

# Radioactivity in produced water from oil and gas installations — doses to biota and man<sup>1</sup>

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**Abstract.** Substantial amounts of produced water containing elevated levels of <sup>226</sup>Ra and <sup>228</sup>Ra are discharged into the sea as a result of oil and gas production on the Norwegian continental shelf. The average concentration in the discharges is 3.3 and 2.8 Bq/L of <sup>226</sup>Ra and <sup>228</sup>Ra, respectively. The main objective of the project described in the paper is to establish radiological safe discharge limits for radium, lead and polonium in produced water from oil and gas installations on the Norwegian continental shelf. One of the objectives of the study is to provide information to enable risk assessment based on doses from ionizing radiation to marine biota and man. Reference organisms for the North Sea area have been chosen for calculation of absorbed dose to biota. The dose calculations rely on specific knowledge of activity concentration in the reference organism, activity concentration in seawater and sediments, dose conversion factors and time spent at different locations relative to the point of discharge. Based on the calculated doses to marine biota, 'potential no effect concentrations' are recommended. Furthermore, committed effective doses to humans caused by the discharge of produced water based on concentrations in seafood and food consumption habits are presented.

## 1. Introduction

Substantial amounts of produced water, about 143 million m<sup>3</sup> in 2004, are discharged to the marine environment in connection with oil and gas production on the Norwegian Continental Shelf. One potential problem with this release of produced water, also referred to as formation water or brine, is that it contains elevated levels of <sup>226</sup>Ra and <sup>228</sup>Ra. A systematic survey of the levels of <sup>226</sup>Ra, <sup>228</sup>Ra and <sup>210</sup>Pb was conducted in 2003 in produced water from all 42 Norwegian platforms discharging produced water. The concentration of <sup>226</sup>Ra and <sup>228</sup>Ra varied between the detection limit (1 Bq/L) to 16 Bq/L and 21 Bq/L respectively. For <sup>210</sup>Pb, the levels were below the detection limit. On the basis of these results, an annual discharge of 440 GBq <sup>226</sup>Ra and 380 GBq <sup>228</sup>Ra was calculated. This corresponds to an average discharge of 3.3 and 2.8 Bq/L of <sup>226</sup>Ra and <sup>228</sup>Ra, respectively [1].

The two platforms discharging most of the <sup>226</sup>Ra and <sup>228</sup>Ra are Troll B and C. In total these two platforms discharged approximately 190 GBq <sup>226</sup>Ra and 155 GBq <sup>228</sup>Ra in 2003. The average <sup>226</sup>Ra and <sup>228</sup>Ra concentration in produced water from these platforms is approx. 9 and 8 Bq/L, respectively. In comparison, the levels of <sup>226</sup>Ra in North Sea water is approx. 1–2 mBq/L.

It is generally assumed that when produced water rich in barium and poor in sulphate is brought into contact with seawater, which is rich in sulphate, radium will co-precipitate with BaSO<sub>4</sub>. Depending on the size of these particles they will either be transported with the water masses, settle more or less immediately or attach to other organic or inorganic particles and sequentially settle to the seafloor. Owing to the chemical similarities of barium and radium, the fate of radium is determined by the speciation of the macro amounts of barium. Data on the speciation of radium and barium, and the effect of components in produced water on the speciation of radium and barium, are however sparse.

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In today's oil production, several chemicals are added, i.e. scale and corrosion inhibitors, emulsion breakers and surfactants, sulphide removers etc. These chemicals are usually organic compounds comprising functional groups, which may also interact with cations such as  $\text{Ra}^{2+}$  and  $\text{Ba}^{2+}$ . Thus, radium may exist in compounds more easily accessible for uptake in biota than the inorganic aqueous or food-borne form. An understanding of how different compounds in produced water affect the mobility, bioavailability and sedimentation of radium is essential to determine the fate and effects of radium discharges. Consequently, sediment-dwelling organisms may be an important group of marine organisms that might be exposed to radionuclides. Once taken up by sediment dwelling invertebrates, the nuclides can be transferred to a higher level of the marine food chain (fish), ultimately forming a potential risk for human consumption. In addition to the food-borne route of exposure, water-borne exposure would be expected to form an alternative route by which fish can be contaminated. The relative uptake from the different exposure routes as well as the effect of chemicals on the bioavailability of radionuclides are of great importance when assessing possible consequences for animal welfare and food safety. For evaluation purposes the behaviour of produced water radium must be compared to radium already present naturally in seawater [2, 3].

The main objective of the PROOF-programme is to establish radiological safe discharge limits for radium, lead and polonium associated with other components in produced water from oil and gas installations on the Norwegian continental shelf. The oil and gas production industry refers to such a limit as 'potential no effect concentration' (PNEC).

## **2. Sub-objectives of the project**

The project has been divided into six work packages:

### *WP 1: Background and sources*

Natural background levels of the relevant radionuclides ( $^{226}\text{Ra}$  and  $^{228}\text{Ra}$ ) in seawater have been established. A few seawater samples from the North Sea have earlier been analysed for  $^{226}\text{Ra}$ . These results indicate that the concentration level is 1–2 mBq/L. Surface water samples from 10 locations, of which 3 include depth profiles, have recently been analysed. The analysis is in progress.

### *WP 2: Speciation, mobility and sedimentation mechanisms*

The study will determine the levels and distribution of relevant radionuclides in produced water. Furthermore, mobility and sedimentation mechanisms of the radionuclides for different discharge scenarios are to be studied.

### *WP 3: Bioavailability*

The study will assess bioavailability and bioaccumulation of radium in biota following exposure through water and through the diet. The effect of organic complexing agents on these processes is also to be studied.

### *WP 4: Biological effects*

The study will assess effects of ionizing radiation on bottom dwelling marine organisms and in vitro fish models.

### *WP 5: Modelling with the DREAM model*

The task of this work package is modelling of the concentration of the radionuclides in seawater and biota using the DREAM model. The model is extended to include adsorption and sedimentation. The amount of water released per day is 35 000 m<sup>3</sup>, corresponding to the release from the Troll B or C installations. The calculations show a dilution of 1 in 100 after 80 s, corresponding to a horizontal distance of 30 m from the point of discharge.

## *WP 6: Risk assessments*

The total absorbed dose and dose rates are to be calculated for selected organisms living in the discharge areas. The calculations will take into account the external dose arising from the radionuclide concentration in the seawater and the internal dose from uptake by the organisms themselves.

### **3. PNEC in the context of doses from ionizing radiation**

The current system of radiation protection of man is based on the linear non-threshold model stating that even very low doses give rise to an increase in risk for stochastic effects. One must, however, keep in mind that the risk from very low doses is very low and will often be unobservable. Recently, the International Commission on Radiological Protection summarized the effects of doses to humans, stating that a total effective dose of less than 10 mSv will lead to extremely small additional cancer risk and will not be observable even in a large exposed group [4]. On this background, an annual effective dose limit in the range 1–100  $\mu$ Sv to the most exposed individuals from consumption of seafood will be proposed. This dose limit will be one of the factors to be taken into account in the proposed PNEC.

Regarding the absorbed dose and dose rate to biota, a conceptual mode of responses of organisms, populations and ecosystems to ionizing radiation in the environment has been proposed [5]. The model considers 5 zones of exposure:

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|----------------------------------|-----------------------|
| 1. Uncertainty, below background | <10–40 $\mu$ Gy/h     |
| 2. Radiation well-being          | 40 $\mu$ Gy/h–5 mGy/h |
| 3. Physiological masking         | 5–50 mGy/h            |
| 4. Ecological masking            | 50 mGy/h–4Gy/h        |
| 5. Obvious action                | 4– >3000 Gy/h         |

A dose limit ensuring that exposure to biota is within zone 1 or 2, i.e. below 5 mGy/h, is suggested to for incorporation into the PNEC value for releases of produced water.

### **4. Strategy for dose calculations**

#### ***4.1 Dose to humans from dietary intake***

The route of intake chosen is the consumption of fish from the affected areas. The committed effective dose to the most exposed individuals will be calculated using a methodology for assessing the radiological consequences of routine releases of radionuclides to the environment [6].

#### ***4.2 Dose to biota***

Reference organisms have been chosen using the selection criteria outlined in the EPIC project [7]. Factors taken into account are; ecological niche, radiosensitivity, radioecological sensitivity, geographic location and usability in research and surveillance. Pelagic fish represented by Atlantic cod (*Gadus morhua*) and bottom feeders represented by European plaice (*Pleuronectes platessa*) are considered to be the most relevant target species.

The total absorbed dose rate, in units of gray per hour, is used as a measure for exposure to ionizing radiation. For the external component, the results of the model calculations of ambient water concentrations and sediment concentrations performed in WP5 are used. In calculation of the internal dose from uptake, the influence of other chemical components present in the produced water is taken into account using the results from WP2 and WP3.

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