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Estimation of Actinide Skeletal Content from a Single Bone Analysis

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“Learning from Plutonium and
Uranium Workers”





Goal

- Estimation of total actinide content (activity) in the skeleton – major depository site for plutonium and americium in the human body



Approaches

- Analysis of the entire skeleton
- Analysis of limited number of bones



Total Skeletal Activity Estimation

- Whole-body, $A_{skel} = \sum A_{bone,i}$
 - ✓ Analysis: right side of the skeleton
 - ✓ Calculation: activities in even ribs and vertebrae
 - ✓ Activity: activity of the right side $\times 2$
- Partial-body, $A_{skel} = M_{skel} \times \hat{C}_{skel}$
 - ✓ Analysis: selected (limited) bones
 - ✓ Calculation: skeleton weight, M , kg;
skeletal concentration, \hat{C} , Bq kg⁻¹
 - ✓ Activity: $(-10.7 + 0.119 \times H) \times \hat{C}$; H (cm) - height
 $10.5 \times \hat{C}$; 10.5 (kg) - for Reference Man

TAM-A.4: Avtandilashvili & Tolmachev: *Updating ICRP 70 Skeleton Weight vs Body Height Equation*



Skeletal Activity Estimation: Studies

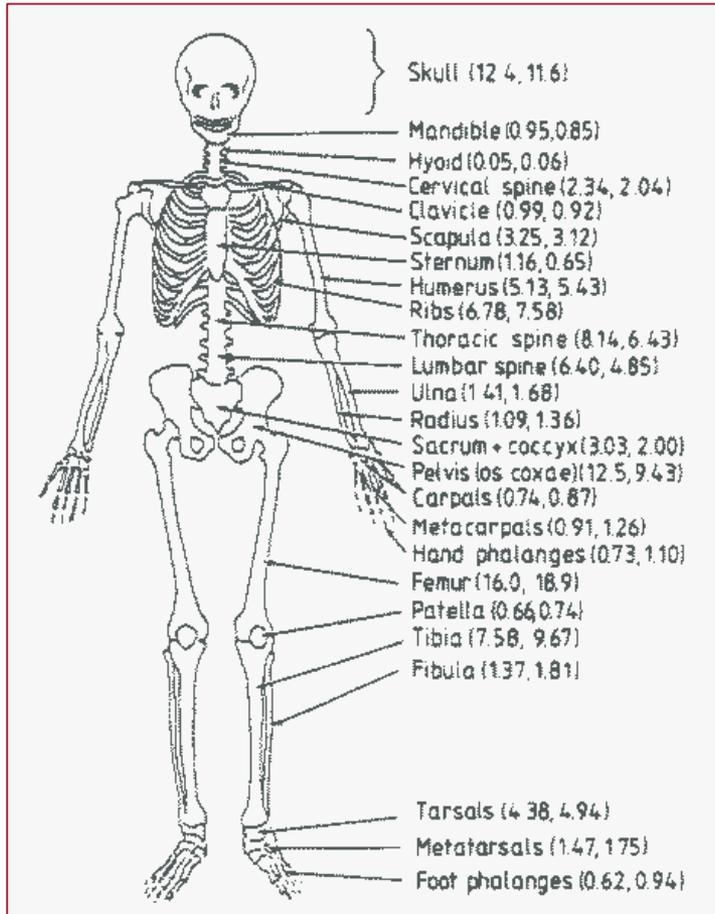
- Lynch *et al* (1988, J Radiol Prot) Macrodistribution of plutonium and americium in four human skeletons
- Hall C. A. (1997, MS Thesis) Estimation of skeletal deposition of plutonium and americium from selected bone subset
- Filipy *et al* (2003, Health Phys) Estimation of actinide skeletal content in humans based on bone samples collected at autopsy
- Matthews T. C. (2009, MS Thesis) Estimation of skeletal plutonium and americium content from samples taken at autopsy
- Suslova *et al* (2016, Rad Prot Dosim, *Accepted*) MWDS2013: Estimation of plutonium skeletal content from limited autopsy bone samples from Mayak PA workers



Pros and Cons

- Entire skeleton analysis:
 - ✓ Most accurate estimation
 - ✓ Very limited opportunities (USTUR only?)
 - ✓ Large number of analyses (70 – 100)
- Analysis of limited number of bones
 - ✓ Typical scenario
 - ✓ Small number of analyses (1 – 9)
 - ✓ How accurate is the estimation?

Lynch *et al* (1988): Plutonium Distribution



- Skull: 12.4 ± 1.1%
- Cervical Spine: 2.3 ± 0.2%
- Thoracic Spine: 8.1 ± 2.2%
- Lumbar Spine: 6.4 ± 2.0%
- Sacrum & Coccyx: 3.0 ± 0.7%
- Pelvis: 12.5 ± 1.2%
- Clavicles: 0.99 ± 0.14%
- Scapulae: 3.3 ± 0.3%
- Ribs: 6.8 ± 0.3%
- Sternum: 1.2 ± 0.2%
- Humeri: 5.1 ± 0.8%
- Femora: 16.0 ± 2.2%
- Tibiae: 7.6 ± 1.1%
- Patellae: 0.66 ± 0.09%



Patella's Pros and Cons

- Easy to collect at autopsy
- Single (whole) bone analysis
- Simple direct scaling to skeleton activity:
$$A_{skel} = k \times A_{patella}$$
- Direct estimation of the uncertainties
- Not commonly taken at autopsy



This Study

- Selected bone: Patella
- Number of cases: 17
- Primary exposure: ^{238}Pu (2) and ^{239}Pu (15)
- ^{241}Am : ^{241}Pu decay
- Post-exposure, y : 15 – 55
- Skeletal activity: ^{238}Pu , ^{239}Pu , and ^{241}Am
- Deposition coefficient: $K_{\text{dep}} = A_{\text{patella}}/A_{\text{skeletal}}$
- Total activity calculation:
 - ✓ Method I: $A_{\text{skeletal}} = 1/K_{\text{dep}} \times A_{\text{patella}}$
 - ✓ Method II: $\log[A_{\text{skeletal}}] = a \times \log[A_{\text{patella}}] + b$



Assumptions

Deposition coefficient (ratio), $K_{dep} = A_{patella}/A_{skel}$, is independent of

- Route of intake: inhalation, wound, ingestion, injection
- Type of exposure: acute, chronic
- Material type: soluble, insoluble, mixture
- Treatment: chelation, wound excision
- Years post-exposure
- Skeletal pathology: osteoporosis, bone cancer



Method I: Deposition Coefficient



Isotopic K_{dep} : ^{238}Pu , ^{239}Pu , and ^{241}Am

Statistical Parameter	Coefficient of Deposition, K_{dep}		
	^{238}Pu	^{239}Pu	^{241}Am
Data points, n	17	17	17
Outliers (Grubbs' test)	No	No	No
Range	0.0017 – 0.0063	0.0019 – 0.0055	0.0021 – 0.0072
Median	0.0038	0.0032	0.0037
Mean \pm SD	0.0038 \pm 0.0016	0.0034 \pm 0.0012	0.0040 \pm 0.0013
RSD, %	40.4%	35.6%	31.2%
95% CI of mean	0.0030 – 0.0046	0.0028 – 0.0040	0.0034 – 0.0047
Paired t-test, p	0.2049		0.0077

- ^{238}Pu Skeletal Activity, $A_{skel} = (260 \pm 105) \times A_{patella}$
- ^{239}Pu Skeletal Activity, $A_{skel} = (294 \pm 105) \times A_{patella}$
- ^{241}Am Skeletal Activity, $A_{skel} = (248 \pm 77) \times A_{patella}$



Combined K_{dep} : $^{238,239}\text{Pu}$ + ^{241}Am

Statistical Parameter	Coefficient of Deposition, K_{dep}
	$^{238,239}\text{Pu}$ and ^{241}Am combined
Repeated ANOVA, p	0.0986
Data points, n	51
Outliers, Grubbs' test	No
Range	0.0017 – 0.0072
Median	0.0034
Mean \pm SD	0.0038 \pm 0.0013
RSD, %	35.9%
95% CI of mean	0.0034 – 0.0041

$$\text{Am/Pu Skeletal Activity, } A_{skel} = (266 \pm 95) \times A_{patella}$$



Method II: Log-Log Correlation



Regression & Statistical Analysis

Radionuclide	n	log(y) = a×log(x)+b, Regression Parameter		
		a ± S.E.	b ± S.E.	R ²
²³⁸ Pu	17	0.956±0.059	2.368±0.122	0.9464
²³⁹ Pu	17	0.876±0.032	2.431±0.032	0.9800
²⁴¹ Am	17	0.939±0.054	2.338±0.074	0.9524

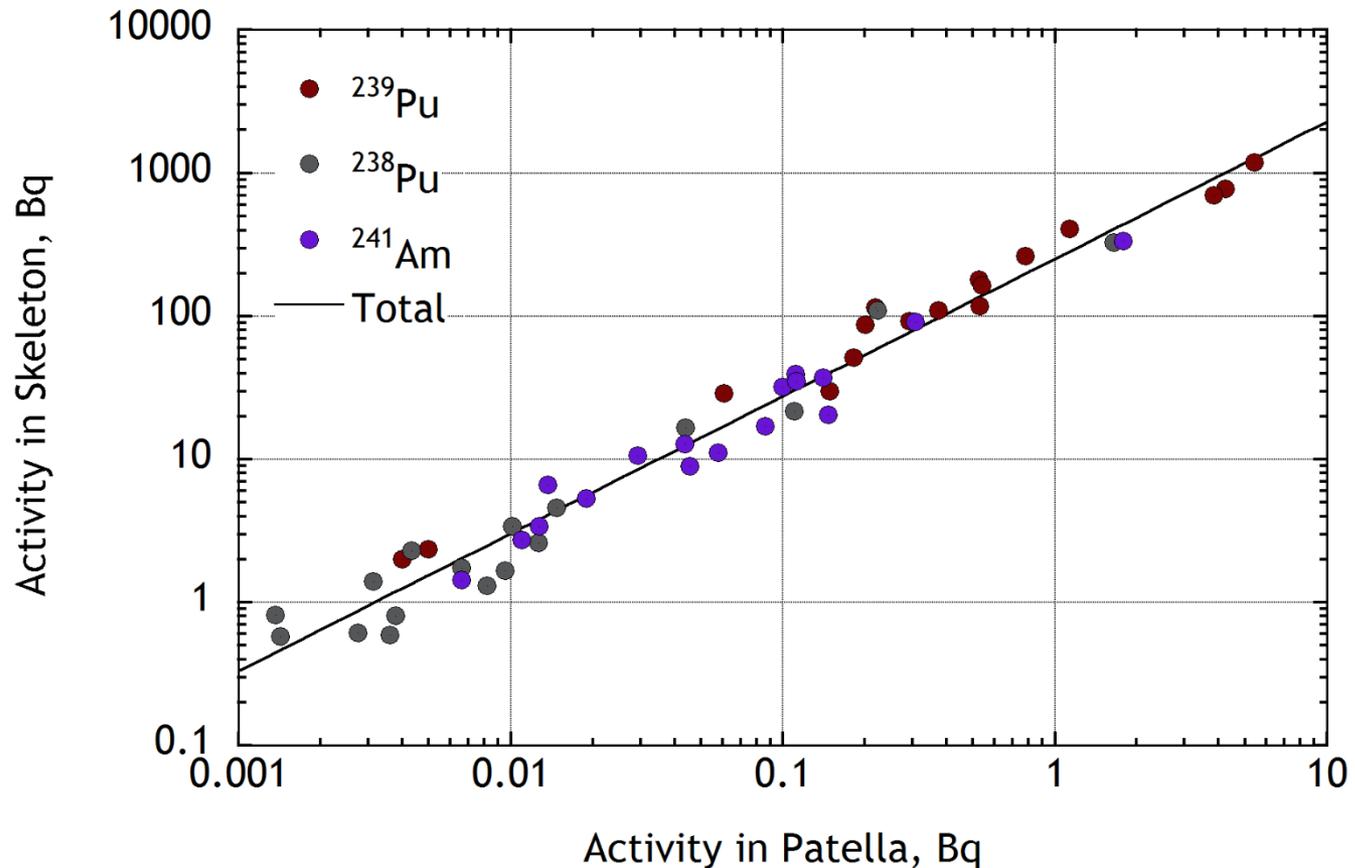
Regression Parameter	n	Statistical Difference, p		
		²³⁹ Pu vs ²³⁸ Pu	²³⁹ Pu vs ²⁴¹ Am	²³⁸ Pu vs ²⁴¹ Am
Slope (a)	17	0.2353	0.3122	0.8446
Intercept (b)	17	0.5886	0.3791	0.9772

Radionuclide	n	log(y) = a×log(x)+b, Regression Parameter		
		a ± S.E.	b ± S.E.	R ²
²³⁸ Pu, ²³⁹ Pu, and ²⁴¹ Am	51	0.960±0.023	2.404±0.036	0.9719





Linear Regression Analysis

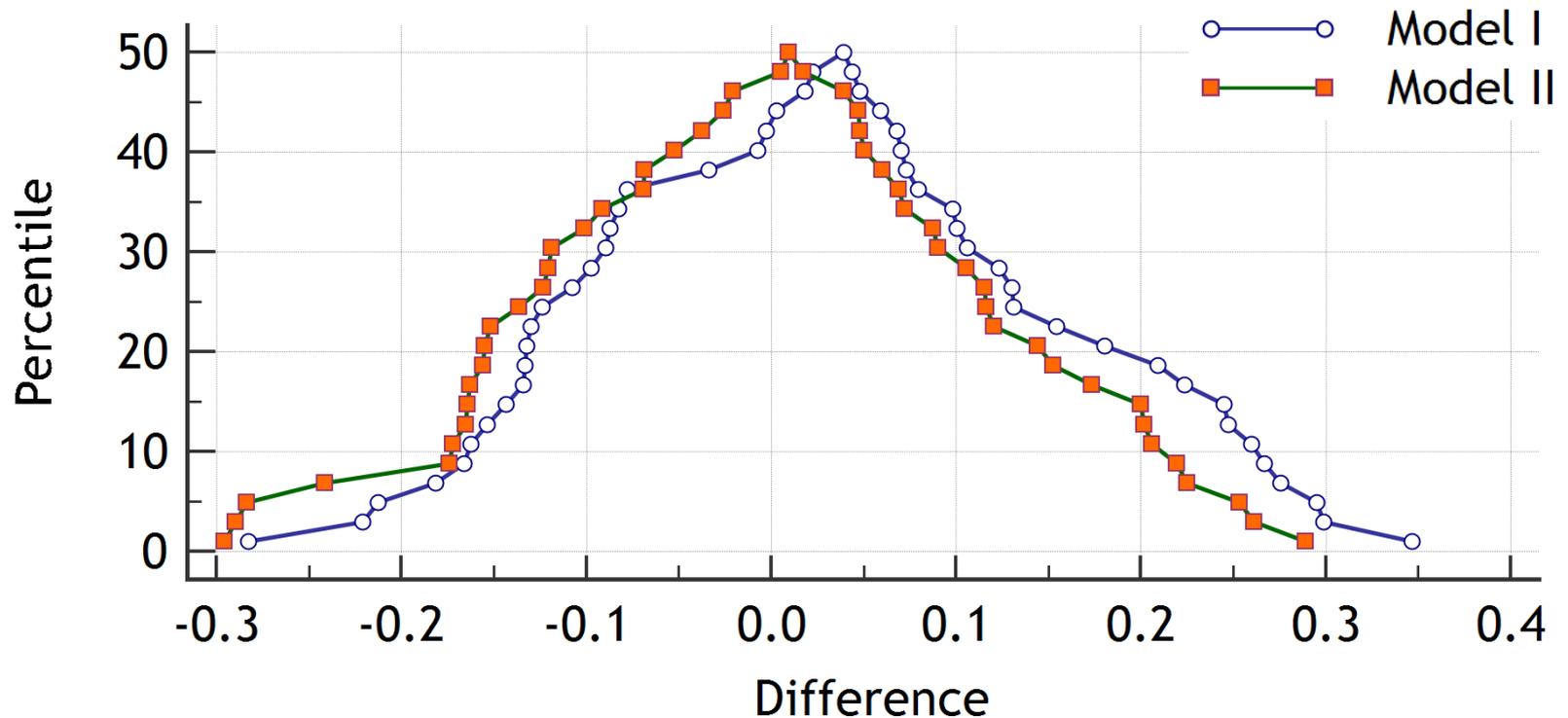


$$\log[A_{\text{skel}}] = (0.960 \pm 0.023) \times \log[A_{\text{patella}}] + (2.404 \pm 0.036)$$



Method Comparison

- Method I: $\text{Askel} = 266 \times \text{Apatella}$
- Method II: $\log[\text{Askel}] = 0.960 \times \log[\text{Apatella}] + 2.404$





Conclusions

- Actinide activity in patella represents 0.38% of total skeletal activity
- Patella analysis allows to estimate plutonium and/or americium skeletal activity with ~35% precision
- No statistical difference was found between retention of plutonium isotopes and ^{241}Am in patella