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From Single Bone Measurement to Total Skeletal Actinide Content

Sergei Y. Tolmachev, USTUR Director
stolmachev@wsu.edu

Research Associate Professor
College of Pharmacy, Washington State University

1845 Terminal Drive, Suite 201, Richland, WA 99354
www.ustur.wsu.edu

"Learning from Plutonium and Uranium Workers"

Goal

- Estimation of total Pu and Am activity in skeleton

Approaches

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

Skeleton Total Activity Estimation

- Whole-body, $A_{skel} = \Sigma A_{bone,i}$
  - ✓Analysis: right side of the skeleton
  - ✓Calculation: activities in even ribs and vertebrae
  - ✓Skeleton: activity of the right side ×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}
  - ✓Skeleton: $(-10.7 + 0.119 \times H) \times \hat{C}$, when height (H, cm) is known or
    $10.5 \times \hat{C}$, using 10.5-kg Reference Man skeleton weight

Pros and Cons

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

Whole vs Partial Body Skeleton Analysis

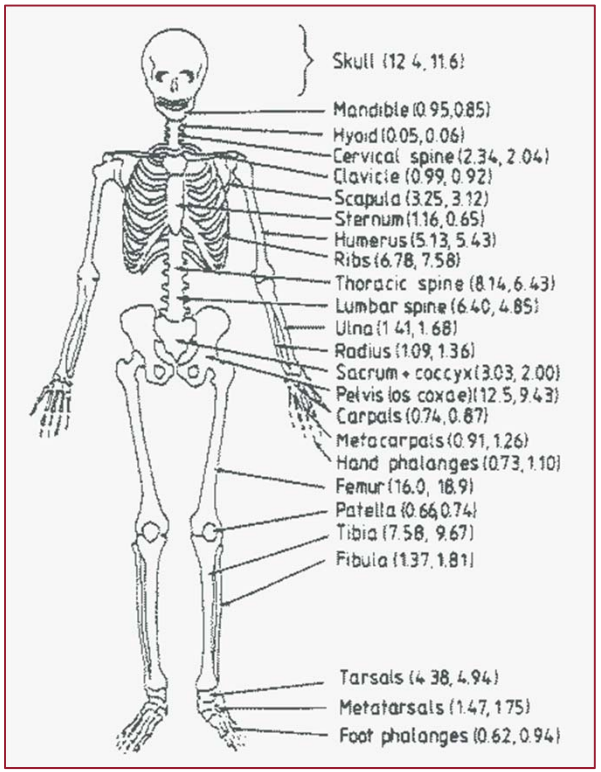
Donation Type	Skeleton	Number of Samples	
		Collected	Analyzed
Whole Body	Axial	110	62
	Limbs	70	50
Partial Body	Total	2 - 6†	2 - 6

† - rib, clavicle, patella, sternum, vertebrae, femur (MS)

Publications

- 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 (2015, In preparation) MWDS2013: Estimation of plutonium skeletal content from limited autopsy bone samples from Mayak PA workers

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

- Easy to collect at autopsy
- Single (whole) bone analysis
- Simple direct scaling to skeleton activity

$$A_{skel} = k \times A_{patella}$$

- Easy to estimate uncertainties

In This Study

- Selected bone: Single patella
- Number of cases: 17
- Primary exposure: ^{238}Pu (2) and ^{239}Pu (15)
- ^{241}Am: ^{241}Pu decay
- Skeleton activity: ^{238}Pu, ^{239}Pu, and ^{241}Am
- Deposition coefficient: $K_{dep} = A_{patella}/A_{skel}$
- K_{dep} statistical analysis: ^{238}Pu, ^{239}Pu, and ^{241}Am
- Simple linear model:

$$A_{skel} = 1/K_{dep} \times A_{patella}$$

- Linear model for log-transformed data:

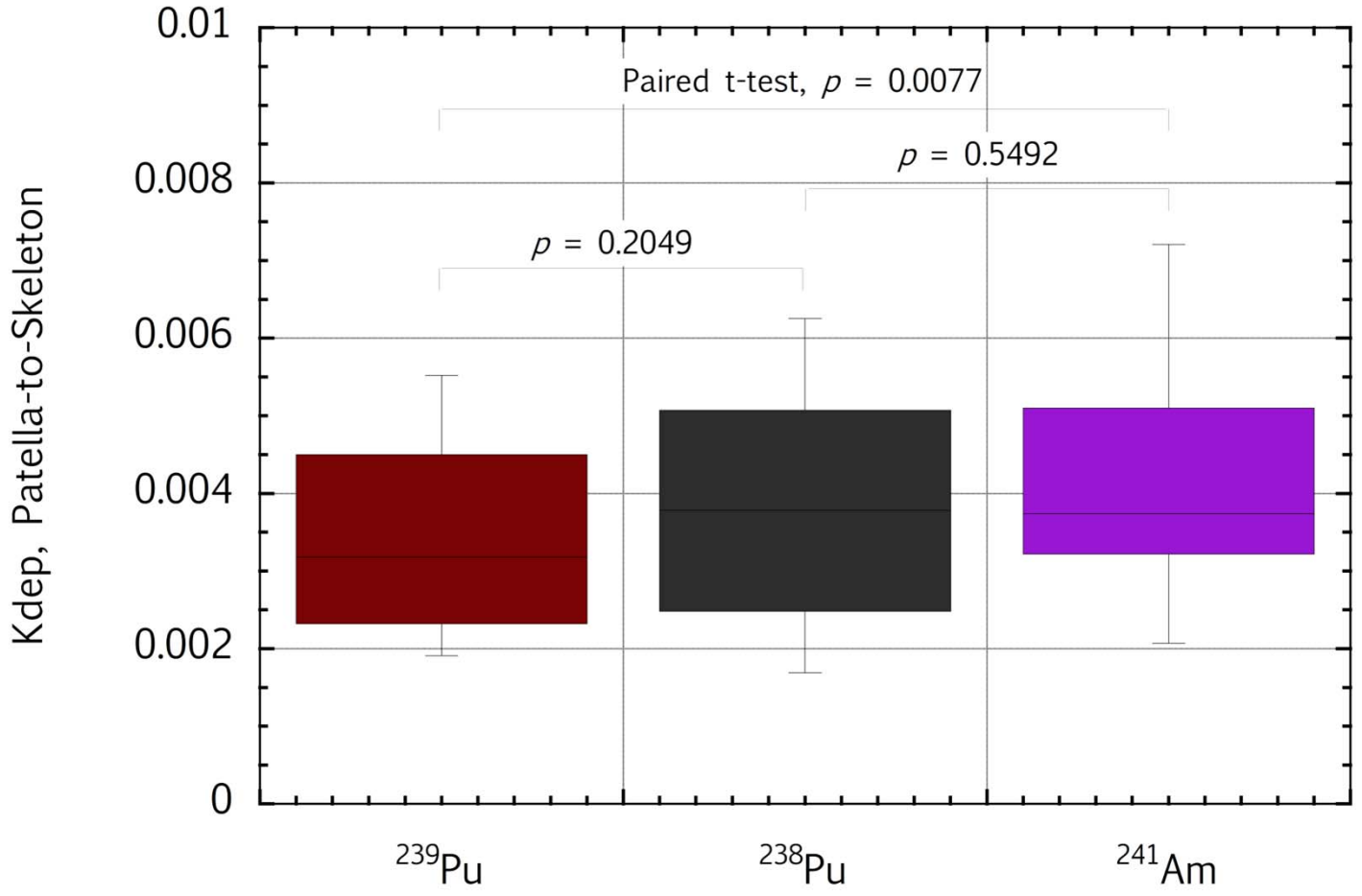
$$\log[A_{skel}] = a \times \log[A_{patella}] + b$$

Kdep Results: ^{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
Range	0.0017 – 0.0063	0.0019 – 0.0055	0.0021 – 0.0072
Outliers (Grubbs' test)	No	No	No
Median	0.0038	0.0032	0.0037
Mean ± SD	0.0038±0.0016	0.0034±0.0012	0.0040±0.0013
RSD, %	40.4%	35.6%	31.2%
95% Confidence Interval	0.0030 – 0.0046	0.0028 – 0.0040	0.0034 – 0.0047
Paired t-test, p	0.2049		0.0077

- ^{238}Pu Skeletal Activity, $A_{skel} = (260\pm105) \times A_{patella}$
- ^{239}Pu Skeletal Activity, $A_{skel} = (294\pm105) \times A_{patella}$
- ^{241}Am Skeletal Activity, $A_{skel} = (248\pm77) \times A_{patella}$

Kdep Results: Paired t-test



K_{dep} Results: $^{238,239}Pu$ *vs* ^{241}Am

Statistical Parameter	Coefficient of Deposition, K_{dep}	
	$^{238,239}Pu$ combined	^{241}Am
Data points, n	34	17
Range	0.0017 – 0.0063	0.0021 – 0.0072
Outliers (Grubbs' test)	No	No
Median	0.0032	0.0037
Mean ± SD	0.0036±0.0014	0.0040±0.0013
RSD, %	38.4%	31.2%
95% CI	0.0031 – 0.0041	0.0034 – 0.0047
Unpaired t-test, p	0.3007	

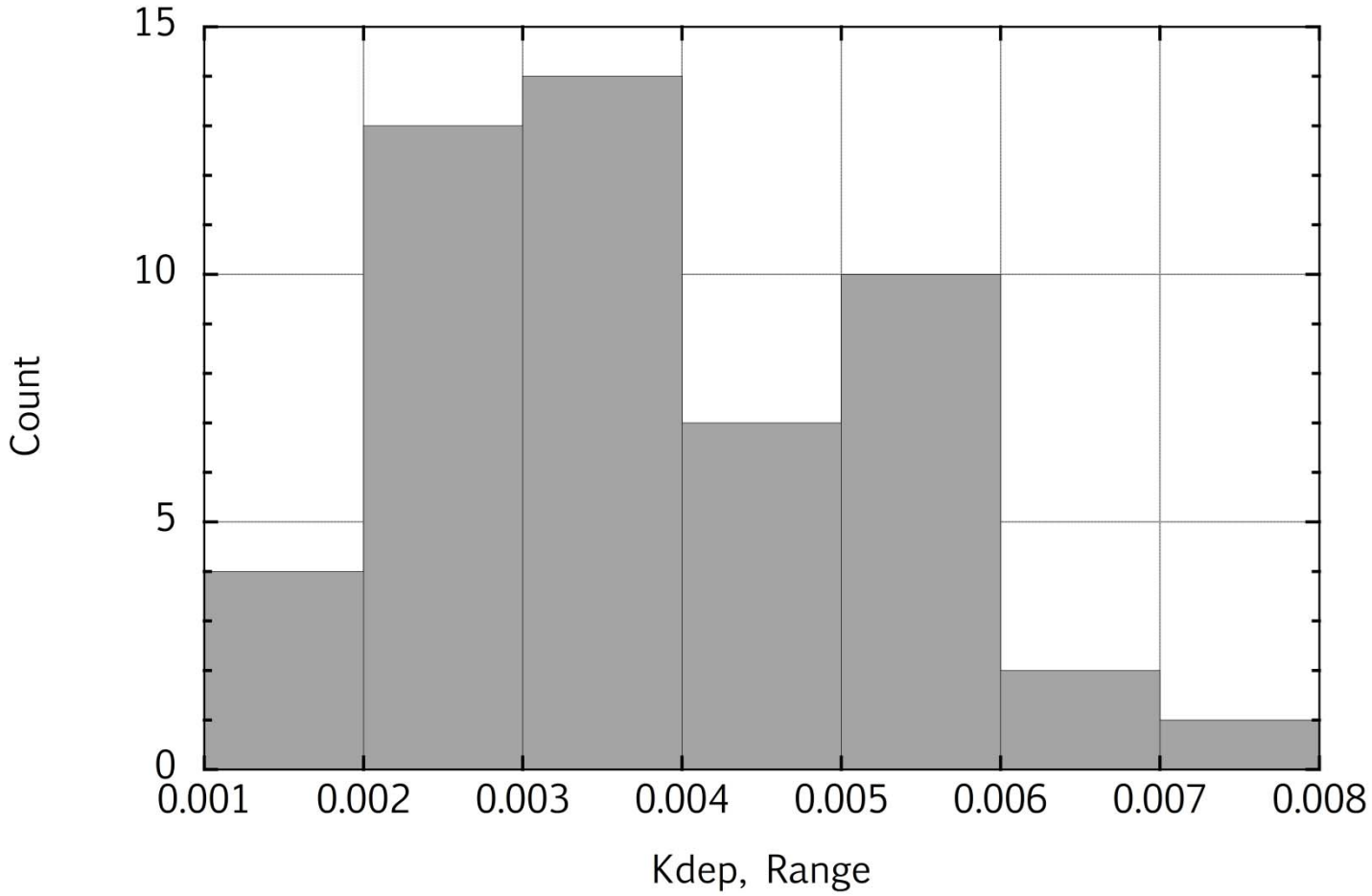
- Pu Skeletal Activity, $A_{skel} = (278 \pm 107) \times A_{patella}$

K_{dep} Results: $^{238,239}Pu$ and ^{241}Am Combined

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

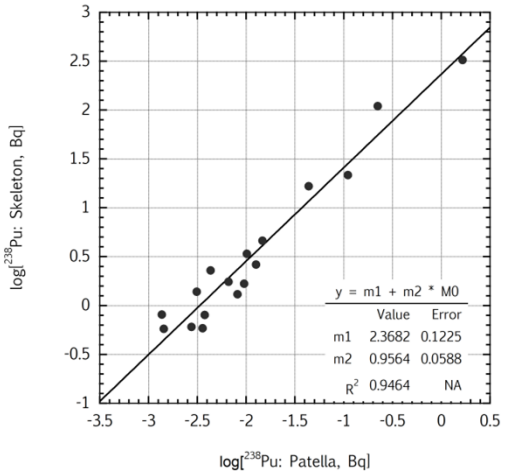
- Am/Pu Skeletal Activity, $A_{skel} = (266 \pm 95) \times A_{patella}$

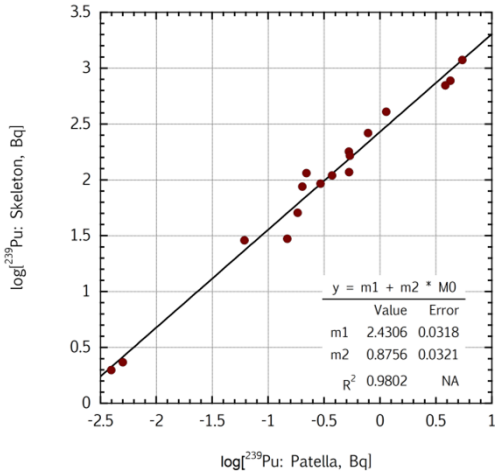
Kdep Distribution: ^{238,239}Pu and ^{241}Am Combined

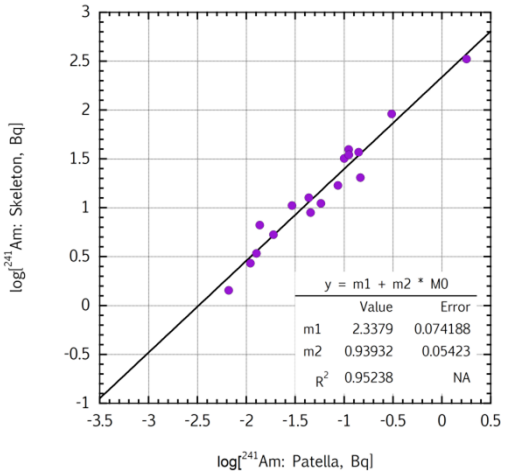


Log-transformed Data Regression Analysis

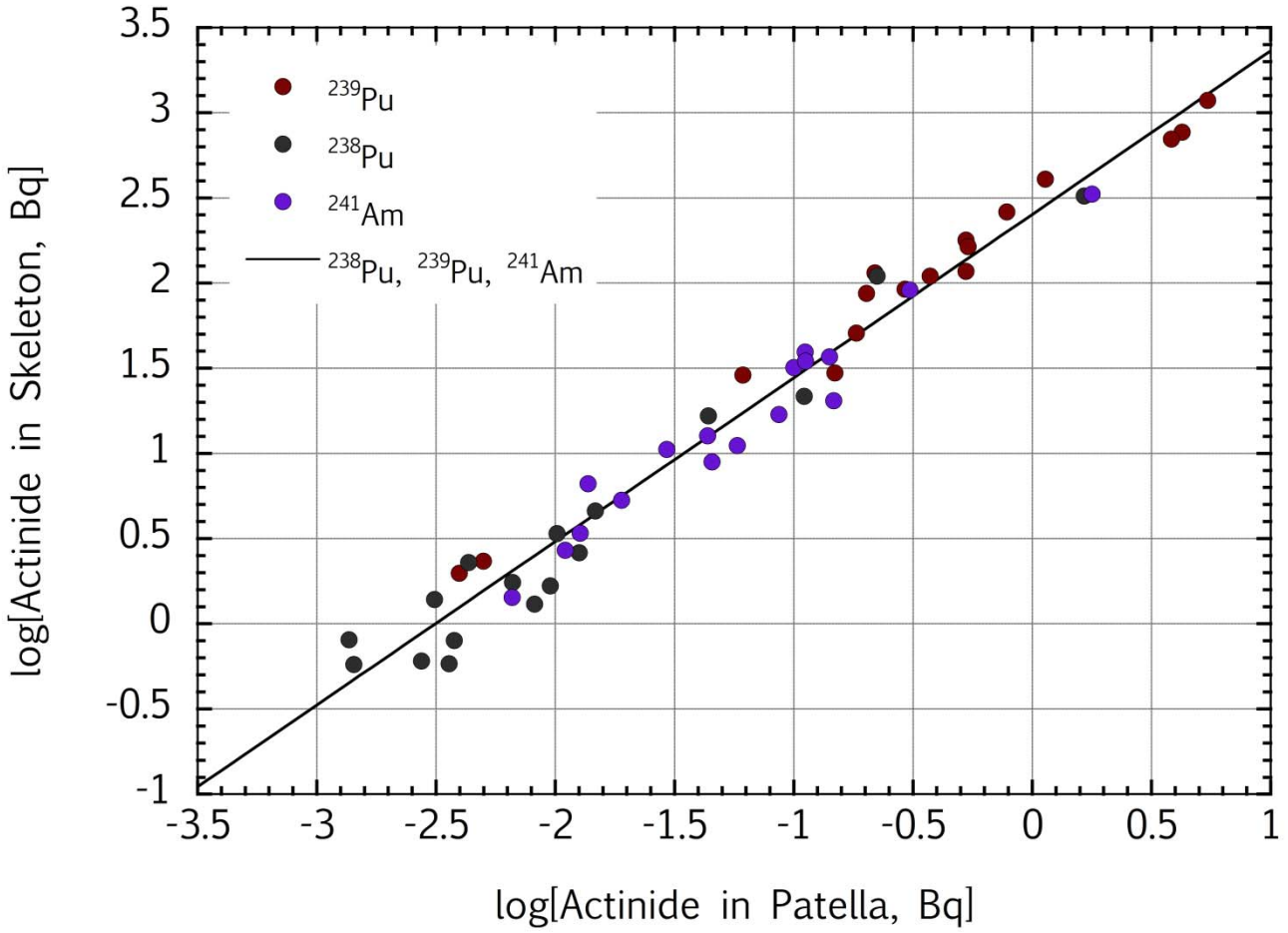
Radionuclide	n	y = ax+b, Regression parameters		
		$a \pm \Delta_a$	$b \pm \Delta_b$	R^2
^{238}Pu	17	0.956±0.059	2.368±0.123	0.9464
^{239}Pu	17	0.876±0.032	2.341±0.032	0.9802
^{241}Am	17	0.939±0.054	2.338±0.074	0.9524
^{238}Pu and ^{239}Pu	34	0.963±0.027	2.428±0.044	0.9759
^{238}Pu, ^{239}Pu, and ^{241}Am	51	0.960±0.023	2.404±0.023	0.9719







Log-transformed Data Correlation



- Am/Pu Skeletal Activity, $\log[A_{skel}] = (0.960 \pm 0.023) \times \log[A_{patella}] + (2.404 \pm 0.023)$