“Low Doses” from Plutonium in the Respiratory Tract

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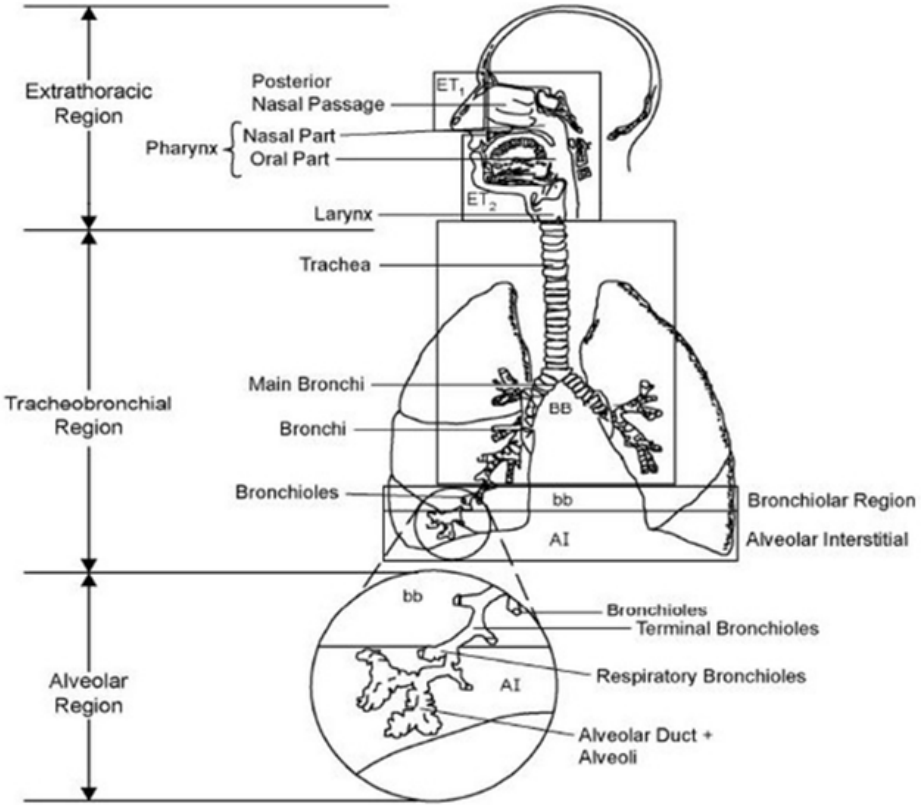
Intro to Plutonium

- Pu-238 (heat sources; HL ~88 yrs) and Pu-239 (weapons, reactors; HL ~24,000 yrs)
- Alpha emitters, long half-lives relative to human life span
- Alphas similar in energy to those from radon/radon daughters
- Much Pu remains in body indefinitely
- Inhaled Pu dissolves into blood plasma, then goes to liver and bones

The ICRP 66 Lung Deposition Model

- Deposition in lungs depends on particle size
- Clearance: Mechanical transport, dissolution to blood, or transport to thoracic lymph nodes
- Regions chosen largely for dosimetric reasons -
- Deposition calculated as average over large regions
- Suitable for predicting cancer risk



Pu Dose to Respiratory Tract

- Highly variable depending on amount inhaled, solubility, and mechanical clearance
- Low-solubility Pu compounds remain in lungs for many years leading to large doses
- Pu deposited in upper respiratory tract mechanically cleared to GI tract
- Poor mechanical clearance may dramatically increase dose

Impact on Respiratory Tract from “High” Pu Doses

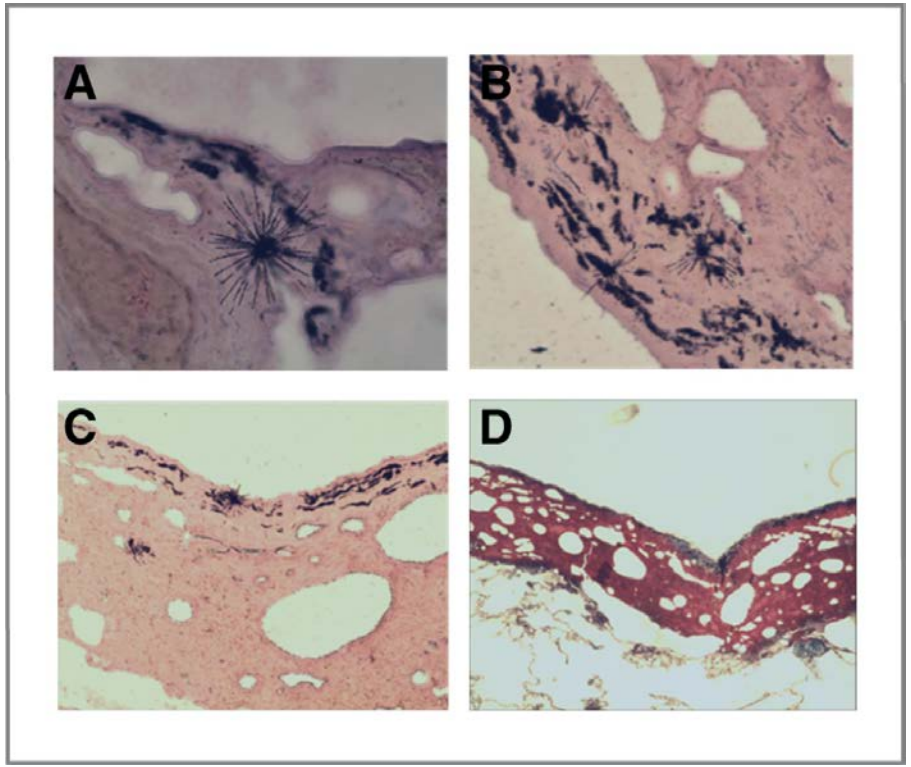
- Significantly increases fatal lung cancer risk
- May induce lung fibrosis (PuLF)
- Severe PuLF associated with lung doses greater than1.4 Gy
- Sub-clinical PuLF recently discovered for doses as small as 0.5 Gy
- This was surprising - what is the threshold for PuLF?

- CT image of lung of Pu worker with pulmonary fibrosis (Newman et al 2005)

The ‘Binding’ Mystery

- Some Pu stays in lungs for decades – even when solubility is very high
- ICRP model: ‘chemical binding’ – material dissolves, is distributed homogenously throughout lungs, and is chemically bound indefinitely
- USTUR and LANL showed chemical binding cannot fully account for observations
- Long-term retention likely due to encapsulation of undissolved Pu particles in scar tissue
- Scar tissue model is supported by autoradiography of dissected lungs
- Could this be the same phenomenon as PuLF?

Autoradiography shows Pu is not uniformly distributed

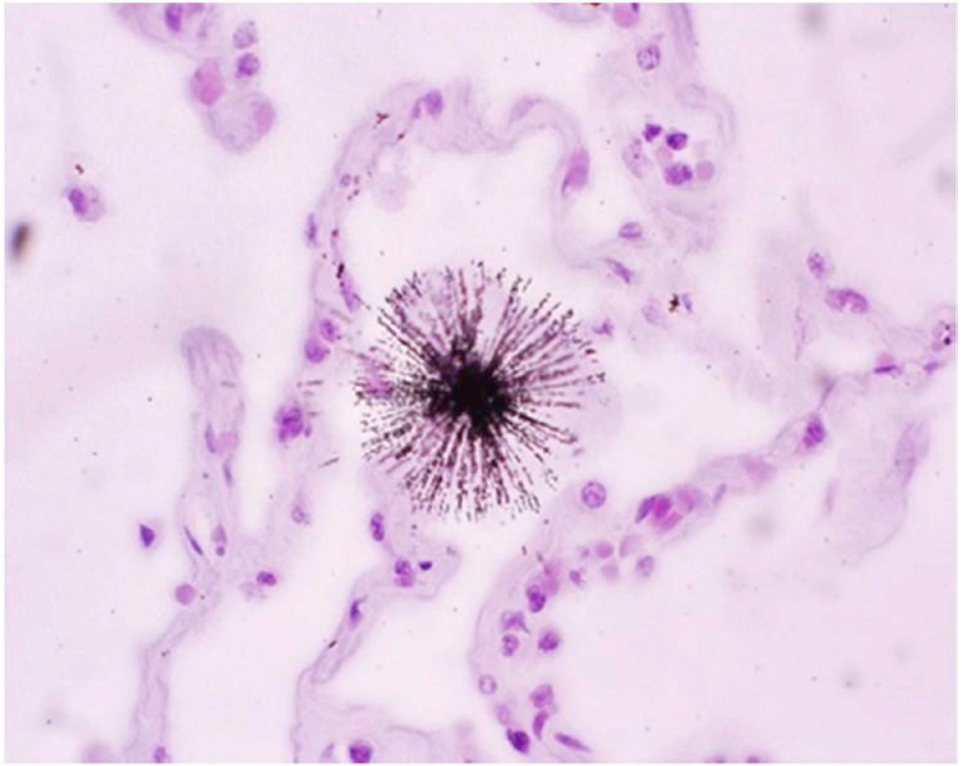


Autoradiography of human respiratory tissues shows alpha star aggregates of Pu, in contrast to what would have been observed if the Pu was uniformly distributed. (Image from Nielsen et al 2012; Interpretation from Poudel et al 2021)

What is a ‘low’ dose?

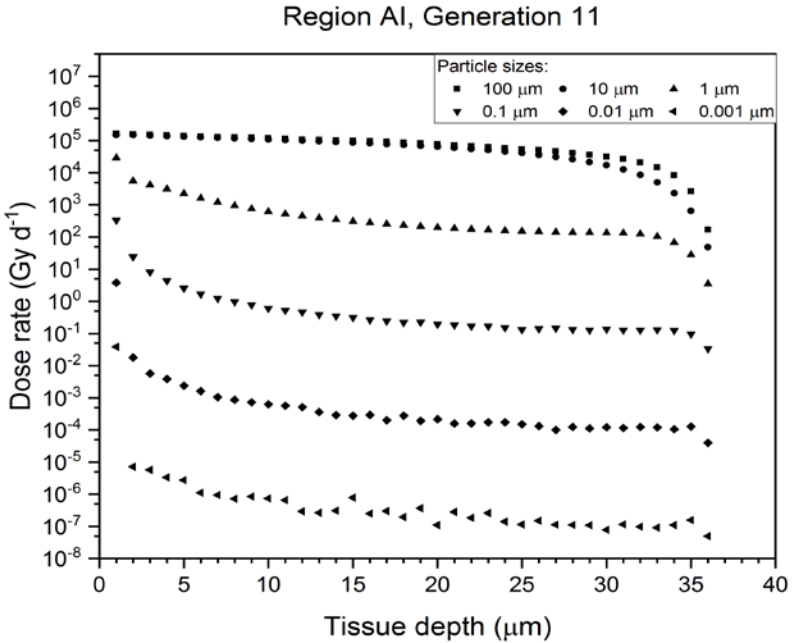
- “Absorbed” dose to lungs is absorbed energy divided by mass of lungs
- Alpha particles from Pu only travel ~$40\mu m$ through lung tissue
- Inhaled Pu is deposited as discrete particles – the dose to irradiated lung tissues is much higher than to total lungs
- Dose to irradiated tissues depends on size of deposited particles; dose to total lung also depends on number of particles inhaled

The mass of irradiated tissues is much smaller than the total mass of lungs



Autoradiograph of Pu in lung (Romanov et al 2020)

Threshold for scar tissue/fibrosis – irradiated tissues or total lung?



Diameter [µm]	Activity [Bq]
100	1.68E+04
10	1.68E+01
1	1.68E-02
0.1	1.68E-05
0.01	1.68E-08
0.001	1.68E-11

Left: Dose rates in the alveolar-interstitial region of the lungs, generation 11 of the tracheobronchial tree, as a function of distance perpendicular to the surface of impacted spheres. Right: Total activity of ^{239}PuO spheres. Due to self-absorption, not all activity escapes spheres. (Ref. Hetrick and Klumpp, manuscript in preparation).

Future Research Needs

- Determine if ‘scar tissue’ is primarily responsible for long term retention
  -Other mechanisms may also play a role

- Test link between particle size and scar tissue formation
  -If it exists, long term retention would depend on particle size

- Investigate link between local scar tissue formation and PuLF

- Understand conditions for scar tissue and fibrotic tissue formation

- New autopsies, in vitro experiments could illuminate these issues

Why it Matters

- Scar tissue may be protective
  - -Irradiation of dead cells is unlikely to lead to cancer
  - -Even in most highly-exposed Soviet workers, lung cancer fatalities were far higher than PuLF fatalities

- Understanding scar tissue formation would improve understanding of risk

- These results could inform risk in a range of alpha-emitter inhalation scenarios:
  - -Environmental radon exposure
  - -Occupational exposure to miners, cave workers, radiation workers
  - -Exposure to public in accidental or intentional release of radionuclides

Questions?

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