RADIOLOGICAL IMPACT OF INDUSTRIAL SOURCES: INFLUENCE OF METEOROLOGICAL CONDITIONS AND PARTICLE SIZE DISTRIBUTION

Cristina P. Tanzi, Harry Eleveld
National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands

INTRODUCTION

Elevated concentrations of naturally occurring radionuclides can originate from ore-processing industries. In the Netherlands, if the radiological impact caused by industrial emissions exceeds a threshold level in any given year, the industry concerned is required to apply for an operating permit. In the permit, a level higher than the threshold may be granted; the burden of proof that this limit is not exceeded lies with the industry. The Ministry of the Environment monitors the compliance to the granted limit. The radiological impact can be assessed using atmospheric dispersion models, and possibly by measurements in the field. For the assessment of the radiological impact over a long period of time, modelling may be the only practical option.

Environmental impact

The relevant pathways for exposure are inhalation, ingestion of locally grown agricultural products, and ingestion of food from a wide area of contaminated farmland. Inhalation is dominant close to the source, while deposition of contaminants on farmland yields a small, but non-negligible, contribution to the general public.

The largest man-made induced radiological impact in the Netherlands can be ascribed to an elemental phosphorus plant. The impact of the emissions of this ore-processing industry has been studied with the latest version of the probabilistic atmospheric dispersion model OPS (*van Jaarsveld, 2004*). The stack is 55 m high and its heat content is 1.5 MW, with all-year-round emission. The environmental effect of the granted limit is studied for the nearest dwellings, which are located at approximately 3.5 km in N-NE direction from the source.

INHALATION: INFLUENCE OF THE WEATHER

The industrial emissions vary from year to year, due to both changes in throughput and composition of the processed ores. The impact of these changes on the emissions had been previously determined using decade-averaged meteorological data (*Bijwaard and Eleveld, 2002*). In this paper the yearly-averaged meteorological data is used (Figure 1), revealing an annual variation of up to 25% in the modelled air concentration at the nearest dwellings, for fixed throughput. The modelled air concentration, which dominates the radiological impact, correlates well (0.91) with the wind direction, shown as the number of days of the year when the wind blows from any direction between South and West.

The meteorological data are from a nearby weather station (Vlissingen), where wind is prevalently from a South-South-West direction, based on 1971-2000 wind data, (*KNMI, 2002*). The year 1996, where the lowest concentration is calculated, is atypical, with the wind almost uniformly distributed over all directions, thus with less contaminants reaching the nearest dwellings (the wind rose is given in Figure 1b, top). The highest concentration is calculated for the year 1998 (Figure 1b, bottom).

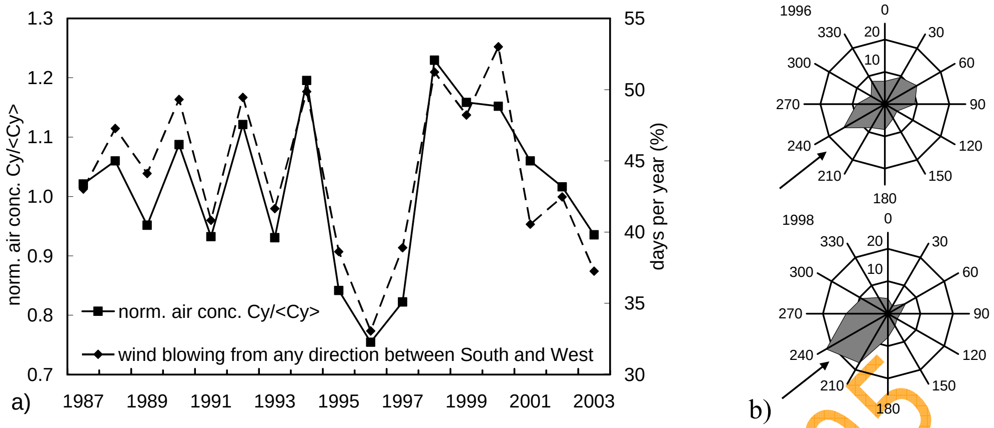


Fig. 1; a) Variation of the yearly air concentration Cy at the nearest dwellings, due to changing meteorological conditions, normalised to the concentration <Cy> based on meteorology averaged over 1990-99, and percentage of days per year when the wind originates between South and West; b) wind rose for 1996 and 1998 (percentage of days on the y-axis). The arrow points to the nearest dwellings. Meteorological wind data from KNMI.

INGESTION: INFLUENCE OF PARTICLE SIZE DISTRIBUTION, LOCAL

The deposition of radioactive contaminants on the ground may contribute to the radiological dose, through the ingestion of contaminated food. We assume that only a few kilograms of locally grown vegetables are consumed. In this case inhalation remains the leading pathway (> 90% of the radiological impact). Ingestion can dominate the inhalation pathway if all sources of food are produced in the vicinity of the source. Close to the source, the size distrib-

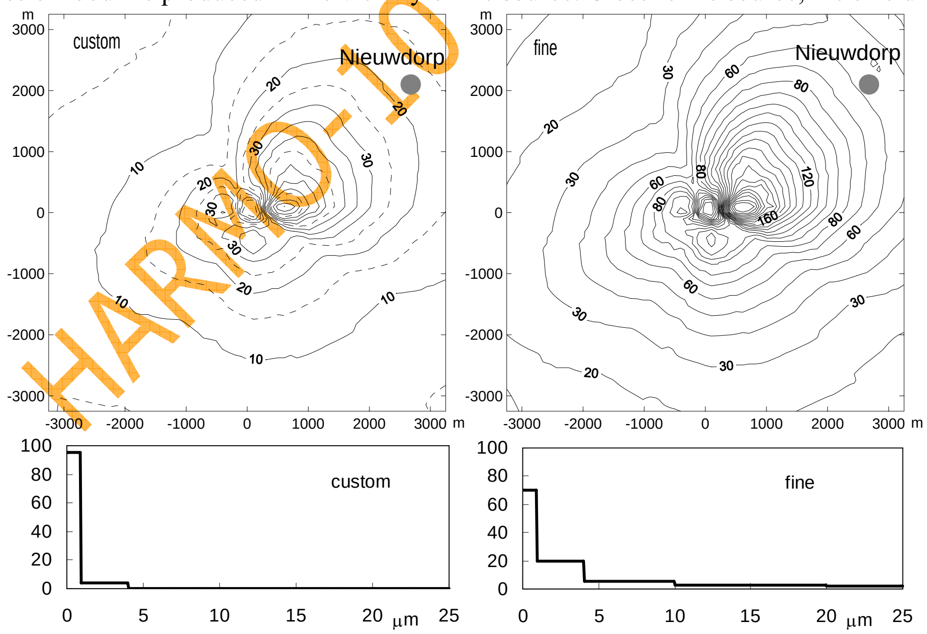


Fig. 2; Top: Dry deposition of emitted particles: multiply by 2 10^{-8} to obtain the ratio to the total emission (in this modelled area the deposition of "custom" and "fine" particle distributions are 0.12% and 0.41% of total emission respectively). The dot shows the position of the nearest dwellings for which the time series is modelled. Bottom: the relative particle distributions shown as percentage of total.

ution of the emitted particles is important. For this plant, most emitted particles have been measured to have a size of 1 µm or smaller ("custom distribution"), while routinely emission is modelled with only 70% of particles smaller than 1 µm ("fine distribution"). The calculated deposition in the evaluated region (6.5 x 6.5 km^2) for the custom distribution (<1 µm) is only 30% of the deposition calculated with the "fine distribution" (Fig. 2)

INGESTION: NATIONWIDE (NETHERLANDS)

The radiation dose from ingestion of products from contaminated farmland has also been modelled, based on a standard consumption of the general public in the Netherlands. The actual use of farmland has been taken into account. In general the average of the deposition over dry land is assumed to give a good estimate, which is true in case of a uniform distribution. Because the uptake of the radiological contaminants in the food chain depends both on the contaminant and on the type of food [*IAEA, 1994*], modelling of actual land use provides a more accurate estimate (here 30% higher) than the simple average. Four classes of land produce are defined, which contribute in different ways to the food chain (see Figure 3).
a) pasture, which will transfer the contamination to both meat and milk; b) grain; c) green vegetables; d) potatoes.

Together with the assumption that all consumed food in these categories originates from the Netherlands, the radiological impact from the plant for the general public can be determined. The phosphorus plant contributes approximately 1 µSv to the dose of the general public. The sievert (Sv) is a measure of absorbed radiation dose, which can be translated to a mortality risk.

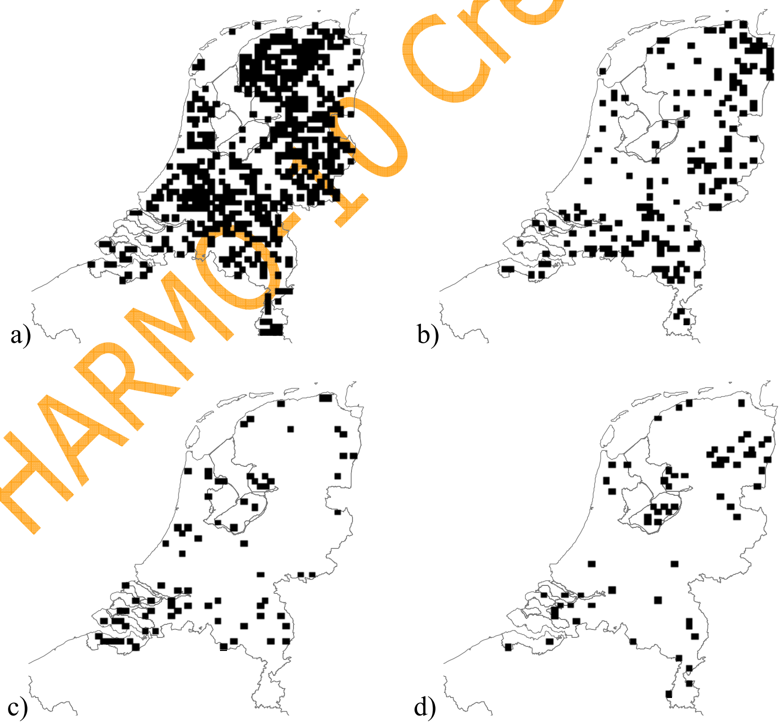


Fig. 3; Land use in the Netherlands for a) pasture b) grains c) green vegetables d) potatoes, here shown on a 5 x 5 km^2 grid (based on the 25 x 25 m^2 Dutch national land-cover LGN3 database, see e.g. van Oort et al., 2004).

Influence of the weather

The influence of the weather on the radiological impact due to deposition over the whole country has also been studied. The radiation dose shows a variation of +/-15% because of changing meteorological conditions (Figure 4).

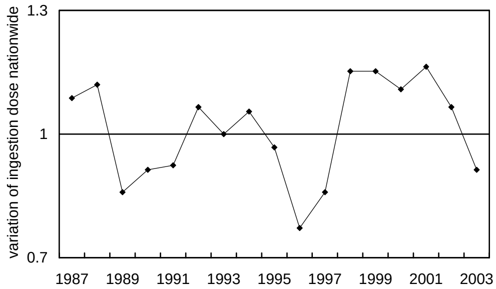
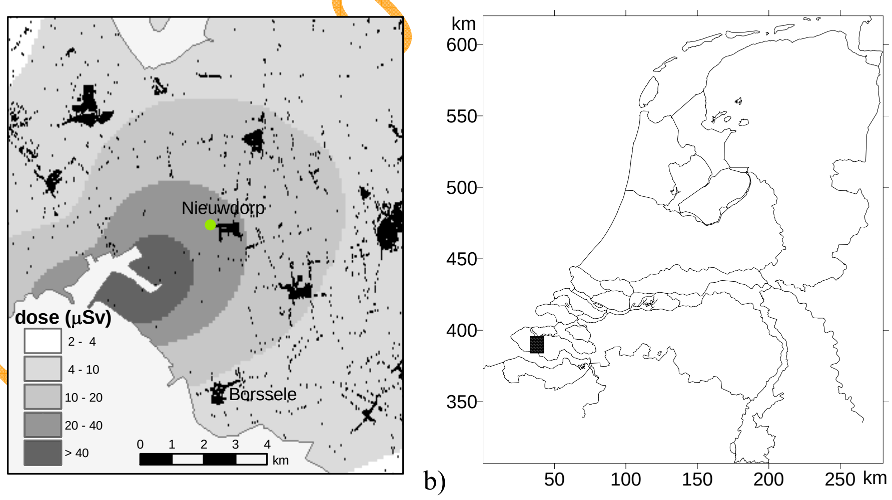


Fig. 4; Variation of the radiological impact from contaminated food consumption over the Netherlands, based on actual land use (LGN3 database, see Figure 3), due to changing meteorological conditions, scaled to the value calculated with meteorology averaged over 1990-99.

RADIOLOGICAL IMPACT FOR THE INHABITANTS

The industrial emission is monitored by us for its radiological impact on the inhabitants of the nearest dwellings. For the year 2003 the complete picture in the vicinity of the factory is given in Figure 5a. If the emission does not cause more than 1 µSv per year no permit is required. In this case a permit has been issued for 40 µSv at the boundary of the factory. For the inhabitants of the nearest dwellings, the dose is calculated to be 70% of the limit (based on a conservative estimate, including both local and nationwide ingestion, as required by law).

a)

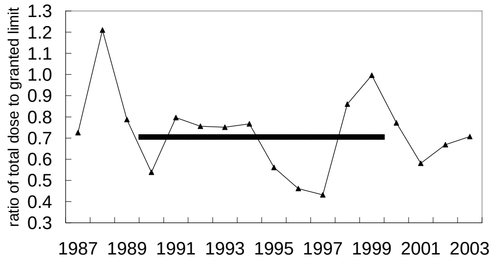


b)

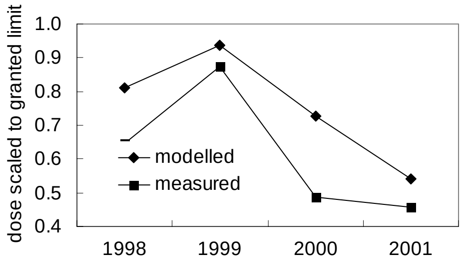
Fig. 5; a): Radiation dose around the phosphorus plant for 2003. The annual dose at the nearest dwellings is 28 □Sv. The permit allows for 40 □Sv outside the terrain of the phosphorus plant. b): location of map a) in the Netherlands.

Combining the influence of the weather with the change in throughput, the complete radiological impact of the plant has been assessed (see Figure 6a). These data are in agreement (Figure 6b) with existing measurements taken in the vicinity of the nearest dwellings (800 m) for the years 1998-2001 (see refs. in *Eleveld et al., 2005*).

To further illustrate the importance of the weather, imagine that measurements to test the compliance to the granted limit are performed in a year with predominantly changing winds, such as was the case for 1996. It would appear that the permit limit would be reached only by more than doubling the throughput. In a year with more representative meteorological conditions, an increase of 50% in throughput clearly causes emissions that exceed the granted limit.



a)



b)

Fig. 6; a): Radiological impact of the elemental phosphorus plant for the nearest dwellings, scaled to the presently granted limit. The impact of the averaged emission over the decade 1990-99 is also shown. b): comparison of modelled inhalation dose with available measurements.

CONCLUSIONS

When determining the radiological impact of industry, one can in general rely on a combination of measurements and models. Sometimes one must extrapolate with models from scarce measurements. In the Netherlands, a phosphorus plant is the industry with the largest radiological impact. For this plant we determined the influence of a small change in the emitted particle distribution. Furthermore, we have shown that the weather is responsible for a variation of ± 25% on the radiological impact (dose). For inhabitants of the nearest dwellings, the dose is dominated by inhalation. For people living further from the source, the radiological impact is dominated by the deposition of particles on the ground, and the subsequent ingestion of contaminated food. At 200 km from the source, the dose is only about 3% of the dose modelled for the inhabitants of the nearest dwellings. The weather also has a noticeable influence on this ingestion dose. The varying meteorological conditions must therefore be accounted for when studying long time series, especially when the radiation dose is close to the emission limits.

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