# EMISSIONS AND DOSES FROM SOURCES OF IONISING RADIATION IN THE NETHERLANDS - RADIATION POLICY MONITORING

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## INTRODUCTION

In 1997 the Ministry of Housing, Spatial Planning and the Environment requested RIVM to develop an information system for policy monitoring. One of the motives was that the European Union requires that the competent authorities of each member state ensure that dose estimates due to practices involving exposure to ionising radiation are made as realistic as possible for the population as a whole and for reference groups in all places where such groups may occur [1].

Emissions of radionuclides and radiation to the environment can be classified as follows: (1) emissions to the atmosphere, (2) emissions to the aquatic system and (3) emission of external radiation from radioactive materials and equipment that produces ionising radiation. Released radioactivity is dispersed via exposure pathways, such as the atmosphere, deposition on the ground and farmland products, drinking water, fish products, etc. This leads to radiation doses due to inhalation, ingestion and exposure to external radiation. To assess the possible radiation doses different kinds of models are applied, varying from simple multiplications with dispersion coefficients, transfer coefficients and dose conversion coefficients to complex dispersion models.

In this paper an overview is given of the human-induced radiation doses in the Netherlands. Also, trends in and the effect of policy on the radiation dose of members of the public are investigated. This paper is based on an RIVM report published recently [2]. A geographical distribution of radiation risks due to routine releases for a typical year in the Netherlands was published earlier [3]

## CATEGORIES

In the Netherlands environmental policy is directed at the source of environmental pollution. Therefore, radiation doses are attributed to the enterprises responsible for these doses. For practical reasons the enterprises are divided into the following categories: nuclear facilities, the process industry, medical institutions and companies for non-destructive testing.

### Nuclear facilities

In the Netherlands there are six nuclear facilities: the nuclear power plants (NPP's) in Borssele (pressurised water reactor of 1366 $MW_{th}$, 485 $MW_e$) and Dodewaard (shut down), a storage facility for radioactive waste called COVRA, a fuel enrichment plant in Almelo (URENCO) and the research facilities in Petten (HFR) and Delft (HOR).

The NPP in Borssele is presented here as an example of the nuclear facilities. During normal operation the emissions of $^{3}$H, $^{14}$C and halides such as $^{131}$I are the most important radionuclides with respect to the radiation dose in ventilation air. The activation product $^{60}$Co and fission products $^{131}$I, $^{134}$Cs and $^{137}$Cs are the most important radionuclides emitted to water.

Process industry

The process industry consists of enterprises that convert raw materials into intermediary or final products by means of chemical or physical processes. The radiation dose is caused by processing and storage of naturally occurring radioactive materials (NORM) which may lead to emissions and concentration of radionuclides. During storage the possible radioactivity of raw materials, waste materials and the products is of concern. Furthermore, the application of X-ray equipment and sealed sources may cause a radiation dose.

A production plant of elementary phosphorous and phosphorous derivatives is presented in this paper as an example of the process industry. In the report four more companies are discussed [2]. However, it must be noted that the process industry has many different types of factories which can not be compared easily. The most important emissions of the phosphorous production plant are $^{210}$Pb and $^{210}$Po in air and in water.

Medical institutions

In the Netherlands there are about 650 permitted medical institutions admitting and nursing patients. The group of 23 institutions which practice radiotherapy using linear accelerators or sealed sources, was investigated in detail. The external radiation due to the linear accelerators and the $^{131}$I emissions by patients treated with $^{131}$I are the most important contributors to radiation dose in this category.

Non-destructive testing

Non-destructive testing in the Netherlands is performed by four relatively big companies that are specialised in non-destructive testing and ten to twenty smaller companies which are not. Radiography with X-ray equipment and linear accelerators or gammagraphy with sealed sources are used out to check weldings and track down roughness in various mostly metal objects such as pipes, bridges, boilers and the hull of ships. Often, the practices are carried out at the premises of industrial sites, but also in special bunkers at the premises of the non-destructive testing companies themselves.

The sealed sources commonly used are $^{60}$Co, $^{137}$Cs, $^{169}$Yb, $^{170}$Tm and $^{192}$Ir. The required activity of these sources depends on the application and ranges from several hundreds of GBq to several TBq per source.

**RADIATION PROTECTION POLICY**

In the Netherlands, the basic legislation governing nuclear activities is contained in the Nuclear Energy Act. The emphasis of the Act has changed from stimulating the safe application of nuclear energy and radioactive techniques to giving rules for protection against the risks of such applications.

The provisions for radiation protection are based on the three principles of the international practice in radiation protection: justification, optimisation and dose limits. Optimisation is achieved by the ALARA concept: exposure to ionising radiation should be kept as low as reasonable achievable, economic and social factors taken into account.

In March 2002 the Decree on radiation protection [4] came into force implementing the EU-Directive 96/29 [1]. Additional to this Decree a Ministerial Order on the assessment of consequences of ionising radiation (mr-AGIS) was laid down, giving rules for the calculation of the radiation dose necessary for application of a permit.

In the Ministerial Order three dose concepts are given:

- individual dose (ID): the dose received by an individual who is unprotected and 24 hours per day exposed to a source or industrial site; this is a conservative approach;
- multifunctional individual dose (MID): the dose received by an individual who lives in the vicinity of the source or location; this is also a conservative approach, considering the fact that the area around an industrial site is usually not intended to be a residential area;
- actual individual dose (AID): the dose received by an individual considering the actual function of the area around an industrial site; the actual individual dose is calculated by correcting the individual dose (ID) by so-called and prescribed Actual Exposure Correction factors.

Following the ICRP recommendations and European directives dose conversion coefficients (DCC's) are employed [1]. Related to these coefficients in the Netherlands radiotoxicity equivalents (Re) are used for permit granting. One radiotoxicity equivalent for inhalation ($Re_{inh}$ [Bq]) is the activity that after total intake results in an committed effective dose of 1 Sv for an adult. For each radionuclide the $Re_{inh}$ is calculated by dividing 1 Sv by the DCC for inhalation.

**EMISSIONS**

In Figure 1 the annual emissions relative to the granted emissions are shown for the NPP in Borssele. The emissions are usually around 10 percent of the granted emissions, whereas since 1995 an increase in the emissions to air can be observed. This can be ascribed to the obligation of the NPP to report $^{14}C$ emissions. The permit was then changed in order to take these $^{14}C$ emissions into account.

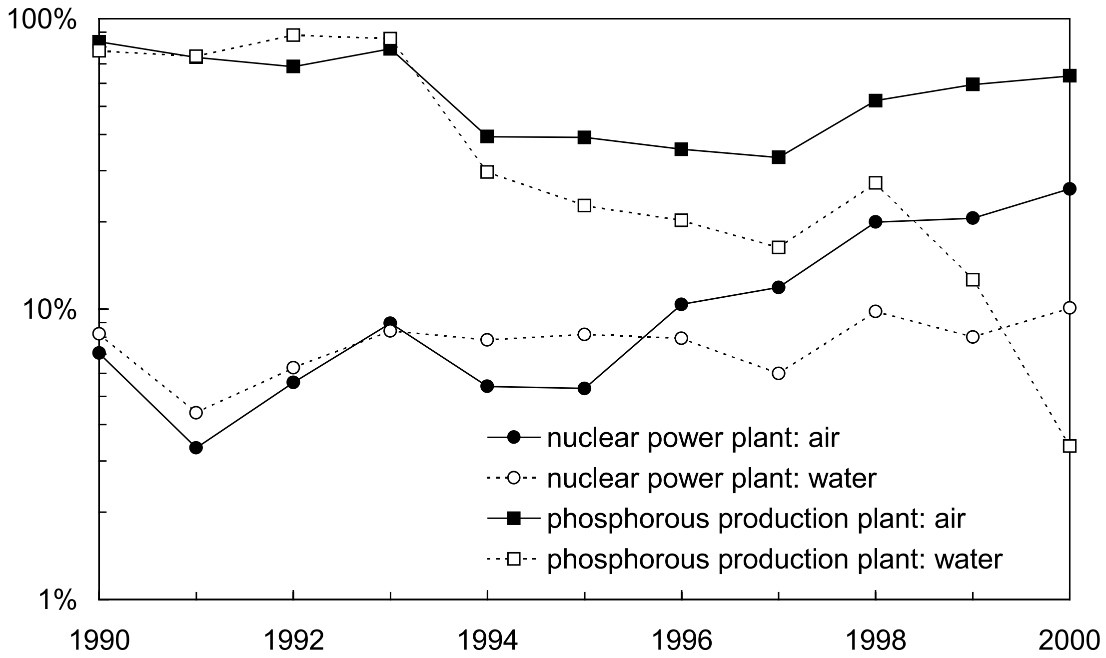


*Figure 1 Two examples of actual emissions relative to granted limits*

The releases to air and water of the elementary phosphorus plant are also shown in Figure 1. The data are presented as a three years moving average, as prescribed in the permits. It can be noted that the releases are typically in the order of several tens of percents of the granted emissions in the permit. Since 1998 there is a decrease in the emissions to water due to improved cleaning techniques.

For medical institutions which have aggregate permits, the permitted stocks and emission limits are presented in Table 1. Also, the granted maximum effective dose at the border of the premises is listed. For the application of a permit the emission limits are calculated according to a directive on radionuclide laboratories. The choice of parameter values as well as the calculation method for the theoretical emissions to water and air vary from one institution to the other. These differences lead to differences in the granted emissions, even when the stocks are the same, as can be seen in Table 1.

The estimated $^{131}$I emissions by discharged patients are presented in Table 2. In total the $^{131}$I activity emitted in 1998 amounted to 8480 $Re_{ing}$ (385 GBq). Compared to these emissions the estimated actual emissions of medical institutions themselves, some 0.8 $Re_{ing}.a^{-1}$ per institution, are relatively low. This effect can be attributed to storage of waste water in tanks in medical institutions, whereas at home patients emit directly into the sewer.

No emissions of radioactive materials to air and water are produced by the non-destructive testing companies. In the permits provisions are laid down regarding maximum individual dose due to external radiation at the borders of the premises. In addition the companies have to comply with specific dose rate limits close to the stocks of radioactive sources. The exposure to the environment due to non-destructive testing is estimated by the number of radiographic recordings using various equipment. The total number of recordings amounts to some 230,000 per year distributed over 460 industrial sites (Table 3).

*Table 1 Summary of stocks, emission limits and dose constraint at the border of the premises of a number of medical institutions*

| type of medical institution | year | stocks | emission limit | | granted effective dose at the border of the premises |
|---|---|---|---|---|---|
| | | | air | water | |
| | | $Re_{inh}$ | $Re_{inh}$ | $Re_{ing}$ | $\mu Sv.a^{-1}$ |
| university hospital | 1997 | 2,0 | 30 | 100 | 40 |
| university hospital | 1999 | 16,0 | 100 | 500 | 1 |
| university hospital | 2000 | 1,5 | - | - | 40 |
| university hospital | 1998 | 1,5 | 0.5 | 500 | 40 |
| university hospital | 1999 | 10,0 | 20 | 200 | 20 |
| university hospital | 2001 | 1,0 | - | - | 10 |
| university hospital | 1996 | 15,0 | 5 | 500 | 80 |
| university hospital | 1997 | 3,0 | 12 | 180 | 10 |
| cancer institute | 1999 | 2,5 | 4 | 400 | 40 |
| cancer institute | 1995 | 20,0 | 5 | 500 | 40 |
| radiotherapy centre | 1999 | 300 | 0.01 | 1 | 20 |
| radiotherapy centre | 1998 | 250 | 0.5 | 10 | 40 |
| radiotherapy centre | 1998 | 400 | 2 | 115 | 20 |
| radiotherapy centre | 1999 | 2,0 | 0.5 | 250 | 30 |

- not reported

*Table 2 Estimate of emissions outside the hospital of $^{131}I$ by patients after $^{131}I$ therapy (1998).*

| | activity administered per patient (MBq) | number of patients | emission per patient (MBq) | total emitted (GBq) | total emitted ($Re_{ing}$) |
|---|---|---|---|---|---|
| hyper thyreoid | < 400 | 2240 | 150 | 336 | |
| hyper thyreoid | > 400 | 1760 | 24 | 42 | |
| thyroid cancer | > 400 | 300 | 24 | 7 | |
| total | | | | 385 | 8480 |

*Table 3 Estimates of the annual number of radiographic recordings at industrial sites (1994).*

| number of industrial sites | number of recordings per sites | total number of recordings |
|---|---|---|
| 122 | 13 | 1,600 |
| 130 | 133 | 17,000 |
| 81 | 333 | 27,000 |
| 66 | 666 | 44,000 |
| 44 | 1,332 | 59,000 |
| 24 | 3,333 | 80,000 |

**RADIATION DOSE**
In Figure 2 the estimated dose is presented for the nuclear power plant in Borssele. The dose is calculated using the models described in [5] and the reported emissions. The individual dose is in general below 0.1 $\mu Sv.a^{-1}$ and is dominated by the emissions to the atmosphere. The individual dose due to emissions to the aquatic environment is in the (sub)nSv range. The

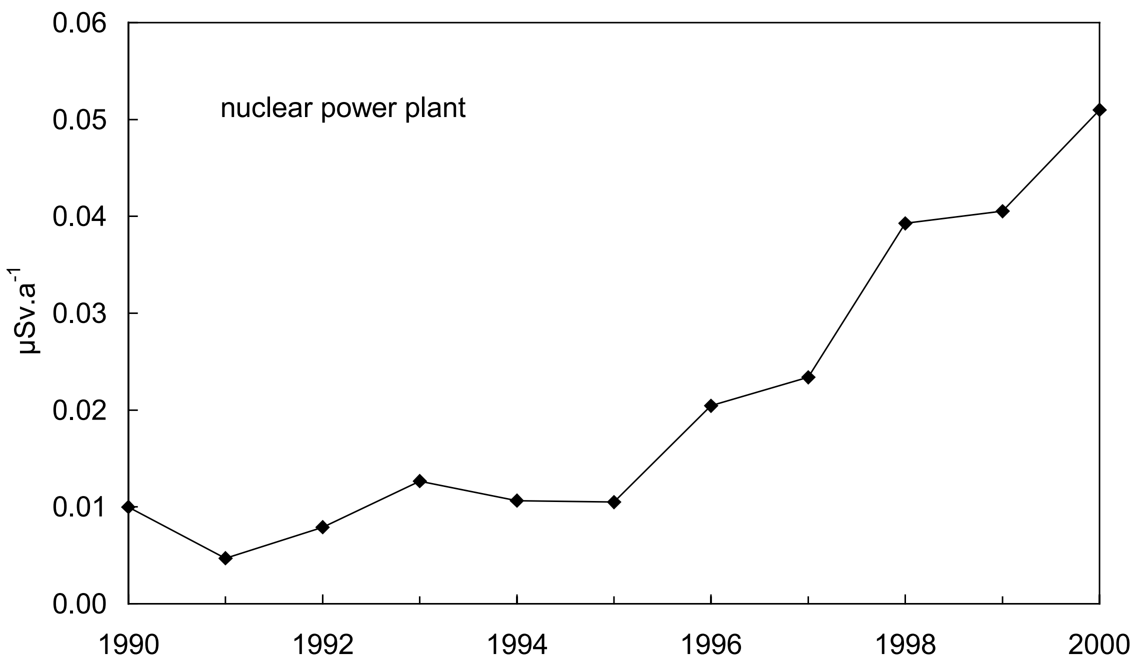


*Figure 2 Individual dose due to emissions to air and water by the nuclear power plant in Borssele*

estimated dose due to emissions increases since 1995, this is ascribed to the reported increasing $^{14}C$ emissions.

The effect of the policy can be indicated to the extent that the radiation dose due to emissions into air and water remain low, partly because reporting requirements in OSPAR (EU) [6] context stipulate that water and air emissions be demonstrably as low as reasonably achievable. In the same framework the participating countries have to demonstrate that the nuclear installations apply the best available techniques (BAT) and the best environmental practices (BEP).

The actual individual dose due to external radiation determined using the Actual Exposure Factor, at the border of the premises amount to a few μSv.a$^{-1}$.

In Figure 3 the multifunctional individual dose estimates for the phosphorus production plant are presented. The dose is calculated applying the method presented in an RIVM report [7], using the current DCC's [1] and exposure pathways as prescribed in [8]. The atmospheric emissions contribute more than 99 percent to the total dose in the year 2000. In contrast, the (inhalation) dose estimates on the basis of immision measurements show results between 10 and 30 μSv.a$^{-1}$ in the years 1998-2000 [2]. The external radiation of this phosphorus production plant is around 1 μSv.a$^{-1}$.

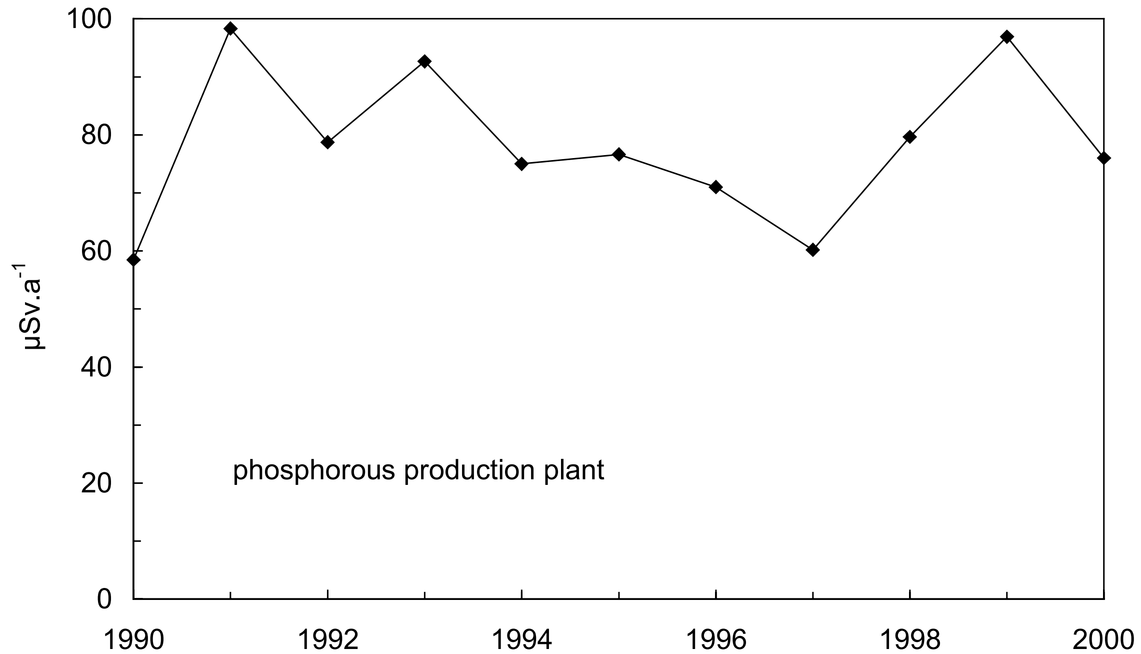


*Figure 3 Individual dose as estimated for the location Nieuwdorp due to emissions to air and water by a phosphorus and phosphorus derivatives production plant*

For the medical institutions the dose due to emissions to air can only be estimated based on the maximum possible emissions of radionuclides to air as calculated by the medical institutions. There is no information available on the actual emissions. Using a conservative approach an individual dose of 0.1 μSv.a$^{-1}$ was calculated [2]. When a conservative approach is followed for emissions to water, the individual dose turned out to be lower than 0.001 μSv.a$^{-1}$. Considering the dose due to external radiation, the results reported by the medical institutions of the maximum ambient dose at the border of the premises vary from less than 0.1 μSv.a$^{-1}$ up to 1500 μSv.a$^{-1}$: see Table 4. With respect to these results some institutions have taken measures to limit the actual individual dose by improvement of shielding and adjustments of borders of premises. For the radiation protection of employees the access of e.g. the roof or the crawl space is restricted.

*Table 4 The ambient dose equivalent reported by medical institutions*

| type of medical institution | ambient dose equivalent# ($\mu$Sv $a^{-1}$) | type of radiation* | floor | distance to border of premises (m) | thickness of concrete shielding (m) |
|---|---|---|---|---|---|
| general hospital | 624 | L6 | 0 | 6.5 | 1 |
| general hospital | 63.8 | L6 | ? | 32 | ? |
| general hospital | 62 | L10 | -1 | 85 | 1.25 |
| general hospital | 11.3 | L15 | 0 | 21 | 1.76 |
| general hospital | 0.8 | P6/23 | -1 | 166 | 2.73 |
| general hospital | 0.78 | P4 | 0 | 130 | 1.7 |
| general hospital | 0.11 | P6/10 | 0 | 55 | 3.15 |
| university hospital | 37 | P6/18 | 0 | 38 | 2.2 |
| university hospital | 12 | L6/18 | -1 | 40 | 1.6 |
| university hospital | 4.4 | ? 6 | 0 | 130 | >1.7 |
| university hospital | 3 | P16 | 0 | 70 | 2.5 |
| university hospital | 0.9 | P6/10 | -1 | 5.5 | 2.25 |
| university hospital | 0.52 | P25 | -1 | 175 | >2.0 |
| university hospital | $5.5.10^{-6}$ | P15 | -2 | 24.3 | 2.25 |
| university hospital | $2.1.10^{-7}$ | P10 | 0 | 80 | 5 |
| cancer institute | 1500 | P6 | 0 | 18 | 1.62 |
| cancer institue | 70 | L50 | -1 | 30 | 1.25 |
| radiotherapy centre | < 40 | L18 | 0 | 42 | 1.25 |
| radiotherapy centre | 35 | ?15 | 0 | 90 | ? |
| radiotherapy centre | 25.5 | L4 | 0 | 37 | 0.98 |
| radiotherapy centre | 19.9 | P6/10/25 | 0 | 23 | 2.5 |
| radiotherapy centre | 15.6 | P10 | 0 | 55 | 2.1 |
| radiotherapy centre | <0.1 | ? | -1 | 60 | 2.45 |

# the ambient dose must converted to the AID to compare this to the granted limit, * P = primary radiation, L = radiation due to leakage, 6/23 = calculated using 6 en 23 MV photons

In order to make an estimate of the actual individual dose due to non-destructive testing more information is needed regarding the number of recordings, the effective dose per recording and the location of the practices. Not all the practices are carried out on industrial sites. Also testing is done for instance on bridges and pipes in public roads. An important amount of the practices takes place at large industrial sites, with distance to the border of the site larger than 150 m. In those cases the dose is not significant, due to the distance and the available shielding. On small industrial sites and on the public road the exposure to radiation can be significant. Due to the lack of information, the dose is calculated using a dose of 0.03 $\mu$Sv per recording [4]. At 50 locations the number of 3300 recordings are exceeded (Figure 4), a number at which the 'location limit' of 100 $\mu Sv.a^{-1}$ is possible exceeded [4]. In these cases the companies for non-destructive testing are obliged to report this to the Ministry of Housing, Spatial Planning and the Environment.

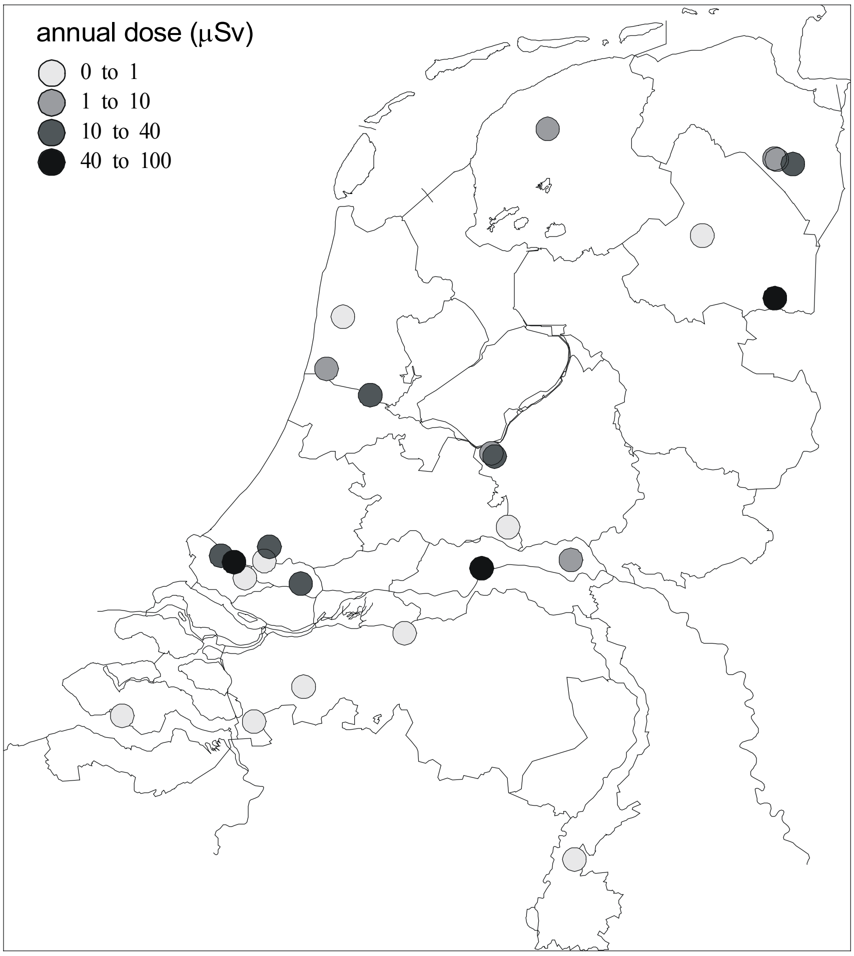


*Figure 4 Estimated multifunctional individual dose due to non-destructive testing outside the border of the premises where the number of 3300 recordings in 1998 are exceeded*

**DISCUSSION AND CONCLUSIONS**

Considering the attention of the public opinion and radiation protection society to nuclear facilities it can be understood that in the past policy and permit granting were primarily focussed on the reduction of emissions of these facilities. Also, the international OSPAR convention contributes to the reduction by demanding the participating countries to demonstrate that the nuclear installations apply the best available techniques and the best environmental practices. In the 1980's radiation protection policy also paid attention to the process industry which applies naturally occurring radioactive materials.

It is plausible that the pursued policy contributed to the fact that the emissions to air and water of nuclear facilities are typically lower than 10 percent of the granted limits and the radiation dose due to these emissions is below 1 $\mu Sv.a^{-1}$.

The emissions of the selected companies in the process industry amount up to 100% of the granted limits resulting in calculated multifunctional individual doses up to 100 $\mu Sv.a^{-1}$.
The emissions of radionuclides from the examined companies in the process industry have decreased, partly because of improved cleaning techniques and partly because of a number of companies stopped their emissions. Here, the influence of environmental policy in general and radiation protection policy in particular is not unambiguously established.

For medical institutions the introduction of aggregate permits has greatly improved the survey of permitted equipment, making the assessment of the radiation levels due to these institutions easier. The dose due to emissions to air and water of the medical institutions are below 0.1 $\mu Sv.a^{-1}$. The ambient dose due to external radiation of these institutions amount up 1500 $\mu Sv.a^{-1}$. A number of medical institutions have adopted measures like improvement of shielding, adjustments of borders of premises and access restrictions.

No discharges of radioactive materials to air and water are produced by the companies for non-destructive testing. Using a standardised multifunctional dose estimate the location limit may be exceeded at 50 locations. In these cases the companies for non-destructive testing are obliged to report this to the Ministry of Housing, Spatial Planning and the Environment.

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