

NATIONAL INSTITUTE OF PUBLIC HEALTH AND THE ENVIRONMENT (RIVM)  
BILTHOVEN, THE NETHERLANDS

Report no. 610053003

**Non-nuclear industries in the Netherlands and  
radiological risks**

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March 1996

This study was commissioned by the Ministry of Housing, Spatial Planning and Environment (VROM), Directorate SVS (project 610053) in the framework of the research programme on the risks of ionizing radiation.

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## **ACKNOWLEDGEMENTS**

During the course of this investigation many members of the staff of the Laboratory of Radiation Research have contributed to the results. The authors wish to acknowledge particularly the contributions of R.O. Blaauboer, C.J. Bartels, M. van der Heiden, W. Hoondert, H. Jeeninga, J.F.M.M. Lembrechts, J.E.T. Moen, R.M.J. Pennders, M.J.M. Pruppers, H. Slaper and the late L.H. Vaas. Mrs R.E. de Wijs-Christensen is acknowledged for editing the English.

## CONTENTS

MAILING LIST	2
ACKNOWLEDGEMENTS	3
ABSTRACT	15
SAMENVATTING	16
1 INTRODUCTION	18
2 METHODOLOGY	19
2.1 Premises, terms and definitions	19
2.1.1 The Dutch risk approach in environmental radiation policy	19
2.1.2 Terms and definitions	19
2.1.3 General risk calculation methods	21
2.2 Data sources	21
2.3 Calculation of risks from emissions into air	21
2.3.1 Screening procedure	24
2.3.2 Closer examination	25
2.4 Calculation of risks from emissions into water	25
2.5 Calculation of risks from external radiation	27
3 RESULTS	29
3.1 Emission data of non-nuclear industries	29
3.2 Risks from emissions into air	30
3.2.1 Screening results	30
3.2.2 Risks at closer examination	32
3.3 Risks of emissions into water	38
3.4 Risks from external radiation	40
3.5 The total risk	40
3.6 Uncertainties in the risk calculations	42
3.7 Dose conversion coefficients	44
4 CONCLUSIONS AND RECOMMENDATIONS	46
REFERENCES	49
APPENDIX A PARAMETERS OF THE REFERENCE MAN	55
A.1 Introduction	55

APPENDIX B	MODELLING DISPERSION IN AIR	58
B.1	Introduction	58
B.2	The OPS model	58
B.2.1	Model validation of OPS	58
B.2.2	Particle size distribution	59
B.2.3	Heat content	59
B.2.4	Climatological data	60
B.2.5	Roughness length	60
B.3	The RDM coordinate system	60
APPENDIX C	MODELLING RISKS OF EMISSIONS TO AIR	62
C.1	Introduction	62
C.2	Inhalation	62
C.3	Ingestion	62
APPENDIX D	MODELLING RISKS OF EMISSIONS TO WATER	68
D.1	Pathway ingestion of fish	68
D.1.1	Elementary phosphorus production plant at Vlissingen	68
D.1.2	Phosphoric acid production plants at Vlaardingen and Pernis	69
D.1.3	Primary iron and steel production plant at IJmuiden	70
D.2	Pathway harbour sludge	70
APPENDIX E	MODELLING EXTERNAL RADIATION	73
APPENDIX F	BASIC DATA	74
F.1	Process descriptions and emissions	74
F.1.1	The elementary phosphorus production plant at Vlissingen	74
F.1.2	The phosphoric acid plants at Vlaardingen and Rotterdam	77
F.1.3	Fertilizer production plants	79
F.1.4	The primary iron and steel production plant at IJmuiden	81
F.1.5	The coal tar treatment plant at Uithoorn	85
F.1.6	Cokes production plants	86
F.1.7	Coal-fired power plants	87
F.1.8	Gas-fired power plants	91
F.1.9	Oil and gas production	92
F.1.10	Cement production	95
F.1.11	Ceramic industry	97
F.1.12	Mineral sands industry	102
F.1.13	Titanium pigment production	103
APPENDIX G	REFERENCE PLANTS	106
G.1	Introduction	106
G.2	Dispersion	106

G.3	Deposition . . . . .	107
G.4	Dose and risk calculations . . . . .	108
<b>APPENDIX H</b>		
	<b>RISKS OF EMISSIONS INTO AIR ABOVE THE SECONDARY LEVEL . . . . .</b>	<b>115</b>
H.1	Introduction . . . . .	115
H.2	Elementary phosphor plant at Vlissingen . . . . .	115
H.2.1	Dispersion in air . . . . .	115
H.2.2	Calculation of MIR and AIR . . . . .	116
H.2.3	Comparison with previous studies . . . . .	117
H.3	Phosphoric acid plant at Vlaardingen . . . . .	118
H.3.1	Dispersion in air . . . . .	119
H.3.2	Calculation of MIR and AIR . . . . .	120
H.3.3	Comparison with previous studies . . . . .	121
H.4	The phosphoric acid plant at Pernis . . . . .	122
H.4.1	Dispersion in air . . . . .	122
H.4.2	Calculation of MIR and AIR . . . . .	123
H.4.3	Comparison with previous studies . . . . .	125
H.5	Fertilizer production plant at Amsterdam . . . . .	125
H.6	The primary iron and steel production plant at IJmuiden . . . . .	126
H.6.1	Dispersion in air . . . . .	126
H.6.2	Calculation of MIR and AIR . . . . .	127
H.6.3	Comparison with previous studies . . . . .	128
H.7	Cement industry at Maastricht . . . . .	128
H.7.1	Dispersion in air . . . . .	129
H.7.2	Calculation of MIR and AIR . . . . .	131
H.8	Mineral sands handling industry at Amsterdam . . . . .	132
H.8.1	Dispersion in air . . . . .	132
H.8.2	Calculation of MIR and AIR . . . . .	133
H.9	Mineral sands handling industry at Geertruidenberg . . . . .	134
H.9.1	Dispersion in air . . . . .	134
H.9.2	Calculation of MIR and AIR . . . . .	135
H.9.3	Comparison with previous studies . . . . .	135
<b>APPENDIX I</b>		
	<b>RISKS FROM EXTERNAL RADIATION . . . . .</b>	<b>137</b>
I.1	Introduction . . . . .	137
I.2	Elementary phoshor plant at Vlissingen . . . . .	137
I.3	Phosphoric acid plant at Vlaardingen . . . . .	138
I.4	Phosphoric acid plant at Pernis . . . . .	138
I.5	Fertilizer production plant at Amsterdam . . . . .	139
I.6	Fertilizer production plant at Sas van Gent . . . . .	140
I.7	Primary iron and steel production plant . . . . .	140
I.8	Coal-fired power plants . . . . .	140

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I.9	Offshore oil and gas exploitation . . . . .	141
I.10	Cement industry . . . . .	141
I.11	Ceramic industry . . . . .	141
I.12	Mineral sands industry at Amsterdam . . . . .	141
I.13	Mineral sands industry at Geertruidenberg . . . . .	142
I.14	Titanium oxyde industry at Rotterdam . . . . .	142
APPENDIX J	RISK MAPS . . . . .	143
J.1	Total risk . . . . .	143
J.2	Local situations . . . . .	145

## LIST OF TABLES

Table 2.1	The three reference situations of emission of radionuclides to air . . .	24
Table 3.1	Review of total annual emissions into air and water by Dutch NNIs .	29
Table 3.2	Summary of the first screening on MIR using reference situations for emissions to air . . . . .	31
Table 3.3	MIR and AIR maxima due to thermic emissions and transshipment at a Vlissingen elementary phosphorus plant . . . . .	33
Table 3.4	MIR and AIR maxima due to emissions during transshipment and exhalation of $^{222}\text{Rn}$ at the Vlaardingen phosphoric acid production plant . . . . .	34
Table 3.5	MIR and AIR maxima due to emissions during transshipment and exhalation of $^{222}\text{Rn}$ at a Rotterdam phosphoric acid production plant .	34
Table 3.6	Contributions to the MIR maximum at 100 m north-east of the source due transshipment at an Amsterdam fertilizer production plant . . . . .	34
Table 3.7	MIR and AIR maxima due to thermic emissions and emissions during transshipment at the IJmuiden iron and steel production plant	35
Table 3.8	MIR and AIR maxima due to thermic emissions and marl extraction, transport and milling at the Maastricht cement production plant . . . . .	36
Table 3.9	MIR and AIR maxima due to transshipment and milling at an Amsterdam mineral sands processing company . . . . .	37
Table 3.10	MIR and AIR maxima due to emissions during transshipment and milling at a Geertruidenberg mineral sands processing company . . .	37
Table 3.11	Overview of risks due to emissions to air by the Dutch NNI . . . . .	38
Table 3.12	Overview of risks due to emissions to water at Dutch NNI . . . . .	39
Table 3.13	Overview of risks due to external radiation of stocks of the Dutch NNI . . . . .	41
Table 4.1	Maximum MIR and maximum AIR per site, calculated for each type of Dutch non-nuclear industry . . . . .	47
Table A.1	Indoor Shielding Factors (ISF) for conversion from IR to MIR . . . . .	55
Table A.2	Actual exposure Conversion Factors (ACF) used for calculating AIR from IR . . . . .	56
Table A.3	Standard diet of the reference person and reduction factors for losses due to food preparation [BSV93, La94] . . . . .	57
Table B.1	Uncertainties in the results of OPS . . . . .	59
Table B.2	Particle-size classification and distribution (%) for three classes [Ja90] . . . . .	60
Table B.3	Area classification of the Netherlands as used in the OPS model [Ja90] and representative values for roughness . . . . .	60
Table B.4	Representative values for the roughness length (m) for different	

	areas as defined in OPS [Ja90] . . . . .	61
Table C.1	Dose conversion coefficients for inhalation and ingestion and transfer coefficients as used in risk calculations . . . . .	65
Table C.2	Concentration factors $B_v$ in four crop classes of Po, Pb, U, Th and Ra . . . . .	66
Table C.3	Retention factor ( $\mu$ ), yield (Y), fraction intercepted (R), exposure time ( $t_a$ ) and preservation time ( $t_b$ ) for four crop classes . . . . .	66
Table C.4	Average time ( $t_b$ ) between production and consumption for milk and beef . . . . .	66
Table D.1	Parameters for modelling risks of emissions to water . . . . .	69
Table D.2	Emissions from the elementary phosphor plant at Vlissingen and resulting activity concentrations of $^{210}\text{Pb}$ and $^{210}\text{Po}$ in the relevant compartments . . . . .	69
Table D.3	Emissions from the phosphoric acid plants at Vlaardingen and Rotterdam resulting activity concentrations of $^{210}\text{Po}$ , $^{210}\text{Po}$ , $^{226}\text{Ra}$ en $^{230}\text{Th}$ in the relevant compartments . . . . .	70
Table D.4	Emissions from the primary iron and steel production plant at IJmuiden resulting activity concentrations of $^{210}\text{Po}$ and $^{210}\text{Pb}$ for the relevant compartments . . . . .	71
Table D.5	MIR from a unit emission of 1 GBq/a to water for four radionuclides . . . . .	72
Table F.1	Input and output of the elementary phosphor production plant at Vlissingen in 1992 . . . . .	76
Table F.2	Input and output of the phosphoric acid plant at Vlaardingen in 1990 <sup>1)</sup> . . . . .	79
Table F.3	Input and output of the phosphoric acid plant at Rotterdam in 1990 <sup>1)</sup> . . . . .	80
Table F.4	Trend in radionuclide discharges (GBq/a) according to the permit of the Pernis plant . . . . .	80
Table F.5	Input and output balance of the fertilizer plant at Amsterdam in 1990 . . . . .	82
Table F.6	Input and output radionuclides balance of the primary iron production plant at IJmuiden in 1990 (all data in GBq/a) . . . . .	84
Table F.7	Input-output materials in 1988 of the coal tar treatment plant at Uithoorn . . . . .	86
Table F.8	Input and output of the cokes production plant at Sluiskil in 1987 <sup>1)</sup> . . . . .	88
Table F.9	Input-output balance of a 600 MW coal-fired power plant <sup>1)</sup> . . . . .	90
Table F.10	Input and output balance of the 360 and 460 MW <sub>el</sub> gas-fired power plant at Velsen in 1990 . . . . .	93
Table F.11	Location-specific information of the onshore product locations of the oil and gas industry . . . . .	95
Table F.12	Output streams of oil and gas exploration and exploitation in 1990 . . . . .	96
Table F.13	Input-output balance of the cement production plant at Maastricht in 1990 . . . . .	98

Table F.14	Input and output balance of the cement production plants at IJmuiden and at Rozenburg in 1990 . . . . .	99
Table F.15	Input and output and emissions into air of the ceramic industry in 1989/1990 <sup>1)</sup> . . . . .	101
Table F.16	Throughput and emissions of the mineral sands industry in 1991 . . .	103
Table F.17	Input and output materials of the titanium pigment production on the basis of the maximal yearly production capacity . . . . .	105
Table G.1	Model parameters used in the calculation of the dispersion of <sup>222</sup> Rn .	107
Table G.2	Model parameters used in the calculation of the dispersion in air for three reference situations using the OPS model [Ja90] . . . . .	107
Table G.3	Risks (a <sup>-1</sup> ) due to emission of eight radionuclides of 1 GBq a <sup>-1</sup> in air for the reference situations . . . . .	109
Table G.4	Location of maximum concentration and deposition for the reference plants . . . . .	108
Table G.5	MIR for reference plant 1 due to emissions of six nuclides at 100 m north-east of the source based on a normalized emission of 1 GBq a <sup>-1</sup> . . . . .	110
Table H.1	Emissions to air (GBq a <sup>-1</sup> ) for the different processes at the elementary phosphor plant at Vlissingen . . . . .	115
Table H.2	Location (x, y) (km), chimney height (m), heat content (MW) and <sup>210</sup> Po and <sup>210</sup> Pb emission (Bq s <sup>-1</sup> ) in the thermic process at Vlissingen . . . . .	116
Table H.3	Particle-size distribution (%) of the gas emitted in the thermic process by the elementary phosphor plant at Vlissingen . . . . .	116
Table H.4	Parameters used in the calculation of the dispersion of radionuclides <sup>(a)</sup> . . . . .	117
Table H.5	MIR and AIR at Nieuwdorp and the aluminum plant site due to thermic and transshipment from the elementary phosphorus plant at Vlissingen . . . . .	118
Table H.6	Main differences between this study and [Ho94] and estimation of the influence on dose and risk: $a = (\text{total MIR [Ho94]}) / (\text{total MIR this report})$ . . . . .	119
Table H.7	Emissions to air (GBq a <sup>-1</sup> ) during transshipment at the phosphoric acid production plant at Vlaardingen . . . . .	119
Table H.8	Location (x,y) (km) and height (m) of chimneys, heat content (MW) and the amount of <sup>222</sup> Rn emitted (Bq s <sup>-1</sup> ) at the Vlaardingen plant [Bo92] . . . . .	119
Table H.9	Parameters used in the calculation of the dispersion of radionuclides emitted during transshipment <sup>(a)</sup> . . . . .	120
Table H.10	MIR (a <sup>-1</sup> ), AIR (a <sup>-1</sup> ) and ACF for the different locations at the terrain border of the Vlaardingen plant . . . . .	121
Table H.11	Maximum MIR and AIR due to releases of <sup>222</sup> Rn at the Vlaardingen plant . . . . .	121

Table H.12	Main differences between this study and [Bo92] and estimation of the difference $a = (\text{total MIR [Bo92]}) / (\text{total MIR this study})$ for $^{222}\text{Rn}$ . . . . .	122
Table H.13	Emissions to air ( $\text{GBq a}^{-1}$ ) during transshipment at the phosphoric acid production plant at Pernis . . . . .	122
Table H.14	Location (x, y) (km) and height (m) of chimneys, heat content (MW) and the amount of $^{222}\text{Rn}$ emitted ( $\text{Bq s}^{-1}$ ) at the Pernis plant [Bos93] . . . . .	123
Table H.15	Parameters used in the calculation of the dispersion of radionuclides emitted during transshipment <sup>(a)</sup> . . . . .	123
Table H.16	MIR ( $\text{a}^{-1}$ ), AIR ( $\text{a}^{-1}$ ) and ACF for the different locations at the terrain border of the Pernis plant . . . . .	124
Table H.17	Maximum MIR and AIR due to releases of $^{222}\text{Rn}$ to air at the Pernis plant . . . . .	124
Table H.18	Main differences between this study and [Bo93] and estimation of the difference $a = (\text{total MIR [Bos93]}) / (\text{total MIR this study})$ . . . . .	125
Table H.19	Emissions to air during transshipment and the corresponding MIR for the fertilizer production plant at Amsterdam . . . . .	126
Table H.20	Emissions to air ( $\text{GBq a}^{-1}$ ) for the different processes at the primary iron and steel production plant at IJmuiden . . . . .	126
Table H.21	Chimney location (x,y) (km), height (m), heat content (MW) and emission ( $\text{Bq s}^{-1}$ ) of the IJmuiden iron and steel plant . . . . .	127
Table H.22	Particle-size distribution (%) of the gas emitted by the IJmuiden plant . . . . .	127
Table H.23	Parameters used in the calculation of the dispersion of radionuclides	128
Table H.24	MIR ( $\text{a}^{-1}$ ) and AIR ( $\text{a}^{-1}$ ) at Velsen-Noord and Beverwijk due to thermic emissions and transshipment from the IJmuiden plant . . . . .	129
Table H.25	Main differences between this study and the ECN-91 study and estimation of the difference $a = (\text{total risk ECN-91}) / (\text{total risk in this study})$ . . . . .	130
Table H.26	Emissions to air ( $\text{GBq a}^{-1}$ ) for the different processes at the cement production plant at Maastricht . . . . .	130
Table H.27	Chimney location (x, y) (km), height (m), heat content (MW) and emitted $^{210}\text{Po}$ ( $\text{Bq s}^{-1}$ ) in the thermic process of the cement production plant at Maastricht . . . . .	130
Table H.28	Parameters used in the calculation of the dispersion of radionuclides <sup>(a)</sup> . . . . .	131
Table H.29	MIR ( $\text{a}^{-1}$ ) and AIR ( $\text{a}^{-1}$ ) at Hoogenweerth and Heugem due to thermic emissions and emissions during marl extraction, transport and milling from the Maastricht plant . . . . .	132
Table H.30	Emissions to air ( $\text{GBq a}^{-1}$ ) during transshipment at a fertilizer plant at Amsterdam . . . . .	133

---

Table H.31	Parameters used in the calculation of the dispersion of radionuclides emitted during transshipment and milling <sup>(a)</sup> . . . . .	133
Table H.32	MIR, AIR and ACF for the different locations due to emissions to air of the fertilizer plant at Amsterdam . . . . .	134
Table H.33	Emissions to air (GBq a <sup>-1</sup> ) during transshipment at Geertruidenberg .	134
Table H.34	Parameters used in the calculation of the dispersion of radionuclides emitted during transshipment and milling <sup>(a)</sup> . . . . .	135
Table H.35	MIR, AIR and ACF for the different locations at the terrain boundary due to emissions at Geertruidenberg . . . . .	136
Table I.1	MIR and AIR due to phosphate ore and slacks at the site at Vlissingen calculated from [Ki94] . . . . .	138
Table I.2	Composition of phosphate ore [FR91] . . . . .	139
Table I.3	Composition of fly ash [MER93] . . . . .	141

## LIST OF FIGURES

Figure 2.1	A dose—risk conversion coefficient of $2.5 \cdot 10^{-2} \text{ Sv}^{-1}$ is used throughout this report. . . . .	20
Figure 2.2	Schematic representation of the pathways to man following emission of radionuclides into air. . . . .	23
Figure 2.3	Schematic representation of the pathways of emissions of radionuclides into water to man. . . . .	26
Figure 2.4	Schematic representation of the pathway of external radiation to man. . . . .	28
Figure 3.1	Risk levels in the Netherlands due to three plants with emissions into air. . . . .	42
Figure B.1	The Dutch National Triangle Measurement coordinate system (RDM coordinates). . . . .	61
Figure G.1	Deposition pattern in reference situation 3 over a COROP area. . . . .	111
Figure G.2	MIR contours for emission of natural radionuclides in reference situation 1: zero emission height, zero heat content and coarse particles. . . . .	112
Figure G.3	MIR contours for emission of natural radionuclides in reference situation 2: emission height 40 m, heat content 10 MW and medium-size particles. . . . .	113
Figure G.4	MIR contours for emission of natural radionuclides in reference situation 3: emission height 175 m, heat content 76 MW and fine particles. . . . .	114
Figure J.1	Risks due to emissions to air from an elementary phosphor plant at Vlissingen, a primary iron and steel production plant at IJmuiden and a cement production plant at Maastricht . . . . .	144
Figure J.2	Risks due to emissions to water and air from an elementary phosphor plant at Vlissingen, a primary iron and steel production plant at IJmuiden and a cement production plant at Maastricht . . . . .	145
Figure J.3	MIR contours on a 5-km grid over the Netherlands due to thermic emissions of $^{210}\text{Po}$ and $^{210}\text{Pb}$ from an elementary phosphor plant at Vlissingen . . . . .	146
Figure J.4.	MIR contours on a 50-m grid due to thermic emissions and emissions during transshipment from an elementary phosphor plant at Vlissingen . . . . .	147
Figure J.5	MIR contours on a 50-m grid due to emissions to air during transshipment at a phosphoric acid production plant at Vlaardingen . . . . .	148
Figure J.6	MIR contours on a 50-m grid due to emissions of $^{222}\text{Rn}$ at a phosphoric acid production plant at Vlaardingen. . . . .	149
Figure J.7	MIR contours on a 50-m grid due to emissions to air during transshipment at a phosphoric acid production plant at Pernis. . . . .	150

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Figure J.8	MIR contours on a 50-m grid due to emissions of $^{222}\text{Rn}$ at a phosphoric acid production plant at Pernis . . . . .	151
Figure J.9	MIR contours on a 5-km grid over the Netherlands due to thermic emissions of $^{210}\text{Po}$ and $^{210}\text{Pb}$ from a primary iron and steel production plant at IJmuiden . . . . .	152
Figure J.10	MIR contours on a 100-m grid due to thermic emissions and emissions during transshipment from a primary iron and steel production plant at IJmuiden . . . . .	153
Figure J.11	MIR contours on a 250-m grid due to thermic emissions and emissions during transshipment from a primary iron and steel production plant at IJmuiden . . . . .	154
Figure J.12	MIR contours on a 50-m grid due to thermic emissions and emissions during marl extraction, transport and milling from a cement production plant at Maastricht . . . . .	155
Figure J.13	MIR contours on a 5-km grid over the Netherlands due to thermic emissions of $^{210}\text{Po}$ from a cement production plant at Maastricht . . . . .	156
Figure J.14	MIR contours on a 50-m grid due to emissions to air during transshipment at a fertilizer production plant Amsterdam . . . . .	157
Figure J.15.	MIR contours on a 50-m grid due to emissions to air during transshipment at a fertilizer production plant at Geertruidenberg . . . . .	158

## ABSTRACT

The report provides a review of the risks imposed on the population due to natural radioactive active substances from non-nuclear industries (NNI) and is, in fact, an update and improvement of a previous review [Pe89]. Since the present report is primarily meant for environmental policy purposes, the risk calculations with respect to modelling and risk analysis are based on guidelines of the Ministry of Housing, Spatial Planning and Environment (VROM). In this way the risks of different branches and plants of non-nuclear industries can be better compared with other environmental risks.

Three pathways contributing to risks are considered: emissions of radionuclides to the air, emissions to surface water and external radiation of bulk materials. Risks were defined as the chances to the population living in the surroundings of a plant considered will die of cancer. The dose to the population was calculated and multiplied by the risk conversion factor of  $2.5 \cdot 10^{-2} \text{ Sv}^{-1}$ , the risk factor for environmental risk calculations being chosen by VROM. Initial NNI screening was done using emission data and generic factors for calculating the dose and risk to a (hypothetical) member of the population in the NNI surroundings. This results in the so-called multifunctional individual risk (MIR). For an NNI with relatively high environmental risks (individual risks  $> 10^{-8}$  per year) a closer examination was carried out using local circumstances and conditions. Apart from MIR, also the actual individual risk (AIR) to members of the population was calculated using data on the environmental use of the NNI.

The initial screening showed 15 industrial plants with a risk higher than  $10^{-8} \text{ a}^{-1}$  from emissions in air, four plants from emissions in water and nine from external radiation. Six plants showed a multifunctional individual risk (MIR) of more than  $10^{-6} \text{ a}^{-1}$ , but taking into account the actual use of the NNI surroundings the actual individual risk (AIR) of only one plant exceeded this level.

Comparison of the results in this report with previous risk estimates indicates that a number of risks are now calculated to be lower because of the use of the guidelines issued by VROM. Especially the contribution from ingestion of contaminated fish was significantly lower because the fish consumption was less than that used in previous reports. The pathway water→harbour sludge→polders→radon was new and contributed considerably to the radiological risk; however, the uncertainty in the estimate is large.

In general, the report gives a review of the risks of non-nuclear industries useful for policy purposes, it indicates the industrial branches with potentially high-risk levels and also broadly shows the uncertainties, which can be reduced by further research.

## SAMENVATTING

Dit rapport geeft een overzicht van de risico's van de natuurlijke radioactiviteit betrokken bij de niet-nucleaire industrieën (NNI) voor de bevolking. Het rapport is een update van eerdere rapporten hierover. Het huidige rapport is vooral bedoeld voor beleidsondersteuning en gebruikt daarom bij de risicoberekeningen de richtlijnen van het Ministerie van VROM met betrekking tot modellering en risico-evaluaties. De conclusies kunnen gebruikt worden voor een verbeterde vergelijking van de risico's van de verschillende industriële bedrijfstakken en fabrieken van niet-nucleaire industrieën en met andere milieurisico's.

In de risicobepalingen zijn drie soorten bijdragen meegenomen: emissies van radionucliden in lucht, emissies in oppervlaktewater en externe straling van grote hoeveelheden materialen. Het beschouwde risico is de verhoogde kans op sterfte door kanker bij leden van de bevolking blootgesteld aan straling in de buurt van niet-nucleaire industrieën. Daartoe werd de jaarlijkse dosis bij de bevolking berekend en vermenigvuldigd met een risicofactor van  $2,5 \cdot 10^{-2} \text{ Sv}^{-1}$ . Deze risicofactor is door VROM aanbevolen voor het berekenen van de risico's van blootstelling aan straling.

Een eerste screening van de NNI is gedaan door, uitgaande van emissiegegevens de dosis te berekenen met generieke factoren en het risico voor een (hypothetisch) lid van de bevolking in de buurt van een industrie te berekenen. Dit geeft een multifunctioneel risico (MIR). Voor bedrijven met een relatief hoog risico (groter dan  $10^{-8} \text{ a}^{-1}$ ) is nader onderzoek gedaan met inacht nemen van het werkelijke gebruik van de omgeving door de bevolking. Dit levert het actuele individuele risico (AIR).

De eerste screening leverde 15 bedrijven met een individueel risico hoger dan  $10^{-8} \text{ a}^{-1}$  door emissies in lucht, vier bedrijven door emissies in water en negen bedrijven door externe straling. Bij zes bedrijven overschrijdt het multifunctioneel individueel risico (MIR)  $10^{-6} \text{ a}^{-1}$ , maar indien het werkelijk gebruik van de omgeving in acht werd genomen, was het actuele risico (AIR) slechts eenmaal boven dit niveau.

Indien de resultaten van dit rapport worden vergeleken met eerdere rapporten hierover, blijkt dat een aantal risicoschattingen nu lager uitkomt, omdat gebruik gemaakt is van de nieuwe richtlijnen van VROM. Vooral de bijdrage door ingestie van besmette vis is lager, omdat een lagere gemiddelde visconsumptie is aangehouden dan in vorige rapporten. Het belastingspad water-havenslib-polderophoging-radon in huizen is voor het eerst beschouwd, geeft een aanzienlijke bijdrage, maar heeft een grote onzekerheid.

In het algemeen geeft het rapport een overzicht van de risico's van niet-nucleaire industrieën, dat bruikbaar is voor beleidsonderbouwing. Het geeft de industrieën aan met een potentieel hoge risico, maar wijst op de inherente onzekerheid in de resultaten, die

verkleind zouden kunnen worden door nader onderzoek. Met name als de resultaten aanleiding zouden kunnen zijn tot beleidsmaatregelen, wordt het aanbevolen nader onderzoek te doen om de onzekerheden te verkleinen.

# 1 INTRODUCTION

This report provides an overview of the emissions of radionuclides and ionizing radiation from the Dutch non-nuclear industry (NNI), and an estimate of the radiological risks involved.

Industrial input materials contain natural radionuclides from the  $^{238}\text{U}$  and the  $^{232}\text{Th}$  series and from  $^{40}\text{K}$ . As a result of industrial processes, enhanced concentrations of these radionuclides may occur in the residual output streams, either in the form of solid waste or as releases into air or water, and may impose radiological risks to the population. In 1988, Peute et al. published the results of a literature study on the radiological impact of releases of natural radionuclides from the Dutch non-nuclear industry [Pe88]. Since then the situation has changed. Radiation measurements have been carried out in the vicinity of the industrial plants which cause the largest risks. In some cases this has led to plants being obliged to reduce their emissions or to apply for a licence for the release of radionuclides. Meanwhile, the Ministry of Housing, Spatial Planning and Environment (VROM) has issued new guidelines with respect to modelling and risk analysis for policy purposes. Consequently, the risk analyses need to be revised and updated using the new guidelines.

The review of Peute et al. [Pe88] has served as a baseline for the choice of the branches of industries to be considered. Other industrial branches have also been included. Data of the industrial activities were updated and, where possible, based on the year 1990. In general, three types of emissions were considered for the calculation of risks: emissions of radionuclides into air, emissions of radionuclides into water and direct exposure to ionizing radiation. Doses and risks were calculated for members of the population in the surroundings of the industrial plants.

The body of the report presents general information on the study. The methods used are outlined in Chapter 2. Chapter 3 summarizes the results obtained for the industries and pathways involved, Chapter 4 gives conclusions and recommendations. Details of the methods and the results are given in the appendixes, where tables and figures are indicated using the corresponding capitals (e.g. Figure B.2).

## 2 METHODOLOGY

### 2.1 Premises, terms and definitions

#### 2.1.1 The Dutch risk approach in environmental radiation policy

In 'Omgaan met Risico's van Straling' (Radiation Protection and Risk Management) [OR90] the Dutch government has presented a policy approach for the protection of the environment, and the general public and workers against the harmful effects of ionizing radiation. In addition, the Ministry of Housing, Spatial Planning and Environment (VROM) has issued a handbook with guidelines for calculating risk assessments for policy development and criteria for permits [BSV93]. These documents provide the framework for the risk calculations in this report.

#### 2.1.2 Terms and definitions

For the risk calculation the following quantities and definitions are used:

**Dose** the term 'dose' is used in the report to indicate the radiation exposure of individuals, i.e. effective dose (external radiation) or effective dose commitment (internal radionuclides), as usually applied in radiation protection [ICRP90, BSV93].

#### **Reference group**

The reference group is a (theoretical) group of people with a certain function of the environment. Members of the reference group are supposed to have average characteristics and behaviour, as given in Appendix A.

**IR** **Individual Risk:** probability an individual has of undergoing a given harmful effect. This location-dependent quantity is calculated for a totally unprotected average member of the population from the effective dose (commitment) multiplied by the risk factor. In Dutch radiation protection policy fatal cancer induction is chosen as the relevant end point, assuming a linear relationship between dose and cancer induction. A dose—risk conversion coefficient (the risk factor) of  $2.5 \cdot 10^{-2} \text{ Sv}^{-1}$  for risks caused by exposure of the population has been chosen [BSV93] (Figure 2.1).

In fact, IR is, per definition, a rather hypothetical quantity: no one will ever always be situated unprotected at a given location. Therefore two other quantities, MIR and AIR, are introduced [BSV93] to be used in this report.

**MIR** **Multifunctional Individual Risk.** The concept of multifunctionality in environmental protection means that it should be possible at any time to use the environment for any desired function. MIR is the 24-hour average individual risk to a member of the reference group for the most critical function of the environment. For radiation protection, in general, the most

critical function is to use that location as a residential area. For inhalation and external radiation, MIR is calculated from IR using the so-called Indoor Shielding Factors ISF (see Table A.1):

$$\text{MIR} = \text{IR} \times \text{ISF} \tag{2.1}$$

Note that for the pathway inhalation and the function, using the location as a residential area,  $\text{ISF} = 1$  and  $\text{MIR} = \text{IR}$ .

For the ingestion pathway, MIR is calculated assuming that members of the population consume agricultural products from the COROP area (see below) they live in (50%) and from their vegetable gardens (50%).

**AIR** Actual Individual Risk. AIR is calculated using the actual exposure of members of the population. For inhalation and external radiation, AIR is derived from IR using the so-called Actual exposure Correction Factors (ACF) (Table A.2):

$$\text{AIR} = \text{IR} \times \text{ISF} \times \text{ACF} \tag{2.2}$$

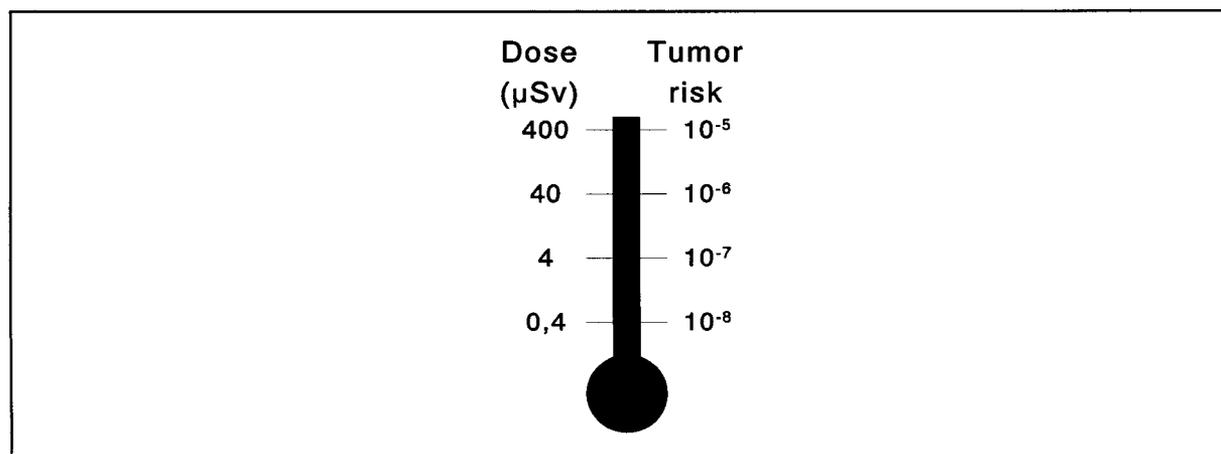
**COROP area**

The Netherlands is divided into so-called **COROP areas**, an agricultural division related to economic aspects of food production and consumption. All risks (IR, MIR and AIR) from ingestion of agricultural products are therefore equally distributed over the population of the COROP area. Risks from ingestion of fish products are supposed to be equally distributed over the entire population of the Netherlands. A standard diet is used for ingestion (Table A.3).

**CAR** Collective Actual Risk. The CAR of a certain source is the sum over the whole population of the Netherlands of the AIR from that source.

Contributions of individuals, for which  $\text{AIR} < 10^{-8} \text{ a}^{-1}$ , are neglected.

**MPR** Maximum Permissible Risk: the limit chosen by the Dutch government as the maximum individual risk to a member of the population caused by a radiation source. This limit is  $10^{-6} \text{ a}^{-1}$  for so-called functional sources, such as nuclear installations, and non-functional sources, such as NNI. The necessity and



**Figure 2.1** A dose—risk conversion coefficient of  $2.5 \cdot 10^{-2} \text{ Sv}^{-1}$  is used throughout this report.

urgency of countermeasures (reconstruction) is determined by comparing MIR and AIR with MPR [OR90].

### Secondary risk level

The **secondary risk level**,  $1/100$  of MPR ( $10^{-8} \text{ a}^{-1}$ ), was defined in [OR90] as a lower limit for policy measures against the harmful effects of radiation. In this report, the secondary risk level is used as the level in the screening of NNI activities to decide, if closer examination would be desirable.

For further details on the definition, purpose and use of these quantities, see [BSV93].

### 2.1.3 General risk calculation methods

Three pathways are taken into account in the dose and risk calculations:

- (1) emission of radionuclides into air,
- (2) emission of radionuclides into water, and
- (3) direct exposure to ionizing radiation from stocked input and output materials.

Risks from industrial products containing radionuclides were not considered.

The methods used for data collection and for the dose and risk calculation are described in sections 2.2 - 2.5.

## 2.2 Data sources

Mass input-output balances were made for the plants considered. Details are given in Appendix F. These mass balances, constructed using (partly confidential) literature data, give insight in the annual throughput of materials and radionuclides in an industrial sector. Where no other data on emissions were available the input-output balances were used to estimate the (maximum possible) emissions of radionuclides to air and water (worst-case scenario). The disadvantage of basing emissions on mass balances is that uncertainties in the emissions may be introduced due to imperfections in the mass balances.

When the quantities of input and output materials and their activity concentrations are known, it is also possible — under certain assumptions — to calculate the risks from external radiation (see section 2.5).

If possible, the data of the input-output balances were taken over the reference year 1990. In some cases, where no data was available, activity concentrations and emissions were estimated using data taken over other years, or for related industries.

### 2.3 Calculation of risks from emissions into air

For most of the plants considered, the emissions into air are most relevant for the calculation of radiological risks. The emissions were obtained from other studies or derived from input-output balances, using the radionuclide composition of the input materials, the emission rate, height, heat content and process temperature.

The radionuclide concentration in air and the subsequent deposition on the ground were calculated using the air dispersion model OPS. A brief description of the OPS model is given in Appendix B. OPS is an "Operational atmospheric transport model for Priority Substances", originally designed to model the dispersion of chemical substances in the Netherlands and Europe. It is a steady-state air transport model, which calculates the concentrations and deposition of the substances very close to the emission sources up to distances of hundreds of kilometers. In the calculations the average particle size, annual climatological conditions and other environmental factors, such as terrain type (roughness length), can be taken into account. The locations of the emission points are given in the Dutch Rijksdriehoeksmeting (RDM) coordinate system, which has its origin near Paris (France) (see also Appendix B).

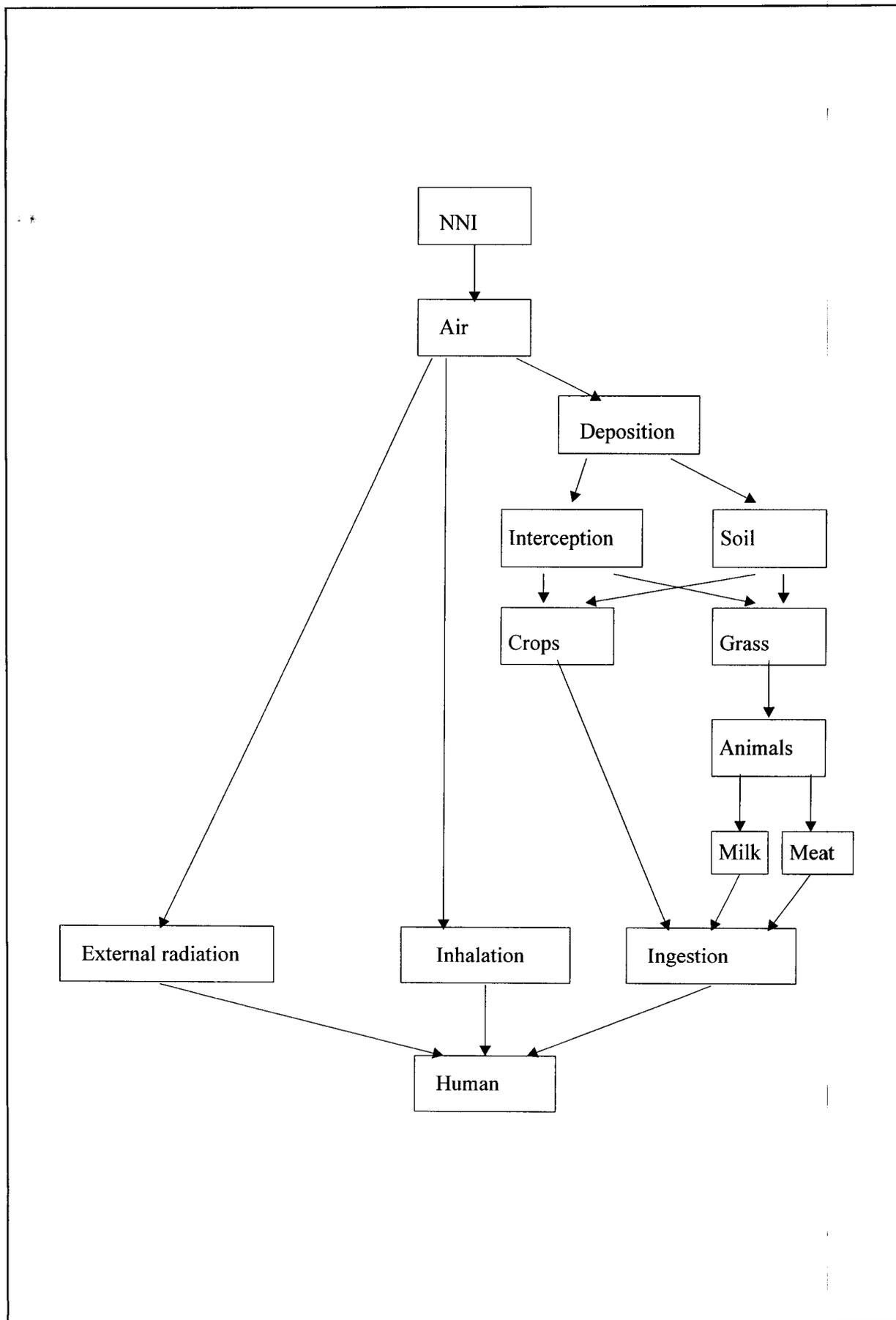
For emissions into air the following pathways contribute to the dose:

- external radiation by radionuclides in the surrounding air,
- direct inhalation of contaminated air,
- ingestion of crops contaminated by interception of deposition or by root uptake from the soil, and
- ingestion of milk or meat from animals eating grass contaminated through deposition (see Figure 2.2).

Appendix C describes the method for the calculation of the dose due to the inhalation and ingestion pathways. It includes the conversion factors describing the relation between concentration in air and total deposition on soil, and total dose of the reference group for the different exposure pathways. In general, dose-conversion factors for inhalation and ingestion were taken from Phipps et al. [NRPB91]. However, it is necessary for the thermal process emissions of iron and steel production, elementary phosphor production and coal-fired power generation to use lung clearance class Y (or S) for  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  [Ka84, GI90]. As [NRPB91] does not provide these factors, the relevant conversion factors were taken from [Kö88]. The use of lung clearance class will be discussed in section 3.6. Using these conversion factors, the total dose can be calculated from the concentration in air and from deposition as calculated with the air dispersion model.

In a pilot study on aerobic radionuclides, the contribution of external radiation from cloud and soil was compared to the total dose. For all nuclides in this study, the contribution of external radiation, as well from the cloud as from deposited radionuclides, appeared to be negligible compared to the other exposure pathways. Therefore, external radiation was further ignored for the air emission pathway.

The consumption pattern of the reference group adopted in the calculation is described in [BSV93]. It is assumed that agricultural products, milk and beef are obtained from the COROP area where the reference group lives. Half of the amount of vegetables consumed is supposed to be obtained from the local vegetable garden, the other half from the COROP area [La94]. Consumption of fruits is not taken into account in the dose calculations.



**Figure 2.2** Schematic representation of the pathways to man following emission of radionuclides into air.

The CAR due to discharges into air and water was calculated using a Geographical Information System (GIS). The CAR from external radiation was not calculated because the dose rate decreases so rapidly with distance that reliable results cannot be expected.

### 2.3.1 Screening procedure

For an initial screening of the risks from emissions to air the multifunctional individual risk (MIR) of members of the population was calculated using generic conditions and parameters.

This first screening was based on three so-called reference situations, which are given in Table 2.1.

**Table 2.1** The three reference situations of emission of radionuclides to air

	Reference situation 1	Reference situation 2	Reference situation 3
Source height (m)	0	40	175
Heat content (MW)	0	10	76
Particle size	Coarse	Medium	Fine
Represents:	Transshipment	Small plant	Large plant or energy-intensive activity

Reference situation 1 was used for emissions from transshipment; in this case a coarse particle size is assumed as the particles remain close to the emission point. Reference situation 2 was used for emissions from industrial processes of small plants; in this case a medium particle size is assumed, as coarse particles will not easily travel the distances involved in this emission situation. Reference situation 3 was used for emissions from industrial processes of large plants involving a high emission point and energy-intensive activities; in this case only fine particles are assumed to be involved in the transfer over large distances.

The MIR of the reference situations was calculated for an emission rate of 1 GBq a<sup>-1</sup> of <sup>210</sup>Pb, <sup>210</sup>Po, <sup>238</sup>U, <sup>228</sup>Th, <sup>232</sup>Th, <sup>226</sup>Ra, <sup>228</sup>Ra and <sup>222</sup>Rn to air. The location of maximum concentration and deposition, and the contribution of the different exposure pathways to the maximum MIR and MIR contours for the three reference situations and nuclides considered can be found in Appendix G.

A crucial step in the first screening of a plant is the selection of the reference situation. This selection was based on matching the chimney height and heat content. When in

doubt, a conservative selection of the reference situation was made, which, consequently, would lead to an overestimation of the risk level. The MIR of the plant was obtained by multiplying the MIR calculated for the reference situation by the actual release of the industrial plant and summing the contributions of all radionuclides involved.

### 2.3.2 Closer examination

When in the first screening the maximum MIR was lower than  $10^{-8} \text{ a}^{-1}$ , the NNI plant, in general, was not considered for further analysis. If, however, the maximum MIR was higher than  $10^{-8} \text{ a}^{-1}$ , in general, a closer examination was made using local specific emission data of the plant and its surroundings if these were available. Plants with maximum MIR  $> 10^{-7} \text{ a}^{-1}$  were always more closely considered. In this second risk calculation the dispersion of the radionuclides was modelled using location-specific parameters such as location of the source, output, source type, release height, heat content, particle-size distribution, form of release, weather conditions, receptor area and roughness length. Multifunctional individual risk (MIR) contour plots were calculated using the method described in Appendix C. The AIR was calculated for local conditions obtained from geographical data [BSV93].

## 2.4 Calculation of risks from emissions into water

From previous studies, dose and risk calculations were available for four plants, which emit, directly or by deposition from air emissions, large quantities of radionuclides into water. These were: an elementary phosphor plant [Kö88], two phosphoric acid production plants [Kö91] and a primary iron and steel production plant [We89].

For the first three plants the two main pathways are:

1. water → fish → ingestion
2. water → sedimentation → harbour sludge → landfill → inhalation of radon.

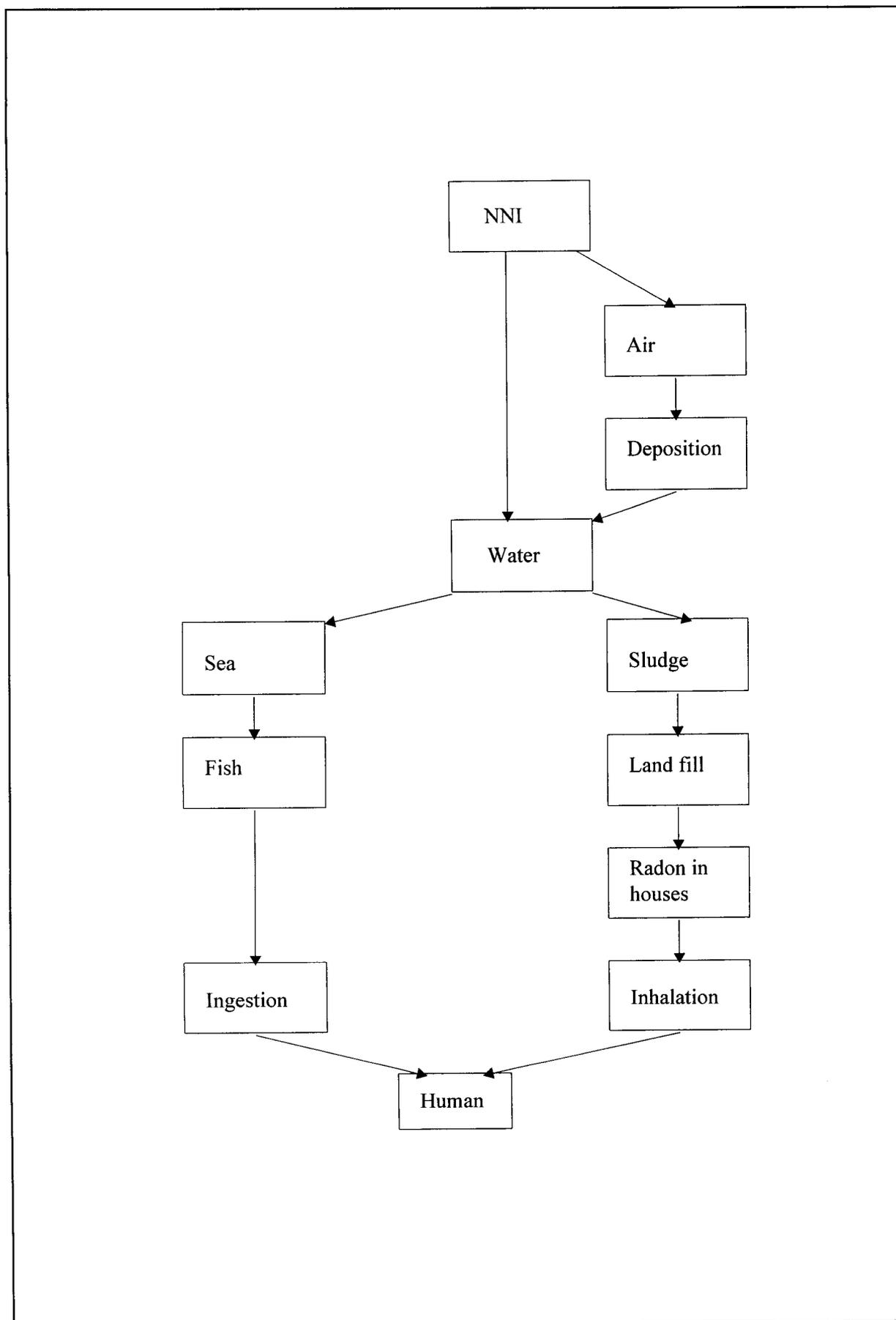
For the primary iron and steel production plant the pathway is:

3. air → deposition on water → fish → ingestion.

See Figure 2.3.

The risk calculations were adapted to the new parameter values and assumptions adopted for the present calculations [BSV93; La94].

The first pathway consists of  $^{210}\text{Pb}$  and  $^{210}\text{Po}$  emitted with the wash water and transported either in dissolved or suspended forms to the North Sea and along the Dutch coast to the north. The average radionuclide concentration in fish and the resulting dose were calculated from the radionuclide concentrations in the sea, concentration factors and amounts of fish caught in different parts of the North Sea. The relevant fish products were assumed to be evenly distributed over the Netherlands. If relevant, radioactive decay and ingrowth were taken into account. The original calculations were corrected for the food consumption pattern as recommended in the VROM guidelines [BSV93; La94]. Details of



**Figure 2.3** Schematic representation of the pathways of emissions of radionuclides into water to man.

the risk calculations of emissions to water can be found in Appendix D.

## 2.5 Calculation of risks from external radiation

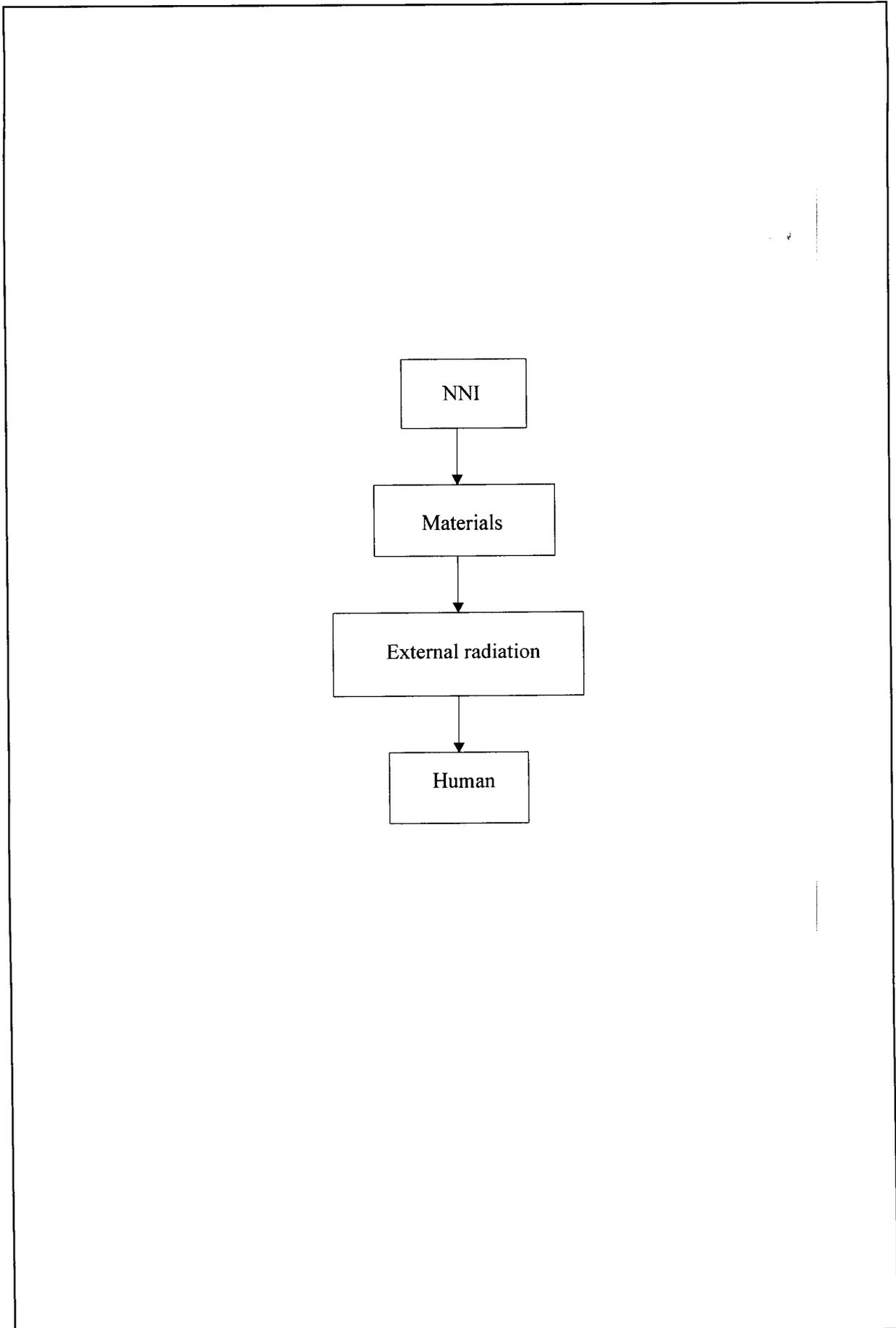
A major risk of large quantities of bulk material, such as raw material and solid waste, is caused by external radiation from gamma radiation (see Figure 2.4).

For environmental policy purposes only the dose to and risks from materials in the plant for members of the population outside the plant site are taken into account. Workers at the site itself are not considered as a reference group in this study. Therefore points of particular interest for the risks are the fence of the industrial site or beyond. For the dose assessment, a literature search for measurements or calculations of radiation levels near raw material stocks and solid waste sites was first performed. The MIR for individuals in the surroundings was calculated from the measured or calculated radiation levels using a shielding factor of  $ISF = 0.25$  [BSV93]. AIR was calculated using the actual exposure correction factors (Appendix A). Workers at nearby plants were assumed to work inside buildings.

If no information on radiation levels was available, the model MARMER [KI89c], a computer program for the calculation of energy absorption and dose from several radiation sources at any point of a complex geometry, was used. It contains a radionuclide library with decay characteristics and gamma yields. It uses a Monte Carlo integration technique to integrate over energy and source volume. A short description of the model is given in Appendix E.

For MARMER the concentration of radionuclides, quantities stacked, dimensions of stocks, location on the industrial site and shielding need to be known. However, this information was, in general, not available from observations. Hence, worst-case situations were considered: assumed were maximum allowable amounts of raw materials and stock heights, and no shielding. The stock size was assumed to be a box. When the location of the stock was not known, several distances to the fence (minimum 25 m) were considered.

The concentration of the radionuclides and the composition of the material was taken primarily from the input-output balance. For the radionuclides, for which no data was found, radioactive equilibrium with the mother nuclide was assumed. Specific details on the calculations for the plants considered are given in Appendix E.



**Figure 2.4** Schematic representation of the pathway of external radiation to man.

### 3 RESULTS

This chapter presents the general results of the risk calculations. In the appendixes, more details of the results are described.

#### 3.1 Emission data of non-nuclear industries

Emission data of the relevant NNIs are given in Appendix F. Information presented on these industries is based on the report of Peute et al. [Pe89]. In addition, other industries, which have been subject to study of natural radiation risks or suspected of relatively high radiological risks have been included. Table 3.1 gives an overview of the types of industry considered and their estimated emissions of  $^{222}\text{Rn}$ ,  $^{210}\text{Pb}$  and  $^{210}\text{Po}$  to air and water.

Emission data represent the totals of each branch of industry. In the second column the numbers of industrial plants which were involved in this study are given. For oil and gas production, the number of production units is given instead, since one oil or gas

**Table 3.1** Review of total annual emissions into air and water by Dutch NNIs

Industry	N <sup>1)</sup>	Year	$^{222}\text{Rn}$					$^{210}\text{Pb}$		$^{210}\text{Po}$	
								Emissions (GBq a <sup>-1</sup> ) to:			
			Air		Air		Water	Air		Water	
Elementary phosphorus plant	1	92	563					66	24	490	166
Phosphoric acid production	2	90	1 859					0.23	1 784	0.29	1 835
Fertilizer production	2	90	221					0.06	0.11	0.05	0.12
Primary iron and steel production	1	90	350					55	0.51	91	8
Coal tar handling	1	88	0					-	-	-	-
Cokes production	3	87	13					0.01	0.03	0.01	0.04
Coal-fired power production <sup>2)</sup>	9	92	200					2.4	0.01	4.8	0.01
Gas-fired power production <sup>2)</sup>	6	90	2 800					0.43	-	0.16	-
Oil and gas production	900	90	521					-	89	-	89
Cement industry	3	90	387					0.23	-	78	-
Ceramic industry	~75	89/90	142					-	-	66	-
Mineral sands industry	2	91	0.74					0.74	0.07	0.74	0.07
Titanium pigment production	1	91	6					0.001	0.003	0.001	0.5
Other industries <sup>3)</sup>		90	4 700					pm	pm	pm	pm
<b>Total</b>			<b>11 800</b>					<b>125</b>	<b>1 900</b>	<b>730</b>	<b>2 100</b>

<sup>1)</sup> Number of plants in the Netherlands

<sup>2)</sup> Many power plants can burn either coal and gas or coal and oil (see Appendix F)

<sup>3)</sup> Emission of  $^{222}\text{Rn}$  due to burning of natural gas

production site can contain several units.

Major sources of  $^{222}\text{Rn}$  are phosphoric acid production (16%), gas-fired power production (24%) and (other) industries burning natural gas (40%).

Elementary phosphorus production and primary iron and steel production are mainly responsible for the emissions of  $^{210}\text{Pb}$  to air. Phosphoric acid production is responsible for most (94%) of the  $^{210}\text{Pb}$  emitted to water.

$^{210}\text{Po}$  emissions to air are mainly released in elementary phosphorus production (67%), primary iron and steel production (12%), cement production (11%) and the ceramic industry (9%).

Phosphoric acid production is responsible for 87% of the  $^{210}\text{Po}$  discharges to water, followed by the elementary phosphorus plant (8%) and oil and gas production (4%).

## 3.2 Risks from emissions into air

### 3.2.1 Screening results

Table 3.2 gives a summary of the first screening on risks caused by emissions to air. The risks were calculated for each industrial plant separately. The table shows the reference situation used for the risk calculation for each branch of industry, the radionuclides most relevant to the risk and their relative contribution, and the maximum MIR. This maximum is sometimes located less than 100 m from the source, where the dispersion model is strictly speaking not valid and the results show large uncertainties. In these cases the risks at 100 m were used as representative for the maximum MIR. For some industries, separate risk estimates were made for activities with different types of emissions (e.g. thermic emissions and emissions during transshipment). In total, 23 risk assessments were made. The results show that

- in 8 cases the maximum MIR is lower than  $10^{-8} \text{ a}^{-1}$ ,
- in 4 cases the maximum MIR is between  $10^{-8}$  and  $10^{-7} \text{ a}^{-1}$ ,
- in 5 cases the maximum MIR is between  $10^{-7}$  and  $10^{-6} \text{ a}^{-1}$ ,
- in 3 cases the maximum MIR is between  $10^{-6}$  and  $10^{-5} \text{ a}^{-1}$  and
- in 3 cases the maximum MIR is higher than  $10^{-5} \text{ a}^{-1}$ .

Although risks lower than  $10^{-8} \text{ a}^{-1}$  were not further examined, it should be noted that due to the choice of reference situations and the evaluation procedure, uncertainties may have been introduced that should be taken into account when examining the results. For example, for the ceramic industries, reference situation 2 was chosen, assuming a 40-m chimney height, a situation expected in large ceramic plants. However, it cannot be ruled out that lower chimneys are used in other plants, which may lead locally to a higher risk than calculated here. More accurate risk assessments can only be made using site specific information.

**Table 3.2** Summary of the first screening on MIR using reference situations for emissions to air

Branch	Reference situation (see table 2.1)	Total MIR maximum ( $a^{-1}$ )	Relevant nuclides
Vlissingen elementary phosphor plant	3	$2.1 \cdot 10^{-7}$	$^{210}\text{Pb}$ $^{210}\text{Po}$
	1	$8.2 \cdot 10^{-6}$	$^{232}\text{Th}$
Vlaardingen phosphoric acid plant	1	$4.9 \cdot 10^{-5}$	$^{222}\text{Rn}$
Pernis phosphoric acid plant	1	$6.3 \cdot 10^{-5}$	$^{222}\text{Rn}$
Amsterdam fertilizer plant	2	$5.8 \cdot 10^{-10}$	$^{222}\text{Rn}$ $^{210}\text{Pb}$
	1	$5.0 \cdot 10^{-7}$	$^{238}\text{U}$ $^{210}\text{Pb}$
IJmuiden primary iron and steel plant	3	$1.1 \cdot 10^{-7}$	$^{210}\text{Pb}$ $^{210}\text{Po}$
	1	$4.7 \cdot 10^{-6}$	$^{232}\text{Th}$ $^{232}\text{U}$
Uithoorn coal tar processing	2	$9.0 \cdot 10^{-8}$	$^{210}\text{Pb}$ $^{210}\text{Po}$
Sluiskil cokes production	2	$3.6 \cdot 10^{-10}$	$^{228}\text{Th}$ $^{238}\text{U}$ $^{210}\text{Pb}$
	1	$9.0 \cdot 10^{-8}$	$^{228}\text{Th}$ $^{238}\text{U}$
600 MW coal-fired power plant	3	$1.0 \cdot 10^{-9}$	$^{210}\text{Pb}$ $^{228}\text{Th}$ $^{210}\text{Po}$
	1	$3.0 \cdot 10^{-7}$	$^{228}\text{Th}$ $^{238}\text{U}$
Velsen 400 MW gas-fired power plant	2	$7.8 \cdot 10^{-10}$	$^{210}\text{Pb}$ $^{222}\text{Rn}$

**Table 3.2** Continued

Branch	reference situation	Total MIR maximum ( $a^{-1}$ )	relevant nuclides
Oil and gas production <sup>1)</sup>	1	$5.7 \cdot 10^{-8}$	$^{222}\text{Rn}$
Maastricht cement production	2	$5.4 \cdot 10^{-8}$	$^{210}\text{Po}$
	1	$6.7 \cdot 10^{-6}$	$^{238}\text{U}$ $^{228}\text{Th}$ $^{210}\text{Pb}$
Rozenburg cement production	2	$1.5 \cdot 10^{-9}$	$^{228}\text{Th}$ $^{238}\text{U}$
IJmuiden cement production	2	$3.8 \cdot 10^{-9}$	$^{228}\text{Th}$ $^{238}\text{U}$
Ceramic industry, large plant	2	$4.8 \cdot 10^{-9}$	$^{210}\text{Pb}$ $^{210}\text{Po}$ $^{238}\text{U}$
Amsterdam mineral sands handling	1	$3.8 \cdot 10^{-5}$	$^{238}\text{U}$ $^{232}\text{Th}$
Geertruidenberg mineral sands handling	1	$9.3 \cdot 10^{-7}$	$^{232}\text{Th}$ $^{238}\text{U}$
Rozenburg titanium pigment production	2	$1.9 \cdot 10^{-9}$	$^{228}\text{Ra}$

<sup>1)</sup> Estimated emission for one major production site.

### 3.2.2 Risks at closer examination

Industrial activities, for which the screening yielded maximum MIR values over  $10^{-8} a^{-1}$ , were examined more closely, using site-specific information where possible. In some cases no site-specific information was available and the first estimate was not corrected further. When the maximum was less than 100 m from the source, the risk at 100 m was determined and given. In general, the result is a number of calculations of AIR at specific points in the vicinity of the plant. For some sources, only an upper limit or worst-case estimate of MIR and AIR is given, which was labelled as such (see table 3.2). The results, given in detail in Appendix H, are reviewed in the following sections.

### 3.2.2.1 *Elementary phosphorus production*

For an elementary phosphorus plant at Vlissingen risk calculations were performed for thermic emissions of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  and emissions of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{226}\text{Ra}$ ,  $^{210}\text{Pb}$  and  $^{210}\text{Po}$ , during transshipment. The highest MIR and AIR values, due to transshipment, are found at the Van Cittershaven (Figure J.12, coordinates: [37.90; 386.70]). At the industrial site of an adjacent aluminum plant MIR reaches a local maximum from thermic emissions. AIR has a local maximum from thermic emissions about 4 km from the source, at Nieuwdorp. Table 3.3 gives a summary of the results.

**Table 3.3** MIR and AIR maxima due to thermic emissions and transshipment at a Vlissingen elementary phosphorus plant

Location <sup>1)</sup> (coordinates)	Nieuwdorp [40.20; 388.00]	Pechiney [38.10; 387.05]	Van Citterhaven [37.90; 386.70]
MIR <sup>2)</sup> ( $10^{-6} \text{ a}^{-1}$ )	5.8	6.9	3.3
AIR <sup>2)</sup> ( $10^{-6} \text{ a}^{-1}$ )	1.0	1.2	3.3

<sup>1)</sup> See Figure J.12

<sup>2)</sup> Total risk due to thermic emission of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$ , and emission of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{226}\text{Ra}$ ,  $^{210}\text{Pb}$  and  $^{210}\text{Po}$  during transshipment

### 3.2.2.2 *Phosphoric acid production*

For two phosphoric acid production plants, one at Vlaardingen and one at Pernis, risk calculations were performed for emissions of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{226}\text{Ra}$ ,  $^{210}\text{Pb}$  and  $^{210}\text{Po}$  to air during transshipment and for  $^{222}\text{Rn}$  exhalation. Appendix H describes the model parameters and calculation method. For the Vlaardingen plant, the maximum MIR at the boundary of the plant site is  $3.1 \cdot 10^{-6} \text{ a}^{-1}$  (location no. 14, AIR =  $2.8 \cdot 10^{-8} \text{ a}^{-1}$ ) (Figure J.5). The highest AIR, for workers at an adjacent factory, is  $2.0 \cdot 10^{-7} \text{ a}^{-1}$ . The AIR in the nearest residential area in Vlaardingen, 1.5 km from the transshipment location, is about  $4 \cdot 10^{-8} \text{ a}^{-1}$ . A summary of the results is given in Table 3.4.

For the Pernis plant, the maximum MIR at the boundary of the site is  $1.1 \cdot 10^{-6} \text{ a}^{-1}$  (see Figure J.7, location no. 4); the AIR at this location is  $2.0 \cdot 10^{-7} \text{ a}^{-1}$  (workers at a nearby industry). No residential areas exist in the vicinity of the plant. A summary of the results is given in Table 3.5.

For both plants, 90% of the risk at the site boundaries arises from inhalation.

**Table 3.4** MIR and AIR maxima due to emissions during transshipment and exhalation of  $^{222}\text{Rn}$  at the Vlaardingen phosphoric acid production plant

Location <sup>1)</sup> (coordinates)	Adjacent plant [81,89; 434,64]	Residential area Vlaardingen [82,20; 435,40]
MIR ( $\text{a}^{-1}$ )	$3.1 \cdot 10^{-6}$	$4.0 \cdot 10^{-8}$
AIR ( $\text{a}^{-1}$ )	$2.8 \cdot 10^{-8}$	$4.0 \cdot 10^{-8}$

<sup>1)</sup> See Figure J.5

**Table 3.5** MIR and AIR maxima due to emissions during transshipment and exhalation of  $^{222}\text{Rn}$  at a Rotterdam phosphoric acid production plant

Location <sup>1)</sup>	# 4; boundary
MIR ( $\text{a}^{-1}$ )	$1.1 \cdot 10^{-6}$
AIR ( $\text{a}^{-1}$ )	$2.0 \cdot 10^{-7}$

<sup>1)</sup> See Figure J.7

### 3.2.2.3 Fertilizer production

The maximum MIR for a fertilizer production plant at Amsterdam was found to be  $5.0 \cdot 10^{-7} \text{ a}^{-1}$ , 100 m north-east of the source and caused by emissions during transshipment. The largest contribution to the risk was from  $^{238}\text{U}$  (Table 3.6). There are no residential areas in the vicinity of the plant. Taking into account that the company area is about 300 m long and 400 m wide and that the nearest industry is located at a distance of more than 200 m, the maximum AIR is most likely below  $10^{-8} \text{ a}^{-1}$ .

**Table 3.6** Contributions to the MIR maximum at 100 m north-east of the source due to transshipment at an Amsterdam fertilizer production plant

Component	$^{238}\text{U}$	$^{228}\text{Th}$	$^{226}\text{Ra}$	$^{222}\text{Rn}$	$^{210}\text{Pb}$	$^{210}\text{Po}$	Total
MIR ( $\text{a}^{-1}$ )	$3.6 \cdot 10^{-7}$	$5.0 \cdot 10^{-9}$	$3.0 \cdot 10^{-8}$	$1.1 \cdot 10^{-9}$	$7.0 \cdot 10^{-8}$	$3.0 \cdot 10^{-8}$	$5.0 \cdot 10^{-7}$

### 3.2.2.4 Primary iron and steel production

For an iron and steel production plant at IJmuiden risk calculations were performed for thermic emissions of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  and emissions during transshipment of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,

**Table 3.7** MIR and AIR maxima due to thermic emissions and emissions during transshipment at the IJmuiden iron and steel production plant

Location <sup>1)</sup> (coordinates)	Beverwijk [105.7; 501.6]	Velsen [103.4; 498.6]
MIR <sup>2)</sup> (a <sup>-1</sup> )	2.1·10 <sup>-7</sup>	1.1·10 <sup>-7</sup>
AIR <sup>2, 3)</sup> (a <sup>-1</sup> )	2.1·10 <sup>-7</sup>	1.1·10 <sup>-7</sup>

<sup>1)</sup> See Figure J.10 and Figure J.11.

<sup>2)</sup> Risks due to thermic emission of <sup>210</sup>Po, <sup>210</sup>Pb and emission during transshipment of <sup>238</sup>U, <sup>232</sup>Th, <sup>226</sup>Ra, <sup>210</sup>Pb and <sup>210</sup>Po

<sup>3)</sup> AIR for urban areas

<sup>226</sup>Ra, <sup>210</sup>Pb and <sup>210</sup>Po. The maximum MIR is from releases during transshipment and is found on the plant site. The maximum AIR is from transshipment in the north-west part of Velsen-Noord, which is an urban area. Another local maximum of MIR and AIR from thermic emissions was found north of Beverwijk. Risk contours resulting from thermic emissions and emissions during transshipment are presented in Figure J.10 and Figure J.11. A summary of the results is given in Table 3.7.

### 3.2.2.5 Oil and gas production

For the emissions to air of oil and gas production only the onshore product locations are considered. For the calculation of MIR of a typical oil and gas production plant (Table 3.2) an emission of 1 GBq/a was used. In Appendix F, however, it is shown that some production locations have higher emissions. Product locations at the Groningen and Friesland concessions have 3 to 4 times the 1 GBq/a emissions. Further, in some concessions up to ten product locations can be found in an area of 10 km<sup>2</sup>. Assuming all production locations in a concession produce an equal amount of gas the total risk as a result of the <sup>222</sup>Rn emissions can be 30 to 40 times larger than calculated in Table 3.2, corresponding to a maximum MIR of about 2.0·10<sup>-6</sup> a<sup>-1</sup>.

### 3.2.2.6 Cement production

For a cement production plant at Maastricht risk calculations were performed for thermic emissions of <sup>210</sup>Po and <sup>210</sup>Pb and non-thermic emissions of <sup>238</sup>U, <sup>232</sup>Th, <sup>226</sup>Ra, <sup>210</sup>Pb and <sup>210</sup>Po to air during marl extraction, transport and mixing. Details of the risk analysis are given in Appendix H. The maximum MIR was found south of the open pit, at the terrain boundary (Figure J.12). The marl extraction takes place in a deep pit. The dispersion model used in this assessment is not valid for this situation. The risks given in Table 3.8

**Table 3.8** MIR and AIR maxima due to thermic emissions and marl extraction, transport and milling at the Maastricht cement production plant

Location <sup>1)</sup> (coordinates)	Hoogenweerth [177.05; 314.70]	Heugem [177.40; 315.35]
MIR thermic emissions <sup>2)</sup> (a <sup>-1</sup> )	9.2·10 <sup>-8</sup>	6.4·10 <sup>-8</sup>
AIR thermic emissions <sup>2)</sup> (a <sup>-1</sup> )	9.2·10 <sup>-8</sup>	6.4·10 <sup>-8</sup>
MIR marl extraction, transport and mixing <sup>3)</sup> (a <sup>-1</sup> )	1.3·10 <sup>-7</sup>	5.2·10 <sup>-8</sup>
AIR marl extraction, transport and mixing <sup>3)</sup> (a <sup>-1</sup> )	1.3·10 <sup>-7</sup>	5.2·10 <sup>-8</sup>
MIR total <sup>3)</sup> (a <sup>-1</sup> )	2.2·10 <sup>-7</sup>	1.2·10 <sup>-7</sup>
AIR total <sup>3)</sup> (a <sup>-1</sup> )	2.2·10 <sup>-7</sup>	1.2·10 <sup>-7</sup>

<sup>1)</sup> See Figure J.2

<sup>2)</sup> Risks are due to the nuclides: <sup>210</sup>Po, <sup>210</sup>Pb

<sup>3)</sup> Risks are *worst-case estimates* and are due to the nuclides <sup>238</sup>U, <sup>232</sup>Th, <sup>226</sup>Ra, <sup>210</sup>Pb and <sup>210</sup>Po.

associated with marl extraction are therefore worst-case estimates. The maxima of both MIR and AIR from thermic emissions are found at Hoogenweerth.

### 3.2.2.7 Mineral sands processing

For a mineral sands company at Amsterdam location-specific calculations were performed on a 50 m grid. The model parameters used are given in Appendix F.

During transshipment and milling <sup>238</sup>U, <sup>232</sup>Th, <sup>226</sup>Ra, <sup>210</sup>Pb and <sup>210</sup>Po are emitted to air. At the boundary of the site MIR reaches a maximum of 9.2·10<sup>-5</sup> a<sup>-1</sup> (see Figure J.14: location no. 5). The AIR at this location (an industrial road) is 8.8·10<sup>-7</sup> a<sup>-1</sup>. The maximum AIR, 1.4·10<sup>-6</sup> a<sup>-1</sup> (for workers at a nearby plant), is at location no. 16 (see Figure J.14). At another industrial road, west of the plant, AIR is 1.5·10<sup>-7</sup> a<sup>-1</sup>. No residential areas exist in the vicinity of the plant. Near the boundary, the inhalation pathway contributes about 90% to the MIR. A summary of the results is given in Table 3.9.

For a mineral sands processing company at Geertruidenberg risk calculations were performed for emissions of <sup>238</sup>U, <sup>232</sup>Th, <sup>226</sup>Ra, <sup>210</sup>Pb and <sup>210</sup>Po during transshipment and milling. The contribution of <sup>222</sup>Rn to the risk is negligible compared to the nuclides just mentioned.

At the boundary of the plant site, MIR reaches a maximum of 5.6·10<sup>-6</sup> a<sup>-1</sup> (location no. 15, see Figure J.15). At this location AIR is 5.4·10<sup>-8</sup> a<sup>-1</sup> for occupational shippers. AIR has a maximum of 6.8·10<sup>-8</sup> a<sup>-1</sup> for workers at a nearby industry at location no. 17. No residential areas exist in the vicinity of the plant. At the boundary, 90% of the risk arises

**Table 3.9** MIR and AIR maxima due to transshipment and milling at an Amsterdam mineral sands processing company

Location <sup>1)</sup> (Reference group for AIR)	# 5 (Traffic industrial road)	# 16 (Workers adjacent plant)
MIR <sup>2)</sup> (a <sup>-1</sup> )	9.2·10 <sup>-5</sup>	7.5·10 <sup>-6</sup>
AIR <sup>2)</sup> (a <sup>-1</sup> )	8.8·10 <sup>-7</sup>	1.4·10 <sup>-6</sup>

<sup>1)</sup> See Figure J.14

<sup>2)</sup> Risks are due to the nuclides <sup>238</sup>U, <sup>232</sup>Th, <sup>226</sup>Ra, <sup>210</sup>Pb, <sup>210</sup>Po

from inhalation. See Table 3.10 for a summary of the results.

**Table 3.10** MIR and AIR maxima due to emissions during transshipment and milling at a Geertruidenberg mineral sands processing company

Location <sup>1)</sup> (Reference group for AIR)	# 15 (industrial road)	# 17 (adjacent industry)
MIR <sup>2)</sup> (a <sup>-1</sup> )	5.6·10 <sup>-6</sup>	3.5·10 <sup>-7</sup>
AIR <sup>2)</sup> (a <sup>-1</sup> )	5.4·10 <sup>-8</sup>	6.8·10 <sup>-8</sup>

<sup>1)</sup> See Figure J.15

<sup>2)</sup> Risks due to emission of <sup>238</sup>U, <sup>232</sup>Th, <sup>226</sup>Ra, <sup>210</sup>Pb and <sup>210</sup>Po

### 3.2.2.8 *Summary of risks from emissions to air*

A summary of the risks from emissions to air using location-specific data is given in Table 3.11. Maxima of MIR and AIR are shown for the reference groups given in the last column. The results of the first screening are shown in the first column for comparison.

**Table 3.11** Overview of risks due to emissions to air by the Dutch NNI

Plant	MIR first screening (a <sup>-1</sup> )	MIR (a <sup>-1</sup> )	AIR (a <sup>-1</sup> )	Reference group (for maximum AIR)
Vlissingen elementary phosphor production	8.2·10 <sup>-6</sup>	3.3·10 <sup>-6</sup> 5.8·10 <sup>-6</sup>	3.3·10 <sup>-6</sup> 1.0·10 <sup>-6</sup>	Residents in Nieuwdorp Workers nearby industry
Vlaardingen phosphoric acid production	4.9·10 <sup>-5</sup>	3.1·10 <sup>-6</sup> 1.1·10 <sup>-6</sup>	2.8·10 <sup>-8</sup> 2.0·10 <sup>-7</sup>	Occupational shippers Workers nearby industry
Pernis phosphoric acid production	6.3·10 <sup>-5</sup>	1.1·10 <sup>-6</sup>	2.0·10 <sup>-7</sup>	Workers nearby industry
Amsterdam fertilizer plant	5.0·10 <sup>-7</sup>	- <sup>1)</sup>		
IJmuiden iron and steel production	4.7·10 <sup>-6</sup>	2.1·10 <sup>-7</sup>	2.1·10 <sup>-7</sup>	Residents in Beverwijk
Uithoorn coal tar handling	9.0·10 <sup>-8</sup>	- <sup>1)</sup>	- <sup>1)</sup>	
Sluiskil cokes production plant	9.0·10 <sup>-8</sup>	- <sup>1)</sup>	- <sup>1)</sup>	
600 MW coal-fired power plant	3.0·10 <sup>-7</sup>	- <sup>1)</sup>	- <sup>1)</sup>	
Oil and gas production	5.7·10 <sup>-8</sup>	2·10 <sup>-6</sup>	- <sup>1)</sup>	
Maastricht cement production	6.7·10 <sup>-8</sup>	2.2·10 <sup>-7</sup> 1.2·10 <sup>-7</sup> 1.3·10 <sup>-6</sup>	2.2·10 <sup>-7</sup> 1.2·10 <sup>-7</sup> 1.5·10 <sup>-8</sup>	Residents in Hoogenweerth Residents in Heugem Traffic public road
Amsterdam mineral sands handling	3.8·10 <sup>-5</sup>	9.2·10 <sup>-5</sup> 7.5·10 <sup>-6</sup>	8.8·10 <sup>-7</sup> 1.4·10 <sup>-6</sup>	Traffic industrial road Workers nearby industry
Geertruidenberg mineral sands handling	9.3·10 <sup>-7</sup>	5.6·10 <sup>-6</sup> 3.5·10 <sup>-7</sup>	5.4·10 <sup>-8</sup> 6.8·10 <sup>-8</sup>	Occupational shippers Workers nearby industry

<sup>1)</sup> No locally specific emission data available for performing second screening

### 3.3 Risks of emissions into water

A first indication of the industrial plants, which have major emissions of radionuclides into water is obtained from Table 3.1. As can be seen by far the largest emissions into water were from an elementary phosphor production plant (at Vlissingen; total emission of <sup>210</sup>Pb and <sup>210</sup>Po 190 GBq/a), two phosphoric acid plants (at Pernis and Vlaardingen; total emission 3619 GBq/a) and from an IJmuiden iron and steel plant (total emission about 8.5 GBq/a). The onshore oil and gas production industry has an important throughput of radionuclides via production water (178 GBq/a total), divided over about 900 oil and gas extraction points, but it is unknown to what extent this is emitted into surface water. Other industries have total emissions less than 0.5 GBq/a.

A summary of the results is presented in Table 3.12. As pointed out in section 2.4 the

risks, in general, are calculated on the basis of the annual emissions to water, dispersion into river and sea, uptake in sea fish and other sea organisms, and consumption by the population (Appendix F). For the two phosphoric acid plants also the pathway water→harbour sludge→polders→radon in houses was included. Details of the results are presented in Appendix D. The risks of emissions to water as a result of the ingestion of sea fishery products are in the  $10^{-8}$  —  $10^{-7}$  a<sup>-1</sup> range or less. The risk is uniformly distributed over the country, and the collective risks are calculated by multiplying the average risk by the total number of inhabitants of the Netherlands.

Compared with earlier studies [Kö88, Kö93 and We89] the risks of emissions to water caused by fish consumption are considerably lower. This is mainly caused by a different consumption pattern of fishery products as assumed in the calculations, based on the recommendations of VROM [BSV93]. The consumption of fishery products is 10 to 20 times lower — depending on the type of fishery products — than the consumption patterns used in earlier risk assessments.

The risks resulting from the harbour sludge pathway were calculated on the basis of the annual emission of <sup>226</sup>Ra (Appendix D). The risk calculation should be considered as a preliminary result because of the uncertainties involved. Table 3.12 shows that the risks from the harbour sludge pathway are in the  $10^{-6}$  —  $10^{-5}$  a<sup>-1</sup> range.

The risks from oil and gas production onshore and in other NNIs are comparatively low, especially when realised that the risks are from many emission points over the country.

**Table 3.12** Overview of risks due to emissions to water at Dutch NNI

Plant	Pathway	MIR (a <sup>-1</sup> )	CAR (a <sup>-1</sup> )
Vlissingen elementary phosphor production	Fishery products	$5.2 \cdot 10^{-8}$	0.78
Vlaardingen phosphoric acid production	Fishery products	$4.5 \cdot 10^{-8}$	0.68
	Harbour sludge	$4.1 \cdot 10^{-5}$ <sup>1)</sup>	? <sup>1)</sup>
Pernis phosphoric acid production	Fishery products	$5.3 \cdot 10^{-8}$	0.80
	Harbour sludge	$5.6 \cdot 10^{-5}$ <sup>1)</sup>	? <sup>1)</sup>
IJmuiden iron and steel production	Fishery products	$1.9 \cdot 10^{-9}$	
Offshore oil and gas production <sup>2)</sup>	Fishery products	$1.1 \cdot 10^{-8}$	0.17
Other industries	Fishery products	$\ll 1 \cdot 10^{-8}$	
Total for fishery products pathway (rounded)		$1.6 \cdot 10^{-7}$	2.5

<sup>1)</sup> Preliminary results. CAR probably less than 0.1 a<sup>-1</sup>

<sup>2)</sup> Total MIR for about 900 installations

### 3.4 Risks from external radiation

The results for the calculations of risks from external radiation are given in Appendix I. Table 3.13 gives a summary of these results.

In general, the industries considered are situated in industrial areas, hence only workers at nearby industrial sites, traffic on industrial roads and, if the industry is near surface water, occupational shippers, were the reference groups. Because of the location of the industrial plants and the fact that external radiation levels decrease rapidly with distance, residents were not considered a relevant reference group for external gamma radiation. If workers at a nearby industrial site were the reference group, they were supposed to work mainly indoors.

Mineral sands industries cause relatively high risks, especially to workers at nearby industrial sites. In the case of phosphate ore processing industries the measurements at a plant at Amsterdam showed high radiation and risk levels [La94], whereas worst-case calculations for two phosphoric acid plants indicated a MIR well below  $10^{-6} \text{ a}^{-1}$  (MPR). Note that for measurements the radiation of products and dust were included.

Some of the tabulated numbers are worst-case calculations, assuming maximum amounts of raw materials without shielding at a distance to the fence of only 25 m. This is indicated in the last column of Table 3.13.

For measurements, the question is whether the situation at monitoring time can be considered representative for the general situation. Information on the amounts of raw materials and solid waste in stock, averaged over long periods, is needed to assess the actual value of the measurements.

For some industries (fertilizer production, ceramic industry, offshore oil and gas exploitation and cement production) not enough information was available to assess the risks of external gamma radiation. Further investigations are recommended for these industries.

### 3.5 The total risk

In the previous sections the radiological risks of emissions to air, to water and of external radiation were described separately. The total risk is, in principle, the sum of these three risks. However, the risks, in general, are not uniformly distributed. The risks from emissions to air are highest in the vicinity of the plant and may extend over considerable

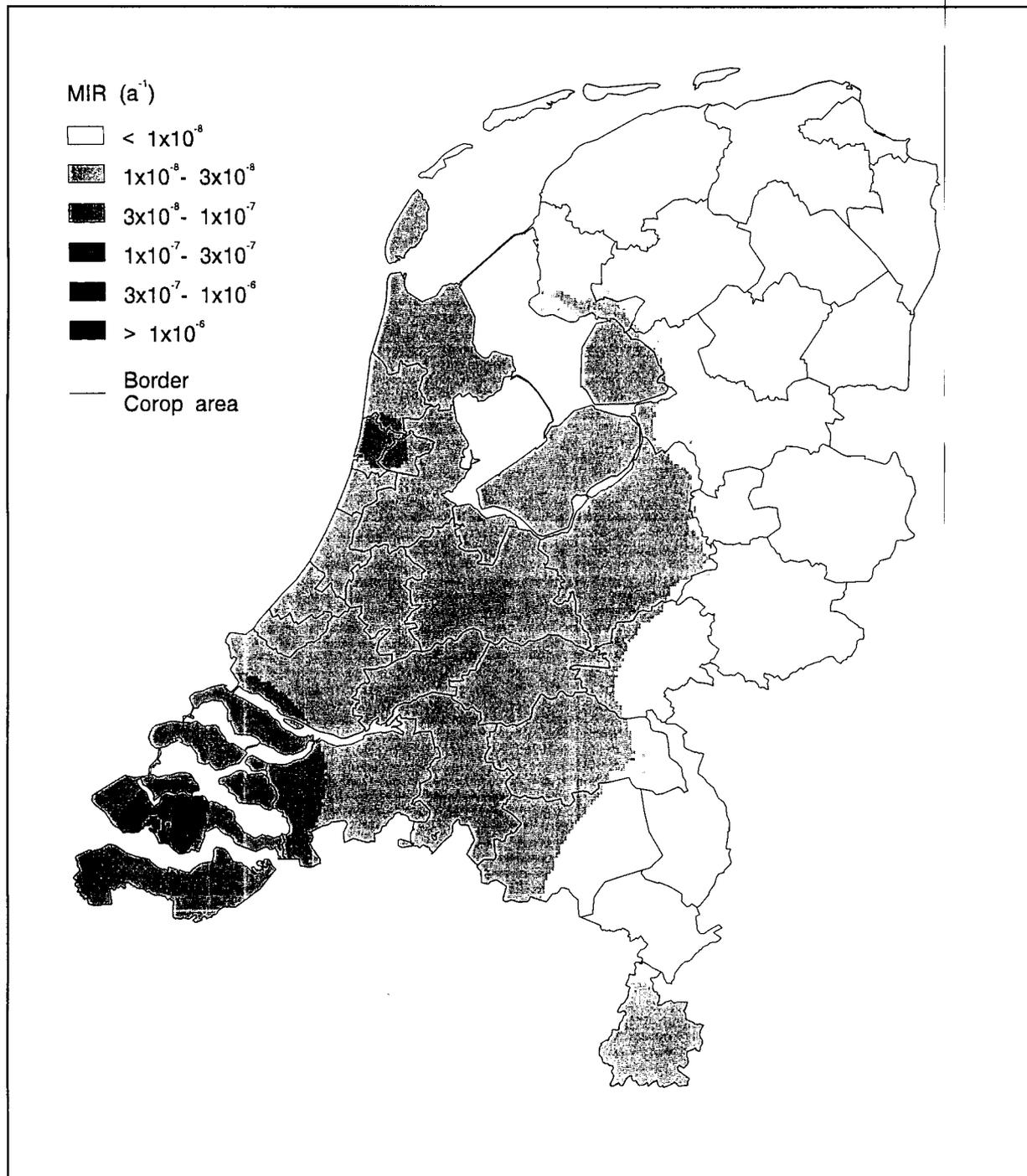
**Table 3.13** Overview of risks due to external radiation of stocks of the Dutch NNI

Industry	Material	MIR (a <sup>-1</sup> )	AIR (a <sup>-1</sup> )	Reference group for AIR calculation	Remarks <sup>1)</sup>
Vlissingen elementary phosphor production	Phosphate ore, calcinate	1.8·10 <sup>-7</sup> 3.3·10 <sup>-8</sup>	7.2·10 <sup>-9</sup> 6.5·10 <sup>-9</sup>	Occupational shippers Workers nearby industry	Measurement [Ki94]
Vlaardingen phosphoric acid production	Phosphate ore	2.9·10 <sup>-7</sup>	5.8·10 <sup>-8</sup>	Workers nearby industry	Worst-case, max. amount
Pernis phosphoric acid production	Phosphate ore	7.2·10 <sup>-8</sup> 2.0·10 <sup>-8</sup>	2.9·10 <sup>-9</sup> 4.0·10 <sup>-9</sup>	Traffic industrial road Workers nearby industry	Worst-case, max. amount
Coal fired power plant, Maasvlakte	Fly-ash	2.6·10 <sup>-6</sup>	1.0·10 <sup>-7</sup>	Traffic industrial road	Worst-case, max. amount, near fence
Amsterdam mineral sands handling	Mineral sands	4.0·10 <sup>-5</sup> 2.6·10 <sup>-5</sup>	8.0·10 <sup>-6</sup> 1.1·10 <sup>-6</sup>	Workers nearby industry Traffic industrial road	Measurement [P94]
Geertruidenberg mineral sands handling	Mineral sands	5.1·10 <sup>-6</sup> 1.3·10 <sup>-6</sup>	2.1·10 <sup>-7</sup> 5.3·10 <sup>-8</sup>	Occupational shippers Traffic industrial road	Measurement [Sc92b]
Amsterdam fertilizer production	Phosphate ore	9.2·10 <sup>-6</sup> 1.3·10 <sup>-6</sup>	3.7·10 <sup>-7</sup> 2.6·10 <sup>-7</sup>	Occupational shippers Workers nearby industry	Measurement [La93]
IJmuiden iron and steel production	Filter cake, slag	1.9·10 <sup>-6</sup>	7.4·10 <sup>-8</sup>	Traffic industrial road	Worst case, near fence
Rotterdam titanium pigment production	Rutile	8.2·10 <sup>-7</sup>	3.3·10 <sup>-8</sup>	Traffic industrial road	Calculation [We88]

<sup>1)</sup> For further details and a discussion of other data see Appendix E

distances, depending on the type of emission. Emissions with a low emission point and no heat content will lead to risks at short distances; emissions with a high emission point and considerable heat content will yield risks over distances up to more than hundred kilometres. The risks from emissions to water via the pathway ingestion of fishery products will be distributed uniformly over the entire country. The maximum risks of external radiation will be very close to the industrial site.

Therefore, simply adding up the maximum risk numbers for the different pathways to calculate the maximum total risk would lead to erroneous results. A thorough study of this aspect is beyond the scope of this project. However, for an indication and as an example of the results which could be obtained, a map of the total risk of ingestion and inhalation from emissions of radionuclides from three main industries in the Netherlands was calculated. The results are given in Figure 3.1. The risks show far-reaching distributions,



**Figure 3.1** Risk levels in the Netherlands due to three plants with emissions into air.

up to more than 100 km from the plants. The highest risks are found in the provinces Zeeland and Limburg. Maximum levels are found close to the plants. Due to the presentation on a 5 km grid, local maxima may be higher.

### 3.6 Uncertainties in the risk calculations

Uncertainties in the risks depend on the uncertainties in the different parts of the calculations. A thorough study is beyond the scope of this report. Here the uncertainties

can only be roughly indicated.

In general, the risk calculation consists of three parts:

- 1 emission data
- 2 dispersion of radionuclides
- 3 exposure of individuals and risk assessment.

The following can, in general, be concluded concerning the uncertainties in these parts:

1. Radioactivity emission data are taken from radioactivity concentrations of bulk materials, characteristics of the industrial processes involved and mass balances. The input and output (kton/year) of materials used in an industrial plant are fairly well known. The figures have, in general, been collected in various studies and compared with the results of a previous RIVM study, the SPIN project: coordination of industrial process descriptions in the Netherlands (e.g. see [An92a,b, Hu92a,b,c, Hu93a, Ko93, Sm93]). The uncertainties amount up to 10%. The activity concentrations of the industrial materials are based on monitoring data of samples taken in a given time period. In the report these data are supposed to be representative for the concentration in general. The error in the monitoring data is estimated to be 25%. In some cases no monitoring data were available and estimates were made on the basis of data of related materials. Taking into account the representativeness of the monitoring data, the uncertainty in the radioactivity data of input and output materials is, in general, estimated to be 40% and in the emission data, as, for example, in Table 3.1, about 50%.

2. The dispersion of radionuclides in air and water is calculated using models. In some cases dispersion models, such as the OPS model for dispersion in air, are fairly generally applicable; in other cases, such as dispersion in water, the dispersion is fairly location-specific. Overall, the uncertainty in dispersion of radionuclides for accidental releases is estimated to be a factor of 2 [S194]. For continuous releases, uncertainties in calculated air concentrations are estimated to be lower, in the order of 10 — 30% (Table C.1). For NNI a rather steady release with sometimes location-specific conditions is expected. In general, a random error of a factor of 2 in the overall release of radionuclides can be considered a reasonable estimate.

3. Exposure of individuals depends on assumptions on their personal characteristics. They include: location, diet, behaviour, age and physiological data. Ultimately, a dose-risk conversion factor is used to calculate the biological effect. In the report these factors are, in general, based on the VROM recommendations for risk calculation and similar in all calculations, for intercomparison purposes. An important uncertainty is the choice of the dose/risk conversion factor of 2.5% Sv<sup>-1</sup>. It is known that the choice of this factor is the subject of international discussion. No uncertainty estimate of the systematic error in this factor and other exposure assumptions can be given.

The random uncertainty in the exposure calculation is estimated to be relatively low because of the well-defined calculation conditions for the individuals concerned and is

estimated to be 25%.

The random uncertainty in the end result is composed of the uncertainty in these three parts and is estimated to be about a factor of 3. In this study no attempt has been made to estimate the uncertainty in specific risk calculations. It is recommended that, when the result is critical for policy measures, special calculations will be performed, taking into account location-specific conditions and/or measurements.

### 3.7 Dose conversion coefficients

One other source of uncertainty is the use of dose conversion coefficients (DCC) for inhalation and ingestion. Sets of DCC used in this report are given in Appendixes C and D. These coefficients depend on the organ risk factors, on the physiological models for uptake of radionuclides in the body and, for inhalation, on the particle characteristics. Several sets are known and, in general, data collected by ICRP and issued by the European Union are used for standardised calculations.

Recently (November 23, 1995) a new set of DCC was issued in a draft document of the European Commission. These DCCs will be of importance for future risk calculations in the Netherlands. Although these new DCCs could not be taken into account in the present calculations, in table 3.14 a comparison is made of these new coefficients with the coefficients used in the present calculations.

**Table 3.14** Comparison of DCC sets

Present report		<sup>210</sup> Po	<sup>210</sup> Pb	<sup>238</sup> U	<sup>232</sup> Th	<sup>228</sup> Th	<sup>228</sup> Ra	<sup>226</sup> Ra	<sup>222</sup> Rn
DCC <sub>inh</sub> (Sv Bq <sup>-1</sup> ) <sup>(1)</sup>		1.9·10 <sup>-6</sup>	2.2·10 <sup>-6</sup>	3.1·10 <sup>-5</sup>	2.2·10 <sup>-4</sup>	8.6·10 <sup>-5</sup>	1.1·10 <sup>-6</sup>	2.1·10 <sup>-6</sup>	7.4·10 <sup>-9</sup> <sup>(2)</sup>
DCC <sub>ing</sub> (Sv Bq <sup>-1</sup> ) <sup>(1)</sup>		2.1·10 <sup>-7</sup>	1.3·10 <sup>-6</sup>	3.6·10 <sup>-8</sup>	1.8·10 <sup>-6</sup>	2.7·10 <sup>-7</sup>	2.7·10 <sup>-7</sup>	2.2·10 <sup>-7</sup>	
EU draft	Type	<sup>210</sup> Po	<sup>210</sup> Pb	<sup>238</sup> U	<sup>232</sup> Th	<sup>228</sup> Th	<sup>228</sup> Ra	<sup>226</sup> Ra	<sup>222</sup> Rn
DCC <sub>inh</sub> (Sv Bq <sup>-1</sup> )	F	6.1·10 <sup>-7</sup>	9.0·10 <sup>-7</sup>	5.0·10 <sup>-7</sup>	1.1·10 <sup>-4</sup>	2.9·10 <sup>-5</sup>	8.9·10 <sup>-7</sup>	3.6·10 <sup>-7</sup>	2.5·10 <sup>-9</sup> (*)
	M	3.3·10 <sup>-6</sup>	1.1·10 <sup>-6</sup>	2.8·10 <sup>-6</sup>	4.5·10 <sup>-5</sup>	3.3·10 <sup>-5</sup>	2.7·10 <sup>-7</sup>	1.8·10 <sup>-6</sup>	
	S	4.3·10 <sup>-6</sup>	5.6·10 <sup>-6</sup>	7.9·10 <sup>-6</sup>	2.5·10 <sup>-5</sup>	4.2·10 <sup>-5</sup>	1.7·10 <sup>-7</sup>	5.2·10 <sup>-6</sup>	
DCC <sub>ing</sub> (Sv Bq <sup>-1</sup> )		1.2·10 <sup>-6</sup>	6.9·10 <sup>-7</sup>	4.4·10 <sup>-8</sup>	2.3·10 <sup>-7</sup>	7.2·10 <sup>-8</sup>	6.9·10 <sup>-7</sup>	2.8·10 <sup>-7</sup>	

<sup>(1)</sup> [Be93; NRPB91]

<sup>(2)</sup> [Va91]

(\*) Calculated from EU draft data.

The table shows that some new coefficients are lower and some other are larger than used in this report. As stated before the risk calculations have to be considered with care when

a specific case is considered. However, in view of the fact that in this report consistently the same methodology and DCC set has been used for all calculations the results can be considered useful to get an overall impression of the intercomparison of the radiological risks of NNI.

## 4 CONCLUSIONS AND RECOMMENDATIONS

This report has presented an overview of calculated risks of non-nuclear industries in the Netherlands due to the emissions from and exposure of individuals to natural radionuclides involved in the industrial processes. This study represents partly an update of previous studies because, in view of the relatively high radiological impacts, industrial processes have sometimes been accommodated in the course of time, partly of the new guidelines recently issued by the Dutch Ministry of Housing, Spatial Planning and Environment for the calculation of environmental radiological risks for policy development.

The risks were calculated for emissions of radionuclides to air and water, and for direct external exposure to gamma rays from the radionuclides involved. In general, the screened industries were selected from previous studies on industrial activities involving application of large amounts of bulk materials.

An initial screening, using a generic and rough method, indicated fifteen industries with a risk higher than  $10^{-8} \text{ a}^{-1}$  from emissions into air, four from emissions to water and nine from external radiation.

For industries having a risk higher than  $10^{-8} \text{ a}^{-1}$  location-specific calculations were made to examine the risks more precisely. Six industries have a maximum MIR over  $10^{-6} \text{ a}^{-1}$  and for four AIR exceeds  $10^{-6} \text{ a}^{-1}$ . A general review of the results is given in Table 4.1.

Comparison with previous risk assessment studies indicates that most of the differences between the present and previous studies can be assigned to different choices of parameters and of the environmental conditions included in the calculations. Particularly the choices for the conditions to be taken into account for the reference groups used in the calculations, taken from the Dutch governmental guidelines have largely influenced the results. As far as possible the differences between the present and previous studies have been indicated in the present report. In general, it can be concluded that for emissions to air reasonable explanations for the differences can be found, except for a few cases where sufficiently detailed original information was not available. In these cases further investigations will be necessary to explain the different results.

Three industries make major contributions to the radiological risks for emissions to water, two of them have a maximum MIR exceeding  $10^{-6} \text{ a}^{-1}$ . The contribution from the pathway water→fish→food was fairly limited and smaller than previously estimated because a lower consumption of fish products was assumed than in previous studies. The pathway water→harbour sludge→polders→radon in houses contributes considerably, but the calculation involves several uncertainties calling for further research on this pathway.

For external radiation, risk calculations were based either on measurements or on model

**Table 4.1** Maximum MIR and maximum AIR per site, calculated for each type of Dutch non-nuclear industry

Industry	Maximum MIR ( $10^{-6} \text{ a}^{-1}$ )				Maximum AIR ( $10^{-6} \text{ a}^{-1}$ )			
	Air	Water	Ext.rad.	Total	Air	Water	Ext.rad.	Total
Elementary phosphor production	5.8	0.05	0.18	6.0	3.3	0.05	<0.01	3.4
Phosphoric acid production at Vlaardingen	3.1	41	0.29	44	0.2	41	0.06	41
Phosphoric acid production at Rotterdam	1.1	56	0.07	57	0.2	56	>0.01	56
Fertilizer production	0.50	<0.01	9.2	9.2-9.7	0.50	<0.01	0.37	0.50-0.87
Primary iron and steel production	0.21	<0.01	1.9	2.1	0.21	<0.01	0.07	2.1
Coal tar processing	0.09	<0.01	?	?	0.09	<0.01	?	<0.01
Cokes production unit	0.09	<0.01	0.01	0.09-0.10	0.09	<0.01	?	0.09
Coal-fired power production unit	0.3	<0.01	2.6	2.6-2.9	0.3	<0.01	0.10	0.3-0.4
Gas-fired power production unit	<0.01	<0.01	?	<0.01	<0.01	<0.01	?	<0.01
Oil and gas extraction site	0.06?	<0.01?	?	0.06?	0.06?	<0.01?	?	0.06?
Cement production	0.13	<0.01	?	0.13	0.13	<0.01	?	0.13
Ceramic industry unit	<0.01	<0.01	?	<0.01	<0.01	<0.01	?	<0.01
Mineral sands milling and transport	92	<0.01	0.40	92-93	1.4	<0.01	8.0	8.0-9.4
Titanium pigment production	<0.01	<0.01	0.82	0.82	<0.01	<0.01	0.03	0.03

calculations. In the case of modelling only worst-case calculations involving direct radiation of individuals in the vicinity of bulk material, without accounting for shielding or sky shine, could be included. More location-specific information is necessary to improve these first risk indications of risks from external radiation. Additional monitoring data could contribute to validation of the calculated results.

The present study can be concluded to give an updated representation of the risks involved in radiological environmental risks of non-nuclear industries in the Netherlands. For only

a few industries do the risks exceed the level of  $10^{-6} \text{ a}^{-1}$  indicated by the Dutch government as the maximum permissible risk level. Further location-specific studies or monitoring data will be necessary to substantiate results, which will be critical for policy development.

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## APPENDIX A      PARAMETERS OF THE REFERENCE MAN

### A.1      Introduction

MIR is calculated for the reference man [ICRP75]. Further, in this report the reference man is defined by a diet and an activity pattern. Indoor Shielding Factors (ISF) are defined for the various activity patterns and exposure pathways as listed in Table A.1. For the actual individual risk (AIR) the actual use of the location has to be taken into account defined by the Actual exposure Conversion Factors as listed in Table A.2. The diet determines the dose by the ingestion route and is given in Table A.3. The physiological and impact parameters are used to determine Dose Conversion Coefficients (DCC), which relate activity intake with committed dose. DCCs are given in Appendix C and D.

**Table A.1** Indoor Shielding Factors (ISF) for conversion from IR to MIR

Path of Exposure	Assumptions	ISF
Direct radiation from the source	<ul style="list-style-type: none"> <li>- 30% of the time resting,</li> <li>- 45% light labour behind at least 20 cm concrete, 3 m average from the fence of the site.</li> <li>- 15% light labour in garden or behind glass, 3 m average from the fence of the site.</li> <li>- 10% out of range of the source</li> </ul>	0.25
Cloud shine	Shielding of roof etc. when inside	0.3
Sky shine	Especially important for neutron radiation	0.3
Ground shine	Shielding due to soil roughness	0.5
	Shielding behind walls	0.2
Inhalation	normal behaviour (breathing rate)	1

**Table A.2** Actual exposure Conversion Factors (ACF) used for calculating AIR from IR

Infrastructure at the location or type of exposure	ACF
Source transported by road	0.001
Waterway used by occupational (transit) shipping	0.01
Harbour for passing ships	0.03
Harbour for yachts, regular harbour for occupational shipping and vegetable gardens	0.1
Camping site	0.2
Recreation area except campings (woods, parks, dune, water, beach)	0.03
Parking lot	0.01
Main road outside residential area or road in industrial area	0.01
Secondary road in the vicinity of residential area	0.1
Agricultural area (meadow)	0.01
Other industry or offices, work inside	0.2
Other industry, work outside	1.0

**Table A.3** Standard diet of the reference person and reduction factors for losses due to food preparation [BSV93, La94]

Food product	Specification	Consumption rate (solids: kg/a, liquids: L/a)	Reduction (%)
Cereals	bread, etc.	66	70
Potatoes		45	50
Tuberous plants	boiled	14	50
	raw	1.5	0
Vegetables	boiled	32	50
	raw	5	0
Leafy vegetables	boiled	9	50
	raw	4	0
Pulses		3	50
Milk(products)	fresh	99	0
	conserved	14	20
Cheese		8	60
Beef		13	50
Sea fish		4	50
Mussels and shrimps		0.3	50
Freshwater fish (eel)		0.3	50

## **APPENDIX B      MODELLING DISPERSION IN AIR**

### **B.1            Introduction**

In the Netherlands, the National Model [Er92] has acquired the status of a consensus model for the calculation of dispersion and deposition. For some applications, however, the model is not suitable, such as for the calculation of dispersion over distances of more than about 20 km and of deposition [Ja90]. Moreover, the reliability of the National Model has never been evaluated thoroughly [Er92]. These limitations were reason for developing another model. The new model, named "Operational atmospheric transport model for Priority Substances" (OPS) [Ja90], has the advantage that the concentration and deposition of a substance very near to the source and far away (up to 350 km) can be calculated, as well as the background deposition at that location caused by other sources. In this study OPS has been used to model the dispersion and deposition of radionuclides emitted into air.

### **B.2            The OPS model**

A short description and specifications of the model are given in [Ja90]. The model can be used for dispersion over distances of 100 m to about 350 km from the source. Atmospheric processes included in the model are dispersion, dry deposition, wet scavenging and chemical transformation. A climatological database is included in the model. Model results are air concentration, dry deposition, wet deposition and total deposition [Ja90].

#### **B.2.1        Model validation of OPS**

The OPS model is validated on a regional scale using observations of the RIVM Air Quality Monitoring Network and the Netherlands National Precipitation Chemistry Network. It is concluded that the model describes monthly variations in the Netherlands very well. A quantification of the uncertainty in calculated values on a regional scale is given in Table B.1 [Ja90].

**Table B.1** Uncertainties in the results of OPS

	concentration in air	deposition (dry + wet)
long term	10 %	15 %
specific year	15 %	20 %
specific half-year	20 %	30 %
specific month	30 %	40 %

### B.2.2 Particle size distribution

In OPS the emitted particles can be divided into five size classes to account for the differences in properties between larger and smaller particles. Small particles have a lower dry and wet deposition velocity than larger particles. The particles are classified according to diameter (Table B.2) [Ja90]. The user of the model can choose three standard distributions, designated 'fine', 'medium' and 'coarse', as given in Table B.2.

### B.2.3 Heat content

In the model the heat content of the emission has to be specified to calculate the effective plume height for the different climatological conditions. The heat content can be calculated from the volume flow and temperature of the flue gas by [Ja90],

$$Q_w = 0.0013 \times V_n \times (T_g - 288) \quad (\text{B.1})$$

with:

- $Q_w$  = heat content of the flue gas (MW)
- $V_n$  = volume flow of the flue gas ( $\text{Nm}^3 \cdot \text{s}^{-1}$ )
- $T_g$  = temperature of the flue gas (K)

**Table B.2** Particle-size classification and distribution (%) for three classes [Ja90]

class	1	2	3	4	5
diameter ( $\mu\text{m}$ )	< 0.95	0.95 – 4	4 – 10	10 – 20	> 20
distribution class:					
fine (%)	70	20	5.5	2.5	2.0
medium (%)	53	28	11.5	4.2	3.3
coarse (%)	42	33	14.5	5.9	4.6

#### B.2.4 Climatological data

Climatological data are included in the OPS model, based on meteorological observations of the RIVM Air Quality Monitoring Network (LML) and the Royal Netherlands Meteorological Institute (KNMI). Long-term time averages, such as 'year', 'summer' and 'winter' can be chosen [Ja90]. In the model, the Netherlands is divided into six areas (Table B.3). For each area and for the Netherlands, time averaged meteo statistics are included in the model [Ja90].

**Table B.3** Area classification of the Netherlands as used in the OPS model [Ja90] and representative values for roughness

area number	area	roughness length (m)
1	coast of Friesland-Groningen, northern part of Noord-Holland	0.10
2	Noord-Holland, Zuid-Holland, Zeeland-Zuid	0.15
3	Drenthe and environments	0.13
4	Zeeland	0.12
5	Twente, Gelderland, Brabant	0.18
6	Achterhoek, Brabant-Oost, Limburg	0.20

#### B.2.5 Roughness length

The roughness length is of special importance when modelling in the immediate vicinity of the source, because terrain roughness is used to determine the initial dispersion [Ja90], taking into account the emission height and heat content. Representative values are listed in Table B.3 and Table B.4. Over large distances, ground roughness is considered to have been taken into account in the meteo-statistics. Therefore, the large-scale roughness was assumed to be the default value of 0.15 m [Ja90].

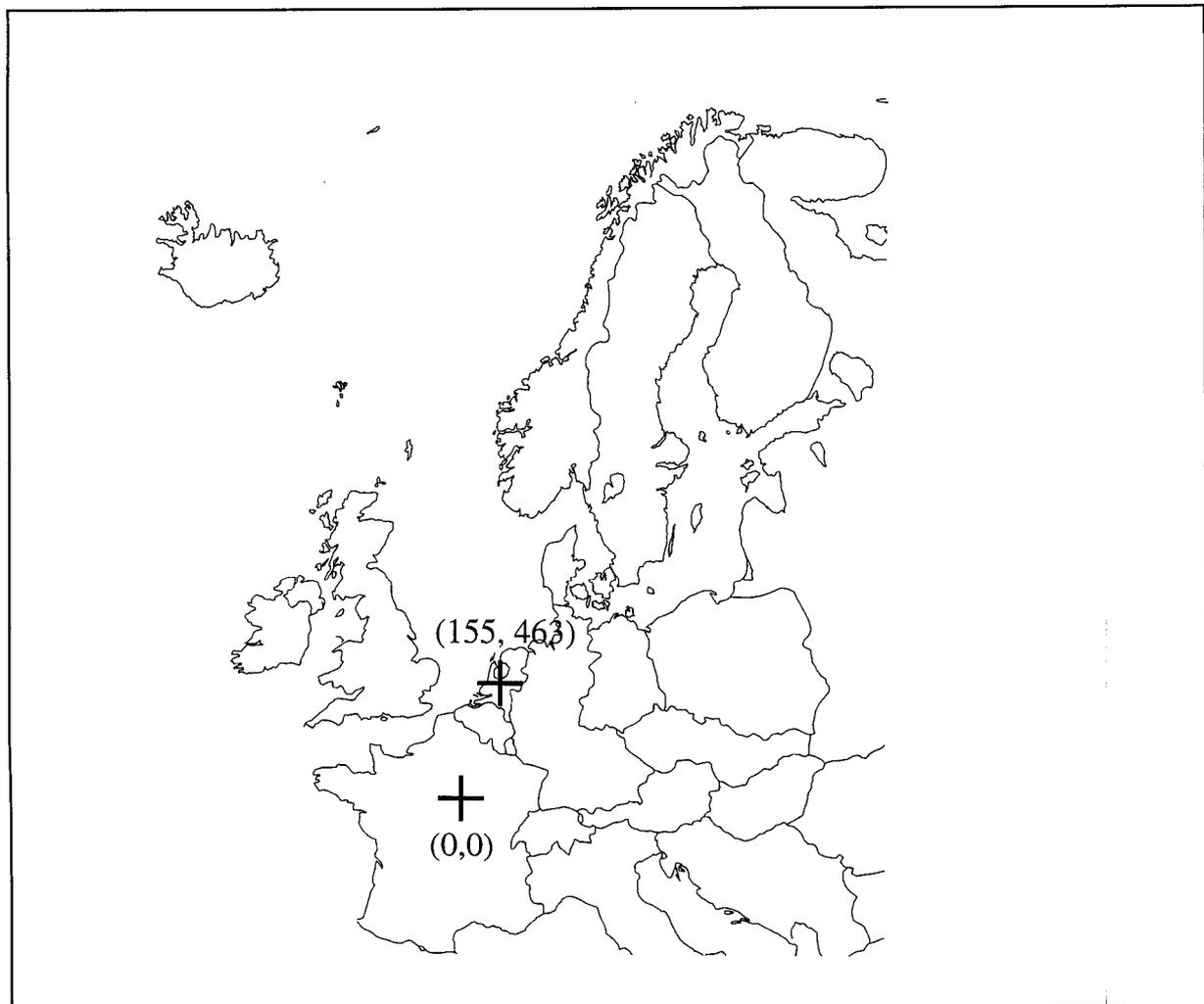
### B.3 The RDM coordinate system

In OPS the Dutch Rijksdriehoekmeting (RDM) (National Triangle Measurement) coordinate system is used. This system is rectangular and the origin is situated near Lille,

**Table B.4** Representative values for the roughness length (m) for different areas as defined in OPS [Ja90]

type of area	estimated roughness length (m)
flat terrain	0.03
agricultural land	0.10
cultivated land	0.30
residential area	1.0
urban area	3.0

France, which implies that the Netherlands is situated in the first quadrant and the y coordinate is always larger than the x coordinate. The centre of the Netherlands is located at  $x = 155$  km and  $y = 463$  km, which corresponds to  $5^{\circ}23'15''$  EL,  $52^{\circ}9'22''$  NL. The origin and the centre of the Netherlands are plotted in Figure B.1. All locations in this study are given in RDM coordinates.

**Figure B.1** The Dutch National Triangle Measurement coordinate system (RDM coordinates).

## APPENDIX C MODELLING RISKS OF EMISSIONS TO AIR

### C.1 Introduction

In general, the equations and parameters used in the risk calculations of radioactive emissions in air are described in two references [BSV93, La94]. The first [BSV93] contains scientific and political choices regarding risk factors, definitions of reference man and reference group. The second [La94] focuses on the suitable models, equations and other technical details. In this appendix a summary of the methods used in the risk calculations of emissions to air is given.

In initial calculations of the risks it was concluded that cloud, sky and ground shine did not contribute significantly compared with the inhalation and ingestion route. Therefore, only inhalation and ingestion are discussed here.

### C.2 Inhalation

The dose rate due to inhalation,  $\dot{D}_{inh}$  (Sv a<sup>-1</sup>), is calculated from the concentration of radionuclides in air as

$$\dot{D}_{inh} = C_{air} \cdot Q_{inh} \cdot DCC_{inh} \cdot O_{cc} \quad (C.1)$$

with

- $C_{air}$  = radionuclide concentration in air (Bq m<sup>-3</sup>)
- $Q_{inh}$  = annual inhalation rate (m<sup>3</sup> a<sup>-1</sup>);  $Q_{inh} = 8.4 \cdot 10^3$  m<sup>3</sup> a<sup>-1</sup>, for the reference man [ICRP75]
- $DCC_{inh}$  = inhalation dose conversion coefficient (Sv Bq<sup>-1</sup>) (Table C.1)
- $O_{cc}$  = residence time as fraction of a year; in general,  $O_{cc} = 1$ .

It is allowed to ignore resuspension for releases of radionuclides with an atomic number smaller than 92 [La94].

### C.3 Ingestion

The dose rate,  $\dot{D}_{ing}$  (Sv a<sup>-1</sup>), due to ingestion of contaminated food products is calculated by

$$\dot{D}_{ing} = \sum C_{ing} \cdot Q_{ing} \cdot DCC_{ing} \quad (C.2)$$

with

- $C_{ing}$  = concentration in food (Bq L<sup>-1</sup>) or (Bq kg<sup>-1</sup>)
- $Q_{ing}$  = annual amount of food consumed (L a<sup>-1</sup>) or (kg a<sup>-1</sup>)
- $DCC_{ing}$  = ingestion dose conversion coefficient (Sv Bq<sup>-1</sup>)

The dose conversion coefficients for the relevant nuclides considered are given in

Table C.1.

The concentration of nuclides in vegetation,  $C_{\text{ing}}$  ( $\text{Bq kg}^{-1}$ ), as a result of root uptake and interception can be calculated by

$$C_{\text{ing}} = \left( \dot{D} \times R \times \frac{(1 - e^{-(\lambda_0 + \lambda_w)t_a})}{Y \times (\lambda_0 + \lambda_w)} + C_{\text{soil}} \cdot B_v \right) e^{-\lambda_0 t_b} \quad (\text{C.3})$$

with

$\dot{D}$	=	deposition rate ( $\text{Bq m}^{-2} \text{ a}^{-1}$ )
$R$	=	fraction intercepted (-)
$Y$	=	yield ( $\text{kg m}^{-2}$ )
$\lambda_w$	=	removal rate from soil ( $\text{a}^{-1}$ ); $\lambda_w = 17.98 \text{ a}^{-1}$ for all nuclides except iodine
$\lambda_0$	=	decay constant ( $\text{a}^{-1}$ )
$t_a$	=	time from exposure to deposition (a)
$t_b$	=	time between harvest and consumption (a)
$C_{\text{soil}}$	=	concentration in dry soil ( $\text{Bq kg}^{-1}$ )
$B_v$	=	concentration coefficient from soil to vegetation ( $(\text{Bq kg}^{-1} \text{ fresh weight})/(\text{Bq kg}^{-1} \text{ dry soil})$ )

The value for the decay constant  $\lambda_0$  is obtained from [ICRP83]. The concentration coefficient  $B_v$  depends, for example, on the type of vegetation and nuclide (Table C.2). The exposure time and the time between harvesting and consumption are given in Table C.3. The fraction intercepted  $R$  (Table C.3) is calculated by

$$R = 1 - e^{-\mu Y} \quad (\text{C.4})$$

with

$\mu$	=	crop-class dependent interception constant ( $\text{m}^2 \text{ kg}^{-1}$ ) (listed in Table C.3).
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The concentration of radionuclides in soil is calculated assuming that the emission to the environment lasts for a period of 25 years [La94]. It is assumed that the radionuclides are distributed homogeneously in the upper 20 cm of the soil (root layer). The concentration in soil,  $C_{\text{soil}}$  ( $\text{Bq kg}^{-1}$ ), is then given by [La94]:

$$C_{\text{soil}} = \frac{\dot{D}}{\rho \times h \times (\lambda_0 + K_{ij})} (1 - e^{-(\lambda_0 + K_{ij})t_d}) \quad (\text{C.5})$$

with

$\dot{D}$	=	deposition rate ( $\text{Bq m}^{-2} \text{ a}^{-1}$ )
$\rho$	=	density of the soil ( $\text{kg m}^{-3}$ ); $\rho = 1300 \text{ kg m}^{-3}$
$h$	=	thickness of the soil layer (m); $h = 0.2 \text{ m}$
$K_{ij}$	=	removal rate from the soil ( $\text{a}^{-1}$ )
$t_d$	=	duration of deposition (a); $t_d = 25 \text{ a}$

The removal rate,  $K_{ij}$  ( $a^{-1}$ ), depends on the nuclide specific  $K_d$  value and is calculated by

$$K_{ij} = \frac{P + I - E}{\theta \times h \times \left(1 + \frac{K_d \cdot \rho}{\theta}\right)} \quad (C.6)$$

with

P	=	precipitation rate ( $m a^{-1}$ )
I	=	irrigation rate ( $m a^{-1}$ )
E	=	evaporation rate ( $m a^{-1}$ )
$\theta$	=	relative humidity in soil (-); $\theta = 0.2$ [La94]
$P + I - E$	=	precipitation surplus; $P + I - E = 0.35 m a^{-1}$
$K_d$	=	distribution coefficient ( $Bk kg^{-1}$ )( $Bq m^{-3}$ ) $^{-1}$ ; values are obtained from [La94]

Substituting equation (C.4), (C.5) and (C.6) in (C.3), the concentration in crops,  $C_{ing}$  ( $Bq kg^{-1}$ ), can be expressed in terms of a nuclide- and crop-dependent conversion coefficient  $F$  ( $m^2 a^{-1} kg^{-1}$ ) and the deposition rate  $\dot{D}_{soil}$  ( $Bq m^{-2} a^{-1}$ ):

$$C_{ing} = \dot{D}_{soil} \cdot F \quad (C.7)$$

The calculated conversion coefficients  $F$  are given in Table C.1.

The average amount of consumed food is corrected for losses during preparation (see Appendix A). With respect to consumption it is assumed that half the amount of vegetables is obtained from the vegetable garden and half is obtained from the COROP area in which the vegetable garden is located. For radiological risks the contribution from the consumption of fruits is not taken into account, because of a lack of concentration coefficients  $B_v$ .

For the total dose from consumption of beef and milk products, first the concentration of radionuclides in these products has to be calculated. In the calculation of the contamination of beef it is assumed that 70 kg fresh grass and 0.56 kg dry soil is consumed by cattle daily [La94; La94a]. The concentration in milk and beef is then given by

$$C_{milk} = F_{milk} \times (C_{grass} \cdot Q_{grass} + C_{soil} \cdot Q_{soil}) \times e^{-\lambda_0 t_b} \quad (C.8)$$

$$C_{meat} = F_{meat} \times (C_{grass} \cdot Q_{grass} + C_{soil} \cdot Q_{soil}) \times e^{-\lambda_0 t_b} \quad (C.9)$$

with

$C_{milk}$	=	concentration in milk ( $Bq L^{-1}$ )
$C_{meat}$	=	concentration in beef ( $bq kg^{-1}$ )
$F_{milk}$	=	concentration coefficient of milk from daily intake ( $Bq L^{-1}$ )( $Bq d^{-1}$ ) $^{-1}$
$F_{meat}$	=	concentration coefficient of meat from daily intake

		$(\text{Bq kg}^{-1})(\text{Bq d}^{-1})^{-1}$
$C_{\text{grass}}$	=	concentration in grass (fresh weight) ( $\text{Bq kg}^{-1}$ )
$Q_{\text{grass}}$	=	daily consumption of (fresh) grass by cattle ( $\text{kg d}^{-1}$ )
$C_{\text{soil}}$	=	concentration in (dry) soil ( $\text{Bq kg}^{-1}$ )
$Q_{\text{soil}}$	=	daily consumption of soil by cattle ( $\text{kg d}^{-1}$ )
$t_b$	=	time between milking, slaughter and consumption (Table C.4)
$\lambda_0$	=	radioactive decay constant ( $\text{a}^{-1}$ )

Equation (C.8) and (C.9) can be rewritten using equation (C.3), (C.4) and (C.5) as

$$C_{\text{milk}} = F_{\text{milk}} \times \dot{D}_{\text{soil}} \quad (\text{C.10})$$

$$C_{\text{meat}} = F_{\text{meat}} \times \dot{D}_{\text{soil}} \quad (\text{C.11})$$

with

$$\dot{D}_{\text{soil}} = \text{total deposition on the soil } (\text{Bq m}^{-2} \text{ a}^{-1})$$

The values for  $F_{\text{milk}}$  and  $F_{\text{meat}}$  for the radionuclides considered are given in Table C.1.

**Table C.1** Dose conversion coefficients for inhalation and ingestion and transfer coefficients as used in risk calculations

	$^{210}\text{Po}$	$^{210}\text{Pb}$	$^{238}\text{U}$	$^{232}\text{Th}$	$^{228}\text{Th}$	$^{228}\text{Ra}$	$^{226}\text{Ra}$	$^{222}\text{Rn}$
$\text{DCC}_{\text{inh}} (\text{Sv Bq}^{-1})$ <sup>(1)</sup>	$1.9 \cdot 10^{-6}$ <sup>(3)</sup>	$2.2 \cdot 10^{-6}$ <sup>(3)</sup>	$3.1 \cdot 10^{-5}$	$2.2 \cdot 10^{-4}$	$8.6 \cdot 10^{-5}$	$1.1 \cdot 10^{-6}$	$2.1 \cdot 10^{-6}$	$7.4 \cdot 10^{-9}$ <sup>(2)</sup>
$\text{DCC}_{\text{ing}} (\text{Sv Bq}^{-1})$ <sup>(1)</sup>	$2.1 \cdot 10^{-7}$	$1.3 \cdot 10^{-6}$	$3.6 \cdot 10^{-8}$	$1.8 \cdot 10^{-6}$	$2.7 \cdot 10^{-7}$	$2.7 \cdot 10^{-7}$	$2.2 \cdot 10^{-7}$	-
$F_{\text{grass}} (\text{m}^2 \text{ a kg}^{-1})$	$5.49 \cdot 10^{-3}$	$1.05 \cdot 10^{-2}$	$5.54 \cdot 10^{-3}$	$6.19 \cdot 10^{-3}$	$5.78 \cdot 10^{-3}$	$5.79 \cdot 10^{-3}$	$5.83 \cdot 10^{-3}$	-
$F_{\text{crop}} (\text{m}^2 \text{ a kg}^{-1})$	$9.29 \cdot 10^{-3}$	$1.50 \cdot 10^{-2}$	$9.44 \cdot 10^{-3}$	$1.07 \cdot 10^{-2}$	$1.02 \cdot 10^{-2}$	$1.03 \cdot 10^{-2}$	$1.04 \cdot 10^{-2}$	-
$F_{\text{grain}} (\text{m}^2 \text{ a kg}^{-1})$	$3.66 \cdot 10^{-3}$	$1.11 \cdot 10^{-2}$	$4.00 \cdot 10^{-3}$	$6.96 \cdot 10^{-3}$	$5.87 \cdot 10^{-3}$	$6.31 \cdot 10^{-3}$	$6.58 \cdot 10^{-3}$	-
$F_{\text{tubers}} (\text{m}^2 \text{ a kg}^{-1})$	$3.04 \cdot 10^{-3}$	$1.00 \cdot 10^{-2}$	$3.32 \cdot 10^{-3}$	$5.83 \cdot 10^{-3}$	$4.88 \cdot 10^{-3}$	$5.24 \cdot 10^{-3}$	$5.47 \cdot 10^{-3}$	-
$F_{\text{milk}} (\text{m}^2 \text{ a kg}^{-1})$	$1.14 \cdot 10^{-3}$	$2.31 \cdot 10^{-4}$	$1.92 \cdot 10^{-4}$	$2.43 \cdot 10^{-6}$	$2.05 \cdot 10^{-6}$	$1.26 \cdot 10^{-3}$	$1.37 \cdot 10^{-3}$	-
$F_{\text{beef}} (\text{m}^2 \text{ a kg}^{-1})$	$1.87 \cdot 10^{-3}$	$3.08 \cdot 10^{-4}$	$1.52 \cdot 10^{-4}$	$9.74 \cdot 10^{-5}$	$8.16 \cdot 10^{-5}$	$3.78 \cdot 10^{-4}$	$4.10 \cdot 10^{-4}$	-

<sup>(1)</sup> [BSV93; NRPB91]

<sup>(2)</sup> [Va91]

<sup>(3)</sup> For use of lung clearance Y, see sections 2.3 and 3.6.

The dose rates due to consumption of contaminated milk  $\dot{D}_{\text{milk}}$  ( $\text{Sv a}^{-1}$ ) and meat  $\dot{D}_{\text{meat}}$  ( $\text{Sv a}^{-1}$ ) are given by

$$\dot{D}_{\text{milk}} = C_{\text{milk}} \times Q_{\text{milk}} \times \text{DCC}_{\text{ing}} \quad (\text{C.12})$$

$$\dot{D}_{\text{meat}} = C_{\text{meat}} \times Q_{\text{meat}} \times \text{DCC}_{\text{ing}} \quad (\text{C.13})$$

with

$Q_{\text{milk}}$	=	annual consumption of milk (kg) (Table C.1)
$Q_{\text{meat}}$	=	annual consumption of beef (kg) (Table C.1)
$\text{DCC}_{\text{ing}}$	=	dose conversion coefficient ( $\text{Sv Bq}^{-1}$ ) (Table C.1)

Using the methods described above, the total dose to the reference group is calculated using the geographical information system (GIS) ARC-INFO. The MIR is calculated by multiplying the total dose by the risk conversion coefficient of  $2.5 \cdot 10^{-2} \text{ Sv}^{-1}$  [BSV93].

**Table C.2** Concentration factors  $B_v$  in four crop classes of Po, Pb, U, Th and Ra

element	$B_v$ (dry soil mass / fresh crop mass)			
	vegetables	grain	tubers	grass
Po	$1.0 \cdot 10^{-3}$	$9.0 \cdot 10^{-6}$	$6.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-3}$
Pb	$7.0 \cdot 10^{-2}$	$7.0 \cdot 10^{-2}$	$7.0 \cdot 10^{-2}$	$7.0 \cdot 10^{-2}$
U	$3.0 \cdot 10^{-3}$	$3.0 \cdot 10^{-3}$	$3.0 \cdot 10^{-3}$	$3.0 \cdot 10^{-3}$
Th	$4.0 \cdot 10^{-3}$	$4.0 \cdot 10^{-3}$	$4.0 \cdot 10^{-3}$	$4.0 \cdot 10^{-3}$
Ra	$3.0 \cdot 10^{-4}$	$3.0 \cdot 10^{-4}$	$3.0 \cdot 10^{-4}$	$3.0 \cdot 10^{-4}$

**Table C.3** Retention factor ( $\mu$ ), yield (Y), fraction intercepted (R), exposure time ( $t_a$ ) and preservation time ( $t_b$ ) for four crop classes

crop class	$\mu$ ( $\text{m}^2 \text{ kg}^{-1}$ )	Y ( $\text{kg m}^{-2}$ )	R	$t_a$ (a)	$t_b$ (a)
grass	2.9	7.4	1	0.082	0
vegetables	0.36	3.8	0.745	0.164	0.014
grain	0.13	0.7	0.087	0.164	0.274
tubers	0.14	4.6	0.475	0.164	0.274

**Table C.4** Average time ( $t_b$ ) between production and consumption for milk and beef

	$t_b$ (a)
milk	$8.2 \cdot 10^{-3}$
beef	$1.6 \cdot 10^{-2}$

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## APPENDIX D MODELLING RISKS OF EMISSIONS TO WATER

The transfer of the radionuclides through the water is modelled for emissions to water. The relevant surface water is divided into compartments and the transfer from one compartment to the next is calculated taking into account the water flow rate. Two pathways of radionuclides into water to humans are relevant: ingestion of fish products and the use of harbour sludge for land-fill of polders.

### D.1 Pathway ingestion of fish

After (partly) dissolving and dispersing in water, a certain fraction of the radionuclides accumulates in fish, shrimps, mussels and eel. Consumption of these products results in a risk for the population. This risk is assumed to be location independent, since the fish is caught at a certain fishing ground and can be consumed at any place in the Netherlands.

Available risk assessments were tested against the following criteria and if necessary adapted (BSV93, La94):

- diet as given in [BSV93]
- uniform transfer factors [La94]
- uniform dose factors [BSV93, NRPB91]
- use of correct assumptions on relevant fishery grounds [La94]

These relevant values are given in Table D.1.

When calculating MIR for emissions into the sea, the North Sea, Eastern and Western Scheldt are the relevant fishery grounds for salt water fish, Lake IJssel for eel, the Wadden Sea and the Eastern and Western Scheldt for mussels. If more than one fishery ground were involved, the one giving the highest risk was chosen to be representative for the calculation.

#### D.1.1 Elementary phosphorus production plant at Vlissingen

Previously, a risk assessment of the Vlissingen phosphorus production plant was made for emissions of 1988 (Kö88). In Table D.2 are given the emission of  $^{210}\text{Pb}$  and  $^{210}\text{Po}$  and the resulting activity concentrations in the relevant compartments. The activity concentrations in the different fishery products can be calculated with nuclide-dependent transfer factors. Multiplication by the relevant dose conversion factors, the quantity of annually consumed fishery products and the food preparation reduction factor (50% [La94]) results in the yearly dose. Finally, the risk factor ( $2.5 \cdot 10^{-2} \text{ Sv}^{-1}$ , [OR90]) is used to determine the resulting risk. The risk for 1992 is calculated using the emissions of  $^{210}\text{Pb}$  and  $^{210}\text{Po}$  for that year (Appendix G.1).

**Table D.1** Parameters for modelling risks of emissions to water

	Consumption patterns (kg/a) [BSV93]	Bio-accumulation factors [La94]				Food preparation reduction factor [La94]
		<sup>210</sup> Pb	<sup>210</sup> Po	<sup>226</sup> Ra	<sup>230</sup> Th	
Fish	4	200	2000	500	600	50%
Eel	0.3	300	500	50	30	50%
Mussels <sup>1)</sup>	0.2625	1 000	10 000	1 000	1 000	50%
Shrimps <sup>1)</sup>	0.0375	1 000	50 000	100	1 000	50%
	Dose conversion factors (Sv Bq <sup>-1</sup> ) [BSV93, NRP91]	$1.3 \cdot 10^{-6}$	$2.1 \cdot 10^{-7}$	$2.2 \cdot 10^{-7}$	$3.5 \cdot 10^{-7}$	

<sup>1)</sup> Since the bio-accumulation factors of <sup>210</sup>Po for shrimps and mussels differ considerably, the contributions of the two are taken into account separately. The ratio of the consumption of shrimps and mussels (1:7) was taken from Table 5.5 of [We89]. The total consumption of (shell)fish was taken from [BSV93].

**Table D.2** Emissions from the elementary phosphor plant at Vlissingen and resulting activity concentrations of <sup>210</sup>Pb and <sup>210</sup>Po in the relevant compartments

		<sup>210</sup> Po	<sup>210</sup> Pb	<sup>210</sup> Po ingrowth
emission in 1988 (GBq/a) [Kö88]		37	37	37
Activity concentration in :	relevant compartment for:			
Oosterschelde (Bq m <sup>-3</sup> )	mussels	0.037	0.05	0.014
Westerschelde (Bq m <sup>-3</sup> )	shrimps/fish	0.4	0.4	0.02

### D.1.2 Phosphoric acid production plants at Vlaardingen and Pernis

A risk assesment for both phosphoric acids production companies is performed for 1987 [Kö88]. In Table D.3 the emissions of the most relevant nuclides and the resulting activity concentrations in the relevant compartments are given. For calculating the risk in 1990 the emissions of 1987 are replaced by the 1990 emissions.

**Table D.3** Emissions from the phosphoric acid plants at Vlaardingen and Rotterdam resulting activity concentrations of  $^{210}\text{Po}$ ,  $^{210}\text{Pb}$ ,  $^{226}\text{Ra}$  en  $^{230}\text{Th}$  in the relevant compartments

	$^{210}\text{Po}$	$^{210}\text{Pb}$	$^{226}\text{Ra}$	$^{230}\text{Th}$ <sup>1)</sup>
emission of the phosphoric acid production plants in 1987 (GBq/a) [Kö91]	1600	1600	1600	800
activity concentration in: relevant compartment for:				
Hoek van Holland (Bq m <sup>-3</sup> ) fish/shrimps	1	1	6	0.3
Waddenzee (Bq m <sup>-3</sup> ) mussels	1	1	5	0.2

<sup>1)</sup> The emission of  $^{230}\text{Th}$  is assumed to be 50% of the emission of  $^{238}\text{U}$  [Wo92a,b]

### D.1.3 Primary iron and steel production plant at IJmuiden

For 1990 a risk assessment was performed [We89], which gives the risk resulting from an emission of 1 Bq s<sup>-1</sup>. The relevant nuclides and compartments are given in Table D.4. Actual emissions are taken from [We91]. The concentrations in the Wadden Sea and Lake IJssel are the result of a reference emission of 1 Bq s<sup>-1</sup> (Tables 5.1 - 5.4 of [We89]).

For emissions to water the resulting dose is dependent on the characteristics of the discharge. In fact three types of reference plants were considered:

- a) a plant emitting radionuclides into an estuary,
- b) a plant emitting into a river,
- c) a plant emitting radionuclides into a sea.

On the basis of the emissions of a plant into water risk assessments can be made using the adjusted consumption patterns from [la94]. Table D.5 presents the risk as a result of an emission of 1 GBq/a for the different radionuclides.

### D.2 Pathway harbour sludge

Only for the two phosphoric acid plants at Pernis and Vlaardingen is the dose resulting from the use of harbour sludge for land-fill purposes relevant. These plants emit radionuclides into the Nieuwe Waterweg, which is dredged yearly. The results have a preliminary status and further investigation of these risks is in progress. For the risk assessment the harbour is divided into a number of (sub)compartments, depending on the

**Table D.4** Emissions from the primary iron and steel production plant at IJmuiden resulting activity concentrations of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  for the relevant compartments

	$^{210}\text{Po}$	$^{210}\text{Pb}$	$^{210}\text{Po}$ ingrowth	
emission direct into water ( $\text{GBq a}^{-1}$ )	8	0.51	0.51	
deposition on water from sifa ( $\text{GBq a}^{-1}$ )	84	54	54	
deposition on water from pefa ( $\text{GBq a}^{-1}$ )	7.4	0.88	0.88	
deposition on water from blast-furnace gas	0.25	0.66	0.66	
activity concentrations ( $\text{Bq m}^{-3}$ ) as a result of emission in:	relevant compartment for:			
Wadden Sea/coast	fish/shrimps/mussels			
	direct emission to water	$5.7 \cdot 10^{-5}$	$7.6 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$
	deposition from sifa	$1.2 \cdot 10^{-5}$	$1.6 \cdot 10^{-5}$	$4.3 \cdot 10^{-6}$
	deposition from pefa	$5.5 \cdot 10^{-6}$	$7.5 \cdot 10^{-6}$	$2.0 \cdot 10^{-6}$
	emission from blast-furnace gas	$5.0 \cdot 10^{-6}$	$6.8 \cdot 10^{-6}$	$1.8 \cdot 10^{-6}$
Lake IJssel	eel			
	deposition from sifa	$8.7 \cdot 10^{-6}$	$1.1 \cdot 10^{-5}$	$2.3 \cdot 10^{-6}$
	emission from pefa	$4.0 \cdot 10^{-6}$	$5.0 \cdot 10^{-6}$	$1.0 \cdot 10^{-6}$
	deposition from blast-furnace gas	$3.6 \cdot 10^{-6}$	$4.5 \cdot 10^{-6}$	$9.5 \cdot 10^{-7}$

Sifa and pefa are two plants on the industrial site.

transport and sedimentation profiles to be modelled; the sludge deposition in each compartment is measured. The compartment in which the highest  $^{226}\text{Ra}$  concentration is measured is used for the risk assessment. The maximum  $^{226}\text{Ra}$  activity concentration from an emission of  $1 \text{ GBq/a}$   $^{226}\text{Ra}$  is  $0.056 \text{ Bq/kg}$  [KEMA94]. Further, it was concluded that an  $^{226}\text{Ra}$  activity concentration of  $25 \text{ Bq/kg}$  in the ground results in a yearly dose of  $1 \text{ mSv/a}$  [Va93, Mo92]. Therefore, the annual risk due to the emission of  $1 \text{ GBq/a}$  of  $^{226}\text{Ra}$  is about  $5.6 \cdot 10^{-8} \text{ a}^{-1}$ . The actual risk can be calculated by multiplying this risk with the emissions of the plants to the Nieuwe Waterweg.

**Table D.5** MIR from a unit emission of 1 GBq/a to water for four radionuclides

Emission compartment	MIR for a reference person (Sv) due to nuclide			
	<sup>210</sup> Po	<sup>210</sup> Pb	<sup>226</sup> Ra	<sup>230</sup> Th
estuary	$2.9 \cdot 10^{-10}$	$1.6 \cdot 10^{-10}$		
river	$2.1 \cdot 10^{-11}$	$1.1 \cdot 10^{-11}$	$2.3 \cdot 10^{-11}$ (*) $5.6 \cdot 10^{-8}$ (#)	$4.3 \cdot 10^{-12}$
sea	$5.9 \cdot 10^{-11}$	$5.9 \cdot 10^{-11}$		
deposition	$6.8 \cdot 10^{-12}$	$1.3 \cdot 10^{-11}$		

(\*) excluding pathway 'harbour sludge on polders'

(#) preliminary figure for pathway 'harbour sludge on polders'

## APPENDIX E MODELLING EXTERNAL RADIATION

For the calculation of dose from external radiation from solid waste and raw materials the model MARMER was used. MARMER is a computer program for the calculation of energy absorption and dose from several radiation sources at any point of a complex geometry [K189c]. It contains a nuclide data library with decay characteristics and gamma yields [K189a]. It makes use of a Monte-Carlo integration technique for the integration over energy and source volume. MARMER is validated with experiments and similar programs [K189a, K189b]. In this study MARMER version 2.0, obtained from the Nuclear Energy Association DATA BANK<sup>1</sup>, was used.

The Monte-Carlo integration procedure is stopped when the relative precision of the integral is below 2%. Hence, the precision of the numbers due to the integration method is 2%. Other uncertainties are attached to, for instance, the input-output balance and associated with the estimation of radionuclide content.

It is assumed that all nuclides from the U and Th decay series and <sup>40</sup>K are relevant. For external gamma radiation the most relevant nuclides are <sup>234</sup>Pa (metastable), <sup>214</sup>Pb, <sup>214</sup>Bi, <sup>228</sup>Ac, <sup>224</sup>Ra, <sup>212</sup>Pb, <sup>212</sup>Bi, <sup>208</sup>Tl and <sup>40</sup>K. The activity of the daughter nuclides is assumed to be the same as the mother nuclide (except for the mother <sup>228</sup>Ac, which has the same activity as the daughter <sup>228</sup>Th). The calculations were performed for a point of 1 m above ground level. No shielding was taken into account.

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<sup>1</sup> The NEA DATA BANK of NEA/OECD is gratefully acknowledged for making MARMER available for RIVM.

## **APPENDIX F BASIC DATA**

### **F.1 Process descriptions and emissions**

This appendix contains the process descriptions and emissions of NNI with the largest throughput of natural radionuclides. The highest natural radionuclide contents are found in phosphate ore, iron ore, fossil fuels and mineral sands like titanium and zirconium. Phosphate ore is used for the production of phosphoric acid, an intermediate product for a lot of applications. The most important one is the production of phosphate fertilizers. Phosphoric acid can be produced in two different ways, by the thermic and by the wet process. In the Netherlands there is only one elementary phosphor plant, while there are four producers of phosphate-containing fertilizers. Two of them produce phosphoric acid as the starting material of these fertilizers. The other two use phosphate rock as starting material for other phosphate-containing fertilizers.

Another industry with a lot of derivative products is an iron and steel production plant. On the site of this plant several processes take place: preparation of the iron ore, production of cokes, production of raw iron and production of raw steel.

Fossil fuels and derivatives, such as cokes, coal and coal tar and natural gas, also contain natural radionuclides. Industries which process these materials include coal tar plants, coal- or gas-fired power plants, and those which produce, refine and deliver gas and oil. Radionuclides are emitted due to the high temperatures of the production process or during treatment of raw materials, such as milling and transshipment. Relevant industries include the mineral sands processing industries, cement production and the ceramic industry (bricks, roof-tiles and earthenware). Finally, the titanium pigment production is considered.

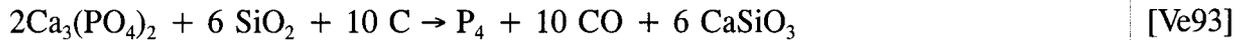
#### **F.1.1 The elementary phosphor production plant at Vlissingen**

The elementary phosphor production plant at Vlissingen produces elementary phosphorus and the detergents NTPP (sodium tripolyphosphate), AS (alkylsulphonate), DMT (dimethyl terephthalate) and TAED (tetra-acetyl ethylenediamine). From the radiological point of view the production of elementary phosphorus is the most relevant.

##### *Process description*

The main input materials for the elementary phosphorus production are phosphate ore, grind and cokes, as well as small amounts of clay (see Table F.1). First, the phosphate ore is sintered at 1000 °C and a slurry of water, clay, filtercake from the wet-acid production, phosphate dust and Cottrell dust (an internal process stream from the phosphorus furnace) is added. The phosphorus is obtained by heating the granulated

pellets up to 1450 °C in an electrothermic furnace, under reducing conditions and using a slag inducer (gravel) and a reducing agent (coke). The corresponding reaction equation is:



From the elementary phosphorus, phosphoric acid is produced with a concentration ranging from 59% to 92%.

#### *Process output and waste materials*

Besides some intermediate products also other process output materials are obtained. These materials are phosphorus slag (calcium silicate), calcinate, phosphogypsum and AsS-filtercake (both from the wet-acid plant). Table F.1 gives the annual amounts processed. The phosphorus slag is reused in hydraulic and road constructions; the other process output materials are not reused. The so-called Cottrell dust (30 kton/a) is obtained from cleaning the gas mixture of the electrothermic furnace by electrofilters. Reuse of this dust in the sinter plant is prohibited by the enlarged zinc concentrations. The zinc-rich fraction, about 10% of the production, is calcined and concentrated to about 1 kton calcinate [Hu93a]. The calcinate is both chemical and radioactive waste and is stored at the company site. In the laboratory, an expensive process was developed which is able to treat the Cottrell dust [Ve93]. Implementation of this process on an industrial scale would reduce the radioactive waste to 15 kton/a. The residue, 400 ton/a, could then be stored on the company site.

#### *Emissions to the environment*

During the thermal processing of the phosphate ore  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  are emitted into air. In 1992  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  emissions to air of respectively 490 and 66 GBq/a were reported [Ho93]. Averaged over five years, the emissions were 617 GBq/a and 54 GBq/a, respectively [Ti93]. The  $^{222}\text{Rn}$  in the ore is assumed to escape during processing (about 563 GBq/a).  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  are released on surface waters, mainly by the sinter plant, where sea water is used for the sinter process, and to a lesser extent by the phosphorus furnace and the wet-acid plant. In 1992, 166 GBq/a  $^{210}\text{Po}$  and 24 GBq/a  $^{210}\text{Pb}$  were released to water [Ho93], the five-year averaged releases are 93 GBq/a  $^{210}\text{Po}$  and 38 GBq/a  $^{210}\text{Pb}$  [Ti93]. Considering the input-output balance of 1992 for the nuclides  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  the output exceeds the input by 38% and 14%, respectively. This is probably due to uncertainties in the calcinate measurements. For nearly all other radionuclides the in- and output is completely balanced. Transshipment emissions are based on the throughput of phosphate ore and estimated to be under 1 GBq/a for all radionuclides.

In 1985, emissions to air were estimated to be 350 and 150 GBq a<sup>-1</sup> for  $^{210}\text{Po}$  and  $^{210}\text{Pb}$ , respectively [UN88]. In Peute et al. [Pe89] emissions in 1984 to air were estimated to be

**Table F.1** Input and output of the elementary phosphor production plant at Vlissingen in 1992

	throughput	<sup>238</sup> U	<sup>232</sup> Th	<sup>226</sup> Ra	<sup>222</sup> Rn	<sup>210</sup> Pb	<sup>210</sup> Po	<sup>40</sup> K
	(kton/a)	(Bq/kg)	(Bg/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)
<b>input</b>								
florida ore <sup>1)</sup>	359	1500	20	1500	1500	1500	1500	110
kovdor ore	113	30		30	30	30	30	
palfos ore	95	110		110	110	110	110	
grind <sup>2)</sup>	360	22	3	22	22	23	23	39
cokes <sup>2)</sup>	120	20	13	20	20	14	3.7	47
clay <sup>3)</sup>	25	39	41	41	41	41	41	582
<b>total (GBq/a)</b>		563	11	563	563	563	562	74
<b>output</b>								
phosphorus slag <sup>4)</sup>	533	1057	20	1057	<sup>i)</sup>	40	18	138
phosphorus	77							
gypsum <sup>5)</sup>	10							
calcinate	0.8					610000	114000	
AsS filtercake <sup>6)</sup>	0.1							
<b>total (GBq a<sup>-1</sup>)</b>		563	11	563	0	537	106	74
<b>emissions to air (GBq a<sup>-1</sup>)<sup>7)</sup></b>					563	66	490	
<b>emissions to water (GBq a<sup>-1</sup>)<sup>7)</sup></b>						24	166	
<b>transshipment emissions <sup>8)</sup>:</b>								
to air (GBq a <sup>-1</sup> )		0.06	0.001	0.06	0.06	0.06	0.06	0.004
to water (GBq a <sup>-1</sup> )		0.18	0.002	0.18	0.18	0.18	0.18	0.013

i) <sup>222</sup>Rn concentration is equal to 0 after thermal process, but rapidly grows into <sup>226</sup>Ra concentration

1) quantities and activity concentrations from [Ho93]

2) estimations on the basis of the total quantity of ore used and reaction equation; activity concentrations in cokes from We91, in gravel assumed to be about chalkstone [We91]

3) quantity small [Hu93a], activity concentration from [Vo93]

4) activity concentration for nuclides other than <sup>210</sup>Po and <sup>210</sup>Pb calculated on balancing input and output.

5) dumped (no chemical waste)

6) exported to Germany; this quantity is reduced to 40 ton/a [Hu93a] in 1993

7) registered emissions for <sup>210</sup>Pb and <sup>210</sup>Po in 1992 [Ho93\*]; <sup>222</sup>Rn emission is estimated

8) transshipment emissions are assumed to be in order of magnitude of other phosphate processing industries (0.011% of ore throughput emitted to air and 0.033% to water [Bo92])

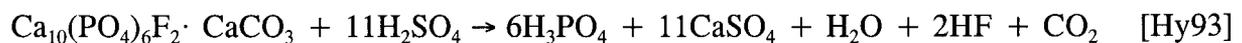
lower than 600 and 400 GBq a<sup>-1</sup>, respectively, assuming a 40% higher phosphate ore throughput.

### F.1.2 The phosphoric acid plants at Vlaardingen and Rotterdam

Two phosphoric acid plants are situated on the Nieuwe Waterweg. In 1987, the Vlaardingen and the Pernis plants produced 200 and 225 kton P<sub>2</sub>O<sub>5</sub>, respectively [Ho92]. As a result of government policy the production was considerably reduced in later years. The starting materials for the production of phosphoric acid are phosphate ore and sulphuric acid. The type of ore used by the plants is different: the Rotterdam plant uses Moroccan ore and the Vlaardingen plant a mixture of Jordan and Florida ore. Moroccan ore is usually the most contaminated with radionuclides [UN82], followed by Florida and Jordan ore [Wo92a]. In this report it is assumed that Jordan ore only is used.

#### *Process description*

The phosphate ore is extracted in presence of the sulphuric acid using the hemihydrate process. At the Vlaardingen plant the process temperature is about 100 °C. The corresponding reaction equation is given by:



Since 1993, one plant produces phosphoric acid using the hemi-dihydrate process. Recently, the other one shut down. The hemi-dihydrate process is nearly identical to the hemihydrate process except for the final process step. The filtered hemihydrate gypsum is recrystallized to dihydrate in a recrystallization tank. The non-extracted ore and the phosphate captured in the hemihydrate are converted to phosphoric acid, resulting in a lower quantity of contaminants in the gypsum.

At the Pernis plant, it is planned to use an extra washing step in the hemi-dihydrate process. Process temperatures are slightly lower (95 °C) and the reaction equation differs only slightly:



#### *Process output and waste materials*

The process output materials of the hemi-dihydrate process are phosphoric acid, small amounts of sulphuric acid and a huge amount of gypsum slurry. Quantities and activity concentrations are given in Table F.2 and Table F.3. The phosphoric acid is used for the production of fertilizers, the sulphuric acid (with negligible activity concentrations) is reused in the process and the gypsum slurry is discharged into the Nieuwe Waterweg.

### *Emissions to the environment*

From the quantities processed in 1990 [Ho92] and the activity concentrations measured in 1991 [Wo92a] a discharge into the Nieuwe Waterweg of about 980 GBq a<sup>-1</sup> <sup>210</sup>Po, 650 GBq a<sup>-1</sup> <sup>210</sup>Pb, 740 GBq a<sup>-1</sup> <sup>226</sup>Ra and 340 GBq a<sup>-1</sup> <sup>238</sup>U from the slurry of the Vlaardingen plant in 1990 is calculated (Table F.2). Emissions to water from transshipment are negligible.

During the hemihydrate process all <sup>222</sup>Rn in the phosphate ore is assumed to escape from the reactors to air (about 820 GBq/a). Transshipment also results in radionuclide emissions to air, but the activity of all radionuclides is estimated to be far lower than 1 GBq a<sup>-1</sup> [Bo92]. For most radionuclides the input-output balance is approximately in equilibrium (Table F.2). Only for <sup>210</sup>Po can about 15% of the radionuclide input not be found in the output.

Discharges from the Vlaardingen plant are of the same order of magnitude (Table F.3). From the quantities processed in 1990 [Ho92] and the activity concentrations measured in 1992 [Wo92b], about 1000 GBq/a <sup>226</sup>Ra, 1130 GBq/a <sup>210</sup>Pb and 840 GBq/a <sup>210</sup>Po is calculated to be discharged in the slurry in 1990. Emissions to water from transshipment are negligible compared to the discharge with the slurry. Here also the <sup>222</sup>Rn content of the ore is assumed to escape during processing (about 1,040 GBq/a) and emissions to air from transshipment are low and estimated to be far lower than 1 GBq a<sup>-1</sup> [Bo93].

The radionuclide balance is in equilibrium for most nuclides (Table F.3), except for <sup>210</sup>Pb and <sup>210</sup>Po, where the output of radionuclides exceeds the input by 20% and 10%, respectively.

In 1985 the maximum throughput of <sup>226</sup>Ra was estimated to be 3500 GBq/a, the total for four companies, including the producers of fertilizers [Pe89]. The total phosphogypsum (for two companies) was estimated to be about 2000 kton [Ko85]. Activity concentrations were lower for <sup>238</sup>U and <sup>210</sup>Pb and somewhat higher for <sup>226</sup>Ra and <sup>210</sup>Po [Ko85, UN82].

### *Trends in discharges*

The discharges from the Vlaardingen plant are limited by the Law on the Pollution of Surface Waters. Until 1991 the maximum annually allowed discharge was 1040 million tonnes dihydrate, from 1991 till 1994 1200 million tonnes and since 1994 this quantity may not exceed 800 million tonnes per year [Hy93]. In the year 2000 radionuclide discharges of the Vlaardingen plant for all possible pathways is not allowed to exceed the MPR level (maximal permissible risk) [OR90, Hy93].

The quantities of radionuclides, which the Pernis plant is allowed to discharge, as given in the permit application [Ke92] are shown in Table F.4. In the year 2000 the radiation risks summed over all exposure pathways as a result of the discharge of radionuclides in the Nieuwe Waterweg should not exceed the maximum allowable risk level (MPR level)

**Table F.2** Input and output of the phosphoric acid plant at Vlaardingen in 1990<sup>1)</sup>

	throughput	<sup>238</sup> U	<sup>228</sup> Th	<sup>226</sup> Ra	<sup>222</sup> Rn	<sup>210</sup> Pb	<sup>210</sup> Po	<sup>40</sup> K
	(kton/a)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)
<b>input</b>								
ore <sup>2)</sup>	700	936	20	1167	1167	977	1773	110
sulphuric acid	500	11	3.0	40			1	
<b>total (GBq/a)</b>		661	16	837	817	684	1242	77
<b>output</b>								
gypsum slurry <sup>3)</sup>	1060	318	7.1	696		618	943	75
product acid <sup>4)</sup>	490	580	5.0	80	i)		110	
silicic acid	27	21	1.0	13	i)		2.3	
<b>total (GBq/a)</b>		621	10	776	0	654	1051	79
<b>emissions to water (GBq/a)<sup>5)</sup></b>		336	8	737		654	997	79
<b>emissions to air (GBq/a)<sup>6)</sup></b>		0.07	0.002	0.09	817	0.08	0.14	.008

i) <sup>222</sup>Rn concentration is equal to 0 after processing, but rapidly grows into activity concentration of <sup>226</sup>Ra

1) quantities from 1990 [Ho92], activity concentrations from 1991 [Wo92a]

2) activity concentration of <sup>222</sup>Rn is assumed to be equal to the one of <sup>226</sup>Ra; K-40 activity concentration from [UN82]

3) gypsum slurry 3778 kton with 28% dry material, thus equal to 1060 kton phosphogypsum

4) P<sub>2</sub>O<sub>5</sub> content 42%, thus equal to about 200 kton P<sub>2</sub>O<sub>5</sub>

5) on the basis of the total gypsum slurry being discharged into the Nieuwe Waterweg, shipment emissions to water are negligible compared to radionuclide quantities in gypsum slurry

6) emissions from shipment and processing; emissions to air during shipment are 0.011% of ore throughput [Bo92]; emissions from processing: the total quantity <sup>222</sup>Rn present in the phosphate ore is assumed to escape to air.

[OR90]. Up to 1994 the total emissions to air for the phosphoric acid and the grain plants are estimated to be less than 0.15 GBq/a and after that time the total radionuclide emissions to air were not allowed to exceed 0.04 GBq/a [Ke92].

### F.1.3 Fertilizer production plants

Besides the phosphoric acid and phosphor producers there are two producers of phosphate-containing fertilizers. The fertilizers are produced by mixing phosphate ore, phosphoric acid, sulphuric acid and other additives (for example, mono-ammonium phosphate, ammonium sulphate and potassium chloride). By taking certain quantities of the input materials, fertilizers with specific characteristics are obtained. The content of the different additives in NPK fertilizers (nitrogen-phosphorus-potassium), in general, is normally given

**Table F.3** Input and output of the phosphoric acid plant at Rotterdam in 1990<sup>1)</sup>

	throughput (kton/a)	<sup>238</sup> U (Bq/kg)	<sup>228</sup> Th (Bq/kg)	<sup>226</sup> Ra (Bq/kg)	<sup>222</sup> Rn (Bq/kg)	<sup>210</sup> Pb (Bq/kg)	<sup>210</sup> Po (Bq/kg)	<sup>40</sup> K (Bq/kg)
<b>input<sup>2)</sup></b>								
ore	650	1364	10	1603	1603	1519	1500	110
<b>total (GBq/a)</b>		887	6.5	1042	1042	987	975	72
<b>output</b>								
gypsum slurry <sup>3)</sup>	1014	19	3.0	990		1114	826	75
product acid <sup>4)</sup>	737	1146	6.0	12	<sup>i)</sup>	100	310	0
<b>total (GBq/a)</b>		864	7.5	1013		1203	1066	76
<b>emissions to water (GBq/a)<sup>5)</sup></b>		19	3.0	1004	0	1130	838	76
<b>emissions to air (GBq/a)<sup>6)</sup></b>		0.13	0.001	0.16	1,042	0.15	0.15	0

i) <sup>222</sup>Rn concentration is equal to 0 after process, but rapidly grows into an activity of <sup>226</sup>Ra

1) quantities from 1990 [Ho92], activity concentrations in 1992 [Wo92b]

2) also 450 kton a<sup>-1</sup> sulphuric acid. activity concentrations negligible

3) 3380 kton gypsum slurry of which 30% dry material, thus equal to 1014 kton phosphogypsum

4) P<sub>2</sub>O<sub>5</sub> content 28%, thus equal to ca. 215 kton P<sub>2</sub>O<sub>5</sub>; negligible activity concentrations

5) on the basis of the total gypsum slurry being discharged into the Nieuwe Waterweg. shipment emissions to water are negligible compared to radionuclide quantities in gypsum slurry.

6) emissions from shipment and processing; emissions to air during shipment [Bo93]; during processing the total quantity <sup>222</sup>Rn present in the phosphate ore is assumed to escape to air.

**Table F.4** Trend in radionuclide discharges (GBq/a) according to the permit of the Pernis plant

date	<sup>228</sup> Ra (*)	<sup>226</sup> Ra (*)	<sup>210</sup> Pb (*)	<sup>210</sup> Po (*)
till 01-01-94	15	975	975	725
01-01-94 till 01-01-97	25	550	550	400
01-01-97 till 31-12-99	18	385	385	280

(\*) quantities based on an emission of 1015 kton phosphogypsum [Ke92]

on the packages.

### Process description

The production processes in the fertilizer industry differ only slightly. The SSP and TSP production processes are described below. The TSP production process consists of mixing phosphate ore and phosphoric acid in a 4:6 ratio [Vo92]. The end product, the NPK (nitrogen-phosphorus-potassium) fertilizer, is produced by mixing the intermediate product

TSP with additives [Ho92]. The reaction equation of the TSP production is:



The SSP production process consists of mixing phosphate ore and sulphuric acid in a 6:4 ratio [Ho92]. The reaction equation is as follows:



The reaction products are processed together to obtain SSP.

#### *Process output and waste materials*

Since in the TSP and SSP production process no by-products are formed, no other process output materials than the intermediate products are formed. This implies that nearly all contaminants are concentrated in the fertilizer product.

#### *Emissions to the environment*

Emissions of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  from the fertilizer plant at Amsterdam were measured in 1990. During processing of the ore  $^{222}\text{Rn}$  (about 220 GBq/a) escapes. Emissions into air of other nuclides are much smaller, about 0.034 GBq/a  $^{210}\text{Po}$  and 0.044 GBq/a  $^{210}\text{Pb}$ . With the process water, 0.057 GBq/a  $^{210}\text{Po}$  and 0.054 GBq/a  $^{210}\text{Pb}$  are released into the surface waters [Vo92]. It must be acknowledged that the uncertainty in the measurements is about 50%. As a result of transshipment losses, low emissions in about the same order of magnitude as the process emissions occur.

Since emissions mainly result from the use of the phosphate ore, emissions of the other plant at Sas van Gent can be estimated by comparing the phosphate ore throughput of these companies. Since production data are not available for the plant at Sas van Gent it is assumed that the emissions are of the same order of magnitude.

The input-output analysis of the fertilizer production plant at Amsterdam is given in Table F.5. This plant produces TSP as well as complex fertilizers. Hence, the input-output balance is simplified. The balance is in equilibrium for most radionuclides except  $^{210}\text{Po}$  and  $^{210}\text{Pb}$ . A possible explanation is the simplification of the input-output balance or the uncertainty in the emission measurements.

#### **F.1.4 The primary iron and steel production plant at IJmuiden**

Primary iron and steel are produced by one company in the Netherlands. In 1990 the total production amounted to about 5.57 million tonnes of raw steel [An92a]. The whole production process from iron ore to raw steel is performed at the company site.

**Table F.5** Input and output balance of the fertilizer plant at Amsterdam in 1990

	throughput		U-238	Th-228	Ra-226	Rn-222	Pb-210	Po-210	K-40
	(kton/a)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)
<b>input</b>									
phosphate ore	150	1450	9		1440	1440	1360	1240	33
phosphoric acid	225	2350	3		24	24	29	124	12
<b>total (GBq/a)</b>		746	2		221	221	211	214	8
<b>output</b>									
TSP	375	2150	5		500	<sup>i)</sup>	790	710	24
<b>total (GBq/a)</b>		806	2		188	0	296	266	9
process emissions :									
<b>to air (GBq/a) <sup>1)</sup></b>						221	0.044	0.034	
<b>to water (GBq/a) <sup>1)</sup></b>							0.054	0.057	
transshipment emissions:									
<b>to air (GBq/a) <sup>2)</sup></b>		0.02	0.0001		0.02	0.02	0.02	0.02	0.001
<b>to water (GBq/a) <sup>2)</sup></b>		0.07	0.0004		0.07	0.07	0.07	0.06	0.002

<sup>1)</sup> see Vo92 for the emissions of Pb-210 and Po-210 from the plant. Rn-222 emissions are estimated

<sup>2)</sup> emissions are estimated by taking the transshipment losses of other phosphate processing industries (0.011% of ore throughput emitted to air and 0.033% to water [Bo92])

### Process description

First, the iron ore has to be handled in the sinter or pellet plant [An92a]. Temperatures are 1200 -1300 °C. <sup>210</sup>Po and <sup>210</sup>Pb are emitted and <sup>222</sup>Rn emission can also be expected. Besides sintered and palletized ore a large amount of cokes is also used in the blast-furnace to create reducing conditions. Furthermore, cokes function as a fuel and as charge carrier. Process temperatures are about 1000 °C. The cokes are also produced at the location. Then these materials are put together in the blast-furnace to produce raw iron. In the blast-furnace raw iron is produced by reduction of iron oxides in the ore using carbon monoxide. There are four blast-furnaces on the plant site, two of which are in use. The process temperature is about 1300 °C. The final step in the production process is the production of raw steel. To produce raw steel, the carbon content of the raw iron must be lowered. This implies that process temperatures must be high enough to reduce the carbon (about 1500 °C). Two oxy-steel plants are on the company site.

### *Process output and waste materials*

All processes described have different input and output materials and corresponding emission profiles. Table F.6 gives the total radionuclide throughput of all processes. Nearly all output materials are reused. The zinc-poor filtercake (sinter plant) and the oxygen (to enrich the blast-furnace gas) are reused internally. The gas from the cokes furnace is partly reused in the cokes plant and partly transported to a local electricity company in Velsen. The coal tar (coal tar handling industry, see F.1.5), the slag granulate (cement industry, F.1.10), the oxychalk slag (hydraulic and road constructions), and the sulphate and sulphuric acid (fertilizer industry, e.g. see F.1.3) are externally reused. The only process output material which is not reused is the zinc-rich filtercake, which is stored at the company site.

### *Emissions to the environment*

The release of radionuclides from all emission points on the company site was measured in 1990 [We91]. The sinter and pellet plants are the major sources of the emissions of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  into the air. In total, about 92 GBq/a  $^{210}\text{Po}$  and 55 GBq/a  $^{210}\text{Pb}$  are emitted. Emissions to water, resulting from the use of gas scrubbers, are 8 GBq/a  $^{210}\text{Po}$  and 0.5 GBq/a  $^{210}\text{Pb}$  in 1990. Discharges are mainly the result of the fluor scrubbers of the pellet plant and the gas scrubbers of the blast-furnace. Depending on the gas fraction used by one's own company at most 0.25 GBq/a  $^{210}\text{Po}$  and 0.66 GBq/a  $^{210}\text{Pb}$  is injected into the gas transportation net and goes to a local electricity company. Considering the radionuclide balance, it can be concluded that especially the  $^{210}\text{Pb}$  output is larger than the input. Zinc-rich filtercake is the most important contributor to the output streams of radionuclides. Obviously, this balance is not perfect. For the other radionuclides, except for  $^{40}\text{K}$ , the balances are nearly in equilibrium; this imbalance probably is the result of not sampling all output materials and emissions of this nuclide [We91]. Transshipment losses were estimated by taking the emission percentages of the phosphate treatment industry [Bo92].

Data is also available on the emissions in 1988 [We89], when 4.8 million ton raw iron was produced. The resulting radionuclide emissions to air were estimated to be, at most, 100 GBq/a for both  $^{210}\text{Po}$  and  $^{210}\text{Pb}$ . The discharge into water was estimated to be 0.87 GBq/a  $^{210}\text{Po}$  and 0.21 GBq/a  $^{210}\text{Pb}$ . The granulate slag contained about 2.5 GBq/a  $^{210}\text{Po}$  and 1.4 GBq/a  $^{210}\text{Pb}$ . The injection into the gas transportation net going to the local electricity company is estimated to be, at most, 0.72 GBq/a, both for  $^{210}\text{Po}$  and  $^{210}\text{Pb}$ . Comparing the two emissions data sets it can be concluded that most emissions are of the same order of magnitude.

In 1988 emissions of  $^{210}\text{Po}$ ,  $^{210}\text{Pb}$  and  $^{222}\text{Rn}$  were estimated to range between 200 and 610 GBq/a, mainly as a result of overestimating the activity concentrations of the input materials [Pe89].

**Table F.6** Input and output radionuclides balance of the primary iron production plant at IJmuiden in 1990 (all data in GBq/a)

	<sup>238</sup> U	<sup>232</sup> Th	<sup>226</sup> Ra	<sup>222</sup> Rn	<sup>210</sup> Pb	<sup>210</sup> Po	<sup>40</sup> K
<b>input</b>							
sinter mixture	76	77	76	76	100	97	89
limestone	13	1.8	13	13	14	14	24
pellet mixture	60	76	60	60	68	65	38
coal	41	32	41	41	48	43	110
injection coal	9.6	5.7	9.6	9.6	9.8	7.8	15
<b>totals (GBq/a)</b>	200	190	200	200	240	230	280
<b>output</b>							
<b>solid materials:</b>							
raw iron					9.9	1.5	
blast-furnace slag	180	180	180	180	11	110	160
zinc-rich filtercake	0.62	0.24	0.62	0.62	210	65	4.2
coal tar					12	37	
<b>emissions to air:</b>							
transshipment losses <sup>1)</sup>	0.01	0.01	0.01	0.01	0.01	0.01	0.01
sinter plant				76	54	84	
pellet plant				60	0.83	7.4	
cokes plant				41	0.048	0.041	
<b>emissions to water:</b>							
transshipment losses <sup>1)</sup>	0.03	0.03	0.03	0.03	0.04	0.04	0.04
fluor scrubbers					0.25	7.9	
blast-furnace gas scrubbers					0.22	0.063	
bio refining					0.043	0.057	
<b>outlet by blast-furnace gas:</b>							
HET-6				67	0.61	0.23	
HET-7				0.86	0.049	0.023	
<b>total (GBq/a)</b>	180	180	180	350	300	210	160

<sup>1)</sup> transshipment losses are estimated with the emission percentages to air and water of the phosphate ore treatment industry (0.011% of ore throughput emitted to air and 0.033% to water [Bo92])

### **F.1.5 The coal tar treatment plant at Uithoorn**

There is only one company treating coal tar in the Netherlands, at Uithoorn. Coal tar is the process output material of the cokes furnace of the primary iron and steel plant at IJmuiden (F.1.4).

#### *Process description*

First, the water is separated from the coal tar at temperatures of about 120 °C. Next several distillation and crystallization steps result in different types of products. Process temperatures are about 350-400 °C [Ko93].

#### *Process output and waste materials*

A lot of different products are produced in the several distillation and crystallization steps. Main output products are naphthalene (16 kton/a), anthracene and anthracene oil (24 kton/a), and electrode pitch (70 kton/a). Besides this, a couple of black mixing products, like creosote oil, carbolineum, soot oil and road tar mix, are produced (40 kton/a), . The input—output balance is given in Table F.7.

**Table F.7** Input-output materials in 1988 of the coal tar treatment plant at Uithoorn

	throughput (kton/a)	<sup>210</sup> Pb (Bq/kg)	<sup>210</sup> Po (Bq/kg)
<b>input</b>			
coal tar <sup>1)</sup>	120	113	342
<b>total (GBq/a)</b>		14	41
<b>output</b>			
electrode pitch <sup>2)</sup>	70	194	586
<b>total (GBq/a)</b>		14	41
<b>emissions to air (GBq/a)</b>		pm	pm

<sup>1)</sup> quantities from [Ko93], activity concentrations from [We91]

<sup>2)</sup> calculated activity concentration assuming all nuclides are concentrated in the electrode pitch

### *Emissions to the environment*

It is assumed that only the radionuclides <sup>210</sup>Pb and <sup>210</sup>Po are in the coal tar (see F.1.4). Based on the activity concentrations in the coal tar produced by the primary iron and steel production plant and the amount of materials the company is able to process [Ko93], the yearly calculated throughput of radionuclides is 14 GBq/a <sup>210</sup>Pb and 41 GBq/a <sup>210</sup>Po. Considering the process temperatures, the radionuclides will not reach the gas phase. However, emissions of these radionuclides are possible when radionuclide particles are stuck to combustion gas particles of the coal tar furnace. Assuming no emission, the nuclides can probably be found in the electrode pitch.

Emissions to water are possible during the separating of the water from the coal tar. The plant has a wastewater refining installation working under aerobic conditions. Emissions mainly registered as PACs (polycyclic aromatic carbons) are registered. To prevent leakage of polluting materials into the surrounding areas, a dam has been built.

### **F.1.6 Cokes production plants**

There are three cokes production plants in the Netherlands, two of which are situated on a company site at IJmuiden. These two plants produced 2070 kton cokes in total in 1987 (see F.1.4). The third one, situated at Sluiskil, produced 680 kton cokes in 1987 [An92b] and is described below.

### *Process description*

Cokes are produced by heating coal without oxygen. Process temperatures are above 1000 °C. The flue gas of the furnace is cooled off by water containing ammonia. After separating the coal tar the gas is transported to the coolers where the temperature is lowered from 80 to 25 °C. Then the gas is led through an electrostatic filter and is washed with sulphuric acid whereby ammonium sulphate is formed.

### *Process output and waste materials*

The main process output is cokes. Other products are coal tar, ammonium sulphate and benzene, which are intermediate products for different branches of industries. The cokes furnace gas is partly reused in the cokes furnace and partly transported to an external user. Quantities and activity concentrations of the input and output materials are given in Table F.8. The quantities are scaled with respect to the cokes plants on the IJmuiden company site and the activity concentrations are assumed to be the same [An92a].

### *Emissions into the environment*

The input and output streams of radionuclides are assumed to be the same as in the cokes plant at IJmuiden. Only the quantities of materials are different. Considering this the throughput for most radionuclides is calculated to be in the order of 10 to 15 GBq/a. For <sup>40</sup>K the throughput is assumed to be about three times larger. According to [An92b] a considerable quantity of coal dust, cokes dust and ash is emitted during transporting and processing the coal on the company site. Assuming that all <sup>222</sup>Rn escapes, an estimated emission to air of about 13 GBq/a of this nuclide results. Emissions of other nuclides are estimated to be about three orders of magnitude smaller. Process emissions to water are the result of gas scrubbing and also are assumed to be in the MBq/a range. Transshipment emissions to air and water are of the same order of magnitude as the process emissions.

## **F.1.7 Coal-fired power plants**

Coal-fired power plants are used to supply the basic stock of the electricity production. In contrast to gas-fired power plants (see F.1.8) they reach maximum power much slower, which makes them unsuitable for turning on and off frequently. Therefore, most power plants operate the entire year and the power delivered equals the generating capacity. In 1992, the total generating capacity of (combined) coal/gas- and coal/oil-fired power plants, was 3532 MW<sub>el</sub> [CBS92]. Since in the eighties the Dutch government decided to favour the use of coal in combined power plants the use of oil declined to negligible quantities. From statistical data [CBS93] it can be concluded that in combined coal/gas-fired power plants the use of coal is 90-100% of the output. Since a couple of power plants are planned to be shut down soon, new power plants will be necessary to supply the still growing energy demand. Since modern plants have generating capacities of about 600

**Table F.8** Input and output of the cokes production plant at Sluiskil in 1987<sup>1)</sup>

	throughput (kton/a)	U-238 (Bq/kg)	Th-228 (Bq/kg)	<sup>226</sup> Ra (Bq/kg)	<sup>222</sup> Rn (Bq/kg)	<sup>210</sup> Pb (Bq/kg)	<sup>210</sup> Po (Bq/kg)	K-40 (Bq/kg)
<b>input</b>								
coal	885	14	11	14	14	16	15	38
<b>total (GBq/a)</b>		12	10	12	12	14	13	34
<b>output<sup>2)</sup></b>								
cokes	690	20	13	20	<sup>i)</sup>	14	3.7	47
coal tar	22					113	342	
<b>total (GBq/a)</b>		14	9.2	14	0	12	10	33
<b>process emissions :</b>								
<b>to air (MBq/a)<sup>3)</sup></b>		13	9.3	13	13000	12	7.2	32
<b>to water (MBq/a)<sup>4)</sup></b>						24	32	
<b>transshipment emissions<sup>5)</sup> :</b>								
<b>to air (MBq/a)</b>		1.4	1.1	1.4	1.4	1.6	1.2	3.7
<b>to water (MBq/a)</b>		4.1	3.2	4.1	4.1	4.8	4.2	11.0

i) <sup>222</sup>Rn concentration is equal to 0 after processing, but rapidly grows into <sup>226</sup>Ra concentration

1) activity concentrations from [We91] unless specified otherwise

2) also 7.7 kton/a ammonium sulphate, 6.9 kton/a benzene and 8 million GJ cokes furnace gas are produced; activity concentrations of these outputs are negligible.

3) consisting of 0.37 kton/a cokes dust, 0.22 kton/a coal dust and 0.018 kton/a ash particles [An92b]; in the case of the emissions of <sup>222</sup>Rn, the total content is assumed to escape.

4) quantity of waste water is 400,000 m<sup>3</sup>; activity concentrations in Bq/m<sup>3</sup> taken from cokes plant in IJmuiden [We91]

5) for the transshipment emissions the emission percentages are taken from the phosphate industry (0.011% of ore throughput emitted to air and 0.033% to water [Bo92])

MW<sub>el</sub> and future plants will have about the same, a modern type will be described below.

### Process description

The starting material for coal-fired power plants is coal. The amount of coal necessary to produce 1 MW electric power depends on the efficiency of the process and the energy content of the coal. Also chalk (or chalkstone) is necessary if an installation for desulphurization of the flue gases is used. The amount depends on the sulphur content of

the coal (normally about 0.7% [An93]). The temperature at which the coal is burned is 1200–1300 °C.

### *Process output and waste materials*

The only process output material is ash. The ash percentage of coal is about 12%, about 80% of which is fly ash and 20% bottom ash [Ti92]. Most units are equipped with electrostatic filters and have emission control up to 99.75%. Hence, only a small amount of fly dust is emitted. Because of the high temperatures in the furnace, fly dust is enriched with nearly all radionuclides. Table F.9 shows the input-output balance of a 600 MW<sub>el</sub> power plant.

All process output materials have good reuse possibilities; at the moment 100% of the fly ash is reused the cement industry (F.1.10), as bitumen filler, in artificial grind, as a filler in concrete and in road constructions. Since about 50% is exported, problems may arise if the fly-ash importing countries decide to use the fly ash they produce themselves.

Of the bottom ash 94% is reused as drainage and filter-bed material, and additional material in concrete and as substitute in light foundation material in road constructions. Here also a considerable share is exported (34%). A small fraction (6%) must be temporarily stored on the company site. At the moment the total amount of desulphurization gypsum is reused in gypsum cardboard plates, building materials and fillers, and as an additive in the cement industry.

### *Emissions to the environment*

With the fly dust several radionuclides are released into air. The major emission, however, is related to <sup>222</sup>Rn and is estimated to be about 34 GBq/a. <sup>210</sup>Po and <sup>210</sup>Pb emissions are estimated to be about 0.8 GBq/a and 0.4 GBq/a respectively [Ti92]. The emissions of other nuclides are estimated to be all below the <sup>210</sup>Pb emission level. The specific activity concentrations of fly ash, bottom ash and fly dust given in Table F.9 and approximate earlier estimates in [Ja81]. Transshipment emissions are considerably lower than the process emissions.

The emissions from the total industry can be estimated assuming that the radionuclide emissions are proportional to the generating power of each plant. This leads to an estimated emission of about six times the emissions of a 600 MW<sub>el</sub> plant for all coal-fired power plants together for 1992, equal to about 200 GBq/a <sup>222</sup>Rn, 4.8 GBq/a <sup>210</sup>Po and 2.4 GBq/a <sup>210</sup>Pb.

**Table F.9** Input-output balance of a 600 MW coal-fired power plant<sup>1)</sup>

	throughput (kton/a)	<sup>238</sup> U (Bq/kg)	<sup>228</sup> Th (Bq/kg)	<sup>226</sup> Ra (Bq/kg)	<sup>222</sup> Rn (Bq/kg)	<sup>210</sup> Pb (Bq/kg)	<sup>210</sup> Po (Bq/kg)	<sup>40</sup> K (Bq/kg)
<b>input</b>								
coal	1350	25	25	25	25	25	25	80
chalkstone <sup>2)</sup>	43	22	3	22	22	23	23	39
<b>total (GBq/a)</b>		35	34	35	35	35	35	110
<b>output</b>								
fly ash	130	200	200	200	- <sup>i)</sup>	220	220	670
bottom ash <sup>3)</sup>	32	240	242	241	- <sup>i)</sup>	151	138	653
fly dust <sup>4)</sup>	0.4	400	200	260	83300	1000	2000	670
gypsum <sup>2)</sup>	77	12	2	12	- <sup>i)</sup>	13	13	21
<b>total (GBq/a)</b>		35	34	35	35	35	35	110
<b>emissions to air (GBq/a)</b>		0.16	0.08	0.11	34	0.40	0.81	0.27
transshipment emissions: <sup>5)</sup>								
<b>to air (GBq/a)</b>		0.004	0.004	0.004	0.004	0.004	0.004	0.012
<b>to water (GBq/a)</b>		0.011	0.011	0.011	0.011	0.011	0.011	0.036

i) <sup>222</sup>Rn concentration equal to 0 after process, but rapidly grows into <sup>226</sup>Ra

1) unless otherwise specified activity concentrations are taken from [Ti92]

2) only if a flue gas desulphurization installation is present. For calculating the activity concentration of the gypsum it is assumed all radionuclides present in the chalkstone can be found in the gypsum. The <sup>226</sup>Ra and <sup>222</sup>Rn are assumed to be in equilibrium with the mother nuclide <sup>238</sup>U. The contribution of the installation on the total radionuclide throughput is at most 2.5%.

3) activity concentrations of bottom ash are determined by taking the difference between the total input of radionuclides and the output radionuclide streams of the fly ash and the fly dust. Actual concentrations will be lower because radionuclides will also accumulate in the electrofilters.

4) the total <sup>222</sup>Rn present in the coal is assumed to escape.

5) transshipment emissions are calculated with the emission percentages of the phosphate industry (0.011% of ore throughput emitted to air and 0.033% to water [Bo92]).

### *Future discharges*

Given new technology, there are two alternatives to reduce the environmental impact of conventional coal-fired power plants: the pulverized coal fired power plant and the coal gasification plant with steam and gas installation (KV-STEG). Both 600 MW<sub>el</sub> types will be described, as well as their radionuclide emissions and waste streams.

### *Pulverized coal-fired power plants*

Process temperatures are about 1000-1200 °C. The decreased quantity of fly ash (4% less than in the conventional plant) results in a proportional decrease of the emissions of radionuclides. The total quantity of ash, thus including bottom ash, is 6% lower.

### *Coal gasification steam and gas installation (KV-STEG)*

Process temperatures are above 1500 °C. The amount of fly ash obtained depends on the degree of reuse in the process. In the case of the maximal output of fly ash (69 kton/a, a reduction of 48% compared to the conventional plant), the emissions of radionuclides are proportionally reduced.

## **F.1.8 Gas-fired power plants**

Gas-fired power plants are used for quickly responding to daily changes in the energy demand pattern. A gas-fired plant is able to supply maximum power within a few minutes, in contrast to a coal-fired power plants. Considering the total quantity of gas used the total electricity supply in 1990 has been about 5,200 MW<sub>el</sub> [CBS91]; this implies that about 50% of the total electricity has been supplied by gas-fired power plants in 1990.

In 1990, about 12% of the total natural gas production in the Netherlands was burned in power plants. This corresponds to  $8.903 \cdot 10^9$  m<sup>3</sup>, which is about 22% of the national gas consumption in 1990 [E190]. According to F.1.9 the burning of the natural gas in power plants results in an estimated <sup>222</sup>Rn emission of about 2800 GBq/a.

The electricity can be produced centrally (by conventional and STEG (steam and gas) units) and decentrally (by city heating STEG units and heat-power coupling). The average generating power of a conventional unit is about 400 MW<sub>el</sub> (range: 150-600) and has an electrical efficiency of about 40%. A STEG unit is smaller (250 MW<sub>el</sub>) but is more efficient (50%). The average yearly load is about 6000 hours (70%). Installations which generate power decentrally are much smaller; the average power from city-heating STEG installations is about 75 MW<sub>el</sub> (range 25-80 MW<sub>el</sub>) and from heat-power installations about 25 MW<sub>el</sub> (range 2-30 MW<sub>el</sub>).

In the plant at Velsen the fuel is a mixture of natural gas, blast-furnace gas, cokes gas and oxygas; the latter three gases are obtained from the primary iron and steel plant (F.1.4) (about two-thirds of the total quantity of produced gas). Because of the presence of <sup>210</sup>Po and <sup>210</sup>Pb in this gas mixture, the radiological risk of this plant is about 1000 times higher than that of the other gas-fired power plants [Ti92]. Therefore the plant in Velsen is discussed below.

### *Process description*

The gas mixture is burned at temperatures of about 1400 °C. The quantity of gas required for the production of 1 MW<sub>el</sub> depends on the heat content of the different types of gas used [Ti92] and the energy efficiency of the plant (about 40%). The yearly load is about 5500 hours.

### *Process output materials*

The production process does not result in solid waste materials. Only gaseous emissions to air are expected.

### *Emissions to the environment*

Two installations of 360 and 460 MW<sub>el</sub> are situated on the company site. The throughput of radionuclides is given in Table F.10. All radionuclides contained in the input gases are expected to escape. This results in an estimated <sup>222</sup>Rn emission of about 303 GBq/a; <sup>210</sup>Pb and <sup>210</sup>Po emissions are expected to be much smaller, 0.43 and 0.16 GBq/a respectively. In 1988 the emissions to air were about 0.37 GBq/a for both <sup>210</sup>Pb and <sup>210</sup>Po, under the assumption that 50% of the gas produced in the primary iron and steel plant was burned in Velsen [We89].

The <sup>222</sup>Rn emissions of a gas-fired power plant are assumed to be about the same order of magnitude. Emissions of a 400 MW<sub>el</sub> natural gas power plant are estimated to be 230 GBq/a (yearly load 6000 hours, efficiency 40%, 337 Bq/m<sup>3</sup>). This estimate of the <sup>222</sup>Rn emission is about twice the earlier estimates made for conventional gas-fired power plants [Ti92]. This is a result of the still growing <sup>222</sup>Rn concentration in natural gas [Sc93].

### *Future discharges*

The declining pressure in the gas producing fields results in an increasing <sup>222</sup>Rn concentration. However, in the short term it is expected the <sup>222</sup>Rn emission will decrease as a result of technological measures [El93]. Later on these measures are probably not sufficient to prevent an upward trend due to the increased <sup>222</sup>Rn concentration in the gas fields.

## **F.1.9 Oil and gas production**

There are two different types of oil and gas production, namely the onshore and offshore production. The production types and levels and thus the effluent profiles, are different. In 1990, about 72·10<sup>9</sup> m<sup>3</sup> gas, 3.5·10<sup>6</sup> ton oil and 600000 m<sup>3</sup> condensate were produced [El93]. The condensate is mainly a by-product of the gas exploitation. Obviously, the gas production is most important on shore, while offshore the oil production dominates, which

**Table F.10** Input and output balance of the 360 and 460 MW<sub>el</sub> gas-fired power plant at Velsen in 1990

	throughput (10 <sup>6</sup> m <sup>3</sup> /a)	<sup>222</sup> Rn (Bq/m <sup>3</sup> )	<sup>210</sup> Pb (Bq/m <sup>3</sup> )	<sup>210</sup> Po (Bq/m <sup>3</sup> )
<b>input<sup>1)</sup></b>				
natural gas <sup>2)</sup>	627	337		
blast furnace gas <sup>3)</sup>	4334	22	0.10	0.04
cokes gas	164			
oxygas	90			
<b>total (GBq/a)</b>		303	0.43	0.16
<b>output</b>				
<b>emissions to air (GBq/a)</b>		303	0.43	0.16

<sup>1)</sup> quantities from [Ti92]

<sup>2)</sup> activity concentration in natural gas from [Sc93]

<sup>3)</sup> activity concentration assumed to be equal to the total quantity of radionuclides divided by the total output quantity of blast furnace gas (see also F.1.4 and [We91])

only started in 1982 (Table F.12).

Onshore, there are 883 production installations at 16 locations (concessions). At two concessions oil and gas are produced (Schoonebeek, 497 installations and Rijswijk, 114 installations). The other 14 locations produce only gas (272 installations, of which 103 in Groningen). Production is realized by 110 gas fields and 19 oil fields. In 1990, there were 49 exploration drillings. Offshore, only 88 installations are part of 57 platforms, 8 of which are used for oil exploitation and 49 for gas production. Some platforms have two or more installations. In total, 135 gas fields and 20 oilfields are exploited. In 1990, there were 30 exploration drillings.

### *Process description*

The oil and gas production proceeds in four different phases. First, seismic investigations are done to assess production locations. Then the exploration drillings are executed to determine whether a location is economically workable. If so, then the exploitation phase starts. Finally, when the location is no longer economically workable, the field is abandoned. Process descriptions of the oil and gas extraction can be found elsewhere [EI93].

### *Process output and waste materials*

The different phases in the oil and gas production have different waste and emission profiles. The exploration drillings result in large quantities of drill grit and slush. Table F.12 shows the input and output streams of the onshore and offshore oil and gas exploitation. No data is available on the activity concentrations in the drill grits.

During the exploitation phase large quantities of production water are used. The production water is mainly associated with the oil production. This water consists of a mixture of formation water and other water streams. Formation water is in the underground production reservoir and reaches the surface during production. It is assumed that radium and several daughter products are able to escape the mineral matrix and can be discharged with the formation water [EP88]. Offshore, the production water is discharged into the sea; onshore, it is reinjected into the underground.

The precipitation of radioactive nuclides at certain places in the oil production net leads to considerable activity concentrations in "scales", even up to levels exceeding the criteria for radioactive waste [Ko84]. It is estimated that for 75% of the oil and gas production installations the scale production is less than 10 ton/a. As the activity concentrations range from 1 Bq/g to more than 1000 Bq/g, it is not possible to make an estimation of the average activity concentration. Furthermore, the total quantity of scale is unknown [EP88].

### *Emissions to the environment*

Emissions to air occur only during burning off and venting of the gas, as well as from stacked waste products. The only emitted nuclide is  $^{222}\text{Rn}$ , for the onshore production estimated to be 384 GBq/a and offshore 137 GBq/a. In view of the total annual activity (24500 GBq/a) this means that about 24000 GBq/a is injected into the gas transportation net. Table F.11 gives location specific information on the different concessions [EZ94]. Multiplying the estimated onshore emission (384 GBq/a) with the relative production quantity of the concession (given in %) results in the  $^{222}\text{Rn}$  emission for the concession. When the result is divided by the number of product locations, the yearly emission for one product location can be obtained. The last column of Table F.11 gives the estimated area of the concession.

The Netherlands export a large share of its gas production. The gas consumption in 1990 was  $41.329 \cdot 10^9 \text{ m}^3$ , of which  $10.411 \cdot 10^9 \text{ m}^3$  was for households and  $8.903 \cdot 10^9 \text{ m}^3$  for power plants [CBS91]. A small fraction, 4%, of the  $^{222}\text{Rn}$  decays during the transportation of the gas [Ti92], resulting in an estimated radionuclide immission into the households of 3300 GBq/a and an estimated emission of the gas-fired power plants of 2800 GBq/a. About 4500 GBq/a is assumed to be emitted by the other industries. In production water

**Table F.11** Location-specific information of the onshore product locations of the oil and gas industry

concession	% of total onshore gas production	number of product locations	emission of product location (GBq/a)	estimated area of concession (km <sup>2</sup> )
Groningen	72	103	2.7	600
Drente	7	58	0.5	south/west: 200 north : 400
Schoonebeek	5	497	0.05	200
Tietjerksteradeel	3	19	0.6	1006
Noord-Friesland	4	4	3.8	30

the radionuclides <sup>228</sup>Ra and <sup>226</sup>Ra are considered to be the most important [Ha92]. It is estimated that with the production water about 93 GBq/a <sup>228</sup>Ra and 89 GBq/a <sup>226</sup>Ra are discharged into the sea. Also, the daughter nuclides from the <sup>226</sup>Ra series, <sup>210</sup>Po and <sup>210</sup>Pb, are expected to be discharged in about the same quantities.

#### *Future discharges*

As a result of the decreasing pressure in the gas-producing fields the <sup>222</sup>Rn concentration will increase. However, it is expected that the <sup>222</sup>Rn emission will decrease as a result of technological measures [El93]. Ultimately, these measures are probably not sufficient to prevent higher emissions, due to the increased <sup>222</sup>Rn concentration in the gas fields. As a result of the growing production from oil and gas fields on the Dutch Continental Shelf and the related discharges of production water into the sea the quantity of released radionuclides is expected to increase. Also, an increase in radioactive waste material, scales, is expected.

#### **F.1.10 Cement production**

In the Netherlands there are three cement production plants, at Maastricht, IJmuiden and Rozenburg. The total cement demand in 1990 is estimated to be about 5500 — 6000 kton, 60%-70% of which is supplied by the plants in the Netherlands [Sm93].

#### *Process description*

At Maastricht cement is produced from marl. The marl is treated in a dry or wet process to produce the starting material. During this treatment silex is separated from the marl.

**Table F.12** Output streams of oil and gas exploration and exploitation in 1990

	offshore (10 <sup>6</sup> m <sup>3</sup> /a)	onshore (10 <sup>6</sup> m <sup>3</sup> /a)	<sup>228</sup> Ra (Bq/kg)	<sup>226</sup> Ra (Bq/kg)	<sup>222</sup> Rn (Bq/kg)	<sup>210</sup> Pb (Bq/kg)	<sup>210</sup> Po (Bq/kg)
<b>Gas exploitation</b>							
gas production <sup>1)</sup>	17856	54585			337		
condensate	0.23	0.59					
production water <sup>2)</sup>	0.39	0.38	3500	42000	42000	42000	42000
<b>total output (GBq/a)</b>			2.7	32	24445	32	32
<b>emissions (GBq/a)</b>							
burning, venting	171	524			234		
stacks	195	597			267		
<b>Oil exploitation</b>							
oil production <sup>3)</sup>	2.7	1.3					
production water <sup>2)</sup>	9.1	13	10000	8000	8000	8000	8000
<b>total output (GBq/a)</b>			217	174	174	174	174
<b>emissions to air</b>							
burning, venting (GBq/a)	37	17			18		
stacks (GBq/a)	4	2			2.0		
<b>emissions offshore</b>							
drilling wastes (kton/a) <sup>4)</sup>		255					
production water (GBq/a)			89	89	89	89	89
burning, venting, stacks (GBq/a)					137		
<b>emissions onshore</b>							
drilling wastes (kton/a) <sup>5)</sup>		66					
production water (GBq/a)			117	117	117	117	117
burning, venting, stacks (GBq/a)					384		

<sup>1)</sup> Most gas fields are small: 89% have a production of less than 10·10<sup>6</sup> m<sup>3</sup> gas

<sup>2)</sup> The activity concentration of <sup>222</sup>Rn, <sup>210</sup>Pb and <sup>210</sup>Po is assumed equal to that of <sup>226</sup>Ra .

<sup>3)</sup> Density of oil is about 0.88 ton/m<sup>3</sup> (gas about 0.88 kg/m<sup>3</sup>) at normal pressure

<sup>4)</sup> Consists for 65% of water-based mud, 25% of water-based mud cuttings and 9% of solid-drilling mud additives, all discharged to sea

<sup>5)</sup> Consists for 55% of cuttings and for 45% of solids from water-based mud, both used for land filling; an unknown quantity of water-based mud is discharged to surface waters.

The remaining marl-slush or marl-flavour is burned in a furnace at 1400 °C to form clinkers. The clinkers are cooled down to 120 °C. Finally, the clinker and other materials are milled in solid mixing systems, resulting in cement. Only at the plant at Maastricht are clinkers and cement produced. At the other two locations cement is only milled. These two plants import clinkers from a foreign cement production concern.

#### *Process output and waste materials*

Main process output materials are the cement types and silex. About 60% of the output quantity of silex is reinjected into the mining pit. The remainder is officially qualified as waste material and is reused in road constructions.

#### *Emissions to the environment*

The input-output balance is made using the known required input materials for the production of the different types of cement (Table F.13 and Table F.14). With these specifications input-output balances can be obtained which are nearly in equilibrium.

Emissions to air are most important during the production process. Because of the temperatures used, both dust and gaseous emissions are expected. In general, dust emissions are estimated to be 0.5-1% of the total production [UvA92]. This results in about 0.2 GBq/a for the radionuclides of the  $^{238}\text{U}$  series and about five times lower for the  $^{228}\text{Th}$  series.

Analogous to the ceramic industry (see F.1.11), it is assumed that 50% of the  $^{210}\text{Po}$  input is emitted to air during the clinker burning.  $^{210}\text{Pb}$  is expected to remain in solid materials. This leads to emissions of about 78 GBq/a  $^{210}\text{Po}$ . Also, the total  $^{222}\text{Rn}$  content is assumed to escape (157 GBq/a). Emissions from the plant at IJmuiden are estimated to be about 0.13 GBq/a for the nuclides in the  $^{238}\text{U}$  series, except for  $^{210}\text{Po}$  and  $^{210}\text{Pb}$ , which are 0.03 and 0.02 GBq/a, respectively. During the cement milling the  $^{222}\text{Rn}$  content is assumed to escape entirely (169 GBq/a). For all nuclides, emissions of the Rozenburg plant are estimated to be 36% of the IJmuiden plant.

### **F.1.11 Ceramic industry**

The total output of the ceramic industry is about 3550 kton in 1989/1990 [Hu92a, Hu92b]. The main products are bricks and roofing, wall and floor tiles. Most brick plants have about the same production capacity; 50% of the brick plants (65) are responsible for 70% of the brick production; further, 70% of the tile plants (10) are responsible for 90% of the tile production. Most brick plants have about the same production capacity. In the fine ceramic industry, two large companies have about 50% of the production (earthenware, wall and floor tiles, sanitary goods and refractories). Most companies are located nearby river beds in the southern parts of the Netherlands.

**Table F.13** Input-output balance of the cement production plant at Maastricht in 1990

	throughput (kton/a)	<sup>238</sup> U (Bq/kg)	<sup>228</sup> Th (Bq/kg)	<sup>226</sup> Ra (Bq/kg)	<sup>222</sup> Rn (Bq/kg)	<sup>210</sup> Pb (Bq/kg)	<sup>210</sup> Po (Bq/kg)	<sup>40</sup> K (Bq/kg)
<b>input<sup>1)</sup></b>								
marl	1588	22	3	22	22	23	23	39
blast furnace slag	300	157	151	157	157	9.6	0.9	136
schist	180	40	56	40	40	40	40	890
fly ash	150	200	200	200	200	220	220	670
anhydrate	90	100	12	100	100	100	100	226
clay	30	41	42	41	41	41	37	582
chalk stone	33	22	3	22	22	23	23	39
pyrites ash	20	40	56	40	40	40	40	890
Portland clinker <sup>2)</sup>	365	79	48	79	79	67	65	241
<b>total (GBq/a)</b>		159	111	159	159	116	112	509
<b>output<sup>2)</sup></b>								
Portland cement	980	72	46	72	i)	63	62	302
Portland fly ash cement	300	102	81	102	i)	100	99	383
blast furnace cement	400	111	97	111	i)	26	21	166
macon cement	70	49	26	49	i)	45	44	178
silex <sup>3)</sup>	357	22	3	22	i)	23	23	39
<b>total (GBq/a)</b>		157	107	157	0	113	110	504
<b>emissions to air (GBq/a)</b>								
marl extraction <sup>4)</sup>	7.5	0.16	0.02	0.16	0.16	0.17	0.17	0.29
cement mixing/transport <sup>4)</sup>	0.4	0.03	0.02	0.03	0.03	0.02	0.02	0.09
thermic process <sup>5)</sup>	0.1	0.01	0.01	0.01	157	0.01	78	0.02

<sup>1)</sup> activity concentration of marl assumed to be equal to chalk stone (We91); of blast furnace slag from [We91], fly ash from [Ti92], clay from [We93], schist, pyrites ash and anhydrate from [Pe89]; anhydrate <sup>226</sup>Ra activity concentration is estimated to be 100 Bq/kg. All nuclides of the <sup>238</sup>U series are assumed to be in equilibrium with the daughter nuclides

<sup>2)</sup> activity concentrations of cement types determined with input materials [Sm93a]. correction made when input exceeds the quantity available

<sup>3)</sup> the silex content of marl is between 20 and 25%. Here 22.5% is taken; 5 kton/a slag iron and 13 kton/a refractory stone are also obtained; total activity contribution is negligible

<sup>4)</sup> dust emissions 0.5% of total marl extraction or throughput by cement mixing and transport [Sm93]

<sup>5)</sup> during the thermic process 50% of the <sup>210</sup>Po content is assumed to escape (analogous with ceramic industry [Vo93, We93]); also the <sup>222</sup>Rn content is assumed to escape.

**Table F.14** Input and output balance of the cement production plants at IJmuiden and at Rozenburg in 1990

IJmuiden	throughput	<sup>238</sup> U	<sup>228</sup> Th	<sup>226</sup> Ra	<sup>222</sup> Rn	<sup>210</sup> Pb	<sup>210</sup> Po	<sup>40</sup> K
	(kton/a)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)
<b>input</b>								
blast furnace slag	875	157	151	157	157	9.6	0.9	136
Portland clinker	313	79	48	79	79	67	65	241
anhydrate	63	100	12	100	100	100	100	226
<b>total (GBq/a)</b>		169	148	169	169	36	28	209
<b>output<sup>6)</sup></b>								
blast furnace cement <sup>7)</sup>	1250	135	118	135	<sup>i)</sup>	29	22	168
<b>total (GBq/a)</b>		169	148	169	0	36	28	210
<b>emissions to air (GBq/a)<sup>8)</sup></b>								
	1.0	0.13	0.12	0.13	169	0.03	0.02	0.17
<b>Rozenburg<sup>9)</sup></b>								
<b>emissions to air (GBq/a)</b>	0.4	0.05	0.05	0.05	61	0.01	0.01	0.07

i) <sup>222</sup>Rn concentration equal to 0 after process, but is rapidly growing in reaching the <sup>226</sup>Ra activity concentration

6) also 4 kton/a slag iron and 0.5 kton/a other slag material obtained

7) activity concentrations of blast furnace cement of the plant at Maastricht is lower as a result of input quantity correction; see <sup>2)</sup> of Table F.13

8) dust emissions mainly from storage of blast furnace slag (180 kton/a)

9) input, output and emissions are assumed to be 36% of the plant at IJmuiden

### Process description

Clay and small amounts of supporting materials like sand, chalk stone and glaze are used as raw materials. First, the starting materials are mixed with water to obtain the required plasticity. After shaping the mixture to fixed dimensions the unfired bricks are dried at 100 °C and if necessary glazed. Then the bricks are fired at temperatures between 1000 and 1200 °C. In the case of the production of fine ceramic goods, 60% of the products are fired twice; in this case the glazing step and the brick-burning step are separated. If decorations are applied on the fine ceramic products they are fired again.

### *Process output waste materials*

The process output materials of the ceramic industry are the ceramic products and the materials dropping out of the different process steps. The main fraction of these are reusable as starting material for the ceramic industry. About 60 kton/a waste material cannot be reused in the process. Most of this debris is used for terrain heightening; only a small fraction is dumped.

The production of an averaged-sized brick plant is 64 kton/a; for an averaged-sized roof tile plant this is lower: 17 kton/a. Two large plants produce about 88 kton/a fine ceramics. Most remaining fine ceramic plants produce between 10 and 20 kton/a.

### *Emissions to the environment*

The process emissions contain  $^{210}\text{Po}$ , which is mainly emitted into air, and  $^{210}\text{Pb}$ , which remains in the final products [We93]. Transshipment emissions of clay are assumed to be negligible. About 80% of the  $^{210}\text{Po}$  fraction escapes (range 40-100%). Measurements of  $^{210}\text{Po}$  emissions to air show that an average of 25% (range 0-40%) of the radionuclide input of  $^{210}\text{Po}$  can be found in the flue gas channels. The input and output of radionuclides are not in equilibrium; e.g. about 50% of the  $^{210}\text{Po}$  input is missing in the output streams.

Input-output balances are derived from the activity concentrations of the input and output solid materials for the brick, roof tile and earthenware production (Table F.15). This gives an indication of the magnitude of the radionuclide emissions. About 56 GBq/a  $^{210}\text{Po}$  is possibly emitted into air by the brick plants. Peute [Pe89] estimated these emissions to be 150-290 GBq/a at the most, assuming an activity concentration in the clay of 37-67 Bq/kg. The estimation of Peute was made using a 50% higher brick output. The  $^{210}\text{Po}$  emission of an averaged-sized plant (about 64 kton/a products) is estimated to be 1.2 GBq/a.

$^{210}\text{Po}$  emissions from the roof tile plants are estimated to be 2.7 GBq/a. This is considerably lower than the estimate of Peute [Pe89], who reported a maximum of 53 GBq/a, assuming equal conditions of the roof tile output. The much higher emissions are the result of assuming an activity concentration of 9600 Bq/kg for the  $^{238}\text{U}$  series in glaze. Measurements of glaze used in roof tile plants showed activity concentrations for  $^{210}\text{Po}$  to be about 150 Bq/kg [We93]. The estimated  $^{210}\text{Po}$  emission of an averaged-sized roof tile plant (about 17 kton/a products) is 0.3 GBq/a.

Using the total earthenware production, being 360 kton/a, emissions can be estimated by scaling the input-output table to the production quantity of the roof tile plants (135 kton/a). In this way the  $^{210}\text{Po}$  emissions from the earthenware plants are estimated to be 7.2 GBq/a, again considerably lower than the estimations of Peute [Pe89]. These amounted, again as a result of the glaze, to a maximum of 190 GBq/a. For  $^{210}\text{Po}$ , emissions from the two very large plants (about 88 kton/a products) are estimated to be

**Table F.15** Input and output and emissions into air of the ceramic industry in 1989/1990<sup>1)</sup>

	throughput	<sup>238</sup> U	<sup>228</sup> Th	<sup>226</sup> Ra	<sup>222</sup> Rn	<sup>210</sup> Pb	<sup>210</sup> Po	<sup>40</sup> K
brick plants	(kton/a)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)
<b>input</b>								
unfired stone <sup>2)</sup>	3198	37	37	37	37	39	33	568
<b>total (GBq/a)</b>		116	115	115	115	120	101	1,763
<b>output</b>								
product	3030	41	40	41	41	37	16	640
<b>total (GBq/a)</b>		120	118	120	120	109	47	1752
emission per plant (GBq/a)						0.23	1.2	0.22
<b>roof tile plants</b>								
<b>input</b>								
unfired tiles <sup>3)</sup>	146	44	48	44	44	44	37	640
<b>total (GBq/a)</b>		6.4	7.0	6.4	6.4	6.4	5.4	93
<b>output</b>								
products <sup>4)</sup>	135	46	52	46	46	42	20	684
<b>total (GBq/a)</b>		6.2	7.0	6.2	6.2	5.7	2.7	92
emission per plant (GBq/a)		0.03		0.03	0.03	0.09	0.34	0.13
<b>earthenware plants</b>								
emission large plant (GBq/a)		0.15		0.15	0.15	0.50	2.0	0.84
emission normal plant (GBq/a)		0.03		0.03	0.03	0.09	0.30	0.14

1) quantities from [Hu92a] and [Hu92b]

2) average of 6 measurements [We93]

3) average of 2 measurements [We93]

4) activity concentrations in roof tiles. Although about twice as much glaze is used (Pe89), the influence on the total radionuclide input is small

1.8 GBq/a. The remaining plants are assumed each to emit 0.2-0.4 GBq/a  $^{210}\text{Po}$ , based on a production capacity between 10 and 20 kton/a.

### **F.1.12 Mineral sands industry**

The mineral sands treatment industry consists of a series of companies importing, transshipping, handling, storing and selling mineral sands. There are only two companies handling zirconium sand, the most relevant from the radiological point of view: at Amsterdam and at Geertruidenberg.

#### *Process description*

In the mineral sands industry no chemical process is involved. The different materials are successively transshipped, stored, dried, granulated, milled, micronized, packed and stored again for transshipment.

#### *Process output and waste materials*

The volume of the process output material is as large as the input material, except for (small) emissions from transshipment and millings. The Amsterdam plant treats about 183 kton mineral sands yearly (which can be expanded to 225 kton), Geertruidenberg about 11 kton. No solid waste materials are obtained.

#### *Emissions to the environment*

Raw materials are dispersed as dust particles, hence all radionuclides from the different decay series of  $^{238}\text{U}$  and  $^{232}\text{Th}$  are emitted.  $^{226}\text{Ra}$  and  $^{222}\text{Rn}$  emissions are assumed to be equal to the  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  emissions and  $^{238}\text{U}$  emissions about 33% higher.  $^{232}\text{Th}$  emissions are estimated to be six times smaller than the  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  emission level. The input-output balance and emissions are summarized in Table F.16.

At Amsterdam, emissions due to transshipment and milling the minerals sands are estimated to be 729 MBq/a for  $^{210}\text{Po}$ ,  $^{210}\text{Pb}$  and the other nuclides from the  $^{238}\text{U}$  series. At Geertruidenberg, emissions are estimated to be 8.2 MBq/a  $^{210}\text{Po}$  and  $^{210}\text{Pb}$ .

Emissions to water are estimated to be 0.01% of the total treated quantity [Sc92b]. This results in estimated emissions of 66 MBq/a  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  for the plant at Amsterdam and 0.6 MBq/a  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  for the plant at Geertruidenberg.

**Table F.16** Throughput and emissions of the mineral sands industry in 1991

	throughput	<sup>238</sup> U	<sup>232</sup> Th	<sup>226</sup> Ra	<sup>222</sup> Rn	<sup>210</sup> Pb	<sup>210</sup> Po
	(kton/a)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)
<b>Amsterdam</b>							
<b>input<sup>1)</sup></b>							
zirconium sand	183	4800	600	3600	3600	3600	3600
bauxite		530	410	370	370	370	370
spodumene		9.8	1.2	5.5	5.5	5.5	5.5
rutile		3800	560	3000	3000	3000	3000
<b>total (GBq/a)</b>		<b>876</b>	<b>110</b>	<b>657</b>	<b>657</b>	<b>657</b>	<b>657</b>
<b>emissions (MBq/a)</b>							
to air <sup>2)</sup>		971	121	729	729	729	729
to water <sup>3)</sup>		88	11	66	66	66	66
<b>Geertruidenberg</b>							
<b>input<sup>4)</sup></b>							
bauxite	10	600	300	400	400	400	400
zirconium sand	0.3	3800	600	3000	3000	3000	3000
ilmenite	0.4	1500	1200	2300	2300	2300	2300
<b>total (GBq/a)</b>		<b>7.7</b>	<b>3.7</b>	<b>5.8</b>	<b>5.8</b>	<b>5.8</b>	<b>5.8</b>
<b>emissions (MBq/a)</b>							
to air <sup>5)</sup>		11	5.2	8.2	8.2	8.2	8.2
to water <sup>6)</sup>		0.8	0.4	0.6	0.6	0.6	0.6

<sup>1)</sup> the main mineral sand is zirconium sand (about 80%, [Sc92a]). Here the maximum radionuclide throughput on the basis of 100% zirconium sand is determined. Activity concentration <sup>232</sup>Th assumed to be equal to <sup>228</sup>Th

<sup>2)</sup> emissions to air consist of transshipment emissions (0.108% of total throughput and milling emissions (5.3 ton/a) [Sc92a]

<sup>3)</sup> emissions to water consist of transshipment emissions (0.01%) [Sc92a]

<sup>4)</sup> quantities from [Sc92b]

<sup>5)</sup> emissions to air consist of transshipment emissions and is assumed to be analogous to the company in Amsterdam. This results in milling emissions of 3.9 ton/a bauxite and 115 kg/a zirconium sand

<sup>6)</sup> emissions to water: analogous to the company in Amsterdam

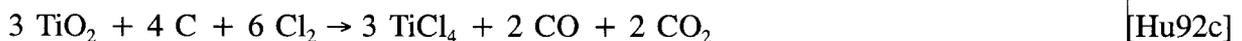
### F.1.13 Titanium pigment production

There is only one titanium production plant in the Netherlands, at Rozenburg. The yearly production capacity is 45 kton coated pigment (41 kton titanium dioxide) [Hu92c]. In 1990, a new production process was introduced, resulting in a production lower than the

maximum capacity. Because it is expected that the production will be continued after 1991, here it is assumed that the annual production equals the production capacity.

### *Process description*

Starting materials for the production of titanium pigment are titanium ore, petroleum cokes and chlorine. Petroleum cokes are process output materials of the oil refining companies. The titanium ore is a synthetic rutile, produced by heating the ore to 1100 °C. First, the ore is chlorinated under addition of the petroleum cokes to the intermediate product  $\text{TiCl}_4$  at temperatures of about 340 °C and a pressure of 3 bar, according to:



Then, the intermediate  $\text{TiCl}_4$  is separated from the other metal chlorides in the refining step at normal temperatures. In the following process step the  $\text{TiCl}_4$  is oxidized to the end product, which is purified  $\text{TiO}_2$  and to the byproduct  $\text{Cl}_2$ . The chlorine is reused in the chlorination step. Finally, the dried titanium pigment is milled, coated, filtered, dried, micronized and packed.

### *Process output and waste materials*

Process output materials are titanium dioxide and a waste material from the chlorinator bed consisting of a large quantity of cokes, ore and  $\text{SiO}_2$  particles (VBM waste). Also, yearly a considerable quantity of filter cake is obtained, which is classified as chemical waste. The cake has to be transported to a  $\text{C}_2$  deposit. As a result of the production process, the radionuclides in the starting materials are assumed to be concentrated in the filtercake and the VBM waste.

### *Emissions to the environment*

Considering the fact the  $^{228}\text{Ra}$  concentration in the rutile is about 157 Bq/kg and the concentration of the mother nuclide  $^{232}\text{Th}$  is about 212 Bq/kg, the thermal processing of the ore leads to partial escape of  $^{228}\text{Ra}$ . The resulting yearly emissions based on the maximal production capacity are estimated to be 2.6 GBq/a  $^{228}\text{Ra}$ . To air  $^{222}\text{Rn}$  emissions are expected from the flue gas of the chlorination step and amount to 6.2 GBq/a at most. The last step involving the treatment of the dried pigment (milling micronizing and packing) results in considerable dust emissions. Emissions to water are expected from the treatment of waste materials from the chlorination step and the filtrate of the filtration step. About 60% of the  $^{228}\text{Ra}$  and  $^{226}\text{Ra}$  content is discharged with the wastewater. In the VBM waste the  $^{210}\text{Po}$  content is mainly concentrated. The other nuclides given in Table F.17 are mainly concentrated in the filtercake.

**Table F.17** Input and output materials of the titanium pigment production on the basis of the maximal yearly production capacity

	throughput	<sup>238</sup> U	<sup>228</sup> Th	<sup>228</sup> Ra	<sup>226</sup> Ra	<sup>222</sup> Rn	<sup>210</sup> Pb	<sup>210</sup> Po
	(kton/a)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)	(Bq/kg)
<b>input</b>								
titanium ore <sup>1)</sup>	48	145	212	157	128	128	104	104
petroleum cokes <sup>2)</sup>	18	1	0.8	0.6	2	2	180	90
chlorine <sup>2)</sup>	95							
<b>total (GBq/a)</b>		7.0	10.2	7.5	6.2	6.2	8.1	6.6
<b>output</b>								
titanium pigment	41							
VBM waste	9.4	150	133	100	130	i)	104	552
filtercake <sup>3)</sup>	2.6	2300	2610	745	708	i)	3000	1100
water outlet <sup>4)</sup>	154		11	30	30	i)		3.3
<b>total (GBq/a)</b>		7.5	9.9	7.5	7.7		8.9	8.6
<b>emissions<sup>5)</sup></b>								
<b>to air (GBq/a)</b>		0.001	0.001	2.6	0.001	6.2	0.001	0.001
<b>to water (GBq/a)</b>		0.002	0.003	0.003	0.002	0.002	0.003	0.002

i) activity concentration after processing equal to 0, but rapidly increases in activity concentration of <sup>226</sup>Ra

1) quantity determined on the basis of TiO<sub>2</sub> content (90%) and humidity (5%); activity concentration of rutile from Sc92b. <sup>232</sup>Th concentration assumed to be equal to <sup>228</sup>Th. Activity concentrations from [We92].

2) quantity determined with the reaction equation and 90% efficiency of the reaction equation; the chlorine is assumed to be reused for 90% in the chlorination process

3) the radionuclides are assumed to concentrate in the filtercake

4) quantity in L, activity concentration in Bq/L

5) process and transshipment emissions; transshipment emissions are estimated with the emission percentages of the phosphate industry.

## APPENDIX G REFERENCE PLANTS

### G.1 Introduction

To evaluate the risks associated with releases to air a number of standard risk calculations were made for so-called reference situations. For the different situations three different reference plants are defined for emissions to air. The reference situations are characterized by emission height, heat content and particle size.

1. For the risks associated with emissions to air from ground level, e.g. during transshipment, reference situation 1 is defined as a point source with 0 MW heat content and a release height of 0 m. Since these emissions will not pass filters etc., the particle size in the OPS dispersion model is set at coarse. The particle size distribution and classes used in the OPS model are described in [Ja90] and Appendix B.
2. Reference situation 2 describes releases to air representative for smaller factories, e.g. the ceramic industry, and is defined by a point source with 10 MW heat content and a release height of 40 m. Since the particles are released by a chimney, it is assumed that the OPS particle size distribution can be described as medium.
3. The third reference situation is representative for all large industrial plants and is based on a 650 MW coal fired power plant [Do94]. Emissions take place at a release height of 175 m with a heat content of 76 MW. Since it is very likely that these large-sized plants are equipped with emission reduction measures, it is assumed that the particle size distribution can be described using the OPS class fine [Do94].

The characteristics of reference situations are given in Table G.2.

### G.2 Dispersion

The dispersion of the radionuclides released into the air is calculated using the atmospheric transport model OPS (Appendix B). It is assumed that the radionuclides are released as particles and attached to aerosols, except for the noble gas  $^{222}\text{Rn}$ . Because the transport time is short compared to the half-life of the nuclides considered, a correction for radioactive decay during transport in air has not been made, except in the case of  $^{222}\text{Rn}$ , where the lifetime has been taken explicitly into account. Hence, the dispersion in air is similar for all radionuclides except  $^{222}\text{Rn}$ .

Dispersion of  $^{222}\text{Rn}$  is calculated separately. Since  $^{222}\text{Rn}$  is a noble gas, the release into air is in a gaseous form. Model parameters used for the calculation of the dispersion of  $^{222}\text{Rn}$  are given in Table G.1.

**Table G.1** Model parameters used in the calculation of the dispersion of  $^{222}\text{Rn}$ 

OPS parameter	
substance	$^{222}\text{Rn}$
molecular weight (g.mol <sup>-1</sup> )	222
form of release	gaseous
dry deposition velocity (m.s <sup>-1</sup> )	$1 \cdot 10^{-6}$
scavenging ratio (rain/air)	0
chemical conversion (decay) (%.h <sup>-1</sup> )	0.76

### G.3 Deposition

Deposition plays a major role in the ingestion pathway. It is assumed that half the vegetables and all other agricultural products consumed by the reference group are obtained from the COROP area where the reference plant is situated (Appendix C). The contribution from the COROP area to the total risk is obtained by averaging the deposition over a so called reference COROP area of  $25 \times 25 \text{ km}^2$ , which is approximately equal to the average size of a COROP area ( $6.6 \cdot 10^2 \text{ km}^2$ ) in the Netherlands. To maximize the average in the COROP-area, the reference plant is assumed to be located at the south-west of the area, since the average wind direction in the Netherlands is south-west. As an example, the deposition pattern for the large-sized reference situation is shown in Figure G.1. Air concentrations are calculated in a similar way.

**Table G.2** Model parameters used in the calculation of the dispersion in air for three reference situations using the OPS model [Ja90]

OPS parameter	reference plant 1	reference plant 2	reference plant 3
substance	average nuclide	average nuclide	average nuclide
molecular weight (g.mol <sup>-1</sup> ) <sup>(*)</sup>	220	220	220
form of release	particle bound	particle bound	particle bound
source strength (GBq.a <sup>-1</sup> )	1	1	1
source height (m)	0	40	175
heat content (MW)	0	10	76
source diameter (m)	0 (point source)	0 (point source)	0 (point source)
particle-size distribution	coarse	medium	fine
climatological data set	the Netherlands	the Netherlands	the Netherlands
climatological period	year	year	year
emission variation	continuous	continuous	continuous
roughness length (m)	0.15	0.15	0.15

(\*) The mass of the nuclide can be ignored when compared to the mass of the particle and is of no importance for the dispersion of the particles in air. Therefore an average value for the molecular weight is taken.

## G.4 Dose and risk calculations

The calculation method outlined in Appendix C is used in the calculation of the MIR. Using the conversion factors given in Table C.1, the dose for the different exposure pathways is calculated from deposition and air concentration. The parameters used in the calculation of the air dispersion for the three reference situations are listed in Table G.2. The MIR is obtained by summing the dose contribution of the exposure pathways and multiplying by a risk conversion factor of  $0.25 \cdot 10^{-3} \text{ Sv}^{-1}$ . For each of the three reference plants, MIR is calculated from a release of  $1 \text{ GBq a}^{-1}$  of  $^{210}\text{Pb}$  (Figure G.2, Figure G.3, Figure G.4). In Figure G.2, only part of the reference COROP area is shown since dispersion takes place at a relatively short distance compared to the size of the reference COROP area. Nevertheless, calculation of average deposition is based on the total area of the reference COROP area. The same calculations are performed for the seven other nuclides, resulting in  $8 \times 3 = 24$  reference maps. Only the maps for  $^{210}\text{Po}$  are shown. Maximum concentration and deposition, their location, the contribution of the relevant pathways and total risk are presented in Table G.3. The location of maximum concentration and/or deposition is shown in Table G.4.

**Table G.4** Location of maximum concentration and deposition for the reference plants

	reference plant 1	reference plant 2	reference plant 3
maximum concentration in air	35 m NE of source <sup>1)</sup>	2600 m NE of source	10700 m of source
maximum deposition		350 m NE of source	35 m NE of source

<sup>1)</sup> Note that OPS calculations are only valid for distances larger than 100 m.

From the 24 maps and the results tabulated, the following observations are made:

- Increasing the height of the chimney relocates maximum MIR at a greater distance of the source. For high chimneys this distance is more than 5 km.
- Increasing the height of the chimney decreases maximum MIR considerably.
- In all cases, maximum deposition and concentration are found north-east of the source.
- For high chimneys the risk due to vegetables from the COROP area has a greater contribution in the total risk.
- The contribution of both cloud shine and ground shine in the total risk due to radionuclides emitted by a NNI was ignored. In most cases, the relative contribution of the milk and meat pathway is also unimportant (<1%).

It should be noted that the MIRs and AIRs as calculated here for transshipment should be treated with care, because:

- the actual particle size might be much larger, resulting in an overestimation of

**Table G.3** Risks ( $a^{-1}$ ) due to emission of eight radionuclides of 1 GBq  $a^{-1}$  in air for the reference situations

Radionuclide	Pathway (*)	reference plant 1 (#)	reference plant 2	reference plant 3
$^{222}\text{Rn}$	inhalation	5.7E-8	1.6E-12 (c)	1.1E-13 (d)
$^{238}\text{U}$	inhalation	2.2E-4	6.9E-9	4.5E-10
	vegetable garden all pathways	2.2E-4	6.9E-9	6.0E-12 4.7E-10
$^{232}\text{Th}$	inhalation	1.6E-3	4.9E-8	3.2E-09
	vegetable garden		1.7E-9	3.4E-10
	vegetables COROP			1.7E-10
	other pathways			3.3E-10
	all pathways	1.6E-3	5.2E-8	4.1E-09
$^{228}\text{Th}$	inhalation	6.2E-4	1.9E-08	1.3E-09
	vegetable garden		2.4E-10	4.9E-11
	all pathways	6.2E-4	2.0E-08	1.4E-09
$^{228}\text{Ra}$	inhalation	7.9E-6	1.0E-10 (a)	
	vegetable garden	4.4E-6	4.2E-10 (a)	9.6E-11 (b)
	vegetables COROP		5.5E-11 (a)	2.5E-11 (b)
	milk		5.2E-11 (a)	2.4E-11 (b)
	other pathways		9.7E-11 (a)	4.4E-11 (b)
	all pathways	1.2E-5	7.3E-10 (a)	1.9E-10 (b)
$^{226}\text{Ra}$	inhalation	1.5E-5	4.7E-10	
	vegetable garden	3.6E-6	2.0E-10	7.9E-11 (b)
	vegetables COROP		4.5E-11	2.0E-11 (b)
	milk		4.6E-11	2.1E-11 (b)
	other pathways		8.3E-11	3.8E-11 (b)
	all pathways	1.9E-5	8.4E-10	1.6E-10 (b)
$^{210}\text{Po}$	inhalation	1.4E-5	4.2E-10	
	vegetable garden	3.1E-6	1.7E-10	6.7E-11 (b)
	vegetables COROP		3.8E-11	1.7E-11 (b)
	milk			1.6E-12 (b)
	meat			1.5E-12 (b)
	other pathways		4.4E-11	2.0E-11 (b)
	all pathways	1.7E-5	6.8E-10	1.1E-10 (b)
$^{210}\text{Pb}$	inhalation	1.6E-5	2.1E-10 (a)	
	vegetable garden	3.1E-5	3.0E-09 (a)	6.7E-10 (b)
	vegetables COROP		3.8E-10 (a)	1.7E-10 (b)
	milk		4.6E-11 (a)	2.1E-11 (b)
	other pathways		8.7E-10 (a)	3.9E-10 (b)
	all pathways	4.6E-5	4.5E-09 (a)	1.3E-09 (b)

(\*) Pathways with a contributions to the total risk < 1% are not reported.

(#) Results should be treated with care. OPS results are reliable for distances exceeding 100 m. The numbers here refer to a distance of 35 m. Risks for a distance of 100 m are listed in Table G.5.

(a) Data for  $^{228}\text{Ra}$  and  $^{210}\text{Pb}$  refer to the location with maximum deposition; data for the other nuclides refer to the location with maximum concentration.

(b) Data for  $^{228}\text{Ra}$ ,  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  refer to the location with maximum deposition; data for the other nuclides refer to the location with maximum concentration.

(c) Maximum concentration about 2600 m ENE of the source

(d) Maximum concentration about 10700 m ENE of the source

**Table G.5** MIR for reference plant 1 due to emissions of six nuclides at 100 m north-east of the source based on a normalized emission of 1 GBq a<sup>-1</sup>

	<sup>238</sup> U	<sup>232</sup> Th	<sup>228</sup> Th	<sup>228</sup> Ra	<sup>226</sup> Ra	<sup>222</sup> Rn	<sup>210</sup> Pb	<sup>210</sup> Po
MIR (a <sup>-1</sup> )	1.8·10 <sup>-5</sup>	1.3 10 <sup>-4</sup>	5.0·10 <sup>-5</sup>	1.0 10 <sup>-6</sup>	1.5·10 <sup>-6</sup>	5.7·10 <sup>-8</sup>	3.5·10 <sup>-6</sup>	1.5·10 <sup>-6</sup>

concentrations and depositions;

- the same effect is expected from nearby buildings;
- deposited dust particles are frequently removed at plant sites by means of sweeping-machines, resulting in a lower accumulated deposition;
- in general, no vegetable gardens are nearby transshipment areas, resulting in an overestimation of both MIR and AIR.

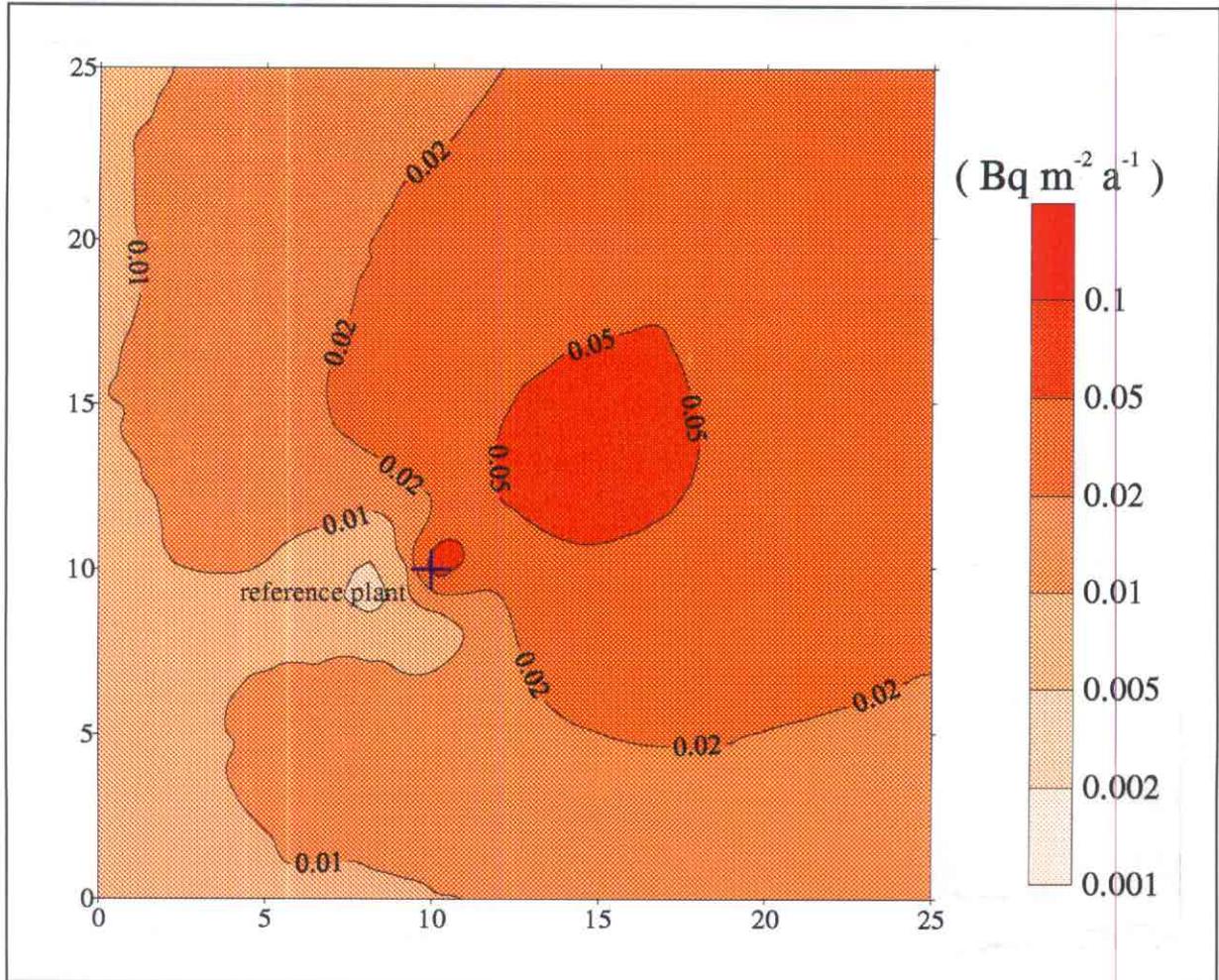
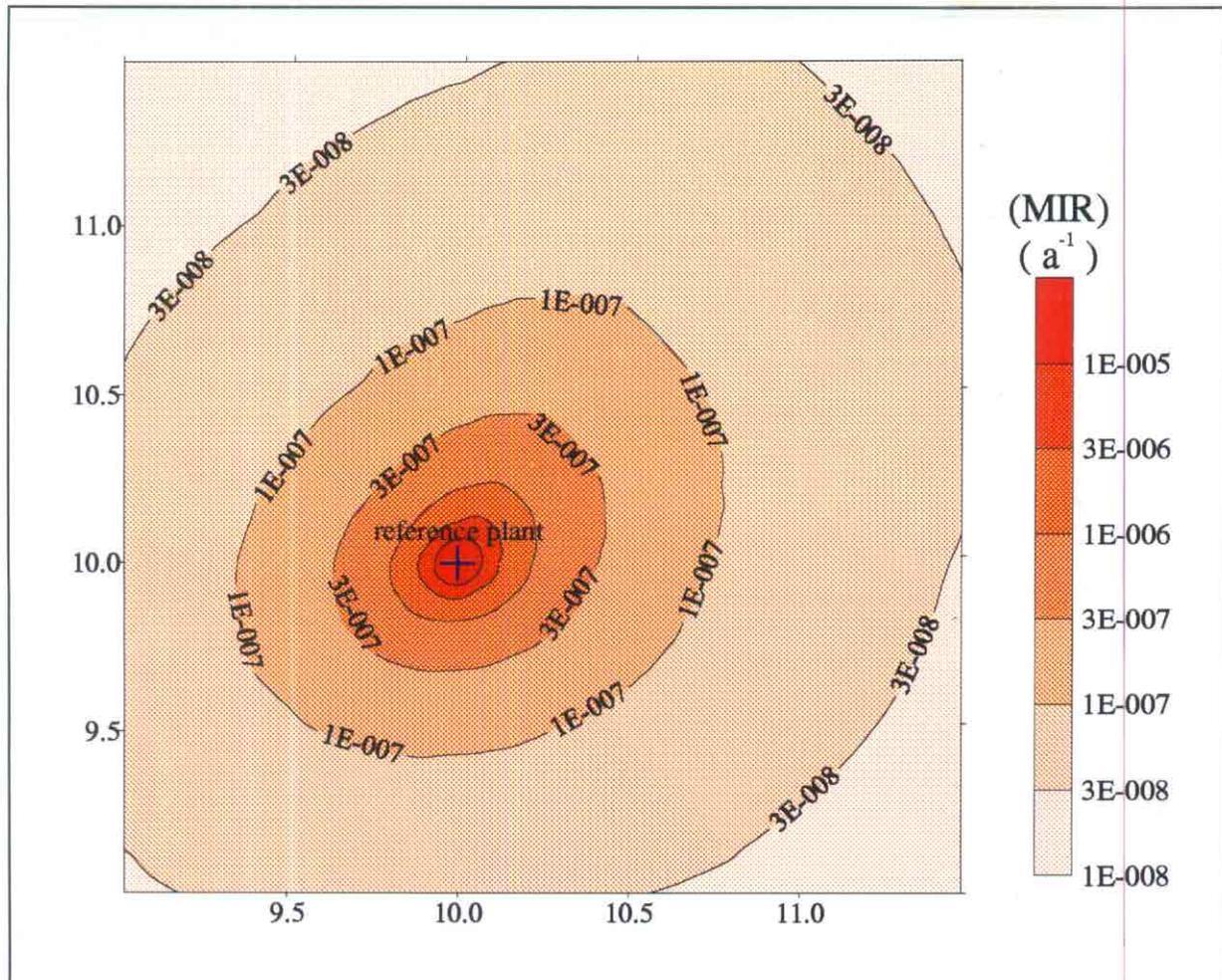
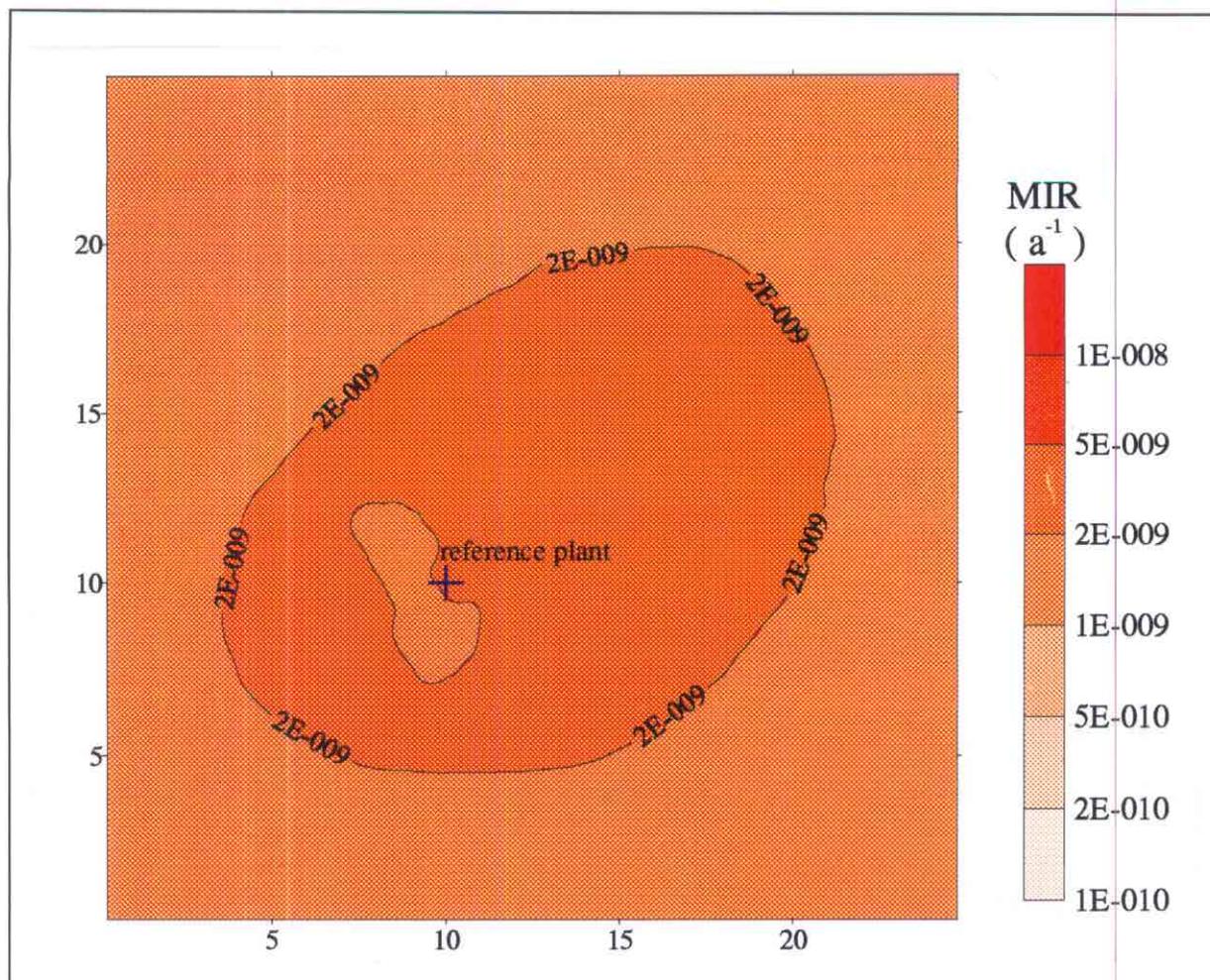


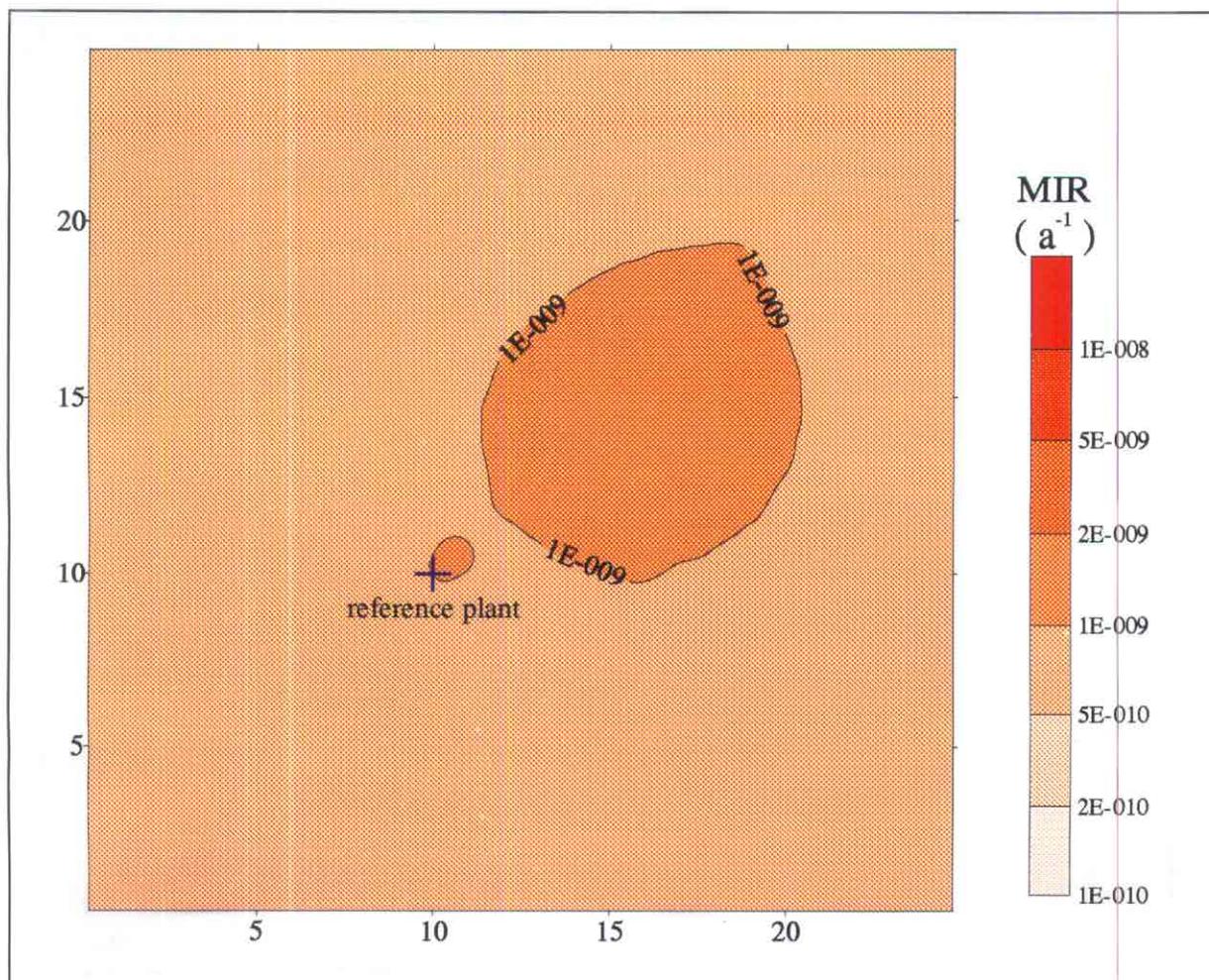
Figure G.1 Deposition pattern in reference situation 3 over a COROP area.



**Figure G.2** MIR contours for emission of natural radionuclides in reference situation 1: zero emission height, zero heat content and coarse particles.



**Figure G.3** MIR contours for emission of natural radionuclides in reference situation 2: emission height 40 m, heat content 10 MW and medium-size particles.



**Figure G.4** MIR contours for emission of natural radionuclides in reference situation 3: emission height 175 m, heat content 76 MW and fine particles.

## APPENDIX H RISKS OF EMISSIONS INTO AIR ABOVE THE SECONDARY LEVEL

### H.1 Introduction

In this appendix the method and results of location-specific risk calculations are described for the industries which have a risk  $> 10^{-8} \text{ a}^{-1}$  using the first screening method.

Risk calculations are performed using the method outlined in Appendix C of this report. The concentration in air and total deposition are calculated using the OPS dispersion model. A brief description of this model is given in Appendix B.

The MIR and AIR calculated in this chapter have uncertainties from e.g. emissions, dispersion and parameters used in the modelling. Especially the MIR and AIR from transshipment should be treated with care since:

- the influence of buildings close to the source is not taken into account. This can lead to considerably differences in air concentration and total deposition.
- the actual particle size might be much larger, resulting in an overestimation of air concentration and total deposition.
- deposited dust particles are frequently removed at the plant site by means of sweeping machines, resulting in a lower accumulated deposition.
- normally, no agricultural areas or vegetable gardens are located in the vicinity of the transshipment location, resulting in an overestimation of both MIR and AIR.

### H.2 Elementary phosphor plant at Vlissingen

Emissions to air can be divided into two main processes: thermic emissions due to phosphate processing and emissions during transshipment.

#### H.2.1 Dispersion in air

Dispersion is calculated using a 50-m and a 5-km grid size. Emissions from transshipment and from the thermic process are given in Table H.1.

**Table H.1** Emissions to air ( $\text{GBq a}^{-1}$ ) for the different processes at the elementary phosphor plant at Vlissingen

	$^{238}\text{U}$	$^{228}\text{Th}$	$^{226}\text{Ra}$	$^{210}\text{Pb}$	$^{210}\text{Po}$
thermic	-	-	-	66	490
transshipment	0.06	0.001	0.06	0.06	0.06

Location and height of chimneys, volume flow and temperature of the flue gases are obtained from the Dutch Emission Registration Service. The heat content is calculated from the throughput and temperature of the gases (see Appendix B). The location of the chimneys, corresponding heat content and radionuclide activity release are given in Table H.2. Assuming that the concentration in the emitted gas in the thermic process is equal for all processes, the emitted nuclides are calculated from the throughput.

**Table H.2** Location (x, y) (km), chimney height (m), heat content (MW) and  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  emission ( $\text{Bq s}^{-1}$ ) in the thermic process at Vlissingen

location	height	heat content	emission of $^{210}\text{Po}$	emission of $^{210}\text{Pb}$
37.10, 386.10	55	1.5	$7.78 \cdot 10^3$	$1.05 \cdot 10^3$
37.12, 386.10	55	1.5	$7.78 \cdot 10^3$	$1.05 \cdot 10^3$

The particle-size distribution of the thermic process emission used in the OPS-model is derived from [Ti93] and given in Table H.3.

**Table H.3** Particle-size distribution (%) of the gas emitted in the thermic process by the elementary phosphor plant at Vlissingen

particle size ( $\mu\text{m}$ )	< 0.95	0.95 – 4	4 – 10	10 – 20	> 20
distribution (%)	95.5	4.1	0.2	0.1	0.1

The exact location with respect to emissions to air during transshipment is unknown. Therefore, it is assumed that the emissions during transshipment take place at the quay in the centre of Cittershaven. It is assumed that the particles emitted can be described by the particle-size distribution class coarse as specified in the OPS model [Ja90], see also Appendix B. Parameters used in the calculation of the dispersion in air are listed in Table H.4.

## H.2.2 Calculation of MIR and AIR

Calculations of the dispersion of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  are performed using a 50-m grid. The maximum MIR calculated is  $3.2 \cdot 10^{-6} \text{ a}^{-1}$  for  $^{210}\text{Pb}$  and  $3.7 \cdot 10^{-6} \text{ a}^{-1}$  for  $^{210}\text{Po}$ . The total maximum MIR due to thermal emissions and transshipment is  $8.4 \cdot 10^{-6} \text{ a}^{-1}$ . MIR contours are shown in Figure J.3.

Local risks, calculated using a 50-m grid, are shown in Figure J.4. The average deposition over the COROP area in which the plant is situated is calculated with the geographical information system ARC-INFO. Average deposition over this COROP area is  $3.45 \text{ Bq m}^{-2} \text{ a}^{-1}$   $^{210}\text{Po}$  and  $0.47 \text{ Bq m}^{-2} \text{ a}^{-1}$   $^{210}\text{Pb}$ .

**Table H.4** Parameters used in the calculation of the dispersion of radionuclides <sup>(a)</sup>

	thermic process	thermic process	transshipment
substance	<sup>210</sup> Po	<sup>210</sup> Pb	average nuclide
molecular weight (g.mol <sup>-1</sup> )	210	210	220
form of release	particle bound	particle bound	particle bound
location of source (x,y) (km)	see Table H.2	see Table H.2	37.50, 386.35
source diameter (m)	0	0	0
source strength (Bq.s <sup>-1</sup> )	see Table H.2	see Table H.2	see Table H.1
source height (m)	see Table H.2	see Table H.2	0
heat content (MW)	see Table H.2	see Table H.2	0
particle-size distribution	see Table H.3	see Table H.3	coarse
emission variation	continuous	continuous	continuous
climatological data set	area 4	area 4	area 4
climatological period	year	year	year
roughness length (m)	0.12	0.12	0.12

<sup>(a)</sup> A description of the parameters used in the OPS model can be found in Appendix B and [Ja90].

The urban area at the shortest distance from the plant is Nieuwdorp. Maximum MIR from the thermic process is found on the terrain of an adjacent aluminum plant. The maximum AIR due to emissions from the thermic process is found at Nieuwdorp. Maximum MIR and AIR due to emissions during transshipment are found in the Cittershaven. For the calculation of the total risk from external radiation and emission to air, the risk of emission to air is calculated at a second location on the aluminum plant terrain. The MIR, AIR and the contributions from the different exposure pathways at Nieuwdorp and the aluminum plant are listed in Table H.5.

### H.2.3 Comparison with previous studies

Previously, risk calculations were performed by the KEMA [Ti93; Ki94]. The calculations were based on emission measurements. The calculated MIR and AIR at Nieuwdorp due to thermic emissions of <sup>210</sup>Po and <sup>210</sup>Pb of  $7.6 \cdot 10^{-7} \text{ a}^{-1}$  and an AIR at Pechiney of  $7.1 \cdot 10^{-7} \text{ a}^{-1}$ . In this study, the MIR and AIR at Nieuwdorp due to thermic emissions of <sup>210</sup>Po and <sup>210</sup>Pb is  $3.3 \cdot 10^{-6} \text{ a}^{-1}$  (Table H.5) and the AIR at the aluminum plant site is calculated at  $1.0 \cdot 10^{-6} \text{ a}^{-1}$ . Thus, risks calculated for Nieuwdorp differ by about a factor of 4; AIR calculated at Pechiney are in agreement.

In [Ti93] the influence of buildings is taken into account in the calculation of the total deposition at the aluminium plant terrain. This factor may increase the total deposition by a factor of 1.5. In the present report no correction for the influence of buildings is made. However, because inhalation is by far the most important exposure pathway, this will probably not affect the dose and risk near the plant. Deposition farther away will reduce

**Table H.5** MIR and AIR at Nieuwdorp and the aluminum plant site due to thermic and transshipment from the elementary phosphorus plant at Vlissingen

	Nieuwdorp	Pechiney	Van Cittershaven
location (x,y) (km)	40.20, 388.00	38.10, 387.05	37.90, 386.70
<b>Thermic emissions of <sup>210</sup>Po</b>			
MIR COROP (10 <sup>-6</sup> a <sup>-1</sup> )	0.006	0.006	0.006
MIR inhalation (10 <sup>-6</sup> a <sup>-1</sup> )	1.6	3.3	2.8
MIR vegetable garden (10 <sup>-6</sup> a <sup>-1</sup> )	0.14	0.3	0.3
total MIR (10 <sup>-6</sup> a <sup>-1</sup> )	1.8	3.7	3.1
total AIR (10 <sup>-6</sup> a <sup>-1</sup> )	1.8	0.7	0.6
<b>Thermic emissions of <sup>210</sup>Pb</b>			
MIR COROP (10 <sup>-6</sup> a <sup>-1</sup> )	0.012	0.012	0.012
MIR inhalation (10 <sup>-6</sup> a <sup>-1</sup> )	1.3	0.3	2.3
MIR vegetable garden (10 <sup>-6</sup> a <sup>-1</sup> )	0.19	0.4	0.4
total MIR (10 <sup>-6</sup> a <sup>-1</sup> )	1.5	3.2	2.7
total AIR (10 <sup>-6</sup> a <sup>-1</sup> )	1.5	0.5	0.5
<b>Emissions during Transshipment of <sup>210</sup>Po, <sup>210</sup>Pb, <sup>238</sup>U, <sup>228</sup>Th and <sup>226</sup>Ra</b>			
MIR COROP (10 <sup>-6</sup> a <sup>-1</sup> )	-	-	-
MIR inhalation (10 <sup>-6</sup> a <sup>-1</sup> )	0.002	0.02	0.06
MIR vegetable garden (10 <sup>-6</sup> a <sup>-1</sup> )	0.0003	0.004	0.010
total MIR (10 <sup>-6</sup> a <sup>-1</sup> )	0.002	0.03	0.07
total AIR (10 <sup>-6</sup> a <sup>-1</sup> )	0.002	0.005	0.013
<b>Total</b>			
MIR (10 <sup>-6</sup> a <sup>-1</sup> )	3.3	6.9	5.8
AIR (10 <sup>-6</sup> a <sup>-1</sup> )	3.3	1.2	1.0

the AIR (and MIR) for Nieuwdorp citizens. The main differences between this study and [Ki94] are given in Table H.6. If the differences in DCC are taken into account, it can be concluded that the results of [Ki94] and [Ti93] are less than a factor of 2 lower for Nieuwdorp and comparable for Pechiney, if the same building correction factor as used in [Ho93] is applied.

### H.3 Phosphoric acid plant at Vlaardingen

Risks from emissions to air are caused by two main processes: emissions from transshipment and emission of <sup>222</sup>Rn.

**Table H.6** Main differences between this study and [Ho94] and estimation of the influence on dose and risk:  $a = (\text{total MIR [Ho94]}) / (\text{total MIR this report})$

	this study	[HOE94]	$a$
DCC $^{210}\text{Po}$	$8.3 \cdot 10^{-6}$	$5.4 \cdot 10^{-6}$	0.65
DCC $^{210}\text{Pb}$	$5.0 \cdot 10^{-5}$	$2.9 \cdot 10^{-5}$	0.58
$^{210}\text{Po}$ concentration in air	OPS model	measurements	0.7
$^{210}\text{Pb}$ concentration in air	OPS model	measurements	0.9
total $^{210}\text{Po}$ deposition	OPS model	STACKS model	1.1 — 1.5
total $^{210}\text{Pb}$ deposition	OPS model	STACKS model	1.1 — 1.5

### H.3.1 Dispersion in air

Dispersion is calculated using a 50-m grid. Emissions from transshipment are given in Table H.7 (see Appendix G).

**Table H.7** Emissions to air ( $\text{GBq a}^{-1}$ ) during transshipment at the phosphoric acid production plant at Vlaardingen

	$^{238}\text{U}$	$^{228}\text{Th}$	$^{226}\text{Ra}$	$^{210}\text{Pb}$	$^{210}\text{Po}$
transshipment	0.07	0.002	0.09	0.08	0.14

$^{222}\text{Rn}$  is released by two chimneys of the extraction installation of two reactors.  $^{222}\text{Rn}$  is also emitted from stock piles in a shed. Location and height of chimneys, volume flow and heat content of the flue gases are taken from [Bo92] and are given in Table H.8. It is assumed that  $^{222}\text{Rn}$  is emitted from the storage shed continuously, while the emission from the chimneys of the extraction installation takes place according to an average industrial process (Appendix B).

**Table H.8** Location (x,y) (km) and height (m) of chimneys, heat content (MW) and the amount of  $^{222}\text{Rn}$  emitted ( $\text{Bq s}^{-1}$ ) at the Vlaardingen plant [Bo92]

location	height	heat content	emission of $^{222}\text{Rn}$
81.900, 434.900	8	0	$4.0 \cdot 10^2$
81.898, 434.995	38.5	0.108	$1.55 \cdot 10^4$
81.881, 434.978	33.5	0.072	$1.04 \cdot 10^4$

The risks due to the emissions from transshipment are calculated using  $x = 81.8$  km and  $y = 434.7$  km as the most probable transshipment location. It is assumed that the particles

emitted have the particle-size distribution class coarse. Parameters used in the calculation of the dispersion in air are listed in Table H.9.

**Table H.9** Parameters used in the calculation of the dispersion of radionuclides emitted during transshipment <sup>(a)</sup>

	transshipment
substance	average nuclide
molecular weight (g.mol <sup>-1</sup> )	220
form of release	particle bound
location of source (x,y) (km)	81.90, 434.67
source diameter (m)	0
source strength (Bq.s <sup>-1</sup> )	see Table H.7
source height (m)	0
heat content (MW)	0
particle-size distribution	coarse
emission variation	continuous
climatological data set	the Netherlands
climatological period	year
roughness length (m)	0.15

<sup>(a)</sup> A description of the parameters used in the OPS model can be found in Appendix B and [Ja90].

### H.3.2 Calculation of MIR and AIR

Location-specific calculations are performed using a 50-m grid. MIR contours from transshipment are shown in Figure J.5. The MIR, the AIR and the ACF for the different locations at the terrain border are given in Table H.10.

The maximum MIR ( $3.1 \cdot 10^{-6} \text{ a}^{-1}$ ) at the boundary of the plant due to transshipment is calculated for location 14 ( $x = 81.98 \text{ km}$ ,  $y = 434.64 \text{ km}$ ) (Figure J.5). The maximum AIR of  $2.0 \cdot 10^{-7} \text{ a}^{-1}$  is calculated for location 12 ( $x = 82.06 \text{ km}$ ,  $y = 434.71 \text{ km}$ ). The inhalation pathway contributes about 90% to the MIR at the boundary of the plant. The remainder originates from the vegetable garden pathway; the contribution of vegetables from the COROP area is negligible. The MIR at the nearest residential area at Vlaardingen due to transshipment is negligible because of the relatively long distance from the source, about 1.5 km.

Maximum MIR and AIR due to emissions of <sup>222</sup>Rn are given in Table H.11. Maximum MIR is calculated for the terrain of the adjacent plant site, about 400 m north-east of the sources (Figure J.6). Maximum AIR is found at the nearest residential area in Vlaardingen.

**Table H.10** MIR ( $a^{-1}$ ), AIR ( $a^{-1}$ ) and ACF for the different locations at the terrain border of the Vlaardingen plant

location	MIR <sup>(b)</sup>	AIR <sup>(c)</sup>	ACF
1	$7.0 \cdot 10^{-7}$	$6.4 \cdot 10^{-9}$	0.01
2	$1.5 \cdot 10^{-7}$	$2.8 \cdot 10^{-8}$	0.2
3	$8.8 \cdot 10^{-8}$	$1.6 \cdot 10^{-8}$	0.2
4	$5.2 \cdot 10^{-8}$	$4.8 \cdot 10^{-10}$	0.01
5	$6.3 \cdot 10^{-8}$	$5.8 \cdot 10^{-10}$	0.01
6	$7.5 \cdot 10^{-8}$	$6.8 \cdot 10^{-10}$	0.01
7	$8.7 \cdot 10^{-8}$	$7.8 \cdot 10^{-10}$	0.01
8	$1.2 \cdot 10^{-7}$	$1.1 \cdot 10^{-9}$	0.01
9	$1.2 \cdot 10^{-7}$	$2.1 \cdot 10^{-8}$	0.2
10	$3.4 \cdot 10^{-7}$	$6.0 \cdot 10^{-8}$	0.2
11	$6.7 \cdot 10^{-7}$	$1.2 \cdot 10^{-7}$	0.2
12	$1.1 \cdot 10^{-6}$	$2.0 \cdot 10^{-7}$	0.2
13	$4.1 \cdot 10^{-6}$	0	0
14	$3.1 \cdot 10^{-6}$	$2.8 \cdot 10^{-8}$	0.01

<sup>(b)</sup> Exposure pathways are inhalation and ingestion from the vegetable garden and the reference COROP area.

<sup>(c)</sup> Exposure pathways are inhalation and ingestion from the reference COROP area.

**Table H.11** Maximum MIR and AIR due to releases of  $^{222}\text{Rn}$  at the Vlaardingen plant

	adjacent industry	Vlaardingen
location	82.15, 435.25	82.20, 435.40
MIR ( $a^{-1}$ )	$4.5 \cdot 10^{-8}$	$3.9 \cdot 10^{-8}$
AIR ( $a^{-1}$ )	$9.0 \cdot 10^{-9}$	$3.9 \cdot 10^{-8}$

### H.3.3 Comparison with previous studies

Previously, risks associated with releases of  $^{222}\text{Rn}$  and radionuclides during transshipment to air were calculated [Bo92]. For  $^{222}\text{Rn}$ , the maximum risk just outside the terrain border north-east of the source was calculated to be  $8.5 \cdot 10^{-9} a^{-1}$ , whereas in this study the maximum risk (MIR) is  $4.5 \cdot 10^{-8} a^{-1}$ , a factor of 5 higher.

Main factors causing the differences between this study and [Bo92] are given in Table H.12. In this study, the OPS model is used for the calculation of the dispersion of  $^{222}\text{Rn}$ , in [Bo92] the LTFD model (Long Term Frequency Distribution model). In contrast to this study, in [Bo92] influences of buildings were taken into account and the exposure time was assumed to be only eight hours a day. The factors outlined in Table H.12 explain the different results for  $^{222}\text{Rn}$  of [Bo92] and this report well.

In [Bo92], the maximum risk for inhalation due to emissions during transshipment is calculated to be  $5.3 \cdot 10^{-8} \text{ a}^{-1}$  at the boundary of the terrain, which corresponds to an AIR of  $3.2 \cdot 10^{-8} \text{ a}^{-1}$  when a correction is made for the residence time. In this study, the maximum AIR at the terrain border is calculated to be  $2.0 \cdot 10^{-7} \text{ a}^{-1}$ . The reason(s) for this difference could not be identified, but could be other DCC values, location of the source (dose-rates are far more localized for dust emissions than for  $^{222}\text{Rn}$ ) and differences in the radionuclide emission (see also Table H.10).

**Table H.12** Main differences between this study and [Bo92] and estimation of the difference  $a = (\text{total MIR [Bo92]}) / (\text{total MIR this study})$  for  $^{222}\text{Rn}$

	this study	[Bo92]	$a$
$^{222}\text{Rn}$			
DCC <sub>inh</sub> (Sv Bq <sup>-1</sup> )	$7.4 \cdot 10^{-9}$	$7.1 \cdot 10^{-9}$	0.96
Maximum concentration in air (Bq m <sup>-3</sup> )	$2.9 \cdot 10^{-9}$	$1.7 \cdot 10^{-9}$	0.59
Exposure time as fraction of a year (-)	1 (*)	1/3	1/3
Total			0.19

(\*) It is assumed that the additions to the indoor and outdoor  $^{222}\text{Rn}$  concentrations are equal.

## H.4 The phosphoric acid plant at Pernis

Risks from emissions to air are caused by two main processes: emissions from transshipment and emissions of  $^{222}\text{Rn}$ .

### H.4.1 Dispersion in air

Dispersion is calculated using a 50-m grid. Emissions from transshipment are given in Table H.13 (see Appendix G).

**Table H.13** Emissions to air (GBq a<sup>-1</sup>) during transshipment at the phosphoric acid production plant at Pernis

	$^{238}\text{U}$	$^{228}\text{Th}$	$^{226}\text{Ra}$	$^{210}\text{Pb}$	$^{210}\text{Po}$
Transshipment	0.13	0.001	0.16	0.15	0.15

$^{222}\text{Rn}$  is released by two chimneys of the extraction installation of reactors.  $^{222}\text{Rn}$  is also emitted from stock piles in a shed. Height of chimneys, volume flow and heat content of the flue gases are given in [Bo93]. The location of the chimneys and the storage shed is

assumed to be at the centre of the terrain (see Table H.14). It is assumed that  $^{222}\text{Rn}$  is emitted from the storage shed continuously, emission from the chimneys of the extraction installation takes place according to an average industrial process (Appendix B).

**Table H.14** Location (x, y) (km) and height (m) of chimneys, heat content (MW) and the amount of  $^{222}\text{Rn}$  emitted ( $\text{Bq s}^{-1}$ ) at the Pernis plant [Bos93]

location	height	heat content	emission of $^{222}\text{Rn}$
82.200, 434.000	60	1.76	$3.3 \cdot 10^4$
82.400, 434.200	4	0	$6.5 \cdot 10^3$

The risks from transshipment are calculated, using  $x = 81.8$  km and  $y = 434.7$  km as the transshipment location. It is assumed that the particles emitted can be described by the particle-size distribution class coarse. Parameters used in the calculation of the dispersion in air are listed in Table H.15.

**Table H.15** Parameters used in the calculation of the dispersion of radionuclides emitted during transshipment <sup>(a)</sup>

	transshipment
substance	average nuclide
molecular weight ( $\text{g} \cdot \text{mol}^{-1}$ )	220
form of release	particle bound
location of source (x,y) (km)	82.30, 434.31
source diameter (m)	0
source strength ( $\text{Bq} \cdot \text{s}^{-1}$ )	see Table H.13
source height (m)	0
heat content (MW)	0
particle size distribution	coarse
emission variation	continuous
climatological data set	the Netherlands
climatological period	year
roughness length (m)	0.15

<sup>(a)</sup> A description of the parameters used in the OPS model can be found in Appendix B and [Ja90].

#### H.4.2 Calculation of MIR and AIR

Local risk calculations are performed using a 50 m grid. MIR-contours on a 50 m grid from transshipment are shown in Figure J.7. MIR, AIR and ACF for the different locations at the terrain border are given in Table H.16.

**Table H.16** MIR ( $a^{-1}$ ), AIR ( $a^{-1}$ ) and ACF for the different locations at the terrain border of the Pernis plant

location	MIR <sup>(b)</sup>	AIR <sup>(c)</sup>	ACF
1	$1.1 \cdot 10^{-7}$	$1.0 \cdot 10^{-9}$	0.01
2	$1.8 \cdot 10^{-7}$	$3.2 \cdot 10^{-8}$	0.2
3	$2.1 \cdot 10^{-7}$	$1.9 \cdot 10^{-9}$	0.01
4	$1.1 \cdot 10^{-6}$	$2.0 \cdot 10^{-7}$	0.2
5	$2.9 \cdot 10^{-7}$	$2.7 \cdot 10^{-9}$	0.01
6	$1.3 \cdot 10^{-7}$	$1.2 \cdot 10^{-9}$	0.01
7	$1.3 \cdot 10^{-7}$	$1.2 \cdot 10^{-9}$	0.01
8	$9.7 \cdot 10^{-8}$	$8.8 \cdot 10^{-10}$	0.01
9	$7.0 \cdot 10^{-8}$	$6.4 \cdot 10^{-10}$	0.01
10	$1.5 \cdot 10^{-7}$	$2.8 \cdot 10^{-8}$	0.2

<sup>(b)</sup> Exposure pathways are inhalation and ingestion from the vegetable garden and the reference COROP area.

<sup>(c)</sup> Exposure pathways are inhalation and ingestion from the reference COROP area.

The maximum MIR ( $1.1 \cdot 10^{-6} a^{-1}$ ) at the boundary of the plant site due to transshipment is calculated for location 4 ( $x = 82.49$  km,  $y = 434.28$  km) (Figure J.7). The maximum AIR ( $2.0 \cdot 10^{-7} a^{-1}$ ) is calculated for the same location. The inhalation pathway contributes about 90% to the MIR. The remainder originates from the vegetable garden pathway; the contribution of vegetables from the COROP area is negligible. The MIR in the nearest residential area due to emissions from transshipment is negligible because of the relatively long distance from the source, about 1.5 km.

Maximum MIR and AIR due to emissions of  $^{222}\text{Rn}$  are given in Table H.17. The maximum MIR is calculated at the terrain of the adjacent plant, about 400 m north-east of the sources (Figure J.8). Maximum AIR is found at the nearest residential area.

**Table H.17** Maximum MIR and AIR due to releases of  $^{222}\text{Rn}$  to air at the Pernis plant

	adjacent industry	Nieuwe Maas	Vlaardingen
location	82.50, 434.25	82.45, 434.30	82.45, 435.40
MIR ( $a^{-1}$ )	$3.8 \cdot 10^{-7}$	$4.4 \cdot 10^{-7}$	$1.0 \cdot 10^{-8}$
AIR ( $a^{-1}$ )	$7.6 \cdot 10^{-8}$	$4.4 \cdot 10^{-9}$	$1.0 \cdot 10^{-8}$

### H.4.3 Comparison with previous studies

Previous studies concentrated mainly on the risks associated with the releases of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  to the Nieuwe Waterweg. In [Bo93] risks associated with releases of  $^{222}\text{Rn}$  and radionuclides during transshipment to air were assessed previously.

For  $^{222}\text{Rn}$ , the maximum risk just outside the terrain border, south-east of the source, was calculated to be  $1.5 \cdot 10^{-8} \text{ a}^{-1}$ , whereas in this report a maximum risk (MIR) of  $4.4 \cdot 10^{-7}$  is calculated north-east of the source at about a factor of 30 higher. The main differences between this study and the calculations of [Bo93] are given in Table H.18. They explain only a factor of 5 difference between the studies. Further, in this study, the OPS model is used for the calculation of the dispersion of  $^{222}\text{Rn}$ , in [Bo93] the LTFD model (Long Term Frequency Distribution model). In [Bo93], influences of buildings are taken into account. The location of the  $^{222}\text{Rn}$  sources is not given in [Bo93], but since the maximum concentration of  $^{222}\text{Rn}$  outside the terrain border is calculated in [Bo93] south-east of the sources and in this study north-east of the sources, it is likely that the emission sources are differently located. The use of a different dispersion model and the effect of buildings may also explain (part of) the remaining differences (see also Section H.3). In [Bo93] the maximum risk for inhalation due to emissions from transshipment is calculated to be  $4.0 \cdot 10^{-7} \text{ a}^{-1}$ , which corresponds to an AIR of  $2.4 \cdot 10^{-7} \text{ a}^{-1}$  when a correction is made for the residence time. In this study, the maximum AIR at the terrain border is calculated to be  $2.0 \cdot 10^{-7} \text{ a}^{-1}$ . Although these results for transshipment are in good agreement, different DCC values, locations of the source and emitted radionuclides may have been used in the two studies (see also Section H.3).

**Table H.18** Main differences between this study and [Bo93] and estimation of the difference  $a = (\text{total MIR [Bo93]}) / (\text{total MIR this study})$

	this study	[Bo93]	$a$
$^{222}\text{Rn}$			
DCC <sub>inh</sub> (Sv Bq <sup>-1</sup> )	$7.4 \cdot 10^{-9}$	$7.1 \cdot 10^{-9}$	0.96
maximum concentration in air (Bq m <sup>-3</sup> )	$2.9 \cdot 10^{-9}$	$1.7 \cdot 10^{-9}$	0.58
exposure time as fraction of a year (-)	1 <sup>(d)</sup>	1/3	1/3
location of maximum concentration	south-east of the terrain border	north-east of the terrain border	?

<sup>(d)</sup> Additional  $^{222}\text{Rn}$  concentrations due to the releases of  $^{222}\text{Rn}$  indoors and outdoors assumed equal.

### H.5 Fertilizer production plant at Amsterdam

Using reference plant 1 (see Appendix G) the MIR for the different nuclides at 100 m north-east of the source was calculated (Table G.5).

Emissions during transshipment are given in Table H.19. Using these emissions and the normalized MIR given in Table G.5, the MIR due to the emissions from transshipment is obtained (see Table H.19).

**Table H.19** Emissions to air during transshipment and the corresponding MIR for the fertilizer production plant at Amsterdam

	$^{238}\text{U}$	$^{228}\text{Th}$	$^{226}\text{Ra}$	$^{222}\text{Rn}$	$^{210}\text{Pb}$	$^{210}\text{Po}$	Total
Emission (GBq a <sup>-1</sup> )	0.02	0.0001	0.02	0.02	0.02	0.02	
MIR (a <sup>-1</sup> )	$3.6 \cdot 10^{-7}$	$5.0 \cdot 10^{-9}$	$3.0 \cdot 10^{-8}$	$1.1 \cdot 10^{-9}$	$7.0 \cdot 10^{-8}$	$3.0 \cdot 10^{-8}$	$5.0 \cdot 10^{-7}$

## H.6 The primary iron and steel production plant at IJmuiden

Emissions to air can be divided into two main processes: thermic emissions from the sinter plant, the pellet plant and the cokes plant and emissions during transshipment.

### H.6.1 Dispersion in air

Dispersion in air is calculated using a 100-m, a 250-m and using a 5-km grid size. Emissions from transshipment and during the thermic process are given in Table H.20.

**Table H.20** Emissions to air (GBq a<sup>-1</sup>) for the different processes at the primary iron and steel production plant at IJmuiden

	$^{238}\text{U}$	$^{228}\text{Th}$	$^{226}\text{Ra}$	$^{210}\text{Pb}$	$^{210}\text{Po}$
thermic	-	-	-	55	91
transshipment	0.01	0.01	0.01	0.01	0.01

Location and height of chimneys, volume flow and temperature of the flue gases are obtained from the Dutch Emission Registration Service. The heat content is calculated from the throughput and temperature of the flue gases (see Appendix B). The location of the chimneys, the heat content and the emissions are given in Table H.21.

It is assumed that radionuclides of the sinter plant are released from a chimney with a height of 150 m [We91a] and those of the pellet plant from a chimney with a height of 70 m [We91a]. Assuming equal concentrations of the radionuclides during the thermic process the emission is calculated from the process and throughput.

The particle-size distribution in the thermic process emissions is calculated from the  $^{210}\text{Pb}$

**Table H.21** Chimney location (x,y) (km), height (m), heat content (MW) and emission (Bq s<sup>-1</sup>) of the IJmuiden iron and steel plant

location	height	heat content	emission of <sup>210</sup> Po	emission of <sup>210</sup> Pb
101.35, 499.00	150	19	2.66·10 <sup>3</sup>	1.71·10 <sup>3</sup>
100.85, 499.05	70	1.5	2.35·10 <sup>2</sup>	2.6·10 <sup>1</sup>
101.05, 499.20	70	0	1.9	4.9
101.95, 498.95	50	0	8·10 <sup>-1</sup>	2.1
101.00, 499.40	50	0	5·10 <sup>-1</sup>	1.2
101.40, 499.05	30	0	3·10 <sup>-1</sup>	8·10 <sup>-1</sup>
102.50, 498.75	80	0	2·10 <sup>-1</sup>	6·10 <sup>-1</sup>

content in fly dust released by the sinter plant [We91a; Ja90]. The particle size used in OPS is given in Table H.22.

**Table H.22** Particle-size distribution (%) of the gas emitted by the IJmuiden plant

particle size (μm)	< 0.95	0.95 — 4	4 — 10	10 — 20	> 20
distribution (%)	91	4	3	1	1

For transshipment, it is assumed that the emissions take place in the centre of the harbour of the Hoogovens steel plant which is about 750 m from the border of the Hoogovens terrain. Further, it is assumed that the emission can be described by the particle size distribution class coarse in the OPS model [Ja90] (see also Appendix B). If the transshipment takes place in the eastern part of the harbour at a location closer to the terrain border, a higher risk could result outside of the terrain border.

The parameters used in the calculation of the dispersion in air are listed in Table H.23.

## H.6.2 Calculation of MIR and AIR

Long-distance dispersion calculations for <sup>210</sup>Po and <sup>210</sup>Pb were performed using a 5-km grid. The MIR is calculated using the multiplication factors given in Appendix C. The maximum MIR is 1.6·10<sup>-7</sup> a<sup>-1</sup> for <sup>210</sup>Pb and 5.6·10<sup>-8</sup> a<sup>-1</sup> for <sup>210</sup>Po. MIR-contours over the Netherlands are shown in Figure J.9. Local calculations are performed using a 100-m grid. Since the location of maximum concentration and deposition is a few kilometres from the source, additional calculations are performed using a 250-m grid. MIR-contours are shown in Figure J.10 and Figure J.11. The average deposition over the COROP area involved calculated with the geographical information system ARC-INFO is 0.68 Bq m<sup>-2</sup> a<sup>-1</sup> for <sup>210</sup>Po and 0.36 Bq m<sup>-2</sup> a<sup>-1</sup> for <sup>210</sup>Pb.

**Table H.23** Parameters used in the calculation of the dispersion of radionuclides

	thermic process	thermic process	transshipment
substance	<sup>210</sup> Po	<sup>210</sup> Pb	average nuclide
molecular weight (g.mol <sup>-1</sup> )	210	210	220
form of release	particle bound	particle bound	particle bound
location of source (x,y) (km)	see Table H.21	see Table H.21	102.85, 499.15
source diameter (m)	0	0	0
source strength (Bq.s <sup>-1</sup> )	see Table H.21	see Table H.21	see Table H.20
source height (m)	see Table H.21	see Table H.21	0
heat content (MW)	see Table H.21	see Table H.21	0
particle size distribution	see Table H.22	see Table H.22	coarse
emission variation	continuous	continuous	continuous
climatological data set	area 2	area 2	area 2
climatological period	year	year	year
roughness length (m)	1	1	1

The nearest urban area is Velsen. Calculations are performed for two locations in Velsen-Noord. Maximum MIR from the thermic process is found north of Beverwijk (see Figure J.10 and Figure J.11). Since this is an urban area, AIR is equal to MIR. The MIR, AIR and the contributions from the different exposure pathways at Velsen-Noord and Beverwijk are listed in Table H.24.

### H.6.3 Comparison with previous studies

Previously risk calculations were performed by the Energy Research Centre Netherlands (ECN) [We89; We91a]. In [We91a] the total maximum risk for thermic emissions is calculated to be  $3.5 \cdot 10^{-7} \text{ a}^{-1}$  and the total maximum MIR  $2.1 \cdot 10^{-7} \text{ a}^{-1}$  (see Table H.24). The total risk calculated in [We91a] is a factor of 1.5 — 2 higher than the MIR calculated in this report. The main differences between this study and the ECN 1991 study are given in Table H.25. If the differences shown are taken into account, it can be concluded that the results of the We91a study and this study are in close agreement.

### H.7 Cement industry at Maastricht

Emissions to air can be divided into two main processes: thermic emissions due to cement production and emissions during marl extraction, transport and milling.

**Table H.24** MIR (a<sup>-1</sup>) and AIR (a<sup>-1</sup>) at Velsen-Noord and Beverwijk due to thermic emissions and transshipment from the IJmuiden plant

	Velsen-Noord	Velsen-Noord	Beverwijk
location (x,y) (km)	103.4, 498.6	103.6, 498.6	105.7, 501.6
<b>Thermic</b>			
nuclide	<sup>210</sup> Po	<sup>210</sup> Po	<sup>210</sup> Po
MIR COROP (a <sup>-1</sup> )	3.0·10 <sup>-8</sup>	1.2·10 <sup>-9</sup>	1.2·10 <sup>-9</sup>
MIR inhalation (a <sup>-1</sup> )	6.9·10 <sup>-9</sup>	3.1·10 <sup>-8</sup>	4.5·10 <sup>-8</sup>
MIR vegetable garden (a <sup>-1</sup> )	1.5·10 <sup>-9</sup>	1.6·10 <sup>-9</sup>	2.5·10 <sup>-9</sup>
total MIR (a <sup>-1</sup> )	3.3·10 <sup>-8</sup>	3.3·10 <sup>-8</sup>	4.9·10 <sup>-8</sup>
total AIR (a <sup>-1</sup> )	3.3·10 <sup>-8</sup>	3.3·10 <sup>-8</sup>	4.9·10 <sup>-8</sup>
<b>Thermic</b>			
nuclide	<sup>210</sup> Pb	<sup>210</sup> Pb	<sup>210</sup> Pb
MIR COROP (a <sup>-1</sup> )	9.3·10 <sup>-9</sup>	9.3·10 <sup>-9</sup>	9.3·10 <sup>-9</sup>
MIR inhalation (a <sup>-1</sup> )	5.5·10 <sup>-8</sup>	6.0·10 <sup>-8</sup>	1.3·10 <sup>-7</sup>
MIR vegetable garden (a <sup>-1</sup> )	6.3·10 <sup>-9</sup>	6.6·10 <sup>-9</sup>	1.4·10 <sup>-8</sup>
total MIR (a <sup>-1</sup> )	7.0·10 <sup>-8</sup>	7.6·10 <sup>-8</sup>	1.6·10 <sup>-7</sup>
total AIR (a <sup>-1</sup> )	7.0·10 <sup>-8</sup>	7.6·10 <sup>-8</sup>	1.6·10 <sup>-7</sup>
<b>Transshipment</b>			
nuclide	<sup>210</sup> Po, <sup>210</sup> Pb, <sup>238</sup> U, <sup>228</sup> Th, <sup>226</sup> Ra	<sup>210</sup> Po, <sup>210</sup> Pb, <sup>238</sup> U, <sup>228</sup> Th, <sup>226</sup> Ra	<sup>210</sup> Po, <sup>210</sup> Pb, <sup>238</sup> U, <sup>228</sup> Th, <sup>226</sup> Ra
MIR COROP (a <sup>-1</sup> )	-	-	-
MIR inhalation (a <sup>-1</sup> )	1.1·10 <sup>-8</sup>	7.8·10 <sup>-9</sup>	9.6·10 <sup>-10</sup>
MIR vegetable garden (a <sup>-1</sup> )	4.4·10 <sup>-10</sup>	3.3·10 <sup>-10</sup>	4.0·10 <sup>-11</sup>
total MIR (a <sup>-1</sup> )	1.1·10 <sup>-8</sup>	8.1·10 <sup>-9</sup>	1.0·10 <sup>-9</sup>
total AIR (a <sup>-1</sup> )	1.1·10 <sup>-8</sup>	8.1·10 <sup>-9</sup>	1.0·10 <sup>-9</sup>
<b>Total</b>			
MIR (a <sup>-1</sup> )	1.1·10 <sup>-7</sup>	1.1·10 <sup>-7</sup>	2.1·10 <sup>-7</sup>
AIR (a <sup>-1</sup> )	1.1·10 <sup>-7</sup>	1.1·10 <sup>-7</sup>	2.1·10 <sup>-7</sup>

### H.7.1 Dispersion in air

Dispersion is calculated using a 50-m and 5-km grid size. Emissions from transshipment and the thermic process are given in Table H.26.

Location and height of chimneys, volume flow and temperature of the flue gases are obtained from the Dutch Emission Registration Service. The heat content is calculated from the throughput and temperature of the gases (see Appendix B). The chimney location, height, heat content and released radionuclides are given in Table H.27. For the calculations it is assumed that both chimneys are located at the same spot and that the radionuclide concentrations are equal during all processes. The emitted activity is calculated from the throughput.

**Table H.25** Main differences between this study and the ECN-91 study and estimation of the difference  $a = (\text{total risk ECN-91}) / (\text{total risk in this study})$

	this study	ECN-91 study	$a$
exposure pathways	inhalation, ingestion of agricultural products	inhalation, ingestion of agricultural and fish products <sup>(a)</sup>	1.3
emission <sup>210</sup> Po (GBq.a <sup>-1</sup> )	91	100	1.03
emission <sup>210</sup> Pb (GBq.a <sup>-1</sup> )	55	100	1.2
DCC's	based on [Kö88]	based on [ICRP79]	0.6 – 0.7
dispersion model	OPS	National Model	1.5 – 2.5

<sup>(a)</sup> The consumption pattern of the reference group used in the calculations in [ECN91] is based on conservative estimates. In [Be93] it is prescribed to use a realistic consumption pattern instead of a worst-case approach. This difference in approach leads to considerable differences in total risk for the fish consumption pathway.

**Table H.26** Emissions to air (GBq a<sup>-1</sup>) for the different processes at the cement production plant at Maastricht

	<sup>238</sup> U	<sup>228</sup> Th	<sup>226</sup> Ra	<sup>210</sup> Pb	<sup>210</sup> Po
thermic	-	-	-	-	78
marl extraction	0.16	0.02	0.16	0.16	0.17
transport and milling	0.03	0.02	0.03	0.03	0.02

**Table H.27** Chimney location (x, y) (km), height (m), heat content (MW) and emitted <sup>210</sup>Po (Bq s<sup>-1</sup>) in the thermic process of the cement production plant at Maastricht

location	height	heat content	emission of <sup>210</sup> Po
176.50, 314.50	150	10.4	$2.3 \cdot 10^3$
176.50, 314.50	16	0.92	$2 \cdot 10^2$

No data is available with respect to the particle size emitted in the thermic process. It is assumed that the emitted particles can be described by the OPS-particle size distribution class 'fine' (Appendix B).

The exact emission locations from transport and milling are unknown. It is assumed that the emissions stem from six point sources, which cover the distance between the pit and the centre of the plant area. Emissions from transport are equally divided over these six points. It is assumed that milling takes place at the centre of the plant area (at the end of the transport track).

It should be noted that the risks associated with the marl extraction process should be handled with extreme care, since the marl is extracted from a deep pit. The OPS model is strictly speaking not suited for treating this type of sources. For an indication of possible risks associated with the marl extraction process, it is assumed that emission is a surface source with a diameter of 200 m. To our own knowledge, this diameter is approximately the diameter of the pit.

It is assumed that the particles emitted during marl extraction, transport and milling can be described by the particle-size distribution class coarse. Parameters used in the calculation of the dispersion in air are listed in Table H.28.

**Table H.28** Parameters used in the calculation of the dispersion of radionuclides <sup>(a)</sup>

	thermic process	marl extraction	transport and milling
substance	<sup>210</sup> Po	average nuclide	average nuclide
molecular weight (g.mol <sup>-1</sup> )	210	220	220
form of release	particle bound	particle bound	particle bound
location of source (x,y) (km)	see Table H.27	176.25, 313.75	176.25, 313.75 176.29, 313.87 176.33, 313.99 176.37, 314.11 176.41, 314.23 176.45, 314.35
source diameter (m)	0	200	0
source strength (Bq.s <sup>-1</sup> )	see Table H.27	see Table H.26	see Table H.26
source height (m)	see Table H.27	0	0
heat content (MW)	see Table H.27	0	0
particle-size distribution	fine	coarse	coarse
emission variation	continuous	average industrial process	average industrial process
climatological data set	area 6	area 6	area 6
climatological period	year	year	year
roughness length (m)	0.20	0.20	0.20

<sup>(a)</sup> A description of the parameters used in the OPS model can be found in Appendix B and [Ja90].

## H.7.2 Calculation of MIR and AIR

Dispersion calculations for <sup>210</sup>Po are performed using a 5-km grid. The maximum MIR is  $1.8 \cdot 10^{-8} \text{ a}^{-1}$  for <sup>210</sup>Po. MIR contours are shown in Figure J.13.

Location-specific calculations are performed using a 50-m grid. MIR-contours are shown in Figure J.12. Average deposition over this COROP area is  $1.2 \text{ Bq m}^{-2} \text{ a}^{-1}$  <sup>210</sup>Po. The nearest residential area is Hoogenweerth. Maximum MIR from the thermic process is

found to the north-east of the plant, approximately halfway Hoogenweerth and Heugem (see Figure J.12). The maximum AIR due to emissions in the thermic process is again found at Hoogenweerth. Maximum MIR due to emissions during marl extraction, transport and milling is found at the border of the terrain to the south of the pit. Maximum AIR is found at Hoogenweerth. MIR, AIR and the contributions from the different exposure pathways at Hoogenweerth and Heugem are given in Table H.29.

**Table H.29** MIR ( $a^{-1}$ ) and AIR ( $a^{-1}$ ) at Hoogenweerth and Heugem due to thermic emissions and emissions during marl extraction, transport and milling from the Maastricht plant

	Hoogenweerth	Heugem
location (x,y) (km)	40.20, 388.00	38.10, 387.05
<b>Thermic</b>		
nuclide	$^{210}\text{Po}$	$^{210}\text{Po}$
MIR COROP ( $a^{-1}$ )	$2.2 \cdot 10^{-9}$	$2.2 \cdot 10^{-9}$
MIR inhalation ( $a^{-1}$ )	$6.9 \cdot 10^{-8}$	$4.7 \cdot 10^{-8}$
MIR vegetable garden ( $a^{-1}$ )	$2.1 \cdot 10^{-8}$	$1.4 \cdot 10^{-8}$
total MIR ( $a^{-1}$ )	$9.2 \cdot 10^{-8}$	$6.4 \cdot 10^{-8}$
total AIR ( $a^{-1}$ )	$9.2 \cdot 10^{-8}$	$6.4 \cdot 10^{-8}$
<b>Marl extraction, transport and milling</b>		
nuclide	$^{210}\text{Po}$ , $^{210}\text{Pb}$ , $^{238}\text{U}$ , $^{228}\text{Th}$ , $^{226}\text{Ra}$	$^{210}\text{Po}$ , $^{210}\text{Pb}$ , $^{238}\text{U}$ , $^{228}\text{Th}$ , $^{226}\text{Ra}$
MIR COROP ( $a^{-1}$ )	-	-
MIR inhalation ( $a^{-1}$ )	$1.2 \cdot 10^{-7}$	$4.8 \cdot 10^{-8}$
MIR vegetable garden ( $a^{-1}$ )	$8.1 \cdot 10^{-9}$	$3.3 \cdot 10^{-9}$
total MIR ( $a^{-1}$ )	$1.3 \cdot 10^{-7}$	$5.2 \cdot 10^{-8}$
total AIR ( $a^{-1}$ )	$1.3 \cdot 10^{-7}$	$5.2 \cdot 10^{-8}$

## H.8 Mineral sands handling industry at Amsterdam

Emissions to air take place during transshipment and milling.

### H.8.1 Dispersion in air

The dispersion in air and deposition are calculated using the OPS-model (see Appendix B). Dispersion is calculated using a 50-m grid. Emissions from transshipment and milling are given in Table H.30. Parameters used in the calculation of the dispersion

in air are listed in Table H.31.

**Table H.30** Emissions to air (GBq a<sup>-1</sup>) during transshipment at a fertilizer plant at Amsterdam

	<sup>238</sup> U	<sup>228</sup> Th	<sup>226</sup> Ra	<sup>210</sup> Pb	<sup>210</sup> Po
transshipment	9.7·10 <sup>2</sup>	1.2·10 <sup>2</sup>	7.3·10 <sup>2</sup>	7.3·10 <sup>2</sup>	7.3·10 <sup>2</sup>

**Table H.31** Parameters used in the calculation of the dispersion of radionuclides emitted during transshipment and milling <sup>(a)</sup>

	transshipment
substance	average nuclide
molecular weight (g.mol <sup>-1</sup> )	220
form of release	particle bound
location of source (x,y) (km)	119.18, 491.15
source diameter (m)	0
source strength (Bq.s <sup>-1</sup> )	see Table H.31
source height (m)	0
heat content (MW)	0
particle size distribution	coarse
emission variation	continuous
climatological data set	the Netherlands
climatological period	year
roughness length (m)	0.15

<sup>(a)</sup> a description of the parameters used in the OPS-model can be found in Appendix B.

## H.8.2 Calculation of MIR and AIR

MIR-contours using a 50 m grid from emissions during transshipment and milling are shown in Figure J.14. MIR, AIR and ACF for the different locations are given in Table H.32.

The maximum MIR of 9.2·10<sup>-5</sup> a<sup>-1</sup> due to emissions from transshipment and milling is calculated at location no. 5 (Figure J.14). The maximum AIR at the boundary site of 1.4·10<sup>-6</sup> a<sup>-1</sup> is at location no. 16. The inhalation pathway contributes about 90% to the MIR for locations at the boundary of the plant. The remainder originates from the vegetable garden pathway, the contribution of vegetables from the COROP area is negligible. The MIR in the nearest residential area at Amsterdam due to emissions during transshipment is negligible because of the relatively large distance from the source.

**Table H.32** MIR, AIR and ACF for the different locations due to emissions to air of the fertilizer plant at Amsterdam

location	MIR <sup>(b)</sup>	AIR <sup>(c)</sup>	ACF
1	$1.5 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$	0.01
2	$2.9 \cdot 10^{-6}$	$2.7 \cdot 10^{-8}$	0.01
3	$4.6 \cdot 10^{-6}$	$4.4 \cdot 10^{-8}$	0.01
4	$2.3 \cdot 10^{-5}$	$2.2 \cdot 10^{-7}$	0.01
5	$9.2 \cdot 10^{-5}$	$8.8 \cdot 10^{-7}$	0.01
6	$3.1 \cdot 10^{-5}$	$2.9 \cdot 10^{-7}$	0.01
7	$8.0 \cdot 10^{-6}$	$7.5 \cdot 10^{-8}$	0.01
8	$7.1 \cdot 10^{-6}$	$6.7 \cdot 10^{-8}$	0.01
9	$2.5 \cdot 10^{-6}$	$4.7 \cdot 10^{-7}$	0.2
10	$3.9 \cdot 10^{-6}$	$7.5 \cdot 10^{-7}$	0.2
11	$5.0 \cdot 10^{-6}$	$9.5 \cdot 10^{-7}$	0.2
12	$6.3 \cdot 10^{-6}$	$1.2 \cdot 10^{-6}$	0.2
13	$5.2 \cdot 10^{-6}$	$1.0 \cdot 10^{-6}$	0.2
14	$4.5 \cdot 10^{-6}$	$8.7 \cdot 10^{-7}$	0.2
15	$5.5 \cdot 10^{-6}$	$1.0 \cdot 10^{-6}$	0.2
16	$7.5 \cdot 10^{-6}$	$1.4 \cdot 10^{-6}$	0.2

<sup>(b)</sup> Exposure pathways are inhalation and ingestion from the vegetable garden and the reference COROP area.

<sup>(c)</sup> Exposure pathways are inhalation and ingestion from the reference COROP area.

## H.9 Mineral sands handling industry at Geertruidenberg

Risks of emissions to air are caused by transshipment and milling. The risks of  $^{222}\text{Rn}$  are negligible compared to the risks of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{226}\text{Ra}$ ,  $^{210}\text{Pb}$  and  $^{210}\text{Po}$ .

### H.9.1 Dispersion in air

Emissions from transshipment are given in Table H.33 (see Appendix G).

**Table H.33** Emissions to air ( $\text{GBq a}^{-1}$ ) during transshipment at Geertruidenberg

	$^{238}\text{U}$	$^{228}\text{Th}$	$^{226}\text{Ra}$	$^{210}\text{Pb}$	$^{210}\text{Po}$
transshipment	11	5.2	8.2	8.2	8.2

The parameters used in the calculation of the dispersion in air are given in Table H.34.

**Table H.34** Parameters used in the calculation of the dispersion of radionuclides emitted during transshipment and milling <sup>(a)</sup>

	transshipment
substance	average nuclide
molecular weight (g.mol <sup>-1</sup> )	220
form of release	particle bound
location of source (x,y) (km)	117.28, 411.20
source diameter (m)	0
source strength (Bq.s <sup>-1</sup> )	see Table H.33
source height (m)	0
heat content (MW)	0
particle-size distribution	coarse
emission variation	continuous
climatological data set	the Netherlands
climatological period	year
roughness length (m)	0.15

<sup>(a)</sup> A description of the parameters used in the OPS model can be found in Appendix B and [Ja90].

## H.9.2 Calculation of MIR and AIR

Local risks are calculated using a 50-m grid. MIR-contours from transshipment and milling are shown in Figure J.15. MIR, AIR and ACF for the different locations are given in Table H.35.

The maximum MIR of  $5.6 \cdot 10^{-6} \text{ a}^{-1}$  due to emissions from transshipment and milling is calculated for location no. 15 (Figure J.14). The maximum AIR of  $6.8 \cdot 10^{-8} \text{ a}^{-1}$  is calculated for location no. 17. The inhalation pathway contributes about 90% to the MIR for locations at the boundary of the plant. The remainder originates from the vegetable garden pathway; the contribution of vegetables from the COROP area is negligible. The MIR for the nearest residential area at Geertruidenberg is negligible because of the relatively long distance from the source.

## H.9.3 Comparison with previous studies

Previously [Sc92b], risk calculations were performed for the emissions to air during transshipment. A maximum risk of  $1.1 \cdot 10^{-10} \text{ a}^{-1}$  due to inhalation was calculated for passers-by north-west of the terrain boundary, which corresponds with a MIR of approximately  $1.2 \cdot 10^{-8} \text{ a}^{-1}$ . In the present study the maximum MIR, north-west of the terrain border, is  $2.7 \cdot 10^{-7} \text{ a}^{-1}$ , which is about a factor of 20 higher than found in [Sc92b]. The factors that may contribute to different results are:

- Different DCCs. DCCs used in [Sc92b] are based on [ICRP79], DCCs used in this study are based on [NRPB91].

**Table H.35** MIR, AIR and ACF for the different locations at the terrain boundary due to emissions at Geertruidenberg

location	MIR <sup>(b)</sup>	AIR <sup>(c)</sup>	ACF
1	2.0·10 <sup>-7</sup>	1.9·10 <sup>-9</sup>	0.01
2	2.9·10 <sup>-7</sup>	2.8·10 <sup>-9</sup>	0.01
3	2.9·10 <sup>-7</sup>	2.8·10 <sup>-9</sup>	0.01
4	2.1·10 <sup>-7</sup>	2.0·10 <sup>-9</sup>	0.01
5	2.0·10 <sup>-7</sup>	2.0·10 <sup>-9</sup>	0.01
6	2.5·10 <sup>-7</sup>	2.4·10 <sup>-9</sup>	0.01
7	1.9·10 <sup>-7</sup>	1.9·10 <sup>-9</sup>	0.01
8	1.9·10 <sup>-7</sup>	1.9·10 <sup>-9</sup>	0.01
9	1.9·10 <sup>-7</sup>	1.9·10 <sup>-9</sup>	0.01
10	2.4·10 <sup>-7</sup>	2.3·10 <sup>-9</sup>	0.01
11	2.8·10 <sup>-7</sup>	2.7·10 <sup>-9</sup>	0.01
12	4.7·10 <sup>-7</sup>	4.6·10 <sup>-9</sup>	0.01
13	1.0·10 <sup>-6</sup>	1.0·10 <sup>-8</sup>	0.01
14	3.6·10 <sup>-6</sup>	3.5·10 <sup>-8</sup>	0.01
15	5.6·10 <sup>-6</sup>	5.4·10 <sup>-8</sup>	0.01
16	5.7·10 <sup>-7</sup>	5.5·10 <sup>-9</sup>	0.01
17	3.5·10 <sup>-7</sup>	6.8·10 <sup>-8</sup>	0.2
18	3.1·10 <sup>-7</sup>	6.0·10 <sup>-8</sup>	0.2
19	2.4·10 <sup>-7</sup>	4.6·10 <sup>-8</sup>	0.2
20	2.0·10 <sup>-7</sup>	3.9·10 <sup>-7</sup>	0.2
21	2.1·10 <sup>-7</sup>	2.0·10 <sup>-9</sup>	0.01
22	2.4·10 <sup>-7</sup>	2.3·10 <sup>-9</sup>	0.01
23	2.7·10 <sup>-7</sup>	2.6·10 <sup>-9</sup>	0.01
24	2.7·10 <sup>-7</sup>	2.7·10 <sup>-9</sup>	0.01

<sup>(b)</sup> exposure pathways are inhalation and ingestion from the vegetable garden and the reference COROP-area

<sup>(c)</sup> exposure pathways are inhalation and ingestion from the reference COROP-area

- Different emissions. In [Sc92b] calculations are based on the dust emitted. Since the radionuclide concentration of this dust was not given, a comparison between this study and [Sc92b] cannot be made.
- Different dispersion models. In [Sc92b] the National Model is used. Especially for distances up to a few hundred metres, large differences can be expected between the OPS model and the National Model [Er92].
- Different model parameters. Model parameters used in the dispersion calculations are not given in [Sc92b]. A quantitative comparison could not be made.

## APPENDIX I RISKS FROM EXTERNAL RADIATION

### I.1 Introduction

The method for the calculation of the risk from external radiation is described in Appendix E.

### I.2 Elementary phosphor plant at Vlissingen

External radiation at the site at Vlissingen is mainly caused by storage of phosphate ore, calcinate and slag. The stored calcinate is about  $4 \cdot 10^6$  kg [BMP94, Ho94]. This amount will increase every year by about  $0.8 \cdot 10^6$  kg until storage elsewhere is possible [Ho94]. The slag is transported to and stored at a nearby industry site.

Radiation levels at different points due to the phosphate ore and slag were considered using numbers as given in [Ki94]. One measurement at a short distance (89 m) from the phosphate ore is used to calculate the radiation levels at other distances, assuming that the radiation level decreases proportionally with the increase of the distance squared and that the slag stock remains similar in shape and radionuclide concentrations [Ki94]. This assumption may not be true, as can be seen in the input-output balance. In Table F.1 it can be seen that in phosphor slag the  $^{210}\text{Pb}$  and  $^{210}\text{Po}$  concentrations are very low compared to  $^{226}\text{Ra}$ . These nuclides do not contribute significantly to the external radiation. An important question is whether the situation during measurement can be considered representative for the situation at other time periods.

The site at Vlissingen is surrounded by other industrial plants and water. The nearest residential area is Nieuwpoort, a few kilometres north-east of the site. External radiation from phosphate ore and slag is negligible at that location. In Table I.1 MIR and AIR at

various locations are given.

**Table I.1** MIR and AIR due to phosphate ore and slacks at the site at Vlissingen calculated from [Ki94]

Location	MIR (a <sup>-1</sup> )	AIR (a <sup>-1</sup> )	Reference group
Van Cittershaven	1.8 · 10 <sup>-7</sup>	7.2 · 10 <sup>-9</sup>	occupational shipping
South east corner	1.1 · 10 <sup>-8</sup>	4 · 10 <sup>-10</sup>	road in industry area
Sloehaven	4.8 · 10 <sup>-8</sup>	1.9 · 10 <sup>-9</sup>	occupational shipping
M&T Chemicals	3.3 · 10 <sup>-8</sup>	6.5 · 10 <sup>-9</sup>	workers nearby industry
Pelt & Hooykaas	1.5 · 10 <sup>-8</sup>	3 · 10 <sup>-9</sup>	workers nearby industry
Pechiney	5 · 10 <sup>-9</sup>	1 · 10 <sup>-9</sup>	workers nearby industry

At the location of M&T chemicals, the MIR of external radiation is  $3.3 \cdot 10^{-8} \text{ a}^{-1}$ , the reference group is workers at nearby industry, implying an AIR of  $6.5 \cdot 10^{-9} \text{ a}^{-1}$ . At the location of Cittershaven the maximum AIR from phosphate ore and slag is  $7.2 \cdot 10^{-9} \text{ a}^{-1}$ . The reference group is boat workers.

### I.3 Phosphoric acid plant at Vlaardingen

External radiation at the site at Vlaardingen is due to stored phosphate ore. Radiation levels due to external radiation were not calculated previously. Therefore, the risks were calculated for a worst case. The maximum amount of stored phosphate ore is  $1.25 \cdot 10^9 \text{ kg}$  [Hy93]. Using a density of  $1500 \text{ kg/m}^3$  [Bo92] this corresponds to  $8333 \text{ m}^3$ . The phosphate hangar covers an area of  $80 \times 23 \text{ m}^2$  [Hy93], which implies an average height of the phosphate stock of 9.06 m, if it is assumed that only half of the available floor space ( $80 \times 11.5$ ) is used. The nearest location at the fence is 106 m east of the length of the hangar [Hy93]. This is an industrial road [To87]. The composition of phosphate ore as used in the calculation is given in Table I.2.

At the fence the dose rate is calculated to be  $5.3 \text{ nSv h}^{-1}$ ; this implies a MIR of  $2.9 \cdot 10^{-7} \text{ a}^{-1}$  and an AIR of  $5.8 \cdot 10^{-8} \text{ a}^{-1}$  for workers of a nearby industry, working indoors.

### I.4 Phosphoric acid plant at Pernis

External radiation of the phosphoric acid plant at Pernis is caused by the storage of phosphate ore. Radiation levels of external radiation were not previously calculated. The

**Table I.2** Composition of phosphate ore [FR91]

	Weight percentage [Fr91]	Weight percentage as used in MARMER
P <sub>2</sub> O <sub>5</sub>	26 — 39	34
CaO	45 — 54	50
F	2 — 4	3
SiO <sub>2</sub>	0 — 12	13
Metal oxides	rest	

risks are calculated for a worst-case situation. The phosphate ore in stock is between 5 and  $40 \cdot 10^8$  kg, in two nearby hangars of  $2.1 \cdot 10^9$  kg each [Ke92]. The total floor space of the two hangars is  $80 \times 80$  m<sup>2</sup>. Using a density of 1500 kg/m<sup>3</sup> [Bo92], the maximum phosphate ore stock is  $2.8 \cdot 10^4$  m<sup>3</sup> or  $80 \times 80 \times 4.38$  m<sup>3</sup>. For the worst case calculation a height of 8.76 m is assumed.

The density and composition of the phosphate ore is the same as for the Vlaardingen plant and tabulated in Table I.2. The nuclide concentrations have been given before in Table F.3.

It should be noted that the Pernis plant changed its phosphate ore composition after January 1994 [Ke92]. From that date on the Pernis plant has used a combination of sediment ore and magmatic ore. This results in lower nuclide concentrations. Before, only sediment ore was used. The implications of this change are not investigated here.

The Pernis plant is surrounded by water, industrial plants and industrial roads. The nearest fence is 200 m south of the hangars. At this location the dose rate is  $1.3 \cdot 10^{-9}$  Sv.h<sup>-1</sup>, resulting in an MIR of  $7.2 \cdot 10^{-8}$  a<sup>-1</sup> and an AIR of  $2.9 \cdot 10^{-9}$  a<sup>-1</sup> for an industrial road. A nearby industrial site at 300 m east of the hangars has a dose rate of  $0.37 \cdot 10^{-9}$  Sv.h<sup>-1</sup>, resulting in a MIR of  $2.0 \cdot 10^{-8}$  a<sup>-1</sup> and an AIR of  $4.0 \cdot 10^{-9}$  a<sup>-1</sup>.

## I.5 Fertilizer production plant at Amsterdam

At the fertilizer plant at Amsterdam external gamma radiation is caused by phosphate ore, which is stored in hangars [Po92]. The plant is surrounded by other industrial plants, industrial roads and water.

During the summer of 1993 radiation levels were measured [La93], which indicated a level of 168 nSv.h<sup>-1</sup> at the side of the North Sea canal (corrected for a background of 70 nSv.h<sup>-1</sup>) [La93]. This results in a MIR of  $9.2 \cdot 10^{-6}$  a<sup>-1</sup>. Assuming occupational boat workers

as the reference group, AIR is  $3.7 \cdot 10^{-7} \text{ a}^{-1}$ . At the border of an nearby industrial plant (Cargill) a radiation level of  $24 \text{ nSv.h}^{-1}$  was measured [La93], resulting in a MIR of  $1.3 \cdot 10^{-6} \text{ a}^{-1}$  and a AIR of  $2.6 \cdot 10^{-7} \text{ a}^{-1}$  for indoor workers of a nearby industry.

It is assumed the situation at the time of measurement, can be considered representative for the situation averaged over a year. However, nothing was mentioned about stock sizes, locations and amounts of waste in [La93].

## **I.6 Fertilizer production plant at Sas van Gent**

External radiation of a fertilizer plant at Sas van Gent is caused by the storage of phosphate ore. No information on measurements, stock sizes or locations is available, no calculation is made.

## **I.7 Primary iron and steel production plant**

External radiation here is mainly due to fly ash, filter cake and slag. The slag is  $7.5 \cdot 10^8 \text{ kg}$  (about  $100 \times 100 \times 10 \text{ m}^3$  with density  $3.5 \text{ g.cm}^{-3}$ ), stored in a building on the site [BMP92]. Fly-ash is transported to cement companies [Sm92]. Quantities are unknown.

For the slag a worst case calculation is made. No shielding is assumed. The slag mainly consists of calcium silicates and aluminium oxide [Sm92],  $\text{Ca}_2\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$ , for the calculation assumed to be in equal amounts and with a density of  $3.5 \text{ g.cm}^{-3}$ .

Using MARMER, at 25 meter from the middle of the long side of the slag stock a radiation level of  $3.4 \cdot 10^{-8} \text{ Sv.h}^{-1}$  is calculated, resulting in a MIR of  $1.9 \cdot 10^{-6} \text{ a}^{-1}$  and an AIR of  $7.4 \cdot 10^{-8} \text{ a}^{-1}$ , for an industrial road. At 500 meter, the radiation level is  $5.6 \cdot 10^{-2} \text{ nSv.h}^{-1}$ , resulting in a MIR of  $3.1 \cdot 10^{-9} \text{ a}^{-1}$  and a AIR of  $1.2 \cdot 10^{-10} \text{ a}^{-1}$ .

## **I.8 Coal-fired power plants**

For coal-fired power plants external radiation is due to (temporary) storage of fly ash. An example of radiation levels and risks is given for the Maasvlakte plant, which has an open storage place for  $1.6 \cdot 10^8 \text{ kg}$  fly ash [MER91]. The composition of this fly ash is given in Table I.3 [MER91]. Nuclide concentrations in the fly ash are given in Table F.9. As a worst case it is assumed that the maximum amount is stored near the fence. Using a density of  $1600 \text{ kg.m}^{-3}$  the volume is  $100 \times 100 \times 10 \text{ m}^3$ . The Maasvlakte plant is surrounded by water with occupational shipping and industrial roads. Using MARMER a radiation level of  $4.7 \cdot 10^{-8} \text{ Sv.h}^{-1}$  was calculated at 25 m from the fly ash stock, resulting in a MIR of  $2.6 \cdot 10^{-6} \text{ a}^{-1}$  and an AIR of  $1.0 \cdot 10^{-7} \text{ a}^{-1}$ .

**Table I.3** Composition of fly ash [MER93]

	Weight percentage
SiO <sub>2</sub>	50
Al <sub>2</sub> O <sub>3</sub>	25
Fe <sub>2</sub> O <sub>3</sub>	7
CaO	3
MgO	2
K <sub>2</sub> O	2.5

### **I.9 Offshore oil and gas exploitation**

External radiation is mainly caused by scaling. Offshore, external radiation does not pose a risk to the surroundings. No data is available on activities onshore. In general, scalings are stored by COVRA [EI93].

### **I.10 Cement industry**

External radiation is due to slag and so-called "hoogovencement". At Maastricht marl is used as raw material, at IJmuiden and Rozenburg the so-called "hoogovencement" [Sm92]. No information on stock sizes and locations is available.

### **I.11 Ceramic industry**

External radiation is due to stacks of mineral sands at the sites of tile and brick industries. No information on stock quantities is available.

### **I.12 Mineral sands industry at Amsterdam**

External radiation at the Amsterdam plant is due to the stock of mineral sands. In 1991 external radiation levels were measured [Sc92a, Sc92c]. A maximum radiation level was found east of the site: 400 nSv/h (corrected for background). This results in a MIR of  $2.2 \cdot 10^{-5} \text{ a}^{-1}$ . At this place other industries are located. Assuming workers inside buildings, AIR is  $4.5 \cdot 10^{-6} \text{ a}^{-1}$ .

In 1992 external radiation was measured again [P94]. Along the east side a maximum radiation level of 733 nSv.h<sup>-1</sup> (corrected for background) was found. This results in a MIR of  $4.0 \cdot 10^{-5} \text{ a}^{-1}$ . Note that in [P94] a mean value of 168 nSv/h has been used and the ISF has not been taken into account. AIR is  $8.0 \cdot 10^{-6} \text{ a}^{-1}$  for workers inside buildings. West of the site a radiation level of 482 nSv.h<sup>-1</sup> was measured [P94]. This results in a MIR of

$2.6 \cdot 10^{-5} \text{ a}^{-1}$  and an AIR of  $1.1 \cdot 10^{-6} \text{ a}^{-1}$  for an industrial road.

These two measurements [Sc92a, P94] indicate that one has to be careful with these numbers. It is not known whether or not the situation at the time of the measurement was representative.

### **I.13 Mineral sands industry at Geertruidenberg**

External radiation at the mineral sands industry at Geertruidenberg is caused by mineral sands (zirconium sands and bauxite). In 1991 external radiation levels were measured [Sc92b]. North of the site, near the bauxite stock, the radiation level is at maximum:  $94 \text{ nSv.h}^{-1}$  (corrected for background). This results in a MIR of  $5.1 \cdot 10^{-6} \text{ a}^{-1}$ . For occupational boatmen as the reference group AIR is  $2.1 \cdot 10^{-7} \text{ a}^{-1}$ . The zirconium sand stock is located near an industrial road. The measured radiation level here is  $24 \text{ nSv.h}^{-1}$ , resulting in a MIR of  $1.3 \cdot 10^{-6} \text{ a}^{-1}$  and an AIR of  $5.3 \cdot 10^{-8} \text{ a}^{-1}$ .

### **I.14 Titanium oxide industry at Rotterdam**

External radiation at titanium oxide industry at Rotterdam is due to the storage of raw and waste materials. The plant is situated in the Botlek area and surrounded by water, other industries and industrial roads [To87]. ECN measured [We92] and calculated [We88] radiation levels at the site. The maximum radiation level was found near the stock of rutile:  $0.25 \cdot 10^{-6} \text{ Sv.h}^{-1}$  (not corrected for background radiation). The exact location was not indicated [We92]. It is not known if the situation at the time of measurement can be considered representative for the situation at hand averaged over a year.

In the supplement "Stralingsbelasting bij deponie" of [We88], a radiation level of  $5.8 \cdot 10^{-6} \text{ Sv.h}^{-1}$  was calculated for waste materials not mixed with non-radioactive waste. At the fence 250 m from the middle of the waste site, a radiation level of  $1.5 \cdot 10^{-8} \text{ Sv.h}^{-1}$  was calculated [We88]. MIR would be  $8.2 \cdot 10^{-7} \text{ a}^{-1}$  and AIR  $3.3 \cdot 10^{-8} \text{ a}^{-1}$ , assuming the location to be an industrial road. Stock sizes, locations and amounts of waste are not mentioned.

## APPENDIX J RISK MAPS

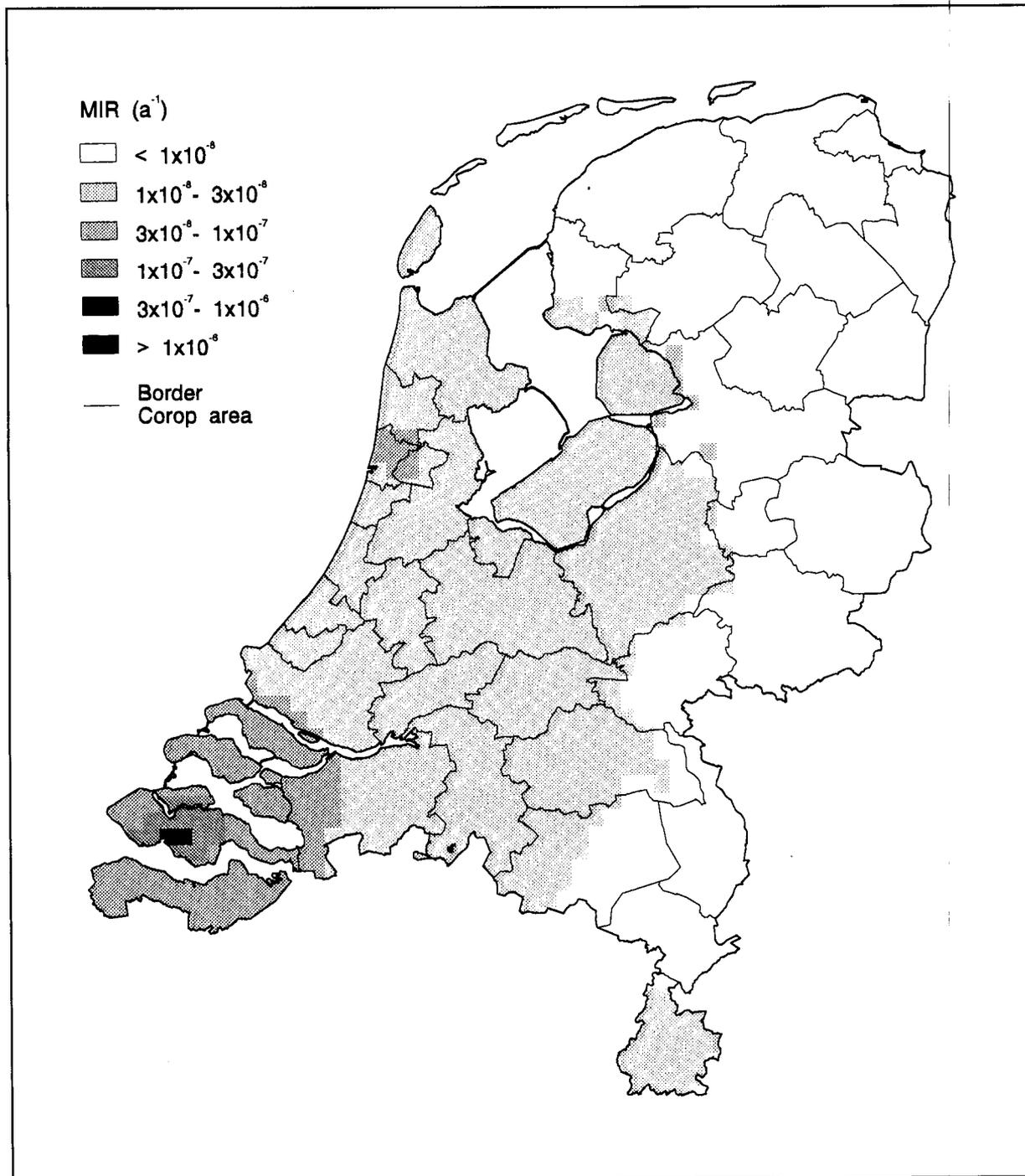
### J.1 Total risk

In this section risk contour plots of three most important non-nuclear industrial plants in the Netherlands are given.

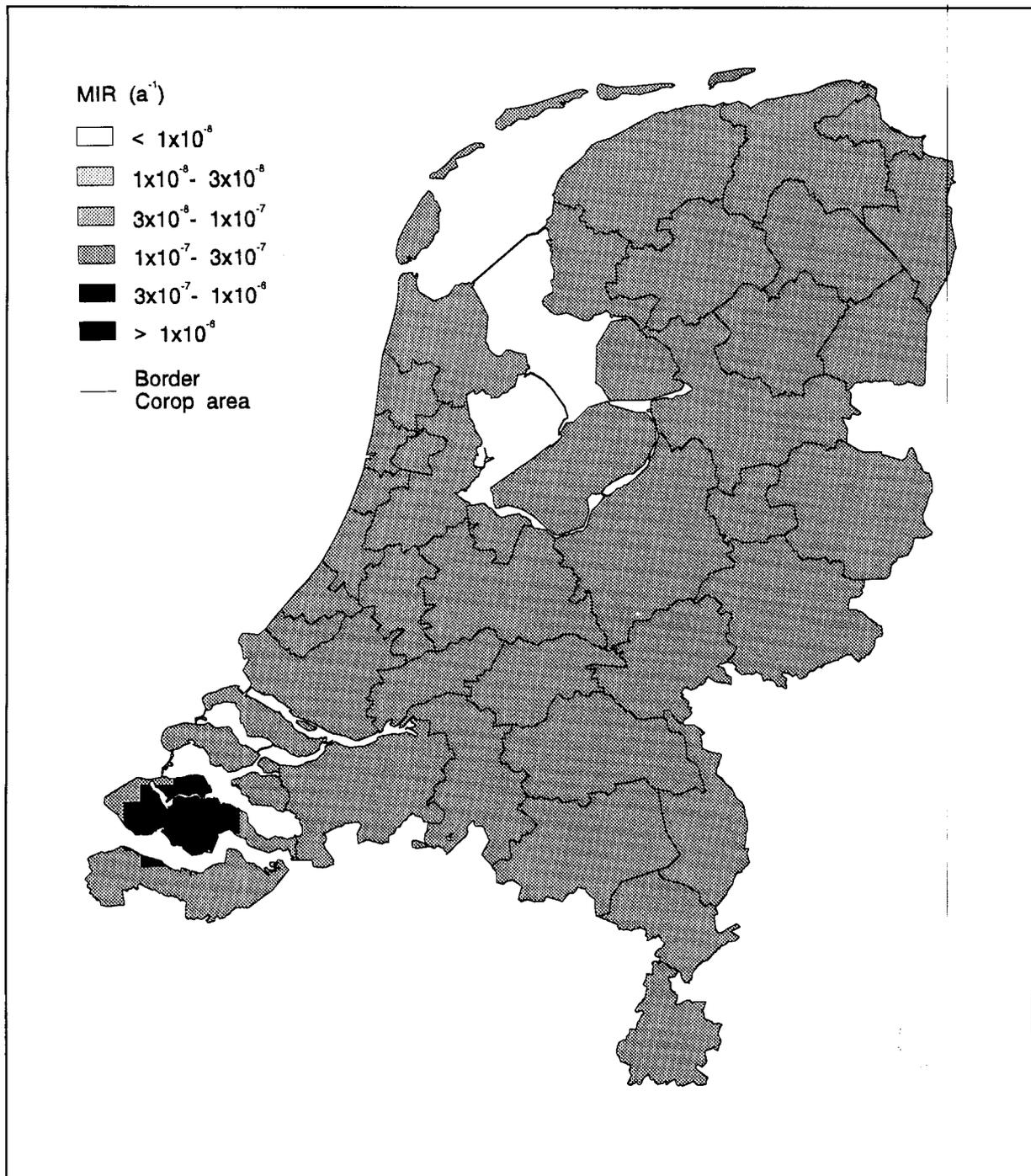
In Fig. J.1 the summed risks due to emissions of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  to air of an elementary phosphor plant at Vlissingen, a primary iron and steel production plant at IJmuiden and a cement production plant at Maastricht is plotted for the Netherlands on a national scale (for the cement production plant at Maastricht only  $^{210}\text{Po}$  has been considered).

In Fig. J.2 the summed risks of emissions to air and to water of the same three plants is shown.

It should be noted that different level classifications are used in the two figures.



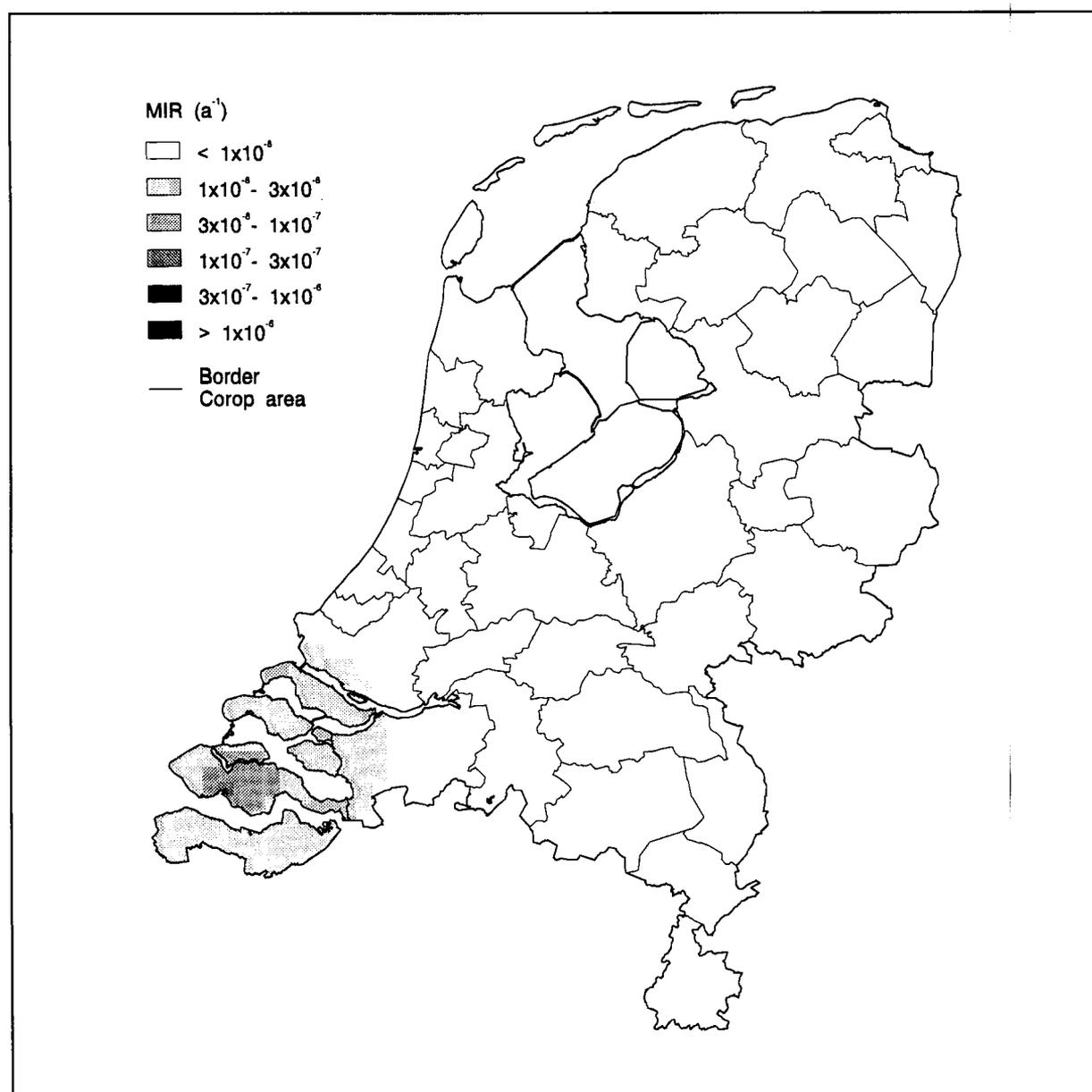
**Figure J.1** Risks due to emissions to air from an elementary phosphor plant at Vlissingen, a primary iron and steel production plant at IJmuiden and a cement production plant at Maastricht



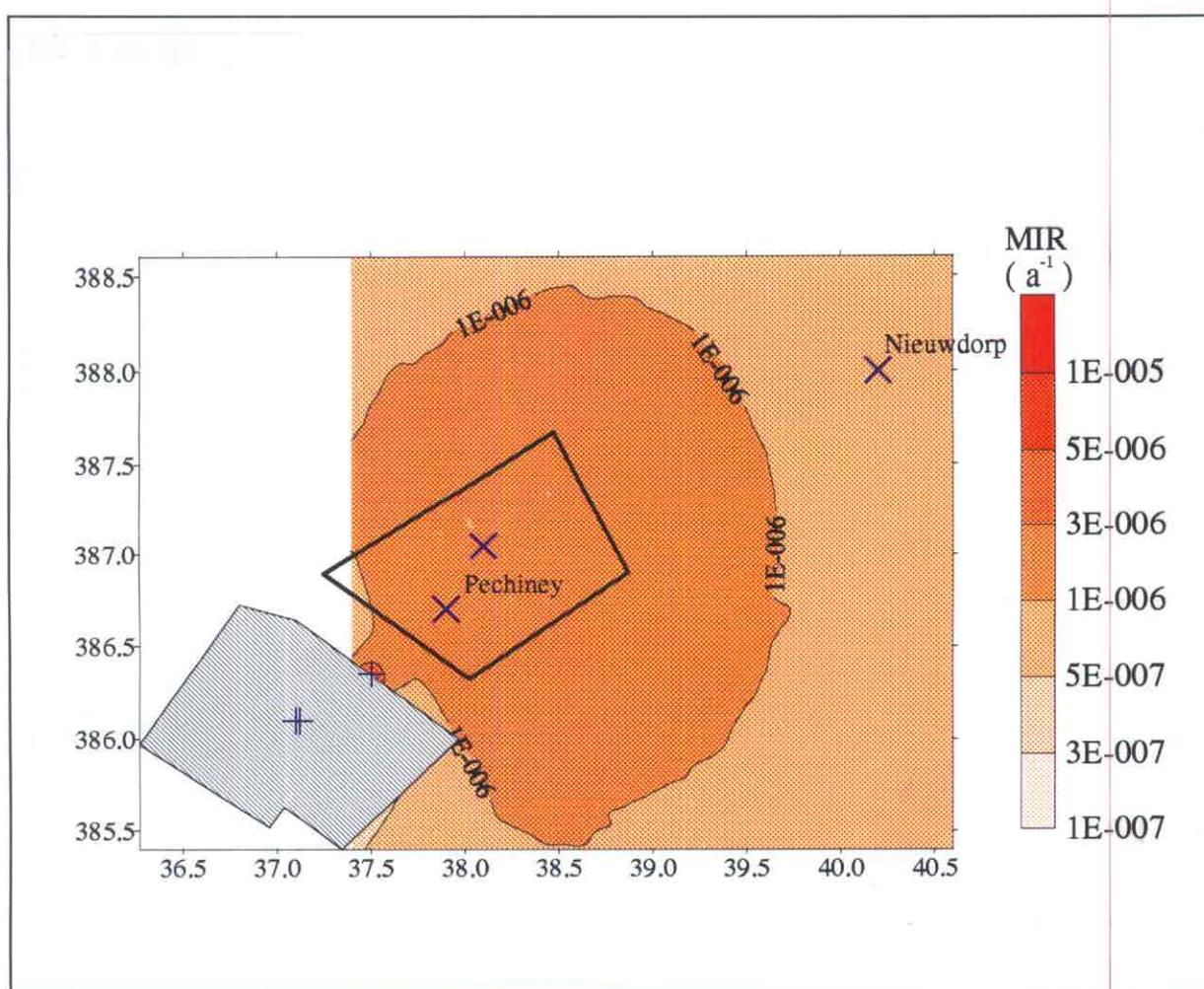
**Figure J.2** Risks due to emissions to water and air from an elementary phosphorus plant at Vlissingen, a primary iron and steel production plant at IJmuiden and a cement production plant at Maastricht

## J.2 Local situations

In this section, for several plants the risk contour plots due to thermic and non-thermic air emissions on a local scale is given. In the figures the "plusses" indicate emission points, and the "crosses" indicate points for which risks are calculated. The numbered "crosses" are points at the fence of the industrial site, for which the dose rate due to external radiation was measured as well.

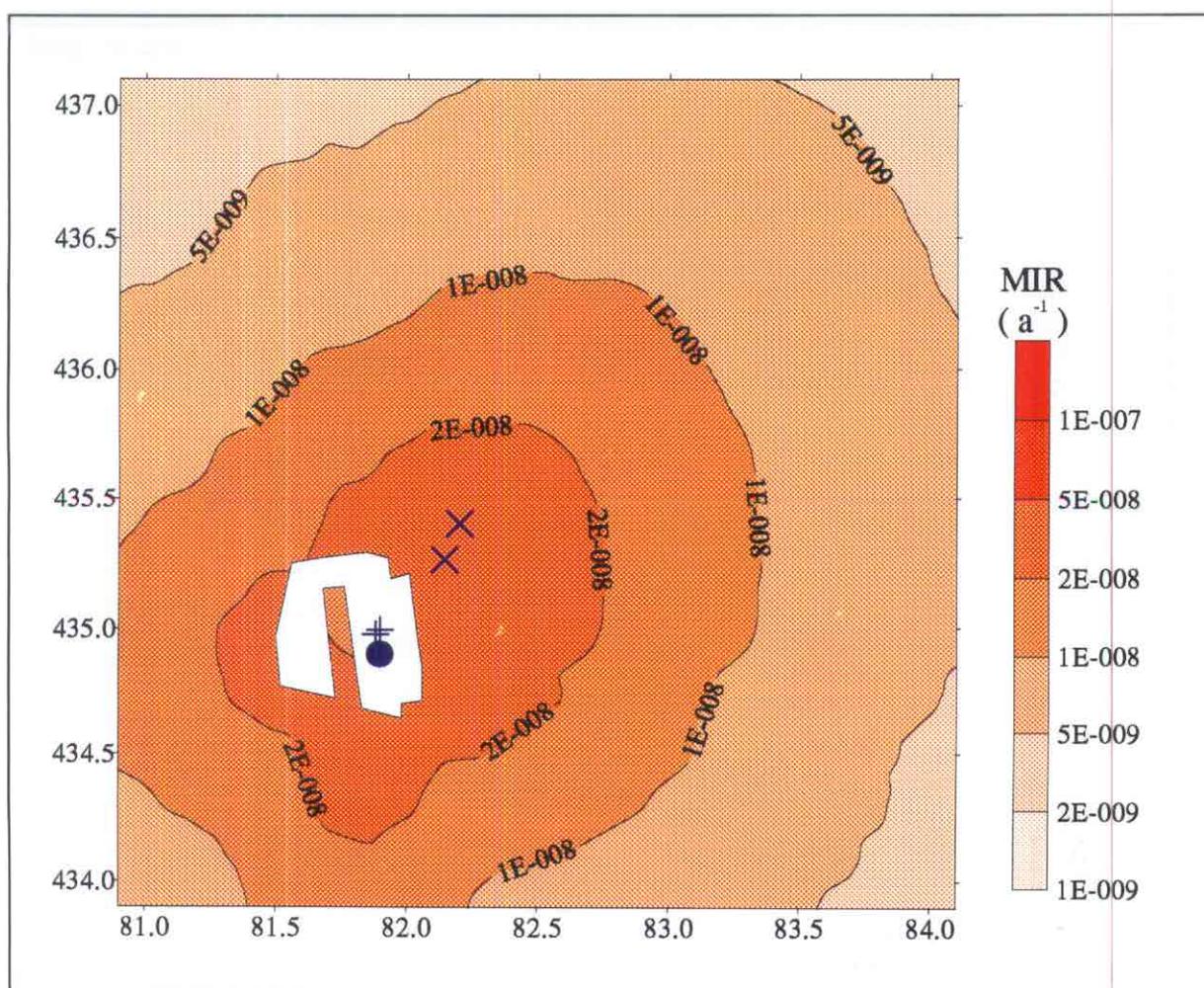


**Figure J.3** MIR contours on a 5-km grid over the Netherlands due to thermic emissions of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  from an elementary phosphor plant at Vlissingen

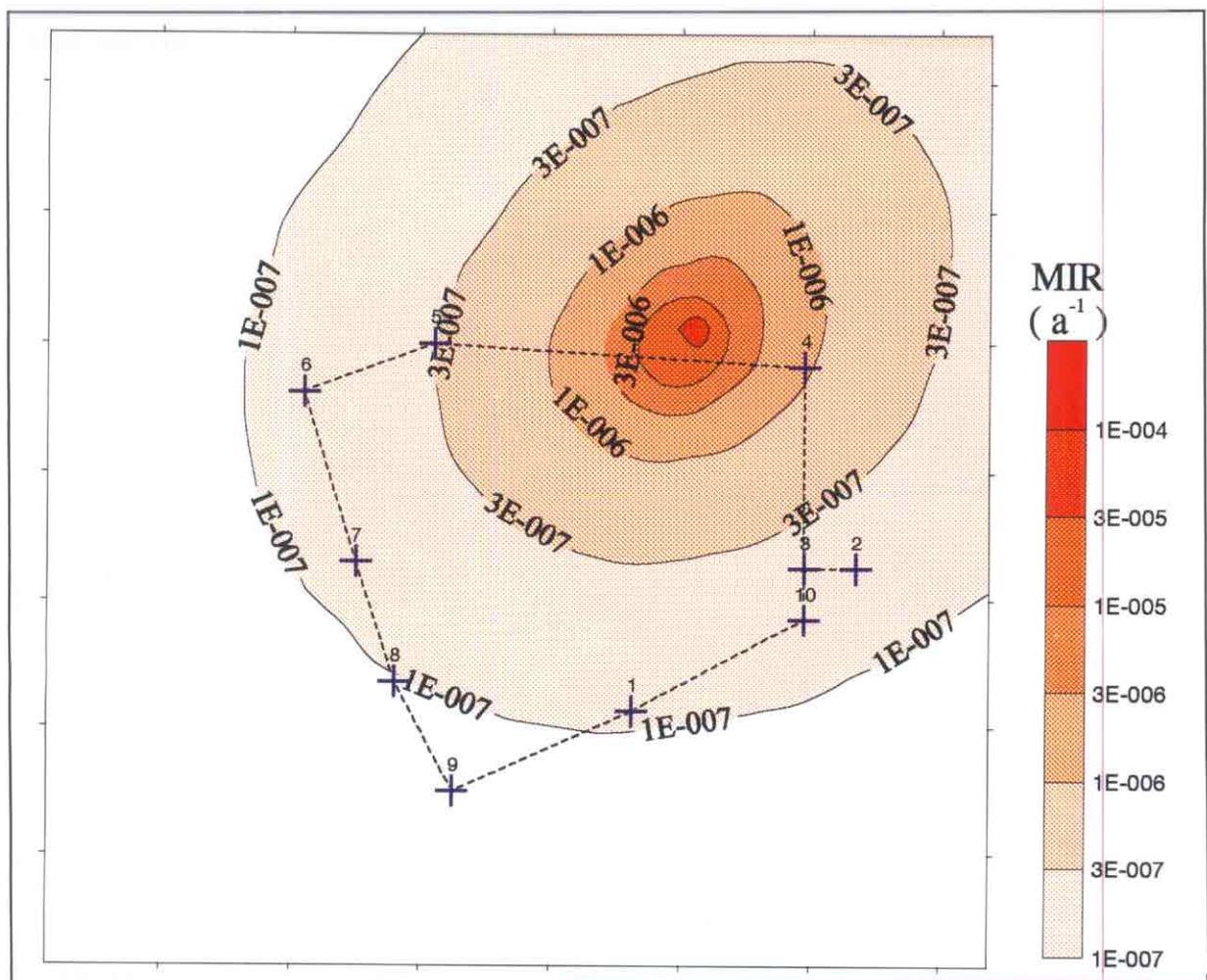


**Figure J.4.** MIR contours on a 50-m grid due to thermic emissions and emissions during transshipment from an elementary phosphor plant at Vlissingen

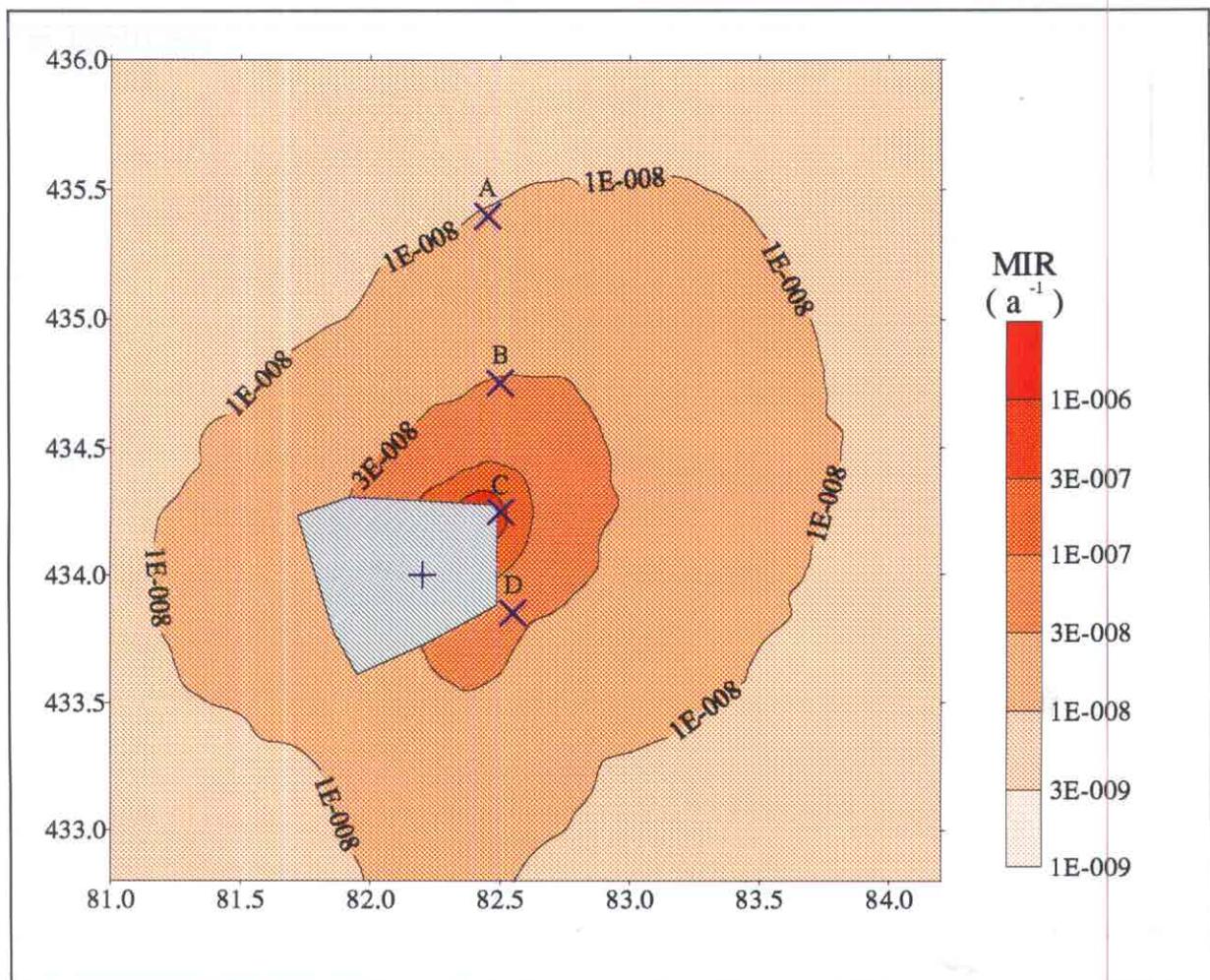




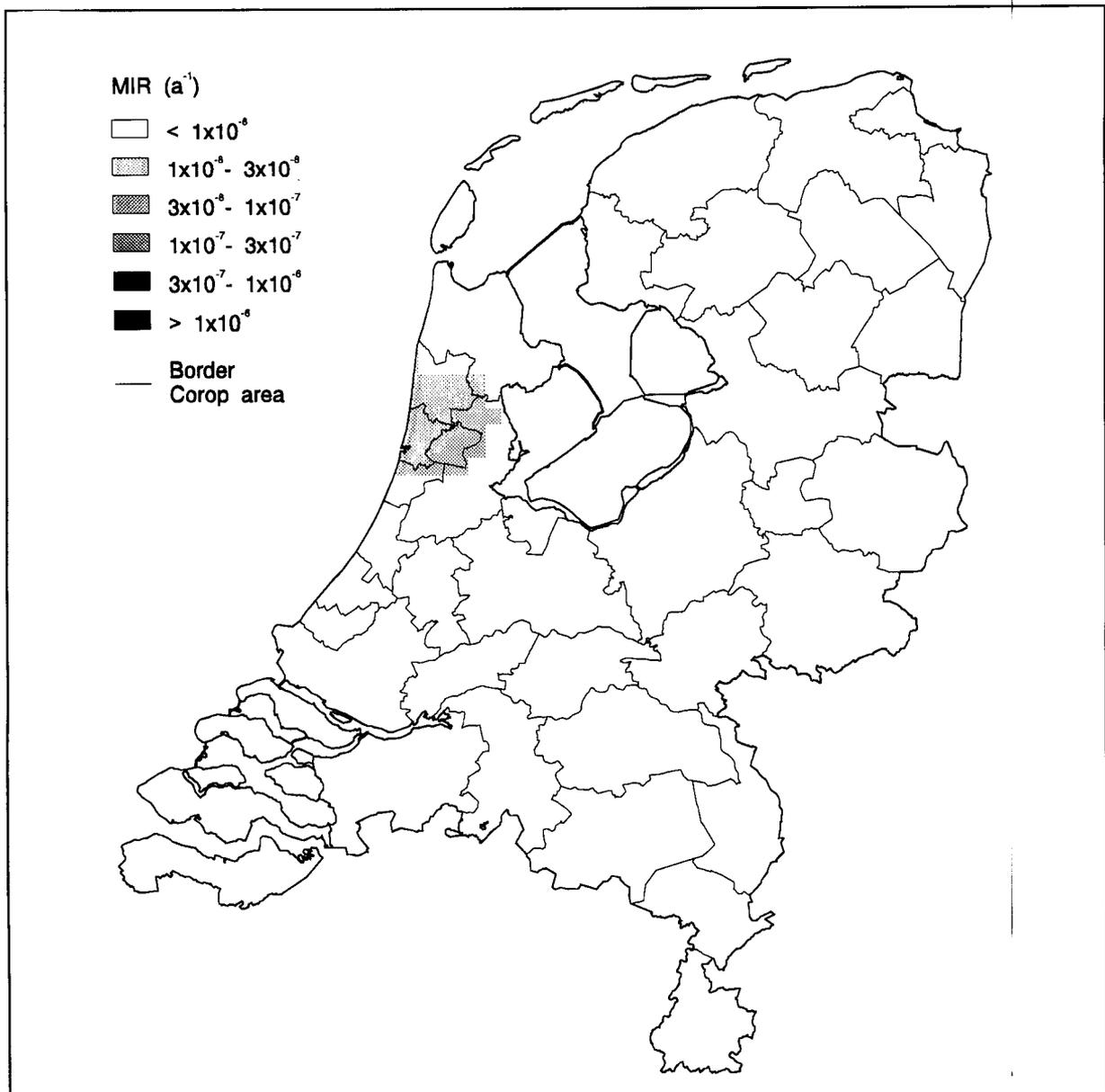
**Figure J.6** MIR contours on a 50-m grid due to emissions of  $^{222}\text{Rn}$  at a phosphoric acid production plant at Vlaardingen.



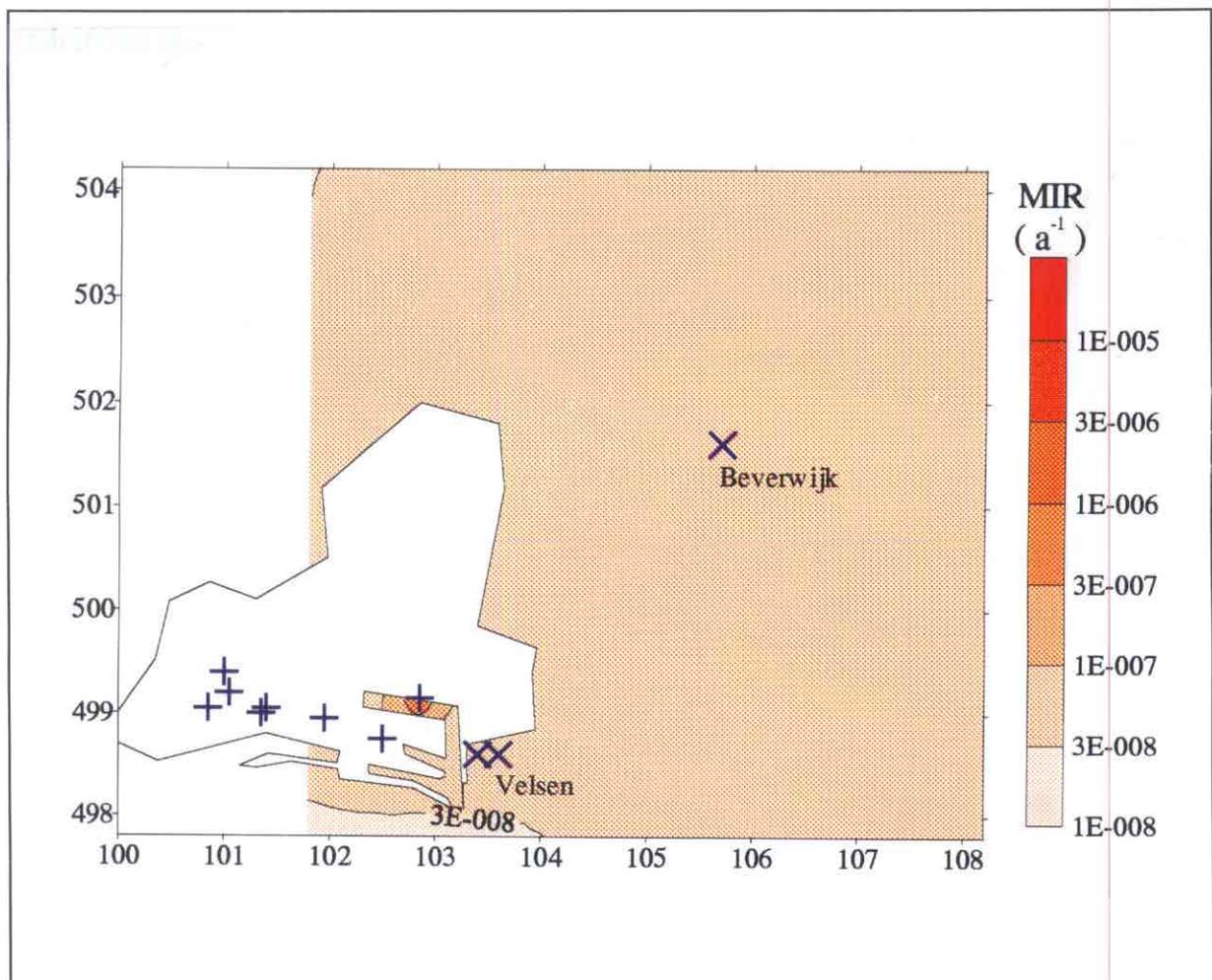
**Figure J.7** MIR contours on a 50-m grid due to emissions to air during transshipment at a phosphoric acid production plant at Pernis.



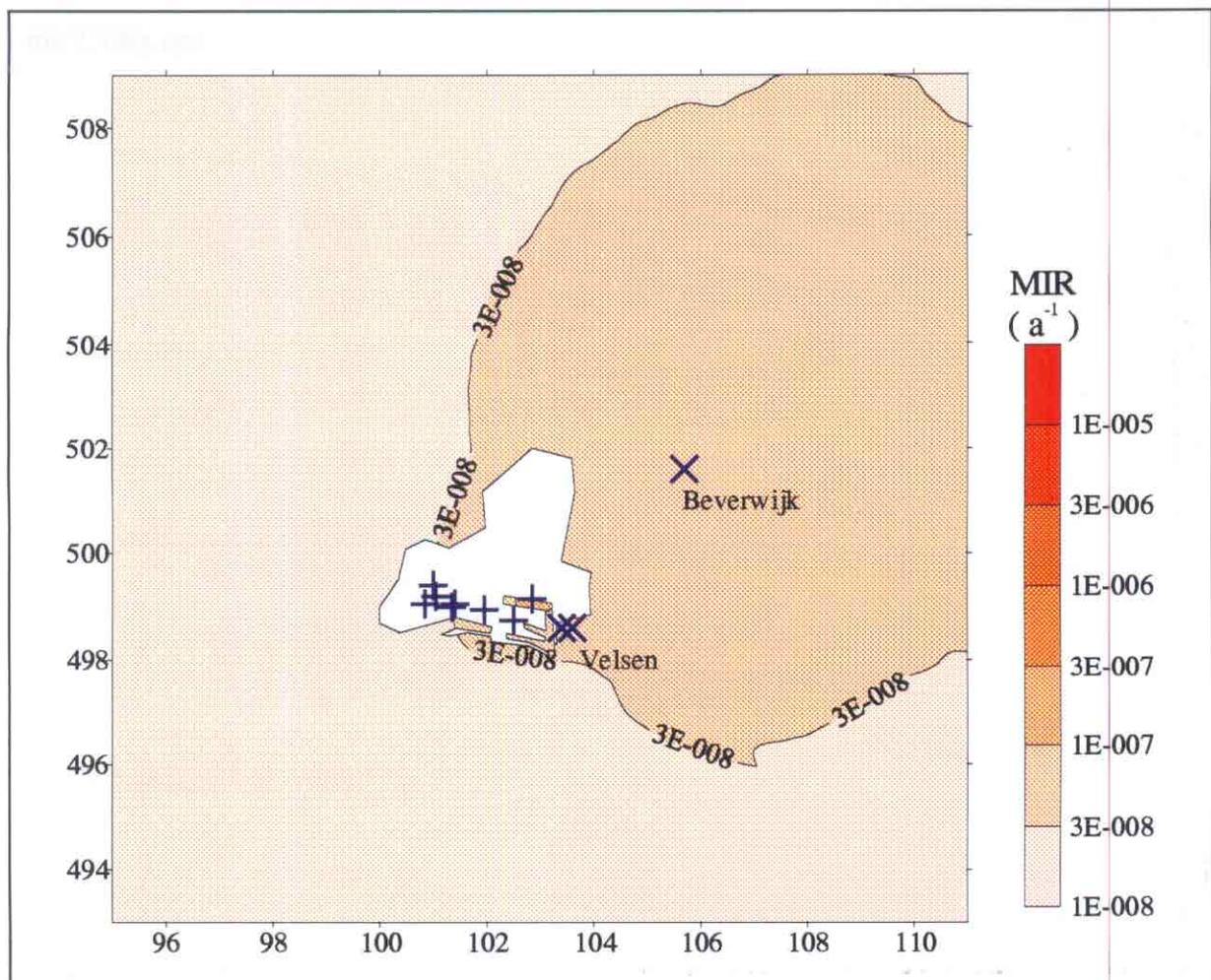
**Figure J.8** MIR contours on a 50-m grid due to emissions of  $^{222}\text{Rn}$  at a phosphoric acid production plant at Pernis



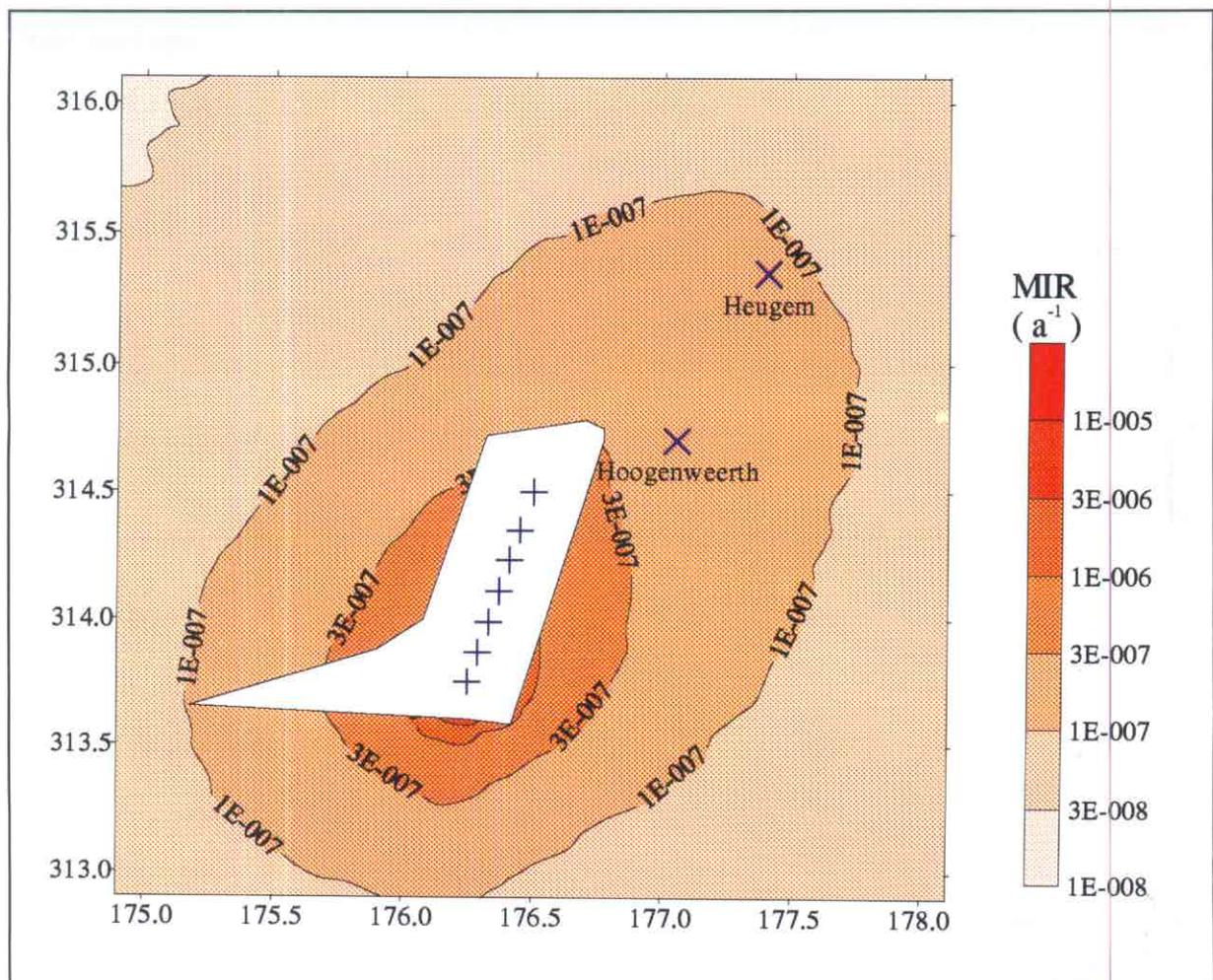
**Figure J.9** MIR contours on a 5-km grid over the Netherlands due to thermic emissions of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  from a primary iron and steel production plant at IJmuiden



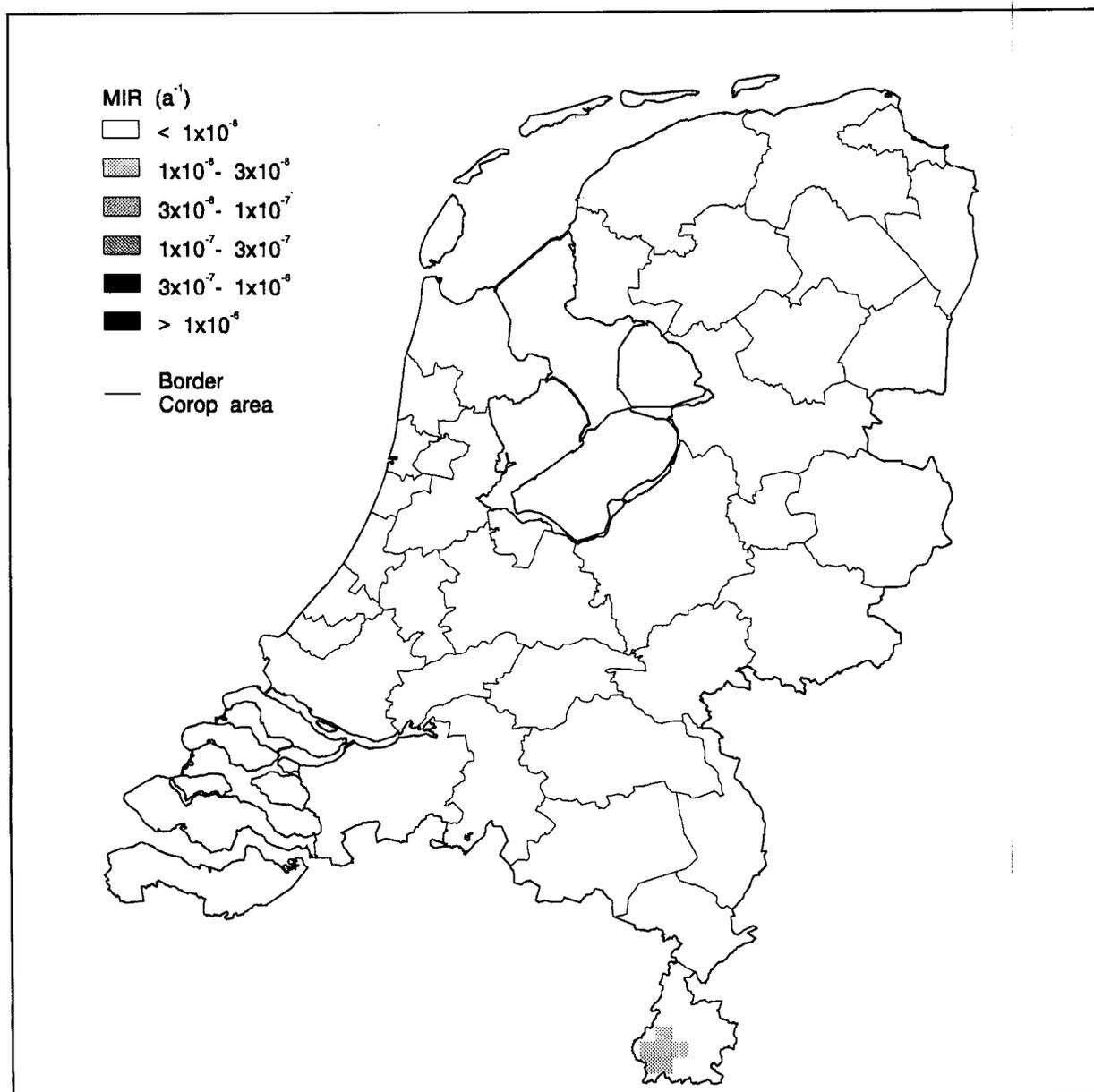
**Figure J.10** MIR contours on a 100-m grid due to thermic emissions and emissions during transshipment from a primary iron and steel production plant at IJmuiden



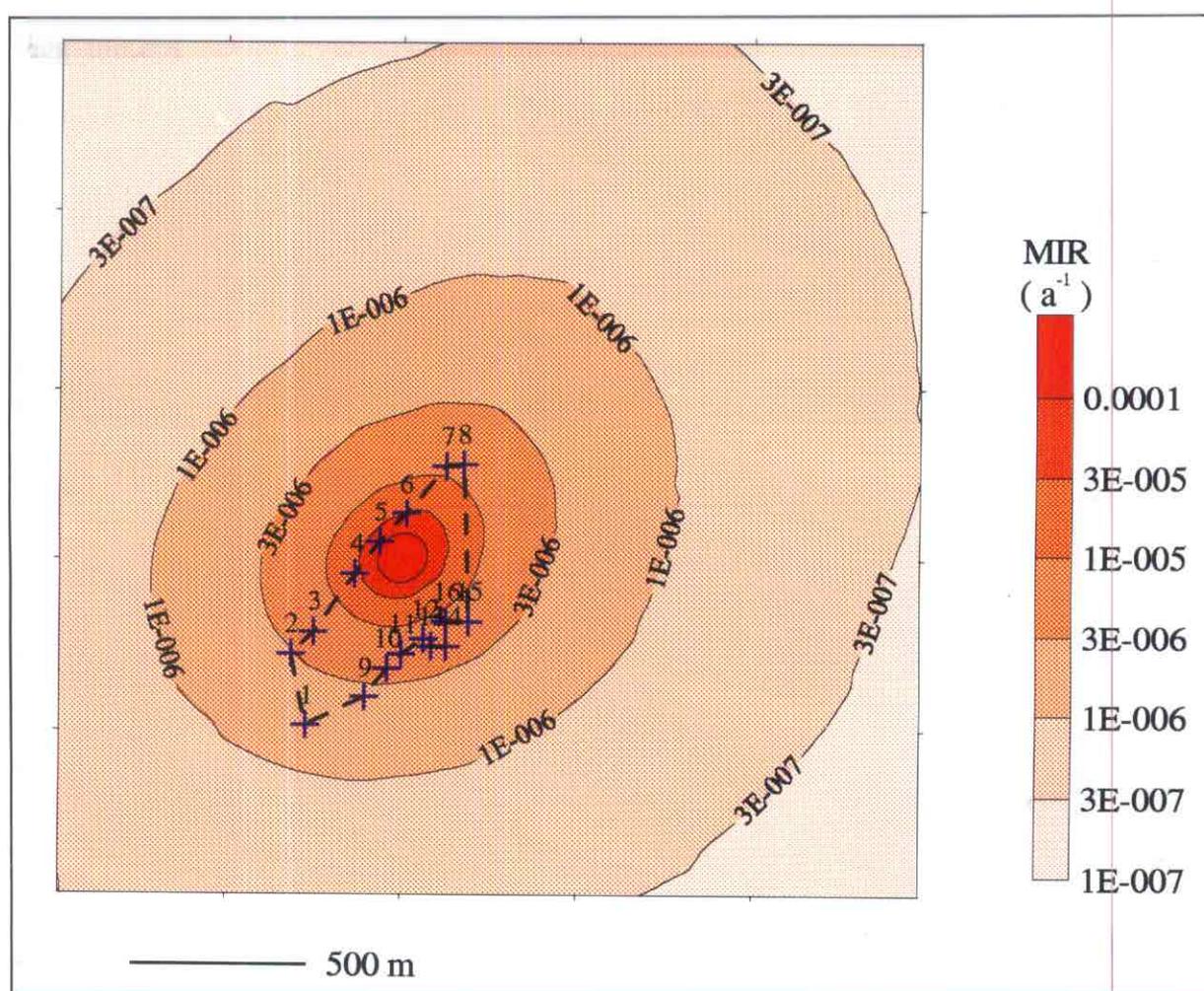
**Figure J.11** MIR contours on a 250-m grid due to thermal emissions and emissions during transshipment from a primary iron and steel production plant at IJmuiden



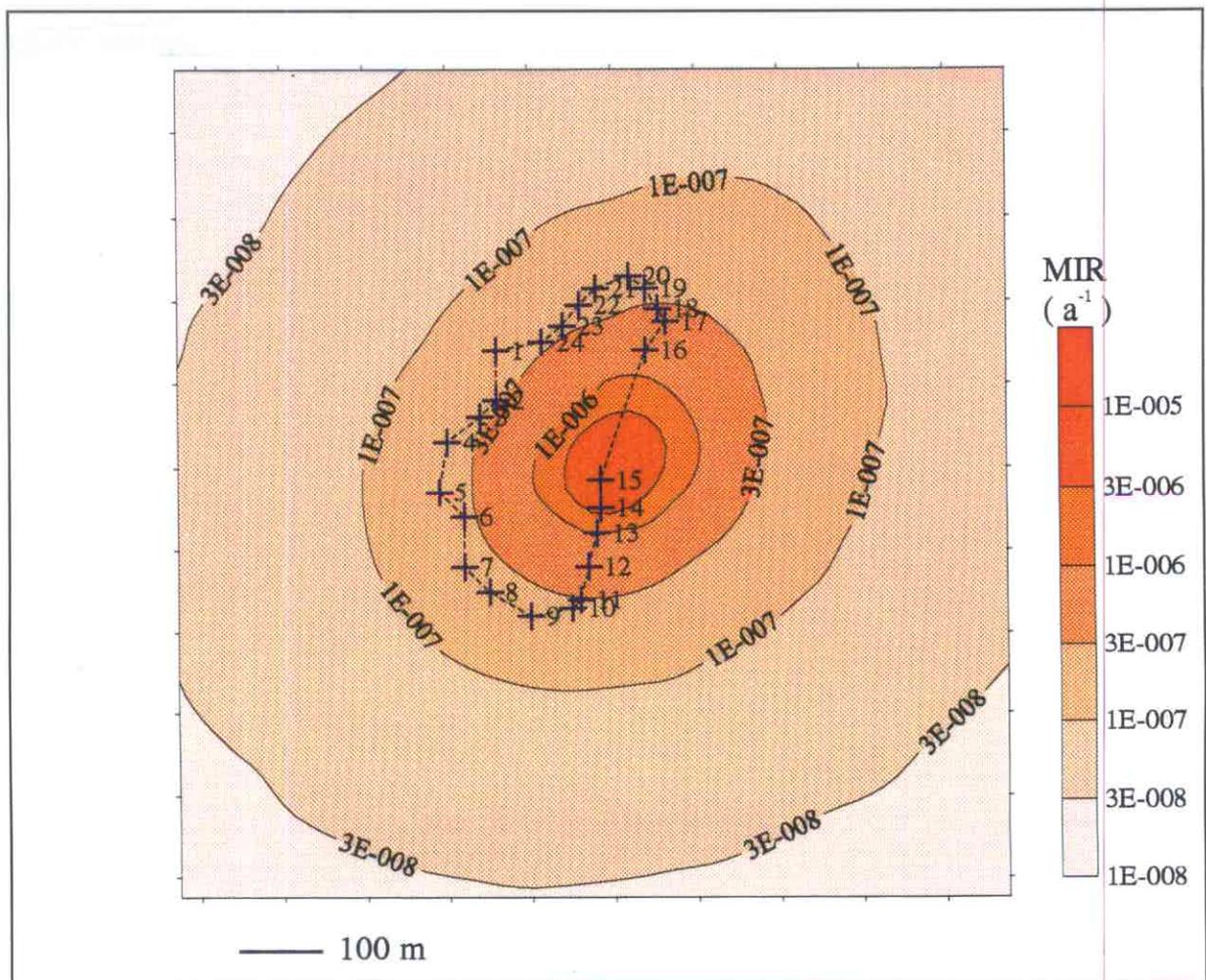
**Figure J.12** MIR contours on a 50-m grid due to thermic emissions and emissions during marl extraction, transport and milling from a cement production plant at Maastricht



**Figure J.13** MIR contours on a 5-km grid over the Netherlands due to thermic emissions of  $^{210}\text{Po}$  from a cement production plant at Maastricht



**Figure J.14** MIR contours on a 50-m grid due to emissions to air during transshipment at a fertilizer production plant Amsterdam



**Figure J.15.** MIR contours on a 50-m grid due to emissions to air during transshipment at a fertilizer production plant at Geertruidenberg