Vedlegg 4

Assessment of radiation dose arising from ^{220}Rn discharged from Oncoinvent in Nydalen

Summary

The doses arising from three different ^{220}Rn discharge scenarios arising from Oncoinvent's operations at Gullhaugveien 7, Nydalen, 0484 Oslo have been calculated.

The calculation is based on currently accepted models of atmospheric dispersion of gaseous discharges, and takes into account the decay of ^{220}Rn in transit from the point of discharge to the point of exposure. The overwhelmingly significant source of dose is found to be that from inhalation of ^{220}Rn by an exposed person in each of the scenarios. Doses arising from external exposure to ^{220}Rn and from the decay products ^{212}Pb, ^{212}Bi, ^{212}Po and ^{208}Tl are found to be insignificant compared to the ^{220}Rn inhalation dose.

In addition, no significant stable lead contamination arises from the decay of the discharged ^{220}Rn to ^{208}Pb.

The outcome of the calculations are:

- Gullhaugveien 7 terrasse: 10 µSv y^{-1}
  10 metres from discharge point, 10 hours per week occupancy.
- Gullhaugveien 7 parkering: 20 µSv y^{-1}
  5,0 metres from discharge point A and 2,5 metres from discharge point B, 2 hours per week occupancy.
- Gjerduns vei 1 hus: 1,6 µSv y^{-1}
  100 metres from discharge point, 20 hours per week occupancy.
- A release of 70 GBq y^{-1} ^{220}Rn generates ~$1,9\times10^{-9}$ g of ^{208}Pb at a mean concentration of ~$0,11\times10^{-15}$ g m^{-3}
  This presents no credible environmental threat.

Contents

1] Document History

		Signature	Name	Title	Date
Version 1.8	Written by:		Simon Jerome	Forsker	2022-02-08
	Approved by:		Lindis Skipperud	Professor	2022-02-08

2] Changes

2.1] Version 1

This is the first version of this document.

3] Scope

This report estimates the potential dose arising from ^{220}Rn discharges from the Oncoinvent facility, situated in Gullhaugveien, Nydalen, Oslo. The assessment is based on commonly used calculations of dispersal of radioactive material released to the atmosphere [for example, Smith and Simmonds, 2009].

Three scenarios were specified by Oncoinvent:

- Exposed person occupies the terrasse at Gullhaugveien 7 for 10 hours each week, 10 metres from the discharge stack, which makes a continuous discharge totalling 70 GBq per year, with an exhaust outflow of 2 000 $m^3 h^{-1}$,
- Exposed person occupies the parkering/service area at Gullhaugveien 7 for 2 hours each week, 2,5 metres from the secondary discharge, which makes a continuous discharge totalling 6 GBq per year, with an exhaust outflow of 6 000 $m^3 h^{-1}$, and
- Exposed person occupies the outside area at Gjerduns vei 1 for 20 hours each week, 100 metres from the discharge stack, which makes a continuous discharge totalling 70 GBq per year, with an exhaust outflow of 2 000 $m^3 h^{-1}$.

4] Calculation model

The calculation of potential dose employs generally accepted mathematical models and is detailed in a Health Protection Agency (UK) report [Smith and Simmonds, 2009]. As noted in annex 1, the equation governing the mean activity concentration is:

$$\overline{X}_i(x,z) = \left[\frac{Q_0}{\alpha_i \cdot x \cdot \sqrt{2 \cdot \pi}}\right] \cdot \sum_j f_{i,j} \cdot \left\{\left[\frac{1}{\sigma_{z,i,j} \cdot u_{i,j}}\right] \cdot e^{-\left[\frac{(z-h_e)^2}{\sigma_{z,i,j}^2}\right]}\right\} \quad (1)$$

4.1] *Transit time*

Note that the distance, x, is linked to the transit time:

$$t_{i,j} = \frac{x}{u_{i,j}} \quad (2)$$

Where $t_{i,j}$ is the transit time, in seconds, in sector i with meteorological conditions j. The transit time is used to calculate the decay of ^{220}Rn between the discharge point and the exposed person. This, in turn modifies equation (2):

$$\overline{X}_i(x,z) = \left[\frac{Q_0}{\alpha_i \cdot x \cdot \sqrt{2 \cdot \pi}}\right] \cdot \sum_j f_{i,j} \cdot \left\{\left[e^{-\left(\frac{\ln 2}{T_{Rn}}\right) \cdot \left(\frac{x}{u_{i,j}}\right)}\right] \cdot \left[\frac{1}{\sigma_{z,i,j} \cdot u_{i,j}}\right] \cdot e^{-\left[\frac{(z-h_e)^2}{\sigma_{z,i,j}^2}\right]}\right\} \quad (3)$$

4.2] *Mixture layer*

The vertical spread of radionuclides in the air will be limited in the atmosphere in the mixture layer. The upper limit of the mixture layer depends on meteorological conditions and temperature which are categorised into atmospheric stability classes. In this analysis, Pasquill's atmospheric stability classes, A, B, C, D, E and F, are used, where A is the least stable and most turbulent and class F is the most stable.

This is further modified for the effects of structure in the local environment, using Hosker and Smith's surface roughness terms.

As an example, the numerical values associated with the Pasquill classification and Hosker and Smith's surface roughness parameters are presented in annex 2 for a source-to-exposed person distance of 10 metres.

4.3] *Source of dose*

Dose to an exposed person arises from is tabulated below. In general, the only significant dose appears to arise from inhalation, the other pathways being insignificant compared with the main dose from inhalation of ^{220}Rn.

Furthermore, the decay products ^{212}Pb, ^{212}Bi, ^{212}Po and ^{208}Tl rapidly associate with particulate matter at the point of production, and so are removed from the gaseous effluent by the filtration system. Thus any inhaled ^{212}Pb, ^{212}Bi, ^{212}Po and ^{208}Tl is present only by ingrowth from released ^{220}Rn.

From ingrowth and decay equations set out in annex 3, the *maximum* activity of ^{212}Pb, relative to an *initial* activity of ^{220}Rn is ~0,0015. However, the observed ratio at any time after discharge (taking account of decay of ^{220}Rn) may be greater than this, as shown in figure 1.

Given the calculated transit time for each of the scenarios, the maximum ^{212}Pb:^{220}Rn activity ratio is ~0,0023 at the house 100 m from the discharge point. Under these circumstances, only the dose arising from inhalation of ^{220}Rn has been calculated.

Figure 1: *Variation in ^{212}Pb:^{220}Rn activity ratios*

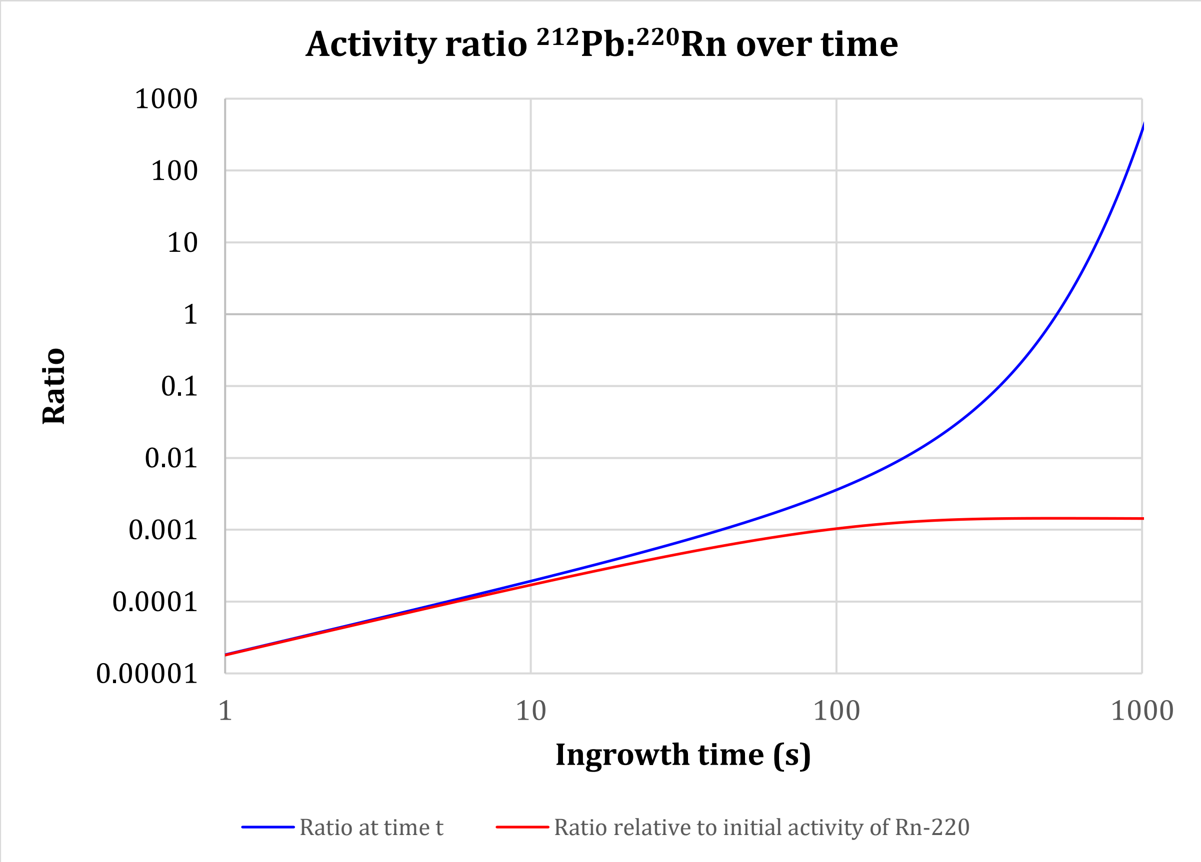


Table 1: *Source of dose*

Source	Units	Value	Description
^{220}Rn inhalation	Sv Bq^{-1} h^{-1} m^{3}	40×10^{-9}	Dose coefficient for ^{220}Rn [UNSCEAR 2000, p 108, paragraph 154]: «*The value of 40 nSv (Bq h m^{-3})$^{-1}$ for equilibrium equivalent concentrations of thoron, derived in Annex A, "Dose assessment methodologies", seems appropriate for evaluating exposures both indoors and outdoors*». Vastly dominant source of dose.
^{220}Rn external γ exposure	Sv Bq^{-1} h^{-1} m^{3}	~1,3×10^{-15}	Inferred from IFE report [Nordhei, 2021, table 3]. Appears to be a factor of ~3×10^{8} less than that for inhalation, and is insignificant in this study.
^{220}Rn external α/β exposure	Sv Bq^{-1} h^{-1} m^{3}	Nil	Taken from IFE report [Nordhei, 2021, table 3].
^{212}Pb inhalation dose coefficient	Sv Bq^{-1} h^{-1} m^{3}	<40×10^{-9}	Given that the inhalation dose from ^{220}Rn is arises from two α-emitters (^{220}Rn and ^{216}Po), the inhalation dose from ^{212}Pb which arises from three β-emitters (^{212}Pb, ^{212}Bi: ~36% of decays and ^{208}Tl: ~64% of decays) and one α-emitter (^{212}Bi: ~64% of decays and ^{212}Po: ~36% of decays), is unlikely to be greater than that for ^{220}Rn.

Source	Units	Value	Description
^{212}Pb external γ exposure	Sv Bq^{-1} h^{-1} m^{3}	~$1{,}4\times10^{-13}$	Inferred from IFE report [Nordhei, 2021, table 3] Appears to be a factor of ~3×10^{5} less than that for inhalation, and is insignificant in this study.

4.4] Common data

Table 2: Parameters common to all calculations.

Parameter	Units	Value	Description
Years	d y^{-1}	365,25	Mean day length over a 4 year cycle
^{220}Rn half life	s	55,8	Currently recommended value [LNHB(a)]
Breathing rate	m^{3} d^{-1}	20	Breathing rate for an adult [UNSCEAR 2000, p 35, paragraph 99]
	m^{3} y^{-1}	7 305	Derived from the daily breathing rate
	m^{3} h^{-1}	0,833	Derived from the daily breathing rate
^{220}Rn inhalation dose coefficient	Sv Bq^{-1} h^{-1} m^{3}	40×10^{-9}	Dose coefficient for ^{220}Rn [UNSCEAR 2000, p 108, paragraph 154]

4.5] Stable lead contamination

All of the ^{220}Rn discharged decays, eventually, to stable ^{208}Pb. For a 70 GBq discharge, the number of atoms of ^{220}Rn may be calculated as:

$$N_{Pb} = N_{Rn} = A_{Rn} \cdot \frac{T_{Rn}}{\ln 2} \quad (4)$$

Where:

A_{Rn}: Activity of ^{220}Rn in Bq

T_{Rn}: Radioactive half-life of ^{220}Rn in s

N_{Rn}: Number of atoms of ^{220}Rn

N_{Pb}: Number of atoms of ^{208}Pb

From this, a release of 70 GBq ^{220}Rn generates ~$5{,}6\times10^{12}$ atoms of ^{208}Pb, which is equivalent to ~$1{,}9\times10^{-9}$ g of ^{208}Pb. As the total discharge volume is $17{,}5\times10^{6}$ m^{3} y^{-1}, any stable lead is present at a mean concentration of ~$0{,}11\times10^{-15}$ g m^{-3} (or ~320 000 *atoms* m^{-3} of ^{208}Pb), the dilution and dispersion of 1,9 ng of lead in $17{,}5\times10^{6}$ m^{3} of effluent air presents no credible environmental threat.

5] Parameters of the Oncoinvent site

Briefly, Oncoinvent are engaged in employing ^{224}Ra for pharmaceutical purposes. Thorium-228 is used as a precursor material from which ^{224}Ra is separated, and the recovery of ^{224}Ra, as well as subsequent manipulations may result in the release of ^{220}Rn into the site fume extract system.

The fume extract system serves all the laboratory areas in the Oncoinvent facility, with a gross flow rate of 2 000 m^{3} h^{-1} (0,556 m^{3} s^{-1}). Downstream from the laboratory fume cupboard exhausts are a bank of three carbon based filtration systems aimed at removing particulate matter and ^{220}Rn from the exhaust air released off site. Radon-220 releases are monitored at a point downstream from the filter beds, but 30 metres upstream from the point of discharge to the atmosphere; at this point the extract duct is 0,45 metres in diameter.

6] Windrose

The windrose information is taken from the Norsk klimat service sentre website [Seklima, 2022] and is shown in annex 4. Data for 2021 is presented and used in calculation, this being the most recent complete annual data set from the Oslo-Blindern site which is the closest to the Oncoinvent premises.

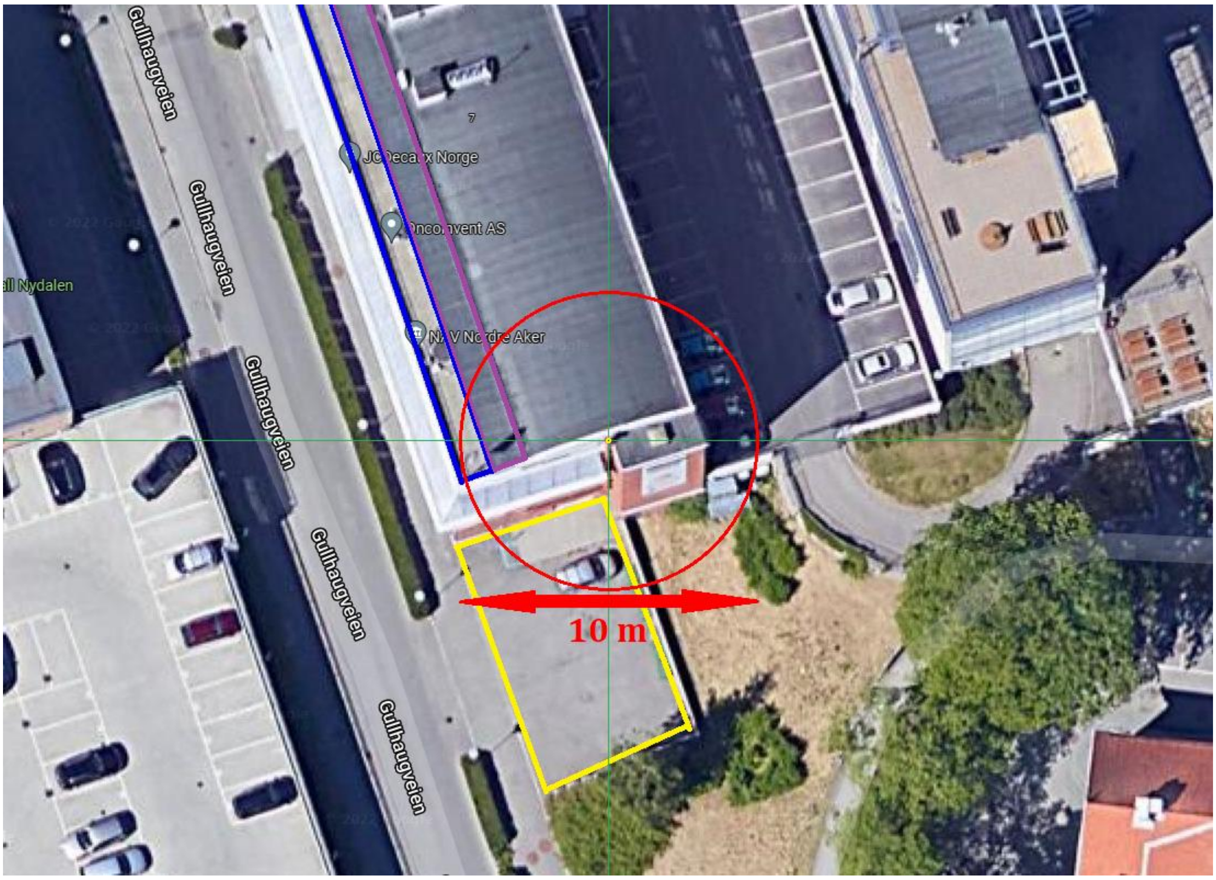
For the short-term terrasse exposure, the windrose data from August 2021 was used.

7] Exposed person

7.1] Scenario 1 – Gullhaugveien 7 terrasse

The exposed person, identified by Oncoinvent, is one who spends some of their time on the terrasse of the building where Oncoinvent is situated. The terrasse is shown in figures 2 and 3.

Figure 2 – plan view of Gullhaugveien 7 (from Google maps)



The discharge point is at the intersection of the green lines and marked with a yellow dot and the red circle has a radius of 10 m and is centred on the discharge point. The terrasse area is outlined in blue with the roofed area outlined in mauve.

The exposure angle is taken as $\frac{\pi}{8}$ radians corresponding to wind *from* Ø sector of the windrose.

In this view, the 10 metre linear distance between the discharge point and the exposure point is marked in blue, with the discharge point approximately 4,2 metres above this datum line (note that this datum line is not the floor of the terrasse). A roof can be seen approximately 1,7 metres above the datum line, and thus approximately 2,5 metres below the discharge point. This is taken to be the effective exposure height.

The exposed person does not occupy the exposure point at all times, but is expected to be in that position for 10 hours per week.

The discharge is stated to be 70 GBq of ^{220}Rn over a period of 1 year, equal to 192 MBq d^{-1} and 2,22 kBq s^{-1}.

Figure 3 – side view of Gullhaugveien 7, from approximately south to north (from Google maps)

Table 3: Calculation input data

Parameter	Units	Value	Description
Q_0	Bq s^{-1}	2 220	Discharge rate
α_i	Radians	$\frac{\pi}{8}$	Angle of discharge, from windrose sector Ø
x	m	10	Distance to exposed person
$u_{i,1}$	m s^{-1}	0,1 *(0,0-0,2)*	Average wind speed in sector with meteorological condition 1
$u_{i,2}$	m s^{-1}	0,9 *(0,3-1,5)*	Average wind speed in sector with meteorological condition 2
$u_{i,3}$	m s^{-1}	2,45 *(1,6-3,3)*	Average wind speed in sector with meteorological condition 3
$u_{i,4}$	m s^{-1}	4,4 *(3,4-5,4)*	Average wind speed in sector with meteorological condition 4
$f_{i,1}$	none	0,06%	Frequency of meteorological condition 1
$f_{i,2}$	none	1,2%	Frequency of meteorological condition 2
$f_{i,3}$	none	0,8%	Frequency of meteorological condition 3
$f_{i,4}$	none	0,2%	Frequency of meteorological condition 4
z	m	2,0	Mouth/nose height above datum of exposed person
h_e	m	4,2	Effective discharge height above datum
Occupancy	h y^{-1}	522	Assuming an occupancy of 10 hours each week.
Stability class	none	C	Assumed 50%
		D	Assumed 50%
Roughness length	m	4	Assumed due to the complexity of the structure.

Using these parameters an annual dose of 10 µSv y^{-1} is obtained for ^{220}Rn exposure with this occupancy pattern.

7.2] Scenario 2 – Gullhaugveien 7 parkering

The exposed person, identified by Oncoinvent, is one who spends some of their time on the service point and visitor parking spot of the building where Oncoinvent is situated. The exposure area is shown in yellow in figures 1 and 2.

The discharge points are shown as a yellow circle and box in figure 2. Due to the geometry of the exposure area, slightly more complex approach is taken.

The discharge is stated to be 6 GBq of ^{220}Rn over a period of 1 year, equal to 16,4 MBq d^{-1} and 190 Bq s^{-1}. The discharge volume is 6 000 m^3 h^{-1}.

7.2.1] Secondary discharge point A

The nominal discharge point is taken to be five metres above ground level and 5 metres distant from the exposed person.

The exposure angle is taken as $\frac{3\cdot\pi}{8}$ radians with the wind coming from sectors NØ, ØNØ and Ø sectors of the windrose.

The exposed person does not occupy the exposure point, 5 metres from the discharge point, at all times, but is expected to be in that position for 2 hours per week.

It is assumed that the discharge is stated to behalf the total secondary discharge of 6 GBq, ie 3 GBq from this point of ^{220}Rn over a period of 1 year, equal to 8,2 MBq d^{-1} and 95 Bq s^{-1}.

Table 4: Calculation input data

Parameter	Units	Value	Description
Q_0	Bq s^{-1}	95	Discharge rate
α_i	Radians	$\frac{3\cdot\pi}{8}$	Angle of discharge, windrose sector
x	m	5	Distance to exposed person
$u_{i,1}$	m s^{-1}	0,1 *(0,0-0,2)*	Average wind speed in sector with meteorological condition 1
$u_{i,2}$	m s^{-1}	0,9 *(0,3-1,5)*	Average wind speed in sector with meteorological condition 2
$u_{i,3}$	m s^{-1}	2,45 *(1,6-3,3)*	Average wind speed in sector with meteorological condition 3
$u_{i,4}$	m s^{-1}	4,4 *(3,4-5,4)*	Average wind speed in sector with meteorological condition 4
$u_{i,5}$	m s^{-1}	6,7 *(5,5-7,9)*	Average wind speed in sector with meteorological condition 4
$f_{i,1}$	none	0,2%	Frequency of meteorological condition 1
$f_{i,2}$	none	6,7%	Frequency of meteorological condition 2
$f_{i,3}$	none	9,9%	Frequency of meteorological condition 3
$f_{i,4}$	none	3,6%	Frequency of meteorological condition 4
$f_{i,5}$	none	0,3%	Frequency of meteorological condition 5
z	m	2,5	Mouth/nose height at exposure point above ground for exposed person
h_e	m	5	Effective discharge height above ground above ground for exposed person
Occupancy	h y^{-1}	104	Assuming an occupancy of 2 hours each week.
Stability class	none	C	Assumed 50%
		D	Assumed 50%
Roughness length	m	4	Assumed due to the complexity of the area.

Using these parameters an an activity concentration of $< 0{,}1$ Bq m^3, resulting in an annual dose of $< 0{,}1$ µSv y^{-1} from this discharge point is obtained for ^{220}Rn exposure with this occupancy pattern; this value is rounded up to 0,1 µSv y^{-1}.

7.2.2] Secondary discharge point B

The nominal discharge point is taken to be 3 metres above ground level and 2,5 metres distant from the exposed person.

In this case, the plume model is inappropriate and so a simple box inflow-outflow model is used.

The exposed person does not occupy the exposure point, 2,5 metres from the discharge point, at all times, but is expected to be in that position for 2 hours per week.

It is assumed that the discharge is stated to behalf the total secondary discharge of 6 GBq, ie 3 GBq from this point of ^{220}Rn over a period of 1 year, equal to 8,2 MBq d^{-1} and 95 Bq s^{-1}. The air inflow from the discharge point is 3 000 m^3 h^{-1}, half of the total outflow from the secondary discharge, equivalent to 0,833 m^3 s^{-1}.

The mean wind speed in this area is ~2,4 m s^{-1} from the ØNØ, Ø, ØSØ, SØ, SSØ, S, SSV, SV and VSV windrose sectors.

The box used to calculate the equilibrium concentration of ^{220}Rn is taken to be a cube with edge length 3 m. The inflow into the box is 0,833 m^3 s^{-1} from the discharge and 21,4 m^3 s^{-1} from the mean wind speed (ie $3 \text{ m} \cdot 3 \text{ m} \cdot 2{,}4 \text{ m s}^1$), giving a total inflow and outflow of 22,2 m^3 s^{-1}.

This inputs give an equilibrium concentration of ^{220}Rn as ~4,2 Bq m^3. Using the dose conversion factor and occupancy stated above, the dose to the exposed person in this area is 17,6 µSv y^{-1} from this discharge point.

7.2.3] Total dose from scenario 2 – Gullhaugveien 7 parkering

The total dose is the combined dose from both secondary discharge points, $(0{,}1 + 17{,}6)$ µSv y^{-1} rounded up to 20 µSv y^{-1}, due to the complex geometry of this area and the contributing inputs.

7.3] Scenario 3 – Gjerduns vei 1 hus

The exposed person, identified by Oncoinvent, is one who spends some of their time outside of a house, 100 metres from the building where Oncoinvent is situated. The house is shown in figure 4.

In this view, the 100 metre linear distance between the discharge point and the exposure point circled in red, with the discharge point approximately 30 metres above ground level. The house is taken to be 1 metre below the discharge point.

The exposure angle is taken as $\frac{\pi}{8}$ radians corresponding to wind *from* the SV sector of the windrose.

The exposed person does not occupy the exposure point at all times, but is expected to be in that position for 20 hours per week.

The discharge is stated to be 70 GBq of ^{220}Rn over a period of 1 year, equal to 192 MBq d^{-1} and 2,22 kBq s^{-1}.

Figure 4 – plan view of Gjerduns vei 1 (from Google maps)

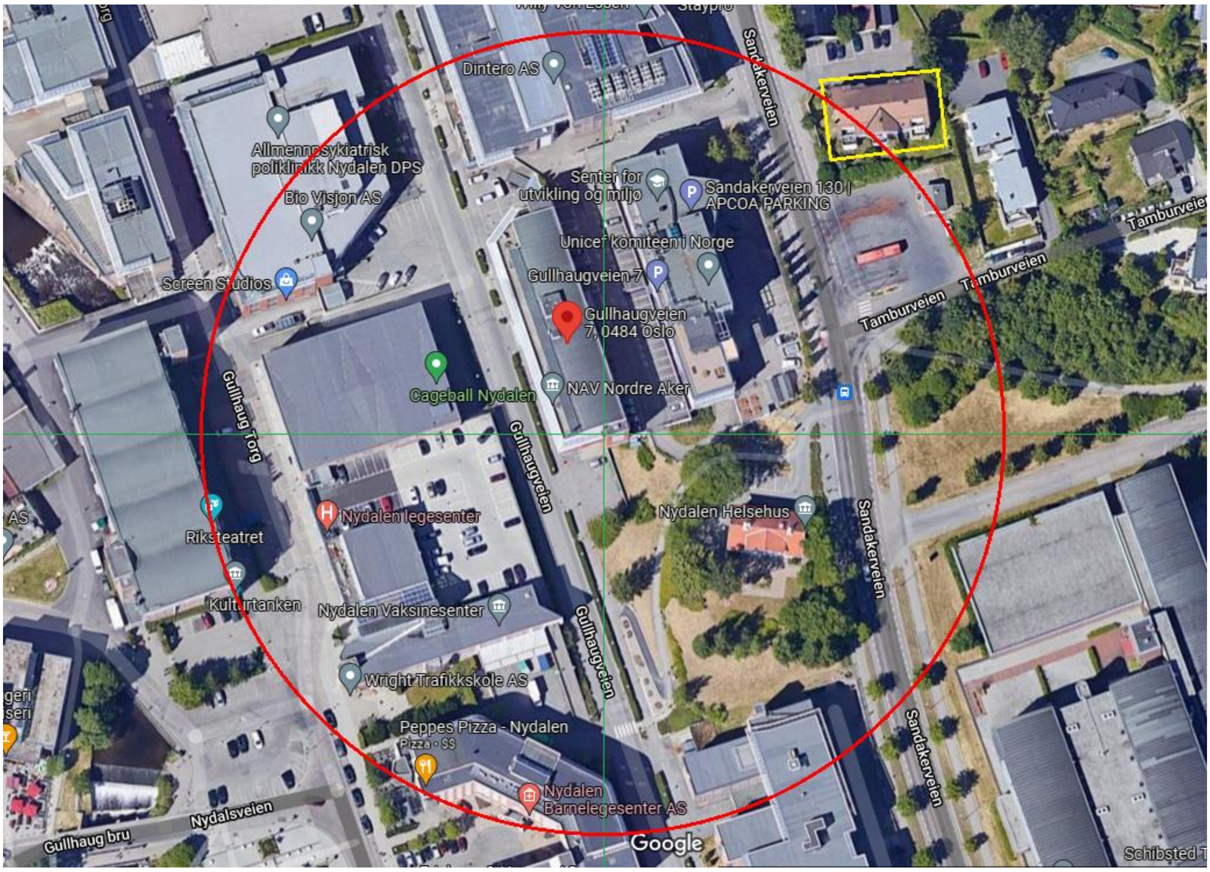


Table 5: Calculation input data

Parameter	Units	Value	Description
Q_0	Bq s^{-1}	2 220	Discharge rate
α_i	Radians	$\frac{\pi}{8}$	Angle of discharge, from windrose sector Ø
x	m	100	Distance to exposed person
$u_{i,1}$	m s^{-1}	0,1 *(0,0-0,2)*	Average wind speed in sector with meteorological condition 1
$u_{i,2}$	m s^{-1}	0,9 *(0,3-1,5)*	Average wind speed in sector with meteorological condition 2
$u_{i,3}$	m s^{-1}	2,45 *(1,6-3,3)*	Average wind speed in sector with meteorological condition 3
$u_{i,4}$	m s^{-1}	4,4 *(3,4-5,4)*	Average wind speed in sector with meteorological condition 4
$u_{i,5}$	m s^{-1}	6,7 *(5,5-7,9)*	Average wind speed in sector with meteorological condition 5
$f_{i,1}$	none	0,06%	Frequency of meteorological condition 1
$f_{i,2}$	none	3,1%	Frequency of meteorological condition 2
$f_{i,3}$	none	4,1%	Frequency of meteorological condition 3
$f_{i,4}$	none	0,9 %	Frequency of meteorological condition 4
$f_{i,5}$	none	0,2 %	Frequency of meteorological condition 5
z	m	29	Mouth/nose height at exposure point above ground at discharge point for exposed person
h_e	m	30	Effective discharge height above ground
Occupancy	h y^{-1}	1 044	Assuming an occupancy of 20 hours each week.
	none	C	Assumed 50%

Parameter	Units	Value	Description
Stability class		D	Assumed 50%
Roughness length	m	4	Assumed due to the complexity of the structure.

Using these parameters an annual dose of 1,6 µSv y^{-1} is obtained for ^{220}Rn exposure with this occupancy pattern.

7.4] Supplementary questions

Three supplementary questions were raised pertaining to exposure on the terrasse at Gullhaugveien 7. The solutions to all these questions are based on the input data for scenario 1 (section 7.1] above), except that a release of 11 GBq of ^{220}Rn was made over a period of one week in August 2021, equivalent to a release of 18,2 kBq s^{-1} at a concentration of 32,7 kBq m^{-3}.

7.4.1] Exposure to a person on the terrasse

During the stated release, a person occupied the terrace at Gullhaugveien 7 for 10 hours. Where different, the inputs are tabulated below.

Table 3: Calculation input data

Parameter	Units	Value	Description
Q_0	Bq s^{-1}	18 200	Discharge rate
$f_{i,1}$	none	0,004%	Frequency of meteorological condition 1
$f_{i,2}$	none	1,1%	Frequency of meteorological condition 2
$f_{i,3}$	none	1,0%	Frequency of meteorological condition 3
$f_{i,4}$	none	0,4%	Frequency of meteorological condition 4
$f_{i,5}$	none	0,1%	Frequency of meteorological condition 5
f_i (total)		2,3%	

The windrose used was for August 2021 and using these parameters a dose of 1,6 µSv is obtained for ^{220}Rn exposure with this occupancy period during the stated release.

7.4.2] Distance at which the ^{220}Rn concentration is 100 Bq m^{-3}

The same calculation was carried out, with the distance from the discharge point, x, being varied until a concentration of 100 Bq m^{-3} was obtained. No meaningful result can be obtained when $z = 2$ metres.

Alternatively, if the difference in height between the discharge point and the exposure point is set to zero (ie $z = h_e$), then a distance of ~4,1 metres is obtained.

7.4.3] Distance at which the ^{220}Rn concentration is 3 Bq m^{-3}

Again, the same conditions are used. In this case, when $z = 2$ metres, a distance of ~17 metres is obtained. Again, if $z = h_e$, then a distance of ~23 metres is obtained.

It should be noted that all of these results are subject to considerable variation, depending on the prevailing weather conditions. In particular, the calculations are for the Ø sector only of the windrose and the values for other windrose sectors differ considerably from those obtained above. Also, the windrose is an average for August 2021 in which 2,3% of the prevailing wind is from the Ø sector and the conditions for a particular week may deviate considerably from the mean value. If the whole windrose is considered, then the average distances increase somewhat, but the variations within each windrose sector are significant.

8] Conclusions

Using the generally accepted equations for dispersal of radioactive gases from a discharge stack, the doses to an exposed person are as follows:

- Gullhaugveien 7 terrasse: 10 μSv y^{-1}
- Gullhaugveien 7 parkering: 20 μSv y^{-1}
- Gjerduns vei 1 hus: 1,6 μSv y^{-1}

All other doses from cloud exposure to ^{220}Rn and ^{212}Pb as well as ground exposure are insignificant compared to these doses.

A release of 70 GBq y^{-1} ^{220}Rn generates ~1,9×10^{-9} g of ^{208}Pb in a total discharge volume of 17,5×10^{6} m^{3} y^{-1}, equating to a mean concentration of ~0,11×10^{-15} g m^{-3} (~320 000 atoms m^{-3} of ^{208}Pb) which presents no credible environmental threat.

9] References

Bateman, H., 1910. *The solution of a system of differential equations occurring in the theory of radioactive transformations*. Proceedings of the Cambridge Philosophical Society, **15(V)**, 423–427)

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LNHB(b) http://www.lnhb.fr/nuclides/Po-216_tables.pdf

LNHB(c) http://www.lnhb.fr/nuclides/Pb-212_tables.pdf

LHNB(d) http://www.lnhb.fr/nuclides/Bi-212_tables.pdf

LNHB(e) http://www.lnhb.fr/nuclides/Po-212_tables.pdf

LNHB(f) http://www.lnhb.fr/nuclides/Tl-208_tables.pdf

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A1] Annex 1 – Dispersion model

A1.1] Uniform dispersal

A Gaussian dispersal model may be used to calculate the activity concentration of ^{220}Rn:

$$X(x,y,z) = \left[\frac{Q_0}{2\cdot\pi\cdot\sigma_y\cdot\sigma_z\cdot u}\right]\cdot e^{-\left[\frac{y^2}{2\cdot\sigma_y^2}+\frac{(z-h_e)^2}{\sigma_z^2}\right]} \qquad \text{(A1.1)}$$

Table A1.1: Parameters for Gaussian dispersal calculations

Parameter	Units	Description
$X(x,y,z)$	Bq m^{-3}	activity concentration at the point (x,y,z)†
x	m	distance in the wind direction from the discharge point
y	m	the distance perpendicular to the wind direction measured from the centre line of the cloud
z	m	height above the ground where the concentration is calculated
σ_y	m	horizontal dispersion coefficient
σ_z	m	vertical dispersion coefficient
Q_0	Bq s^{-1}	emission rate at the point of discharge $(0,0,0)$
u	m s^{-1}	average wind speed
h_e	m	effective discharge height

The model assumes a stable situation without changes in wind direction (ie a uniform wind rose‡); this is not the case for emissions over an extended time period.

A1.2] Non-uniform dispersal

For a discharges over an extended time period, there will no longer be a Gaussian distribution of the concentration in the horizontal direction. Instead, the area around the discharge point is divided into sectors according to the wind rose, where a constant concentration is assumed in each sector. The activity concentration in each sector then becomes:

$$\overline{X}_i(x,z) = \left[\frac{Q_0}{\alpha_i\cdot x\cdot\sigma_{z,i}\cdot u_i\cdot\sqrt{2\cdot\pi}}\right]\cdot e^{-\left[\frac{(z-h_e)^2}{\sigma_{z,i}^2}\right]} \qquad \text{(A1.2)}$$

Table A1.2: Parameters for sector dispersion calculations

Parameter	Units	Description
$\overline{X}_i(x,z)$	Bq m^{-3}	mean activity concentration at the point (x,z) in sector i
u_i	m s^{-1}	average wind speed in sector i
α_i	radian*	sector i angle
$\sigma_{z,i}$	m	vertical dispersion coefficient in sector i

Differing conditions

As differing weather conditions may prevail during discharge, then the different contributors must be recognised, such that:

$$\overline{X}_i(x,z) = \sum_j f_{i,j}\cdot X_{i,j}(x,z) \qquad \text{(A1.3)}$$

or

$$\overline{X}_i(x,z) = \left[\frac{Q_0}{\alpha_i\cdot x\cdot\sqrt{2\cdot\pi}}\right]\cdot\sum_j f_{i,j}\cdot\left\{\left[\frac{1}{\sigma_{z,i,j}\cdot u_{i,j}}\right]\cdot e^{-\left[\frac{(z-h_e)^2}{\sigma_{z,i,j}^2}\right]}\right\} \qquad \text{(A1.4)}$$

† The point of emission has coordinates $(0,0,0)$

‡ Wind speed and direction distribution at a given location

* Radians are dimensionless

Table A1.3: Parameters for summation of sector dispersion calculations

Parameter	Units	Description
$X_{i,j}(x,z)$	Bq m^{-3}	activity concentration in sector i with meteorological conditions j
$f_{i,j}$	None	frequency of wind direction in sector i with meteorological conditions j
$u_{i,j}$	m s^{-1}	average wind speed in sector i with meteorological conditions j
$\sigma_{z,i,j}$	m	vertical dispersion coefficient in sector i with meteorological conditions j

A2] Annex 2 – Determining the vertical dispersion coefficient

This is based on empirical input data [Smith and Simmonds, 2009], and is calculated from the Pasquill/Smith/Hosker model.

The value of $\sigma_{z,}$ is calculated from this equation:

$$\sigma_z = \left[\frac{a\cdot x^b}{(1+c\cdot x^d)}\right]\cdot \ln\left[f\cdot x^g\cdot\left(1+\frac{1}{h\cdot x^j}\right)\right] \quad \text{(A2.1)}$$

If $z_0 > 0{,}1\ m$ and:

$$\sigma_z = \left[\frac{a\cdot x^b}{(1+c\cdot x^d)}\right]\cdot \ln\left[\frac{f\cdot x^g}{(1+h\cdot x^j)}\right] \quad \text{(A2.2)}$$

If $z_0 < 0{,}1\ m$ where z_0 is a measure of the surface roughness index, and is approximately 10% of the average height of surface protrusions. In this case we take $z_0 > 0{,}1\ m$, as suggested for urban areas.

To calculate $\frac{a\cdot x^b}{(1+c\cdot x^d)}$, Pasquill's atmospheric stability classes, A, B, C, D, E and F, are used, where A is the least stable and most turbulent and class F is the most stable.

Table A2.1 - Pasquill's atmospheric stability classes

Stability category	a	b	c	d	$\frac{a\cdot x^b}{(1+c\cdot x^d)}$ where $x = 10\ m$
A	0,112	1,06	$5{,}38\times10^{-4}$	0,815	1,281
B	0,13	0,95	$6{,}52\times10^{-4}$	0,750	1,154
C	0,112	0,92	$9{,}05\times10^{-4}$	0,718	0,927
D	0,098	0,889	$1{,}35\times10^{-3}$	0,688	0,754
E	0,0609	0,895	$1{,}96\times10^{-3}$	0,684	0,474
F	0,0638	0,783	$1{,}36\times10^{-3}$	0,672	0,385

To calculate $\frac{f\cdot x^g}{(1+h\cdot x^j)}$, Hosker and Smith's surface roughness term classes are used. In an urban environment a roughness length of 1 or 4 is most appropriate. These are the tabulated values for f, g, h, and j:

Table A2.2 - Hosker and Smith's surface roughness term

Roughness length	f	g	h	j	$\frac{f\cdot x^g}{(1+h\cdot x^j)}$ where $x = 10\ m$	$\ln\left[\frac{f\cdot x^g}{(1+h\cdot x^j)}\right]$
0.01	1,56	0.048	6.25×10^{-4}	0.45	1.74	0.553
0.04	2,02	0.0269	7.76×10^{-4}	0.37	2.15	0.763
					$f\cdot x^g\cdot\left(1+\frac{1}{h\cdot x^j}\right)$ where $x = 10\ m$	$\ln\left[f\cdot x^g\cdot\left(1+\frac{1}{h\cdot x^j}\right)\right]$
0.1	2,72	0	0	0	2.72	1.001
0.4	5,16	-0.098	18.6	-0.225	4.49	1.502
1	7.37	-0.0957	4.29×10^{3}	-0.6	5.92	1.778
4	11.7	-0.128	4.59×10^{4}	-0.78	8.71	2.165

Combining both, a complete table of outcomes may be constructed:

Table A2.3 - Vertical dispersion coefficient

σ_z values	Surface roughness	0,01	0,04	0,1	0,4	1	4
		0,553	0,763	1,001	1,502	1,778	2,165
Atmospheric stability							
A	1,281	0,709	0,978	1,282	1,924	2,278	2,774
B	1,154	0,639	0,881	1,155	1,734	2,053	2,499
C	0,927	0,513	0,708	0,928	1,392	1,649	2,007
D	0,754	0,417	0,576	0,755	1,132	1,341	1,632
E	0,474	0,262	0,362	0,474	0,711	0,842	1,026
F	0,385	0,213	0,294	0,385	0,578	0,684	0,833

A3] Annex 3 – decay and ingrowth in radioactive decay chains

As ^{220}Rn is a short-lived radionuclide, with a half-life of 55,8 seconds [LNHB(a)}, the decay and ingrowth of the decay products must also be considered. In practical terms, the decay series may be treated as two separate systems. These are:

- ^{220}Rn-^{216}Po: Always in the gaseous phase, and speciation is minimal, sue to the short half-life of ^{216}Po (148 ms, [LNHB(b)]). The decay of ^{220}Rn-^{216}Po 'feeds' the ^{212}Pb sub-chain.
- ^{212}Pb-^{212}Bi-^{212}Po-^{208}Tl: The first nuclide of this sub-series, ^{212}Pb is long lived enough 10,64 hours [LNHB(c)] to separate from ^{220}Rn, and behaves differently. It may be assumed that ^{212}Bi does not separate appreciably from ^{212}Pb, due to chemical similarity and shorter half-life [LNHB(d)]and that ^{212}Po and ^{208}Tl also do not separate, due to their short half-lives [LNHB(e), LNHB(f)].

Applying decay and ingrowth calculations [Bateman,1910] we find that the activity of ^{212}Pb at any time, t, after separation is given by:

$$A_{Pb,t} = A_{Rn,0} \cdot \left[\frac{T_{Rn} \cdot T_{Pb}}{(T_{Rn} - T_{Pb}) \cdot (T_{Po-216} - T_{Pb})}\right] \cdot \left[e^{-\left(\frac{\ln 2}{T_{Rn}}\right) \cdot t} - e^{-\left(\frac{\ln 2}{T_{Pb}}\right) \cdot t}\right] \qquad \text{(A3.1)}$$

Or

$$A_{Pb,t} \approx A_{Rn,0} \cdot 0{,}001459 \cdot \left[e^{-\left(\frac{\ln 2}{T_{Pb}}\right) \cdot t} - e^{-\left(\frac{\ln 2}{T_{Rn}}\right) \cdot t}\right] \qquad \text{(A3.2)}$$

Table A3.1: Parameters for decay and ingrowth calculations

Parameter	Units	Description
$A_{Rn,0}$	Bq	activity of ^{220}Rn at the time of discharge, ie $t = 0$
$A_{Pb,t}$	Bq	activity of ^{212}Pb at some time, t, after discharge
t	s	time elapsed since discharge
T_{Rn}	s	radioactive half-life of ^{220}Rn: 55,8 seconds
T_{Po-216}	s	radioactive half-life of ^{216}Po: 0,148 seconds
T_{Pb}	s	radioactive half-life of ^{212}Pb: 10,64 hours

A4] Annex 4 – Windrose for Blindern, Oslo

Table A4.1: Windrose data

Middelvind og retningen vinden kommer fra for Oslo - Blindern (SN18700) i perioden 01.2021-12.2021. (%) Mnd: 1,2,3,4,5,6,7,8,9,10,11,12																	
Middelvind (m s^{-1})	**N**	**NNØ**	**NØ**	**ØNØ**	**Ø**	**ØSØ**	**SØ**	**SSØ**	**S**	**SSV**	**SV**	**VSV**	**V**	**VNV**	**NV**	**NNV**	**SUM (%)**
0,0-0,2	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*1,0*
0,3-1,5	1,8	3,4	3,5	1,7	1,1	1	1	1	1,3	2,1	3	1,8	1,1	1,2	0,7	1,1	26,9
1,6-3,3	1,4	9,8	7,7	1,5	0,9	0,5	1	1,2	4,5	5,6	4,3	1,5	0,8	0,7	0,6	0,5	42,6
3,4-5,4	1,7	7,7	3,4	0,5	0,2	0,2	0,2	0,3	2,7	2,6	1,1	0,2	0,6	0,7	0,8	0,4	23,3
5,5-7,9	0,8	2,6	0,3	0	0	0	0	0	0,6	0,1	0,1	0,1	0,2	0,2	0,1	0,2	5,5
8,0-10,7	0,1	0,4	0,1	0	0	0	0	0	0	0	0	0	0	0	0	0	0,6
10,8-13,8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13,9-17,1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17,2-20,7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20,8-24,4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24,5-28,4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28,5-32,6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>32,6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUM (%)	5,8	24,0	15,1	3,7	2,3	1,7	2,2	2,5	9,2	10,4	8,6	3,6	2,6	2,8	2,2	2,3	**100**
Data er gyldig per 27.01.2022 (CC BY 4.0), Meteorologisk institutt (MET)																	

Assessment of radiation dose arising from ^{220}Rn discharged from Oncoinvent in Nydalen:

Additional scenarios

Summary

The doses arising from three additional ^{220}Rn discharge scenarios arising from Oncoinvent's operations at Gullhaugveien 7, Nydalen, 0484 Oslo have been calculated.

The calculation is based on currently accepted models of atmospheric dispersion of gaseous discharges, and takes into account the decay of ^{220}Rn in transit from the point of discharge to the point of exposure. The overwhelmingly significant source of dose is found to be that from inhalation of ^{220}Rn by an exposed person in each of the scenarios. Doses arising from external exposure to ^{220}Rn and from the decay products ^{212}Pb, ^{212}Bi, ^{212}Po and ^{208}Tl are insignificant compared to the ^{220}Rn inhalation dose.

The outcome of the calculations are:

- Nydalen Helsehus: 3,0 µSv y^{-1}

  60 metres from discharge point, 40 hours per week occupancy.
- Ground level: 3,6 (± 3,5) µSv y^{-1}

  60 metres from discharge point, 40 hours per week occupancy. Refer to section 6.1 for individual windrose sector data
- Nydalen Helsehus: 0,67 µSv

  40 metres from discharge point, 40 hours occupancy during a week in August 2021 when 11 GBq ^{220}Rn were released.

Contents

1] Document History

		Signature	Name	Title	Date
Version 1.2	Written by:		Simon Jerome	Forsker	2022-02-25
	Approved by:		Lindis Skipperud	Professor	2022-02-25

2] Changes

2.1] Version 1

This is the first version of this document.

3] Scope

This report details estimates the potential dose arising from ^{220}Rn discharges from the Oncoinvent facility, situated in Gullhaugveien, Nydalen, Oslo. The assessment is in response to a request for additional information from Oncoinvent and, as before, is based on commonly used calculations of dispersal of radioactive material released to the atmosphere [for example, Smith and Simmonds, 2009].

Three scenarios were specified by Oncoinvent:

- Exposed person at 60 metres from the discharge duct at Gullhaugveien 7 for 40 hours each week, which makes a continuous discharge totalling 70 GBq per year, with an exhaust outflow of 2 000 m^3 h^{-1}, plus the dose arising from the secondary discharge points near to the parkering/service area at Gullhaugveien 7 which makes a continuous discharge totalling 6 GBq per year, with an exhaust outflow of 6 000 m^3 h^{-1},
- Exposed person occupies the outside area at the Nydalen Helsehus, 60 metres distant from the discharge points for 40 hours each week with the same level of ^{220}Rn discharge, and
- Exposed person occupies the outside area at the Nydalen Helsehus, 40 metres distant from the discharge points for 40 hours during a week in August 2021 when 11 GBq of ^{220}Rn was released; it is assumed that a proportionate discharge of 0,95 GBq was made from the secondary discharge points.

4] Calculation model

The same calculation model was used as in the previous report, and will not be repeated here.

Table 1: Source of dose

Source	Units	Value	Description
^{220}Rn inhalation	Sv Bq^{-1} h^{-1} m^{3}	40×10^{-9}	Dose coefficient for ^{220}Rn [UNSCEAR 2000, p 108, paragraph 154] Vastly dominant source of dose.
^{220}Rn external γ exposure	Sv Bq^{-1} h^{-1} m^{3}	~1,3×10^{-15}	Inferred from IFE report [Nordhei, 2021, table 3].
^{220}Rn external α/β exposure	Sv Bq^{-1} h^{-1} m^{3}	Nil	Taken from IFE report [Nordhei, 2021, table 3].
^{212}Pb inhalation dose coefficient	Sv Bq^{-1} h^{-1} m^{3}	<40×10^{-9}	Unlikely to be greater than that for ^{220}Rn.
^{212}Pb external γ exposure	Sv Bq^{-1} h^{-1} m^{3}	~1,4×10^{-13}	Inferred from IFE report [Nordhei, 2021, table 3]

4.1] Common data

Table 2: Parameters common to all calculations.

Parameter	Units	Value	Description
Years	d y^{-1}	365,25	Mean day length over a 4 year cycle
^{220}Rn half life	s	55,8	Currently recommended value [LNHB(a)]
Breathing rate	m^{3} d^{-1}	20	Breathing rate for an adult [UNSCEAR 2000, p 35, paragraph 99]
	m^{3} y^{-1}	7 305	Derived from the daily breathing rate
	m^{3} h^{-1}	0,833	Derived from the daily breathing rate
^{220}Rn inhalation dose coefficient	Sv Bq^{-1} h^{-1} m^{3}	40×10^{-9}	Dose coefficient for ^{220}Rn [UNSCEAR 2000, p 108, paragraph 154]

5] Parameters of the Oncoinvent site

Ground level at the Oncoinvent site is 98,1 MOH, and the height of the discharge duct exhaust is stated to be 20 metres above this datum. The secondary discharge points (see previous reports) are taken to be 5 metres above the ground level datum for discharge point A, and 2,5 metres above the ground level datum for discharge point B.

The ground level MOH for each of the windrose points 60 metres from the discharge point is given in table 3:

Table 3: Height data

Direction	MOH (metres)	Direction	MOH (metres)	Direction	MOH (metres)	Direction	MOH (metres)
N	108,0	**Ø**	113,8	**S**	99,7	**V**	96,4
NNØ	112,4	**ØSØ**	112,1	**SSV**	99,6	**VNV**	98,0
NØ	113,4	**SØ**	111,7	**SV**	96,6	**NV**	100,0
ØNØ	114,8	**SSØ**	106,9	**VSV**	96,1	**NNV**	100,8

6] Windrose

The windrose information is taken from the Norsk klimat service sentre website [Seklima, 2022] as before and is shown in annex 1. Data for 2021 is presented and used in calculation, this being the most recent complete annual data set from the Oslo-Blindern site which is the closest to the Oncoinvent premises.

For the short-term exposure at the Nydalen Helsehus, windrose data from August 2021 was used.

7] Exposed person

7.1] Scenario 1 – 60 metre ring

Exposed person at 60 metres from the discharge duct at Gullhaugveien 7 for 40 hours each week, with the dose calculated at all points of the windrose. It can be seen that the variation in dose is ~30, this variation is due to the differences in *Δh* for all the exposure points and variation in the windrose. MOH data is taken from the Norgeskart website [Norgeskart, 2022].

The results are shown in figure 1 as a «*doserose*» and set out in table 4 (rounded to two significant figures).

Figure 1 – «Doserose» at 60 metres

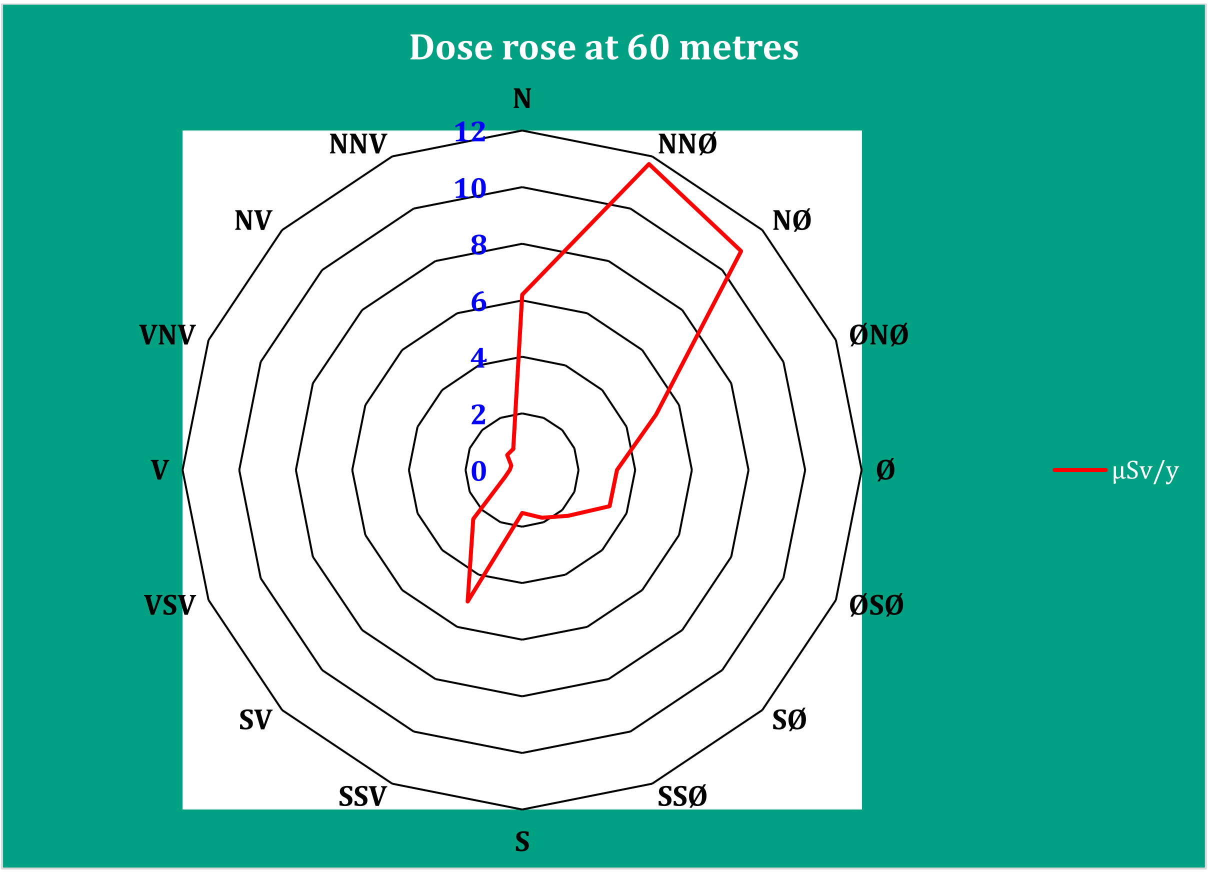

Table 4: Annual dose at 60 metres, exposed person at ground level

Direction	MOH (metres)	*Δh* (metres)	Contributing values			Total (µSv y⁻¹)
			Stack (µSv y⁻¹)	Point A (µSv y⁻¹)	Point B (µSv y⁻¹)	
N	108,0	-10,1	5,7	0,22	0,28	**6,2**
NNØ	112,4	-5,7	11,4	0,14	0,20	**11,7**
NØ	113,4	-4,7	10,7	0,10	0,15	**11,0**
ØNØ	114,8	-3,3	5,0	0,03	0,05	**5,1**
Ø	113,8	-4,3	3,3	0,03	0,04	**3,4**
ØSØ	112,1	-6,0	3,2	0,04	0,06	**3,3**
SØ	111,7	-6,4	2,2	0,03	0,05	**2,3**
SSØ	106,9	-11,2	1,6	0,08	0,11	**1,8**
S	99,7	-18,4	0,91	0,31	0,30	**1,5**
SSV	99,6	-18,5	3,0	1,0	1,0	**5,0**

Direction	MOH (metres)	Δh (metres)	Contributing values			Total (µSv y[-1])
			Stack (µSv y[-1])	Point A (µSv y[-1])	Point B (µSv y[-1])	
SV	96,6	-21,5	1,1	0,73	0,65	**2,5**
VSV	96,1	-22,0	0,27	0,21	0,18	**0,66**
V	96,4	-21,7	0,19	0,13	0,12	**0,44**
VNV	98,0	-20,1	0,21	0,11	0,10	**0,41**
NV	100,0	-18,1	0,46	0,14	0,14	**0,75**
NNV	100,8	-17,3	0,53	0,14	0,14	**0,81**

An average value of 3,6 µSv y^{-1} may be derived, but this is subject to a large standard deviation of ± 3,5 µSv y^{-1}.

7.2] Scenario 2 – Nydalen Helsehus

The exposed person, identified by Oncoinvent, is one who spends some of their time outside of the Nydalen Helsehus.

The exposure angle is taken as $\frac{\pi}{4}$ radians with the wind coming from sectors NV and VNV sectors of the windrose.

The exposed person does not occupy the exposure point, 60 metres from the discharge point, at all times, but is expected to be in that position for 40 hours per week.

Table 5: Calculation input data

Parameter	Units	Value	Description
Q_0	Bq s^{-1}	2 410	Discharge rate
α_i	Radians	$\frac{\pi}{4}$	Angle of discharge, windrose sector
x	m	60	Distance to exposed person
$u_{i,1}$	m s^{-1}	0,1 *(0,0-0,2)*	Average wind speed in sector with meteorological condition 1
$u_{i,2}$	m s^{-1}	0,9 *(0,3-1,5)*	Average wind speed in sector with meteorological condition 2
$u_{i,3}$	m s^{-1}	2,45 *(1,6-3,3)*	Average wind speed in sector with meteorological condition 3
$u_{i,4}$	m s^{-1}	4,4 *(3,4-5,4)*	Average wind speed in sector with meteorological condition 4
$u_{i,5}$	m s^{-1}	6,7 *(5,5-7,9)*	Average wind speed in sector with meteorological condition 5
$f_{i,1}$	none	0,1%	Frequency of meteorological condition 1
$f_{i,2}$	none	1,8%	Frequency of meteorological condition 2
$f_{i,3}$	none	1,5%	Frequency of meteorological condition 3
$f_{i,4}$	none	1,5%	Frequency of meteorological condition 4
$f_{i,5}$	none	0,4%	Frequency of meteorological condition 5
z	m	113,0	Mouth/nose height at exposure point, expressed as MOH
h_e	m	118,1	Effective discharge stack height, expressed as MOH
		103,1	Effective discharge point A height, expressed as MOH
		101,1	Effective discharge point B height, expressed as MOH
Occupancy	h y^{-1}	2 087	Assuming an occupancy of 40 hours each week.

Parameter	Units	Value	Description
Stability class	none	C	Assumed 50%
		D	Assumed 50%
Roughness length	m	4	Assumed due to the complexity of the area.

Using these parameters an annual dose of 3,0 μSv y^{-1} from all ^{220}Rn discharges is obtained for ^{220}Rn exposure with this occupancy pattern.

7.3] Scenario 3 – Short term release, exposure at Nydalen Helsehus

The exposed person, identified by Oncoinvent, is one who spends some of their time outside of Nydalen Helsehus house, 40 metres from the building where Oncoinvent is situated. The house is shown in figure 4.

The exposure angle is taken as $\frac{\pi}{4}$ radians corresponding to wind *from* the NV and VNV sector of the windrose.

The exposed person does not occupy the exposure point at all times, but is expected to be in that position for 40 hours during the week of discharge.

In this period, 11 GBq of ^{220}Rn was released, equivalent to a release of 18,2 kBq s^{-1} from the discharge stack; it is assumed that a proportionate discharge of 0,95 GBq was made from the secondary discharge points.

Table 6: Calculation input data

Parameter	Units	Value	Description
Q_0	Bq s^{-1}	18 200	Discharge rate
α_i	Radians	$\frac{\pi}{4}$	Angle of discharge, from windrose sector Ø
x	m	40	Distance to exposed person
$u_{i,1}$	m s^{-1}	0,1 *(0,0-0,2)*	Average wind speed in sector with meteorological condition 1
$u_{i,2}$	m s^{-1}	0,9 *(0,3-1,5)*	Average wind speed in sector with meteorological condition 2
$u_{i,3}$	m s^{-1}	2,45 *(1,6-3,3)*	Average wind speed in sector with meteorological condition 3
$u_{i,4}$	m s^{-1}	4,4 *(3,4-5,4)*	Average wind speed in sector with meteorological condition 4
$f_{i,1}$	none	0,13%	Frequency of meteorological condition 1
$f_{i,2}$	none	1,4%	Frequency of meteorological condition 2
$f_{i,3}$	none	2,2%	Frequency of meteorological condition 3
$f_{i,4}$	none	0,3 %	Frequency of meteorological condition 4
z	m	112,4	Mouth/nose height at exposure point above ground at discharge point for exposed person
h_e	m	118,1	Effective discharge stack height, expressed as MOH
		103,1	Effective discharge point A height, expressed as MOH
		101,1	Effective discharge point B height, expressed as MOH
Occupancy	h	40	Assuming an occupancy of 40 hours each week.
Stability class	none	C	Assumed 50%
		D	Assumed 50%
Roughness length	m	4	Assumed due to the complexity of the structure.

Using these parameters a dose of 0,67 μSv is obtained for ^{220}Rn exposure with this occupancy pattern.

8] Conclusions

Using the generally accepted equations for dispersal of radioactive gases from a discharge stack, the doses to an exposed person occupying the relevant area for 40 hours each week are as follows:

- Nydalen Helsehus at 60 metres: 3,0 μSv y^{-1}
- Distance of 60 metres: Mean value of 3,6 (± 3,5) μSv y^{-1} where $k = 1$.
  The mean value is provided for information; the data given in section 6.1 provides data for each sector of the windrose.

For a short term release of 11 GBq during one week in August 2021

- Nydalen Helsehus at 40 metres: 0,67 μSv

All other doses from cloud exposure to ^{220}Rn and ^{212}Pb as well as ground exposure are insignificant compared to these doses.

9] References

Norgeskart, 2022. https://www.norgeskart.no/

Nordhei, C., 2021. *Beregning av doser til allmennheten fra mulig utslipp av ^{220}Rn i 2020 og 2021*. Institutt for Energiteknikk rapport nummer 52598, versjon 1, Kjeller, Norge

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UNSCEAR, 2000. *Sources and effects of ionizing radiation, volume 1 - sources*. United Nations report number E.00.IX.3, ISBN 92-1-142238-8, New York, United States of America

A1] Annex 1 – Windrose for Blindern, Oslo

Table A1.1: Windrose data for 2021

Middelvind og retningen vinden kommer fra for Oslo - Blindern (SN18700) i perioden 01.2021-12.2021. (%) Mnd: 1,2,3,4,5,6,7,8,9,10,11,12																	
Middelvind (m s^{-1})	**N**	**NNØ**	**NØ**	**ØNØ**	**Ø**	**ØSØ**	**SØ**	**SSØ**	**S**	**SSV**	**SV**	**VSV**	**V**	**VNV**	**NV**	**NNV**	**SUM (%)**
0,0-0,2	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*1,0*
0,3-1,5	1,8	3,4	3,5	1,7	1,1	1,0	1,0	1,0	1,3	2,1	3,0	1,8	1,1	1,2	0,7	1,1	26,9
1,6-3,3	1,4	9,8	7,7	1,5	0,9	0,5	1,0	1,2	4,5	5,6	4,3	1,5	0,8	0,7	0,6	0,5	42,6
3,4-5,4	1,7	7,7	3,4	0,5	0,2	0,2	0,2	0,3	2,7	2,6	1,1	0,2	0,6	0,7	0,8	0,4	23,3
5,5-7,9	0,8	2,6	0,3	0,0	0,0	0,0	0,0	0,0	0,6	0,1	0,1	0,1	0,2	0,2	0,1	0,2	5,5
8,0-10,7	0,1	0,4	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,6
10,8-13,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
13,9-17,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
17,2-20,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
20,8-24,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
24,5-28,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
28,5-32,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
>32,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
SUM (%)	5,8	24,0	15,1	3,7	2,3	1,7	2,2	2,5	9,2	10,4	8,6	3,6	2,6	2,8	2,2	2,3	**100**
Data er gyldig per 27.01.2022 (CC BY 4.0), Meteorologisk institutt (MET)																	

Table A1.2: Windrose data for August 2021

Middelvind og retningen vinden kommer fra for Oslo - Blindern (SN18700) i perioden 08.2021-08.2021. (%)																	
Middelvind (m s-1)	**N**	**NNØ**	**NØ**	**ØNØ**	**Ø**	**ØSØ**	**SØ**	**SSØ**	**S**	**SSV**	**SV**	**VSV**	**V**	**VNV**	**NV**	**NNV**	**SUM (%)**
0,0-0,2	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*0,06*	*1,0*
0,3-1,5	1,7	2,8	2,1	0,7	1,1	0,4	1,8	1,4	1,3	2,1	2,1	0,4	0,7	0,7	0,1	1,0	20,3
1,6-3,3	1,4	10,4	6,1	0,4	1,0	0,0	0,4	1,3	5,6	6,8	6,9	1,8	0,4	1,8	0,8	0,8	46,0
3,4-5,4	2,6	8,5	3,3	0,3	0,4	0,6	0,1	0,1	3,2	2,2	0,6	0,0	0,0	0,3	0,3	0,1	22,6
5,5-7,9	2,5	4,9	1,1	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,3	9,2
8,0-10,7	0,3	1,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,4
10,8-13,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
13,9-17,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
17,2-20,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
20,8-24,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
24,5-28,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
28,5-32,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
>32,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
SUM (%)	8,5	27,5	12,8	1,5	2,6	1,0	2,4	2,8	10	11,1	9,7	2,2	1,1	2,8	1,3	2,2	100
Data er gyldig per 25.02.2022 (CC BY 4.0), Meteorologisk institutt (MET)																	