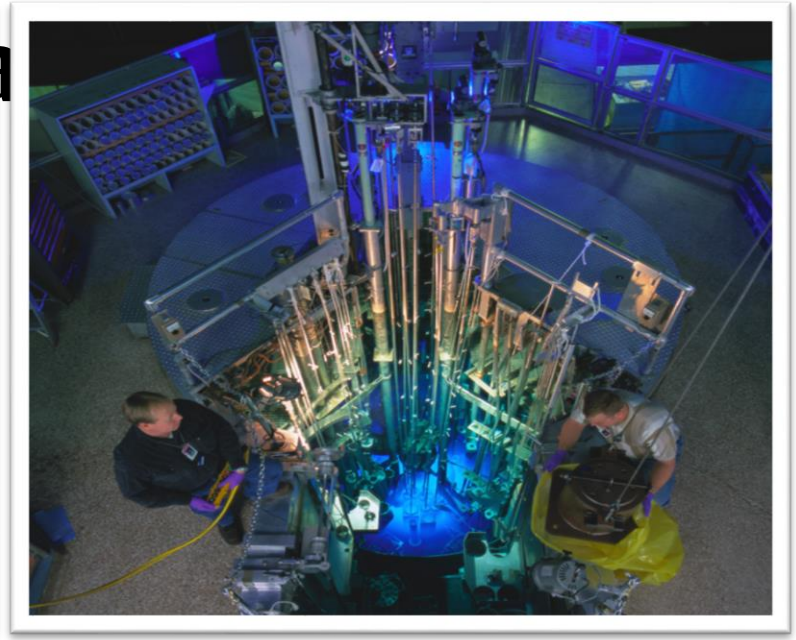
Current Research at the University of Missouri



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Lance Schell
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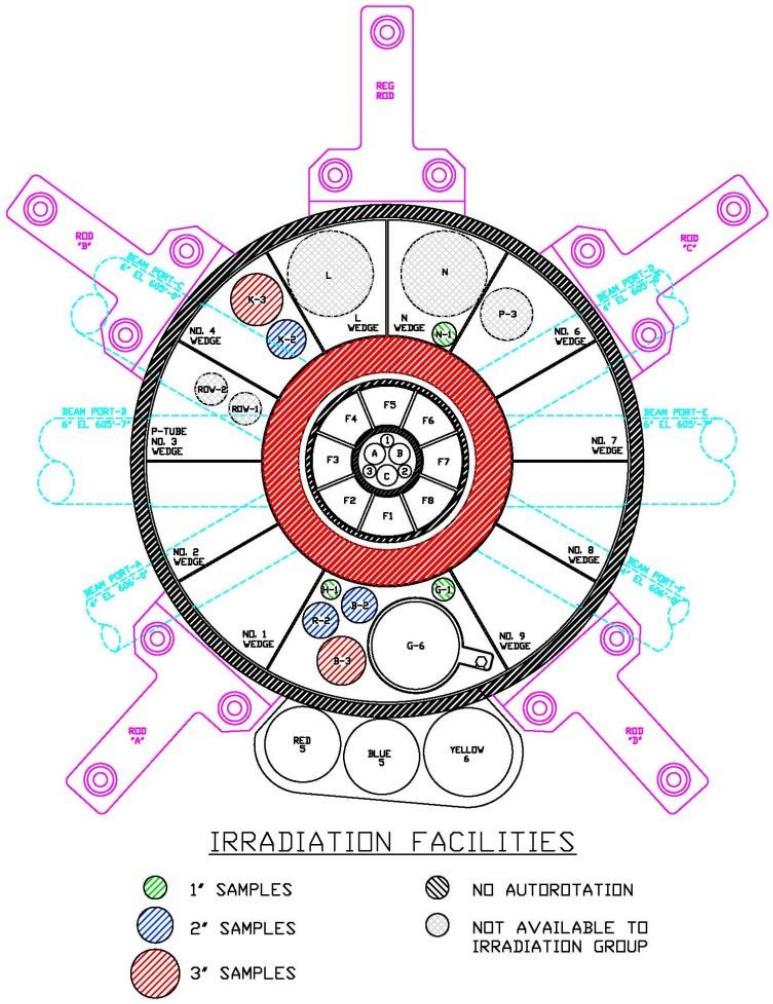
MURR

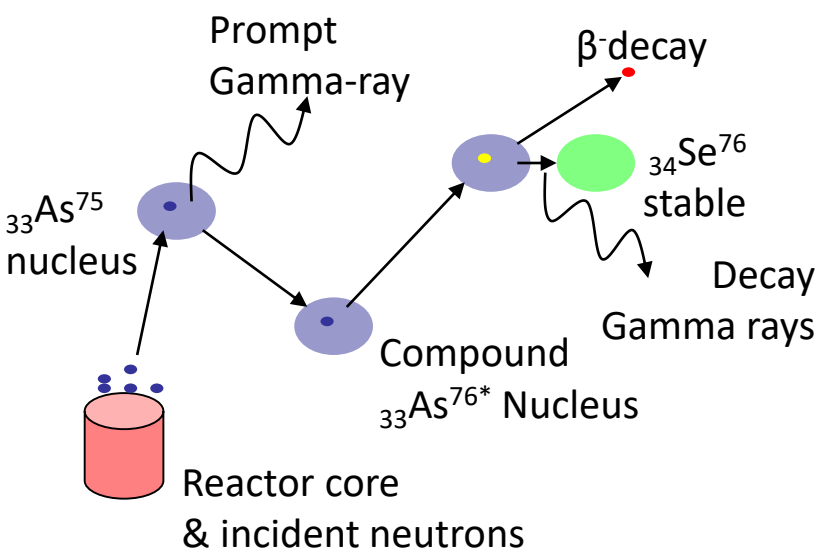
MISSOURI

The central tool



- Trace element epidemiology
- Nuclear forensic analysis
- Fission product migration in graphitic materials
- Radiolysis and transmutation of materials
- Neutron capture therapy

Collaborative Trace Element Epidemiology Research



Determination of Se and Hg by INAA

Comparator standards:
20µl of standard solution → Quartz vial → Freeze dried and sealed

- 50 samples,
- 5 duplicate samples,
- 6 comparator standards,
- 12 qualitity control materials
- 6 empty vials (Blanks)
- Co/Al flux wire

Al can

Graphite reflector region

Flux:
5.5×10^{13} n/cm^2·s^{-1}

Irradiated in a rotating position for 40 h

Decay time: ≈30 days

Counting time:
2 hours
2.5 cm from HPGe detector

Reactions:
^{202}Hg (n,γ)^{203}Hg
^{74}Se(n,γ)^{75}Se

INAA

^{75}Se: 136 and 264 keV
$t_{1/2}$ = 119.8 d

Contribution of Se at 279 keV measured in single element Se standards

^{203}Hg: 279 keV
$t_{1/2}$ = 46.6 d

Sum of ^{75}Se and ^{203}Hg

^{203}Hg: 279 keV
Determined by subtracting the ^{75}Se contribution.

W.D. Ehmann, et al, Biological Trace Element Research 13(1) (1987) 19-33.

- **The Memory and Aging Study (MAP) and Alzheimer Disease**

Association of Seafood Consumption, Brain Mercury Level, and *APOE ε4* Status With Brain Neuropathology in Older Adults

Martha Clare Morris, ScD[1]; John Brockman, PhD[2]; Julie A. Schneider, MD, MS[3,4,5]; et al

» Author Affiliations | Article Information

JAMA. 2016;315(5):489-497. doi:10.1001/jama.2015.19451

Moderate seafood consumption was correlated with lesser burden of brain Alzheimer disease neuropathology ($P<0.02$)

Evaluation of Se as an antagonist of Hg toxicity → No association

Seafood consumption → higher brain levels of Hg
Hg levels were not correlated with brain neuropathology ($P>0.05$)

REasons for Geographic and Racial Differences in Stroke (REGARDS) Study

- Dr He Ka PI at University of Indiana
- The cohort initially included 30,239 individuals enrolled between January 2003 and October 2007.
- A random sample (n=2,486) was selected within the entire cohort trace metal analysis; All incident ischemic stroke cases (n=671) were included.
- Se, Mg, Ca, Zn, Fe, Hg in 3157 blood serum samples, As Cd in 3157 urine samples. Arsenic speciation measurements in 400 urine samples

Talanta 165 (2017) 76–83

Contents lists available at ScienceDirect

Talanta

journal homepage: www.elsevier.com/locate/talanta

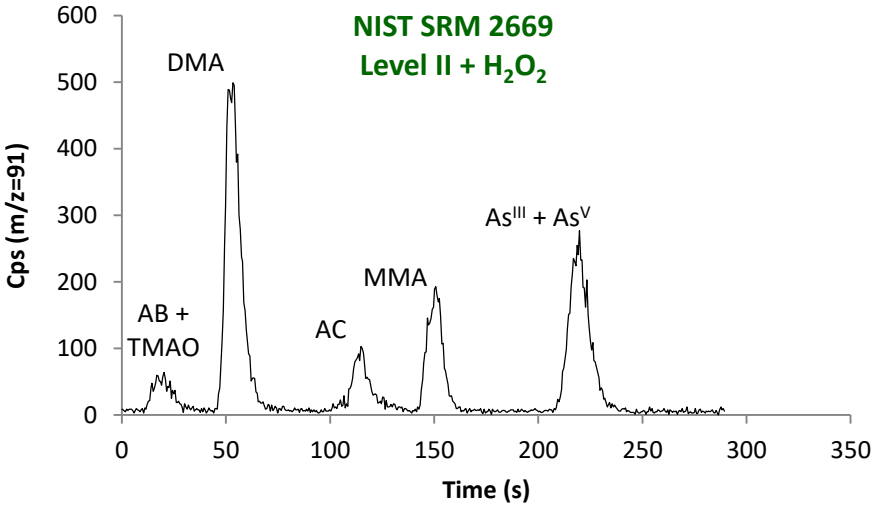
Fast and reliable method for As speciation in urine samples containing low levels of As by LC-ICP-MS: Focus on epidemiological studies

V.M.O. Carioni[a], J.A. McElroy[a,b], J.M. Guthrie[a], R.A. Ngwenyama[a], J.D. Brockman[a,*]

[a] University of Missouri Research Reactor, University of Missouri - Columbia, 1513 Research Park Drive, Columbia, MO 65211, United States
[b] University of Missouri - Columbia, Family and Community Medicine, University of Missouri, 1 Hospital Dr, Columbia MO 65212, United States

IonPac AG7 Dionex; mixed bed ion exchange

LC-ICPMS at MURR



Stroke

ORIGINAL CONTRIBUTION

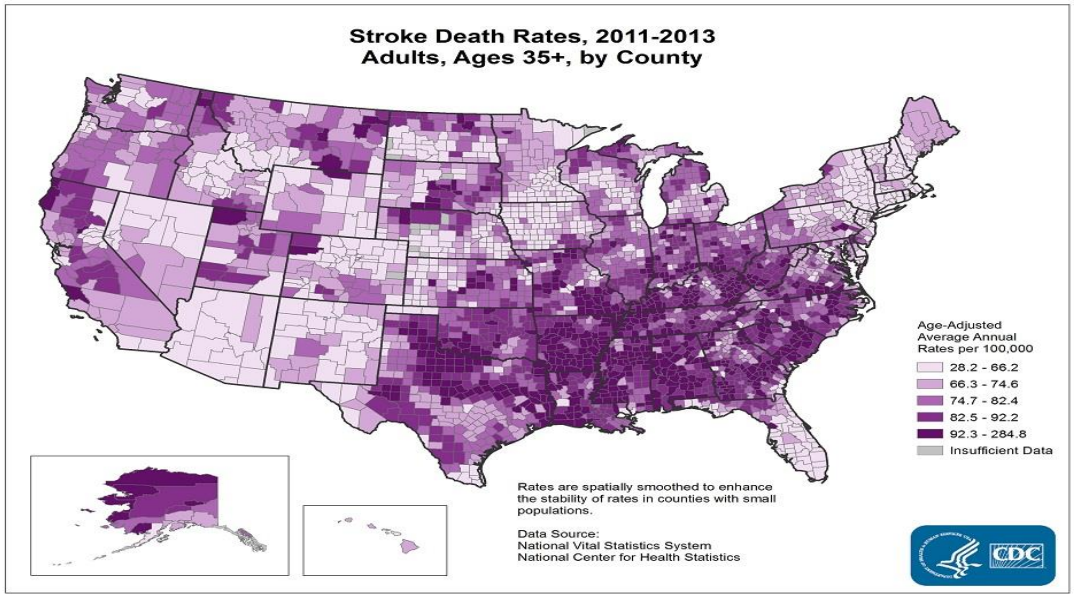
Arsenic Exposure in Relation to Ischemic Stroke

The Reasons for Geographic and Racial Differences in Stroke Study

Cari L. Tsinovoi, Pengcheng Xun, Leslie A. McClure, Vivian M.O. Carioni, John D. Brockman, Jianwen Cai, Eliseo Guallar, Mary Cushman, Frederick W. Unverzagt, Virginia J. Howard, Ka He

Download PDF

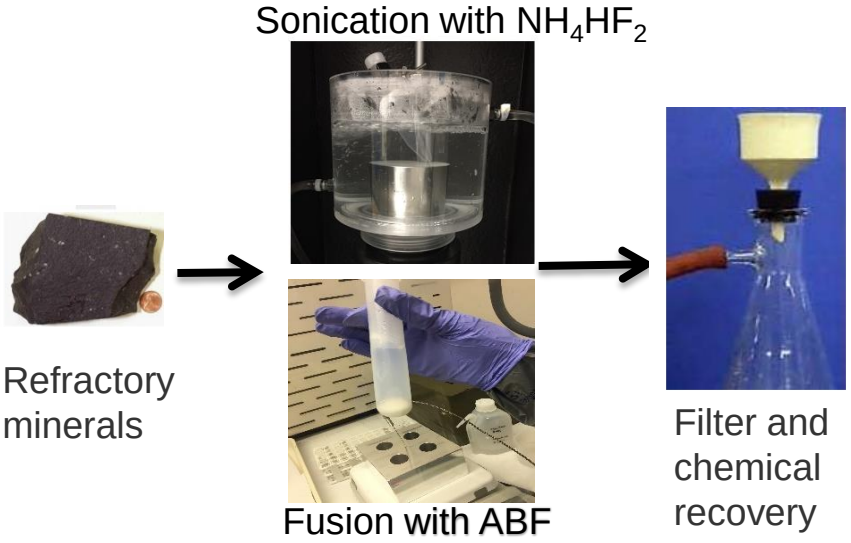
DOI https://doi.org/10.1161/STROKEAHA.117.018891
Stroke. 2018;49:19-26
Originally published December 6, 2017



Evaluation of Novel, Inorganic Salt Fusions and Sonication to Dissolve Refractory Nuclear Debris, John Brockman, MURR, DTRA1-15-1-0016

Objective: Develop chemistry to dissolve refractory silicates and minerals by inorganic fusion.

Relevance: development of dissolution methods for rapid onsite dissolution of refractory minerals to support nuclear forensic analysis



Approach: evaluate dissolution chemistry based on measurement of undissolved solids, loss of volatile fission products, and elemental recovery.

Personnel Support: 2 faculty, 1 postdoc, 2 graduate students, 1 undergraduate student.

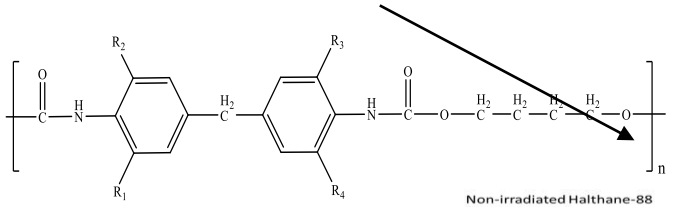
ABF fusion dissolution results
LiM fusion dissolution results
ABF sonication dissolution results
3 peer reviewed publications
2 ACS national meeting presentations
Seaborg student fellowship LANL

John D. Brockman PI
J. David. Robertson CoI
Nick Hubley, grad student
Dana Wegge, undergrad → grad student
Christian Mason, Postdoctoral Fellow

Chronomorphic characterization and Modeling of Radiation Effects on Dismantled Nuclear Arsenal Element Materials, HDTRA1-16-0019

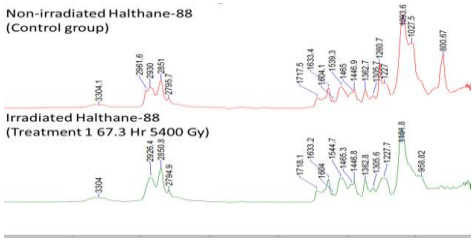
Objective: There are few studies that examine fast neutron radiolysis damage in polymers. Radiolysis results in chain scission or cross linking depending on functional group, aromaticity, radiation type, and environmental factors. This work explores the effects of 0.5-14 MeV fast neutrons on polymeric materials.
Method: Calibrated fast neutron irradiations (at MURR) of polymers (Y12) followed by physical and chemical analysis (MURR and Y12).

0.5 – 14 MeV neutron



Polyurethane

Measurements to identify radiolysis effects

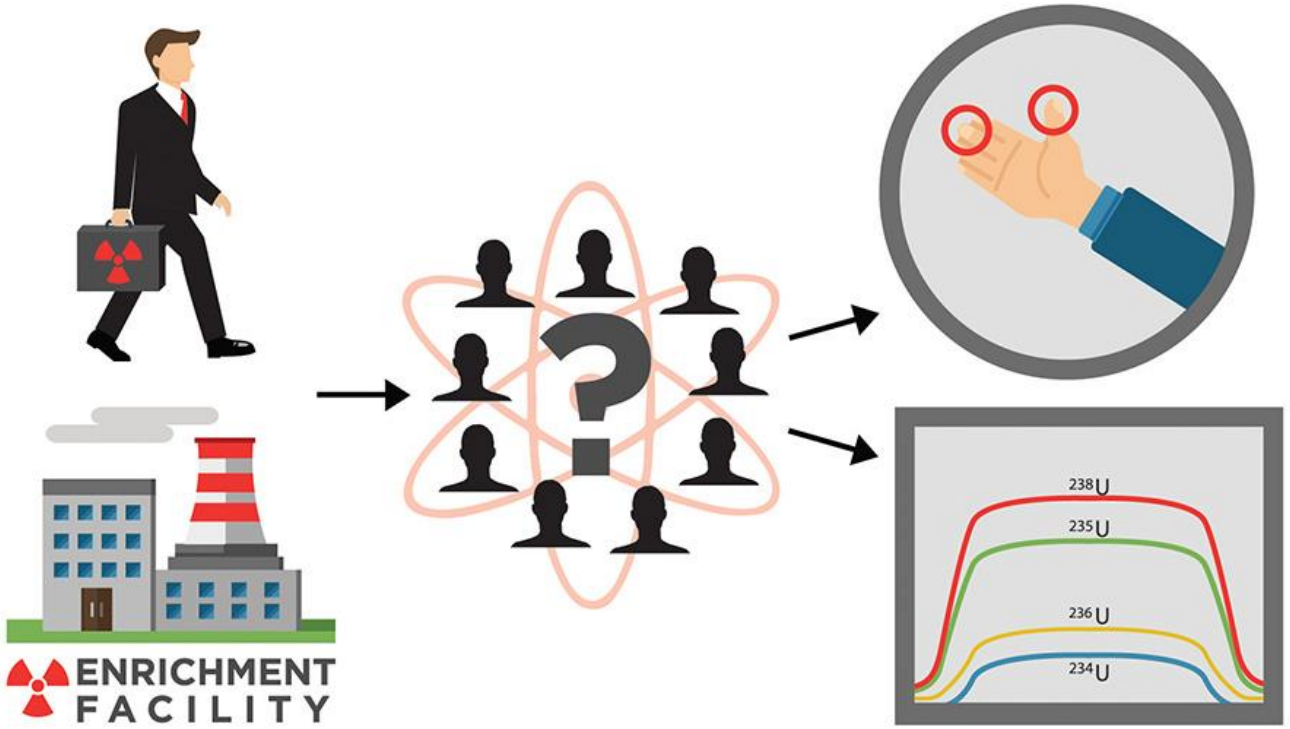


Status of effort: Fast neutron position has been built and characterized. First year polyurethane samples have been irradiated and are under investigation at MURR and Y12.

Personnel Supported: 2 Faculty, 1 Post-Doc, 2 graduate students (Missouri). 1 staff scientist, 2 summer engineering interns (Y12) **Publications & Meetings:** A manuscript is in preparation on the fast neutron position built at the MURR 16.5 MeV cyclotron. Additional manuscripts describing fast neutron radiolysis in polyurethane are anticipated in year 2.

Year 1: 1. construction of fast neutron position. 2. synthesis of test samples. 3. irradiation. 4. characterization at MURR and Y12. **Year 2**: 1. wider dose range if necessary. 2. selection and irradiation, 2 additional test materials. 3. characterization at MURR and Y12. **Year 3:** 1. Characterization, publish.
Funding Profile $359k 5/5/16 -5/4/17 $360k 5/5/17 – 5/6/18 $350k 5/5/18 – 5/4/19
Contact information John Brockman, brockmanjd@Missouri.edu 573-884-8095, Michael Quinn, Michael.Quinn@cns.doe.gov, 865-574-8311

Use of Hair and Nail as a non-invasive, integrative monitor of U and Pu for nuclear forensic analyses



Hair and nail as an integrative monitor of exposure

- Hair and nails are a stable metabolic endpoint
- Easy to collect, transport and analyze
- Biokinetic model for U in hair
- The FBI uses hair analysis in criminal investigations

Exposure

- Natural uranium exposure
  - 1 µg/d exposure in USA
  - Present in water and food.
- Occupational uranium exposure
  - Mining, milling, enrichment, chemical processing, fuel and device fabrication…
- Plutonium exposure
  - Fallout, weapons and reactor release, reprocessing, research, fuel and device fabrication

Isotope Ratios

Isotope Ratio	Indicates	Natural
$^{235}U/^{238}U$	enrichment	0.00726
$^{236}U/^{238}U$	reactor irradiation Reprocessing	<1E-8%
$^{233}U/^{238}U$	Th fuel cycle Reprocessing	NA
$^{239}Pu/^{240}Pu$	Reprocessing Pu separation	Fallout 5.6 Weapon 9.0

Plutonium Signatures

Source	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu
Global fallout		83.5	15.0	1.2	0.3
Medical ^{238}Pu	90.4	9.0	0.6	0.3	0.1
LWR 60 GWd/t	4.4	46.3	24.9	12.7	11.7
Chernobyl env. Sample	0.21-0.31	66.2-71.8	21.98-26.1	4.7-6.21	1.2-1.8
Weapons Grade	0.04	93.3	6.0	0.6	0.04
Nagasaki		94.3	5.5		

Occupational Exposure Study with Human Volunteers

- Task 1: IRB Approval
  - Approval from UMC HS IRB
  - Approval from DOE Central IRB
  - Review by DTRA board

- Approved Documents
  - Letter of introduction/waiver of consent
  - Sample collection instructions
  - Survey
  - Telephone script for contact
  - Advertisement for controls

Identification of eligible participants

- Dr. Jonathan Morrell at Y12 and Dr. Brandon Chung at LLNL

- Case recruitment
  - **Compile list of potential volunteers based on knowledge of work History**

- Initial contact with follow up phone interview with Dr. Brockman
  - if verbal agreement, subject is mailed collection packet within 2 weeks of phone contact

Biospecimen and Survey Collection

- Collection packet mailed to volunteer
  - Letter of introduction with approved waiver of consent
  - Short survey focused on work history and occupational exposure to U, Pu and Th
  - Collection instructions
  - Self addressed collection packet with stamp

Mass spectrometry challenges

	Interference	Strategy	Action
$^{236}U^{+}$	$^{235}U^{1}H^{+}$	Desolvating nebulizer	Dries solution and limits formation of hydrides
		Mathematical correction based on $^{238}U/^{238}U^{1}H$	Subtracted from signal at m/z 236
$^{239}Pu^{+}$	$^{238}U^{1}H^{+}$, $^{204}Pb^{35}Cl^{+}$, $^{207}Pb^{16}O_2^{+}$	Chemical separation Desolvating Nebulizer	Eichrome separation with reported DF of $>1X10^{4}$

Sample Digestion

Microwave Digestion (Concentrated HNO_3 + 30% H_2O_2)

Dilute Digested Sample + ^{242}Pu spike (3 M HNO_3 + 1 M $AlNO_3$)

Valence Adjustment

Reduce Pu -> Pu^{3+} (1.5 M Ascorbic acid + 1.5 M Sulfamic acid)

Oxidize Pu^{3+} -> Pu^{4+} (3.5 M Sodium Nitrite)

Separation

TEVA

UTEVA

Transfer Uranium to UTEVA (3 M HNO3)

Uranium Fraction

UTEVA

Rinse Uranium (3 M HNO_3)

Elute Uranium 5 mL (0.02 M HNO_3 + $5x10^{-3}$ M HF) Acid

Plutonium Fraction

TEVA

DGA

Pu to DGA (3 M HNO_3 + 0.1 M Ascorbic acid + 0.02M Ferrous Nitrate

DGA

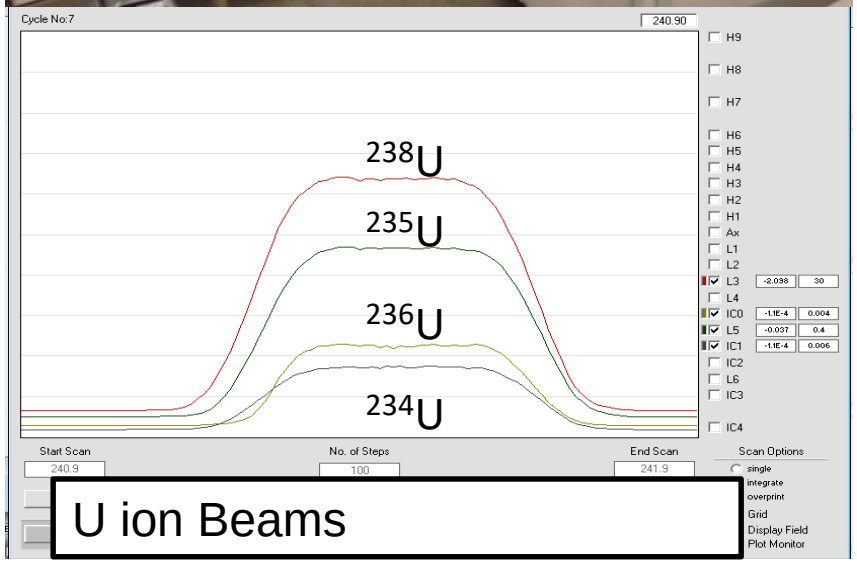
Pu^{3+} -> Pu^{4+} (8 M HNO_3)

Rinse (0.1 M HNO_3)

Elute Pu, Pu^{4+} -> Pu^{3+} 11 mL (0.02 M HCl + $5x10^{-3}$ M HF + $1x10^{-4}$ M $TiCl_3$)

Isotope Ratio Measurements

Multi Collector ICP-MS



U ion Beams

Dr. John Brown diligently analyzing samples

MC-ICPMS Results

- Mass bias calibration and ion counter gain calibration.
- Sample bracketed with blanks and standards.
- U Isotope Ratio measurements
  - Natural U standard $^{235}U/^{238}U = 7.178 \times 10^{-3}$ (9×10^{-6})
  - Expected: 0.007248 - 0.007257
  - 105% (4) recovery of spiked U
- ^{239}Pu concentration measured by isotope dilution mass spectrometry
  - 0.02 ng ^{242}Pu spike
  - QC, Eckert and Zeigler ^{239}Pu standard.
    - Measured 2.1 (0.08) ng/kg
    - actual 2.2 ng/kg
  - Detection limit for $^{239}Pu < 1$ ng/kg
  - Decontamination factor of 10,000 for chemical separation of Pu from U.

Brown et al. Talanta, 129, 481-485

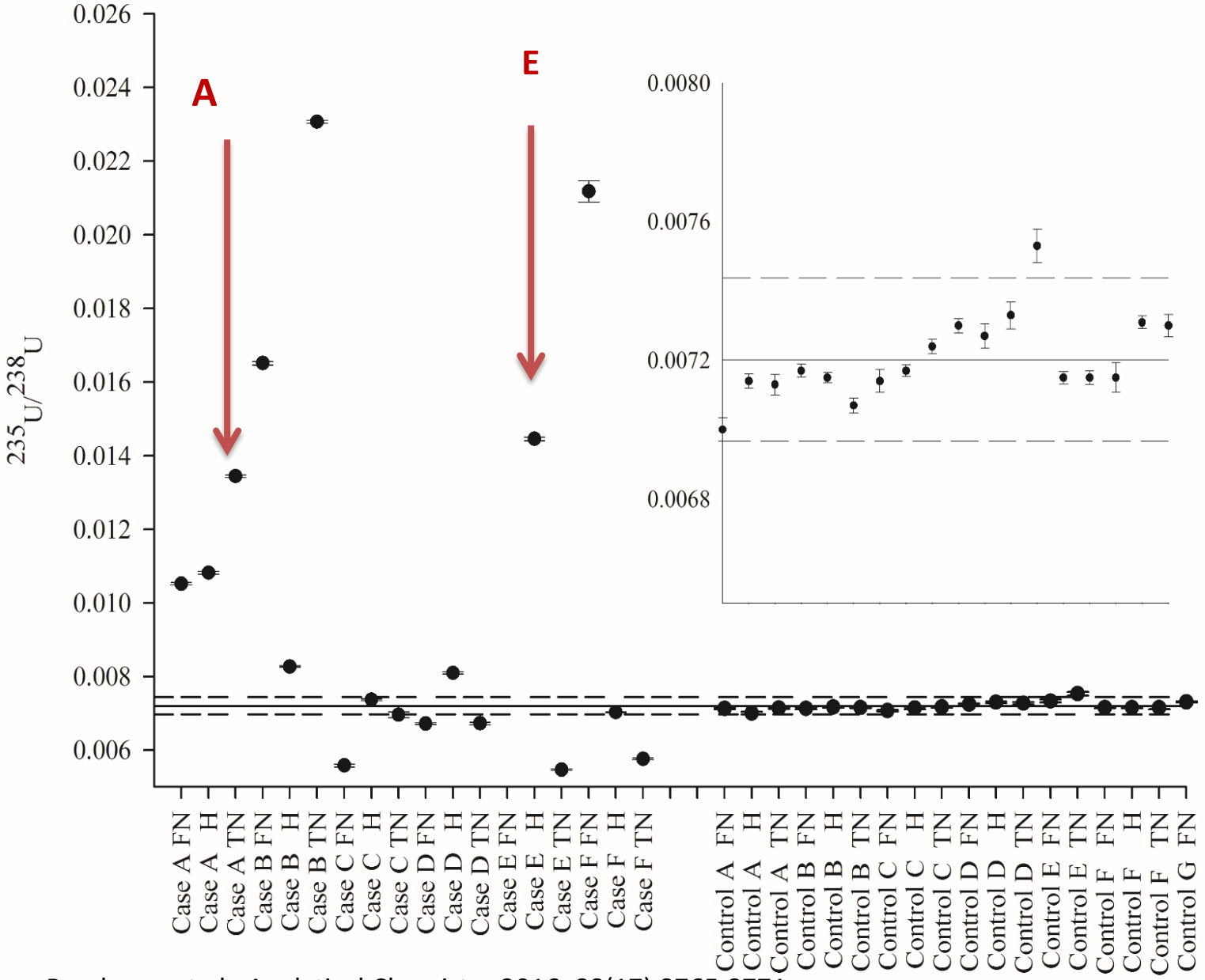
Control group

- Controls
  - $^{235}U/^{238}U$ ratio = $7.19 \times 10^{-3} \pm 4 \times 10^{-5}$
  - ^{236}U was not detected
  - U concentration: 8 ng/g to 1661 ng/g
- Cases
  - U concentration: 5 ng/g up to 383 ng/g

Case	Matrix	$^{236}U/^{238}U$	error	Exposure
Case A	Hair	<LOD		>90% ^{235}U, HEU, DU,
	Fingernail	<LOD		Last exposure 1 year prior to enrollment
	Toenail	3.20×10^{-5}	3.2×10^{-6}	U urine analysis elevated
Case B	Hair	7.20×10^{-6}	9.8×10^{-7}	HEU
	Fingernail	4.21×10^{-5}	3.4×10^{-6}	Current worker
	Toenail	1.260×10^{-4}	3.7×10^{-6}	U urine analysis not elevated
Case C	Hair	2.21×10^{-5}	4.0×10^{-6}	DU, HEU, >90% ^{235}U
	Fingernail	1.230×10^{-4}	7.1×10^{-6}	current worker
	Toenail	1.01×10^{-4}	1.2×10^{-5}	U urine analysis not elevated
Case D	Hair	2.6×10^{-5}	1.4×10^{-5}	>90% ^{235}U, HEU, DU, NU, LEU
	Fingernail	1.50×10^{-4}	1.4×10^{-5}	Current worker
	Toenail	7.04×10^{-5}	4.1×10^{-6}	U urine analysis elevated
Case E	Hair	7.39×10^{-5}	3.7×10^{-6}	>90% ^{235}U, HEU, DU, NU, LEU
	Fingernail	N/A		current worker
	Toenail	5.37×10^{-5}	1.7×10^{-6}	U urine analysis not elevated
Case F	Hair	6.88×10^{-6}	3.9×10^{-7}	>90% ^{235}U, HEU, DU, NU, LEU
	Fingernail	2.91×10^{-4}	3.3×10^{-5}	Current Worker
	Toenail	4.15×10^{-5}	1.6×10^{-6}	U urine analysis not elevated

error = expanded uncertainty at k=2, N/A = not available

$^{235}U/^{238}U$ Results



Brockman et al., Analytical Chemistry 2016, 88(17) 8765-8771

U Discussion

- To wash or not to wash?
- $^{235}U/^{238}U$ and ^{236}U in cases deviates from natural ratio,
  - High person to person variance
- Several self-reported last exposure more than 12 months after sample collection.
- ^{236}U measured in cases but not controls.

Pu Case	Matrix	^{239}Pu, ng/kg	Self-reported exposure history
Case 1	Hair	$<7\times10^{-2}$	Sub-Critical Assembly Last exposure >3 years prior
	Fingernail	0.78 (0.05)	
	Toenail	$<8\times10^{-3}$	
Case 2	Hair	0.081 (0.007)	Pu tracers, Environmental analysis Currently working with Pu
	Fingernail	$<6\times10^{-2}$	
	Toenail	0.71 (0.03)	
Case 3	Hair	$<4\times10^{-2}$	Born in Japan, post WWII Last exposure > 50 years prior
	Fingernail	0.64 (0.03)	
	Toenail	$<3\times10^{-2}$	
Case 4	Hair	$<2\times10^{2}$	Redox, separation, thermodynamics, alkaline chemistry, isotope separation, electrochemistry Last exposure >1 year
	Fingernail	0.15 (0.01)	
	Toenail	0.055 (0.007)	
Case 5	Hair	$<7\times10^{-3}$	Born in Japan, post WWII Last exposure >50 years prior
	Fingernail	$<2\times10^{-3}$	
	Toenail	0.07 (0.02)	
Case 6	Hair	$<6\times10^{-1}$	Pu measurement and recovery processing within glovebox. Currently working with Pu.
	Fingernail	$<3\times10^{-2}$	
	Toenail	$<5\times10^{-2}$	
Case 7	Hair	$<5\times10^{-2}$	Worked with contaminated equipment in gloveboxes. Currently working with Pu.
	Fingernail	$<3\times10^{-2}$	
	Toenail	$<6\times10^{-2}$	

Pu Discussion

- 5 of 7 individuals who self-reported Pu exposure had measureable ^{239}Pu in hair and nail samples.
- ^{239}Pu in every control group sample less than LOD.
- Large Intra-person variability
- In some cases Pu exposure occurred decades prior to sample collection

Brown et al., Applied Radiation and Isotopes, 2017, 128. 132-135

Limitations

- Controls were not regionally matched
- Small study
- Self-reported exposure history

Conclusions

- Individuals that self-reported exposure to enriched or depleted U had non-natural U isotope ratios in hair and nail samples.
- 5 of 7 individuals who self-reported exposure to Pu had measurable levels of ^{239}Pu in hair and nail samples.
- This work warrants further study of keratinous materials

Future Work, USTUR Collaboration!

- US Transuranium and Uranium Registries (USTUR)
  - Nuclear forensic applications…
    - FBI routinely uses hair and nail analysis in legal cases.
    - Establish scientific basis for the use of keratinous materials as a bioassay of human exposure to actinides.
  - Nuclear accident exposure monitoring?
  - Support development of biokinetic models used for actinide dose estimation

Acknowledgements

- Students
  - Dr. John W. Brown
  - Lance Schell
  - Dana Wegge
- Technical support
  - Jim Guthrie
  - Barry Higgins
- Funding
  - Defense Threat Reduction Agency, HYDTRA1-12-1-0021
  - NRC Fellowship, NRC-HQ-84-15-G-0036

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