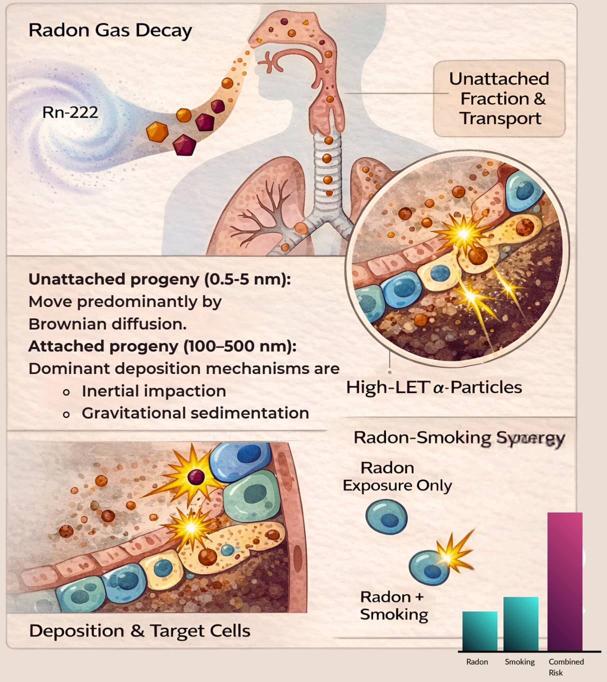
The Biological Hazard

From inhalation to cellular dose



The radiological hazard of radon arises primarily from its solid, short-lived decay products (^{218}Po, ^{214}Pb, ^{214}Bi).

Ultrafine, unattached progeny deposit efficiently in the bronchial epithelium, where alpha-particle emissions deliver high localized doses to basal and secretory cells. Combined exposure to radon and tobacco smoke results in a multiplicative increase in lung cancer risk.

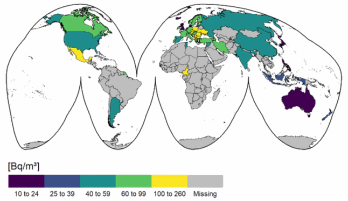
High-LET alpha irradiation of bronchial epithelium is the dominant pathway for radon induced lung cancer

Global Data & Reference Levels

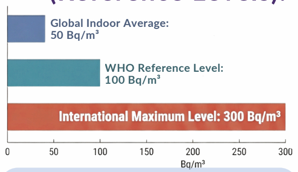
Radiological Parameter	India	Worldwide
Activity Concentration of ^{222}Rn in Indoor Air	40 Bq/m³	50 Bq/m³
Activity Concentration of ^{222}Rn in Outdoor Air	Range:(10-36.6) Bq/m³	10.0 Bq/m³
Equilibrium Equivalent Concentration (EEC) of ^{222}Rn Outdoors	13.0 Bq/m³ Range:(6.8–24.2) Bq/m³	6.6 Bq/m³
Activity Concentration of ^{220}Rn in Indoor Air	79 Bq/m³ Range:(10-171) Bq/m³	8-28 Bq/m³
Equilibrium Equivalent Concentration (EEC) of ^{220}Rn Outdoors	1.65 Bq/m³ Range:(0.98–3.27) Bq/m³	0.3 Bq/m³
Activity Concentration of ^{222}Rn in Drinking Water	Range:(1.2- 87.2) Bq/L	10 Bq/L
Activity Concentration of ^{238}U in Soil	27 Bq/kg	30 Bq/kg
Activity Concentration of ^{232}Th in Soil	54 Bq/kg	42 Bq/kg
Activity Concentration of ^{40}K in Soil	471 Bq/kg	512 Bq/kg
Absorbed Gamma Dose Rate in Air	52 nGy/h	49 nGy/h

Global Radon Levels:

National indoor averages are typically 25–59 Bq/m³, with some ≥ 60 Bq/m³ and fewer ≥ 100 Bq/m³



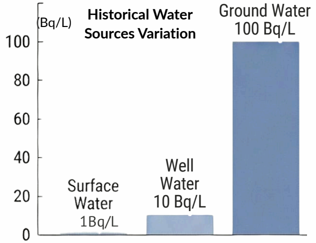
Radon in Air (Reference Levels):



HBRA: India's average indoor radon (40 Bq/m³) is slightly below the global mean. However, Th^{232} in Indian soils (54 Bq/kg vs 42 Bq/kg global), contributes to higher effective doses (>3mSv/y) in dwellings, especially in Areas HBRAs like Kerala and Odisha.

Radon in Water (Reference Levels):

Radon concentration in drinking water reflects local uranium distribution, aquifer lithology, porosity, and groundwater residence time. Surface waters typically exhibit low levels due to continuous atmospheric degassing, whereas confined aquifers can retain elevated concentrations.



Rn-222: Assessment & Mitigation

From Concentration to Dose

Assessment Framework

Pulmonary Deposition (Lung Dose):

Inhalatoin dose due to gas and short-lived progeny.

$$E_{inh} = [(C_{gas} \times DCF_{gas}) + (C_{gas} \times EF \times DCF_{progeny})] \times T$$

E_{inh}: Annual Effective Dose from inhalation (mSv/y)
C_{Rn}: Activity Concentration of ^{222}Rn in air (Bq/m³)
EF: Equilibrium Factor (0.4 indoors / 0.6 outdoors)
T: Occupancy Time (hours/year).
Standard: 7,000 h (Indoor) / 1,760 h (Outdoor)

$DCF_{progeny}$: Dose Conversion Factor for equilibrium equivalent concentration. Value: 9 nSv/(Bq·h·m^{-3})
DCF_{gas}: Dose Conversion Factor for gas. Value: 0.17 nSv per Bq·h·m^{-3}

Estimation of annual dose (E) from Rn^{222} and Rn^{220}

Source	Global Average Concentration	Average Effective Dose (mSv/y)	Total (mSv/y)	Dose Range (mSv/y)
Radon – Indoor Air	50 Bq/m³	Lung: 1.26; Tissue: 0.06	1.32	0.3-7
Radon – Outdoor Air	10 Bq/m³	Lung:0.095; Tissue: 0.0032	0.10	0.01-0.5
Total Radon	—	—	1.42	0.3-7.5
Thoron – Indoors	1.2 Bq/m³ EECT	Lung: 0.336 Tissue: 0.008	0.34	0.15-3
Thoron – Outdoors (EECT 0.3 Bq/m³)	0.3 Bq/m³ EECT	Lung: 0.02 Tissue: 0.002	0.02	0.01-0.15
Total Thoron	—	—	0.36	0.15-3.2
Terrestrial Radionuclides		0.006	0.006	
Total Dose due to ^{222}Rn + ^{220}Rn = **1.8 mSv/y**				

(Compare to the world avg natural background of 3 mSv/y)

Key Takeaway

- Radon exposure depends on source strength, transport, and indoor accumulation.
- Radon dose is dominated by short-lived alpha-emitting progeny, not radon gas itself.
- Accurate assessment requires integrated radon physics.
- Effective mitigation must interrupt radon transport pathways

RADON: An Information Guide

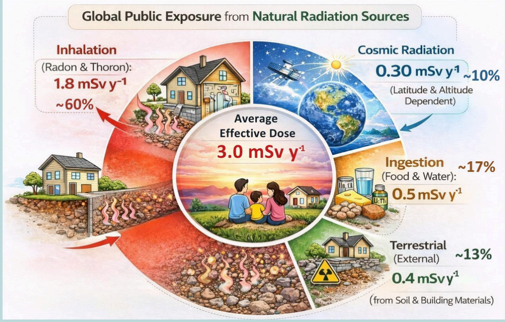
EnvRad 2026

- Bhabha Atomic Research Centre

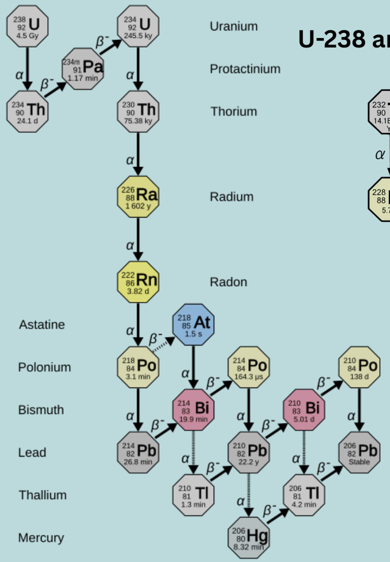
Radon as Natural Radiation

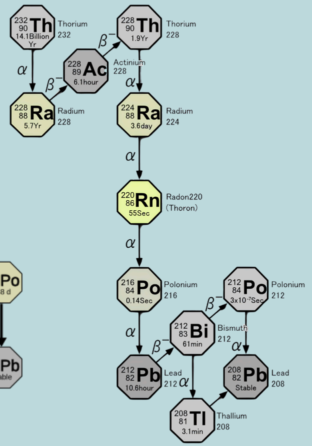
Natural radiation arises from cosmic rays, terrestrial radionuclides, and internal radionuclides. Among these, radon and thoron dominate internal exposure.

Radon (Rn-222) is the largest contributor in the background radiation Study. According to UNSCEAR 2024, it accounts for 60% of the total annual effective dose received by the global population.



U-238 and Th-232 Decay Series





Radon as Natural Radiation (Continued..)

U-238 Decay Series

Nuclide	α (MeV, %)	β (MeV, %)	γ (MeV, %)
Uranium-238	4.15 (25%), 4.20 (75%)	-	-
Thorium-234	-	0.103 (21%), 0.193 (79%)	0.063 (3.5%), 0.093 (4%)
Protactinium-234	-	2.29 (98%)	0.765 (0.30%), 1.001 (0.60%)
Uranium-234	4.72 (28%), 4.77 (72%)	-	0.053 (0.2%)
Thorium-230	4.62 (24%), 4.68 (76%)	-	0.068 (0.6%), 0.142 (0.07%)
Radium-226	4.785 (94%), 4.602 (6%)	-	0.186 (4%)
Radon-222	5.490 (100%)	-	0.510 (0.07%)
Polonium-218	6.003 (99.98%)	0.33 (~0.019%)	
Lead-214	-	0.650 (50%), 0.71 (40%), 0.98 (6%)	0.292 (19%), 0.352 (36%)
Bismuth-214	-	up to 3.26 MeV	-
Polonium-214	7.687 (100%)	-	-
Lead-210	-	0.015 (81%)	-
Bismuth-210	-	1.161 (100%)	-
Polonium-210	5.303 (100%)	-	-

Th-232 Decay Series

Nuclide	α (MeV, %)	β (MeV, %)	γ (MeV, %)
Thorium-232	3.95 (24%), 4.01 (76%)	-	-
Radium-228	-	0.055 (100%), 1.18 (35%)	34 (15%)
Actinium-228	-	1.75 (12%), 2.09 (12%)	0.908 (25%), 0.96 (20%)
Uranium-234	4.72 (28%), 4.77 (72%)	-	0.053 (0.2%)
Thorium-228	5.34 (28%), 5.43 (71%)	-	0.084 (1.6%), 0.214 (0.3%)
Radium-224	5.45 (6%), 5.68 (94%)	-	0.241 (3.7%)
Radon-220	6.29(100%)	-	0.55 (0.07%)
Polonium-216	6.78 (99.98%)	-	-
Lead-212	-	0.346 (81%), 0.586 (14%)	0.239 (47%), 0.300 (3.2%), 0.040 (2%)
Bismuth-212	6.05 (25%), 6.09 (10%)	1.55 (5%), 2.26 (55%)	0.727 (7%), 1.620 (1.8%)
Polonium-212	8.78 (100%)	-	-
Thallium-208	-	1.28 (25%), 1.52 (21%), 1.80 (50%)	0.511 (23%), 0.583 (86%), 0.860 (12%), 2.614 (100%)
Lead-208	-	-	-

Unlike external irradiation, radon represents a unique internal hazard. Its short-lived decay products (progeny) , present in both attached and unattached forms, are inhaled and deposit in the bronchial epithelium, where subsequent alpha emissions deliver highly localized radiation doses.

Quantities & Units

Quantity	Unit	Definition
Activity concentration (C_{Rn})	Bq/m^3	Activity of the radionuclide present per unit volume of sample
Radon^{222} Emanation Factor (ϵ)	Unitless	Fraction of radon produced in the grains of porous matrix, which is released to the pore space of the matrix and is available for further transport.
Porosity (η)	Unitless	Ratio of pore volume to the bulk volume of the porous matrix
Tortuosity (τ)	Unitless	Measure of the geometric complexity of the pore space, representing the ratio of the actual, meandering path length a radon atom must travel through pores compared to the straight-line distance
Rn^{222} Surface Exhalation Rate	$Bq/m^2/s$	Radon activity released from a material's surface per unit area from ground or material surfaces and unit time.
Rn^{222} Mass Exhalation Rate	Bq/kg/s	Radon activity released per unit time from a unit mass of the soil matrix
Equilibrium factor (EF)	Unitless	Ratio describing the fraction of radon decay products present relative to radon gas concentration in the environment
Potential Alpha Energy (PAE)	MeV	The potential alpha energy (MeV) of an atom within the $^{222}Rn/^{220}Rn$ decay chain is the cumulative sum of alpha energies (in MeV) released during its decay through the chain to the stable radionuclide ^{210}Pb for ^{222}Rn and ^{208}Pb for ^{220}Rn.
Potential Alpha Energy Concentration (PAEC)	J/m^3 or WL	The potential alpha energy concentration characterizes the collective alpha energy potentially emitted by all radon and thoron decay product atoms with a given volume of air.
Exposure	WLM (Working Level Month)	Historic Exposure unit corresponding to 170 hours at 1WL $1\ WL = 2.08\ \times 10^{-6}\ mJ.m^{-3}$ $1\ Bq.m^{-3} = 5.56\ \times 10^{-6}\ mJ.m^{-3}$
Dose Coefficient	nSv/(Bq·h·m⁻³) or mSv/WLM	The committed effective dose to a tissue or organ resulting from an intake of unit activity of a specified radionuclide by a specified means (usually ingestion or inhalation) **UNSCEAR:** Rn-222 (Inhalation) : 9 nSv per (Bq·h·m⁻³) ; Rn-220 (Inhalation) : 40 nSv per (Bq·h·m⁻³) **ICRP** : Rn-222 : 10 mSv/WLM
Equilibrium Equivalent Concentration (EEC)	Bq/m^3	EEC for radon represents the concentration at which radon is in a state of equilibrium with its decay products, thereby leading to an equivalent PAEC for the decay products in the air. $EEC = C_{Rn} \times EF$

Key Relationships

$$\frac{\partial C_{Rn}}{\partial t} = D_e \frac{\partial^2 C_{Rn}}{\partial x^2} - \lambda C + S$$

$$S = \frac{\lambda R \rho \epsilon}{\eta}$$

$$C_{Rn} = \frac{\sum(F_w \times A)}{V(\lambda + \lambda_v)}$$

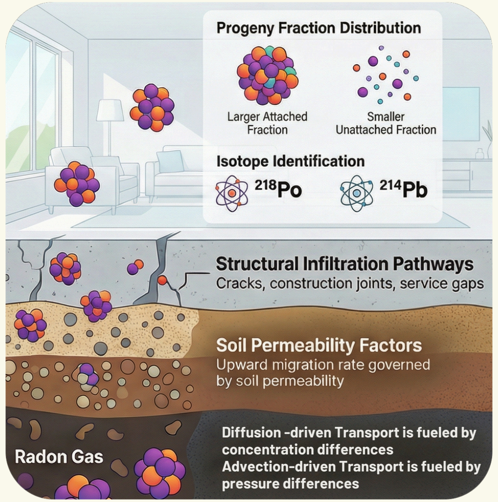
D_e: Effective Diffusion Coefficient (10^{-7} to 10^{-5} $m^2 s^{-1}$)
λ : Radon decay constant (s^{-1})
S : Radon Source term
R . Radium Content ($Bq.kg^{-1}$)
F_w: Radon exhalation flux from the building wall
A : Surface area of the i-th building wall (m^2)
V . Volume of the room (m^3)
λ_v: Ventilation rate (s^{-1})

Radon Transport Mechanism

From pore space to indoor air

Once in the pore space, transport to the surface is driven in two ways

Diffusion	Advection
Radon migration occurs due to concentration gradient between pore space and surroundings.	Pressure difference between soil pores and atmosphere drives radon migration.



- **Alpha Recoil:** Upon decay, Ra-226 emits an alpha particle. To conserve momentum, the Rn-222 atom recoils (range: 20–70 nm). If this occurs near the grain surface, it is ejected into the pore space.

- **The Moisture Paradox:** Pore moisture is critical. In dry soil, recoil atoms may re-embed in adjacent grains. A specific fraction of water (moisture film) absorbs the recoil energy, stopping the atom in the pore space and increasing emanation efficiency.