

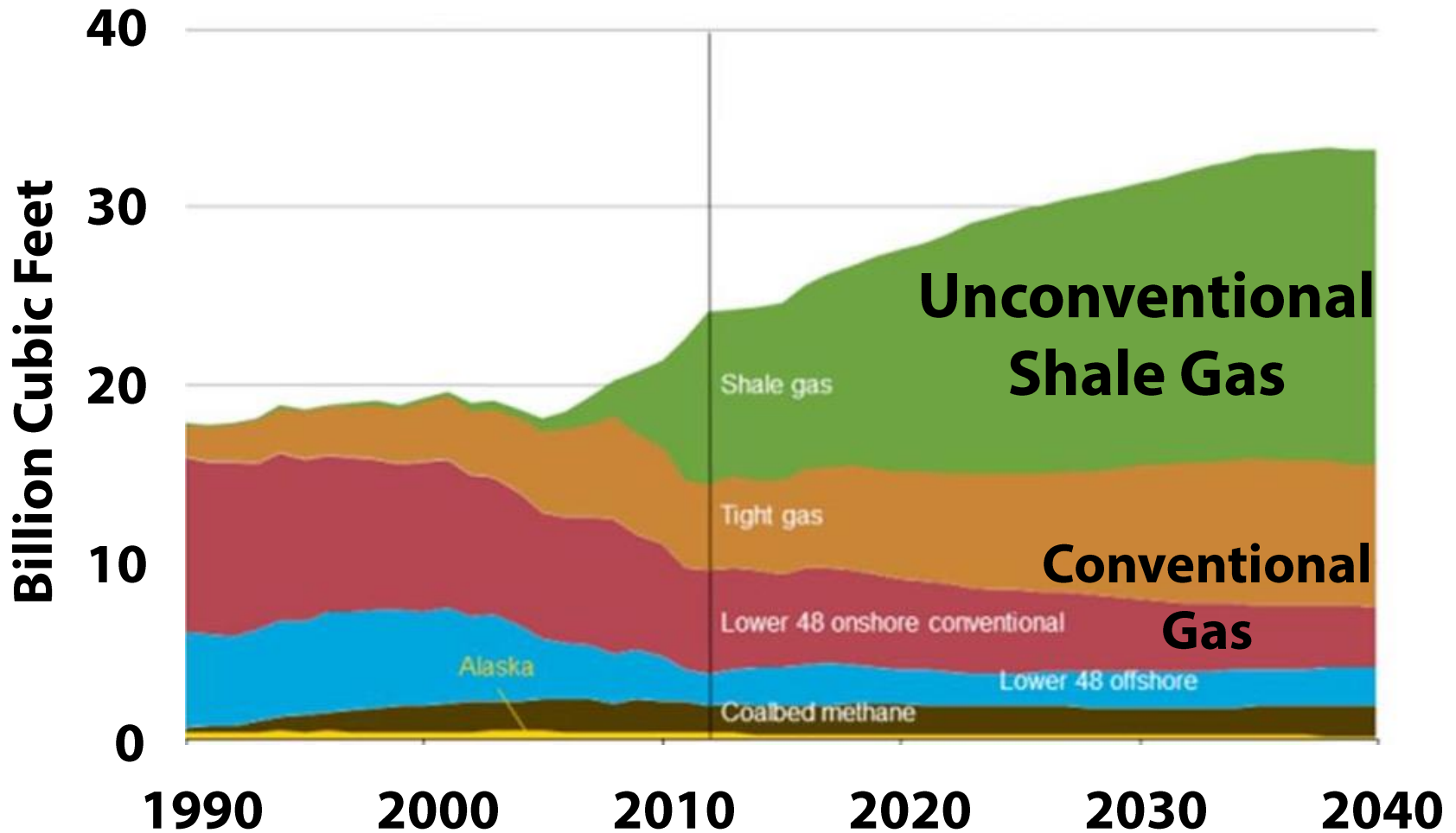
Measuring Radioactivity Associated with Solid and Liquid Waste from Marcellus Shale

Andrew W. Nelson, MPH PhD

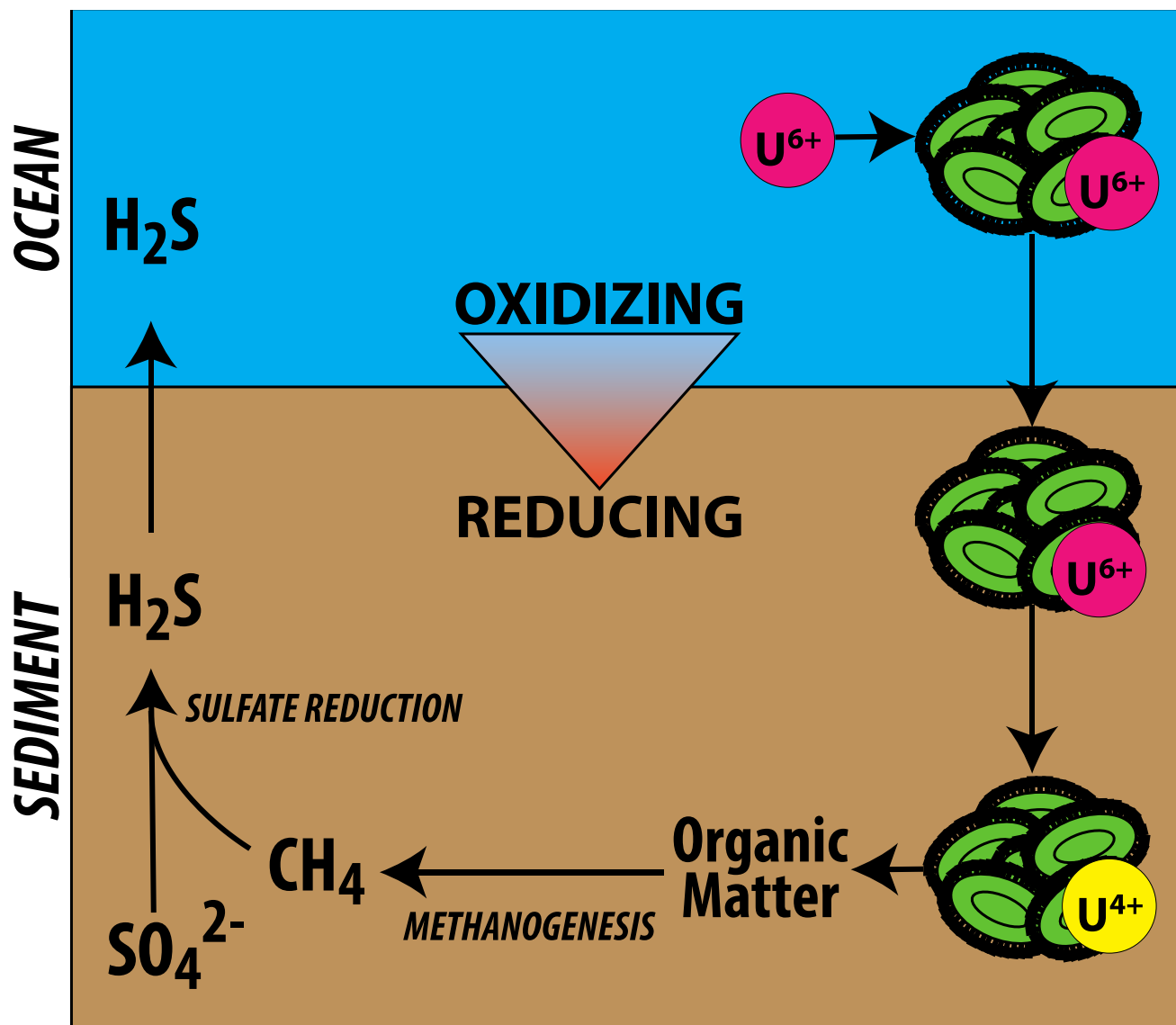


Unconventional Drilling Rapidly Expanding

3

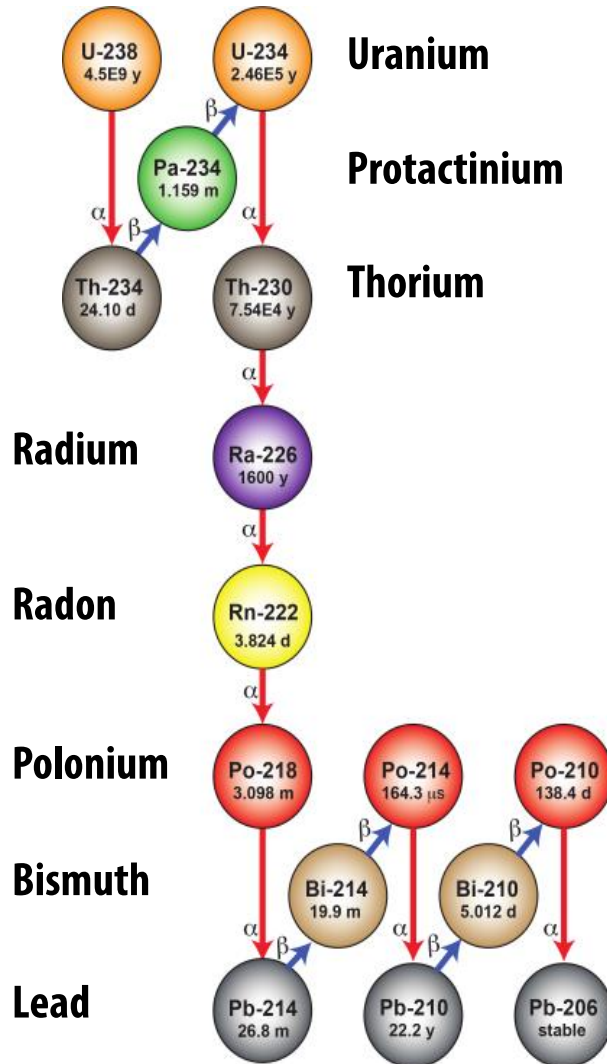


Incorporation of Uranium into Shale Formations



Parent Decay & Decay Product Ingrowth

Uranium-238 Decay Series



Marcellus Shale

- ~300 million years old

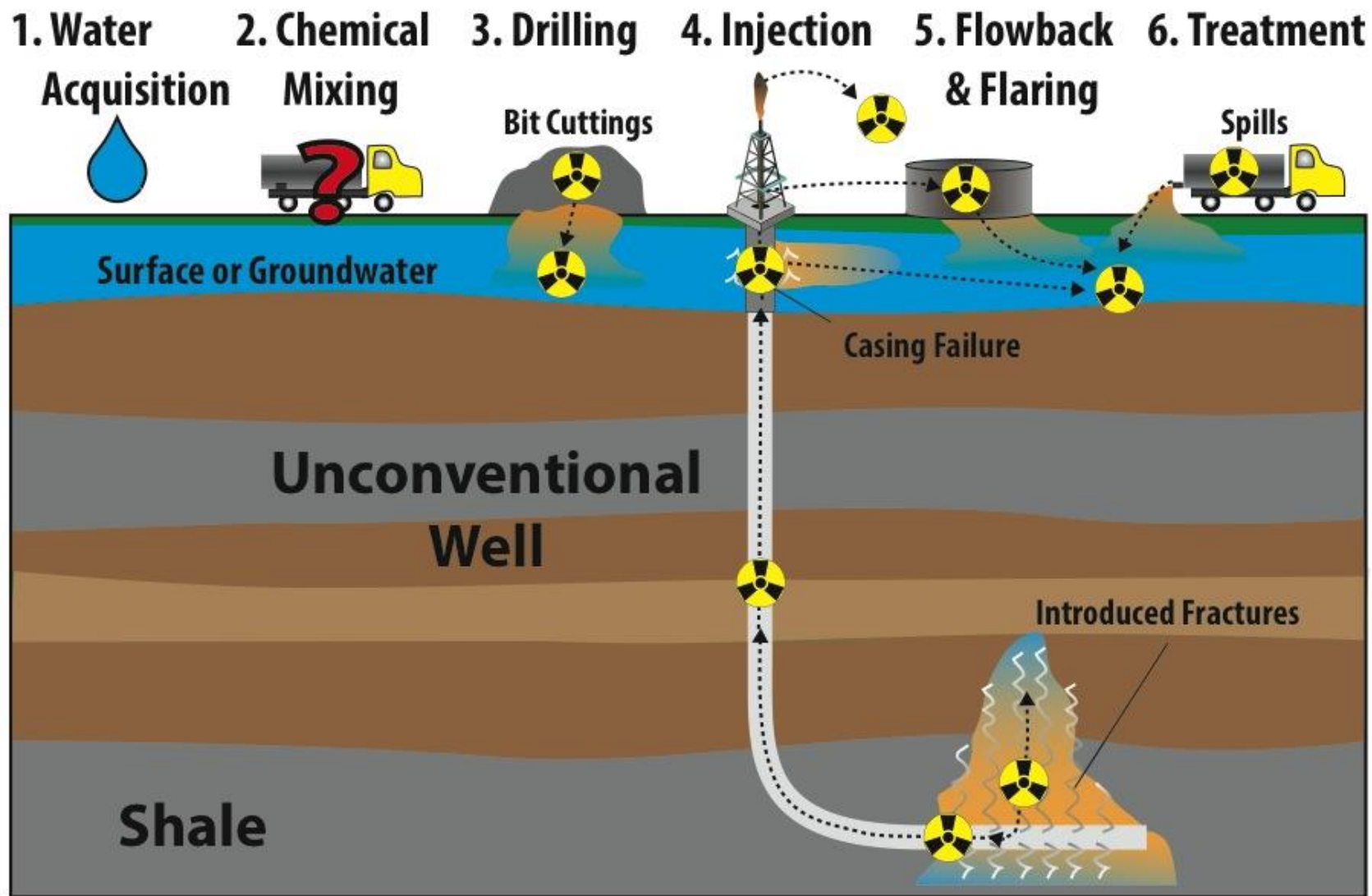
→ 95% of U-238 deposited still present

- Radioactivity of decay products equal to U-238 after
 - ~2 million years

Chemical & Radiochemical Properties Are Important

Periodic Table of the Elements																			
1 IA 1A		2 IIA 2A												13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 H Hydrogen 1.008																			
3 Li Lithium 6.941	4 Be Beryllium 9.012												5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180	
11 Na Sodium 22.990	12 Mg Magnesium 24.305												13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948	
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.972	35 Br Bromine 79.904	36 Kr Krypton 84.798		
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.603	53 I Iodine 126.905	54 Xe Xenon 131.29		
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.084	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon [222]		
87 Fr Francium [223]	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [293]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown		
Lanthanide Series			57 La Lanthanum 138.905	58 Ce Cerium 140.12	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967		
Actinide Series			89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]		
Alkali Metal		Alkaline Earth		Transition Metal		Basic Metal		Semimetal		Nonmetal		Halogen		Noble Gas		Lanthanide		Actinide	

Major Stages of Unconventional Drilling



Overarching Research Goals ***To Develop Tools for Assessing:***

1.) What Comes Up?

Activity Levels and Equilibrium Status

2.) Where Does it Go?

Partitioning

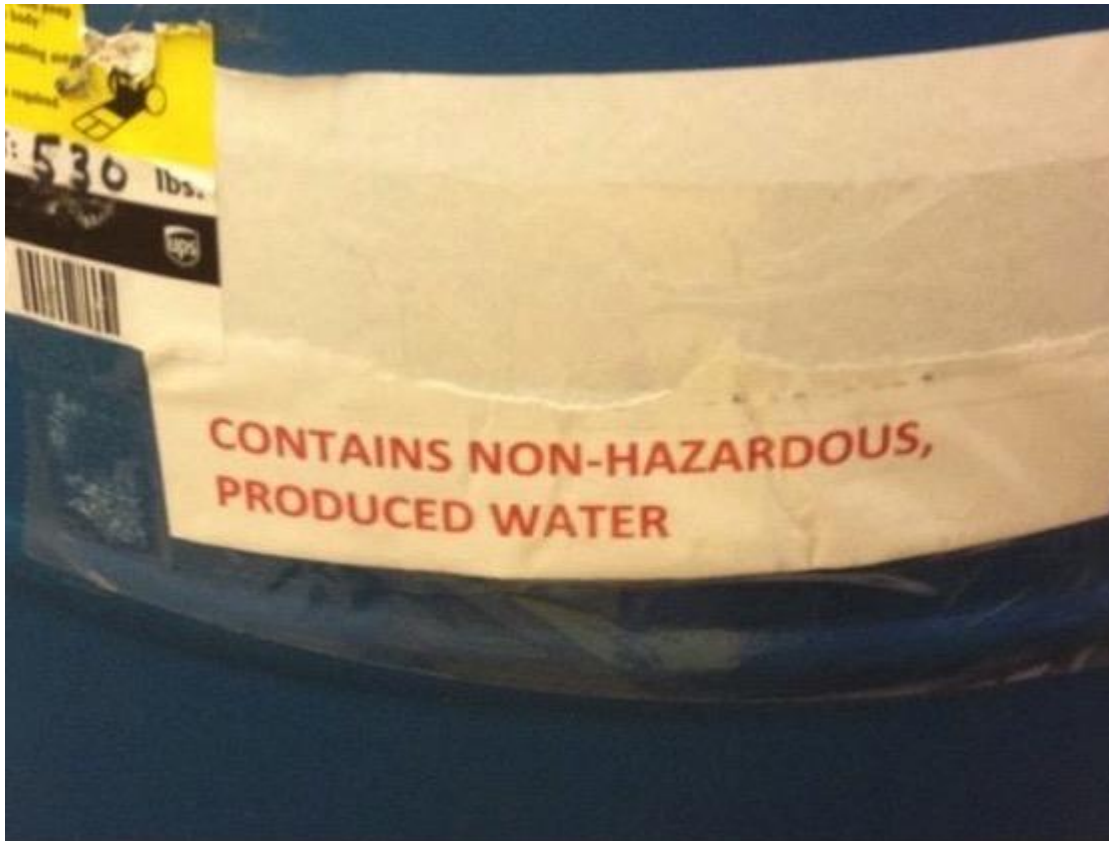
What comes up?



<http://ehp.niehs.nih.gov.proxy.lib.uiowa.edu/122-a50/>

EPA Gross Alpha/Beta Method for Produced Fluids

10



Photos taken by Andrew Nelson

What was the goal of method?



Concentrate

U, Th, Ra, Pb, Po



Volume: 0.1-1 L

Detection Limit:

alpha ~0.2 Bq/L

beta ~.5 Bq/L

Gas Flow



Liquid Scintillation

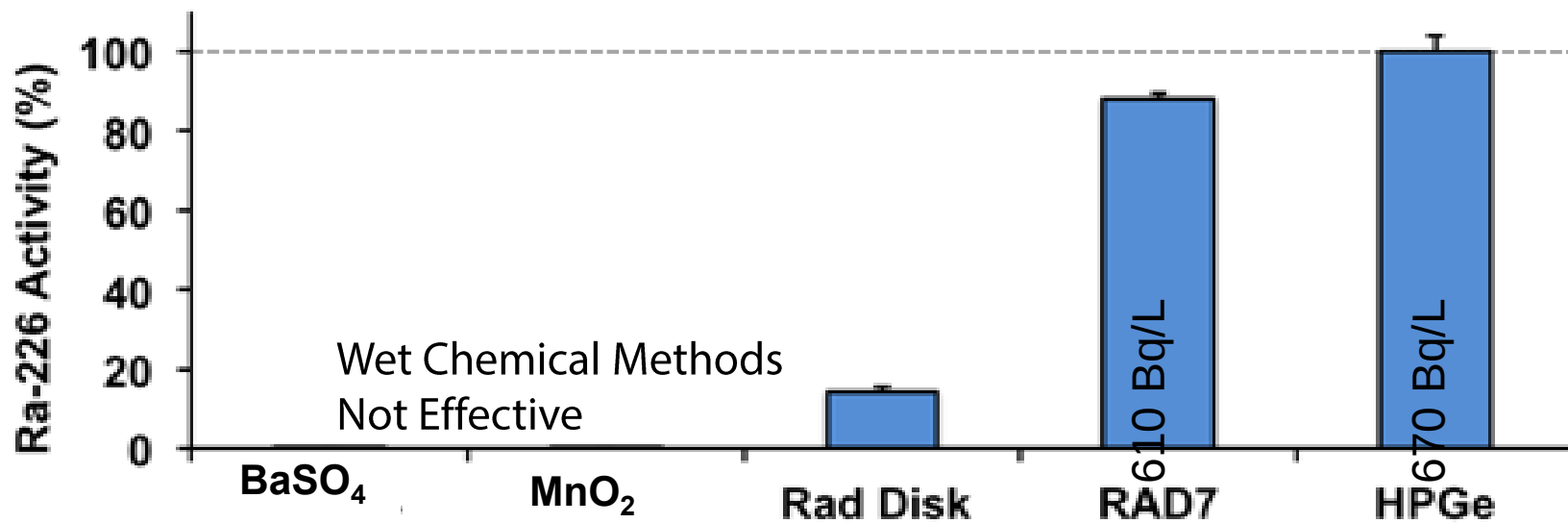


Chemical Matrix

1 1A 1A H Hydrogen 1.008	
3 Li Lithium 6.941	4 2 IIA 2A Be Beryllium 9.012
11 Na Sodium 22.990	12 Mg Magnesium 24.305
19 K Potassium 39.098	20 Ca Calcium 40.078
37 Rb Rubidium 85.468	38 Sr Strontium 87.62
55 Cs Cesium 132.905	56 Ba Barium 137.328
87 Fr Francium 223.020	88 Ra Radium 226.025

Analyte	Concentration (mg/L)
Chloride	146,667
Sodium	29,333
Magnesium	853
Calcium	13,000
Strontium	36,333
Barium	9,000
Manganese	3
Iron	43
Total Solids	277,666
Suspended Solids	783

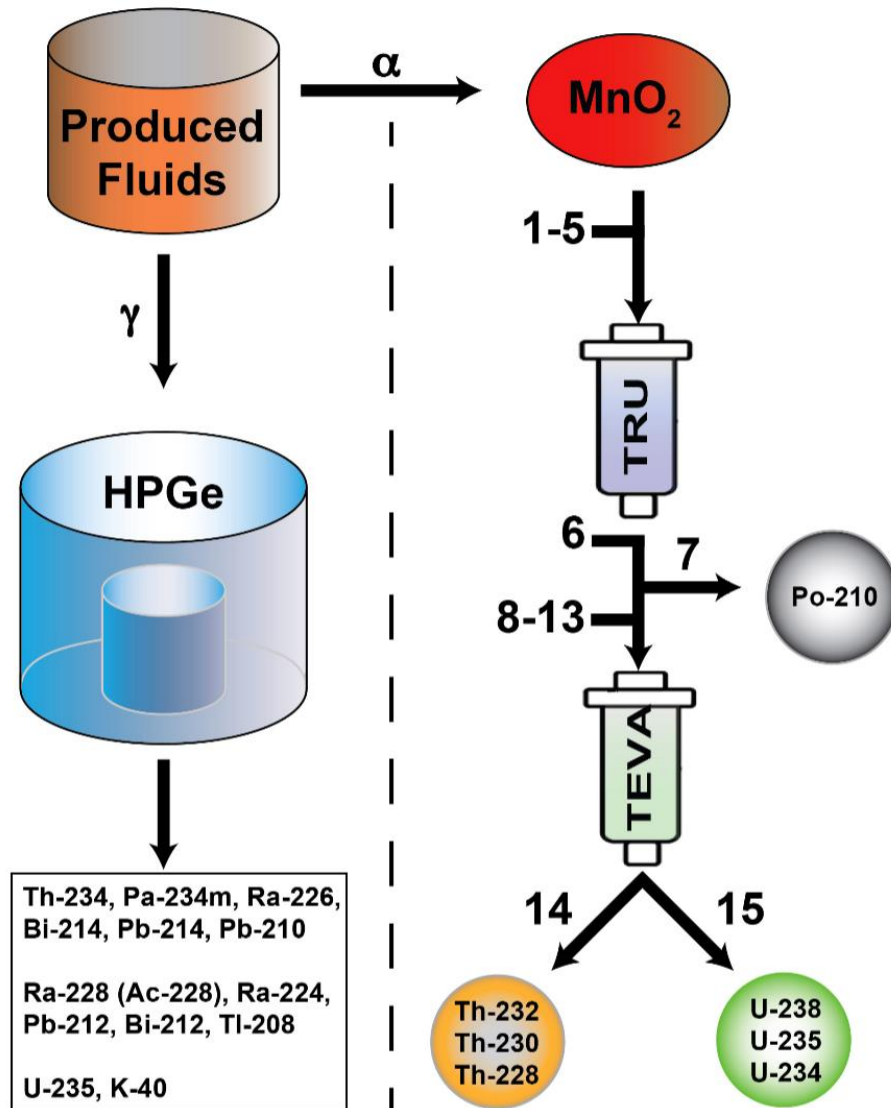
Matrix Complications in the Determination of Ra



$$\text{Ba:Ra} \approx 10^9$$

Nelson *et al.* (2014). Environ. Sci. Technol. Lett.

Gross Alpha/Beta Doesn't Always Work



Overarching Research Questions:

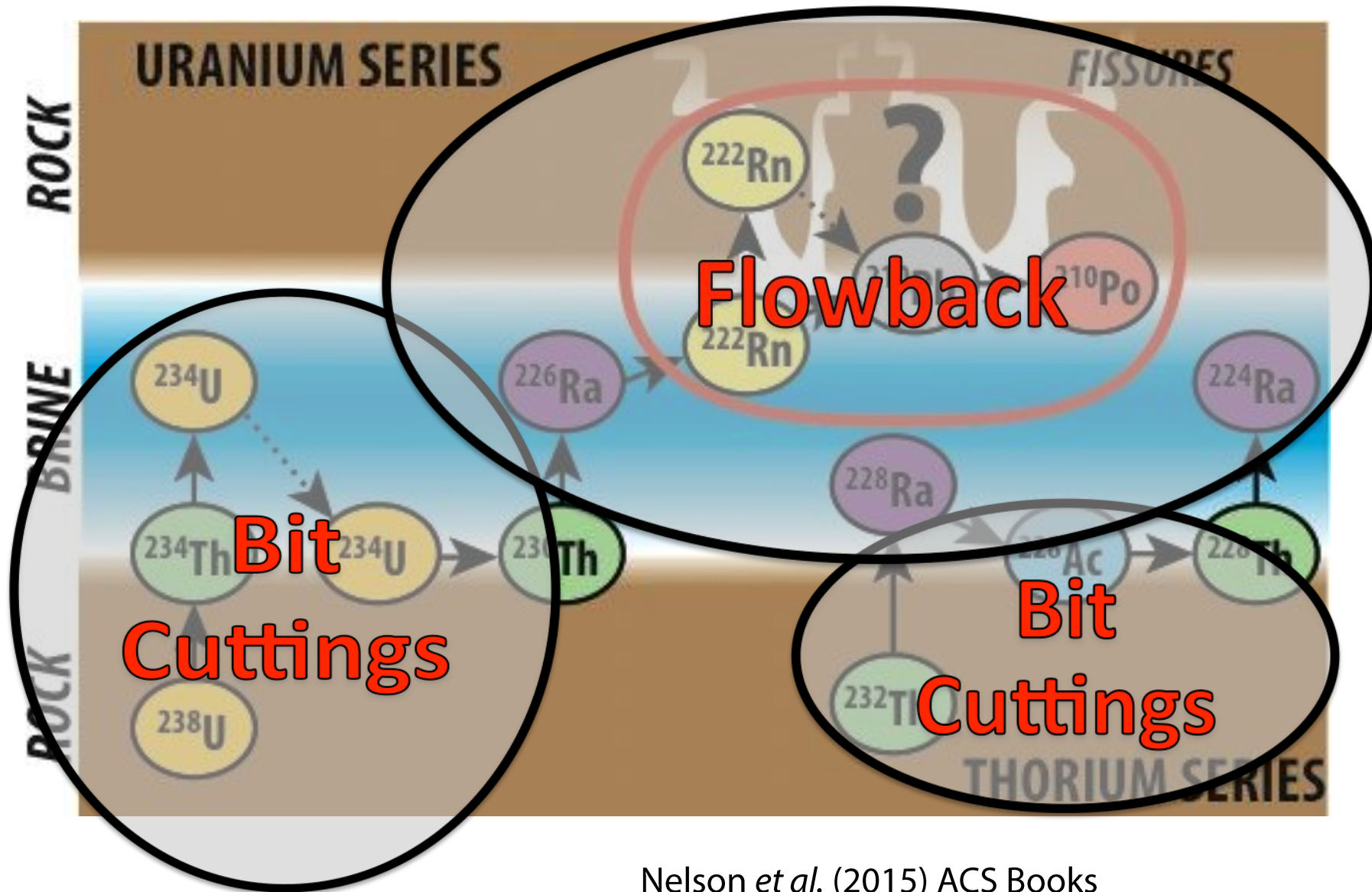
1.) What Comes Up?

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Partitioning

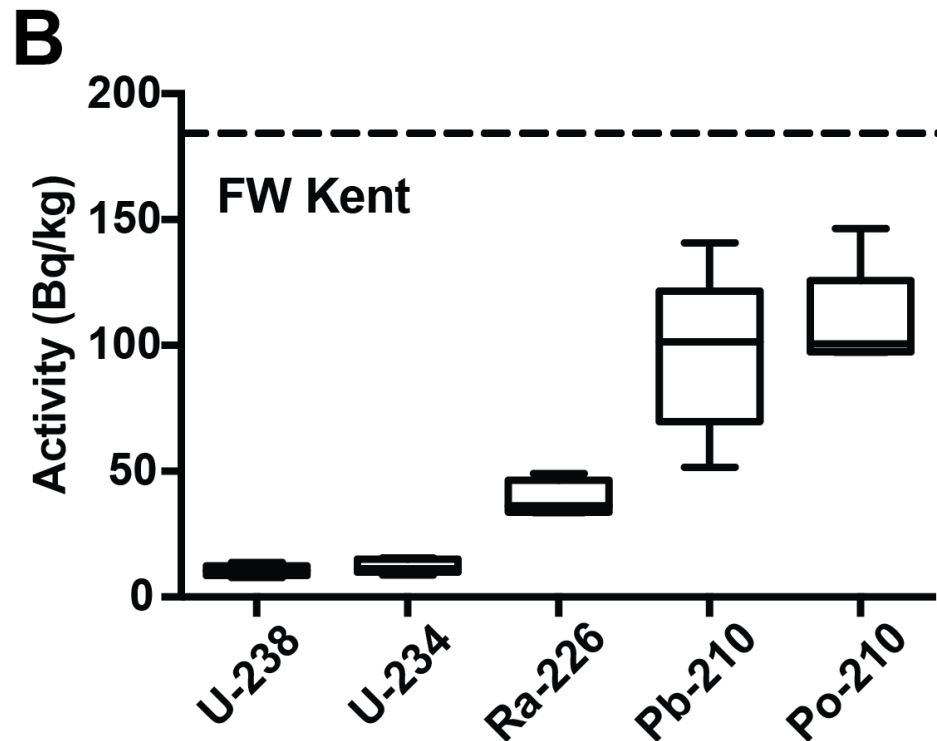
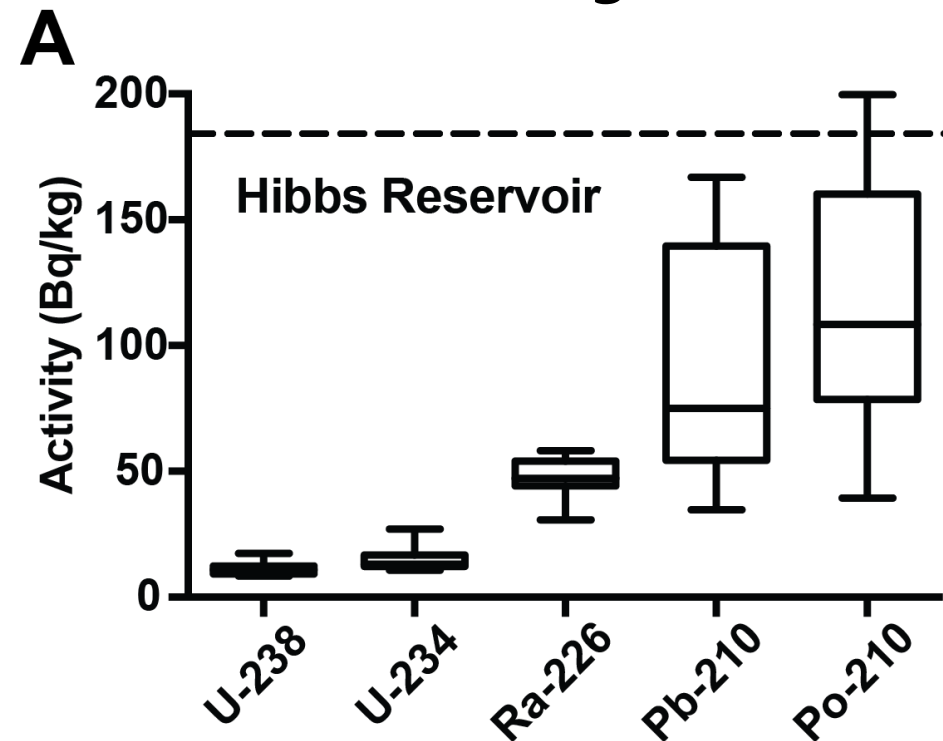
Partitioning Model



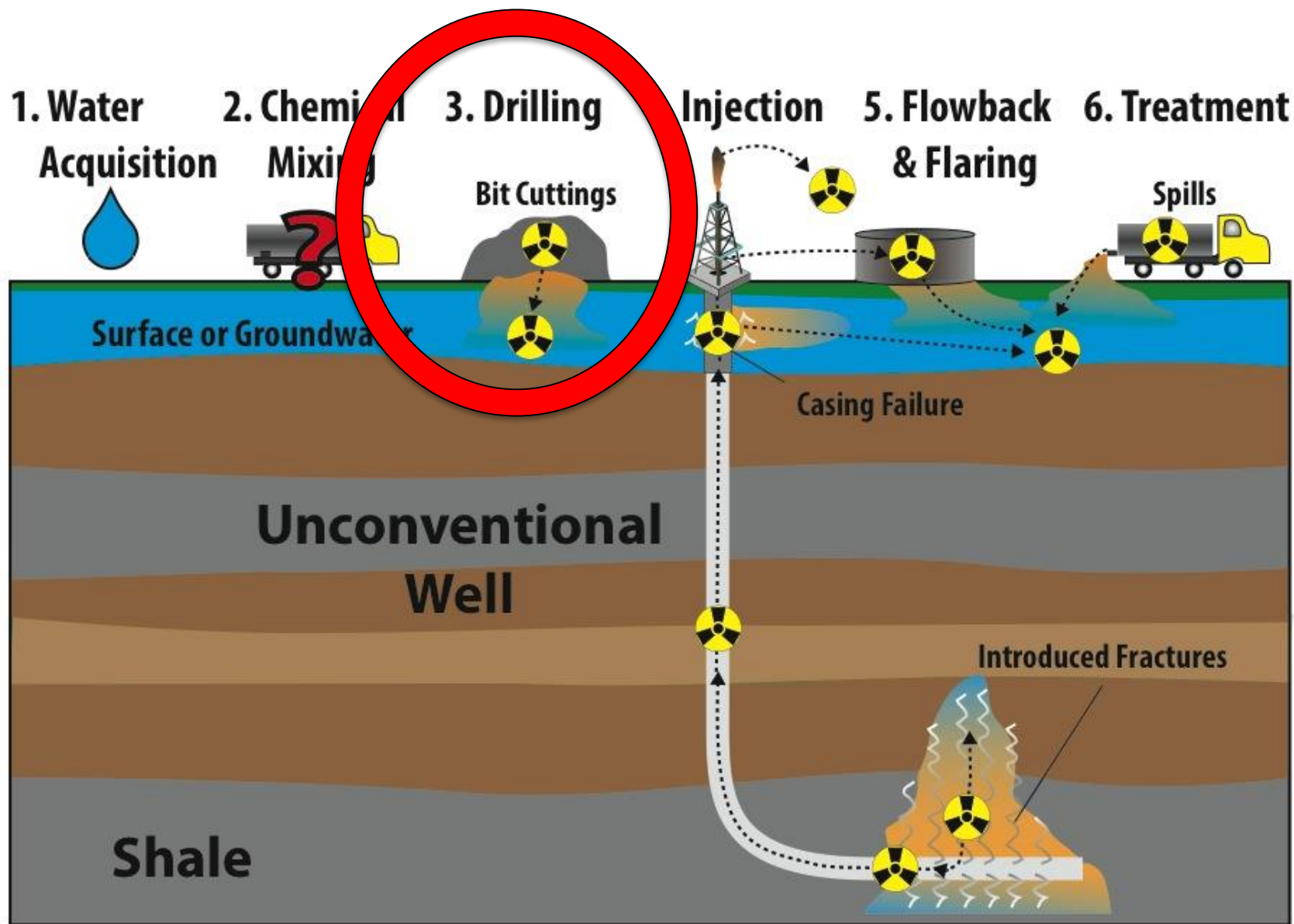
NORM in a Lake Bottom Sediments

West Virginia

Iowa



Does drilling pose radiation risks?



Overarching Research Questions:

1.) What Comes Up?

Activity Levels and Equilibrium Status

2.) Where Does it Go?

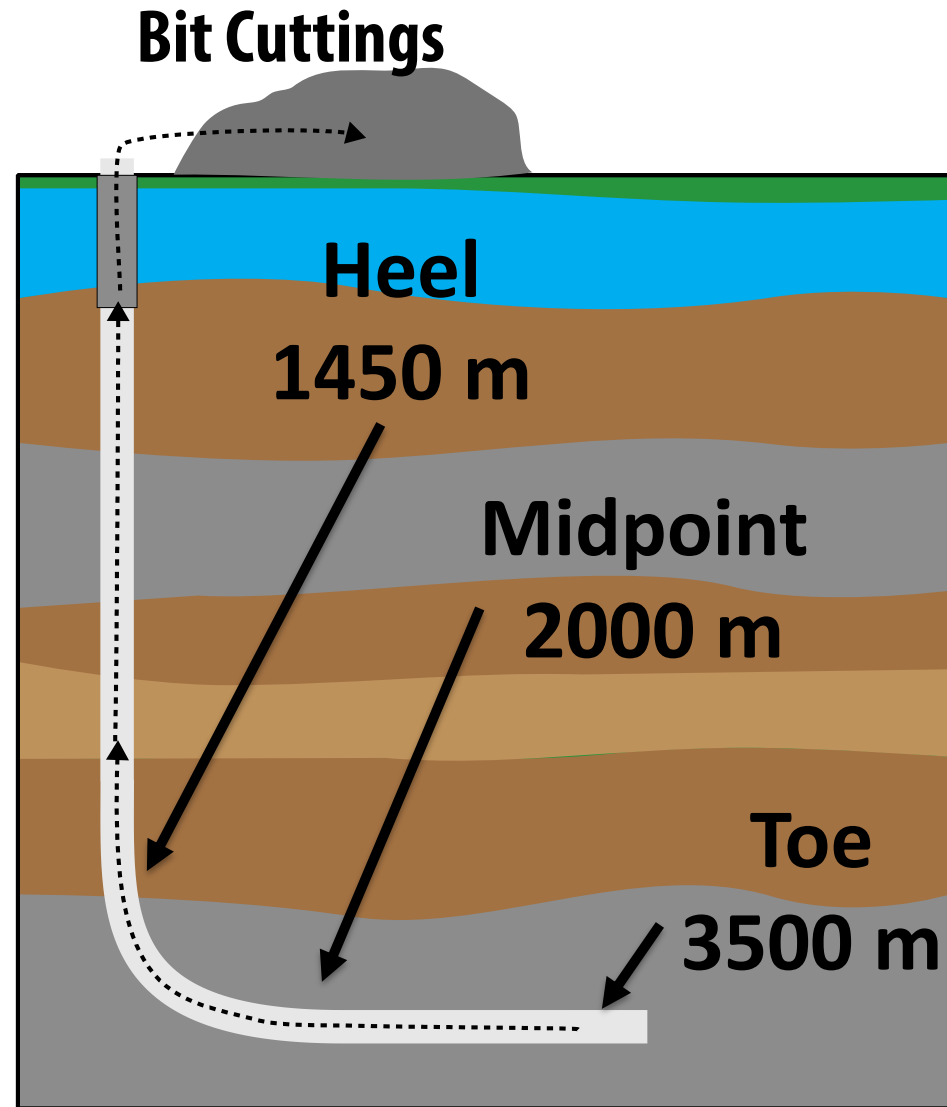
Partitioning

Stage 3: Drilling

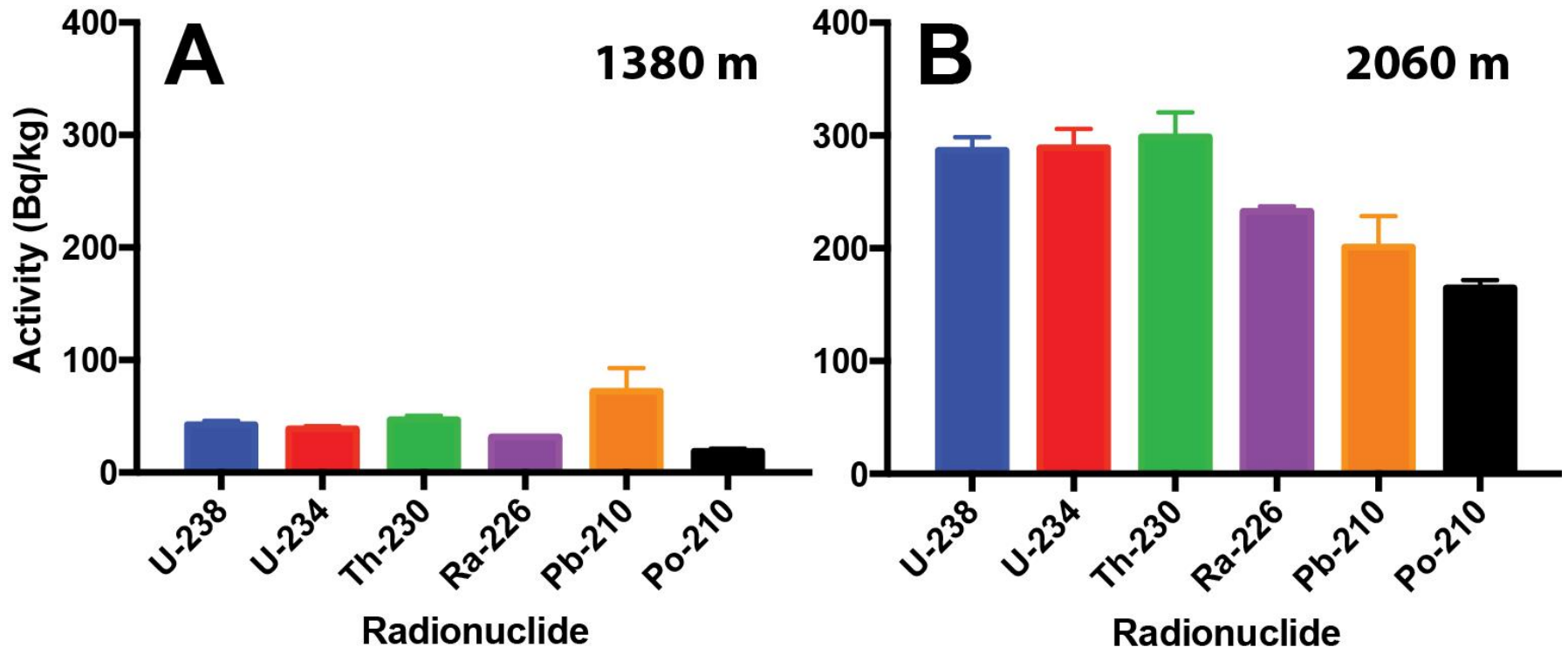


Photo taken by Andrew Nelson

Drill Cutting Study



Drill Cuttings Data



Overarching Research Questions:

1.) What Comes Up?

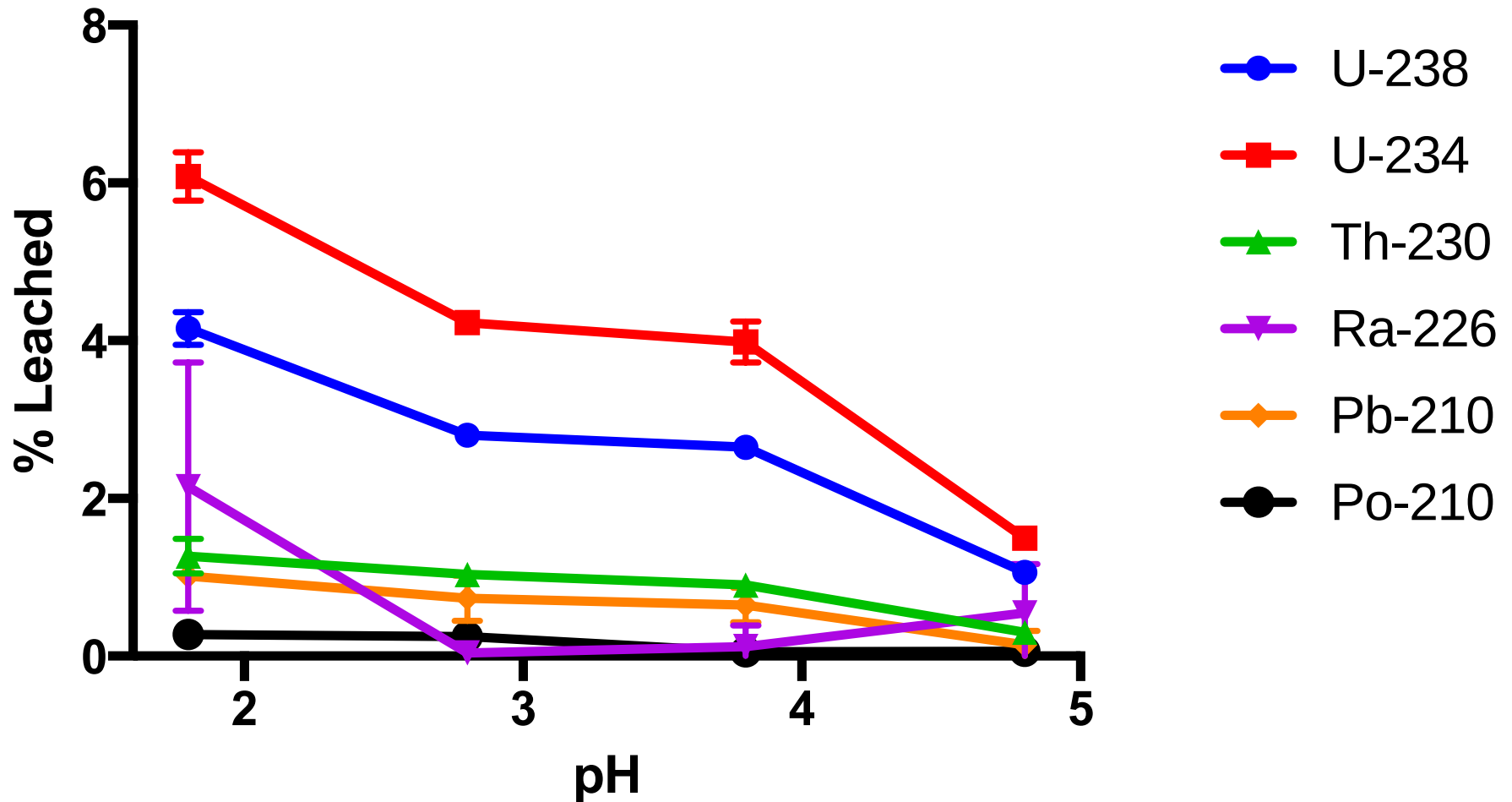
Activity Levels and Equilibrium Status

2.) Where Does it Go?

Partitioning

TCLP Leachates

NORM Leached from Bit Cuttings



Acknowledgements

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