdot L^{-1}$) at 4 of the 182 production stations (on an average of 11 analyses over a total of 439). Further investigation into these slightly elevated levels in untreated water revealed that the gross α activity concentration in associated finished drinking water was well below the screening level. The gross β activity concentrations were below the screening level (1.0 $Bq \cdot L^{-1}$) and the ^{3}H activity concentrations were below the parametric value of 100 $Bq \cdot L^{-1}$.

The results of the monitoring programme for milk and food are presented in Table S1. Radioactivity was measured in 638 milk samples and in about 2,100 food products. Of these food products, 33 samples of game and two samples of fruit jam originating from Poland contained ^{137}Cs: the activity concentration varied from 5 up to 380 $Bq \cdot kg^{-1}$. None of the samples exceeded the limit of 600 $Bq \cdot kg^{-1}$ for food or the limit of 370 $Bq \cdot kg^{-1}$ for milk and dairy products.

The measured activity concentrations of ^{90}Sr, ^{134}Cs and ^{137}Cs in food in $Bq \cdot kg^{-1}$ were converted to an average daily intake value per person per day ($Bq \cdot day^{-1}$) using food consumption patterns. The average daily intake per person of ^{134}Cs, ^{137}Cs and ^{90}Sr is < 5 $Bq \cdot day^{-1}$, for each of the nuclides separately. The contribution to the effective yearly dose calculated from these average daily intake values is < 0.12 mSv. The actual daily intake (and following dose contribution) is most likely much lower.

None of the grass and feed samples contained measurable levels of artificial radionuclides (^{60}Co, ^{131}I, ^{132}Te, ^{134}Cs and ^{137}Cs).

Data on environmental samples taken near the Borssele nuclear power plant are presented in Table S2.

Samenvatting

In het kader van het Euratom Verdrag uit 1957 is de Nederlandse overheid verplicht om voorzieningen te treffen om radioactiviteitsgehalten te monitoren in de compartimenten lucht, water en bodem. In 2000 heeft de Europese Commissie aanbevelingen uitgegeven waarin in detail is beschreven wat moet worden gemeten (luchtstof, het omgevingsdosisequivalenttempo, oppervlaktewater, drinkwater, melk en voedsel) en met welke frequentie. De resultaten dienen jaarlijks te worden gerapporteerd aan de Europese Commissie.

Dit rapport bevat de resultaten van radioactiviteitsmetingen in het Nederlandse milieu in 2018. De metingen zijn verricht door RIVM, RWS, RIKILT, NVWA en, in opdracht van N.V. EPZ, NRG. Nederland voldeed in 2018 aan de Europese aanbevelingen ten aanzien van de jaarlijkse radioactiviteitsmetingen in het milieu en in voedsel.

In luchtstof werd de jaargemiddelde activiteitsconcentratie bepaald van totaal-α, totaal-β, ^{7}Be, ^{137}Cs en ^{210}Pb. In depositie werd de totale jaarlijkse activiteit bepaald van totaal-α, totaal-β, ^{3}H, ^{7}Be, ^{137}Cs, ^{210}Pb en ^{210}Po. Totaal-α respectievelijk totaal-β is de totale activiteit aan α- dan wel β-straling uitzendende radionucliden. De resultaten zijn weergegeven in Tabel S1 en vallen binnen de spreiding van de resultaten van voorgaande jaren.

Met het Nationaal Meetnet Radioactiviteit (NMR) werden activiteitsconcentraties bepaald in luchtstof voor totaal-α en kunstmatige-β (β-straling uitgezonden door radionucliden, ontstaan door menselijk handelen). Er is een verschil tussen de NMR-metingen en bovenstaande totaal-α- en totaal-β-metingen, wat wordt veroorzaakt door de bijdrage van kortlevende natuurlijke radionucliden (radondochters).
Het jaargemiddelde voor de totaal-α-activiteitsconcentratie in luchtstof was 4,1 Bq·m^{-3}; dat is hoger dan voorgaande jaren, en is toe te schrijven aan een lange periode met heel weinig neerslag. Het jaargemiddelde voor de kunstmatige β-activiteitsconcentratie in luchtstof week niet significant af van nul. Met het NMR werd daarnaast het omgevingsdosisequivalenttempo bepaald; het jaargemiddelde was 82 nSv·h^{-1}.

In oppervlaktewater werd de jaargemiddelde activiteitsconcentratie bepaald van totaal-α, rest-β (totaal-β minus het van nature aanwezige ^{40}K), ^{3}H, ^{90}Sr en ^{226}Ra en de jaargemiddelde activiteitsconcentratie van ^{60}Co, ^{131}I, ^{137}Cs en ^{210}Pb in zwevend stof.
In zeewater werd de jaargemiddelde activiteitsconcentratie bepaald van totaal-α, rest-β, ^{3}H en ^{90}Sr. In zwevend stof in zeewater werd de jaargemiddelde activiteitsconcentratie bepaald van ^{137}Cs en ^{210}Pb. De resultaten zijn weergegeven in Tabel S1.

De jaargemiddelde activiteitsconcentraties van totaal-α, rest-β (totaal-β minus het van nature aanwezige ^{40}K), ^{3}H, ^{90}Sr en ^{226}Ra in oppervlaktewater vallen binnen de spreiding van de resultaten van voorgaande jaren. De jaargemiddelde activiteitsconcentraties van ^{60}Co,

^{131}I, ^{137}Cs en ^{210}Pb in zwevend stof in oppervlaktewater vallen binnen de spreiding van de resultaten van voorgaande jaren.
De jaargemiddelde totaal α-, rest β-, ^{3}H- en ^{90}Sr-activiteitsconcentraties in zeewater vallen binnen de spreiding van de resultaten van voorgaande jaren. De jaargemiddelde ^{137}Cs- en ^{210}Pb-activiteitsconcentraties in zwevend stof in zeewater vallen binnen de spreiding van de resultaten van voorgaande jaren.

Gangbare activiteitsconcentraties die in water (zowel ongezuiverd als gezuiverd) voor de drinkwaterproductie gevonden worden, zijn weergegeven in Tabel S1. In dit water is een geringe hoeveelheid kalium, en dus ^{40}K, aanwezig. In 2018 overschreed de totaal α-activiteitsconcentratie in ongezuiverd water voor drinkwaterproductie per productiestation de screeningswaarde van 0,1 $Bq \cdot L^{-1}$ bij 4 van de 182 productiestations (een gemiddelde van 11 uitgevoerde analyses over een totaal van 439). Deze verhogingen zijn zodanig laag dat ze niet schadelijk zijn voor de gezondheid. Additioneel onderzoek naar aanleiding van de licht verhoogde niveaus in ongezuiverd water toonde aan dat de niveaus in het gezuiverde drinkwater ruim onder de screeningswaarden lagen. De totaal β-activiteitsconcentraties waren lager dan de screeningwaarde van 1,0 $Bq \cdot L^{-1}$ en de ^{3}H-activiteitsconcentraties waren lager dan de parametrische waarde van 100 $Bq \cdot L^{-1}$.

De resultaten van het meetprogramma voor melk en voedsel zijn weergegeven in Tabel S1. Radioactiviteit werd geanalyseerd in 638 melkmonsters en ongeveer 2100 voedselproducten, waarvan 33 monsters wild en twee monsters jam afkomstig uit Polen, ^{137}Cs bevatten. De gemeten activiteitsconcentraties van ^{137}Cs lagen tussen 5 en 380 $Bq \cdot kg^{-1}$. De limieten voor radiocesium (som van ^{134}Cs en ^{137}Cs) in voedsel (600 $Bq \cdot kg^{-1}$) en melk en melkproducten (370 $Bq \cdot kg^{-1}$) werden niet overschreden.

De gemeten activiteitsconcentraties ^{90}Sr, ^{134}Cs en ^{137}Cs ($Bq \cdot kg^{-1}$) in voedsel zijn omgerekend naar een gemiddelde dagelijkse opname per persoon per dag ($Bq \cdot dag^{-1}$) door gebruik te maken van voedselconsumptiepatronen. De gemiddelde dagelijkse opname per persoon is < 5 $Bq \cdot dag^{-1}$ afzonderlijk voor elk van de nucliden ^{134}Cs, ^{137}Cs en ^{90}Sr. De bijdrage aan de effectieve jaardosis berekend uit deze waarden was < 0,12 mSv. De werkelijke dagelijkse opname (en daaruit volgende bijdrage aan de jaardosis) is vermoedelijk veel lager.

Geen van de geanalyseerde monsters gras en veevoer bevatten meetbare hoeveelheden van kunstmatige radionucliden (^{60}Co, ^{131}I, ^{132}Te, ^{134}Cs en ^{137}Cs).

Gegevens betreffende milieumonsters genomen rondom de kerncentrale Borssele zijn weergegeven in Tabel S2.

Table S1 Summary of the results from the Dutch monitoring programme in 2018

Matrix	Parameter	Locations	Values	Frequency (per year)
Air dust (1)	Gross α	1	0.023 mBq·m^{-3}	51
	Gross β	1	0.448 mBq·m^{-3}	51
	^{7}Be	1	3.540 mBq·m^{-3}	51
	^{137}Cs	1	0.000266 mBq·m^{-3}	51
	^{210}Pb	1	0.368 mBq·m^{-3}	51
Deposition (2)	Gross α	1	67.8 Bq·m^{-2}	12
	Gross β	1	95.3 Bq·m^{-2}	12
	^{3}H	1	960 Bq·m^{-2}	12
	^{7}Be	1	1,194 Bq·m^{-2}	52
	^{137}Cs (3)	1	0.01–1.01 Bq·m^{-2}	52
	^{210}Pb	1	91.6 Bq·m^{-2}	52
	^{210}Po (3)	1	51.5 Bq·m^{-2}	12
Surface water (1)	Gross α	8	29–307 mBq·L^{-1}	13
	Residual β	8	14–125 mBq·L^{-1}	13
	^{3}H	8	1,900–24,000 mBq·L^{-1}	6–13 (4)
	^{90}Sr	3	<0.8–<2.2 mBq·L^{-1}	6–7 (4)
	^{226}Ra	4	2.9–7.0 mBq·L^{-1}	6–7 (4)
Suspended solids in surface water (1)	^{60}Co	8	< 1–7.3 Bq·kg^{-1}	4–52 (4)
	^{131}I	8	< 0.6 –29 Bq·kg^{-1}	4–52 (4)
	^{137}Cs	8	3.2–9.5 Bq·kg^{-1}	4–52 (4)
	^{210}Pb	4	74–143 Bq·kg^{-1}	6–7 (4)
Seawater (1)	Gross α	8	250–640 mBq·L^{-1}	4–13 (4)
	Residual β	8	31–140 mBq·L^{-1}	4–13 (4)
	^{3}H	8	860–5,300 mBq·L^{-1}	4–13 (4)
	^{90}Sr	4	< 0.7–4.1 mBq·L^{-1}	4–11 (4)
Suspended solids in seawater (1)	^{137}Cs	1	2.9 Bq·kg^{-1}	4 (4)
	^{210}Pb	1	56 Bq·kg^{-1}	4 (4)
Drinking water (1)	Gross α	182	< 0.04 Bq·L^{-1}	439 (5)
	Gross β	184	< 0.1 Bq·L^{-1}	447 (5)
	Residual β	164	< 0.1 Bq·L^{-1}	406 (5)
	^{3}H	180	< 3.9 Bq·L^{-1}	459 (5)
Milk (1)	^{40}K	23	51.1 Bq·kg^{-1} (6)	576 (5)
			69.0 Bq·kg^{-1} (7)	10
	^{60}Co	23	< 1.4 Bq·kg^{-1}	576 (5)
	^{90}Sr	23	< 0.2 Bq·kg^{-1} (6)	46 (5)
			< 0.2 Bq·kg^{-1} (7)	6 (5)
	^{131}I	23	< 0.6 Bq·kg^{-1}	576 (5)
	^{134}Cs	23	< 0.6 Bq·kg^{-1}	576 (5)
	^{137}Cs	23	< 0.5 Bq·kg^{-1}	576 (5)

Continued on next page

Table S1 Continued

Matrix	Parameter	Locations	Values	Frequency (per year)
Food [8, 9]				
Grain and grain products	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	74 (0) [11]
Vegetables	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	62 (0) [11]
Fruit and fruit products	^{137}Cs [10]	-	24-116 Bq·kg^{-1}	37 (2) [11]
Milk and dairy products	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	55 (0) [11]
Salads	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	22 (0) [11]
Oil and butter	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	33 (0) [11]
Honey	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	53 (0) [11]
Tea	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	33 (0) [11]
Mineral water	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	29 (0) [11]
Fish	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	29 (0) [11]
Food [8, 13]				
Vegetables and fruits	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	200 (0) [11]
	^{90}Sr	-	< 5 Bq·kg^{-1}	47 (0) [11]
Meat and meat products	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	673 (0) [11]
	^{90}Sr	-	< 5 Bq·kg^{-1}	29 (0) [11]
Game	^{137}Cs [10]	-	5–380[12] Bq·kg^{-1}	129 (33) [11]
	^{90}Sr	-	< 5 Bq·kg^{-1}	12 (0) [11]
Poultry	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	402 (0) [11]
	^{90}Sr	-	< 5 Bq·kg^{-1}	8 (0) [11]
Eggs	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	89 (0) [11]
	^{90}Sr	-	< 5 Bq·kg^{-1}	6 (0) [11]
Fish and seafood products	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	125 (0) [11]
	^{90}Sr	-	< 5 Bq·kg^{-1}	37 (0) [11]
Ready meals	^{137}Cs [10]	-	< 5 Bq·kg^{-1}	63 (0) [11]
	^{90}Sr	-	< 5 Bq·kg^{-1}	42 (0) [11]

[1] Yearly average.
[2] Yearly total.
[3] A 68% confidence interval.
[4] Frequency depends on location.
[5] Total number of samples taken combined over all locations.
[6] Yearly average in cow's milk.
[7] Yearly average in goat's milk.
[8] Given range represents values of individual (positive) samples.
[9] As measured by the Netherlands Food and Consumer Product Safety Authority.
[10] Samples were analysed for ^{134}Cs as well, but measurements were below the detection limit of 5 Bq·kg^{-1}.
[11] Total number of samples taken (number of samples where the minimum detectable activity is exceeded in brackets).
[12] The average activity concentration in the samples with activity concentrations above the detection limit is 68 Bq·kg^{-1}.
[13] As measured by RIKILT Wageningen UR.

Table S2 Summary of the results of the monitoring programme in the vicinity of the Borssele nuclear power plant in 2018

Matrix	Para-meter	Locations	Values [1]	Frequency (per year)
Air (dust)	Gross α	5	0.002–0.099 mBq·m^{-3}	12
	Gross β	5	0.02–1.09 mBq·m^{-3}	12
	^{60}Co	5 [2]	< 0.04–< 0.06 mBq·m^{-3}	12
	$^{131}I_{el}$ [3]	5 [2]	< 0.1–< 0.4 mBq·m^{-3}	12
	$^{131}I_{or}$ [4]	5 [2]	< 0.3 –< 1 mBq·m^{-3}	12
	^{137}Cs	5 [2]	< 0.03–< 0.05 mBq·m^{-3}	12
	Nat. [5]	5 [2]	< 1.3–< 2 mBq·m^{-3}	12
Grass	^{60}Co	5 [2]	< 0.9–< 3 Bq·kg^{-1}	12
	^{131}I	5 [2]	< 0.9–< 2 Bq·kg^{-1}	12
	^{137}Cs	5 [2]	< 0.9–< 2 Bq·kg^{-1}	12
Soil	^{54}Mn	4	< 0.2–< 0.3 Bq·kg^{-1}	1
	^{60}Co	4	< 0.2–< 0.3 Bq·kg^{-1}	1
	^{134}Cs	4	< 0.2 Bq·kg^{-1}	1
	^{137}Cs	4	1.11–1.13 Bq·kg^{-1}	1
Water	Residual β	4	0.012–0.496 Bq·L^{-1}	12
	^{3}H	4	2.1–7.8 Bq·L^{-1}	12
Suspended solids	Gross β	4	0.3–17 kBq·kg^{-1}	12
Seaweed	^{60}Co	4 [2]	< 1–< 2 Bq·kg^{-1}	12
	^{131}I	4 [2]	< 1–< 2 Bq·kg^{-1}	12
	^{137}Cs	4 [2]	< 0.8 –< 2 Bq·kg^{-1}	12
Sediment	^{60}Co	4 [2]	< 0.2–< 0.4 Bq·kg^{-1}	12
	^{131}I	4 [2]	< 0.2–< 0.8 Bq·kg^{-1}	12
	^{137}Cs	4 [2]	0.39 –0.99 Bq·kg^{-1}	12

[1] Given range represents the range of values of individual samples.
[2] Analysis was performed on a combined sample of the monthly samples collected in different locations.
[3] Elemental ^{131}I.
[4] Organically bound ^{131}I.
[5] Naturally occurring γ-emitters.

1 Introduction

Radioactivity of natural and artificial origin can be found in low concentration levels all around the globe. So-called naturally occurring radionuclides can be found in soil, water and air, and have existed since the creation of the universe or are continually generated, either from the decay of primordial isotopes or as a result of cosmic radiation. Concentration levels of naturally occurring radionuclides, such as ^{40}K and daughters from the uranium and thorium series, may be enhanced as a result of human activities within or outside national borders (e.g. discharges from the ore-processing industry).

Man-made radionuclides are found in the environment as a result of events such as nuclear weapons tests and discharges from medical facilities and nuclear installations.

It is important to monitor radioactivity levels in the environment, as the intake of radioactivity and exposure to ionising radiation can lead to an effective dose that may eventually result in adverse health effects. Monitoring radioactivity levels in the environment provides background radioactivity levels under normal circumstances that enable the detection and confirmation of abnormal levels.

This report presents the results of radioactivity measurements performed in the environment in the Netherlands in 2018.

The aim of this report is threefold:

i) to present a survey of radioactivity measurements performed in the Dutch environment, providing information on the exposure of the population to ionising radiation;
ii) to provide information on typical environmental radioactivity levels, which can be used as a reference in the event of a radiological or nuclear incident or emergency;
iii) to show the compliance of monitoring programmes in the Netherlands with the corresponding European obligations and recommendations and to report possible omissions.

In the following chapters, the results of the measurements will be presented in graphs and tables. More detailed information is presented in Appendix A. Chapters 2 to 8 are subdivided according to the structure of the Commission Recommendation on the Application of Article 36 of the Euratom Treaty [1] and present the results of measurements for various environmental compartments. Chapter 9 contains data on radioactivity levels in grass and feed. Chapter 10 contains data on environmental samples taken near the Borssele nuclear power plant. General conclusions are presented in Chapter 11.

Appendix B describes the methods used for the presentation of data. A glossary of frequently occurring terms is given in Appendix C.

2 Airborne particles

2.1 Introduction

Table 2.1 describes the monitoring programme for the determination of radionuclides in air dust. The sampling was performed at the RIVM premises in Bilthoven, the Netherlands. Air dust samples for the measurement of gross α, gross β and γ-emitters were collected weekly using a high-volume sampler. The high-volume sampler described in [2] was replaced by a Snow White high-volume sampler from Senya Ltd [3] in 2011.

The change in equipment coincided with a change in the filter type (polypropylene G-3 instead of glass fibre GF10), the volume sampled (125,000 m^3 instead of 50,000 m^3) and the sampling height (on the rooftop of a three-storey building instead of 1.8 m above ground level). Samples were collected weekly according to a standard procedure [4].

The collection efficiency of the filter type G-3 was determined to be 96 ± 2%, with a flow rate of approximately 760 (normalized) $m^3 \cdot h^{-1}$ based on ^{7}Be and ^{210}Pb results [3]. The results presented in this chapter take this collection efficiency into account.

After sampling, the G-3 filters were dried and weighed to determine the dust load. Then a sub-sample was taken from the filter for the determination of gross α and gross β according to a standard procedure [5]. The remainder of the filter was folded into a 250 ml container and measured on a coaxial HPGe detector (4 days delay time, 100,000 seconds counting time) to determine volatile γ-emitters according to standard procedures [5, 6].

Following this measurement, the filter was dry-ashed at 450 °C for 16 h. Calcium sulphate was added to the resulting residue to achieve a sample of 4 g, which was homogenized and transferred to a polyethylene vial. Measurements were carried out on a coaxial well-type HPGe detector (178,200 seconds counting time) according to standard procedures [5, 6].

The period between sampling and the gross α and gross β analysis was five to ten days, which is long compared with the decay time of the short-lived decay products of ^{222}Rn and ^{220}Rn. This is done to ensure that these naturally occurring short-lived decay products do not contribute to the measured α and β activity concentrations.

In 2005, the data from 1991 to 2004 were re-analysed to determine the yearly averages following the method described in Appendix B [7]. This might have led to small differences between the data presented in this report and the data reported prior to 2005.

Table 2.1 Monitoring programme for the determination of radionuclides in air dust

Matrix	Location	Parameter	Sample period	Sample volume	Analysis frequency
Air dust	Bilthoven	gross α, gross β	1 week	925 m^3 (2)	weekly
Air dust	Bilthoven	γ-emitters (1)	1 week	125,000 m^3	weekly

(1) γ-spectroscopic analysis of specific γ-emitting radionuclides.
(2) A sub-sample of 0.74% from the total filter, through which approximately 125,000 m^3 of air was sampled.

2.2 Results for long-lived α and β activity

The weekly results of gross α and β activity concentrations in air dust are given in Figure 2.1 and Table A1 (see Appendix A). Due to large uncertainties caused by variations in the amount of dust on the filters, gross α activity concentrations in air dust should be regarded as indicative values [5]. The frequency distributions of gross α activity and gross β activity concentrations in air dust are given in Figures 2.2 and 2.3, respectively.

The yearly average activity concentrations in air dust were 0.023 $mBq \cdot m^{-3}$ for gross α and 0.448 ± 0.007 $mBq \cdot m^{-3}$ for gross β. The yearly averages of the gross α and β activity concentrations of long-lived radionuclides in 2018 were within the range of the results from the period 1992–2017, as illustrated in Figure 2.4. Since 2007, a new (more realistic) calibration for gross α has been applied to the measurements. The current calibration factor is 1.4 times higher than the one used before 2007, resulting in lower reported gross α activities.

In 2011, a change in equipment, coupled with a coinciding change in filter type, resulted in changes in the reported gross α (-24%) and gross β (-15%) results, for which no correction is applied [3]. A possible explanation for these changes is a deeper permeation of the air dust in the present filter type G-3 than was the case in the previous filter type GF10. This results in a difference in the self-absorption of the α and β particles measured, i.e. lower gross α and gross β results in the present G-3 filter than those found in the previous GF10 filter.

Normally, there is a good correlation between gross β and naturally occurring ^{210}Pb (in equilibrium with its β-emitting daughter ^{210}Bi) activity concentrations, which suggests that, under normal conditions, $^{210}Pb/^{210}Bi$ is the main contributor to the gross β value (see Figure 2.8).

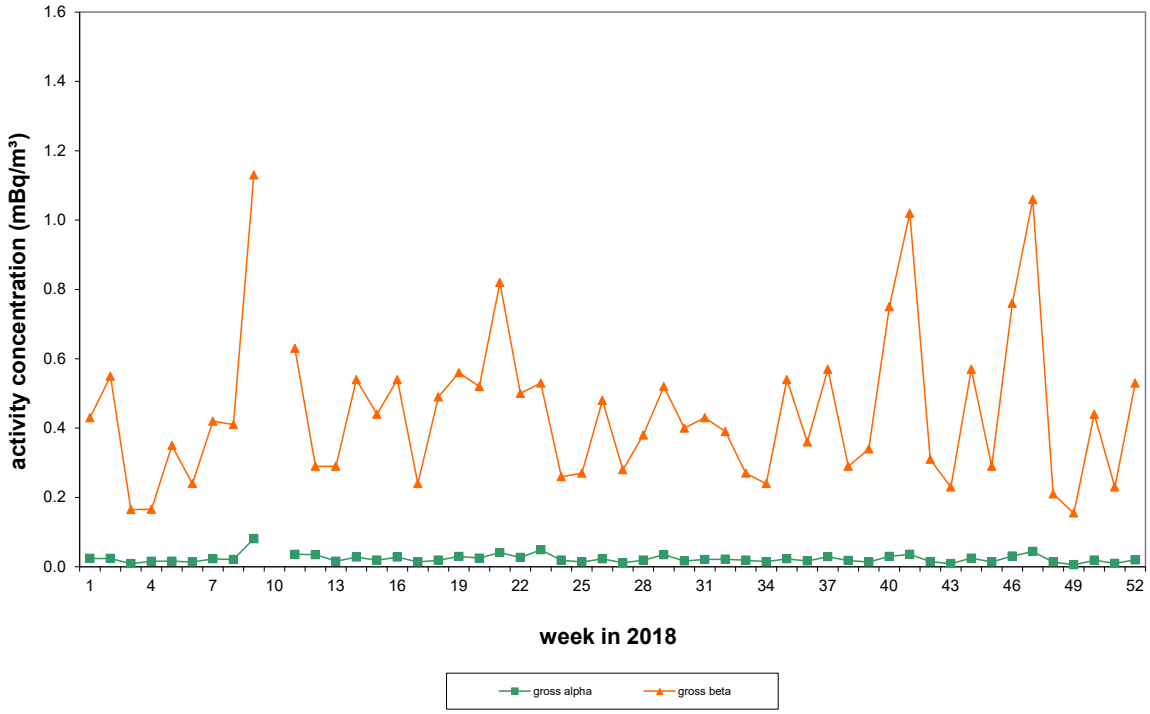


Figure 2.1 Weekly average gross α and β activity concentrations of long-lived radionuclides in air dust sampled at RIVM in 2018. Between 5 and 14 March 2018 no measurements are available due to a malfunction of the high-volume sampler.

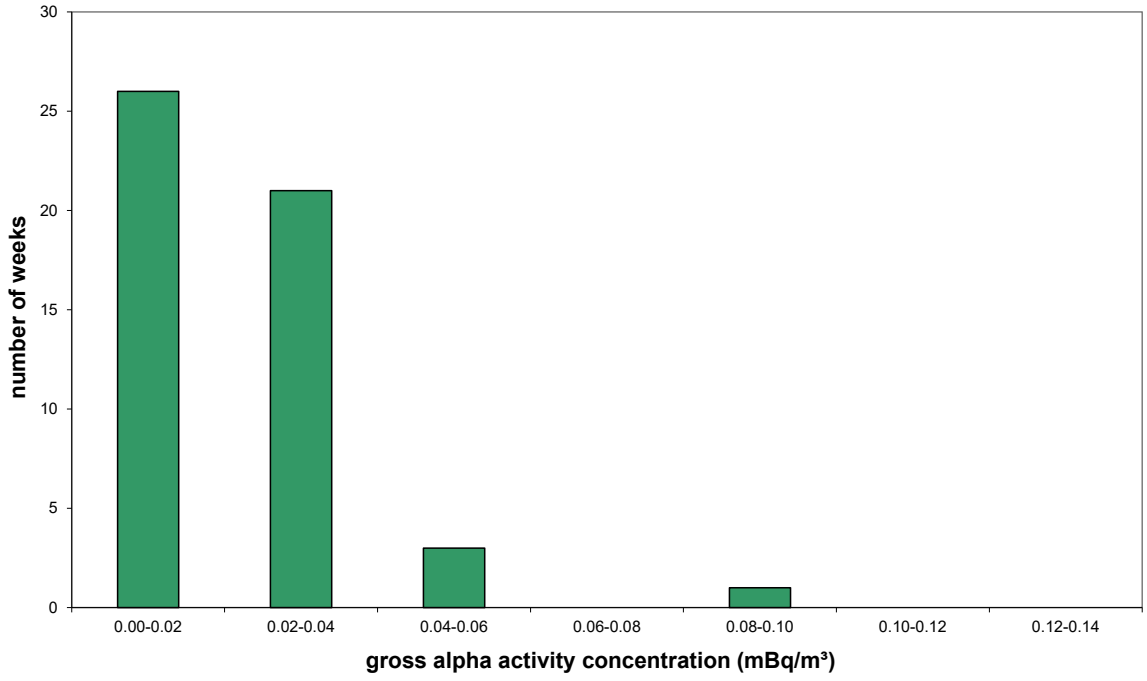


Figure 2.2 Frequency distribution of gross α activity concentration of long-lived radionuclides in air dust collected weekly in 2018

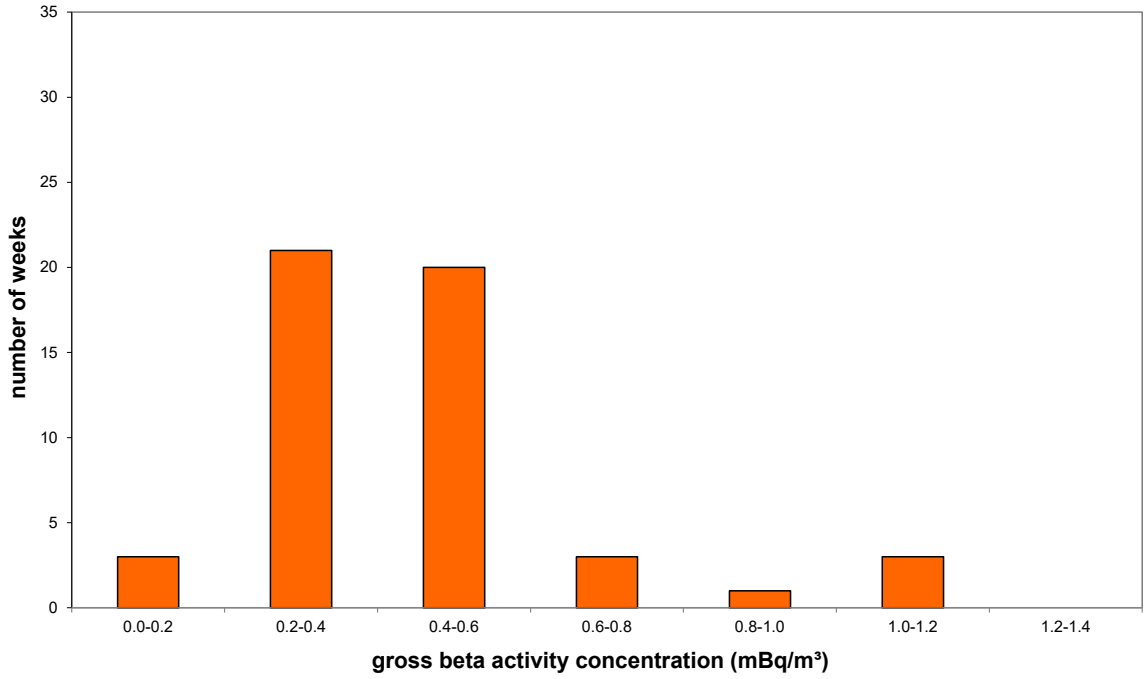


Figure 2.3 Frequency distribution of gross β activity concentration of long-lived radionuclides in air dust collected weekly in 2018

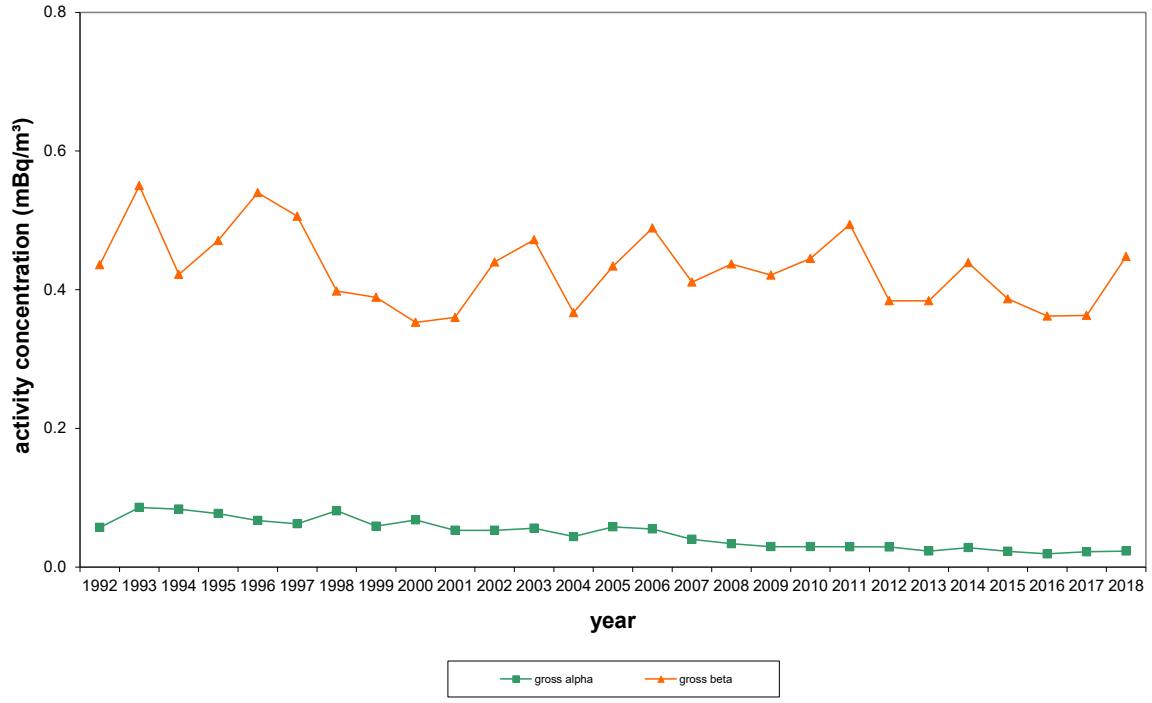


Figure 2.4 Yearly average gross α and gross β activity concentrations of long-lived radionuclides in air dust at RIVM since 1992

2.3 Results for γ-emitting radionuclides

Several γ-emitting radionuclides were detected in the sampled air dust: ^{7}Be (51 times), ^{137}Cs (51 times) and ^{210}Pb (51 times). The results are presented in Table A3 and Figures 2.5, 2.6 and 2.7. The detection limits for radionuclides considered in the γ-spectroscopic analysis of the HVS samples are given in Table A2.

The yearly average activity concentrations of ^{7}Be, ^{137}Cs and ^{210}Pb were 3,540 ± 40, 0.266 ± 0.005 and 368 ± 4 μBq·m^{-3}, respectively.

The behaviour of ^{7}Be in the atmosphere has been studied worldwide [8, 9, 10, 11, 12, 13, 14]. Natural ^{7}Be (half-life of 53.3 days) is formed by spallation reactions of cosmogenic radiation with atmospheric nuclei such as nitrogen and oxygen, resulting in the formation of BeO or $Be(OH)_2$. Approximately 70% of ^{7}Be is produced in the stratosphere and the remainder is produced in the troposphere. It has an estimated residence time of one to two years in the stratosphere and approximately six weeks in the troposphere. Most of the ^{7}Be produced in the stratosphere does not reach the troposphere, except during spring, when seasonal thinning of the tropopause takes place at mid-latitudes, resulting in air exchange between the stratosphere and the troposphere. In the troposphere, ^{7}Be rapidly associates mainly with submicron-sized aerosol particles. Gravitational settling and precipitation processes accomplish transfer to the earth's surface. Seasonal variations in the concentration of ^{7}Be in surface air are influenced by the following main atmospheric processes: wet and dry deposition, mass exchange between stratosphere and troposphere, vertical transport in the troposphere, and horizontal transport of air masses from the subtropics and mid-latitudes to the tropics and polar regions.

The red line in Figure 2.5 shows the seasonal variation of the ^{7}Be activity concentration, with peaks during the spring and summer periods, reflecting the seasonal variations in the transport rate of air from the stratosphere to the troposphere. Figure 2.5 shows further the influence of the solar cycle. The maxima of 1997 and the 2007–2009 period, and the minimum of the 2000–2002 period are consistent with the solar minima (measured by radio flux and sunspot count) of the 1996–1997 and 2008–2009 periods, and the solar maximum of the 2000–2002 period, respectively [15]. In the summer of 1991, two severe geomagnetic storms caused a significant worldwide disturbance of the earth's geomagnetic field. This resulted in a considerable decrease in cosmogenic radiation, which was unprecedented in at least the previous four decades [16]. The absence of a 1991 summer peak in the ^{7}Be activity concentration can be explained by the decrease in cosmogenic radiation. The concentrations found for ^{7}Be in 2018 fit into the pattern described above.

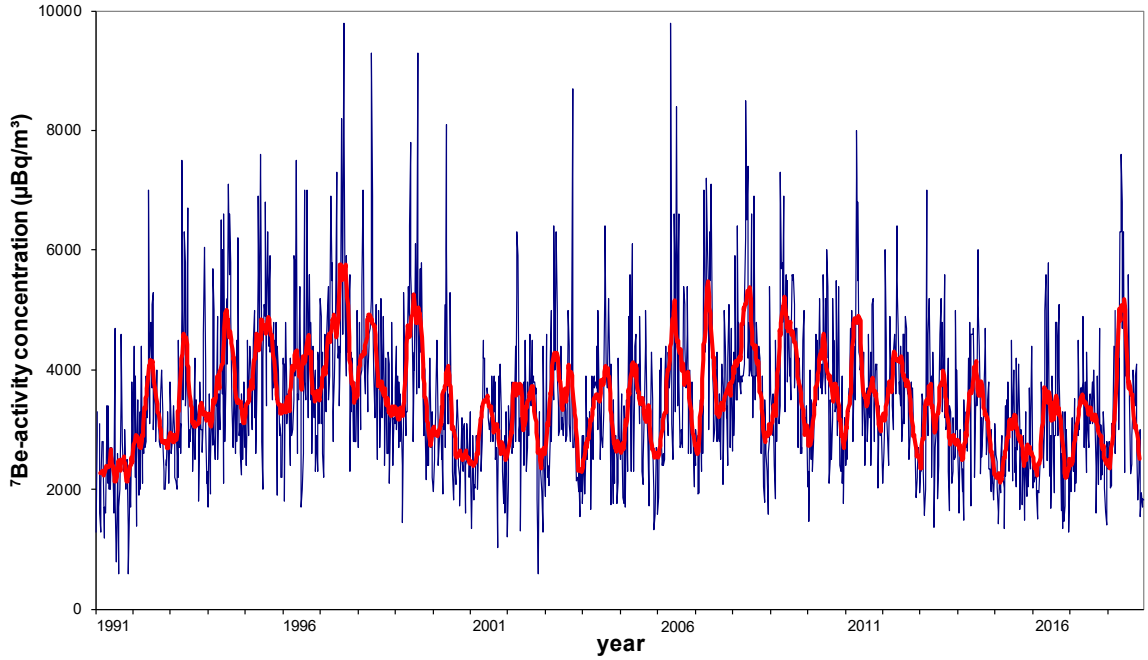


Figure 2.5 Weekly average ^{7}Be activity concentrations (blue) in air dust at RIVM since 1991. The red line is a moving average of 13 weeks.

The nuclide ^{137}Cs (half-life of 30.2 years) is of anthropogenic origin. The two main sources of ^{137}Cs in the environment are atmospheric nuclear weapons tests and some nuclear accidents, most notably the Chernobyl accident of 1986 and the Fukushima Daiichi accident of 2011. Resuspension of previously deposited activity has been the main source of airborne ^{137}Cs activity in the Netherlands since 1986.

Figure 2.6 shows a peak in May 1992. During that month, several wildfires occurred near the Chernobyl area [17] and the level of airborne ^{137}Cs activity increased ten times in the 30 km exclusion zone around Chernobyl. It is possible that the airborne ^{137}Cs was transported to Western Europe by a strong easterly wind in the same period [18]. On 29 May 1998, an incident occurred at Algeciras (Spain): an iron foundry melted a ^{137}Cs source concealed in scrap metal [19]. As a result, elevated levels of airborne ^{137}Cs activity were measured in France, Germany, Italy and Switzerland during late May and early June. Figure 2.6 shows a slightly elevated level of ^{137}Cs activity (second peak) around the same period (29 May to 5 June 1998). Such slightly elevated levels are not uncommon, as can be seen in Figure 2.6. These elevations may be related to the resuspension of previously deposited dust, especially during a period of strong winds from the continent [19]. From 18 March to 10 June 2011, elevated levels of ^{137}Cs activity were measured as a result of the incident at Fukushima (Japan). More detailed results on ^{137}Cs and other radionuclides during that period are presented in [20].

Figure 2.6 shows a lack of data between 2000 and the middle of 2009. During that period the detection limit was higher than it had been during the 1991–1999 period due to a different detector set-up. Since July

2009, a new detector set-up has been used, which results in lower detection limits (similar to those used before 2000).

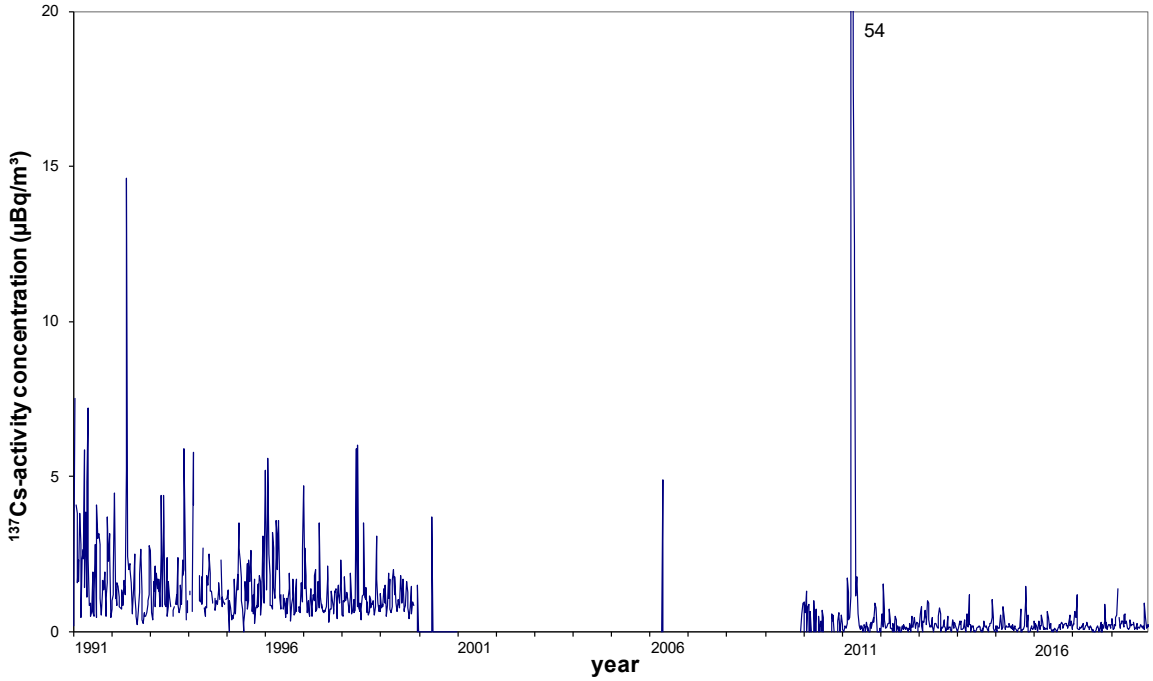


Figure 2.6 Weekly average ^{137}Cs activity concentrations in air dust at RIVM since 1991

The primary source of atmospheric ^{210}Pb (half-life of 22.3 years) is the decay of ^{222}Rn exhaled from continental surfaces. Therefore, the atmospheric concentration of ^{210}Pb over continental areas is generally higher than it is over oceanic areas (^{222}Rn exhalation from the ocean is 1,000 times less than it is from the continents). The reported UNSCEAR reference level of ^{210}Pb in air dust is 500 $\mu Bq \cdot m^{-3}$ [21]. In the atmosphere, this radionuclide is predominantly associated with submicron-sized aerosol particles [22, 23]. The mean aerosol (carrying ^{210}Pb) residence time in the troposphere is approximately 5 days [24].

Other sources of ^{210}Pb in air dust are volcanic activity and industrial emissions [25, 26, 27, 28, 29, 30]. Examples of industrial emissions are discharges from power plants that use fossil fuels, discharges from the fertilizer and phosphorus industries, and exhaust gases from traffic. In the Netherlands, emissions by power plants are only of local importance with respect to ^{210}Pb deposition. Emissions by the phosphorus industry contribute a negligible part of the yearly total of ^{210}Pb deposition [30]. Furthermore, the phosphorus industry ceased to be operational in the Netherlands in 2012. Volcanic eruptions bring uranium decay products into the atmosphere, such as ^{226}Ra, ^{222}Rn, ^{210}Pb and ^{210}Po. Beks et al. [27] estimate that volcanoes contribute 60 $TBq \cdot year^{-1}$ to the atmospheric ^{210}Pb stock. Unusual (high) ^{210}Pb values might be explained by natural phenomena such as an explosive volcanic eruption, Saharan dust [31, 32, 33] or the resuspension of (local) dust. Normally there is a good correlation between ^{210}Pb (in equilibrium with its β-emitting daughter ^{210}Bi) and gross β activity concentrations, as was the case in 2018 (Figure 2.8). This suggests that, under normal conditions,

$^{210}Pb/^{210}Bi$ is the main contributor to the gross β value. The weekly average ^{210}Pb activity concentrations in 2018 were within the range of those found in previous years (Figure 2.7).

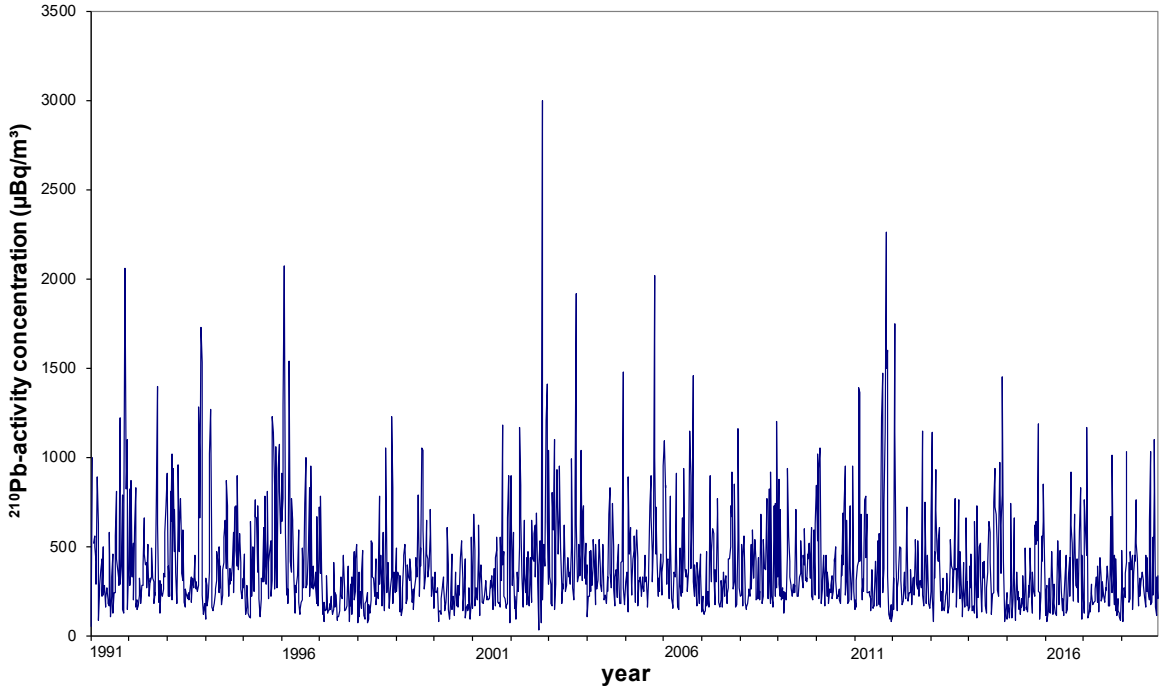


Figure 2.7 Weekly average ^{210}Pb activity concentrations in air dust at RIVM since 1991

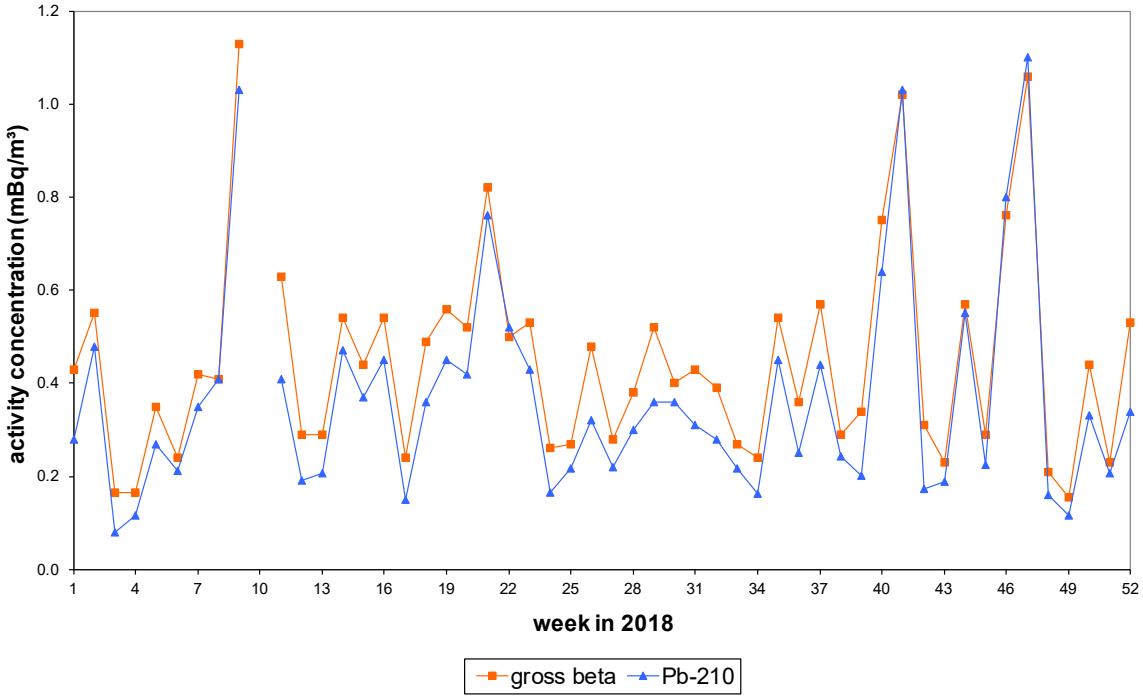


Figure 2.8 The weekly average gross β and ^{210}Pb activity concentrations in air dust at RIVM show a good correlation. Between 5 and 14 March 2018 no measurements are available due to a malfunction of the high-volume sampler.

3 Deposition

3.1 Introduction

Table 3.1 describes the monitoring programme for determining radionuclides in deposition. Sampling was done on the RIVM premises in Bilthoven. Samples were collected weekly for γ-emitters and monthly for gross α, gross β, ^{3}H and ^{210}Po according to a standard procedure [34].

The samples – weekly for γ-emitters and monthly for gross α and gross β – were acidified with sulphuric acid and evaporated to dryness. The resulting sulphate residue was analysed according to standard procedures [6, 35, 36].

The monthly samples for ^{3}H were analysed by Rijkswaterstaat (RWS). The samples were made alkaline by the addition of sodium carbonate and then distilled. A 65 ml aliquot of the distillate was mixed with an equal amount of scintillation solution in a plastic counting vial and then counted on a liquid scintillation counter for 600 minutes per sample.

The monthly samples for ^{210}Po were reduced in volume by evaporation. The resulting solution was analysed according to a standard procedure [37] with a minor difference: the ingrowth of ^{210}Po from ^{210}Pb was derived from the ^{210}Pb results from the weekly samples for γ-emitters, rather than by using the procedure described in [37].

In 2005, the data collected from 1993 to 2004 were re-analysed to determine the yearly totals by the method described in Appendix B [7]. This can lead to small differences between the data presented in this report and the data reported prior to 2005.

Table 3.1 Monitoring programme for the determination of radionuclides in deposition

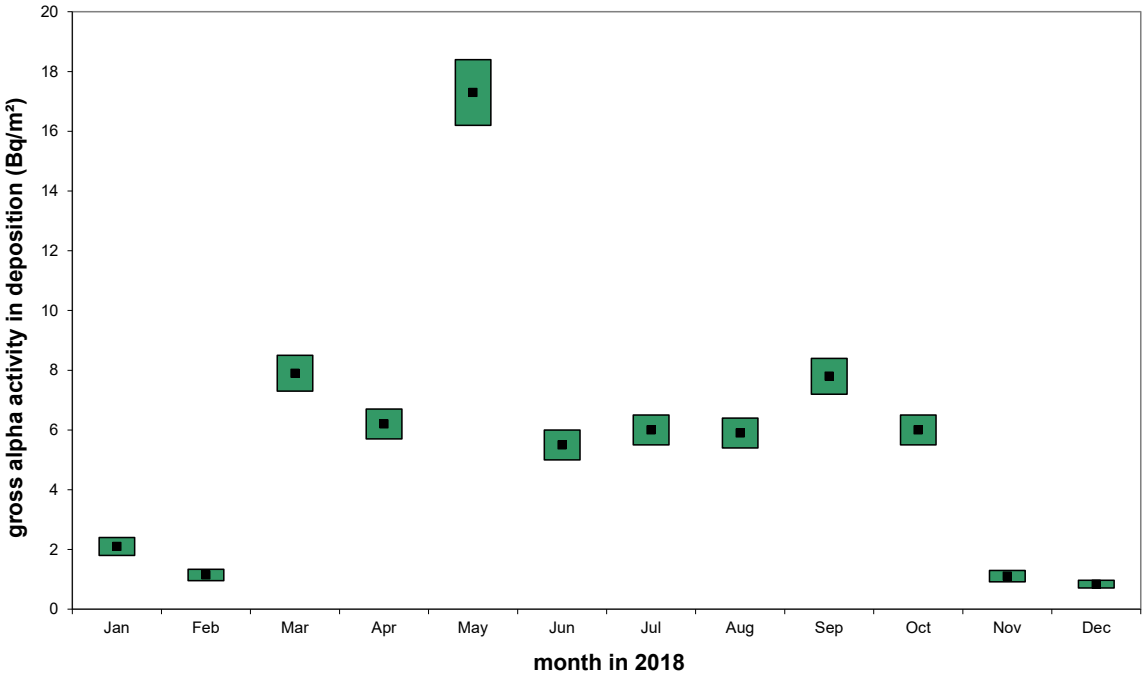
Matrix	Location	Parameter	Sample period	Sample volume
Deposition	Bilthoven	γ-emitters (1)	1 week	variable
Deposition	Bilthoven	gross α, gross β, ^{3}H, ^{210}Po	1 month	variable

(1) γ spectroscopic analysis of specific γ-emitting radionuclides.

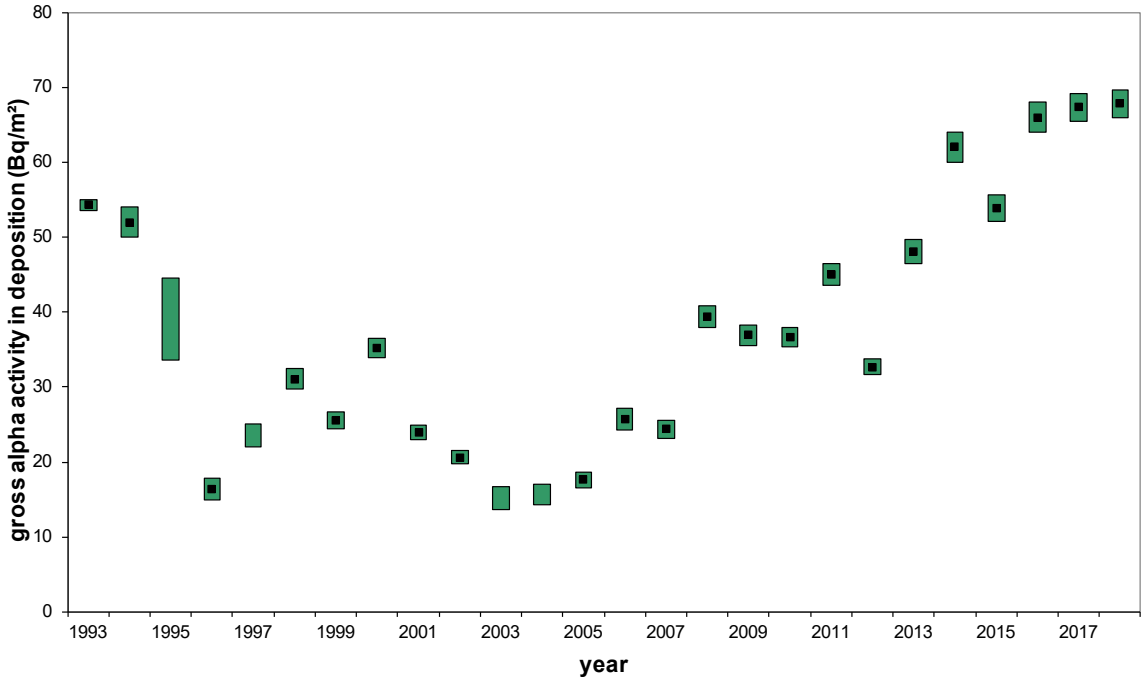
3.2 Results for long-lived α and β activity

The monthly deposited gross α and gross β activities of long-lived radionuclides are given in Figure 3.1, Figure 3.3 and Table A4. The yearly total depositions of gross α and gross β were 67.8 ± 1.8 and 95.3 ± 1.5 $Bq \cdot m^{-2}$, respectively. In May 2018 a higher deposition of gross α with respect to all other months is visible in Figure 3.1. The yearly total deposition of gross α is similar to the one in 2016 and 2017, as reported in and Table A6 and illustrated in Figure 3.2. The yearly total deposition of gross β is within the range of those from previous years, as illustrated in Figure 3.4 and Table A6.

The monthly deposition of ^{3}H is given in Table A4. In 2018, the yearly total deposition of ^{3}H was 960 ± 30 Bq·m^{-2}. The yearly total consisted of 12 samples which were all above the detection limit. The range in 2018 did not differ significantly from those measured since 1993, as illustrated in Figure 3.5 and Table A6. Up to 1998, samples were electrolytically enriched before counting, which resulted in a much lower detection limit than the one achieved from 1998 onwards (1.6-2.0 Bq·L^{-1}). Since 2017 the samples are analysed by Rijkswaterstaat (RWS) with a lower detection limit (0.3 Bq·L^{-1}) than in the period between 1998 and 2016.

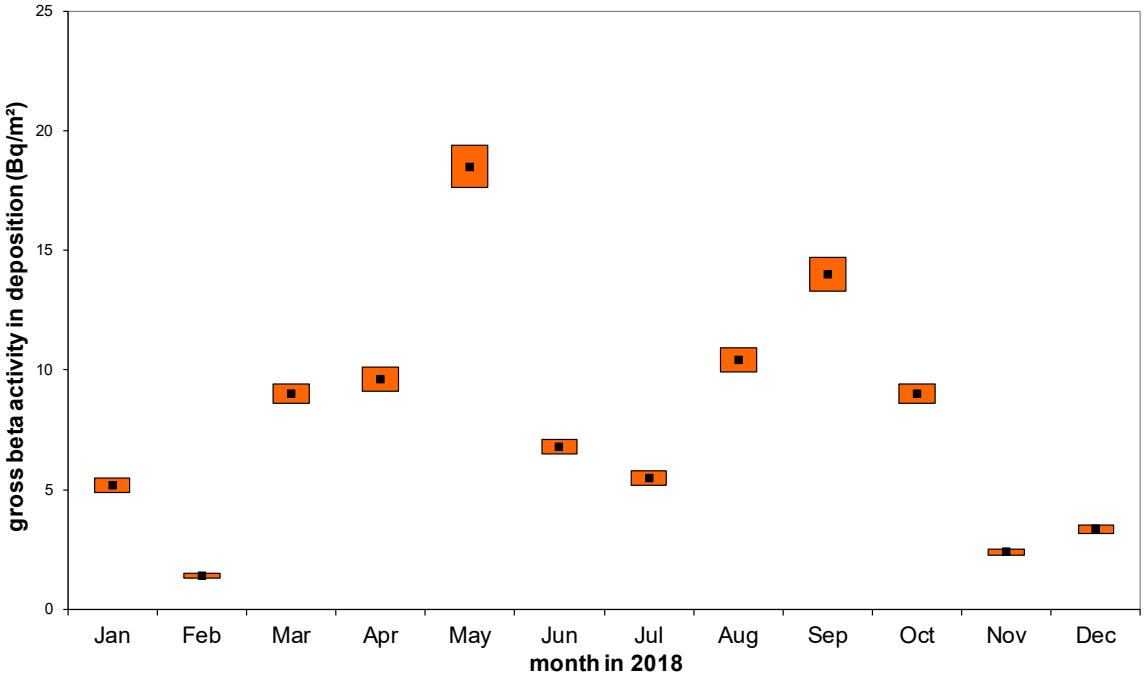


Monthly totals (black dots) are shown with a 68% confidence interval (coloured bars).
Figure 3.1 Monthly deposition of gross α activity of long-lived radionuclides at RIVM



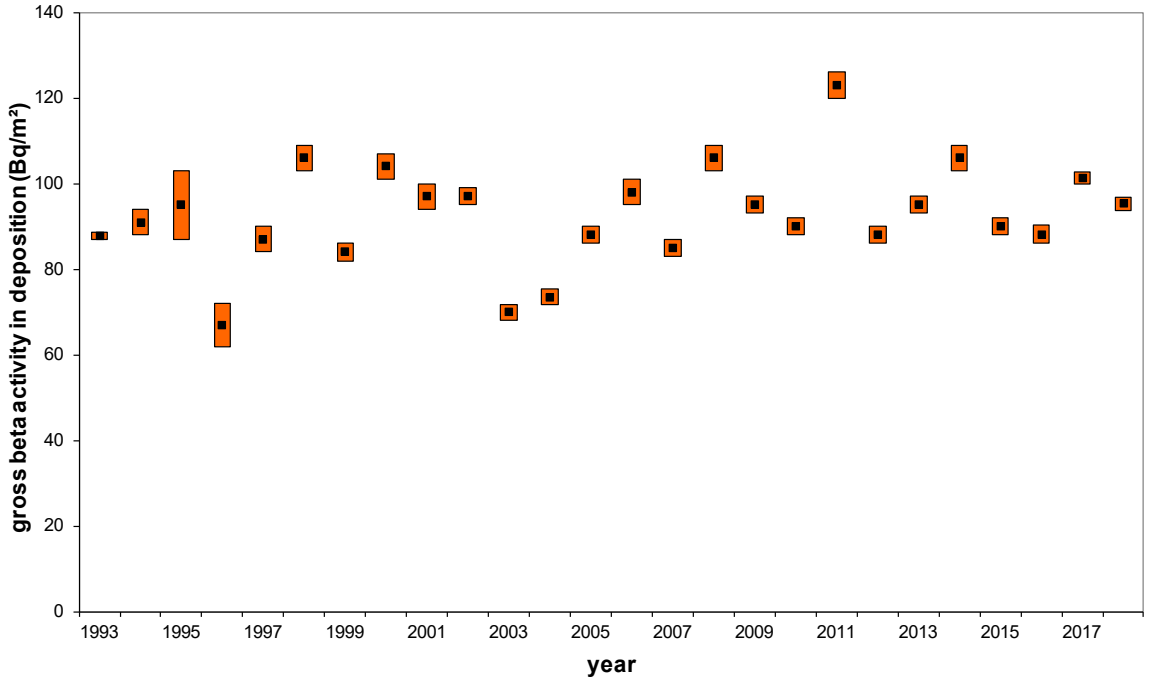
Yearly totals (black dots) are shown with a 68% confidence interval (coloured bars). Only the 68% confidence interval is shown if the sum leading to the yearly total contains at least one detection limit.

Figure 3.2 Yearly deposition of gross α activity of long-lived radionuclides at RIVM since 1993



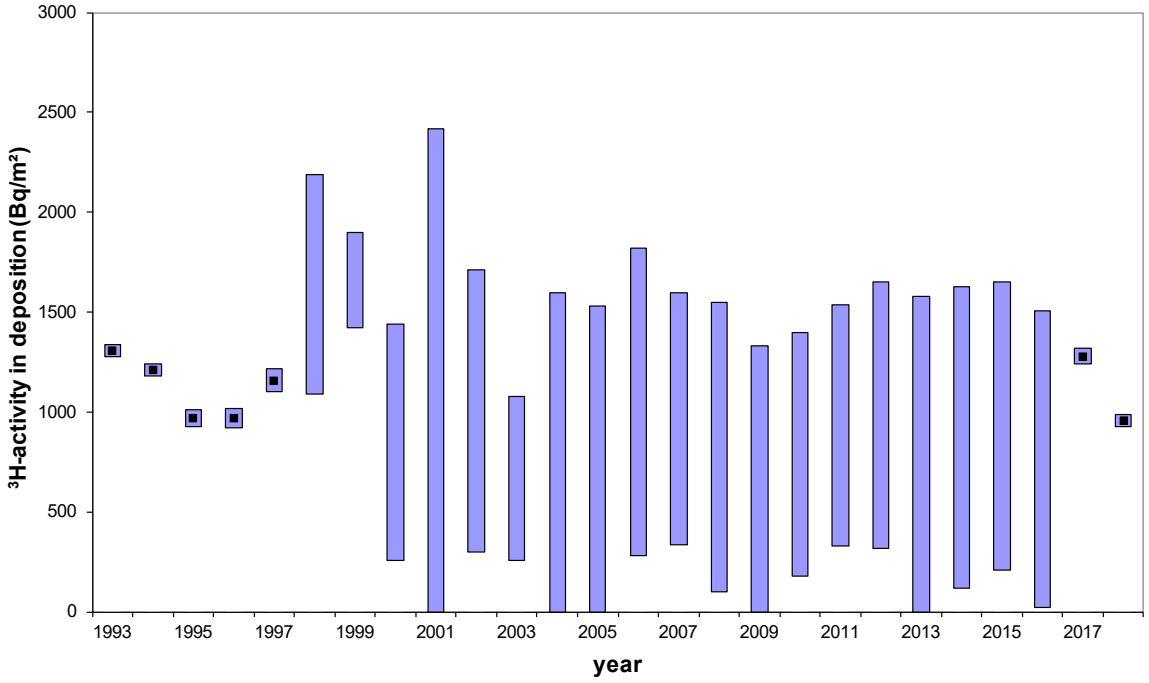
Monthly totals (black dots) are shown with a 68% confidence interval (coloured bars).

Figure 3.3 Monthly deposition of gross β activity of long-lived radionuclides at RIVM



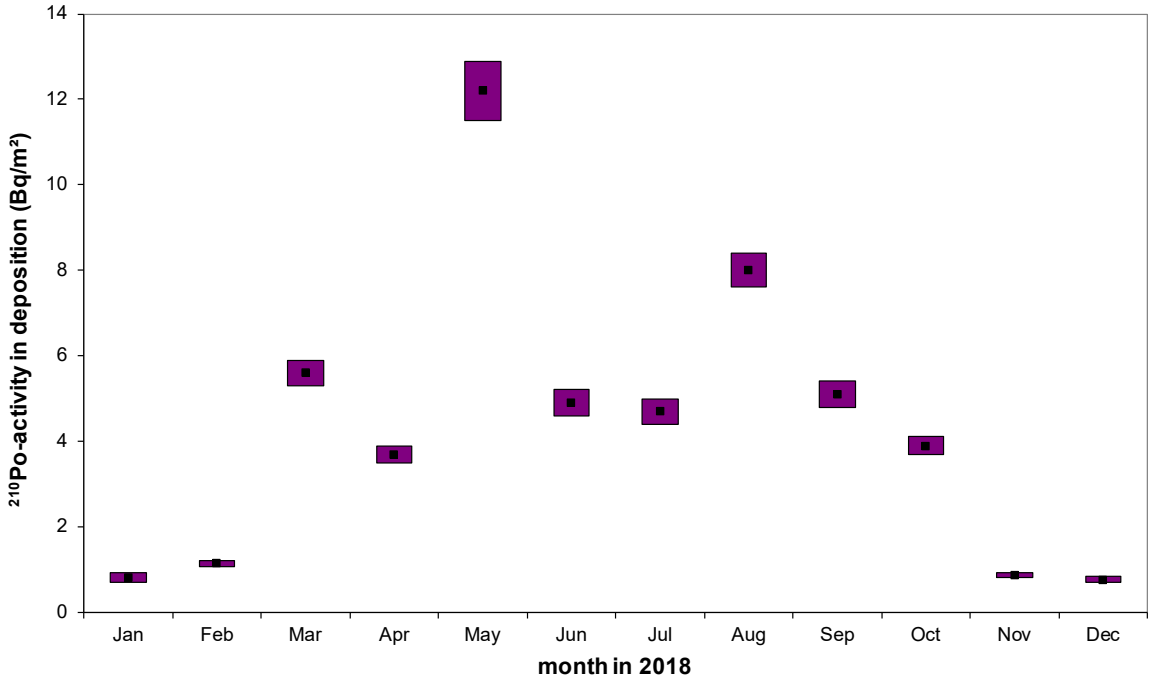
Yearly totals (black dots) are shown with a 68% confidence interval (coloured bars).

Figure 3.4 Yearly deposition of gross β activity of long-lived radionuclides at RIVM since 1993



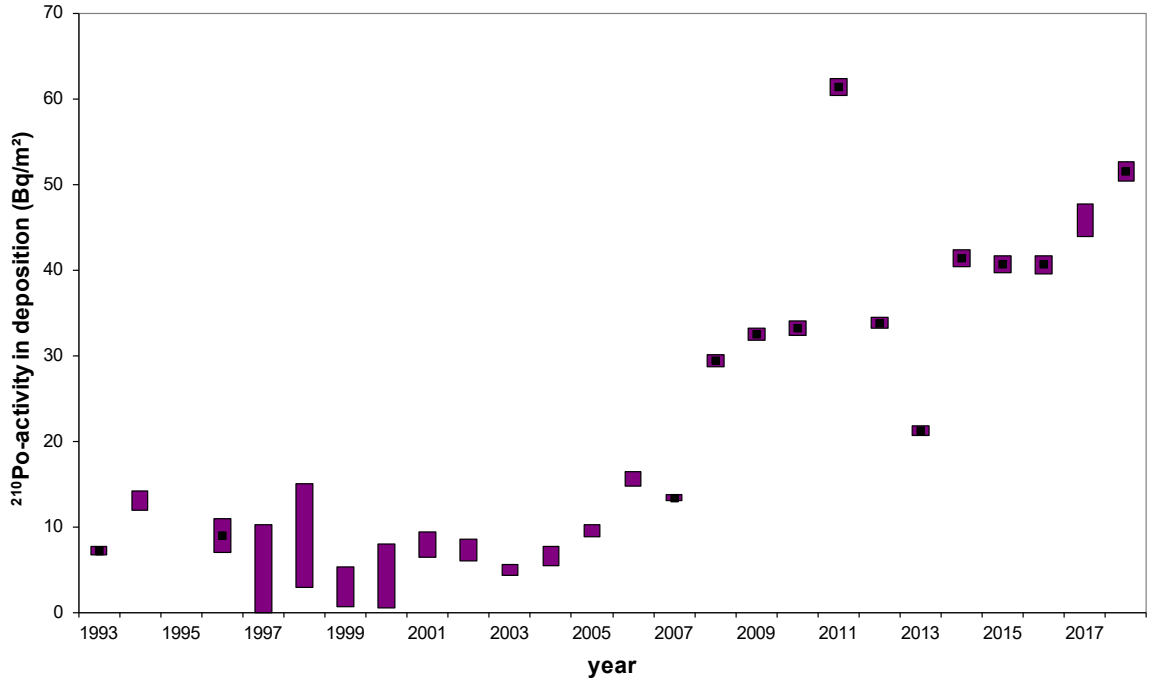
Yearly totals (black dots) are shown with a 68% confidence interval (coloured bars). Only the 68% confidence interval is shown if the sum leading to the yearly total contains at least one detection limit. Since 2017, the samples are analysed by Rijkswaterstaat (RWS).

Figure 3.5 Yearly deposition of ^{3}H sampled at RIVM since 1993.



Monthly totals (black dots) are shown with a 68% confidence interval (coloured bars), or with a simple dot if the measurement is a detection limit.

Figure 3.6 Monthly deposition of ^{210}Po activity at RIVM



Yearly totals (black dots) are shown with a 68% confidence interval (coloured bars). Only the 68% confidence interval is shown if the sum leading to the yearly total contains at least one detection limit.

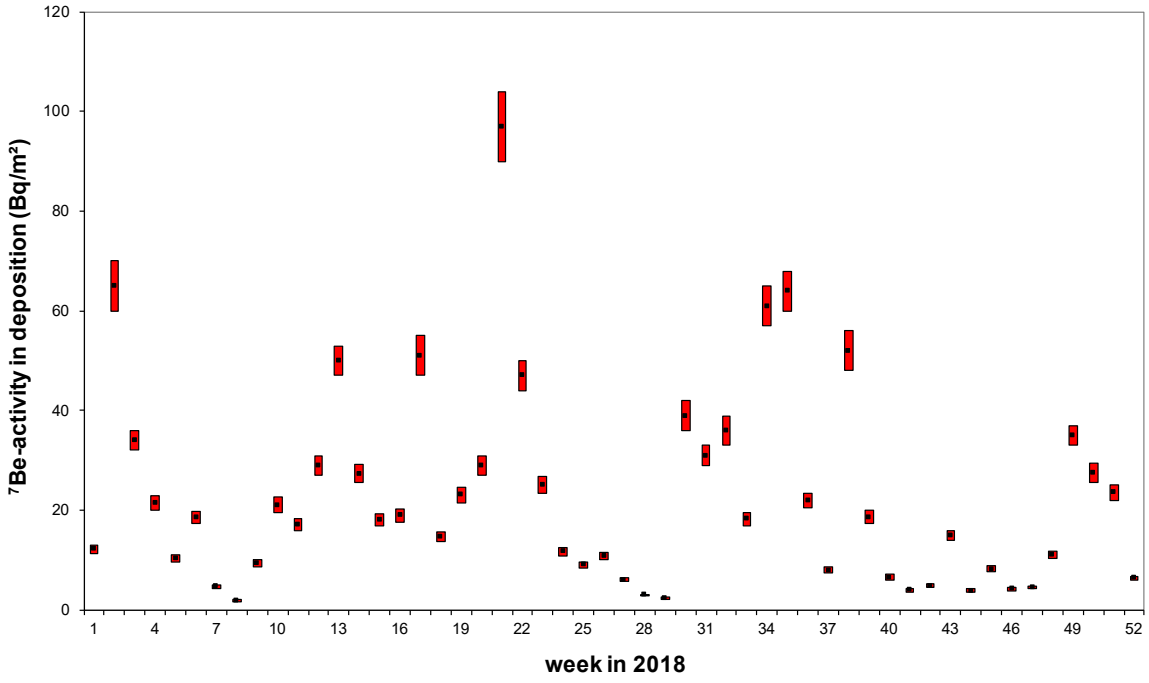
Figure 3.7 Yearly deposition of ^{210}Po activity at RIVM since 1993

The monthly α spectroscopy results for ^{210}Po are given in Figure 3.6 and Table A5. The results for previous years are given in Figure 3.7 and Table A7. The yearly total deposition of ^{210}Po in 2018 was 51.5 ± 1.1 Bq·m^{-2}. This value falls within the range of the values from previous years, as illustrated in Figure 3.7 and Table A7.

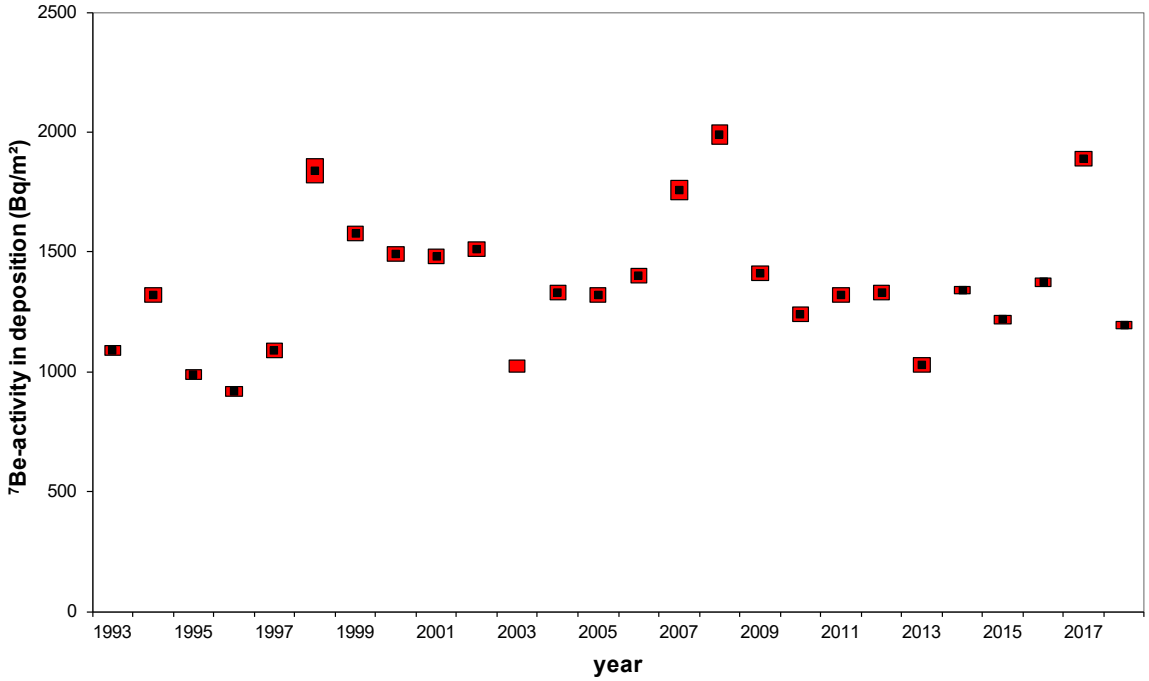
3.3 Results for γ-emitting radionuclides

The naturally occurring radionuclides ^{7}Be and ^{210}Pb were found in all of the 52 weekly deposition samples. The yearly total deposition of ^{7}Be was 1,194 ± 15 Bq·m^{-2} and the yearly total deposition of ^{210}Pb was 91.6 ± 1.3 Bq·m^{-2}. The nuclide ^{137}Cs was below the detection level in 51 of the 52 weekly samples (the detection limit for ^{137}Cs is 0.02 Bq·m^{-2} on average). The yearly total deposition of ^{137}Cs ranged between 0.01 and 1.01 Bq·m^{-2} (68% confidence interval). The weekly results for deposition of ^{7}Be, ^{137}Cs and ^{210}Pb are given in Table A8 and Figures 3.8 and 3.11. The results for previous years are given in Table A7 and Figures 3.9, 3.10 and 3.12.

Figure 3.10 shows a change in the trend for ^{137}Cs between 2000 and the middle of 2009. During that period, the detection limit was higher than it had been during the 1993–1999 period due to a different detector set-up. Since July 2009, a new detector set-up has been used, which results in lower detection limits. Since the ^{137}Cs deposition values are mostly below the detection limit, no conclusion can be drawn concerning the correlation between the measured ^{137}Cs values in air dust and the measured ^{137}Cs deposition values.

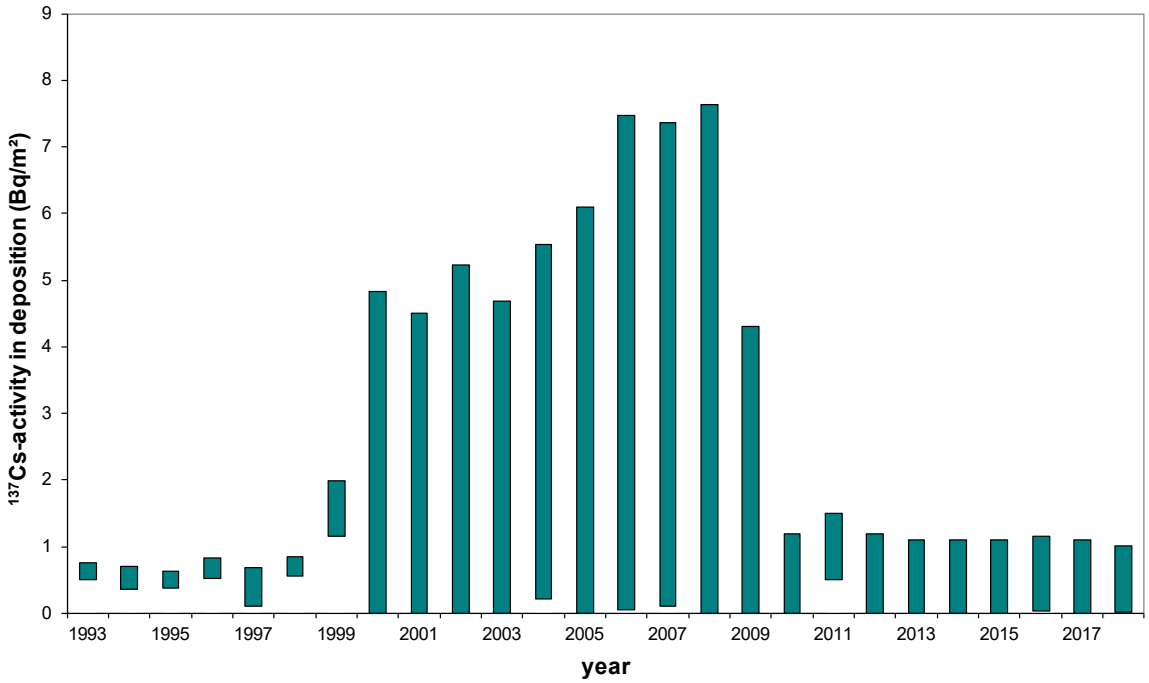


Weekly totals (black dots) are shown with a 68% confidence interval (coloured bars).
Figure 3.8 Weekly deposited ^{7}Be activity at RIVM



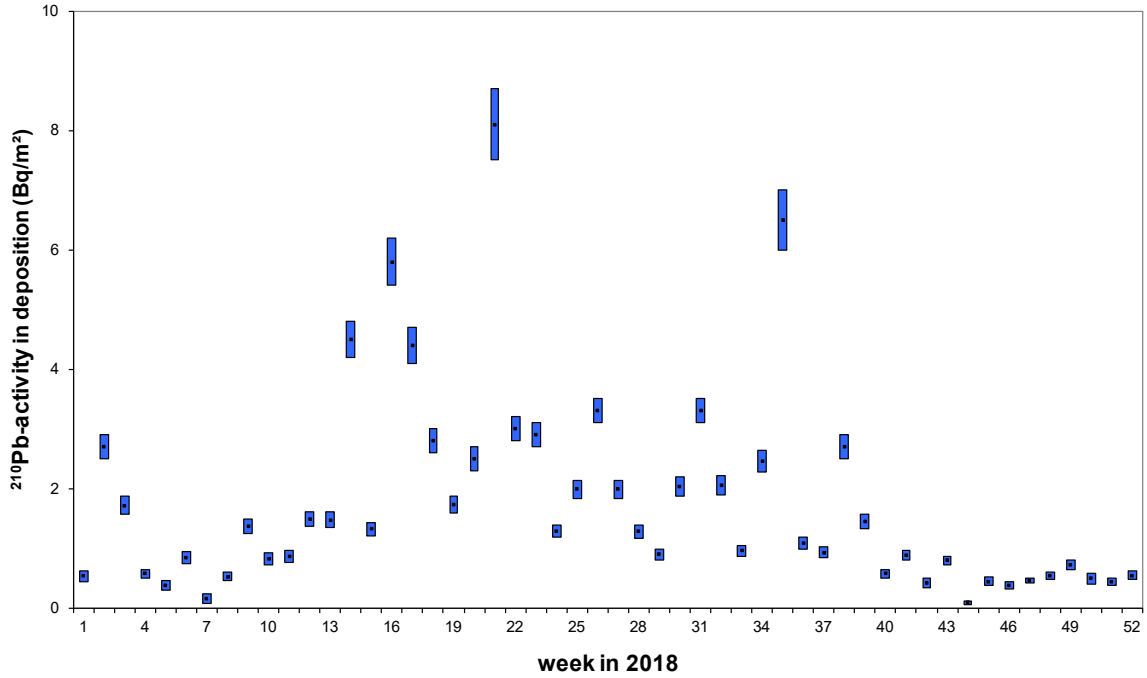
Yearly totals (black dots) are shown with a 68% confidence interval (coloured bars). Only the 68% confidence interval is shown if the sum leading to the yearly total contains at least one detection limit.

Figure 3.9 Yearly ^{7}Be activity deposited at RIVM since 1993



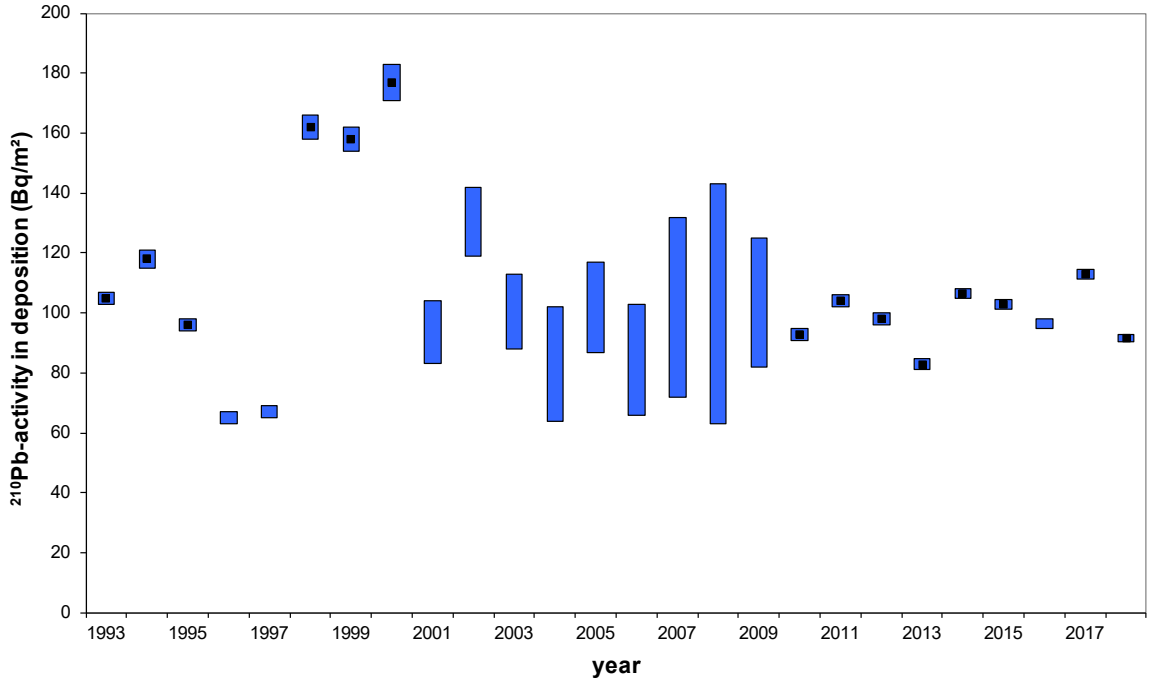
Yearly averages are shown solely as a 68% confidence interval since the sum leading to the yearly total contains at least one detection limit.

Figure 3.10 Yearly ^{137}Cs activity deposited at RIVM since 1993



Weekly averages (black dots) are shown with a 68% confidence interval (coloured bars).

Figure 3.11 Weekly deposited ^{210}Pb activity at RIVM



Yearly averages (black dots) are shown with a 68% confidence interval (coloured bars). Only the 68% confidence interval is shown if the sum leading to the yearly total contains at least one detection limit.

Figure 3.12 Yearly ^{210}Pb activity deposited at RIVM since 1993

4 National Radioactivity Monitoring Network

4.1 Introduction

This chapter presents data on gross α and artificial β activity concentrations in air dust and ambient dose equivalent rates, as measured by the National Radioactivity Monitoring Network (Nationaal Meetnet Radioactiviteit, NMR). The data on gross α and artificial β differ in sample size, sampling frequency and analytical procedures (including a different approach to the contribution of short-lived natural radionuclides, i.e. radon daughters) from those given in Chapter 2.

The NMR consists of 167 sites, at which the ambient dose equivalent rate is determined. At 14 measuring sites, gross α and artificial β activity concentrations are determined, as well as the ambient dose equivalent rate (at a height of 3.5 m above ground level) [38]. At the other 153 measuring sites, only the ambient dose equivalent rate is determined (at 1 m above ground level).

Since the dose equivalent rate monitors are placed differently at 14 of the 167 sites with regard to height and surface covering, results can differ between the two types of measuring site [39]. For this reason, these 14 dose equivalent rate monitors are not taken into account when calculating the yearly average ambient dose equivalent. The reported artificial β activity concentrations are calculated from the difference between the measured gross β activity concentration and the natural gross β activity derived from the measured gross α activity concentration.

During the second half of 2002, the 14 aerosol FAG FHT59S monitors were gradually replaced by 14 Berthold BAI 9128 monitors. Due to differences in detection method, filter transport, calibration radionuclides and algorithms, the results for the activity concentrations from the two types of monitor are not exactly the same. By running both monitors simultaneously at the same location, the measured gross α activity concentration was compared. On average, the Berthold monitor systematically reported about 20% higher values than the FAG monitor [40]. The estimated random uncertainty for both types of monitor is about 20%. No correction was applied for the difference in the gross α activity concentration between the Berthold and FAG monitors.

From November 2014 until the end of 2015, most of the ambient dose equivalent monitors were replaced. The Bitt RS03 monitors (proportional counters) were replaced by new Saphymo XL-2-3 monitors (Geiger-Müller). The energy response, cosmic response and self-effect of the two types of monitor differ slightly. Compared with the Bitt monitor, the Saphymo monitor measurements are, on average, 8 $nSv \cdot h^{-1}$ higher at the natural background radiation level in the Netherlands. No correction for this difference is applied.

The data presented in this chapter are based on 10-minute measurements. Averages over the year are calculated for each location using daily averages derived from the 10-minute measurements (Tables

A9 and A10). The data on external radiation, expressed in ambient dose equivalent, contain a systematic uncertainty because of an overestimation of the cosmogenic dose rate due to the characteristics of the detectors. NMR data are not corrected for these response uncertainties.

4.2 Results

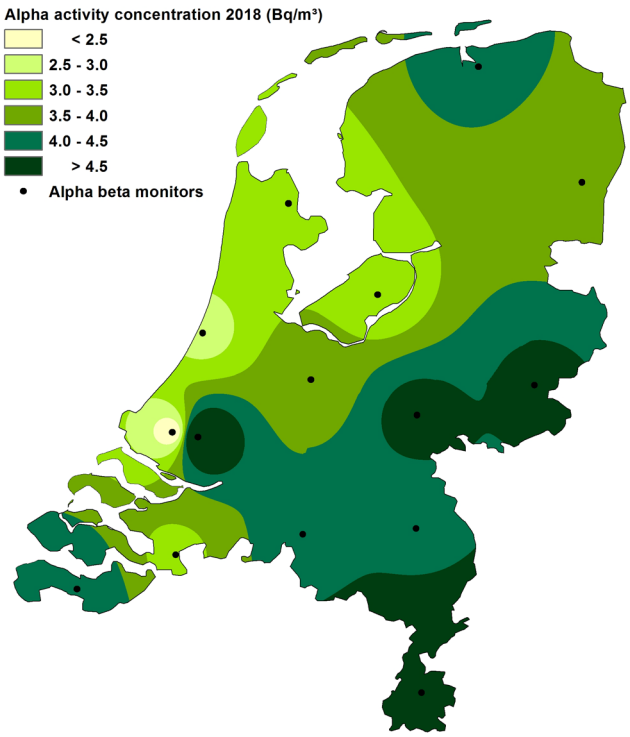
An impression of the spatial variation in the yearly averages of the NMR data, constructed by using the RIVM's Geographical Information System (GIS), is shown in Figures 4.1 and 4.3. An inverse distance weight interpolation algorithm was applied to calculate values between the NMR stations.

Figure 4.2 presents the yearly averages of the gross α activity concentration since 1990, while Figure 4.4 presents the yearly averages of the ambient dose equivalent rate since 1996.

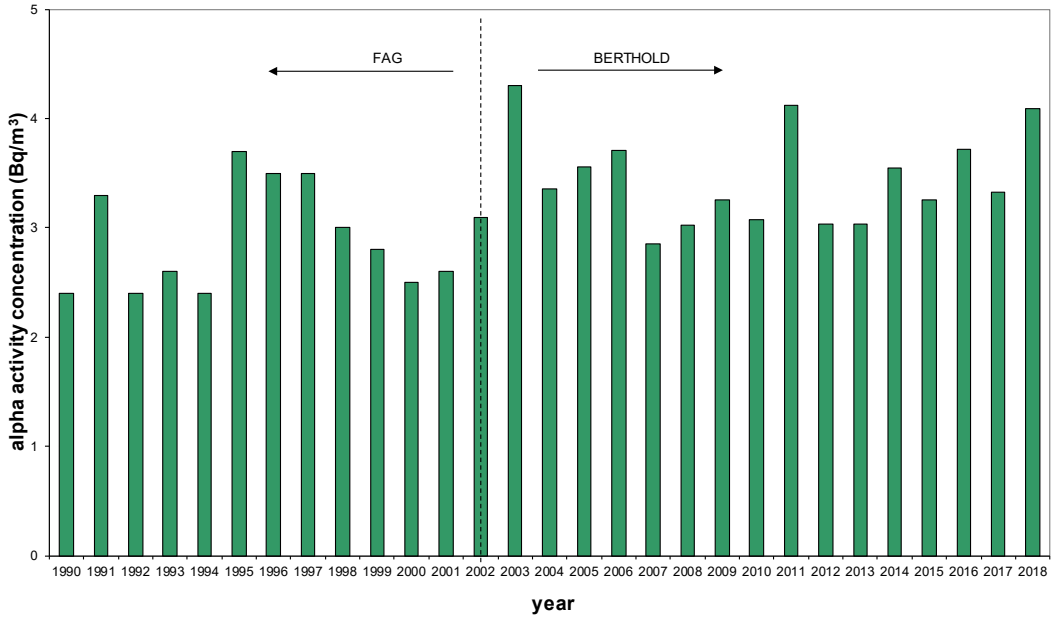
In 2018, the yearly average gross α activity concentration in air dust was 4.1 $Bq \cdot m^{-3}$ (based on the yearly averages of the 14 measurement locations). The yearly average gross α activity concentration in air dust is higher than the concentration in previous years, as illustrated in Figure 4.2: this can be attributed to a long period with little precipitation in 2018. When comparing this value (yearly average of 4.1 $Bq \cdot m^{-3}$) with data collected before 2002, it should be noted that the Berthold measurements are 20% higher than the FAG measurements. The yearly average of the artificial β activity concentration does not deviate significantly from zero.

Since 2004, the analysis of the ambient dose equivalent rate has been based on a set of 153 stations. The yearly average ambient dose equivalent rate in 2018 was calculated using all 153 stations.

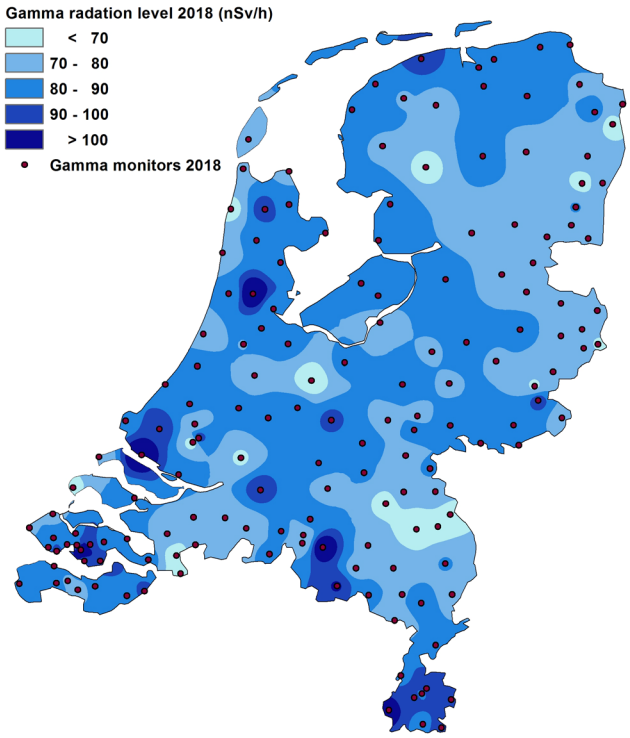
In 2018, the yearly average for the ambient dose equivalent rate was 81.9 $nSv \cdot h^{-1}$. This value, similar to the values of 2015-2017, is significantly higher than the values measured before 2014, as can be seen in Figure 4.4. This increase of the ambient dose equivalent rate coincides with and is attributable to the replacement of the old Bitt RS03 proportional counter monitors with the new Saphymo XL 2-3 Geiger-Müller monitors.



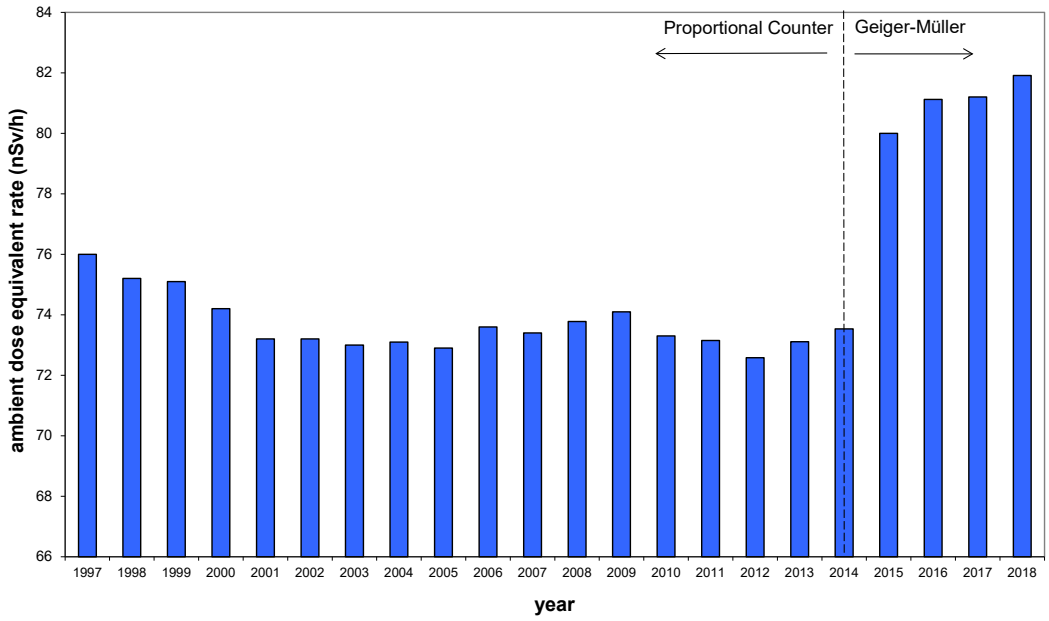
Dots represent the locations of the aerosol monitors.
Figure 4.1 An impression of spatial variation in the average gross α activity concentration of (mainly) short-lived radionuclides in air dust



During the second half of 2002, the FAG monitors were replaced by Berthold monitors.
Figure 4.2 Yearly average gross α activity concentration of (mainly) short-lived radionuclides in air dust.



Dots represent the locations of the dose equivalent rate monitors.
Figure 4.3 An impression of spatial variation in the average ambient dose equivalent rate



During the course of 2015, most of the proportional counter monitors were replaced by Geiger-Müller monitors.
Figure 4.4 The yearly average ambient dose equivalent rate

Figure 4.5 shows the cosmogenic contribution to the effective dose rate, which is related to the ambient dose equivalent rate. Figure 4.5 also shows the influence of the 11-year solar cycle on the cosmogenic contribution.

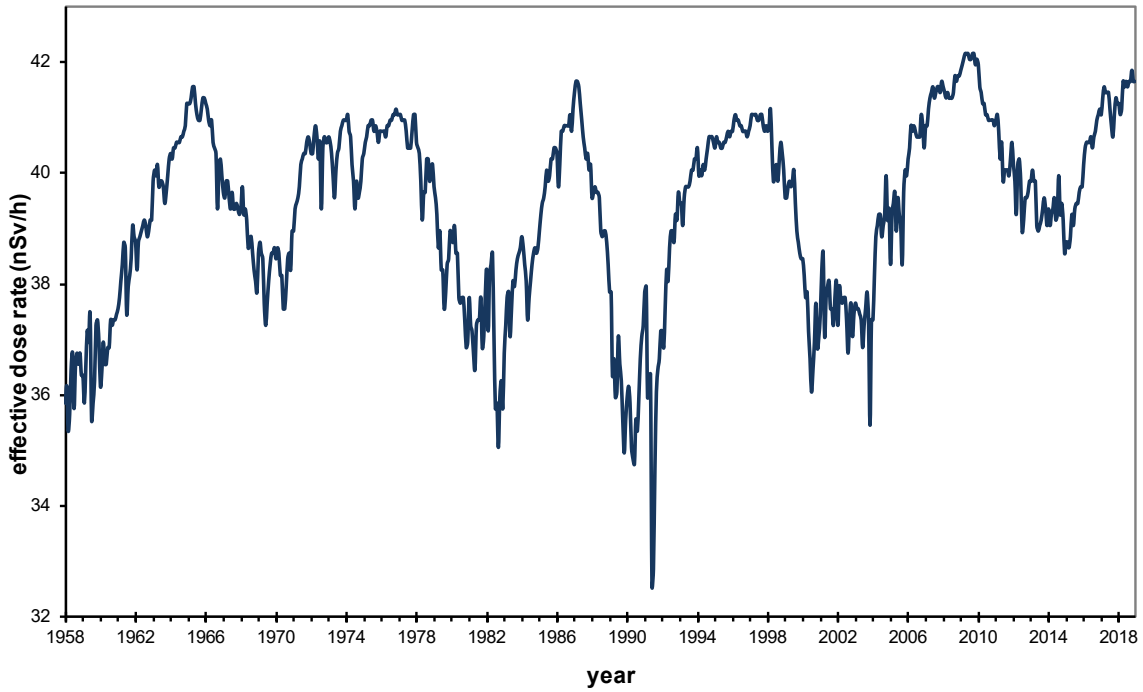


Figure derived from data supplied by the Federal Aviation Administration [41].

Figure 4.5 Cosmogenic contribution to the effective dose rate (at sea level), influenced by the solar cycle, calculated for the location 51° 26′ north and 3° 43′ east (in the south-western part of the Netherlands) and air pressure 1019 hPa.

5 Surface water and seawater

5.1 Introduction

Rijkswaterstaat (RWS) regularly monitors the concentration of a large number of radionuclides in surface water and seawater. A representative part of the RWS's monitoring programme is presented here. A more detailed description of the monitoring programme, its underlying strategy and the results of radioactivity measurements in Dutch waters are reported elsewhere [42, 43, 44, 45].

The general monitoring strategy used for surface water is to monitor the inland and transborder water bodies of the Netherlands. Therefore, the locations mentioned in Table 5.1 are used for monitoring, as they represent the major inland, incoming and outgoing waters of the Netherlands. The locations for seawater presented in this report have been chosen to represent the major areas of seawater.

The monitoring programme used for determining radionuclides in surface water and seawater is shown in Tables 5.1 and 5.2 and in Figure 5.1. Radionuclides were measured in water and in suspended solids. The samples were collected at equidistant times.

Since 2010, measurements in sediment have been added to the RWS monitoring programme, but the results are not presented in this report.

The radionuclides were measured according to standard procedures [44].

Table 5.1 Monitoring programme for the determination of radionuclides in surface water in 2018

Location	Parameter	Matrix	Monitoring frequency (per year)
IJsselmeer (Vrouwezand)	Gross α	Water	13
	Residual β	Water	13
	^{3}H	Water	7
	^{60}Co	Suspended solids	13
	^{131}I	Suspended solids	13
	^{137}Cs	Suspended solids	13
Noordzeekanaal (IJmuiden)	Gross α	Water	13
	Residual β	Water	13
	^{3}H	Water	13
	^{60}Co	Suspended solids	6
	^{131}I	Suspended solids	6
	^{137}Cs	Suspended solids	6

Continued on next page

Table 5.1 Continued

Location	Parameter	Matrix	Monitoring frequency (per year)
Nieuwe Waterweg (Maassluis)	Gross α	Water	13
	Residual β	Water	13
	^{3}H	Water	6
	^{90}Sr	Water	6
	^{226}Ra	Water	6
	^{60}Co	Suspended solids	13
	^{131}I	Suspended solids	13
	^{137}Cs	Suspended solids	13
	^{210}Pb	Suspended solids	6
Rhine (Lobith)	Gross α	Water	13
	Residual β	Water	13
	^{3}H	Water	13
	^{90}Sr	Water	7
	^{226}Ra	Water	7
	^{60}Co	Suspended solids	24
	^{131}I	Suspended solids	24
	^{137}Cs	Suspended solids	24
	^{210}Pb	Suspended solids	7
Scheldt (Schaar van Ouden Doel)	Gross α	Water	13
	Residual β	Water	13
	^{3}H	Water	7
	^{226}Ra	Water	7
	^{60}Co	Suspended solids	13
	^{131}I	Suspended solids	13
	^{137}Cs	Suspended solids	13
	^{210}Pb	Suspended solids	7
Meuse (Eijsden)	Gross α	Water	13
	Residual β	Water	13
	^{3}H	Water	13
	^{90}Sr	Water	7
	^{226}Ra	Water	7
	^{60}Co	Suspended solids	52
	^{131}I	Suspended solids	52
	^{137}Cs	Suspended solids	52
	^{210}Pb	Suspended solids	7
Ghent-Terneuzen Canal (Sas van Gent)	Gross α	Water	13
	Residual β	Water	13
	^{3}H	Water	6
	^{60}Co	Suspended solids	4
	^{131}I	Suspended solids	4
	^{137}Cs	Suspended solids	4
Haringvliet (Haringvlietsluis)	Gross α	Water	13
	Residual β	Water	13
	^{3}H	Water	7
	^{60}Co	Suspended solids	4
	^{131}I	Suspended solids	4
	^{137}Cs	Suspended solids	4

Table 5.2 Monitoring programme for the determination of radionuclides in seawater

Area	Location	Parameter	Matrix	Monitoring frequency (per year)
Coastal Area (KZ)	Noordwijk 2 (1)	Gross α	Water	4
		Residual β	Water	4
		^{3}H	Water	4
Southern North Sea (ZN)	Noordwijk 70 (1)	Gross α	Water	4
		Residual β	Water	4
		^{3}H	Water	4
		^{90}Sr	Water	4
Central North Sea (CN)	Terschelling 235 (1)	Gross α	Water	4
		Residual β	Water	4
		^{3}H	Water	4
		^{90}Sr	Water	4
Delta Coastal Waters (VD)	Schouwen 10 (1)	Gross α	Water	12
		Residual β	Water	12
		^{3}H	Water	12
		^{90}Sr	Water	4
Western Scheldt (WS)	Vlissingen Boei	Gross α	Water	13
		Residual β	Water	13
		^{3}H	Water	13
		^{90}Sr	Water	11
		^{137}Cs	Suspended solids	4
		^{210}Pb	Suspended solids	4
Eems-Dollard (ED)	Huibergat Oost	Gross α	Water	4
		Residual β	Water	4
		^{3}H	Water	4
Wadden Sea West (WW)	Marsdiep Noord	Gross α	Water	4
		Residual β	Water	4
		^{3}H	Water	4
Wadden Sea East (WO)	Dantziggat	Gross α	Water	4
		Residual β	Water	4
		^{3}H	Water	4

(1) Number indicates distance from shore. For example, 'Noordwijk 2' means Noordwijk 2 km offshore.

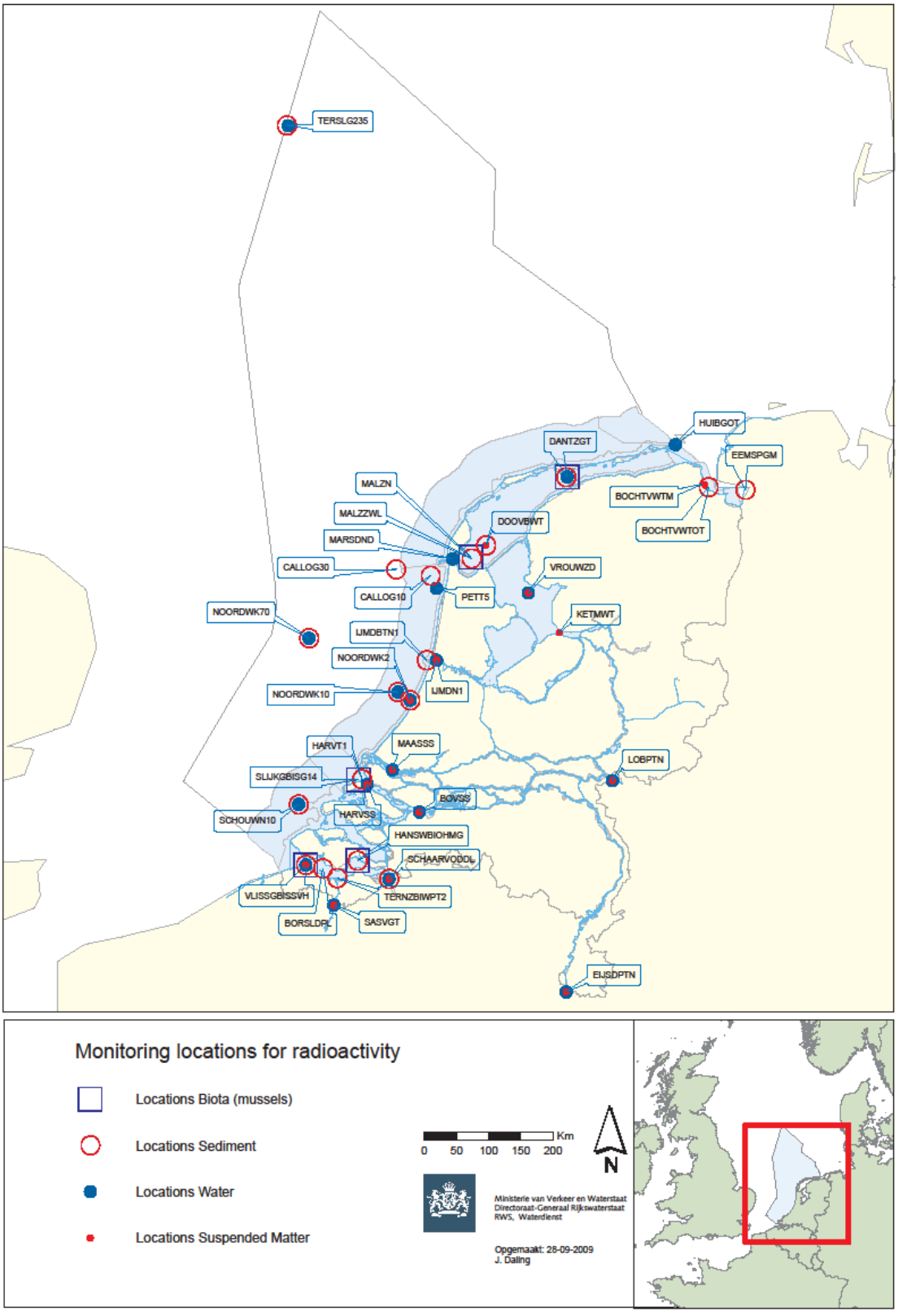


Figure 5.1 Overview of monitoring locations for the entire monitoring programme for surface water and seawater, as given by Rijkswaterstaat

5.2 The results for surface water

The results of measurements of radioactivity in surface water are presented in Tables A11 and A12 and in Figures 5.2 to 5.19.

Gross α and residual β are indicative parameters. In general, gross α and β analysis is used as a screening method to determine the total radioactivity present in the form of α and β radiation, without regard to the identity of specific radionuclides.

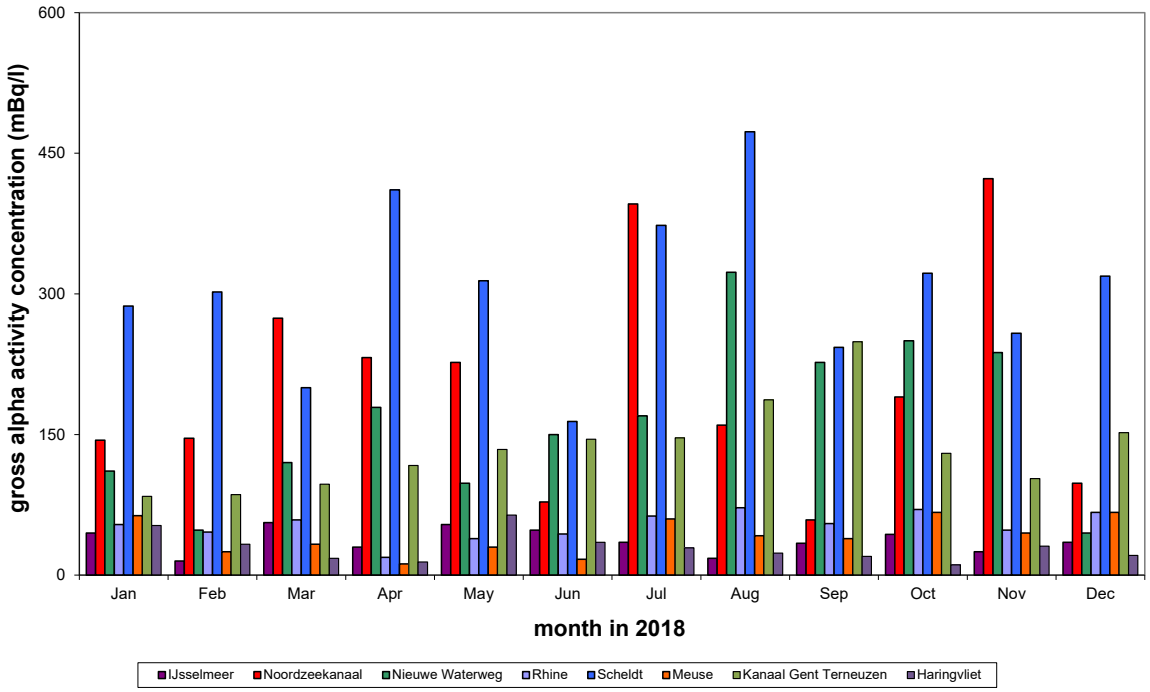
The yearly average activity concentrations of gross α for the IJsselmeer, North Sea Canal (Noordzeekanaal), Nieuwe Waterweg, Rhine, Scheldt, Meuse, Ghent-Terneuzen Canal and Haringvliet were 37, 205, 169, 53, 307, 43, 137 and 29 $mBq \cdot L^{-1}$, respectively. The yearly average activity concentrations of residual β for the IJsselmeer, North Sea Canal (Noordzeekanaal), Nieuwe Waterweg, Rhine, Scheldt, Meuse, Ghent-Terneuzen Canal and Haringvliet were 23, 22, 49, 32, 125, 18, 29 and 14 $mBq \cdot L^{-1}$, respectively. The yearly average activity concentrations of gross α and residual β in 2018 were within the range of those in previous years.

Residual β in the North Sea Canal (Noordzeekanaal), Nieuwe Waterweg and Scheldt has shown a change in trend since 1994, which was caused by a change in the measuring technique that applies only to salt and brackish water [42]. This change in trend was therefore not seen for residual β in the IJsselmeer, Rhine or Meuse.

The yearly average ^{3}H activity concentrations for the IJsselmeer, North Sea Canal (Noordzeekanaal), Nieuwe Waterweg, Rhine, Scheldt, Meuse, Ghent-Terneuzen Canal and Haringvliet were 2.7, 3.2, 3.9, 4.0, 9.6, 24.0, 1.9 and 4.2 $Bq \cdot L^{-1}$, respectively. The yearly average ^{3}H activity concentrations in 2018 were within the range of those in previous years. Elevated levels of ^{3}H in the Rhine may originate from several nuclear power plants or research reactors in Germany, France or Switzerland. Elevated levels of ^{3}H in the Meuse could have originated from the nuclear power plants at Tihange (Belgium) or Chooz (France). Elevated levels of ^{3}H in the Scheldt could have originated from the nuclear power plant at Doel (Belgium).

The nuclide ^{90}Sr is released into the environment by nuclear power plants and nuclear reprocessing plants. The yearly average ^{90}Sr activity concentrations for the Nieuwe Waterweg, Rhine and Meuse were < 2.2, < 0.8 and < 0.8 $mBq \cdot L^{-1}$, respectively. The yearly average ^{90}Sr activity concentrations in 2018 were within the range of those in previous years.

The nuclide ^{226}Ra is released into the environment by the ore-processing industry and transhipment. ^{226}Ra in the Nieuwe Waterweg and Scheldt might originate from these industries in the port areas of Rotterdam-Rijnmond and Antwerp, respectively. The yearly average ^{226}Ra activity concentrations for the Nieuwe Waterweg, Rhine, Scheldt and Meuse were 7.0, 5.0, 5.0 and 2.9 $mBq \cdot L^{-1}$, respectively. The yearly average ^{226}Ra activity concentrations in 2018 were within the range of those in previous years.



Average values are shown in cases of multiple measurements per month.

Figure 5.2 Gross α activity concentrations for the IJsselmeer, North Sea Canal (Noordzeekanaal), Nieuwe Waterweg, Rhine, Scheldt, Meuse, Ghent-Terneuzen Canal and Haringvliet

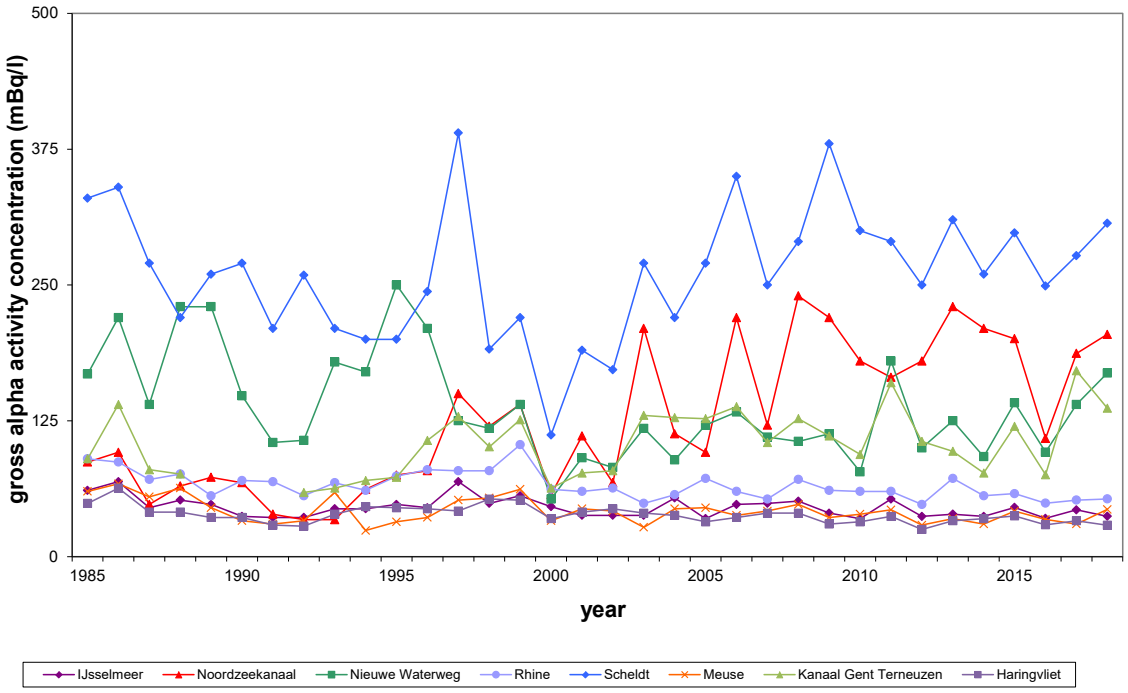
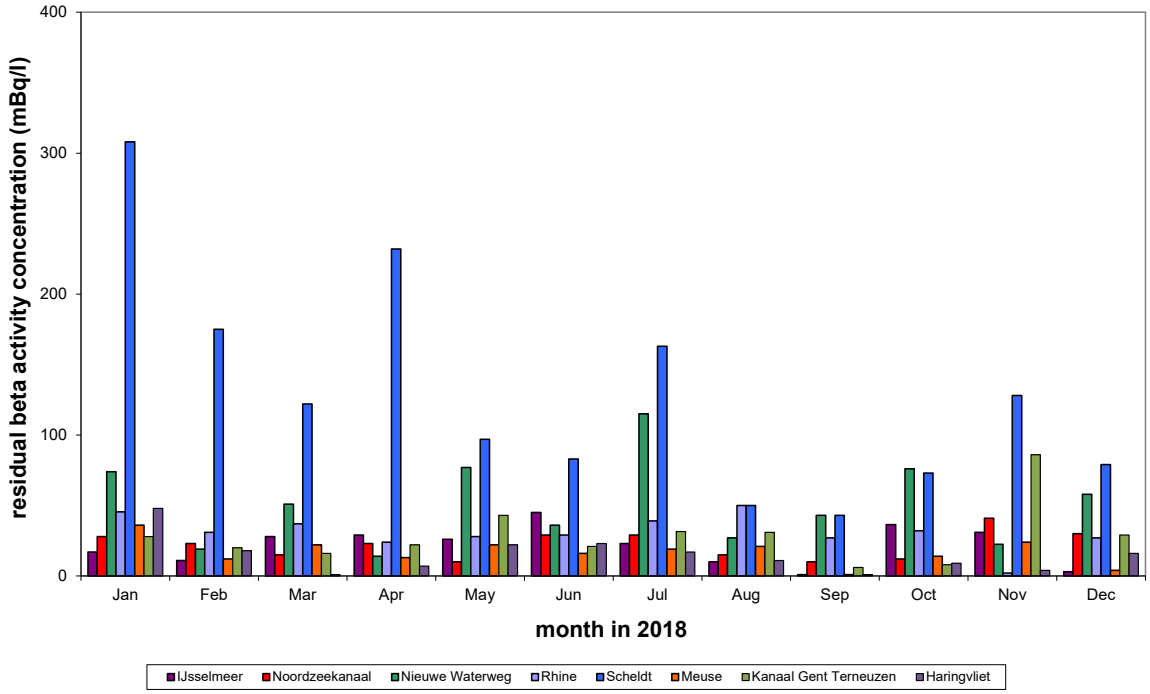


Figure 5.3 Yearly average gross α activity concentrations



Average values are shown in cases of multiple measurements per month.

Figure 5.4 Residual β activity concentrations for the IJsselmeer, North Sea Canal (Noordzeekanaal), Nieuwe Waterweg, Rhine, Scheldt, Meuse, Ghent-Terneuzen Canal and Haringvliet

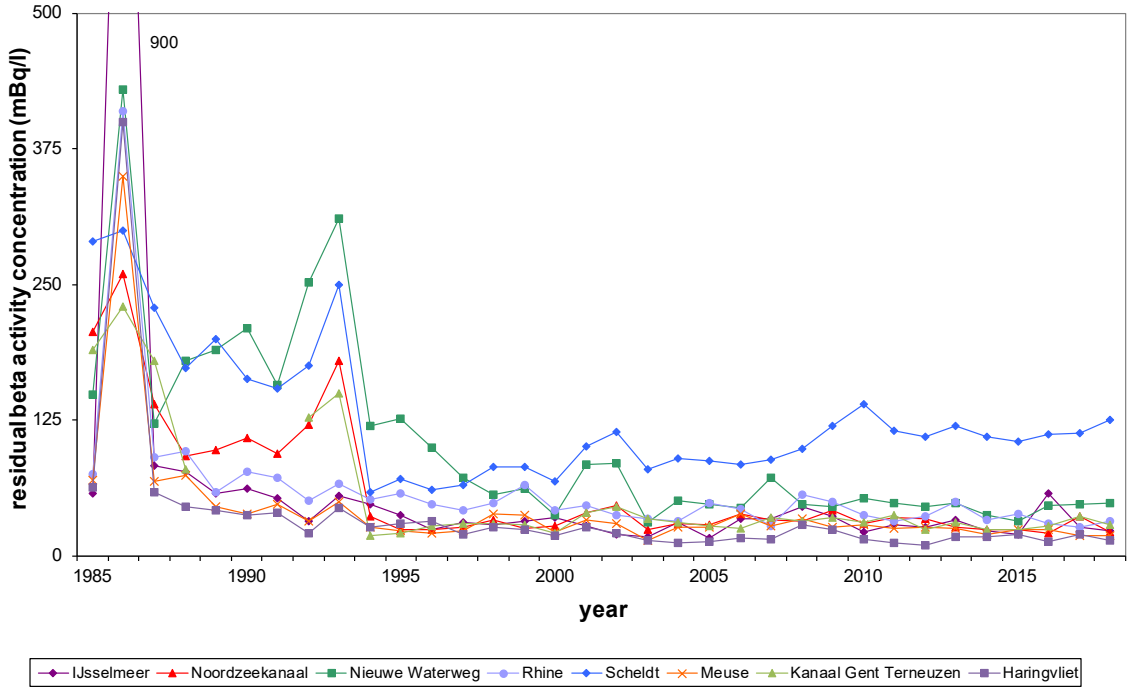
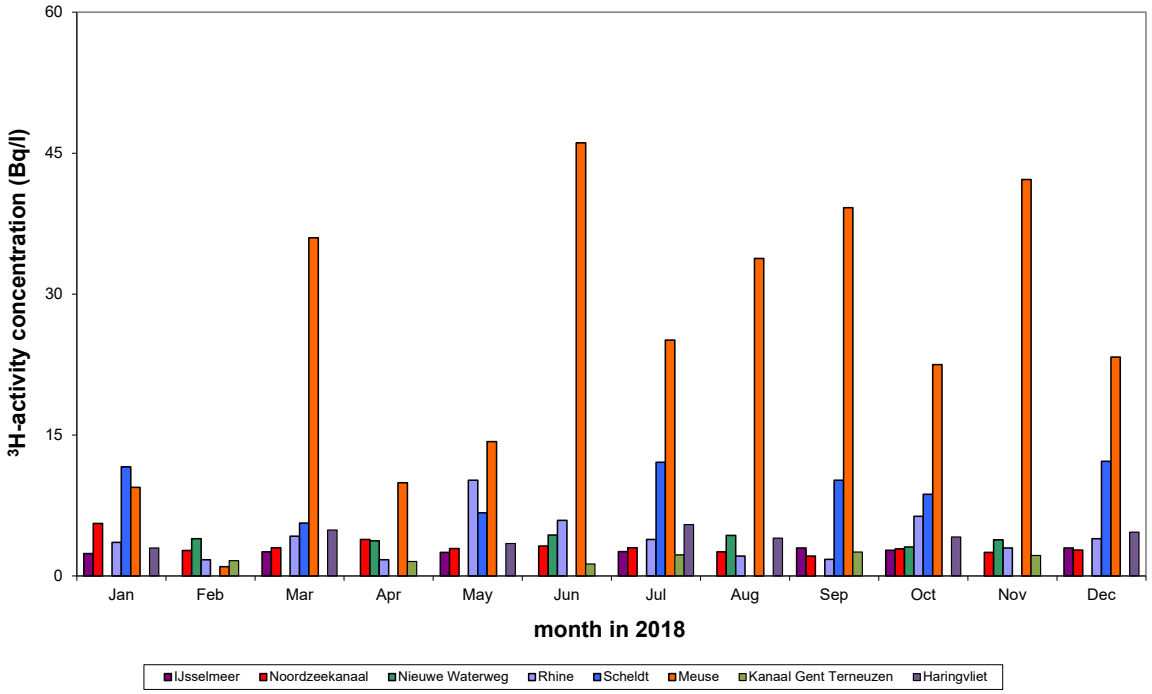


Figure 5.5 Yearly average residual β activity concentrations



Average values are shown in cases of multiple measurements per month.

Figure 5.6 ^{3}H activity concentrations for the IJsselmeer, North Sea Canal (Noordzeekanaal), Nieuwe Waterweg, Rhine, Scheldt, Meuse, Ghent-Terneuzen Canal and Haringvliet

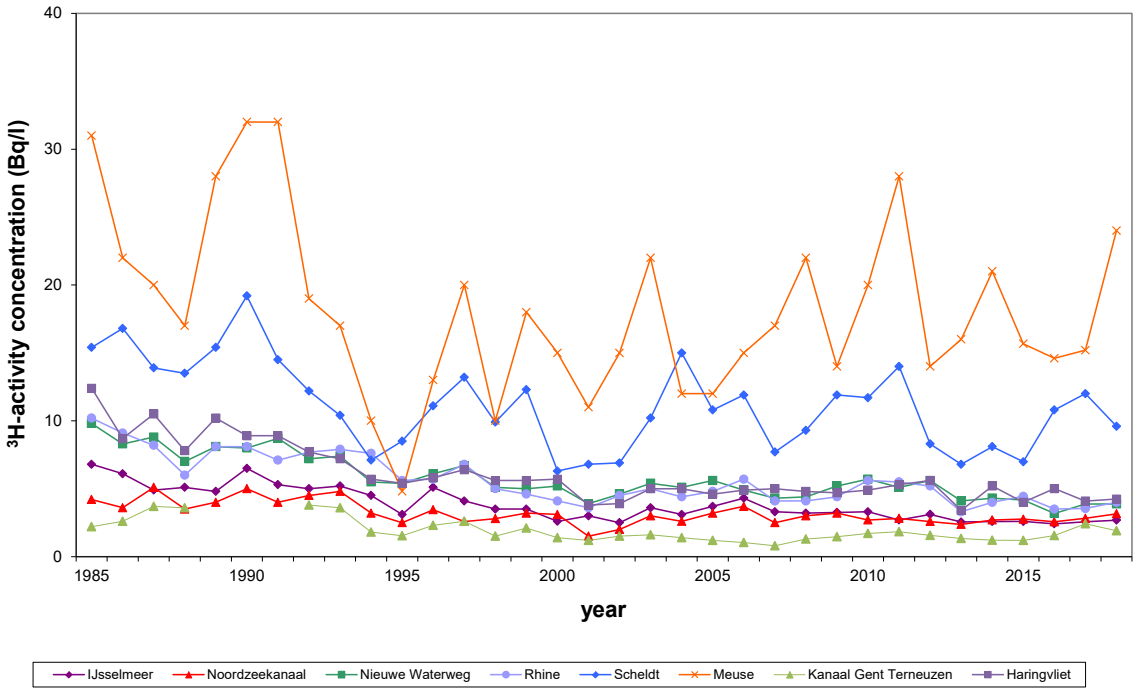
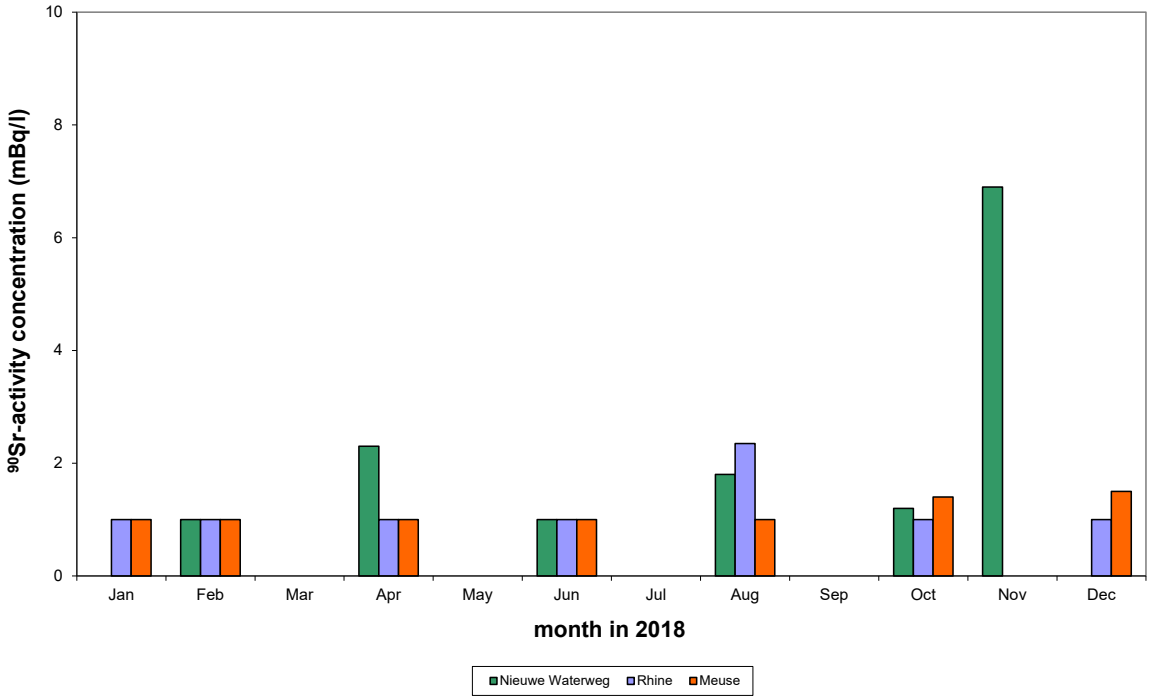
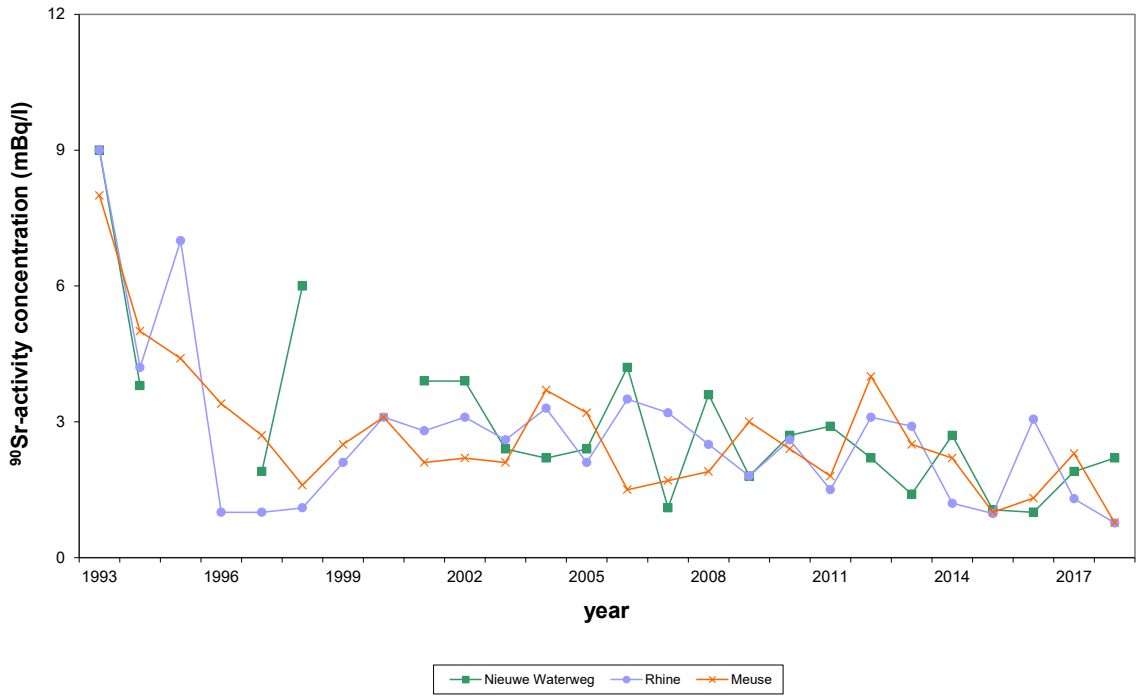


Figure 5.7 Yearly average ^{3}H activity concentrations



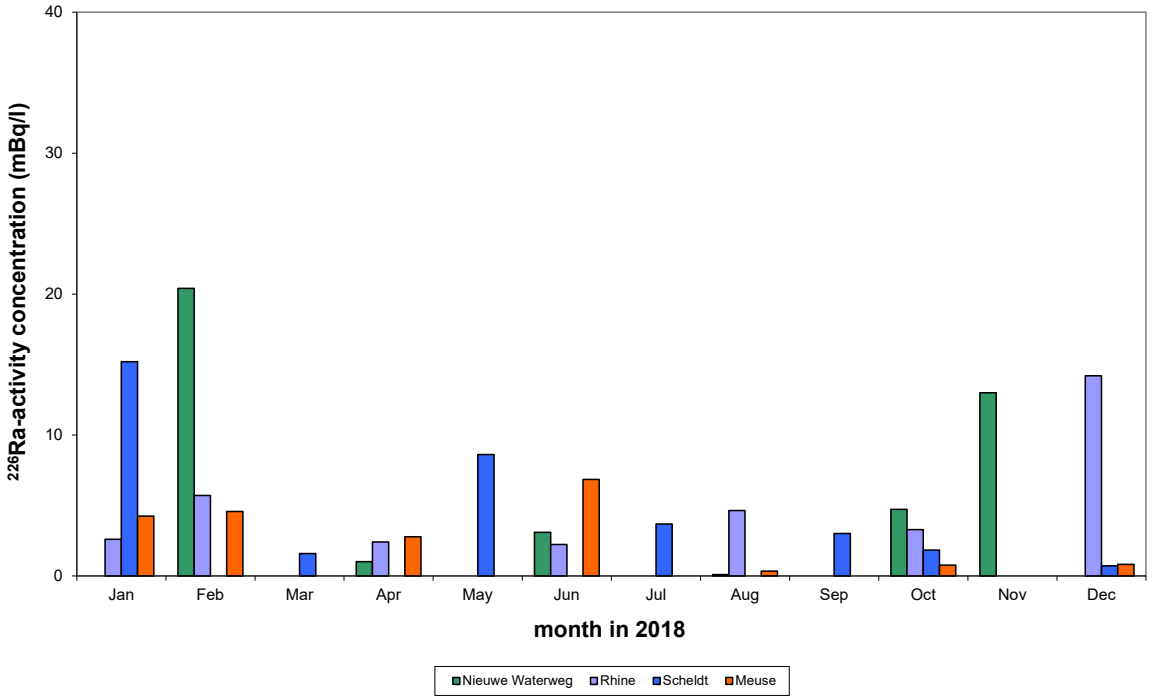
Average values are shown in cases of multiple measurements per month.

Figure 5.8 ^{90}Sr activity concentrations for the Nieuwe Waterweg, Rhine and Meuse



Data are not available for the Nieuwe Waterweg in 1995, 1996, 1999 and 2000.

Figure 5.9 Yearly average ^{90}Sr activity concentrations



Average values are shown in cases of multiple measurements per month.

Figure 5.10 ^{226}Ra activity concentrations for the Nieuwe Waterweg, Rhine, Scheldt and Meuse

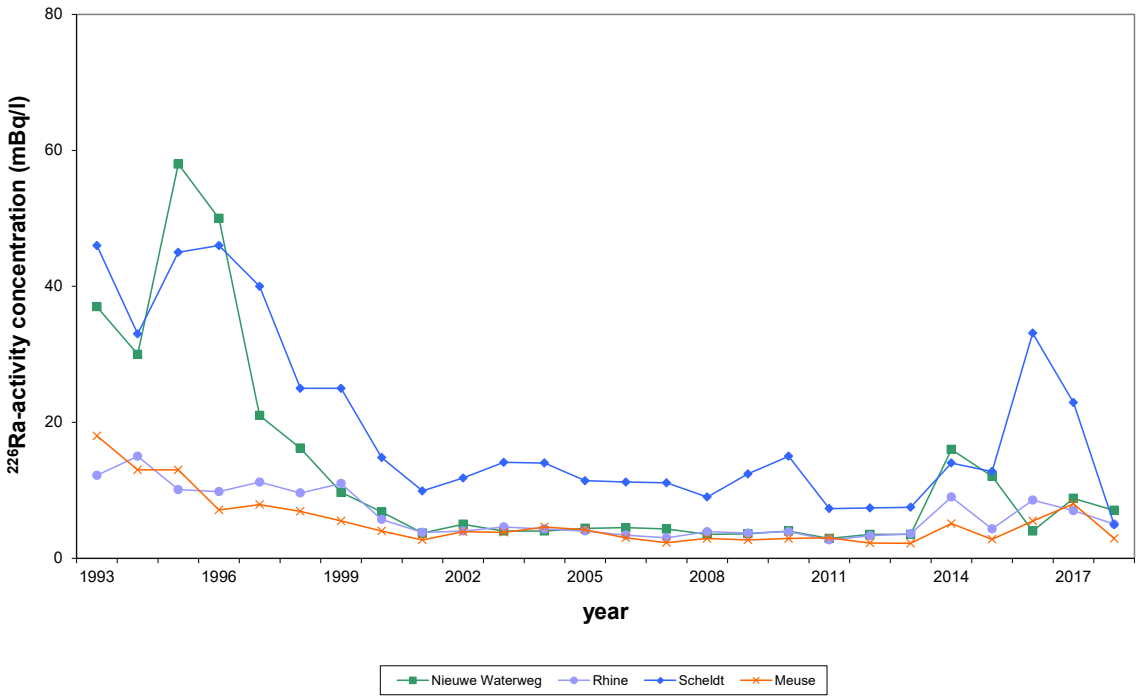


Figure 5.11 Yearly average ^{226}Ra activity concentrations

Nuclear power plants discharge radionuclides, including ^{60}Co and ^{137}Cs. ^{60}Co activity concentrations are higher in the Meuse than elsewhere. ^{60}Co (and ^{137}Cs) in the Meuse could have originated from the nuclear power plants at Tihange (Belgium) or Chooz (France).

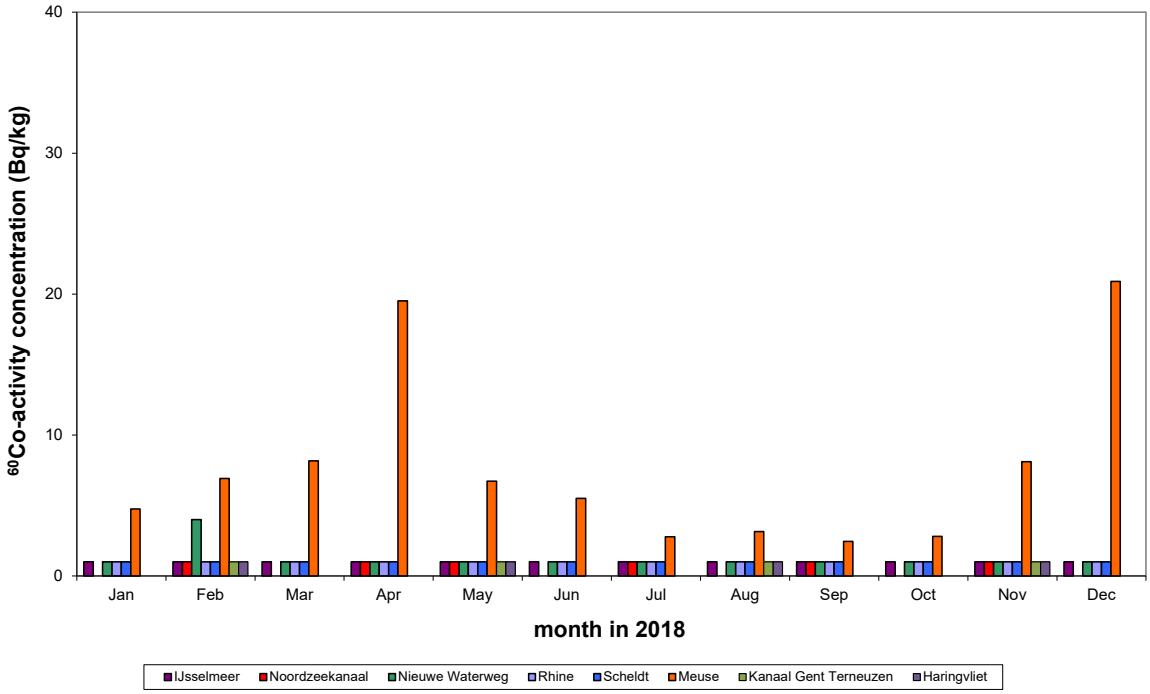
The yearly average ^{60}Co activity concentrations in suspended solids for the IJsselmeer, North Sea Canal (Noordzeekanaal), Nieuwe Waterweg, Rhine, Scheldt, Meuse, Ghent-Terneuzen Canal and Haringvliet were all < 1 Bq·kg^{-1} except for the Meuse (7.3 Bq·kg^{-1}).

The yearly average ^{137}Cs activity concentrations in suspended solids for the IJsselmeer, North Sea Canal (Noordzeekanaal), Nieuwe Waterweg, Rhine, Scheldt, Meuse, Ghent-Terneuzen Canal and Haringvliet were 3.3, 4.1, 7.9, 8.1, 5.1, 9.5, 3.2 and 7.8 Bq·kg^{-1}, respectively. In 2018, the yearly average ^{60}Co and ^{137}Cs activity concentrations in suspended solids were within the range of those in previous years.

The nuclide ^{131}I is released into the environment primarily by medical facilities. ^{131}I activity concentrations are higher in the North Sea Canal (Noordzeekanaal) and Meuse than elsewhere. ^{131}I in the North Sea Canal and Meuse might originate from a sewage treatment plant in the port area of Westpoort and medical facilities in Belgium, respectively.

The yearly average ^{131}I activity concentrations in suspended solids for the IJsselmeer, North Sea Canal (Noordzeekanaal), Nieuwe Waterweg, Rhine, Scheldt, Meuse, Ghent-Terneuzen Canal and Haringvliet were < 1, 29, < 1.5, < 2.2, < 0.6, < 7, < 1 and < 1 Bq·kg^{-1}, respectively. In 2018, the yearly average ^{131}I activity concentrations in suspended solids were within the range of those in previous years. For the North Sea Canal (Noordzeekanaal, (at location IJmuiden), the presence of ^{131}I most likely originates from a sewage treatment facility. One of the contributions to the sewage waters is discharge from medical facilities. It has not been determined which changes in discharges over time might be related to the observed changes of activity concentrations over the years.

The radionuclides ^{210}Po and ^{210}Pb originate from the uranium decay chain and are released by the ore-processing industry [42]. Since ^{210}Po is usually in equilibrium with ^{210}Pb in suspended solids, RWS reports only ^{210}Pb. ^{210}Pb in the Nieuwe Waterweg and Scheldt might originate from these types of industries in the port areas of Rijnmond and Antwerp, respectively. The yearly average ^{210}Pb activity concentrations in suspended solids for the Nieuwe Waterweg, Rhine, Scheldt and Meuse, were 112, 113, 74 and 143 Bq·kg^{-1}, respectively. In 2018, the yearly average ^{210}Pb activity concentrations in suspended solids were within the range of those in previous years.



Average values are shown in cases of multiple measurements per month.

Figure 5.12 ^{60}Co activity concentrations in suspended solids for the IJsselmeer, North Sea Canal (Noordzeekanaal), Nieuwe Waterweg, Rhine, Scheldt, Meuse, Ghent-Terneuzen Canal and Haringvliet

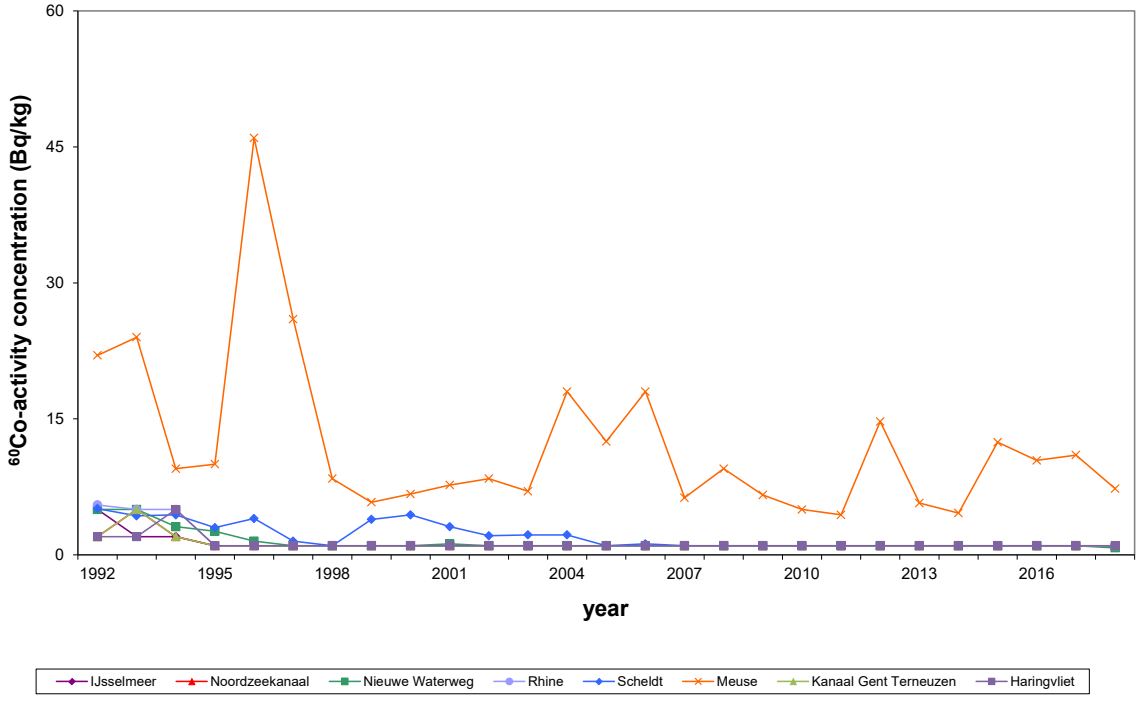
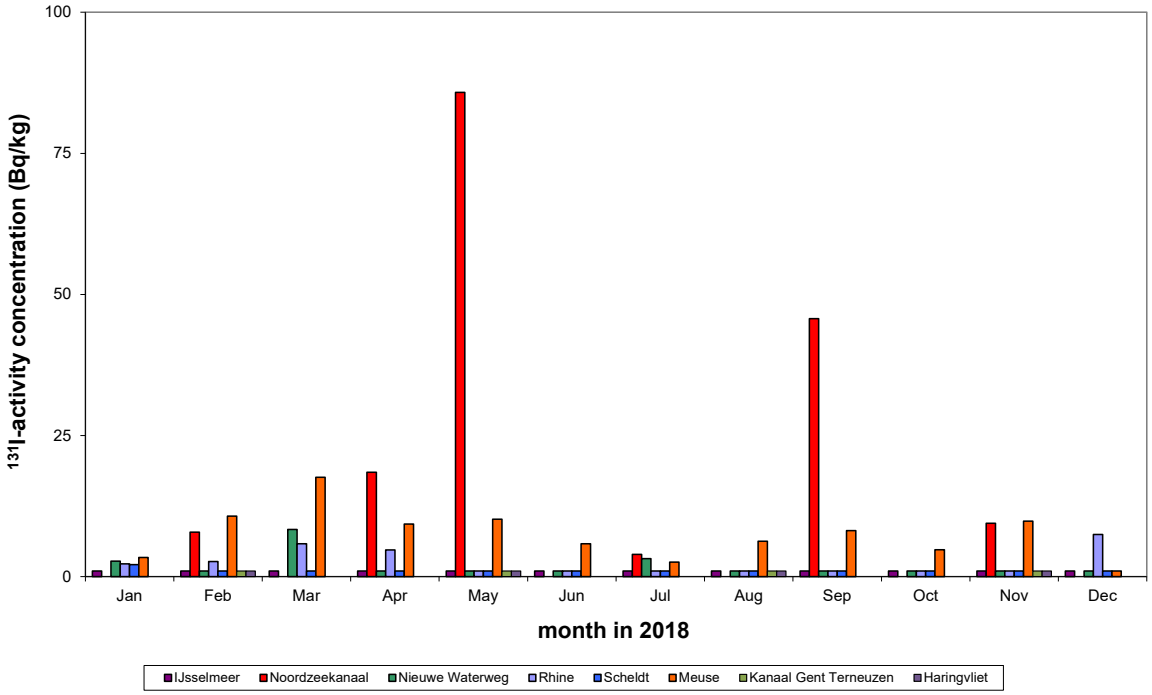


Figure 5.13 Yearly average ^{60}Co activity concentrations in suspended solids



Average values are shown in cases of multiple measurements per month.

Figure 5.14 ^{131}I activity concentrations in suspended solids for the IJsselmeer, North Sea Canal (Noordzeekanaal), Nieuwe Waterweg, Rhine, Scheldt, Meuse, Ghent-Terneuzen Canal and Haringvliet

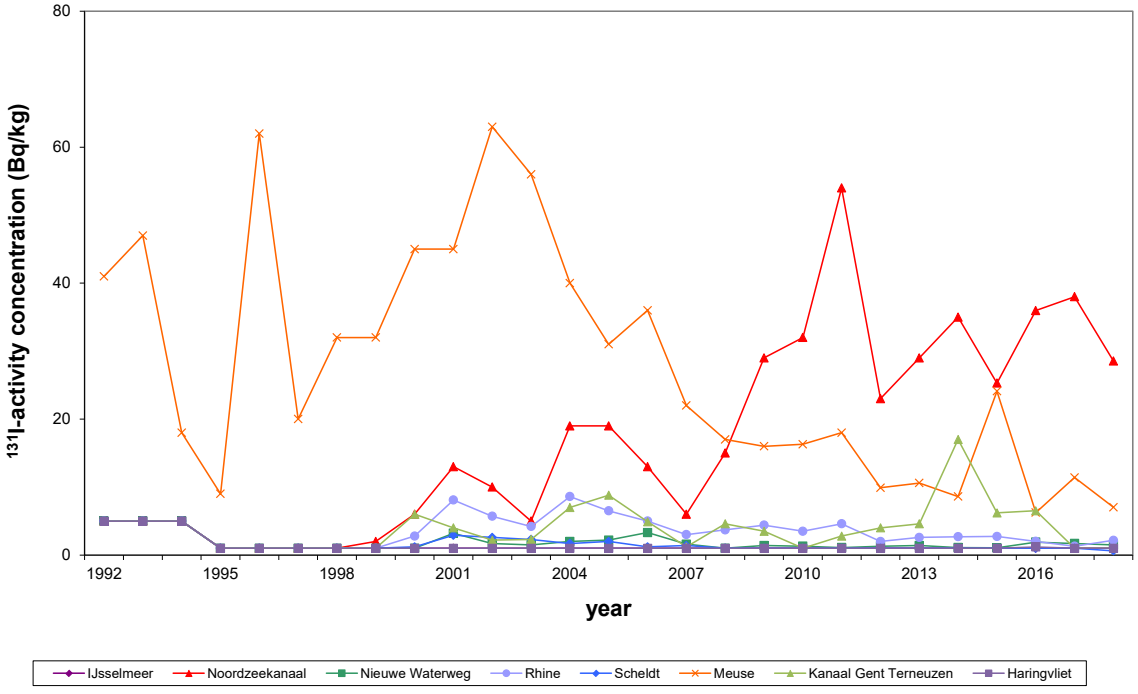
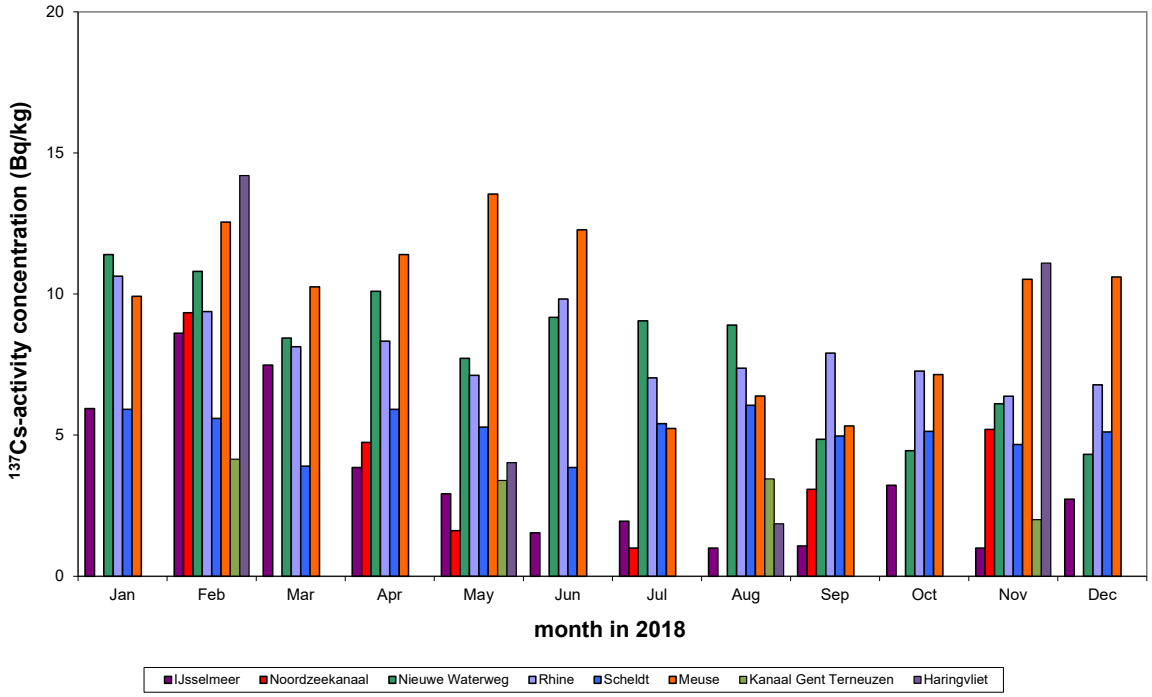


Figure 5.15 Yearly average ^{131}I activity concentrations in suspended solids



Average values are shown in cases of multiple measurements per month.

Figure 5.16 ^{137}Cs activity concentrations in suspended solids for the IJsselmeer, North Sea Canal (Noordzeekanaal), Nieuwe Waterweg, Rhine, Scheldt, Meuse, Ghent-Terneuzen Canal and Haringvliet

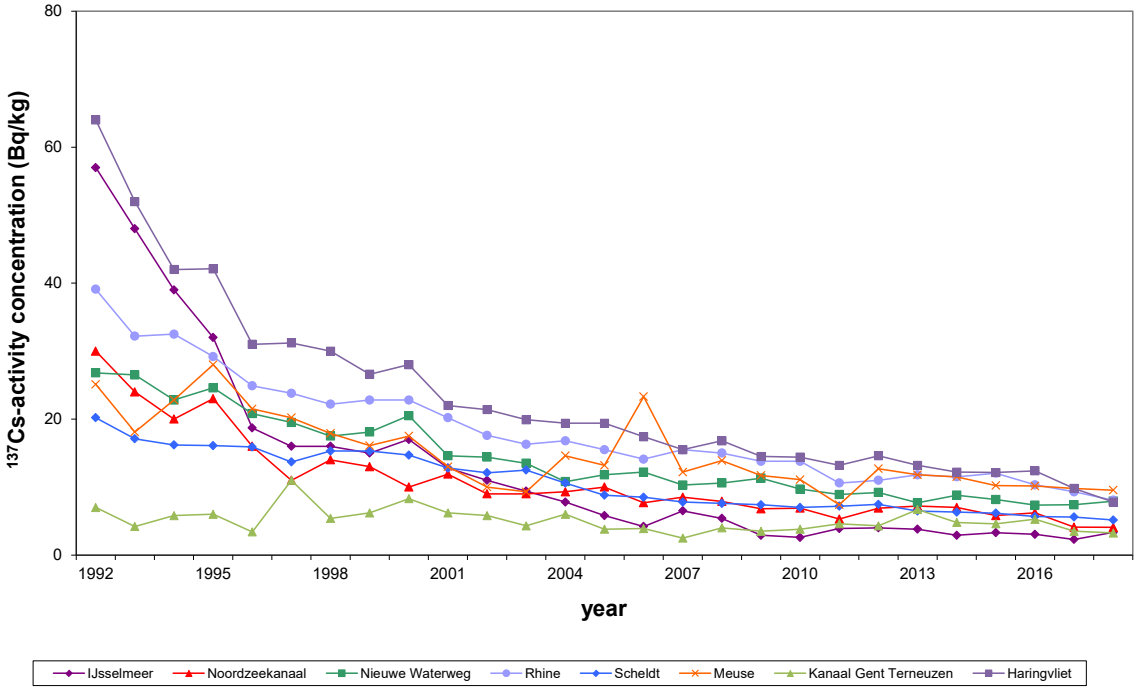
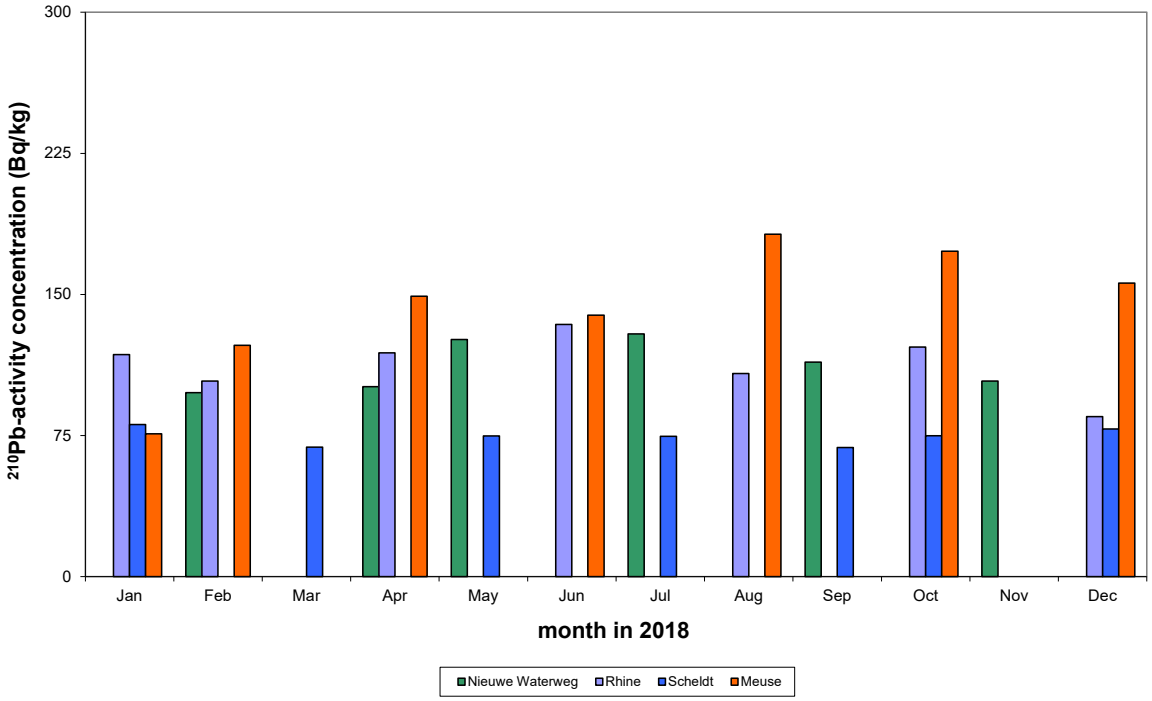


Figure 5.17 Yearly average ^{137}Cs activity concentrations in suspended solids



Average values are shown in cases of multiple measurements per month.

Figure 5.18 ^{210}Pb activity concentrations in suspended solids

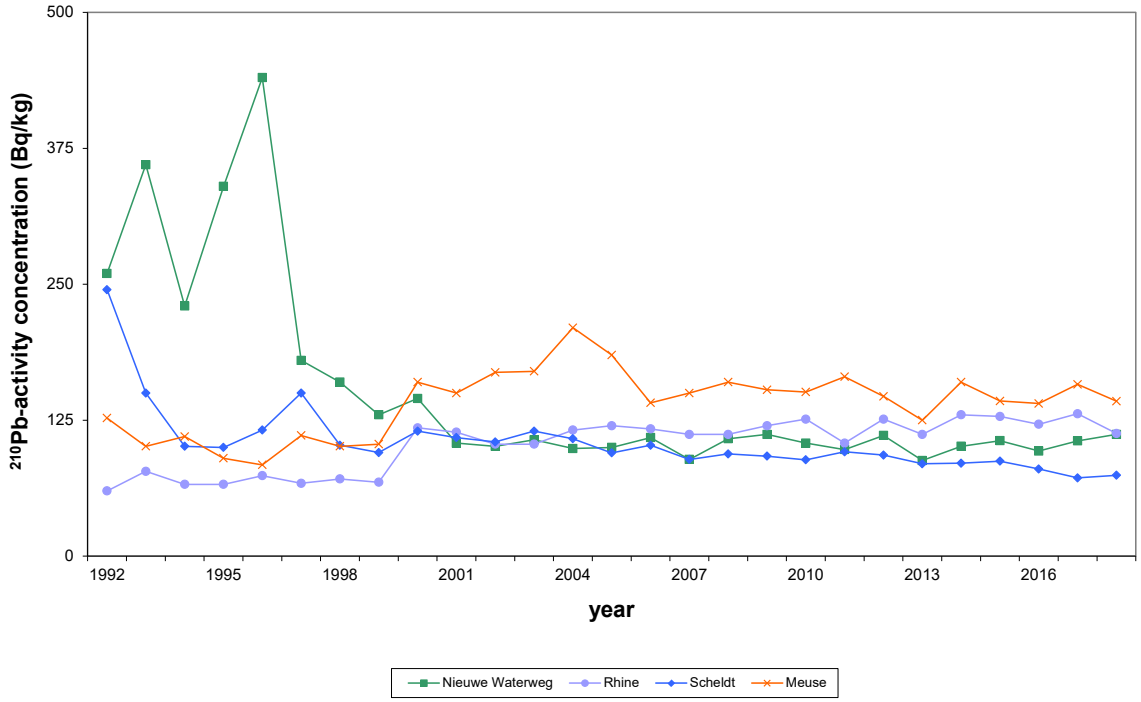


Figure 5.19 Yearly average ^{210}Pb activity concentrations in suspended solids

5.3 The results for seawater

The results of measurements of radioactivity in seawater are presented in Tables A13 and A14 and in Figures 5.20 to 5.31.
Gross α and residual β are indicative parameters [42]. In the first half of 2000, the background of the measuring equipment was unstable and higher than usual, which resulted in lower results. Therefore, yearly average concentrations of gross α in 2000 were based on data starting from the end of July 2000. Changes in the trend of gross α in the period 1985–1997 are explained elsewhere [42].

The yearly average activity concentrations of gross α in seawater for the Coastal Area, Southern North Sea, Central North Sea, Delta Coastal Waters, Western Scheldt, Eems-Dollard, Wadden Sea West and Wadden Sea East were 450, 480, 380, 410, 450, 250, 640 and 480 $mBq \cdot L^{-1}$, respectively. The yearly average gross α activity concentrations in 2018 were within the range of those in previous years (Figure 5.21).

Residual β shows an apparent change in trend since 1994 (Figure 5.23). This was caused by a change in measuring technique that applies to salt and brackish water [42]. The yearly average activity concentrations of residual β in seawater for the Coastal Area, Southern North Sea, Central North Sea, Delta Coastal Waters, Western Scheldt, Eems-Dollard, Wadden Sea West and Wadden Sea East were 51, 40, 31, 55, 90, 56, 46 and 140 $mBq \cdot L^{-1}$, respectively. The yearly average residual β activity concentrations in 2018 were within the range of those in previous years (Figure 5.23).

Nuclear power plants discharge the radionuclides ^{3}H and ^{137}Cs, among others. Nuclear fuel reprocessing plants discharge the radionuclides ^{3}H and ^{90}Sr, among others. Discharges from the nuclear power plants at Doel (Belgium) and Borssele (Netherlands) are monitored in the Western Scheldt (WS) area. The impact of reprocessing plants at Sellafield (England) and Le Havre (France) is monitored in the Central North Sea (CN) and Southern North Sea (ZN) areas, respectively [42]. The impact of both sources (nuclear power and reprocessing plants) is monitored indirectly in the Delta Coastal Waters (VD) area.

The yearly average ^{3}H activity concentrations in seawater for the Coastal Area, Southern North Sea, Central North Sea, Delta Coastal Waters, Western Scheldt, Eems-Dollard, Wadden Sea West and Wadden Sea East were 4.3, 3.4, 0.9, 4.6, 5.3, 4.4, 4.0 and 4.0 $Bq \cdot L^{-1}$, respectively.

The yearly average ^{90}Sr activity concentrations in seawater for the Southern North Sea, Central North Sea, Delta Coastal Waters and Western Scheldt were 4.1, < 1.2, < 2.2 and <0.7 $mBq \cdot L^{-1}$, respectively. The yearly average ^{3}H and ^{90}Sr concentrations in 2018 were within the range of those in previous years (Figures 5.25 and 5.27).

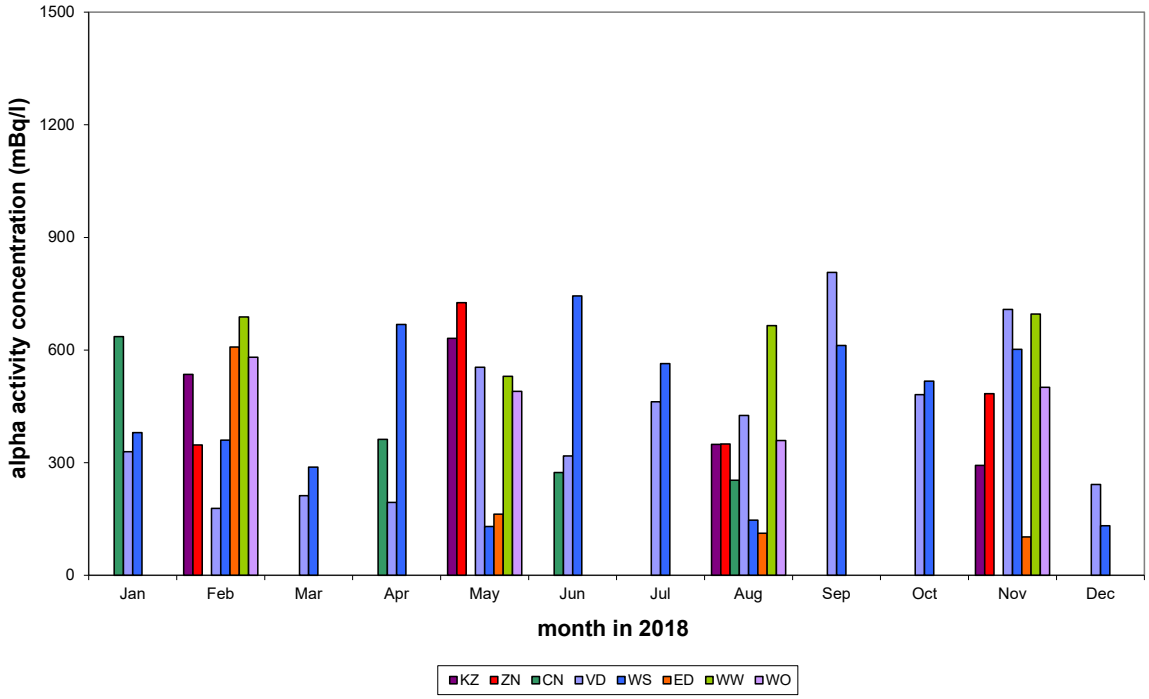


Figure 5.20 Gross α activity concentrations in seawater for the Coastal Area (KZ), Southern North Sea (ZN), Central North Sea (CN), Delta Coastal Waters (VD), Western Scheldt (WS), Eems-Dollard (ED), Wadden Sea West (WW) and Wadden Sea East (WO)

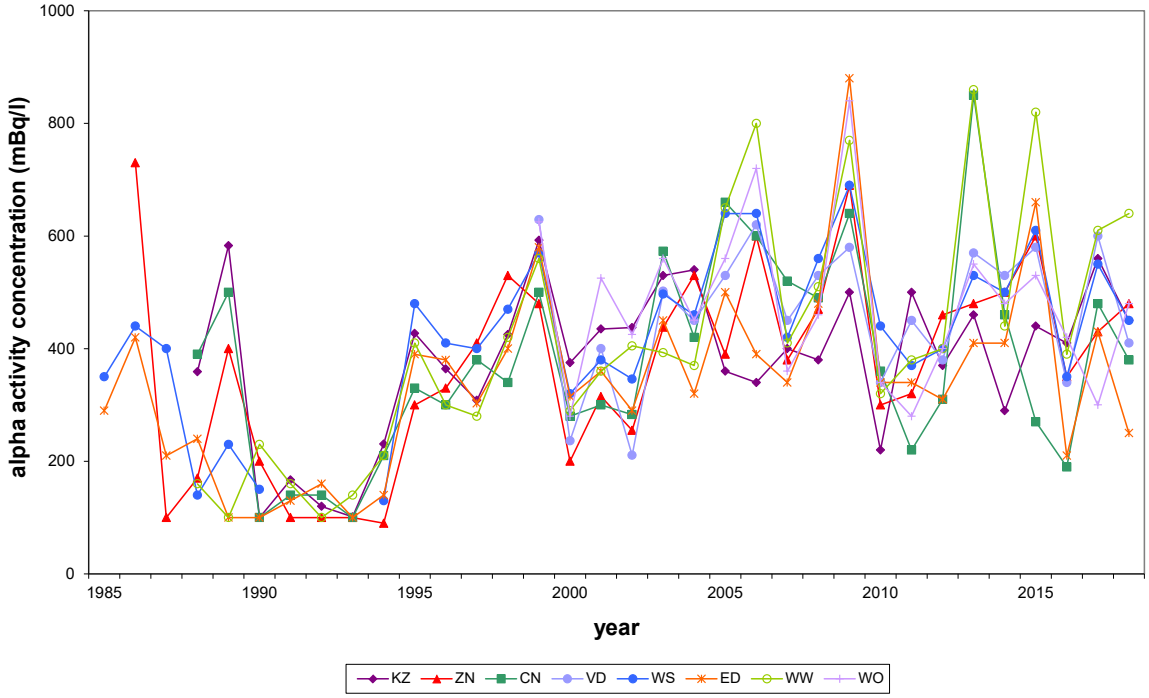


Figure 5.21 Yearly average gross α activity concentrations

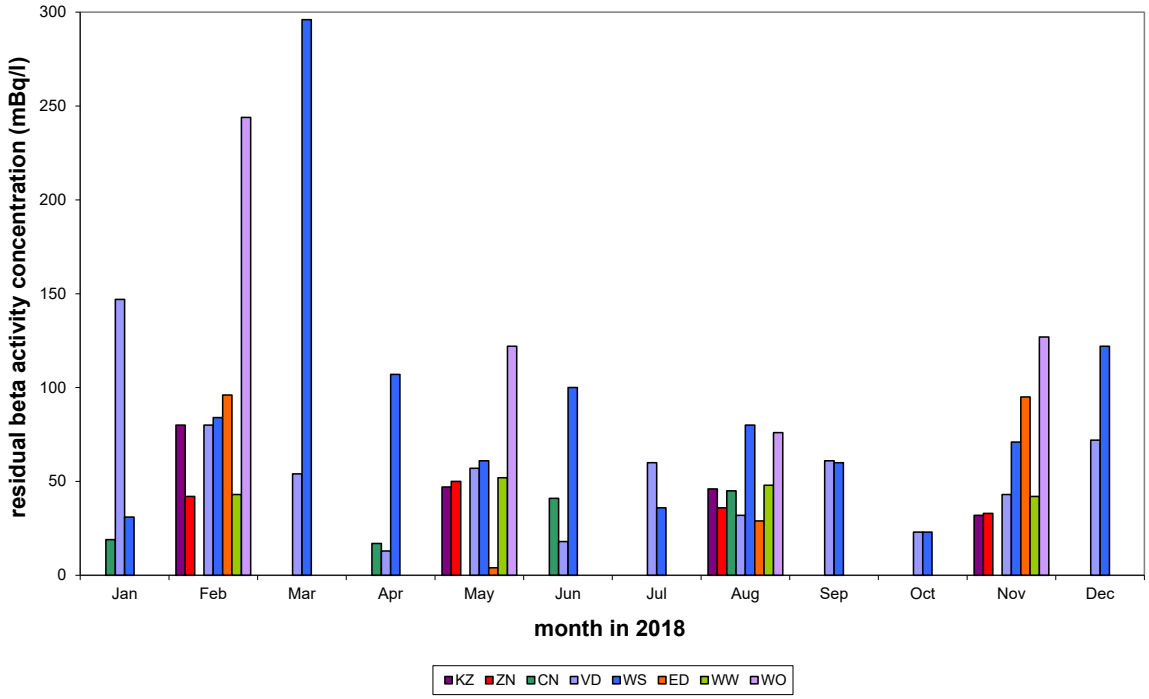


Figure 5.22 Residual β activity concentrations in seawater for the Coastal Area (KZ), Southern North Sea (ZN), Central North Sea (CN), Delta Coastal Waters (VD), Western Scheldt (WS), Eems-Dollard (ED), Wadden Sea West (WW) and Wadden Sea East (WO)

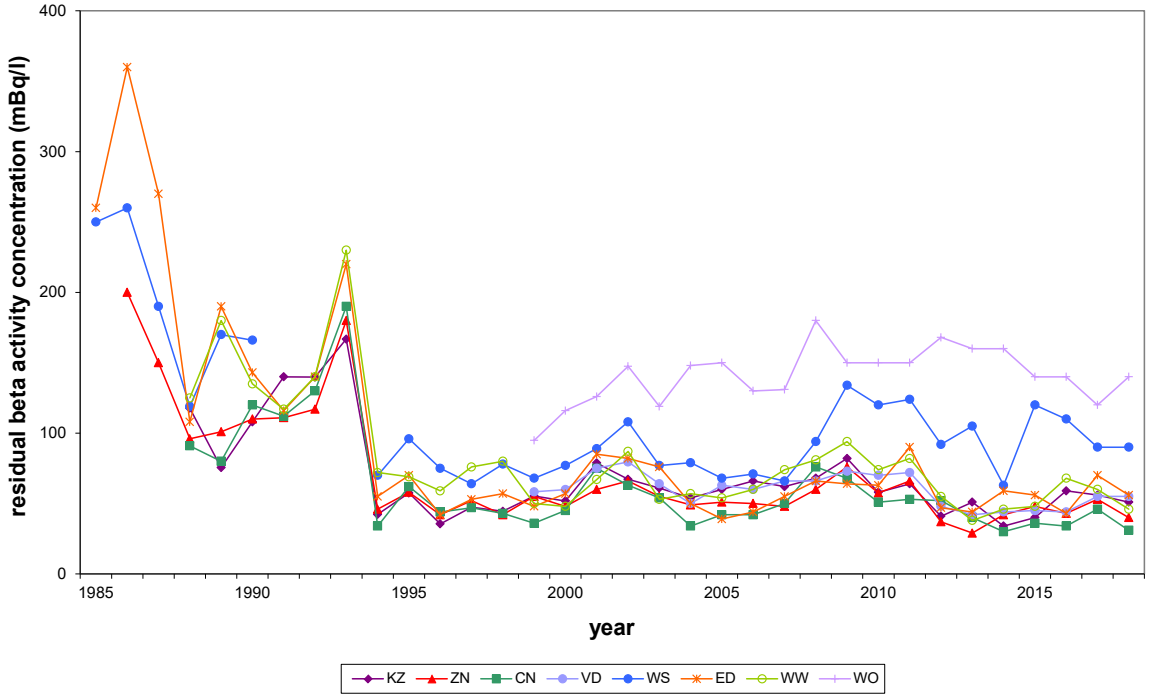


Figure 5.23 Yearly average residual β activity concentrations

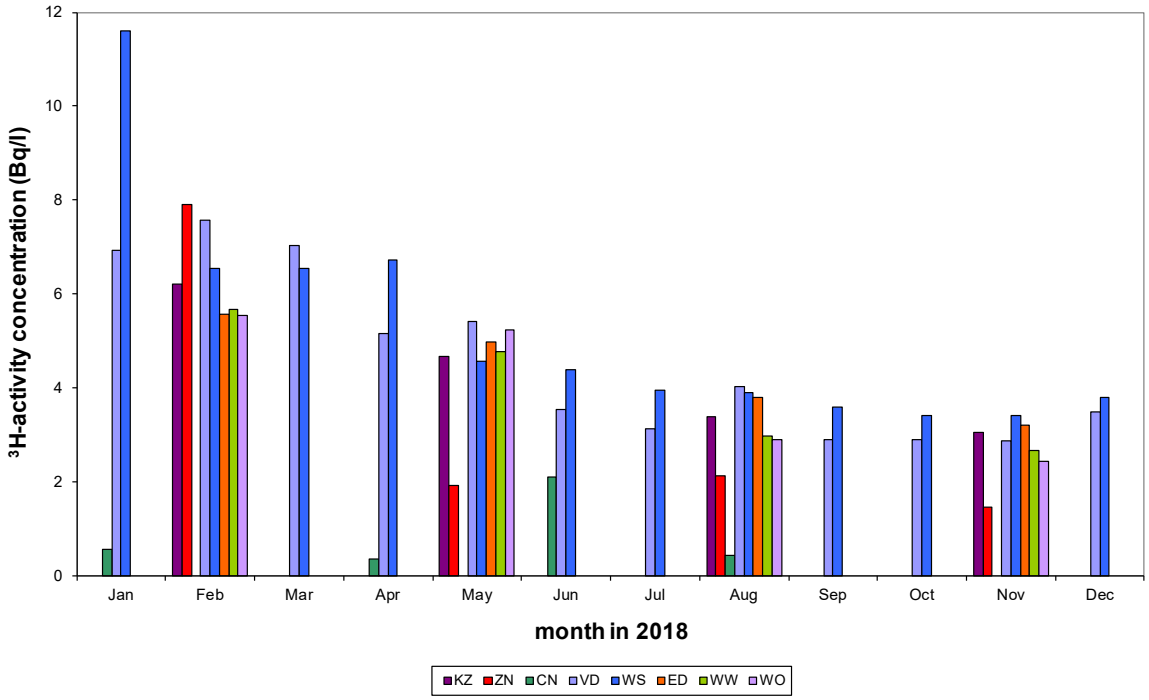


Figure 5.24 ^{3}H activity concentrations in seawater for the Coastal Area (KZ), Southern North Sea (ZN), Central North Sea (CN), Delta Coastal Waters (VD), Western Scheldt (WS), Eems-Dollard (ED), Wadden Sea West (WW) and Wadden Sea East (WO)

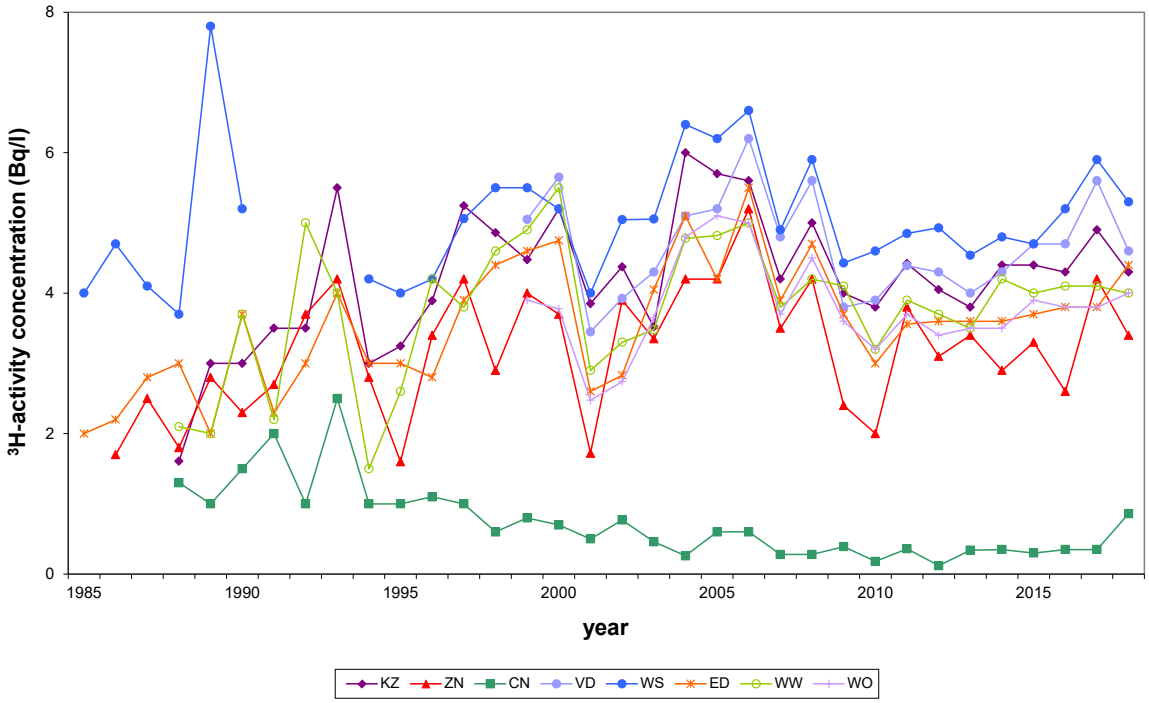


Figure 5.25 Yearly average ^{3}H activity concentrations

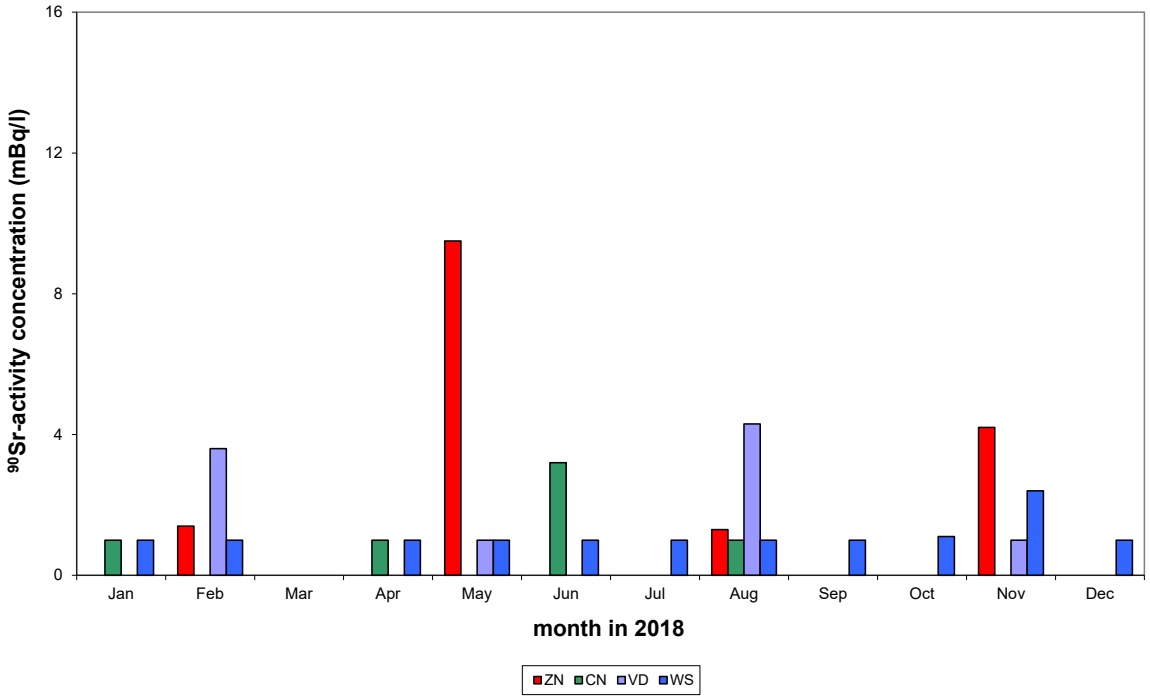


Figure 5.26 ^{90}Sr activity concentrations in seawater for the Southern North Sea (ZN), Central North Sea (CN), Delta Coastal Waters (VD) and Western Scheldt (WS)

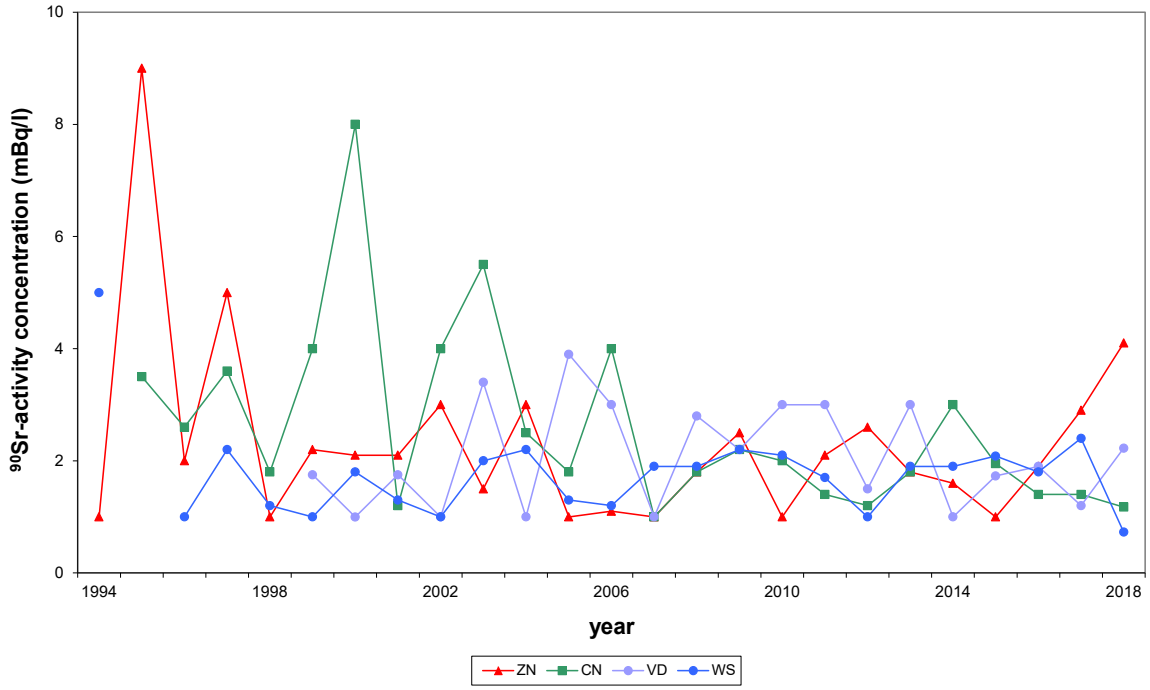


Figure 5.27 Yearly average ^{90}Sr activity concentrations

The radionuclides ^{210}Pb and ^{210}Po originate from the uranium decay chain and are released, for example, by the phosphate-processing industry and production platforms for oil and gas [42]. The phosphate-processing industry has not been operational in the Netherlands since 2012. Since ^{210}Po is usually in equilibrium with ^{210}Pb in suspended solids, RWS reports only on ^{210}Pb (as in surface water). In cases in which a strong increase in the gross α value is noticed, however, ^{210}Po is determined as well. Discharges via the main rivers are monitored in the Coastal Area (KZ). Discharges from the ore- and phosphate-processing industries in Belgium and the Netherlands are monitored in the Western Scheldt (WS) area. Discharges from Delfzijl, Eemshaven and plants in Germany are monitored in the Eems-Dollard (ED) area. The impact of these discharges, together with activity originating from the North Sea, is monitored indirectly in the Wadden Sea (WW and WO) area.

Since 2009, Wadden Sea West has replaced Wadden Sea East as a monitoring location. Since 2014, the monitoring of suspended solids has been discontinued in the Coastal Area, Eems-Dollard and Wadden Sea West.

The yearly average ^{137}Cs and ^{210}Pb activity concentrations in suspended solids for Western Scheldt were 2.9 and 56 Bq·kg^{-1}, respectively. The yearly average ^{137}Cs and ^{210}Pb activity concentrations in 2018 were within the range of those in previous years (Figures 5.29 and 5.31).

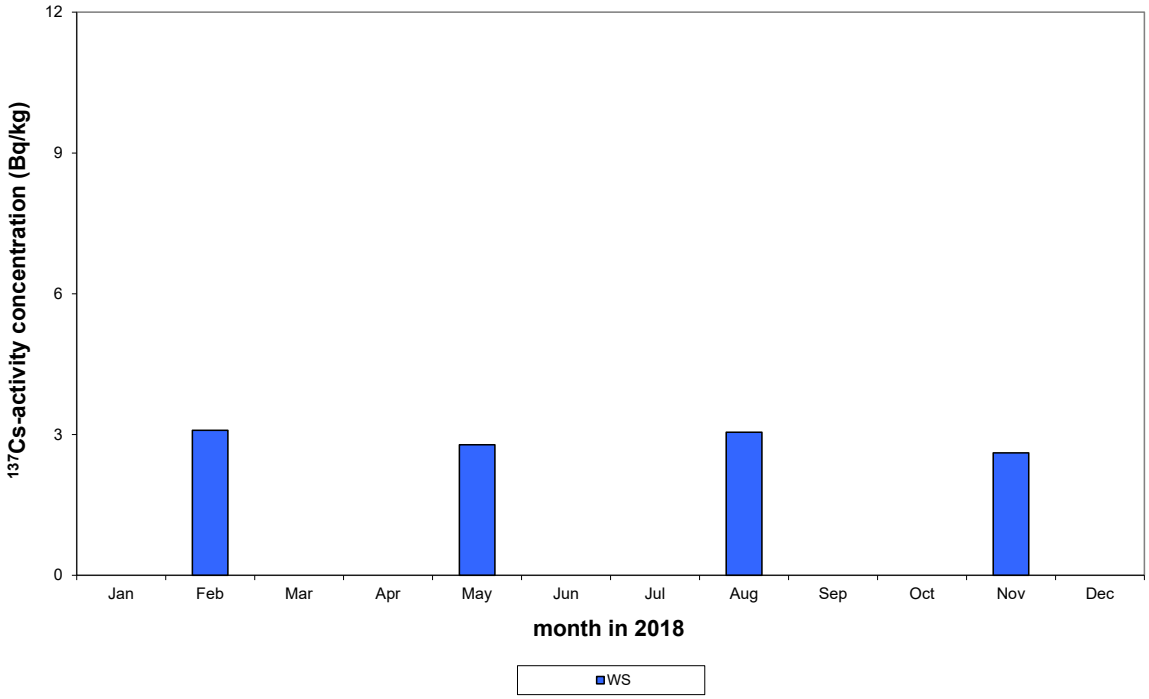
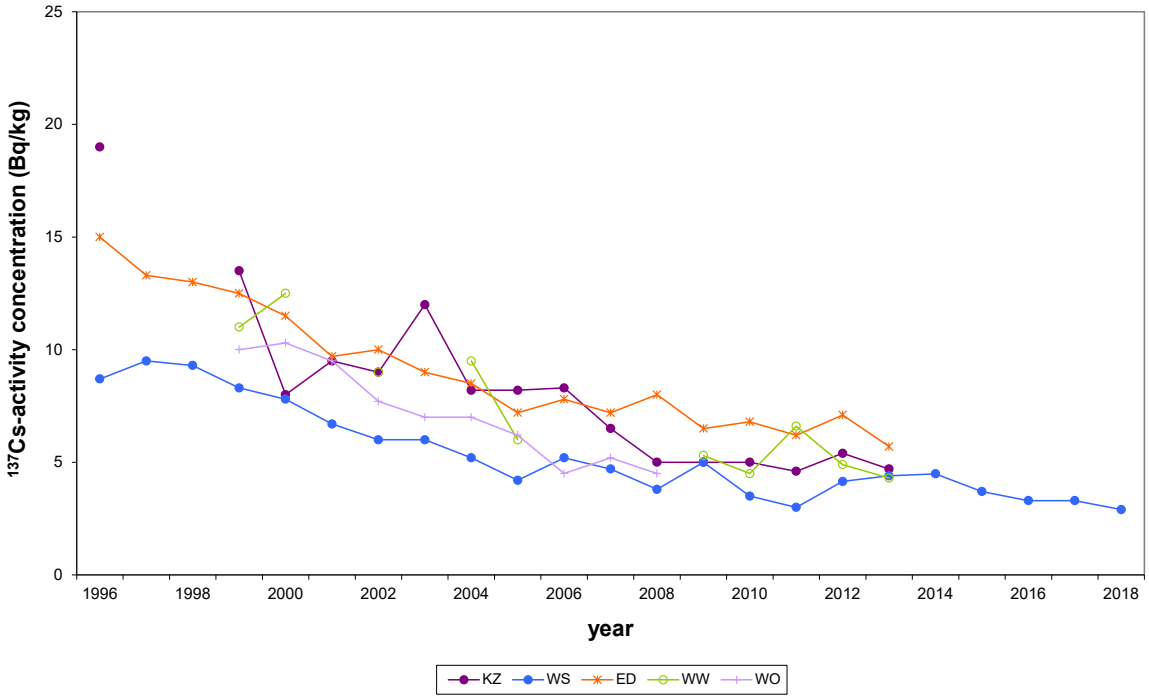


Figure 5.28 ^{137}Cs activity concentrations in suspended solids in seawater for the Western Scheldt (WS)



Since 2009, Wadden Sea West (WW) has replaced Wadden Sea East (WO) as a monitoring location. Since 2014, the monitoring of suspended solids has been discontinued in the Coastal Area (KZ), Eems-Dollard (ED) and Wadden Sea West (WW).

Figure 5.29 Yearly average ^{137}Cs activity concentrations in suspended solids

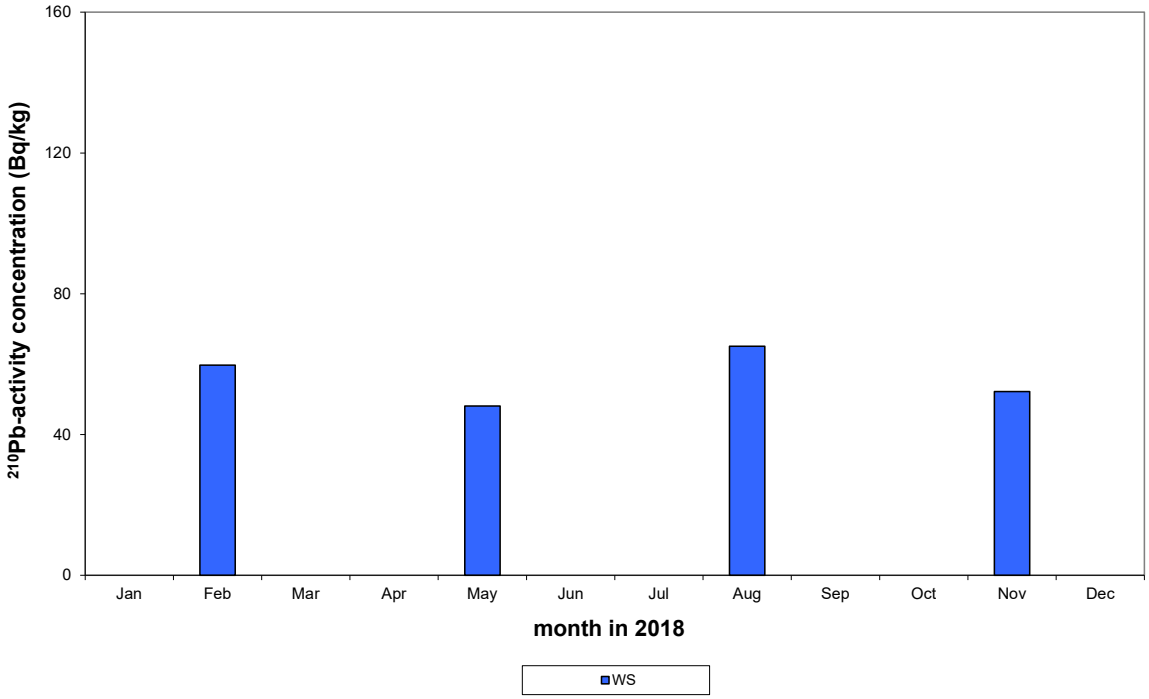
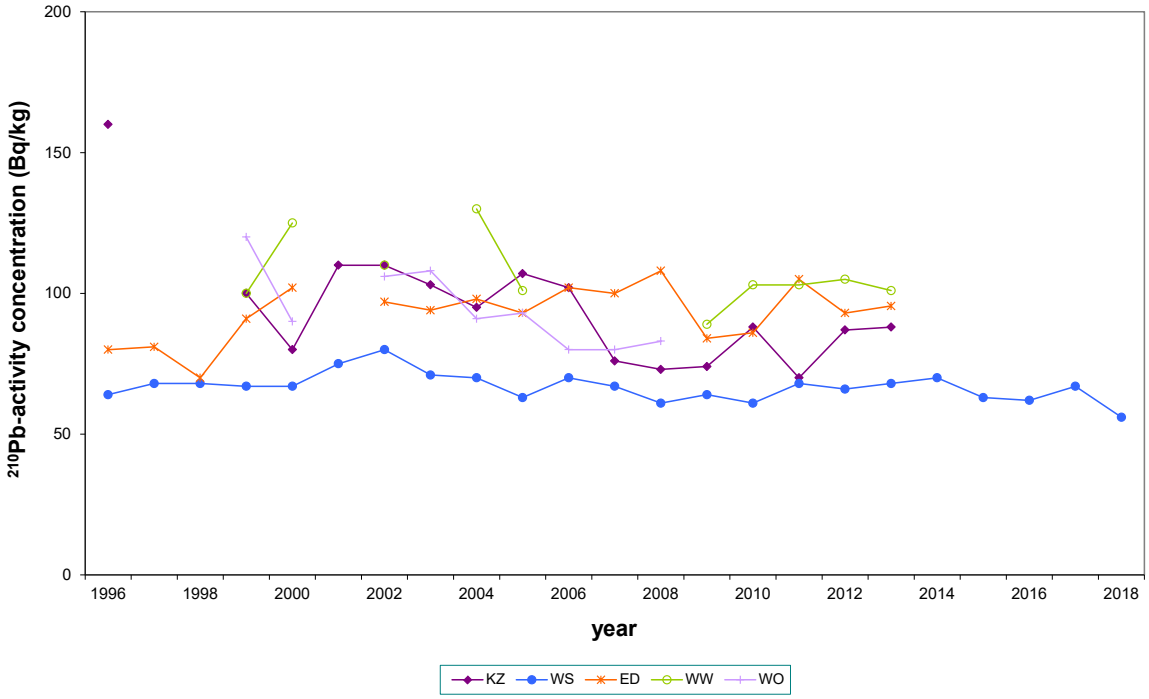


Figure 5.30 ^{210}Pb activity concentrations in suspended solids in seawater for the Western Scheldt (WS)



Since 2009, Wadden Sea West (WW) has replaced Wadden Sea East (WO) as a monitoring location. Since 2014, the monitoring of suspended solids has been discontinued in the Coastal Area (KZ), Eems-Dollard (ED) and Wadden Sea West (WW).

Figure 5.31 Yearly average ^{210}Pb activity concentrations in suspended solids

6 Water for human consumption

6.1 Introduction

In addition to the Recommendation on the Application of Article 36 of the Euratom Treaty [1], requirements for the monitoring of drinking water are given in Council Directive 2013/51/EC [46]. According to this directive, the parameters ^{3}H and the total indicative dose should be monitored. Screening methods for gross α and gross β activity concentrations may be used to monitor the total indicative dose. If the gross α and gross β activity concentrations are less than the screening levels of 0.1 and 1.0 $Bq \cdot L^{-1}$, respectively, it can be assumed that the total indicative dose is less than the parametric value of 0.1 $mSv \cdot year^{-1}$ [47, 48, 49].

In the Netherlands, drinking water production stations monitor untreated water and treated water for gross α, gross β, residual β and ^{3}H-activity concentrations. The monitoring frequency per location ranges from 1 to 26 times per year, depending on the volume of water produced. The activity concentrations are averaged over a year for each production station.

6.2 Results

The results for 2018 (treated and untreated water) are presented in Table 6.1. For gross α, gross β, residual β and ^{3}H, several hundred analyses were performed at a number of production stations. The number of production stations where sampling was carried out varied between 164 and 184.

Table 6.1 Drinking water analyses in 2018

Parameter	Gross α	Gross β	Residual β	^{3}H
Average value (1)	< 0.04 $Bq \cdot L^{-1}$	< 0.1 $Bq \cdot L^{-1}$	< 0.1 $Bq \cdot L^{-1}$	< 3.9 $Bq \cdot L^{-1}$
No. of all production stations	182	184	164	180
No. of all analyses	439	447	406	459
Maximum value (2)	0.3 $Bq \cdot L^{-1}$	0.6 $Bq \cdot L^{-1}$	0.2 $Bq \cdot L^{-1}$	< 17 $Bq \cdot L^{-1}$
No. of production stations (3)	1	1	1	1
No. of analyses (4)	2	1	1	13
Screening value	0.1 $Bq \cdot L^{-1}$	1.0 $Bq \cdot L^{-1}$	-	100 $Bq \cdot L^{-1}$
No. of production stations above (5)	4	0	-	0
No. of analyses (6)	11	0	-	0

(1) Activity concentration averaged over all production stations.
(2) Maximum value of activity concentration averaged per production station.
(3) Number of production stations where the average of all analyses per production station is equal to the maximum value.
(4) Number of all analyses performed where the average per production station is equal to the maximum value.
(5) Number of production stations where the average of all analyses exceeds the screening value.
(5) Number of all analyses performed where the average per production station exceeds the screening value.

In 2018, the gross α activity concentration in untreated water used for drinking water production, averaged per production station, exceeded

the screening level of 0.1 $Bq \cdot L^{-1}$ at four of the 182 production stations (the average of 11 analyses on a total of 439). The measured radioactivity levels do not, however, pose a threat to public health. Further investigation into these slightly elevated levels in untreated water revealed that the gross α activity concentration in associated finished drinking water was well below the screening level.

For gross β, residual β and ^{3}H, the results were within the range of those in previous years [7, 20, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63]. Since ^{40}K was almost absent, for most stations there was no significant difference between average gross β and residual β activity concentrations. The gross β activity concentrations were below the screening level of 1.0 $Bq \cdot L^{-1}$ and the ^{3}H activity concentrations were below the parametric value of 100 $Bq \cdot L^{-1}$ [46, 48, 49].

Following Council Directive 2013/51/EC [46], it is not necessary to incorporate ^{222}Rn in the yearly Dutch drinking water monitoring programme if it is clearly demonstrated that all data are well below accepted levels. The routine determination of gross α, gross β and ^{3}H covers most radioactivity parameters and gives an accurate estimation of the dose (indicative dose).

In 2015, a survey was carried out to determine radon activity in Dutch water [64]. The results of the 2015 survey have been summarized in [61]: the parametric value of 100 $Bq \cdot L^{-1}$ of ^{222}Rn was not exceeded. The highest concentration of ^{222}Rn in groundwater was 16.7 $Bq \cdot L^{-1}$, with consistently lower amounts of ^{222}Rn in finished drinking water than in groundwater. All observed ^{222}Rn activities originated from unsupported ^{222}Rn, i.e. without any ^{226}Ra present in the water phase.

7 Milk

7.1 Introduction

RIKILT Wageningen UR monitors radioactivity in milk on a weekly basis, mainly via the National Monitoring Network of Radioactivity in Food (Landelijk Meetnet Radioactiviteit in Voedsel, LMRV). The LMRV has been set up as an emergency network for monitoring relatively high contamination levels in case of an accident. The LMRV consists of 52 low-resolution γ-spectrometers (NaI-detectors) located throughout the Netherlands, 23 of which are located at dairy factories.

7.2 Results

The results of the weekly samples of cow's milk taken from all locations are combined into a monthly average for the whole country. The monthly averages for 2018 are presented in Table 7.1. Figure 7.1 shows the spatial variation of the yearly average ^{40}K concentrations per region and the distribution of the sampling locations across the Netherlands.

Table 7.1 Monthly average activity concentrations in cow's milk in 2018.

Month	Number of samples	^{40}K (1) Bq·kg^{-1}	^{60}Co (2) Bq·kg^{-1}	^{131}I (2) Bq·kg^{-1}	^{134}Cs (2) Bq·kg^{-1}	^{137}Cs (2) Bq·kg^{-1}
January	49	48.7 ± 10.6	< 1.4	< 0.6	< 0.6	< 0.5
February	43	50.6 ± 14.7	< 1.4	< 0.6	< 0.6	< 0.5
March	47	51.9 ± 11.5	< 1.4	< 0.6	< 0.6	< 0.5
April	47	48.2 ± 13.8	< 1.4	< 0.6	< 0.6	< 0.5
May	54	53.3 ± 15.5	< 1.4	< 0.6	< 0.6	< 0.5
June	50	52.9 ± 12.4	< 1.4	< 0.6	< 0.6	< 0.5
July	48	51.3 ± 15.6	< 1.4	< 0.6	< 0.6	< 0.5
August	47	49.3 ± 13.8	< 1.4	< 0.6	< 0.6	< 0.5
September	40	51.1 ± 15.6	< 1.4	< 0.6	< 0.6	< 0.5
October	51	51.5 ± 13.4	< 1.4	< 0.6	< 0.6	< 0.5
November	55	51.3 ± 14.6	< 1.4	< 0.6	< 0.6	< 0.5
December	45	52.2 ± 13.9	< 1.4	< 0.6	< 0.6	< 0.5
Average	576 (3)	51.1 ± 13.8	< 1.4	< 0.6	< 0.6	< 0.5

(1) Uncertainty is given as 1σ.
(2) Calculated minimal detectable activity concentrations for the respective radionuclides, based on 1 litre Marinelli beaker measurements on the Food Monitor Systems.
(3) Yearly total.

In none of the samples were anthropogenic γ-emitters measured above the minimal detectable activity, as is shown in Table 7.1, so the limit of 370 Bq·kg^{-1} for the radiocesium activity (sum of ^{134}Cs and ^{137}Cs) set by the European Union [65, 66] was not exceeded. The activity concentration of the natural radionuclide ^{40}K is given as a reference value. The yearly average concentration was 51.1 ± 13.8 Bq·kg^{-1}. This value is within the range of those found in previous years.

Additionally, 10 goat's milk samples were analysed. As in cow's milk, anthropogenic γ-emitters were not measured above the minimal detectable activity. The yearly average ^{40}K concentration in these samples was 69.0 ± 13.0 Bq·kg^{-1}. This value is within the range of those found between 2013 and 2017.

In addition to the LMRV samples, 52 milk samples (46 cow's milk and 6 goat's milk samples) were analysed for a range of γ-emitters on a high-resolution gamma spectrometer in the RIKILT laboratory in Wageningen. The samples were collected across the Netherlands. None of the samples showed any anthropogenic gamma activity above the minimal detectable activity (<1 Bq·kg^{-1} for ^{137}Cs in 0.5 L Marinelli beakers). The average concentration found for the natural radionuclide ^{40}K in the 46 cow's milk samples was 46.7 ± 8.0 Bq·kg^{-1}; for the 6 goat's milk samples the average was 67.0 ± 6.7 Bq·kg^{-1}.

The same 52 raw milk samples were analysed for the presence of the β-emitter ^{90}Sr using low-level liquid scintillation counting (LSC). The ^{90}Sr activity concentration was below the minimal detectable activity (0.2 Bq·kg^{-1}) in all samples taken, so none of the samples exceeded the set limit of 125 Bq·kg^{-1} used in new emergency exposure situations [67]. No limit for ^{90}Sr has been set for existing exposure situations as defined in [68].

RIKILT also monitors raw milk specifically for export certification. For this purpose, samples were analysed for ^{137}Cs and ^{90}Sr. All results were below minimum detectable activities as well.

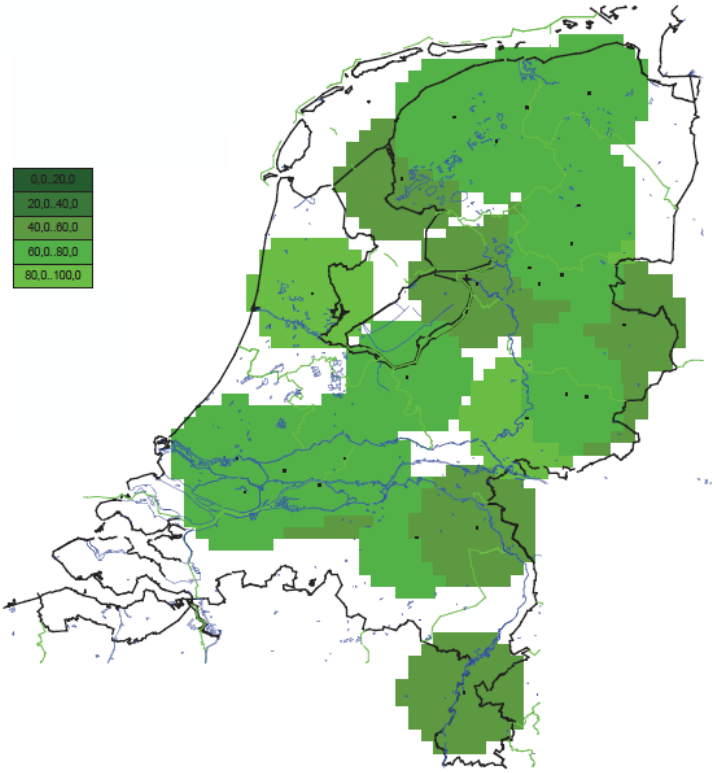


Figure 7.1 Impression of the spatial variation of ^{40}K activity concentrations (Bq·kg^{-1}) in cow's milk in 2018, based on data provided by dairy factories.

8 Food

8.1 Introduction

The Netherlands Food and Consumer Product Safety Authority (NVWA) performs measurements on finished products from retail shops, wholesale produce auctions and distribution centres, while RIKILT Wageningen UR performs measurements on samples from earlier stages in the food production chain.

The measurements performed on food by the NVWA were carried out according to standard procedures [69,70]. The NVWA monitors activity concentrations in a 'mixed diet' every year by sampling and measuring separate ingredients. In 2018, 427 samples were taken from retail shops, wholesale produce auctions and distribution centres, including 53 samples of honey [71]. Though honey is not considered to be part of the mixed diet, samples are taken each year because it regularly contains higher levels of radioactivity (mainly ^{137}Cs).

The separate ingredients were categorized into the following product groups: grain and grain products, vegetables, fruit and fruit products, milk and dairy products, salads, oil and butter, honey, tea, mineral water, and fish. The results from 2018 are presented in Table 8.1. With the exception of two samples of fruit jam, all samples contained no ^{137}Cs above the minimum detectable activity of 5 Bq·kg^{-1}. None of the samples exceeded the set limit for radiocesium activity (sum of ^{134}Cs and ^{137}Cs) of 600 Bq·kg^{-1} for food or 370 Bq·kg^{-1} for milk and dairy products [65, 66].

In 2018, RIKILT analysed radioactivity in food products as part of the governmental monitoring programme. Samples were taken throughout the year and measurements were carried out according to standard procedures. About 1,700 food samples were analysed for the presence of γ-emitters. The results are presented in Table 8.2. None of the samples exceeded the set limit for radiocesium activity (sum of ^{134}Cs and ^{137}Cs) of 600 Bq·kg^{-1} (for food) or 370 Bq·kg^{-1} (for dairy products).

Of these food samples, 181 samples were additionally analysed for ^{90}Sr content. The results are presented in Table 8.3. These results are well below the set limit for new emergency exposure situations of 750 Bq·kg^{-1} for major food products [67]. No limit for ^{90}Sr has been set for existing exposure situations as defined in [68].

RIKILT also monitors food specifically for export certification. For this purpose, samples were analysed for ^{137}Cs and ^{90}Sr. All results were below the limits set for ^{137}Cs and below minimal detectable activity for ^{90}Sr.

8.2 Results for fruit and fruit products

In the product group 'fruit and fruit products' analysed by NVWA, two samples of fruit jam from Poland contained ^{137}Cs: the activity of the two samples was 24 and 116 Bq·kg^{-1}. Thus, no sample exceed the limit of 600 Bq·kg^{-1} [65, 66].

8.3 Results for game

In the product group 'game' analysed by RIKILT, 33 samples of game contained ^{137}Cs. The activity varied from 5 up to 380 Bq·kg^{-1}. Thus, no sample exceeded the limit of 600 Bq·kg^{-1} [65, 66].

8.4 Results for average daily intake

The measured concentrations of ^{90}Sr, ^{134}Cs and ^{137}Cs in food in Bq·kg^{-1} were converted to an average daily intake value per person per day (Bq·day^{-1}) using food consumption patterns, according to the method described in Appendix B. From these intake values, a contribution to the effective yearly dose was calculated using standard dose conversion coefficients for ingestion.

The average daily intake per person of ^{134}Cs, ^{137}Cs and ^{90}Sr is estimated at < 5 Bq·day^{-1} for each of the three radionuclides. These estimates are mainly based on the minimal detectable activities for these radionuclides in the different food categories, as shown in Tables 8.1 to 8.3.

The contribution to the effective yearly dose calculated from these average daily intake values is < 0.12 mSv. The actual daily intake (and therefore the calculated dose) is probably much lower. This is because the dose is calculated with the minimum detectable level as an input to the calculation.

Table 8.1 Results of the analysis of food in 2018 for ^{134}Cs and ^{137}Cs as measured by the Netherlands Food and Consumer Product Safety Authority

Product	Number of samples	^{134}Cs (1) Bq·kg^{-1}	^{137}Cs (1) Bq·kg^{-1}
Grain and grain products	74	< 5 (0)	< 5 (0)
Vegetables	62	< 5 (0)	< 5 (0)
Fruit and fruit products	37	< 5 (0)	24 - 116 (2)
Milk and dairy products	55	< 5 (0)	< 5 (0)
Salads	22	< 5 (0)	< 5 (0)
Oil and butter	33	< 5 (0)	< 5 (0)
Honey	53	< 5 (0)	< 5 (0)
Tea	33	< 5 (0)	< 5 (0)
Mineral water	29	< 5 (0)	< 5 (0)
Fish	29	< 5 (0)	< 5 (0)

(1) Number of samples above the given reporting limit is shown in brackets.

Table 8.2 Results of 2018 analysis of food for ^{134}Cs and ^{137}Cs as measured by RIKILT Wageningen UR

Product	Number of samples	^{134}Cs (1) Bq·kg^{-1}	^{137}Cs (1) Bq·kg^{-1}
Vegetables and fruits	200	< 5 (0)	< 5 (0)
Meat and meat products	673	< 5 (0)	< 5 (0)
Game	129	< 5 (0)	5–380 (33)
Poultry	402	< 5 (0)	< 5 (0)
Eggs	89	< 5 (0)	< 5 (0)
Fish and seafood products	125	< 5 (0)	< 5 (0)
Ready meals	63	< 5 (0)	< 5 (0)

(1) Number of samples above the given detection limit is shown in brackets.

Table 8.3 Results of 2018 analysis of food for ^{90}Sr as measured by RIKILT Wageningen UR

Product	Number of samples	^{90}Sr (1) Bq·kg^{-1}
Vegetables and fruits	47	< 5 (0)
Meat and meat products	29	< 5 (0)
Game	12	< 5 (0)
Poultry	8	< 5 (0)
Eggs	6	< 5 (0)
Fish and seafood products	37	< 5 (0)
Ready meals	42	< 5 (0)

(1) Number of samples above the minimum detectable activity level is shown in brackets.

9 Grass & feed

The National Monitoring Network of Radioactivity in Food (Landelijk Meetnet Radioactiviteit in Voedsel, LMRV), referred to in Chapter 7, is an important monitoring network used in cases of a nuclear or radiological emergency, as described in the National Crisis Management Plan for Radiation Incidents (Nationaal Crisisplan Stralingsincidenten, NCS). In addition to measuring radioactivity levels in milk and food samples, the network is used to measure radioactivity levels in grass samples. For this purpose, reference pastures and fields have been designated across the Netherlands in proximity to the companies and organizations that participate in the LMRV. In this way, the extent of radioactive deposition can be assessed rapidly by the LMRV in the event of a nuclear or radiological incident.

It is important to have accurate and recent information on the natural background levels of radioactivity in grass to compare with samples analysed during a nuclear or radiological incident. For this reason, all LMRV locations are requested to take a grass sample every year from their reference pasture or field according to a standardized protocol, and to measure this sample using the food monitoring system.

In 2018, 33 grass samples were taken at 13 locations and measured on the food monitoring system. None of the grass samples taken contained artificial radionuclides above the minimal detectable activities. The minimal detectable activities were approximately 20 $Bq \cdot m^{-2}$ (i.e. with a yield of 250 grams of grass per m^2) for the artificial radionuclides ^{60}Co, ^{131}I, ^{132}Te, ^{134}Cs and ^{137}Cs. Natural ^{40}K was found in all samples. In some samples, natural radionuclides from the uranium and thorium decay chains deposited during rainfall were detected as well.

The results of the grass measurements can be plotted on a map of the Netherlands, resulting in a deposition map that can be used in the event of contamination in an emergency situation. The spatial variation of the natural ^{40}K activity in grass is shown in Figure 9.1. This variation in ^{40}K activity can be attributed to factors such as fertilization, grass species, length of stalk and soil type.

In addition, 520 feed samples were analysed for γ-emitters as part of the monitoring programme of RIKILT Wageningen UR. No artificial radioactivity was found in these samples; the results for ^{134}Cs and ^{137}Cs were all lower than the minimal detectable activity (< 5 $Bq \cdot kg^{-1}$).

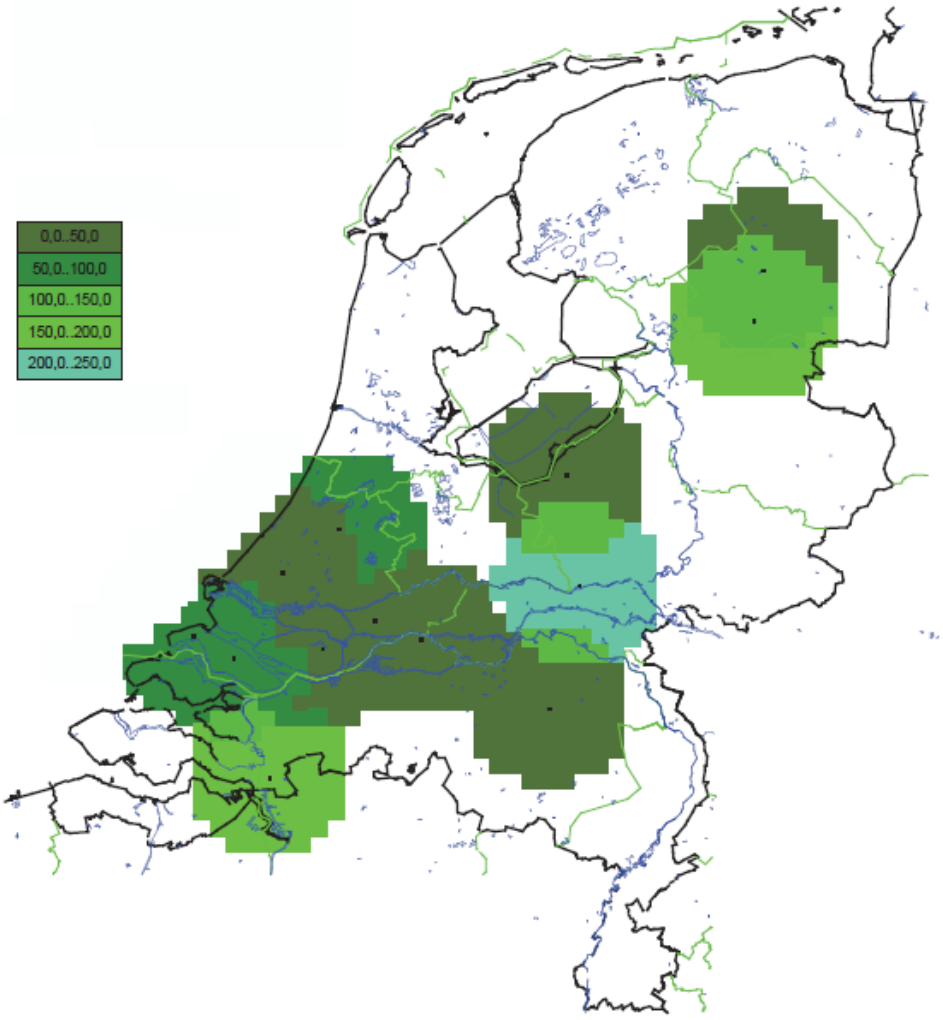


Figure 9.1 Impression of spatial variation of ^{40}K activity in grass in $Bq \cdot m^{-2}$, as measured in 2018

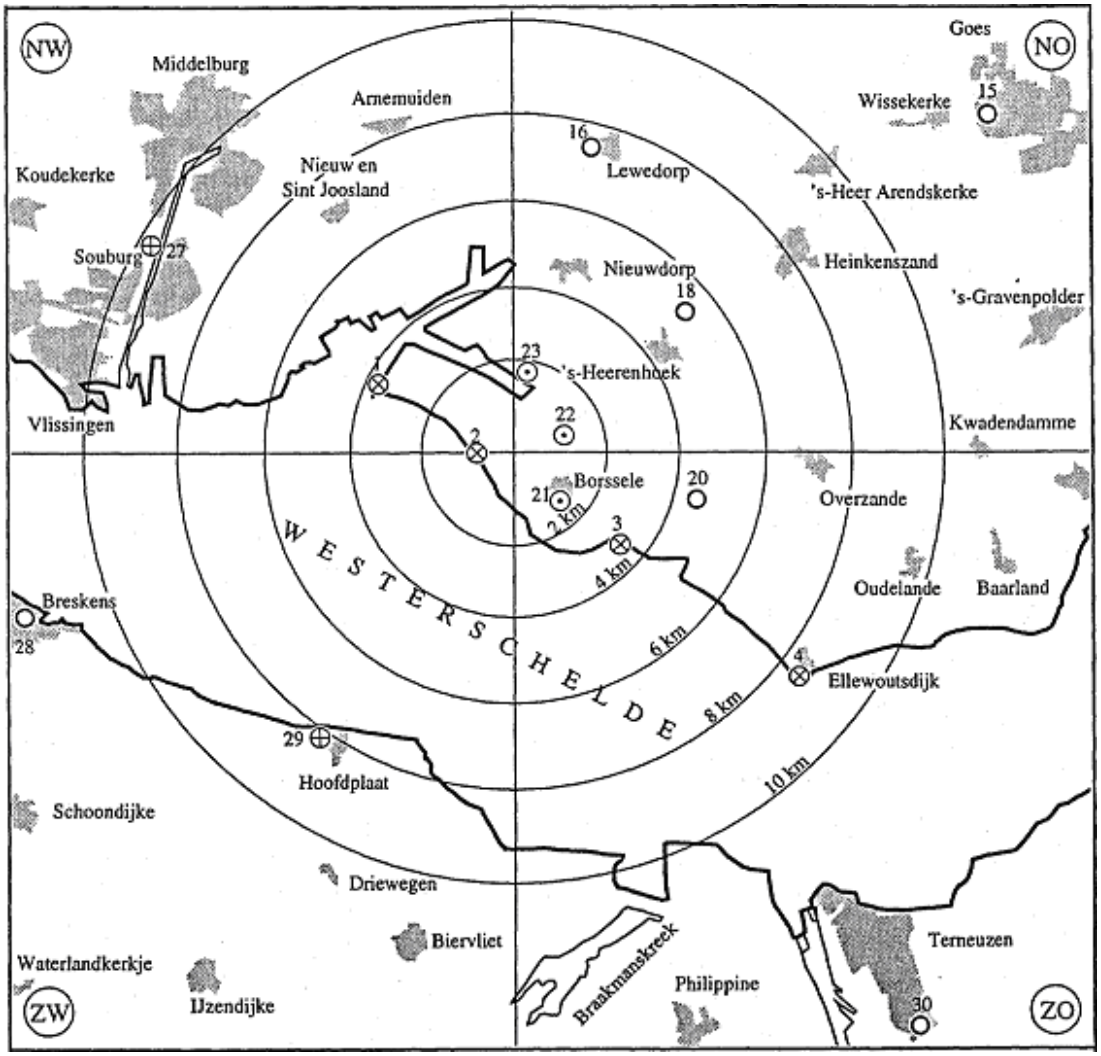
10 The Borssele nuclear power plant

The Nuclear Research & Consultancy Group (NRG) is commissioned by Elektriciteits-Produktiemaatschappij Zuid-Nederland (N.V. EPZ) to perform monthly measurements on environmental samples taken in the vicinity of the Borssele nuclear power plant (owned by N.V. EPZ). Samples are taken in order to monitor the compartments of air, water and soil [72]. A more detailed description of the monitoring programme and underlying strategy can be found elsewhere [73]. The 2018 monitoring programme for environmental samples is outlined in Table 10.1 and Figure 10.1. Radionuclides were determined in air dust, grass, soil, water, suspended solids, seaweed and sediment.

Table 10.1 Monitoring programme for environmental samples taken near the Borssele nuclear power plant in 2018

Matrix	Location	Parameter	Monitoring frequency (per year)
Air dust	21, 22, 23, 27 and 29	gross α, gross β	12
		γ-emitters (1)	12 (2)
Grass	21, 22, 23, 27 and 29	γ-emitters (3)	12 (2)
Soil	O1, O2, O3 and O4 (4)	γ-emitters (5)	1
Water	1, 2, 3 and 4	residual β, ^{3}H	12
Suspended solids	1, 2, 3 and 4	gross β	12
Seaweed	1, 2, 3 and 4	γ-emitters (3)	12 (2)
Sediment	1, 2, 3 and 4	γ-emitters (3)	12 (2)

The location numbers correspond to the location numbers given in Figure 10.1.
(1) γ-spectroscopic analysis of specific γ-emitting radionuclides: ^{60}Co, ^{137}Cs, naturally occurring radionuclides and elemental and organically bound ^{131}I.
(2) Analysis was performed on a combined sample of monthly samples taken from all four or five locations.
(3) γ-spectroscopic analysis of specific γ-emitting radionuclides: ^{60}Co, ^{131}I and ^{137}Cs.
(4) The four locations where samples were taken near the outlet are not shown in Figure 10.1.
(5) γ-spectroscopic analysis of specific γ-emitting radionuclides: ^{54}Mn, ^{60}Co, ^{134}Cs and ^{137}Cs.



The numbers given in Table 10.1 correspond with the locations on the map.

Figure 10.1 Overview of monitoring locations for the monitoring programme conducted by NRG near the Borssele nuclear power plant

10.2 Air

The results for gross α and β activity concentrations in air dust are presented in Tables A15 and A16. Due to large uncertainties caused by variations in the amount of dust on the filters, gross α activity concentrations in air dust should be regarded as indicative values [5]. The period between sampling and analysis was at least five days, which is long relative to the decay time of the short-lived decay products of ^{222}Rn and ^{220}Rn. This is to ensure that these naturally occurring decay products do not contribute to the measured α and β activity concentrations.

The 2018 yearly averages of the gross α and β activity concentrations of long-lived radionuclides were within the range of the results from previous years, as illustrated in Figures 10.2 and 10.3.

The results for the radionuclides considered in the γ-spectroscopic analysis are given in Table A17.

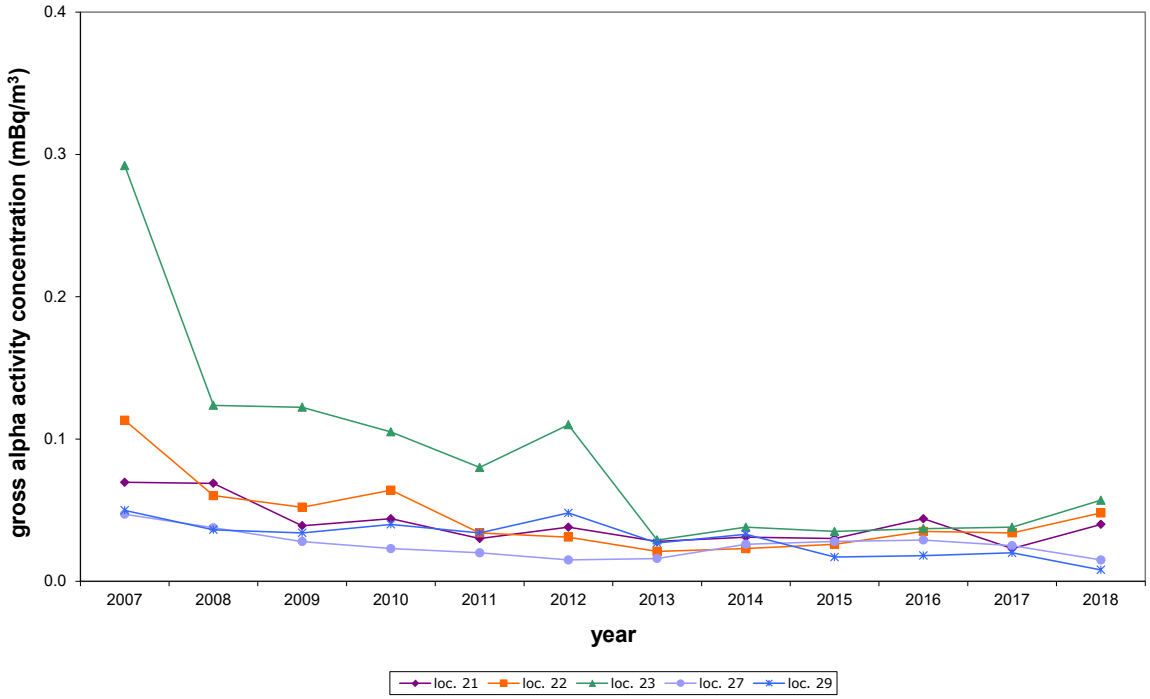


Figure 10.2 Yearly average gross α activity concentrations in air dust at five locations near the Borssele nuclear power plant (see Figure 10.1)

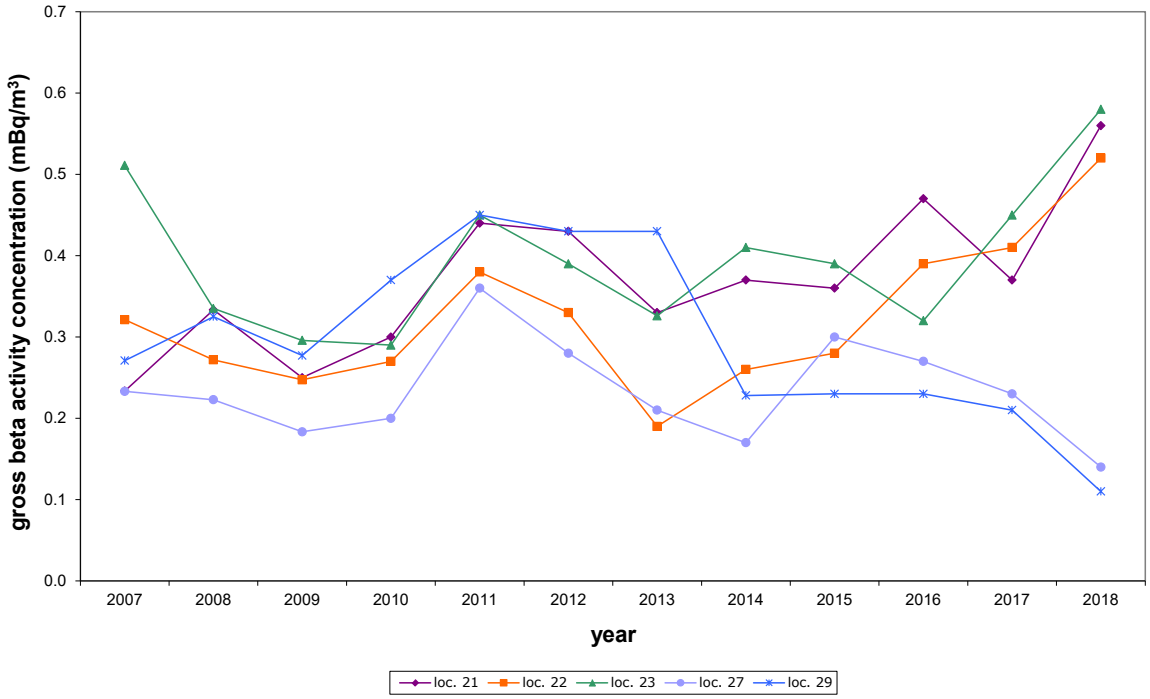


Figure 10.3 Yearly average gross β activity concentrations in air dust at five locations near the Borssele nuclear power plant (see Figure 10.1)

10.3 Soil and grass

The results for the radionuclides considered in the γ-spectroscopic analysis of grass and soil are given in Tables A18 and A19. The four soil

samples were taken near the outlet of the nuclear power plant. In 2018, the yearly average concentrations in grass of ^{131}I, ^{60}Co and ^{137}Cs and the yearly concentrations in soil of ^{54}Mn, ^{60}Co, ^{134}Cs and ^{137}Cs were within the range of those in previous years [20, 54, 55, 56, 57, 58, 59, 60, 61, 62]. Except for ^{137}Cs in soil, all results were below the minimum detectable activities. The yearly concentrations of ^{137}Cs in soil are shown in Figure 10.4.

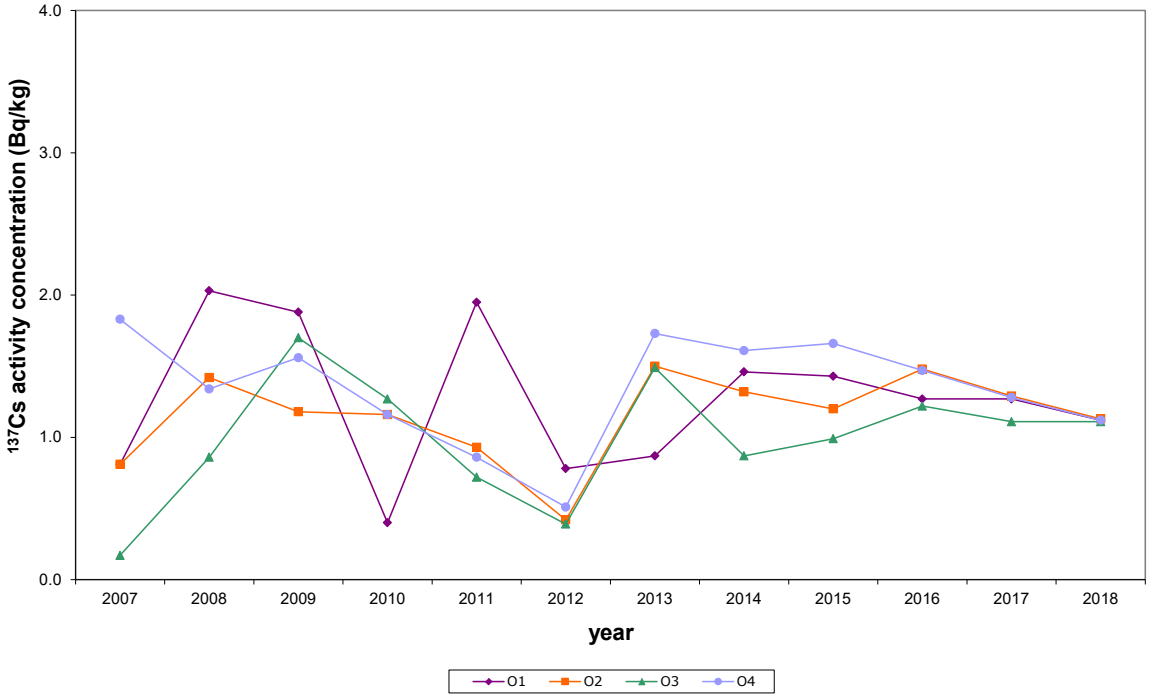


Figure 10.4 ^{137}Cs activity concentrations of yearly soil samples at four locations near the outlet of the Borssele nuclear power plant (see Figure 10.1)

10.4 Water

The results for residual β and ^{3}H activity concentrations in surface water and gross β activity concentrations in suspended solids in the Western Scheldt area are presented in Tables A20, A21 and A22.

In 2018, the yearly averages of the residual β concentrations in surface water were within the range of the results from previous years, as illustrated in Figure 10.5. The yearly averages of the residual β concentrations are, moreover, within the range of the yearly averages of the residual β concentrations in the Scheldt measured by RWS, which are reported in Chapter 5.2.

The ^{3}H activity concentrations in water since 2012 have been significantly lower than those found in previous years, as illustrated in Figure 10.6. This change in trend of ^{3}H was investigated, and no significant changes in analysis procedures were found.

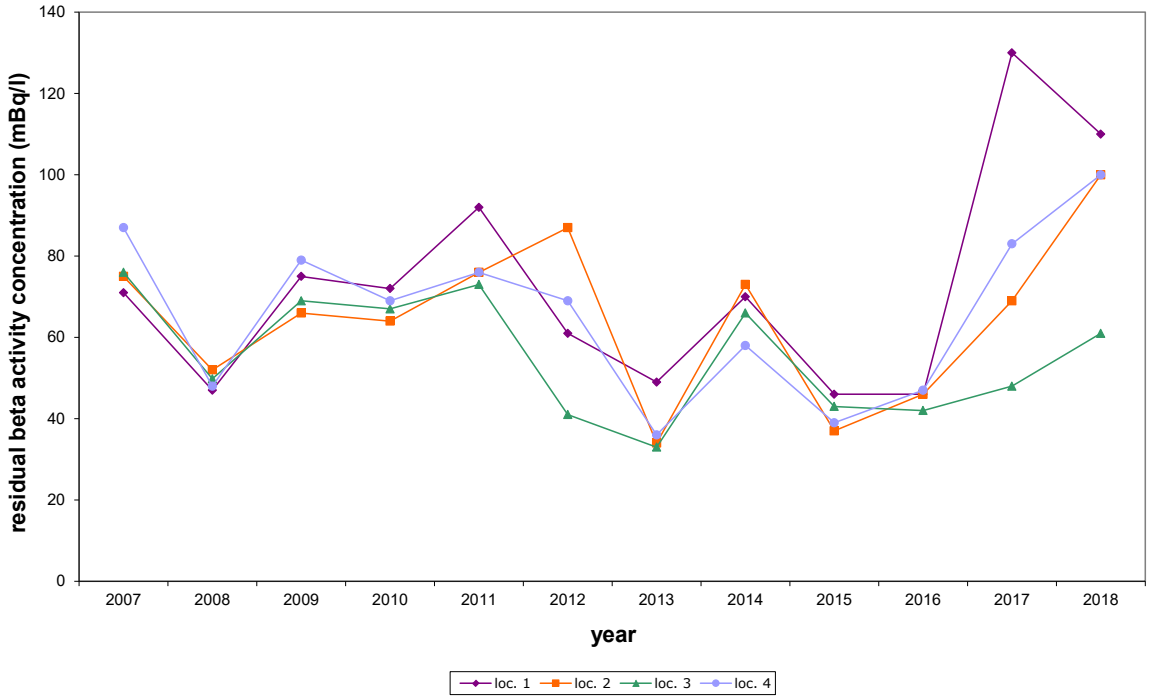


Figure 10.5 Yearly average residual β activity concentrations in surface water in the Western Scheldt area at four locations near the Borssele nuclear power plant (see Figure 10.1)

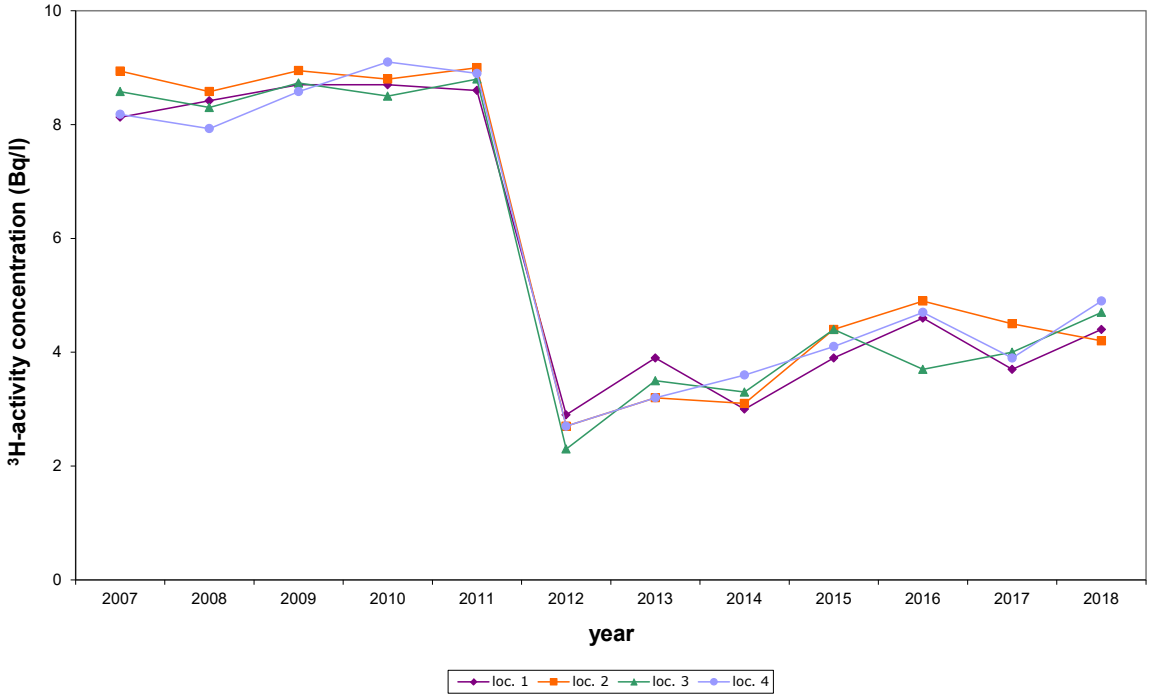


Figure 10.6 Yearly average ^{3}H activity concentrations in surface water in the Western Scheldt area at four locations near the Borssele nuclear power plant (see Figure 10.1)

Since 2012, the gross β activity concentrations in suspended solids have been higher than those found in previous years. In 2018 in particular, the measured values have doubled, as illustrated in Figure 10.7. The change in trend of gross β activity concentrations are being investigated. In 2012 there has been a change in the counting efficiency used, which is a plausible explanation for the change in trend since then. The change observed in 2018 is still being investigated, but coincides with dredging activities near the sampling locations.

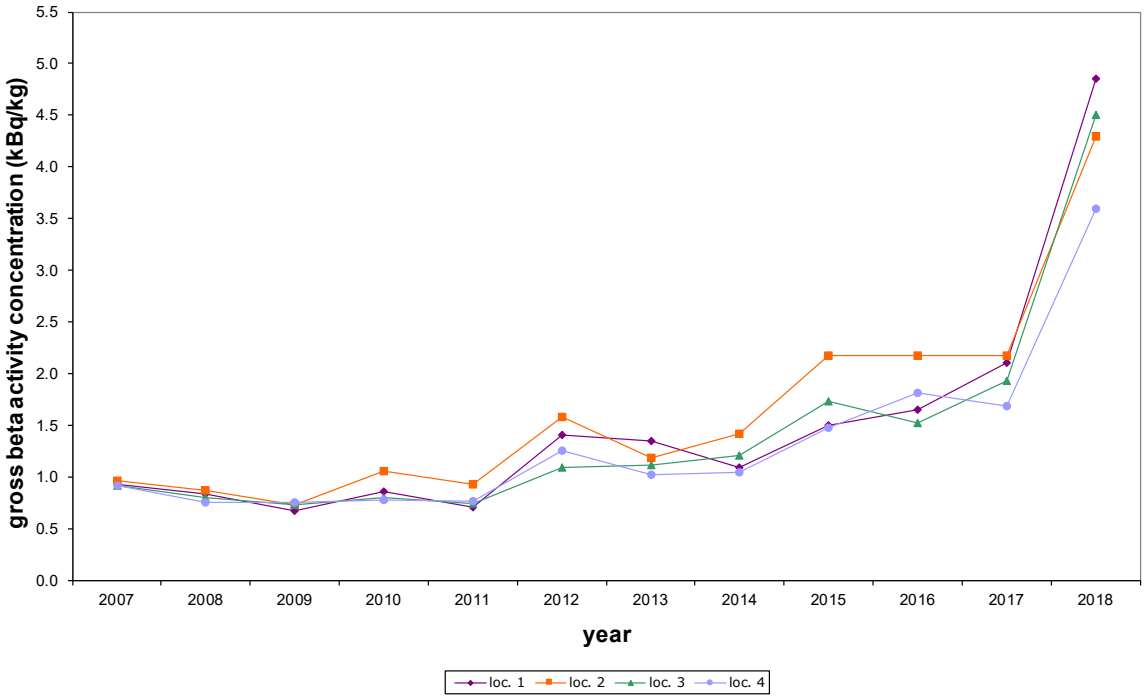


Figure 10.7 Yearly average gross β activity concentrations in suspended solids in the Western Scheldt area at four locations near the Borssele nuclear power plant (see Figure 10.1)

The results for the radionuclides considered in the γ-spectroscopic analysis of seaweed and sediment are given in Tables A23 and A24. Except for ^{137}Cs in sediment, all results were below the minimum detectable activities. The yearly concentrations of ^{137}Cs in sediment are shown in Figure 10.8.

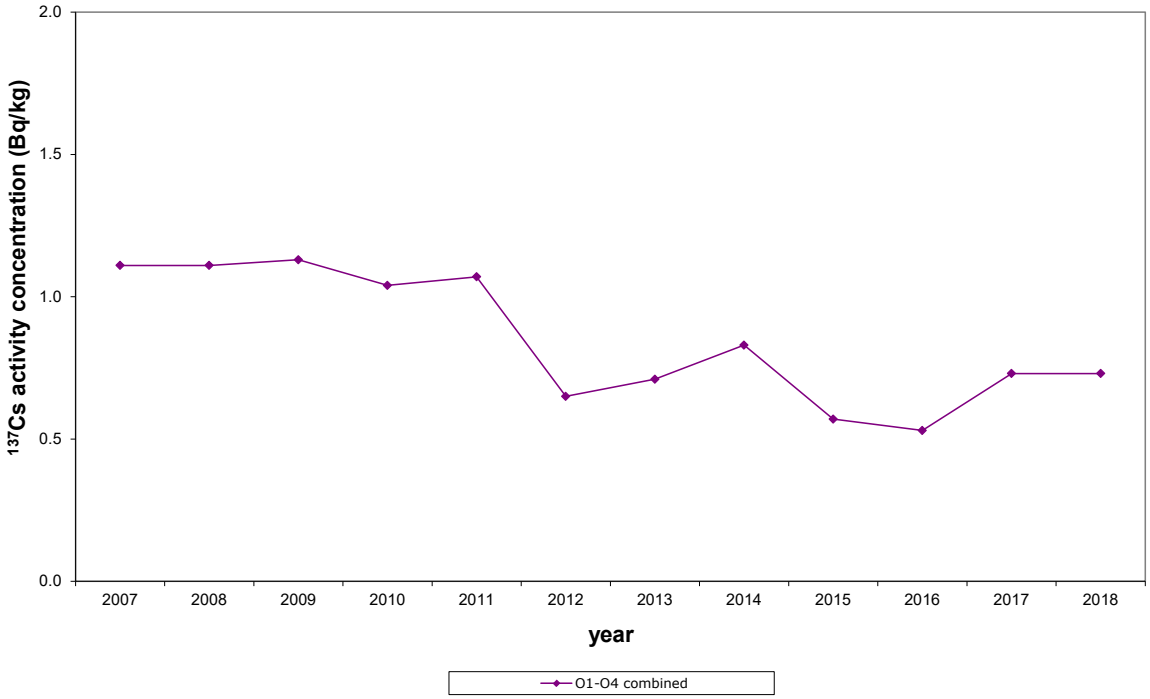


Figure 10.8 Yearly average ^{137}Cs activity concentrations in sediment based on combined samples at four locations near the Borssele nuclear power plant

11 Conclusions

In 2018, the Netherlands was in compliance with the Euratom recommendations on annual measurement of radioactivity in the environment and in food.

The gross α activity concentration in untreated water used for drinking water production, averaged per production station, exceeded the screening level (0.1 $Bq \cdot L^{-1}$) at four of the 182 production stations (the average of 11 analyses on a total of 439). The measured radioactivity levels do not, however, pose a threat to public health. Further investigation into these slightly elevated levels in untreated water revealed that the gross α activity concentration in associated finished drinking water was well below the screening level.

Radioactivity was measured in about 2,100 food products. Of these, 33 samples of game and two samples of fruit jam originating from Poland contained ^{137}Cs: the activity varied from 5 to 380 $Bq \cdot kg^{-1}$. No samples of food were above the set limit of 600 $Bq \cdot kg^{-1}$ and no samples of milk and dairy products were above the set limit of 370 $Bq \cdot kg^{-1}$ for the activity of radiocesium (sum of ^{134}Cs and ^{137}Cs).

The measured concentrations of ^{90}Sr, ^{134}Cs and ^{137}Cs in food in $Bq \cdot kg^{-1}$ were converted to an average daily intake value per person per day ($Bq \cdot day^{-1}$) using food consumption patterns. The average daily intake per person of ^{134}Cs, ^{137}Cs and ^{90}Sr is < 5 $Bq \cdot day^{-1}$ for each of the three radionuclides. The contribution to the effective yearly dose calculated from these values is < 0.12 mSv. The actual daily intake (and consequent dose contribution) is probably much lower.

All other radioactivity measurements were within the range of those in previous years.

Appendix A Tables of results

Table A1 Weekly average gross α and gross β activity concentrations in air dust sampled with the Snow White high-volume sampler at RIVM in 2018

Week[1] number	Gross α[2] mBq.m^{-3}	Gross β mBq.m^{-3}	Week[1] number	Gross α[2] mBq.m^{-3}	Gross β mBq.m^{-3}
1	0.024	0.43 ± 0.04	27	0.012	0.28 ± 0.03
2	0.024	0.55 ± 0.06	28	0.019	0.38 ± 0.04
3	0.009	0.165 ± 0.017	29	0.035	0.52 ± 0.05
4	0.016	0.166 ± 0.018	30	0.017	0.40 ± 0.04
5	0.016	0.35 ± 0.04	31	0.021	0.43 ± 0.04
6	0.014	0.24 ± 0.03	32	0.022	0.39 ± 0.04
7	0.023	0.42 ± 0.04	33	0.019	0.27 ± 0.03
8	0.021	0.41 ± 0.04	34	0.015	0.24 ± 0.02
9 [3]	0.081	1.13 ± 0.12	35	0.023	0.54 ± 0.06
10 [4]			36	0.017	0.36 ± 0.04
11	0.036	0.63 ± 0.07	37	0.029	0.57 ± 0.06
12	0.035	0.29 ± 0.03	38	0.018	0.29 ± 0.03
13	0.016	0.29 ± 0.03	39	0.014	0.34 ± 0.04
14	0.028	0.54 ± 0.06	40	0.030	0.75 ± 0.08
15	0.019	0.44 ± 0.05	41	0.036	1.02 ± 0.11
16	0.028	0.54 ± 0.06	42	0.015	0.31 ± 0.03
17 [3]	0.014	0.24 ± 0.03	43	0.009	0.23 ± 0.02
18 [3]	0.019	0.49 ± 0.05	44	0.025	0.57 ± 0.06
19	0.030	0.56 ± 0.06	45	0.014	0.29 ± 0.03
20	0.025	0.52 ± 0.05	46	0.031	0.76 ± 0.08
21 [3]	0.041	0.82 ± 0.09	47	0.044	1.06 ± 0.12
22 [3]	0.027	0.50 ± 0.05	48	0.014	0.21 ± 0.02
23	0.049	0.53 ± 0.05	49	0.0058	0.155 ± 0.017
24	0.019	0.26 ± 0.03	50	0.019	0.44 ± 0.05
25	0.014	0.27 ± 0.03	51	0.010	0.23 ± 0.03
26	0.023	0.48 ± 0.05	52	0.020	0.53 ± 0.06
Average				0.023	0.448 ± 0.007[5]
SD [6]				0.012	0.2

[1] The precise sampling period is given in Table A3.
[2] Values are indicative due to large uncertainties caused by variations in the amount of dust on the filters [5].
[3] The sampling period deviated from the regular 7-day sampling period.
[4] No measurements are available for week 10 (between 5 and 14 March 2018) due to a malfunction of the high volume sampler.
[5] The uncertainty in the yearly average is equal to the square root of the sum of the squared weekly uncertainties divided by the number of weeks. Uncertainties are given as 1σ.
[6] SD is the standard deviation of the weekly results.

Table A2 Detection limits (μBq/m³) in the residue measurement of air dust sampled during a 7-day sampling period with the Snow White high-volume sampler at RIVM in 2018

Nuclide	Detection limit μBq·m^{-3}
^{7}Be	2.0
^{22}Na	0.2
^{60}Co	0.1
^{131}I	1.9 (1)
^{137}Cs	0.2
^{210}Pb	3.7

Measurements were carried out on ash residue using a well-type detector, with a 7-day delay between sampling and the start of measurement. The sample volume was about 125,000 m³. Between January 2000 and July 2009, the detection limits were higher than they had been before 2000 [74] due to a different detector set-up. The detector set-up was changed again in the second half of 2009, paired with a change in counting time from 100,000 seconds to 178,200 seconds. Detection limits were therefore lower from July 2009 up to January 2011, when a change in the high-volume sampler (and consequently the sample volume) resulted in a further reduction of the detection limits.
(1) The detection limit is given for the filter measurement on the coaxial detector (4-day delay time, 100,000 seconds counting time). Due to the sample preparation procedure, the volatile radionuclide ^{131}I cannot be determined in the residue measurement on the well-type detector.

Table A3 Weekly average ^{7}Be, ^{137}Cs and ^{210}Pb activity concentrations in air dust sampled with the Snow White high-volume sampler at RIVM in 2018

Week number	Period	^{7}Be μBq·m^{-3}	^{137}Cs μBq·m^{-3}	^{210}Pb μBq·m^{-3}
1	04/01-11/01	2,650 ± 180	0.22 ± 0.03	280 ± 20
2	11/01-18/01	2,340 ± 160	0.41 ± 0.04	480 ± 30
3	18/01-25/01	2,800 ± 200	0.09 ± 0.02	81 ± 6
4	25/01-01/02	2,380 ± 170	0.12 ± 0.02	116 ± 8
5	01/02-08/02	2,030 ± 140	0.22 ± 0.03	268 ± 19
6	08/02-15/02	2,060 ± 140	0.19 ± 0.02	213 ± 15
7	15/02-22/02	3,100 ± 200	0.45 ± 0.04	350 ± 20
8	22/02-01/03	2,900 ± 200	0.54 ± 0.05	410 ± 30
9 (1)	01/03-05/03	4,400 ± 300	1.40 ± 0.12	1,030 ± 70
10 (2)	05/03-14/03			
11 (1)	14/03-22/03	5,000 ± 300	0.45 ± 0.04	410 ± 30
12	22/03-29/03	2,610 ± 180	0.13 ± 0.02	191 ± 14
13	29/03-05/04	3,700 ± 300	0.24 ± 0.03	207 ± 14
14	05/04-12/04	4,700 ± 300	0.26 ± 0.03	470 ± 30
15	12/04-19/04	4,200 ± 300	0.33 ± 0.03	370 ± 30
16	19/04-26/04	4,200 ± 300	0.35 ± 0.04	450 ± 30
17	26/04-03/05	3,000 ± 200	0.14 ± 0.03	151 ± 11
18 (1)	03/05-09/05	6,300 ± 400	0.55 ± 0.05	360 ± 30
19 (1)	09/05-17/05	6,300 ± 400	0.57 ± 0.05	450 ± 30
20	17/05-24/05	7,600 ± 500	0.26 ± 0.03	420 ± 30
21	24/05-31/05	6,800 ± 500	0.33 ± 0.03	760 ± 50
22	31/05-07/06	4,700 ± 300	0.10 ± 0.02	520 ± 40
23	07/06-14/06	6,300 ± 400	0.13 ± 0.02	430 ± 30
24	14/06-21/06	2,290 ± 160	0.06 ± 0.02	166 ± 12
25	21/06-28/06	4,700 ± 300	0.15 ± 0.03	216 ± 16

Continued on next page

Table A3 Continued

Week number	Period	^{7}Be µBq·m^{-3}	^{137}Cs µBq·m^{-3}	^{210}Pb µBq·m^{-3}
26	28/06-05/07	5,000 ± 300	0.40 ± 0.04	320 ± 20
27	05/07-12/07	3,900 ± 300	0.20 ± 0.03	220 ± 16
28	12/07-19/07	4,300 ± 300	0.24 ± 0.03	300 ± 20
29	19/07-26/07	3,700 ± 300	0.24 ± 0.03	360 ± 30
30	26/07-02/08	5,600 ± 400	0.210 ± 0.018	360 ± 30
31	02/08-09/08	3,900 ± 300	0.32 ± 0.03	310 ± 20
32	09/08-16/08	3,500 ± 200	0.062 ± 0.018	280 ± 20
33	16/08-23/08	2,260 ± 160	0.10 ± 0.02	217 ± 16
34	23/08-30/08	2,420 ± 170	0.11 ± 0.02	164 ± 12
35	30/08-06/09	2,900 ± 200	0.25 ± 0.03	450 ± 30
36	06/09-13/09	3,400 ± 200	0.077 ± 0.019	251 ± 18
37	13/09-20/09	4,000 ± 300	0.15 ± 0.03	440 ± 30
38	20/09-27/09	3,500 ± 200	0.14 ± 0.02	242 ± 17
39	27/09-04/10	3,400 ± 200	0.11 ± 0.02	202 ± 15
40	04/10-11/10	3,900 ± 300	0.21 ± 0.03	640 ± 40
41	11/10-18/10	4,100 ± 300	0.24 ± 0.03	1,030 ± 70
42	18/10-25/10	2,830 ± 190	0.16 ± 0.02	172 ± 12
43	25/10-01/11	1,830 ± 130	0.12 ± 0.02	189 ± 13
44	01/11-08/11	2,280 ± 160	0.20 ± 0.03	550 ± 40
45	08/11-15/11	2,510 ± 170	0.09 ± 0.02	226 ± 16
46	15/11-22/11	3,000 ± 200	0.94 ± 0.08	800 ± 60
47	22/11-29/11	1,560 ± 120	0.47 ± 0.04	1,100 ± 90
48	29/11-06/12	1,940 ± 150	0.11 ± 0.02	159 ± 12
49	06/12-13/12	1,710 ± 130	0.12 ± 0.02	116 ± 9
50	13/12-20/12	1,840 ± 140	0.21 ± 0.03	330 ± 30
51	20/12-27/12	1,830 ± 140	0.15 ± 0.03	207 ± 16
52	27/12-03/01	2,100 ± 160	0.22 ± 0.03	340 ± 30
Average		3,540 ± 40 (3)	0.266 ± 0.005 (3, 4)	368 ± 4 (3)
SD (5)		1,400	0.2	200

(1) The sampling period deviated from the regular 7-day sampling period.
(2) No measurements are available for week 10 (between 5 and 14 March 2018) due to a malfunction of the high volume sampler.
(3) The uncertainty in the yearly average is equal to the square root of the sum of the squared weekly uncertainties divided by the number of weeks. Uncertainties are given as 1σ.
(4) The detection limits are omitted in the calculation of the averages.
(5) SD is the standard deviation of the weekly results.

Table A4 Precipitation per month and monthly deposited ^{3}H, long-lived gross α and gross β activity sampled at RIVM in 2018

Month	Precipitation mm	^{3}H (1) Bq·m^{-2}	Gross α Bq·m^{-2}	Gross β Bq·m^{-2}
January	67.4	87 ± 8	2.1 ± 0.3	5.2 ± 0.3
February	22.2	24 ± 2	1.15 ± 0.19	1.41 ± 0.09
March	47.3	94 ± 8	7.9 ± 0.6	9.0 ± 0.4
April	105.3	154 ± 14	6.2 ± 0.5	9.6 ± 0.5
May	45.4	118 ± 9	17.3 ± 1.1	18.5 ± 0.9
June	23.6	51 ± 4	5.5 ± 0.5	6.8 ± 0.3
July	4.5	9.5 ± 0.7	6.0 ± 0.5	5.5 ± 0.3
August	76.8	124 ± 11	5.9 ± 0.5	10.4 ± 0.5
September	77.8	135 ± 12	7.8 ± 0.6	14.0 ± 0.7
October	33.2	42 ± 4	6.0 ± 0.5	9.0 ± 0.4
November	34.3	34 ± 4	1.11 ± 0.19	2.40 ± 0.13
December	104.0	94 ± 11	0.84 ± 0.13	3.36 ± 0.18
Total	641.5	960 ± 30	67.8 ± 1.8(2)	95.3 ± 1.5(2)
Lower limit(3)	-	–		
Upper limit(3)	-	–		

(1) Since 2017, samples have been analysed by Rijkswaterstaat (RWS) with a detection limit of 0.3 Bq·L^{-1}.
(2) The uncertainty in the sum is equal to the square root of the sum of the squared monthly uncertainties. Uncertainties are given as 1σ.
(3) The lower and upper limits are defined in Appendix B.

Table A5 Monthly deposited ^{210}Po activity (1) sampled at RIVM in 2018

Month	^{210}Po Bq·m^{-2}
January	0.81 ± 0.12
February	1.14 ± 0.08
March	5.6 ± 0.3
April	3.7 ± 0.2
May	12.2 ± 0.7
June	4.9 ± 0.3
July	4.7 ± 0.3
August	8.0 ± 0.4
September	5.1 ± 0.3
October	3.9 ± 0.2
November	0.87 ± 0.06
December	0.76 ± 0.07
Total	51.5 ± 1.1 (2)
Lower limit (3)	-
Upper limit (3)	-

(1) Measurements were carried out using α-spectroscopy. Uncertainties are given as 1σ.
(2) The uncertainty in the sum is equal to the square root of the sum of the squared monthly uncertainties. Uncertainties are given as 1σ.
(3) The lower and upper limits are defined in Appendix B.

Table A6 Yearly totals for long-lived gross α, gross β and ^{3}H activity in deposition since 1993

Year	Precipitation mm	^{3}H Bq·m^{-2}	Gross α Bq·m^{-2}	Gross β Bq·m^{-2}
1993	886	1,310 ± 30	54.3 ± 0.7	87.8 ± 0.8
1994	1,039	1,210 ± 30	52 ± 2	91 ± 3
1995	724	970 ± 40	33.6–44.6	95 ± 8
1996	626	970 ± 50	16.4 ± 1.5	67 ± 5
1997	760	1,160 ± 60	22.0–25.0	87 ± 3
1998	1,238	1,090–2,190	31.1 ± 1.3	106 ± 3
1999	916	1,420–1,900	25.5 ± 1.1	84 ± 2
2000	935	260–1,440	35.2 ± 1.3	104 ± 3
2001	1,053	0–2,420	23.9 ± 1	97 ± 3
2002	965	300–1,710	20.6 ± 0.9	97 ± 2
2003	605	260–1,080	13.6–16.7	70.0 ± 1.8
2004	875	0–1,600	14.3–17.1	73.5 ± 1.8
2005	856	0–1,530	17.6 ± 1.0	88 ± 2
2006	854	280–1,820	25.7 ± 1.5	98 ± 3
2007	984	335–1,600	24.4 ± 1.2	85 ± 2
2008	908	102–1,550	39.4 ± 1.5	106 ± 3
2009	794	0–1,330	36.9 ± 1.3	95 ± 2
2010	868	180–1,400	36.7 ± 1.3	90 ± 2
2011	895	332–1,540	45.0 ± 1.5	123 ± 3
2012	922	316–1,650	32.7 ± 1.1	88 ± 2
2013	851	0–1,580	48.1 ± 1.6	95 ± 2
2014	878	117–1,630	62 ± 2	106 ± 3
2015	878	210–1,650	53.9 ± 1.8	90 ± 2
2016	853	22–1,510	66 ± 2	88 ± 2
2017	993	1,280 ± 40	67.3 ± 1.8	101.4 ± 1.4
2018	642	960 ± 30	67.8 ± 1.8	95.3 ± 1.5

Either the yearly total with uncertainty [(1)] or the lower and upper limits [(2)] of the 68% confidence interval are given.
[(1)] Uncertainties are given as 1σ.
[(2)] Lower and upper limits are given as defined in Appendix B.

Table A7 Yearly totals for ^{7}Be, ^{137}Cs, ^{210}Pb and ^{210}Po activity in deposition since 1993

Year	^{7}Be (3) Bq·m^{-2}	^{137}Cs (3) Bq·m^{-2}	^{210}Pb (3) Bq·m^{-2}	^{210}Pb (4) Bq·m^{-2}	^{210}Po (4) Bq·m^{-2}
1993	1,090 ± 20	0.50–0.76	105 ± 2	78 ± 3	7.2 ± 0.5
1994	1,320 ± 30	0.36–0.71	118 ± 3	82 ± 3	12.0–14.2
1995	990 ± 20	0.37–0.63	96 ± 2	n/a (5)	n/a (5)
1996	920 ± 20	0.52–0.83	63–67	57 ± 3	9 ± 2
1997	1,090 ± 30	0.11–0.69	65–69	80 ± 4	0–10.2
1998	1,840 ± 50	0.56–0.85	162 ± 4	91 ± 4	3.0–15.1
1999	1,580 ± 30	1.16–1.99	158 ± 4	-(6)	0.7–5.3
2000	1,490 ± 30	0–4.82	177 ± 6	-	0.6–8.0
2001	1,480 ± 30	0–4.50	83–104	-	6.5–9.4
2002	1,510 ± 30	0–5.22	119–142	-	6.1–8.5
2003	1,000–1,050	0–4.69	88–113	-	4.3–5.6
2004	1,330 ± 30	0.22–5.53	64–102	-	5.4–7.7
2005	1,320 ± 30	0–6.09	87–117	-	8.9–10.2
2006	1,400 ± 30	0.06–7.47	66–103	-	14.8–16.4 (7)
2007	1,760 ± 40	0.11–7.37	72–132	-	13.4 ± 0.4 (7)
2008	1,990 ± 40	0–7.63	63–143	-	29.4 ± 0.7
2009	1,410 ± 30	0–4.3	82–125	-	32.5 ± 0.7
2010	1,240 ± 30	0–1.2	93 ± 2	-	33.2 ± 0.8
2011	1,320 ± 30	0.5–1.5	104 ± 2	-	61.4 ± 1.0
2012	1,330 ± 30	0–1.2	98 ± 2	-	33.8 ± 0.6
2013	1,030 ± 30	0–1.1	82.9 ± 1.8	-	21.2 ± 0.6 (8)
2014	1,341 ± 17	0–1.1	107 ± 2	-	41.4 ± 1.0
2015	1,219 ± 16	0–1.1	102.8 ± 1.5	-	40.7 ± 1.0
2016	1,375 ± 18	0.04–1.15	95–98	-	40.6 ± 1.0 (9)
2017	1,890 ± 30	0–1.10	113.0 ± 1.6	-	43.9–47.7
2018	1,194 ± 15	0.01–1.01	91.6 ± 1.3	-	51.5 ± 1.1

Either the yearly total with uncertainty (1) or the lower and upper limits (2) of the 68% confidence range are given.
(1) Uncertainties are given as 1σ.
(2) Lower and upper limits are given as defined in Appendix B.
(3) Data from γ-spectroscopy.
(4) Data from α-spectroscopy.
(5) Not available. Result rejected [75].
(6) α-spectroscopy analysis of ^{210}Pb stopped in 1999.
(7) Results revised in RIVM Report 610791003.
(8) The yearly total deposition is based on 10 monthly results.
(9) The yearly total deposition is based on 11 monthly results.

Table A8 Weekly deposited ^{7}Be, ^{137}Cs and ^{210}Pb activity (1) sampled at RIVM in 2018

Week no.	Period	Precipi-tation mm	^{7}Be Bq·m^{-2}	^{137}Cs Bq·m^{-2}	^{210}Pb Bq·m^{-2}
1	04/01-11/01	5.8	12.2 ± 0.9	< 0.02	0.54 ± 0.09
2	11/01-18/01	31.0	65 ± 5	< 0.02	2.7 ± 0.2
3	18/01-25/01	18.5	34 ± 2	< 0.02	1.72 ± 0.15
4	25/01-01/02	12.1	21.5 ± 1.5	< 0.02	0.58 ± 0.07
5	01/02-08/02	11.3	10.3 ± 0.7	< 0.02	0.38 ± 0.08
6	08/02-15/02	10.5	18.6 ± 1.3	< 0.019	0.84 ± 0.10
7	15/02-22/02	0.3	4.7 ± 0.3	< 0.02	0.15 ± 0.08
8	22/02-01/03	0.2	1.89 ± 0.13	< 0.02	0.53 ± 0.07
9	01/03-08/03	4.9	9.4 ± 0.7	< 0.02	1.37 ± 0.13
10	08/03-15/03	20.8	21.1 ± 1.5	< 0.02	0.82 ± 0.10
11	15/03-22/03	4.8	17.1 ± 1.2	< 0.02	0.86 ± 0.10
12	22/03-29/03	16.9	29 ± 2	< 0.02	1.49 ± 0.13
13	29/03-05/04	25.8	50 ± 3	< 0.02	1.48 ± 0.13
14	05/04-12/04	5.8	27.4 ± 1.9	< 0.02	4.5 ± 0.3
15	12/04-19/04	8.4	18.0 ± 1.2	< 0.02	1.32 ± 0.12
16	19/04-26/04	6.6	19.0 ± 1.3	0.017 ± 0.005	5.8 ± 0.4
17	26/04-03/05	58.8	51 ± 4	< 0.02	4.4 ± 0.3
18	03/05-09/05	0.0	14.7 ± 1.0	< 0.02	2.8 ± 0.2
19	09/05-17/05	4.2	23.1 ± 1.6	< 0.02	1.74 ± 0.14
20	17/05-24/05	3.8	29 ± 2	< 0.02	2.5 ± 0.2
21	24/05-31/05	37.5	97 ± 7	< 0.02	8.1 ± 0.6
22	31/05-07/06	15.0	47 ± 3	< 0.02	3.0 ± 0.2
23	07/06-14/06	7.7	25.0 ± 1.7	< 0.019	2.9 ± 0.2
24	14/06-21/06	0.9	11.7 ± 0.8	< 0.019	1.29 ± 0.11
25	21/06-28/06	0.0	9.1 ± 0.6	< 0.02	1.99 ± 0.15
26	28/06-05/07	0.0	10.8 ± 0.8	< 0.02	3.3 ± 0.2

Continued on next page

Table A8 Continued

Week no.	Period	Precipi-tation mm	^{7}Be Bq·m^{-2}	^{137}Cs Bq·m^{-2}	^{210}Pb Bq·m^{-2}
27	05/07-12/07	0.2	6.1 ± 0.4	< 0.02	1.99 ± 0.15
28	12/07-19/07	0.0	3.0 ± 0.2	< 0.019	1.28 ± 0.11
29	19/07-26/07	0.0	2.35 ± 0.18	< 0.02	0.90 ± 0.09
30	26/07-02/08	4.3	39 ± 3	< 0.02	2.04 ± 0.16
31	02/08-09/08	5.0	31 ± 2	< 0.02	3.3 ± 0.2
32	09/08-16/08	27.5	36 ± 3	< 0.019	2.06 ± 0.16
33	16/08-23/08	5.3	18.3 ± 1.3	< 0.02	0.96 ± 0.09
34	23/08-30/08	39.0	61 ± 4	< 0.019	2.46 ± 0.19
35	30/08-06/09	23.5	64 ± 4	< 0.02	6.5 ± 0.5
36	06/09-13/09	14.0	21.9 ± 1.5	< 0.02	1.08 ± 0.10
37	13/09-20/09	0.5	8.0 ± 0.6	< 0.02	0.93 ± 0.09
38	20/09-27/09	31.5	52 ± 4	< 0.02	2.7 ± 0.2
39	27/09-04/10	8.3	18.7 ± 1.3	< 0.02	1.45 ± 0.12
40	04/10-11/10	0.0	6.6 ± 0.5	< 0.019	0.58 ± 0.07
41	11/10-18/10	0.0	4.0 ± 0.3	< 0.02	0.88 ± 0.08
42	18/10-25/10	1.2	4.9 ± 0.4	< 0.02	0.42 ± 0.08
43	25/10-01/11	32.0	14.9 ± 1.0	< 0.009	0.80 ± 0.07
44	01/11-08/11	7.5	3.9 ± 0.3	< 0.009	0.09 ± 0.03
45	08/11-15/11	16.3	8.3 ± 0.6	< 0.019	0.45 ± 0.07
46	15/11-22/11	0.0	4.2 ± 0.3	< 0.019	0.38 ± 0.06
47	22/11-29/11	10.5	4.6 ± 0.3	< 0.009	0.46 ± 0.04
48	29/11-06/12	17.5	11.1 ± 0.8	< 0.02	0.54 ± 0.06
49	06/12-13/12	40.0	35 ± 2	< 0.019	0.72 ± 0.08
50	13/12-20/12	12.5	27.6 ± 1.9	< 0.02	0.50 ± 0.09
51	20/12-27/12	31.5	23.6 ± 1.6	< 0.018	0.44 ± 0.06
52	27/12-03/01	2.5	6.4 ± 0.4	< 0.019	0.55 ± 0.07
Total [2]		641.5	1,194 ± 15	-	91.6 ± 1.3
Lower limit [3]		-	-	0.01	-
Upper limit [3]		-	-	1.01	-

[1] Measurements were carried out using γ-spectroscopy.
[2] The uncertainty in the sum is equal to the square root of the sum of the squared weekly uncertainties. Uncertainties are given as 1σ.
[3] The lower and upper limits are defined in Appendix B.

Table A9 Yearly average α activity concentration in air and ambient dose equivalent rate in 2018, as measured by the NMR stations equipped with aerosol monitors

Station	No.	α activity concentration $Bq.m^{-3}$	Ambient dose equivalent rate (1) $nSv.h^{-1}$
Rotterdam-Tarwewijk(2)	968	5.4	95
Arnhem	970	4.6	78
Kollumerwaard	972	4.1	88
Valthermond	974	3.6	68
Vlaardingen(2)	976	2.3	80
Braakman	978	4.3	76
Huijbergen	980	3.4	65
Houtakker	982	4.1	71
Wijnandsrade	984	9.0	88
Eibergen	986	4.6	69
De Zilk	988	2.9	72
Wieringerwerf	990	3.1	82
Vredepeel	992	4.3	63
Biddinghuizen	994	3.3	86
Bilthoven	998	3.8	69

(1) These dose equivalent rate monitors are placed differently from the dose equivalent rate monitors mentioned in Table A10 with regard to height and surface covering.
(2) The Vlaardingen station was operational until 5 March 2018, when its role was taken over by station Rotterdam-Tarwewijk, which was operational from 13 August 2018.

Table A10 Yearly average ambient dose equivalent rate for the NMR stations in 2018

Station	No.	Ambient dose equivalent rate nSv.h^{-1}	Station	No.	Ambient dose equivalent rate nSv.h^{-1}
Den Burg	1001	77	Rutten	1099	88
Den Helder	1002	78	Lelystad	1103	83
Den Oever	1003	78	Urk	1105	85
Petten	1006	67	Eemshaven	1106	83
Kolhorn	1007	94	Uithuizen	1107	89
Egmond aan Zee	1009	71	Wagenborgen	1109	80
Heerhugowaard	1011	84	Winschoten	1110	82
Nederhorst Den Berg	1015	83	Ter Apel	1111	73
Velsen	1016	80	Stadskanaal	1112	73
Enkhuizen	1018	83	Nieuweschans	1113	79
Oosthuizen	1019	82	Bellingwolde	1114	67
Zaandam (1)	1021	113	Groningen	1116	84
Gouda	1024	82	Leens	1117	89
Dordrecht	1027	69	Grijpskerk	1118	81
Zuid Beijerland	1028	88	Meppel	1125	76
Rotterdam-Schiebroek	1031	73	Hoogeveen	1126	71
Pijnacker	1032	83	Steenwijksmoer	1129	75
Maasvlakte	1035	84	Nw. Amsterdam	1130	80
Rotterdam-Waalhaven	1036	65	Nw. Schoonebeek/	1131	71
Maassluis	1037	99	Weiteveen		
Hellevoetsluis	1038	112	Emmen	1132	80
Ouddorp	1039	70	Laren (Gld)	1134	79
Hoenderloo (2)	1040	72	Hengelo (Ov)	1135	79
Otterlo (2)	1042	88	Vroomshoop	1138	77
Wageningen	1043	75	Enschede	1139	74
Amersfoort	1046	82	Losser	1140	69
Harderwijk	1050	74	Oldenzaal	1141	77
Wijk bij Duurstede	1056	92	Rijssen	1143	84
Nieuwegein	1062	87	's Heerenberg	1144	82
Zegveld	1063	76	Dinxperlo	1145	87
Lopik (Cabauw)	1064	86	Varsseveld	1146	82
Apeldoorn	1066	79	Groenlo	1147	93
Heerenveen	1071	68	Deventer	1148	88
Oosterwolde	1072	86	Etten-Leur	1154	76
Bergum	1074	77	Den Bosch	1157	77
Harlingen	1076	86	Raamsdonkveer	1159	95
Sneek	1077	80	Ulvenhout	1160	72
St Jacobiparochie	1081	87	Baarle Nassau	1161	81
Holwerd	1082	94	Mill	1163	73
Leeuwarden	1085	80	Volkel	1164	67
Zwolle	1088	87	Oss	1167	81
Ommen	1093	76	Nuenen	1172	78
Hardenberg	1095	75	Bergeijk	1174	100
Assen	1097	76	Waalre	1175	77

Continued on next page

Table A10 Continued

Station	No.	Ambient dose equivalent rate nSv.h^{-1}	Station	No.	Ambient dose equivalent rate nSv.h^{-1}
Someren (Dorp)	1176	75	Hoensbroek	1225	98
Oisterwijk	1178	84	Gennep	1228	76
Riel	1179	81	Elst (Gld)	1229	84
Oostelbeers	1180	111	Zevenaar	1230	83
Hilvarenbeek	1181	74	Nijmegen	1231	76
Venray	1183	67	Amstelveen	1233	87
Nieuw-Bergen	1184	67	Amsterdam	1234	82
Sevenum	1185	80	Aalsmeer	1236	80
Reuver	1188	77	Nispen	1237	72
Nederweert	1189	80	Groesbeek	1240	81
Heythuysen	1190	84	Tubbergen	1243	78
Mariahoop	1191	81	Haaksbergen	1244	71
Stramproy	1192	72	Scheveningen	1247	85
Eerbeek	1193	79	Zaltbommel	1251	82
Leiden	1196	88	IJzendijke	1252	85
Hulst	1197	85	Ritthem	1253	95
Terneuzen	1199	82	Vlissingen Haven	1254	81
Sluis	1201	81	Nieuwdorp	1255	84
Vlissingen	1202	86	's-Heerenhoek [3]	1256	124
Halsteren	1204	75	Driewegen	1257	97
Oud Gastel	1206	76	Arnemuiden	1258	87
Goes	1207	82	Heinkenszand	1259	98
Bruinisse	1209	83	Baarland	1260	99
Burgh-Haamstede	1211	69	Biervliet	1261	78
Vrouwenpolder	1212	71	Nummer Een	1262	90
Yerseke	1213	89	Rilland	1263	83
Middelburg	1215	89	Putte	1264	63
Westkapelle	1216	76	Nieuw Namen	1265	92
Maasband	1218	88	Beneden Leeuwen	1272	87
Maastricht	1220	105	Denekamp	1278	74
Ravensbos (Arensgehout)	1221	92	Winterswijk (Kotten)	1279	76
Vaals	1222	97	Bilthoven	1280	63
Gulpen	1223	86	Gastel (Maarheze)	1281	81
Kerkrade	1224	96			

[1] The Zaandam station showed a significantly higher value than most other stations. This is due to a higher background level of the surrounding surface at the site since the end of 2014.
[2] The Otterlo station was operational until the end of November 2018, and was relocated to Hoenderloo at the beginning of December 2018.
[3] As in previous years, the 's-Heerenhoek station showed a significantly higher value than all other stations. This is due to a higher background level of the ground surface at the site. Since September 2009, this background level has been reduced by covering the surrounding ground surface with a layer of shells.

Table A11 Gross α, residual β, ^{3}H, ^{90}Sr and ^{226}Ra activity concentrations ($mBq \cdot L^{-1}$) in surface water in 2018 as measured by RWS

Date	Gross α $mBq \cdot L^{-1}$	Residual β $mBq \cdot L^{-1}$	^{3}H $mBq \cdot L^{-1}$	^{90}Sr $mBq \cdot L^{-1}$	^{226}Ra $mBq \cdot L^{-1}$
Location	**IJsselmeer**				
23/01/18	45	17	2,380		
21/02/18	15	11			
20/03/18	56	28	2,570		
17/04/18	30	29			
15/05/18	54	26	2,500		
12/06/18	48	45			
10/07/18	35	23	2,580		
07/08/18	18	10			
05/09/18	34	< 1	2,990		
03/10/18	65	48			
30/10/18	22	25	2,740		
27/11/18	25	31			
18/12/18	35	3	2,980		
Average	37	23	2,680		
Location	**North Sea Canal (Noordzeekanaal)**				
08/01/18	144	28	5,580		
05/02/18	146	23	2,720		
05/03/18	274	15	3,010		
03/04/18	157	24	3,700		
30/04/18	307	22	4,050		
28/05/18	227	10	2,910		
25/06/18	78	29	3,180		
23/07/18	396	29	3,000		
20/08/18	160	15	2,570		
17/09/18	59	10	2,110		
15/10/18	190	12	2,880		
12/11/18	423	41	2,500		
10/12/18	98	30	2,750		
Average	205	22	3,150		
Location	**Nieuwe Waterweg**				
25/01/18	111	74			
22/02/18	48	19	3,960	< 1	20.4
22/03/18	120	51			
19/04/18	179	14	3,730	2.3	1.0
17/05/18	98	77			
14/06/18	150	36	4,360	< 1	3.1
12/07/18	170	115			
08/08/18	323	27	4,320	1.8	< 0.1
05/09/18	227	43			
04/10/18	250	76	3,090	1.2	4.7
01/11/18	274	27			
29/11/18	201	18	3,840	6.9	13.0
27/12/18	45	58			
Average	169	49	3,880	< 2.2	7.0

Continued on next page

Table A11 Continued

Date	Gross α mBq·L^{-1}	Residual β mBq·L^{-1}	^{3}H mBq·L^{-1}	^{90}Sr mBq·L^{-1}	^{226}Ra mBq·L^{-1}
Location	**Rhine**				
03/01/18	40	45	5,580	< 1	2.6
31/01/18	68	46	1,590		
28/02/18	46	31	1,720	< 1	5.7
28/03/18	59	37	4,240		
25/04/18	19	24	1,730	< 1	2.4
23/05/18	39	28	10,200		
20/06/18	44	29	5,920	< 1	2.2
18/07/18	63	39	3,890		
15/08/18	72	50	2,110	2.4	4.6
12/09/18	55	27	1,760		
10/10/18	70	32	6,340	< 1	3.3
07/11/18	48	2	2,970		
05/12/18	67	27	3,960	< 1	14.2
Average	53	32	4,000	< 0.8	5.0
Location	**Scheldt**				
22/01/18	287	308	11,600		15.2
20/02/18	302	175			
19/03/18	200	122	5,640		1.6
19/04/18	411	232			
17/05/18	314	97	6,720		8.6
14/06/18	164	83			
09/07/18	373	163	12,100		3.7
06/08/18	473	50			
03/09/18	243	43	10,200		3.0
01/10/18	303	74			
29/10/18	341	72	8,700		1.8
26/11/18	258	128			
17/12/18	319	79	12,200		0.7
Average	307	125	9,600		5.0
Location	**Meuse**				
02/01/18	75	49	16,800	< 1	4.3
30/01/18	52	23	2,060		
27/02/18	25	12	994	< 1	4.6
27/03/18	33	22	36,000		
24/04/18	12	13	9,930	< 1	2.8
22/05/18	30	22	14,300		
19/06/18	17	16	46,100	< 1	6.9
17/07/18	60	19	25,100		
14/08/18	42	21	33,800	< 1	0.3
11/09/18	39	< 1	39,200		
09/10/18	67	14	22,500	1.4	0.8
06/11/18	45	24	42,200		
04/12/18	67	4	23,300	1.5	0.8
Average	43	18	24,000	< 0.8	2.9

Continued on next page

Table A11 Continued

Date	Gross α mBq·L^{-1}	Residual β mBq·L^{-1}	^{3}H mBq·L^{-1}	^{90}Sr mBq·L^{-1}	^{226}Ra mBq·L^{-1}
Location	**Ghent-Terneuzen Canal**				
15/01/18	84	28			
12/02/18	86	20	1,620		
12/03/18	97	16			
09/04/18	117	22	1,550		
07/05/18	134	43			
04/06/18	145	21	1,270		
03/07/18	141	25			
30/07/18	152	38	2,250		
27/08/18	187	31			
24/09/18	249	6	2,540		
22/10/18	130	8			
20/11/18	103	86	2,170		
17/12/18	152	29			
Average	137	29	1,900		
Location	**Haringvliet**				
17/01/18	53	48	2,990		
14/02/18	33	18			
14/03/18	18	< 1	4,890		
11/04/18	14	7			
14/05/18	64	22	3,460		
06/06/18	35	23			
04/07/18	29	17	5,460		
02/08/18	19	21			
29/08/18	28	< 1	4,020		
26/09/18	20	< 1			
24/10/18	11	9	4,160		
22/11/18	31	4			
19/12/18	21	16	4,670		
Average	29	14	4,240		

Table A12 ^{60}Co, ^{131}I, ^{137}Cs and ^{210}Pb activity concentrations in suspended solids ($Bq \cdot kg^{-1}$) in surface water in 2018 as measured by RWS

Date	**^{60}Co $Bq \cdot kg^{-1}$**	**^{131}I $Bq \cdot kg^{-1}$**	**^{137}Cs $Bq \cdot kg^{-1}$**	**^{210}Pb $Bq \cdot kg^{-1}$**
Location	**IJsselmeer**			
23/01/18	< 1	< 1	5.9	
20/02/18	< 1	< 1	8.6	
20/03/18	< 1	< 1	7.5	
17/04/18	< 1	< 1	3.9	
15/05/18	< 1	< 1	2.9	
12/06/18	< 1	< 1	1.5	
10/07/18	< 1	< 1	2.0	
07/08/18	< 1	< 1	< 1	
05/09/18	< 1	< 1	1.1	
03/10/18	< 1	< 1	2.7	
30/10/18	< 1	< 1	3.8	
27/11/18	< 1	< 1	< 1	
18/12/18	< 1	< 1	2.7	
Average	< 1	< 1	3.3	
Location	**North Sea Canal (Noordzeekanaal)**			
05/02/18	< 1	8	9.3	
03/04/18	< 1	19	4.7	
28/05/18	< 1	86	1.6	
23/07/18	< 1	4	< 1	
18/09/18	< 1	45.7	3.1	
12/11/18	< 1	9	5.2	
Average	< 1	29	4.1	
Location	**Nieuwe Waterweg**			
11/01/18	< 1	2.7	11.4	
08/02/18	4.0	< 1	10.8	98
08/03/18	< 1	8.4	8.4	
05/04/18	< 1	< 1	10.1	101
03/05/18	< 1	< 1	8.1	
30/05/18	< 1	< 1	7.4	126
28/06/18	< 1	< 1	9.2	
26/07/18	< 1	3.2	9.1	129
23/08/18	< 1	< 1	8.9	
20/09/18	< 1	< 1	4.9	114
18/10/18	< 1	< 1	4.5	
15/11/18	< 1	< 1	6.1	104
13/12/18	< 1	< 1	4.3	
Average	< 0.8	< 1.5	7.9	112

Continued on next page

Table A12 Continued

Date	^{60}Co Bq·kg^{-1}	^{131}I Bq·kg^{-1}	^{137}Cs Bq·kg^{-1}	^{210}Pb Bq·kg^{-1}
Location	**Rhine**			
03/01/18	< 1	< 1	11.1	118
17/01/18	< 1	4.8	10.3	
31/01/18	< 1	< 1	10.5	
14/02/18	< 1	< 1	11.0	
28/02/18	< 1	4.3	7.8	104
14/03/18	< 1	6.4	8.6	
28/03/18	< 1	5.3	7.7	
11/04/18	< 1	8.5	8.8	
25/04/18	< 1	< 1	7.9	119
08/05/18	< 1	< 1	6.0	
23/05/18	< 1	< 1	8.3	
05/06/18	- (1)	- (1)	- (1)	
20/06/18	< 1	< 1	9.8	134
04/07/18	< 1	< 1	7.0	
17/07/18	- (1)	- (1)	- (1)	
01/08/18	< 1	< 1	7.1	
15/08/18	< 1	< 1	7.7	108
29/08/18	< 1	< 1	7.3	
12/09/18	< 1	< 1	8.3	
26/09/18	< 1	< 1	7.5	
09/10/18	< 1	< 1	7.7	122
24/10/18	< 1	< 1	6.9	
07/11/18	< 1	< 1	5.8	
22/11/18	< 1	< 1	7.0	
05/12/18	< 1	< 1	4.7	85
19/12/18	< 1	13.9	8.8	
Average	< 1	< 2.2	8.1	113
Location	**Scheldt**			
22/01/18	< 1	2.1	5.9	81
20/02/18	< 1	< 1	5.6	
19/03/18	< 1	< 1	3.9	69
19/04/18	< 1	< 1	5.9	
17/05/18	< 1	< 1	5.3	75
14/06/18	< 1	< 1	3.9	
09/07/18	< 1	< 1	5.4	75
20/08/18	< 1	< 1	6.1	
03/09/18	< 1	< 1	5.0	69
01/10/18	< 1	< 1	5.8	
29/10/18	< 1	< 1	4.5	75
26/11/18	< 1	< 1	4.7	
17/12/18	< 1	< 1	5.1	79
Average	< 1	< 0.6	5.1	74

Continued on next page

Table A12 Continued

Date	^{60}Co Bq·kg^{-1}	^{131}I Bq·kg^{-1}	^{137}Cs Bq·kg^{-1}	^{210}Pb Bq·kg^{-1}
Location	**Meuse**			
02/01/18	< 1	< 1	8.8	76
09/01/18	19.8	< 1	11.5	
16/01/18	< 1	4.0	11.3	
23/01/18	< 1	3.9	8.6	
30/01/18	< 1	7.1	9.4	
05/02/18	< 1	< 1	13.5	
13/02/18	10.5	17.9	10.8	
19/02/18	12.6	8.9	13.4	
26/02/18	3.6	15.1	12.5	123
05/03/18	3.7	12.1	9.0	
12/03/18	11.1	30.0	9.4	
19/03/18	8.4	9.4	10.7	
26/03/18	9.5	18.9	12.0	
03/04/18	6.1	18.3	10.7	
09/04/18	7.1	16.9	10.8	
16/04/18	38.0	< 1	12.1	
23/04/18	26.9	< 1	12.0	149
01/05/18	4.9	15.3	12.9	
07/05/18	10.1	18.6	15.3	
14/05/18	12.2	15.0	14.8	
22/05/18	< 1	< 1	12.8	
28/05/18	5.5	< 1	11.9	
04/06/18	2.4	< 1	11.0	
11/06/18	5.1	14.8	12.1	
18/06/18	7.3	< 1	13.6	139
25/06/18	7.2	6.6	12.4	
02/07/18	2.6	< 1	4.0	
09/07/18	4.0	< 1	4.9	
16/07/18	< 1	8.8	5.4	
23/07/18	3.8	< 1	7.3	
30/07/18	2.5	< 1	4.6	
06/08/18	1.9	< 1	5.1	
13/08/18	4.6	14.9	8.0	182
20/08/18	2.3	8.2	4.9	
27/08/18	3.8	< 1	7.6	
03/09/18	2.7	< 1	4.8	
10/09/18	4.0	< 1	5.8	
17/09/18	2.1	< 1	5.2	
24/09/18	< 1	29.6	5.5	
01/10/18	< 1	< 1	8.1	
08/10/18	3.5	< 1	5.7	173
15/10/18	1.8	< 1	3.9	
22/10/18	3.5	19.8	8.0	
29/10/18	4.4	< 1	10.1	
05/11/18	5.2	< 1	10.1	
12/11/18	6.7	11.7	11.0	
19/11/18	10.5	25.6	10.1	
26/11/18	10.0	< 1	10.9	

Continued on next page

Table A12 Continued

Date	^{60}Co Bq·kg^{-1}	^{131}I Bq·kg^{-1}	^{137}Cs Bq·kg^{-1}	^{210}Pb Bq·kg^{-1}
Location	**Meuse**			
03/12/18	7.5	< 1	10.0	156
10/12/18	16.8	< 1	10.5	
17/12/18	55.3	< 1	12.4	
27/12/18	4.1	< 1	9.5	
Average	7.3	< 7	9.5	143
Location	**Ghent-Terneuzen Canal**			
22/02/18	< 1	22/02/18	< 1	22/02/18
28/05/18	< 1	28/05/18	< 1	28/05/18
22/08/18	< 1	22/08/18	< 1	22/08/18
20/11/18	< 1	20/11/18	< 1	20/11/18
Average	< 1	Average	< 1	Average
Location	**Haringvliet**			
15/02/18	< 1	< 1	14.2	
14/05/18	< 1	< 1	4.0	
02/08/18	< 1	< 1	1.9	
22/11/18	< 1	< 1	11.1	
Average	< 1	< 1	7.8	

(1) No sample available.

Table A13 Gross α, residual β, ^{3}H and ^{90}Sr activity concentrations ($mBq \cdot L^{-1}$) in seawater in 2018 as measured by RWS

Date	Gross α $mBq \cdot L^{-1}$	Residual β $mBq \cdot L^{-1}$	^{3}H $mBq \cdot L^{-1}$	^{90}Sr $mBq \cdot L^{-1}$
Location	**Coastal Area**			
14/02/18	535	80	6,210	
14/05/18	631	47	4,660	
16/08/18	349	46	3,390	
15/11/18	293	32	3,040	
Average	450	51	4,300	
Location	**Southern North Sea**			
14/02/18	347	42	7,910	1.4
14/05/18	726	50	1,930	9.5
16/08/18	350	36	2,130	1.3
14/11/18	484	33	1,470	4.2
Average	480	40	3,400	4.1
Location	**Central North Sea**			
30/01/18	636	19	556	< 1
17/04/18	362	17	357	< 1
12/06/18	274	41	2,100	3.2
14/08/18	253	45	426	< 1
Average	380	31	860	< 1.2
Location	**Delta Coastal Waters**			
23/01/18	329	147	6,920	
13/02/18	178	80	7,560	3.6
15/03/18	212	54	7,040	
18/04/18	194	13	5,160	
16/05/18	554	57	5,420	< 1
11/06/18	318	18	3,540	
19/07/18	462	60	3,120	
16/08/18	426	32	4,030	4.3
12/09/18	807	61	2,910	
17/10/18	481	23	2,890	
12/11/18	708	43	2,860	< 1
10/12/18	242	72	3,500	
Average	410	55	4,600	< 2.2
Location	**Western Scheldt**			
11/01/18	380	31	11,600	< 1
06/02/18	360	84	6,540	< 1
05/03/18	288	296	6,540	
03/04/18	499	107	6,930	
30/04/18	837	107	6,540	< 1
28/05/18	130	61	4,560	< 1
26/06/18	744	100	4,390	< 1
23/07/18	564	36	3,940	< 1
23/08/18	147	80	3,900	< 1
20/09/18	612	60	3,580	< 1
18/10/18	517	23	3,410	1.1
12/11/18	602	71	3,410	2.4
11/12/18	132	122	3,800	< 1
Average	450	90	5,300	< 0.7

Continued on next page

Table A13 Continued

Date	Gross α mBq·L^{-1}	Residual β mBq·L^{-1}	^{3}H mBq·L^{-1}	^{90}Sr mBq·L^{-1}
Location	**Eems-Dollard**			
14/02/18	608	96	5,560	
09/05/18	163	4	4,980	
20/08/18	112	29	3,790	
20/11/18	102	95	3,200	
Average	250	56	4,400	
Location	**Wadden Sea West**			
14/02/18	688	43	5,660	
14/05/18	530	52	4,770	
09/08/18	665	48	2,970	
20/11/18	696	42	2,660	
Average	640	46	4,000	
Location	**Wadden Sea East**			
09/02/18	581	244	5,550	
15/05/18	490	122	5,230	
16/08/18	359	76	2,900	
16/11/18	501	127	2,430	
Average	480	140	4,000	

Table A14 ^{137}Cs and ^{210}Pb activity concentrations in suspended solids (Bq·kg^{-1}) in seawater in 2018 as measured by RWS

Date	^{137}Cs Bq·kg^{-1}	^{210}Pb Bq·kg^{-1}
Location	**Western Scheldt**	
23/02/18	3.1	60
16/05/18	2.8	48
21/08/18	3.1	65
19/11/18	2.6	52
Average	2.9	56

Table A15 Monthly average gross α activity concentrations in air dust near the Borssele nuclear power plant in 2018

Date (1)	Gross α (2) mBq·m^{-3}				
Location	**21**	**22**	**23**	**27**	**29**
07/02/18	0.04	0.052	0.032	0.023	0.016
07/03/18	0.017	0.045	0.06	0.004	0.01
04/04/18	0.036	0.06	0.08	0.007	0.012
07/05/18	0.049	0.092	0.057	0.03	0.015
06/06/18	0.027	0.087	0.085	0.016	0.004
04/07/18	0.026	0.04	0.039	0.007	0.009
06/08/18	0.038	0.045	0.04	0.029	0.006
05/09/18	0.034	0.008	0.099	0.01	0.003
03/10/18	0.04	0.039	0.059	0.008	0.002
08/11/18	0.09	0.062	0.055	0.031	0.005
06/12/18	0.064	0.007	0.07	0.008	0.003
03/01/19	0.024	0.042	0.009	0.009	0.003

(1) End date of monthly sampling period.
(2) Gross α activity concentrations in air dust are given as indicative values.

Table A16 Monthly average gross β activity concentrations in air dust near the Borssele nuclear power plant in 2018

Date [1]	**Gross β mBq·m^{-3}**				
Location	**21**	**22**	**23**	**27**	**29**
07/02/18	0.42 ± 0.05	0.48 ± 0.04	0.46 ± 0.06	0.28 ± 0.05	0.138 ± 0.017
07/03/18	0.38 ± 0.07	0.58 ± 0.05	0.43 ± 0.09	0.10 ± 0.06	0.25 ± 0.03
04/04/18	0.48 ± 0.06	0.77 ± 0.08	0.42 ± 0.07	0.06 ± 0.06	0.06 ± 0.02
07/05/18	0.40 ± 0.05	0.86 ± 0.06	0.55 ± 0.07	0.03 ± 0.05	0.271 ± 0.018
06/06/18	0.54 ± 0.05	0.87 ± 0.06	0.68 ± 0.07	0.25 ± 0.06	0.094 ± 0.017
04/07/18	0.40 ± 0.07	0.64 ± 0.07	0.31 ± 0.07	0.22 ± 0.06	0.138 ± 0.018
06/08/18	0.49 ± 0.05	0.44 ± 0.05	0.51 ± 0.06	0.02 ± 0.05	0.086 ± 0.012
05/09/18	0.12 ± 0.06	0.09 ± 0.05	0.38 ± 0.07	0.03 ± 0.06	0.050 ± 0.014
03/10/18	0.62 ± 0.06	0.45 ± 0.04	0.73 ± 0.08	0.32 ± 0.07	0.056 ± 0.014
08/11/18	1.08 ± 0.07	0.52 ± 0.03	0.94 ± 0.06	0.04 ± 0.05	0.071 ± 0.012
06/12/18	1.09 ± 0.07	0.21 ± 0.03	1.05 ± 0.09	0.25 ± 0.08	0.070 ± 0.016
03/01/19	0.67 ± 0.07	0.35 ± 0.03	0.46 ± 0.07	0.11 ± 0.08	0.034 ± 0.016

[1] End date of monthly sampling period.

Table A17 Monthly average activity concentrations of γ-emitters in air (dust) near the Borssele nuclear power plant in 2018 [1]

Date [2]	**^{60}Co mBq·m^{-3}**	**$^{131}I_{el}$** [3] **mBq·m^{-3}**	**$^{131}I_{or}$** [4] **mBq·m^{-3}**	**^{137}Cs mBq·m^{-3}**	**Nat.** [5] **mBq·m^{-3}**
07/02/18	< 0.047	< 0.1	< 0.3	< 0.033	< 1.4
07/03/18	< 0.052	< 0.2	< 0.4	< 0.037	< 1.7
04/04/18	< 0.06	< 0.2	< 1	< 0.048	< 2
07/05/18	< 0.039	< 0.3	< 0.7	< 0.030	< 1.6
06/06/18	< 0.052	< 0.4	< 0.7	< 0.040	< 1.7
04/07/18	< 0.06	< 0.2	< 0.4	< 0.034	< 1.7
06/08/18	< 0.039	< 0.2	< 0.4	< 0.029	< 1.5
05/09/18	< 0.042	< 0.2	< 0.5	< 0.029	< 1.5
03/10/18	< 0.049	< 0.1	< 0.4	< 0.030	< 1.3
08/11/18	< 0.037	< 0.1	< 0.3	< 0.025	< 1.6
06/12/18	< 0.043	< 0.2	< 0.6	< 0.032	1.54 ± 0.14
03/01/19	< 0.042	< 0.1	< 0.6	< 0.030	< 1.5

[1] Analysis was performed on a combined sample of the monthly samples taken from all five locations (21, 22, 23, 27 and 29).
[2] End date of monthly sampling period.
[3] Elemental ^{131}I.
[4] Organically bound ^{131}I.
[5] Naturally occurring γ-emitters.

Table A18 Activity concentrations of γ-emitters in grass near the Borssele nuclear power plant in 2018 (1)

Date	Mass $kg \cdot m^{-2}$	^{60}Co $Bq \cdot kg^{-1}$ (2)	^{131}I $Bq \cdot kg^{-1}$ (2)	^{137}Cs $Bq \cdot kg^{-1}$ (2)
07/02/18	0.86	< 2	< 1.0	< 0.9
07/03/18	0.744	< 0.9	< 0.9	< 0.9
04/04/18	0.603	< 2	< 1	< 2
07/05/18	0.452	< 2	< 2	< 1
06/06/18	0.543	< 1	< 2	< 1
04/07/18	0.549	< 2	< 2	< 2
06/08/18	0.767	< 2	< 2	< 1
05/09/18	0.419	< 3	< 2	< 2
03/10/18	0.570	< 2	< 1	< 1
08/11/18	0.464	< 2	< 2	< 2
06/12/18	0.475	< 2	< 1	< 1
03/01/19	0.424	< 1	< 2	< 1

(1) Analysis was performed on a combined sample of the monthly samples taken from all five locations (21, 22, 23, 27 and 29).
(2) Dry weight.

Table A19 Activity concentrations of γ-emitters in soil near the Borssele nuclear power plant in 2018 (1)

Location	Mass $kg \cdot m^{-2}$	^{54}Mn $Bq \cdot kg^{-1}$ (2)	^{60}Co $Bq \cdot kg^{-1}$ (2)	^{134}Cs $Bq \cdot kg^{-1}$ (2)	^{137}Cs $Bq \cdot kg^{-1}$ (2)
O1	84.8	< 0.3	< 0.2	< 0.2	1.12 ± 0.04
O2	88.8	< 0.2	< 0.2	< 0.2	1.13 ± 0.05
O3	79.2	< 0.3	< 0.2	< 0.2	1.11 ± 0.04
O4	82	< 0.3	< 0.3	< 0.2	1.12 ± 0.04

(1) Analysis was performed on four samples taken near the outlet of the plant on 8 May 2018.
(2) Dry weight.

Table A20 Residual β activity concentrations in water from the Western Scheldt near the Borssele nuclear power plant in 2018

Date	Residual β $Bq \cdot L^{-1}$			
Location	**1**	**2**	**3**	**4**
07/02/18	0.447 ± 0.010	0.496 ± 0.011	0.109 ± 0.008	0.488 ± 0.007
07/03/18	0.058 ± 0.008	0.052 ± 0.008	0.078 ± 0.008	0.068 ± 0.007
04/04/18	0.080 ± 0.010	0.092 ± 0.006	0.031 ± 0.007	0.081 ± 0.008
07/05/18	0.053 ± 0.008	0.058 ± 0.008	0.032 ± 0.008	0.057 ± 0.007
06/06/18	0.100 ± 0.010	0.085 ± 0.009	0.117 ± 0.009	0.068 ± 0.009
04/07/18	0.242 ± 0.011	0.076 ± 0.008	0.071 ± 0.007	0.083 ± 0.008
06/08/18	0.059 ± 0.008	0.040 ± 0.009	0.022 ± 0.009	0.098 ± 0.009
05/09/18	0.032 ± 0.009	0.038 ± 0.009	0.027 ± 0.008	0.012 ± 0.009
03/10/18	0.043 ± 0.009	0.049 ± 0.009	0.023 ± 0.009	0.033 ± 0.009
08/11/18	0.086 ± 0.009	0.112 ± 0.009	0.075 ± 0.008	0.093 ± 0.009
06/12/18	0.078 ± 0.011	0.059 ± 0.008	0.086 ± 0.008	0.071 ± 0.010
03/01/19	0.036 ± 0.008	0.024 ± 0.009	0.052 ± 0.011	0.039 ± 0.012

Table A21 ^{3}H activity concentrations in water from the Western Scheldt near the Borssele nuclear power plant in 2018

Date		**^{3}H Bq·L^{-1}**		
Location	**1**	**2**	**3**	**4**
07/02/18	3.3 ± 1.4	< 5	< 5	< 5
07/03/18	7.0 ± 1.5	6.0 ± 1.4	5.1 ± 1.4	6.9 ± 1.5
04/04/18	4.2 ± 1.4	< 4	5.7 ± 1.5	4.7 ± 1.4
07/05/18	3.7 ± 1.3	2.4 ± 1.2	4.4 ± 1.4	5.3 ± 1.4
06/06/18	< 5	< 5	2.9 ± 1 .3	< 5
04/07/18	< 5	4.1 ± 1.4	< 5	2.7 ± 1.3
06/08/18	3.5 ± 1.4	2.3 ± 1.2	< 5	< 4
05/09/18	< 5	< 5	< 5	< 5
03/10/18	4.9 ± 0.8	6.0 ± 0.8	7.8 ± 1.1	< 3
08/11/18	< 3	< 3	< 3	< 3
06/12/18	< 2.5	< 2.6	2.1 ± 0.8	< 2.6
03/01/19	< 3	< 3	< 3	< 3

Table A22 Gross β activity concentrations in suspended solids from the Western Scheldt near the Borssele nuclear power plant in 2018

Date	**Gross β kBq·kg^{-1}**			
Location	**1**	**2**	**3**	**4**
07/02/18	5.7 ± 1.0	4.8 ± 0.9	8 ± 2	14.2 ± 0.4
07/03/18	5.2 ± 1.5	5.4 ± 0.9	1.3 ± 0.5	2.6 ± 0.5
04/04/18	10.0 ± 1.7	9 ± 4	8.3 ± 1.4	2.5 ± 0.6
07/05/18	0.3 ± 0.7	4 ± 5	8 ± 4	8 ± 3
06/06/18	17 ± 3	10 ± 3	4.5 ± 1.5	4.3 ± 1.4
04/07/18	3.8 ± 1.9	6 ± 3	9 ± 3	3.5 ± 1.6
06/08/18	7.7 ± 0.9	1.3 ± 1.1	4.4 ± 1.1	0.8 ± 0.7
05/09/18	1.9 ± 0.8	2.1 ± 0.5	2.1 ± 0.7	1.4 ± 0.4
03/10/18	3 ± 3	2.8 ± 1.0	2.1 ± 0.9	1.9 ± 1.0
08/11/18	1.8 ± 0.6	2.1 ± 0.4	2.1 ± 0.5	1.9 ± 0.5
06/12/18	1.5 ± 0.5	1.64 ± 0.13	1.7 ± 0.4	1.1 ± 0.3
03/01/19	1.1 ± 0.4	2.0 ± 0.5	1.9 ± 0.3	1.2 ± 0.2

Table A23 Activity concentrations of γ-emitters in seaweed from the Western Scheldt near the Borssele nuclear power plant in 2018 (1)

Date	Mass kg	^{60}Co Bq·kg^{-1} (2)	^{131}I Bq·kg^{-1} (2)	^{137}Cs Bq·kg^{-1} (2)
07/02/18	0.156	< 1	< 1	< 0.8
07/03/18	0.132	< 1	< 1	< 1
04/04/18	0.11	< 1	< 1	< 1
07/05/18	0.128	< 2	< 1	< 1
06/06/18	0.099	< 2	< 2	< 2
04/07/18	0.114	< 2	< 1	< 2
06/08/18	0.187	< 1	< 1	< 1
05/09/18	0.146	< 2	< 1	< 1
03/10/18	0.111	< 2	< 1	< 2
08/11/18	0.089	< 2	< 2	< 2
06/12/18	0.099	< 2	< 1	< 2
03/01/19	0.108	< 1	< 1	< 1

(1) Analysis was performed on a combined sample of the monthly samples taken from all four locations (1, 2, 3 and 4).
(2) Dry weight.

Table A24 Activity concentrations of γ-emitters in sediment from the Western Scheldt near the Borssele nuclear power plant in 2018 (1)

Location	Mass kg·m^{-2}	^{60}Co Bq·kg^{-1} (2)	^{131}I Bq·kg^{-1} (2)	^{137}Cs Bq·kg^{-1} (2)
07/02/18	71.0	< 0.3	< 0.3	0.592 ± 0.008
07/03/18	74.7	< 0.2	< 0.2	0.39 ± 0.05
04/04/18	77.4	< 0.2	< 0.2	0.40 ± 0.04
07/05/18	59.8	< 0.3	< 0.3	0.79 ± 0.07
06/06/18	58.9	< 0.2	< 0.4	0.99 ± 0.05
04/07/18	67.5	< 0.2	< 0.2	0.70 ± 0.03
06/08/18	66.3	< 0.3	< 0.2	0.81 ± 0.04
05/09/18	64.0	< 0.2	< 0.4	0.81 ± 0.04
03/10/18	69.4	< 0.2	< 0.3	0.67 ± 0.04
08/11/18	58.1	< 0.3	< 0.4	0.78 ± 0.04
06/12/18	67.6	< 0.3	< 0.3	0.82 ± 0.04
03/01/19	49.2	< 0.4	< 0.8	0.98 ± 0.06

(1) Analysis was performed on a combined sample of the monthly samples from all four locations (1, 2, 3 and 4).
(2) Dry weight.

Appendix B Presentation of data

The methods described below were applied to the data provided by RIVM (e.g. air dust and deposition), unless otherwise stated. Data from the other institutions are reported as provided, unless otherwise stated.

B.1 Correction for radioactive decay

In general, the activities of specific radionuclides are corrected for radioactive decay. The activities measured in the sample are multiplied by a decay factor, combining the time from halfway through the sampling period to the time of analysis, the decay during the measurement and the half-life of the radionuclide. If the radionuclides are unknown, as with gross α and gross β, no correction for radioactive decay is made.

B.2 Calculation of sums and averages

In the calculation of weekly, monthly or yearly averages or sums, the original results before rounding-off are used. If a certain radionuclide was not detected, the detection limit is used in the calculation of the sums. In that case, only a range (lower and upper limit) is given instead of a total with an uncertainty. Both range and total with an uncertainty are presented with a 68% confidence interval.

The lower and upper limits are calculated as follows:

$$\text{Lower limit} = \sum x_i - \sqrt{\sum s_i^2}$$

$$\text{Upper limit} = \sum x_i + \sqrt{\sum s_i^2} + \sum MDA_j$$

where

x_i = weekly or monthly result that is not a detection limit;

$\sqrt{\sum s_i^2}$ = the uncertainty in the sum;

s_i = uncertainty in the weekly or monthly result (1σ);

MDA_j = weekly or monthly result that is a detection limit.

The detection limits are omitted in the calculation of the averages. If data are not reported (e.g. a sample was not analysed/available), the sampling period is not taken into account for the calculation of the sum or average.

B.3 Calculation of uncertainties

The uncertainties given in Tables A1–A8 are a combination of the statistical uncertainties and the estimations of the experimental uncertainties. In the yearly total, the uncertainty is the square root of the sum of the squared weekly or monthly uncertainties. In the yearly average, the uncertainty is the square root of the sum of the squared weekly uncertainties divided by the number of weeks.

B.4 Mixed diets: conversion from Bq·kg^{-1} to intake in Bq·day^{-1}

With respect to the results presented for mixed diets (Chapter 8), RIKILT Wageningen UR used food consumption patterns to convert the measured concentrations of ^{90}Sr, ^{134}Cs and ^{137}Cs in food (Bq·kg^{-1}) to an average daily intake value per person per day (Bq·day^{-1}). For the Netherlands, the food consumption patterns were investigated by the RIVM and the results can be found in the report 'Dutch National Food Consumption Survey 2007–2010. Diet of children and adults aged 7 to 69 years' [76]. In this report, the consumption patterns are presented by food category, sex and age group in grams per consumption day, as well as the percentage of consumption days. For the calculations in the current report, these values were combined to produce an average consumption amount in g·day^{-1} for each food category, sex and age group.

For each sex and age group and specific radionuclide, the daily intake ($DI_{a,s,n}$) is then calculated as follows:

$$DI_{a,s,n} = \sum_{i} \frac{DI_{a,s,i}}{1000} \times AC_{i,n}$$

where

$DI_{a,s,n}$ = daily intake per age group, sex and radionuclide (Bq·day^{-1});
i = food category;
$DI_{a,s,i}$ = daily intake per age group, sex and food category (g·day^{-1});
$AC_{i,n}$ = activity concentration per food category and radionuclide (Bq·kg^{-1}).

These daily intakes were then averaged over the different age groups and sexes to obtain the total daily intake per person for each radionuclide. To include the monitoring results of ready meals in the final result, the assumption was made that ready meals make up 10% of the consumption of the categories meat, fish and vegetables.

Appendix C Glossary

Ambient dose equivalent	An operational quantity used when monitoring radiation in the environment. The unit of ambient dose equivalent is the Sievert (Sv).
Becquerel (Bq)	One radioactive transformation per second.
Decay product	A decay product (also known as a daughter product, daughter isotope, or daughter nuclide) is a nuclide resulting from the radioactive decay of a parent isotope or precursor nuclide. The decay product may be stable or it may decay to form a daughter product of its own.
Dose rate	The radiation dose delivered per unit of time.
Effective dose	The sum of the equivalent doses from internal and external radiation in all tissue and organs of the body, having been weighted by their tissue weighting factors. The unit of effective dose is the Sievert (Sv).
Gross alpha activity	Gross α (or total α) activity is the total activity of radionuclides emitting α radiation.
Gross beta activity	Gross β (or total β) activity is the total activity of radionuclides emitting β radiation. Depending on the measurement methodology, it might exclude tritium and/or radon daughters.
Limit	Consumption limits in milk, foodstuffs and of feeding stuffs set in European legislation [65, 66, 67].
Parametric value	The value of radioactive substances in drinking water, above which Member States shall assess whether the presence of radioactive substances in water intended for human consumption poses a risk to human health that requires action and, where necessary, shall take remedial action to improve the quality of water to a level which complies with the requirements for the protection of human health from a radiation protection point of view [46].
Radioactivity	The emission of α particles, β particles, neutrons and γ or X radiation from the disintegration of an atomic nucleus. The unit of radioactivity is the Becquerel (Bq).
Radiocesium activity	Sum of the activity of ^{134}Cs and ^{137}Cs.
Radionuclide	An unstable form of an element that undergoes radioactive decay.

Residual beta activity	The residual β activity is the gross β activity (total β activity) minus the β activity of naturally occurring ^{40}K. For brackish and salt water, the RWS uses a direct method to determine residual β activity [43].
Screening level	Level for gross α or gross β activity in drinking water ($Bq \cdot L^{-1}$), below which it can be assumed that the individual dose is less than the parametric value of 0.1 mSv and radiological investigation is not needed, unless it is known from other sources of information that specific radionuclides are present in the water that are liable to cause an individual dose in excess of 0.1 mSv [46].

References

[1] EC, 2000. Recommendation of the Commission of the European Communities on the Application of Article 36 of the Euratom Treaty. EC Brussels, 2000/473/Euratom.

[2] R.B. Tax, P.J.M. Kwakman, A.P.P.A. van Lunenburg, M.H. Tijsmans, 1994. Development of a High Volume Air Sampler for the sensitive detection of γ-emitting radionuclides attached to aerosols. Results obtained in the test period 1991–1992. RIVM Bilthoven, Report no. 610056005.

[3] G.J. Knetsch, 2011. Afnametest Snow White. RIVM Bilthoven, internal report.

[4] NEN, 2009. NEN 5621, Radioactivity measurements – Sampling of airborne substances. NEN, Delft.

[5] NEN, 2006. NEN 5636, Radioactivity measurements – Determination of artificial gross-alpha activity, artificial gross-beta activity and gamma spectrometry of air filters and calculation of the volumic activity of sampled air. NEN, Delft.

[6] NEN, 2016. NEN 5623, Radioactivity measurements – Radioactiviteitsmetingen — Bepaling van de activiteit van gammastraling uitzendende nucliden in een telmonster met halfgeleider-gammaspectrometrie. NEN, Delft.

[7] G.J. Knetsch (ed.), 2006. Environmental radioactivity in the Netherlands. Results in 2005. RIVM Bilthoven, Report no. 861020013.

[8] S. Sugihara, N. Momoshima, Y. Maeda, S. Osaki, 2000. Variation of atmospheric ^{7}Be and ^{210}Pb depositions at Fukuoka, Japan. IRPA 10th congress, Web page: www2000.irpa.net/irpa10/cdrom/00822.pdf (January 2019).

[9] C. Ródenas, J. Gómez, L.S. Quindós, P.L. Fernández, J. Soto, 1997. ^{7}Be concentrations in air, rainwater and soil in Cantabria (Spain). Applied Radiation and Isotopes 48, 545–548.

[10] S. Talpos and V. Cuculeanu, 1997. A study of the vertical diffusion of ^{7}Be in the atmosphere. Journal of Environmental Radioactivity 36 (1), 93–106.

[11] K.N. Yu and L.Y.L. Lee, 2002. Measurements of atmospheric ^{7}Be properties using high-efficiency gamma spectroscopy. Applied Radiation and Isotopopes 57, 941–946.

[12] C. Papastefanou and A. Ioannidou, 1995. Aerodynamic size association of ^{7}Be in ambient aerosols. Journal of Environmental Radioactivity 26, 273–282.

[13] H.W. Feely, R.J. Larsen, C.G. Sanderson, 1989. Factors that cause seasonal variations in ^{7}Be concentrations in surface air. Journal of Environmental Radioactivity 9, 223–249.

[14] C.L. Fogh, J. Roed, K.G. Andersson, 1999. Radionuclide resuspension and mixed deposition at different heights. Journal of Environmental Radioactivity 46, 67–75.

[15] Solar Cycle Progression. Web page: www.swpc.noaa.gov/products/solar-cycle-progression (January 2019).

[16] R.C.G.M. Smetsers and R.O. Blaauboer, 1997. A dynamic compensation method for natural ambient dose rate based on 6 years' data from the Dutch Radioactivity Monitoring Network. Radiation Protection Dosimetry 69 (1), 19–31.
[17] S.I. Dusha-Gudym, 2005. Transport of radioactive materials by wildland fires in the Chernobyl accident zone: how to address the problem. International Forest Fire News 32. Web page: gfmc.online/wp-content/uploads/20-Dusha-Gudym-3.pdf (January 2019).
[18] KNMI database. Web page: www.knmi.nl/klimatologie (January 2019).
[19] T. Hantke, F.J. Aldenkamp, R.M.W. Overwater, H. Slaper, 1998. De jacht op een ^{137}Cs-wolk in Zuid-Europa – 'aftermath' van een ongeval in Algeciras. NVS Nieuws 23 (4).
[20] G.J. Knetsch (ed.), 2013. Environmental radioactivity in the Netherlands. Results in 2011. RIVM Bilthoven, Report no. 610891004.
[21] UNSCEAR, 2000. Sources and effects of ionizing radiation. Volume 1: Sources.
[22] E.A. Bondietti, C. Papastefanou, C. Rangarajan, 1987. Aerodynamic size associations of natural radioactivity with ambient aerosols. In: Radon and its Decay Products: Occurrence, Properties and Health Effects, ACS Symposium Series No. 331, P.K. Hopke (ed.), American Chemical Society, Washington, DC, 377–397.
[23] T. Suzuki, Y. Maruyama, N. Nakayama, K. Yamada, K. Ohta, 1999. Measurement of ^{210}Po/^{210}Pb activity ratio in size fractionated aerosols from the coast of the Japan Sea. Atmospheric Environment 33, 2285–2288.
[24] T. Tokieda, K. Yamanaka, K. Harada, S. Tsunogai, 1996. Seasonal variations of residence time and upper atmospheric contribution of aerosols studied with Pb-210, Bi-210, Po-210 and Be-7. Tellus, 48B, 690–702.
[25] G. Lambert, P. Bristeau, G. Polian, 1976. Emission and enrichments of radon daughters from Etna volcano magma. Geophysical Research Letters 3 (12), 724–726.
[26] J. Sato, T. Doi, T. Segawa, S. Sugawara, 1994. Seasonal variation of atmospheric concentrations of ^{210}Pb and ^{7}Be at Tsukuba, Japan, with a possible observation of ^{210}Pb originating from the 1991 eruption of the Pinatubo volcano, Philippines. Geochemical Journal 28, 123–129.
[27] J.P. Beks, D. Eisma, J. van der Plicht, 1998. A record of atmospheric ^{210}Pb deposition in the Netherlands. Science of the Total Environment 222, 35–44.
[28] J. Sato, 2003. Natural radionuclides in volcanic activity. Applied Radiation and Isotopes 58, 393–399.
[29] G. Lambert, B. Ardouin, G. Polian, 1982. Volcanic output of long-lived radon daughters. Journal of Geophysical Research 87 (C13), 11103–11108.

[30] C.P. Tanzi and G.J. Knetsch, 2012. ^{210}Po and ^{210}Pb in the Netherlands: releases to air from industrial plants compared to environmental monitoring. Proceedings of EU-NORM 1st International Symposium, 5–8 June, Tallinn, Estonia, 59–66.
[31] E.Y. Nho, B. Ardouin, M.F. Le Cloarec, M. Ramonet, 1996. Origins of ^{210}Po in the atmosphere at Lamto, Ivory Coast: biomass burning and Saharan dust. Atmospheric Environment 30 (22), 3705–3714.
[32] M.A. Mélières, M. Pourchet, S. Richard, 2003. Surface air concentration and deposition of lead-210 in French Guiana: two years of continuous monitoring. Journal of Environmental Radioactivity 66, 261–269.
[33] P.G. Appleby, A.O. Koulikov, L. Camarero, M. Ventura, 2002. The input and transmission of fall-out radionuclides through Redó, a high mountain lake in the Spanish Pyrenees. Water, Air & Soil Pollution: Focus 2, 19–31.
[34] NEN, 2009. NEN 5628, Radioactivity measurements – Sampling of the Deposition. NEN, Delft.
[35] NEN, 2006. NEN 5622, Radioactivity measurements – Determination of massic gross-alpha activity of a solid counting sample by the thick source method. NEN, Delft.
[36] NEN, 2016. NEN 5627, Radioactivity measurements – Determination of massic gross beta activity and massic rest beta activity of a solid counting sample. NEN, Delft.
[37] ISO 13161:2011 Water quality – Measurement of Polonium-210 activity concentration in water by alpha spectrometry.
[38] C.J.W. Twenhöfel, C. de Hoog van Beynen, A.P.P.A. van Lunenburg, G.J.E. Slagt, R.B. Tax, P.J.M. van Westerlaak, F.J. Aldenkamp, 2005. Operation of the Dutch 3rd Generation National Radioactivity Monitoring Network. In: Automatic Mapping Algorithms for Routine and Emergency Monitoring Data, Spatial Interpolation Comparison 2004 by IES, G. Dubois (ed.), European Committee, JRC, EUR 21595 2005, 19–31.
[39] R.O. Blaauboer and R.C.G.M. Smetsers, 1996. Variations in outdoor radiation levels in the Netherlands. Thesis University of Groningen, Groningen.
[40] C. de Hoog and R.B. Tax, 2003. Achtergronddocument bij NMR integrale rapportage 2002. RIVM Bilthoven, internal report.
[41] Federal Aviation Administration. Web page: www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/heliocentric/ (last accessed on 18 September 2019).
[42] E.J. de Jong and O.C. Swertz, 2000. Radioactieve stoffen in de zoute wateren. RIKZ, The Hague, Report no. RIKZ/2000.041.
[43] L.J. Gilde, K.H. Prins, C.A.M. van Helmond, 1999. Monitoring zoete rijkswateren. RIZA Lelystad, Report no. 99.004.
[44] MWTL Meetplan 2016, Monitoring Waterstaatkundige Toestand des Lands, Milieumeetnet Rijkswateren chemie en biologie, 19 augustus 2015.
[45] Web page: https://www.helpdeskwater.nl/onderwerpen/monitoring/gegevensinwinning/chemisch-fysisch/artikel/ (October 2019).

[46] EC, 2013. Council Directive laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption. EC Brussels, 2013/51/EURATOM.
[47] H.A.J.M. Reinen, C. de Hoog, F. Wetsteyn, J.G.M.M. Smeenk, H.A.M. Ketelaars, A.D. Hulsmann, J.M. van Steenwijk, A.J. Stortenbeek, 2003. Meetstrategie drinkwater bij kernongevallen. VROM-Inspectie Den Haag, Report No. 15060/177.
[48] Dutch Drinking Water Decree (2011), until 30 June 2018.
[49] Dutch Drinking Water Decree (2018), from 1 July 2018 onwards.
[50] G.J. Knetsch (ed.), 2003. Monitoring of radiation in the environment in the Netherlands. Results in 2002. RIVM Bilthoven, Report no. 861020005.
[51] G.J. Knetsch (ed.), 2004. Monitoring of radiation in the environment in the Netherlands. Results in 2003. RIVM Bilthoven, Report no. 861020010.
[52] G.J. Knetsch (ed.), 2005. Monitoring of radiation in the environment in the Netherlands. Results in 2004. RIVM Bilthoven, Report no. 861020011.
[53] G.J. Knetsch (ed.), 2007. Environmental radioactivity in the Netherlands. Results in 2006. RIVM Bilthoven, Report no. 610791001.
[54] G.J. Knetsch (ed.), 2008. Environmental radioactivity in the Netherlands. Results in 2007. RIVM Bilthoven, Report no. 610791002.
[55] G.J. Knetsch (ed.), 2010. Environmental radioactivity in the Netherlands. Results in 2008. RIVM Bilthoven, Report no. 610791003.
[56] M.C.E. Groot and G.J. Knetsch (eds), 2011. Environmental radioactivity in the Netherlands. Results in 2009. RIVM Bilthoven, Report no. 610891002.
[57] G.J. Knetsch (ed.), 2012. Environmental radioactivity in the Netherlands. Results in 2010. RIVM Bilthoven, Report no. 610891003.
[58] G.J. Knetsch (ed.), 2014. Environmental radioactivity in the Netherlands. Results in 2012. RIVM Bilthoven, Report no. 610891005.
[59] G.J. Knetsch (ed.), 2015. Environmental radioactivity in the Netherlands. Results in 2013. RIVM Bilthoven, Report no. 2015-0040.
[60] G.J. Knetsch (ed.), 2016. Environmental radioactivity in the Netherlands. Results in 2014. RIVM Bilthoven, Report no. 2016-0182.
[61] G.J. Knetsch (ed.), 2017. Environmental radioactivity in the Netherlands. Results in 2015. RIVM Bilthoven, Report no. 2016-0183.
[62] C.P. Tanzi (ed.), 2019. Environmental radioactivity in the Netherlands. Results in 2016. RIVM Bilthoven, Report no. 2018-0160
[63] C.P. Tanzi (ed.), 2019. Environmental radioactivity in the Netherlands. Results in 2017. RIVM Bilthoven, Report no. 2019-0103
[64] P.J.M. Kwakman, J.F.M. Versteegh, 2015. Radon-222 in groundwater and finished drinking water in the Dutch provinces Overijssel and Limburg. Measuring campaign 2015. RIVM Bilthoven, RIVM Letter report no. 2016-0048.

[65] EC, 2009. Council Regulation on the conditions governing imports of agricultural products originating in third countries following the accident at the Chernobyl nuclear power station. EC Brussels, No. 1048/2009.
[66] EC, 2008. Council Regulation on the conditions governing imports of agricultural products originating in third countries following the accident at the Chernobyl nuclear power station. EC Brussels, No. 733/2008.
[67] EC, 1989. Council Regulation amending Regulation (Euratom) No. 3954/87 laying down maximum permitted levels of radioactive contamination of foodstuffs and of feeding stuffs following a nuclear accident or any other case of radiological emergency. EC Brussels, No. 2218/89.
[68] EC, 2013. Council Directive laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. EC Brussels, No. 2013/59/Euratom.
[69] Keuringsdienst van Waren Oost, 1998. Werkvoorschrift CHE01-OT802, Keuringsdienst van Waren Oost, Bepaling van de activiteit van gammastraling uitzendende nucliden in een telmonster met halfgeleiderspectrometrie. Nijmegen.
[70] Keuringsdienst van Waren Oost, 2003. Werkvoorschrift CHE01-WV143, Keuringsdienst van Waren Oost, Bepaling van de activiteit van gammastraling uitzendende nucliden in een telmonster met de LMRV voedselmonitor. Zutphen.
[71] Jaarverslag NPK 2018. Nederlandse Voedsel en Waren Autoriteit.
[72] J.J. Donk, D.P.M. Zeegers, 2018. Resultaten van de dosistempo- en radioactiviteitsmetingen in de omgeving van Borssele over het jaar 2018. NRG Arnhem, Report No. 23969/19.152212 (commissioned by N.V. EPZ), and priv. comm. D.P.M. Zeegers to G-J Knetsch on 19 November 2019
[73] KEMA, 1994. Uitgangspunten voor de omgevingsbewakingsprogramma's van de kerncentrales te Dodewaard en Borssele. KEMA Arnhem, Report no. 40318/40575-NUC 94-5935.
[74] J.E.M. Jacobs (ed.), 2001. Monitoring of radiation in the Environment. Results in the Netherlands in 1999. RIVM Bilthoven, Report no. 610056046.
[75] Letter to the State Health Inspectorate of the Ministry of Housing, Spatial Planning and Environment, 13 January 1997. Reference no. 23/97 LSO Le/Ald/jdk. Onderzoek naar de slechte resultaten in 1995 van de bepaling van ^{210}Po en ^{210}Pb in natte en droge depositie. RIVM Bilthoven, internal report.
[76] C.T.M. van Rossum, H.P. Fransen, J. Verkaik-Kloosterman, E.J.M. Buurma-Rethans, M.C. Ocke, 2011. Dutch National Food Consumption Survey 2007–2010: Diet of children and adults aged 7 to 69 years. RIVM Bilthoven, Report no. 350050006.

C.P. Tanzi

RIVM report 2019-0216

Published by

National Institute for Public Health and the Environment, RIVM
P.O. Box 1 | 3720 BA Bilthoven
The Netherlands
www.rivm.nl/en

February 2020

Committed to *health and sustainability*