Radon-related lung cancer cases in Swedish above-ground workplaces

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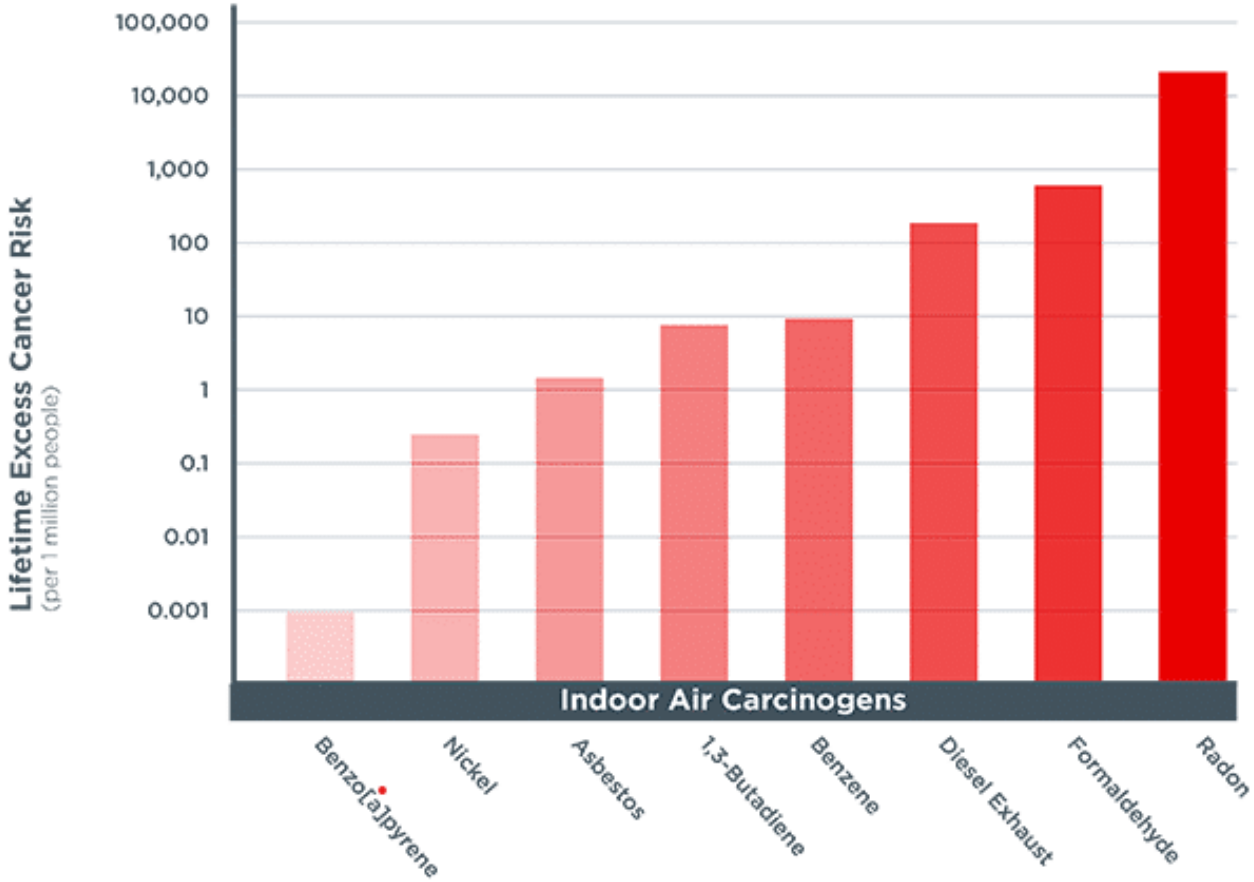
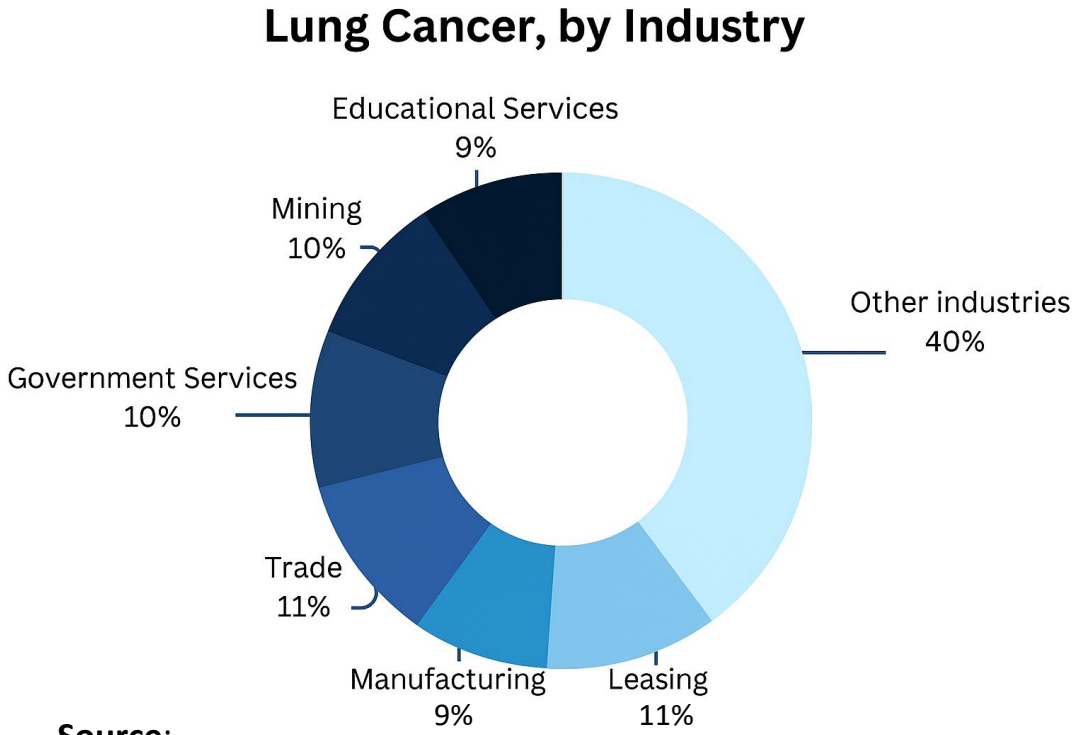
Indoor Environments ™ 2025 - Radon and Vapor Intrusion Symposium

Occupational exposure – Canada

- About **3,200 radon-related lung cancer cases (16%)** per year in Canada (population ~40 million)
- About **190 cases (6%)** linked to radon at the workplace
- **190,000 workers** exposed to radon levels above the Canadian reference value of **5.4 pCi/L** (200 Bq/m³)





Source:

- Setton et al. (2013) *Environmental Health*, 12:15
- https://www.occupationalcancer.ca/radon/
- https://www.carexcanada.ca/profile/radon-occupational-exposures/

Risk of lung cancer

- From the Swedish Radiation Safety Authority (SSM): **14% of lung cancer cases in Sweden are caused by ^{222}Rn**
  - Corresponds to about **500 cases per year** (population ~5.5 million)
  - About **10% of these are non-smokers**

The risk of lung cancer increases **16% for every 2.7 pCi/L (100 Bq/m³).**

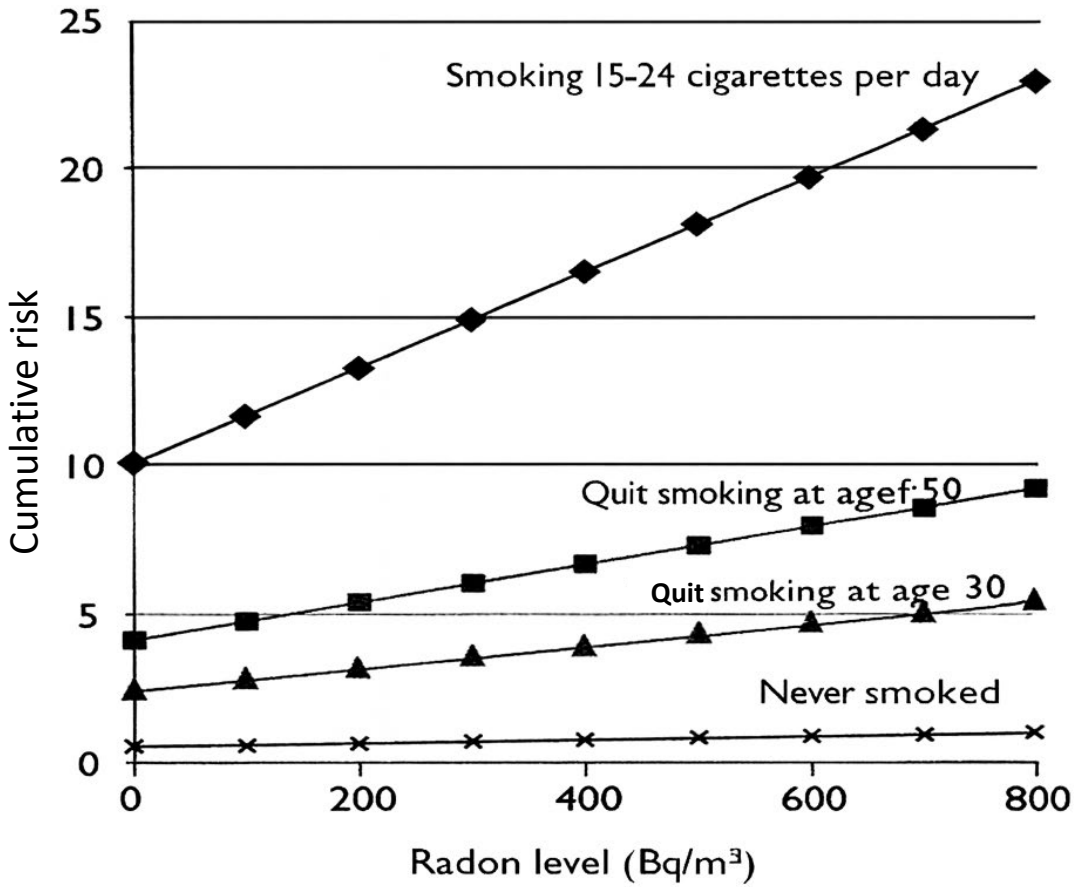


Fig 2. Risk of developing lung cancer by the age of 75 at different indoor radon levels and smoking habits.

1/2005 SSM

Estimated number of work-related deaths per year (15 years old and older)

Faktor	Antal arbetsrelaterade dödsfall per år		
	Kvinnor	Män	Totalt
Olycksfall	4,0	33,0	37,0
Stress	360,3	412,2	772,4
Skiftarbete	280,9	446,8	727,7
Damm (KOL)	246,6	174,8	421,4
Asbest	45,0	222,5	267,5
Kvarts	9,0	116,2	125,2
Motoravgaser	222,7	324,7	547,4
Passiv rökning	75,2	119,6	194,8
Svetsrök	32,0	39,0	71,0
Joniserande strålning	1,0	3,8	4,8
Osäkrare samband			
Buller	338,4	439,0	777,4
Ihållande fysiskt tungt arbete	0,0	1 548,8	1 548,8

Swedish Work Environment Authority (SWEA): Table 16

Work-related mortality in Sweden – subreports 1 and 2 (RAP 2019:3 and 2019:4), knowledge compilations

4.8 **work-related deaths per year due to ionizing radiation?**

How was this estimate reached?

Estimated number of work-related deaths per year (15 years old and older)

Faktor	Antal arbetsrelaterade dödsfall per år		
	Kvinnor	Män	Totalt
Joniserande strålning	1.0	3.8	4.8

Swedish Work Environment Authority:

Work-related mortality in Sweden – subreports 1 and 2 (RAP 2019:3 and 2019:4), knowledge compilations

4.8 work-related deaths per year?

How was this estimate reached?

Data: SWEA used data from underground workers only

- About **10,000 people** regularly **work underground (0.2% of the working population)**
- 3,700 lung cancer cases per year (roughly doubled risk at 1000 Bq/m³ and 40 years of work)
- Assumed average radon concentration of ~**17.5 pCi/L (650 Bq/m³) – too high!**
- The estimate of **4.8 radon-related deaths per year** in underground work is an **overestimate**

Estimated number of work-related deaths per year (15 years old and older)

Faktor	Antal arbetsrelaterade dödsfall per år		
	Kvinnor	Män	Totalt
Joniserande strålning	1,0	3,8	4,8

Swedish Work Environment Authority:

Work-related mortality in Sweden – subreports 1 and 2 (RAP 2019:3 and 2019:4), knowledge compilations

4.8 work-related deaths per year?

How was this estimate reached?

Data: underground workers

- About **10,000 people** regularly **work underground (0.2% of the working population)**

What about the **99.8%** of workers who work above ground?

Shouldn't risk estimates be made for these workplaces as well?

Radon Oversight in Swedish Workplaces

Authorities

- **AV (Arbetsmiljöverket / Work Environment Authority)** – Enforces *Arbetsmiljölagen (AML)*
- **SSM (Strålsäkerhetsmyndigheten / Radiation Safety Authority)** – Enforces *Radiation Protection Act*

Limit

~9,700 pCih/L (**0.36 MBq m^{-3} h**; above ground WP)

= Equivalent to **5.4 pCi/L over 1800 work h/y**

F = 0.4 – 0.5 → ~0.23 – 0.29 WLM/yr

The employer is responsible for compliance with the regulations. 'Not knowing' by itself is a violation.

Rules

Measure radon: Employers must measure ≥2 months (Oct–Apr)

Reference level: **5.4 pCi/L** (annual average, work hours)

<5.4 pCi/L: Oversight by AV (AML)

>5.4 pCi/L: AV (AML) + SSM (Radiation Protection Act)

Employer duties:

Reduce levels if **>5.4 pCi/L**

Notify SSM if cannot reduce

Identify & monitor exposed workers

Re-checks

Recommended every 10 years or after major renovations

Radon measurements at Swedish workplaces - measurement protocol

Reference value: 5.4 pCi/L (200 Bq/m^3)

The first step, the “annual” average value measurement, takes place over a period of at least 2 months:

- Measurement during the heating period **October-April**
- Floors with ground contact:
  - Measurement in at **least every 5th room** and at **least 1 measuring point per 2,153 ft^2** (200 m^2) .
- Upper floor: At least one measuring point per ~2,153 ft^2 (200 m^2)

If the first long-term radon measurement in a building with time-controlled ventilation exceeds the reference value, further investigations can be carried out with time-resolved radon measuring devices in a so-called **follow-up measurement** according to the measurement protocol in workplaces by SSM.

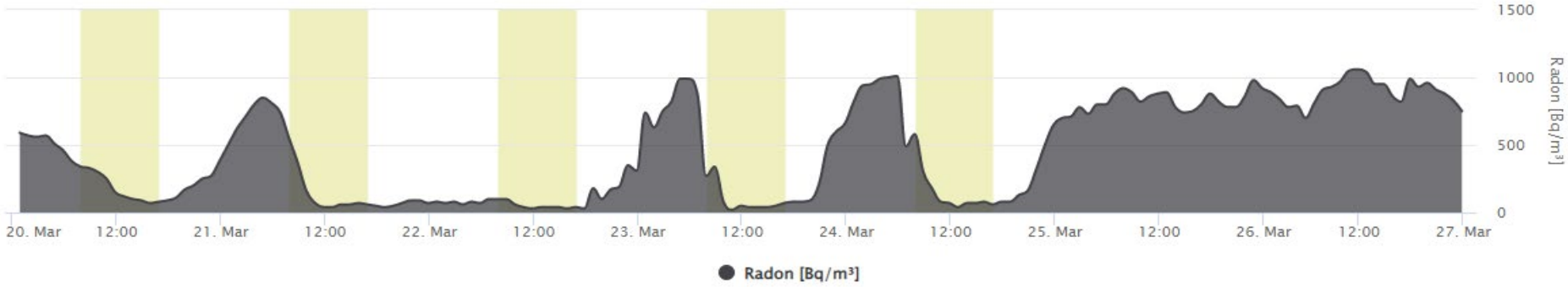
Estimated long-term average during working hours

The follow-up measurement **must**:

- be carried out during the **same measurement conditions**
- provide **two different radon results**, the average radon value during the working day and the average radon value during the entire measurement period (7 days)*.

Long-term measurements with nuclear track detectors

Time-resolved measuring device for follow-up measurements



Average in selection
100 ± 20 Bq/m³

Average level for all points
450 ± 60 Bq/m³

Factor
0.22

X

Previous long term measurement
550 Bq/m³

=

Corrected result from previous long term measurement
130 Bq/m³

Corrected result of the previous long-term measurement

=

Previous long-term measurement (LT)

X

Average level during occupation (ST_{OH})

Average level during the measurement period (ST)

Turtiainen et al. (2021) Improving the assessment of occupational exposure to radon in above-ground workplaces. Radiation Protection Dosimetry Vol. 196. No. 1-2, pp. 44-52.

Swedish workplaces – different WORKPLACE types (Radon LT measurements with 5 or more measurement points – analyzed by Radonova 2017-2020)

Workplace type	No.	Mean no. of measure points per measurement	Median (pCi/L; Bq/m³)		Average (pCi/L; Bq/m³ + 1 SD)		Median over 5.4 pCi/L	Some values over 5.4 pCi/L*	Highest value** (pCi/L; Bq/m³)	
Gen. Overview	**3347**	**12.5**	**2.1**	***79***	**2.9**	**106 (75%)**	**7.1%**	**34%**	**>946**	***> 35,000***
Office	639	14.1	2.2	*80*	3	110 (78%)	6.6%	35%	324	*12,200*
Industry	307	13.4	2.1	*76*	3	100 (75%)	9.4%	31%	>946	*> 35,000*
School	1005	12.7	2.1	*76*	2.8	105 (81%)	6.0%	**40%**	603	*22,300*
Daycare & Preschool	665	9.0	1.7	*62*	2	73 (60%)	4.5%	24%	90	*3,330*
Nursing homes	234	13.3	**0.9**	***35***	1.3	49 (78%)	2.6%	19%	**64**	***2,350***
Water works	*25*	*11.3*	*9.5*	*350*	*17*	*630 (102%)*	*44%*	*72%*	*>722*	*> 26,700*
Tunnels	*39*	*11.8*	*13.7*	*507*	*15.4*	*569 (69%)*	*44%*	*69%*	*150*	*5,550*

* **2018-2020 from all 11,000 workplaces: 24% of workplaces had some value above 5.4 pCi/L (200 Bq/m³)**

** from all measurement points analyzed 2018–2020

DATA: Rönnqvist, T. (2021). *Analysis of radon levels in Swedish dwellings and workplaces*. Report number: 2021:28. ISSN:2000-0456. Available at: www.ssm.se

Swedish workplaces – ventilation types (Radon LT measurements with 5 or more measurement points – analyzed by Radonova 2017-2020)

Ventilation Type	No.	Mean no. of measure points per measurement	Median (pCi/L; Bq/m³)		Average (pCi/L; Bq/m³ + 1 SD)		Median over 5.4 pCi/L	Some values over 5.4 pCi/L*
Gen. Overview	**3347**	**12.5**	**2.1**	**79**	**2.9**	***106 (75%)***	**7.1%**	**34%**
Mechanical exhaust F	72	11.5	2.1	*77*	2.9	*106 (78%)*	12.5%	47%
Mechanical exhaust with heat recovery FX	79	14.5	2.1	*79*	2.6	*96 (75%)*	10.1%	39%
Mechanical supply and exhaust ventilation FT	476	11.1	2.5	*93*	3.3	*123 (72%)*	9%	32%
Mechanical supply and exhaust ventilation with heat recovery FTX	**1344**	12.6	1.8	*65*	2.3	*86 (74%)*	5.3%	31%
Natural draft S	105	10.3	**5.7**	***211***	6.1	*227 (58%)*	21%	46%

DATA: Rönnqvist, T. (2021). *Analysis of radon levels in Swedish dwellings and workplaces*. Report number: 2021:28. ISSN:2000-0456. Available at: www.ssm.se

Follow-up measurements at Swedish workplaces

Follow-up measurements from Radonova's radon database between 2022-2024.

Measuring devices "rented" and returned to Radonova.

The measuring method is accredited according to ISO 17025.

Data presented at conferences in Dresden (Germany) and Orlando (USA) in 2024.

332 measurements (216 schools/kindergartens, 100 offices/industry, 16 others) with **time-controlled mechanical supply and exhaust ventilation** (with or without heat recovery):

- Mean factor ‘office’ **0.51 ±0.23**
- Mean factor ‘industry’ **0.66 ±0.28**
- Mean factor ‘school’ **0.38 ±0.31**
- Mean factor ‘daycare’ **0.28 ±0.22**

Corrected result of the previous long-term measurement

=

Previous long-term measurement (LT)

x

Average level during occupation (ST_{OH})

Average level during the measurement period (ST)

Swedish workplaces – WORKPLACE types

(Radon measurements with 5 or more measurement points – analyzed by Radonova 2017-2020)

Workplace type	No.	Mean no. of measure points per measurement	Average (pCi/L; Bq/m³)		"Factor" (*)	Average during working hours (pCi/L; Bq/m³)(**)	
Gen. Overview	**3347**	**12.5**	**2.9**	***(106)***	**0.41**	**1.6**	***(58)***
Office	639	14.1	3	*(110)*	0.51	1.7	*(64)*
Industry	307	13.4	2.7	*(100)*	0.66	1.8	*(68)*
School	1005	12.7	2.8	*(105)*	0.38	1.3	*(48)*
Daycare - Preschool	665	9.0	2	*(73)*	0.28	0.7	*(26)*

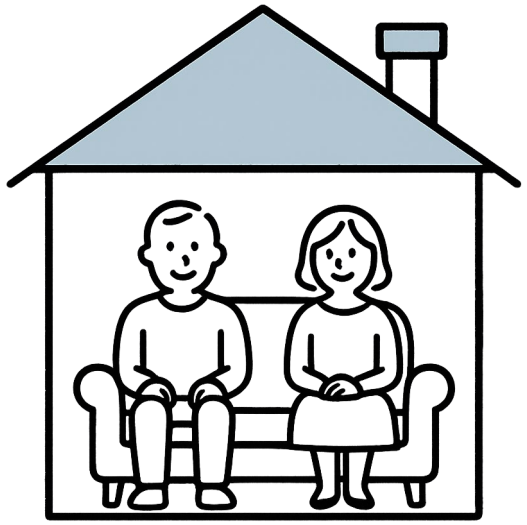
(*) Factor between Rn conc during WH and the entire measurement period, from follow-up measurements 2022-2024
(**) Factor not used if the ventilation type was natural draft

- measurement points >5.4 pCi/L from long-term measurements: **9.6%**
- Proportion of measurement points >5.4 pCi/L **after** correction with factor: **3.6%**

Estimate in Canada for percentage of workers working in concentrations above 150 Bq/m³ (~4.1 pCi/L): 4.8%
(International Archives of Occupational and Environmental Health (2020) 93:871–876 , *Estimating the burden of lung cancer in Canada attributed to occupational radon exposure using a novel exposure assessment method)*

Estimate of work-related lung cancer cases - METHODS

(based on Swedish risk estimates and measurement data from Radonova)



Indoor time share:

- 20 h indoors / day → 7,300 h / year
- 1,440 h at work / year ÷ 7,300 h = 0.20 → 20% of indoor time at work
- Only ~50% of the population works → 0.20 × 0.5 = **10%** of total lifetime indoors at work

Radon levels:

- Radon levels: National home average = 83 Bq/m³
- Workplace average = 58 Bq/m³

Risk attribution:

- Total radon-related lung cancer cases (SSM) = 500 / year
- Weighted by exposure ratio (58/83) × 10 % × 500 ≈ **35 work-related cases**

If ignoring post-retirement years:

- Workplace time share rises to 12.4%

  (58/83) × 12.4% × 500 ≈ **43 work-related cases**.

Estimated **35–40 lung cancer cases** per year in Sweden linked to workplace radon exposure.

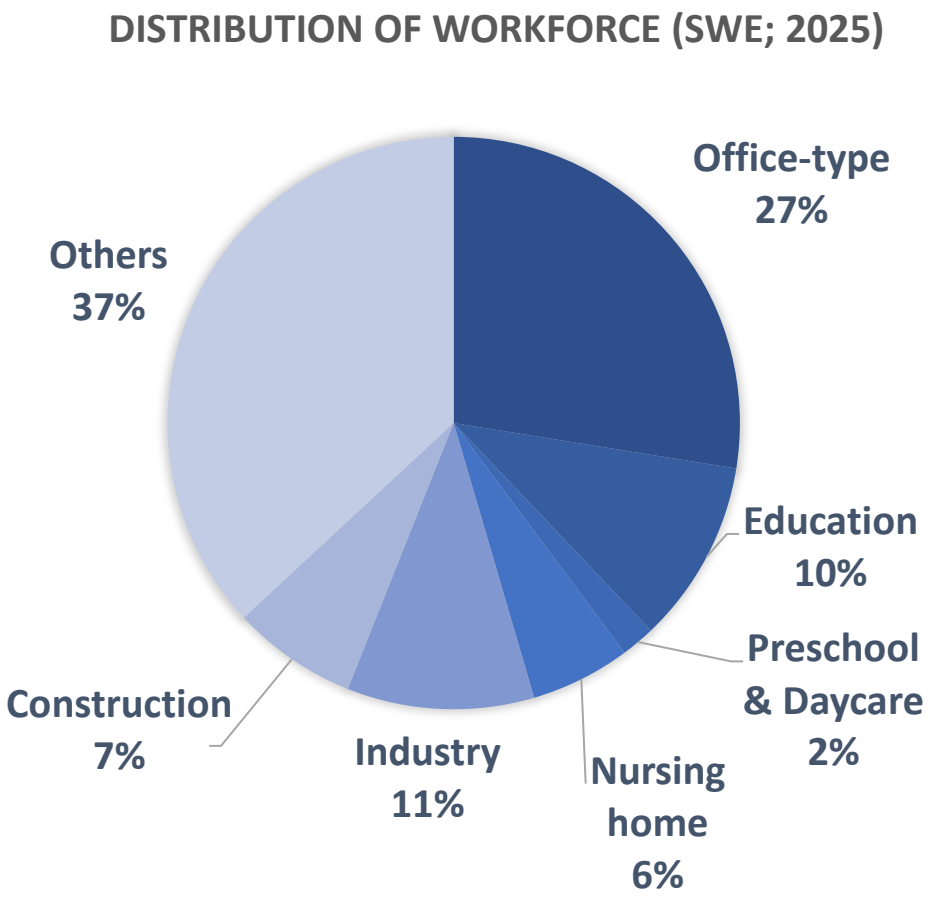
Estimate of work-related lung cancer cases – METHODS

(based on Swedish risk estimates and measurement data from Radonova)

Workplace type	No. of employees	Average during working hours 12.4% (pCi/L; Bq/m³)	
Office	1,465,115	1.3	*48*
Education	551,590	~1	*36*
Preschool & Daycare	102,000	0.5	*19*
Nursing home	300,000	1	*37*
Industry	562,000	1.4	*51*
Construction	376,000	0.2	*7*
Others	1,963,295	1.2	*43*

Estimated radon-attributable lung cancers by occupation:

$(Rn_{field}/83) \times 12.4\% \times 500 \times (\text{No. WF in field}/5{,}320{,}000) \approx$ work-related cases per field



Data sources: SCB *(Statistics Sweden);* ***AKU/LFS*** *(Labour Force Surveys, 5.32 M employed aged 15–74 yrs, Aug 2025);* ***RAMS*** *(Register-based Labour Market Statistics).*

Estimate of work-related lung cancer cases – RESULTS

(based on Swedish risk estimates and measurement data from Radonova)

Workplace type	No. of employees	Average during working hours 10% (pCi/L; Bq/m3)		Average during working hours 12.4% (pCi/L; Bq/m³)		Rn-attributable lung cancers by occupation
Office	1,465,115	1.1	39	1.3	*48*	**13**
Education	551,590	0.8	29	~1	*36*	**4**
Preschool & Daycare	102,000	0.4	16	0.5	*19*	**0**
Nursing home*	300,000	0.8	30	1	*37*	**2**
Industry	562,000	1.1	41	1.4	*51*	**5**
Construction**	376,000	0.2	6	0.2	*7*	**1**
Others	1,963,295	0.9	35	1.2	*43*	**16**

Total **41**

VS

SWEA = 4.8 work-related deaths per year due to ionizing radiation!

**Radon concentration not factor adjusted; **Assumed outdoor radon concentration*

Underestimation of radon's occupational impact in above-ground workplaces in Sweden

- National statistics **exclude** above-ground workplaces from radon-related cancer estimates
- Swedish Work Environment Authority lists only 4.8 deaths under "ionizing radiation"
- Our analysis suggests ≈41 cases/year (~**8% of all lung cancers**) — **a tenfold underestimation**
  - With offices most affected (13/41 cases)
- Our conclusions align with the Canadian estimate of **6% lung cancer cases** linked to radon exposure at workplaces = validation of our method

Thank you for your attention

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