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Bilaga 6; Combustion of peat

1 Introduction

When burning radioactive peat, radionuclides can be released to air and be inhaled by humans leading to a radiation dose. The review of SR-Site performed by SSM has pointed out that there is no justification given in SR-Site reports for omitting this exposure pathway (SSM2011-2426-92); taking into account that it was considered important in the previous preliminary safety assessment (SR-97).

The exposure via inhalation from peat burning was indeed considered in SR-97 (Bergström et al. 1999). However, the conclusion from that assessment was in fact that burning of peat was not an important pathway (see page 79 in Bergström et al. 1999):

"Several terrestrial exposure pathways are considered in the peat bog module in similarity to the agricultural land module. ***In addition inhalation of gases from combustion of peat is included. This pathway, however, gives insignificant contributions to any exposure.*** *Inhalation of dust consisting of resuspended particles is on the other hand a major exposure pathway for Zr-93, Sm-151, Ho-166m and actinides"*

Nevertheless, in order to respond to the questions received from SSM, we have performed further assessments of this exposure pathway. The results from these complementary assessments will be presented in detail in a SKB report, which is currently under preparation (to be published as a supporting report to the safety assessment SR-PSU). Below we present a summary of the work done and the results obtained.

1.1 Method

We considered the following calculations cases:

- Combustion of peat in a power plant resulting in exposure of an individual that stays outdoors at the downwind distance where maximum air activity concentrations are predicted. The power plant is assumed to have an effect of 100 MW. Releases to air are assumed to occur at two different stack heights: 50m and 100m. These are the same configurations as considered in (Möre and Hubbard 2003). The power plant is assumed to have flue gas filter which is able to remove 99% of the particulates. Power plants in the Nordic countries normally have filters that can remove over 99% of the particulates (Ericson 1985).
- Combustion of peat in a household resulting in exposure of an individual that stays outdoors in the vicinity of the house. The energy needed to heat the house was assumed to be 16 800 kWh/y, which was the average energy used for heating (excluding household electricity) in one- or two-dwelling buildings in Sweden in 2012 (Statens energimyndighet 2013).The height of the building is assumed to be 4 m and the width of the wall closest to the receptor is selected as 30 m. The

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selected height of the wall is thought to be appropriate for a one storey building and the width of the wall is selected to yield conservative estimates for the average air activity concentration.

The following assumptions are used for all considered calculation cases:

- It is assumed that the wind blows towards the receptor 25% of the time. This is slightly higher than the value for the dominant wind direction observed at Forsmark (the duration of the wind was about 22% in the 30 degree sector which had the dominating wind direction (Johansson and Öhman 2008)).
- The wind speed at the height of the release is assumed to be 1.7 m/s and a neutral atmospheric stability class is assumed to prevail. This was the average wind speed observed at Forsmark station Högmasten at height 10 m during 2003-2007 (Johansson and Öhman 2008). The wind speed at the lower release from a household is considered to differ only slightly from this wind speed. Moreover, a wind speed of 2 m/s is recommended as a conservative value in IAEA (2001). The choice of wind speed is considered to be more conservative for releases from the power plant, which occur from higher release points.
- The peat is assumed to have a porosity of 0.89 and a density of 86 kgDW/m^3 (Löfgren 2010, Chapter 13) and the energy content is assumed to be 5.8 kWh/kg dry weight (Möre and Hubbard 2003). The calculations of activity concentration in air are performed using unit activity concentration (1 Bq/kgDW) in peat.

The annual average discharge rate is calculated as described in Appendix A. Ground level activity air concentrations at the receptor resulting from the release from the power plant were calculated using the model for *Dispersion in the lee of an isolated point source from* the IAEA Safety Reports Series No. 19 (equation 2, section 3.4 in IAEA 2001). The parameters used for the calculations in the power plant case are shown in Table A-*2*.

Activity air concentrations resulting from the household release were calculated using equation 8, section 3.6.2 in IAEA (2001) (*Dispersion in the lee of a building inside the cavity zone - source and receptor not on the same building surface)* and *equation 2, section 3.4 in IAEA (2001)(Dispersion in the lee of a building inside the wake zone).*

The models in IAEA Safety Reports Series No. 19 *(*IAEA 2001) are appropriate for performing screening assessments for releases that are either continuous or long term intermittent, with a receptor located within a few kilometres from the source (IAEA 2001). The air concentration at a given location from the source depends on the wind direction, wind speed, the height of the release and the horizontal distance in the downwind direction from the receptor to the release point.

The annual dose per unit activity concentration in peat is calculated as described in Appendix A. The parameter values used for calculating the annual average discharge rate, the activity air concentration and annual dose per unit activity concentration in peat are shown in Table A-*3*.

Annual doses per unit activity concentration in peat (Sv/y per Bq/kgDW) were calculated using the equation presented in Appendix A from calculated values of activity concentration in air per unit activity concentration in peat (Bq/m^3 per Bq/kgDW), assuming an inhalation rate of 1.5 m^3/h (the inhalation rate for an adult male in light work, Table 4 in ICRP (1995)) and an exposure time of 2920 h/year. The dose coefficient for inhalation (Sv/Bq) from Nordén et al. (2010) was used in the dose calculations.

Doses for the power plant scenarios were calculated using the highest predicted air concentration (obtained at 300 m for the 50 m stack power plant and at 900 m for the 100 m stack). For the household, doses were calculated using the average air concentration in the area between 5 and 200 m from the house.

To facilitate comparison of estimated doses from burning of peat with SR-Site LDF values (Sv/y per Bq/y), the above annual doses per unit activity concentration in peat were multiplied with the peak values of activity concentration in peat per unit release rate into the biosphere (Bq/kgDW per Bq/y). This was done for the 17 biosphere objects in the SR-Site landscape model. The highest obtained annual doses per unit release rate into the biosphere were then compared to the baseline LDF values, i.e. the LDF values for the Interglacial scenario (Avila et al. 2010).

1.2 Results and Discussion

Burning of peat in power plants

For the power plant case with a stack height of 50 m, releases of Th-232, Pu-242 and Pu-239 gave rise to doses per unit release rate into the biosphere that exceed 10% of the baseline LDF value for these radionuclides, with the highest value of 69% for Th-232 (Figure 1). Doses for the case with a stack height of 100 m were in all cases lower.

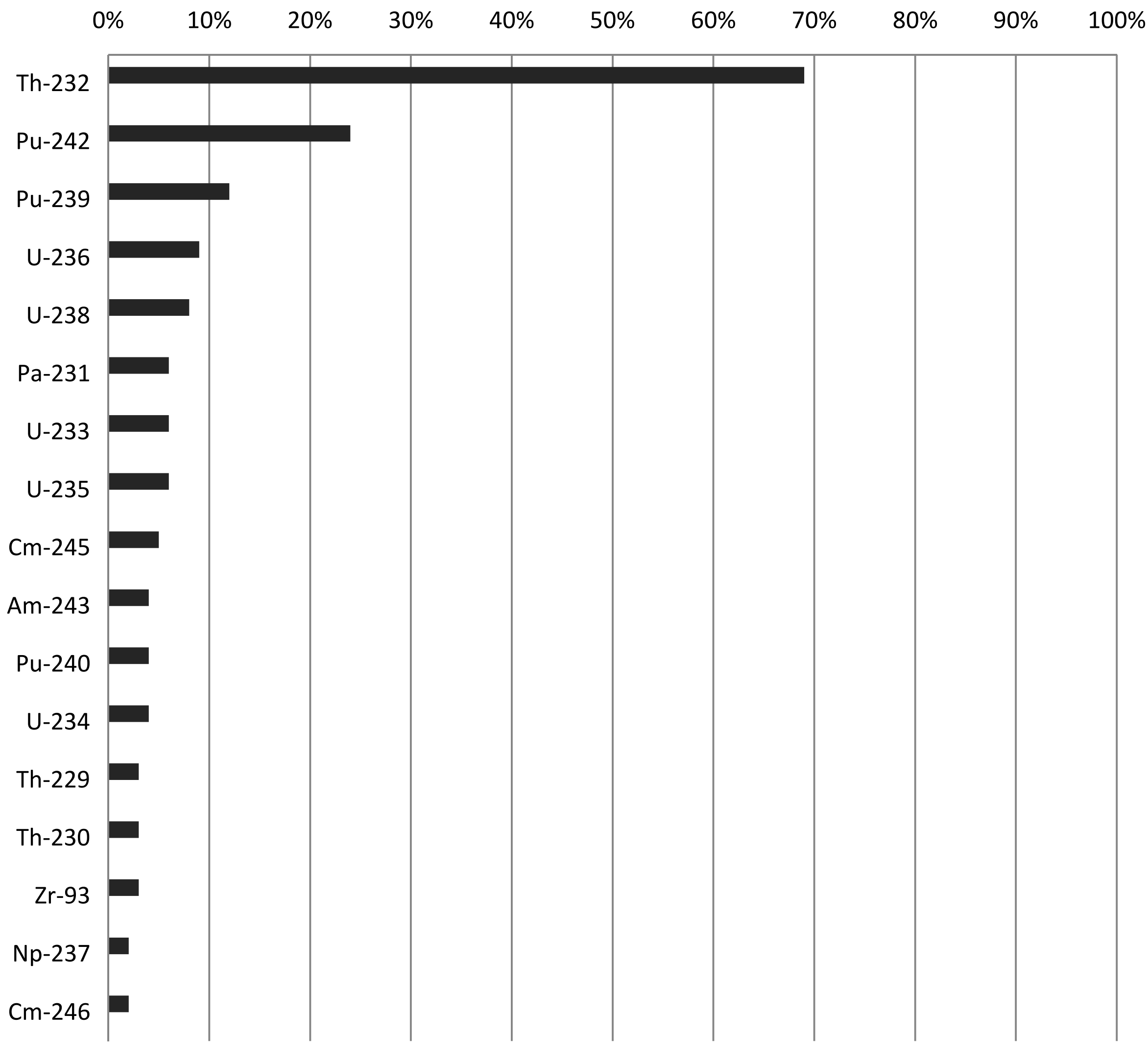

Figure 1. *Annual dose per unit release rate into the biosphere for exposures from peat burning in a power plant presented as percentage of the baseline LDF (Interglacial). Values are shown for the case of the power plant with a 50 m stack. Only radionuclides with values exceeding 1% of the LDF are shown.*

The obtained results must be seen in relation to the size and availability of fuel matter in the biosphere objects before the dose estimates are interpreted as average annual doses over a life time.

The size and amount of peat that is theoretically available in each of the three biosphere objects that gave rise to the highest annual doses per unit release into the biosphere are shown in Table 1. The largest object in SR-Site (object 114) and estimated total amount of peat available for all 17 biosphere objects are also shown in Table 1.

Table 1. Availability and energy content of the peat and wood in the three biosphere objects (124, 121_03 and 120) that gave rise to the highest annual doses per unit release rate into the air. The area and volume of the biosphere objects are given. The number of households that can sustain their long term (50 years) energy consumption is calculated from the energy content of the potential peat in the object and the assumed energy needed for heating (16 800 kWh/y). Object 114 is the largest object in SRSsite but is expected to give rise to lower doses than the three other objects. The total maximum amount of peat contained in all SRSsite objects is also shown.

Object	Area ($10^5 m^2$)	Volume ($10^4 m^3$)	Peat		
			Mass ($10^5 kgDW$)	*Energy content (GWh)*	*Households (50 years)*
120	3	35	33	19	23
124	0.8	7	7	4	5
121_03	0.8	6	5	3	4
114	2	377	357	207	246
SR-site	120	1680	1588	921	1097

None of the biosphere objects with the most contaminated peat (objects 120, 124 and 121_03) contains enough peat to sustain the fuel consumption during one year of a 3 MW power plant and the largest biosphere object in SR-Site (object 114) does not contain enough peat to sustain the consumption during one year of a 24 MW power plant. The maximum theoretical availability of peat in all objects in SR-Site is expected to sustain the fuel consumption of one 100 MW power plant for only one year and a 30 MW power plant for 3.5 years. Based on these results, it is not realistic that peat from Forsmark will be used for industrial energy production.

Burning of peat in households

For the household using peat as fuel, the highest annual dose per unit release rate into the biosphere was obtained for Th-232 (31% of the baseline LDF) and 16 additional radionuclides exceed 1% of the LDF (Figure 2).

The three biosphere objects that gave rise to the highest annual doses per unit release rate into the biosphere (objects 120, 124 and 121_03) are not large enough to sustain the fuel consumption during a lifetime of more than about 30 households. The largest biosphere object in SR-Site, object 114 can theoretically contain peat to fuel about 250 households for 50 years, but this object is expected to give lower doses per unit release rate into the biosphere. These calculations are based on the assumption that the objects are used exclusively for providing fuel. If the objects are also used for providing food, then the availability of peat for fuel will be lower.

Parameter uncertainties and sensitivity of the results to the parameter values

The activity air concentrations and annual doses obtained for releases from the power plant can be directly scaled to other values of energy effect and filter efficiencies. For example, the air concentration and subsequent doses from a 30 MW plant will be 30% of the air concentrations reported here for the 100 MW plant. Also, a 95% filter efficiency results in five times larger activity air concentrations and doses than those reported here for the 99% filter efficiency.

Calculations made of releases from a 5 m high building (house) results in approximately 20% lower activity air concentrations closest to the house than those reported here for a 4 m house. The width of the wall closest to the receptor was selected to give conservative results: The activity air concentration (and also the calculated doses) averaged 5-200 m downwind reported for the 30 m wide wall is about 25 % larger than for a 10 m wide wall.

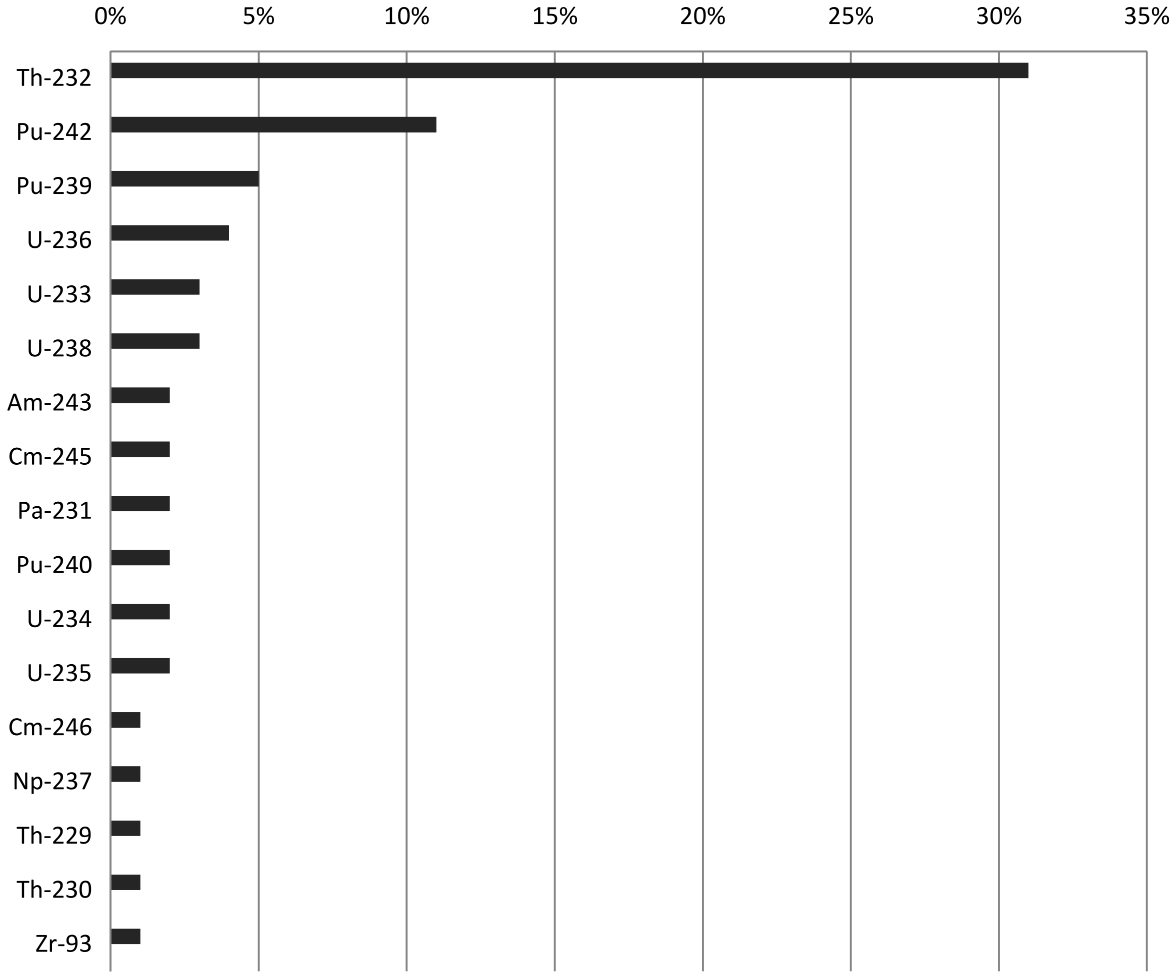

Figure 2. *Annual dose per unit release rate into the biosphere for exposures from peat burning in a household presented as percentage of the baseline LDF (Interglacial). Only radionuclides with values exceeding 1% of the LDF are shown.*

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Appendix A.

Annual average discharge rate

The annual average discharge rate (Bq/s) when fuel is burned is calculated from the radionuclide concentration in fuel (Bq/kg), the fuel usage rate (Kg/s) and the fraction of radionuclides that is released into the air

$$Q_i = C_p \cdot F_{rate} \cdot R_{frac}$$

where

Q_i = Annual average discharge rate of radionuclide i [Bq/s]
C_p = Activity concentration of radionuclide in peat [Bq/Kg]
F_{rate} = Fuel usage rate. The amount of fuel burned per second [Kg/s]
R_{frac} = Fraction of radionuclides released, i.e. not contained within a filter [unitless]

Annual dose per unit activity concentration in peat

Annual doses per unit activity concentration in peat (Sv/y per Bq/kg) are calculated by multiplying activity concentrations in air ($\mathrm{Bq/m^3}$ per Bq/kg) with the inhalation rate ($\mathrm{m^3/h}$), the exposure time (h/year) and the dose coefficients for inhalation (Sv/Bq):

$$D_{inh} = C_a \cdot R_{inh} \cdot ET \cdot DCC_{inh}$$

where

D_{inh} = Annual dose for inhalation [Sv/y per Bq/kg]
C_a = Concentration of radionuclides in air [Bq/m^3 per Bq/kg]
R_{inh} = Inhalation rate [m^3/h]
ET = Exposure time [$h/year$]
DCC_{inh} = Dose coefficient for inhalation [Sv/Bq]

Parameter values

The parameter values used for calculating the annual average discharge rate and the activity air concentrations for the household and power plant calculation cases are shown in Table A-*1* and Table A-*2*, respectively.

Table A-1. Parameter values used for the calculation of activity air concentrations for the household calculation case.

Parameter	*Notation*	*Value*	*Unit*	*Reference*
Energy consumption	-	16 800	kWh/y	Statens energimyndighet 2013
Peat energy content	-	5.8	kWh/kg	Möre and Hubbard 2003
Activity concentration in peat	C_p	1	Bq/kg	Assumed value
Fuel usage rate	F_{rate}	$9.2 \cdot 10^{-5}$	Kg/s	-
Fraction of radionuclides released	R_{frac}	1	-	Assumed value
The fraction of the time during the year that the wind blows towards the	P_p	0.25	-	Johansson and Öhman 2008

receptor of interest				
Geometric mean of the wind speed at the height of release representative of one year	μ_a	1.7	m/s	Johansson and Öhman 2008
Height of building	H_B	4	m	Assumed value
Width of the building wall closest to the recipient	W_B	30	m	Assumed value

Table A-2. Parameter values used for the calculation of activity air concentrations for the power plant calculation case. The energy production assumes a 100 MW power plant.

Parameter	*Notation*	*Value*	*Unit*	*Reference*
Energy production	-	$8.7 \cdot 10^8$	kWh/y	-
Energy content of peat	-	5.8	kWh/kg	Möre and Hubbard 2003
Fuel usage rate	F_{rate}	4.8	Kg/s	-
Activity concentration in peat	C_p	1	Bq/kg	-
Fraction of radionuclides released	R_{frac}	0.01	-	Ericson 1985
The fraction of the time during the year that the wind blows towards the receptor of interest	P_p	0.25	-	Johansson and Öhman 2008
Geometric mean of the wind speed at the height of release representative of one year	μ_a	1.7	m/s	Johansson and Öhman 2008

Table A-3. Parameters used to calculate the doses per unit concentration in peat.

Parameter	*Notation*	*Value*	*Unit*	*Reference*
Inhalation rate	R_{inh}	1.5	m^3/h	ICRP 1995
Exposure time	ET	2920	$h/year$	-
Dose coefficient for inhalation	DCC_{inh}	Table 6-2 in Nordén et al. 2010.	Sv/Bq	Nordén et al. 2010