Long-Term Retention of Plutonium in the Respiratory Tract Compartments: Arguments Against Chemical Binding

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Binding

Chemical binding is the process by which a fraction of dissolved material binds to the epithelium of the respiratory tract. For Plutonium (Pu), ICRP recommends a bound fraction (f_b) of 0.002 (and s_b of 0 d^{-1}) inferred from the following three studies:

1. USTUR Case 0269 data:[1,2]: f_b = 0.004
2. Lung-retention data from beagle study[2,3]: f_b = 0.008
3. Autopsy data from 20 Mayak workers[2,4]: f_b = 0.0014

Need for binding

The retention of Pu in the respiratory tract of USTUR Case 0269 – who inhaled pure plutonium nitrate – 38 years after the intake provided important data to obtain inferences on the long-term behavior of plutonium in the respiratory tract.

Table 1. Effects of different model assumption (5 µm AMAD Pu nitrate inhalation)

	A_{URT}/A_{RT}
No binding and:	
default parameters	2.5×10^{-8}
f_{seq} = 0.01	1.3×10^{-7}
K_{PT}, $K_{PT(seq)}$ = 0.2	1.9×10^{-3}
Measured for Case 0269	0.364 ± 0.002
Binding, f_b = 0.002	0.07

Impact of binding assumptions on dosimetry

Because the bound material irradiates the sensitive epithelial lining of the respiratory tract, the dosimetric consequence of even a small bound fraction is substantial.

Table 2. Effects of bound fraction assumption, 0.002 vs 0 (5 µm AMAD Pu nitrate inhalation)

Target region	% increase
Lungs	41.0%
Bronchi-bas	100.4%
Bronchi-sec	180.5%
Brchiol-sec	49.4%
AI	9.4%
Effective dose	**7.6%**

Arguments against binding

Histopathological studies

Autoradiography and histological examination of tissue samples from the lungs of USTUR Case 0269 and beagle dogs[5,6] showed alpha star aggregates of Pu localized within connective tissue. This observation is inconsistent with the presence of bound state, which would predict a diffuse, uniform distribution of Pu.

The authors of the three studies, upon which the ICRP recommendation was based on, point to “physical binding” as an alternative or additional retention mechanism[1,2].

Value of f_b dependent on solubility

All reviewed studies (Table 3) estimated a remarkably higher bound fraction for materials with lower solubility; this is inconsistent with the definition of binding as used in the HRTM.

Table 3. Published values of f_b

Study	Inhaled form		
	Soluble	Mixed	Insoluble
2 Mayak workers[7]	5.3%		56.2%
530 Mayak workers[8]	2%	3-7%	15-19%
Beagles study[2,3]	0.79%		
40 Mayak workers[2,4]	0.14%		4.70%
USTUR studies[1,2,9-11]	0.37%	1-4%	[a]

[a]cannot be explained

Other possible mechanisms

Systemic uptake

A post-mortem study to look at the Pu contents of the respiratory tract of USTUR Case 0303 (wound intake)[12] indicated that approximately 4% of the activity in the “rest of the body” is retained in lungs. This was consistent with the inferences obtained from animal studies (rats[13] and non-human primates[14]; injected with Pu). On the other hand, the lungs of USTUR Case 0269 contained 12% of the activity in the “rest of the body”. This indicates that a different mechanism is responsible for most of the observed retention in the lungs of Case 0269.

Encapsulation in scar tissues

Another mechanism by which a certain fraction of inhaled plutonium can be indefinitely retained in the lung tissue is by its encapsulation in scar tissues. Although the ICRP HRTM does not account for this mechanism of plutonium retention, literature review[9-10] points to the presence of – and a significant retention of – plutonium activity in scar tissues of the lungs. This mechanism is referred by some authors[15] as ‘physical binding’.

References

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