Commercializing a next-generation source of CLENR energy

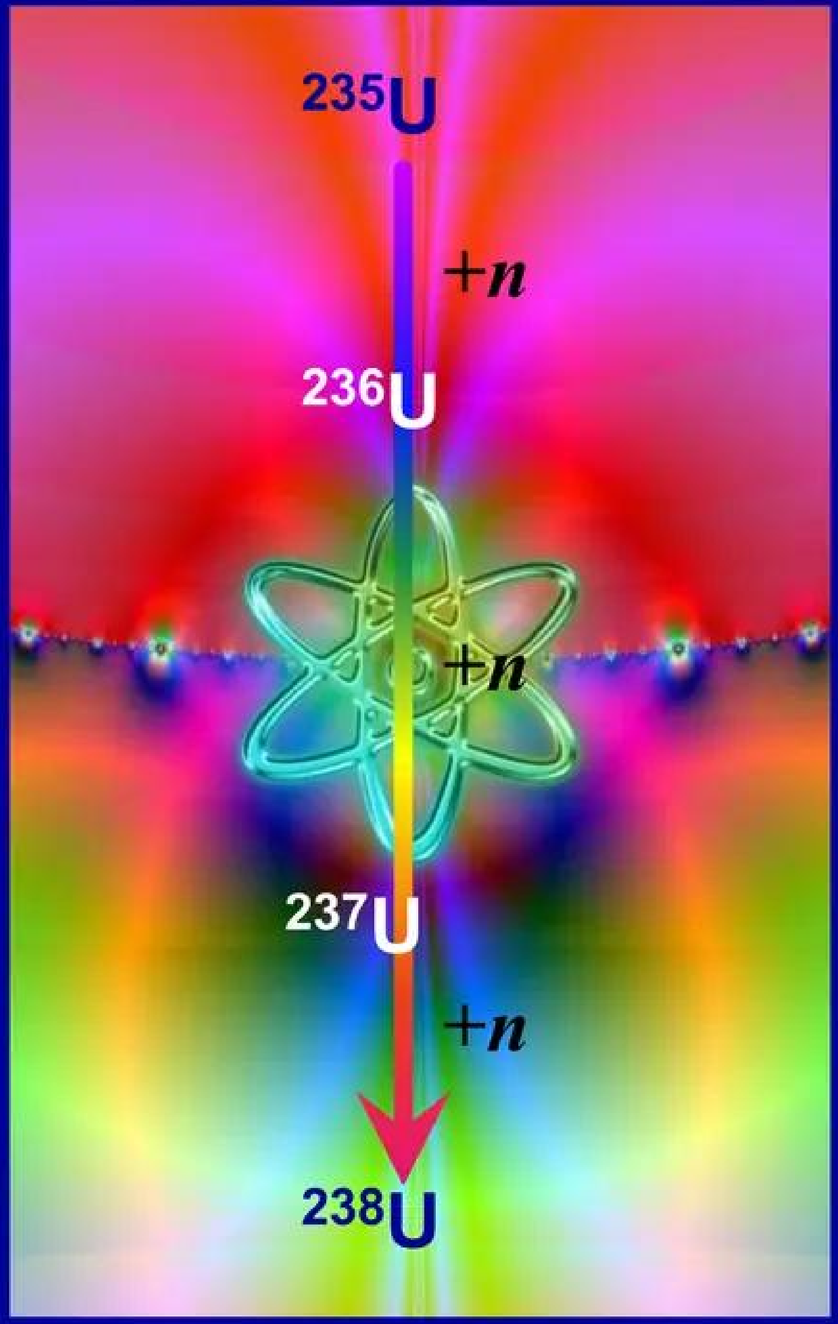
Low Energy Nuclear Reactions (LENRs)

Terrestrial Uranium $^{238}U/^{235}U$ isotopic ratio is not invariant over time

Hiess et al. (Science, 2012) confirm failure of invariance assumption; propose corrected value for ratio

Technical Overview

Transmutation of Uranium isotopes



^{232}Th-'seed' Actinide LENR network

Lewis Larsen

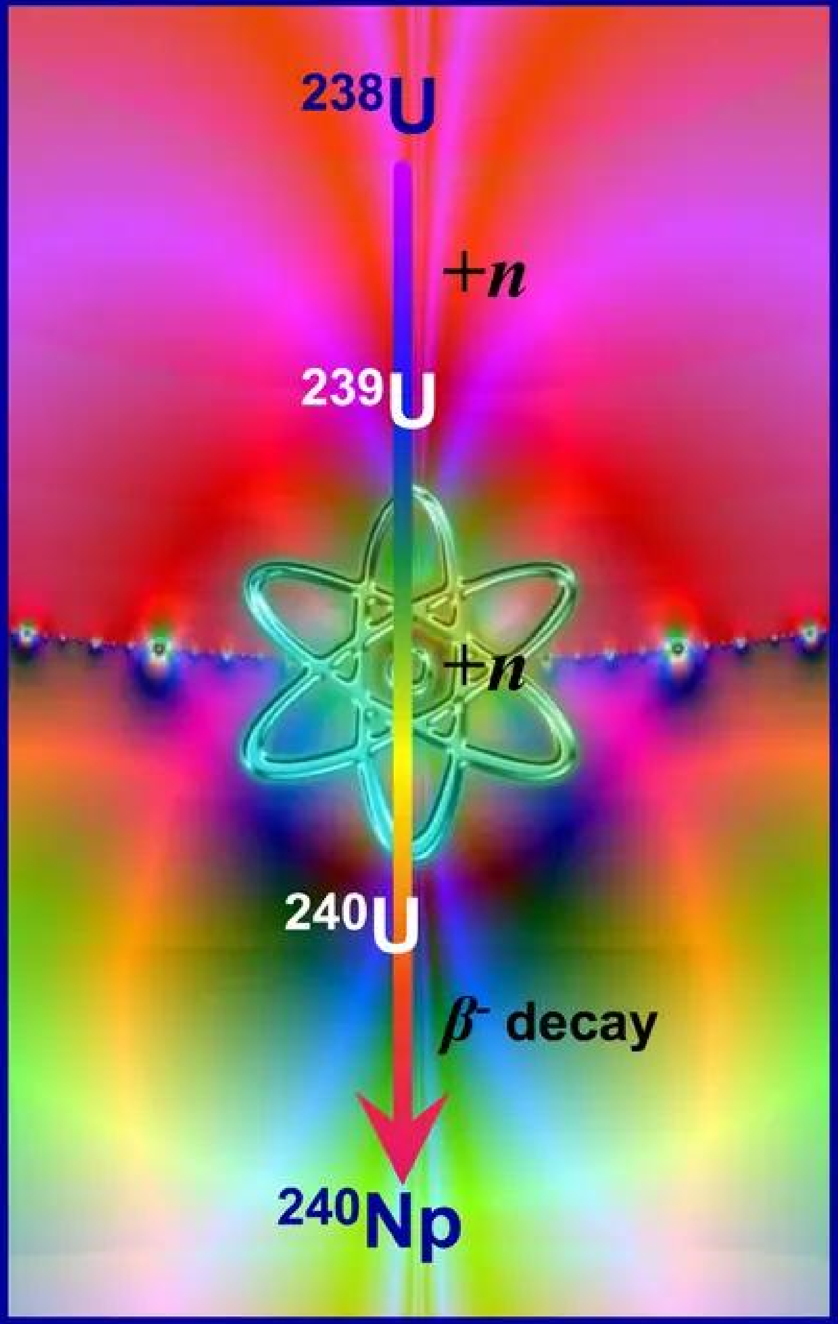
President and CEO
Lattice Energy LLC
April 12, 2012

"An era can be said to end
when its basic illusions are exhausted."

Arthur Miller, American playwright and essayist
"When it came apart," *New York Magazine*
Dec. 30, 1974 - Jan. 6, 1975

<u>Conjectured fissionless LENR transmutation network</u>: it 'avoids' 'unwanted' neutron-induced fission by tightly controlling ULM neutron energies in capture resonance regions so that neutron capture and gamma emission processes **(n,γ)** and any subsequent beta and/or alpha decays will greatly dominate. Gamma emissions will be converted directly to infrared photons by heavy e^{-*} electrons always present in the same *μm*-scale regions as ULM neutron production; thus > ~0.5 to ~10^{+} MeV γ suppressed

Transmutation of Uranium isotopes



^{232}Th-'seed' Actinide LENR network

Contents

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Main objectives of presentation

For 35 years: widely assumed that terrestrial $^{238}U/^{235}U$ ratio is invariant over time

If this longstanding assumption is truly erroneous, then what processes could cause such variance?

- ✓ **Note clear failure of $^{238}U/^{235}U$ invariance assumption**
- ✓ **Discuss new paper by Hiess *et al*. and its consequences**
- ✓ **Explore issues with chemical fractionation theories**
- ✓ **Suggest LENRs may better explain some isotopic data**
- ✓ **Overview of LENR Actinide transmutation network**
- ✓ **Discuss experimental data on bacterial isotopic shifts**
- ✓ **Speculative conjecture about LENRs and ‘electric bacteria’**
- ✓ **Argue more investigation needed: major opportunities**

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Relevant technical documents

"^{238}U/^{235}U Systematics in Terrestrial Uranium-Bearing Minerals"
J. Hiess *et al*.
Science **335** no. 6076 pp. 1610-1614 (30 March 2012)
DOI: 10.1126/science.1215507
http://www.sciencemag.org/content/335/6076/1610.full

Abstract: "**The present-day ^{238}U/^{235}Uratio has fundamental implications for uranium-lead geochronology and cosmochronology. A value of 137.88 has previously been considered invariant and has been used without uncertainty to calculate terrestrial mineral ages.** We report high-precision ^{238}U/^{235}U measurements for a suite of Uranium-bearing minerals from 58 samples representing a diverse range of lithologies. This data set exhibits a range in ^{238}U/^{235}U values of >5 per mil, with no clear relation to any petrogenetic, secular, or regional trends. Variation between comagmatic minerals suggests that ^{238}U/^{235}U fractionation processes operate at magmatic temperatures. A mean ^{238}U/^{235}Uvalue of 137.818 ± 0.045 (2σ) in Zircon samples reflects the average Uranium isotopic composition and variability of terrestrial zircon. This distribution is broadly representative of the average crustal and '*bulk Earth'* ^{238}U/^{235}U composition."

"New neutron data consistent with WLS mechanism in lightning - Surprisingly large fluxes of low-energy neutrons well-correlated with thunderstorm EMF fluctuations"
L. Larsen, Lattice Energy LLC, April 4, 2012 [73 MS-PowerPoint slides – not peer-reviewed]
http://www.slideshare.net/lewisglarsen/lattice-energy-llcnew-russian-data-supports-wlt-neutron-production-in-lightningapril-4-2012

Summary: **Neutron fluxes are produced during lightning discharges in earth's atmosphere; presumably this would also be true for lightning associated with dust in terrestrial volcanic eruptions as well as similar discharges occurring on other planetary bodies in our solar system. WLS weak interaction neutron production mechanism is the only theoretical approach that can readily explain all of the published experimental data; Gurevich et al.'s new results rule-out previously popular photonuclear mechanism (nuclear fusion processes had been decisively ruled-out as a reasonable explanation some years earlier).** Vast majority of neutrons produced in lightning discharges will likely be captured by nearby atoms before newly created free neutrons can decay (half-life of a free neutron is ~13 minutes); therefore, neutron-catalyzed nucleosynthesis at low rates has likely been occurring continuously in earth's atmosphere for perhaps ~4.5 billion years.

"Some bacteria appear capable of altering isotopic ratios of Uranium - Is it the result of prosaic chemical fractionation processes and/or LENRs?"
L. Larsen, Lattice Energy LLC, December 7, 2010 [50-page 8.5 x 11 MS-Word document – not peer-reviewed]
http://www.slideshare.net/lewisglarsen/bacteria-lenrsand-isotopic-shifts-in-uraniumlarsenlattice-energy-dec-7-2010-6177275

Summary: **provides description of theoretical W-L LENR Actinide nucleosynthetic network and selected examples of published mainstream, peer-reviewed experimental data which report anomalous isotopic shifts clearly associated with the metabolic activities of bacteria --- some or all of the hypothesized network pathways are potentially present in soils, ocean sediments, dusty chemical explosions, volcanic eruptions, and extraterrestrial impact events.** Much more readable, uncompressed versions of Figs. 1 and 2 (found in the above-listed Document) that outline hypothesized LENR Actinide nucleosynthetic network are also available in a separate MS-PowerPoint presentation [4 slides]
http://www.slideshare.net/lewisglarsen/thoriumseed-lenr-networkfigslattice-energydec-7-2010-6177745

Isotopic shift anomalies: are 100% of them just chemistry?

Old paradigm of invariant $^{238}U/^{235}U$ ratio is challenged by new mass spec data

"Some bacteria appear capable of altering isotopic ratios of Uranium - Is it the result of prosaic chemical fractionation processes and/or LENRs?" L. Larsen, Lattice Energy LLC, December 7, 2010
http://www.slideshare.net/lewisglarsen/bacteria-lenrsand-isotopic-shifts-in-uraniumlarsenlattice-energy-dec-7-2010-6177275

See Slide #68 of the April 4, 2012, neutron-production-in-lightning document; there we quote directly from pp. 3 of the earlier Dec. 7, 2010, Lattice SlideShare document (cited above) as follows:

"**Old paradigm - Earth's Uranium isotope ratios are essentially invariant:** Up until relatively recently, it was widely presumed that present-era 238U/235U ratios were, within some characteristic range of natural variance, essentially identical throughout the planet earth and its environs. Obvious exceptions to the above 'rule' were ancient Oklo-type natural fission reactors, man-made stable and unstable isotopes produced in fission reactors and detonations of nuclear weapons, as well as captured interstellar debris produced during 'nearby' supernova explosions."

"**New experimental evidence - challenges the old paradigm: Recently, greatly increased use of various types of mass spectroscopy by geochemists, microbiologists, and environmental scientists has revealed that the longstanding assumption of effective natural uniformity of $^{238}U/^{235}U$ratios across the earth [over geological time] is clearly erroneous;** importantly, present-era abiological and/or biologically mediated processes appear to be responsible for such anomalous variances."

"**Question - how might significant changes in $^{238}U/^{235}U$ ratios occur?:** Are anomalous variances in such isotopic ratios the result of purely chemical 'fractionation' process or processes of some sort, and/or could they be caused by low energy nuclear reactions (LENRs), either abiologically or somehow induced by the actions of bacteria through some yet to be clarified mechanism?"

Isotopic shift anomalies: are 100% of them just chemistry?

LENRs can potentially cause problems for chemical fractionation theories

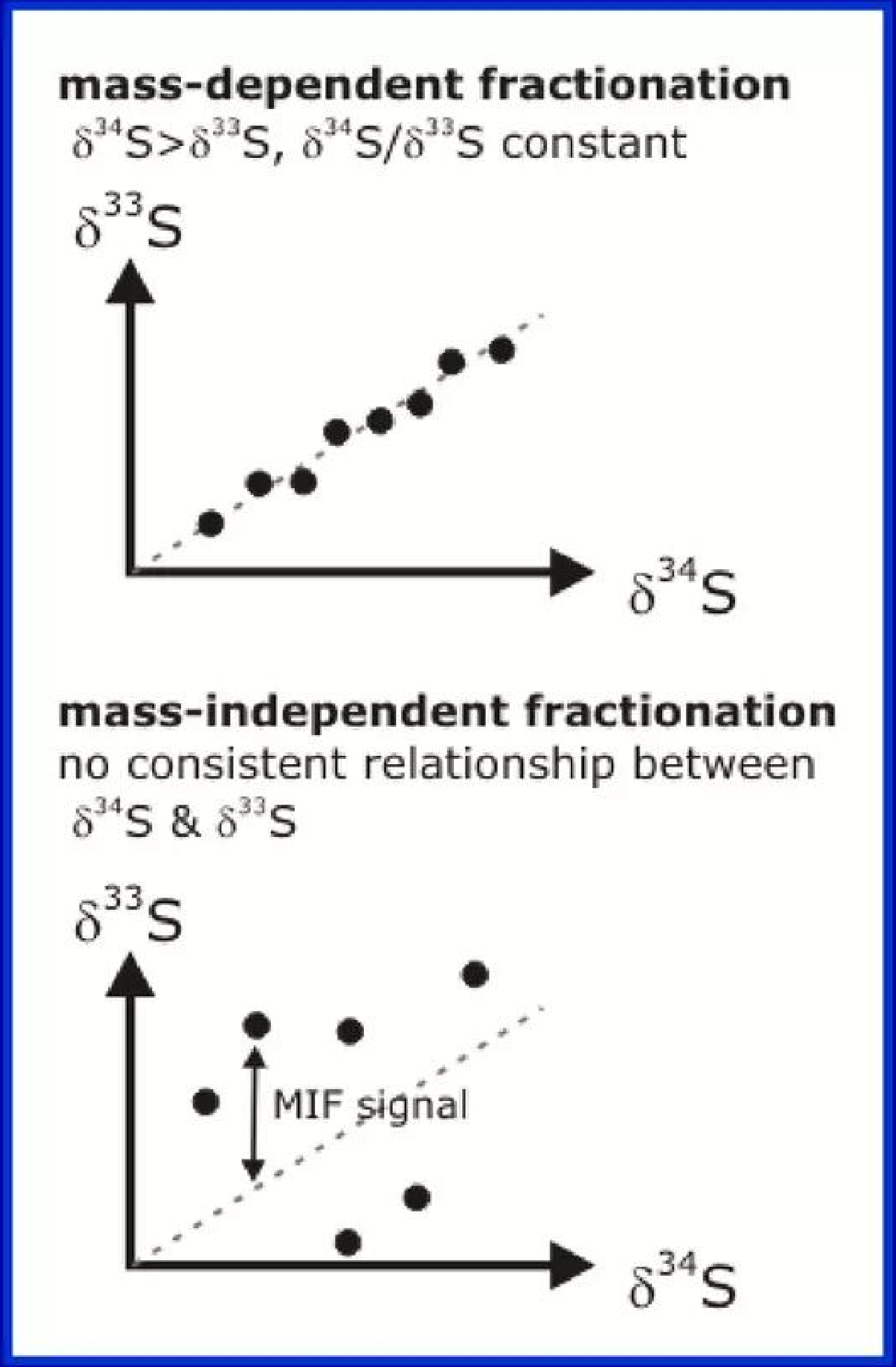
- ✓ For ~ 60 years, a body of chemical fractionation theory has been developed and articulated to explain progressively increasing numbers of stable isotope anomalies observed in a vast array of mass spectroscopic data obtained from many different types of natural and experimental, abiological and biological, systems. Central ideas in "chemical fractionation" theory embody equilibrium and irreversible, mass-dependent and mass-independent, chemical and recently so-called "*nuclear field shift*" processes that are claimed to be able to separate isotopes, thus explaining reported isotopic anomalies

- ✓ Although not explicitly acknowledged by fractionation theorists, an intrinsic *fundamental assumption* underlying this body of theory and interpretation of data is that no indigenous nucleosynthetic processes are presently occurring anywhere in any of these systems, or at any time since the initial formation of the presolar nebula, that are/were capable of altering isotope ratios and/or producing new mixtures of different elements over time; ergo, chemistry must explain everything

- ✓ However, if WLS theory is correct, for certain isotopic data the above fundamental assumption could potentially be incorrect; for example, in the case of Sulfur:

  Sulfur natural abundances: ^{32}S = 94.93%; ^{33}S = 0.76%; ^{34}S = 4.29%; ^{36}S = 0.02%

  Beginning with ^{32}S, Sulfur's four stable isotopes have similar thermal neutron capture cross-sections of 0.55, 0.46, 0.30, and 0.23 barns, respectively; they are all $1/v$ isotopes. All other things being equal, at low LENR ULM neutron fluxes, $\delta^{33}S$, $\delta^{34}S$, and $\delta^{36}S$ would all tend to increase; ^{35}S is unstable (H-L = 87 days) and beta$^-$ decays to ^{35}Cl. Higher ULM neutron fluxes could produce ^{37}S which is unstable (H-L = 5.1 minutes) and β^- decays into Chlorine ^{37}Cl (which is stable but *very* reactive)



Isotopic shift anomalies: are 100% of them just chemistry?

Problems with chemical fractionation theories in case of Uranium isotopes

Prior to publication of seminal work on bacterial transmutations in Russia (Vysotskii *et al.* 2003, 2008), prosaic explanations for many observed Fe and other isotope anomalies observed in many studies assumed that biological systems (mainly bacteria) are able to effectively "fractionate" heavier isotopes through various types of biochemical pathways that utilize purely chemical, non-nuclear mechanisms. *Unfortunately, very specific, believable biophysical details of precisely how such processes are supposed to operate are lacking in our opinion, especially for significantly heavier elements, e.g., Iron and beyond.*

Lattice can readily accept that chemical kinetic processes in biological systems are able to discriminate between isotopes of comparatively light elements (e.g., hydrogen, carbon, nitrogen, and perhaps up to oxygen) and can somehow physically separate them from each other; that is, via purely chemical "fractionation." However, we have difficulty believing that ordinary, prosaic chemical processes alone are capable of easily and efficiently discriminating and significantly enriching various isotopes of substantially heavier elements, especially beyond the atomic masses of Fe isotopes and/or transition metals.

In particular, peer-reviewed papers have recently been published in which *Geobacter* species are seemingly observed to "fractionate" Uranium isotopes (Bopp *et al.,* 2010). In such papers authors attempt to explain Uranium isotope changes with the so-called "nuclear field shift effect" and nuclear volume/shape effects (Bigeleisen, 1996). In our view, such explanations for isotopic data could potentially be erroneous in the case of Uranium.

Why? Because the reason giant high-speed gas centrifuges are used to "fractionate", i.e., enrich, uranium isotopes for use in nuclear weapons and fission reactor fuel is that 'unassisted' wet chemical kinetic fractionation/separation processes by themselves have been found to be inadequate in terms of practical efficacy. The only other known-to-be practical method for sufficiently enriching Uranium isotopes employs powerful lasers and the same Uranium hexafluoride gas used in high-speed centrifuges.

If the recently hypothesized chemical fractionation mechanisms truly worked as well on Uranium isotopes in non-gas-phase systems as their proponents claim, one would surely think that such effects would have been utilized long ago in one or more of the government nuclear weapons and/or commercial Uranium enrichment programs scattered around the world (e.g., Iran today). To our knowledge, during the past 60 years they have never been used for such a purpose anywhere. That well-established fact is the basis for our strong skepticism about "nuclear field "or "nuclear volume" shift effects being correct explanations for the underlying mechanism(s) responsible for creating observed changes in Uranium isotope ratios.

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Isotopic shift anomalies: are 100% of them just chemistry?

Problems with chemical fractionation theories in case of Uranium isotopes

> ***"Some bacteria appear capable of altering isotopic ratios of Uranium - Is it the result of prosaic chemical fractionation processes and/or LENRs?"*** L. Larsen, Lattice Energy LLC, December 7, 2010
> http://www.slideshare.net/lewisglarsen/bacteria-lenrsand-isotopic-shifts-in-uraniumlarsenlattice-energy-dec-7-2010-6177275

With certain exceptions, most known isotopes generally follow the so-called 1/*v* rule: that is, neutron capture cross-sections (measured in barns - *b*) for different 'target' isotopes are roughly a linear function of the incident neutron kinetic energy (directly related to *v*) --- the lower the energy, the higher the capture cross-section. However, in the course of such measurements on many different isotopes, in some cases certain ranges of incident neutron energies were discovered in which both neutron capture and induced fission cross-sections varied enormously in parallel, e.g., 10^3, and non-linearly with very small changes in incident neutron energy; these are referred to as "resonance regions;" an example with ^{235}U follows in the next Slide.

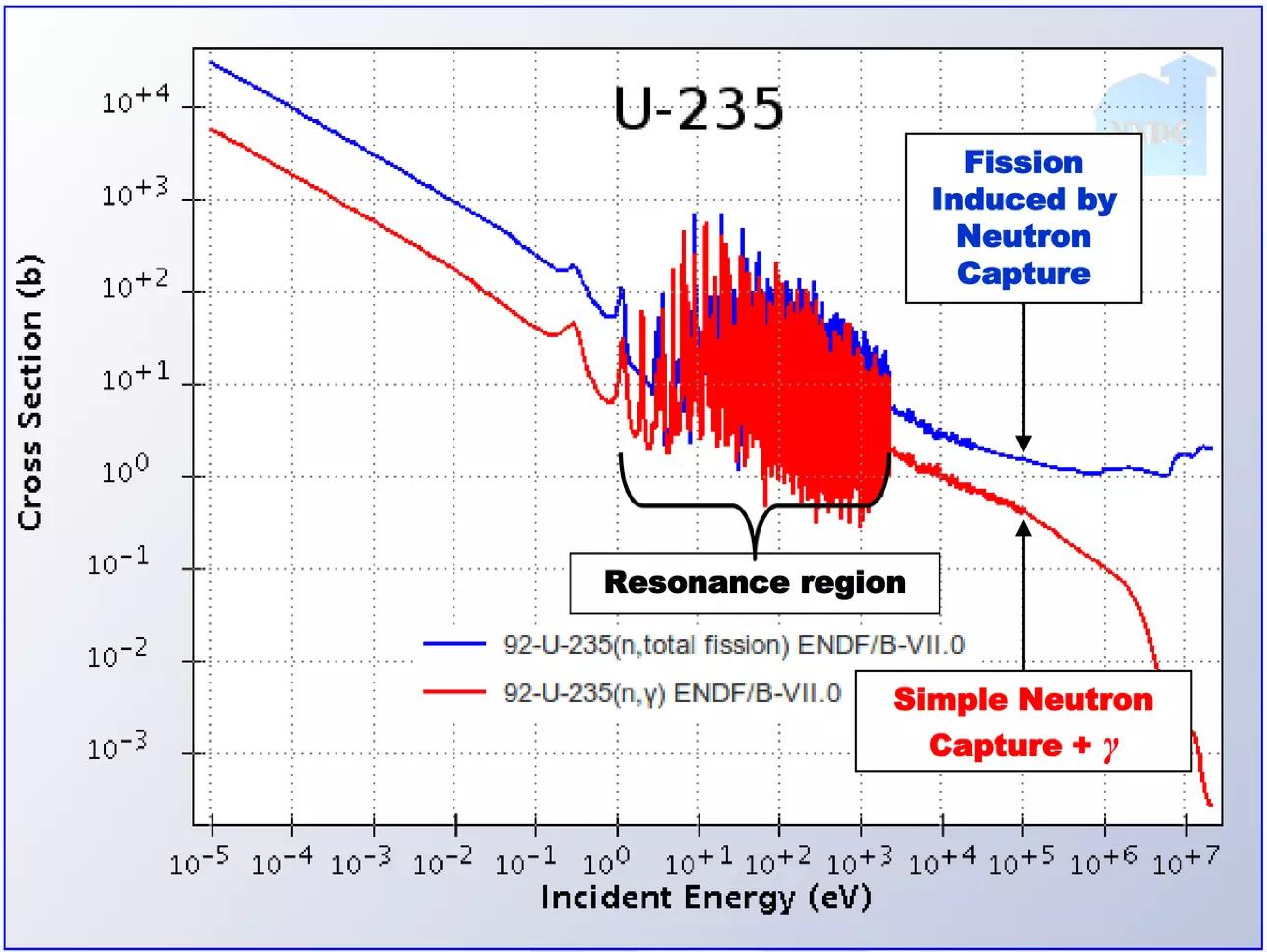
Please note that the blue line shown in the next Slide is the mostly measured neutron capture cross-section for fission; the red line is for 'simple' capture and prompt gamma emission. At most energies, fission is a significantly more likely event than neutron capture for ^{235}U. However, in so-called "resonance region" that is not the case; depending on a neutron's exact energy, capture can sometimes be as or *more likely* than fission. So, if one somehow had extremely precise control over produced neutron energy one could in principle create a situation in which neutron capture events were substantially more likely than fission.

For ^{235}U and other fissile Actinides, comparative cross-sections for neutron captures vs. fission have never been measured in the region of ultra low momentum energies (which are vastly lower than the 10^{-5} eV shown in the next Slide). That said, there is nothing in the laws of nuclear physics that would a priori prevent the existence of additional, analogous resonance regions in the ultra low momentum (ULM) neutron regime. *We will now hypothesize that such low-energy resonance regions exist in Nature and explore potential consequences of that possibility, recognizing that direct evidence for such resonances has not yet been observed experimentally; it is presently a speculative conjecture.*

For any microorganism assumed capable of producing ULM neutrons via the weak interaction that then uses such neutrons to create LENR-based nucleosynthetic networks (for whatever purpose), there would be strong selective pressures to evolve an ability to minimize the number of neutron-induced fissions versus 'simple' neutron captures (i.e., make heavier isotope + gamma conversion to IR by heavy electrons): *it is the difference between dealing with very damaging, essentially uncontrolled release of large amounts of energetic fission fragments and gamma radiation versus other, vastly less damaging nuclear processes.*

Isotopic shift anomalies: are 100% of them just chemistry?

An example of a measured resonance region for Uranium-235 is shown in Chart 1 below:



Fission Induced by Neutron Capture

Resonance region

Simple Neutron Capture + γ

Fissioning ^{235}U (U-235) nucleus releases ~181 MeV of energy in complex mixture of very energetic fission fragments and prompt gammas; by contrast, 'simple' ULMN capture (n, γ) on U-235 releases only ~6.6 MeV

Isotopic shift anomalies: are 100% of them just chemistry?

W-L theory provides an alternative nuclear mechanism for isotopic shifts

Summarizing: while these new types of chemical fractionation theories may well be logically consistent, do not violate accepted physics, and are capable of supporting detailed calculations that do agree with some data, *in the case of Uranium isotope shifts such agreement may be phenomenological rather than fundamental.* Until too many planets were discovered, Ptolemaic epicycles permitted real calculations that more-or-less agreed with astronomers' observations *up until that point*. However, ever-growing numbers of postulated epicycles required to explain volumes of (then) newly collected astronomical data were ultimately replaced by Newtonian mechanics --- a much simpler, *fundamental* theory of planetary orbits which enabled even better calculations that could explain a vastly broader range of natural phenomena.

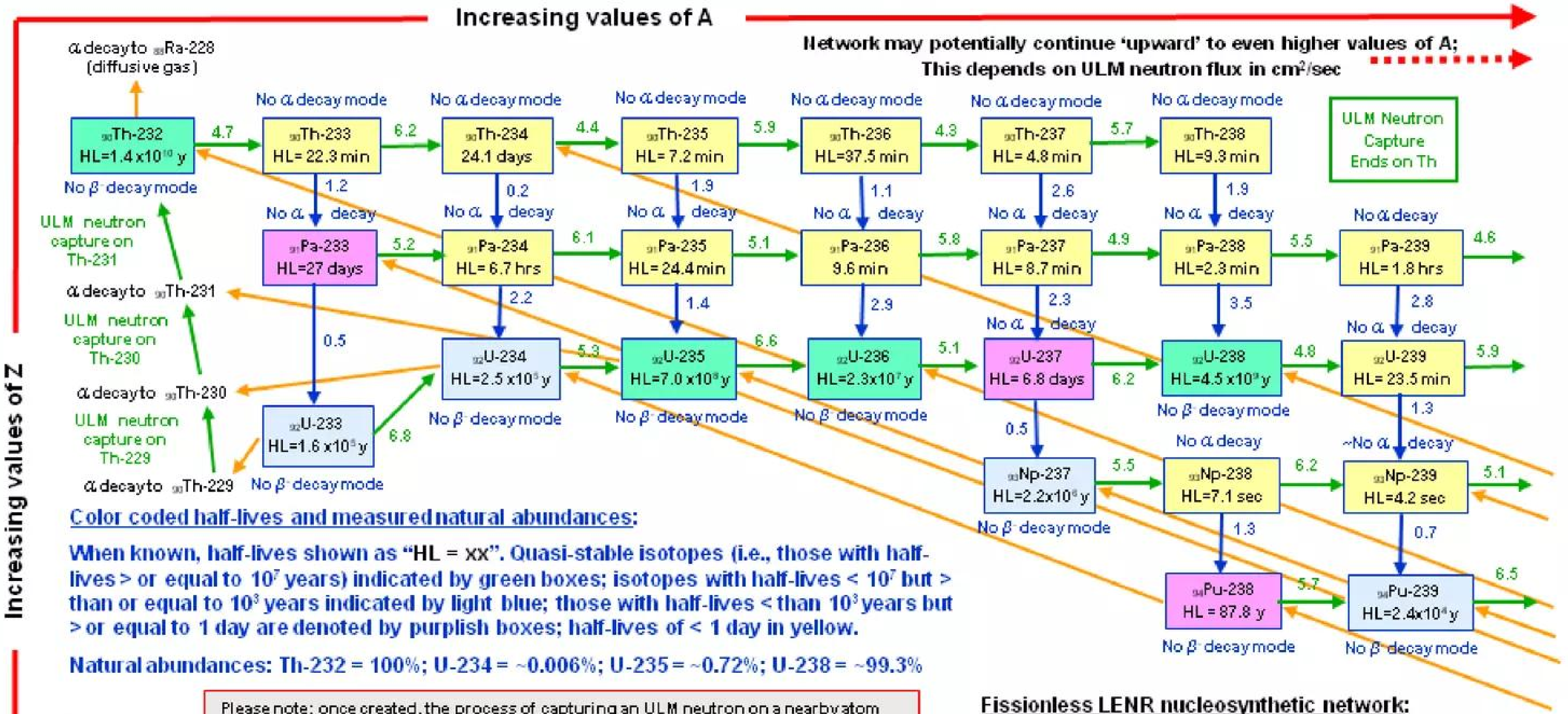
New Widom-Larsen theory of LENRs explains nuclear transmutations of isotopes – parallel operation of prosaic chemical "fractionation" processes along with LENRS may better explain some anomalous isotopic data: Lattice is not claiming that the existing chemical fractionation paradigm fails to adequately explain most reported isotope anomalies with respect to statistically significant deviations from natural abundances and/or established isotopic standards (e.g., SMOW) --- *indeed it may well explain the vast majority of them*. However, present literature does contain a non-trivial subset of cases in which the chemical fractionation paradigm must be pushed very hard (which includes use of various *ad hoc* constructs) to explain certain data, i.e., it is being overly stretched to be able to comfortably accommodate some observed isotope anomalies. *What is proposed is that in Nature a variety of prosaic chemical fractionation processes operate in parallel with abiotic and/or biological low energy nuclear reaction (LENR) transmutations, producing a vast range of different isotopic shifts and anomalies observed in a rapidly increasing body of high quality experimental data.*

ULM neutron-catalyzed LENR network starting from ${}_{90}Th^{232}$: somewhat analogous to a prosaic chemical or biochemical reaction network, Figures 1 and 2 shown in the following two Slides describe a hypothetical ~fissionless, Widom-Larsen ULM neutron catalyzed, LENR-based nucleosynthetic network characterized by an interlocking series of neutron captures beginning on Thorium-232 (${}^{232}Th$) 'seed' nuclei (100% natural abundance) and subsequent beta decays, alpha decays, electron capture (one instance), neutrino (ν) emissions, and direct conversion of prompt and delayed gamma photons to infrared (heat) by heavy e^{-*} electrons involved in weak interaction ULM neutron production via the [$e^{-*} + p^+ \rightarrow n + \nu$] weak reaction. Where known, neutron capture and beta decay Q-values are shown in MeV; where applicable, neutrino and gamma emissions are implicit and not shown to reduce visual clutter.

LENR network creates isotopic shifts and heavier elements

Fig. 1 - ULMN catalyzed LENR network starting from $_{90}$Th^{232}

ULMN capture on Thorium, neutron-rich isotope production, and related decays



Color coded half-lives and measured natural abundances:

When known, half-lives shown as "HL = xx". Quasi-stable isotopes (i.e., those with half-lives > or equal to 10^7 years) indicated by green boxes; isotopes with half-lives < 10^7 but > than or equal to 10^3 years indicated by light blue; those with half-lives < than 10^3 years but > or equal to 1 day are denoted by purplish boxes; half-lives of < 1 day in yellow.

Natural abundances: Th-232 = 100%; U-234 = ~0.006%; U-235 = ~0.72%; U-238 = ~99.3%

Please note: once created, the process of capturing an ULM neutron on a nearby atom happens very quickly --- on the order of picoseconds (0.000000000001 seconds).

Legend:

ULM neutron captures proceed from left to right except for upper-left corner; Q-value of capture reaction (MeV) in green either above or below horizontal arrow. ⟶

Beta decays proceed from top to bottom; denoted with blue vertical arrow with Q-value (MeV) in blue either to left or right. ⟶

Alpha decays, where shown with orange arrows, proceed mostly from right to left with Q-value (MeV) in black on either side of the arrow. ⟵

Electron captures (e.c.) indicated by purple vertical arrow; Q-value (MeV) to left or right. ↑

Fissionless LENR nucleosynthetic network:

Conjecture: this LENR network 'avoids' 'unwanted' neutron-induced fission by tightly controlling ULM neutron energies in capture resonance regions so that neutron capture and gamma emission (n, γ) and any subsequent beta and/or alpha decays vastly dominate

Any gamma emissions are automatically converted directly to infrared photons by heavy e^* electrons always present in the same nanoscale regions as LENR ULMN production (> ~0.5 MeV to ~10 MeV suppressed)

LENR network creates isotopic shifts and heavier elements

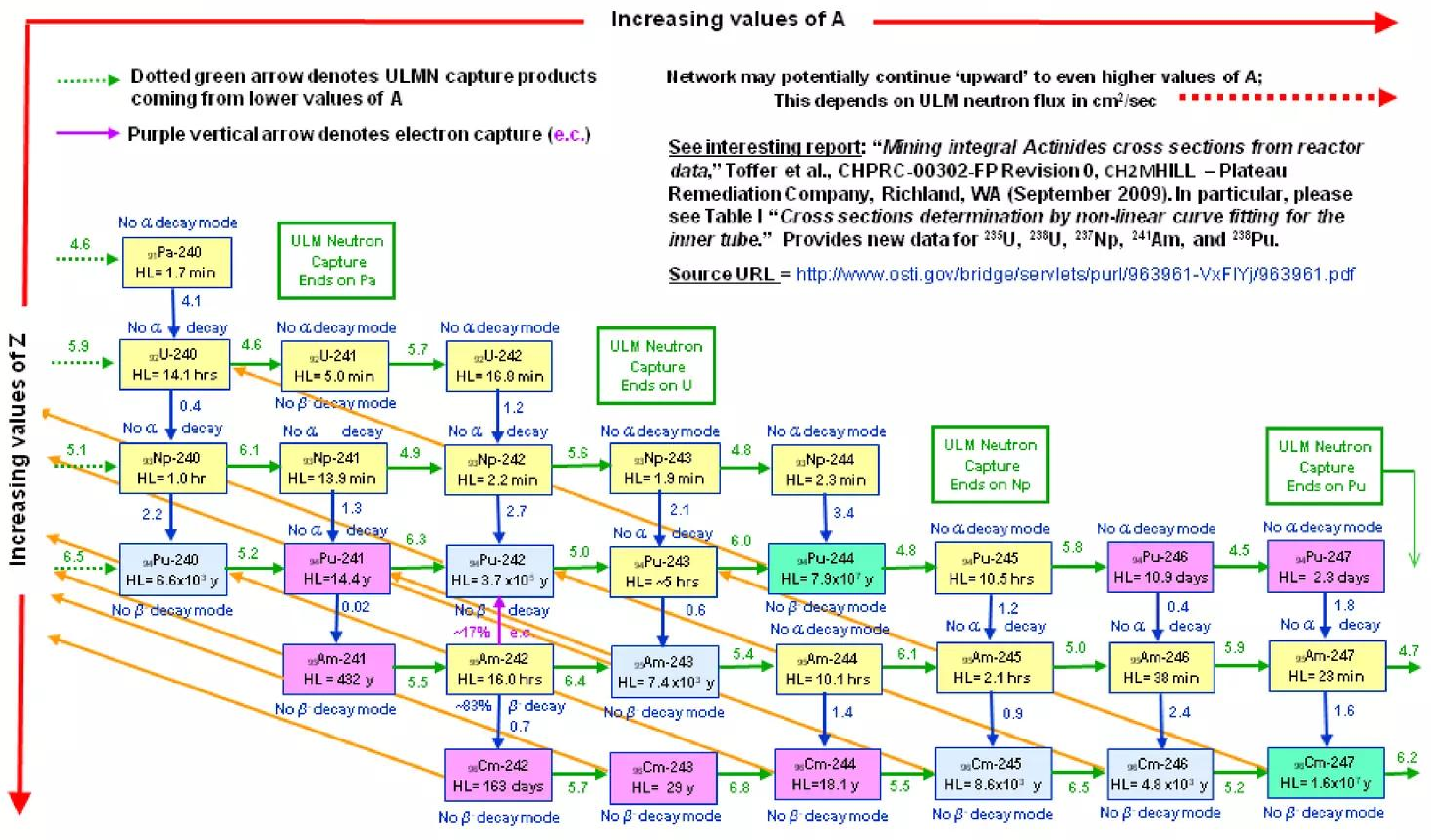


Fig. 2 - ULMN catalyzed LENR network starting from $_{90}Th^{232}$

ULMN capture on Thorium, neutron-rich isotope production, and related decays

Dotted green arrow denotes ULMN capture products coming from lower values of A

Purple vertical arrow denotes electron capture (e.c.)

Network may potentially continue 'upward' to even higher values of A; This depends on ULM neutron flux in cm²/sec

See interesting report: "*Mining integral Actinides cross sections from reactor data,*" Toffer et al., CHPRC-00302-FP Revision 0, CH2MHILL – Plateau Remediation Company, Richland, WA (September 2009). In particular, please see Table I "*Cross sections determination by non-linear curve fitting for the inner tube.*" Provides new data for ^{235}U, ^{238}U, ^{237}Np, ^{241}Am, and ^{238}Pu.

Source URL = http://www.osti.gov/bridge/servlets/purl/963961-VxFIYj/963961.pdf

Are bacteria involved in $_{90}Th^{232}$ -seed LENR network?

Nucleosynthetic capabilities could have evolved early in the history of life

- ✓ What is shown in the two preceding Figures is a ‘full network’ of nucleosynthetic possibilities; in any given situation in Nature, only a portion of this network may be operating at any given point time and/or at any particular geospatial location. Furthermore, some portions of the network may operate abiologically, whereas some or all of it may also operate biologically, albeit perhaps spread across a wide variety of different ecologically interacting species of microorganisms found in natural environments, e.g., *Geobacter*, *Shewanella*, etc.

- ✓ In our view, isotopic ‘nodes’ in the above Actinide network where neutron-induced fission is ‘avoided’ after ULM neutron capture (e.g.,^{235}U, ^{233}U, ^{237}U, ^{239}Pu, ^{241}Pu, etc.) are likely to be mediated most effectively by biological systems. Lattice believes this could be the case because exquisitely fine-grained, highly reproducible control over produced neutron energies would appear to be necessary to achieve such a result. Since *abiological* processes cannot ‘learn’ and in essence store chemical information over time (i.e., ‘embed’ it in physical structures of evolved proteins specified by a genetic code), *it would seem to be more difficult to abiologically ‘optimize’ an effectively spontaneous, multistep, many-body collective LENR process.*

If truly present in bacteria, nucleosynthetic capabilities could have evolved early in the history of life:

- ✓ If certain microorganisms can truly engage in isotopic nucleosynthesis (not decisively proven yet), one can imagine that various species of bacteria now on Earth could have easily spent the last 3 – 4 billion years of natural selection and trial-and-error evolution ‘learning’ how to accomplish such an amazing feat.

- ✓ Frankly, it should be unsurprising that certain bacteria, other microorganisms, and some fungi exhibit extreme resistance to radiation (e.g., *Deinococcus radiodurans*, which can thrive under huge radiation fluxes present inside operating light water ^{235}U fission reactors; *Chroococcidiopsis*, *Thermococcus gammatolerans,* and some species of *Rubrobacter*) and/or are apparently able to alter isotopic ratios of heavy elements. Roughly 3.5+ billion years ago, at a much early point in the evolution of life on Earth, there is no doubt whatsoever that there were vastly larger quantities of radioisotopes and various forms of hard radiation present in the natural terrestrial environment. Given such a history, we shouldn’t be shocked that early life adapted and evolved to deal with high-radiation regimes; evidence of such early adaptation has perhaps been preserved through eons of time and remains today in some modern microorganisms.

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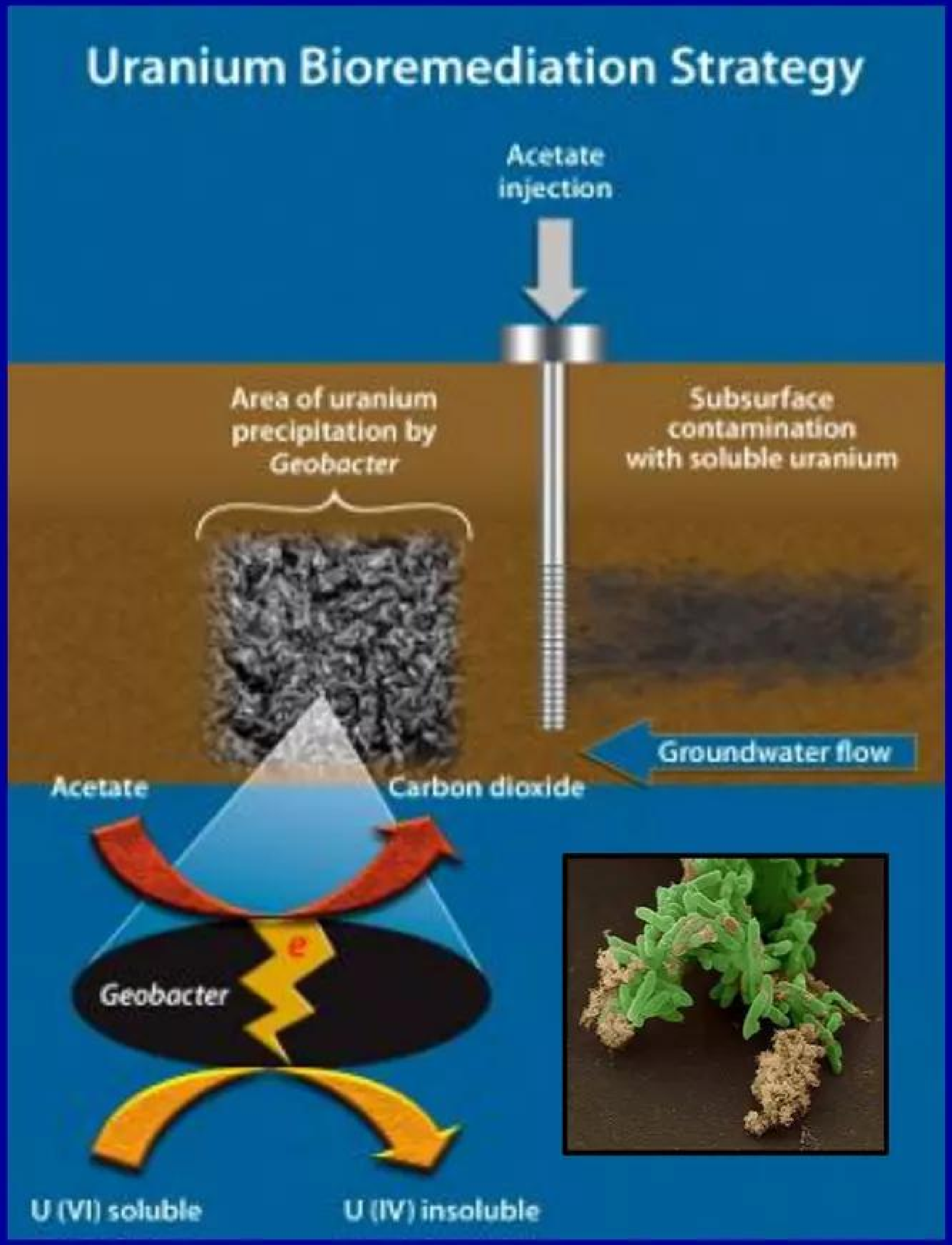
Are bacteria involved in $_{90}Th^{232}$ -seed LENR network?

Nucleosynthetic capabilities could have evolved early in the history of life

- ✓ For a moment, let us speculatively travel even further back in time to the era of the presolar nebula from which our solar system's planets condensed: if in fact some sort of primitive Ur-microbial life was then living on isolated dust grains embedded in the radiation-laced, hydrogen-rich dusty presolar cloud, the ability to create needed elements/isotopes when necessary, utilize heavy-mass e^{-*} electrons as gamma radiation shields, and perhaps even generate 'raw' heat via nucleosynthesis to help accelerate Ur-microbes' kinetically-driven *chemical* reactions, would have provided valuable competitive advantages for any living organisms possessing such capabilities that were living in such a harsh environment.

- ✓ Who knows, perhaps water in some form was also present somewhere in the dusty presolar cloud. This possibility is suggested by the recent, very surprising discovery of a team of astronomers led by L. Decin ("*Warm water vapour in the sooty outflow from a luminous carbon star*," *Nature* 467 pp. 64-67 September 2010). Using infrared observations from the ESA's Herschel Space Observatory, Decin *et al.* concluded that water vapor was definitely present at ~700° C in the outer atmosphere of an aging carbon-rich star named IRC+100216 located 500 light-years from earth. Prior to this new discovery, the presence of large amounts of water vapor as such in and around hot stellar atmospheres was thought to be impossible.



Graphic of DOE-funded studies re *Geobacter* bioremediation of Uranium-contaminated mill tailings site at Rifle, Colorado; inset shows *Geobacter* growing on inorganic substrate

Commercializing a next-generation source of CLENR energy

Are bacteria involved in ${}_{90}Th^{232}$ -seed LENR network?

Discussion of two important papers re bacterial Uranium isotope "fractionation"

"*Uranium $^{238}U/^{235}U$ isotope ratios as indicators of reduction: results from an in situ biostimulation experiment at Rifle, Colorado, U.S.A.*"
C. Bopp *et al.*
Environmental Science & Technology 44 pp. 5927 - 5933 (2010)
http://escholarship.org/uc/item/5sh867k9 [Univ. of California - LBNL website: copy of galley proof manuscript of published paper]

"*Experimentally determined Uranium isotope fractionation during reduction of hexavalent U by bacteria and zero valent iron*"
L. Rademacher *et al.*
Environmental Science & Technology 40 pp. 6943 - 6948 (2006)
http://pubs.acs.org/doi/abs/10.1021/es0604360

Lattice discussion of above two papers by Bopp *et al.* and Rademacher *et al.*: a contradiction of sorts is apparent here. On one hand, a comparatively well-controlled and characterized microbiological laboratory study by Rademacher *et al.* (2006) reported a significant reduction in the measured concentration of dissolved $U(VI)_{(aq)}$ Uranium in conjunction with a parallel ***increase*** in the $U(VI)_{(aq)}$'s $^{238}U/^{235}U$ ratio over time after the addition of acetate (as an electron donor) to the experimental culture medium. On the other, a bioremediation field experiment by Bopp *et al.* (2010) reported similar reduction in measured concentration of soluble $U(VI)_{(aq)}$ Uranium but instead observed a parallel ***decrease*** in the $U(VI)_{(aq)}$ $^{238}U/^{235}U$ ratio over time after analogous injection of acetate-amended groundwater into tailings (soil) of an old Uranium mill in Rifle, Colorado. *Comparing these two published reports, at first glance we seem to see an opposite effect on the $U(VI)_{(aq)}$ $^{238}U/^{235}U$ ratio after roughly the same causative action (adding acetate to stimulate the growth of "dissimilatory metal-reducing bacteria").*

In both papers, the authors presume a chemical process paradigm; i.e., Uranium isotopes must somehow be "fractionating" between soluble U(VI)(aq) compounds (measured w. mass spectroscopy in withdrawn aliquots of aqueous solution) and U(IV)(s) compounds *assumed* to be precipitated out of solution as insoluble particulates during bacterial reduction of U(VI) (aq) to U(IV)(s). Note that $^{238}U/^{235}U$ ratios are not measured in uncollected insoluble U(IV) (s) residues, *so the true mass balance of elemental Uranium is not known in such cases*. However, presuming a purely chemical paradigm, there would be no reason to ever suspect that total mass balance of Uranium could potentially change and/or that neutron captures might be occurring.

Are bacteria involved in $_{90}Th^{232}$ -seed LENR network?

Discussion of two important papers re bacterial Uranium isotope "fractionation"

Effects of the underlying chemical paradigm on researchers' thinking about their experiments can sometimes be subtly pernicious. For example, in the case of Rademacher *et al.,* [quoting directly from pp. 6946] *"…we assume the produced U(IV)(aq) was bound within a precipitate (even though it was not clearly visible in the experiments used for isotopic analysis) and was unable to interact with the dissolved U(VI)*(aq). *Accordingly, the Rayleigh model is appropriate."* So in effect, they assumed a solid precipitate that they *did not* in fact observe experimentally because of an underlying subconscious belief in a chemical conceptual paradigm. Interestingly, *explanations* for the observed isotopic shifts also differ somewhat between the two papers. While Rademacher *et al.* did not come to a hard-and-fast conclusion about the likely physical mechanism behind the observed shifts in $^{238}U/^{235}U$ ratios, they leaned more-or-less toward the idea that they were the result of *mass-dependent* (i.e., purely kinetic) processes related to the idea that [quoting directly] *"…In reaction steps that involve breakage of chemical bonds, reaction rates for lighter isotopes tend to be greater than those for heavier isotopes."*

By contrast, to explain $U(VI)_{(aq)}$ $^{238}U/^{235}U$ shifts in the *opposite direction* in somewhat similar experiments, Bopp *et al.* invoked a [quoting directly], *"…nuclear field shift effect during enzymatic reduction of $U(VI)_{(aq)}$ to $U(IV)_{(s)}$."* They go on to say that, *"…Conversely, a mass-independent effect known as the nuclear field shift (NFS; 38-40) appears to provide a mechanism by which $U(VI)_{(aq)}$ ^{238}U could react faster than $U(VI)_{(aq)}$ ^{235}U. The NFS has been shown to be important for heavier elements such as mercury, and it has been applied to explain U isotope fractionation in recent studies (11-13). Unlike mass dependent effects, the NFS is controlled by the shape and volume of the atomic nuclei independently of atomic mass."*

So we have one competent group (Rademacher *et al.*) suggesting that observed $^{238}U/^{235}U$ shifts during bacterial reduction of U(VI) (aq) to U(IV)(s) are the result of *mass-dependent* chemical kinetic effects, and the other competent group (Bopp *et al.*) saying that their observed $^{238}U/^{235}U$ shifts *in the opposite direction* are the result of theoretically very different *mass-independent* chemical fractionation processes based on nuclear field-shift and volume effects that were first proposed by Bigeleisen (1996) and further elaborated by Schauble (2007). *From the standpoint of underlying mechanisms, these alternative explanations are contradictory.*

Commercializing a next-generation source of CLENR energy

Are bacteria involved in ${}_{90}Th^{232}$ -seed LENR network?

Discussion of two important papers re bacterial Uranium isotope "fractionation"

Before attempting to reconcile these two sets of apparently conflicting experimental observations, a few comments about important differences between the two types of experimental systems are in order:

- ✓ **First, only two relatively well-characterized species of bacteria were involved in Rademacher *et al.*'s laboratory experiments; by contrast, Bopp *et al.*'s Rifle, Colorado, field site undoubtedly involved a very large array of many different types of soil microorganisms (only some of which are identified and well-characterized) embedded in a complex, dynamically interacting, rapidly changing natural micro-ecology.**

- ✓ **Second, the input Uranium U(VI)(aq) compounds being reduced by specified bacteria in Rademacher *et al.*'s controlled laboratory experiments were created from extraordinarily well-characterized, NBS-certified material, NIST's Standard Reference Material U-500 (established in 1981 --- has an isotopic composition guaranteed to be ^{234}U = 0.5181 atom percent +/- 0.0008; ^{235}U = 49.696 a.p. +/- 0.050; ^{236}U = 0.0755 a.p +/- 0.0003; ^{238}U = 49.711 a.p +/- 0.050). *Note that NIST SRM U-500 does not contain any Thorium.***

By contrast, in Bopp *et al.*'s field experiments, the 'input' U(VI)(aq) Uranium isotopes actually being reduced by bacteria are whatever isotopic mixture happens to be naturally present at the particular time acetate is injected into the mine tailings to stimulate growth of whatever "*reducing dissimilatory bacteria*" may then be present.

Also note that in Bopp *et al.*'s Rifle bioremediation site, significant quantities of customary natural Uranium decay products are invariably present in tailings, including Thorium-232 as well as probably some Plutonium isotopes derived from atmospheric fallout contamination.

Importantly, the presence of significant amounts of ^{232}Th has been unequivocally verified in the Rifle test site tailings in multiple test pits. Please see "*Radiological survey of the inactive Uranium-mill tailings at Rifle, Colorado,*" F. Hayward et al., Report #ORNL-5455, Oak Ridge National Laboratory, Health and Safety Research Division, Contract # W-7405-eng-26, published June 1980 at http://www.osti.gov/bridge/servlets/purl/5345200-AR4QVh/5345200.pdf

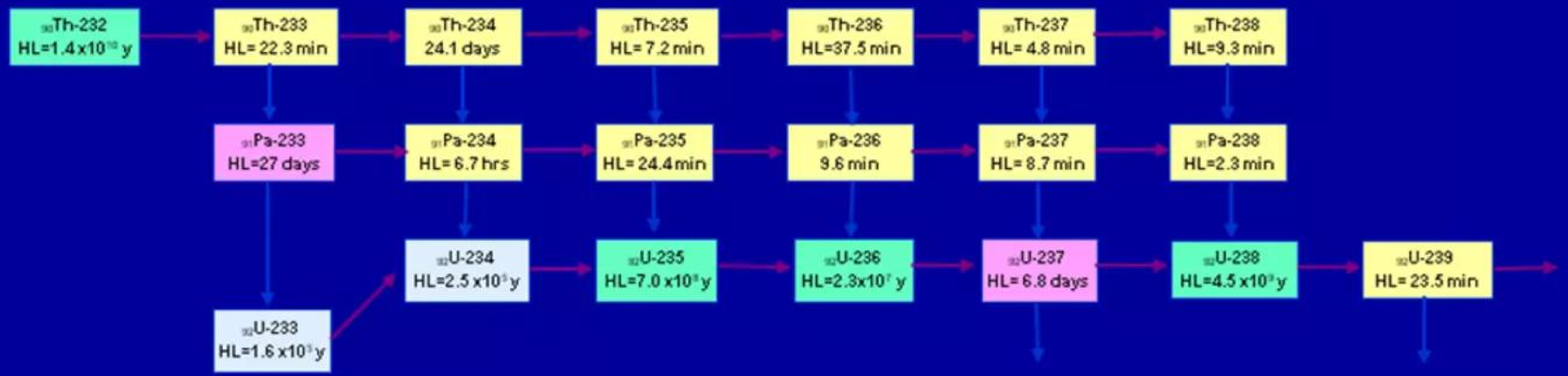
Are bacteria involved in $_{90}Th^{232}$ -seed LENR network?

Discussion of two important papers re bacterial Uranium isotope “fractionation”

The potential significance of ^{232}Th being present at the natural Rifle test site soils versus its very likely absence in Rademacher *et al.*’s controlled laboratory experiments will be explained momentarily.

Please be aware that some or all of this theorized LENR transmutation network, if present in Nature, is likely to be distributed across multiple species of microorganisms; vary spatially on sub-meter length-scales; and change dynamically over short time-scales in response a variety of environmental factors.

Thorium ‘seed’ nuclei present : in a given experimental system that has a functioning W-L LENR Actinide nucleosynthetic network, any ^{232}Th atoms initially present therein can potentially be transmuted via ULM neutron capture and decays into Uranium isotopes via the following subset of network pathways:



Possible reconciliation of differences between the results of Rademacher *et al.* versus Bopp *et al.*:

The segment of the hypothetical LENR Actinide nucleosynthetic network shown above illustrates how Thorium-232 (^{232}Th) can be transmuted into ^{235}U and/or ^{238}U by a combination of fissionless ULM neutron captures and subsequent radioactive decays.

Please recall that ^{232}Th was almost assuredly NOT present in significant amounts at the beginning of Rademacher *et al.*’s controlled laboratory experiments, but it undoubtedly was present in significant quantities in the tailings at the beginning of Bopp *et al.*’s field experiments in Rifle, Colorado.

Commercializing a next-generation source of CLENR energy

Are bacteria involved in ${}_{90}Th^{232}$ -seed LENR network?

Discussion of two important papers re bacterial Uranium isotope "fractionation"

If one looks at the differences in their results through the conceptual lens of a purely chemical paradigm, they look somewhat contradictory and confusing. That lack of clarity is probably what impelled the two groups to invoke diametrically opposite chemical fractionation mechanisms to explain their $^{238}U/^{235}U$ isotopic data (i.e., mass-dependent versus mass-independent processes). *By contrast, if one applies the new LENR paradigm, the observed differences are simply the result of a combination of: (1) different initial conditions (^{232}Th was initially present in one set of experiments but not the other); and (2) different segments of the LENR Actinide nucleosynthetic network possibly operating at different relative rates during the two sets of experiments. Under an LENR paradigm, these results appear to be more-or-less understandable as opposed to being confusing.*

Please see following paper re Sulfur $\delta^{34}S$ shifts that were observed during redox processes occurring at same Rifle, CO, site:

"Sulfur isotopes as indicators of amended bacterial sulfate reduction processes influencing field scale Uranium bioremediation"
J. Druhan *et al.*
Environmental Science & Technology 42 pp. 7842 - 7849 (2008)
http://www.osti.gov/bridge/servlets/purl/961529-3R6Vg7/961529.pdf

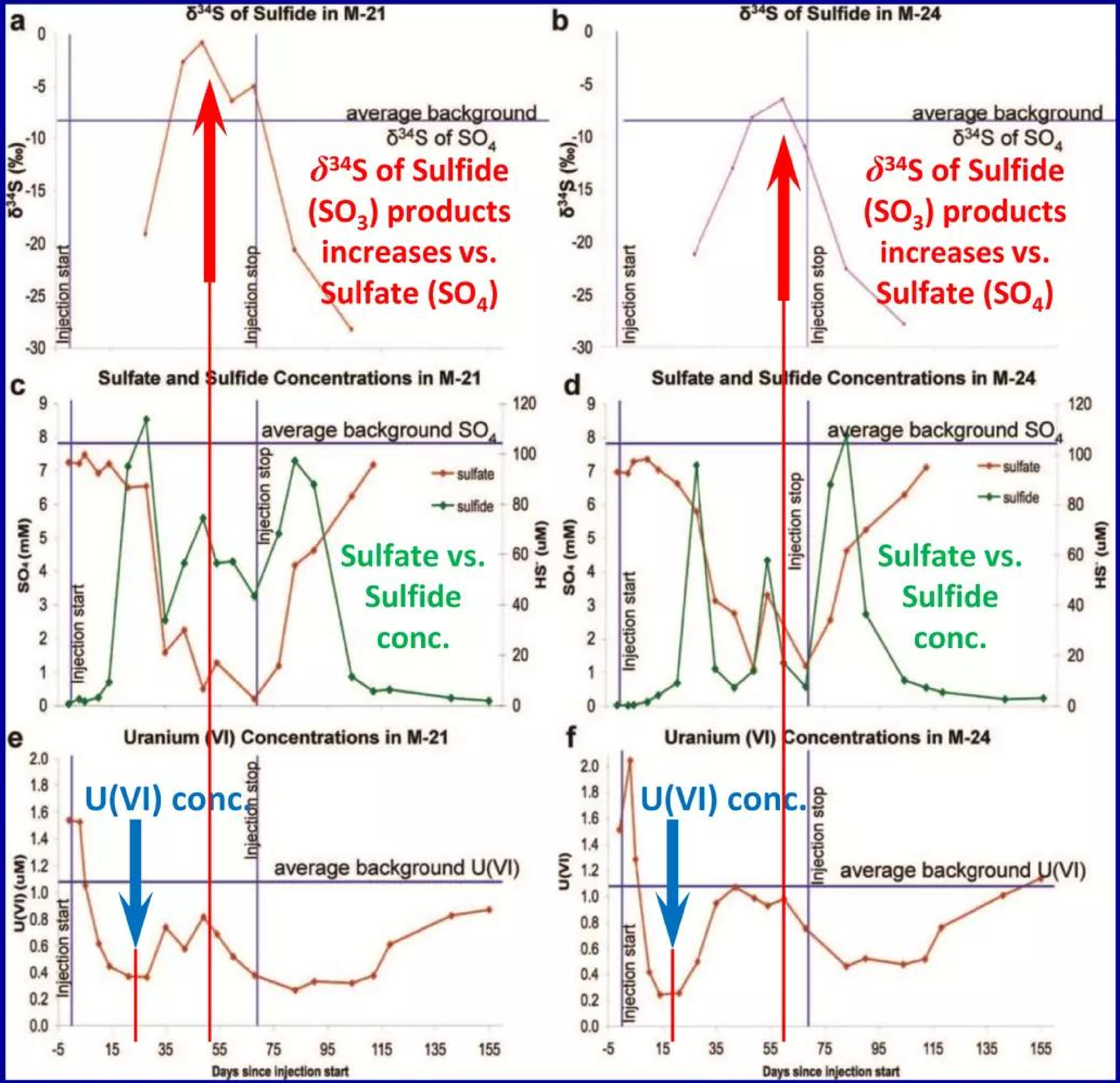
Abstract: "Aqueous uranium U(VI) concentrations in a contaminated aquifer in Rifle, CO, have been successfully lowered through electron donor amended bioreduction. Samples collected during the acetate amendment experiment were analyzed for aqueous concentrations of Fe(II), sulfate, sulfide, acetate, U(VI), and $\delta^{34}S$ of sulfate and sulfide to explore the utility of sulfur isotopes as indicators of in situ acetate amended sulfate and uranium bioreduction processes. Enrichment of up to 7‰ in $\delta^{34}S$ of sulfate in down-gradient monitoring wells indicates a transition to elevated bacterial sulfate reduction. A depletion in Fe(II), sulfate, and sulfide concentrations at the height of sulfate reduction, along with an increase in the $\delta^{34}S$ of sulfide to levels approaching the $\delta^{34}S$ values of sulfate, indicates sulfate-limited conditions concurrent with a rebound in U(VI) concentrations. Upon cessation of acetate amendment, sulfate and sulfide concentrations increased, while $\delta^{34}S$ values of sulfide returned to less than -20‰ and sulfate $\delta^{34}S$ decreased to near-background values, indicating lower levels of sulfate reduction accompanied by a corresponding drop in U(VI). Results indicate a transition between electron donor and sulfate limited conditions at the height of sulfate reduction and suggest stability of biogenic FeS precipitates following the end of acetate amendment."

Sulfide products' δ^{34}S shifted in parallel with redox reactions

"Sulfur isotopes as indicators of amended bacterial sulfate reduction processes influencing field scale Uranium bioremediation"
J. Druhan *et al.*
***Environmental Science & Technology* 42 pp. 7842 - 7849 (2008)**
http://www.osti.gov/bridge/servlets/purl/961529-3R6Vg7/961529.pdf

Lattice comment: in these charts, it is interesting to note that measured Uranium U(VI)$_{(aq)}$ concentrations (in mM) first decreased significantly during reduction of U(VI)$_{(aq)}$ to U(IV)$_{(s)}$ at Rifle, Colorado, study wells M-21 and M-24 (Bopp *et al.,* 2010); this occurred during very roughly the same time interval that Sulfur was being reduced from Sulfate to Sulfide and redox-related chemical 'fractionation.' For a period of time, δ^{34}S in Sulfide redox products increased significantly (see a. and b. in Fig. 4 at right) relative to average measured 'background' δ^{34}S of SO_4, and then dropped sharply. Alternatively to chemical fractionation, a sequence of LENR ULM neutron captures such as $^{32}S \rightarrow {}^{33}S \rightarrow {}^{34}S$ would be consistent with at least some of this set of δ^{34}S shift data. Per W-L theory, Sulfur could eventually be transmuted to Chlorine via additional ULM neutron captures and beta decays of heavier neutron-rich Sulfur isotopes. Such a transmutation into elemental Chlorine could then in theory produce chlorate ($-ClO_3$) or perchlorate anions ($-ClO_4$) which were not measured in these studies. Interestingly, such a 'disappearance' of Sulfur into Chlorine might explain other oddities in this data. Clearly, these results are quite complex with many types of chemical and perhaps even LENR processes operating in parallel

Figure 4 in Druhan *et al.* is quite interesting; reproduced below for readers' convenience:



δ^{34}S of Sulfide (SO_3) products increases vs. Sulfate (SO_4)

δ^{34}S of Sulfide (SO_3) products increases vs. Sulfate (SO_4)

Sulfate vs. Sulfide conc.

Sulfate vs. Sulfide conc.

U(VI) conc.

U(VI) conc.

FIGURE 4. Stable sulfur isotopes of sulfide vs. time for a) well M-21 and b) well M-24. Sulfate and sulfide concentrations for c) well M-21 and d) well M-24 and Uranium (VI) concentrations for e) well M-21 and f) well M-24 are also given for comparison. Background δ^{34}S of SO_4, sulfate, sulfide, and uranium (VI) concentrations are given as averages of all measurements in well B-05 throughout the course of the experiment. The background value for sulfide concentration (not labeled) is 1.25 μM.

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Important new paper by Hiess *et al.*

What are the consequences?

"^{238}U/^{235}U Systematics in Terrestrial Uranium-Bearing Minerals"
J. Hiess *et al.*
***Science* 335 no. 6076 pp. 1610-1614 (30 March 2012)**
DOI: 10.1126/science.1215507 http://www.sciencemag.org/content/335/6076/1610.full

Quoting directly: "The uranium-lead (U-Pb) system is widely used as an isotopic chronometer for geological and meteoritic materials that are less than 1million to greater than 4.5 billion years old. This system is particularly useful because it has two long-lived isotopes, ^{238}U and ^{235}U, which decay at different rates to ^{206}Pb and ^{207}Pb, respectively, permitting the evaluation of closed system behavior, and because both decay constants have been determined to relatively high precision. Daughter isotope determinations from the two decay systems may also be combined to calculate a ^{207}Pb-^{206}Pb date in concert with an assumed or measured present-day ^{238}U/^{235}U ratio. With recent advances in sample preparation, isotope ratio mass spectrometry, and gravimetric calibration of tracers for isotope dilution methods, the precision of an individual U-Pb or Pb-Pb age determination can exceed 0.1%. The U-Pb chronometer has been used to improve the accuracy of other radioisotopic systems such as ^{40}Ar/^{39}Ar, Lu-Hf, Rb-Sr, and Re-Os, and to anchor extinct nuclide cosmochronometers that are used to place early solar system events in sequence. Thus, the U-Pb system has far-reaching impacts on the determination of absolute time in geological and meteoric materials."

"Historically, the kinetic fractionation of U isotopes was expected to be small because of their high mass; until recently, the present-day ^{238}U/^{235}U ratio of all natural materials was considered invariant. In geo- and cosmochronology, a ^{238}U/^{235}U value equal to 137.88 has been used almost exclusively for the past 35 years and is based on studies of magmatic and sedimentary uranium ore deposits. As published, this presumed invariant ratio and its references cannot be traced back to the International System (SI) of Units. More recently, IUPAC recommended a value of 137.80 from the analysis of six natural ore deposits, confirmed by high-precision isotope ratio analyses using the IRMM-3636 ^{233}U-^{236}U double spike whose isotopic composition is traceable to SI units. The invariance of the present-day ^{238}U/^{235}U ratio has been brought into question by studies that have demonstrated U isotopic fractionation in terrestrial materials. Such fractionation occurs during oxidation-reduction reactions (U^{VI} to/from U^{IV}), coordination change during adsorption, or leaching, and is due to thermodynamic or nuclear field shift effects. In extraterrestrial materials, excess ^{235}U may result from a decay of the short-lived ^{247}Cm, which has been detected in carbonaceous chondrites and their calcium- and aluminum-rich inclusions. Recent cosmochronology studies have highlighted the need for coupled ^{238}U/^{235}U and ^{207}Pb/^{206}Pb data sets in order to determine accurate ^{207}Pb-^{206}Pb dates. Thus, it is crucial to reevaluate the range of natural variation of ^{238}U/^{235}U ratios in U-bearing minerals commonly analyzed for U-Pb age determinations." [i.e., will only measure terrestrial hi-temp magmatic & related minerals]

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Quoting directly: "We performed 141 ^{238}U/^{235}U determinations on a suite of 58 samples of U-bearing accessory minerals that are used for U-Pb geochronology (zircon, monazite, apatite, titanite, uraninite, xenotime, and baddeleyite), spanning the Quaternary to the Eoarchean and covering a diverse range of igneous and metamorphic petrogenetic settings and geographic locations. These data are traceable to SI units because they were measured using a gravimetrically calibrated ^{233}U-^{236}U tracer; measurement uncertainties are on the order of 70 parts per million (ppm) or better. Our data set has a >5.4 per mil (‰) range in ^{238}U/^{235}U (Fig. 1). The lowest measured value is 137.743 from the pegmatite-derived Moacyr monazite, and the highest is 138.490 for the Fish Canyon Tuff titanite, erupted in a large-volume silicic ash flow. Two other samples yield ^{238}U/^{235}U values greater than 138: BLR-1 titanite (138.068) and Table Cape zircon (138.283)." [all of these 141 measurements on 58 rock and mineral samples containing U-bearing accessory minerals fall into the category labeled "Terrestrial --- high-temperature/Magmatic and related" (minerals) shown in Fig. 3 of their paper]

Lattice comment: Hiess *et al.* cite an earlier paper by Bopp *et al.* as follows: "*Variations in ^{238}U/^{235}U in Uranium ore deposits: isotopic signatures of the U reduction process?"* C. Bopp *et al., Geology* 37 pp. 611 - 614 (2009) ftp://rock.geosociety.org/pub/reposit/2009/2009143.pdf

Abstract of paper: "The ability to measure ^{238}U/^{235}U to high precision presents an important new opportunity to study the fate and transport of uranium in the environment. The ratio of ^{238}U/^{235}U was determined by multicollector–inductively coupled plasma–mass spectrometer in six uranium ore samples representing two different classes of deposits. Significant offsets in ^{238}U/^{235}U are observed between uranium ores precipitated from groundwaters at low temperature versus hydrothermal deposits precipitated at high temperatures, reinforcing an observation made previously but lacking the needed precision. Specifically, tabular sandstone-type uranium deposits were found to be depleted in ^{235}U, with a total offset between low-temperature deposits and higher temperature deposits of 1.0 . We attribute this offset to reflect a temperature-dependent fractionation related to the nuclear field shift effect during chemical reduction of uranium in ambient temperature groundwaters."

Lattice comment: in the 2009 paper, Bopp *et al.* report *significant differences* in ^{238}U/^{235}U ratios between natural uranium ores located in sandstone deposits formed at low temperatures vs. those from hydrothermal magmatic deposits formed at much higher temperatures

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Lattice comments (continued): unnerved by significant observed variation of the ^{238}U/^{235}U ratio reported by Bopp *et al.* (2009) and others (this data was disturbing because it clearly violated a longstanding assumption that the ^{238}U/^{235}U ratio was effectively invariant in terrestrial materials) and anxious to find a more stable 'anchor point' which could then be used in U-Pb geochronology studies, Hiess *et al.* correctly chose to concentrate their new measurement efforts on a subset of the array of rocks/minerals and formative environments (especially high vs. low temperature) in which there was the least apparent variability in the ^{238}U/^{235}U ratio. Those considerations thus led Hiess *et al.* to focus on measuring the ^{238}U/^{235}U ratio in Zircons as follows:

Quoting directly: "Of 45 zircon ^{238}U/^{235}U measurements, 44 of them are within a range of ~1‰, from 137.772 (Zim265) to 137.908 (168952). There is resolvable variation between samples, but no first-order correlation with age, petrogenetic setting, or geographic location. All five samples of uraninite, apatite, xenotime, and baddeleyite fall within the compositional range of zircon. The resolvable ^{238}U/^{235}U differences between samples could arise from multiple processes, including incorporation of uranium from a protolith with fractionated ^{238}U/^{235}U into parental magma and isotopic fractionation associated with magmatic or mineral crystallization processes. Samples of similar genetic affinity typically show agreement in ^{238}U/^{235}U values, suggesting isotopic homogenization within some magmatic systems ... " [Details of these 44 selected samples described in their Fig. 1 on next Slide]

"Of the zircon samples measured, 44 of 45 define an approximately normally distributed population with a mean of 137.818 and standard deviation of 0.022, with population parameters calculated using (28), which corrects for the expected additional dispersion from analytical uncertainties. We propose that this average zircon value and its associated variability (137.818 T 0.045/0.050, 2σ), which is traceable to the SI system of units, is applicable for the majority of U-Pb determinations and, in the absence of an independently determined ^{238}U/^{235}U value, should be adopted for future use in U-Pb geochronology of zircon."

"Adoption of the average ^{238}U/^{235}U zircon value of 137.818 +/- 0.045 for use in zircon geochronology will decrease ^{207}Pb-^{206}Pb, ^{207}Pb-^{235}U, and ^{206}Pb-^{238}U dates relative to those calculated using the conventional ^{238}U/^{235}U value of 137.88. For ^{207}Pb-^{206}Pb dates, the ^{238}U/^{235}U ratio is implicit in the age equation and the magnitude of the difference is largest, changing gradually from ~1 million years for samples dated 100 million years ago (Ma) to ~700,000 years for samples dated 4 billion years ago (Ga) (Fig. 2A)."

Fig. 1 (A) $^{238}U/^{235}U$ mineral summary plot including the 44 samples used to define our recommended zircon composition (represented by the yellow band).

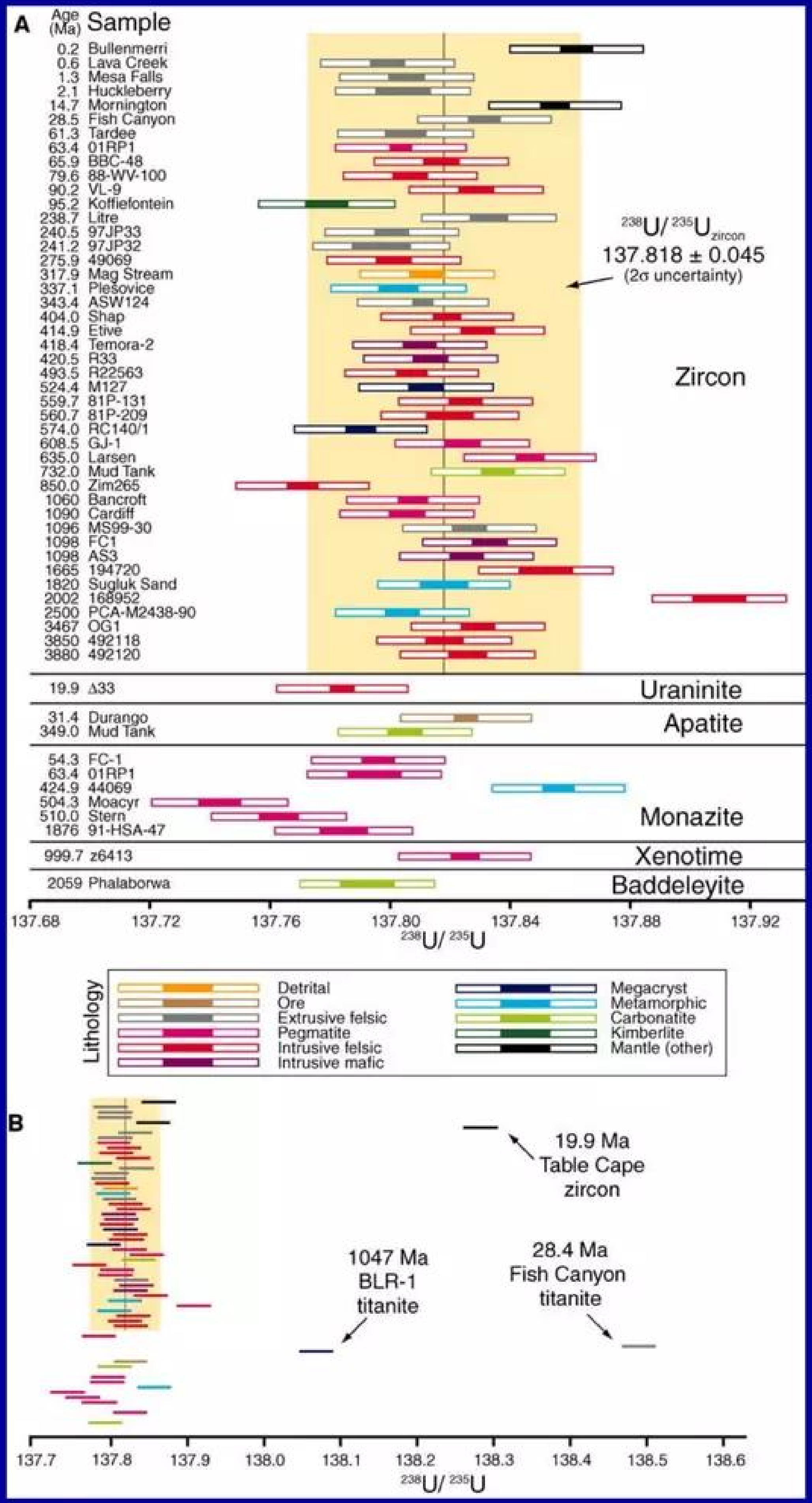

Fig. 1. (A) $^{238}U/^{235}U$ mineral summary plot including the 44 samples used to define our recommended zircon composition (represented by the yellow band). Solid and open boxes for each sample represent 2s measured and total uncertainties, respectively. (B) One additional zircon sample and two additional titanite samples shown relative to the data in (A), highlighting the total range of sample compositions observed. Sample solid boxes represent 2σ total uncertainties.

J. Hiess *et al.* Science 2012;335:1610-1614

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J. Hiess *et al.*
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Hiess *et al*. then proceed to discuss their Fig. 3 reproduced on next Slide as follows (quoting directly):

"An emerging $^{238}U/^{235}U$ data set for a wide range of rocks, minerals, and meteorites is now available (Fig. 3). Given that natural $^{238}U/^{235}U$ variation has been demonstrated up to ~0.13%, it might be expected that a corresponding variation be observed in the U-bearing mineral data set, because $^{238}U/^{235}U$ fractionated material from low-temperature environments is incorporated into higher-temperature systems through crustal recycling processes. A first order observation from the compiled $^{238}U/^{235}U$ data is that materials formed in near-surface environments (e.g., chemical precipitates) record a wider range than crustal rocks and minerals formed in higher-temperature magmatic environments. This suggests that uranium in magmatic and derived crustal reservoirs (e.g., siliciclastic sediments) is isotopically well mixed relative to uranium in materials formed in near-surface environments, and that the low-temperature materials with highly fractionated $^{238}U/^{235}U$ constitute volumetrically minor reservoirs that are continually and efficiently homogenized via crustal recycling processes."

"Second, modern seawater and Quaternary seawater precipitates are systematically lower than the 'bulk Earth' $^{238}U/^{235}U$ composition, indicating ^{235}U enrichment in the marine reservoir. Seawater enrichment in ^{234}U by ~147‰ relative to radioactive secular equilibrium is a well-known consequence of radioactive α-recoil processes and the preferential release of the non–lattice-bound ^{234}U daughter nuclide into the hydrological environment. Previous studies demonstrated a broad positive correlation between ^{234}U and ^{235}U depletion in near-surface environments, but an α-recoil–related mechanism cannot account for $^{235}U/^{238}U$ fractionation [in terrestrial near-surface environments], as both are lattice-bound."

"This agreement suggests that a uniform $^{238}U/^{235}U$ was achieved relatively early during planetary accretion and that U isotope compositions in the high-temperature terrestrial crust and upper mantle are also likely to apply to the lower mantle, thereby defining the bulk silicate Earth isotope composition. In light of the agreement of terrestrial and meteoritic isotope compositions and current Earth accretion models, this average $^{238}U/^{235}U$ value of 137.818 +/- 0.050 would also represent the isotope composition of 'bulk Earth'."

Fig. 3 Compilation of ^{238}U/^{235}U data obtained on a wide variety of geological and extraterrestrial materials.

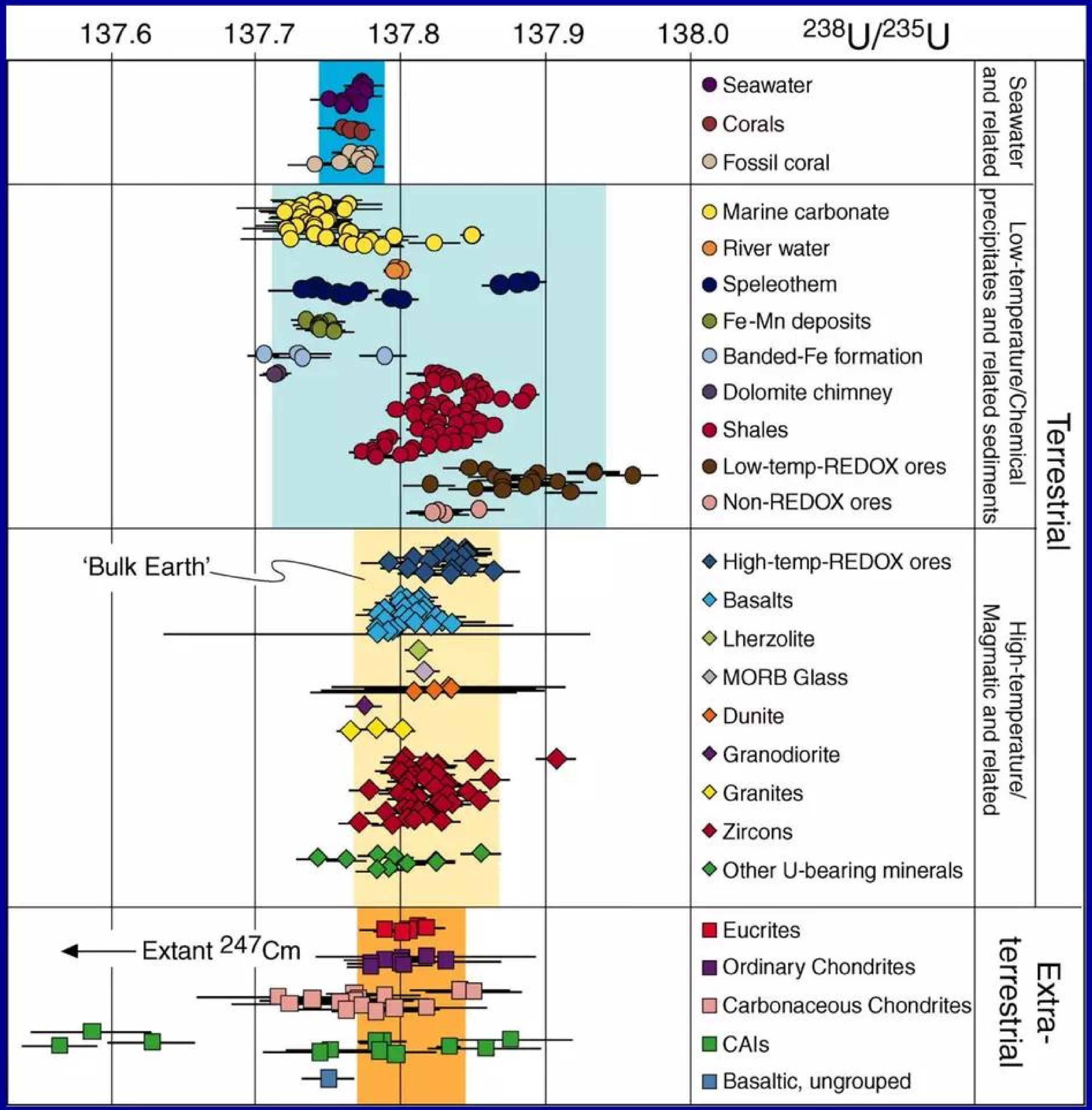


Fig. 3. Compilation of ^{238}U/^{235}U data obtained on a wide variety of geological and extraterrestrial materials. The "bulk Earth" field (yellow band) is based on the terrestrial/high-temperature data set, consistent with eucrites and ordinary chondrites. Seawater and related precipitates show a systematic enrichment in ^{235}U relative to the "bulk Earth" field. Data are from literature sources (17, 18, 25, 30–33, 39–41) and this study (zircon and other U-bearing minerals).

J. Hiess *et al.* Science 2012;335:1610-1614

Commercializing a next-generation source of CLENR energy

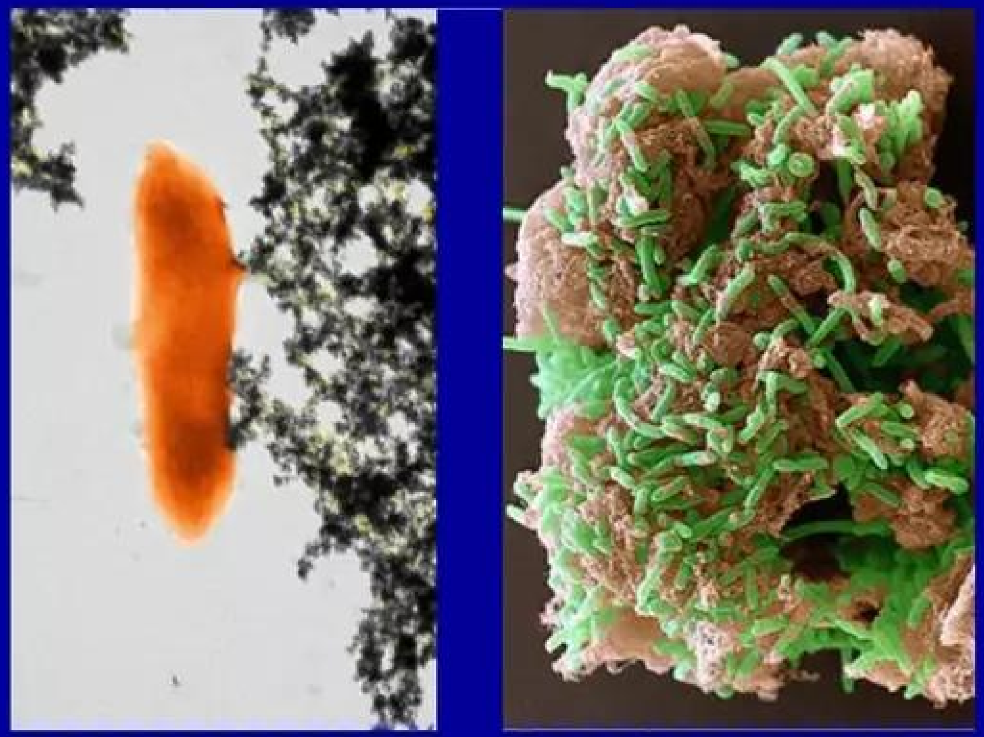
Important new paper by Hiess *et al.*

What are the consequences?

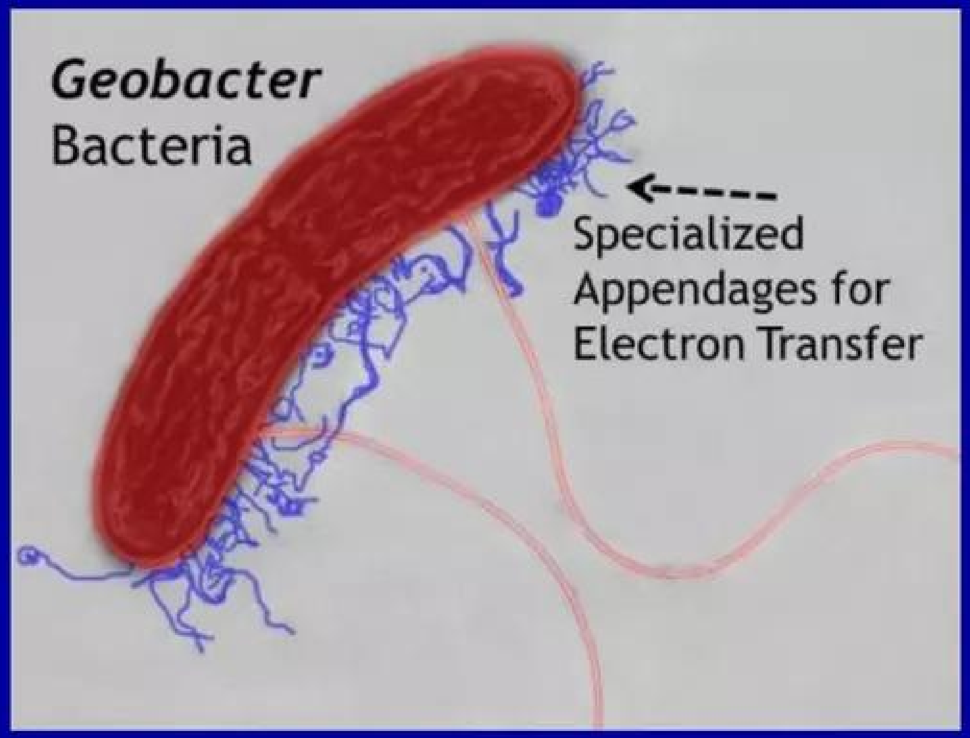
Lattice comments re Hiess *et al.*'s Fig 3 - in many ways, this data is astounding:

- ✓ First observation: overall variability in the $^{238}U/^{235}U$ ratio is relatively low in extraterrestrial materials; it increases further in terrestrial materials from high-temperature magmatic and related environments; it Is greatest of all in terrestrial materials originating in low-temperature chemical precipitates and/or sedimentary environments; oddly, it finally drops to its lowest variability of all in liquid seawater and life-produced undersea structures such as living and fossil corals
- ✓ Second observation: highest variability in the $^{238}U/^{235}U$ ratio occurs in terrestrial materials originating in low-temperature chemical precipitates, REDOX ores, and/or sedimentary environments. This category accurately describes the natural environment found in the Rifle, Colorado, study site in which soil bacteria are clearly involved in shifting the $^{238}U/^{235}U$ ratio as well as triggering significant, time-varying shifts in Sulfur isotope abundances during roughly contemporaneous, spatially nearby redox reactions. Fig. 3 again strongly suggests that terrestrial bacteria are the culprits behind observed isotopic shifts in Uranium and Sulfur in soils and rocks. *The question is: are these observed shifts produced by 'simple' chemical fractionation or LENR processes?* This issue begs for further investigation
- ✓ Third observation and open question: surprisingly, the lowest variability in the $^{238}U/^{235}U$ ratio is associated with earth's oceans. *Why is this so?* Is it maybe because bacteria living therein are somehow prevented from doing 'electric' fractionations or LENR transmutations that may occur more readily in soils or rock pore spaces? This also begs for investigation
- ✓ Final comment: earth's lower 11 km of atmosphere plus uppermost 5 km of the planet's crust, all of which is inhabited by bacteria, together amount to < ~0.9% of total volume of the planet itself and 75% of its atmosphere. If bacteria are creating isotopic shifts in these 'tiny' subvolumes, they *" ... Constitute volumetrically minor reservoirs that are continually and efficiently homogenized via crustal recycling processes,"* exactly as stated by Hiess *et al.* in their important paper. IOW, isotopically shifted materials are 'diluted' in bulk earth over time

"Electric bacteria"



Geobacter sp. **attached to mineral substrates**



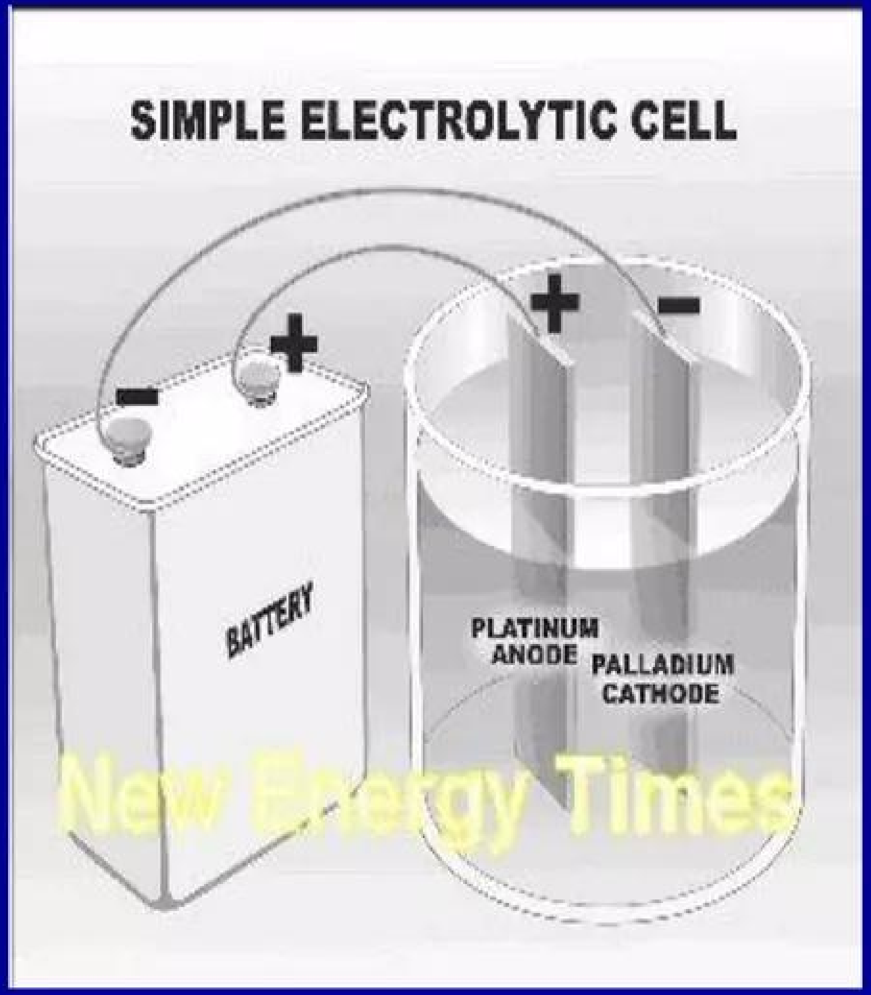
Graphic of *Geobacter sp.* bacteria showing special electron-carrying 'pipes'. Source: Prof. D. Lovely, Univ. of Massachusetts

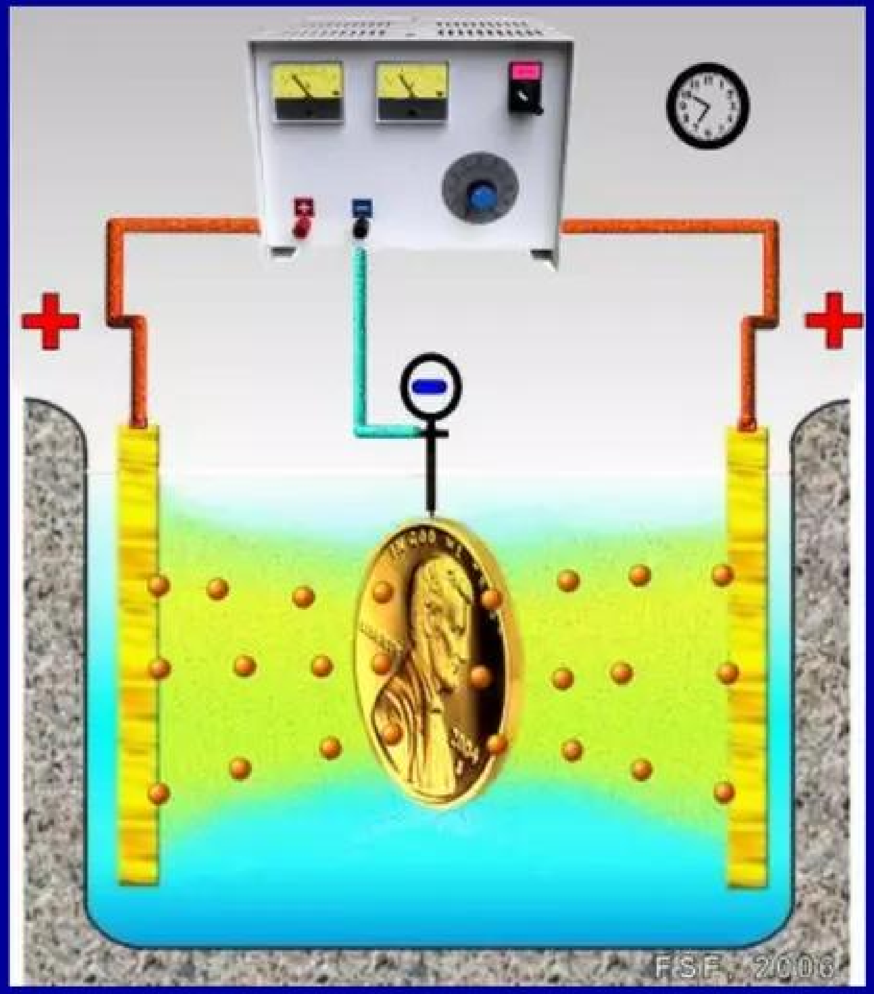
New possibility: LENRs and 'electric bacteria'

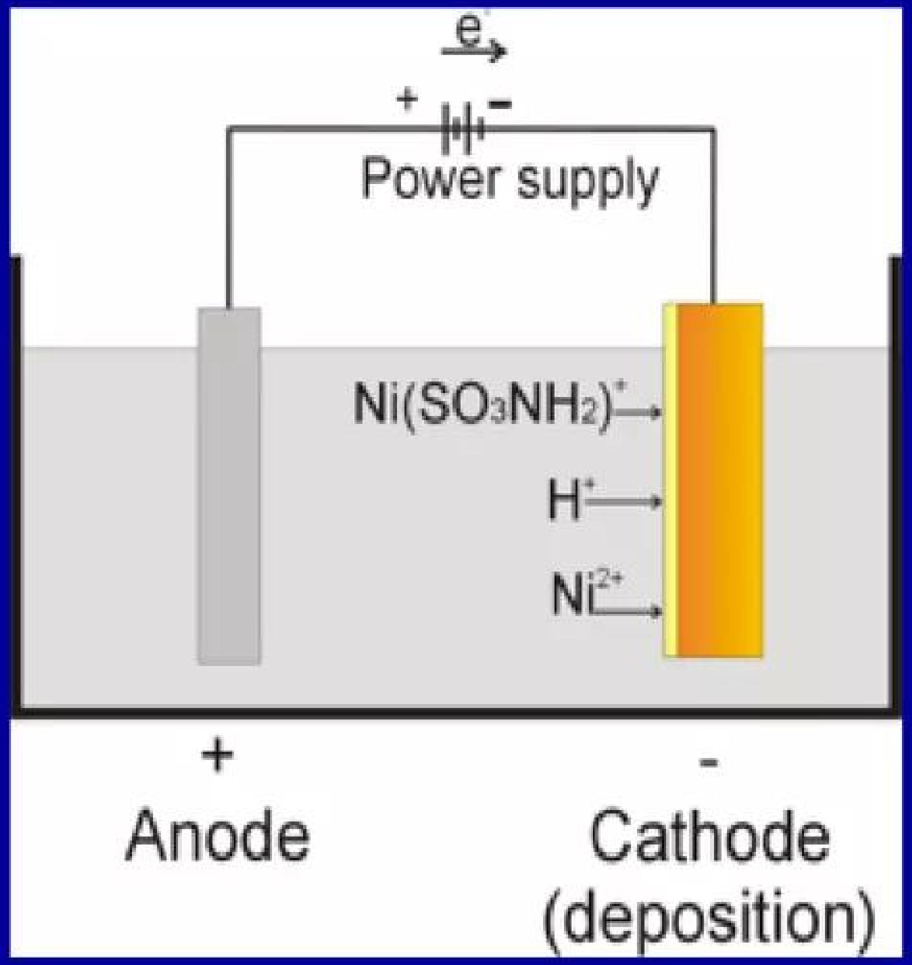
Conceptual analogy: aqueous electrolytic cell?

Now, fascinating new facts and speculation about 'electric bacteria' - recent exciting discoveries by microbiologists have revealed that electric potentials, currents, and 'nanowires' are associated with the activities of various species of bacteria; might this possibly have anything to do with biological LENRs?

First, let's examine the concept of a LENR electrolytic chemical cell:







Above are various conceptual schematics of a type of aqueous light-water electrolytic chemical cells used in many LENR experiments (typically would use DC power supply instead of a battery as a source of electrical current). Please note that using mass spectroscopy for post-experiment analyses, LENR researchers have carefully documented and reported production (via transmutation) of minute amounts of many different elements and isotopically shifted stable isotopes on the surfaces of cathodes found in such cells. In certain cases, array of transmutation products was huge

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New possibility: LENRs and 'electric bacteria'

Conceptual analogy: aqueous electrolytic cell?

How do key attributes of a typical laboratory LENR electrolytic cell compare conceptually with what is present inside bacterial cells and/or in their immediate environment? – please see Table below:

Present in electrolytic cells used in laboratory experiments that produced LENR transmutation products	Analogously present somewhere either inside microorganisms or located in their immediate physical environments?	Comments
Aqueous electrolyte containing mobile ions as well as sources of protons or deuterons (i.e., H_2O or D_2O)	Yes	Obvious
Disequilibrium electrical (electron) current from DC power source	Yes	See papers cited in Slides to follow --- recent discoveries re microbial electric currents via bacterial 'nanowires'
Conductive metallic anode and cathode structures that support redox reactions on their surfaces; also can absorb hydrogen (form hydrides) which enters metallic lattice as *p+* protons	Yes	Various metals are commonly present inside bacteria; in some cases tightly integrated with macromolecules (e.g., enzyme cofactors); not clear to me exactly what biological systems' nanoscale structural equivalents of metallic laboratory cathodes/anodes are really like; aromatic rings embedded in macromolecules very plausible candidates
Metallic wires that can conduct electrical currents	Yes	Bacteria now known to have electrically conductive, mostly nonmetallic nanowires; currents were measured
Oxidation-reduction (Redox) chemical reactions occur at the anodes and cathodes immersed in electrolyte	Yes	Redox reactions occur in metal-reducing bacteria --- observed isotopic shifts are now known to be closely associated with bacterial reduction processes; e.g., Uranium, Sulfur isotopes as discussed herein

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New possibility: LENRs and ‘electric bacteria’

Speculative details and open questions about this conjecture

In the Widom-Larsen theory of LENRs in condensed matter, production of ultra low momentum (ULM) neutrons takes place via the weak interaction: $e^- + p^+ \rightarrow n_{ulm}$ + electron neutrino. Mass-renormalized heavy electrons that can react directly with protons are created by high nanoscale local electric fields enabled by ‘surface’ many-body collective effects. An external energy source is required to drive this reaction forward (about 0.78 MeV per e^{-*} to react with a proton; ~=2.6 million ATP molecules); this can be provided by a disequilibrium input electrical current. LENR ULMN transmutations occur when ULM neutrons are absorbed by nearby ‘target’ nuclei; heavy-mass electrons also present locally convert neutron capture gammas to much lower- energy infrared photons (i.e., simply ‘ordinary’ heat)

Luckily for bacteria, high local nanoscale electric fields only have to exist for a number of attoseconds to ‘get the job done.’ How are these fields turned on/off; how is field-strength is controlled and finely modulated on a nanoscale? What types of macromolecular structural/conformational dynamics are involved in this process?

Another example of an intriguing open question for researchers is the mechanism(s) by which bacteria are able to ‘deliver’ and ‘control’ exactly which ‘target’ atoms/elements are ‘allowed’ to capture (i.e., absorb) ULM neutrons as they are produced inside a cell? If this process were not tightly controlled by bacteria, it could potentially create a form of intracellular chemical chaos with one element unexpectedly changing into another (please recall that neutron captures occur in picoseconds)

Active sites of enzymes and membrane surfaces/interfaces would be logical possibilities where one might expect key aspects of biological LENRs could be occurring. How does this new possibility relate to our present knowledge of biophysical processes already thought to be occurring at such locations in or around cellular macromolecules?

With regard to theoretical energetics of biological transmutations, it ‘costs’ the energy equivalent of ~2.6 million ATP molecules to produce a single ULM neutron from a proton. On the Internet, we discovered an estimate that a single *E. coli* cell can supposedly sustain an ATP production rate of ~0.8 to 4.0 x 10^{10} ATP molecules/cell/hr. That being the case, the energetic ‘cost’ of ULM neutron production would be fairly ‘expensive’ for a bacterium but maybe not too onerous if the end result was important enough for an organism’s growth and/or likelihood of survival

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New possibility: LENRs and 'electric bacteria'

Recent papers that are very informative and worth reading

Selected peer-reviewed publications concerning bacterial nanowires, observations of electrodic potential anomalies and related electron currents, and bacterial electrokinesis – exciting papers:

"*Extracellular electron transfer via microbial nanowires*"
G. Reguera *et al.*
***Nature* 435 pp. 1098 - 1101 (2005) includes another document w. additional supplementary material**
http://www.geobacter.org/publications/Nature_2005_Jun.pdf

"Electrically conductive bacterial nanowires produced by Shewanella oneidensis strain MR-1 and other microorganisms"
Y. Gorby *et al.*
***Proceedings of the National Academy of Sciences* (PNAS) 103 pp. 11358 - 11363 (2006)**
http://www.pnas.org/content/103/30/11358.full.pdf+html

"*Analyses of current-generating mechanisms of Shewanella loihica PV-4 and Shewanella oneidensis MR-1 in microbial fuel cells*"
G. Newton *et al.*
***Applied and Environmental Microbiology* 75 pp. 7674 - 7681 (2009)**
http://aem.asm.org/cgi/reprint/75/24/7674

"*Harnessing self-organizing bacterial networks for microbial fuel cells*"
R. Nakamura and K. Hashimoto
SPIE DOI: 10.1117/2.1200901.1477 (2009)
http://spie.org/documents/Newsroom/Imported/1477/1477_5515_0_2009-01-16.pdf

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New possibility: LENRs and ‘electric bacteria’

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Selected peer-reviewed publications concerning bacterial nanowires, observations of electrodic potential anomalies and related electron currents, and bacterial electrokinesis – continued:

“*Electrical transport along bacterial nanowires from Shewanella oneidensis MR-1*”
M. El-Naggar *et al.*
***Proceedings of the National Academy of Sciences* (PNAS) DOI: 10.1073/pnas.1004880107 (2010)**
http://foundry.lbl.gov/assets/docs/pubs/MFNF_101001_UserElectrical.pdf
Free supplementary material:
http://www.pnas.org/content/suppl/2010/09/28/1004880107.DCSupplemental/pnas.201004880SI.pdf

“*Electrokinesis is a microbial behavior that requires extracellular electron transport*”
H. Harris *et al.*
***Proceedings of the National Academy of Sciences* (PNAS) 107 pp. 326 - 331 (2010)**
http://nanobio.usc.edu/publications/assets/Harris2009.pdf
Free supplementary material:
http://www.pnas.org/content/suppl/2009/12/14/0907468107.DCSupplemental/pnas.200907468SI.pdf

“*Electrodic voltages accompanying stimulated bioremediation of a Uranium-contaminated aquifer*”
K. Williams *et al.*
***Journal of Geophysical Research* 115 DOI:10.1029/2009JG001142 (2010)**
http://www.geobacter.org/publications/2009JG001142.pdf

“Extracellular reduction of Uranium via Geobacter conductive pili as a protective cellular mechanism”
D. Cologgi *et al.*
***Proceedings of the National Academy of Sciences* (PNAS) 108 pp. 15248 - 15242 (2011)**
http://www.pnas.org/content/108/37/15248.full.pdf+htm

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This is a fascinating, must-read paper: for the moment, let's speculatively assume that the analogy we discussed between so-called 'electric bacteria' and LENR aqueous electrolytic cells is appropriate;

1. **Now if that were true, an enterprising bacterium would probably try to place metallic transmutation 'targets' directly in the path of an electrical current**

2. **If the 'target' happened to be Uranium and the organism couldn't perfectly control produced neutrons energies in the resonance region (discussed earlier), there would be a risk of occasionally triggering very damaging fission reactions instead of desired neutron captures on Uranium isotopes**

***Geobacter,* which is known to uptake and manipulate Uranium isotopes as discussed herein, appears to have solved both issues by: (1) precipitating Uranium inside its electrically conducting pili wires; and (2) *doing Uranium redox reactions extracellularly inside the pili*, rather than the internal periplasm**

Lastly, also see: "*Tunable metallic-like conductivity in microbial nanowire networks*," N. Malvankar *et al.*,
***Nature Nanotechnology* 6 pp 573 - 579 (2011)**
http://www.nature.com/nnano/journal/v6/n9/full/nnano.2011.119.html

***Geobacter* : image by A. Klimes and E. Carbone, Univ. Mass. - Amherst**

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Conclusions and questions

Much more investigation is needed; major opportunities for experimentalists

- ✓ In a Dec. 7, 2010, Lattice SlideShare presentation re biological LENRs, we stated that, *"Recently, greatly increased use of various types of mass spectroscopy by geochemists, microbiologists, and environmental scientists has revealed that the longstanding assumption of effective natural uniformity of $^{238}U/^{235}U$ ratios across the earth is clearly erroneous; importantly, present-era abiological and/or biologically mediated processes appear to be responsible for such anomalous variances."* That opinion is supported by Hiess *et al.* cited and discussed herein; furthermore, data presented in Fig. 3 of their 2012 paper suggests involvement of biological systems in $^{238}U/^{235}U$ shifts

- ✓ In an April 4, 2012, Lattice SlideShare presentation re lightning, we explained how low rates of lightning-driven, non-stellar, abiotic nucleosynthesis have probably been occurring in the environs of what is now earth since condensation of the presolar nebula > 4.5 billion years ago; such processes may be causing isotopic shifts observed in Nitrogen and Oxygen on earth and elsewhere in the solar system

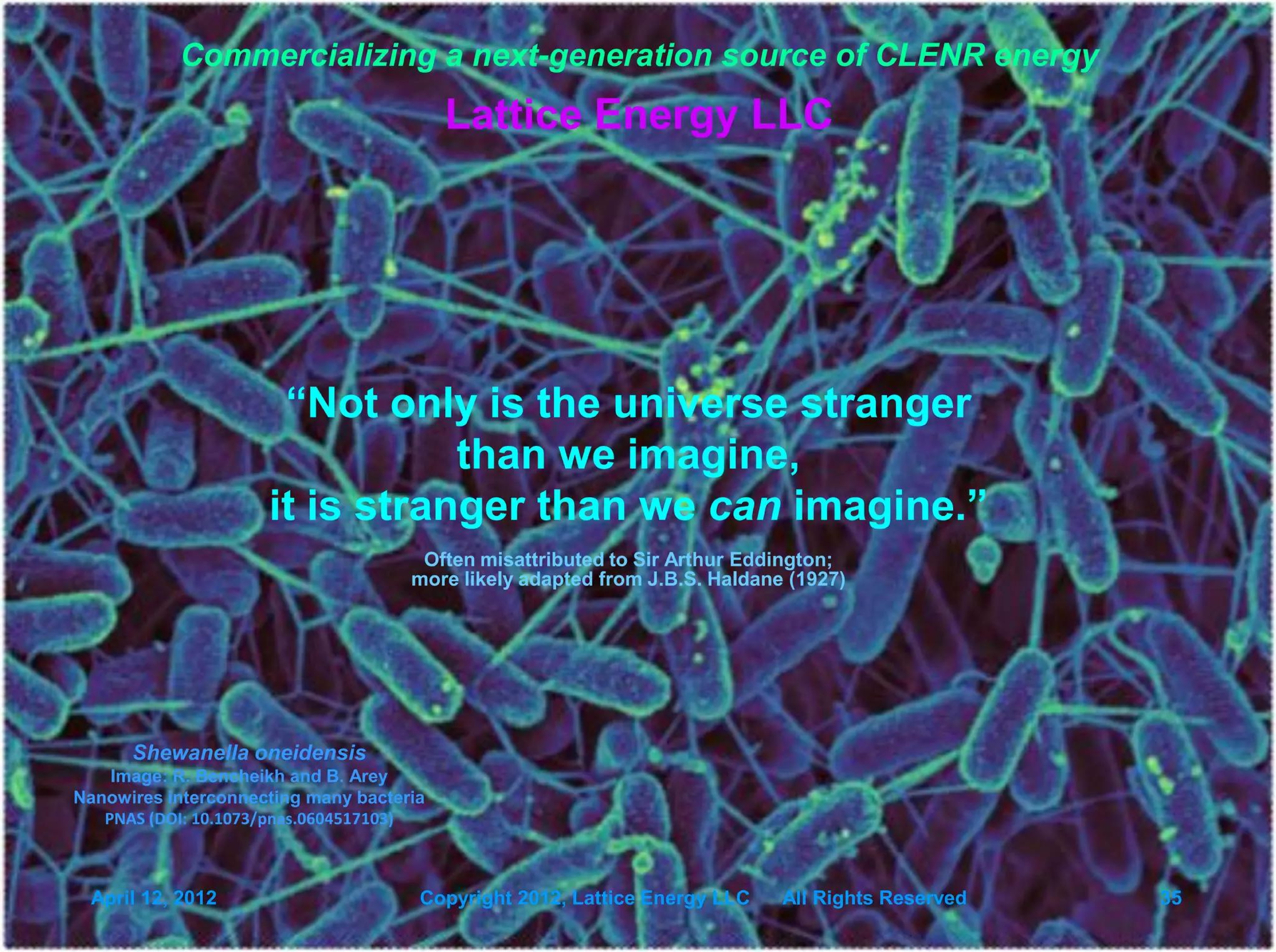
- ✓ Herein, we have provided compelling, published peer-reviewed experimental evidence that strongly implicates bacteria as causative agents in isotopic shifts observed in Uranium, Sulfur, and probably other elements; these 'chemical fractionation' and/or conjectured LENR transmutation processes seem to be associated with redox reactions in bacteria

- ✓ Presuming bacteria can engage in LENR nucleosynthesis, why pray tell would earthly microorganisms still be manipulating isotopes of Actinide elements? Is it simply an ancient vestigial capability coded in organisms' genomes, or does it serve some useful biological purpose in the present era? Specifically, what network pathways are typically traversed, what organisms are involved in each segment of those pathways, and in what natural environments does/can such processes occur?

- ✓ Are the observed biologically-induced *decreases* in measured U(VI) Uranium concentration and changes $^{238}U/^{235}U$ ratios over time simply a reflection of the conversion of Uranium isotopes into different chemical forms and concomitant chemical "fractionation" between those forms, e.g., from mobile and bioavailable U(VI) compounds (measured by Rademacher *et al*. and Bopp *et al*.) to fractionated, highly insoluble reduced U(IV) compounds (not presently measured); or are some, at the moment, indeterminate percentages of U(VI) and/or U(IV) Uranium atoms actually being transmuted to other elements entirely? If so, which elements/isotopes are produced and where do they go in the natural environment?

- ✓ Is non-anthropogenic Plutonium produced by the Actinide LENR network in Nature? If so, is it further transmuted from there?

- ✓ To answer such questions, an exhaustive isotopic 'inventory' and total mass balance of elements/isotopes comprising the theorized Actinide LENR transmutation network would have to be measured by experimentalists in different types of laboratory experiments and natural environments. In Lattice's opinion, many important discoveries await experimentalists who conduct this work.



“Not only is the universe stranger than we imagine, it is stranger than we *can* imagine.”

Often misattributed to Sir Arthur Eddington;
more likely adapted from J.B.S. Haldane (1927)

Shewanella oneidensis
Image: R. Bencheikh and B. Arey
Nanowires interconnecting many bacteria
PNAS (DOI: 10.1073/pnas.0604517103)