3.1

The risk of unit discharges of naturally occurring radioactive matter by oil and gas industry from the Dutch part of the continental shelf

R. Heling

KEMA

The Netherlands

THE RISK OF UNIT DISCHARGES OF NATURALLY OCCURRING RADIOACTIVE MATTER BY OIL AND GAS INDUSTRY FROM THE DUTCH PART OF THE CONTINENTAL SHELF

R. Heling [1]

ABSTRACT

Water co-produced with the production of oil and gas can contain enhanced levels of natural radionuclides. This paper presents the results of a screening analysis that has been carried out to determine the order of magnitude of the radiological risks to the Dutch population, due to unit discharges into the Dutch Continental Shelf of all relevant radionuclides that might be present in naturally occurring radioactive material (NORM) associated with produced water by the Exploration & Production (E&P) industry. The released radionuclides lead to an exposure of the population by different aquatic pathways.

For the assessment, compartment models have been applied for the hydrological dispersion, using generic information to estimate the risk. The radiological risks are calculated assuming a steady state situation of a discharge of 1 GBq per year of each of the relevant radionuclides in each of the discharge locations. An estimate of the total discharge of radioactive isotopes from the oil and gas platforms on the Dutch Continental Shelf indicates that the total individual risk for each of the reference groups following these discharges is below the maximal allowable risk.

INTRODUCTION

A large number of oil- and gas platforms are located on the Continental Shelf of the North Sea. Waste water is discharged into the direct environment of the platform (Van Hattum, 1992). Pollutants, heavy metals, hydrocarbons, and natural occurring radioactive matter from the underseas oil and gas reservoirs are discharged with the produced water in the vicinity of the production platforms. Dispersion over large distances leads to the transfer of contaminants to the population via contaminated fishery produce, to exposure via seaspray and resuspended sediments, and by residence on the beach.

The natural radionuclides discharged are generally from the ^{238}U and ^{232}Th decay chain. Especially the radium isotopes contribute significantly to the radioactive levels of the produced water. Studies carried out on the discharges of radium isotopes in the Gulf of Mexico demonstrated a concentration ranging from 0.1 up to 60 Bq/l ^{226}Ra (Snavely, 1989; Stephonson, 1991; SAIC, 1991). Similar ranges were found in the produced water discharged from the platforms located on the Dutch part of the Continental Shelf or DCS (NOGEPA, 1991).

Two distinct fractions are discharged from the platforms, granulated scales, i.e waste from the maintenance of the installations, and dissolved and particulate nuclides in the produced water. The present study emphasis on the latter form.

In 1994 KEMA has performed a risk assessment commissioned by the E&P industry to evaluate risk of discharges from offshore platforms including from those located in the 12-mile territorial zone. Although various studies indicated that the radiological effects both to the marine biota as to the population can be expected to be relatively low (Stephenson, 1992). This study was performed to get insight in the order of magnitude of the risks in order to compare them with the maximum allowable risk of 10^{-6} per year as defined by the Dutch Policy. Besides that the presence of radionuclides in produced water seems to

[1] KEMA Nederland B.V., P.O. Box 9035, 6800 ET Arnhem, the Netherlands

depend upon the geological formations from which the water is produced (Stephenson et al., 1990). This implies that the levels on the DCS could deviate from the reported data in literature. Furthermore the studies were mainly based on discharges of radium, and it is known that the radionuclide composition of produced water from oil and gas producing platforms may differ considerably.

An assessment of the risk due to discharges of radionuclides into the environment can be performed in different levels. The first level is a screening analysis using simple models and conservative assumptions, which results in an assessment of the order of magnitude of the risks. Generally, such assessments lead to an overestimation of risks. When the assessment leads to a significant risk, with respect to the criteria used, more realistic and complex models might be used in a second level.

This study is the result of first level approach to determine the order of magnitude of the radiological risks, due to unit discharges of NORM associated with produced water by the E&P industry on the DCS. Due to the fact that not from all platforms on the DCS the levels of nuclides in the produced water was known, this risk assessment study is in principle meant to give the risks of unit discharges. Additional measurements can give a more complete view on the problem. However, both an estimation of the total amount of discharged radium as well as some examples of real discharges are presented. More detailed information can be found elsewhere (Heling & Van der Steen, 1994).

THE MODEL STRUCTURE

To model the dispersion of radionuclides discharged in the coastal areas and on the DCS two different compartment models have been applied.

The first model, called RADCS-1, is applied to calculate the dispersion over long distances of nuclides discharged from installations in the northern part of the DCS, and is based on the compartment structure as applied in the MARINA study (MARINA, 1990), and as applied in a dose assessment study performed on the Sellafield discharges (Nicholson & MacKenzie, 1988; MacKenzie and Nicholson, 1987), and consist of two large compartments in the horizontal direction, and two compartments to model the vertical migration into the sediment layers of the seabed.

The seabed can be considered as a storage layer, which is filled by sedimentation but from which radionuclides can be released to the water phase on the long term. This interaction causes two effects; long lived radionuclides are removed out of the water column faster then on the basis of sedimentation only, but on the longer term it may cause an enhancement of radionuclides in the sea water years after the period in which the discharges took place. The interaction between the seabed and the overlying water column due to several processes is included in the two-compartments model RADCS-1, in accordance with the studies of MacKenzie and Nicholson (MacKenzie & Nicholson, 1987; Nicholson & MacKenzie, 1988). The processes incorporated in the model are bioturbation and sediment reworking, burial, the downward transport of radionuclides to deeper layers, and diffusion. The theoretical description of the model can be found in both studies.

In the MARINA model, the North Atlantic Coastal Waters are divided into large compartments (MARINA, 1990). For this study, two compartments are of importance being the Central North Sea and the Southern North Sea. This approach is used to calculate the transport of radionuclides discharged from platforms located in the compartment "Central North Sea" at the northern part of the DCS. In this compartment the main hydrodynamic transport moves into the northern direction (Müller-Navarra & Mittelstadt, 1988; Van Pagee et al., 1992). The interaction by transport in southern direction to the Southern North Sea compartment is of minor importance. All parameter values, like exchange rates between the compartments, sedimentation rates, sediment reworking rates, bioturbation rates and depths, have been established in the MARINA project.

Current velocities along the Dutch coast are significantly higher than on the DCS, being in the order of 3 - 6 $m.s^{-1}$, and due to the large compartments of the MARINA model predictions might underestimate the concentration in the coastal regions, specifically for releases in these regions. Therefore, for discharge locations which are closer to the Dutch coast, another model approach is used with ten compartments describing the coastal part of the North Sea. This second dispersion model applied in this study, called RADCS-2, is based on a study performed on the dispersion of nuclides discharged by the nuclear installations located in the Netherlands (Van Hienen et al., 1990). It consist of ten compartments to model the hydrodynamic dispersion in the horizontal direction. Nine of the compartments are located along the Dutch coast, following the current into the northern direction.

Because of the strong currents in the coastal regions, sedimentation and subsequent remobilisation of radionuclides will play a minor role in comparison with outflow in the ten-compartments model. Therefore, the specific seabed interactions as described in RADCS-1, with the exception of sedimentation, are omitted in this model. The exchange rate between compartments is estimated using the residence times and compartment volumes reported by Van Hienen (Van Hienen et al, 1990). Simple mass balances under the assumption of a constant volume exchange in the northern direction and intensive interaction between the coastal and the continental part of the DCS, supplied the inflow and outflow rates. A conservative estimation of the extent to which radionuclides in the continental part of the DCS enter the coastal compartments have been adopted by assuming that the flow between the coastal compartment into the northern direction remains constant up to the German Bight.

Both models are applied assuming the steady - state situation, which is a reasonable assumption for the temporal and spatial scale of the model application.

In the two-compartments model RADCS-1 fish catch data as presented in the MARINA-study are used. In the ten-compartment model RADCS-2 the risk is calculated using annual fish catch data from the study of Van Hienen in which they are related with the coastal compartments. The effect of the import and export of fishery produce between the several European countries is not taken into account, it is assumed that the Dutch population consumes fish originating from these parts of the North Sea. This causes an overestimation of the dose by ingestion of contaminated foodstuffs.

The pathways taken into account are the consumption of seafood (fish, crustaceans and molluscs), external exposure from contaminated beach sediments and sea water, inhalation of resuspended beach sediments, and the inhalation of seaspray. Additionally, the risk of the use of sand from the sea bottom for landfill of housing areas has been assessed. The sand is assumed to be originating from the southern part of the North Sea. To assess the individual dose to the population three reference groups are identified. According to the Dutch policy standpoints on radiation protection (VROM, 1993), doses and risks are calculated for a reference person of the population, being an adult. With respect to the exposure pathways, groups can be identified that are more exposed than the average individual of the population. The reference groups which can be identified are: 1. those who stay on the beach for recreative purposes, 2. those who live close to the beach, 3. those who live on a sea sand landfill area. Since consumption of seafood is considered to take place throughout the whole population, the risks due to this exposure pathway are to be added to the risks due to the other pathways. So, to assess the total risk for each of the groups the consumption of seafood is added to the risk due to this specific behaviour.
Beach occupancy leads to external irradiation by sand, by water during swimming and by boating. Radionuclides discharged from the oil and gas platforms reach the beaches due to tidal excursion. It has been shown in several studies that beach occupancy, leading to external exposure due to contact with sand and seawater, is an important exposure route (MARINA, 1990; McKay & Pattenden, 1990; Howorth & Eggleton, 1988). This pathway can be divided in three exposure routes, namely exposure on the beach,

exposure during boating and exposure during swimming. This pathway is described in accordance with the MARINA study.

Living near the beach leads to a dose as a consequence of inhalation of seaspray and resuspended particles. In several studies the internal exposure due to the inhalation of resuspended beach sediments and seaspray has been identified as a significant pathway, especially for local inhabitants living close to the beach (McKay & Pattenden, 1990; Howorth & Eggleton, 1988; MARINA, 1990).

Doses arising from the inhalation of resuspended beach sediment and seaspray are calculated in accordance with methods described by IAEA (IAEA, 1984; IAEA, 1986). Resuspended particles comprise of fine beach sediment particles, dried sea salt particles, and particle associated water. In seaspray, airborne radionuclides are generated by resuspension of sea water and by co-evaporation with water by means of single phase distillation.

Living on a seasand landfill area results in the inhalation of indoor radon. In accordance with the Ministery of Housing, Physical Planning and the Environment, calculations are based on the assumption that the top 20 - 30 cm of the seabed sediment is grabbed. This approach is applied in the two-compartment model RADCS-1, in RADCS-2 however no sediment layer is modelled, the nuclide concentration in the sand is therefore in this case derived from the nuclide concentration in the water column. For the dose calculation due to radon inhalation a simple approach have been applied. In the Netherlands, the average indoor concentration of ^{222}Rn is 30 Bq.m^{-3} from which 2/3 might be considered as being caused by an averaged level of 26 Bq.kg^{-1} ^{226}Ra in the soil. This leads to a risk of approximately 3.33.10^{-5} per year (Vaas, 1991). Consequently the risk, calculated by means of these figures, is about 1.33*10^{-6} per Bq ^{226}Ra per kg in the soil.

A schematic overview of the exposure pathways is given in figure 1.

Uptake in the biota is calculated by means of the concentration factor method assuming equilibrium between the nuclide concentration in the sea water and in the marine organisms. The average yearly seafood consumption by the Dutch population is 4 kg fish and 0.3 kg shellfish (crustaceans and molluscs) (VROM, 1993). It is assumed that this amount is originating from all the compartments, and comprise of a mix of seafood proportional to the fish catch per compartment. In the two-compartment model RADCS-1 it is assumed, that 40% of the fish (total catch: 2 10^{5} tonnes), 100% of the mollusca (total catch: 7.6 10^{4} tonnes), and 24 % of the crustaceans (total catch: 5.4 10^{3} tonnes), is caught in the Central part of the North Sea (MARINA, 1990). The fish catch in RADCS-2 is distributed over the DCS and the coastal areas. About 50% of the fish (total catch: 6 10^{4} tonnes) is caught in the Southern North Sea, the remaining fraction is distributed over the coastal compartments, with the highest contribution from the German Bight (30%). The amount of molluscs (total catch: 8.5 10^{3} tonnes) originates from the Wadden Sea (34%) and the Easterscheldt (66%). The major fraction of crustaceans (total amount: 970 tonnes) is originating from the German Bight (46%), and in the Wadden Sea (30%), the other fraction is caught in remaining coastal areas along the Dutch coast.

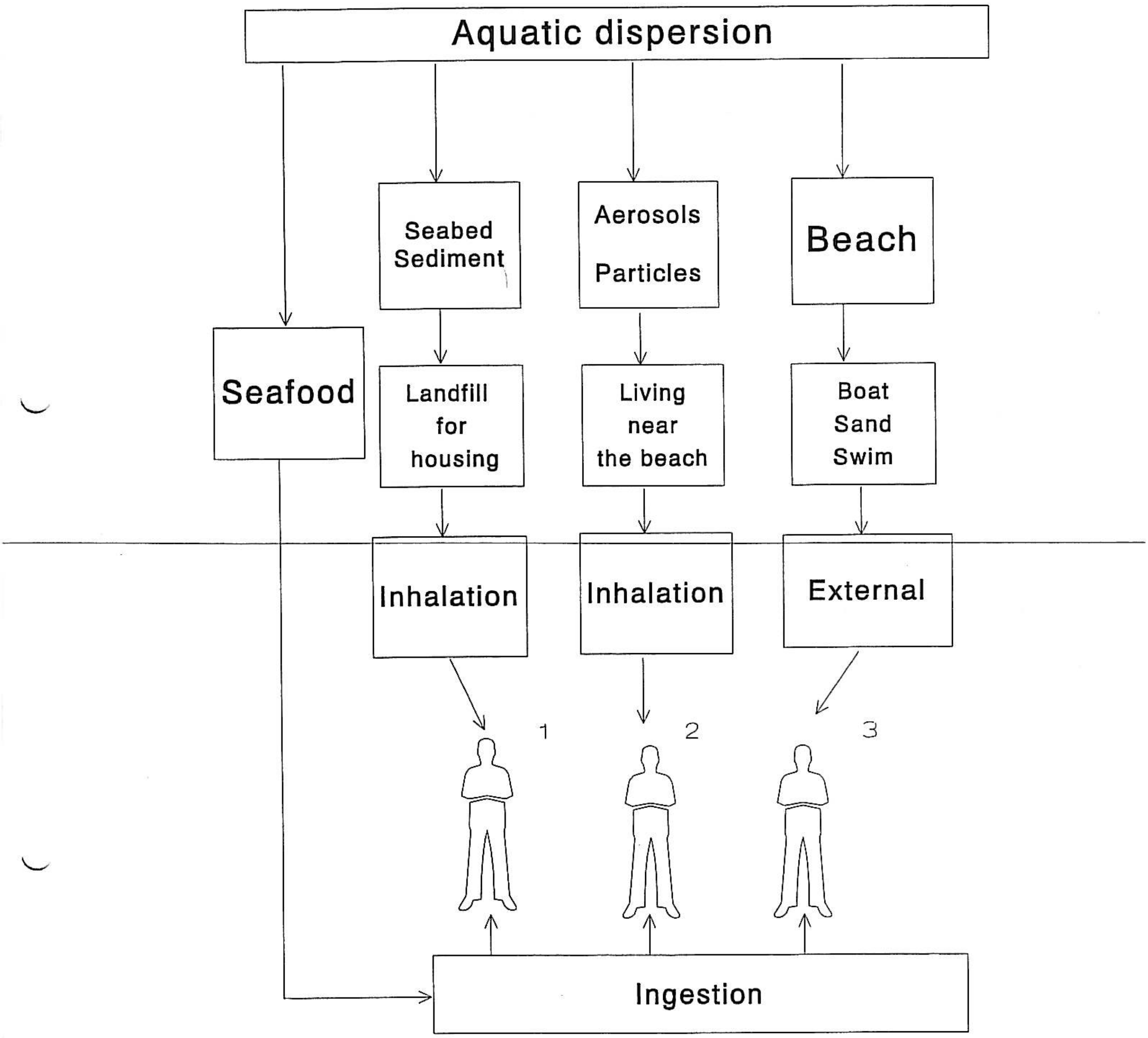


Fig. 1 Schematic overview of the exposure pathways. The numbers refer to the three critical groups.

RESULTS

The results of the model calculations for the different discharge locations are presented in table 1. For the risk of beach occupancy the maximum is taken of the three external exposure routes (beach, swimming and boating). With the assumptions made, external irradiation during swimming is in all cases the most restrictive exposure route for beach occupancy. The total risk of the different reference groups is the risk due to their specific exposure routes combined with the risk due to consumption of seafood.

For discharges from platforms located on the Northern Part of the DCS the continental compartment Central North Sea is selected as the discharge compartment in the two-compartments model RADCS-1. For the other discharges RADCS-2 has been applied. A few platforms are present in this northern region from which only a small fraction of the total amount of radionuclides is discharged.

As a example in table 1 one set of calculated risks of a 1 GBq release of each of the nuclides of the ^{232}Th and ^{238}U in the coastal area between Rotterdam and Den Helder is presented. The risk of the unit discharge in this compartment is higher than for the other locations (Southern North Sea, Wadden Coast, Central North Sea). From table 1 it is obvious that none of the calculated values exceed the maximum permitted risk value of 10^{-6}. The results for the other discharge loactions are presented elsewhere (Heling & Van der Steen, 1994). In Figure 2 - 4 the relative contribution of each of the nuclides of the three reference groups is presented.

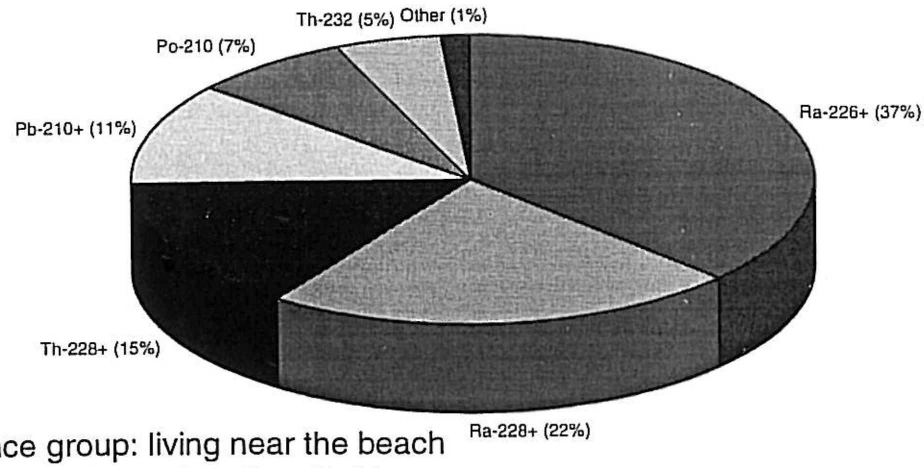
A rough estimation of the total amount of the radium isotopes discharged from the oil and gas platforms on the DCS leads to an annual discharge of approximately 100 GBq.y^{-1} of ^{228}Ra and ^{226}Ra each. This calculation is based on measurement data from NOGEPA (1991) and 1991 data on volumes of discharged produced water (EZ, 1993; Van Hattum et al, 1992).

Table 1: Risks of yearly discharges of 1 GBq of each of the radionuclides of the ^{238}U and ^{232}Th chain, in the coastal area between Rotterdam and Den Helder for each of the reference groups.

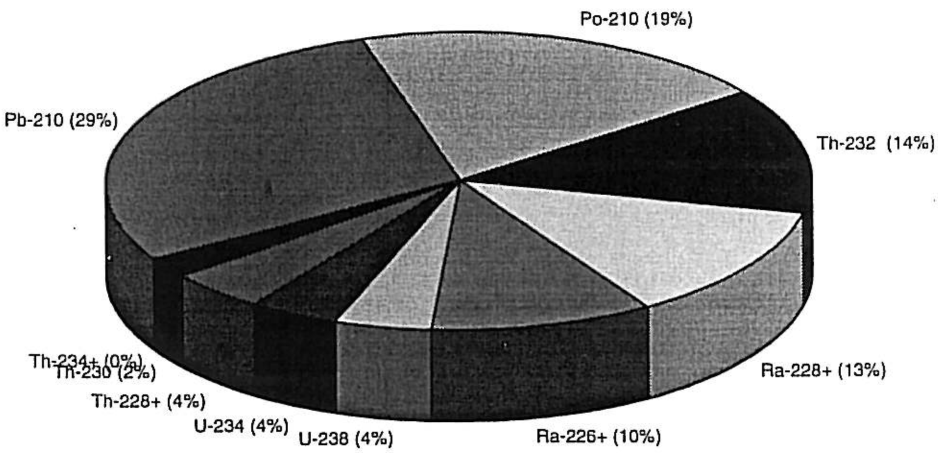
Nuclide	Beach occupancy (swimming)	Living close to the beach (inhalation)	Living on a landfill (radon)	Consumption of seafood (ingestion)	Total risk reference groups (swimm., ingest.)	(inhal., ingest.)	(radon, ingest.)
^{238}U	1.2E-12	6.5E-12	8.6E-25	3.0E-13	1.5E-12	6.8E-12	3.0E-13
^{234}Th+	6.4E-13	3.2E-17	1.2E-25	3.7E-14	6.8E-13	3.7E-14	3.7E-14
^{234}U	1.2E-14	6.5E-12	5.4E-19	3.0E-14	4.2E-14	6.5E-12	3.0E-14
^{230}Th	3.8E-14	4.1E-13	8.4E-14	3.0E-12	3.0E-12	3.4E-12	3.1E-12
^{226}Ra+	1.3E-10	4.0E-13	3.1E-10	1.5E-11	1.5E-10	1.5E-11	3.3E-10
^{210}Pb+	2.8E-13	6.7E-14	-	4.4E-11	4.4E-11	4.4E-11	4.4E-11
^{210}Po	4.4E-16	8.5E-15	-	2.9E-11	2.9E-11	2.9E-11	2.9E-11
^{232}Th	1.5E-12	1.9E-12	-	1.9E-11	2.0E-11	2.1E-11	1.9E-11
^{228}Ra+	6.9E-11	2.3E-13	-	1.9E-11	8.7E-11	1.9E-11	1.9E-11
^{228}Th+	5.3E-11	7.9E-13	-	5.7E-12	5.9E-12	6.5E-12	5.7E-12
Total	2.6E-10	1.7E-11	3.1E-10	1.3E-10	3.9E-10	1.5E-10	4.5E-10

Figure 2 - 4: Relative contribution of each radionuclides to the risks for each of the three reference groups. Discharge of 1 $GBq.y^{-1}$ of all radionuclides in compartment Rotterdam-Den Helder.

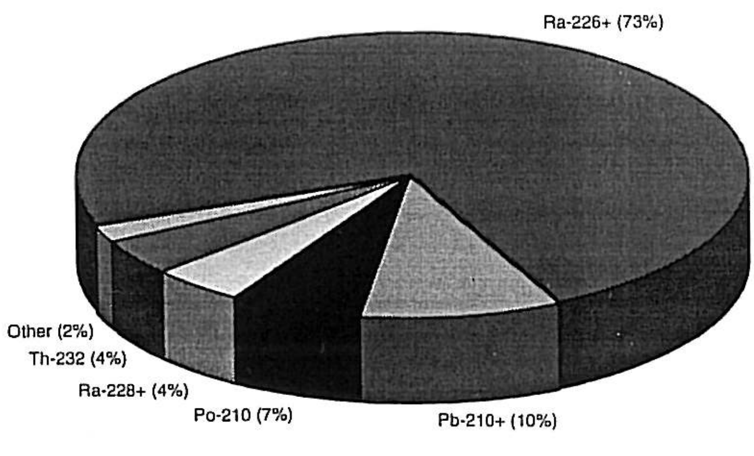
Reference group: beach occupancy
Discharge Rotterdam-Den Helder



Reference group: living near the beach
Discharge Rotterdam-Den Helder



Reference group: living on a landfill
Discharge Rotterdam-Den Helder



DISCUSSION

Considering the many assumptions and uncertainties in the model, like complete mixing in the compartments, extreme interaction between the continental and coastal part of the DCS, the use of generic instead of site-specific concentration factors for seafood, the results of this present study suggest, that the risks associated with the discharge of 1 GBq per year of naturally occurring radionuclides with produced water are negligible.

For all discharge locations, radon exposure by sea sand used as landfill for housing areas seems to be the dominating pathway. However, it should be remembered that for the risk assessment only a simple equation rule is used and such an interpretation should be taken with care. In calculating the concentrations of the radionuclides in the sea sand and the resulting risks from radon exposure, a steady state of the discharges over 25 year is assumed and there is no delay between the grabbing of the sea sand and living on the landfill. This means that the risks for this pathway are calculated for the instantaneous situation, without waiting for equilibrium between the long lived radionuclides.

For beach occupancy, the most restrictive exposure route is swimming in all cases. One should keep in mind however, that the residence time for exposure on the beach, during swimming and during boating was assumed to be same. Specifically for swimming this assumption is overconservative.

The risks associated with an assumed discharge of 1 $GBq.y^{-1}$ per radionuclide are far below the maximal allowable risk level of 10^{-6} per year. According to a preliminary estimation of the total risk using indicative data of the total annual amount of radionuclides discharged with the produced water, even the risks for such discharges are far below this level.

REFERENCES

EZ (1993); Personal communication.

Heling, R., Van der Steen, J. (1994). Risks of Discharges of Naturally Occuring Radioactive Matter by Oil and Gas Production Platforms on the Dutch Part of the Continental Shelf. KEMA report 40287-NUC, 94-5272

Howorth, J.M., Eggleton, A.E.J. (1988); Studies of Environmental Radioactivity in Cumbria. Part 12: Modelling the Sea-to-Land Transfer of Radionuclides and an Assessment of the Radiological Consequences. AERE R-11733.

IAEA (1986); Definition and Recommendations for the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972, 1986 Edition, Safety Series No 78, International Atomic Energy Agency, Vienna.

IAEA (1984); The Oceanographic and Radiological Basis for the Definition of High-Level Wastes Unsuitable for Dumping at Sea, Safety Series No 66, International Atomic Energy Agency, Vienna.

MacKenzie. J Nicholson S. (1987); COLDOS - A Computer code for the estimation of collective doses from radioactive releases to the sea. Safety and Reliability Directorate, UKAEA, SRD Report R 389.

MARINA, (1990); The radiological exposure of the population of the European Community from radioactivity in North European marine waters - Project 'Marina'. EUR - 12483, Commission of the European Communities, Luxembourg.

McKay, W.A., Pattenden N.J. (1990); The Transfer of Radionuclides from Sea to Land via the Air: A Review, J. Environ. Radioactivity, Vol. 12, pp 49-77.

Müller-Navarra, S.H, Mittelstadt, E. (1988); Modeluntersuchungen zur Ausbreitung künstlicher Radionuklide in der Nordsee. Deutsches Hydrographisches Institut, BMU-1988-205.

Nicholson, S, MacKenzie J. (1988); The remobilisation of radionuclides from marine sediments; implication for the collective dose assessment, Safety and Reliability Directorate, UKAEA, SRD Report R 453.

NOGEPA (1991); Investigation on the presence of natural radionuclides in procuded water. Inspections NOGEPA 1991

(In Dutch). Personal communications of unpublished data.

Onderzoek naar de natuurlijke radioactieve stoffen in produktiewater. Inspecties NOGEPA 1991 , personal communication.

SAIC, 1991; Produced Water Pollutant Variability Factors and Filtration Efficacy Assessments from the Three Facility Oil and Gas Study, Science Applications International Corporation, EPA Contract No. 68-C0-0035.

Snavely, E.S. (1989); Radionuclides in Produced Water, A Literature Review, Report to American Petroleum Institute.

Stephenson, M.T., Supernaw, I.R., (1990); Offshore Operators Committee 44 Platform Study Radionuclide Analysis Results, Offshore Operators Committee, New Orleans, Louisiana.

Stephenson, M.T. (1992); A Survey of Produced Water Studies. In: Produced Water, Technological/Environmental Issues and Solutions. Eds. J.P. Ray, F.R. Engelhart, Plenum Press, New York.

Vaas, L.H., Jal, H.B., De Jong, P., Slooff, W. (1991); Basisdocument Radon, RIVM rapport 710401014.

Van Hattum, B., Cofino, W.P., Feenstra, J.F. (1992); Environmental Aspects of Produced Water Discharges from Oil and Gas Production on the Dutch Continental Shelf. Part II, A Literature Review of Characteristics of Produced Water from Offshore Platforms. Institute for Environmental Effects.

Van Hienen, J.F.A., Roelofsen, P.M., Van Weers, A.W., Poley, A.D. (1990); Consequences of regular discharges of nuclides by the nuclear installations in the Netherlands (In Dutch). ECN-C-90-015, Petten.

VROM, (1993); Beleidsstandpunten Stralingshygiene tbv Vergunningverlening, Deel 1, Toepassingen, VROM/SVS, Straling en Nucleaire Veiligheid, versie 15 December.