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Radiation protection during storage of NORM contaminated equipment and waste

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RADIATION PROTECTION DURING STORAGE OF NORM CONTAMINATED EQUIPMENT AND WASTE

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ABSTRACT

NORM in oil- and gasfields manifests itself in scale and sludge. Hence operations involving equipment containing sludge or scale could be subject to radiation protection requirements. In the Netherlands, onshore supply bases which are used for the transit of materials contaminated with NORM from offshore platforms are required to have a license for the import of radioactive material. An application for such a license requires an assessment of the maximum annual dose to an individual member of the population resulting from the handling and storage of the maximum amount of imported radioactive material authorized by the license. The main contribution to this annual dose results from the temporary storage of radioactive material at the supply base when the connecting transport is delayed.
ECN performs such (risk) assessments for the oil- and gas industry. Results of exposure rate calculations used for these assessments are presented for stored equipment and waste containers with material contaminated with NORM. Implications of these results for radiation protection during storage are discussed.

INTRODUCTION

Waste from oil- and gas production facilities, such as sludge and secondary waste, often contains naturally occurring radioactive material (NORM). NORM also occurs as material deposited inside tubing and other equipment (scale).

In the Netherlands operations involving material contaminated with NORM with a specific activity of more than 100 Bq/g (dry weight) are required to have a license according to the Nuclear Energy Act. For example, supply bases for offshore operations need to have such a license in order to import equipment contaminated with NORM with such a high specific activity. Part of the license application procedure is an assessment of the maximum annual dose to an individual member of the population resulting from the handling and storage of the maximum amount of imported radioactive materials to be authorized by the license. For occupational radiation protection, the license application should also include an estimate of the exposure rates expected during handling and storage of these materials.

Waste contaminated with NORM is stored in containers and drums and equipment contaminated with NORM such as tubing is closed off by "protectors". Hence, exposure pathways such as inhalation and ingestion of dispersed radioactive material, are not considered here. The dose therefore results entirely from the exposure to external radiation.

In this paper the calculation of exposure rates and the maximum annual dose to an individual member of the population due to temporary storage of equipment and waste contaminated with NORM is described. The results of such calculations will be presented for several source configurations and NORM compositions. The implications of these results for the occupational radiation protection during temporary storage and the maximum amount of activity to be stored are discussed.

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DESCRIPTION OF THE CALCULATION

Composition of NORM

Waste and equipment contaminated with NORM from oil and gas production installations contain mostly radium isotopes and their decay products such as lead and polonium isotopes. Radium isotopes result from the decay of ^{238}U en ^{232}Th. In addition to emissions of α- en β-particles, which are not important for exposures to external radiation, γ-radiation is emitted by these isotopes. Sources containing radium and its decay products such as ^{214}Pb en ^{214}Bi (from ^{226}Ra) and ^{228}Ac, ^{212}Pb, ^{212}Bi en ^{208}Tl (from ^{228}Ra) have a high exposure rate per unit of activity.

The composition of the NORM from oil- and gas production facilities may be described as a mixture of four groups of radionuclides:
^{226}Ra in equilibrium with ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po;
^{210}Pb in equilibrium with ^{210}Bi and ^{210}Po;
^{228}Ra in equilibrium with ^{228}Ac;
^{228}Th in equilibrium with ^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb, ^{212}Bi, ^{208}Tl (0.36) and ^{212}Po (0.64). The latter two numbers are the branching ratios of the decay of ^{212}Bi.

Each group has a long-lived "parent" radionuclide and one or more short-lived "daughters", where secular equilibrium with the "parent" has been assumed. This means that the activity of each "daughter" is equal to the activity of the "parent". The total activity of the radionuclides pertaining to the ^{226}Ra, ^{210}Pb, ^{228}Ra and ^{228}Th group is respectively, 6 x activity of ^{226}Ra, 3 x activity of ^{210}Pb, 2 x activity of ^{228}Ra and 7 x activity of ^{228}Th. The contribution of each of these groups varies per type of NORM. Exposure rates have been calculated for the individual groups as well as for typical mixtures of these groups. Reference mixtures assumed are a "radium type" mixture and a "lead type" mixture. The "radium type" mixture contains equal activities of the four "parents", i.e. ^{226}Ra : ^{210}Pb : ^{228}Ra : ^{228}Th is 1 : 1 : 1 : 1. For the "lead type" mixture the ratio of the activities of the four "parents" is 1 : 17 : 1 : 1.

Source configurations

In this paper five source configurations (geometry, density and shielding) are used. The source configuration "Tubing-F" consists of a stack of 300 steel pipes. The pipes have an length of 9 m and an internal diameter of 10 cm. Inside each pipe a uniform layer of scale has been deposited. The exposure rate will be calculated at the front of the stack. The source configuration "Tubing-S" describes the same stack of pipes, however the exposure rate will be calculated at the side of the stack. The steel pipe and layer of scale inside these pipes have thicknesses of 1 and 0.1 cm, respectively. Source configuration "Container-F" is a cylindrical steel container with a diameter of 1.6 m and a length of 4 m which is stored horizontally. This container contains sludge contaminated with NORM. The exposure rate is calculated at the front of the container ("Container-F") and at the side of the cylinder ("Container-S"). The last source configuration ("Drum") is a steel drum with a diameter of 0.4 m and a length of 0.64 m which is stored in upright position. The drum contains secondary waste. The exposure rate around this drum will be calculated at 1 m above ground level. A reference value of 2.5 g/cm^3 has been assumed for the mass density of scale and sludge inside the pipes and the container. The secondary waste has a density of 0.5 g/cm^3. The steel of the drum and container has a thickness of 0.5 cm.

Method of calculation

The exposure rates are calculated with the computer programme MARMER which uses a point-kernel method [1]. Geometry, density and shielding of the source are taken into account. From these exposure rates the occupational doses due to temporary storage of NORM may be estimated. This storage also contributes to the annual dose of an individual member of the population living next to the supply base (annual individual dose). The maximum contribution to this annual individual dose has been calculated as follows:

1. The maximum value of the exposure rate at the site boundary is calculated. This maximum value will be equal to the exposure rate at the nearest point on the site boundary with respect to the storage location, if there are no obstacles between this location and the site boundary.
2. From this maximum value and the duration of the storage, the maximum dose received at the site boundary due to the storage is calculated (dose received by a person standing 24 hours per day at the site boundary.
3. The maximum contribution to the annual individual dose is equal to this maximum dose times a factor which takes into account the probability of exposure and the average shielding when living permanently near the site boundary of the supply base. The value of 0.25 has been used.

From a given constraint to the annual individual dose at the site boundary, the maximum amount of activity which could be stored per day at a specific location at the site can be calculated for a specific source configuration and NORM composition.

RESULTS

Exposure rates

Exposure rates calculated at several distances from a source with a "radium type" mixture are presented in Table 1 for different source configurations. The values calculated for a "lead type" mixture are a factor 3 to 4 smaller than the values presented in Table 1, depending on the source configuration. Exposure rates calculated for ^{228}Ra at equilibrium with ^{228}Ac are a factor 2 larger than the values for a "radium type" mixture.

As expected, the values at close distances to the stack of pipes do not follow the inverse-square law. The exposure rate at positions near the front as well as the side of the stack decreases almost linearly with distance to the stack. At large distances the exposure rate decreases according to the inverse-square law.

Exposure rates calculated at close distances to a container hardly depend on the geometry (plane-source). At somewhat larger distances, the exposure rates at the side of the container are about a factor of 2 larger than the exposure rates at the front, at the same distance.

In order to estimate the effects of (self)shielding of the activity in the container, the exposure rates have also been calculated from a point source of 1 GBq of activity with the "radium type' mixture of radionuclides. A factor of 13 is found for the effective shielding of the radiation in the forward direction. A factor of 7 is found for the effective shielding of the radiation directed sideways.

The exposure rate outside a drum with NORM decreases roughly in accordance with the inverse-square law with the distance, also at small distances. The high exposure rate calculated for the drum is a consequence of the small self-shielding of the material inside the drum (low density).

Maximum amount of temporary stored activity

The maximum amount of activity which can be stored for 1 day per year at 10 and 20 m from the nearest site boundary (assuming a dose constraint of 0.4 μSv per year) has been calculated for a "radium type" mixture. The results are presented in Table 2 for the different source configurations. The maximum amounts of activity which can be stored for a "lead type" mixture are a factor 3 to 4 larger than the values presented in Table 2.

DISCUSSION

The results in Table 1 show that the temporary storage of NORM in a container or a stack of pipes does not result in high exposure rates per GBq. Exposure rates near the container and stack do not decrease rapidly with the distance (plane- and line-source). In general the amount of activity stored at a supply base will not more than a few GBq. For example, the total activity in a stack of pipes contami-

Table 1: Exposure rates calculated for several source configurations containing NORM with a "radium type" mixture[a]). The exposure rate is calculated at 1 m above ground level for distances of 1, 2, 4 and 10 m from the outside of the source.

Source-configuration	Exposure rate [μGy/h] per 1 GBq activity at variable distances [m]			
	1	2	4	10
Tubing-F	0.09	0.05	0.02	0.015
Tubing-S	0.6	0.3	0.11	0.02
Container-F	0.8	0.3	0.07	0.013
Container-S	0.7	0.4	0.14	0.03
Drum	11	4	1.2	0.2

[a]) For the "lead type" mixture the exposure rates will be a factor 3 to 4 smaller than for the "radium type" mixture. For an extreme mixture containing only ^{228}Ra and ^{228}Ac, the exposure rates will be a factor 2 larger.

Table 2: Calculated amount of activity [GBq] to be stored during 1 day per year[a]) in a specific source configurations at a supply base for which the annual individual dose at the site boundary is equal to 0.4 μSv per year. For the activity a "radium type" mixture has been assumed.

Distance	Tubing-F	Tubing-S	Container-F	Container-S	Drum
10 m	4	3	5	2	0.3
20 m	14	12	20	10	1.3

[a]) The values presented could also be interpreted as GBq per 0.4 μSv/day. For example, during 1 day per year, 20 GBq may be stored in a container with its front at 20 m from the nearest site boundary. This also means that five times per year 1 GBq of activity can be stored during 2 days.