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Welzijn en Sport*

Kennisnotitie

Environmental monitoring in the vicinity of the Borssele nuclear power plant. Results in 2023.

RIVM

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1. Introduction

The ANVS tasked RIVM to regularly perform a check on a subsection of the measurements which are carried out by the Nuclear Research and Consultancy Group (NRG) on samples taken in the vicinity of the Borssele nuclear power plant (NPP).
The NPP Borssele commissioned NRG to carry out monthly sampling of air dust, grass, water (+ suspended solids), seaweed, sediment, and yearly sampling of sand near the cooling water outlet. All these samples were taken by NRG on July 3rd around the NPP Borssele on fixed locations as described in an environmental monitoring programme [i]. All analyses were carried out by NRG.
In 2023 various samples were separately collected on July 5th, and analyzed by RIVM in the laboratory in Bilthoven.

Short summary
NRG and RIVM both analyzed environmental samples for gamma-emitters, gross alpha and gross beta activity, and water samples for ^{3}H.
The analytical results indicate that, in the samples taken by NRG on 3rd and by RIVM on 5th July 2023, no radiological contamination as a result of business operations from the nuclear power plant can be found.

Accreditation
The department Radiation, Monitoring and Analyses (SMA) of the Centre for Safety and Security (VLH) of the National Institute for Public Health and the Environment (RIVM) has an accreditation for a number of analyses by the Council for Accreditation (RvA) according to NEN-EN-ISO/IEC 17025:2018 (RvA: L153 Testen).
These analyses are an independent verification of the measurement results commissioned by the nuclear power plant Borssele (hereafter referred to as KCB, an acronym for KernCentrale Borssele). The accreditation concerns specifically the analytical results of tritium in water, indicated with a 'Q' in Table 1. All other analyses are not accredited, mainly because of the sample matrix. An interpretation of the results in this report is not within the scope of the accreditation.

Disclaimer and source of KCB data
Data and information related to sampling and analysis by contractor NRG and commissioned by KCB, are delivered by KCB and indicated with "KCB" in all Tables. The quality of these data is the responsibility of KCB.

2. Sampling Programme by KCB and RIVM

The sampling programme by KCB, carried out by contractor NRG.

The sampling programme, which is carried out by the Nuclear Research and Consultancy Group (NRG), Petten, is described in Table 1. This programme has been routinely carried out by NRG with a monthly frequency for a large number of years.
Samples are taken in order to monitor radionuclides in air dust, grass, sand, water, suspended solids, seaweed and sediment [i]. The monitoring programme for environmental samples is outlined in Table 1 and the sampling locations in Figure 1.

Table 1 Monitoring programme for environmental samples taken by contractor NRG near the Borssele nuclear power plant in 2023; monthly sample taken by RIVM are indicated with [R]

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

The location numbers correspond to the location numbers shown in Figure 1. The index [R] means that this matrix is also sampled by RIVM. The index (Q) means that the analysis of tritium in water is carried out according to NEN-EN-ISO/IEC 17025:2018 (RvA: L153 Testen).
(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 1.
(5) γ-spectroscopic analysis of specific γ-emitting radionuclides: ^{54}Mn, ^{60}Co, ^{134}Cs and ^{137}Cs.

The map in Figure 1 shows the vicinity and larger area around the Borssele nuclear power plant. The NPP is situated in the red circle in the centre of the map. The circles represent distances of 2, 4, 6, 8 and 10 km.
The Westerscheldt is basically the estuary of the river Scheldt ("Schelde" in Dutch). Just some 30 km upstream, in Belgium, the Doel nuclear power plant is situated. This NPP, containing 4 reactors, also discharges waste water to the river Scheldt.

In Figure 1 sampling location "Vlissingen-Boei" is indicated just for comparison with analytical data in sea water from Rijkswaterstaat. This sampling location is not part of the environmental data produced by KCB (NRG) or RIVM in this report.

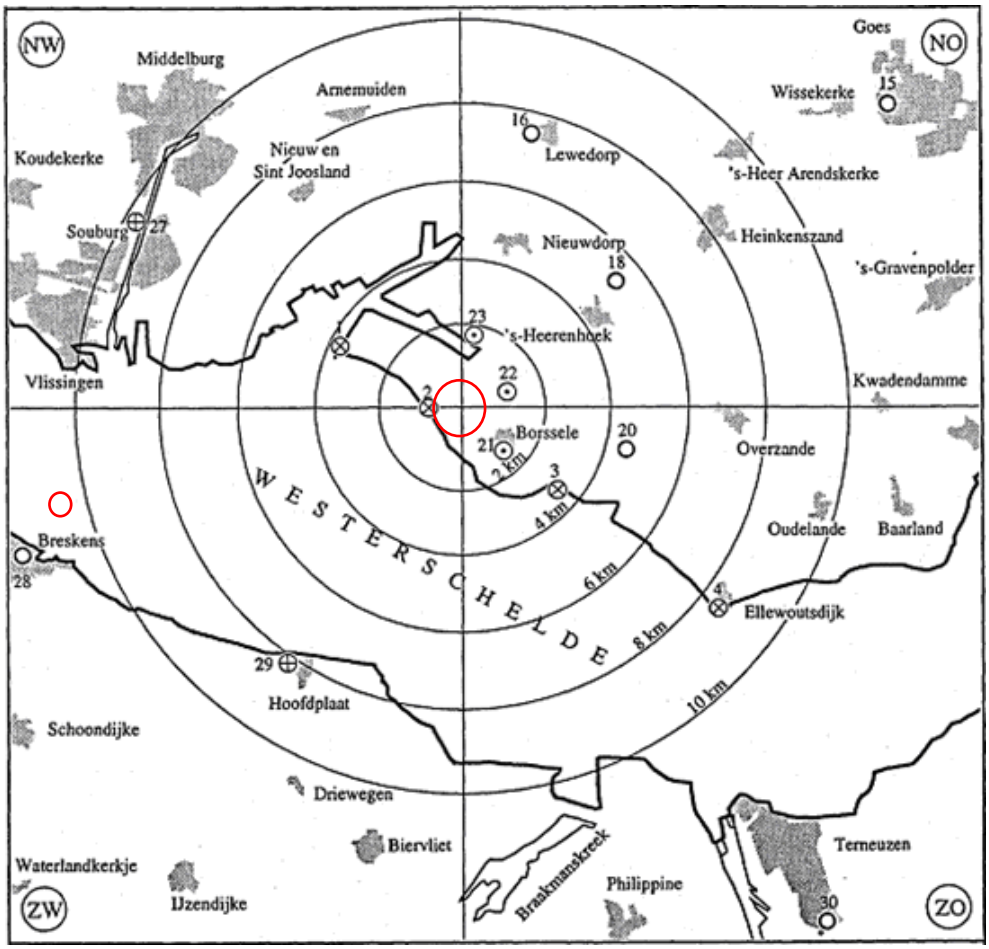

Figure 1 Surroundings of the Borssele nuclear power plant (in red circle). The numbers on the map refer to sampling locations. The small red circle near Breskens represents the "Vlissingen Boei" sampling location of Rijkswaterstaat.

Sampling programme and analyses by RIVM

Starting from 2018 the ANVS tasked RIVM to yearly carry out a check on a subselection of the monthly samples taken by NRG. Originally, parts of samples of one selected month were transferred to the RIVM for analysis. Due to the Covid-19 pandemic sampling was not carried out in 2021.
In 2023 RIVM carried out an independent sampling procedure on samples in one specific month. The analyses were performed on samples taken on July 5th, 2023, see Table 1. The only exception is air dust which is not sampled by RIVM. It is both costly and not practical to operate duplicate air sampling equipment.

In Table 2, an overview is given on sample handling and the proposed analyses.

Table 2 Overview of analyses by RIVM in 2023

Sample matrix	(Sub)samples*	Parameter
Grass	1 bag of grass.	γ- spectrometry
Seaweed	300-400 g seaweed	γ- spectrometry
Sediment	Half of sample	γ- spectrometry
Sand	Sample of ~0,5 kg	γ- spectrometry
Water from river Scheldt	1 L of filtrate	Gross α/β, ^3H (LSC)
Suspended solids	Precipitate in filtrate after NH_4OH addition	Gross α/β

* Samples of grass and seaweed are stored in a freezer until sample treatment.

Comparison of RIVM and KCB data

Where applicable, a comparison of RIVM and KCB (=NRG) data is carried out based on measurement data with uncertainties. See also the previous report[ii].
The comparison of the data from KCB ($x_{KCB} \pm u_{KCB}$) and from RIVM ($x_{RIVM} \pm u_{RIVM}$) is expressed as the difference Δ (= x_{KCB} - x_{RIVM}) in relation to the uncertainty $U\Delta$ in this difference; $U\Delta = \sqrt{(u_{KCB}^2 + u_{RIVM}^2)}$. This way of comparing is identical to a usual z-test in intercomparison exercises.

The agreement between the measurement data from RIVM and KCB is categorized as A1, A2, B and C. See Figure 2.

A1:	$\lvert\Delta\rvert \leq U\Delta$	probability ~68%, or 2 out of 3
A2:	$U\Delta < \lvert\Delta\rvert \leq 2\,U\Delta$	probability ~27%, or 1 out of 4
B:	$2\,U\Delta < \lvert\Delta\rvert \leq 3\,U\Delta$	probability ~4,3%, or 1 out of 20
C:	$3\,U\Delta < \lvert\Delta\rvert$	probability ~0,26%, or 1 out of 400

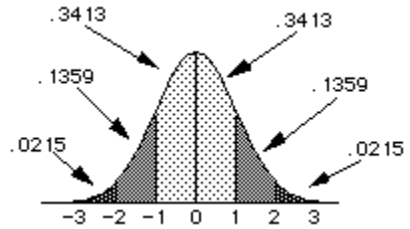

Figure 2 Schematic presentation of a normal (Gauss) distribution

In cases where a detection limit is involved a comparison will not be made.

3. Results and discussion

The NRG data of sampling period 2023 were reported to KCB in February 2024 [iii]. See Table 3 for a summary of the results relevant for the comparison of RIVM and KCB data, with the exception of air dust monitoring.

Overview of analytical data by RIVM and NRG in July 2023

In Table 3, a summary of all analytical data of the RIVM and NRG are given. RIVM took all samples on July 5th, NRG performed sampling on July 3rd for grass, water and suspended solids, seaweed and sediment. The yearly sand sample was taken by NRG on May 31st. In Annex A, all data are presented in separate tables A1 – A7.

Table 3 Summary of RIVM and NRG measurement results in July 2023; samples taken by RIVM on July 5. NRG samples taken on July 3, and the yearly sand sampled by NRG on May 31st. Where more locations are sampled minimum and maximum values are given.

Matrix	Parameter	Number of Locations	Values RIVM; July 2023	Minimum and maximum values NRG [iii]; July 2023
Grass	^{60}Co	5 (1)	< 7(2)	< 0.8
(Bq·kg^{-1})	^{131}I	5 (1)	< 110(2)	< 0.7
	^{137}Cs	5 (1)	< 7(2)	< 0.7
Sand	^{54}Mn	4	< 0.5	< 0.2
(Bq·kg^{-1})	^{60}Co	4	< 0.6	< 0.2
	^{134}Cs	4	< 0.9	< 0.2
	^{137}Cs	4	0.26 ± 0.05 – 0.66 ± 0.12	0.26 ± 0.06 - 1.11 ± 0.12
Water	Gross β	4	< 0.11	<0.03 – 0.615 ± 0.012
(kBq·m^{-3})	^{3}H	4	< 5 – 14.0 ± 1.9	4.0 ± 1.7 - 5.6 ± 1.8
Suspended solids (kBq·kg^{-1})	Gross β	4	< 0.12 0.42 ± 0.02	0.81 ± 0.16 – 6.2 ± 0.7
Seaweed	^{60}Co	4 (1)	< 4	< 2
(Bq·kg^{-1})	^{131}I	4 (1)	< 32(2)	< 1
	^{137}Cs	4 (1)	< 3	< 1
Sediment	^{54}Mn	4 (3)	< 0.7	
	^{60}Co	4 (3)	< 0.8	< 0.2
(Bq·kg^{-1})	^{131}I	4 (3)		< 0.3
	^{137}Cs	4 (3)	< 0.4 - 1.5 ± 0.2	0.88 ± 0.14

(1) Analysis was performed by NRG and RIVM on a mix of samples taken in one month on four or five locations.
(2) The detection limit of NRG is lower than that of RIVM due to a much larger measurement subsample. RIVM uses a 250 mL counting box, where NRG uses a 1.0 L Marinelli geometry. For ^{131}I radioactive decay in the time period between sampling and analysis leads to higher detection limits.
(3) Analysis was performed by NRG on a mix of the four or five samples taken in the same month. RIVM analyzed all individual samples. A given range represents minimum and maximum values of individual samples; see Annex A for individual data.

Discussion of the results

In 2023, RIVM took the samples on July 5th, where NRG took the samples on July 3rd. The coordinates of the sampling locations are well defined and this results in samples taken on a small area. This means that the analytical data from RIVM can be used to verify the data from NRG. Only in the unlikely case of a radioactive discharge between the evening of July 3rd until the morning of July 5th the measurement data can not be compared with each other.

The RIVM and NRG data on 2023 presented in Table 3 are reasonably in agreement. Most activity concentrations are below the detection limit or just above.

Grass and seaweed
Both RIVM and NRG did not find any artificial radionuclides, such as ^{60}Co, ^{131}I and ^{137}Cs, in monthly grass and seaweed samples.

Sand and dried sediments
Very low levels of ^{137}Cs were found in sand and dried sediments. These levels are consistent with data in previous years. This is not unusual in Dutch soil as a result of the Chernobyl accident [iv]. This is a known surface contamination of about 90 – 100 Bq.m^{-2} ^{137}Cs in the Netherlands.
In sand the agreement between the RIVM and NRG results is acceptable.

Water from river Scheldt
For gross beta activity in water from river Scheldt, the RIVM results for the detection limit (< 0.11 kBq.m^{-3}) were somewhat higher than the NRG results (< 0.03 kBq.m^{-3}). This may have to do with the different sample treatment and measuring techniques. RIVM uses a precipitation of a 10 ml subsample, NRG uses a larger volume and measures 10 times a planchet each with 250 mg.
The result of 0.615 ± 0.012 kBq.m^{-3} by NRG is not found by RIVM and may have to do with the different sampling date. This activity concentration is very low and within the range of natural activity concentrations in surface water (waterinfo.rws.nl).

Suspended solids samples from river Scheldt
RIVM found a very low gross beta activity in the four suspended solid samples (< 0.12 - 0.42 ± 0.02 Bq.kg^{-1}), where NRG reported gross beta activities in the range of 1.0 – 6.2 kBq.kg^{-1}. It should be noted that the exact sampling location and sampling day is different. Next, the sample treatment and the preparation of a counting sample by NRG and RIVM is not exactly the same. And therefore, the gross beta results are difficult to compare.

Tritium in water from river Scheldt at location Vlissingen Boei.
The RIVM tritium data range from < 5 – 14 kBq.m^{-3} and NRG data range from 4.0 – 5.6 kBq.m^{-3}. This compares well with data from Rijkswaterstaat, Ministry of Infrastructure and Water Management. Rijkswaterstaat is responsible for the quality of inland waters, river water and sea water (www.rijkswaterstaat.nl). See Figure 3 with quarterly tritium data at location Vlissingen Boei (see location in Figure 1), sampled by Rijkswaterstaat in the period 1995 – 2023. Data were taken from the database of Rijkswaterstaat (waterinfo.rws.nl).

In general, detection limits reported by RIVM are higher than those of NRG. Detection limits are dependent on sample size, sample treatment, counting time and detector efficiency.

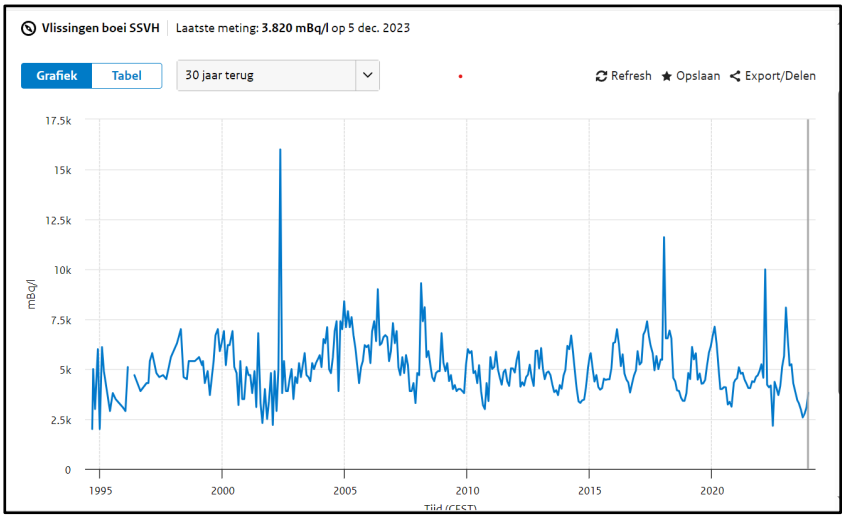

Figure 3 Activity concentration of tritium in surface water sampled at Vlissingen Boei (mBq.l^{-1}) from 1995 - 2023. Data achieved from Rijkswaterstaat (waterinfo.rws.nl).

The exact origin of traces of ^{3}H in water from the Scheldt cannot be determined from these measurements. ^{3}H may originate from discharges from NPP Borssele or from NPP Doel further upstream, just across the Belgian border. In 2023, the activity concentration of ^{3}H at Vlissingen-Boei, according to Rijkswaterstaat (Fig 3), ranged from 3 – 8 kBq.m^{-3}. This is practically the same range as in the ^{3}H-data in Table 3 which were found in water samples taken at the shoreline close to the NPP Borssele.

4. Conclusions

The ANVS tasked RIVM to regularly perform a check on parts of the measurements which are carried out by the Nuclear Research and Consultancy Group (NRG) on samples taken in the vicinity of the Borssele nuclear power plant (NPP).
The NPP Borssele assigned NRG to carry out monthly sampling of water, air dust, sediment, seaweed, and yearly sampling of sand. All these samples were taken around the NPP Borssele on fixed locations as described in an environmental monitoring programme [i]. NRG analyzed these samples for gamma-emitters, gross beta activity, and the water sample for ^{3}H. NRG reports these data to client KCB.

In 2023 samples of grass, seaweed, sediment, sand, and river water (including suspended solids) were also taken and analyzed by RIVM. The analytical results in the samples taken by NRG on 3rd and by RIVM on 5th July 2023 indicate that no radiological contamination as a result of business operations from the nuclear power plant can be found.

In general, the RIVM and NRG data agree reasonably. In most samples, RIVM reports detection limits, or a very low amount of natural activity, or in a sand sample a negligible activity of ^{137}Cs.

The levels of radioactivity in grass, sand, and dried sediments for artificial radionuclides were close to the detection limit or below. The data were reasonably consistent with data from NRG.

Gross-bèta data from NRG and RIVM in river Scheldt water and suspended solids compared poorly, possibly due to different measurement techniques.

A low amount of tritium is found in water from the river Scheldt, but due to the upstream location of the Doel nuclear power plant in Belgium, the exact origin of this trace activity of tritium is hard to determine.

Annex A Data tables 2023

KCB commissioned NRG to carry out sampling and analyses and therefore, NRG is mentioned in the header of all Tables. KCB is responsible for all data and is indicated with "**KCB**" on top of the columns in the Tables.

Table A1 Gamma activity in grass sampled by NRG on July 3rd, and by RIVM on July 5th, 2023 (Bq.kg-1).

Sample*	Nuclide	RIVM#	KCB#
Grass	^{60}Co	< 7	< 0.8
	^{137}Cs	< 7	< 0.7
	^{131}I	< 110	< 0.7

* The sampling locations are nr. 21, 22, 23, 27 and 29 (see Fig 1).
n.d. = not detected due to short half-life of I-131
# NRG and RIVM both analyzed a mix sample of all 5 sampling locations.
For NRG data, see ref [iii], Table 7 and 8.

Table A2 Gamma activity in sand sampled on by NRG on May 31st, and by RIVM on July 5th, 2023 (Bq.kg-1).

Sample location*	Nuclide	RIVM#	KCB#
1, 2, 3, 4	^{54}Mn	< 0.3 - < 0.5	< 0.1 - < 0.2
	^{60}Co	< 0.3 - < 0.6	< 0.1 - < 0.2
	^{134}Cs	< 0.5 - < 0.9	< 0.1 - < 0.2
	^{137}Cs	0.66 ± 0.12 (1)	1.11 ± 0.12 (1)
		0.38 ± 0.07 (2)	0.43 ± 0.09 (2)
		0.57 ± 0.14 (3)	0.95 ± 0.13 (3)
		0.26 ± 0.05 (4)	0.26 ± 0.06 (4)

* The sampling locations are shown in Fig 1. Values are minimum and maximum values
# For NRG data, see ref [iii], Table 9.

Table A3 Gross beta activity in water from river Scheldt, sampled by NRG on July 3rd, and by RIVM on July 5th, 2023 (kBq.m-3)

Sample location nr	RIVM gross-β	KCB# gross-β
1 (West)	< 0.11	< 0.033
2 (Centr.)	< 0.10	0.004 ± 0.017
3 (East)	< 0.10	0.615 ± 0.012
4 (El.dijk)*	< 0.08	< 0.031

* El. Dijk = Ellewoutsdijk
# For NRG data, see ref [iii], Table 10.

Table A4 Gross beta activity in suspended solids from river Scheldt water, sampled by NRG on July 3rd, and by RIVM on July 5th, 2023 (Bq.kg-1).

Sample location nr	RIVM gross-β	KCB# gross-β
1 (West)	0.13 ± 0.02	0.81 ± 0.16
2 (Centr.)	0.34 ± 0.03	6.2 ± 0.7
3 (East)	< 0.12	1.03 ± 0.09
4 (El.dijk)*	0.42 ± 0.02	1.38 ± 0.04

* El. Dijk = Ellewoutsdijk
For NRG data, see ref [iii], Table 11 and 12.

Table A5 Tritium activity in water from river Scheldt water, sampled by NRG on July 3rd, and by RIVM on July 5th, 2023 (kBq.m^{-3})

Sample location nr	RIVM ^{3}H	KCB# ^{3}H
1 (West)	< 5	5.6 ± 1.8
2 (Centr.)	6.5 ± 1.7	5.0 ± 1.8
3 (East)	14.0 ± 1.9	5.2 ± 1.7
4 (El.dijk)*	6.7 ± 1.7	4.0 ± 1.7

* El. Dijk = Ellewoutsdijk
# For NRG data, see ref [iii], Table 13.

Table A6 Gamma activity in seaweed, sampled by NRG on July 3rd, and by RIVM on July 5th, 2023 (Bq.kg^{-1}).

Sample mix (4 loc.)*	RIVM Bq.kg^{-1}	KCB# Bq.kg^{-1}
^{60}Co	< 4	< 2
^{137}Cs	< 3	< 1
^{131}I	< 32	< 1

* NRG and RIVM both analyzed a mix sample of all 4 sampling locations: West, Centrale, East, Ellewoutsdijk.
# For NRG data, see ref [iii], Table 14.

Table A7 Gamma activity in dried sediments, sampled by NRG on July 3rd, and by RIVM on July 5th, 2023 (Bq.kg^{-1})

Samples	RIVM* (4 loc.)	KCB# (mix)
^{54}Mn	< 0.4 - < 0.7	
^{60}Co	< 0.4 - < 0.8	< 0.2
^{131}I	n.d.	< 0.3
^{137}Cs	< 0.4 (1) 0.68 ± 0.13 (2) 1.5 ± 0.2 (3) 1.2 ± 0.2 (4)	0.88 ± 0.14

< * RIVM analyzed all 4 samples separately. The data shown are a 'min – max' range.
NRG analyzed a mixed sample of all 4 samples. For NRG data, see ref [iii], Table 15.

References

i Uitgangspunten voor de omgevingsbewaking programma's van de kernenergiecentrales te Dodewaard en Borssele, J. van der Steen, (1994), rapport nr. 40318/40575-NUC 94-5935.

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iv The Atlas of Caesium-137 Contamination of Europe after the Chernobyl Accident, Luxembourg, 1998, ISBN 92-828-3140-X.