

## What Is Radon?

Radon is a naturally occurring, radioactive noble gas. It is colorless, odorless, and tasteless, so you cannot detect it without special testing. It forms from the natural breakdown of uranium in soil, rock, and groundwater.

Radon can seep into buildings through:

- Cracks in foundations
- Gaps around pipes and drains
- Floor joints and construction seams
- Well water (in some areas)

## How Does Radon Affect Health?

### 1) Lung Cancer (Main Risk)

Radon is the second leading cause of lung cancer after smoking.

When radon gas is inhaled, it decays inside the lungs and releases alpha particles. These particles can damage lung tissue and DNA, increasing the risk of cancer over long-term exposure.

- Risk increases with higher concentration
- Risk increases with longer exposure
- Risk is much higher in smokers

### 2) No Immediate Symptoms

Radon exposure does not cause short-term symptoms like coughing or headaches. The health effects usually appear only after many years of exposure.

## Who Is Most at Risk?

- People living in homes with poor ventilation
- Residents of basements or ground floors
- People using private well water
- Smokers (very high combined risk)

### How Is Radon Measured?

Radon levels are measured in:

- Becquerels per cubic meter ( $\text{Bq}/\text{m}^3$ ) (international unit)
- pCi/L (used mainly in the United States)

Many health agencies recommend action if levels exceed:

- 100–300  $\text{Bq}/\text{m}^3$  (varies by country)

### How Can Radon Levels Be Reduced?

1. Improve ventilation
2. Seal cracks in floors and walls
3. Install a sub-slab depressurization system
4. Treat well water if needed

The full physics of the **Rn-222 decay chain**, from a nuclear-structure and radiation standpoint.

- **Parent Nuclide**

#### Radon (Rn-222)

- Atomic number: 86
- Mass number: 222

- Half-life: **3.8235 days**
- Decay mode: **Alpha decay**
- Alpha energy:  $\sim 5.49$  MeV
- **Complete Decay Chain to Stable Lead**

The Rn-222 chain proceeds as follows:

Step	Nuclide	Decay Mode	Half-life	Main Radiation
1	Rn-222	$\alpha$	3.82 d	5.49 MeV $\alpha$
2	Po-218	$\alpha$ (99.98%)	3.10 min	6.00 MeV $\alpha$
3	Pb-214	$\beta^-$	26.8 min	$\beta + \gamma$
4	Bi-214	$\beta^-$	19.9 min	$\beta +$ strong $\gamma$
5	Po-214	$\alpha$	164 $\mu$ s	7.69 MeV $\alpha$
6	Pb-210	$\beta^-$	22.3 y	low-energy $\beta$
7	Bi-210	$\beta^-$	5.01 d	$\beta$
8	Po-210	$\alpha$	138 d	5.30 MeV $\alpha$
9	Pb-206	Stable	—	—

- **Energy Considerations**

Total alpha energy released in the chain (excluding long Pb-210 part):

Approximately:  $5.49 + 6.00 + 7.69 \approx 19.2$  MeV

Including Po-210:  $+5.30 \approx 24.5$  MeV

So each original Rn-222 atom ultimately deposits  $\sim 25$  MeV of alpha energy.

This is why radon progeny dominate lung dose.

- **Health-Relevant Physics**

The most hazardous isotopes in lungs:

- Po-218 and Po-214

Reason:

- Short half-lives
- High alpha energy
- Attach to aerosols
- Deposit in bronchial epithelium

Alpha particles have:

- High LET ( $\sim 100$  keV/ $\mu\text{m}$ )
- Short range ( $\sim 40\text{--}70$   $\mu\text{m}$  in tissue)

This causes **clustered DNA double-strand breaks**.

- **Mathematical Form of the Chain**

Described by **Bateman equations**:

For a simple two-member chain: 
$$N_2(t) = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_1(0) (e^{-\lambda_1 t} - e^{-\lambda_2 t})$$

For full 9-member chain, generalized Bateman solution applies.

- **Long-Term Component (Pb-210)**

Pb-210 (22.3 years) causes:

- Long-term environmental contamination
- Surface accumulation
- Dose contribution over decades

In nuclear physics, the Bateman equation is a mathematical model describing abundances and activities in a decay chain as a function of time, based on the decay rates and initial abundances. The model was formulated by Ernest Rutherford in 1905 and the analytical solution was provided by Harry Bateman in 1910.

If, at time  $t$ , there are  $N_i(t)$  atoms of isotope  $i$  that decays into isotope  $i + 1$  at the rate  $\lambda_i$ , the amounts of isotopes in the  $k$ -step decay chain evolves as:

$$\begin{aligned}\frac{dN_1(t)}{dt} &= -\lambda_1 N_1(t) \\ \frac{dN_i(t)}{dt} &= -\lambda_i N_i(t) + \lambda_{i-1} N_{i-1}(t) \\ \frac{dN_k(t)}{dt} &= \lambda_{k-1} N_{k-1}(t)\end{aligned}$$

Bateman found a general explicit formula for the amounts by taking the [Laplace transform](#) of

the variables. 
$$N_n(t) = N_1(0) \times \left( \prod_{i=1}^{n-1} \lambda_i \right) \times \sum_{i=1}^n \frac{e^{-\lambda_i t}}{\prod_{j=1, j \neq i}^n (\lambda_j - \lambda_i)}$$

this can be solved explicitly for  $i = 2$ , the formulas quickly become cumbersome for longer chains.

## Principles of a Healthy Home Design

### 1. Fresh Air & Ventilation

- Cross-ventilation (windows on opposite walls)
- Kitchen & bathroom exhaust fans
- Avoid sealing the house too tightly
  - 👉 Good air = better sleep, fewer headaches

 2. Natural Light

- Big windows, especially east/south facing
- Light-colored walls to reflect daylight
- Use curtains that let light in but keep privacy
  - 👉 Sunlight boosts mood & vitamin D

 3. Healthy Building Materials

- Low-VOC or VOC-free paints
- Natural materials: wood, stone, clay, gypsum
- Avoid strong chemical smells in furniture & adhesives
  - 👉 Reduces allergies and breathing problems

 4. Thermal Comfort

- Proper insulation (walls + roof)
- Ceiling height  $\geq 3$  m if possible (hot climates)
- Shading devices, balconies, overhangs
  - 👉 Keeps home cool naturally (important for Iraq 🌞)

 5. Clean Water & Sanitation

- Safe plumbing layout (no leaks, no stagnation)
- Easy-to-clean bathrooms
- Separate drinking water line or filter
  - 👉 Prevents mold & bacteria

 6. Connection to Nature

- Indoor plants (snake plant, pothos, aloe)
- Courtyard, balcony, or small garden
- Natural colors (earth tones)
  - 👉 Lowers stress & improves focus

### 7. Acoustic Comfort

- Distance bedrooms from noisy streets
- Use curtains, rugs, and bookshelves to absorb sound
- Solid doors for bedrooms
  - 👉 Quiet = better sleep & mental health

### 8. Ergonomic & Safe Layout

- Clear walking paths
- Rounded furniture edges
- Good lighting on stairs
- Non-slip floors
  - 👉 Fewer injuries, less daily stress

### 9. Mental Well-Being Design

- Decluttered spaces
- Personal corners for relaxation or prayer
- Soft lighting in the evening
  - 👉 Home should feel calm, not crowded