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Commercializing a Next-Generation Source of Safe Nuclear Energy

Low Energy Nuclear Reactions (LENRs)

Widom-Larsen theory, weak interactions, transmutations, nanoscale evidence for nuclear effects, and the road to commercialization

Technical Overview

Lewis Larsen, President and CEO

"Energy, broadly defined, has become the most important geostrategic and geoeconomic challenge of our time."

Thomas Friedman
New York Times, April 28, 2006

Summary - I

- ✓ This presentation is a technically oriented overview of Low Energy Nuclear Reactions or LENRs, an exciting new energy technology with a controversial history dating back 20 years. Herein we will cover some history, the Widom-Larsen theory of LENRs, evaluate experimental evidence in the context of that theory, and outline Lattice's approach and roadmap to commercialization.
- ✓ Aside from continued controversy, an expanding body of varied experimental data and major theoretical breakthroughs now position LENRs to potentially be developed into a carbon-free, environmentally 'green' source of low cost nuclear energy.
- ✓ LENRs differ sharply from fission and fusion technologies in that their unique distinguishing features are dominated by weak interactions rather than the strong interaction.

Summary - II

- ✓ Dominance of weak interactions is a crucial difference that enables LENRs to release large amounts of nuclear binding energy over long periods under moderate conditions (no star-like temperatures or pressures needed) without producing large fluxes of deadly energetic neutron or gamma radiation or environmentally significant quantities of long-lived radioactive isotopic waste.
- ✓ Lacking serious radiation and radioactivity problems, onerous and expensive shielding, containment, and waste disposal requirements that have endlessly plagued fission and fusion power generation could be non-issues for commercial versions of LENR technologies. Thus, LENRs have the potential to be vastly less costly than competing nuclear energy technologies.
- ✓ 'Weak interactions' are not weak energetically. In fact, they have the potential to produce just as much energy as fusion reactions.

Summary - III

- ✓ In a 2006 paper published in the respected, peer reviewed *European Physical Journal C – Particles and Fields*, we outlined a practical LENR fuel cycle based on low-cost ordinary Lithium that can produce a net ~27 MeV of energy. This is roughly comparable to energy releases from D-D and D-T fusion reactions. Herein, readers will see how even larger energy releases from LENR nucleosynthetic paths may be possible.
- ✓ If commercialized, LENR-based power generation systems could potentially be much better than fusion. Such a development would have a major impact on global energy markets.
- ✓ Selected technical references and URLs to Internet resources have been provided herein for readers who may wish to learn more about LENRs, explore reported experimental data for themselves, and draw their own independent conclusions about the subject matter and ideas contained in this document.

Contents

Note: Slides # 60 – 67 were added on July 14, 2009

History

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Anomalies observed in many LENR experiments

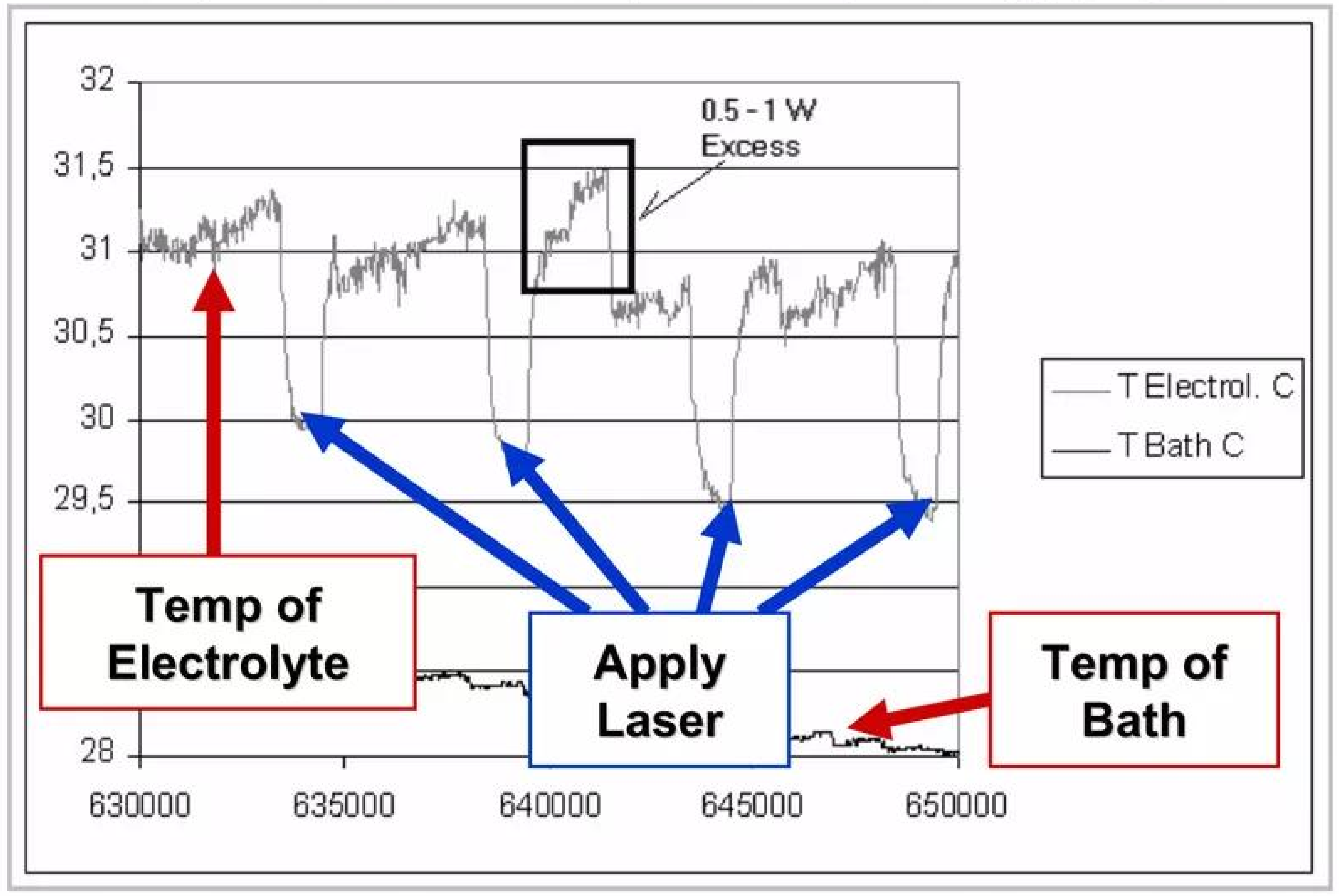
Since 1989, LENR researchers have reported a variety of anomalies in different types of heavy and light hydrogen (e.g., D_2O and H_2O) experimental systems, all involving 'heavily-loaded' metallic hydrides. Have observed electrical current-, laser-, RF-, and pressure-driven triggering of various types of anomalous, arguably nuclear effects as follows:

- ✓ **Calorimetrically measured excess heat effects – wide range of values from just milliwatts to tens of Watts in some cases**
- ✓ **Production of helium isotopes (mostly He-4, rarely He-3); rarely detect tritium, H-3 unstable H isotope**
- ✓ **Production of modest fluxes of MeV-energy alpha (α) particles and protons as well as minuscule emissions of low energy X- and gamma ray photons (no large fluxes of MeV-energy gammas/neutrons)**
- ✓ **Production of arrays of different stable isotopic transmutation products (e.g., different elements)**

In 1831, Michael Faraday was pilloried as a charlatan by fellow scientists when he claimed that he could generate an electric current simply by moving a magnet in a coil of wire. Stung by these vicious accusations, Faraday said, "Nothing is too wonderful to be true if it be consistent with the laws of nature."

Experimental example of laser triggering

Sharp increase in excess power/temp after applying laser



Source: Violante et al (ENEA – Italy), Asti Conference, 2004

Some scientists remain skeptical about LENR anomalies

Status of reported LENR experimental anomalies by type:

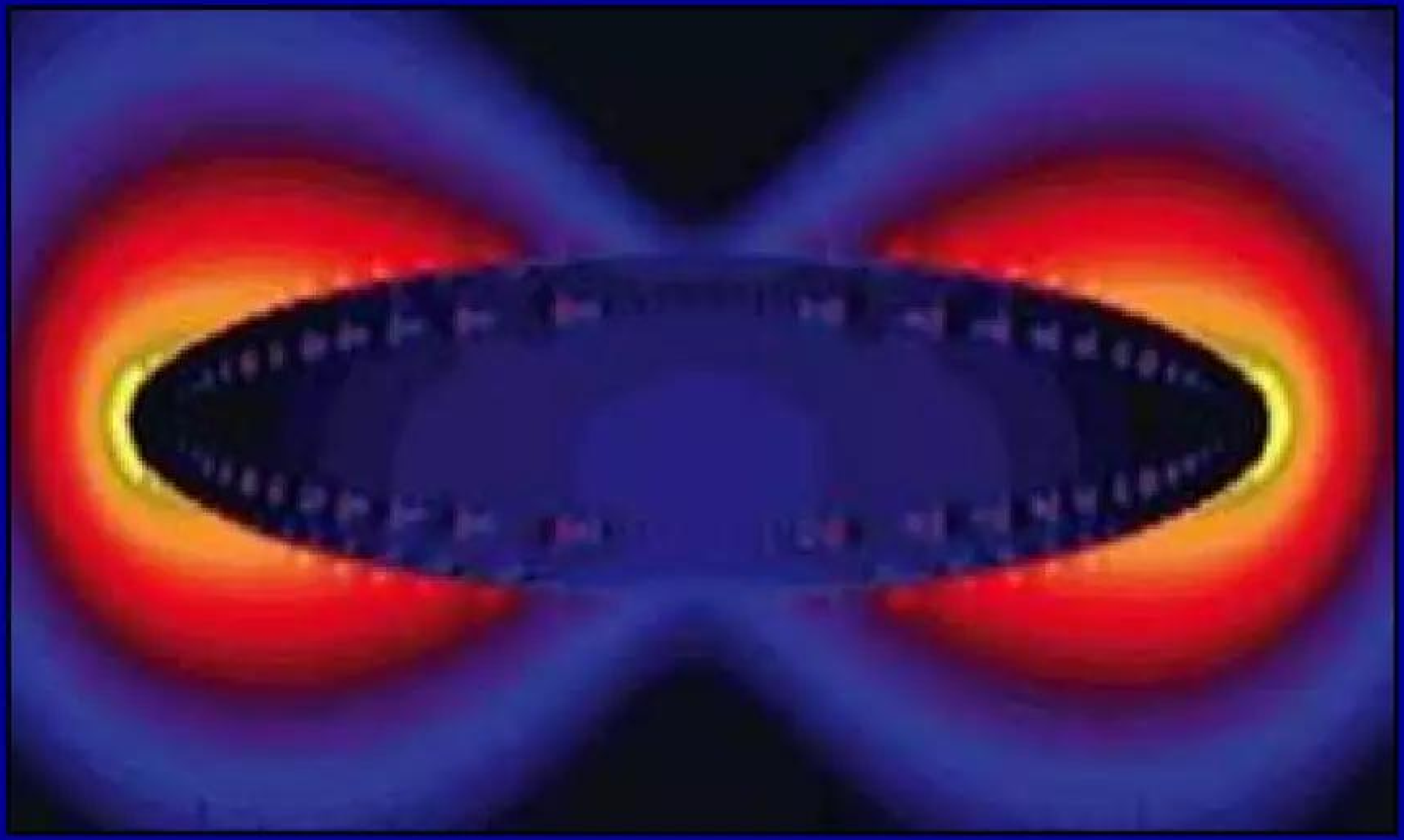
- ✓ Calorimetrically measured macroscopic excess heat effects – remain extremely contentious: still very hard to reproduce --- nobody can "boil tea" yet; many physicists still distrust calorimetry as chemists' 'black art' measurements

- ✓ Production of gaseous helium isotopes – difficult to detect reliably and be able to unquestionably exclude external contamination as a possibility; still only accurately measured in a handful of LENR experiments. Most researchers do not look for gaseous He-4 due to expense/skill necessary for good measurements

- ✓ Production of modest fluxes of MeV-energy alpha particles and protons – readily reproduced and reported by number of LENR researchers; some such results published in lesser mainstream journals. While supportive, not conclusive

- ✓ Production of a broad array of different transmutation products – widely reported in many experiments by LENR researchers located all over the world; unlike excess heat, transmutations are much easier to reproduce. Difficult for skeptics to argue with competent mass spectroscopy and like measurements; when pressed, they still invoke the 'external contamination' red herring, which is disingenuous considering large number and significant reliability of such results

Widom-Larsen theory of LENRs



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W-L theory successfully addresses longstanding issues

Widom-Larsen developed theory after careful evaluation of a large body of experimental data on LENRs; it addresses longstanding issues about LENRs that "cold fusion" theorists have been unable to answer to satisfaction of mainstream physicists, e.g., Huizenga (1993):

- ✓ **Overcoming the Coulomb energy barrier: weak interaction-based W-L theory posits that ultra low momentum neutrons and neutrinos are created from protons and heavy-mass surface electrons in very high electromagnetic fields found on surfaces of 'loaded' metallic hydrides. Unlike charged-particle D-D fusion, no Coulomb barrier to ultra low momentum (ULM) neutron absorption by nuclei; neutrons have no charge**

- ✓ **Absence of large emissions of dangerous high-energy neutrons: ULM neutrons of the W-L theory have extraordinarily low energies and huge absorption cross sections --- are therefore very efficiently captured by nearby nuclei. Consequently, ULMNs are very difficult to detect directly**

- ✓ **Absence of large, dangerous emissions of gamma radiation: in condensed matter LENR systems, heavy-mass surface plasmon polariton (SPP) electrons have a unique ability to absorb gamma rays and convert them directly to lower-energy infrared photons. In LENR systems, gammas produced during neutron captures and beta decays are thus absorbed and converted to heat internally rather than being emitted to the outside**

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Widom-Larsen theory is based on established physics

- ✓ **W-L theory is based on accepted physics; no "new physics" is postulated**
- ✓ **Built upon well-established 'bedrock' of electroweak theory and many-body collective effects; no ad hoc mechanisms**
- ✓ **Explains collective neutron production in condensed matter with e + p, e + d, e + t weak interactions that occur in micron-scale H+ ion 'patches' having very high local electric fields that form on 'loaded' metal hydride surfaces**
- ✓ **Collectively produced neutrons have huge DeBroglie wavelengths and ultra low momentum (energy); thus have gigantic capture cross sections and are virtually all absorbed locally. Cannot be detected directly; no external release of free neutrons**
- ✓ **Explains unexpected absence of 'hard' MeV-energy gamma radiation in such systems**

→ ***First observed by Chadwick in 1932, a neutron is unstable as an isolated 'free' neutral particle; outside of a atomic nucleus it has a half-life of ~13 minutes, spontaneously decaying into a proton and an electron. If free neutrons or new capture-products are observed in an experimental system, it means that they were either recently produced in some sort of nuclear reaction(s), or released from nuclei via decay processes***

→ ***Neutrons are extremely effective as 'catalysts' of nuclear reactions in that being uncharged, there is no Coulomb barrier to their merging with another nucleus, so they are readily absorbed or 'captured' by atomic nuclei. Such captures are in fact transmutation reactions that can produce new chemical elements or isotopes that may be stable or unstable (in which case they undergo some form of decay)***

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W-L theory explains anomalies in LENRs

Widom-Larsen theory of LENRs can:

- ✓ Explain absence of certain ‘normal’ nuclear products and abnormal proportions compared to what is known about D-D fusion reactions (as reported in original work of Pons & Fleischmann and thousands of other experiments since 1989) - according to W-L, this is because LENRs simply do not involve appreciable amounts of D-D or D-T fusion processes
- ✓ Explain insignificant production of dangerous long-lived radioactive isotopes (as reported in the original work of Pons & Fleischmann as well as thousands of other LENR experiments since 1989)
- ✓ Explain details of the mechanism for laser triggering of excess heat and transmutations in H or D LENR systems (as reported by Letts, Cravens, Violante, and McKubre)
- ✓ Calculate reaction rates that are in agreement with the range of rates (10^9 to 10^{16} cm^2/sec) that have been observed in different types of LENR experimental systems (as reported by Miles, McKubre, Miley and others)

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W-L theory also explains many other aspects of LENRs

Widom-Larsen theory of LENRs also explains:

- ✓ Source of excess heat seen in D and H (heavy and light water) systems (e.g., Pons & Fleischmann, McKubre, Miley, Miles, Focardi et al.)
- ✓ ^{4}He and ^{3}He observed in D electrolytic systems (e.g., McKubre, Miles)
- ✓ Unusual 5-peak stable transmutation product mass spectra observed in H and D systems (e.g., Miley, Mizuno)
- ✓ Transmutation products frequently seen in H and D LENR systems (e.g., Miley, Mizuno, Iwamura, Violante, and many others) as well as in certain types of high-current exploding wire and vacuum diode experiments (US, UK, Russia - in experiments back as far as 1905)
- ✓ Variable fluxes of soft X-rays seen in some experiments (e.g., Violante, Karabut)
- ✓ Small fluxes of high-energy alpha particles observed in certain LENR systems (e.g., Lipson, Karabut)

Basics of W-L theory in condensed matter LENR systems

Weak interaction processes are very important in LENRs

→ *No strong interaction fusion or heavy element fission occurring below, only weak interactions*

1. **E-M radiation on metallic hydride surface increases mass of surface plasmon electrons**
2. **Heavy-mass surface plasmon polariton electrons ($\tilde{e}^-$) react directly with surface protons (p^+) or deuterons (d^+) to produce ultra low momentum (ULM) neutrons (n_{ulm} or $2n_{ulm}$, respectively) and an electron neutrino (ν_e)**
3. **Ultra low momentum neutrons (n_{ulm}) are captured by nearby atomic nuclei (Z, A) representing some element with charge (Z) and atomic mass (A). ULM neutron absorption produces a heavier-mass isotope ($Z, A+1$) via transmutation. This new isotope ($Z, A+1$) may itself be stable or unstable**
4. **Certain unstable isotopes β^- decay, producing: transmuted element with increased charge ($Z+1$), ~ same mass ($A+1$) as 'parent' nucleus; β^- particle (e^-); and antineutrino ($\bar{\nu}_e$)**

1.
$$(\text{radiation}) + e^- \rightarrow \tilde{e}^-$$

2.
$$\tilde{e}^- + p^+ \rightarrow n_{ulm} + \nu_e$$
$$\tilde{e}^- + d^+ \rightarrow 2n_{ulm} + \nu_e$$

3.
$$n_{ulm} + (Z, A) \rightarrow (Z, A+1)$$

Unstable or Stable

4.
$$(Z, A+1) \rightarrow (Z+1, A+1) + e^- + \bar{\nu}_e$$

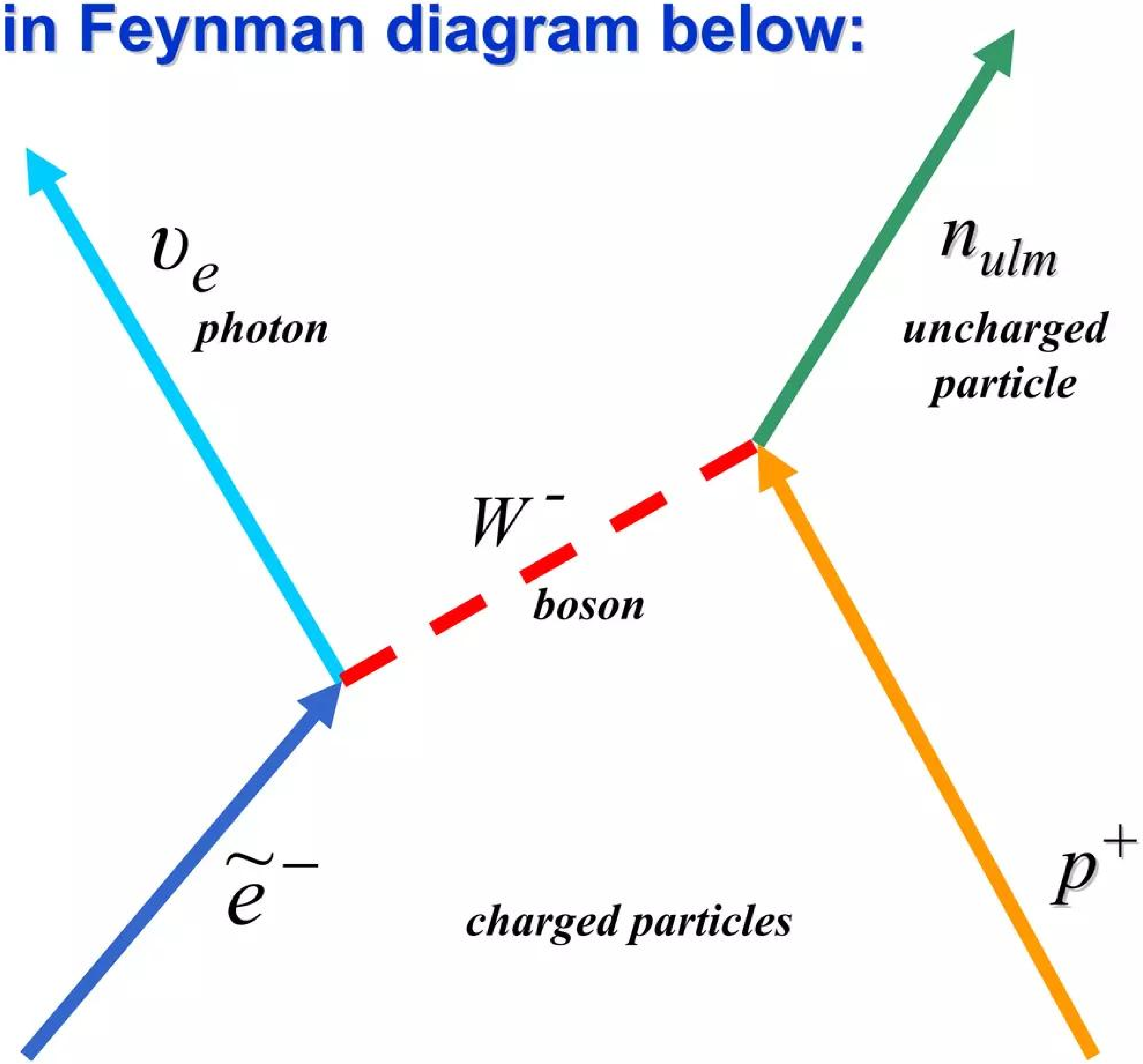
Unstable Isotope

New element – stable or unstable

→ *Weak interaction β^- decays (shown above), direct gamma conversion to infrared (not shown), and α decays (not shown) produce most excess heat observed in LENR systems*

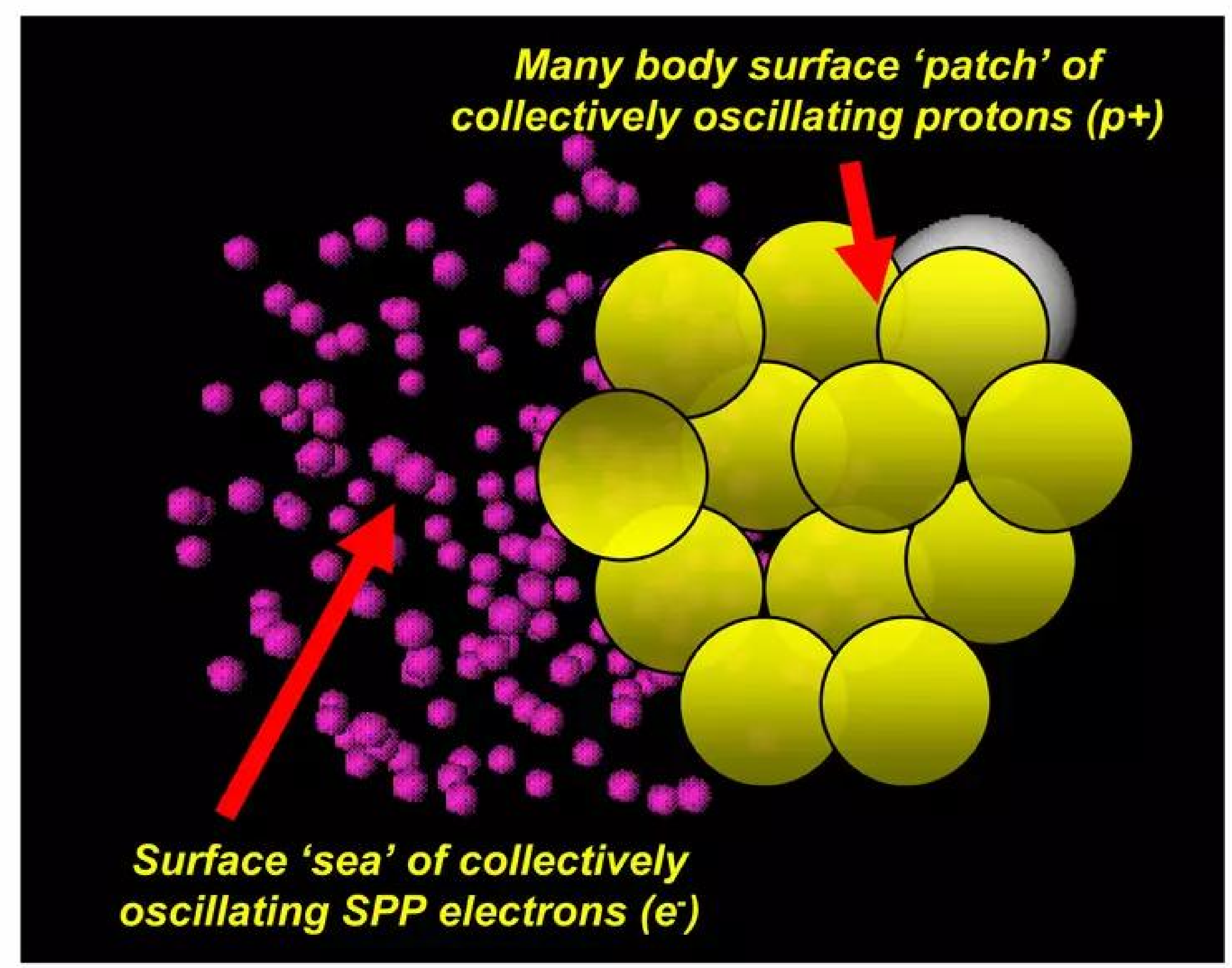
Widom-Larsen extend collective effects to Standard Model

Simple two-body collision shown in Feynman diagram below:



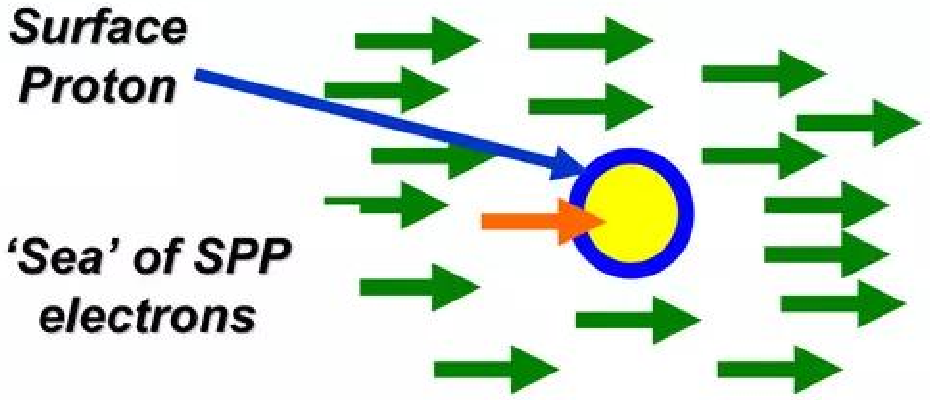
$$\tilde{e}^- + p^+ \longrightarrow n_{ulm} + \nu_e$$

Now add collective rearrangements from condensed matter effects. It is not just a two body collision !!!



Collective many-body effects extremely important in LENRs

- ✓ Collective effects lie at the heart of W-L physics of condensed matter LENRs
- ✓ LENRs can occur at modest temperatures and pressures in condensed matter because of collective electromagnetic coupling (caused by a breakdown of the Born-Oppenheimer approximation) that occurs between two types of intrinsically collective oscillations found on metallic hydride surfaces:
  - – Surface plasmon polariton (SPP) electrons (determine colors of metals)
  - – Contiguous, coherent surface 'patches' of protons, deuterons, or tritons that can form on H, D, or T 'loaded' hydrides
- ✓ Such coupling helps create very high local electric fields > 10^{11} V/m that can renormalize masses of SPPs above threshold for ULM neutron production

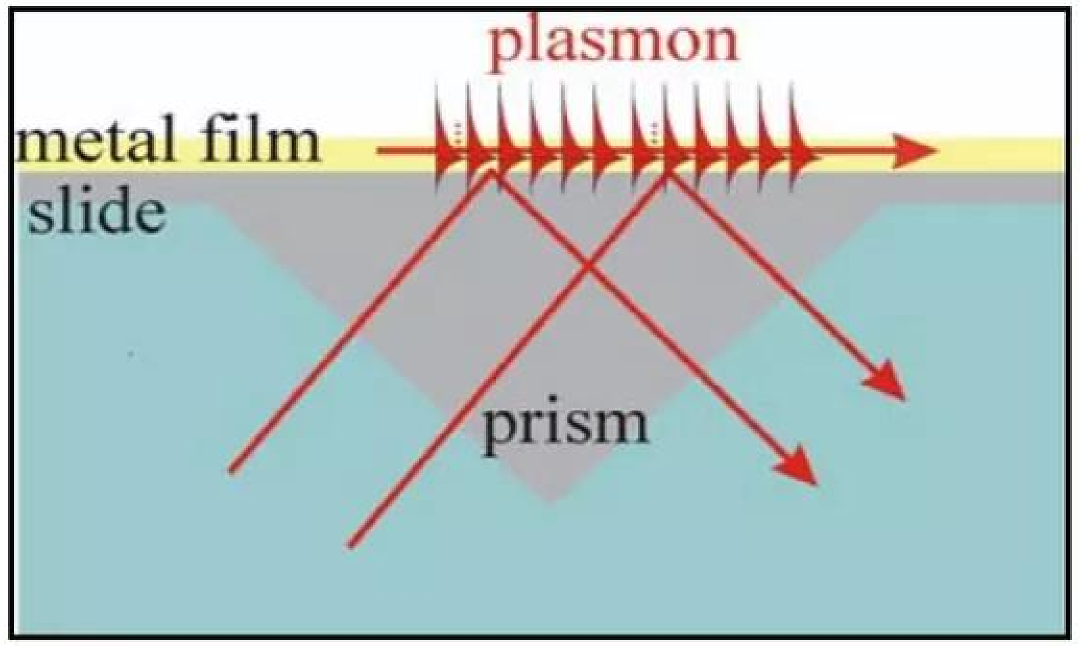


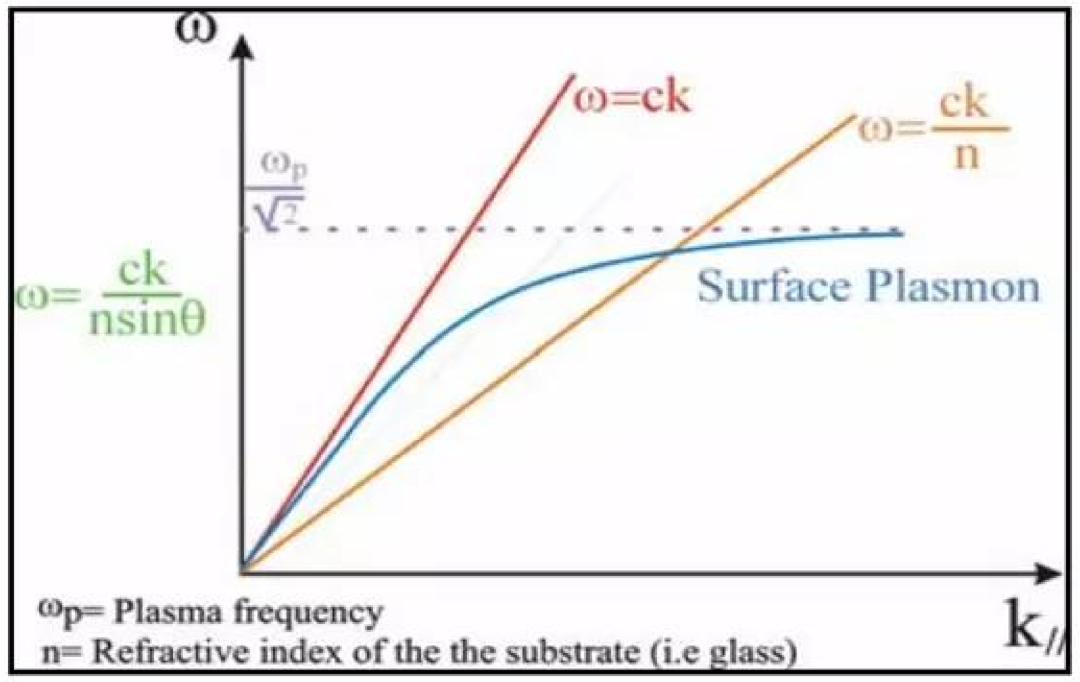
When many electrons interact with a proton, only one electron may pierce into the proton's inside. That electron dies. All of the other electrons have but donated a little energy. The SPP plasma modes are collective and in synchronization

It is not difficult to throw a baseball at a target with an energy of 10^{23} electron volts, but one will not see any nuclear transmutations. The electrical currents must be collective and the electrons must transfer energy coherently and all together to trigger nuclear effects

Collective oscillations: surface plasmon polariton electrons

- ✓ **Confined to surfaces and near-surface regions**
- ✓ **Surface plasmons (SPs) are a collective oscillation of free electron gas at optical frequencies. Exist on all metallic surfaces; some elements 'fire-off' SP excitations 'easier' than others (e.g., gold, silver)**
- ✓ **Surface Plasmon Polaritons (SPPs) are effectively quasiparticles resulting from strong coupling of electromagnetic waves with an electric or magnetic dipole-carrying excitation; under the right conditions, SPPs can couple with laser light**
- ✓ **Play very important role in Surface Enhanced Raman Spectroscopy (SERS) and plasmonics**
- ✓ **Extremely sensitive to the physical properties of substrate materials on which they propagate**
- ✓ **Interact very strongly with nanoparticles located on surfaces: changes in relative nanoparticle size, composition, and placement geometry can create huge variations in local electric field strengths**
- ✓ **Can be conceptualized as a collectively oscillating 'film' of electrons covering the surface of metals**





The rich dynamical behaviors, exquisite spatial sensitivity, and complex energetics of SPP electrons in and around 'patches' of hydrogenous ions found on the surfaces of 'loaded' metallic hydrides are in some ways reminiscent of electrons involved in <u>vastly lower-energy</u> 'chemicurrents,' which are fluxes of " … fast (kinetic energy ~> 0.5 – 1.3 eV) metal electrons caused by moderately exothermic (1 - 3 eV) chemical reactions over high work function (4 – 6 eV) metal surfaces." e.g., Pd

See: S. Maximoff and M. Head-Gordon, "Chemistry of fast electrons," PNAS USA 106(28):11460-5, July 2009

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Collective oscillations: surface protons, deuterons, tritons

- ✓ **Under proper conditions, micron-scale many-body 'patches' comprising many-body homogeneous collections of p+, d+, or t+ ions will form spontaneously on the surfaces of hydrogen-'loaded' metals in various sizes at variable numbers of sites scattered at random across such surfaces**

- ✓ **Protons, deuterons, or tritons found within such many-body 'patches' spontaneously oscillate coherently/collectively; their quantum mechanical (QM) wave functions are effectively 'entangled' with each other and w. SPP electrons**

- ✓ **Unrelated to LENRs, researchers in other fields have detected the presence of such entangled many-body quantum systems using various techniques that include neutron and electron Compton scattering experiments**

- ✓ **Collective oscillation and effective QM entanglement of protons and electrons is widespread in nature: e.g., from a chemical perspective, water is simply H_2O. However, when water molecules are 'imaged' with electron and deep inelastic neutron Compton scattering techniques, one instead 'sees' $H_{1.5}O$. Anomalously 'fewer' protons or deuterons are observed by such methods because of B-O breakdown and related QM entanglement of particles**

For example, C. A. Chatzidimitriou-Dreismann (Technical University of Berlin) et al. have published extensively on this subject for years. In particular, please see:

→ ***"Attosecond quantum entanglement in neutron Compton scattering from water in the keV range" - 2007; can be found at***

http://arxiv.org/PS_cache/cond-mat/pdf/0702/0702180v1.pdf

"Several neutron Compton scattering (NCS) experiments on liquid and solid samples containing protons or deuterons show a striking anomaly, i.e. a shortfall in the intensity of energetic neutrons scattered by the protons; cf. [1, 2, 3, 4]. E.g., neutrons colliding with water for just 100 − 500 attoseconds (1 as = 10^{-18} s) will see a ratio of hydrogen to oxygen of roughly 1.5 to 1, instead of 2 to 1 corresponding to the chemical formula H_2O. … Recently this new effect has been independently confirmed by electron-proton Compton scattering (ECS) from a solid polymer [3, 4, 5]. The similarity of ECS and NCS results is striking because the two projectiles interact with protons via fundamentally different forces, i.e. the electromagnetic and strong forces."

→ ***Also, J. D. Jost et al., "Entangled mechanical oscillators" Nature 459 pp. 683 – 685 4 June 2009, in which "mechanical vibration of two ion pairs separated by a few hundred micrometres is entangled in a quantum way."***

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Creation of ULM neutrons on loaded hydride surfaces - I

- Hydride forming elements, e.g., Palladium (Pd), Nickel (Ni), Titanium (Ti), etc. can be viewed as akin to metallic 'sponges' that can absorb significant amounts of hydrogen isotopes in atom % via 'loading' mechanisms
- Analogous to loading a bone-dry sponge with H_2O by gradually spilling droplets of water onto it, hydrogen isotopes can actually be 'loaded' into hydride-forming metals using different techniques, e.g., various levels of DC electric currents, pressure gradients, etc.
- Just prior to entering a metallic lattice, molecules of hydrogen isotopes dissociate, become monatomic, and then ionize by donating their electrons to the metallic electron 'sea,' thus becoming charged interstitial lattice protons (p^+), deuterons (d^+), or tritons (t^+) in the process
- Once formed, ions of hydrogen isotopes migrate to and occupy specific interstitial structural sites in metallic hydride bulk lattices; this is a material-specific property

→ *Part of a longstanding mythology propagated by "cold fusion" promoters is that Palladium (Pd) is a uniquely suitable material for producing LENRs; that idea been shown to be false*

A number of different hydride-forming metals have experimentally produced substantial amounts of excess heat and nuclear transmutations, including Nickel, Titanium, and Tungsten, among others

→ *Another such myth is that D/Pd LENR systems typically produce excess heat and He-4 whereas H/any-metal systems produce little heat, mostly transmutations. An array of reported results demonstrate otherwise; e.g., the largest excess heat flux ever reported came from an Italian H/Ni gas-phase system in 1994*

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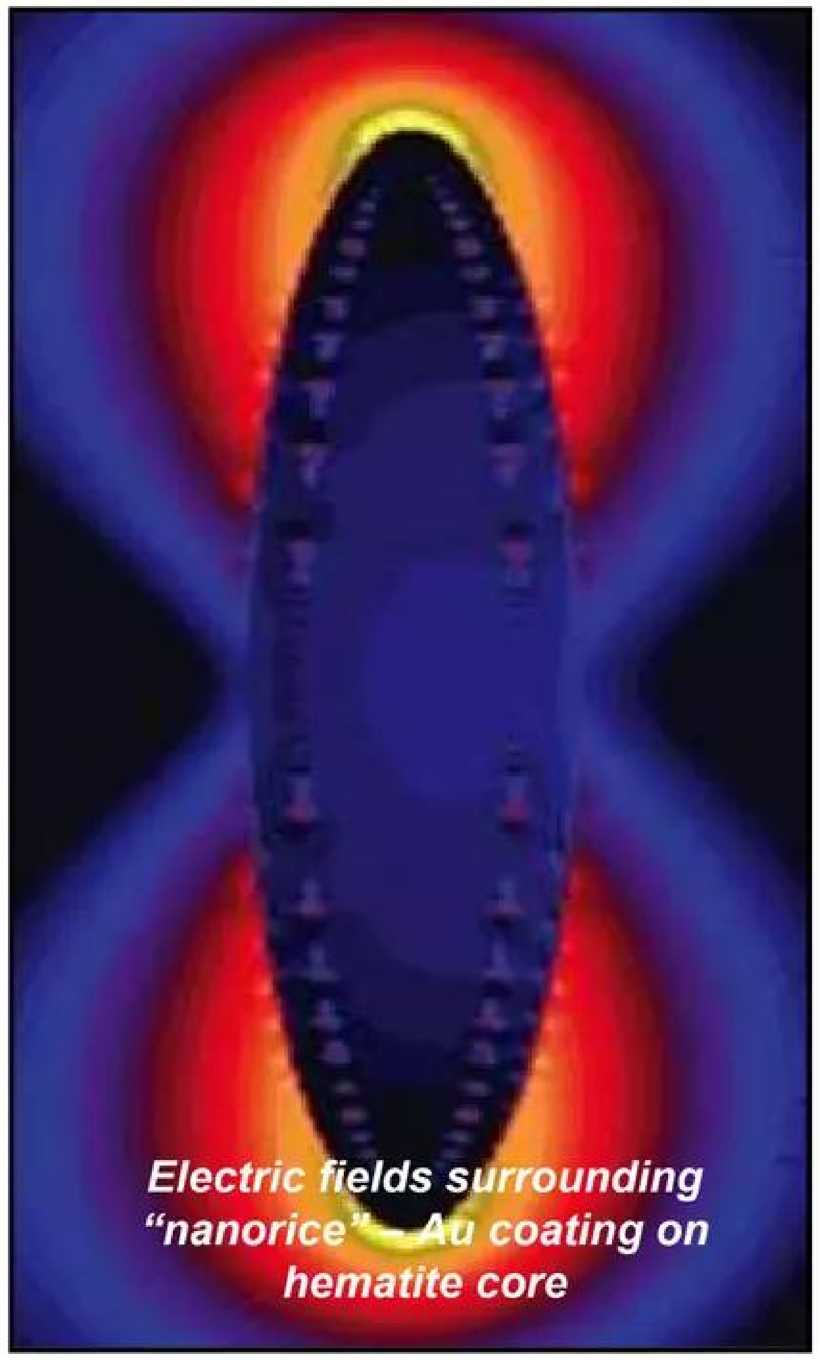
Creation of ULM neutrons on loaded hydride surfaces - II

- ✓ **When all available interstitial sites in the interior of a bulk lattice are occupied by hydrogenous ions, a metallic hydride is ‘fully loaded,’ i.e., saturated. At that point, a dynamic balance between loading and deloading begins (so-called “breathing” mode) during which some of those ions start ‘leaking back out’ of the bulk onto the surface. This localized deloading is a dynamic process, occurring in discrete, island-like, micron-scale surface ‘patches’ or ‘droplets’ (scattered randomly across the surface) comprised of many contiguous p+, d+, and/or t+ ions (or admixtures thereof)**

- ✓ **Homogeneous (limited % admixtures; large % destroy coherence) collections of p^+, d^+, or t^+ found in many-body patches on loaded metallic hydride surfaces oscillate in unison, collectively and coherently; their QM wave functions are effectively ‘entangled.’ Such coherence has been demonstrated in many experiments involving deep inelastic neutron- and electron-scattering measurements on loaded hydrides**

- ✓ **Collective oscillations of hydrogenous ions in many-body surface patches set the stage for local breakdown of the Born-Oppenheimer approximation; this enables loose electromagnetic coupling between p^+, d^+, or t^+ ions located in patches and nearby ‘covering’ surface plasmon polariton (SPP) electrons. B-O breakdown creates nuclear-strength local electric fields (above 10^{11} V/m) in and around such patches. Effective masses of SPP electrons (e-) exposed to intense local electric fields are thereby increased (e-*), enabling neutron production via $e^{-*} + p^+$, $e^{-*} + d^+$, $e^{-*} + t^+$ reactions above key isotope-specific threshold values for electric field strength**


Electric fields surrounding “nanorice” – Au coating on hematite core

See: A. Bushmaker et al., “Direct observation of Born-Oppenheimer approximation breakdown in carbon nanotubes” in Nano Lett. 9 (2) pp. 607-611 Feb. 11, 2009

Why are LENR neutrons on surfaces ultra low momentum?

Technically detailed answer – adapted from S-W-L ACS 2009 "Primer" paper

In condensed matter LENRs the many-body 'system' of collective interaction is a surface 'patch' of N_p collectively oscillating protons that are electromagnetically coupled to many nearby collectively oscillating SPP electrons N_e via local breakdown of the Born-Oppenheimer approximation. After SPP electron mass renormalization and neutron production via the weak interaction occur, the final state of such localized systems contains ($N_p - 1$) protons, ($N_e - 1$) SPP electrons and according to the W-L theory, one freshly produced neutron. Such a system's final state might be naively pictured as containing an isolated free neutron at roughly thermal energies with a DeBroglie wavelength λ of ~2 Angstroms (2×10^{-8} cm) - typical for thermalized free neutrons in condensed matter. Here that is not the case: in a many-body collective system's final state, a particular proton, say number k, has been converted to a neutron. The resulting many-body state together with all the unconverted protons may be denoted by the neutron localized $|k\rangle$. However, neutrons produced by a many-body collective system are not created in a simple state. Wave functions of such a neutron in a many-body patch of N_p identical protons is in fact a superposition of many N_p localized states, best described by a delocalized band state:

$$|\psi\rangle \approx \frac{1}{\sqrt{N_p}} \sum_{k=1}^{N} |k\rangle$$

Thus, the DeBroglie wavelength λ of ULM neutrons produced by a condensed matter collective system must be comparable to the spatial dimensions of many-proton surface 'patches' in which they were produced. Wavelengths of such neutrons can be on the order of $\lambda \approx 3 \times 10^{-3}$ cm or more; ultra low momentum of collectively created neutrons follows directly from the DeBroglie relation:

$$p = \frac{h}{\lambda} = \frac{2\pi\hbar}{\lambda} = \frac{\hbar}{\lambda\!\!\!^{-}}$$

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Local capture of ULM neutrons on loaded hydride surfaces

- ✓ **Unlike energetic neutrons produced in most nuclear reactions, collectively produced LENR neutrons are effectively 'standing still' at the moment of their creation in condensed matter. Since they are vastly below thermal energies (ultra low momentum), ULM neutrons have huge DeBroglie wavelengths and commensurately large capture cross-sections on any nearby nuclei; virtually all will be locally absorbed; not detectable as 'free' neutrons**

- ✓ **For the vast majority of stable and unstable isotopes, their neutron capture cross-section (relative to measurements of cross-sections at thermal energies where v = 2,200 m/sec and the DeBroglie wavelength is ~ 2 Angstroms) is directly related to ~1/v, where v is velocity of a neutron in m/sec. Since v is extremely small for ULM neutrons, their capture cross-sections on atomic nuclei will therefore be correspondingly large. After being collectively created, virtually all ULMNs will be locally absorbed <u>before</u> any scattering on lattice atoms can elevate them to thermal kinetic energies; per S. Lamoreaux (Yale) thermalization would require ~0.1 to 0.2 msec, i.e. 10^{-4} sec., a long time on typical 10^{-16} – 10^{-19} sec. time-scale of nuclear reactions**

→ ***Ultra low momentum neutrons have enormous absorption cross-sections on 1/v isotopes. For example, Lattice has estimated ULMN fission capture cross-section on U-235 @ ~1 million barns and on Pu-239 @ 49,000 barns (b), vs. ~586 b and ~752 b, respectively, for neutrons @ thermal energies. A neutron capture expert recently estimated ULMN capture on He-4 @ ~20,000 b vs. value of <1 b for thermal neutrons***

By comparison, the highest known thermal capture cross section for any stable isotope is Gadolinium-157 @ ~49,000 b. The highest measured cross-section for any unstable isotope is Xenon-135 @ ~2.7 million b

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What suppresses gamma ray emissions in LENR systems?

- ✓ **SPP electron masses are substantially increased by high local electric fields in and around ‘patches’ of collectively oscillating protons, deuterons, or tritons**
- ✓ **Surface ‘patches’ of heavy-mass SPP electrons exhibit:**

- <u>No heavy electron photoelectric effect</u> – heavy SPP electrons are *all* conduction electrons. They do not occupy bound core states because their energy is much too high. Incident energetic gamma photons < ~10 MeV coming from any direction cannot forcibly eject them from a ‘patch’

- <u>Anomalously high local surface electrical conductivity</u> – this anomaly occurs as the threshold proton (or deuteron or triton) density for neutron-catalyzed LENRs is approached (this would be very difficult to observe)

- <u>Compton scattering from heavy SPP electrons</u> - when a hard gamma photon is scattered from a heavy electron, the final state of the radiation field consists of many very ‘soft’ photons. Conserving energy, a single high energy gamma photon can be converted directly into many lower-energy infrared photons, sometimes with a small ‘tail’ in soft X-rays (this ‘tail’ has occasionally been observed experimentally, e.g., Violante, Karabut)

- <u>Creation of heavy SPP electron-hole pairs</u> – in LENR systems, energy differences between electron states in heavy electron conduction states increase “particle-hole” energy spreads up into the MeV range. Normally, metals have particle-hole energy spreads in the eV range near the Fermi surface, so they are relatively transparent to gamma rays. Unusually large energy spreads are what enable gamma absorption in LENR systems

→ ***“In certain non-equilibrium metallic hydride systems, surface heavy electrons play a dual role in allowing both Eqs. (49) for catalyzing LENR and Eq. (50) for absorbing the resulting hard prompt photons. Thus, the heavy surface electrons can act as a gamma ray shield.”***

→ ***“… prompt hard gamma photons get absorbed within less than a nanometer from the place wherein they were first created.” W-L, 2005 (from paper below)***

→ ***See: “Absorption of Nuclear Gamma Radiation by Heavy Electrons on Metallic Hydride Surfaces” arXiv:cond-mat/0509269 Widom and Larsen***

Why do LENRs create few long-lived radioactive isotopes?

- ✓ In comparison to fusion and fission, LENR systems typically emit particles and photons at much lower energies and produce end-product nuclei that comprise mostly stable isotopes; this distinguishing feature of LENRs has been observed in thousands of experiments since 1989
- ✓ This happens partly because weak interactions are prominent in LENRs: intermediate excited reaction products' 'excess' available energy can readily be 'bled-off' and rapidly carried away from 'patch' reaction sites in the form of MeV-energy neutrino photons, which interact very little with ordinary local matter and simply fly off into outer space at *c*
- ✓ Under nonequilibrium conditions in surface patches that are 'cooked' with large fluxes of ULM neutrons, over time, populations of unstable, very neutron-rich 'halo' nuclei will tend to build-up; they will continue to capture ULMNs as long as the Q-values are favorable (capture gammas are converted into infrared by heavy electrons). This happens because their half-lives are likely to be much longer than those of isolated nuclei if they are unable to emit β^- electrons or shed neutrons (Fermions) into unoccupied states in the local continuum. Thus, in 'patches' otherwise short β^- or *n* decay half-lives ranging from milliseconds to a few days may be temporarily increased (very difficult to measure experimentally)
- ✓ When nonequilibrium energy inputs creating large numbers of heavy electrons and ULM neutrons cease (e.g., electric current going into an LENR electrolytic cell is turned-off completely), large numbers of unoccupied local states begin opening-up. This will trigger serial cascades of fast beta decays from neutron-rich into stable isotopes; few long-lived radioisotopes would remain after such a process ended

➡ ***While extensions of otherwise short half-lives have never been directly observed in LENR systems, there are many theoretical/experimental papers about atomic-environmental density-of-states effects that can alter effective half-lives of nuclei. Opposite retardation of continuum-state decay that likely occurs in LENR systems, published work mainly covers decreasing half-lives of isotopes that decay via electron capture or weak interaction β processes; this encompasses topics such as bound-state beta-decay (which even applies to neutrons):***

"Theory of bound-state beta decay," J. Bahcall, Physical Review 124 pp. 495 1961

"Half-life measurement of the bound-state beta decay of $^{187}Re^{75+}$," Nuclear Physics A621 pp. 297c 1997 (in this remarkable experiment the measured half-life of fully-ionized 187-Re decreases from 4.4 x 10^{10} years to ~33 years)

"Electron-capture decay rate of ^{7}Be encapsulated in C_{60} cages", T. Ohtsuki, K. Hirose, and K. Ohno, J. Nuclear and Radiochemical Sciences 8 pp. A1 2007

"Observation of the acceleration by an electromagnetic field of nuclear beta decay", H. R. Reiss, EPL 81 42001 2008

"Continuum-state and bound-state β^- decay rates of the neutron," M. Faber et al., arXiv:0906.0959v1 [hep-ph] 4 June 2009

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Where does 'excess heat' come from in LENR systems?

- ✓ In LENRs, 'excess heat' is generally measured calorimetrically; where does such heat come from?
- ✓ LENRs do not involve "free energy." There is a 'cost' in the form of input energy needed to create neutrons that release nuclear binding energy from 'fuel' nuclei
- ✓ Produced ULM neutrons act as catalytic 'matches' needed to 'light the logs' of 'fuel' nuclei, releasing nuclear binding energy stored in those 'logs' since they were created in stars many billions of years ago
- ✓ Excess heat measured in LENR systems comes from:
  - Energetic charged particles (e.g., alphas, betas, protons, deuterons, tritons) 'banging into' the nearby environment, heating it by transferring kinetic energy
  - Direct conversion of gamma photons into infrared photons which are then absorbed by nearby matter
- ✓ Note: neutrino photons do not contribute to excess heat; they bleed-off excess nuclear energy into space

→ *"There's no such thing as a free lunch."*

Milton Friedman, famous Nobel prize winning economist, 1975

→ *Depending on whether hydrogen or deuterium is used as a 'base fuel' to create ULM neutrons, it 'costs' either 0.78 or 0.39 MeV to produce a single ULM neutron*

→ *Depending on exactly which 'target' nucleus serves as fuel, a single ULM neutron can be used to release up to ~20 MeV in clean non-fission, non-fusion nuclear binding energy*

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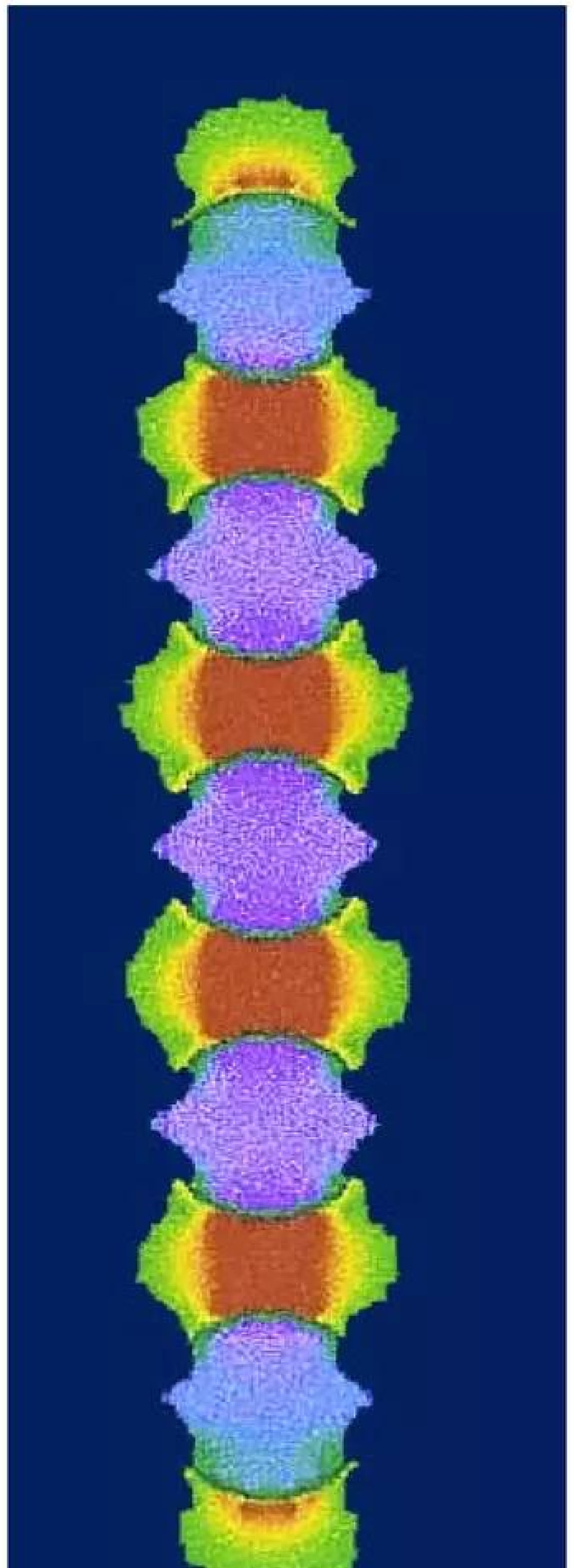
No free lunch: input energy is required to initiate LENRs

- ✓ **Input energy is required to create non-equilibrium conditions necessary for producing ULM neutrons (0.78 MeV/neutron for H; 0.39 for D; 0.26 for T); includes (can be used together):**
  - **Electrical currents (i.e., an electron 'beam')**
  - **Ion currents across the interface on which SPP 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 to input energy is by imposing a pressure gradient (Iwamura et al. 2002)**
  - **Coherent incident photon 'beams' (under the right conditions, SPP electrons can be directly excited with a laser that is 'tuned' to emit at certain wavelengths); discovered by Letts and Cravens (2002)**
  - **Magnetic fields at very, very high current densities**
- ✓ **In condensed matter LENR systems, input energy is mainly mediated by many-body SPP electron surface 'films;' they function as a system 'transducer' that helps transfer or transport energy to and from 'patches' of H, D, or T atoms**



Surface Plasmon Fields Around Nanoparticles

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Publications on the Widom-Larsen theory of LENRs

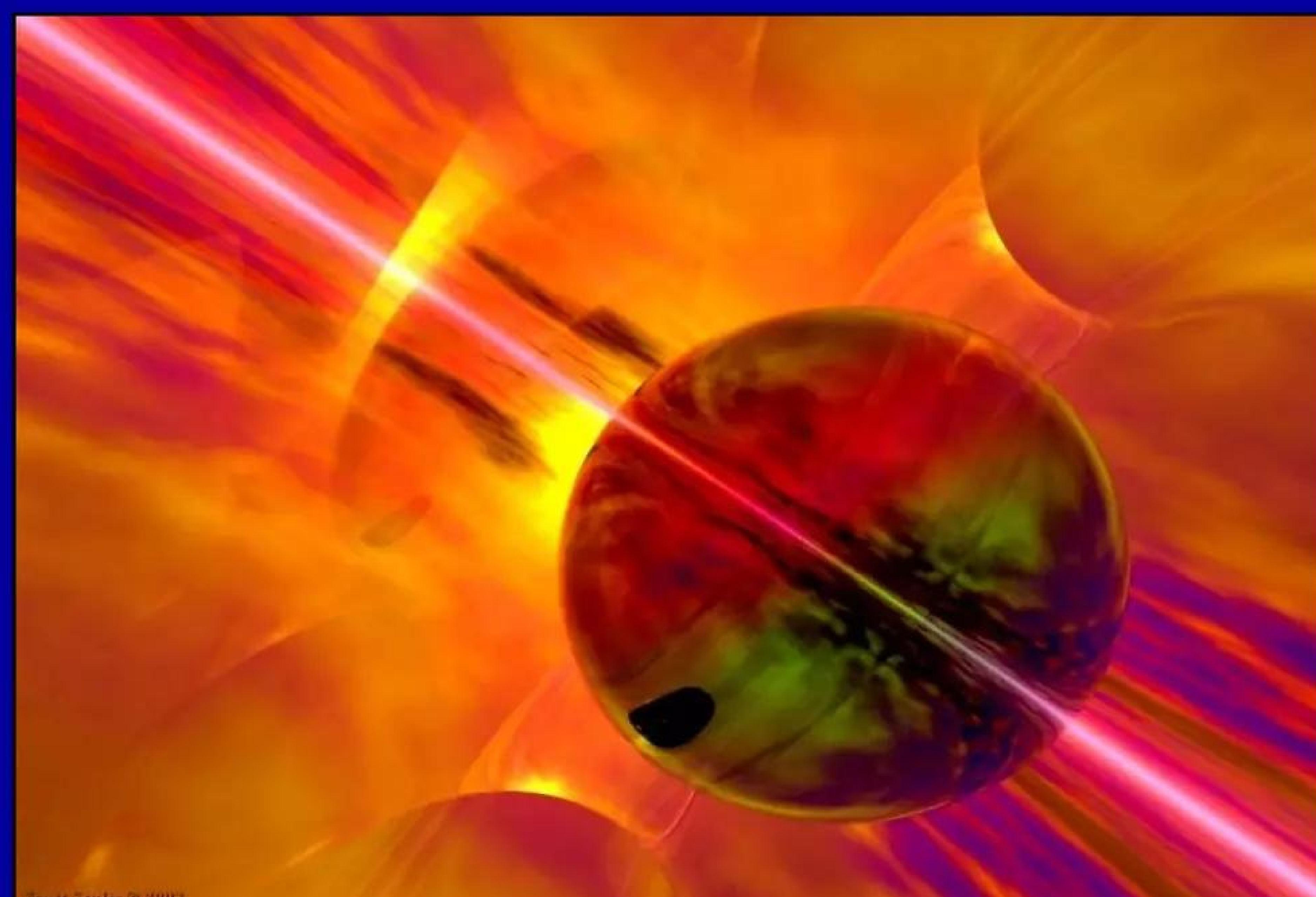
Since May 2005, we have publicly released seven papers on selected non-proprietary basic science aspects of this theory of LENRs:

- "*Ultra Low Momentum Neutron Catalyzed Nuclear Reactions on Metallic Hydride Surfaces*", Eur. Phys. J. C 46, 107 (2006 – arXiv in May 2005) Widom and Larsen
- "*Absorption of Nuclear Gamma Radiation by Heavy Electrons on Metallic Hydride Surfaces*" arXiv:cond-mat/0509269 *(Sept 2005)* Widom and Larsen
- "*Nuclear Abundances in Metallic Hydride Electrodes of Electrolytic Chemical Cells*" arXiv:cond-mat/0602472 *(Feb 2006)* Widom and Larsen
- "*Theoretical Standard Model Rates of Proton to Neutron Conversions Near Metallic Hydride Surfaces*" arXiv:nucl-th/0608059v2 (Sep 2007) Widom and Larsen
- "*Energetic Electrons and Nuclear Transmutations in Exploding Wires*" arXiv:nucl-th/0709.1222 (Sept 2007) Widom, Srivastava, and Larsen
- "*High Energy Particles in the Solar Corona*" arXiv:nucl-th/0804.2647 (April 2008) Widom, Srivastava, and Larsen
- "*A Primer for Electro-Weak Induced Low Energy Nuclear Reactions*" arXiv:gen-ph/0810.0159v1 (Oct 2008) Srivastava, Widom, and Larsen (ACS *LENR Sourcebook* 2009 – in press)

"When a new truth enters the world, the first stage of reaction to it is ridicule, the second stage is violent opposition, and in the third stage, that truth comes to be regarded as self-evident." - Arthur Schopenhauer, 1800s

"[New] Theories have four stages of acceptance:
i) this is worthless nonsense;
ii) this is an interesting, but perverse, point of view.
iii) this is true but quite unimportant.
iv) I always said so."
- J.B.S. Haldane, 1963

Experimental evidence in context of theory



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Brief recap of status of LENR experimental anomalies

- ✓ <u>Calorimetrically measured macroscopic excess heat effects</u> – still strongly questioned by the skeptics because no one has created a macroscopic LENR device that can reliably "boil a cup of tea" yet

- ✓ <u>Production of gaseous helium isotopes</u> – rarely measured lately due to expense and limited funding for such difficult measurements

- ✓ <u>Production of modest fluxes of MeV-energy *α* particles and protons</u> – presently measured by many researchers with CR-39 chips; however, only a few of them have utilized the most rigorous analytical protocols that can measure approximate energies and discriminate between different types of energetic charged particles

- ✓ <u>Production of a broad array of different types of nuclear transmutation products</u> – reported in ICCF conference proceedings by many LENR researchers. Since it is difficult for skeptics to argue with such data on a factual basis, they simply sidestep the evidence or just ignore it. Doubters still try to invoke 'external contamination' red herring with little or no substantive justification for doing so

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Further discussion of LENR excess heat measurements

- ✓ **Calorimetrically measured, device-level macroscopic 'excess heat' is at best indirect evidence for nuclear effects in LENRs; heat production all by itself does not 'prove' a nuclear origin for any observed heat**

Properly done calorimetry measures the sum total net amount of heat being produced, if any, in a given enclosed system over time. Such heat can be created by a variety of different physical processes, both chemical and/or nuclear. As such, calorimetry is a relatively crude macroscopic 'thermodynamic' measurement that says little about underlying mechanisms

- ✓ **One must argue that measured 'excess' macroscopic heat is so large that it greatly exceeds what could typically be produced by prosaic chemical reactions**

"It is our view that there can be little doubt that one must invoke nuclear processes to account for the magnitudes of the enthalpy releases, although the nature of these processes is an open question at this stage."

- Fleischmann et al., *J. Electroanal. Chem.*, 287 p. 293 1990

- ✓ **Circa 2009, excess heat produced by LENR devices in highly successful experiments (still generally << 1 – 2 Watts) remains small relative to total input power. This is not enough to "boil tea," so some skeptics continue to contend that most reports of LENR excess heat are erroneous**

Largest amount and duration of excess heat ever calorimetrically measured in an LENR experimental system, 44 Watts for 24 days (~ 90 Megajoules) occurred in a Nickel-Light Hydrogen gas-phase system at the University of Siena in Italy in 1994. Published in a respected refereed journal, the then inexplicable, spectacular results were ignored by everyone. This particular experimental device most certainly would have "boiled tea" for the skeptics

- See Focardi et al., *Il Nuovo Cimento.*, 107 pp. 163 1994

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Further discussion of gaseous Helium-4 measurements

- ✓ **Detection of significant gaseous He-4 production, unquestionably a nuclear product, provides excellent evidence that LENRs are the result of some type of nuclear process**
- ✓ **However, the devil is in the details …**
- ✓ **While He-4 (= α) can be produced by fusion reactions, it can also easily be produced in other nuclear reactions, including minor alternative branches of neutron captures and various alpha (α) particle decays, e.g., Be-8**
- ✓ **Thus, simply detecting gaseous He-4 production in an LENR experiment does not say exactly which nuclear process(es) actually took place in it**

Well accepted 'normal' D-D fusion reactions produce products in three branches with ~1:1 ratio between #1 and #2:

#1 [~ 50 %] $d + d \rightarrow t + p$

#2 [~ 50 %] $d + d \rightarrow {}^{3}_{2}He + n$

→ **#3 [~ 10^-5 %]** $d + d \rightarrow {}^{4}_{2}He + \gamma^{radiation}$

Contrary to mainstream physicists, "cold fusion" researchers simply assume that He-4 production observed in certain electrolytic experiments only occurs via branch #3 of the D-D fusion reaction. They then 'wave away' gamma emission issue and ignore possibility that He-4 can also be produced via neutron capture on lithium isotopes present in LiOD found in electrolytes of same experiments:

$${}^{6}_{3}Li + n \rightarrow {}^{7}_{3}Li$$
$${}^{7}_{3}Li + n \rightarrow {}^{8}_{3}Li$$
$${}^{8}_{3}Li \rightarrow {}^{8}_{4}Be + e^{-} + \bar{\nu}_e$$
→
$${}^{8}_{4}Be \rightarrow {}^{4}_{2}He + {}^{4}_{2}He.$$

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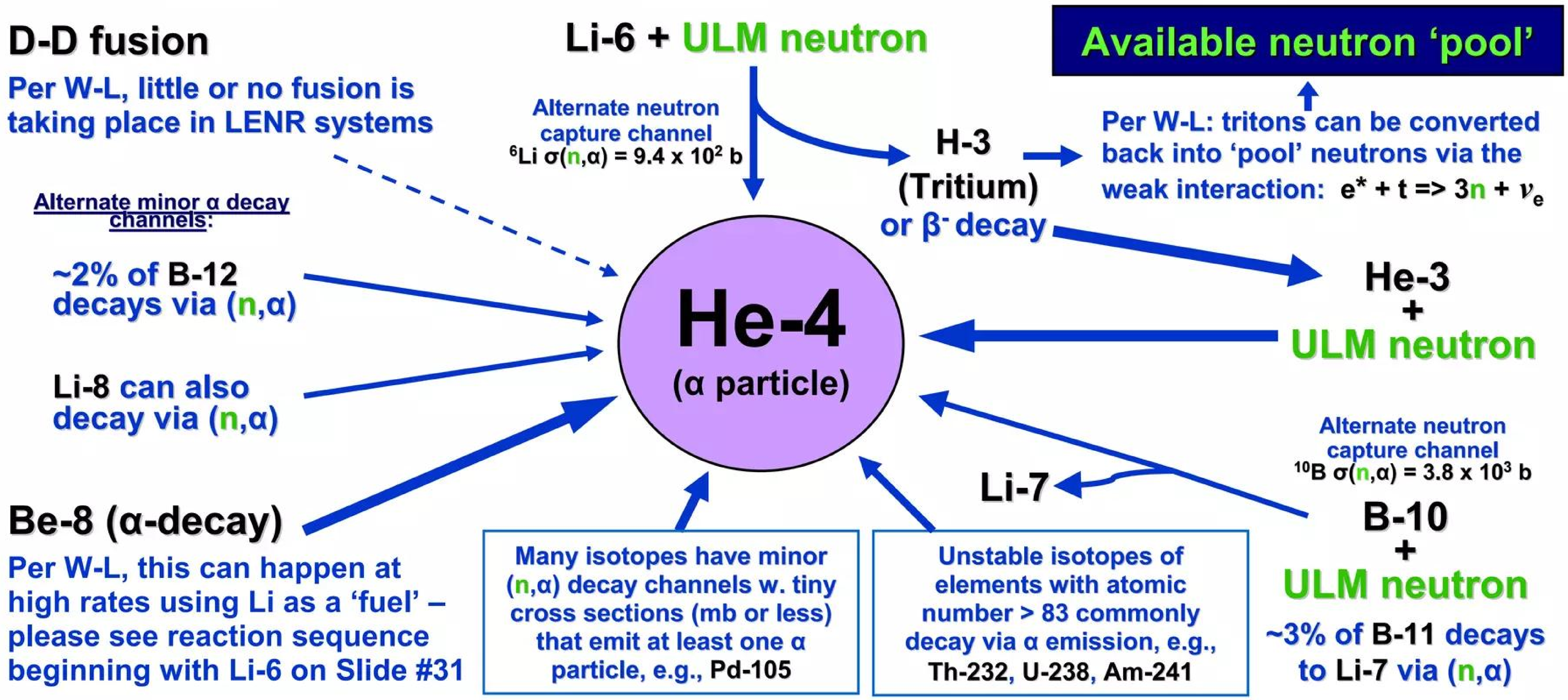
Helium-4 can be produced by a variety of nuclear reactions

In LENR experiments, He-4 could be produced by a variety of nuclear reactions and decays besides fusion and Be-8 α-decay:

σ(n,α) = total cross-section for α decay with the capture of a single neutron by a given isotope



Presence of He-4 all by itself does not tell us exactly what happened

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Pons & Fleischmann measured Helium-4 back in 1989

- ✓ P&F's claimed gaseous Helium-4 measurements in Pd/LiOD cells were questioned by other scientists, e.g. Lewis
- ✓ P&F's He-4 claim was subsequently retracted because of intense pressure from Prof. Nathan Lewis (Caltech), who contended that P&F had merely measured He-4 present in laboratory air. The logic behind Lewis' criticism was that: (1) if the reaction D + D -> He-4 + gamma radiation (somehow transformed into excess heat) were assumed to be correct ; then (2) Pons' mass spectrometer was not sensitive enough to detect the amount of He-4 that would be produced in a P&F cell that was generating 0.5 Watts of excess heat
- ✓ Since according to the Widom-Larsen theory of LENRs D-D fusion was very likely not taking place in their experiments, Lewis' criticism was in error. In retrospect, P&F's He-4 measurement was probably a correct observation
- ✓ From 1989 through early 2000s, other LENR researchers (e.g., McKubre at SRI and Miles at USN-China Lake) made improved, very well documented measurements of He-4 production, mostly in LENR heavy water LiOD Pd-cathode electrolytic cells. They demonstrated rough correlations between He-4 and excess heat production; however, their estimates of energy in MeV per He-4 atom were inaccurate

At the April 17, 1989, news conference, "Pons announced a new piece of supporting evidence: mass spectroscopy of the gases evolving from a working fusion cell revealed the presence of ^{4}He in quantities consistent with the reported energy production, if all deuteron-deuteron fusions produce ^{4}He rather than tritium and a proton or ^{3}He and a [energetic] neutron."

- *Nature News* 338 pp. 691 1989

"Our cold fusion experiments show a correlation between the generation of excess heat and power and the production of He, established in the absence of outside contamination. This correlation in the palladium/D_2O system provides strong evidence that nuclear processes are occurring in these electrolytic experiments. The major gaseous fusion product in D_2O + LiOD is He-4 rather than He-3."

B. Bush and J. Lagowski, *J. Electroanal. Chem.* 304 pp. 271 – 278 1991

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Further discussion of LENR charged particle measurements

- ✓ **2001 - 2002**: A. Lipson (RAS – Moscow) et al. report unambiguous detection of small fluxes of ~1.7 MeV protons and 13.5 ± 2.5 MeV α particles using CR-39 plastic detectors in P-F type H_2SO_4 light water electrolytic cells with thin-film Pd/Ni cathodes; clear evidence for nuclear processes taking place in system (Lattice-supported work; used very rigorous measurement protocols to measure energies)
- ✓ **2002 - 2003**: using CR-39 detectors, small fluxes of MeV-energy protons and α particles with roughly the same energies were also observed by Lipson, Karabut, and others in a number of very different types of LENR experiments that included Ti -D_2O glow discharge cells, laser irradiation of TiD_x and TiH_x targets, and controlled deuterium desorption from Pd/PdO:D_x heterostuctures
- ✓ **2003 – 2009**: many more LENR researchers began to measure and report charged particles, mostly using CR-39 chips. Most notable effort was at USN SPAWAR using electrolytic Pd-D_2O co-deposition; published results in *Naturwissenschaften*. Unfortunately, SPAWAR and other LENR groups did not use protocols that can measure energies and characterize particles, i.e. protons vs. alphas

→ *Measurements of charged particle production and their energy spectra can provide direct evidence for nuclear phenomena, especially if measured particle energies exceed an MeV (which cannot possibly be the result of purely chemical mechanisms in the eV range). Commonly detected and measured heavy charged particles typically include protons, deuterons, tritons, and/or alphas (He-4 nuclei). Light beta particles are almost never measured during LENR experiments, since ~80 – 90% of them involve aqueous electrolytic cells in which energetic electrons are very rapidly attenuated in water*

Several different types of well-accepted, proven measurement techniques can be used to measure charged particles, including various types of solid-state electronic detectors and CR-39 solid plastic detectors (which inherently integrate particle counts over time and can be used in electrolytic systems which are often unsuitable for electronic detectors)

During the past 8 years, plastic CR-39 detectors have become popular among LENR researchers because of their low cost, 'built in' count integration (which is helpful for measuring small fluxes of particles), and ease of integration into various types of experimental systems. However, most LENR researchers do not utilize the much more rigorous protocols that are required to measure energies, accurately 'score' pits, and characterize particles

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Further discussion of LENR transmutation measurements

- ✓ <u>1989 to mid-1990s</u>: reliable reports of nuclear transmutations seen in LENR experiments began to surface in the early 1990s; this work was done by researchers in Russia, Italy, U.S. (Bockris, Dash), India, Japan (Mizuno, Ohmori)
- ✓ <u>Circa mid-1990s</u>: Miley (US) observed a distinctive 5-peak mass spectrum of stable transmutation products comprising a wide variety of elements not initially present in light water electrolytic cells. Mizuno subsequently observed very similar multi-peak mass spectrum, only in heavy water LENR electrolytic cells. Such results were inexplicable at the time
- ✓ <u>2002</u>: at ICCF-9 in Beijing, China, Iwamura et al. (Mitsubishi Heavy Industries, Japan) report on very expensive, carefully executed experiments demonstrating transmutation of selected 'target' elements to other elements: results clearly showed that Cs was transmuted to Pr and Sr was transmuted to Mo by some means
- ✓ <u>2002 – 2009</u>: using a variety of different analytical techniques, progressively greater numbers of LENR researchers located all over the world began to measure and report reliable observations of LENR transmutation products

→ *While qualitative and quantitative measurements of elements/isotopes in samples obtained from LENR experiments (e.g., metallic cathodes in electrolytic cells) requires specialized analytical skills and lab equipment that can be quite expensive, done properly it provides extremely powerful evidence for reality of LENR nuclear effects. Production of new elements that were not previously present in an experimental system, and/or significant changes in isotopic ratios from natural abundances, simply cannot be the result of prosaic chemical processes*

→ *Well-accepted, uncontroversial techniques and equipment used for detecting and measuring transmutation products in LENR experiments include, for example: inductively coupled plasma-mass spectroscopy (ICP-MS); secondary ion mass spectroscopy (SIMS); neutron activation analysis (NAA); scanning electron microscopes (SEM) integrated with energy dispersive X-ray spectrometers (EDX); and X-ray photoelectron spectroscopy (XPS), among others. All have various pros and cons*

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LENR-related transmutation measurements predate 1989

- ✓ Early 1900s: from about 1905 - 1927 some of the most famous people in British science (J.J. Thomson, Ramsay, etc.) published a number of experimental reports in premier refereed journals, e.g., *Nature*, *Proceedings of the Royal Society*, of what were with today's knowledge and the W-L theory, clearly nuclear transmutation anomalies that were observed during a variety of different types of electrical discharge experiments

- ✓ 1922: Wendt and Irion, chemists at the University of Chicago, reported results of experiments consisting of exploding tungsten wires with a very large current pulse under a vacuum inside of flexible sealed glass 'bulbs.' Controversy erupted when they claimed to observe anomalous helium inside sealed bulbs after the tungsten wires were exploded, suggesting that transmutation of hydrogen into helium had somehow occurred during the "disintegration of tungsten." Their article in *Amer. Chem. Soc.* 44 (1922) triggered a response from the scientific establishment in the form of a negative critique of Wendt and Irion's work by Sir Ernest Rutherford that promptly published in *Nature* 109 pp. 418 (1922). We have since determined that Rutherford was wrong – see preprint

→ *See: J. J. Thomson (who discovered the electron in 1897), "On the appearance of Helium and Neon in Vacuum tubes," where he says, "At the last meeting of the Chemical society, William Ramsay … describes some experiments which they regard as proving the transmutation of other elements into Helium and Neon …"*
Nature 90 pp. 645 - 647 1913

→ *"The energy produced by breaking down the atom is a very poor kind of thing. Anyone who expects a source of power from the transformations of these atoms is talking moonshine."*

-Ernest Rutherford, 1933

→ *More recently: "Energetic Electrons and Nuclear Transmutations in Exploding Wires" in which we state that, "It is presently clear that nuclear transmutations can occur under a much wider range of physical conditions than was heretofore thought possible," arXiv:nucl-th/0709.1222 Widom, Srivastava, and Larsen 2007*

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Any strong experimental evidence for fusion in LENRs?

***Answer*: no**

- ✓ **P&F's hypothesis of "cold" D-D fusion immediately ran into trouble in 1989 because, although Helium-4 was detected, none of the other 'normal' products of D-D fusion were observed in the amounts and proportions that would be expected based on 50 years of study on nuclear fusion reactions by thousands of scientists**
- ✓ **From 1989 through early 2000s, subsequent LENR researchers (e.g., McKubre et al. at SRI and Miles at USN-China Lake) continued to improve and correlate measurements of Pd-D loading, He-4, and excess heat. Despite all such efforts, "cold fusion" proponents have never been able to demonstrate large fluxes of tritium, protons, He-3, neutrons, and/or gamma radiation that would be directly commensurate with measured excess heat according to well-accepted knowledge about the three known branches of the D-D fusion reaction**
- ✓ **To address this issue, some LENR theorists (e.g., Hagelstein, Chubbs, etc.) developed ad hoc theories of "cold fusion" invoking questionable 'new physics' to explain discrepancy with known D-D branching ratios**

→ ***Well accepted 'normal' D-D fusion reactions produce products in three branches with ~ 1:1 ratio between 1-2:***

#1 [~ 50 %] $d + d \rightarrow t + p$

#2 [~ 50 %] $d + d \rightarrow {}^{3}_{2}He + n$

#3 [~ 10-5 %] $d + d \rightarrow {}^{4}_{2}He + \gamma^{radiation}$

→ ***As of 2009, there is still no believable experimental evidence or theoretical support for the idea that the branching ratios of the D-D fusion reaction change appreciably at low energies***

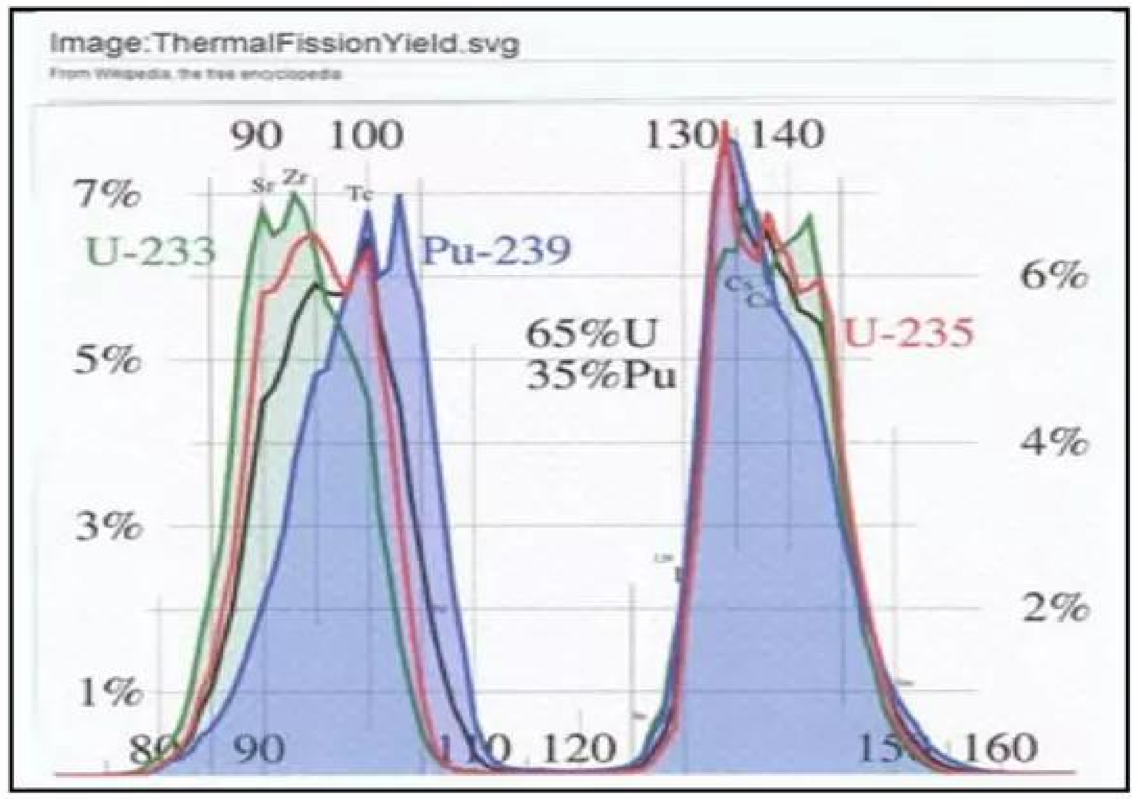
→ ***As of 2009, "cold fusion" theories have not achieved any significant degree of acceptance amongst members of the mainstream nuclear physics community***

Any strong experimental evidence for fission in LENRs?

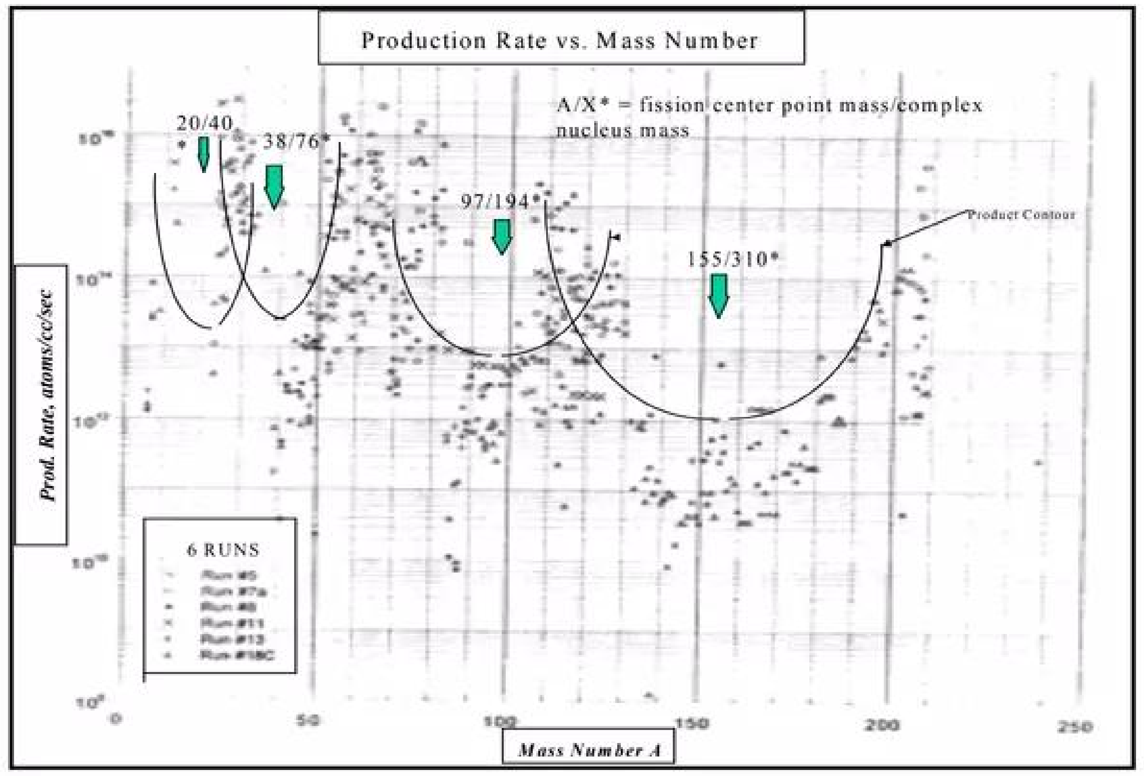
***Answer*: no**

- **Since heavy fissile nuclei like Uranium-235, Uranium-233, and Plutonium-239 never fission into two fragments at exactly the same place every time, neutron-catalyzed nuclear fission processes usually produce complex mixtures of nuclear transmutation products that form a characteristic two-peak "fission spectrum" of isotopic products statistically centered on the 'average' mass of each fission fragment**
- **Two-peak product mass spectra are unique 'fingerprints' of heavy element nuclear fission**
- **Researchers have never observed two-peak product spectra in any LENR experiments, nor have large fluxes of MeV-energy neutrons or gammas ever been reported in LENR systems**
- **However, in 1990s Miley and Mizuno reported reliable measurements of anomalous 5-peak product spectra in different LENR experiments**

Fission product spectra of isotopes U-235, Pu-239



Miley's anomalous transmutation product spectra



Any experimental evidence for other nuclear processes?

***Answer**: yes, for neutron production/capture and α and/or β decays*

- ✓ **Question**: Let us assume that a hypothetical LENR experiment begins with some array of stable isotopes, say on the surface of a Pd cathode in a LiOD electrolytic cell. Then, post-experiment mass spectroscopy reveals the presence of new elements and/or changed isotope ratios on the cathode surface that were not present when the experiment began; i.e., transmutation products are observed. If such data were correct, i.e., it was not contamination, then what could have happened to initially stable isotopes that caused nuclear transmutations to occur?

- ✓ **Comment**: If fusion and heavy element fission processes are not responsible for creating observed transmutation products, then only a limited number of other possibilities are reasonable explanations: neutron production/capture process(es); and/or weak interaction process(es); and/or α / β- decays of unstable isotopes

- ✓ **Answer and more questions**: absorption of neutrons by stable isotopes of elements can create new stable isotopes (which may alter a given element's 'normal' isotopic ratios) or, create unstable isotopes that undergo beta decay producing higher-atomic-number (i.e., higher Z) elements as transmutation products; those are well known phenomena. However, what sort of process is capable of creating large fluxes of neutrons that can be captured and cause transmutations in LENR systems? Then why aren't fluxes of energetic neutrons ever detected? Why aren't MeV-energy gammas from beta decays and/or neutron captures ever observed?

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Why are transmutations important? What do they tell us?

Measurement of nuclear products provides crucial technical information

Measurements of transmutation products, so called "nuclear ash," if reliably observed upon the conclusion of an LENR experiment, are important because they indicate that new chemical elements have somehow been produced and/or isotopic ratios of some elements previously present have been significantly altered. This provides important evidence that LENRs involve nuclear processes because:

- ✓ **Prosaic chemical processes cannot cause transmutations**
- ✓ **Several types of well understood nuclear processes can readily produce transmutation products: strong interaction fusion reactions (e.g., D-D or D-T); strong interaction fission (e.g., fissile isotopes U-235 or Pu-239); neutron captures on nuclei that produce new elements or isotopes; α and/or β decays; and/or weak interaction neutron production via e + p -> 1n + υ_e, e + d -> 2n + υ_e, e + t -> 3n + υ_e**
- ✓ **Accurate detection and analysis of whatever types of transmutation products may be produced during an LENR experiment can potentially allow one to determine exactly which type(s) nuclear process(es) occurred and the reaction(s) that created the products**

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W-L theory explains Miley's transmutation product spectra

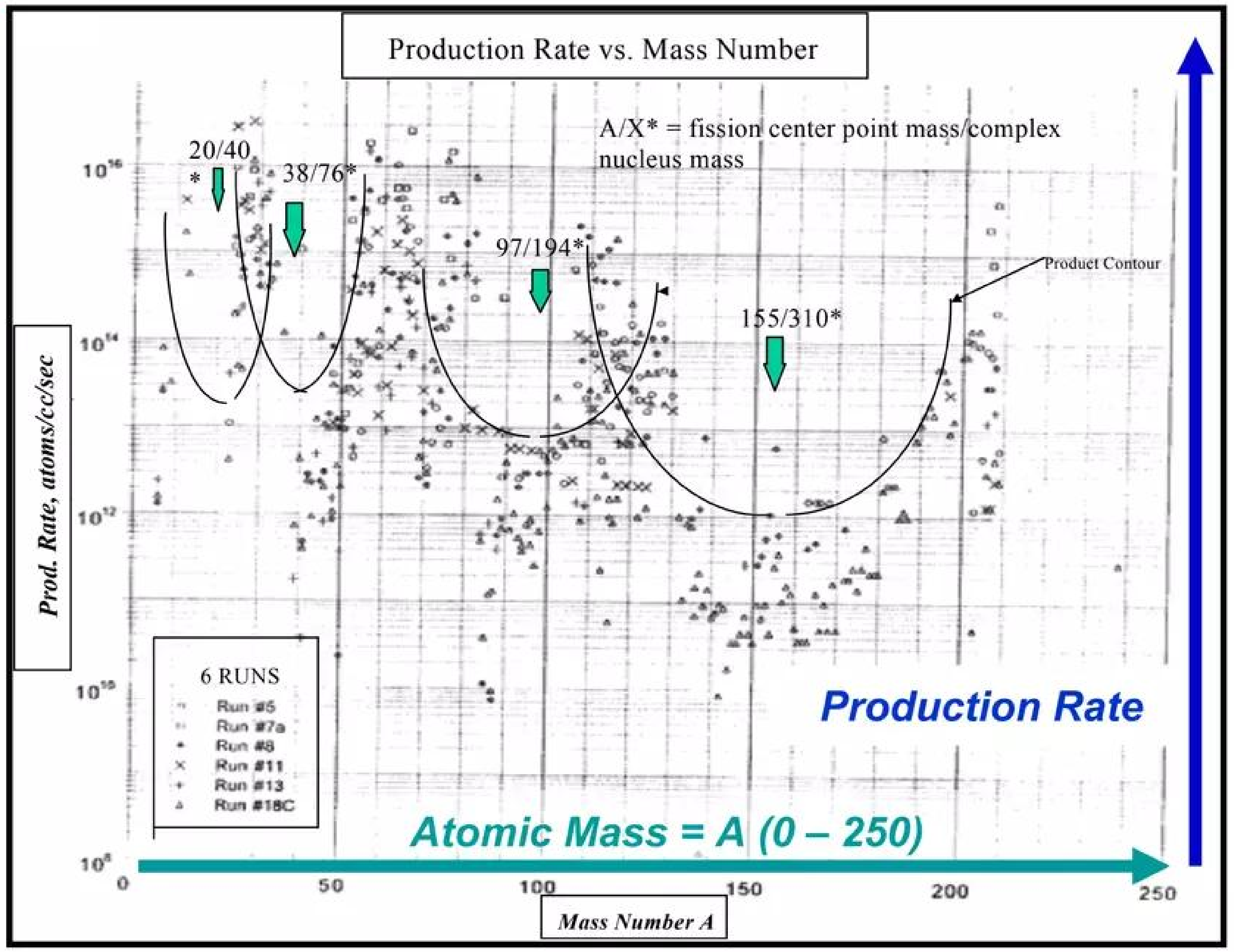
Production and capture of LENR ULM neutrons and beta decays

- ✓ **Five-peak transmutation product mass spectra reported by Miley is extremely anomalous; very different from 2-peak fission mass spectra such as for U-235 or Pu-239 (see Slide #38)**

- ✓ **Miley explained observed 5 spectral peaks as being the result of fission processes involving hypothesized unstable, very neutron-rich compound nuclei at masses A = 40, 76, 194, and 310, a conjectured superheavy element**

- ✓ **Unanswered issues with Miley's speculative explanation were: (a.) since the cathodes were Nickel (A~58) and Palladium (A~106), what nuclear process(es) occurred that produced the compound nuclei at A=194 and 310 from Pd and/or Ni ?; (b.) superheavy nuclei at A=310 have never been observed experimentally**

- ✓ **<u>W-L theory</u>: successive rounds of in situ neutron production and capture, coupled with β- decays to higher-A elements, can explain this data; it is similar to neutron catalyzed r- and s-process elemental nucleosynthesis in stars, but at vastly lower temperatures and more benign conditions**



<u>Source</u>: "Possible Evidence of Anomalous Energy Effects in H/D-Loaded Solids - Low Energy Nuclear Reactions (LENRs)," Journal of New Energy, 2, No. 3-4, pp.6-13, (1997)

<u>Note</u>: Miley's experiments used light water P-F electrolytic cells. Importantly, Mizuno observed a very similar 5-peak transmutation product spectrum, only with heavy water cells. This suggests same mechanism for both datasets. Neither Miley nor Mizuno detected any energetic gammas or neutrons

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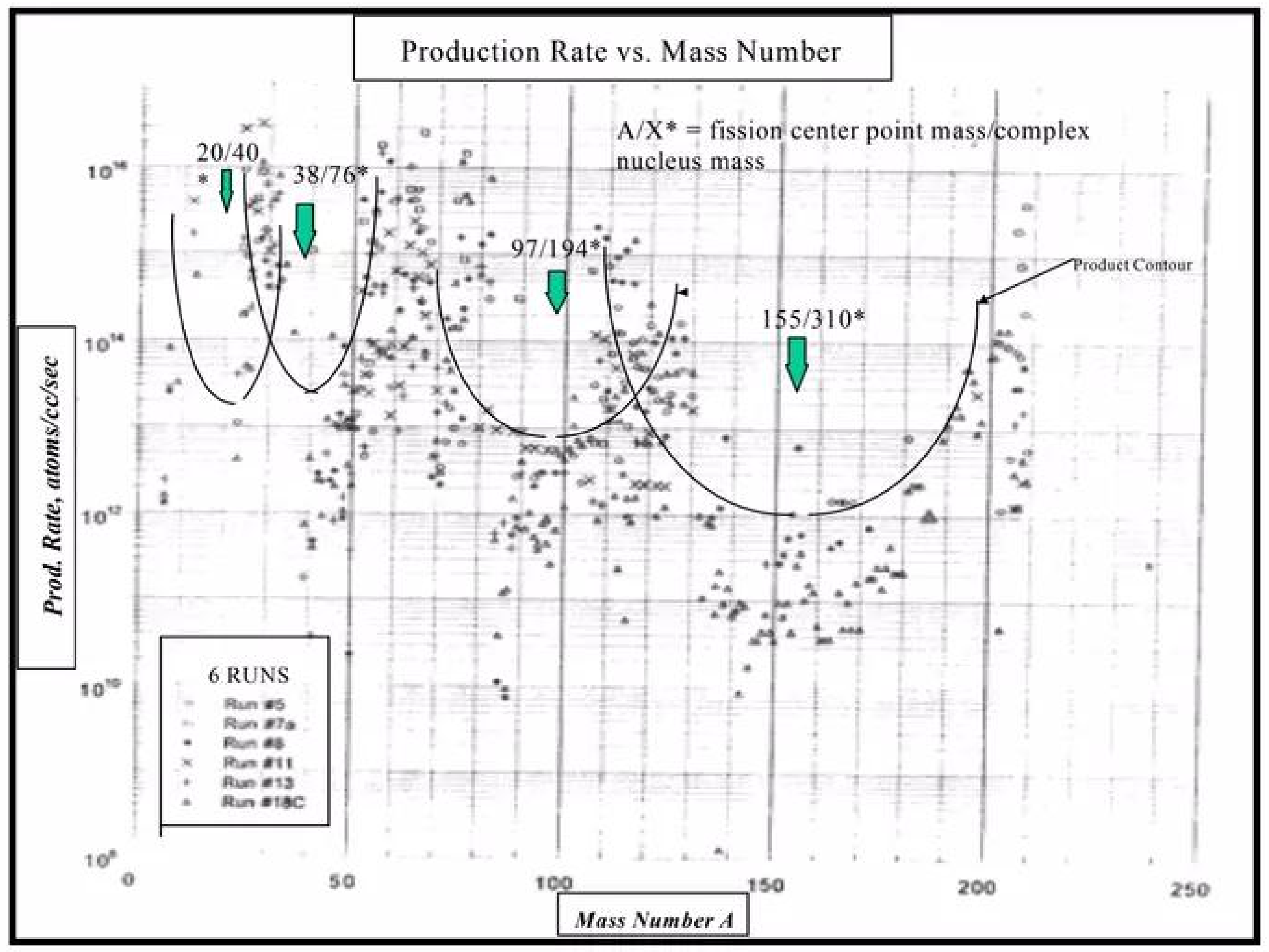
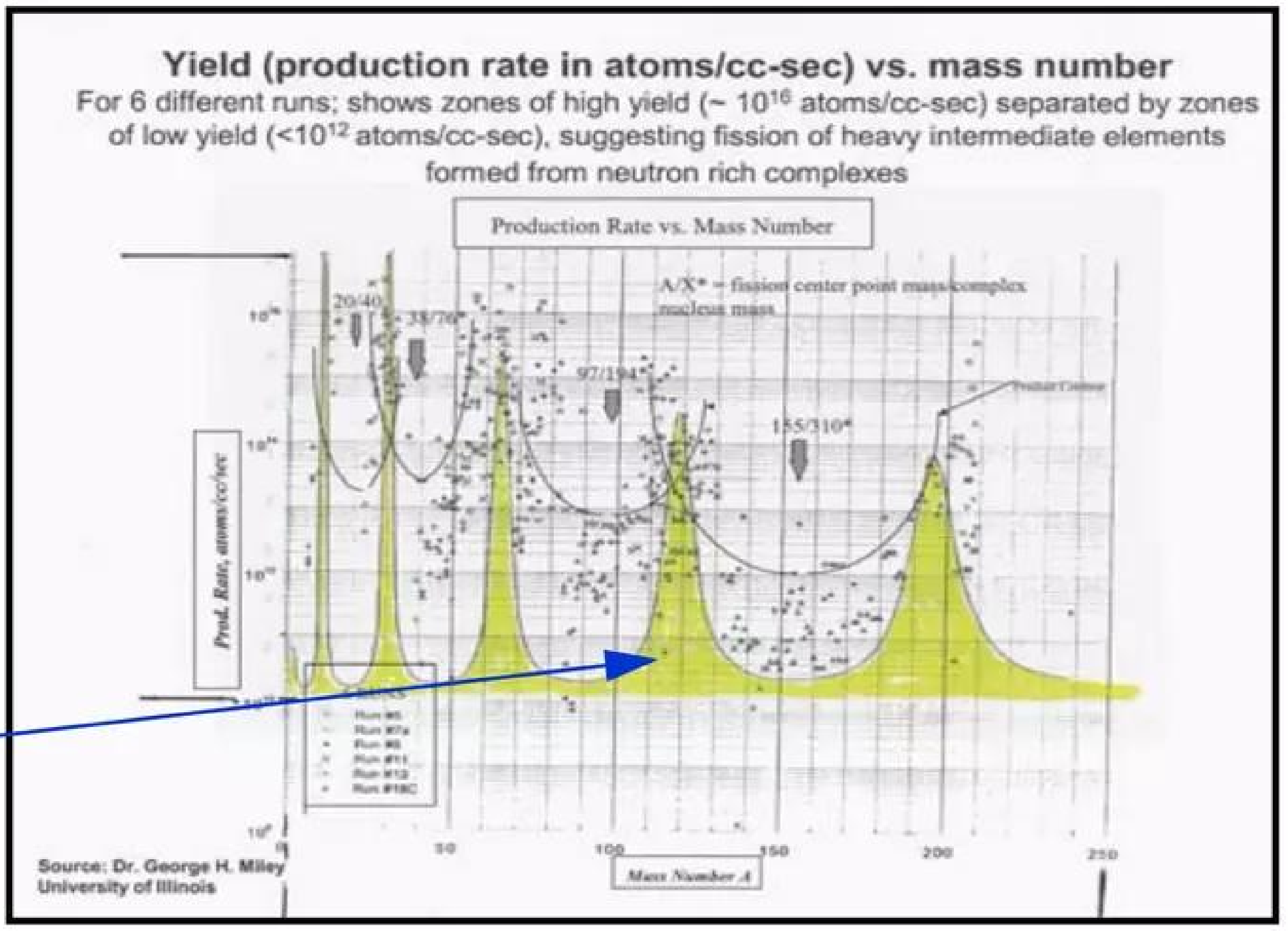
Five-peak mass-spectrum is a 'fingerprint' of ULM neutrons

Miley's dataset is 'smoking gun' for ULM neutron absorption by nuclei

- **Top chart to right is Miley's raw data; chart below is same data only with results of W-L neutron optical potential model of ULMN neutron absorption by nuclei (yellow peaks) superimposed on top of Miley's data; very close correspondence**
- **Model not fitted to data: only 'raw' output**
- **W-L model only generates a five-peak resonant absorption spectrum at the zero momentum limit; neutrons at higher energies will not produce the same result**
- **This means that 5-peak product spectrum experimentally observed by Miley and Mizuno is a unique signature of ULM neutron production/absorption in LENRs**





See: "*Nuclear abundances in metallic hydride electrodes of electrolytic chemical cells*" arXiv:cond-mat/0602472 (Feb 2006) A. Widom and L. Larsen

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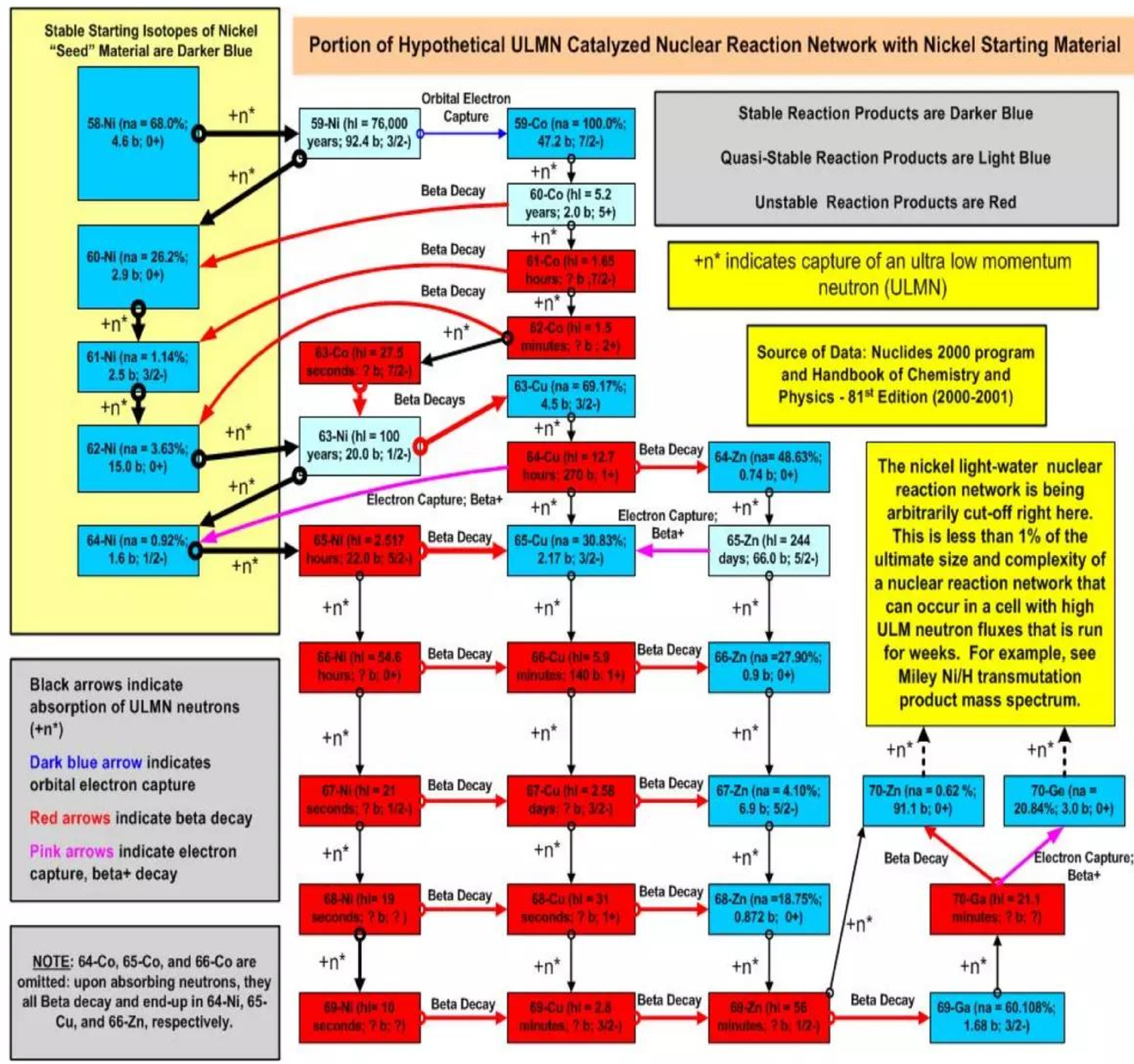
ULMN nuclear reaction networks are complex and evolving

- ✓ According to W-L theory, LENRs occur in micron-scale 'patches' of collectively oscillating H ions found on loaded metallic hydride surfaces
- ✓ Large fluxes of ULM neutrons (ULMNs) may be produced in electrolytic LENR systems; have implicitly been measured at 10^9 - 10^{16} cm^2/sec in certain well-performing electrolytic cells. High-current pulsed power systems may be able to achieve neutron fluxes of 10^{18} – 10^{20} cm^2/sec. By contrast, H loading via pressure gradients produces <<< smaller ULMN fluxes
- ✓ Over time, large ULMN fluxes will produce complex, rapidly evolving nuclear reaction networks as illustrated to the right beginning with a Ni 'target' (cut-off at A = 70)
- ✓ At micron scales, neutron 'dose histories' can have huge variations across an active working surface
- ✓ <u>Proximity counts</u>: all nuclei inside micron-scale domain of ULMN wave function will 'compete' to absorb it



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W-L theory explains Iwamura et al. transmutation data - I

Production and capture of LENR ULM neutrons and beta decays

- ✓ **In 2002, Iwamura and colleagues at Mitsubishi Heavy Industries (Japan) first reported expensive, carefully executed experiments clearly showing transmutation of selected stable 'target' elements to other stable elements**
- ✓ **Experiments involved permeation of D_2 gas under 1 atm pressure gradient at 343° K through a Pd:Pd/CaO thin-film heterostructure with Cs and Sr 'target' elements placed on the outermost Pd surface; electric current was not used to load Deuterium into Pd, only the applied pressure differential**
- ✓ **Result: Cs 'target' transmuted to Pr; Sr transmuted to Mo**
- ✓ **Invoked Iwamura et al.'s EINR model (1998) to explain data**

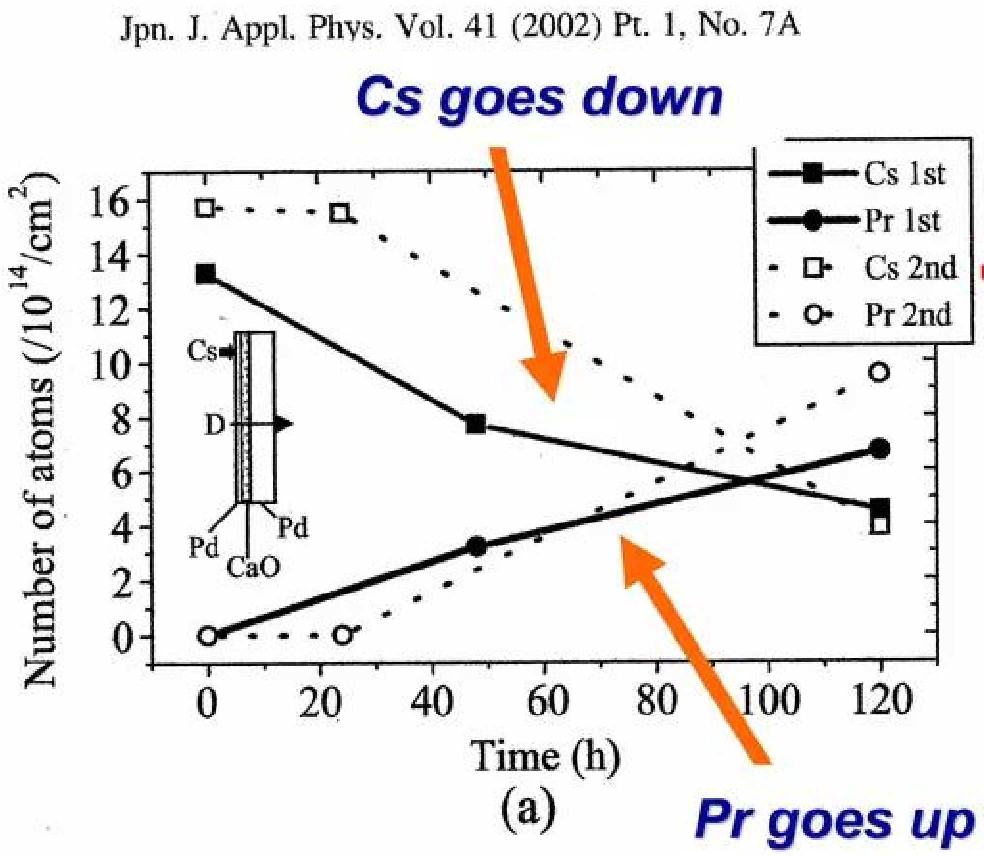
→ ***Iwamura et al., Advanced Technology Research Center, Mitsubishi Heavy Industries, "Elemental Analyses of Pd Complexes: Effects of D_2 Gas Permeation," Japanese Journal of Applied Physics 41 (July 2002) pp. 4642-4650***

→ ***The central result of this work was as follows:***

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

$$^{88}_{38}Sr \rightarrow {}^{96}_{42}Mo$$

Isotopes on samples' surfaces are analyzed in 'real time' during the course of the experiments with XPS



→ ***Iwamura et al. make an interesting qualitative observation on pp. 4648 in the above paper, "…more permeating time is necessary to convert Sr into Mo than Cs experiments. In other words, Cs is easier to change than Sr."***

The observation is consistent with W-L theory neutron catalyzed transmutation; this result would be expected because Cs-133's neutron capture cross-section of 29 barns at thermal energies is vastly higher than Sr-88 's at 5.8 millibarns. Ceteris paribus, Cs transmutes faster because it absorbs neutrons more readily

W-L theory explains Iwamura et al. transmutation data - II

Production and capture of LENR ULM neutrons and beta decays

Question: using W-L theory of LENRs, are there plausible nucleosynthetic pathways that have adequate Q-value energetics, half-lives, and capture cross-sections that can explain the central result of Iwamura et al's. transmutation of ^{133}Cs and ^{88}Sr ? Yes, two are as follows:

All numbers approximate; ULMN capture cross-sections vastly higher than thermal; not all cross-sections have been measured

$^{133}_{55}Cs + 1\text{ ulm n} \rightarrow {}^{134}_{55}Cs + \gamma$ (Q = 6.9 MeV; 2.1 yrs; $\sigma_{thermal}$ = 140b)
$^{134}_{55}Cs + 1\text{ ulm n} \rightarrow {}^{135}_{55}Cs + \gamma$ (Q = 8.8 MeV; hl = 2.3 x 10^6yrs; $\sigma_{thermal}$ = 8.9b)
$^{135}_{55}Cs + 1\text{ ulm n} \rightarrow {}^{136}_{55}Cs + \gamma$ (Q = 6.8 MeV; hl = 13.2 days; $\sigma_{thermal}$ = ?)
$^{136}_{55}Cs + 1\text{ ulm n} \rightarrow {}^{137}_{55}Cs + \gamma$ (Q = 8.3 MeV; hl = 30.1 yrs; $\sigma_{thermal}$ = 0.25b)
$^{137}_{55}Cs + 1\text{ ulm n} \rightarrow {}^{138}_{55}Cs + \gamma$ (Q = 4.4 MeV; hl = 33.4 min; $\sigma_{thermal}$ = ?)
$^{138}_{55}Cs + 1\text{ ulm n} \rightarrow {}^{139}_{55}Cs + \gamma$ (Q = 6.6 MeV; hl = 9.3 min; $\sigma_{thermal}$ = ?)
$^{139}_{55}Cs + 1\text{ ulm n} \rightarrow {}^{140}_{55}Cs + \gamma$ (Q = 4.4 MeV; hl = 64 sec; $\sigma_{thermal}$ = ?)
$^{140}_{55}Cs + 1\text{ ulm n} \rightarrow {}^{141}_{55}Cs + \gamma$ (Q = 5.5 MeV; hl = 25 sec; $\sigma_{thermal}$ = ?)
$^{141}_{55}Cs$ decays 100% via $\beta^- \rightarrow {}^{141}_{56}Ba + \gamma$ (Q = 5.3 MeV; hl = 18.3 min)
$^{141}_{56}Ba$ decays 100% via $\beta^- \rightarrow {}^{141}_{57}La + \gamma$ (Q = 3.2 MeV; hl = 3.9 hrs)
$^{141}_{57}La$ decays 100% via $\beta^- \rightarrow {}^{141}_{58}Ce + \gamma$ (Q = 2.5 MeV; hl = 32 days)
$^{141}_{58}Ce$ decays 100% via $\beta^- \rightarrow {}^{141}_{59}Pr$ + X-rays (Q = 580 keV; stable)

$^{88}_{38}Sr + 1\text{ ulm n} \rightarrow {}^{89}_{38}Sr + \gamma$ (Q = 6.4 MeV; 50.5 days)
$^{89}_{38}Sr$ decays 100% via $\beta^- \rightarrow {}^{89}_{39}Y$ + X-rays (Q = 1.5 MeV; stable)
$^{89}_{39}Y + 1\text{ ulm n} \rightarrow {}^{90}_{39}Y + \gamma$ (Q = 6.9 MeV; hl = 64hrs; $\sigma_{thermal}$ = 6.5b)
$^{90}_{39}Y + 1\text{ ulm n} \rightarrow {}^{91}_{39}Y + \gamma$ (Q = 7.9 MeV; hl = 59 days; $\sigma_{thermal}$ = ?)
$^{91}_{39}Y + 1\text{ ulm n} \rightarrow {}^{92}_{39}Y + \gamma$ (Q = 6.5 MeV; hl = 3.5 hrs; $\sigma_{thermal}$ = ?)
$^{92}_{39}Y + 1\text{ ulm n} \rightarrow {}^{93}_{39}Y + \gamma$ (Q = 7.5 MeV; hl = 10.2 hrs; $\sigma_{thermal}$ = ?)
$^{93}_{39}Y$ decays 100% via $\beta^- \rightarrow {}^{93}_{40}Zr + \gamma$ (Q = 2.9 MeV; hl = 1.5 *x* 10^6 yrs; $\sigma_{thermal}$ = <4b)
$^{93}_{40}Zr + 1\text{ ulm n} \rightarrow {}^{94}_{40}Zr + \gamma$ (Q = 8.2 MeV; stable; $\sigma_{thermal}$ = 0.05b)
$^{94}_{40}Zr + 1\text{ ulm n} \rightarrow {}^{95}_{40}Zr + \gamma$ (Q = 6.5 MeV; hl = 64 days; $\sigma_{thermal}$ = ?)
$^{95}_{40}Zr$ decays 100% via $\beta^- \rightarrow {}^{95}_{41}Nb$ + X-rays (Q = 1.1 MeV; hl = 35 days; $\sigma_{thermal}$ = <7b)
$^{95}_{41}Nb + 1\text{ ulm n} \rightarrow {}^{96}_{41}Nb + \gamma$ (Q = 6.9 MeV; hl = 23.4 hrs; $\sigma_{thermal}$ = ?)
$^{96}_{41}Nb$ decays 100% via $\beta^- \rightarrow {}^{96}_{42}Mo + \gamma$ (Q = 5.3 MeV; stable)

Comments: neutron-rich isotopes build-up; serial neutron captures are interspersed with β-decays. Neutron capture on stable or unstable isotopes releases substantial nuclear binding energy; much ends-up in gamma emissions. Hard gamma and X-ray emissions were not observed in any of these experiments, indicating that W-L gamma-conversion mechanism is operating; 1 atm pressure gradient will only produce relatively small fluxes of ULM neutrons

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W-L theory: heat and transmutations with Palladium - I

Production/capture of LENR ULM neutrons on Pd and related α decays to Ru

- ✓ **Palladium (Pd) has a long history w. LENRs**
- ✓ **Many "cold fusioneers" continue to promote a false myth that Pd has special properties that make it uniquely suitable for LENRs**
- ✓ **While Pd readily loads large amounts of Hydrogen, other hydride-forming metals, e.g., Ni, Ti, W, can also perform well if LENR device fabrication is done properly on a nanoscale according to W-L theory; this is not presently being done by CF researchers**
- ✓ **Pd has 6 stable isotopes that are closely spaced mass-wise. Besides being a H-storing substrate and surface where collectively oscillating 'patches' of H ions can form, Pd isotopes can also potentially capture ULM neutrons, release nuclear binding energy, and help produce excess heat and He-4. This possibility has been totally overlooked by 'CF' researchers**

$^{102}_{46}Pd, ^{104}_{46}Pd, ^{105}_{46}Pd, ^{106}_{46}Pd, ^{108}_{46}Pd, ^{110}_{46}Pd$ are stable

$^{102}_{46}Pd + 1\ ulm\ n \rightarrow ^{103}_{46}Pd + \gamma$ (Q =7.6 MeV; 17 days; Q_α = 5.3 MeV)

$^{103}_{46}Pd + 1\ ulm\ n \rightarrow ^{104}_{46}Pd + \gamma$ (Q =10 MeV; stable; Q_α = 7.4 MeV)

$^{104}_{46}Pd + 1\ ulm\ n \rightarrow ^{105}_{46}Pd + \gamma$ (Q =7.1 MeV; stable; Q_α = 4.2 MeV)

$^{105}_{46}Pd + 1\ ulm\ n \rightarrow ^{106}_{46}Pd + \gamma$ (Q =9.6 MeV; stable; Q_α = 6.3 MeV)

$^{106}_{46}Pd + 1\ ulm\ n \rightarrow ^{107}_{46}Pd + \gamma$ (Q =6.5 MeV; 6.5 x 10^6 yrs; Q_α = 3 MeV)

$^{107}_{46}Pd + 1\ ulm\ n \rightarrow ^{108}_{46}Pd + \gamma$ (Q =9.2 MeV; stable; Q_α = 5.4 MeV)

$^{108}_{46}Pd + 1\ ulm\ n \rightarrow ^{109}_{46}Pd + \gamma$ (Q =6.2 MeV; 13.7 hrs; Q_α = 2.1 MeV)

$^{109}_{46}Pd + 1\ ulm\ n \rightarrow ^{110}_{46}Pd + \gamma$ (Q =8.8 MeV; stable; Q_α = 4.4 MeV)

$^{110}_{46}Pd + 1\ ulm\ n \rightarrow ^{111}_{46}Pd + \gamma$ (Q =5.7 MeV; 23.4 min; Q_α = 1.2 MeV)

$^{111}_{46}Pd + 1\ ulm\ n \rightarrow ^{112}_{46}Pd + \gamma$ (Q =8.4 MeV; 21 hrs; Q_α = 3.3 MeV)

$^{112}_{46}Pd + 1\ ulm\ n \rightarrow ^{113}_{46}Pd + \gamma$ (Q =5.4 MeV; 93 sec; Q_α = 161 keV)

$^{113}_{46}Pd + 1\ ulm\ n \rightarrow ^{114}_{46}Pd + \gamma$ (Q =7.9 MeV; 2.4 min; Q_α = 1.9 MeV)

$^{114}_{46}Pd + 1\ ulm\ n \rightarrow ^{115}_{46}Pd + \gamma$ (Q =5 MeV; 25 sec; Q_α = none)

$^{115}_{46}Pd + 1\ ulm\ n \rightarrow ^{116}_{46}Pd + \gamma$ (Q =7.6 MeV; 12 sec; Q_α = 727 keV)

Note: neutron capture on $^{105}_{46}Pd$ has a measured Q_α cross-section of 0.5 μbarns for $^{106}_{46}Pd \rightarrow ^{102}_{46}Ru + He^4$

ULM neutron capture on Pd isotopes can release significant amounts of binding energy; all stable Pd isotopes will have large ULMN capture cross-sections. Albeit having relatively small, rarely measured cross-sections, α (He-4) decays have positive Q-values

W-L theory: heat and transmutations with Palladium - II

Capture of LENR ULM neutrons on Pd, Ag, and Ru; related β^- and α decays

- ✓ In LENR systems, neutron capture on stable Palladium isotopes and subsequent β^- decays of neutron-rich Pd isotopes, in conjunction with W-L direct conversion of prompt neutron capture and β^- decay gammas to locally absorbed infrared energy, could easily contribute to observed excess heat production as well as to minor fluxes of He-4 produced by small-cross-section α-decays
- ✓ β^- decay of neutron-rich Pd isotopes are dominant channels, leading to production of Silver (Ag) which only has two stable isotopes: Ag-107 (natural abundance 51.8%) and Ag-109 (48.2%)
- ✓ On neutron capture, Ag also has minor α-decay channels for unstable neutron-rich Ag isotopes that lead to production of Rhodium (Rh) which only has one stable isotope, Rh-103 ($\sigma_{thermal}$ n=134 b)
- ✓ Ruthenium (Ru) has 7 stable isotopes: Ru-96, 98, 99, 100, 101, 102, and 104. ULM neutrons can capture on these; unstable neutron-rich Ru isotopes β^- decay to Rh and then to Pd; this could readily convert Ru back into various Pd isotopes

Is there experimental evidence for such conjectures based on the W-L theory? Yes

→ *For example, Passell (ICCF-10) analyzed virgin and reacted particulate Pd taken from hollow cores of Arata-Zhang-type cathodes with NAA and TOF-SIMS and found significant isotopic enrichment of: Pd-110 vs. Pd-108; Li-7 vs. Li-6; and of Ag-109 (Ag-107 was not measured). This is evidence for ULM neutron captures*

→ *While Ru is not often detected as an LENR transmutation product as did K. Wolf at Texas A&M in 1992, several researchers have reported observations of significant amounts of Rh on Pd surfaces in various experiments*

→ *For example, Karabut (Phys. Lett. A. 170 pp. 265 1992) detected unstable isotopes of Rh and Pd-109, as well as He-3 and He-4, in an experiment involving an electric discharge in gaseous deuterium with a Pd cathode 'target'*

→ *Ag often reported as transmutation product on Pd surfaces: e.g. Miley papers; Zhang/Dash on Slide #69. All such observations are evidence for ULM neutron captures on Pd. Rh data suggests that He-4 decay channels may sometimes have anomalously higher cross-sections in LENRs*

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He-4 production not necessarily evidence for D-D fusion

W-L theory suggests substantial He-4 production via non-fusion processes

- ✓ **Over the past 20 years, vast majority (probably at least 80%) of all LENR experiments conducted worldwide used electrolytic cells w. Pd cathodes**
- ✓ **In most LENR experiments to date, the primary objective was to produce and measure macroscopic excess heat via calorimetry; serious post-experiment measurements of various types of transmutation products were pursued by only a relatively small subset of LENR researchers**
- ✓ **Only a relative handful of LENR researchers, e.g., McKubre, Miles, De Ninno, etc., had sufficient funding and analytical skills to accurately measure gaseous He-4 production in their experiments**
- ✓ **Only a few LENR researchers, e.g., Bockris, Dash, Miley, Mizuno and some others, made strenuous attempts to exhaustively detect/measure as many transmutation products as practically possible (besides gaseous He-4) post-experimentally**
- ✓ **Thus, reported experimental data on transmutation products from LENRs is spotty and non-systematic**

That having been said, several things are presently clear about Pd 'targets' used in most LENR experiments:

→ ***ULM neutron captures on Pd can produce substantial amounts of excess heat that will be included in sensitive calorimetry measurements***

Minor decay channels of unstable Pd isotopes produced by neutron capture on Pd can also produce He-4; there is some reported experimental evidence that these typically minor decay channels may be unexpectedly 'wider' in some LENR systems; many pathways potentially produce He-4

→ ***As seen in Slide #32, presence of Li or B anywhere near an LENR-active surface (e.g., in electrolyte or cathode) may result in significant production of excess heat and He-4 by various non-fusion neutron capture and related α, β^- decay processes***

→ ***If true, then McKubre, Miles, and De Ninno's estimates of energy in MeV per observed He-4 atom: ~21–31; 25–88; and 88-124, respectively, are probably inaccurate because their calculations assume that D + D -> He-4 + heat is the ONLY nuclear reaction taking place in their systems. If neutrons are present, that assumption is clearly wrong; they all overestimate energy in MeV/He-4***

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Extensive evidence for transmutations via W-L mechanism

- ✓ Utilizing the W-L theory of LENRs, readers are encouraged to examine reported experimental data and evaluate evidence for transmutations and nuclear energy releases in LENR systems
- ✓ In doing so, please be aware that:
  - Any element or isotope present in LENR experimental apparatus having an opportunity to move into close physical proximity to surfaces or nanoparticles on which ULM neutrons are being created can potentially 'compete' with other nuclei (that are located within the same micron-scale domains of spatially extended ULM neutron wave functions) to absorb produced ULMNs
  - Some reported transmutation products may appear mystifying until one determines exactly what elements/isotopes were initially present in the apparatus when an experiment began. In many cases, materials located inside systems are poorly characterized; thus, 'starting points' for ULMN captures on nuclei may be unclear

→ *There is an extensive body of experimental data on LENRs. Some of it can be found via the following resources:*

- *References cited in publications by Widom, Larsen, and Srivastava on the W-L theory of LENRs*
- *Go to the free website www.lenr-canr.org Several hundred .pdf downloadable papers are available on site*
- *Go to the free website www.newenergytimes.com Investigative articles and news, as well as number of downloadable papers on site*
- *Query Internet search engines like Google using various key words such as: "low energy nuclear reactions", "cold fusion energy –Adobe" , "cold fusion", and so forth*

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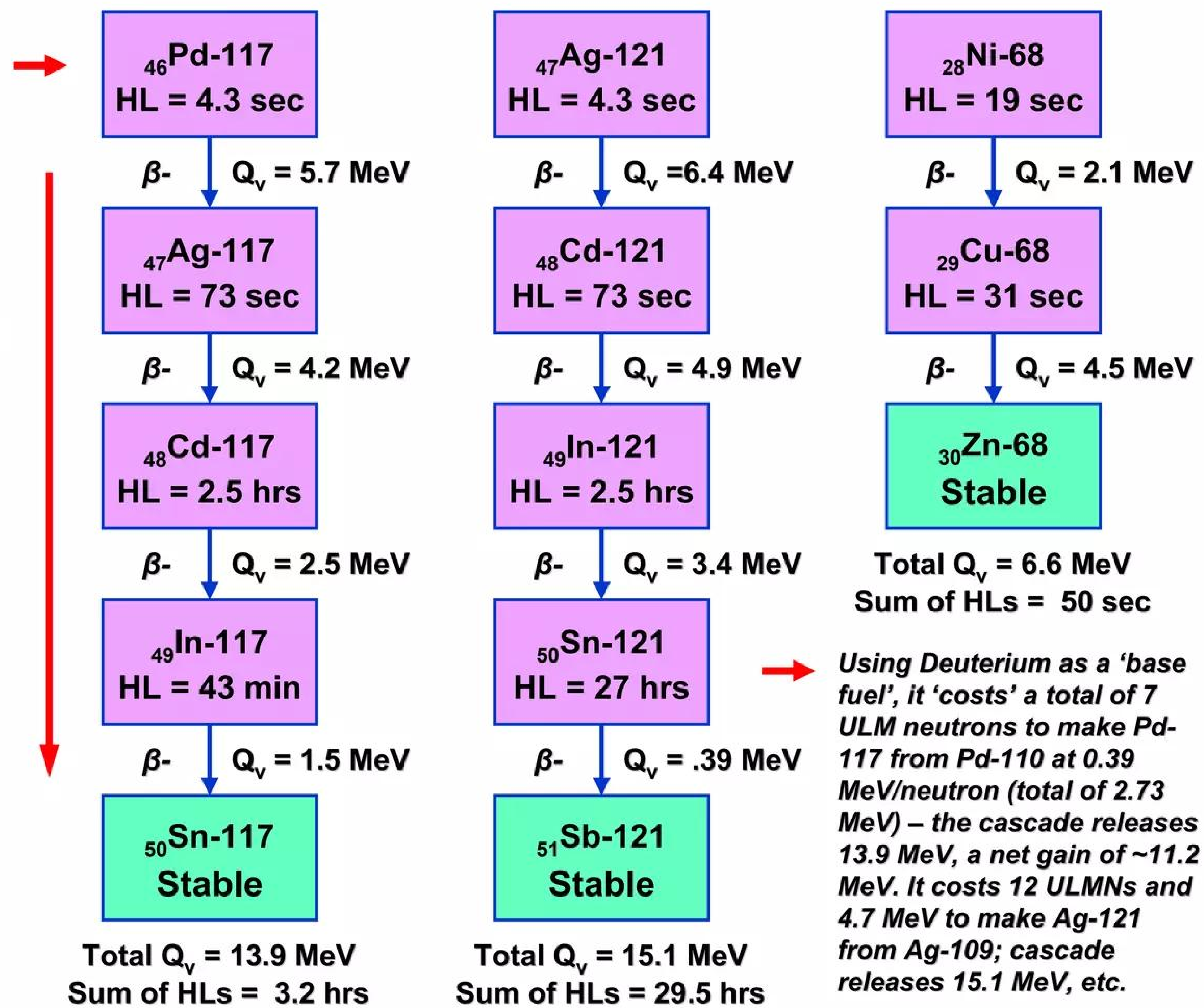
β^- chains: neutron-rich nuclei decay into stable isotopes

Cascades of rapid, energetic β-decays are a feature of LENR systems

- **Acc. to W-L theory, over time, large fluxes of ULM neutrons will result in a build-up of large populations of unstable, very neutron-rich isotopes**
- **At some point, all such n-rich isotopes will decay, mainly by series of rapid β^- cascades**
- **β^- decays release energetic β particles (electrons) that transfer kinetic energy to local matter, heating it up**
- **Depending on half-lives, β^- chains can rapidly traverse rows of the periodic table, terminating in production of stable, higher-Z elements. Long-running experiments with large ULMN fluxes can produce many elements**

Representative examples of β- decay cascades:



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Possibilities for energy production with LENR devices - I

Being nuclear, future commercial versions of LENR-based portable and stationary power sources should be able to achieve effective energy densities that are much higher than competing chemical energy technologies:

- ✓ Eq. 30 in W-L's 2006 *EPJC* paper provides an example of a practical fuel cycle that can produce substantial excess heat from a series of LENR reactions beginning with Lithium-6 as a 'target fuel' which is in summary:
- ✓ Lithium-6 + 2 neutrons => 2 Helium-4 + beta particle + neutrinos + 26.9 MeV
- ✓ Value of ~27 MeV comparable to energy releases from D-D or D-T fusion
- ✓ Conversion of net energy release from above Li-6 based reactions into Joules is: 26.9 $MeV/cm^2/sec = 4.28 \times 10^{-12}\ J/cm^2/sec$ ($1\ eV = 1.602 \times 10^{-19}\ J$)
- ✓ Assume that 'haircut' for energy losses to neutrino emissions is fully compensated by energy production from ULMN captures on other 'target' elements that are present on the surface of a hypothetical LENR device

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Possibilities for energy production with LENR devices - II

Now assume that: the 'base fuel' used to produce ULM neutrons in a hypothetical LENR device is deuterium and, the device has an active working surface area of 1 cm^2 :

- ✓ Assume that there are ~ 10^{14} of these 26.9 MeV energy releases taking place per second on the 1 cm^2 LENR device; this value is consistent with measured rates in some electrolytic cells and W-L's theoretical calculations
- ✓ Total energy release is thus 4.28 x 10^{-12} J/cm^2/sec x 10^{14} = 428 J /cm^2/sec
- ✓ This number represents 428 Watts/cm^2 for the device, a large power density
- ✓ At lower ULMN production rate of 1 x 10^{12}/cm^2/sec, overall rate of device heat production drops down to 4.28 J/cm^2/sec or 4.28 W/cm^2
- ✓ At an even lower ULMN production rate of 1 x 10^{11}/cm^2/sec, device heat production would drop further to ~0.428 J/cm^2/sec or 0.428 W/cm^2; interestingly, this value is similar to excess heat outputs that have in fact been observed in some LENR experiments to date

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Large energy releases have occurred in LENR experiments

- ✓ There have been sporadic reports of dramatic energy releases in LENR experiments, the first being Pons and Fleischmann's unattended overnight experiment in 1985 that ended-up melting entirely through the apparatus and a laboratory bench on which it rested (see C. Beaudette)
- ✓ In his 1998 book, Mizuno describes a D/Pd P&F-type electrolytic experiment that occurred in 1991, "An Anomalous Heat Burst," that ultimately produced a roughly estimated 1.14 x 10^8 Joules of excess heat
- ✓ In 1992, a violent energy release occurred in an experiment at SRI that was later explained as a hydrogen-oxygen recombination explosion ignited by hot Pd metal
- ✓ Rapid, anomalously large macroscopic energy releases occurring in 1991 and 2004 were reported by Zhang and Biberian, respectively. USN SPAWAR even reported evidence for frequent micro-explosions (circa 2003)
- ✓ While most of the large-scale, rare macroscopic events were sketchily documented at best and could not be reproduced, Mizuno saw a large heat release in a 2005 electrolytic experiment with tungsten cathode/K_2CO_3 light water cell that he was able to document and report. We will briefly analyze his observations in the light of W-L theory

→ *C. Beaudette, "Excess Heat – Why Cold Fusion Research Prevailed," on pp. 35-37 in a subsection titled, "The meltdown," 2nd Edition, Oak Grove Press, LLC, South Bristol, ME 2002*

T. Mizuno, "Nuclear Transmutation – The Reality of Cold Fusion," on pp. 66-70 in a subsection titled, "An anomalous heat burst," Infinite Energy Press, Concord, NH 1998

S. Smedley et al., "The January 2, 1992, Explosion in a Deuterium-Palladium Electrolytic System at SRI International," Frontiers of Cold Fusion; Proc. 3rd Int. Conf. Cold Fusion, Nagoya, 1992, Universal Academy Press, Tokyo, 1993

X. Zhang et al., "On the Explosion in a Deuterium-Palladium Electrolytic System," Frontiers of Cold Fusion; Proc. 3rd Int. Conf. Cold Fusion, Nagoya, 1992, Universal Academy Press, Tokyo, 1993

J-P. Biberian, "Unexplained Explosion During an Electrolysis Experiment in an Open Cell Mass Flow Calorimeter, " J. Cond. Mat. Nuc. Sci. 2 pp. 1 – 6 May 2009

PowerPoint presentation by S. Szpak et al. of USN SPAWAR dated May 2009 and titled, "Twenty Year History in LENR Research Using Pd/D Co-deposition" in slide titled, "Piezoelectric Response: Evidence of Mini-Explosions and Heat Generation" http://research.missouri.edu/vcr_seminar/U%20of%20Mo/spawar.ppt

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Implications of W-L theory on small length scales - I

- According to W-L theory, LENRs are a surface and near-surface phenomenon on substrates
- Nuclear-active sites on loaded metallic hydrides occur at locations in which there are many-body homogeneous, collectively oscillating 'patches' of protons, deuterons, or tritons
- Therefore, all other things being equal, the larger the effective surface area, the greater the opportunity will be for hydrogenous many-body patches to form spontaneously on such surfaces
- When enough input energy, say in the form of an electric current, has been 'injected' to drive local electric fields in micron-scale patches past required thresholds for ULM neutron production, neutron captures on nearby nuclei and direct conversion of prompt-capture gammas can begin
- All of these W-L effects are nanoscale, occurring in and around certain types of surface features and nanoparticles on length scales ranging from a few nanometers to perhaps as much as 100 microns or so; that being the case, effective surface area relevant to LENRs is much larger than it would be for a perfectly smooth surface

→ *See: T. Mizuno and Y. Toriabe, "Anomalous energy generation during conventional electrolysis," on pp. 65 - 74 in "Condensed Matter Nuclear Science – Proceedings of the 12th International Conference on Cold Fusion," A. Takahashi, K. Ota, and Y. Iwamura, eds., World Scientific 2006*

A free version of this interesting paper along with additional PowerPoint slides is available at: http://www.lenr-canr.org/acrobat/MizunoTanomalouse.pdf

→ *Importantly, on a nanoscale the surfaces of LENR devices, e.g., metallic cathodes in electrolytic cells, are fractal. That being the case, effective working surface area can be much larger than a very smooth surface when viewed on larger length-scales. Area of a fractal surface a la Mandelbrot described by:*

$$A \approx A_0 l^{-(D_s - 2)}$$

where A is the area, A_0 a constant, l the length scale, and D_s the fractal dimension (~2.5 for Pd)

Nanoscale surface roughening, as occurs during normal electrolysis, can dramatically increase reactive surface area of cathodes

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Implications of W-L theory on small length scales - II

- ✓ **To date, no LENR researchers have used both advanced nanotech fabrication techniques and types of experimental systems (most have used aqueous electrolytic environments that are vastly more difficult to keep in the 'sweet spot' of the nuclear-active LENR parameter space than gas-phase systems) in which they have truly had nanoscale control over geometry and composition of surfaces and relevant operating parameters during fabrication as well as during the course of extended experimental runs**
- ✓ **That having been said, many experimentalists occasionally get lucky and wind-up with a well-performing device in which key parameters have spontaneously 'lined-up' at random in such a manner that a significant portion of the surface area is nuclear-active for sufficient time to generate significant fluxes of excess heat**
- ✓ **Mizuno was very fortunate in this case and importantly, managed to document the event well-enough so that further analysis and some simple calculations could be done on his results**

Two papers and one US patent application are relevant to our discussion of Mizuno's heat event:

→ ***A. Arvia, R. Salvarezza, and W. Triaca, "Noble metal surfaces and electrocatalysis – Review and perspectives," J. New. Mat. Electrochem. Systems 7 pp. 133-143 2004. They note that, "… the comparison of the voltammetric charge for rough and massive palladium confirms the substantial increase in surface area for roughened palladium."***

→ ***X. Cui et al., "Electrochemical deposition and characterization of conducting polymer polypyrrole/PSS on multichannel neutral probes," Sensors and Actuators A 93 pp. 8-18 2001***

→ ***Dao Min Zhou, ELECTRODE SURFACE COATING AND METHOD FOR MANUFACTURING THE SAME, United States Patent Application No. US 2007/0092750 A1 filed August 17, 2006, and published April 26, 2007, in which the abstract reads, " An electrode surface coating and method for manufacturing the electrode surface coating comprising a conductive substrate; and one or more surface coatings comprising one or more of the following metals titanium, niobium, tantalum, ruthenium, rhodium, iridium, palladium, or gold, or an alloy … or metal layers thereof having an increase in the surface area of 5 times to 500 times of the corresponding surface area resulting from the basic geometric shape."***

W-L theory sheds light on Mizuno's large energy release - I

- ✓ For details on the heat event, see paper by Mizuno & Toriabe cited in Slide #54
- ✓ Summarizing: over ~25 seconds, a 1.5 mm dia. tungsten cathode wire with 3 cm of it being exposed to 0.2 M K_2CO_3 electrolyte, released an estimated total of ~132,000 Joules (1.32×10^5 J) as heat.
- ✓ Nominal surface area for 3 cm of exposed W cathode as a perfectly smooth cylinder was ~0.1021 cm^2. However, per citations on the previous slide, effective reactive surface area for LENRs on Mizuno's W cathode is estimated to be ~10x larger: 1.021 cm^2, i.e. roughly one square cm
- ✓ See assumptions/calculations to right →
- ✓ Using W-L theory, we calculate a rough orders-of-magnitude agreement with Mizuno's estimated heat release. This suggests that his estimates were likely more or less correct; W-L may thus provide useful insights into dramatic energy releases occasionally seen in some LENR systems. However, we still need to try to resolve an apparent 100-fold discrepancy between the number of neutrons that can be made with 300 J input power vs. the number of W atoms that apparently reacted w. neutrons; that issue will be addressed in the next slide

1 Joule = 6.2415×10^{12} MeV; 1.3×10^5 J = 8.2388×10^{17} MeV Depending on lattice structure exposed at a surface, 'virgin' W metal will average ~6×10^{14} tungsten atoms per cm^2 of surface area

Isotopically weighted-average Q-value for ULM neutron captures on stable W isotopes is ~6.0 MeV; for stable K isotopes it is ~7.8 MeV (this will be further discussed in the next slide)

Fractal increase in effective W cathode surface area is conservatively estimated at 10 times. In Table 2 of cited patent application by D. Zhou, five experiments with electrolytically roughened Pd produced surface area increases of 10, 56, 73, 70, and 60x; Zhou claims 5x minimum. Note that substantial surface roughening and ablation (loss of material) are clearly visible in the post-explosion image of the W cathode in Fig. 9 of Mizuno's paper and additional SEM images of the cathode at: http://www.lenr-canr.org/acrobat/MizunoTanomalouse.pdf

Mizuno estimated the event's heat release at 8.2388×10^{17} MeV. Simply assuming that all such heat resulted from neutron captures on surface W atoms would imply that (dividing 8.2388×10^{17} MeV by 6.0×10^0MeV) about 1.373×10^{17} tungsten atoms reacted with neutrons; at least that number of neutrons would have to be produced over the 25 second period. Since effective surface area of Mizuno's W cathode was ~1 cm^2, dividing 1.373×10^{17} by $.25 \times 10^2$ sec implies ULMN production rate of 5.49×10^{15} cm^2/sec., which is theoretically reasonable and consistent with the range of experimentally measured rates in LENR electrolytic cells

Per W-L, neutron capture on W atoms can produce intense local heating to > 4,000 - 6,000° K, which drastically reworks and roughens cathode surfaces on a nanoscale, increasing effective surface area and removing reacted W atoms from the surface by ablation. Thus 'fresh' unreacted tungsten atoms are exposed on new surface and can then react with produced neutrons. Dividing 1.373×10^{17} by 6×10^{14} surface W atoms implies that 0.229×10^3 or ~229 atomic layers of tungsten atoms were reacted and removed from the surface. Since W's unit cell is 3.165 Angstroms, this implies that on average ~725 Angstroms (72.5 nanometers or 0.00000725 cm) was removed from the 'virgin' tungsten cathode's surface, which is very plausible when you view Mizuno's SEM images of the cathode in Slide #59

Lastly, Mizuno independently very roughly estimated input power for the heat event at ~300 Joules or 1.87×10^{15} MeV. According to W-L theory, it 'costs' 0.78 MeV to produce one ULM neutron in a light water LENR system; therefore 300 J would be enough energy to make ~2.4×10^{15} neutrons, which is a factor of ~100 less than our estimate of 1.373×10^{17} neutrons produced in the event. How might one reconcile this apparent difference?

W-L theory sheds light on Mizuno's large energy release - II

- ✓ **First issue** - Mizuno's estimate of total input power of ~300 J may be low: examining his Fig. 7 and text above it ("*Input power was supplied for 10 s …*"), it appears that he counted/calculated input power only while V and I were constant, which was for ~ 10 seconds. In fact, power was supplied to the cell for a total of ~25 sec. If one accounts for added power input while the current was rising and falling (over additional period of 15 sec), one ends-up with somewhat larger estimate of input power of roughly 540 J

- ✓ **Second issue** – further analyzing the ~100-fold discrepancy noted on previous slide; several clues provide hints toward a resolution: (1) K was observed on the cathode surface - like Li, significant admixtures of K on cathode surface would be expected; (2) substantial amounts of Ca is observed on cathode with mass spec – this suggests transmutations via neutron captures on surface K; (3) Ti is also observed on cathode but in lesser amounts – more evidence for neutron captures and beta-decay cascades of neutron-rich isotopes, i.e., a nucleosynthetic pathway that follows: K -> Ca -> Sc -> Ti

- ✓ See assumptions/calculations to right where we explore a potential sequence of nuclear reactions that may help resolve our issue

→ **Note: all of these neutron captures and beta decays have positive Q-values**

Begin ULM neutron captures on K-39; most common isotope

Natural abundance is 93.3%

Net cumulative Q-value = total sum of Q's in nucleosynthetic chain minus 0.78 MeV 'cost' per neutron

Values for energy rounded to nearest 10^{th}; begin neutron capture to create very neutron-rich K isotopes

$^{39}_{19}K + 1\text{ ulm n} \rightarrow {}^{40}_{19}K + \gamma$ (Q=7.8-0.78 MeV; Q_{net}=7.0 MeV; stable nat. ab. ~0.01%; Q_α = 1.4 MeV)

$^{40}_{19}K + 1\text{ ulm n} \rightarrow {}^{41}_{19}K + \gamma$ (Q=10.1-0.78 MeV; Q_{net}=16.3 MeV; stable nat. ab. 6.7%; Q_α = 3.9 MeV)

$^{41}_{19}K + 1\text{ ulm n} \rightarrow {}^{42}_{19}K + \gamma$ (Q=7.5-0.78 MeV; Q_{net}=23.0 MeV; hl =12.4 hrs ; Q_α = none)

$^{42}_{19}K + 1\text{ ulm n} \rightarrow {}^{43}_{19}K + \gamma$ (Q=9.6-0.78 MeV; Q_{net}=31.8 MeV; hl =22.3 hrs ; Q_α = 425 keV)

$^{43}_{19}K + 1\text{ ulm n} \rightarrow {}^{44}_{19}K + \gamma$ (Q=7.3-0.78 MeV; Q_{net}=38.3 MeV; hl =22.1 min; Q_α = none)

$^{44}_{19}K + 1\text{ ulm n} \rightarrow {}^{45}_{19}K + \gamma$ (Q=8.9-0.78 MeV; Q_{net}=46.4 MeV; hl =17.3 min; Q_α = none)

$^{45}_{19}K + 1\text{ ulm n} \rightarrow {}^{46}_{19}K + \gamma$ (Q=6.9-0.78 MeV; Q_{net}=52.5 MeV; hl =105 sec; Q_α = none)

$^{46}_{19}K + 1\text{ ulm n} \rightarrow {}^{47}_{19}K + \gamma$ (Q=8.4-0.78 MeV; Q_{net}=60.1 MeV; hl =17.5 sec; Q_α = none)

$^{47}_{19}K + 1\text{ ulm n} \rightarrow {}^{48}_{19}K + \gamma$ (Q=4.5-0.78 MeV; Q_{net}=63.8 MeV; hl =6.8 sec; Q_α = none)

$^{48}_{19}K + 1\text{ ulm n} \rightarrow {}^{49}_{19}K + \gamma$ (Q=6.3-0.78 MeV; Q_{net}=69.3 MeV; hl =1.26 sec; Q_α = none)

$^{49}_{19}K + 1\text{ ulm n} \rightarrow {}^{50}_{19}K + \gamma$ (Q=3.1-0.78 MeV; Q_{net}=71.6 MeV; hl =472 msec; Q_α = none)

Now begin β^- weak interaction decay cascade down to stable elements:

$^{50}_{19}K$'s β^- decay has two branches: (1) to $^{50}_{20}Ca$ (71%) and (2) to $^{49}_{20}Ca + n(29\%)$

Because of densely occupied local fermionic states, hard to emit a neutron via branch #2

Thus, in this situation we will assume that branch #1 will be very strongly favored

$^{50}_{19}K \rightarrow {}^{50}_{20}Ca + \gamma$ (Q=14.2-0.78 MeV; Q_{net}=85.0 MeV; hl =13.9 sec)

$^{50}_{20}Ca \rightarrow {}^{50}_{21}Sc + \gamma$ (Q=5.0-0.78 MeV; Q_{net}=89.2 MeV; hl =102.5 sec)

$^{50}_{21}Sc \rightarrow {}^{50}_{22}Ti + \gamma$ (Q=6.9-0.78 MeV; Q_{net}=95.3 MeV; stable)

Over ~25 seconds, this energetic ULM neutron-catalyzed nucleosynthetic chain:

Stable $^{39}_{19}K + 11$ ulm neutrons $\rightarrow$ stable $^{50}_{22}Ti + 95.3$ MeV

→ **If ULMN flux is high enough, path can release net total of 95.3 MeV quickly**

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W-L theory sheds light on Mizuno's large energy release - III

- ✓ Per W-L theory once ULM neutron production begins at high rates, populations of unstable, very neutron-rich 'halo' isotopes build-up locally on ~2-D surfaces. As explained in Slide #24, such nuclei likely have somewhat retarded decays because they can have a difficult time emitting beta electrons or neutrons (both of which are fermions) into locally unoccupied states. Consequently, these unstable halo nuclei will continue capturing ULM neutrons (which is in fact energetically favorable – see K example in previous slide) until they finally get so neutron-rich, or a previously occupied local state opens-up, that 'something breaks' and beta decay cascades ending in stable isotopes can begin
- ✓ Importantly, as one can see with K isotopes, the neutron-capture phase can release substantial amounts of nuclear binding energy, much of it in the form of prompt and delayed gammas. Unique to LENR systems and according to W-L theory, those gammas are converted directly to infrared by heavy SPP electrons present on surfaces in LENR systems
- ✓ As explained in Slide #50, beta- decay cascades of unstable isotopes with short half-lives can proceed very rapidly, release relatively large amounts of energy, and can produce complex arrays of different transmutation products that rapidly traverse rows of the periodic table; Mizuno went from K to Fe in <2 min
- ✓ Please see assumptions/calculations to the right
- ✓ In the end, we have reduced the apparent discrepancy from factor of ~100x to roughly 2x. Considering all the uncertainties and unknowns in the experimental measurements, this may be a relatively reasonable agreement under the circumstances, illustrating how W-L can help provide insights into such data

→ ***Revised estimate of total energy input:***

540 J = 5.4×10^2
Convert to MeV = (5.4×10^2) x (6.2415×10^{12}) = 33.7×10^{14}
(3.37×10^{15}) divided by (0.78×10^0) = 4.32×10^{15} neutrons
So, 540 J of input energy can produce ~ 4.32×10^{15} ULMNs

→ ***Revised estimate of total number of atoms that capture ULM neutrons:***

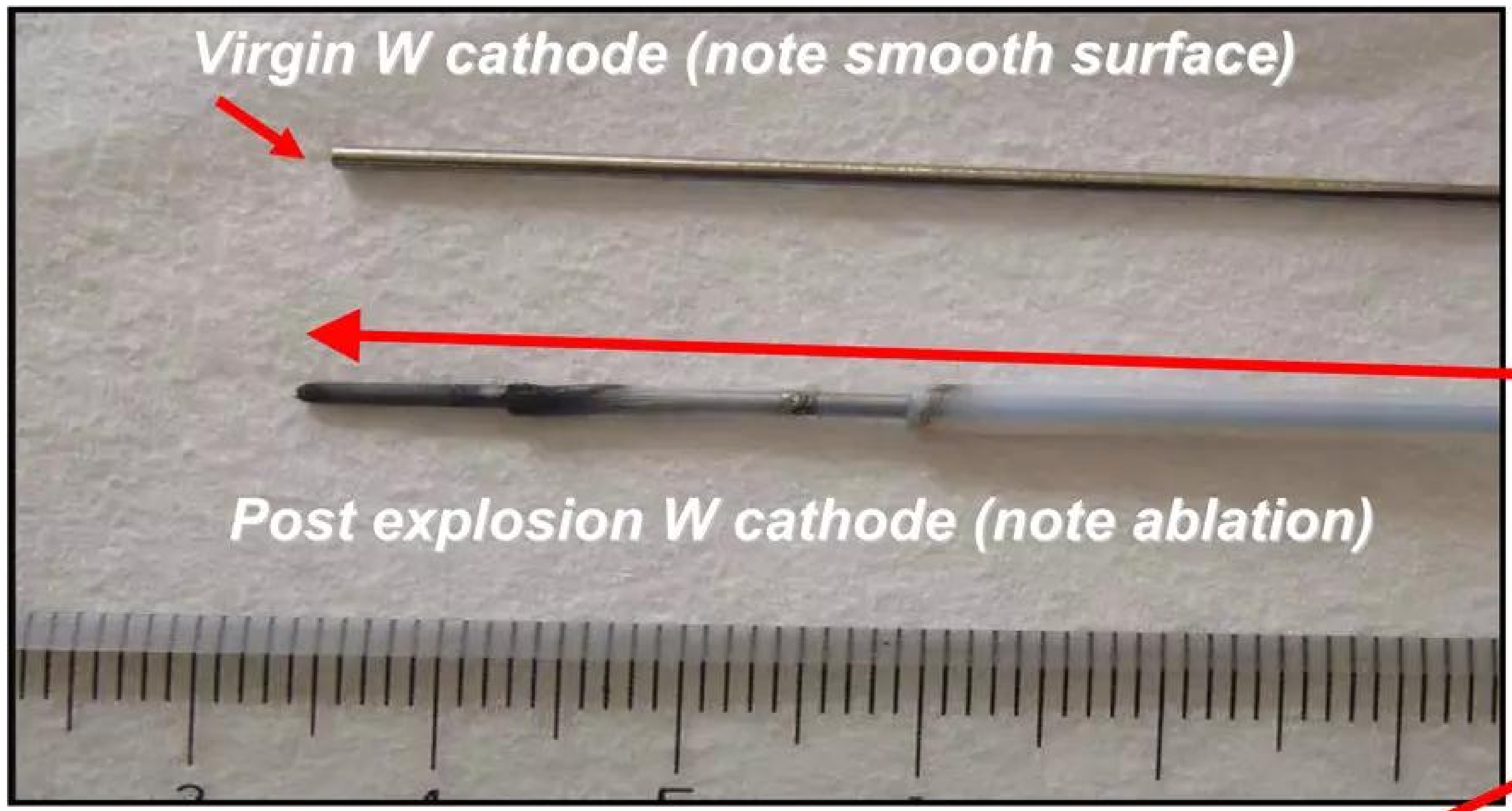
Previously, we simply assumed that all neutron captures took place on Tungsten nuclei and released an average ~6.0 MeV. Now, we will instead assume that all neutron captures take place on Potassium (K) and that subsequent nuclear reactions proceed along the nucleosynthetic path outlined in the previous slide.

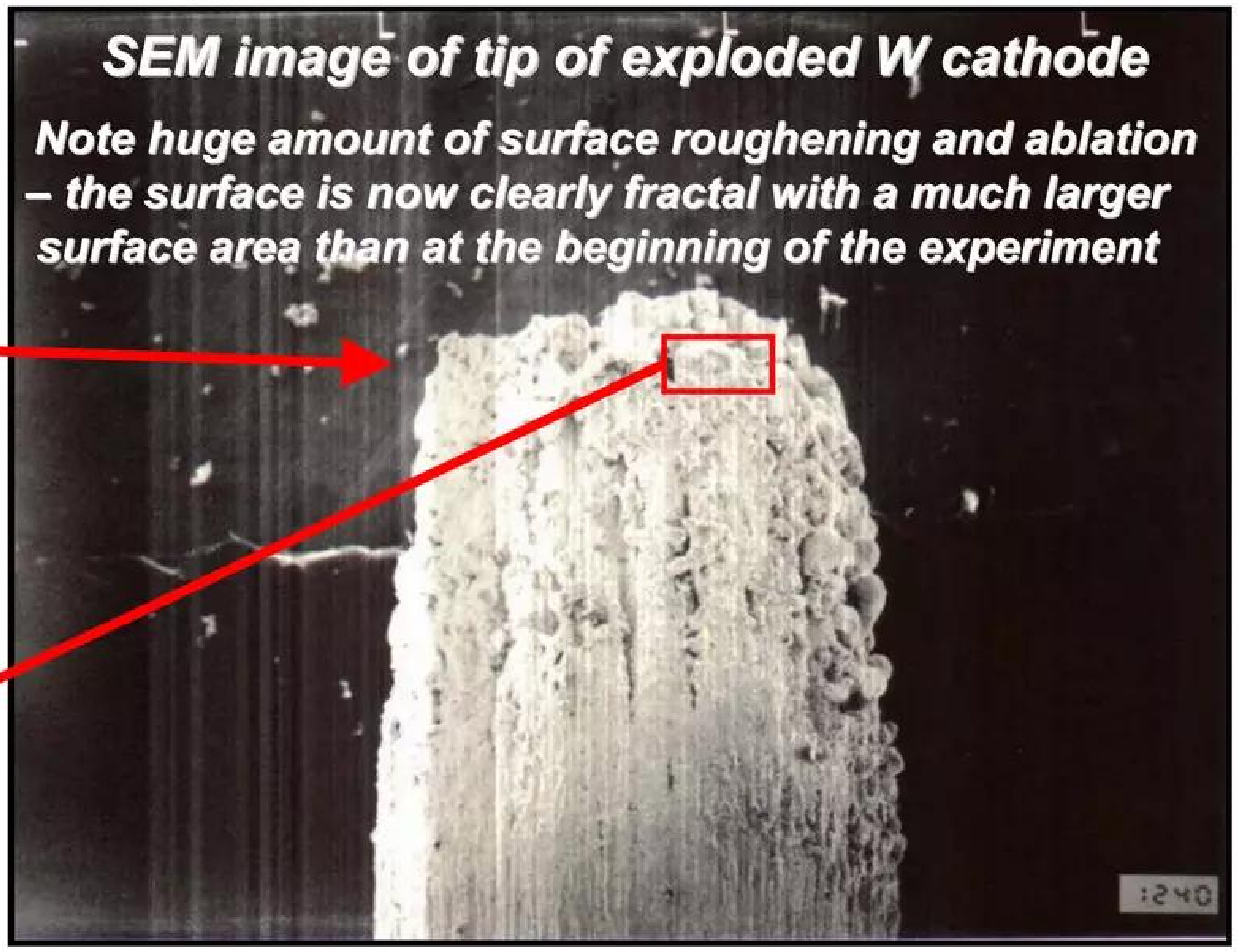
Recalling that Mizuno's rough estimate of total heat release was ~8.2388×10^{17} MeV. Dividing that number by the estimated value for total net energy release for neutron captures starting with K-39, we take (8.2388×10^{17}) divided by (0.95×10^2) and obtain an estimated 8.7×10^{15} K atoms that could have reacted with ULM neutrons; this is within a factor of two of 4.32×10^{15}, which is the estimated number of neutrons that could be created with 540 J of input energy; this would appear to be a reasonable agreement. Dividing (8.7×10^{15}) by ($.25 \times 10^2$) = ULMN estimated production rate of ~3.5×10^{14} neutrons/cm^2/sec, which is reasonable

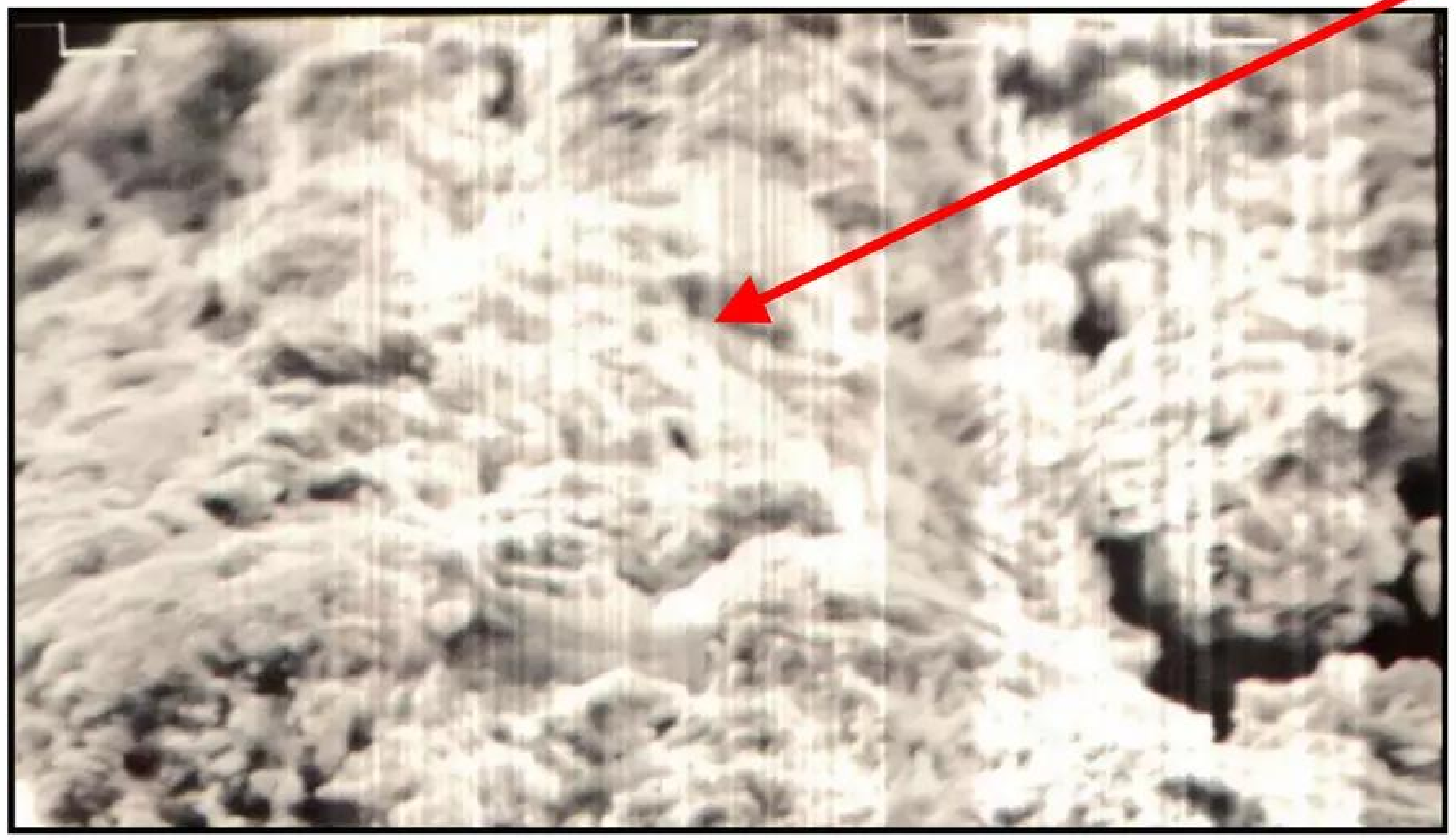
Obviously, not all produced neutrons captured on K atoms; the point of this exercise is to show how it is plausible that extremely energetic nuclear reaction networks can be taking place in LENR systems over very short time spans. Importantly, there are hints in the observed transmutation products that suggest more such processes occurred during Mizuno's experiment … there is some fragmentary evidence for a heavy element transmutation chain Ba -> La -> Ce .> Pr -> Nd -> Pm -> Sm; it is unclear where the 'seed' for this path came from. S could have come from captures on Si leached from vessel walls or on F from PTFE sleeve on cathode

W-L theory sheds light on Mizuno's large energy release - IV

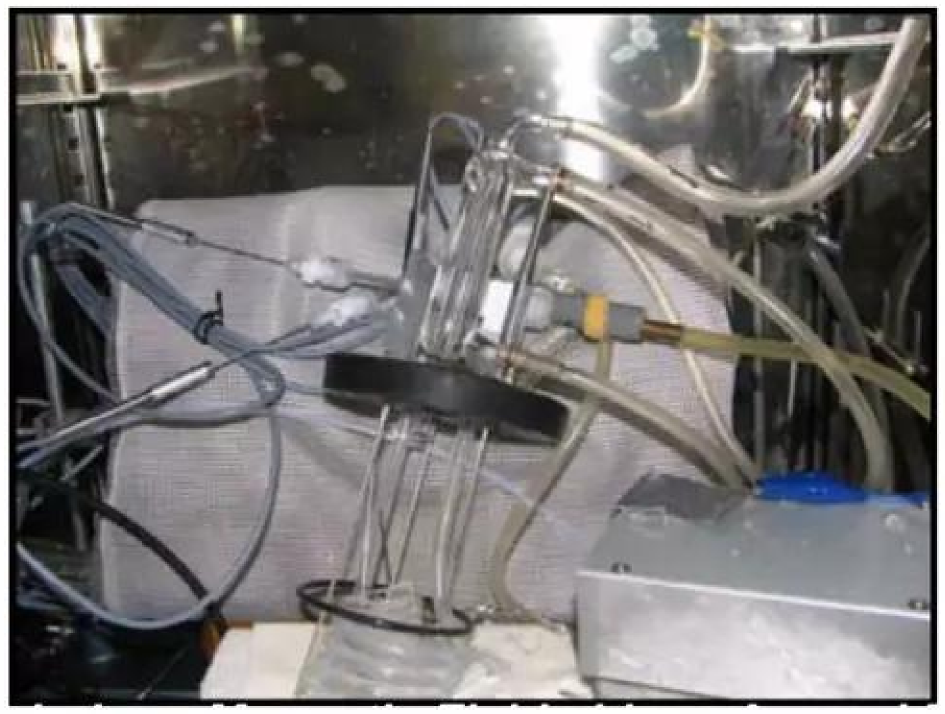
Sometimes a picture is truly worth a thousand words







All four images are taken from Mizuno's paper and PowerPoint slides



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ULMN catalyzed LENR network starting from $_{56}Ba^{130}$ - I

Dynamic evolution and production of neutron-rich isotopes followed by β-decays

- ✓ **Applying W-L theory, we will now outline a hypothetical Barium-seeded ULM neutron-catalyzed LENR network model that has many possible nucleosynthetic pathways through it**
- ✓ **This LENR network model will illustrate a matrix of energetically permissible *possibilities* that could occur in experimental systems; in the 'real world,' nucleosynthetic pathways actually taken through it and final stable products produced can vary greatly between experiments and even on micron-scales across a given device surface**
- ✓ **Hypothetical Barium-seeded LENR network is only a static qualitative picture of what *could* happen; a dynamic quantitative modeling approach having some degree of predictive capability of what *will* happen requires complex, spatially-aware computerized nuclear reaction network codes with est. values for capture cross-sections and half-lives, many of which have never been measured for one reason or another**

→ ***ULM neutron-catalyzed LENR networks occur in nuclear-active 'patches' that form spontaneously on surfaces***

LENR networks are very dynamic: over time they appear, run for a short while producing/capturing neutrons and unstable/stable products, and then 'die'

During course of a long experiment, a given micron-scale surface location may have had none, one, or many local episodes of nucleosynthesis taking place on it. In case of multiple episodes, each in turn 'picks-up' where the previous LENR network left-off, with the transmutation products of the prior networks serving as input 'target seeds' for the next. They are born and reborn

Thus, at the end of an experiment, depending on the size/duration of ULM neutron fluxes and specifics of local nucleosynthetic 'seeds,' an LENR device surface may have substantial variations in final stable products that are distributed randomly across its surface

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ULMN catalyzed LENR network starting from $_{56}Ba^{130}$ - II

Neutron-driven nucleosynthesis in LENRs akin to stars, but with differences

- In some ways, LENR networks strongly resemble so-called r- and s-processes thought to account for nucleosynthesis of elements in stars wherein large neutron fluxes also capture on 'seed' nuclei, creating a variety of neutron-rich isotopes that ultimately decay into stable elements
- In fact, neutron fluxes of condensed matter LENRs and stars appear to be comparable:
  - s-process - thought to occur in AGB stars, e.g., red giants (10^5 to 10^{11} n/cm^2/sec)
  - r-process - thought by astrophysicists to occur in supernova explosions (~10^{22} n/cm^2/sec)
  - LENR electrolytic cells (implicitly measured at 10^9 to 10^{16} n/cm^2/sec)
  - High-current pulsed, magnetic-regime dominated LENR systems such as exploding wires and apparatus such as Proton-21 in Kiev, Ukraine (estimated to be ~10^{18} to 10^{20} n/cm^2/sec)
- Condensed matter LENR networks differ significantly from stars in that they:
  - Are much more 'on-and-off' than stars, which burn more-or-less continuously except in the case of supernova explosions that are thought to take place over 1 to 100 seconds
  - Typically occur in smaller 'natural' spatial volumes under much 'milder' physical conditions
  - Produce long-wavelength ULM neutrons that have vastly larger capture cross-sections
  - Suffer much less from (gamma, n) photodissociation reactions, mainly because heavy SPP electrons absorb gammas from ~0.5 MeV to ~10.0 MeV that are produced in various types of nuclear reactions, including most neutron captures and some but not all, beta decays

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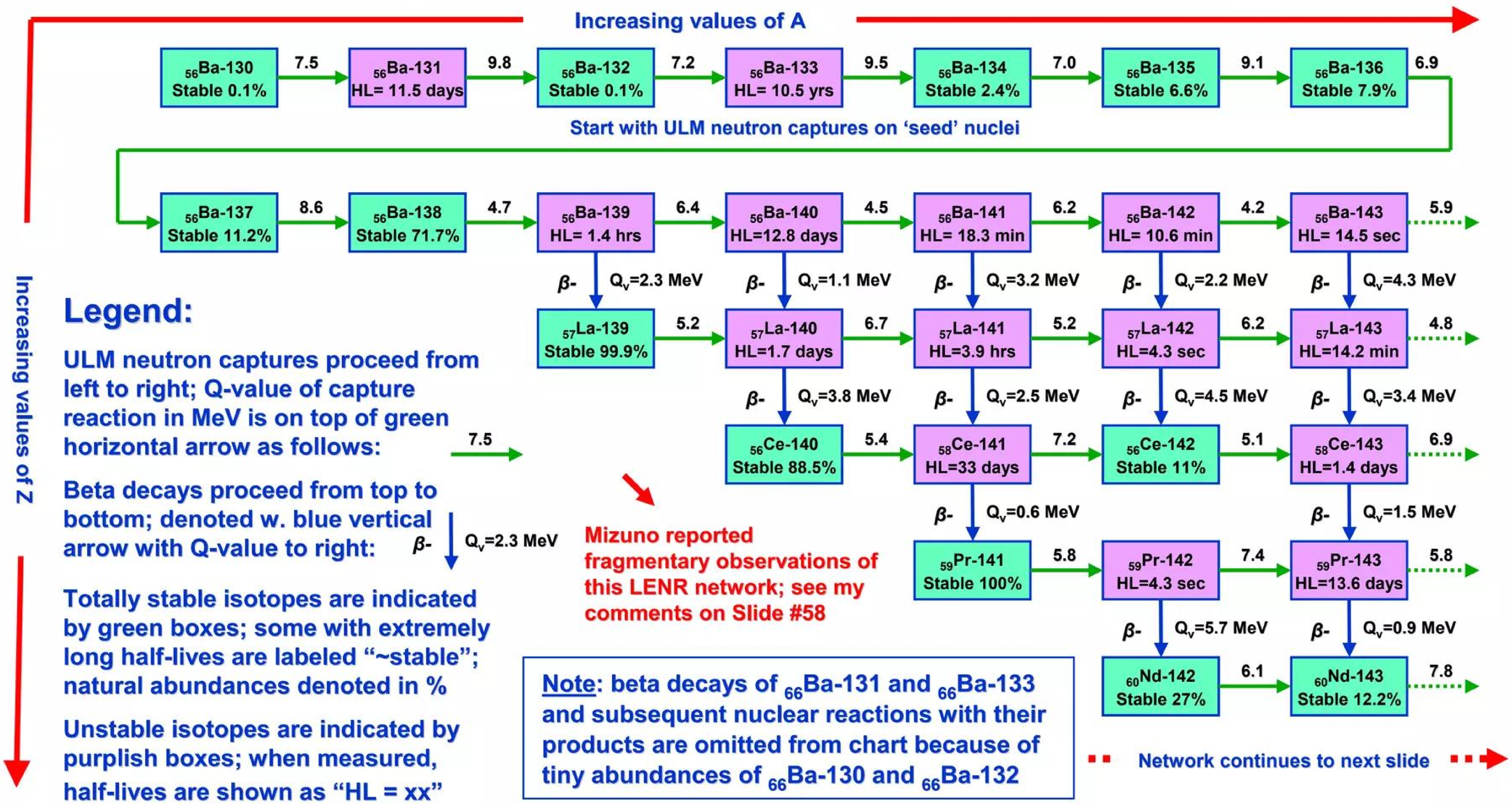
ULMN catalyzed LENR network starting from $_{56}Ba^{130}$ - III

ULM neutron capture on ‘seeds,’ neutron-rich isotope production, and β-decays

‘Target’ seed nuclei on or very near surface: Ba-130, Ba-132, Ba-134, Ba-135, Ba-136, Ba-137, and Ba-138



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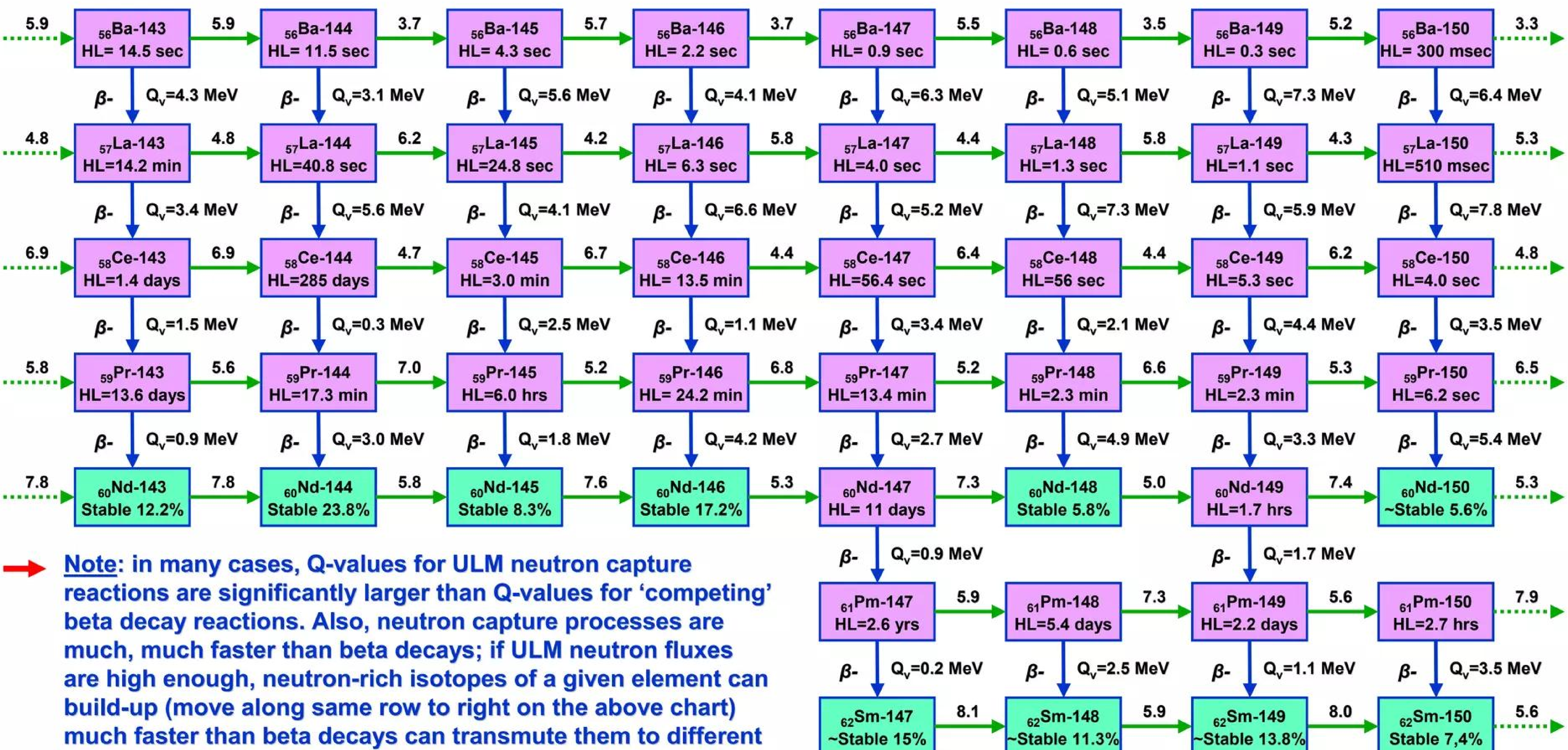
ULMN catalyzed LENR network starting from $_{56}Ba^{130}$ - IV

ULMN capture on products, neutron-rich isotope production, and β-decays

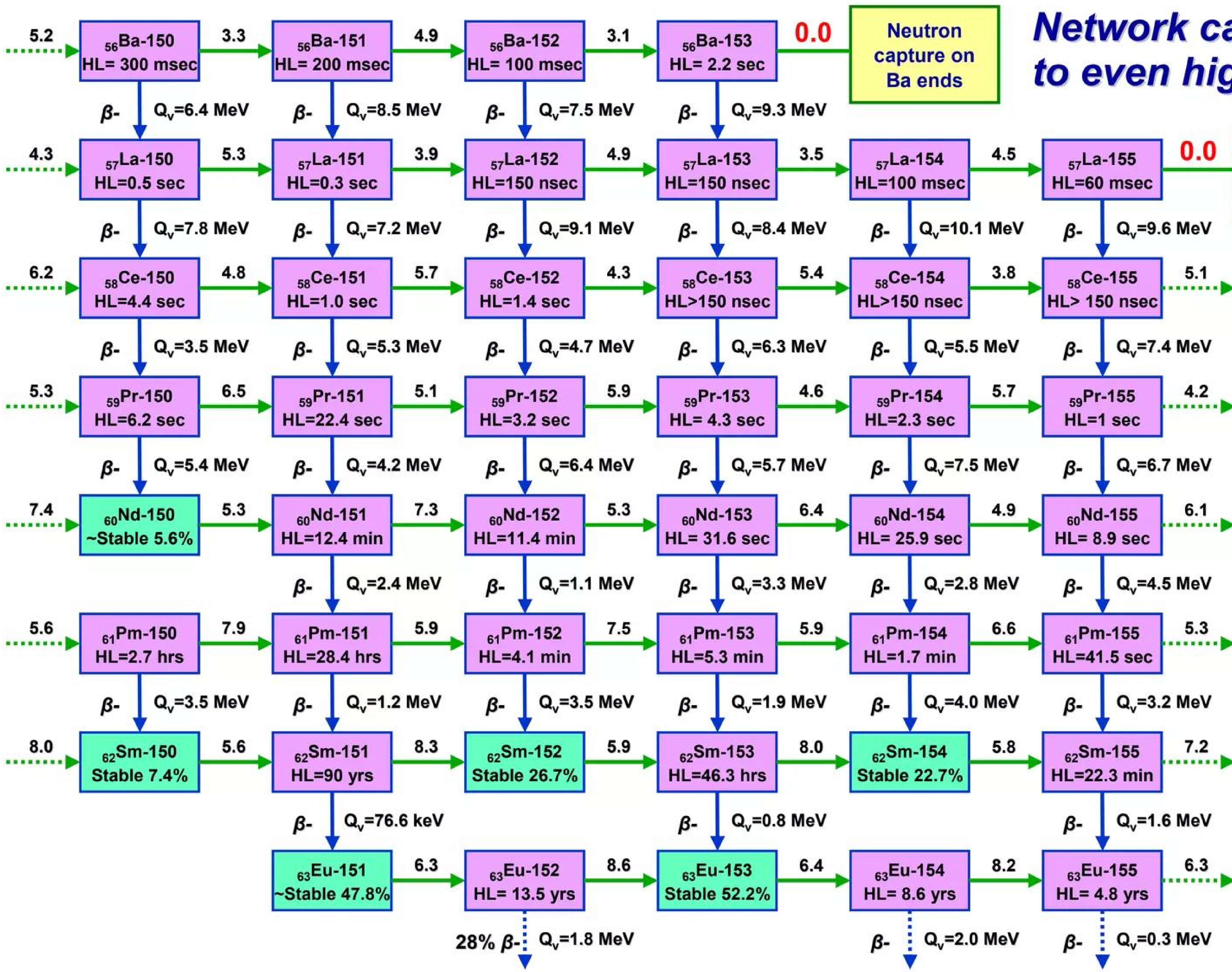


→ <u>Note</u>: in many cases, Q-values for ULM neutron capture reactions are significantly larger than Q-values for 'competing' beta decay reactions. Also, neutron capture processes are much, much faster than beta decays; if ULM neutron fluxes are high enough, neutron-rich isotopes of a given element can build-up (move along same row to right on the above chart) much faster than beta decays can transmute them to different chemical elements (move downward to other rows on chart)

Network continues to next slide

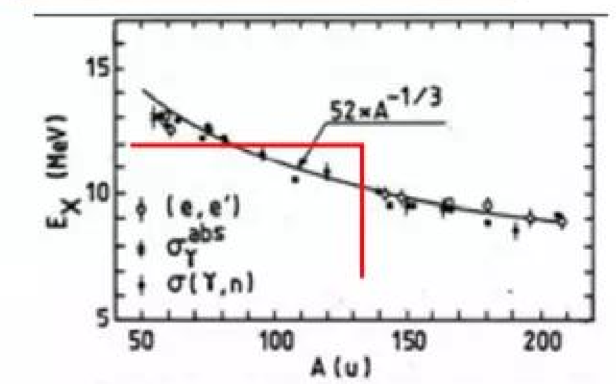
ULMN catalyzed LENR network starting from $_{56}Ba^{130}$ - V

Network can continue further to even higher values of A



Note: unlike stars, photodissociation or photonuclear reactions by energetic gammas from ~0.5 up to ~10.0 MeV that can 'knock-off' neutrons from neutron-rich nuclei (thus hampering their quickly reaching higher values of A) are not much of an issue in certain LENR networks, thanks to gamma conversion by heavy electrons. This effect is very important for neutron-rich isotopes, especially those with A>~140 of Ba, La, Ce, Pr, Nd, Pm, Sm, and Eu that are present in this Ba-seeded LENR network

For details on this issue please see: "*Photonuclear reactions for astrophysical applications,*" B. S. Dolbilkin, which can be found at http://nucl.sci.hokudai.ac.jp/~omeg07/pdf/Dobilkin-084.pdf



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Iwamura et al. experiments with $_{56}Ba^{130-138}$ 'target seeds' - I

Reported results in 2004 claiming transmutation of Ba to $_{62}Sm^{149}$ and $_{62}Sm^{150}$

- ✓ Used experimental set-up very similar to what was utilized in the work reported in 2002 *JJAP* paper (see Slide #44)
- ✓ Natural abundance Ba as well as Ba-137 enriched 'targets' were electrochemically deposited on the surfaces of thin-film "Pd-complex" device heterostructures
- ✓ Ba 'targets' subjected to a D^+ ion flux for 2 weeks; flux created by forcing D_2 gas to permeate/diffuse through the thin-film structure via a pressure gradient imposed between the target side and a mild vacuum on the other
- ✓ Central results of their LENR experiments were the observations of Ba isotopes being transmuted to Samarium isotopes $_{62}Sm^{149}$ and $_{62}Sm^{150}$ over a period of two weeks (see documents cited to the right for experimental details)
- ✓ XPS and SIMS were used to detect elements and isotopes
- ✓ Among other things, they concluded that, " *… a very thin surface region up to 100 angstrom seemed to be active transmutation zone*," which is consistent with W-L theory

→ *See: Iwamura et al., Advanced Technology Research Center, Mitsubishi Heavy Industries, "Observation of nuclear transmutation reactions induced by D_2 gas permeation through Pd complexes," Condensed Matter Nuclear Science – Proceedings of the 11th International Conference on Cold Fusion, J-P. Biberian, ed., World Scientific 2006 ISBN 981-256-640-6*

This paper is also available online in the form of their original conference PowerPoint slides at: http://www.lenr-canr.org/acrobat/IwamuraYobservatioc.pdf

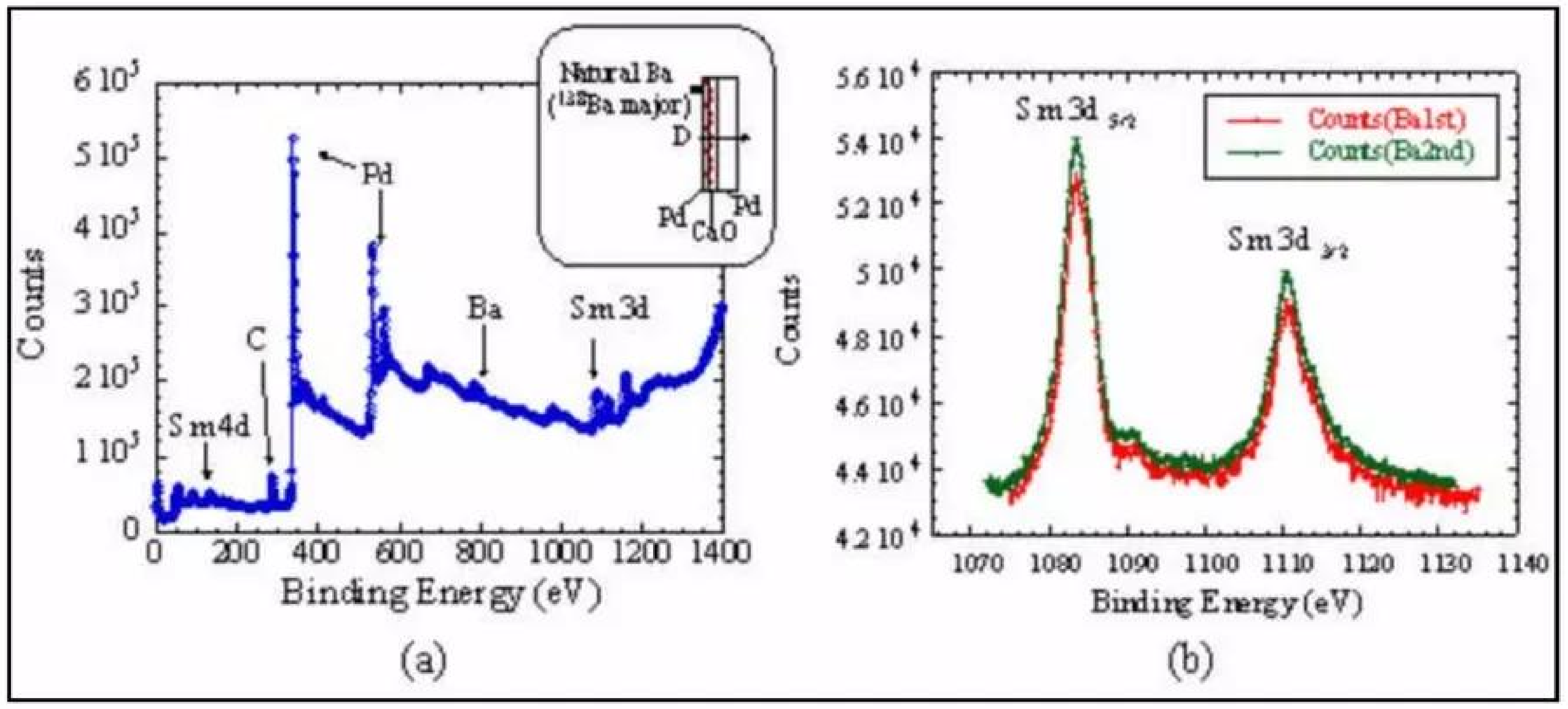
and online as Proceedings paper published by World Scientific at: http://www.lenr-canr.org/acrobat/IwamuraYobservatiob.pdf

Iwamura et al. experiments with $_{56}Ba^{130\text{-}138}$ 'target seeds' - II

Discussion of Mitsubishi's published results in light of LENR network model

- ✓ Central results/conclusions of Iwamura et al. consistent with ULM neutron captures per W-L theory and related Ba-seed LENR network model; it is both feasible and energetically favorable for Ba isotopes to be transmuted to $_{62}Sm^{149}$ and $_{62}Sm^{150}$ over two weeks by a flux of D^+ ions produced by an externally imposed pressure gradient
- ✓ XPS post-experiment spectral scan of device surface with 'natural' Ba targets (see Figure 4 from their paper to right) shows presence of Pd, Ba, Sm, and C, *but no other metallic elements*. Based on LENR network model, since La, Ce, Pr, Nd, and Pm were not detected/reported, their data suggests that ULM neutron captures on Ba isotopes reached at least as far as Ba-147 before beta decays began
- ✓ Hard to imagine nuclear process besides ULMNs and production of neutron-rich Ba isotopes that can explain stable product 'gap' from Ba to Sm and lack of Pm; all Pm isotopes have huge capture c-s
- ✓ Eu was not detected/reported; based on network model, their published data would suggest that Ba-153 was probably not produced in significant quantities during Iwamura et al.'s experiments

XPS spectra Figure 4 from Iwamura et al. paper cited on Slide #65



Post-experiment XPS spectral scan of surface w. 'natural' Ba seed 'target'
Note: Iwamura et al. could not get clear spectrum w. Ba-137 enriched seed

➡ ***Initially, there would be very roughly 8 x 10^{14} atoms/cm^2 on the 'target' surface of Iwamura et al's. experimental device. Thus, there could be ~5.6 x 10^9 atoms potentially involved in a hypothetical LENR nuclear-active surface 'patch' that was 30 microns in diameter. Now the shortest half-life of any Ba isotope is about 0.1 seconds (see model: it is Ba-152 @ 100 msec). This means that an ULM neutron flux of about 10 ULMNs/atom/sec would be just sufficient to allow the model LENR network to produce Ba-153, after which neutron capture is energetically unfavorable. Within the reference frame of a 30 micron nuclear-active patch, this would imply an effective ULM neutron flux of ~5.6 x 10^{10} /sec, which seems reasonable***

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Iwamura et al. experiments with $_{56}Ba^{130-138}$ ‘target seeds’ - III

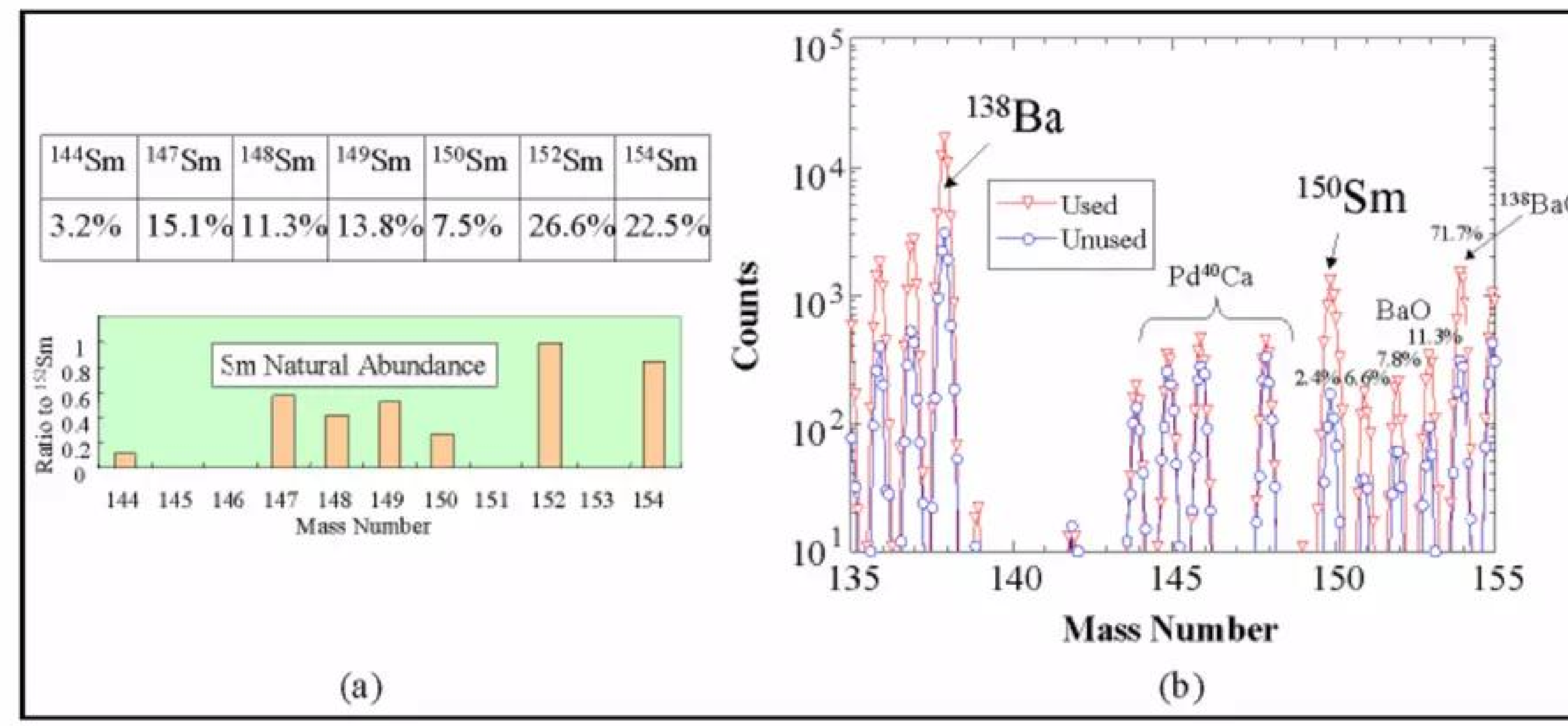
Mitsubishi’s results consistent with W-L theory and related LENR network model

- ✓ **In their paper, they comment, “*The ^{138}Ba for unused and used samples does not match. We assume this is because the Ba deposition is not uniform*.” While this prosaic explanation is very reasonable, their data is also consistent with ULM neutron captures on lower-mass Ba isotopes, which would tend to increase ^{138}Ba counts, exactly as observed in their experiments**

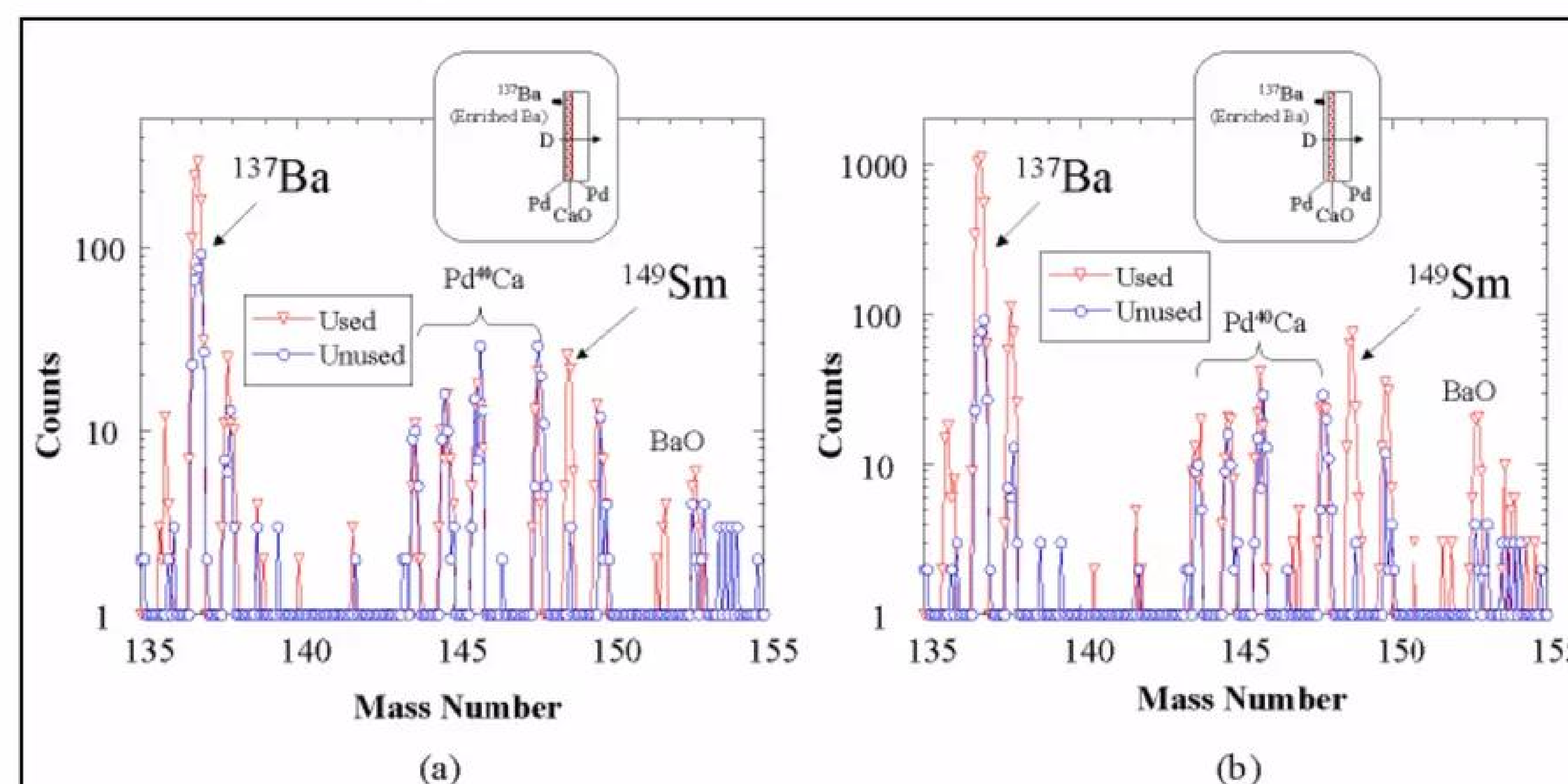
- ✓ **Some SIMS peaks attributed to BaO could well be Sm isotopes besides $^{149-150}$Sm. For example, see their Fig. 6 (a) and (b) where an entirely new peak appears at A=152 (red color in Fig.); this could potentially be Sm-152, which is a stable isotope**

- ✓ **While they could well be BaO, significant post-experiment increases in SIMS peak counts for A = 150 (Fig.6b), 153 (Fig.6b) and 155 (Fig. 6b) are also consistent with production of ^{150}Sm, ^{153}Sm, and ^{155}Sm respectively, according to LENR network model. In Fig. 5 (b), ^{149}Sm is absent; however, significant post-experiment increases occur in the SIMS peak counts for A = 150, 151, 152, 153, and 154 that could be Sm isotopes. Note: such isotopic variations between experiments would in fact be *expected* w. dynamic, evolving LENR networks**

SIMS spectra in Figure 5 from Iwamura et al. paper cited on Slide #65



SIMS spectra in Figure 6 from Iwamura et al. paper cited on Slide #65



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Experimental evidence for W-L theory on small length scales

- ✓ **According to W-L theory, LENRs can produce huge amounts of clean nuclear heat in tiny 'hot spots' (that correspond to nanometer up to micron-scale, collectively oscillating patches of protons, deuterons, or tritons) located on the surfaces of loaded metallic hydride substrates**
- ✓ **W-L have calculated the 'noise temperature' for LENR 'hot spots' to be ~4,000^{o} to 6,000^{o} K, comparable to temperature on the surface of the sun and above the boiling point of any known metal. This theoretical result is also consistent with many experimental observations**

→ ***See: "Theoretical Standard Model Rates of Proton to Neutron Conversions Near Metallic Hydride Surfaces" arXiv:nucl-th/0608059v2 (Sep 2007) Widom and Larsen***

→ ***There is direct experimental evidence for the existence of such hot spots in before-and-after scanning electron microscope (SEM) images of the surfaces of experimental LENR devices, many of which also exhibit surface transmutations. In post-experiment SEM images, a host of new, weird looking micron-scale structures are observed scattered randomly across metallic surfaces. Various researchers have described these unusual surface structural features as resembling "craters", "volcanoes", melted and cooled "puddles," "gas holes", "ejecta from craters", "cauliflowers", etc. Based on their morphology, some features appear to result from explosive 'flash' melting or boiling of the surface in small sites at many locations***

→ ***US Navy SPAWAR imaged an operating cathode with a high speed infrared camera: tiny surface hot spots looked like fireflies 'blinking' on and off in a field at night***

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Transmutation products correlated with surface structures

Nuclear products associated with intense localized heat production

- ✓ **Please see Zhang and Dash paper for details**
- ✓ **With Palladium (Pd) as a 'target element' present on Pd cathode surface, Silver (Ag) is experimentally observed; likely to be direct product of ULM neutron captures on Pd with beta decays to Ag isotopes**
- ✓ **In a SEM image from their paper (copied below) they directly correlate LENR transmutation products with specific sites on post-experiment surface structures:**

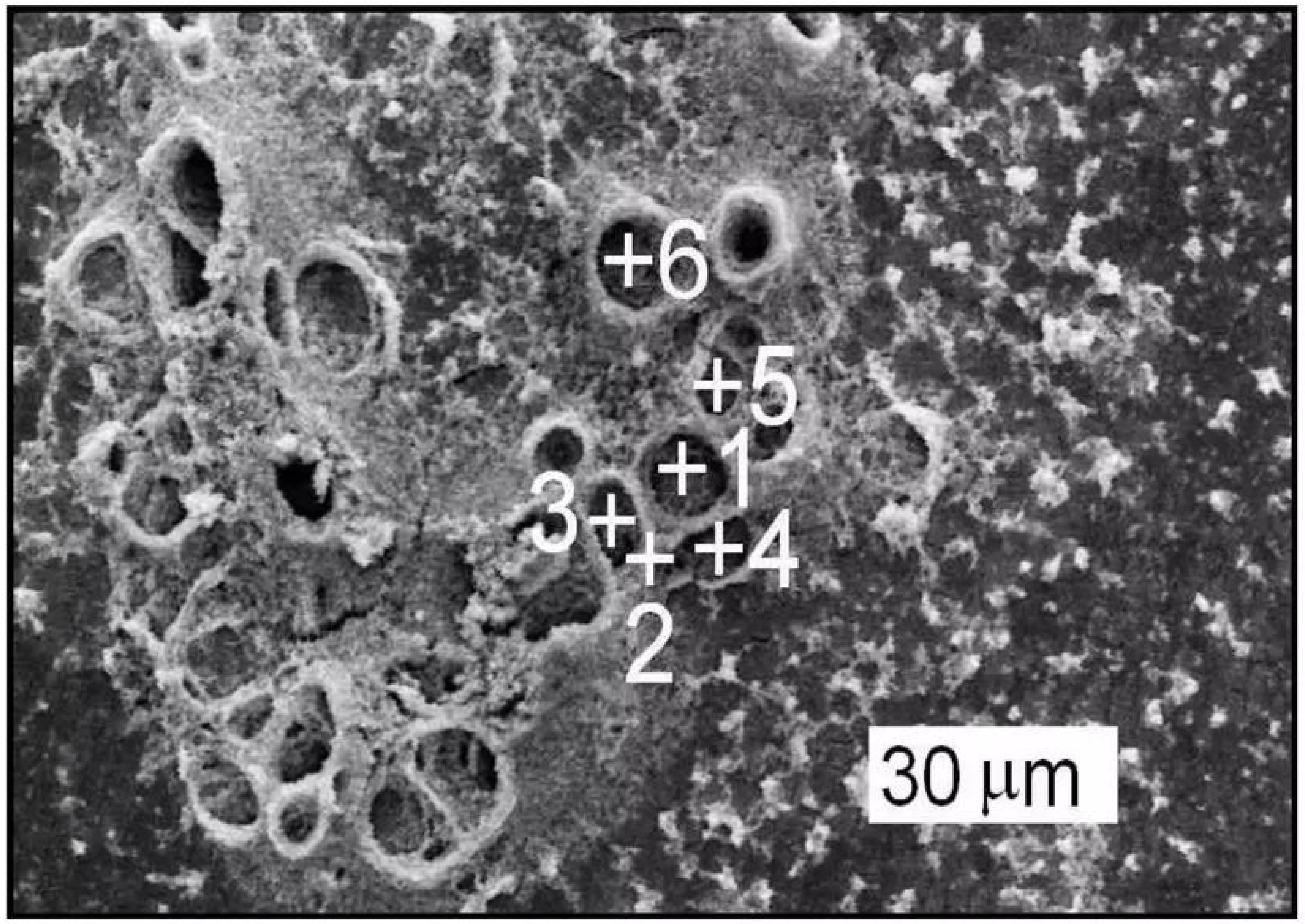

Fig. 8 on p. 14: "*most common finding is that Ag occurs in craters*"

➡ ***See: W. Zhang and J. Dash, "Excess heat reproducibility and evidence of anomalous elements after electrolysis in Pd/D_2O + H_2SO_4 electrolytic cells" in The 13th International Conference on Condensed Matter Nuclear Science, Sochi, Russia 2007***

Free copy of paper available at: http://www.lenr-canr.org/acrobat/ZhangWSexcessheat.pdf

➡ ***Note: Their observations of Nickel (Ni) on the Pd cathode surfaces, if correct, may have resulted from LENR ULM neutron captures on Iron (Fe) that somehow 'leached-out' of the walls of the Pyrex glass vessel comprising the cell containing the electrolyte. It is well known that metallic elements that are compositionally present in Pyrex can leach from glass during extended exposure to hot electrolytes under such experimental conditions. Fe is known to be a minor constituent in many types of Pyrex, e.g., Corning #7740 Fe_2O_3 = 0.04%. Such embedded Fe could potentially leach out of the walls of a Pyrex electrolytic cell into the electrolyte and migrate to the cathode surface, where it could provide yet another local 'target element' able to absorb LENR ULM neutrons and be transmuted***

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Can't boil tea, but LENRs can boil metals on a nanoscale

- ✓ **While LENR devices cannot "boil a cup of tea" yet, Cirillo and Iorio have reported results wherein post-experiment SEM images show unusual surface structures that appear to have resulted from flash boiling of Tungsten cathodes (MP = 3,410 C; BP = 5,666 C) in roughly circular 50 – 100 micron patches**
- ✓ **With W's high boiling point, it is unlikely that such features were produced by oxidative chemical processes, since the hottest known chemical 'flames' are cyanogen-oxygen under pressure at 4,367^{o} C; carbon subnitride burning in pure O^2 at 4,987^{o} C**
- ✓ **One might argue that such heating was caused by local electrical discharges (prosaic arcing). Perhaps, but micron-scale arcing events result in somewhat different surface morphologies (see next slide). More importantly, in the same experiments Rhenium (Re), Osmium (Os), and Gold (Au) were observed as nuclear transmutation products on the cathode surface**
- ✓ **According to W-L theory, ULM neutron production and successive ULM neutron captures interspersed with beta decays would be expected to produce W -> Re -> Os -> Au, which are in fact observed**

→ ***See: D. Cirillo and V. Iorio, "Transmutation of metal at low energy in a confined plasma in water" on pp. 492-504 in "Condensed Matter Nuclear Science – Proceedings of the 11th International Conference on Cold Fusion," J-P. Biberian, ed., World Scientific 2006***

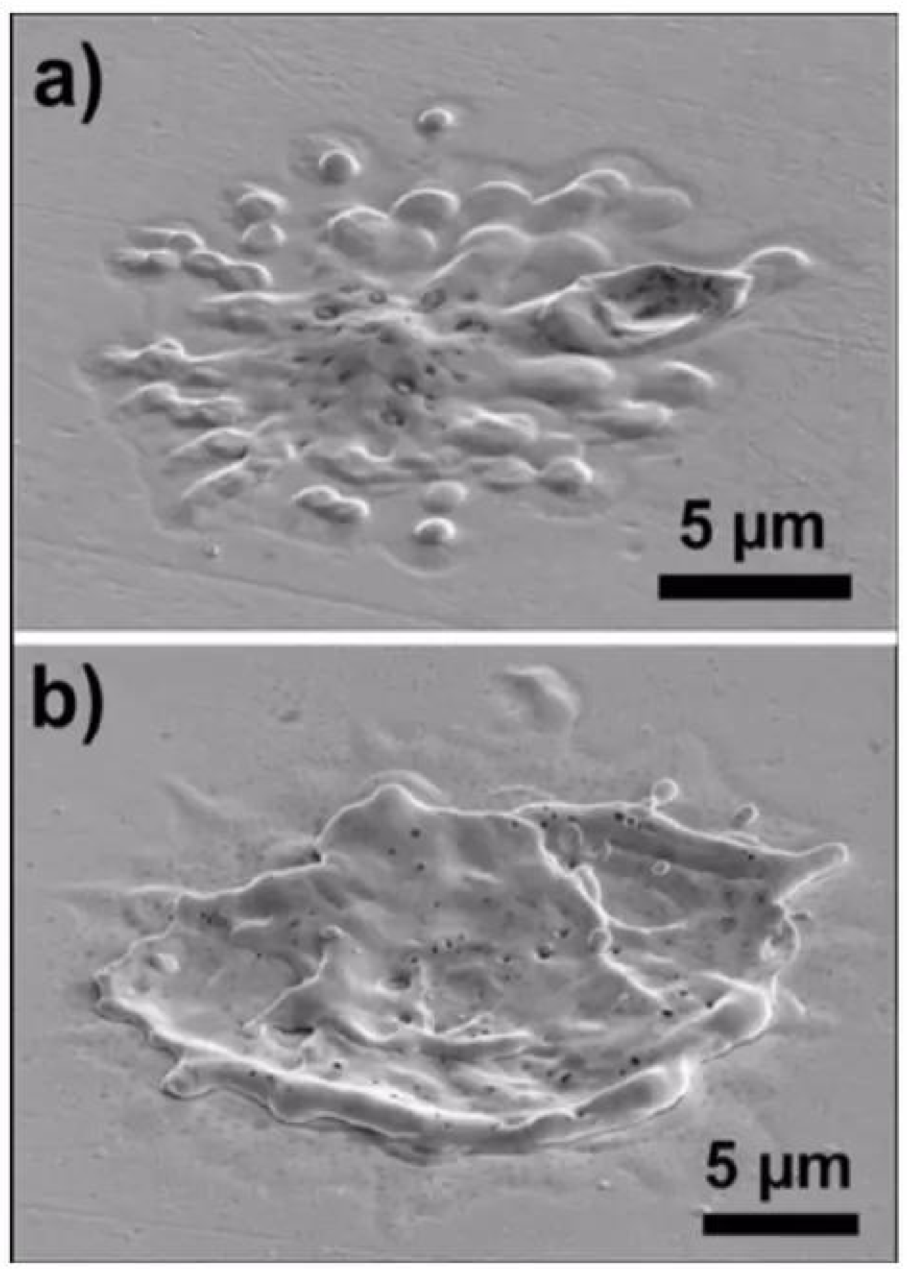
Free copy of paper available at: http://www.lenr-canr.org/acrobat/CirilloDtransmutat.pdf

→ ***Note: unbeknownst to the experimenters, they may have had either Barium (Ba) titanate and/or Dysprosium (Dy) as component(s) in the composition of the dielectric ceramic sleeve that was partially covering the cathode immersed in the electrolyte; Ba and/or Dy are often present in such ceramics. Under the stated experimental conditions, Ba and Dy could easily 'leach-out' from the surface of the ceramic into the electrolyte, creating yet another 'target' element that could migrate onto the surface of their Tungsten cathode. Since none of the potential intermediate transmutation products such as Nd (Neodymium), Sm (Samarium), and Gd (Gadolinium) were observed/reported, it is possible that there may have been LENR ULM neutron captures starting with Dy -> Er (Erbium) -> Tm (Thulium) ->Yb (Ytterbium) which are transmutation products that were in fact observed in their experiments***

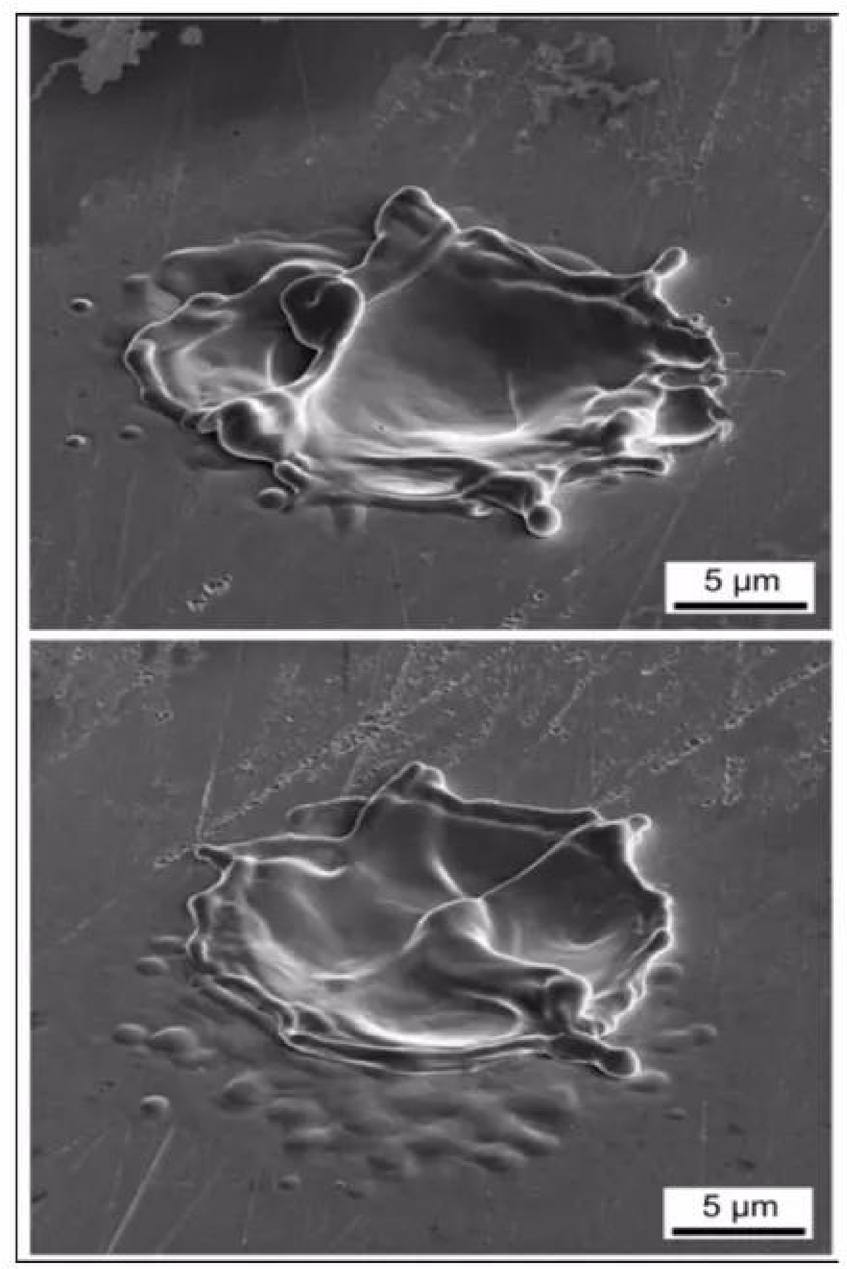
Micro-arcing events produce slightly different morphologies

Morphological features of micron-scale 'beam' discharges differ from LENRs

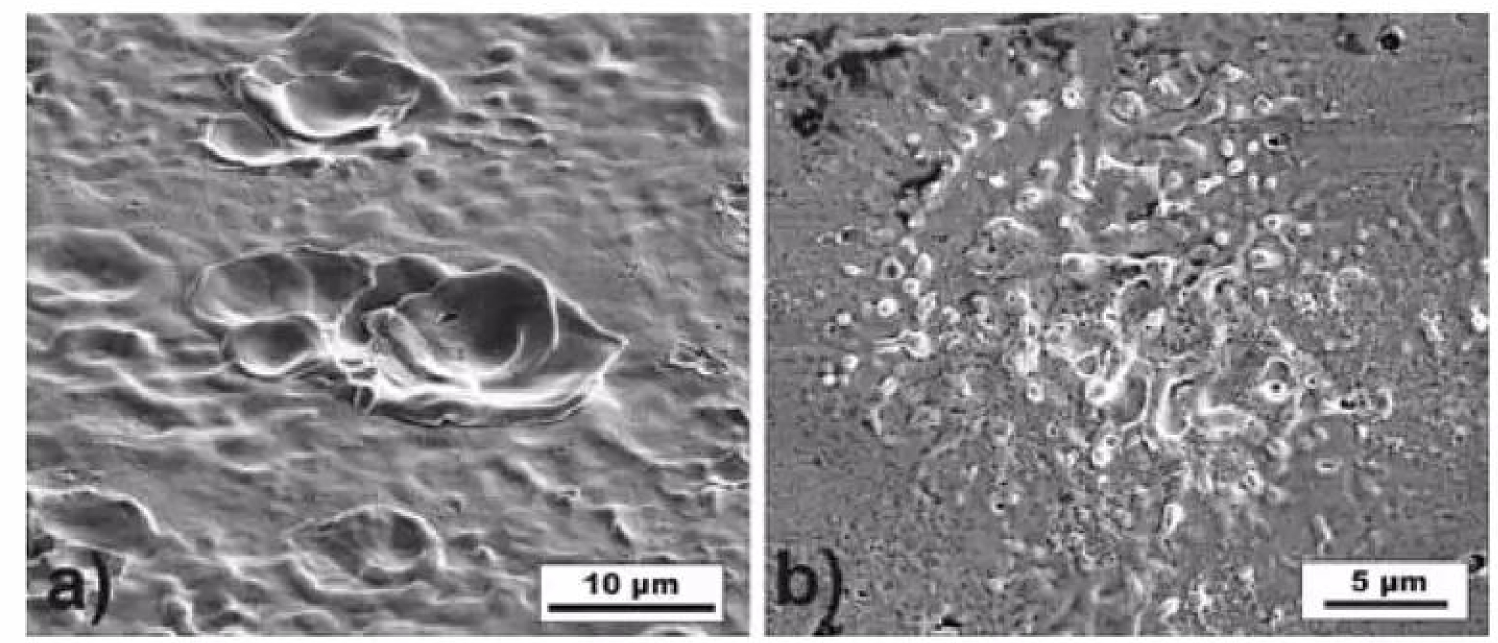
While electron/ion 'beams' and LENRs both heat and melt 'spots' on metal surfaces, morphologies differ. Jeanvoine et al.'s (2009) detailed simulation for creation of such structures used an: ion beam with mean energy 26-29 eV; surface E-field strength of 1-5 x 10^9 V/m; power densities of 10^{10} – 10^{12} W/m^2 over durations of 0.1 – 10 μsec, found that spot temperatures 'saturated' at 5,000 – 5,500^O K



N. Jeanvoine et al., "Microstructure characterisation of electrical discharge craters using FIB/SEM dual beam techniques" Adv. Eng. Materials 10 pp. 973-977 2008



N. Jeanvoine and F. Muecklich, "FEM Simulation of the temperature distribution and power density at platinum cathode craters caused by high voltage ignition discharges" J. Phys. D: Appl. Phys. 42 035203 2009



N. Jeanvoine et al, "Investigation of the arc and glow phase fractions of ignition discharges in air and nitrogen for Ag, Pt, Cu and Ni electrodes" 28th ICPIG, Prague, Czech Republic, July 15-20, 2007

→ **Jeanvoine et al. provide support for the idea that the unusual structural features observed on LENR device surfaces are most likely the result of intense local heating of the surface in micron-scale regions over very short time periods**

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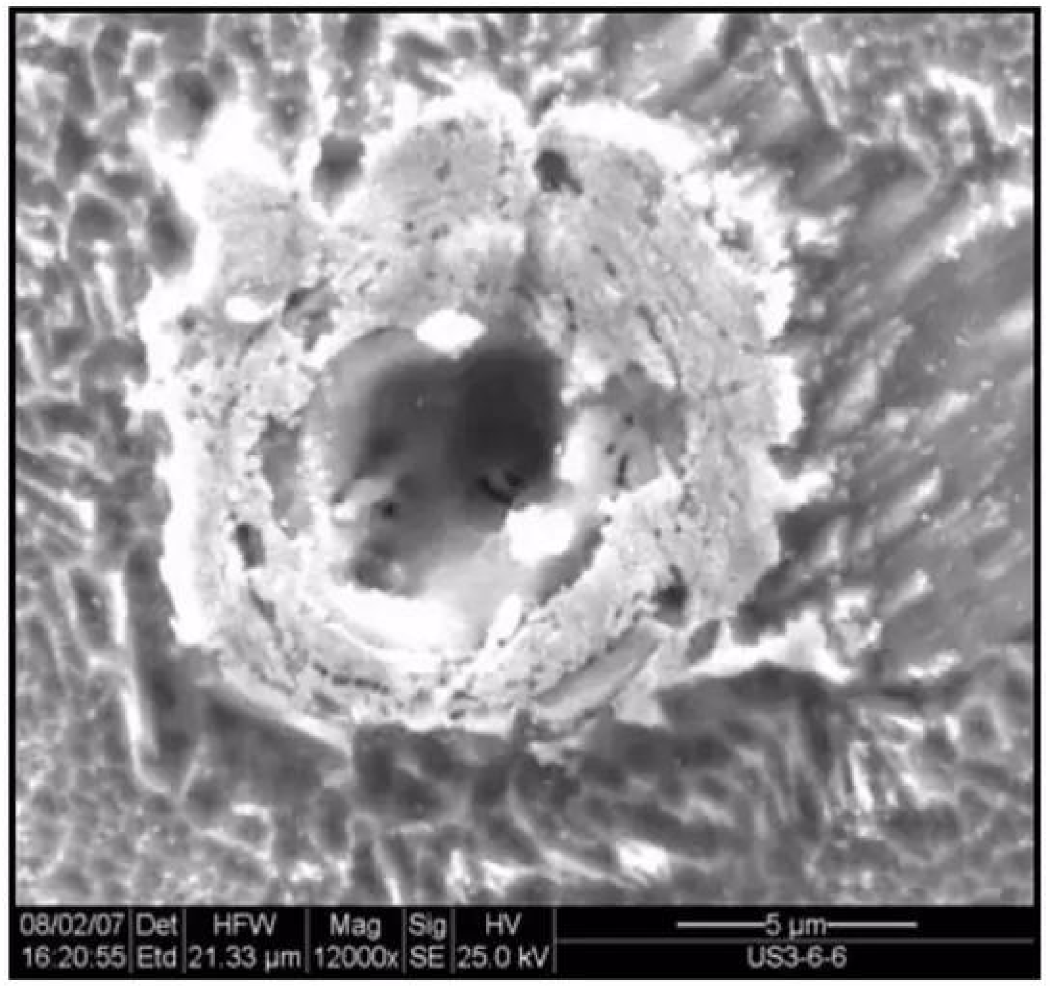
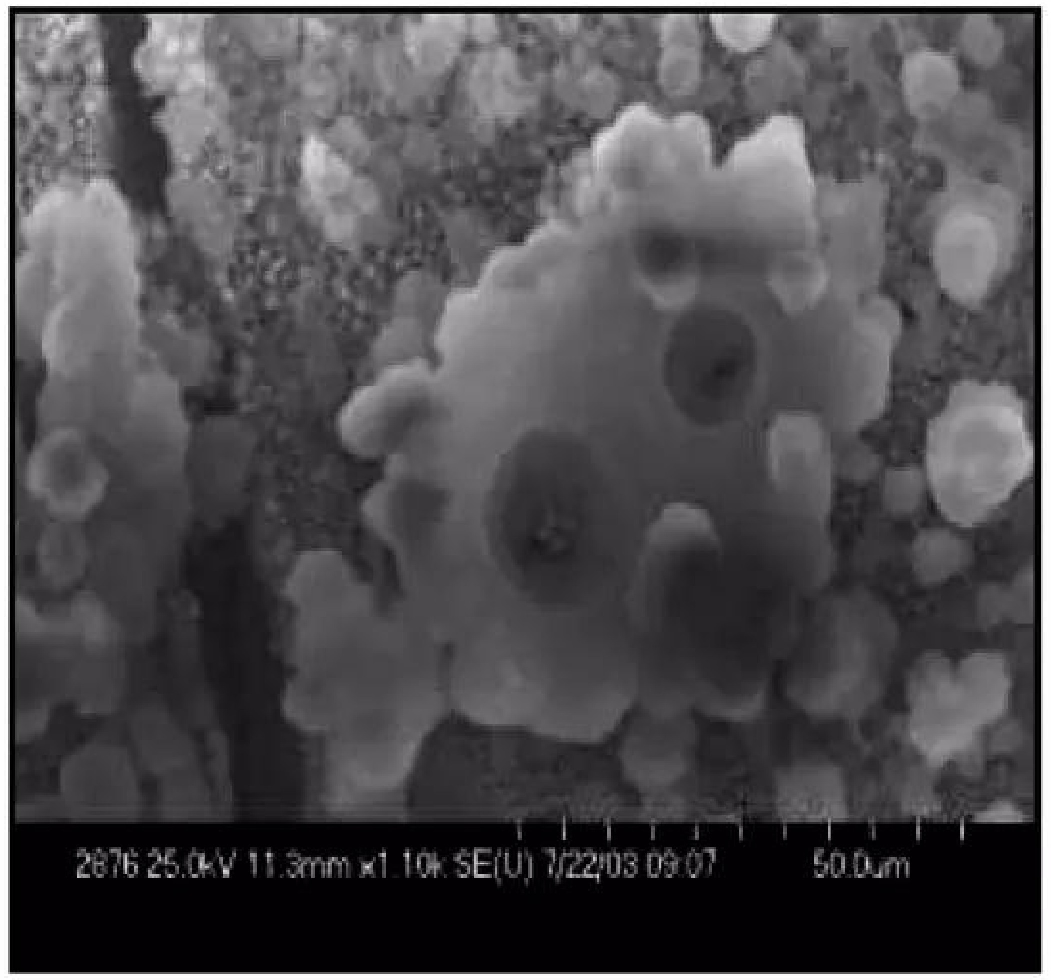
SEM images of LENR post-experiment surface features

View the evidence and form your own conclusions about such structures

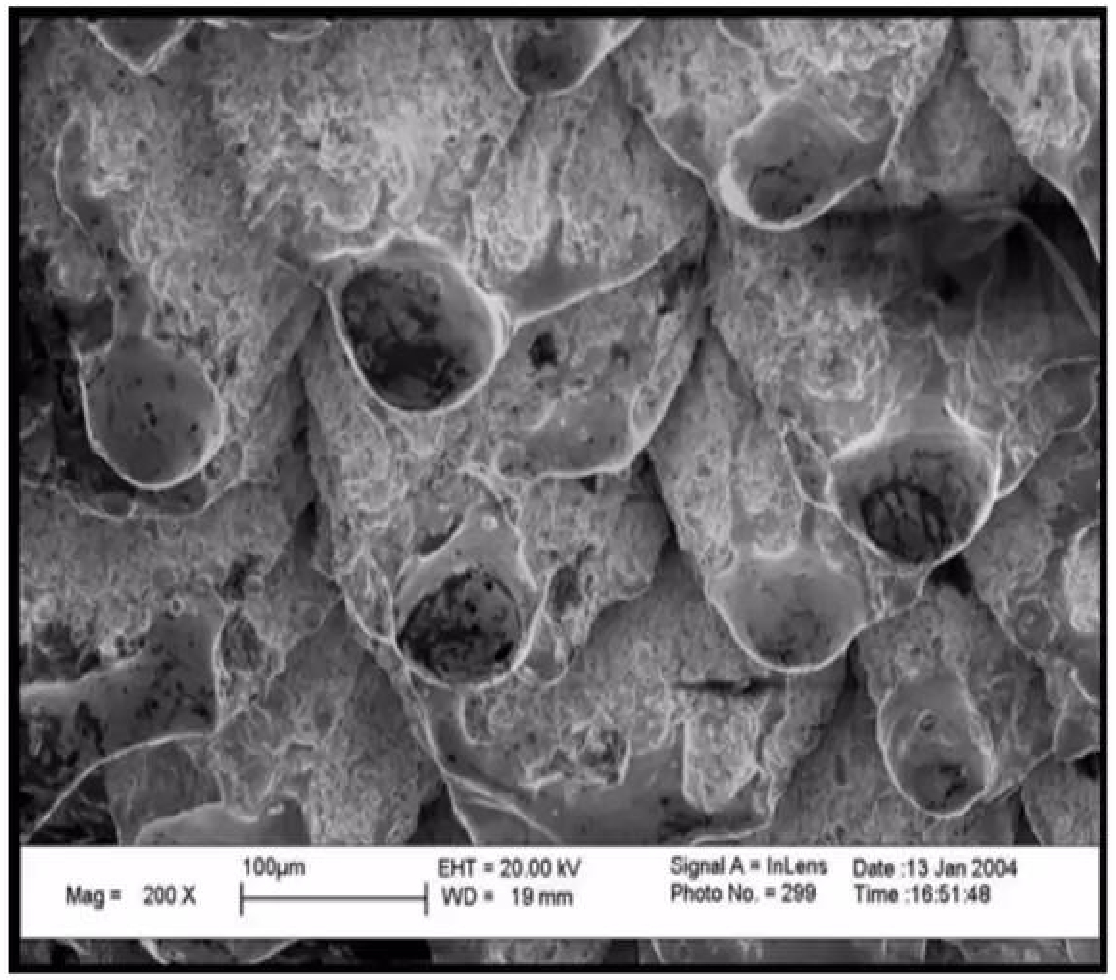
- ✓ **Readers encouraged to examine reported SEM images of LENR surface features**
- ✓ **To find more images, please go to the free website: www.lenr-canr.org as noted before, several hundred downloadable papers are available thereon**
- ✓ **Here are additional examples of SEM images from various LENR researchers:**



Pd surface: image source is Energetics Technologies, Omer, Israel



Pd surface: image source is US Navy SPAWAR (San Diego, CA)



W surface: image source is D. Cirillo and V. Iorio, Laboratorio M. Ruta, 81100, Caserta, Italy

Lattice's road to commercialization

W-L theory helps enable more productive R&D on LENRs

- ✓ Since 1989, most "cold fusion" researchers have focused primarily on the 'holy grail' goal of creating macroscopic LENR devices that can produce substantial fluxes of calorimetrically measured excess heat
- ✓ Absent a usable theory of LENRs and a detailed understanding of nanoscale device physics, achieving 'success' with such an approach is at best a random, hit-or-miss proposition. It is a bit like trying to fabricate modern microprocessor chips with sub-micron feature sizes on silicon dies using machinists' T-squares, rulers and scribes rather than utilizing advanced lithography and CMOS process technologies
- ✓ Even when substantial macroscopic excess heat is achieved in a 1 cm^2 device, heat as the sole metric of success provides little or no insight into underlying mechanisms of heat production or what one might do to improve the quantity and duration of heat output in future devices
- ✓ For example, exhaustive detection/identification of all nuclear reaction products to whatever extent possible is crucial technical information
- ✓ Unguided, random Edisonian exploration of LENRs' vast physics and materials parameter space is very likely responsible for the lack of readily reproducible experimental results and limited R&D progress and that have characterized the field of LENRs for the past 20 years

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Lattice's unique approach to LENR R&D is nanocentric

- ✓ At the present stage of LENR technology (TRL-2), trying to fabricate cm-scale and larger devices that can reliably and controllably produce macroscopically large fluxes of excess heat, i.e., "boil a cup of tea," is putting the cart before the horse
- ✓ Unlike its competitors, Lattice plans to use its unique proprietary knowledge of LENR devices and key operating parameters (e.g., achieving and maintaining very high local surface electric fields) to first get key LENR effects --- such as excess heat, transmutations --- working well microscopically; that is, to be able to cause them to occur reproducibly on specific nanoparticulate structures with dimensions ranging from nanometers to microns that are fabricated using existing, off-the-shelf nanotechnology techniques/methods and deliberately emplaced, along with suitable 'target fuel' nuclei (e.g., Lithium) in close proximity, at specific types of sites located on loaded metallic hydride surfaces
- ✓ Once this technical goal has been successfully achieved, scaling-up total device-level heat outputs could then be achieved simply by increasing the total number of nuclear-active LENR 'hot spot' sites per cm^2 of effective working surface area
- ✓ Lattice's nanocentric approach to R&D is unique in that it is highly interdisciplinary, being guided by various aspects of the W-L theory and applying relevant knowledge derived from advanced materials science, plasmonics, and nanotechnology

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Straightforward scale-up of LENR system power outputs

- ✓ LENRs can presently boil metals in relatively limited numbers of localized 'hot spots' on laboratory device surfaces. That being the case, it is not a huge stretch to imagine that, given further device engineering and substantial R&D programs, it should eventually be possible for Lattice to design and manufacture optimized, high-performance heat sources that can reliably and controllably produce large fluxes of device-level macroscopic excess heat that is scaled-up by fabricating larger area-densities of LENR 'hot spots' on commercial device surfaces
- ✓ In LENR-based power generation systems, nuclear reactions would be used to produce environmentally clean heat which could then be converted into usable power by separate, integrated energy conversion subsystems
- ✓ A variety of off-the-shelf energy conversion subsystems could be integrated with LENR-based heat sources to meet application-specific requirements for total system power output and duty-cycle duration. They involve various types of heat-to-electricity conversion, heat-to-shaft-rotation, heating of working fluids, etc.
- ✓ Available energy conversion subsystems that could potentially be used with commercial LENR heat sources include: thermoelectrics or thermionics; Stirling engines; steam engines; steam turbines; microturbines; boilers and various types of steam plants. Other more speculative possibilities involve new types of direct energy conversion technologies still under development, e.g., IR rectenna systems

Lattice Energy LLC

Lattice Energy LLC's road ahead

The company's long term business goal is to commercialize LENR-based integrated power generation systems for a broad range of important, high-unit-volume market applications:

- ✓ Lattice's unique understanding of LENRs should enable the development of safe, revolutionary nuclear power sources, initially for use in distributed power generation applications, including small battery-like devices for portable electronics
- ✓ Lattice's proprietary breakthroughs could enable a radically different, better nuclear power generation technology based mainly on environmentally friendly weak interactions, not on strong interaction fusion or heavy element fission processes
- ✓ LENR-based power sources could potentially have substantial competitive advantages in energy density, longevity, and cost/kWh over system duty cycles compared to chemically-based batteries, fuel cells, and fossil fuel microgenerators

Lattice Energy LLC

The future of LENR technology

"No single solution will defuse more of the Energy-Climate Era's problems at once than the invention of a source of single solution abundant, clean, reliable, and cheap electrons. Give me abundant clean, reliable, and cheap electrons, and I will give you a world that can continue to grow without triggering unmanageable climate change. Give me abundant clean, reliable, and cheap electrons, and I will give you water in the desert from a deep generator-powered well. Give me abundant clean, reliable, and cheap electrons, and I will put every petrodictator out of business. Give me abundant clean, reliable, and cheap electrons, and I will end deforestation from communities desperate for fuel and I will eliminate any reason to drill in Mother Nature's environmental cathedrals. Give me abundant clean, reliable, and cheap electrons, and I will enable millions of the earth's poor to get connected, to refrigerate their medicines, to educate their women, and to light up their nights."

Thomas Friedman in "Hot, Flat, and Crowded" 2008

