Derivation of a dose factor for Rn-222 release to a well

1 Introduction

In the SR-Site assessment, doses from Rn-222 releases to the biosphere were not considered and therefore a Landscape Dose Factor (LDF) value was not derived for this radionuclide. SSM has required that doses from different uses of water from a well that receives releases of Rn-222 be estimated and presented.

In this paper we derive a Dose Factor for Rn-222 that could be used to estimate doses from the use of water from a well that receives direct continuous releases from the geosphere. This Dose Factor ((Sv/year)/(Bq/year)) is defined as the average annual effective dose during life time (Sv/year) resulting from a continuous unit release rate (Bq/year) to a well. This Dose Factor is to be used in dose assessments for continuous long term releases to the biosphere in the same way as the LDF is used for other radionuclides; i.e. the release rate is multiplied by the Dose Factor for converting the release to annual dose.

The assumptions made for deriving the Dose Factors for Rn-222 are presented in Section 2. It should be noted that the approach for deriving the Dose Factor for Rn-222 is somewhat different from the approach that was used for deriving the LDF for other radionuclides. For Rn-222, only releases to a well are taken into account, whereas for the LDF both releases to a well and the landscape are considered. This is motivated by the relative short half life of Rn-222. Another difference is that for Rn-222, indoor inhalation doses associated to different household uses of water are considered, since this radionuclide can be easily released from water, especially when water is agitated. This exposure pathway is not considered in the derivation of LDF values for other radionuclides; since exposures from household uses of water, other than using it for drinking, is not significant for them.

2 Methods

2.1 Assumptions

For deriving the Rn-222 Dose Factor we make the following assumptions:

- Due to the short half life of Rn-222, releases to the landscape are not considered, since it can be expected that their contribution will be much lower than releases to a well.
- We assume that releases to the well are continuous and constant in time and that an equilibrium Rn-222 concentration in well water is readily established. This concentration is calculated in the same way as it was calculated for the derivation of LDF values for other radionuclides, i.e. by dividing the constant release rate by the well capacity.
- Doses are calculated for a representative individual of the most exposed group, who uses the well for drinking and other household uses, such as showering, clothes-washing or dishwashing, cooking, etc.
- Rn-222 doses from the use of well water for irrigation are considered to be substantially lower due to the short half life of Radon and the high dilution of Radon in the atmosphere, which is volatilized during irrigation.

- Doses from Pb-210 and Po-210 in well water resulting from decay of Rn-222 are not included in the Rn-222 Dose Factor, since their concentrations are much lower than Rn-222 concentrations. This is because of the short residence time of radionuclides in the well, determined by the high exchange rate of the well water, and the longer half life of these radionuclides relative to Rn-222.

2.2 Rn-222 concentrations in well water

The Rn-222 concentrations in water are calculated in the same way as these concentrations were calculated for the derivation of LDFs for other radionuclides, i.e.:

$$\boldsymbol{Conc_{WellWater} = \frac{RelRate}{WellCapacity}} \quad (1)$$

where,
$Conc_{WellWater}$ is the Rn-222 concentration in well water [Bq/m^3],
RelRate is the Rn-222 release rate to the well (assumed to be 1 Bq/year for derivation of Dose Factors) [Bq/year],
WellCapacity is the capacity of the well [m^3/year].

2.3 Dose from ingestion of well water

The dose from ingestion of well water is calculated in the same way as for the derivation of LDF values for other radionuclides, i.e.:

$$\boldsymbol{Dose_{ingWater} = Conc_{WellWater} * ingRate_{Water} * DCC_{ing}} \quad (2)$$

where,
$Dose_{ingWater}$ is the Rn-222 dose from ingestion of well water [Sv/year],
$Conc_{WellWater}$ is the Rn-222 concentration in well water [Bq/m^3],
$ing_{RateWater}$ is the ingestion rate of water [m^3/year],
DCC_{ing} is the Rn-222 dose coefficient for ingestion [Sv/Bq].

2.4 Dose from other uses of water in a house

Radon found in well water will enter a home whenever this water is used. In many situations such as showering, washing clothes, and flushing toilets, radon is released from the water and mixes with the indoor air. Thus, radon from water contributes to the total inhalation risk associated with radon in indoor air.

The dose from inhalation of indoor air is calculated in the same way as inhalation doses are calculated for derivation of LDF values, i.e.:

$$\boldsymbol{Dose_{inh} = Conc_{indoorAir} * ExpTime * DCC_{inh}} \quad (3)$$

where,
$Dose_{inh}$ is the Rn-222 dose from inhalation of indoor air [Sv/year],
$Conc_{indoorAir}$ is the Rn-222 concentration in indoor air [Bq/m^3],
ExpTime is the exposure time indoors [h/year],
DCC_{inh} is the Rn-222 dose coefficient for inhalation indoors [Sv/h per Bq/m^3].

The concentration of Radon in indoor air is estimated using the model proposed in Nazaroff et al. (1987) and US NRC (1999):

$$\boldsymbol{Conc_{indoorAir} = Conc_{WellWater} * \frac{waterUsage * TE_{waterToAir}}{rate_{exch} * V}} \quad (4)$$

where,
$Conc_{indoorAir}$ is the Rn-222 concentration in indoor air [Bq/m^3],
$Conc_{WellWater}$ is the Rn-222 concentration in well water [Bq/m^3],

waterUsage is the time averaged water use rate in the house per occupant [m^3/h/person],
$rate_{exch}$ is the air exchange rate in the house [1/h],
V is the house volume per occupant [m^3/person],
$TE_{waterToAir}$ is the Rn-222 transfer efficiency from water to indoor air [unitless].

2.5 Dose Factor for releases to a well

The Dose Factor for the case of a release of Rn-222 to a well is calculated by adding the doses from ingestion of well water (Eq. 2) and inhalation (Eq. 3) obtained for the case with a unit release rate of Rn-222 to a well.

2.6 Parameter values

The parameter values used in the calculation of the Dose Factors are presented in Table 1.

Table 1. Parameters used in the derivation of Dose Factors for calculation of doses from Rn-222 releases to a well. Best Estimate (BE) values are used in deterministic simulations and probability density functions (PDF) are used in probabilistic simulations.

Symbol	Units	Full name	BE	PDF	Ref	Comments
WellCapacity	m^3/year	Capacity of the well	82502	LGN (82502, 4.3) Min: 1892 Max: 630720	Löfgren 2010	The same values were used in derivation of LDF of other radionuclides.
$ing_{RateWater}$	m^3/year	Ingestion rate of water	0.6	constant	Norden et al. 2010	The same values were used in derivation of LDF of other radionuclides
DCC_{ing}	Sv/Bq	Rn-222 dose coefficient for ingestion	3.5E-9	Constant model parameter	US NRC 1999 (Tab. 4,5a)	The chosen value (“base case”) is the one recommended by the NRC committee, while the value of 3.8E-8 Sv/Bq used in Pensado (2012) from the same table (column “saturated diffusion”) of US NRC (1999) refers to a conservative assumption on Radon concentration in the stomach wall.
ExpTime	h/year	Exposure time indoors	6570	Constant model parameter	assumption	Assuming that the exposed individual stays in the affected house 75 % of the time
waterUsage	m^3/h	time averaged water use rate in the house	0.0079	LGN (0.0079, 1.6)	Nazaroff et al. 1987	See Section 2.6.1
$rate_{exch}$	1/h	is the air exchange rate in the house	0.68	LGN (0.68, 2)	Nazaroff et al. 1987	See Section 2.6.1
V	m^3	indoor volume of the house	99	1.9	Nazaroff et al. 1987	See Section 2.6.1
$TE_{waterToAir}$	unitless	Rn-222 transfer efficiency from	0.55	LGN (0.55, 1.1)	Nazaroff et al. 1987	See Section 2.6.1

		water to indoor air				
DCC_{inh}	Sv/h per Bq/m^3	Rn-222 dose coefficient for inhalation indoors	2.86E-9	constant	Calculated here	See Section 2.6.2

LGN means lognormal distribution with parameters geometric mean (GM) and geometric standard deviation (GSD). For the well capacity a truncated PDF, by the minimum and maximum values presented in the table, is used. When sampling from the truncated distribution the normalization of the PDF to probability 1 is maintained.

2.6.1 Parameter values used for calculation of Rn-222 concentrations in indoor air

The parameters values used in the calculation of Rn-222 concentration in indoor air presented here were taken from Nazaroff et al. (1987), which are based on studies carried out for houses in USA. These parameters were revised in US NRC (1999), which yielded very similar recommended values. The house volume, the ventilation rate and the water usage are relatively easy to estimate for an existing situation, for example by performing statistical surveys. However, for assessments of future situations the values can only be assumed.

The most uncertain parameter for calculation of the indoor air concentrations is the Transfer Efficiency, which values will depend on the type of use of the water in the house. The transfer efficiency is the fraction of the radon in the water that is released to the air during the activities that use water (showering, clothes-washing or dishwashing, cooking, etc). The values used here are from Nazaroff et al. (1987) and US NRC (1999) where use-weighted transfer efficiencies are reported. Hence, the predicted Radon air concentrations in indoor air represent all types of water usage in a house.

2.6.2 Rn-222 Dose Coefficient for inhalation indoors

ICRP in Publication 115 (ICRP 2010) has recommended that a lifetime excess absolute risk of 5×10^{-4} per WLM (Working Level Month) should now be used as the nominal probability coefficient for radon- and radon-progeny-induced lung cancer, replacing the previous ICRP Publication 65 (ICRP 1993) value of 2.8×10^{-4} per WLM. However, an updated dose coefficient for inhalation of radon has not been yet officially published by ICRP. An estimation is given below as follows:

Marsh et al. (2009) have shown that equating the total detriment using ICRP Publication 103 (ICRP 2007) values leads to an equivalent dose expression of 9 mSv/WLM for members of the public. The WLM is a unit of exposure used (US EPA 2009) to express the accumulated human exposure to radon decay products at one Working Level (WL) during one month (170 hours). The WL is defined (US EPA 2009) as any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of 130,000 MeV of potential alpha energy, which is approximately the total alpha energy released from the short-lived decay products in equilibrium with 100 pCi of Rn-222 per liter of air (3700 Bq/m^3). Further, EPA Radon Mitigation Standards (US EPA 2009) use an Equilibrium Ratio (ER) of 0.5 to convert radon exposure to WLM. Hence, converting from WLM to conventional units (Bq h/m^3) gives a dose factor for inhalation of radon in equilibrium with its progeny: 7.15×10^{-9} Sv/h per Bq/m^3.

UNSCEAR (2006) states that determinations of the equilibrium factor for radon indoors generally confirm the typical value of 0.4 previously asserted by UNSCEAR. While indoor measurements show a range from 0.1 to 0.9, most are within 30% of the typical value of 0.4 (UNSCEAR 2006). This means that an appropriate dose coefficient for inhalation of radon and its progeny in indoor conditions is 2.86×10^{-9} Sv/h per Bq/m^3.

2.7 Model implementation and Simulations

The model was implemented in Ecolego (www.ecolego.facilia.se, 2013-12-05), which was used to perform deterministic and probabilistic simulations. For the probabilistic simulations, 10, 000 iterations using latin hypercube sampling were carried out.

3 Results

Results from deterministic and probabilistic simulations are presented in Table 2. The estimates show an approximately equal contribution of water ingestion and inhalation to the Rn-222 Dose Factor.

Table 2. Annual Doses per unit release rate of Rn-222 to a well via water ingestion, inhalation indoors and total (Dose Factor).

Statistic	Dose water ingestion Sv/Bq	Dose inhalation indoors Sv/Bq	Dose Factor Sv/Bq
BE (deterministic)	2.5E-14	1.5E-14	4.0E-14
Median	2.9E-14	1.7E-14	5.1E-14
Mean	7.0E-14	7.2E-14	1.4E-13
standard deviation	1.2E-13	2.3E-13	3.1E-13
5 % percentile	4.8E-15	1.4E-15	7.6E-15
95 % percentile	2.8E-13	2.9E-13	5.7E-13

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