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RADIOLOGICAL RISKS OF NON-NUCLEAR INDUSTRIES IN THE NETHERLANDS

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ABSTRACT

Non-nuclear industries use large amounts of raw materials like ore, marl or clay which contain natural radionuclides from the ^{238}U and ^{232}Th series and ^{40}K. As a result of industrial processing enhanced concentrations of these radionuclides occur in the residual output streams, either in the form of solid waste or as releases into air or water. These radionuclides impose a radiological risk on members of the general public nearby those industries. Following a literature study completed in 1988, the total radiation dose of most of the non-nuclear industries in the Netherlands was calculated. The industries under study produce elemental phosphorus, phosphoric acid, iron and steel, cement, fertilisers, ceramic products like bricks and roof tiles, etc. The investigation focused on the radiation dose due to emissions of radionuclides to air, discharges to surface water and direct external radiation from bulk materials. Two types of results are presented in this paper. Firstly, the geographical distribution of the individual dose due to all sources at a national scale is presented. Differences in this distribution are dominated by the emissions to air. Secondly, for a few single sources more detailed results on the actual individual and collective dose are presented. The investigation showed that the individual and collective doses due to releases of radionuclides by non-nuclear industries in the Netherlands are dominated by only a few sources. The actual individual dose due to non-nuclear industries is relevant, but the dose caused by a single source does not exceed 0.1 mSv per year.

INTRODUCTION

The first review of the radiation dose due to non-nuclear industries in the Netherlands was completed in 1988 by Peute *et al.* [1]. This review, which gives the situation in 1985, was used as the starting point of our investigation. We examined the literature for more recent data on emissions and in some cases we had to estimate the emissions from data on throughput of raw materials and radionuclide concentrations in these materials. The relevant sources are industries that use large amounts of raw materials and high temperature processes.

Raw materials like ore, marl and clay contain natural radionuclides from the ^{238}U series (^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{222}Rn, ^{210}Pb and ^{210}Po) and the ^{232}Th series (^{232}Th, ^{228}Ra and ^{228}Th) and ^{40}K. As a result of industrial processing enhanced concentrations of these radionuclides occur in the residual output streams, either in the form of solid waste or as releases into air or water. These radionuclides impose a radiological risk on members of the general public who live and work primarily nearby those industries [2].

In the environmental policy of the Netherlands the risk scale was chosen as the reference scale, on which environmental problems are to be ranked [3]. In this context risk is defined as the unwanted consequences of a particular activity in relation to the likelihood that these may occur. The radiation protection policy is based on this risk approach and the effective dose[2] is used to assess radiation risks. Two dose limits are defined. The cumulative individual dose limit for members of the general public due to all sources amounts 1 mSv per year. The individual dose limit per source is set at

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[2] In this paper 'dose' is used to indicate effective dose, unit sievert (Sv)

100 μSv per year, because it is assumed that a member of the general public is exposed to a maximum of ten sources simultaneously [4]. The dose limits are applicable to exposures from human activities and, thus, also to doses from the enhancement of radionuclide concentrations in the residual output streams of non-nuclear industries.

At RIVM two studies on the radiological risks of non-nuclear industries were conducted. The so called CUMU-project focused on the accumulation of environmental risks to human health due to major accidents, radioactive substances and radiation, carcinogenic and toxic substances and noise [5]. The activities in the CUMU-project aimed at comparing and mapping of various environmental risks on a national scale. In the CUMU-project these risks were calculated for an individual person permanently living at a certain location. The risks are therefore called *potential individual risks* and were calculated also for locations where nobody lives or will live in the near future.

In the other study the potential individual risks due to the non-nuclear industries were investigated in more detail [2]. Also the actual situation of people living or working near several industries was examined more closely and the *actual individual dose* was calculated.

This paper summarises the results of the two studies. The main issues are the geographical distribution of the potential and actual dose around a source and the comparison of different sources in the Netherlands.

MATERIALS AND METHODS

The radiation dose due to the emissions and discharges by non-nuclear industries were calculated using source-effect-chain models. A source is defined as the combination of emission and discharge points and the bulk materials stored on the site of a plant or factory. Three types of emissions by a source are distinguished: emissions of radionuclides to air, discharges to surface water and direct external radiation from bulk materials.

The yearly averaged radionuclide concentrations in air and the subsequent deposition on the ground were calculated using the Gaussian plume dispersion model OPS [6]. This probabilistic model uses long term weather conditions for the Netherlands. The exposure pathways considered are inhalation, external radiation by radionuclides in air and on the ground, and ingestion of crops and milk or meat from animals eating grass. External radiation from radionuclides in the air and on the ground turned out to be of minor importance. Standard diet of the reference person and reduction factors for losses due to food preparation were taken from governmental guidelines [7]. The dose conversion coefficients for inhalation and ingestion are those from the recent EU-directive. Table 1 gives the coefficients for the most important nuclides [8]. The dose conversion coefficients are different from those used in our previous studies. Therefore, the results presented in this paper differ from earlier results [2, 5].

Table 1 Dose conversion coefficients in Sv.Bq-1 according to the EU-directive [8].

inhalation		ingestion	
^{210}Pb	^{210}Po	^{210}Pb	^{210}Po
5.6×10^{-6}	4.3×10^{-6}	6.9×10^{-6}	1.2×10^{-6}

The calculations of the doses due to emissions to air were carried out in two steps. In the first screening the dose was calculated for all sources using three so called reference situations. Each reference situation represents a certain type of process (transhipment; small plant; large plant or energy-intensive activity) and has generic values for model parameters like source height, heat content of the plume and particle size [2]. Subsequently, only the sources with a dose higher than about 1 μSv per year were examined more closely, using available location specific data.

The dose due to discharges to water was calculated for two exposure pathways: ingestion of fish and fish products and the use of harbour sludge for land-fill of polders. In this paper only the results of the first pathway are given; the pathway 'harbour sludge on polders' is discussed elsewhere [9]. The average radionuclide concentrations in fish and the resulting dose were calculated from the radionuclide concentrations in the sea, concentration factors and the quantities of fish caught in different parts of the North Sea [10, 11]. It is assumed that the consumption of relevant fish and fish products is evenly distributed over the Netherlands.

The external radiation dose for members of the general public due to large amounts of raw material or solid waste on the site of the plant or factory was estimated from measurements or calculations of radiation levels near raw material stocks and solid waste sites reported in the literature [12]. If no information on radiation levels was available the model MARMER was used. This computer code calculates energy absorption and dose from several radiation sources at any point of a complex geometry [13].

Initially the (potential individual) dose was calculated for every location througout the Netherlands, irrespective of the presence of residents. The actual individual dose was calculated by multiplying the potential individual dose by the so called Actual exposure Correction Factors (ACF's). The value of the ACF depends on the actual use of a certain location (see table 2).

Table 2 Actual exposure Correction Factors (ACF's) used for calculating the actual dose from the potential dose [2].

Type of infrastructure or use at the location	ACF
source transported by road	0.001
waterway used by occupational (transit) shipping; parking lot; main road outside residential area or road in industrial area; agricultural area (meadow)	0.01
harbour for passing ships; recreation area exept campings (woods, parks, dune, water, beach)	0.03
harbour for yachts, regular harbour for occupational shipping ans vegetable gardens; secondary road in the vicinity of residential area	0.1
camping site; other industry or offices, work inside	0.2
other industry, work outside	1.0

For the emissions to air the collective dose per source to the population of the Netherlands was calculated by multiplying the potential individual dose map per source with a map of the population density, and subsequently summing up the results in all grid elements. For the discharges to water the potential individual dose is assumed to be independent of the location and is therefore multiplied by the total number of inhabitants ($15x10^6$) to obtain the collective dose. The collective dose due to direct external radiation of bulk material was not calculated because only a few members of the general public in the direct neighbourhood are exposed to this radiation.

RESULTS AND DISCUSSION

The most important sources and the estimated emissions to air and discharges to water of the relevant radionuclides are listed in table 3.

Table 3 Emissions to air and discharges to water in GBq per year by the most important non-nuclear industries in The Netherlands [2]

production or processing	N[1]	year	^{222}Rn to air	^{210}Pb to air	^{210}Po to air	^{210}Pb to water	^{210}Po to water
elemental phosphorus	1	92	563	66	490	24	166
phosphoric acid	2	90	1859	0.23	0.29	1784	1835
iron and steel	1	90	350	55	91	0.15	8
ceramic products	~75	89/90	142	-	66	-	-
cement	3	90	387	0.23	78	-	-
coal-fired power	9	92	200	2.40	4.8	0.01	0.01
gas-fired power	6	90	2800	0.43	0.16	-	-
~~fertilisers~~	~~2~~	~~90~~	~~221~~	~~0.06~~	~~0.05~~	~~0.11~~	~~0.12~~
mineral sands	2	91	0.74	0.74	0.74	0.07	0.07

[1] number of plants or factories in the Netherlands

The CUMU-project resulted in a series of maps showing the geographical distribution of the dose due to the emissions to air. The doses due to discharges to surface water are not included in the maps,

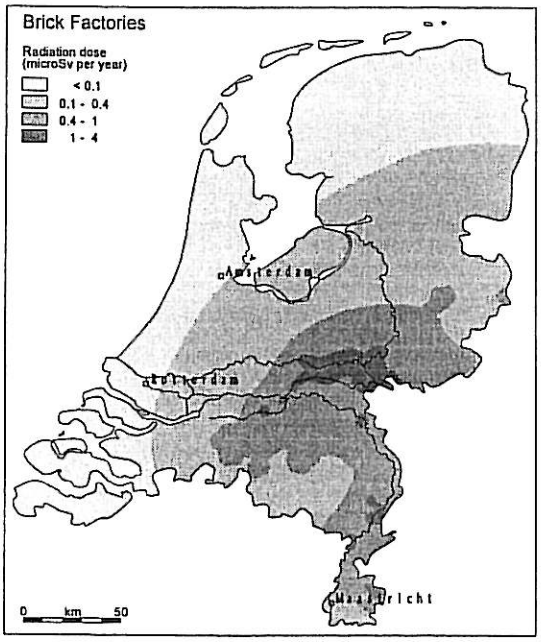

Figure 1 Potential individual dose due to regular emissions to air by brick factories in the Netherlands.

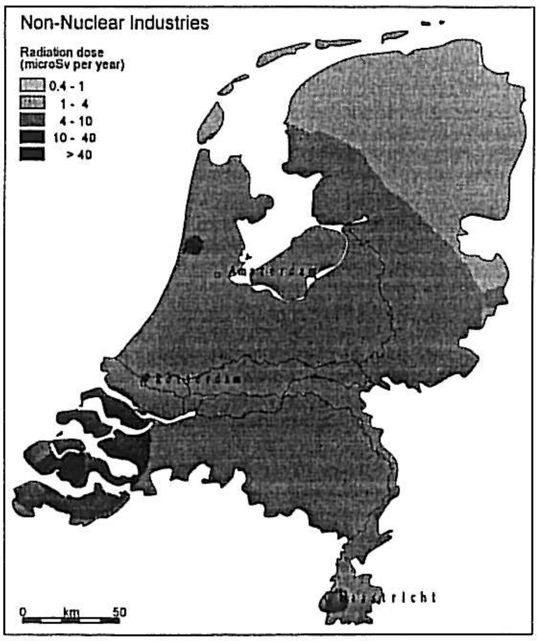

Figure 2 Potential individual dose due to regular emissions to air by all the non-nuclear industries in the Netherlands.

neither the direct external radiation dose which would not be visible on a national scale map. As an example of an industry with many sources in a relative small area the dose distribution due to emissions to air from brick factories is shown in figure 1 [4]. These factories are situated along the large rivers in the central eastern part of the Netherlands. A single brick factory causes a maximum individual dose not higher than 0.4 µSv per year. However, at the location of the highest density of factories the total individual dose is as high as 4 µSv per year.

Figure 2 shows the geographical distribution of the dose due to emissions to air by all the non-nuclear industries in the Netherlands. Three sources dominate the map: an elemental phosphorus production plant at Vlissingen in the south west, an iron and steel production plant at IJmuiden in the north west and a cement production plant near Maastricht in the south east. The dose is higher than 40 µSv per year in areas close to these sources only. In most parts of the country the dose is in the order of 1 µSv per year.

The geographical distribution of the dose near a few individual sources is given in more detail in the figures 3, 4 and 5. In the national maps the borders of the site of a plant are not shown in the maps. In the local maps, however, these geographical details become important. As can be seen in the

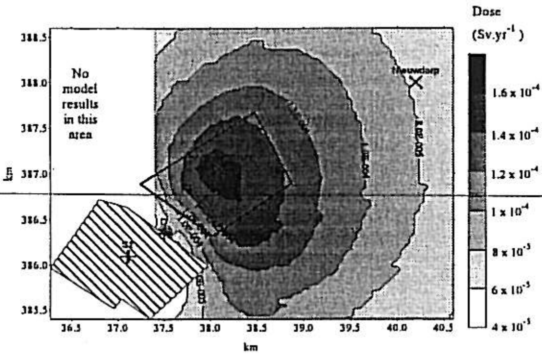

Figure 3 Dose contours around the elemental phosphorus production plant at Vlissingen.

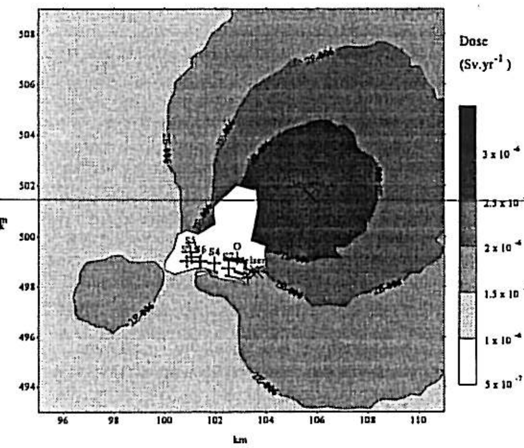

Figure 4 Dose contours around the iron and steel production plant at IJmuiden.

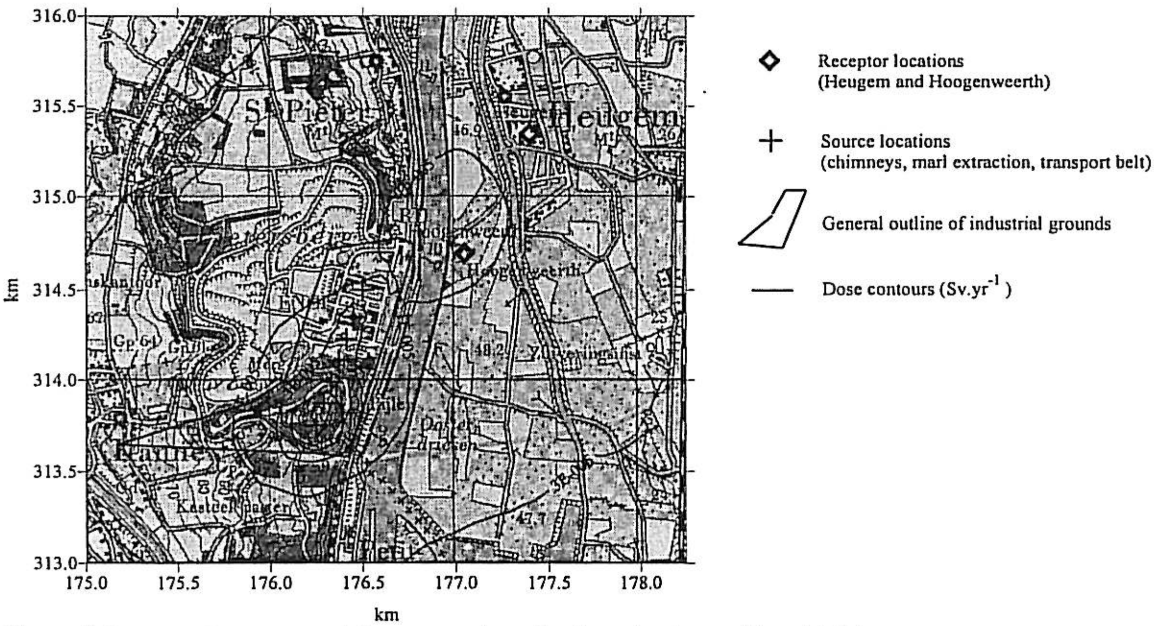

Figure 5 Dose contours around the cement production plant near Maastricht.

the figures a source is generally composed of a number of emission points which are represented by the symbol '+' in the figures. Emissions during transhipment (at the locations marked 'O') occur at groundlevel and lead only to higher values of the dose near the emission point, whereas emissions from high stacks lead to a maximum dose several kilometres from the source to the north east (figures 3 and 4). Only a careful combination of the contours of the potential dose with the actual use of space at the receptor locations makes it possible to estimate the maximum actual dose.

A summary of the results of the dose calculations for individual sources is given in table 4. The maimum potential and actual doses are given for receptor locations near the source with different type of infrastructure or use at the receptor location. For the discharges to water the actual dose is equal to the potential dose, because it is assumed that every person in the Netherlands has the same probability to eat the contaminated fish or fish products. For residents the actual dose due to the emissions to air is also equal to the potential dose.

Table 4 Maximum potential individual dose (PID) and actual individual dose (AID) in μSv per year at several receptor locations due to emissions to air, discharges to water and external radiation from bulk materials

production or processing	type of infrastructure or use (reference group)	emissions to air		discharg es to water	external radiation bulk materials	
		PID	AID	AID=PID	PID	AID
elemental phosphorus, Vlissingen	workers other industry	160	33	11	1.3	0.26
	occupational shipping and/or traffic industrial area	-	-	11	7.2	0.29
	residents	76	76	11	-	-
phosphoric acid, Vlaardingen	workers other industry	44	8.0	5.7	12	2.3
	residents	-	-	5.7	-	-
	occupational shipping	120	1.1	5.7	-	-
phosphoric acid, Pernis	workers other industry	44	8.0	5.4	0.8	0.16
	occupational shipping and/or traffic industrial area	-	-	5.4	2.9	0.12
	residents	-	-	5.4	-	-
iron and steel, IJmuiden	occupational shipping and/or traffic industrial area	-	-	0.44	76	3.0
	residents	2.9	2.9	0.44	-	-
cement, Maastricht	residents	12	12	-	-	-
coal-fired power, several locations	occupational shipping and/or traffic industrial area	-	-	-	104	4.0
fertilisers, Amsterdam	workers other industry	-	-	-	52	10
	occupational shipping and/or traffic industrial area	-	-	-	368	15
mineral sands, Amsterdam	workers other industry	300	56	-	160 0	320
	occupational shipping and/or traffic industrial area	3700	35	-	104 0	44
mineral sands, Geertruidenberg	workers other industry	14	2.7	-	-	-
	occupational shipping and/or traffic industrial area	220	2.2	-	204	8.4

For most investigated sources the calculated actual individual doses are lower than 100 μSv per year. The estimates of the actual dose from mineral sand handling and transhipment are relatively uncertain, because of unknown effects of buildings close to the source and the uncertainty in the actual size of the emitted particles. Moreover, actual doses might be lower because deposited dust particles are frequently removed at the plant site by means of sweeping machines.

The maximum individual dose due to all exposure pathways can not be calculated by simply adding the maximum doses from the emissions to air, the discharges to water and the direct external radiation, because, generally, the maximum doses from external radiation are at a different location than those from emissions to air. Calculation of this overall maximum can only be done when more site specific information is available and taken into account to obtain the doses for all possible receptor locations.

Finally, in table 5 the collective dose for the emissions to air and for the discharges to water is given. The highest collective doses are caused by the production of elemental phosphorus and phosphoric acid. These three sources cause 95 % of the total collective dose due to emissions and discharges by the non-nuclear industries in the Netherlands.

Table 5 Collective dose in manSv per year

production or processing	emissions to air	discharges to water	total
elemental phosphorus, Vlissingen	22	165	187
~~phosphoric acid, Vlaardingen~~	~~0.18~~	~~86~~	~~86~~
phosphoric acid, Pernis	0.20	81	81
iron and steel, IJmuiden	4.7	6.6	11
ceramic products, several locations	4.5	-	4.5
cement, Maastricht	2.3	-	2.3
coal-fired power, several locations	0.34	-	0.34
fertilisers, Amsterdam	0.013	-	0.013
total:	34	338	373

CONCLUSIONS AND RECOMMENDATIONS

Insight in the importance of the several types of non-nuclear industries in the Netherlands was obtained by studying the potential and actual individual dose and the geographical distribution of dose to members of the general public. The dose calculations were carried out similarly for all the sources using a uniform set of models and model parameters. The use of the geographical distribution of doses turned out to be extremely important for risk comparison and calculation of cumulated doses.

Only a few sources dominate the geographical distribution of the individual dose. Although there are locations where the potential individual dose due to a single source is larger than 100 μSv per year it is likely that the actual individual dose does not exceed 100 μSv per year.

Collective dose is an indicator of the effects on the health of the total population in the Netherlands. It appeared that the production of elemental phosphorus and phosphoric acid causes 95 % of the total collective dose due to emissions and discharges by the non-nuclear industries in the Netherlands.

More work need to be done on the gathering of more recent data on emissions and discharges in a uniform way. Especially more information is needed on the use of space at locations where the potential dose is high. To calculate the overall maximum dose from a source more site specific information is needed. It is also recommended to study the dose due to emissions during transhipment more closely because of the large uncertainties and the possibly high dose levels.

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