LENRs: radiation-free ultralow energy neutron reactions

Bacteria may be using LENRs to alter isotopes and transmute elements

Korean scientists used experimental mixtures of bacteria to reduce the concentration of radioactive Cesium-137 present in aqueous solutions irradiated with light at 12-hour intervals, shaken, and incubated at 25^{o} C

During experiments, and compared to controls, measured gamma radiation for flasks containing bacteria decreased at vastly higher rates than would be expected for 'normal' rate of Cs-137 β-decay: is radioactive Cesium actually being transmuted into heavier Cs isotopes and other elements by living bacteria?

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February 21, 2019

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Summary

- Four Korean scientists experienced in radiation measurements, mixed bacterial cultures, and materials science conducted experiments in which 500 ml mixtures of bacteria growing in sealed flasks appeared to reduce effective concentration of 55 kBq of Cesium-137 added to flasks at time = t_o
- Beta-decay of ^{137}Cs results in gamma radiation that has distinctive emission peak at energy = 662 keV. Such radiation is experimentally measured with gamma spectrometers. Periodic measurements of 662 keV peak effectively tracks time-series concentration of ^{137}Cs in aqueous growth media in flasks
- Rate of beta-decay for a given unstable, radioactive isotope is determined by its characteristic half-life (total elapsed time after time = t_o required for 50% of that isotope's atoms to decay), e.g. ^{137}Cs half-life = 30.1 years. With very few exceptions, nuclear science assumes that half-lives of unstable isotopes are immutable: radioactive decay rates are constant - don't change over time
- Experimental anomaly reported by Korean researchers was that in flasks containing bacteria and ^{137}Cs, measured amounts of gamma radiation in vicinity of 662 keV ^{137}Cs peak decreased at rates that were *substantially higher* that what would be expected from its well-known half-life of 30.1 years
- Three possible explanations for anomaly: (1) gamma radiation measurements were erroneous; (2) under influence of bacteria, decay rate of ^{137}Cs somehow changed during experiments; or (3) bacteria transmuted ^{137}Cs into different Cs isotopes and other elements: Widom-Larsen theory provides a mechanism

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Note: purplish-colored hyperlinks in PowerPoint are 'live'. Double-clicking on link uploads referenced source document into another window of Internet browser

LENRs occur at very moderate temperatures and pressures

Can transmute dangerous radioactive isotopes into other stable elements

Fission and fusion → 'Greening' of nuclear technology → Safe green LENRs

Laura 13

No deadly MeV-energy gamma radiation

No dangerous energetic neutron radiation

Insignificant production of radioactive waste

Vastly higher energies vs. chemical processes

Revolutionary, no CO_2 , and environmentally green

Is fully explained by physics of Widom-Larsen theory

Image credit: co-author Domenico Pacifici
"Nanoscale plasmonic interferometers for multispectral, high-throughput biochemical sensing"
J. Feng et al., *Nano Letters* pp. 602 - 609 (2012)

Three nuclear technologies: fission, fusion, and LENRs (new)

Fission and fission both produce deadly radiation and radioactive wastes

LENRs are greener than fission and fusion because no deadly radiation or wastes

TRL = technology readiness level   MeV = Megaelectron Volt = 1 million (10^6) eV

Nuclear process	Energetic MeV gamma γ radiation?	Energetic MeV neutron radiation?	Long-lived radioactive waste products?	Basic description of nuclear process	Energy release in MeVs Chemical only produces eVs
Fission: TRL 9^+ Uranium^{235}	Yes	Yes	Yes	Heavy Uranium-235 nuclei capture neutrons; shatter into many lighter elements	~ 200 MeV many different end-products
Fusion: TRL $4^{+\ 2019}$ ITER D+T reactor in France^{2025}	Yes All fusion	Yes For D+T	No Induced	Gigantic temperatures enable two light ionized nuclei to smash together and then fuse into heavier chemical elements	Depending on specific fusion reaction, value ranges from ~ 3 to ~ 24 MeV
LENRs: TRL 4 In 2019, Japanese project had best-ever excess heat	No Heavy electrons convert γ rays to IR	No ~ All ULE neutrons captured locally	No Neutron-rich LENR products decay fast	Input energy creates ultra low energy neutrons (via $e + p$ reaction) that capture on target atoms. Gammas from neutron captures are converted into infrared; very neutron-rich products decay into stable elements	Depending on targets and subsequent reactions as well as decays, values range from ~ 0.1 MeV up to ~ 22 MeV

IR = infrared (heat)

Electroweak ULE neutron production in Widom-Larsen theory

Protons or deuterons can react directly with electrons to make neutrons

Input energy required to trigger many-body $e_n + p_n$ reactions in LENR active sites

Input energy boosts electric fields $>10^{11}$ V/m

Collective many-body quantum effects: many SP electrons each transfer little bits of energy to a much smaller number of *sp* electrons also bathed in same nuclear-strength local electric field $\geq 1.4 \times 10^{11}$ V/m

Heavy-mass e^{-*} electrons react directly with protons

Quantum electrodynamics (QED): smaller number of electrons that absorb energy directly from local electric field will increase their effective masses ($m = E/c^2$) above key thresholds β_0 where they can react directly with a proton (or deuteron) ⟶ neutron and neutrino

Input energy

$$\mathrm{Energy}_{\text{E-field}} + e^-_{n\ SP} \rightarrow e^{-*}_{n\ SP} + p^+_n \rightarrow n^0_{ule} + \nu_e$$

ν_e neutrinos: ghostly unreactive particles that fly-off into space; n^0 neutrons capture on nearby atoms

Induces safe hard-radiation-free nuclear transmutation processes

Neutrons + atomic nuclei ⟶ heavier elements + decay products

Neutron capture: $$n + (Z, A) \rightarrow (Z, A+1)$$

Beta decay: $$(Z, A+1) \rightarrow (Z+1, A+1) + e^-_\beta + \bar{\nu}_e$$

Neutron capture-driven transmutation of isotopes and elements

External input energy required to produce neutrons via *e* + *p*

Electron or ion currents; E-M photon fluxes; or organized magnetic fields

Input energy required to produce neutrons: to create non-equilibrium conditions that enable nuclear-strength local E-fields which produce populations of heavy-mass e^{-*} electrons that react with many-body surface patches of p^+, d^+, or t^+ to produce neutrons via $e^{-*} + p^+ \rightarrow 1\ n$ or $e^{-*} + d^+ \rightarrow 2\ n$, $e^{-*} + t^+ \rightarrow 3\ n$ (energy cost = 0.78 MeV/neutron for H; 0.39 for D; 0.26 for T); includes (can combine sources):

- Electrical currents - i.e., an electron 'beam' of one sort or another can serve as a source of input energy for producing neutrons via *e* + *p* electroweak reaction
- Ion currents - passing across a surface or an interface where SP electrons reside (i.e., an ion beam that can be comprised of protons, deuterons, tritons, and/or other types of charged ions); one method used for inputting energy is a d^+ ion flux caused by imposing a modest 1 atm pressure gradient (Iwamura et al. 2002)
- Incoherent and coherent electromagnetic (E-M) photon fluxes - incoherent E-M radiation inside resonant electromagnetic cavities or from external light sources; with proper momentum coupling, SP electrons can also be directly energized with coherent laser beams comprised of E-M photons at resonant wavelengths
- Organized magnetic fields with cylindrical geometries - many-body collective magnetic LENR regime with direct acceleration of particles operates at very high electron/proton currents; includes organized and so-called dusty plasmas; scales-up to stellar flux tubes on stars with dimensions measured in kilometers

W-L theory explains absence of energetic gamma radiation

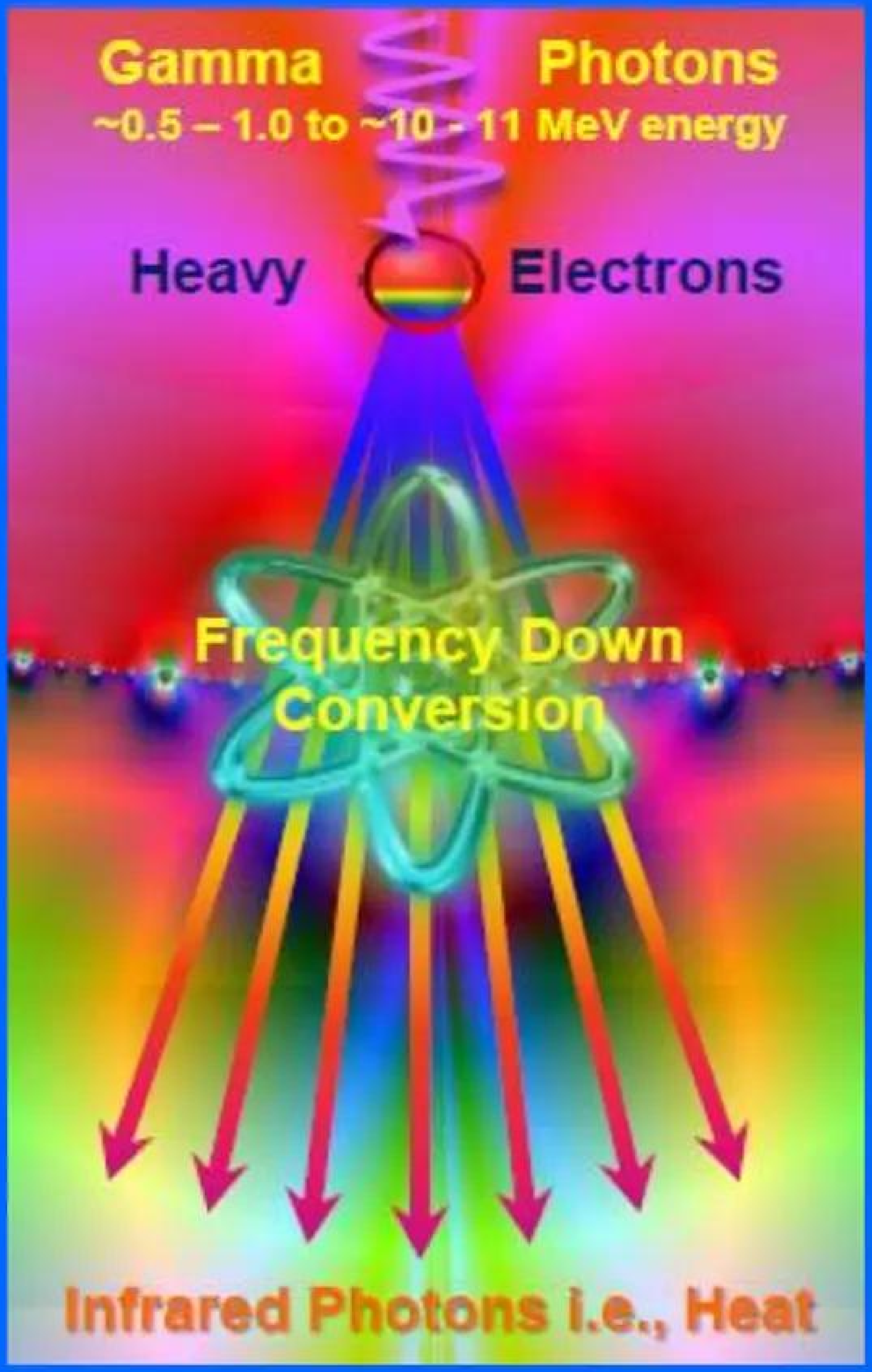
Heavy-mass electrons in LENR active sites convert gammas into infrared

"Apparatus and method for absorption of incident gamma radiation and its conversion to outgoing radiation at less penetrating, lower energies and frequencies"

https://www.slideshare.net/lewisglarsen/us-patent-7893414-b2

U.S. Patent #7,893,414 B2
Inventors: Lewis Larsen, Allan Widom
Issued: February 22, 2011
Assignee: Lattice Energy LLC

Unreacted heavy electrons naturally present in nm- to μ-scale LENR active sites (in which ultralow energy neutrons are produced) will automatically and directly convert deadly MeV-energy gamma photon radiation produced locally by ULE neutron captures or nuclear decays into benign infrared (IR) photons (heat) that can be harvested to provide motive power or electricity. Absence of deadly energetic gamma and neutron radiation emissions from active sites enables LENRs to be safe and green, unlike nuclear fission and fusion processes



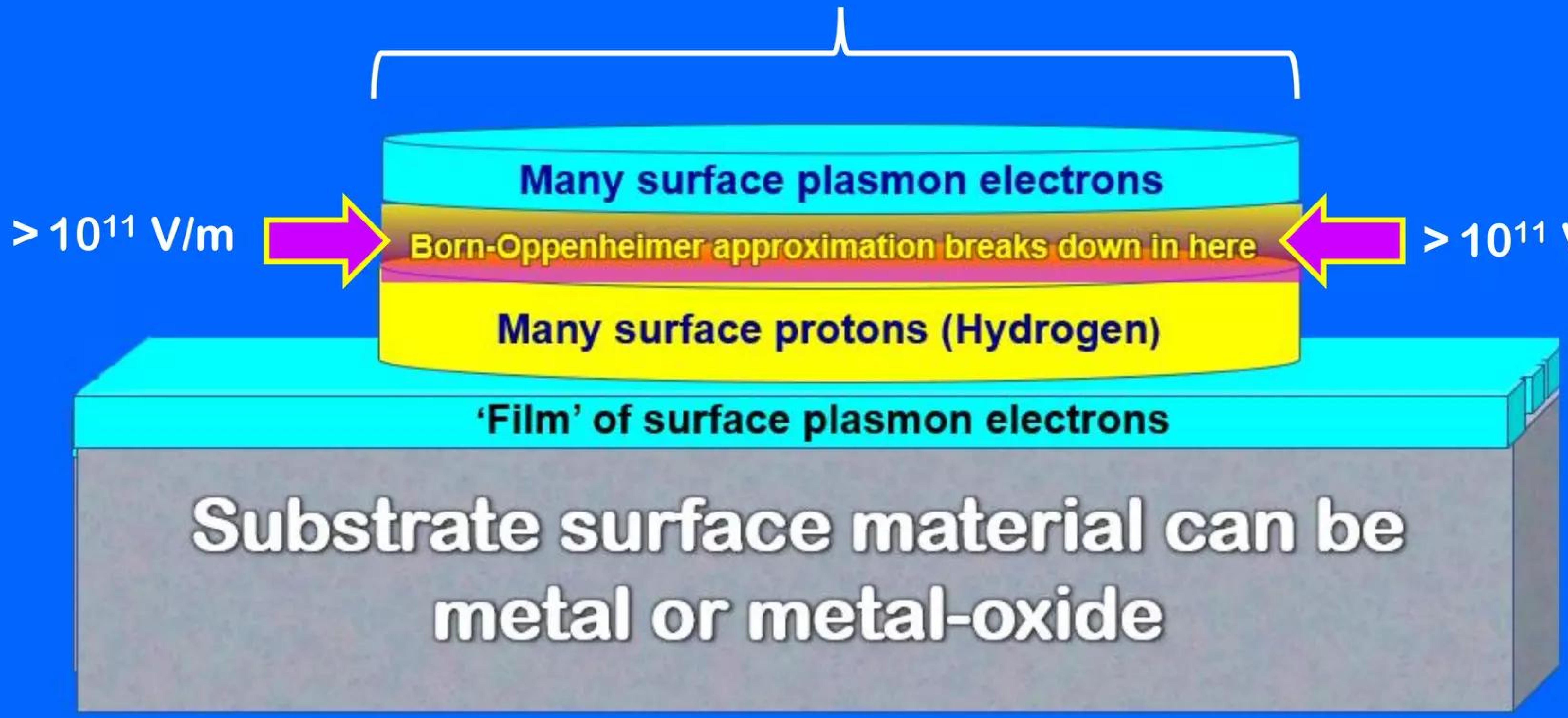
Widom-Larsen theory specifies details of LENR active sites

Much is known about their characteristics in non-living abiotic systems

High electric fields > 1.4 x 10^{11} V/m occur where Born-Oppenheimer breaks down

IDEALIZED AND NOT TO SCALE

Single nascent LENR active site; sizes range from ~ 2 nm up to 100 - 200 microns



Many-body SP electron + proton subsystems shown above form one Widom-Larsen active site on a planar surface; active sites can also form on surfaces of nanoparticles or at various types of interfaces

Key steps in Widom-Larsen theory of LENR active sites

5-step process occurs in active sites over est. ~ 300 - 400 nanoseconds

W-L theory can explain why energetic neutron & gamma radiation are not emitted

1. Collectively oscillating, quantum mechanically entangled, many-body 'patches' of Hydrogen (+-charged protons or deuterons) will form spontaneously on fully loaded hydride surfaces & at certain interfaces: e.g. metal/oxide, gas/oxide, etc.

2. Born-Oppenheimer approximation spontaneously breaks down, allows E-M coupling between local surface plasmon electrons and protons within patches; application of input energy creates nuclear-strength local electric fields $\geq 1.4 \times 10^{11}$ V/m - increases effective masses of surface plasmon electrons in patches

3. Heavy-mass surface plasmon electrons formed in many-body patches can then react directly with electromagnetically interacting protons; process creates neutrons and neutrinos via a many-body collective electroweak $e_n + p_n$ reaction

4. Neutrons collectively created in patches have ultralow kinetic energies and are all absorbed locally by nearby atoms – fluxes of energetic neutrons will not be emitted externally. Any locally produced or incident gammas will get converted directly into safe infrared photons (IR heat) by unreacted heavy electrons (Lattice patent US# 7,893,414 B2) - no deadly energetic gamma radiation will be emitted

5. Transmutation of elements and reworking of surfaces by active sites then begins

Before W-L $e + p$ thought to occur only in stellar explosions

Simple two-body reaction requires 10 billion degrees Kelvin inside stars

W-L theory: many-body collective quantum effects allow $e_n + p_n$ to occur on Earth

LENRs resemble enzymes in that temperature for $e_n + p_n$ reaction is radically decreased

Crab nebula: expanding gas cloud of huge supernova explosion of a star that was observed by many Chinese astronomers in 1054 A.D.

"Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces"
A. Widom and L. Larsen *EPJC* (2006)

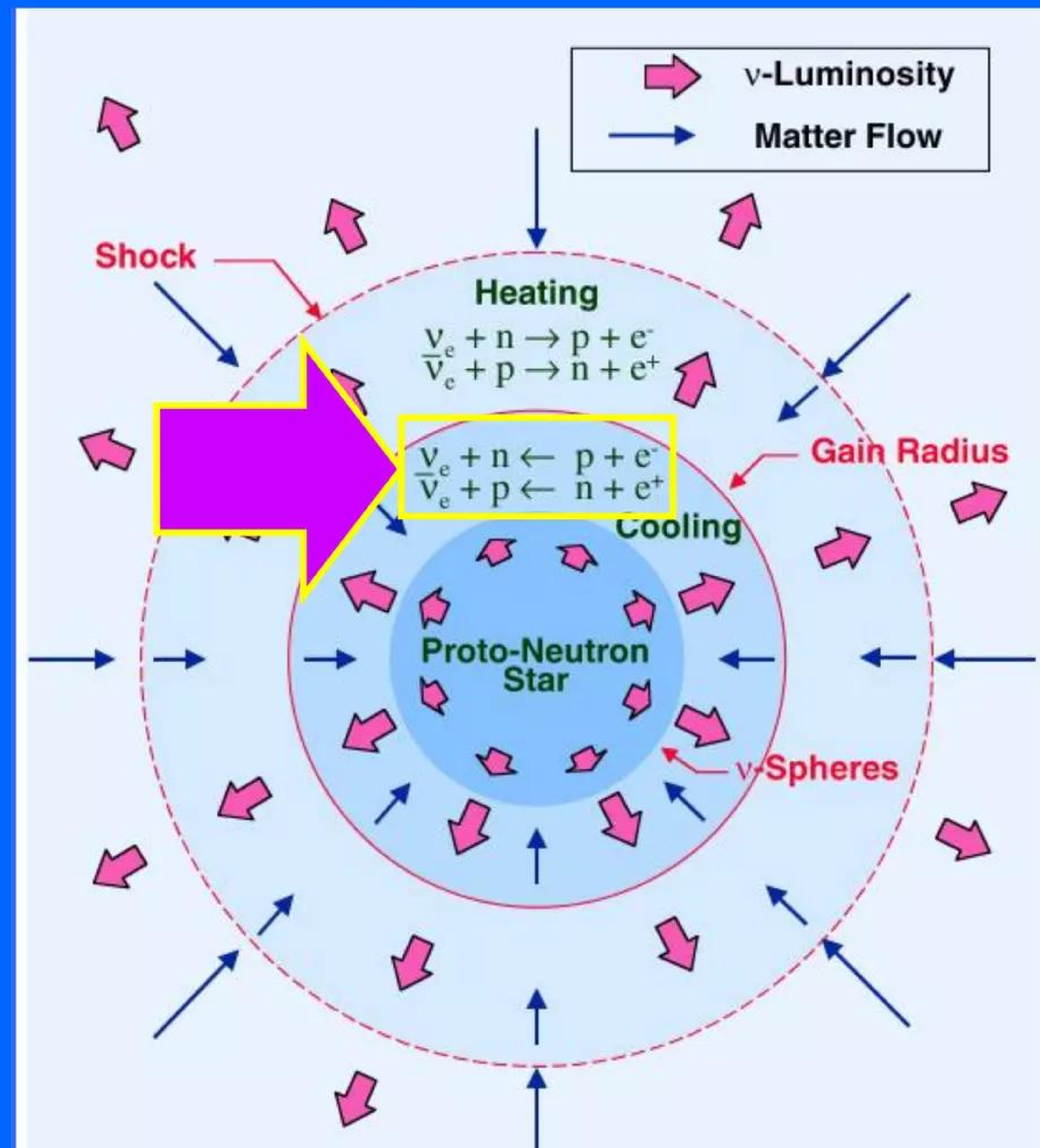


Image credit: TeraScale Supernova Initiative

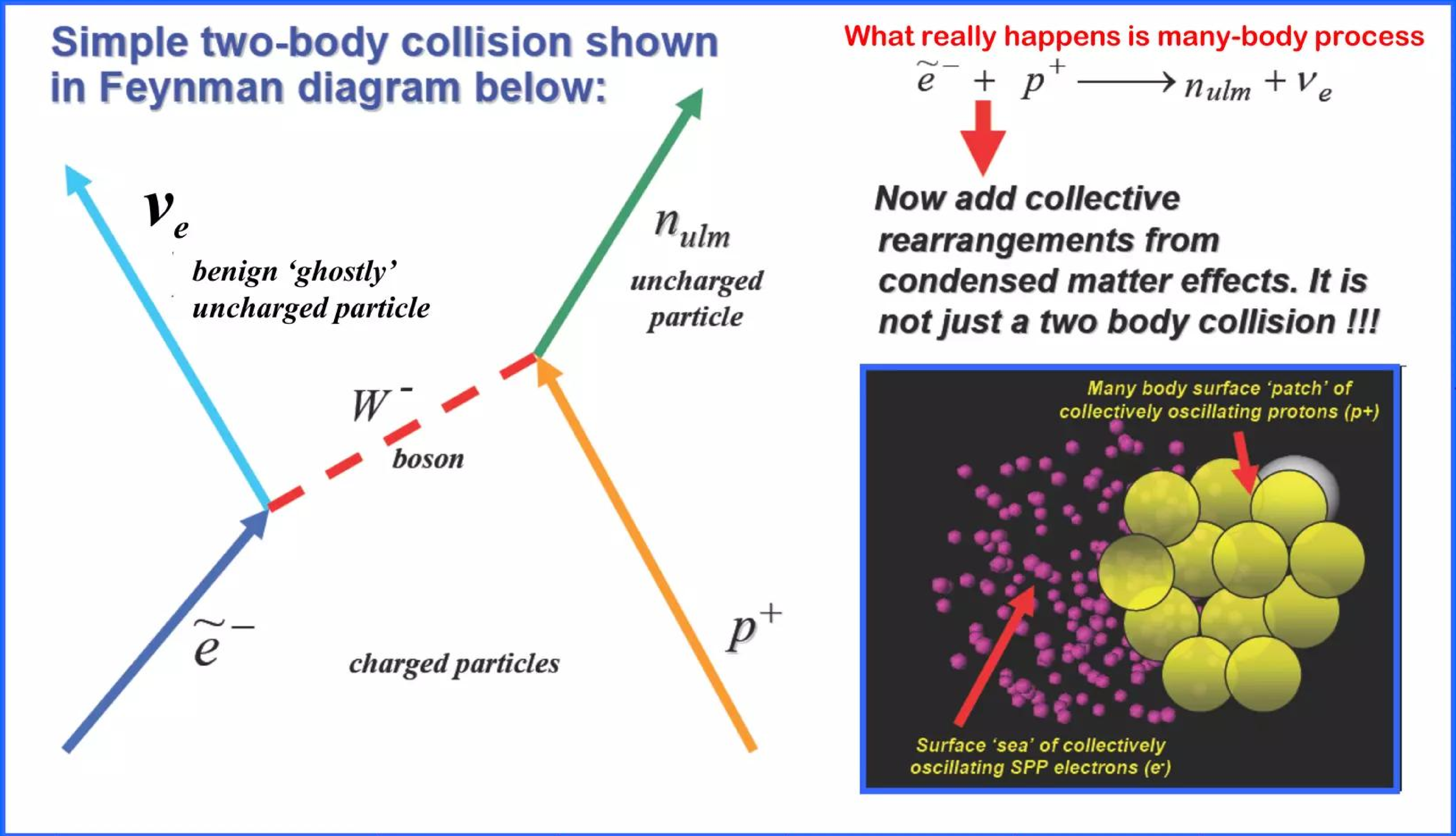
Many-body collective quantum effects are crucial to LENRs

Diagram shows two-body $e^- + p^+$ reaction - what happens is many-body

Many-body collective effects involve quantum entanglement of particles

What occurs is many-body reaction between Q-M entangled electrons and protons

LENR reaction is more accurately written as: $e_n + p_n \rightarrow n_{ule} + \nu_e$



Many-body collective quantum effects are crucial for LENRs

Enable LENR transmutation reactions at moderate temps & pressures

Many-body collective

quantum $e^{*-}_{n} + p^{+}_{n} \rightarrow 1\ n_{ule} + \nu_e$ effects

$$n_{ule} + (Z, A) \rightarrow (Z, A+1)$$

$$(Z, A+1) \rightarrow (Z+1, A+1) + e_{\beta}^{-} + \bar{\nu}_e$$

LENRs do not involve any 2-body fission or hot fusion reactions --- key step that produces ULE neutrons is many-body collective $e_n + p_n$ reaction between quantum mechanically entangled electrons and protons on solid-state surfaces or at interfaces

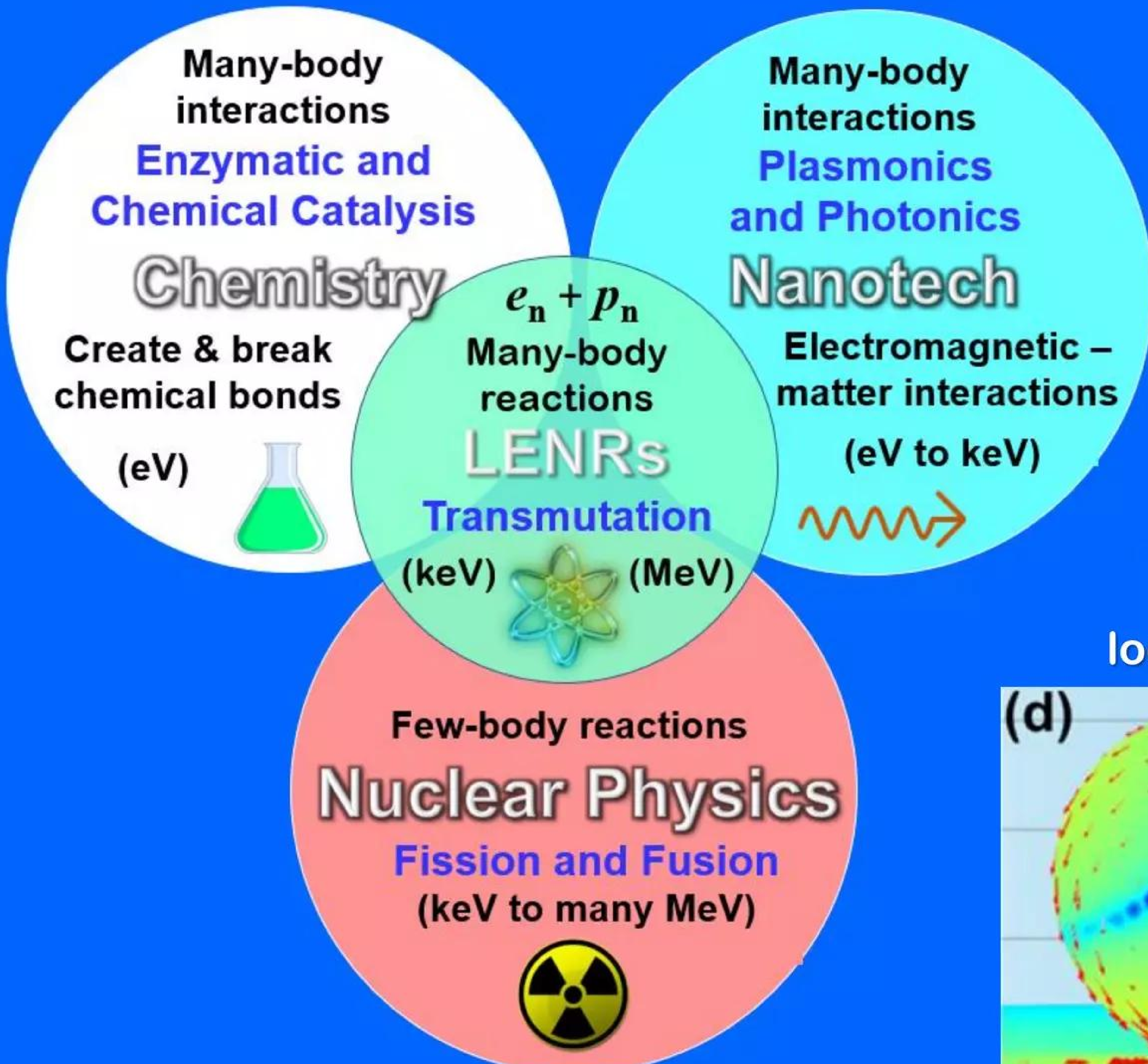
"Quantum entanglement in physics - What it means when two particles are entangled"
Andrew Z. Jones for *ThoughtCo* July 10, 2017
https://www.thoughtco.com/what-is-quantum-entanglement-2699355

Credit: MARK GARLICK/SCIENCE PHOTO LIBRARY/Getty Images

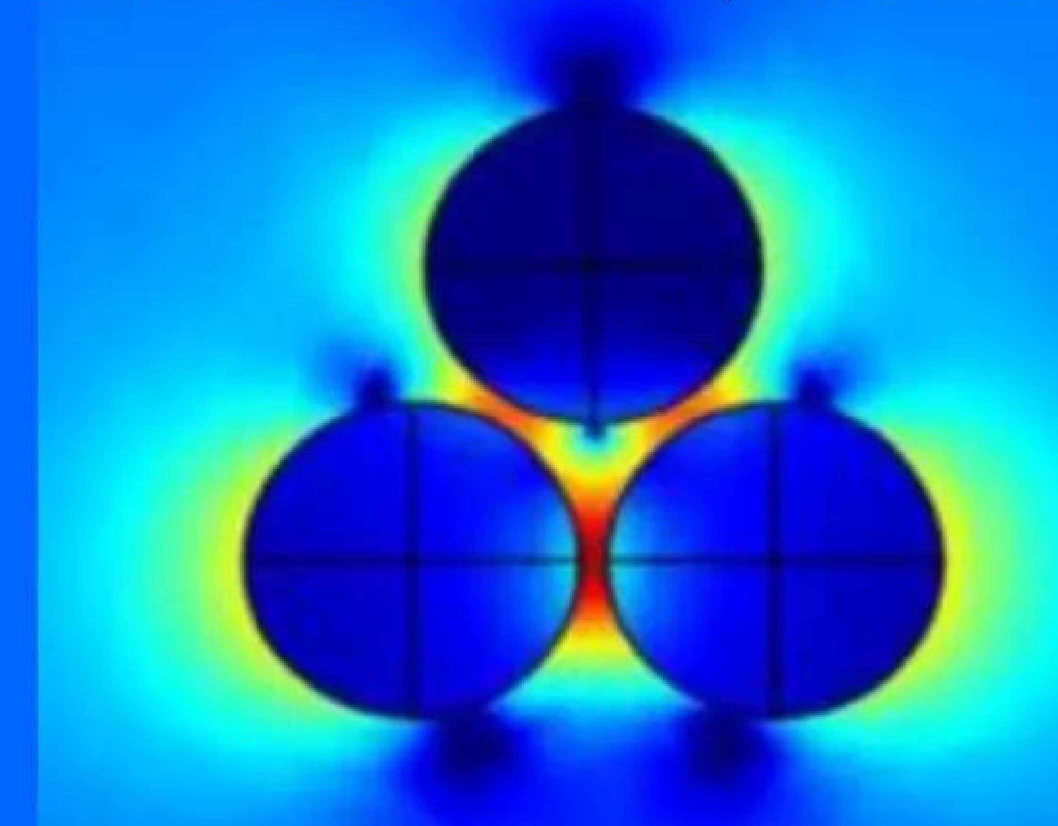
Radiation-free LENRs are not as exotic as one might assume

Widom-Larsen theory: LENR physics, nanotech & chemistry interrelated

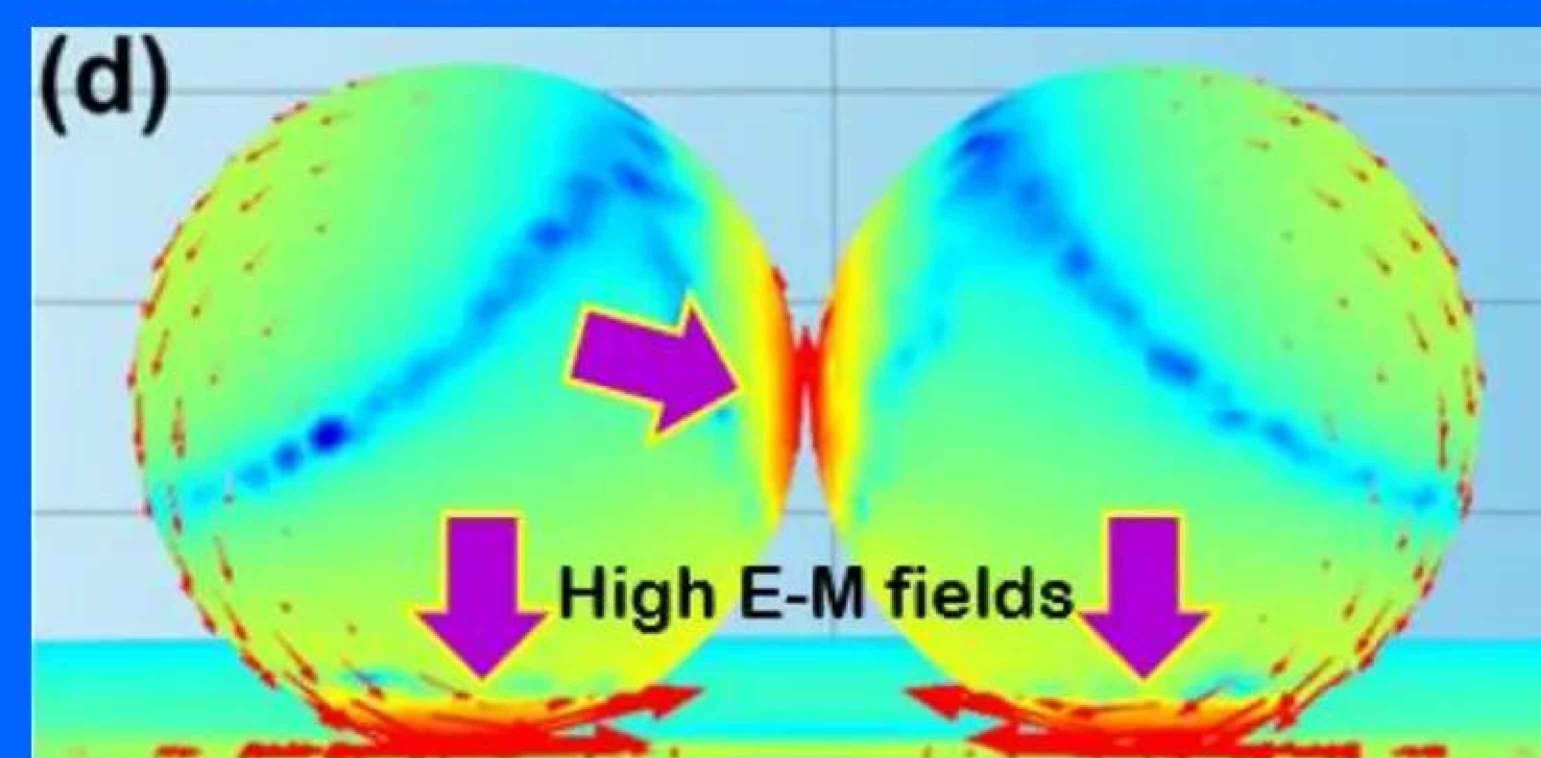
Leverage W-L theory & nanotech know-how to accelerate LENR development



Electric field strengths on surfaces of nanoparticles



$e_n + p_n$ reaction requires local E-fields $\geq 1.4 \times 10^{11}$ V/m



Important papers by Fried & Boxer about enzymatic catalysis

Experiments measured electric > fields 10^{10} V/m in enzyme active sites

Electric field strength is key contributor to catalytic abilities of many enzymes

"Electric fields and enzyme catalysis"

S. Fried and S. Boxer in *Annual Review of Biochemistry* 86 pp. 387 - 415 (2017)

https://docs.wixstatic.com/ugd/4006c9_4bd285496dab421080e63a577b3a1928.pdf

https://docs.wixstatic.com/ugd/4006c9_57d9b28edb084f6a887b247a8dd2399f.pdf

Abstract: "What happens inside an enzyme's active site to allow slow and difficult chemical reactions to occur so rapidly? This question has occupied biochemists' attention for a long time. Computer models of increasing sophistication have predicted an important role for electrostatic interactions in enzymatic reactions, yet this hypothesis has proved vexingly difficult to test experimentally. Recent experiments utilizing … vibrational Stark effect make it possible to measure … electric field a substrate molecule experiences when bound inside its enzyme's active site. These experiments have provided compelling evidence supporting a major electrostatic contribution to enzymatic catalysis … we review these results and develop a simple model for electrostatic catalysis that enables us to incorporate disparate concepts introduced by many investigators to describe how enzymes work into a more unified framework stressing the importance of electric fields at the active site."

Fried & Boxer “Electric fields and enzyme catalysis” (2017)

Quote from paper: “Electrostatic catalysis is pervasive in enzymology”

“Support … notion that electrostatic catalysis is a key strategy enzymes use. Appreciating the centrality of electrostatic catalysis has enabled us to incorporate disparate concepts, such as geometric discrimination and distal binding interactions, into a unified framework …”

Summary points:

1. “Noncovalent interactions between a given molecule and its environment (including H-bonds) can be expressed and quantified in terms of the electric field the environment exerts on the molecule.”
2. “Electric field created by an environment can be experimentally measured through … vibrational Stark effect, which maps … frequencies of vibrational probes to the electric field experienced by that vibration.”
3. “A chemical reaction can be catalyzed by an electric field if … reactant’s charge configuration (dipole moment) changes upon passing to a transition state. If the dipole moment increases (decreases) in magnitude, an electric field of greater (smaller) magnitude will accelerate the reaction; if the dipole reorients, an electric field aligned with the transition state’s dipole orientation will accelerate the reaction.
4. “Electrostatic catalysis is pervasive in enzymology because most chemical reactions in biology involve charge rearrangements.”

Electric field strength determines chemical vs. LENR process

N_2 bond is broken at ~1.0 x 10^{11} V/m; threshold for LENRs ≥ 1.4 x 10^{11} V/m

Nitrogen (N≡N) molecule's triple bond is 2nd strongest chemical bond in Nature with dissociation energy of 9.79 eV

Carbon monoxide (C≡O) dissociation energy highest = 11.16 eV

Approximate electric field strength needed to break N_2 triple bond is ~ 8.9 V/Å or ~ 8.9 x 10^{10} V/m

Approximate electric field strength needed to break CO triple bond is ~ 9.9 V/Å or ~ 9.9 x 10^{10} V/m

E-field that breaks C≡O bond is almost 1.0 x 10^{11} V/m; is close to 1.4 x 10^{11} V/m minimum field-strength threshold needed to catalyze neutron-producing $e + p$ electroweak reaction in LENR active sites. Rapid movement of charged groups in such sites can locally increase E-field strength above LENR threshold for several hundred attoseconds, which is adequate time to make ULE neutrons. ULE neutron captures only require 10s of picoseconds.

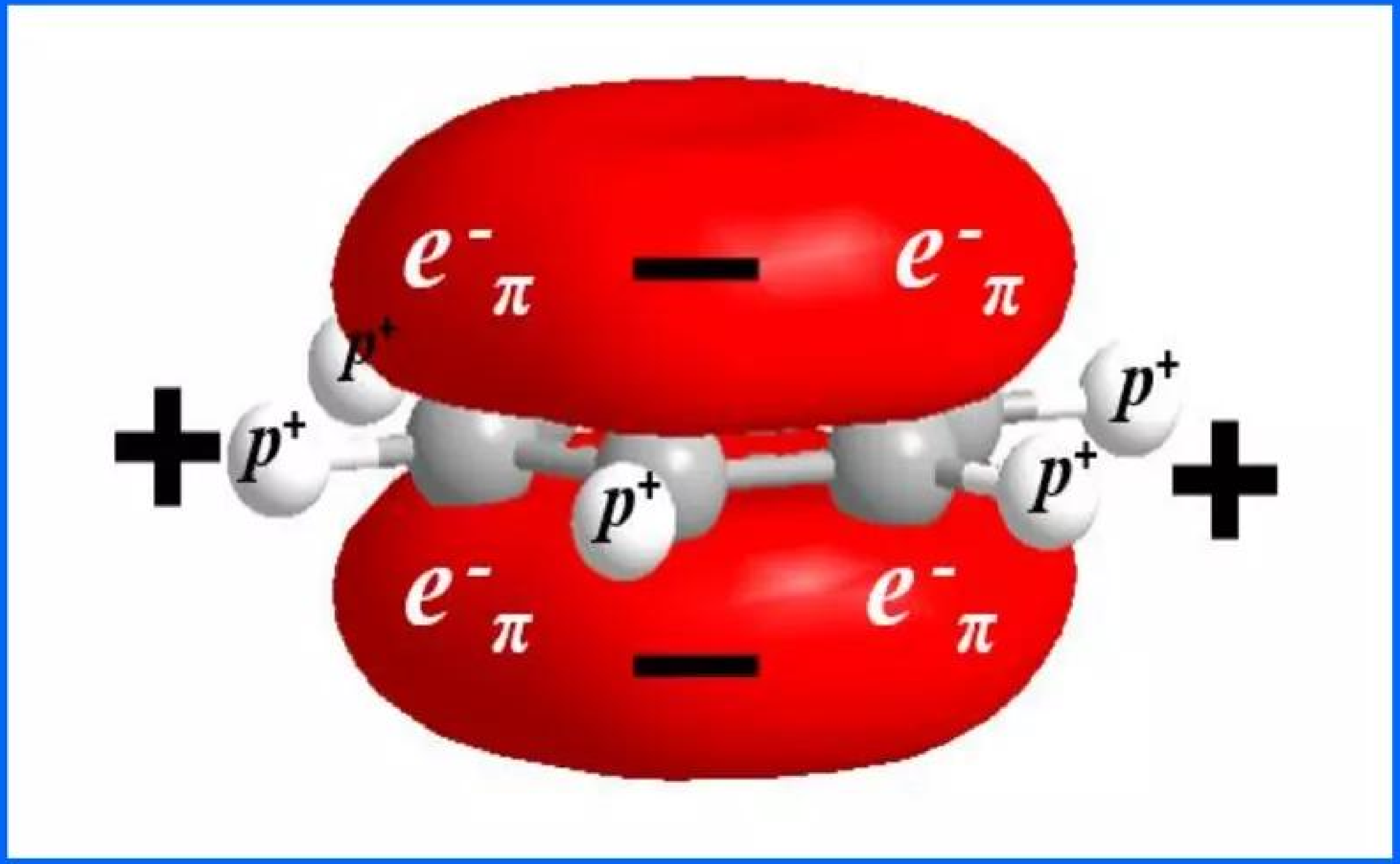
Ammonia molecule in background (NH_3)

Lattice extended Widom-Larsen theory to aromatic rings

Carbon aromatic rings can function as 2 nm molecular LENR active sites

Lattice's conjecture (2009) that π electrons on aromatic rings can behave like the functional equivalents of surface plasmons on metals was finally confirmed by A. Manjavacas et al. (2013)

Red indicates many-body π electron clouds on both sides of Carbon aromatic ring



Only tiny fraction of total number of π electrons are shown in this graphic

- Delocalized clouds of π electrons situated above and below 6-Carbon aromatic ring structures are in very close physical proximity to protons (hydrogen atoms), all oscillate collectively, and are mutually Q-M entangled (Manjavacas et al. 2013)
- Protons that are also attached to an aromatic ring's Carbon atoms oscillate collectively and are Q-M entangled with each other (was first observed and reported by Chatzidimitriou-Dreismann, 2005)

Lattice extended Widom-Larsen theory to aromatic rings

Carbon aromatic rings can function as 2 nm molecular LENR active sites

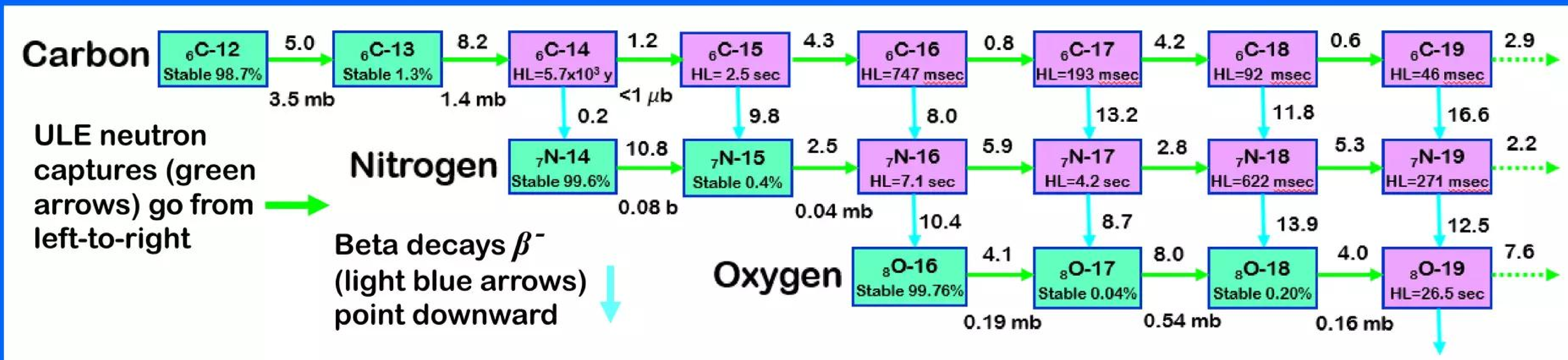
- Local breakdown of Born-Oppenheimer approximation occurs on aromatic ring structures; this enables electromagnetic (EM) coupling and energy transfers between collectively oscillating π electrons and nearby protons (H) on aromatic ring; during E-M energy input, very high fluctuating local electric fields are created in vicinity of the ring
- When aromatic structures are adsorbed onto the surface of metallic substrate, ring will spontaneously orient itself as it approaches so that ~flat ring plane of the aromatic molecule ends-up ~parallel to the substrate surface. Born-Oppenheimer approximation also breaks down at such locations, enabling further E-M coupling and energy transfers between Carbon-ring π electrons and 'thin-film' of surface plasmon electrons on substrate surfaces (S. Jenkins, *Proc. Royal Soc*. 465, 2009). Surface plasmons absorb and transport E-M energy
- Dynamics very much analogous to manner in which LENR active sites function on loaded metallic hydride surfaces. Molecular aromatic ring structure becomes functional analogue of a many-body LENR active site in which ULE neutrons are produced collectively via electroweak $e + p$ reaction; neutrons will tend to capture on nearby ring Carbons; same thing for multi-ring polycyclic aromatic hydrocarbons (PAHs)

Lattice extended Widom-Larsen theory to aromatic rings

Aromatic molecular chemistry changes when ring Carbon is transmuted

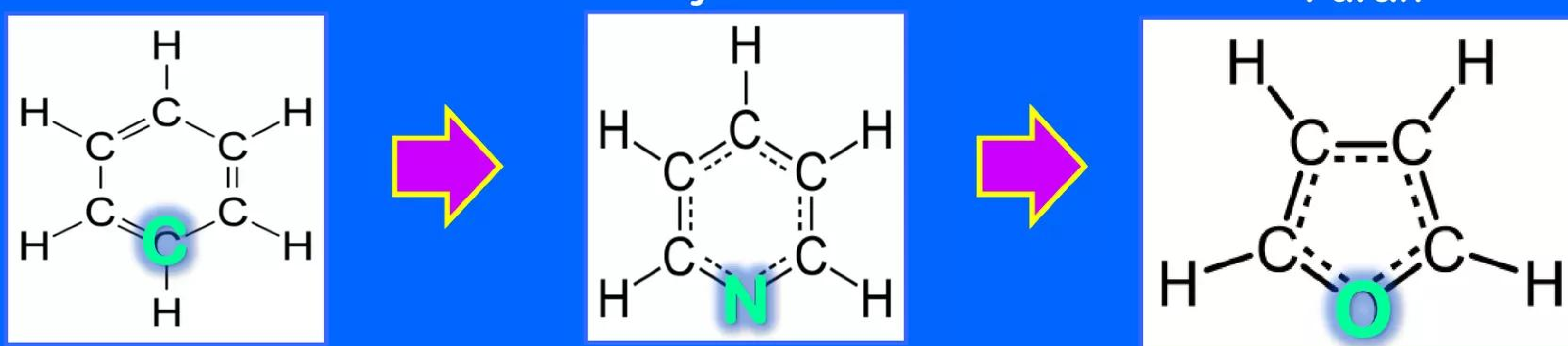
Nuclear transmutation and chemical reactions can occur in close proximity and perhaps not surprisingly, may sometimes interoperate in LENR systems

ULE neutron-catalyzed LENR transmutation network beginning with stable Carbon-12



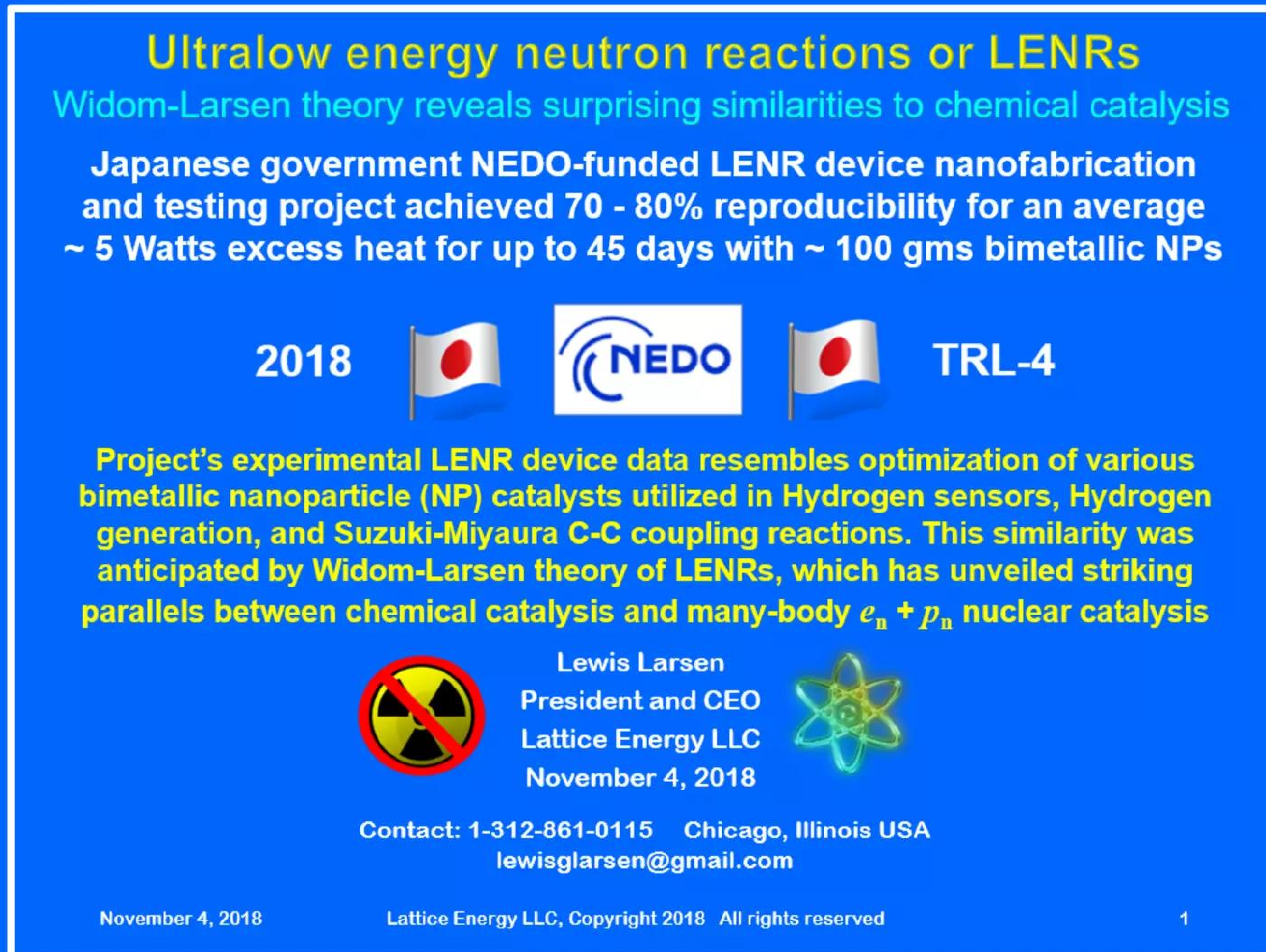
LENR transmutation of aromatic Carbon breaks rings and helps enable different chemistry

Benzene — Pyridine — Furan



See online public Lattice PowerPoint dated November 4, 2018

Reveals surprising similarities between LENRs and chemical catalysis



https://www.slideshare.net/lewisglarsen/lattice-energy-llc-widomlarsen-theory-reveals-surprising-similarities-and-connections-between-lenrs-and-chemical-catalysis-nov-4-2018

Chinese chemists claimed LENR triggering with visible light

Produced Deuterium & Helium and transmuted Potassium into Calcium

Ultralow energy neutron reactions (LENRs)

Disruptive new source of safe, radiation-free nuclear energy

Experiments reported in 2017 by Prof. Gong-xuan Lu et al. at Lanzhou Institute of Chemical Physics, in Lanzhou, China showed photocatalytic triggering of LENRs at NTP with visible light

Lanzhou Institute of Chemical Physics,
Chinese Academy of Sciences

Very significant discovery if experimental claims can be independently confirmed by other researchers using same methods

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June 30, 2018 1

https://www.slideshare.net/lewisglarsen/lattice-energy-llc-chinese-chemists-report-photochemical-triggering-of-lenrs-at-ntp-in-aqueous-cells-by-irradiation-with-visible-light-june-30-2018

LENRs are a conceptual paradigm shift in nuclear science

Radiation-free transmutation of chemical elements under mild conditions

NTP (per NIST) = normal temperature and pressure: about 20 ºC and 1 atmosphere

At center of 30-year battle swirling around ultralow energy neutron reactions (LENRs) is a revolutionary, still ongoing paradigm shift in nuclear thinking *a la* Thomas Kuhn. Advent of LENRs has caused ongoing controversy and consternation within the global nuclear community because long-venerated sacred cows are being gored. With many-body 'green' LENRs, hard-radiation-free nucleosynthesis and transmutation of elements without long-lived radioactive wastes can occur in condensed matter systems under comparatively mild, NTP-like macroscopic temperatures and pressures. Existence of LENRs is thus heretical and anathema to many nuclear physicists still mired in tight grip of presently dominant, 70-year-old conceptual paradigm. This older, widely accepted, now-erroneous paradigm posits nucleosynthetic processes can *only* occur in super-hot stellar plasmas, manmade or natural fission reactors, man-made 150 million ºC fusion reactors like the ITER D+T Tokamak, explosions of nuclear weapons, and/or particle accelerators --- all of which emit readily detected, deadly energetic gamma and/or neutron radiation.

LENRs: radiation-free ultralow energy neutron reactions

Bacteria may be using LENRs to alter isotopes and transmute elements

"Nothing is too wonderful to be true,

if it be consistent with the laws of Nature;

and in such things as these experiments

is the best test of such consistency."

Michael Faraday

Discovered electromagnetic induction

on August 29, 1831 (laboratory journal entry)

Above-quoted laboratory journal entry #10,040
was dated March 19, 1849

Data shows mixed bacteria can reduce ^{137}Cs gamma radiation

Korean scientists reported laboratory experiments with amazing results

"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

Data first presented at international conference: "Application of Microorganisms for Radioactive Waste Treatment" held in Busan, South Korea, May 2018

Kyu-Jin Yum (Coenbio R&D Center, Seongnam, South Korea), Jong-Man Lee (Korea Research Institute of Standards and Science, Daejeon, South Korea), GunWoong Bahngz (Dept. of Mechanical Engineering, State University of New York, Incheon, South Korea), and Shanghi Rheex (Green Life Intellectual Network, Seoul, South Korea)

***Journal of Condensed Matter Nuclear Science* 28 pp. 1 - 6 (2019)**

https://www.lenr-canr.org/acrobat/BiberianJPjcondensedza.pdf

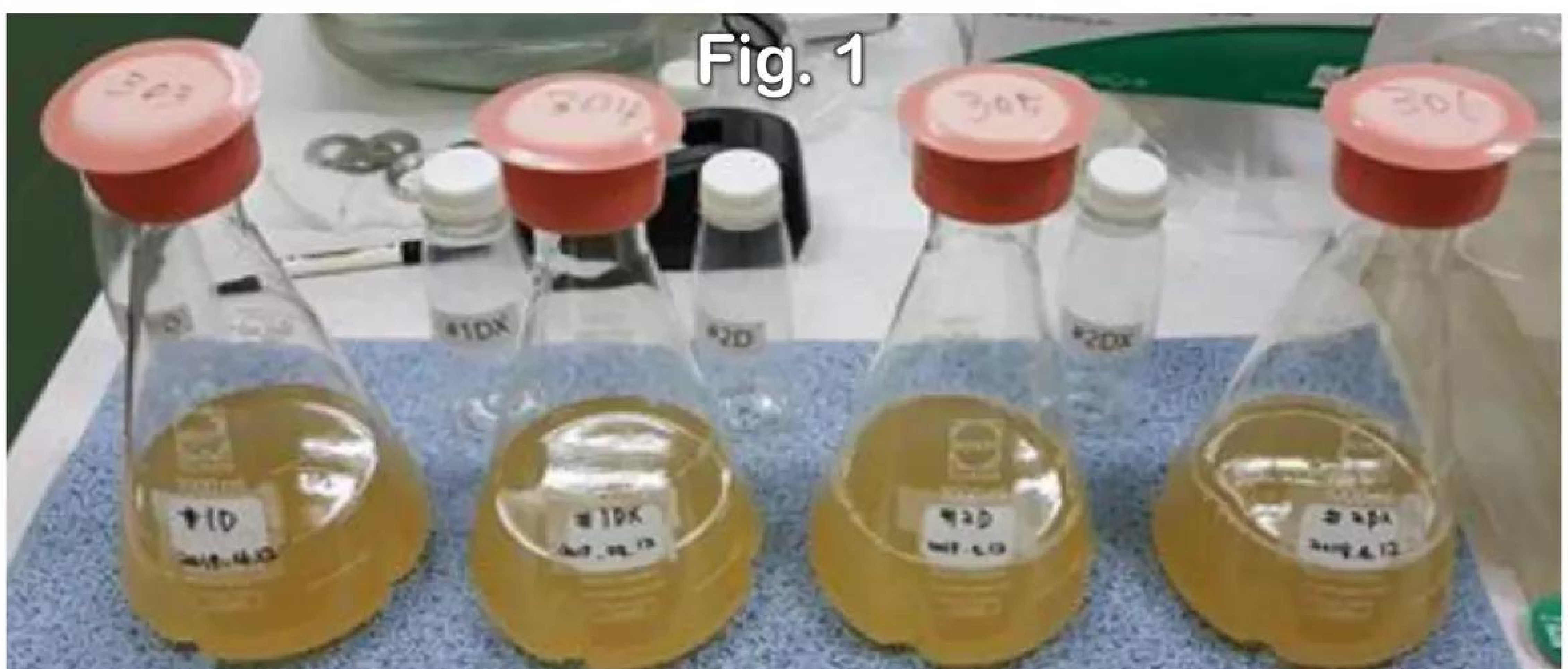


Fig. 1

Data shows mixed bacteria can reduce ^{137}Cs gamma radiation

Korean scientists reported laboratory experiments with amazing results

"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

https://www.lenr-canr.org/acrobat/BiberianJPjcondensedza.pdf

Abstract: "In order to observe the effect of multi-component microorganisms on the radiation intensity of a radioactive ^{137}Cs solution, a multi-component microorganism composed with 10 strains was designed and utilized in the experiment. It was composed of the radioactivity resistant *Bacillus spp.*, aerobic bacteria which have a high temperature resistant and good biodegrade ability, anaerobic lactic acid bacteria, highly resistant to toxicity and good polymer degradable yeast, and photosynthetic strains with a better utilization of proton and high production rate of H^+. An amount of 120 ml of this multi-component microorganism was mixed with 380 ml of deionized water. An amount of 0.159 ml of hydrochloric acid solution (0.1 mol/l) containing ^{137}Cs was added to this mixture to adjust the final radioactivity to be 50 kBq. The mixed 500 ml samples were irradiated at 12-hour intervals with light and shaken at about 120 rpm at 25^{o} C in a shaking incubator. The radioactivity of the mixed solution was measured by a counter equipped with a high-purity Ge detector every other or 3 days. It was observed that the radiation intensity increased slightly at the beginning and then decreased to the 80% level compared to the control."

Data shows mixed bacteria can reduce ^{137}Cs gamma radiation

Korean scientists reported laboratory experiments with amazing results

"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

Materials and methods: "[Aqueous] solution (0.1 mol/l) contain[ing] ^{137}Cs was dissolved in hydrochloric acid to make its final radioactivity to be about 100 Bq/g … experimental samples of 500 ml were prepared by mixing 120 ml of the solution of microorganisms and 380 ml of deionized water. To this mixture, 159 μl of hydrochloric acid containing ^{137}Cs was added to make the total radioactivity of the sample 50 kBq. This sample was poured into 1-liter capacity Erlenmeyer flask (Fig. 1) … prepared samples were irradiated at 12-hour intervals with room light and shaken at about 120 rpm at 27° C in a shaking incubator … gamma rays from … mixed solution were measured every other or 3 days with a counter equipped with a high purity p-type detector having relative detection efficiency of 70%. Figure 2 shows arrangement of the flask in a custom designed holder above the detector."

Fig. 2

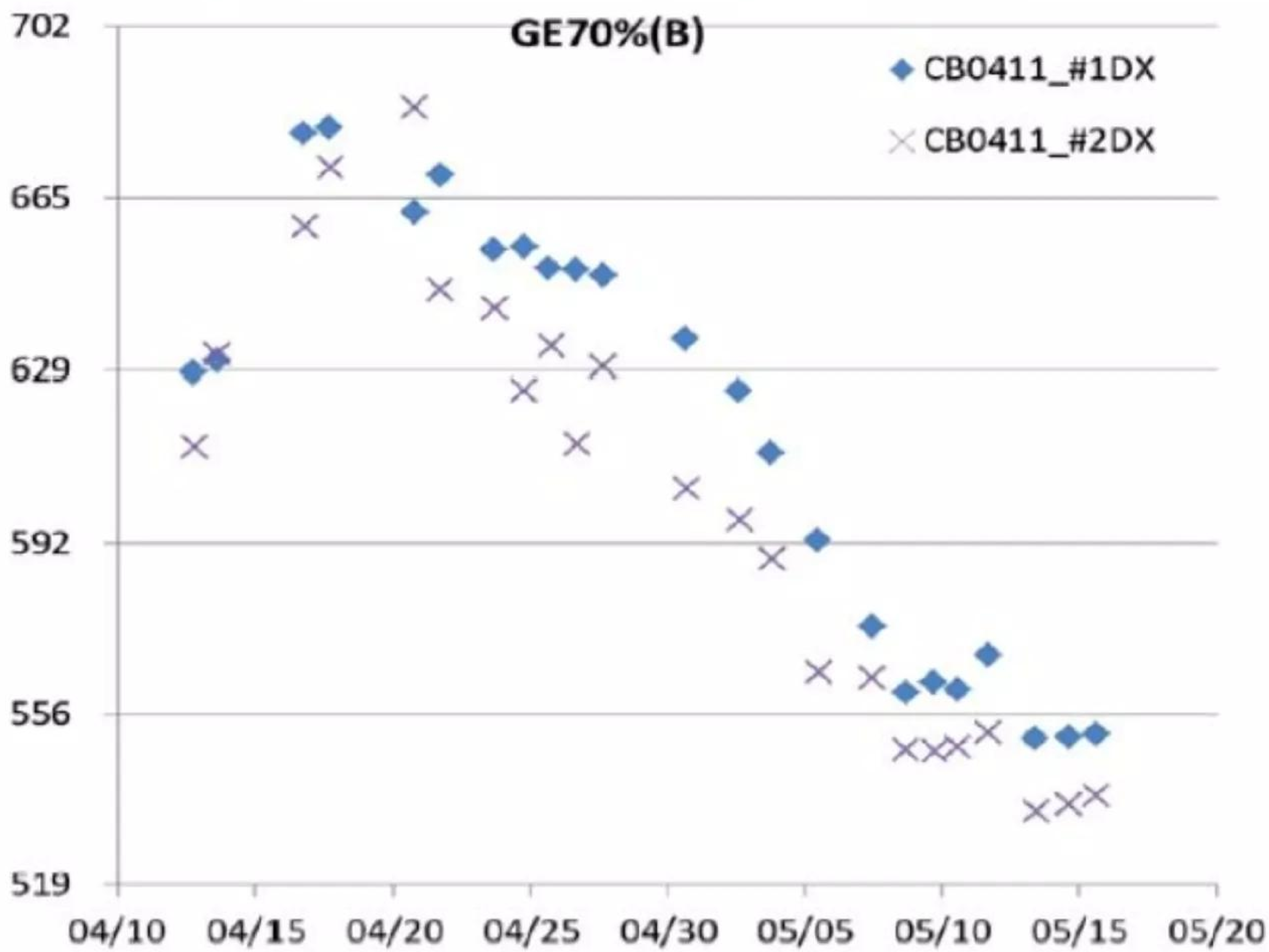
(a) (b)

Data shows mixed bacteria can reduce ^{137}Cs gamma radiation

Observed an anomalous decrease in gamma counts after initial increase

"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

Fig. 3: "Change of γ-ray counting rate (s^{-1}) from ^{137}Cs over time (month/day)"



Data shows mixed bacteria can reduce ^{137}Cs gamma radiation

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"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

https://www.lenr-canr.org/acrobat/BiberianJPjcondensedza.pdf

Results and discussion: "Figure 3 shows the result of count rate measurements. It is clearly demonstrated that the gamma-ray intensity from ^{137}Cs has been decreased to the level of less than 90% compared to the initial level. Interestingly, the count rate increased by 8% at the beginning and then it began decreasing. This is the same tendency which was observed by Vysotskii and Kornilova [6]. The control sample did not show any change in the level of the activity until the experiment was finished. The unique pattern of count rate variation, increase and then decrease, implies that there would be two different mechanisms in biological transmutation. They may be related to the acceleration of ^{137}Cs decay and transmutation, respectively. The analysis on the composition of the sample is undergoing and we focused on the observation of ^{138}Ba, transmutation of ^{137}Cs as explained above. This result shows that multi-component microorganisms can be utilized for the remediation of soil and groundwater contaminated with radioactive materials, and to restore the contaminated ecosystem. Further experiments will be carried out to explore the mechanism of biotransmutation."

Data shows mixed bacteria can reduce ^{137}Cs gamma radiation

"Multicomponent organism can … decrease … radioactivity of ^{137}Cs"

"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

Journal of Condensed Matter Nuclear Science

https://www.lenr-canr.org/acrobat/BiberianJPjcondensedza.pdf

Journal of Condensed Matter Nuclear Science

Conclusion: "It has been shown that a multicomponent organism with a smaller number of species, less than 10 kinds of species, can be effectively utilized for the decrease of radioactivity of ^{137}Cs. This phenomenon is an additional evidence of biological transmutation and it seems that there are two stages of reaction in biological transmutation. Acceleration of decay occurs first and is then followed by an overall decrease in the counting rate."

Acknowledgment: "This research was supported by the National Research foundation of Korea (NRF) funded by the Ministry of Science and Technology 2017M2B2A9071803."

NRF 한국연구재단 National Research Foundation of Korea http://www.nrf.re.kr/eng/main

"Aim of the NRF is to optimize and advance the national basic research funding system that encompasses all academic research fields."

Prof. GunWoong Bahng is corresponding author on paper

Ph.D. and M.S. in Materials Science from Northwestern University in USA

"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

Website: "He is currently carrying a project, 'Verification of a radioactive waste treatment technology utilizing multi-complex microorganisms', funded by the NRF."

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1980-1982 Ph.D. Mat. Sci. and Eng., Northwestern University

1978-1980 MS, Mat. Sci. and Eng., Northwestern University

1972-1976 BSc in Engineering, Dept. of Metallurgical Eng., Seoul National University

http://me.sunykorea.ac.kr/node/106

Dr. Jong-Man Lee was responsible for gamma measurements

Recognized expert in measurements of gamma-emitting radionuclides

"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

KRISS website - Points of Contact document: Jong-Man Lee is "Head of The Center for Ionizing Radiation is in charge of development, maintenance, and dissemination of the national measurement standards for ionizing radiation: dosimetry, radioactivity, and neutron measurements."

Standardization of gamma-emitting radionuclides
Dr. Jong-Man Lee (5377) e-mail: jmlee@kriss.re.kr

https://www.researchgate.net/profile/Jong_Man_Lee

KRISS
한국표준과학연구원
Korea Research Institute of Standards and Science

Mission: "As a government-funded research institute, KRISS has provided the foundation for the advancement of science and technology through the establishment of national measurement standards, R&D of measurement technologies, and dissemination of national measurement standards. KRISS has contributed to stronger development of national S&T, higher national industrial competitiveness and a better quality of life for the people."

Kyu-Jin Yum is CEO of COENBIO Corporation of South Korea

Company uses expertise in mixed bacterial cultures for soil remediation

"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

Image credit: Park Hae-mook of *The Korea Herald*

"Using microbes to clean up pollution"
By *The Korea Herald* August 30, 2012

"The firm … holds over 300 strains of microorganisms and scores of domestic and international patents on them … landed a milestone deal (US$ 7M) last year in China … to supply microbial products to improve agricultural land in three provinces of Northeast China, including Heilongjiang."

e-mail: ceb@coenbio.com

http://www.koreaherald.com/view.php?ud=20120830000734

http://coenbio.koreasme.com/company_business.html

http://sagecoen.com/theme/basic/include/Company/Company2.php

Dr. Shang-hi Rhee, Green Life Intellectual Network (Korea)

“Experiments have shown that … biological transmutation is possible”

“An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains”

Education: Ph.D. Pharmacy, Seoul National University

Current: CEO Coordinator, Green Life Intellectual Network

Current: Patent attorney and Chairman of Organizing Committee, World Intellectual Property Association of Korean Practitioners

Past: Minister - Korean Ministry of Science &Technology

Past: Member of Korean National Assembly

Past: President of Korea Patent Attorneys Association

e-mail: rheeshph@gmail.com

Russian Science Foundation, Korea Research Foundation, and the Korea Green Life Intellectual Network are cooperating on scientific research & development in advanced technologies; see 2016 and 2017 news stories from *Korea Joongang Daily* :

http://koreajoongangdaily.joins.com/news/article/article.aspx?aid=3037146

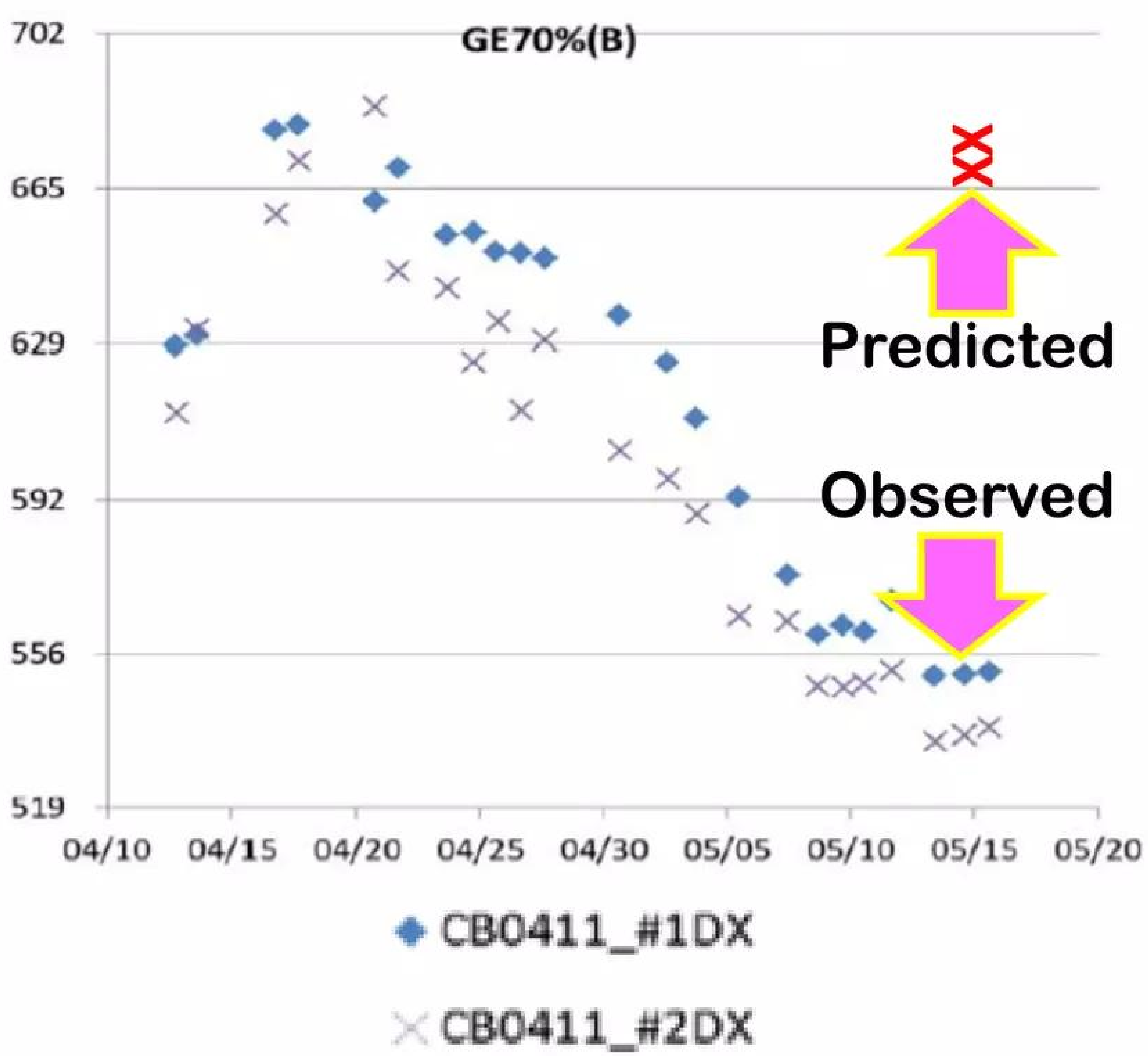
http://koreajoongangdaily.joins.com/news/article/article.aspx?aid=3027365

Lattice commentary about paper by Kyu-Jin Yum et al. (2019)

Plot: gamma counts vs. time for experiments CB0411_#1DX, CB0411_#2DX

"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

Fig. 3: "Change of γ-ray counting rate (s^{-1}) from ^{137}Cs over time (month/day)"



CB0411_#1DX:
Period: 4/16/2017 to 5/15/2017
Beginning counts: ~674 cps = 40,440 cpm
Ending counts: = ~550 cps = 33,000 cpm
Predicted end counts: 672.7 = 40,366 cpm
Variance: predicted decrease of ~0.18% but instead measured a decrease of ~18.4%

CB0411_#2DX:
Period: 4/16/2017 to 5/15/2017
Beginning counts: ~670 cps = 40,200 cpm
Ending counts: ~538 cps = 32,160 cpm
Predicted end counts: ~668.8 = 40,127 cpm
Variance: predicted decrease of ~0.18% but instead measured a decrease of ~20.0%

Comment: very large variance compared to predicted counts based on 30.1 yr half-life

Lattice commentary about paper by Kyu-Jin Yum et al. (2019)

CB0411_#1DX: calculate predicted ^{137}Cs γ counts at end of experiment

"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

Decay Calculator

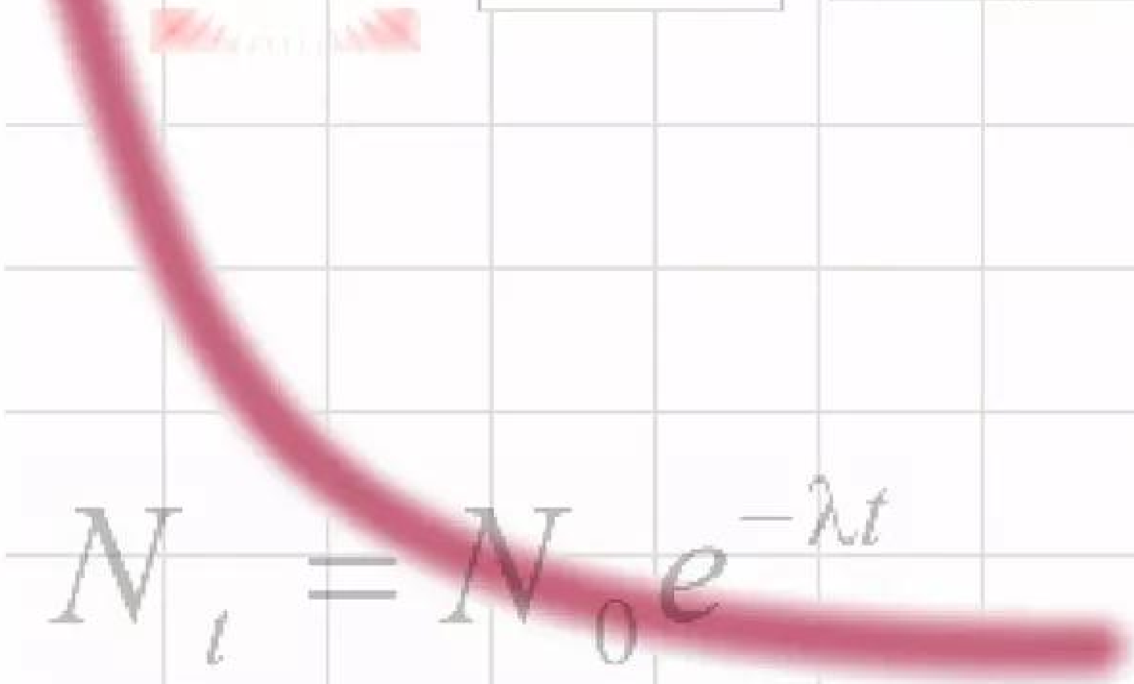
HPS Specialists in Radiation Protection

Results for Cs-137 Decay

The half-life of Cs-137 is 30.1671 years.[1]

Cs-137 decays to roughly 99.82% of the initial activity over the period of 0.0793993684191 year.
another radionuclide.

	Amount:	Units:	Begin Date:	End Date:		
Cs-137	40440	Counts per Minute	04/16/2017	05/15/2017	=	**40,366** CPM



http://hps.org/publicinformation/decay.cfm

Lattice commentary about paper by Kyu-Jin Yum et al. (2019)

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another radionuclide.

	Amount:	Units:	Begin Date:	End Date:		
Cs-137	40200	Counts per Minute	04/16/2017	05/15/2017	=	**40,127** CPM

$$N_t = N_0 e^{-\lambda t}$$

http://hps.org/publicinformation/decay.cfm

Lattice commentary about paper by Kyu-Jin Yum et al. (2019)

Dr. Lee's expertise with radiation measurements suggests data is correct

"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

- Coauthor Jong-man Lee's deep expertise in measuring nuclear gamma radiation suggests that unusually large rate of decline in measured ^{137}Cs gamma counts observed and reported by Yum et al in paper are probably correct and not caused by any detector artifacts or measurement errors

- If gamma measurements are correct, then what was responsible for causing ^{137}Cs gamma counts to decrease at rate substantially higher than what could be accounted for by known ^{137}Cs half-life of 30.1 years?

- As to causation, this leaves changing ^{137}Cs decay rate or transmutation. Noted earlier, nuclear science generally assumes half-lives of unstable isotopes are immutable, i.e. radioactive decay rates are constant and do not change over time. While different types of periodic oscillations in beta-decay rates have been observed and published, they remain controversial and are much smaller in magnitude than ~18% variances reported by Yum et al; theory that could explain such oscillations in β-decay rates is unclear

- Before further Lattice commentary about this paper, is there any other published experimental data similar to Yum et al's? Yes, from Japan (2016)

Data shows mixed bacteria reduce $^{134,137}Cs$ gamma radiation

Japanese researchers conducted experiments quite similar to Yum et al

"Microbial contribution as countermeasures against radioactive contamination"

Data was presented at 3rd International Conference of Universal Village (UV2016), Nagoya, Japan 6-8 Oct 2016

Shuichi Okumoto, Masaki Shintani, and Teruo Higa

Abstract: "The large area was radioactively contaminated by the Fukushima Daiichi Nuclear Power Plant accident in 2011. Among many disastrous problems, agriculture was of the most concern from the point of food safety. Aiming at developing countermeasures against radioactive contamination in farmlands, we started a series of experiments, starting from May 2011 in Fukushima prefecture, with Effective Microorganisms (EM) Technology. We report here our experimental results regarding the microbial contribution to the suppression of radioactive cesium transfer from soil to agricultural products. In addition, a challenging possibility of microbial potential for reduction of soil radioactivity is discussed."

http://dndi.jp/19-higa/images/161121okumotopaper.pdf

Data shows mixed bacteria reduce $^{134,137}Cs$ gamma radiation

Okumoto et al had conducted ^{137}Cs field experiments near Fukushima

"Microbial contribution as countermeasures against radioactive contamination"

B. "Does EM per se deactivate radioactivity?"

"Preliminary observation in Belarus showed that radiation doses declined by EM [Effective Microorganisms] spraying over the some farmlands contaminated by Chernobyl Nuclear accident. In Takizawa dairy farm as well, an observation existed that the radioactivity in the soil of EM-sprayed area declined more extensively compared with the adjoining area which used chemical fertilizer [8]. In order to confirm and extend this observation, we set up an experimental field in blueberry farm in Iitate village, Fukushima. We repeatedly sprayed activated EM over the field, and radioactivity of Cs was measured before and after EM spraying. At the start, the radioactivity of Cs was 20,000 Bq/kg. Two months afterwards, it declined to 5,000 Bq/kg. A possibility was excluded that radioactive Cs penetrated into the deep part of the soil or was washed away due to rain [10]."

Data shows mixed bacteria reduce $^{134,137}Cs$ gamma radiation

Okumoto et al conducted laboratory experiments with Cs and bacteria

"Microbial contribution as countermeasures against radioactive contamination"

"Based on this observation, we conducted a laboratory experiment to examine in a more defined way the potential of EM *per se* for deactivating radioactivity. The soil collected from contaminated land in Fukushima was added EM or water as scheduled, and sealed in U8 container as described in Materials and Methods. Firstly, the radioactivity of ^{134}Cs before and 690 days after the treatments was measured (Fig.6). Since the half-life of ^{134}Cs is 2.065 years, the theoretical reduction rate during 690 days was calculated to be 47.0%. The reduction rate of control group was 46.5%, very close to the theoretical estimate. For other treatment groups, the reduction rate was 47.3% for Water, 52.4% for EM25%, 54.8% for EM50%, 57% for EM75% and 56.7% for EM100%. These data show the reduction rate of EM groups was significantly higher ($p<0.01$) than Control group, and support the previous [field] observations in Belarus and in Takizawa Farm. There were significant differences in all EM treated. Also, noted is that the reduction rate seems to increase as does the concentration of EM."

Data shows mixed bacteria can reduce ^{134}Cs gamma radiation

^{134}Cs radiation decreased ~ in parallel with increasing % of EM bacteria

"Microbial contribution as countermeasures against radioactive contamination"

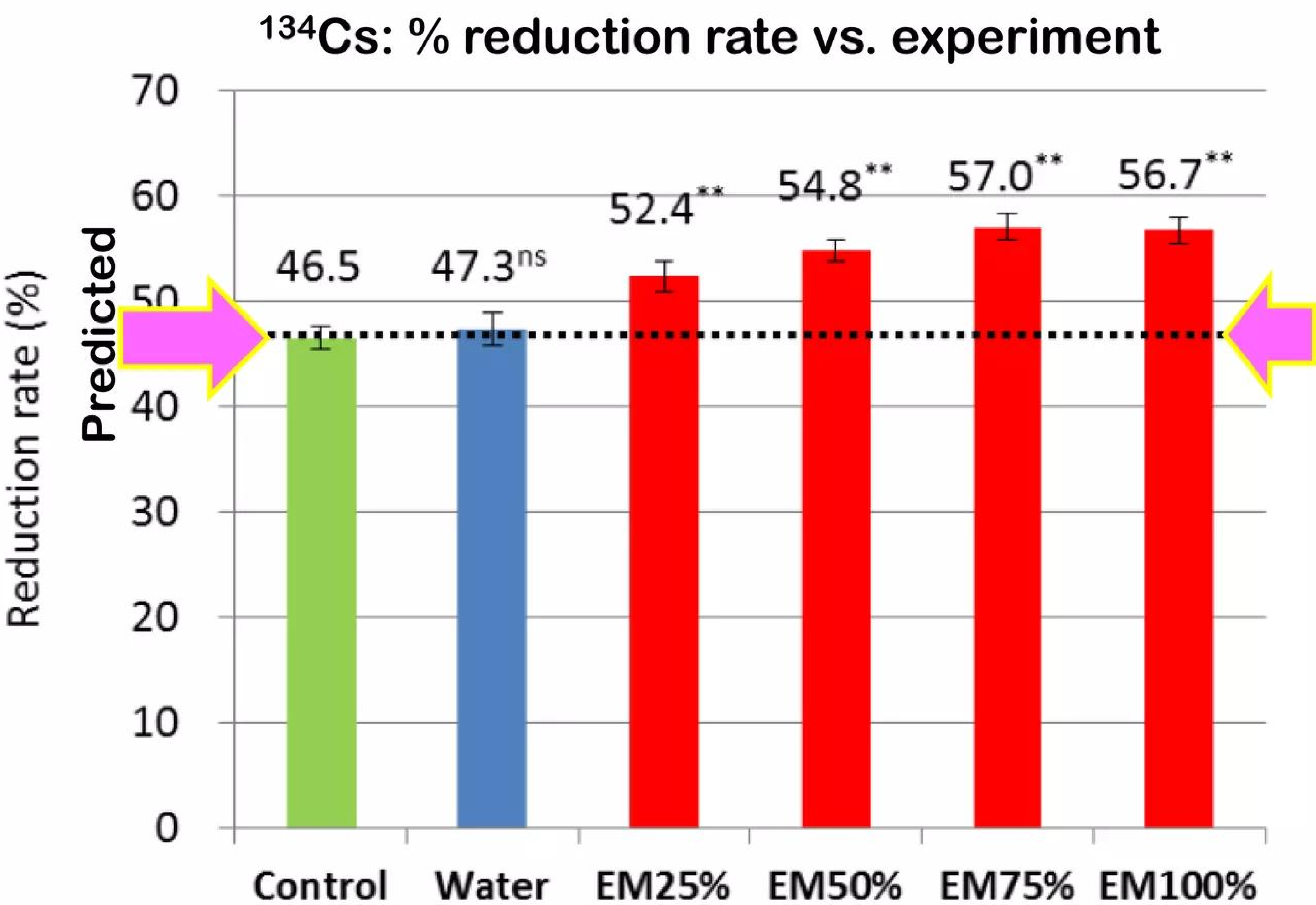


Fig.6. "Effect of EM application on reduction rate of ^{134}Cs. Values are expressed as mean ±SD (n=3). **: significant difference at the 0.01 level in comparison to the Control (Dunnett's test). ns: no significant difference."

Dotted line: "Theoretical reduction rate of ^{134}Cs after 690 days is 47.0% (half life 2.065 years)"

Data shows mixed bacteria can reduce ^{134}Cs gamma radiation

Calculate predicted ^{134}Cs γ counts at end of Okumoto et al experiment

"Microbial contribution as countermeasures against radioactive contamination"

Decay Calculator

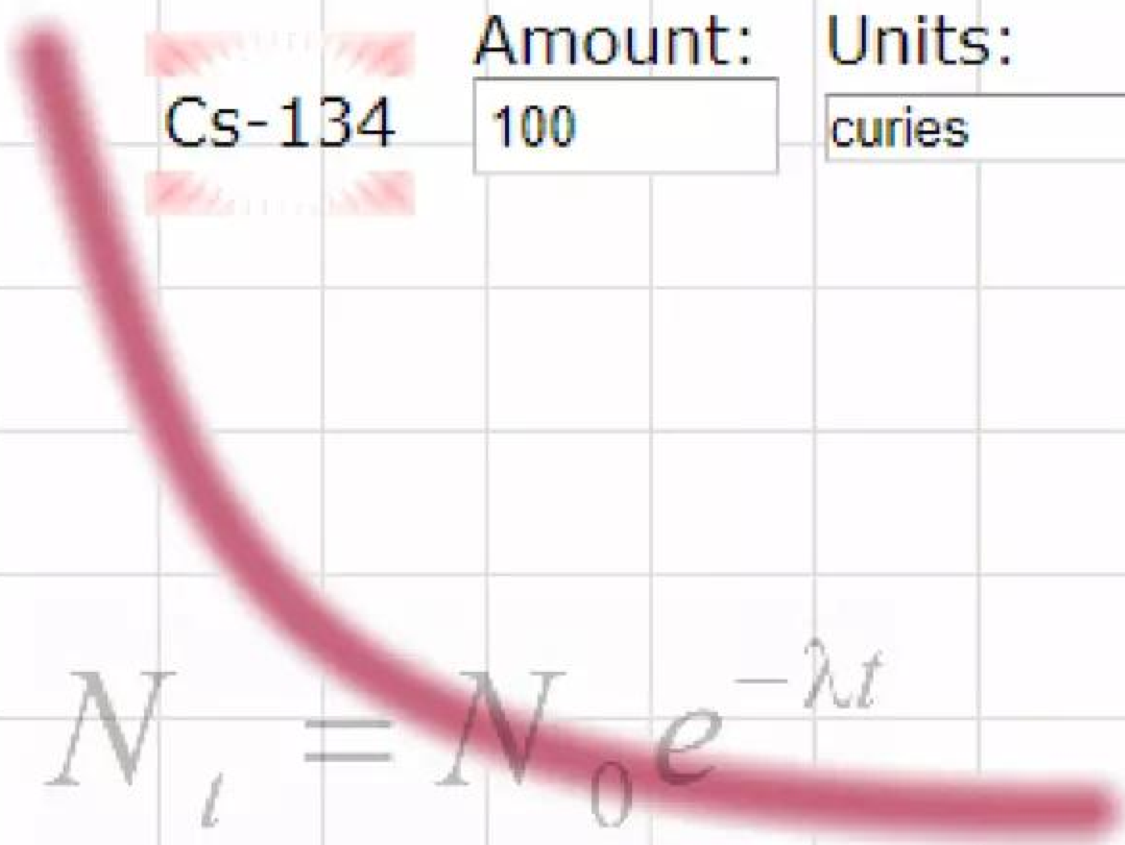
HPS Specialists in Radiation Protection

Results for Cs-134 Decay

The half-life of Cs-134 is 2.0648 years.[1]

Cs-134 decays to roughly 53.04% of the initial activity over the period of 1.88915738652 years.
another radionuclide.

	Amount:	Units:	Begin Date:	End Date:		
Cs-134	100	curies	03/26/2017	02/14/2019	=	**53.0368** Ci



$N_t = N_0 e^{-\lambda t}$

100.0000
<u>-53.0368 over total of 690 days</u>
46.9632 or ~ 47% decrease

Data shows mixed bacteria reduce $^{134,137}Cs$ gamma radiation

Decay rates on controls were normal; EM experiments were much higher

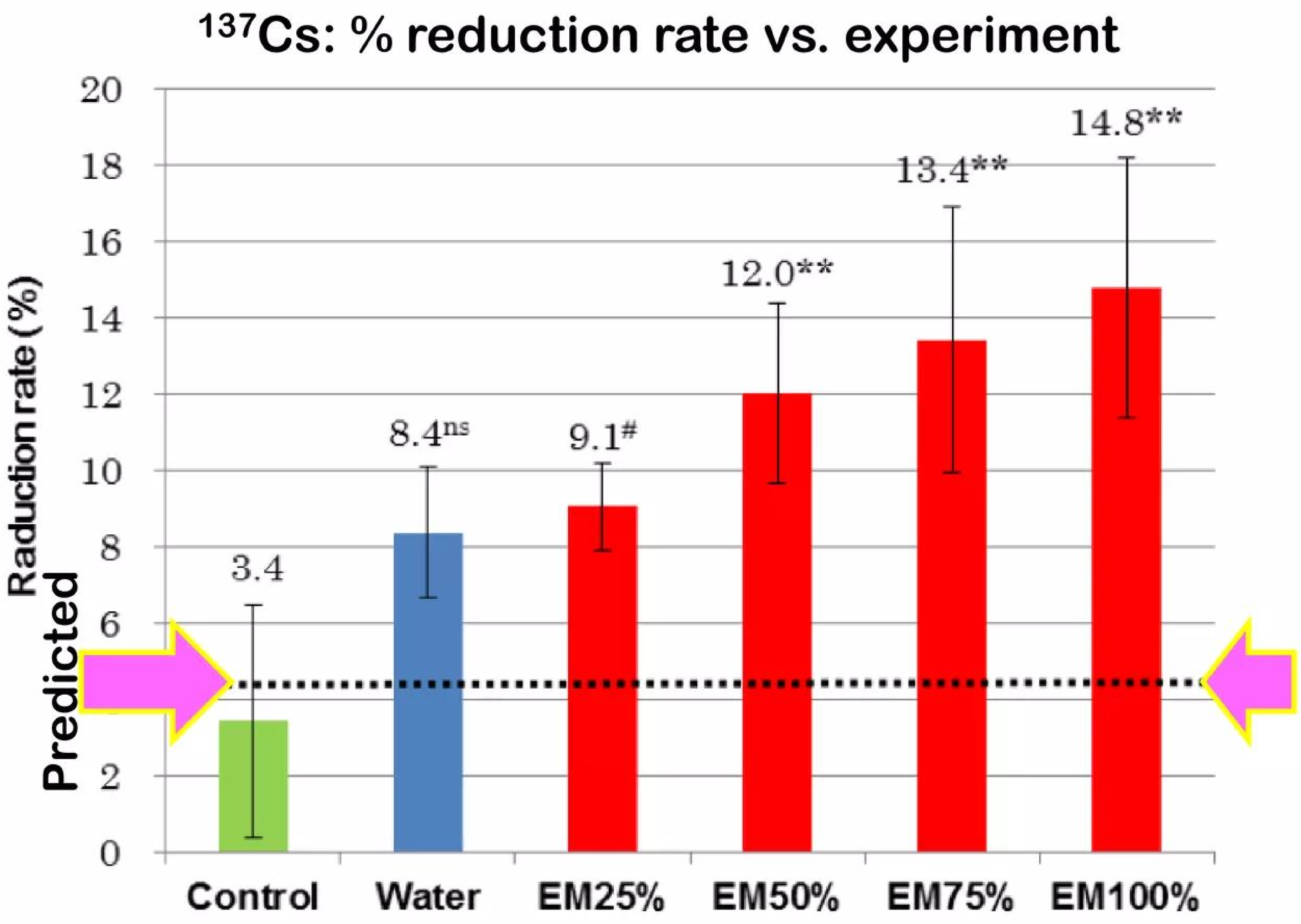
"Microbial contribution as countermeasures against radioactive contamination"

"Next, the radioactivity of ^{137}Cs before and 690 days after the treatment were measured (Fig.7). ^{137}Cs has a longer physical half-life of 30.04 years and the theoretical reduction rate during 690 days is 4.3%. The reduction rate of the Control group was 3.4%, which was very close to the theoretical reduction rate. For the other experimental groups, the reduction rate was 8.4% for Water, 9.1% and for the EM25%, 12.0% for EM50%, 13.4% for EM75% and 14.8% for EM100%. Compared with the reduction rates of these groups with the Control group, those of EM groups were all significantly higher difference ($p<0.01$, except EM25%). Again, the reduction rate increased along with the concentration of EM."

Data shows mixed bacteria can reduce ^{137}Cs gamma radiation

^{134}Cs radiation decreased ~ in parallel with increasing % of EM bacteria

"Microbial contribution as countermeasures against radioactive contamination"



http://dndi.jp/19-higa/images/161121okumotopaper.pdf

Fig.7. "Effect of EM application on reduction rate of ^{137}Cs. Values are expressed as mean ±SD (n=3). **: significant difference at the 0.01 level in comparison to the Control (Dunnett's test). #: significant difference at the 0.06 level in comparison to the Control (Dunnett's test, p-value=0.058). ns: no significant difference."

Dotted line: "Theoretical reduction rate of ^{137}Cs after 690 days is 4.3% (half life 30.04 years) ."

Data shows mixed bacteria can reduce ^{137}Cs gamma radiation

Calculate predicted ^{137}Cs γ counts at end of Okumoto et al experiment

"Microbial contribution as countermeasures against radioactive contamination"

Decay Calculator

Results for Cs-137 Decay

HPS Specialists in Radiation Protection

The half-life of Cs-137 is 30.1671 years.[1]

Cs-137 decays to roughly 95.75% of the initial activity over the period of 1.88915738652 years.
another radionuclide.

	Amount:	Units:	Begin Date:	End Date:		
Cs-137	100	curies	03/26/2017	02/14/2019	=	**95.7522** Ci

$$N_t = N_0 e^{-\lambda t}$$

100.0000
-95.7522 over total of 690 days
4.2478 or ~ 4.3% decrease

http://hps.org/publicinformation/decay.cfm

Data shows mixed bacteria reduce $^{134,137}Cs$ gamma radiation

EM experiments indicate that mixed bacteria can remediate radioactivity

"Microbial contribution as countermeasures against radioactive contamination"

"The physical half-life of radionuclides is known to be quite stable against environmental change. Therefore, this observation stands in a flat contradiction with the current view. Quite challenging though, some scientists referred to the possibility of biological transmutation. In view of the magnitude of these findings in mitigating the radiation disaster, we should stay open to all possibilities. Further experiments are currently in progress to confirm and to extend what were observed."

IV. CONCLUSION

"Based on the field research and green house experiments described above, it is clear that EM and EM fermented compost can reduce the soil-to-plant transfer of radioactive Cs. A challenging possibility was experimentally suggested and is currently pursued that EM *per se* acts on mitigating radioactivity. Also, noted is the correlation between the extent of reduction and the concentration of EM."

Lattice commentary about paper by S. Okumoto et al. (2016)

Experimental data provides strong evidence bacteria affect radioactivity

“Microbial contribution as countermeasures against radioactive contamination”

- In parallel with notable declines in ^{137}Cs gamma radiation, Okumoto et al also measured similar substantial decreases in gamma radiation emitted from beta-decay of ^{134}Cs nuclear fission product that was also present in contaminated Fukushima soils; ^{134}Cs β-decay gamma peak is at 698 keV
- Although microbial species comprising mixed cultures were different, data for measured anomalous reductions in ^{137}Cs gamma radiation were qualitatively similar for lab experiments of Okumoto et al (2016) and Yum et al (2019). Quantitatively, % decrease in radiation observed during experiments differed by under 1 order of magnitude for all $^{134,137}Cs$ data
- Additional striking feature in Okumoto et al’s data: % reduction in $^{134,137}Cs$ gamma radiation clearly *increased* in in step with increasing concentrations of mixed EM microbes present in growth flasks. Result strengthens argument that microbes are causing observed decreases in gamma radiation emitted from sealed growth flasks during experiments
- Growth flasks being totally sealed during experiments, no ^{134}Cs or ^{137}Cs can escape; loss of isotopes cannot explain radiation decrease anomaly

Bacteria altered $^{238}U/^{235}U$ isotopic ratio in lab experiments

Control experiments without bacteria did not exhibit isotopic fractionation

"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)

https://pubs.acs.org/doi/abs/10.1021/es0604360

- **Abstract excerpt: "Presented here are measurements of mass-dependent U isotope fractionation induced by U(VI) reduction by zerovalent iron (Fe^0) and bacteria under controlled pH and HCO_3^- conditions. In abiotic experiments, Fe^0 reduced U(VI), but the reaction failed to induce an analytically significant isotopic fractionation. Bacterial reduction experiments using *Geobacter sulfurreducens* and *Anaeromyxobacter dehalogenans* reduced dissolved U(VI) and caused enrichment of ^{238}U relative to ^{235}U in the remaining U(VI)."**

- **Abiotic Fe^0 reduction experiments: "Despite decreasing concentration and apparent U reduction in these experiments, no measurable changes in isotope ratios were detected, with $^{238}U/^{235}U$ remaining constant ..."**

- **Bacterial reduction experiments: "Both *A. dehalogenans* and *G. sulfurreducens* successfully reduced Uranium during experiments when acetate was added as an electron donor. Bacterial experiments were terminated after 96 hours ... Control experiments, which contained no cells, indicated that U reduction did not occur in the absence of either bacterium."**

Bacteria altered $^{238}U/^{235}U$ isotopic ratio in lab experiments

Reported anomalous initial increase in key parameter: similar to Yum et al

"Experimentally determined Uranium isotope fractionation during reduction of hexavalent U by bacteria and zero valent Iron"

- "Anomalous changes in concentration occurred in the early stages of all of the bacterial reduction experiments (Figure 2A). Samples extracted at time zero (within 30 min of the experiment start) had U(VI) concentrations lower than expected initial values based on the amount of U added during experimental setup. During the first 8 h after the addition of U to the reaction vessels, U concentrations increased to approximately 14 mgL-1 +/- 25% followed by a steady, gradual decrease through the remainder of the experiment. The initial increase in U(VI) concentration during bacterial experiments was unexpected, as we anticipated a monotonic decrease in dissolved U as U(VI) was reduced to U(IV) and precipitated from solution." See earlier discussion of Yum et al where they reported initial increase in ^{137}Cs gamma counts followed by steady decline
- "Used … enriched U standard, SRM U-500 from … National Institute of Standards and Technology (NIST) (25) as … U source for … experiments … NBS SRM U-500 contains nearly equal quantities of ^{238}U and ^{235}U and has a $^{238}U/^{235}U$ ratio = 1.0003 +/- 0.001." [natural Uranium: $^{238}U/^{235}U$ = 137.85 +/- 0.4]
- For decades prior to ~ 2000, geochemists assumed value of 137.88 for $^{238}U/^{235}U$ ratio was invariant in Earth's crust. They were wrong: highest variability occurs in rocks where living biota had originally been present at some point in the past

Bacteria changed $^{238}U/^{235}U$ isotopic ratio in lab experiments

$^{238}U/^{235}U$ ratio increased with time in experiments with bacteria present

"Experimentally determined Uranium isotope fractionation during reduction of hexavalent U by bacteria and zero valent Iron"

TABLE 1. Summary of Isotopic results from Abiotic and Bacterial Reduction Experiments

Experiment	Time (min)	$\Delta\delta^{238}U$ (‰)[a]	error[b]
Fe^0	0	-0.03	0.07
	41	-0.08	0.09
	64	-0.02	0.10
A. dehalogenans	0	-0.09	0.09
	120		
	240		
	480	-0.10	0.06
	2160	-0.03	0.05
	4320	0.19	0.06
	5760	0.26	0.04
G. sulfurreducens	0	-0.02	0.10
	480	-0.02	0.06
	2160	0.04	0.05
	4320	0.19	0.05

[a] $\Delta\delta^{238}U$ represent the offset of the data point relative to the standard [NIST SRM U-500]

[b] Standard analytical error

- Table 1 in paper: data shows an increase in $^{238}U/^{235}U$ ratio with time in the bacterial experiments and the absence of significant change during Fe^0 experiments
- Delta notation for isotopes:

$$\delta^a X = \left(\frac{{}^a R_X - {}^a R_{std}}{{}^a R_{std}} \right) \times 1000$$

- Delta notation for Oxygen:

$$\delta^{18}O = \left[\frac{({}^{18}O/{}^{16}O)_{sam} - ({}^{18}O/{}^{16}O)_{SMOW}}{({}^{18}O/{}^{16}O)_{SMOW}} \right] \times 10^3$$

Lattice comments re experiments of Rademacher et al (2006)

Do some bacteria have the capability to transmute Cesium *and* Uranium ?

"Experimentally determined Uranium isotope fractionation during reduction of hexavalent U by bacteria and zero valent Iron"

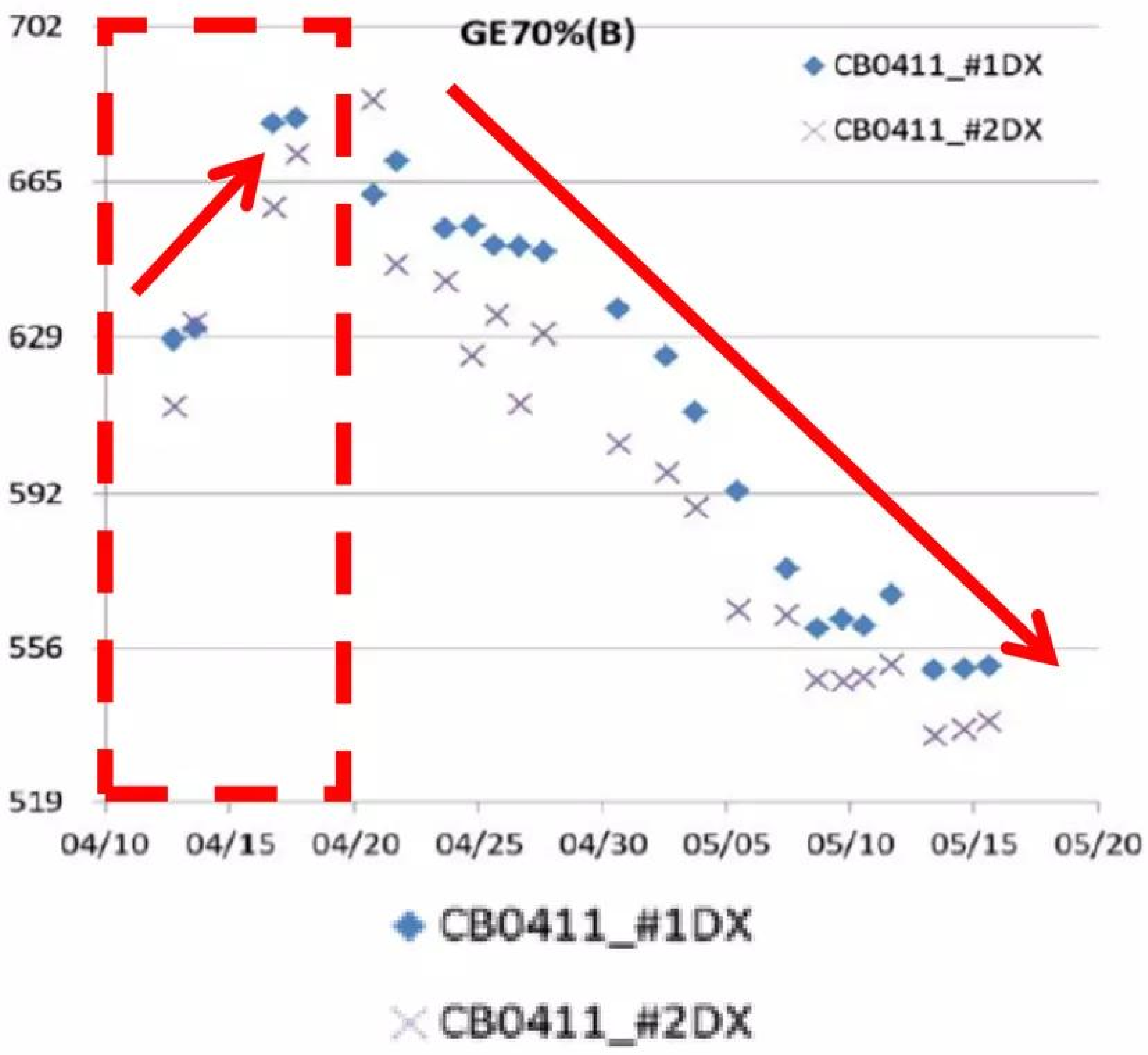
- **Interestingly, LENR ULE neutron capture on Uranium isotopes present in Rademacher et al's bacterial cultures would have produced similar qualitative results with regard to causing increases in the $^{238}U/^{235}U$ ratio**
- **Upon exposure to ULE neutrons, Uranium-235 could have either undergone fission and/or radiatively captured ULE neutrons and then been transmuted into heavier unstable Uranium isotopes that decay into heavier transuranic elements. Observationally, water soluble Uranium-VI would 'disappear' from aqueous media. In any case, since neutron capture cross-section of ^{238}U is much smaller than ^{235}U, isotopically lighter ^{235}U will react with ULE neutrons at much higher rate than with ^{238}U, which will increase the $^{238}U/^{235}U$ ratio. Increases in $^{238}U/^{235}U$ occur in fuel cycle of ^{235}U fission reactors and were also observed in rock samples collected from 2 billion year-old, natural fission reactor discovered in an Okla, Gabon mine in 1972**
- **Idea of bacteria transmuting heavy, uncommon elements like Cesium and Uranium may seem fantastical. However, radioactive elements were much more prevalent in Earth's environment during early days of life 3^{+} billion years ago. Perhaps natural selection produced bacteria that were well-adapted to such environments; those capabilities remain in their genomes**

Further Lattice discussion about paper by Yum et al. (2019)

Initial increase in γ counts for experiments CB0411_#1DX, CB0411_#2DX

"An experiment in reducing the radioactivity of radionuclide (^{137}Cs) with multi-component microorganisms of 10 strains"

Fig. 3: "Change of γ-ray counting rate (s^{-1}) from ^{137}Cs over time (month/day)"

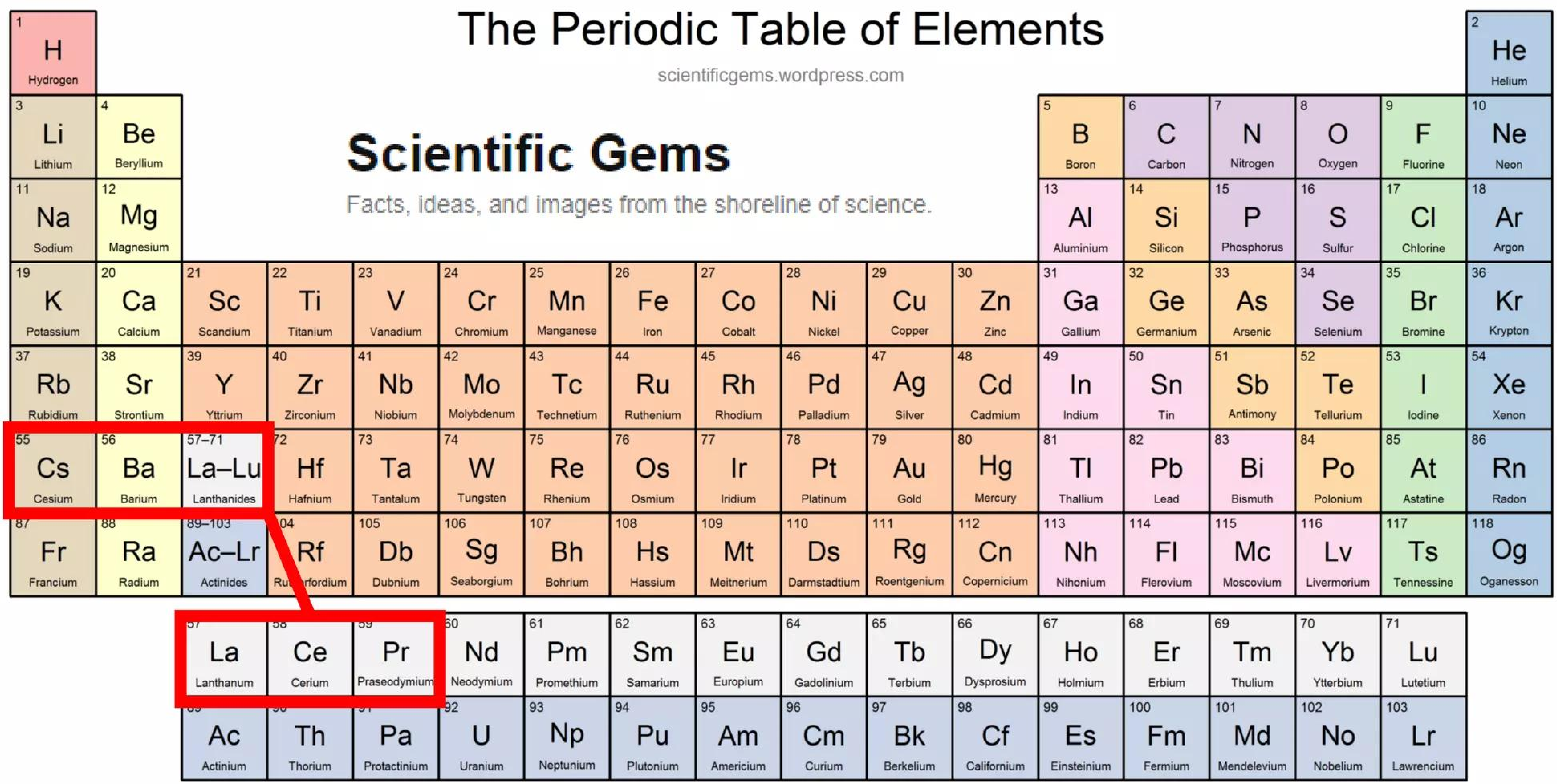


- **Under "Results and discussion" they noted: "Figure 3 shows the result of count rate measurements … count rate increased by 8% at the beginning and then it began decreasing. This is the same tendency which was observed by Vysotskii & Kornilova (2010)."**
- **While an initial increase wasn't observed by Okumoto et al (2016), and assuming it is real and not an artifact, there are several possible explanations that don't involve "two different mechanisms" or "two stages of reaction" as proposed by Yum et al; LENRs could explain increase**
- **Will discuss ULE neutron-catalyzed LENR transmutation network predicted by the Widom-Larsen theory, starting with ^{133}Cs**

Further Lattice discussion about paper by Yum et al. (2019)

Cesium - Cs, Barium - Ba, Lanthanum - La, Cerium - Ce, Praseodymium - Pr

LENRs transmute chemical elements and produce stable or unstable isotopes



Source: https://scientificgems.files.wordpress.com/2016/06/periodic_table_complete.png

Further Lattice discussion about paper by Yum et al. (2019)

Main Cesium isotopes found in the environment are shown in Table at left

Main Cesium isotopes found in Nature

Isotope			Decay	
	abun-dance	half-life ($t_{1/2}$)	mode	pro-duct
^{133}Cs	100%	stable		
^{134}Cs	trace	2.0648 y	ε	^{134}Xe
			β^-	^{134}Ba
^{135}Cs	trace	2.3×10^6 y	β^-	^{135}Ba
^{137}Cs	trace	30.17 y[1]	β^-	^{137}Ba

Source: Wikipedia

"Cesium has 40 known isotopes … atomic masses of these isotopes range from 112 to 151. Only one isotope, ^{133}Cs, is stable … longest-lived radioisotopes are ^{135}Cs with a half-life of 2.3 million years, ^{137}Cs with half-life of 30.1671 years and ^{134}Cs with half-life of 2.0652 years. All other isotopes have half-lives < 2 weeks, most under an hour."

Elements ordered by increasing atomic number

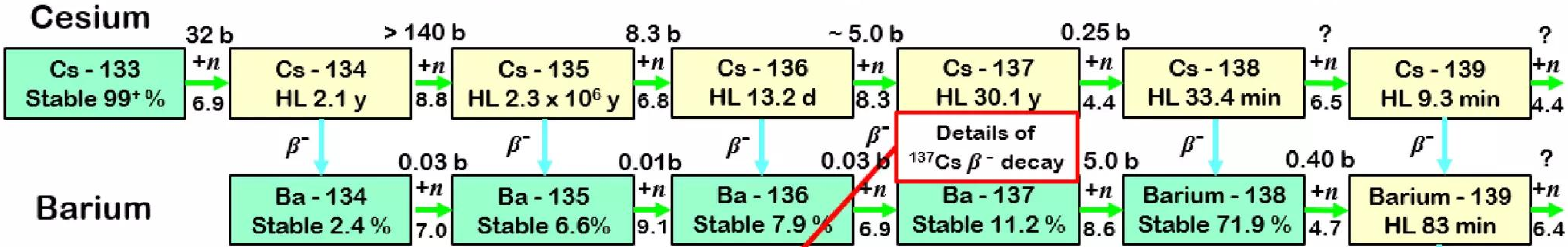
55	56	57	58	59
Cs	Ba	La	Ce	Pr
Cesium	Barium	Lanthanum	Cerium	Praseodymium

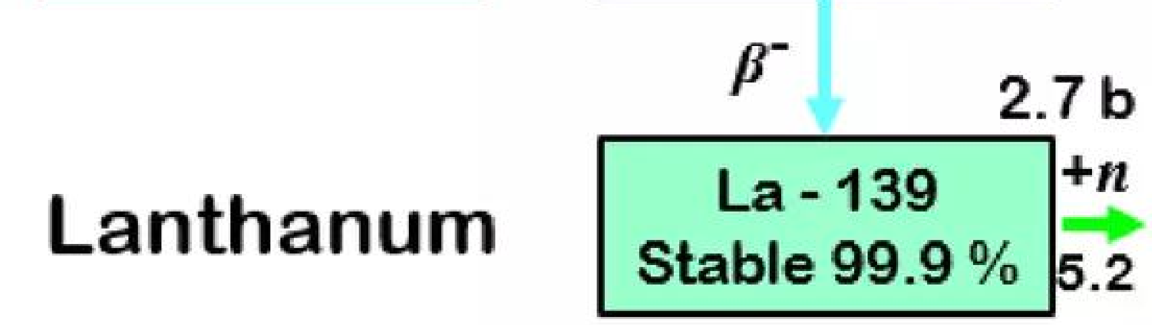
- **Neutron capture:** creates heavier, more neutron-rich isotopes of same chemical element; they may be stable or unstable
- **Beta-decay:** common decay for unstable neutron-rich isotopes of elements. It transmutes one element into a heavier element with higher (+1) atomic number
- **LENRs:** ULE neutron-catalyzed nuclear transmutation processes will commonly proceed from left-to-right along rows of the Periodic Table of chemical elements
- **Per Widom-Larsen theory:** LENRs create complex, branching networks of stable and unstable transmutation products

Further Lattice discussion about paper by Yum et al. (2019)

Neutron-catalyzed LENR transmutation network starting with Cesium-133

Possible transmutation pathways according to Widom-Larsen theory of LENRs

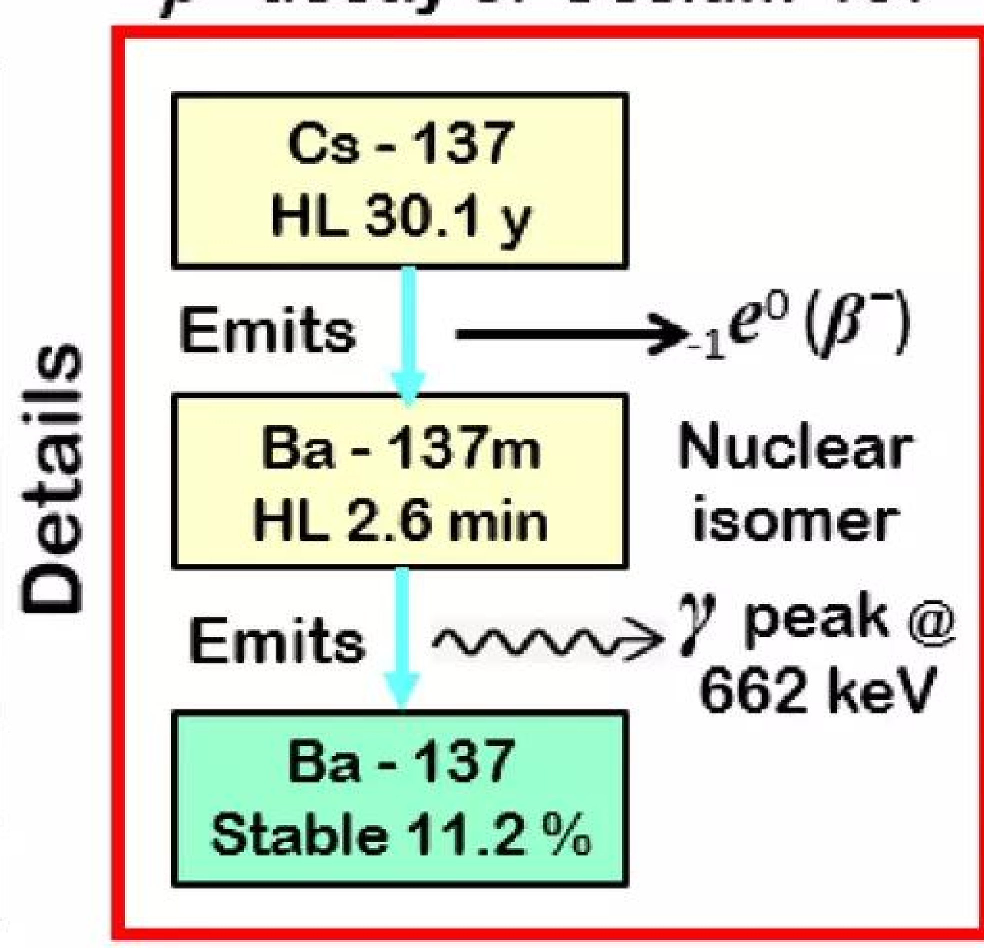




Latest capture data

Cesium Isotope	Thermal neutron capture cross section (barns)
Cs-133	32.0 b
Cs-134	> 140.0 b
Cs-135	8.3 b
Cs-136	~5.0 b
Cs-137	0.25 b

β^- decay of Cesium-137



Energetic gammas not shown because from ~ 0.5 - 1.0 MeV up through ~ 10.0 - 11.0 MeV (boundaries vary depending on details) they all get converted directly into infrared photons (heat) by unreacted heavy-mass SP electrons per Widom-Larsen theory

Legend:

Stable isotopes are indicated with green boxes; natural abundance is listed in %

Unstable isotopes are indicated with yellow boxes; half-life is listed down below

ULE neutron captures (green arrows) go from left-to-right; Q-value (MeV) is number below green arrow and thermal neutron capture cross-section (b = barns) above it

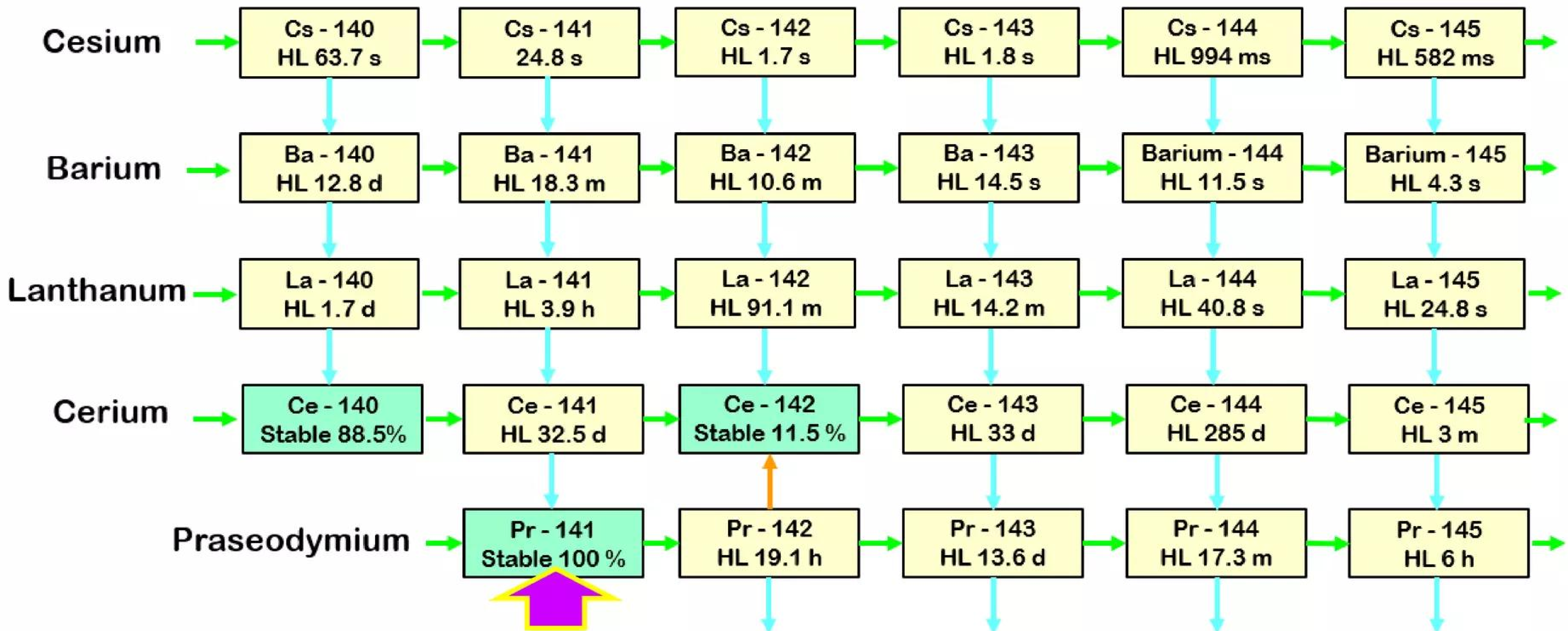
Beta decays β^- (light blue arrows) point downward; isotope's decay energy (MeV unless otherwise noted) is to right of arrow

Electron capture (ε) is upward orange arrow

Further Lattice discussion about paper by Yum et al. (2019)

Neutron-catalyzed LENR transmutation network starting with Cesium-133

Possible transmutation pathways according to Widom-Larsen theory of LENRs



Key paper published by MHI researchers in *Japanese Journal of Applied Physics* (2002)

Abiotic LENRs 2002

MITSUBISHI HEAVY INDUSTRIES, LTD.

Our Technologies, Your Tomorrow

$$^{133}_{55}Cs \rightarrow \, ^{141}_{59}Pr$$

Implanted Cesium

↓

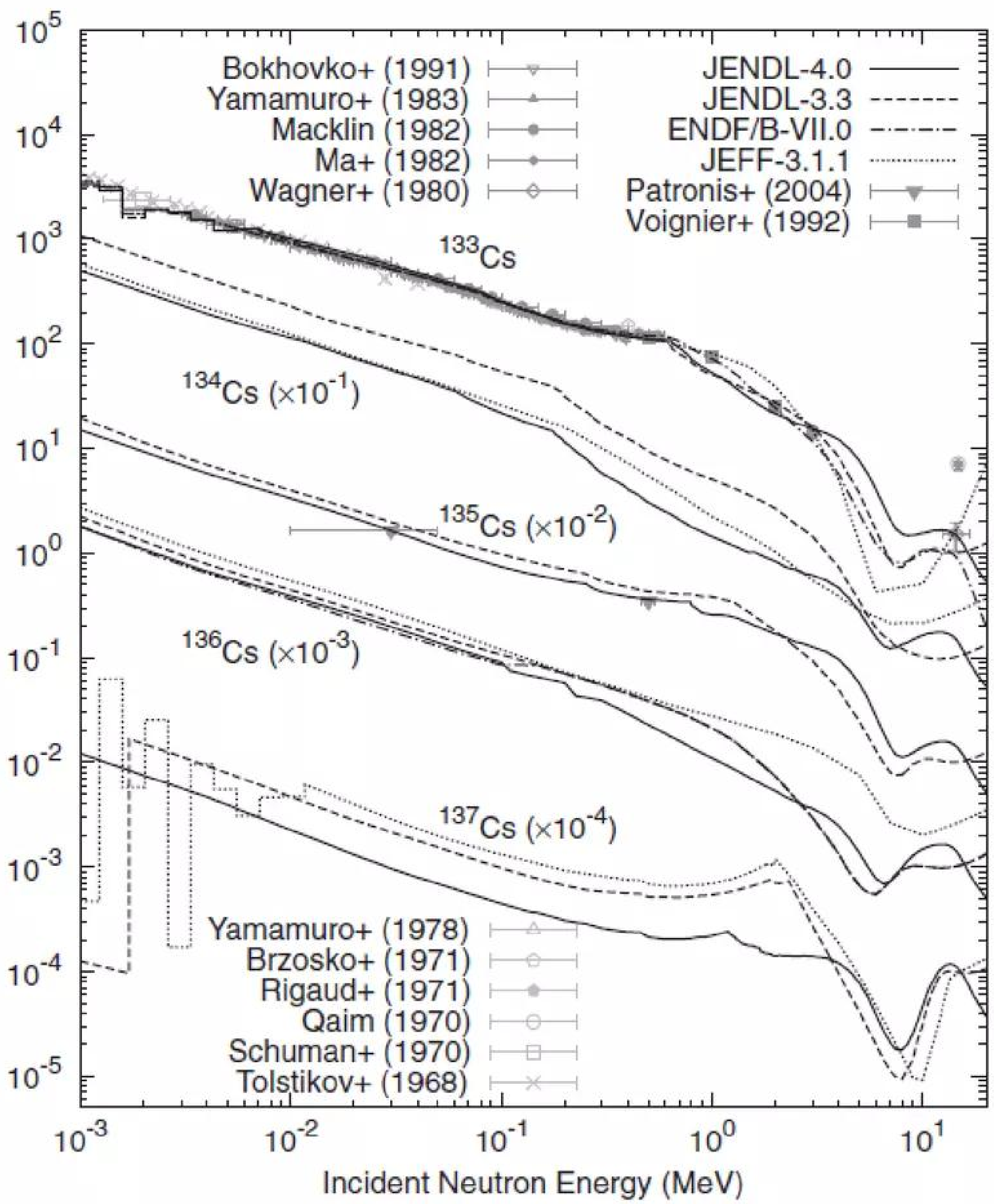
Praseodymium

https://www.lenr-canr.org/acrobat/IwamuraYelementalaa.pdf

Further Lattice discussion about paper by Yum et al. (2019)

ULE neutron captures on small admixtures of lighter Cesium isotopes

Comparison of neutron capture cross-sections for ^{133}Cs, ^{134}Cs, ^{135}Cs, ^{136}Cs, and ^{137}Cs versus incident neutron energy



- **In chart (left): heavier Cesium isotopes have progressively lower neutron capture cross-sections, irrespective of energy; ^{137}Cs is by far lowest of 5 isotopes. Refer to Cesium LENR transmutation network on two previous slides**
- **Assume: no detectable Cesium isotopes were present in mixed bacterial cultures prior to their adding "159 μl of hydrochloric acid containing ^{137}Cs … to make total radioactivity of the sample 50 kBq." Further assume: added 159 μl with ^{137}Cs also contained tiny admixtures of one, some, or all lighter Cesium isotopes starting with ^{133}Cs**
- **In bacterial LENR active sites: ULE neutrons will be captured at much higher rates on lighter Cs isotopes vs. ^{137}Cs. This would have net effect of temporarily increasing ^{137}Cs concentrations in flasks until all lighter isotopes were transmuted, creating initial increase in low-energy 662 keV ^{137}Cs gamma emission and progressive decrease in counts thereafter; both effects were observed**

Further Lattice discussion about paper by Yum et al. (2019)

Other nuclear processes could increase counts attributed to ^{137}Cs decay

Thermal Neutron Capture Gamma-rays

Thermal Neutron Capture Gammas — Target Nucleus ^{138}Ba

Target Nucleus=^{138}Ba

Strongest transition Eγ=627.26+-0.10 keV %Iγ=92.10+-4.61

Eγ (keV)	ΔEγ (keV)	Iγ/Iγ(max) (%)	Δ(Iγ/Iγ(max))
295.00	5.00	1.00	0.05
352.00	5.00	1.00	0.05
454.67	0.10	29.00	2.02
627.26	0.10	100.00	7.08
666.20	0.70	1.44	0.10
686.70	0.50	0.22	0.02
687.60	0.50	0.16	0.02
708.40	0.10	1.29	0.14
731.90	0.50	0.15	0.02
738.40	0.20	0.54	0.04
744.70	0.20	0.23	0.02
749.50	0.20	0.45	0.04
755.40	0.30	0.09	0.01
758.70	0.20	0.12	0.01
765.70	0.20	0.11	0.01
793.40	0.30	0.26	0.03
822.60	0.40	0.13	0.01
866.90	0.00		

IAEA NUCLEUS For Nuclear Knowledge and Information

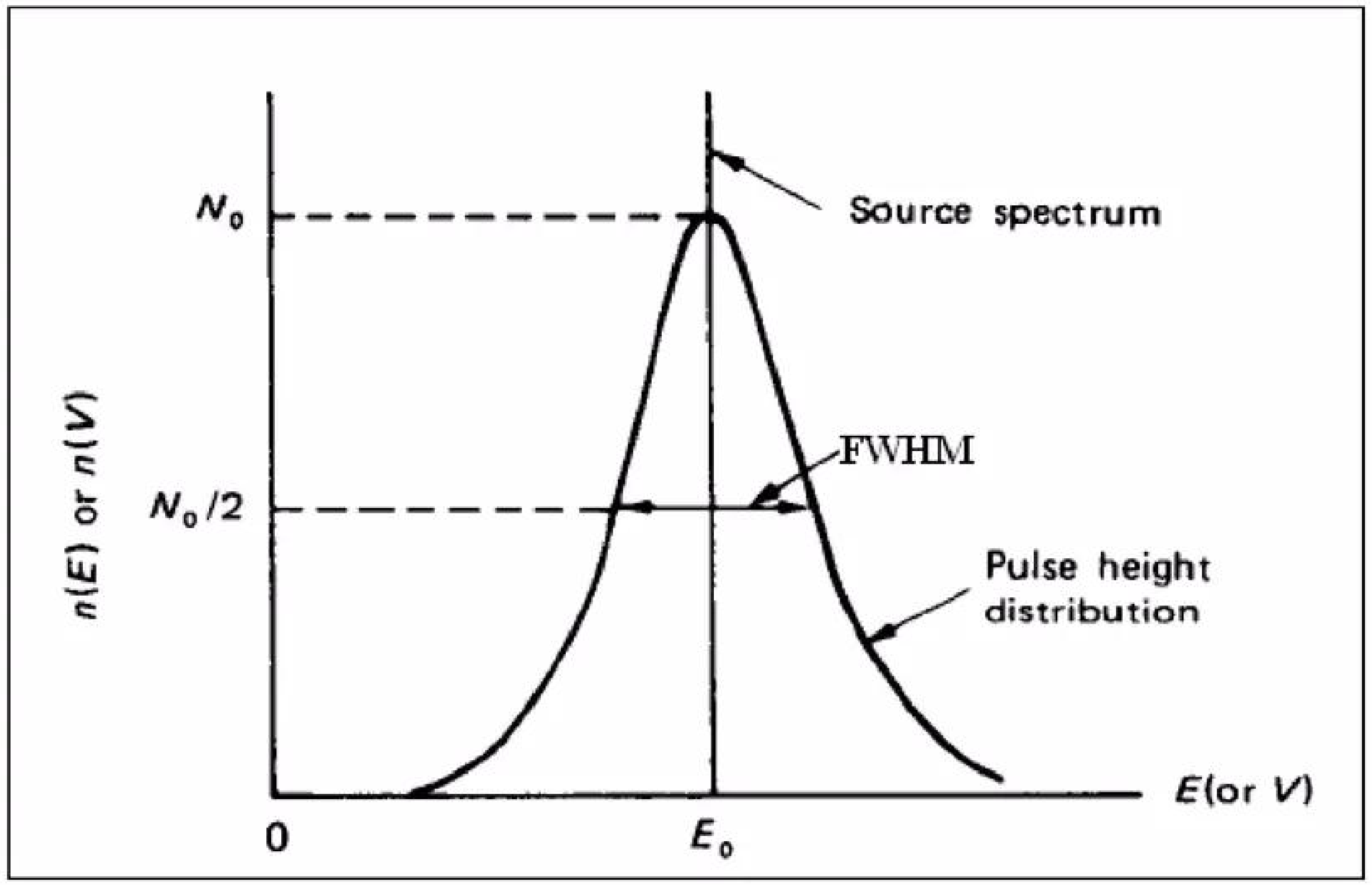
https://www-nds.iaea.org/capgam/byn/page152.html

- **In chart (left):** ULE neutron captures on ^{138}Ba results in gamma emission peak centered at 627 keV. **Refer to Cesium LENR transmutation network on earlier slides:** neutron capture on ^{137}Cs creates ^{138}Cs that β-decays into ^{138}Ba; neutron capture on ^{137}Ba can also produce ^{138}Ba, which is most abundant stable Ba isotope
- **Assume:** no Barium isotopes present in initial bacterial solution. **Further assume:** since ^{137}Cs is constantly decaying, small amounts of stable ^{137}Ba will inevitably be present in added "159 μl … containing ^{137}Cs" as well as in very close proximity to or inside bacterial LENR active sites
- **In bacterial LENR active sites:** neutron capture on ^{137}Ba makes ^{138}Ba that emits 627 keV gammas when it captures ULE neutrons. Depending on the resolution of gamma detector, might add to counts attributed to ^{137}Cs, causing apparent temporary increase in gamma emissions

Further Lattice discussion about paper by Yum et al. (2019)

Energy resolution is important issue in evaluating gamma measurements

PhysicsOpenLab
Modern DIY Physics Laboratory for Science Enthusiasts



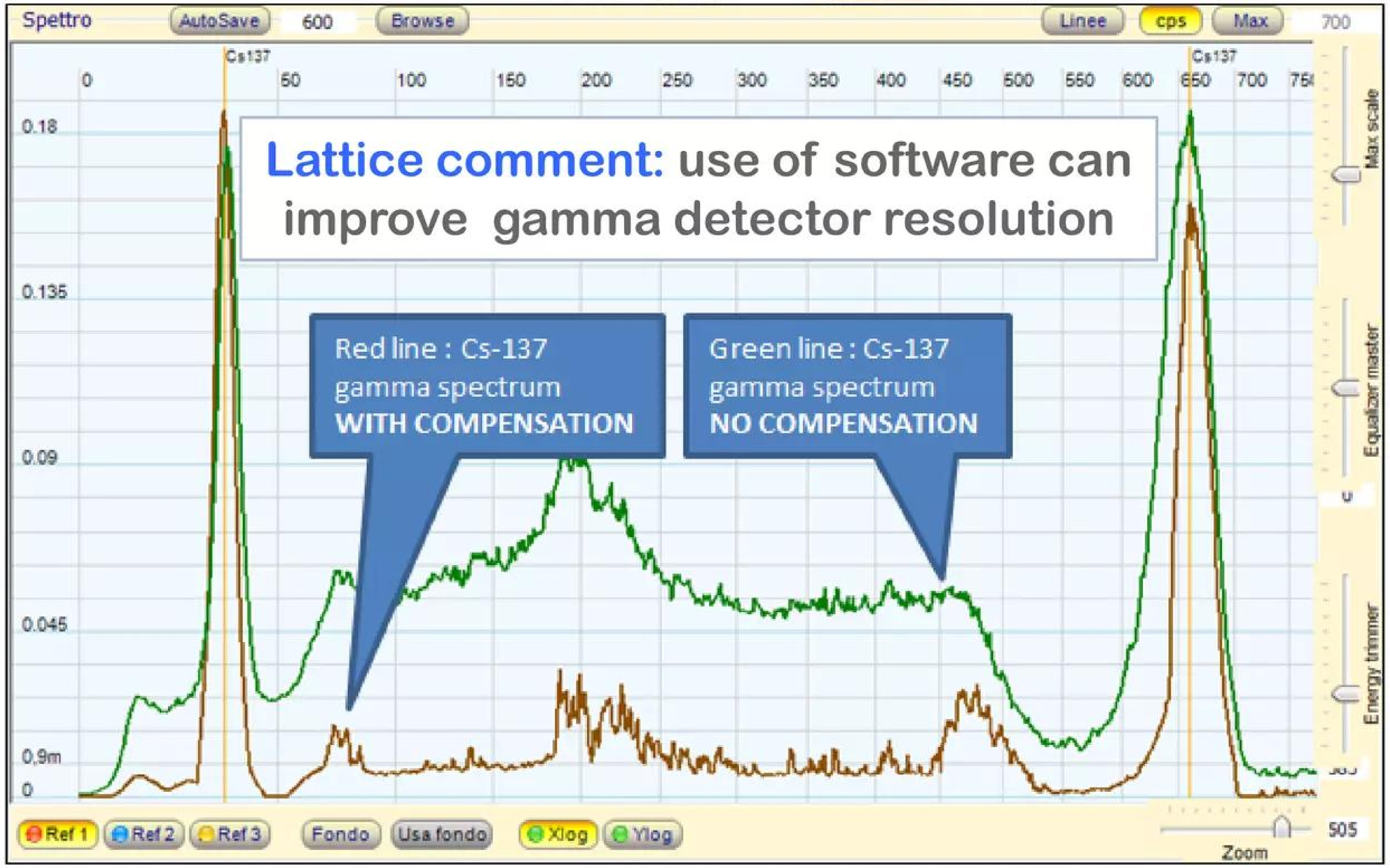
"Absorption of gamma rays inside … scintillation crystals and … production of photo-electrons inside [photomultiplier tubes] are essentially random processes, thus the Poisson and Gaussian statistical distribution could be applied to explain … broadening of the lines."

"Energy resolution is measured as … full width at half maximum (FWHM). To a first approximation … gamma ray line width (FWHM) is 2.35σ, where σ is … standard deviation of the Gaussian distribution related to … statistical fluctuations in … number of photo-electrons, N_e, that are collected from … photocathode of … phototubes. Energy resolution should be inversely proportional to … square-root of the gamma ray energy … [thus] energy resolution improves as gamma ray energy is increased."

https://physicsopenlab.org/2016/02/07/energy-resolution-in-gamma-spectrometry/

Further Lattice discussion about paper by Yum et al. (2019)

Graph shows how software can improve resolution of gamma detectors



"For the NaI (Tl) scintillation crystals the energy resolution is about from 5% to 10% but could be improved with software algorithm which can partially compensate the crystal broadening, like in the Theremino MCA."

https://physicsopenlab.org/2016/02/07/energy-resolution-in-gamma-spectrometry/

Further Lattice discussion about paper by Yum et al. (2019)

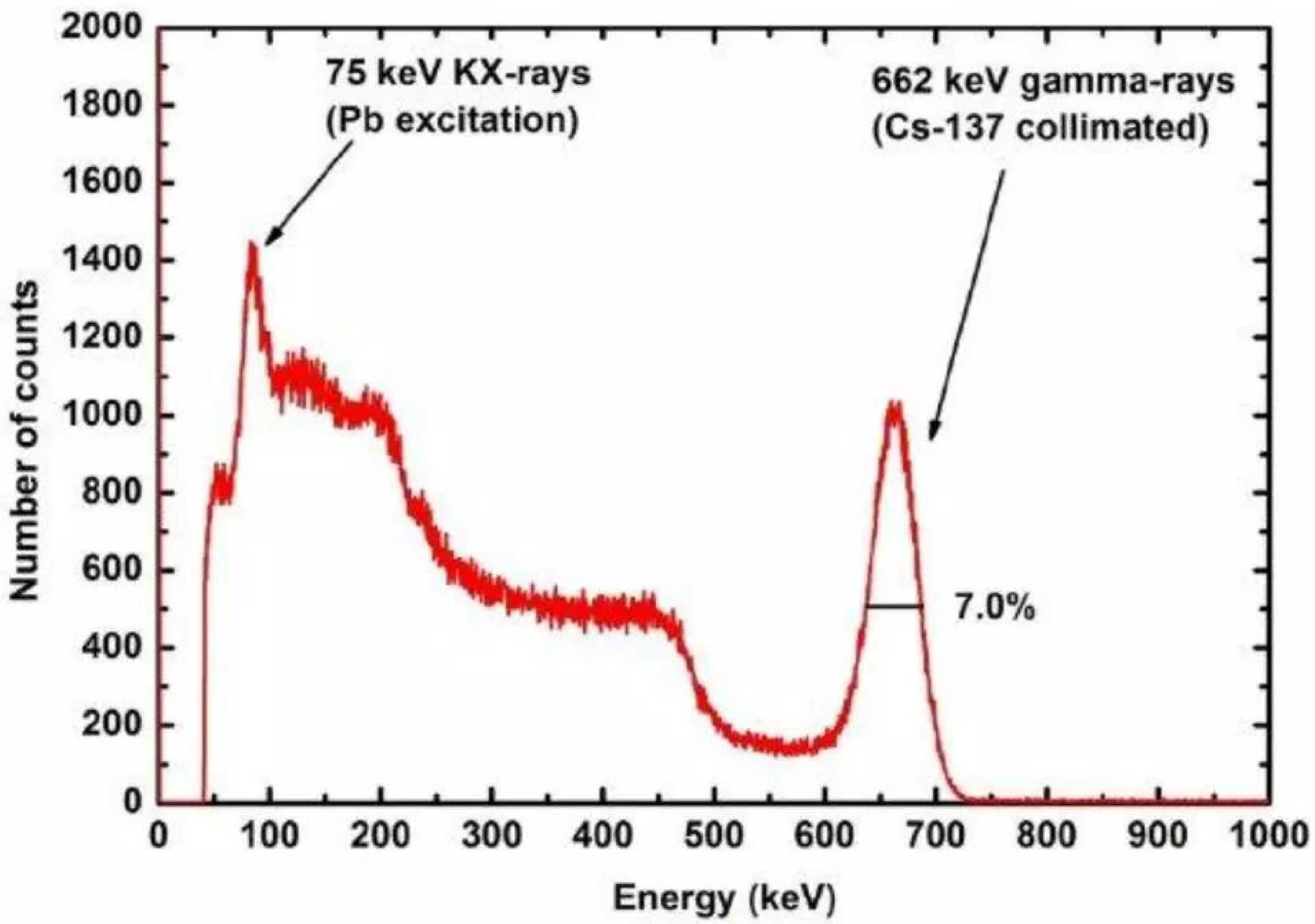
Figure in 2015 paper shows 7% resolution of 662 keV ^{137}Cs gamma-rays

Example of a ^{137}Cs gamma measurement

Scintillation response of Xe gas studied by gamma-ray absorption and Compton electrons

July 2015 · Journal of Instrumentation 10(07):P07003
DOI: 10.1088/1748-0221/10/07/P07003

Lukasz Swiderski · R. Chandra · A. Curioni · Show all 14 authors · Marek Szawłowski

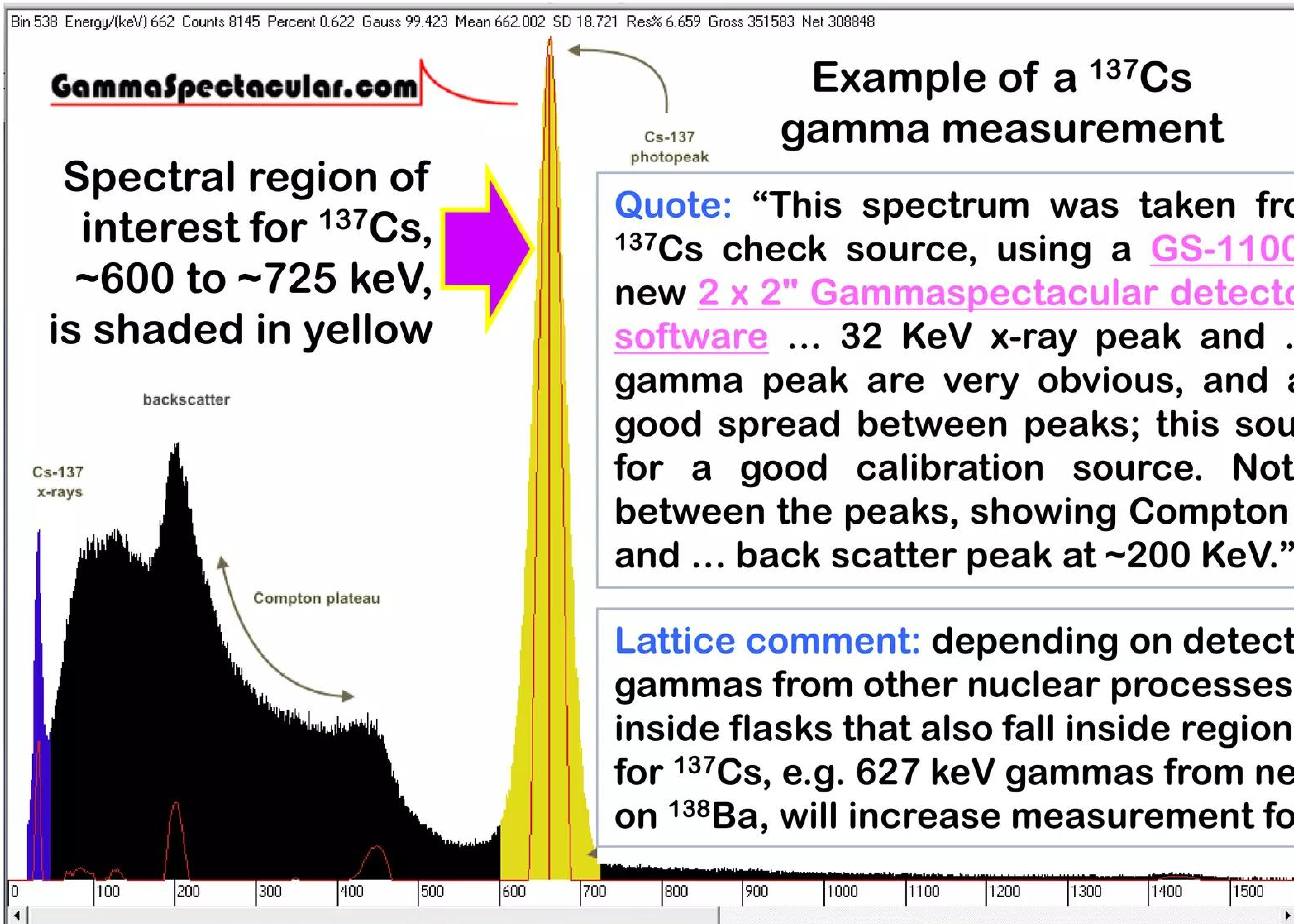


Quote: **"Two photomultipliers coupled to both windows at the end of the vessel allowed for registration of 3700 photoelectrons/MeV, which resulted in 7.0% energy resolution registered for 662 keV γ-rays from a ^{137}Cs source."**

https://www.researchgate.net/publication/280095066_Scintillation_response_of_Xe_gas_studied_by_gamma-ray_absorption_and_Compton_electrons/figures?lo=1

Further Lattice discussion about paper by Yum et al. (2019)

Example: gamma photons from ~600 - 725 keV contribute to ^{137}Cs counts



Example of a ^{137}Cs gamma measurement

Spectral region of interest for ^{137}Cs, ~600 to ~725 keV, is shaded in yellow

Quote: "This spectrum was taken from a 1 μC ^{137}Cs check source, using a GS-1100-PRO with new 2 x 2" Gammaspectacular detector and PRA software ... 32 KeV x-ray peak and ... 662 keV gamma peak are very obvious, and as there is good spread between peaks; this source makes for a good calibration source. Note ... area between the peaks, showing Compton continuum and ... back scatter peak at ~200 KeV."

Lattice comment: depending on detector resolution, gammas from other nuclear processes which occur inside flasks that also fall inside region of interest for ^{137}Cs, e.g. 627 keV gammas from neutron capture on ^{138}Ba, will increase measurement for ^{137}Cs counts

https://www.gammaspectacular.com/blue/cs137-spectrum

Lattice's final conclusions about paper by Yum et al. (2019)

ULE neutron-catalyzed LENR transmutation network can explain the data

- Yum et al's ^{137}Cs gamma measurements appear correct: probably are not a result of detector artifacts or measurement errors; controls exhibited normal ^{137}Cs decay rates. Supported by Okumoto et al (2016): also reported anomalous declines in ^{137}Cs gamma emissions during laboratory experiments with mixed bacteria. Rademacher et al (2006): saw very peculiar initial rise then steady decline in U(VI) concentrations
- If Yum et al's data is correct, then what caused anomalous decreases in gammas? Given current knowledge about nuclear decay, it seems reasonable to assume that major changes in ^{137}Cs decay rates induced by bacteria would be quite implausible. Since flasks are totally sealed after adding ^{137}Cs, it cannot be 'lost' from system. If 662 keV counts decreased abnormally, something happened to ^{137}Cs atoms. What?
- If ^{137}C decay rates did not change: then nuclear transmutation of ^{137}Cs to heavier Cs isotopes or other elements by mixed bacteria in flasks provides a possible, albeit controversial, explanation for anomalous decreases seen in ^{137}Cs gamma emissions
- Widom-Larsen theory of LENRs provides mechanism that explains Yum et al's data: ULE neutron capture on ^{137}Cs atoms followed by beta-decay of heavier unstable, neutron-rich Cesium isotopes as shown in neutron-catalyzed LENR transmutation network presented on earlier slides. Several nuclear processes that could occur in this network may explain the initial temporary increase in ^{137}Cs counts followed by a prolonged anomalous decrease. Detection of Barium-138 would confirm presence of network, assuming Barium-138 is not present in flasks when experiments begin

Input energy in forms of light and electricity can drive LENRs

Bacteria may be using LENRs to alter isotopes and transmute elements

"Not only is the Universe stranger than we imagine, it is stranger than we *can* imagine."

Laura 13

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

Electrically conductive bacterial nanowires interconnect *Shewanella oneidensis* cells
Image credit: Yuri Gorby, Rensselaer Polytechnic institute

Remarkable types of "electric bacteria" recently discovered

Some species can thrive with just electricity as their input energy source

"Could electricity-producing bacteria help power future space missions?"
Christina L. Cheung and Abby Tabor, NASA *Phys.org* June 28, 2018
https://phys.org/news/2018-06-electricity-producing-bacteria-power-future-space.html#jCp

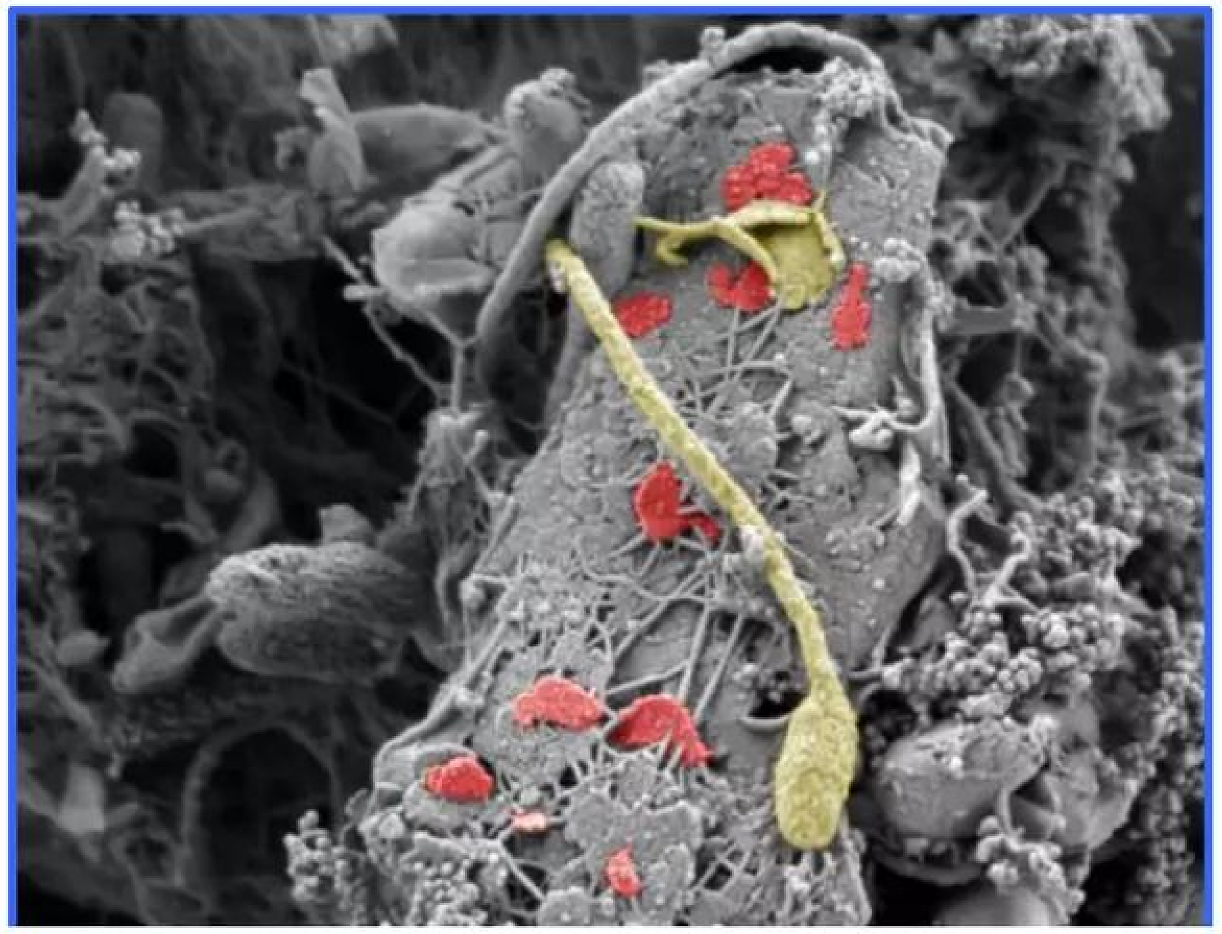
"Humans aren't the only ones who have harnessed the power of electricity. [*Shewanella oneidensis* MR-1 does this] too by producing structures that extend from their surface like wires to transfer electrons over distances."

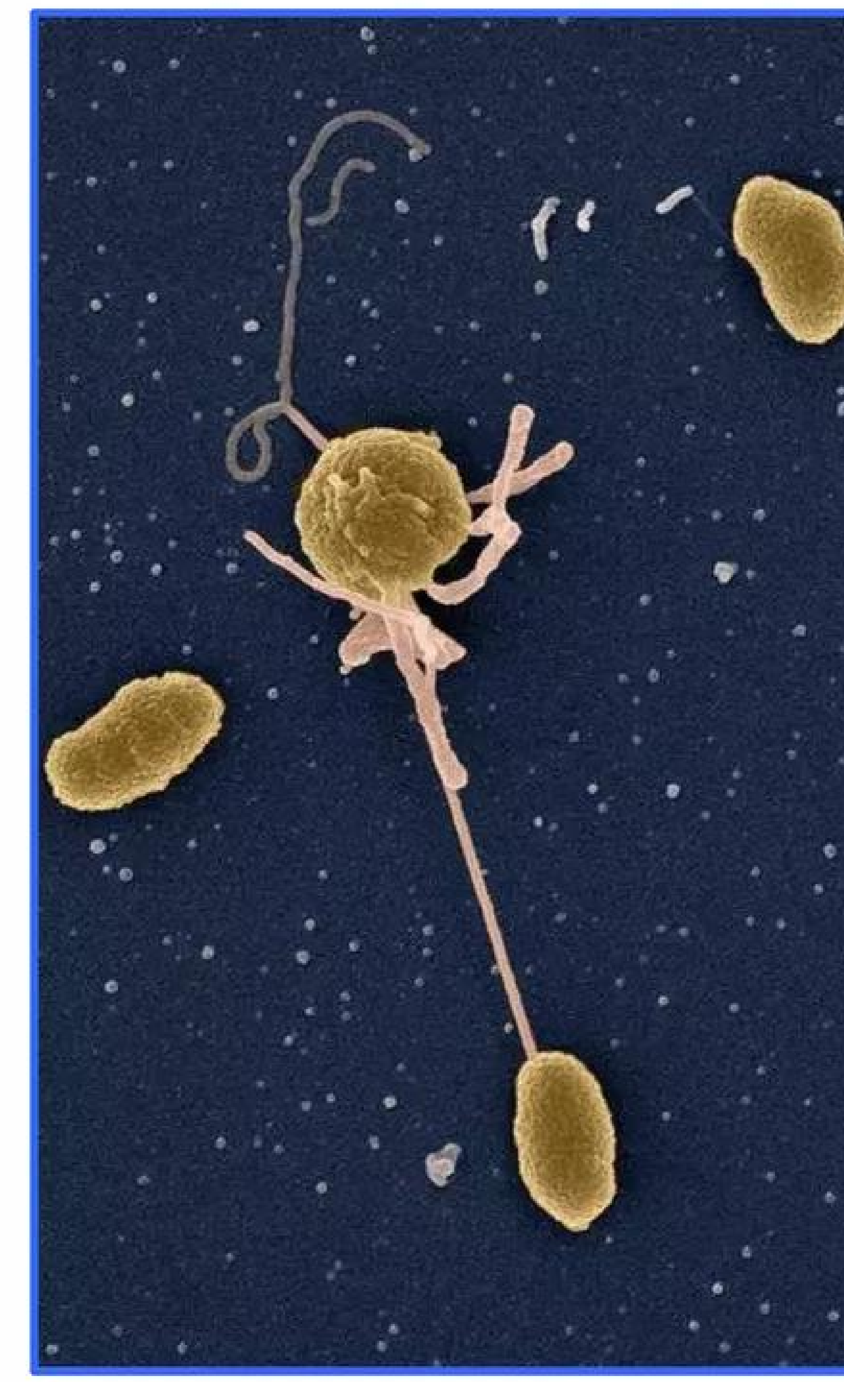
"*Shewanella* generally forms biofilms on metal-containing surfaces, such as rocks. The bacteria can make direct contact with molecules of metal in the rock using very thin appendages, known as bacterial nanowires, that extend from their outer surface. These are incredibly thin --- about 10 nanometers, which is about 10,000 times thinner than a human hair. Much like an electrical cord carries electricity from the socket to recharge your phone, they transport electrons a long distance, from the bacterial point of view. Scientists think that these organisms can also connect to each other using nanowires to pass electrons to other members of the community."

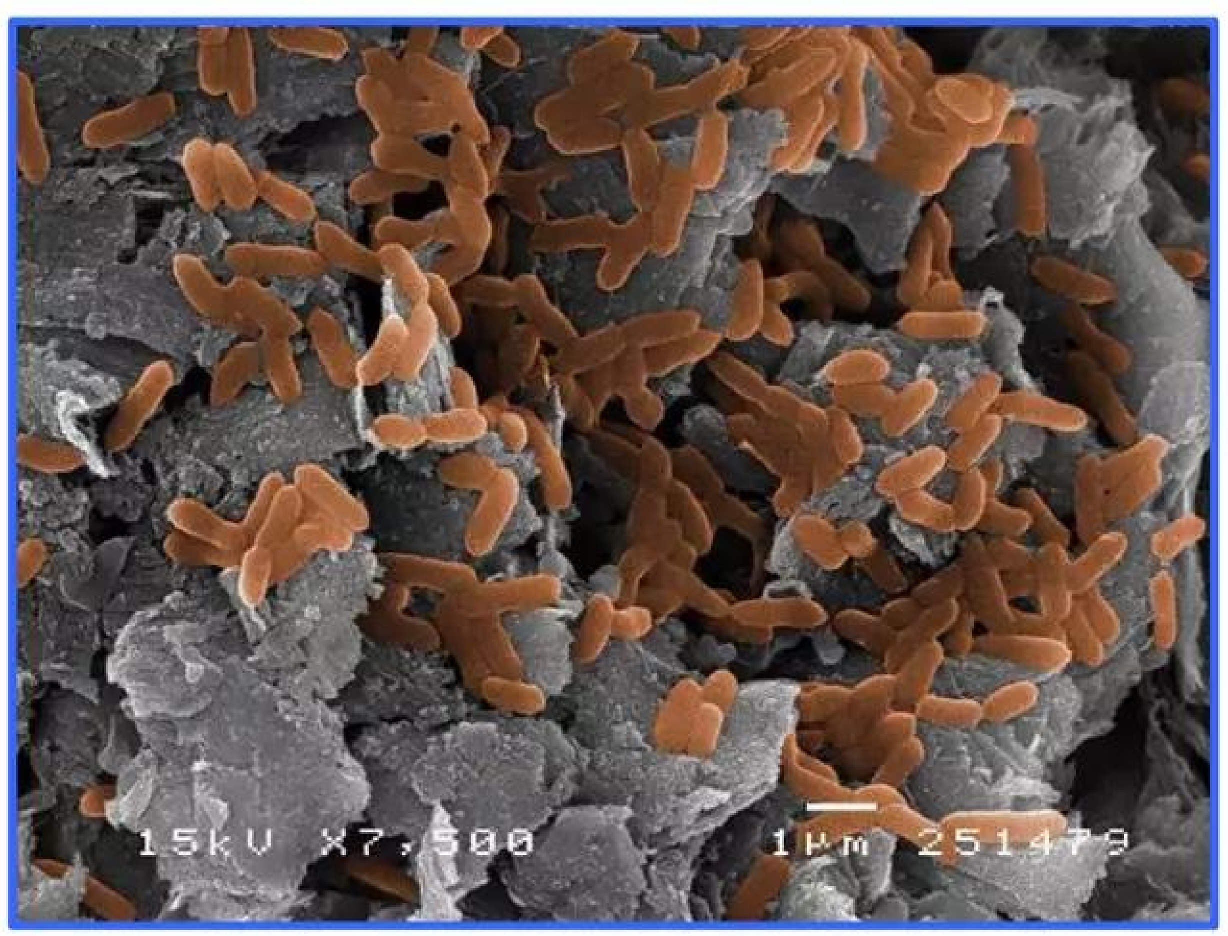
***Shewanella* "… has a back-up system that kicks in when … environment is low on oxygen. *Shewanella* keeps calm and carries on producing energy by using metals, like Iron and Manganese, instead."**

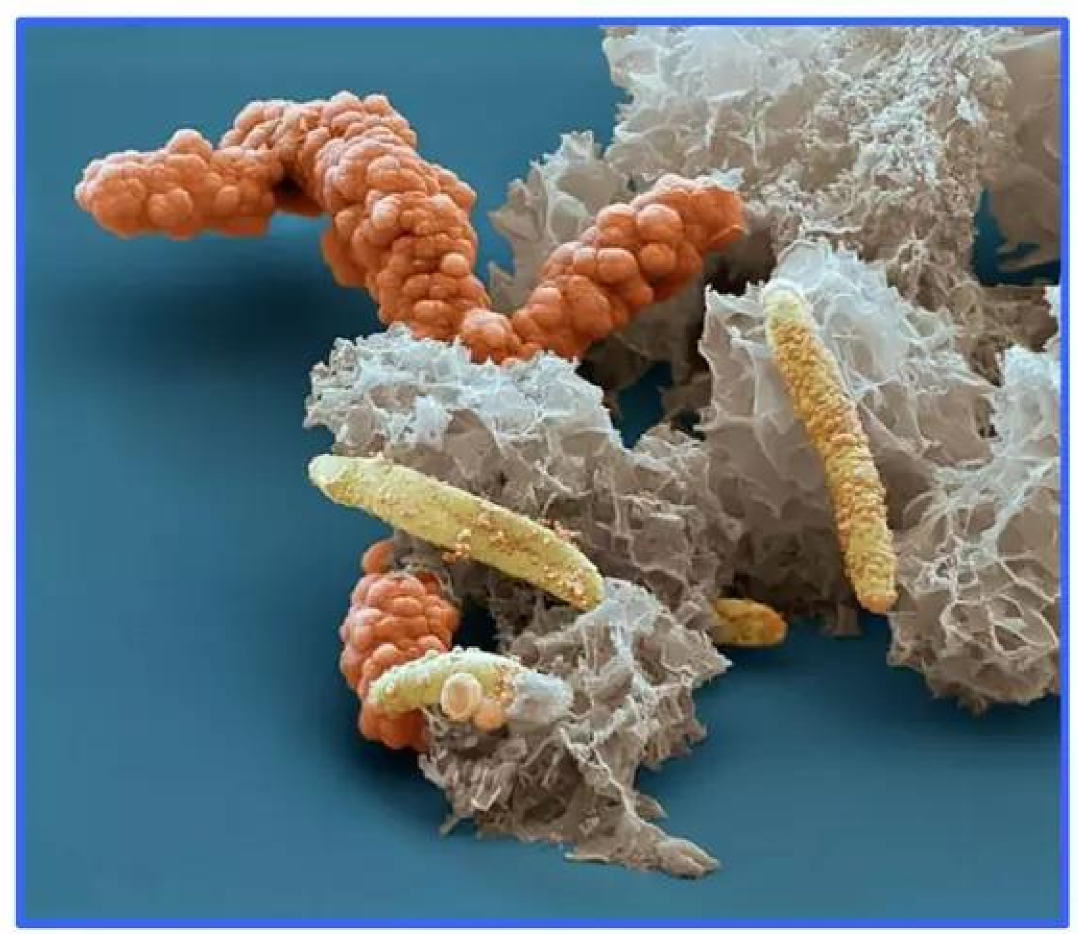
Bacteria often grow on or near mineral surfaces out in Nature

While not fully visible in every image, all of these bacteria have nanowires









Both authors are well-known researchers in electric bacteria

Recent major discoveries are "launching a new field of microbiology"

Live Wires

"Discoveries of microbial communities that transfer electrons between cells and across relatively long distances are launching a new field of microbiology."

Mohamed Y. El-Naggar and Steven E. Finkel *The Scientist* May 1, 2013

https://www.the-scientist.com/features/live-wires-39406

"Unique population architectures in which thousands of microbes act in concert as a multicellular unit."

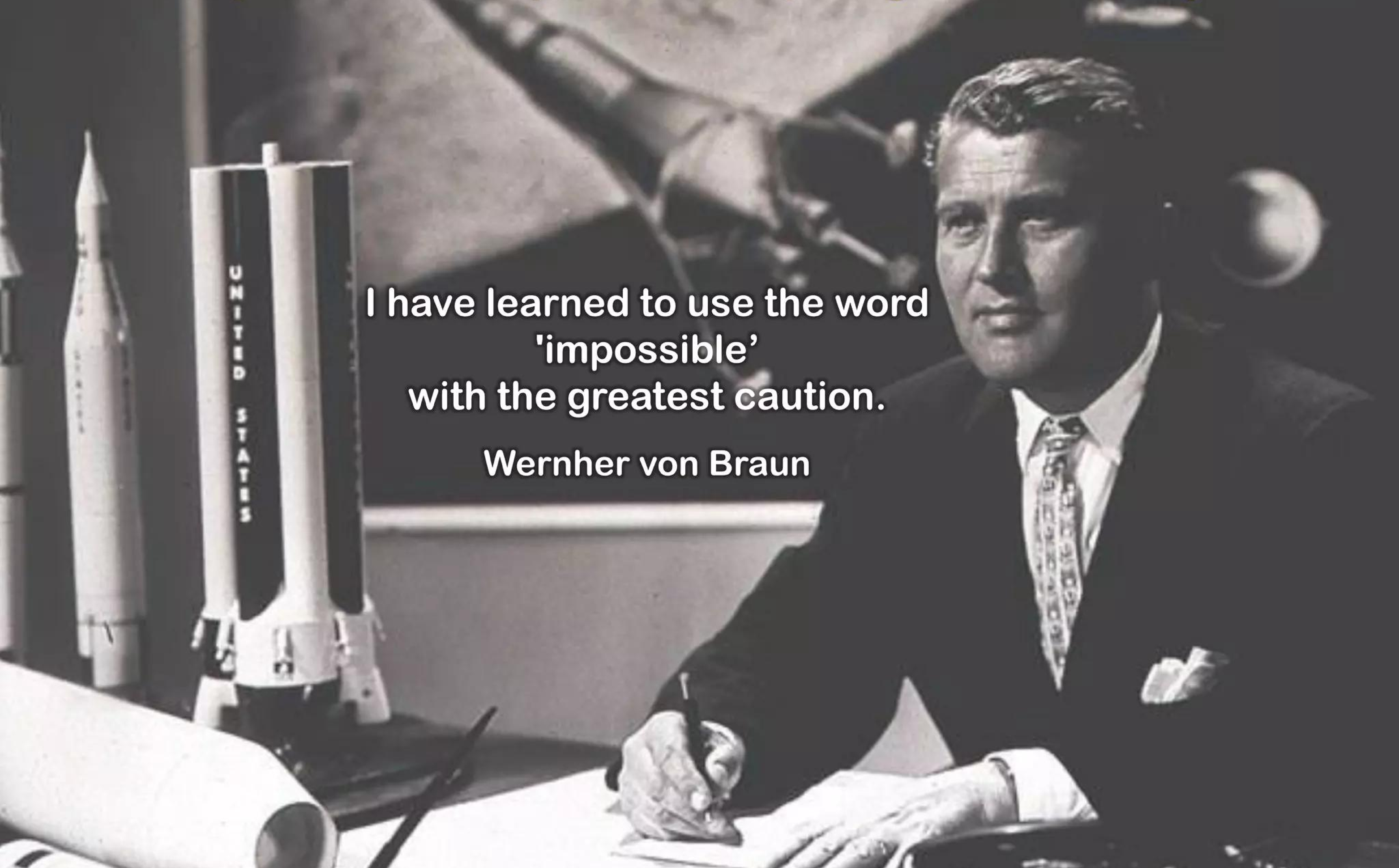
El-Naggar & Finkle

5.5 minute YouTube science video about electric bacteria – circa 2014

https://www.youtube.com/watch?v=_z0vkaJX_gs

Many think nuclear transmutation by microbes is impossible

Recent experimental data provides compelling evidence it may be real



I have learned to use the word
'impossible'
with the greatest caution.

Wernher von Braun

Possibility that bacteria are capable of transmuting elements

Paradigm shift in thinking that many scientists are very averse to believe

- Most recent thread of experimental mass-spectroscopy evidence dates back to Vysotskii & Kornilova (book published by Mir Publishing House – Moscow, 2003). Using Mossbauer spectroscopy, their data was credible; indicated mixed bacterial cultures could transmute Manganese into Iron. Their proposed theory for the process invoked "cold fusion" and was not believable. As a result, their otherwise good data was generally ignored
- V. Vysotskii & A. Kornilova's experimental data found in Chapter 4 of 2003 book indicated that laboratory cultures with *Deinococcus radiodurans* M-1 and *Bacillus subtilis* GSY-228 were able to synthesize elemental Iron (Fe – four stable isotopes) from Manganese (Mn - one stable isotope) present in Iron-free culture medium. In 2010, their 2003 book was republished with permission by the Pentagon Press (India) under a new title, "Nuclear transmutation of stable and radioactive isotopes in biological systems"
- In 2011, scientists at India's Indira Gandhi Centre for Atomic Research (IGCAR) publicly claimed that they had confirmed Vysotskii & Kornilova's earlier Mn → Fe transmutation results. To date, R. George et al. have been unable get their paper titled "Microbial catalyst transmutation of stable isotopes (Mn-55 to Fe-57) by biogranules" published in a first-tier journal. Mainstream journals have been extremely reluctant to publish such work

Widom-Larsen theory specifies details of LENR active sites

Bacterial LENR active sites: key requirements and likely locations in cells

- Widom-Larsen theory of LENRs posits that safe ULE neutron-producing, $e + p$ reaction is many-body collective process between quantum mechanically entangled protons (Hydrogen) and electrons in nm- μ-scale active sites where local electric field strength must exceed key threshold of ~1.4 x 10^{11} V/m for > 100 - 200 attoseconds
- While LENR active sites in biological systems are expected to differ from those that form spontaneously in abiotic condensed matter systems, they must still fulfill all the basic requirements noted above
- In what types of locations might such requirements be satisfied in bacteria? Four possibilities are apparent: (1) in or near active sites of enzymes in which msec-time-averaged E-fields are already known to exceed 10^{10} V/m; (2) on or near outer membrane surfaces, perhaps in close proximity to trans-membrane p^+ (H^+) proton pumps; (3) on or near mitochondrial membranes; and (4) inside, on surfaces of, or near points of attachment for modified pili (e.g. *Geobacter*) or extensions of outer cell wall membranes (e.g. *Shewanella*) --- both of which are called "nanowires" --- that carry electrical currents. They can connect bacteria to substrates or interconnect multiple species of many bacterial in cooperative energy transfer & sharing networks

Widom-Larsen theory specifies details of LENR active sites

Bacterial LENR active sites: key requirements and likely locations in cells

- Biological LENR active sites would have high concentrations of Q-M entangled protons (Hydrogen) & electrons (reactants for *e* + *p* reaction) in close proximity to each other in small regions where local injection of energy and/or rapid motion of charged groups operate to briefly increase local electric field strength above key 1.4 x 10^{11} V/m. Since produced neutrons have ultralow energy, intended 'targets' for neutron capture must be positioned inside or very close to active sites

- Many-body collective *e* + *p* reaction is endothermic; requires input energy equivalent to ~10-15 million ATP molecules per neutron. It is energetically 'expensive' to operate LENR transmutation networks; seems likely that bacteria would probably only do it for good reasons, whatever those might be. External light sources could provide bacteria with needed input energy; G. Lu et al (Lanzhou Institute of Chemical Physics, China 2016) claimed abiotic LENRs were triggered with light from a 300 Watt Xenon lamp. Electric currents can provide input energy for LENRs; remarkable types of "electric bacteria" recently discovered

- Widom-Larsen theory extends to aromatic molecules; that being the case, one might reasonably expect that aromatic groups are likely to be located in or near LENR active sites found in biological systems

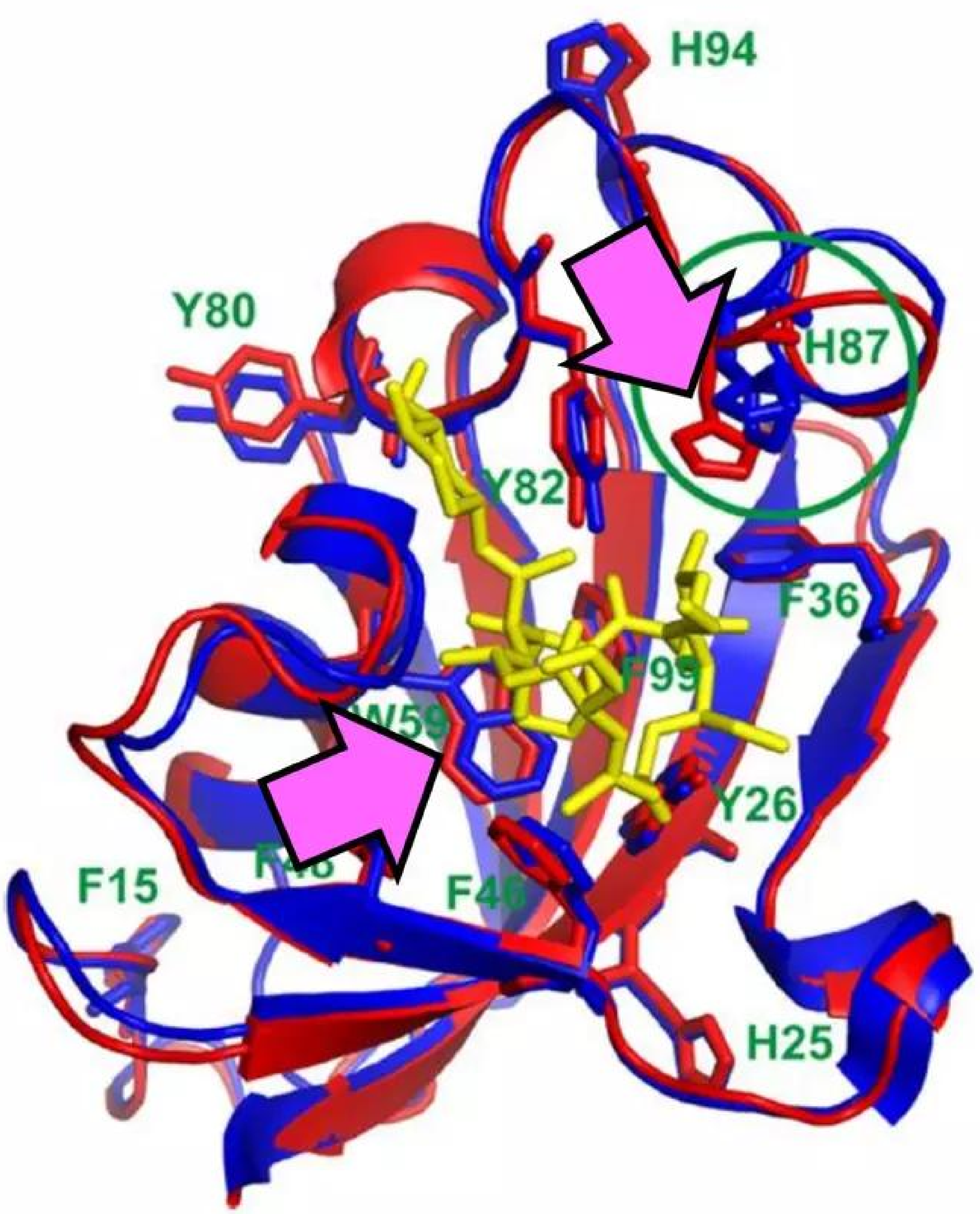
Widom-Larsen theory specifies details of LENR active sites

Aromatic groups and Hydrogen bonding common in enzyme active sites

"Dynamics of aromatic side chains in the active site of FKBP12"
U. Weininger et al. *Biochemistry* 56 pp. 334 - 343 (2016)
https://pubs.acs.org/doi/pdf/10.1021/acs.biochem.6b01157

Quote: "Aromatic side chains are overrepresented in substrate binding sites."

Fig.1. "Ribbon presentation of FKBP12"



- "FKBP12 … small human enzyme, aids protein folding by catalyzing cis-trans isomerization of peptidyl-prolyl bonds …
- involved in cell signaling pathways, calcium regulation … immune response."
- "Underlying molecular mechanisms are not fully understood, but it is well-known that aromatic residues in the active site and neighboring loops are important for substrate binding and catalysis."
- "Isomerase activity and the inhibitor-mediated immunosuppressive function both involve the active site of FKBP12, which contains 9 aromatic residues, but only 2 methyl-bearing side chains."

Widom-Larsen theory specifies details of LENR active sites

Bacterial LENR active sites could be located on or near outer membranes

"Bacterial outer membrane Porins as electrostatic nanosieves: exploring transport rules of small polar molecules"
H. Bajaj et al. *ACS Nano* 11 pp. 334 - 343 (2017)
https://pubs.acs.org/doi/pdf/10.1021/acsnano.6b08613

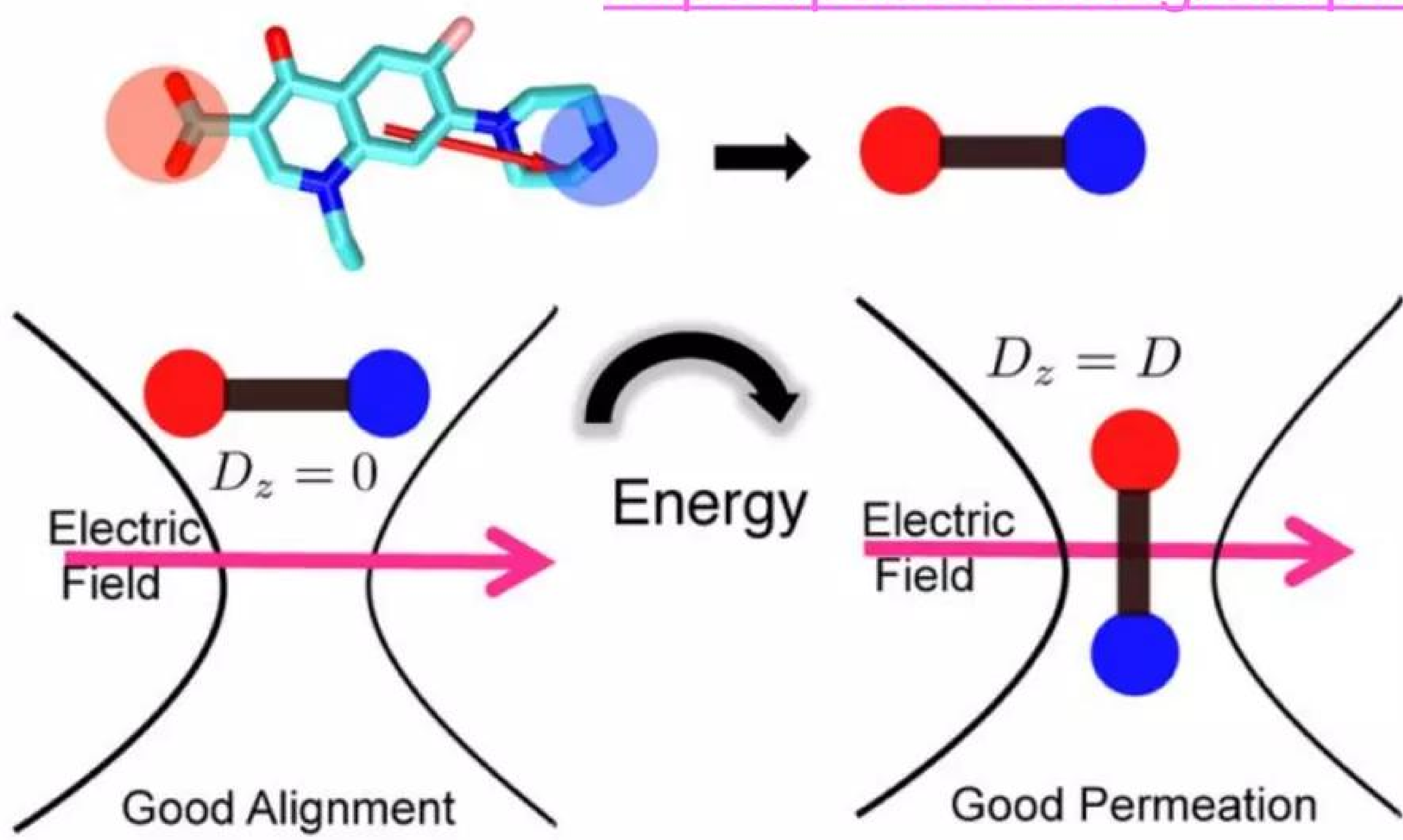
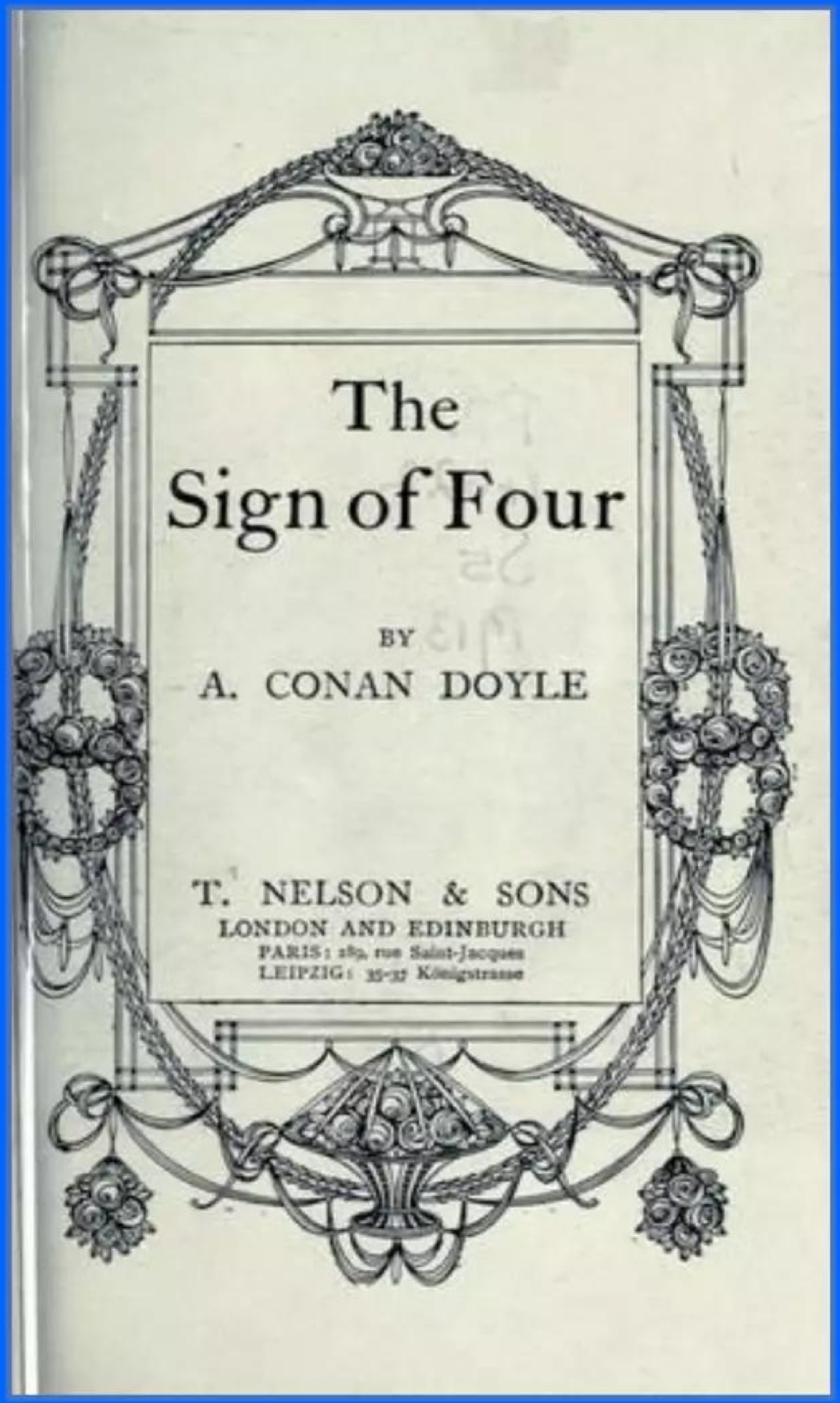


Figure 7. "Schematic representation of the kinetic model suggested in this work. From top: norfloxacin seen as a rigid dipole; norfloxacin interacting with internal electric field near and at CR; energetics of norfloxacin near (MD-ES0) and at (MD-ES1/ ES1) CR purple square indicates affinity site where current is blocked."

- "We sensed internal electrostatics of two most abundant outer membrane channels of Escherichia coli, using norfloxacin as a dipolar probe in single molecule electrophysiology."
- "Transversal electric field E_t should be equal to external one, ~ 210 mV over 7 Å, or 30 mV/Å [~3 x 10^8 V/m]. This upper value is in … good agreement with results of MD simulations and other theoretical and experimental values which predicted an electric field in range 10 - 30 mV/ inside the OmpF … use of dipoles that couple with electric field represents an appealing way to manipulate molecules of any size."

LENRs: radiation-free ultralow energy neutron reactions

Bacteria may be using LENRs to alter isotopes and transmute elements



"When you have eliminated the impossible, whatever remains, however improbable, must be the truth."

Arthur Conan Doyle
Sherlock Holmes:
"The Sign of the Four"
February 1890

Key publications about Widom-Larsen theory of LENRs

"Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces"
A. Widom and L. Larsen (author's copy)
European Physical Journal C - Particles and Fields 46 pp. 107 - 112 (2006)
http://www.slideshare.net/lewisglarsen/widom-and-larsen-ulm-neutron-catalyzed-lenrs-on-metallic-hydride-surfacesepjc-march-2006

"A primer for electro-weak induced low energy nuclear reactions"
Y. Srivastava, A. Widom, and L. Larsen (author's copy)
Pramana - Journal of Physics 75 pp. 617 - 637 (March 2010)
http://www.slideshare.net/lewisglarsen/srivastava-widom-and-larsenprimer-for-electroweak-induced-low-energy-nuclear-reactionspramana-oct-2010

"Theoretical Standard Model rates of proton to neutron conversions near metallic hydride surfaces"
A. Widom and L. Larsen
Cornell physics preprint arXiv:nucl-th/0608059v2 12 pages (2007)
http://arxiv.org/pdf/nucl-th/0608059v2.pdf

"Hacking the Atom" (Volume 1 - 484 pages) popular science book
Steven B. Krivit, Pacific Oaks Press, San Rafael, CA, September 11, 2016
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99
https://www.amazon.com/dp/0996886451

Working with Lattice Energy LLC, Chicago, Illinois USA

Partnering on LENR commercialization and consulting on other subjects

1-312-861-0115 lewisglarsen@gmail.com

L. Larsen c.v.: http://www.slideshare.net/lewisglarsen/lewis-g-larsen-cv-june-2013

- We believe Lattice is the world-leader in proprietary knowledge about LENR device engineering required to develop high-performance, long lived, scalable power sources. Our published peer-reviewed theoretical papers rigorously explain the breakthrough device physics of LENR processes, including the absence of dangerous energetic neutron or gamma radiation and lack of long-lived radioactive waste production
- Lattice welcomes inquiries from large, established organizations that have an interest in discussing the possibility of becoming Lattice's strategic capital and/or technology development partner
- Lewis Larsen also independently engages in consulting on variety of subject areas that include: bacterial transmutation; Lithium-ion battery safety issues; long-term electricity grid reliability and resilience; and evaluating potential future impact of LENRs from long-term investment risk management perspective for certain types of large CAPEX projects

