U.S. Defense Threat Reduction Agency (DTRA) favorably evaluated Widom-Larsen theory of LENRs in official report originally published back in March 2010

Unclassified document recently became publicly available on the U.S. Dept. of Homeland Security's digital library website

Quoting from conclusions: "Could the W-L theory be the breakthrough needed to position LENR as a major source of carbon-free, environmentally clean source of source of low-cost nuclear energy??"

Screenshots of key slides from now-public DTRA document reproduced herein

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May 29, 2017

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Revolutionary ultralow energy neutron reactions (LENRs)

Radiation-free LENRs transmute stable elements to other stable elements

Fission and fusion

Evolution of nuclear technology

Safe green LENRs

Laura 13

No deadly MeV-energy gamma radiation

No dangerous energetic neutron radiation

Insignificant production of radioactive waste

Vastly higher energies vs. chemical processes

Revolutionary, no CO_2 , and environmentally green

Is fully explained by physics of Widom-Larsen theory

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

Comparison of LENRs to fission and fusion

Fission, fusion, and LENRs all involve controlled release of nuclear binding energy (heat) for power generation: no CO_2 emissions; scale of energy release is MeVs (nuclear regime) > 1,000,000x energy density of chemical energy power sources

Heavy element fission: involves shattering heavy nuclei to release stored nuclear binding energy; **requires massive shielding and containment structures to handle radiation; major radioactive waste clean-up issues and costs;** limited sources of fuel: today, almost entirely Uranium; Thorium-based fuel cycles now under development; **heavy element U-235 (fissile isotope fuel) + neutrons → complex array of lower-mass fission products** (some are very long-lived radioisotopes) + energetic gamma radiation + energetic neutron radiation + **heat**

Fusion of light nuclei: involves smashing light nuclei together to release stored nuclear binding energy; present multi-billion $ development efforts (e.g., ITER, NIF, other Tokamaks) focusing mainly on D+T fusion reaction; **requires massive shielding/containment structures to handle 14 MeV neutron radiation;** minor radioactive waste clean-up $ costs vs. fission

Two key sources of fuel: Deuterium and Tritium (both are heavy isotopes of Hydrogen)

Most likely to be developed commercial fusion reaction involves the following:

D + T → He-4 (helium) + neutron + heat (total energy yield 17.6 MeV; ~14.1 MeV in neutron)

Ultralow energy neutron reactions (LENRs): distinguishing feature is neutron production via electroweak reaction; neutron capture on fuel + gamma conversion to IR + decays [β^-, α] releases nuclear binding energy; early-stage technology; **no emission of energetic neutron or gamma radiation and no long-lived radioactive waste products; LENR systems would not require massive, expensive radiation shielding or containment structures → much lower $$$ cost;** many possible fuels --- any element/isotope that can capture LENR neutrons; involves **neutron-catalyzed transmutation of fuels into heavier stable elements; process creates heat**

Electroweak reaction in Widom-Larsen theory is simple

Protons or deuterons react directly with electrons to make neutrons

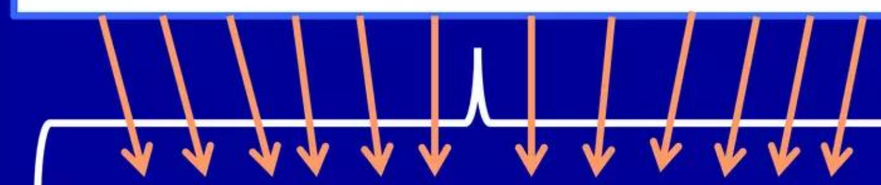
W-L explains how $e + p$ reactions occur at substantial rates in condensed matter

Draw energy from electric fields > 10^{11} V/m

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

Collective many-body quantum effects: many electrons each transfer little bits of energy to a much smaller number of electrons also bathed in the very same extremely high local electric field

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



$$\text{Energy}_{\text{E-field}} + e^-_{sp} \rightarrow e^{-}*_{sp} + p^+ \rightarrow n^0 + \nu_e$$

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

Induces safe hard-radiation-free nuclear transmutation

Neutrons + atomic nuclei ⟶ heavier elements + decay products

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Can download pdf copy from URL at U.S. Homeland Security's digital library:

https://www.hsdl.org/?abstract&did=717806

Applications of Quantum Mechanics: Black Light Power and the Widom-Larsen Theory of LENR [open pdf - 4MB]

This document consists of a set of slides on the topic of Low Energy Nuclear Reactions (LENR) "theoretical modeling" and "experimental observations". It also discusses efforts to: "Catalogue opponent/proponent views on LENR theories and experiments", "Review data on element transmutation", "Prepare assessment and recommendations", and "Critically examine past and new claims by Black Light Power Inc [...] power generation using a newly discovered field of hydrogen-based chemistry". Note: This document has been added to the Homeland Security Digital Library in agreement with the Project on Advanced Systems and Concepts for Countering WMD (PASCC) as part of the PASCC collection. Permission to download and/or retrieve this resource has been obtained through PASCC.

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Author:	Ullrich, George Toton, Edward
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Applications of Quantum Mechanics:
Black Light Power
and
the Widom-Larsen Theory of LENR

Edward Toton,
TOTON Incorporated

George Ullrich
Science Applications International Corporation

March 2010

Last bullet on slide #35 of Ulrich & Toton re Widom-Larsen

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The Widom-Larsen Theory Summary

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"Could the W-L theory be the breakthrough needed to position LENR as a major source of carbon-free, environmentally clean source of source of low-cost nuclear energy??"

Defense Threat Reduction Agency
Advanced Systems and Concepts Office
Report Number ASCO 2010 014
Contract Number DTRA01-03-D-0017, T.I. 18-08-04

Conclusions slide #35 of Ulrich & Toton re Widom-Larsen

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The Widom-Larsen Theory Summary

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- The Widom-Larsen (W-L) theory of LENR differs from the mainstream understanding in that the governing mechanism for LENR is presumed to be dominated by the weak force of the standard theory, instead of the strong force that governs nuclear fission and fusion
  - Assumption of weak interactions leads to a theoretical framework for the LENR energy release mechanism consistent with the observed production of large amounts of energy, over a long time, at moderate conditions of temperature and pressure, without the release of energetic neutrons or gamma radiation
- W-L theory is built upon the well-established theory of electro-weak interactions and many-body collective effects
- W-L theory explains the observations from a large body of LENR experiments without invoking new physics or ad-hoc mechanisms
  - So far, no experimental result fatally conflicts with the basic tenets of the W-L theory
  - In fact, an increasing number of LENR anomalies have been explained by W-L
  - In one case, W-L theory provided a plausible explanation for an anomalous observation of transmutation in an exploding wire experiment conducted back in 1922
- Could the W-L theory be the breakthrough needed to position LENR as a major source of carbon-free, environmentally clean source of source of low-cost nuclear energy??

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17

Slide #19 of Ulrich & Toton presentation re Widom-Larsen

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Applications of Quantum Mechanics

Highlights of the Widom-Larsen Theory of LENR and Some of Its Implications

DTRA01-03-D-0017
Task Order 0018
TI 18-08-04
Report Number ASCO 2010 014

The lack of testable theories for (LENRs) is a major impediment to acceptance of experimental claims … What is required for the evidence (presented) is either a testable theoretical model or an engineering demonstration of a self-powered system …

2004 DOE LENR Review Panel

31 March 2010

Much of the information in this briefing has been drawn from various papers and briefings posted on the Internet and copyrighted by Lattice Energy, LLA. The information is being used with the expressed permission of Dr. Lewis Larsen, President and CEO of Lattice Energy LLC.

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The Theoretical Dilemma posed by Cold Fusion

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- On 23 March 1989 Pons and Fleischman revealed in a news conference that they had achieved thermonuclear fusion (D – D) in an electrochemical cell at standard pressure and temperature
- D – D reactions and their branching ratios
  - D + D → ^{3}He (0.82 MeV) + n^{0} (2.45 MeV) (slightly less than 50% of the time)
  - D + D → T (1.01 MeV) + n^{0} (3.02 MeV) (slightly less than 50% of the time)
  - D + D → ^{4}He (0.08 MeV) + γ (23.77 MeV) (less than 1% of the time)
- But the Pons & Fleischman* results did not indicate neutron emissions at expected rates, nor show any evidence of γ emissions
- Subsequent experiments, while continuing to show convincing evidence for nuclear reactions, have largely dispelled thermonuclear fusion as the underlying responsible physical mechanism
- Some other Low Energy Nuclear Reaction (LENR) was likely in play

A new theory was needed to explain "LENR"

* Pons and Fleischman reported detecting He^{4} but subsequently retracted this claim as a flawed measurement.

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Observations from LENR Experiments

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- Macroscopic "excess heat" measured calorimetrically
  - Weakly repeatable and extremely contentious
  - Richard Garwin says, "Call me when you can boil a cup of tea*"
- Production of gaseous helium isotopes
  - Difficult to detect reliably and possibility of contamination
  - Observed by only a few researchers but most do not go to the expense of looking for helium
- Modest production of MeV alpha particles and protons
  - Reproducible and reported by a number of researchers
- Production of a broad spectrum of transmuted elements
  - More repeatable than excess heat but still arguments over possible contamination
  - Difficult to argue against competent mass spectoscopy

* Largest amount and duration of excess heat measured in an LENR experiment was 44 W for 24 days (90 MJ) in nickel-light hydrogen gas phase system.

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Widom-Larsen Theory

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- The Widom-Larsen (W-L) theory provides a self-consistent framework for addressing many long-standing issues about LENR
  - Overcoming the Coulomb barrier – the most significant stumbling block for thermonuclear "Cold Fusion" advocates
  - Absence of significant emissions of high-energy neutrons
  - Absence of large emissions of gamma rays
- The W-L theory does not postulate any new physics or invoke any ad hoc mechanisms to describe a wide body of LENR observations, including
  - Source of excess heat in light and heavy water electrochemical cells
  - Transmutation products typically seen in H and D LENR experimental setups
  - Variable fluxes of soft x-rays seen in some experiments
  - Small fluxes of high-energy alpha particles in certain LENR systems

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W-L Theory – The Basics

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- Electromagnetic radiation on a metallic hydride surface increases mass of surface plasmon electrons (e^-)
- Heavy-mass surface plasmon polariton (SPP) electrons react with surface protons (p^+) or deuterons (d^+) to produce ultra low momentum (ULM) neutrons and an electron neutrino (v)
- ULM neutrons are readily captured by nearby atomic nuclei (Z,A), resulting in an increase in the atomic mass (A) by 1 thereby creating a heavier mass isotope (Z,A+1) .
- If the new isotope is unstable it may undergo beta decay*, thereby increasing the atomic number by 1 and producing a new transmuted element (Z+1, A+1) along with a beta particle (e^-) and an anti-neutrino (v_e)
- The energy released during the beta decay is manifest as "excess heat"

1. $\tilde{e}^- + p^+ \rightarrow n^0_{ulm} + \nu_e$
2. $\tilde{e}^- + d^+ \rightarrow 2n^0_{ulm} + \nu_e$
3. $n^0_{ulm} + (Z,A) \rightarrow (Z,A+1)$
4. $(Z,A+1) \rightarrow (Z+1,A+1) + e^- + \bar{\nu}_e$

*It could also undergo alpha decay or simply release a gamma ray, which in turn is converted to infrared energy

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W-L Theory Invokes Many Body Effects

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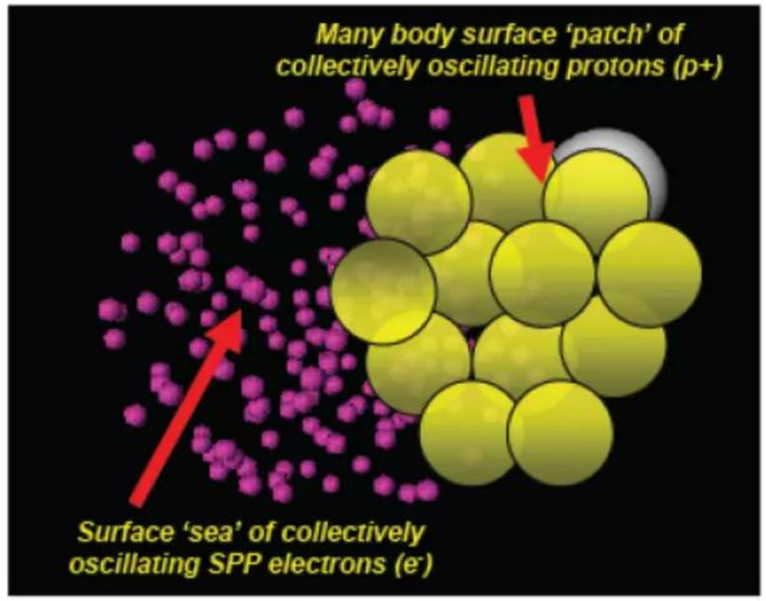
- Certain hydride forming elements, e.g., Pd, Ni, Ti, W, can be loaded with H, D, or T, which will ionize, donating their electrons to the sea of free electrons in the metal
- Once formed, ions of hydrogen isotopes migrate to specific interstitial structural sites in the bulk metallic lattice, assemble in many-body patches, and oscillate collectively and coherently (their QM wave functions are effectively entangled) setting the stage for a local breakdown in the Born-Oppenheimer approximation[1]
- This, in turn, enables the patches of hydrogenous ions to couple electromagnetically to the nearby sea of collectively oscillating SSP electrons
- The coupling creates strong local electric fields ($>10^{11}$ V/m) that can renormalize the mass of the SSPs above the threshold for ULM neutron production
- ULM neutrons have huge DeBroglie wavelengths[2] and extremely large capture cross sections with atomic nuclei compared even to thermal neutrons
  - Lattice Energy LLC has estimated the ULM neutron fission capture cross section on U^{235} to be ~ 1 million barns vs. ~586 barns for thermal neutrons

It's not just a two-body collision



[1] The Born-Oppenheimer approximation allows the wavefunction of molecule to be broken down into its electronic and nuclear (vibrational and rotational) components. In this case, the wavefunction must be constructed for the many body patch.

[2]The DeBroglie wavelength of ULM neutrons produced by a condensed matter collective system must be comparable to the spatial dimension of the many-proton surface patches in which they were produced.

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W-L Theory Insights

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Insight 1: Overcoming Coulomb energy barrier

- The primary LENR process is driven by nuclei absorbing ULM neutrons for which there is no Coulomb barrier

Insight 2: Suppression of gamma ray emmisions

- Compton scattering from heavy SSP electrons creates soft photons
- Creation of heavy SSP electron-hole pairs in LENR systems have energy spreads in the MeV range, compared to nominal spreads in the eV range for normal conditions in metals, thus enabling gamma ray absorption and conversion to heat

Insight 3: Origins of excess heat

- ULM neutron capture process and subsequent nuclei relaxation through radioactive decay or gamma emission generates excess heat
  - Alpha and beta particles transfer kinetic energy to surrounding medium through scattering process
  - Gamma rays are converted to infrared photons which are absorbed by nearby matter

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W-L Theory Insights Cont'd

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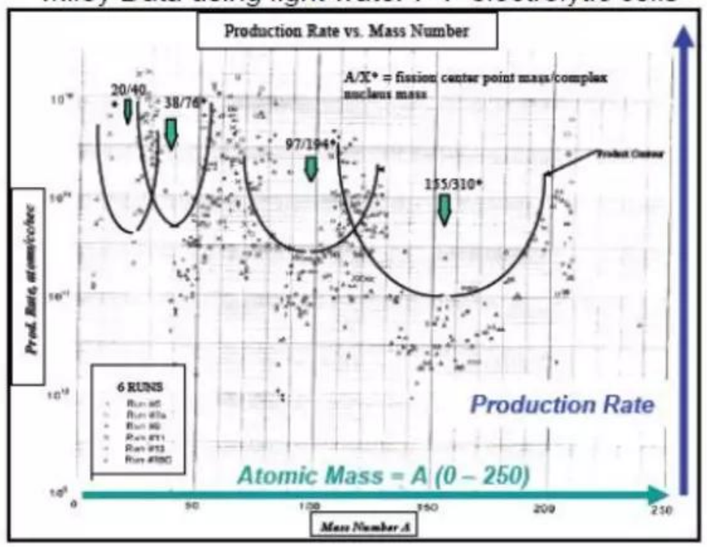
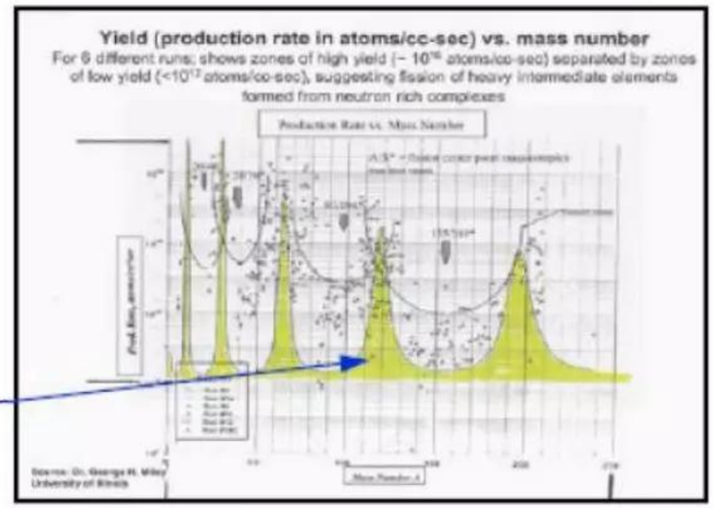
Insight 4: Elemental transmutation

- Five-peak transmutation product mass spectra reported by several researchers
  - One researcher (Miley) hypothesized that these peaks were fission products of very neutron-rich compound nuclei with atomic masses of 40, 76, 194, and 310 (a conjectured superheavy element)
- According to W-L theory, successive rounds of ULM neutron production and capture will create higher atomic mass elements consistent with observations
  - The W-L neutron optical potential model of ULM neutron absorption by nuclei predicts abundance peaks very close to the observed data

Miley Data using light water P-F electrolytic cells





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W-L Theory Transmutation Pathways for Iwamura Experiments

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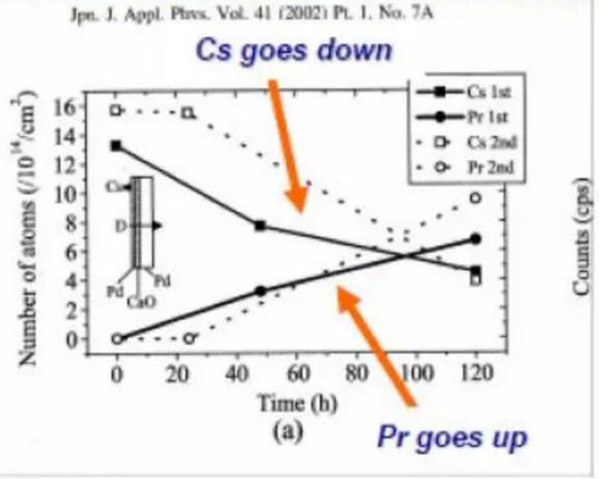
- Transmutation data from Iwamura, Mitsubishi Heavy Industries
  - Experiments involved permeation of a D_2 gas through a Pd:Pd/CaO thin-film with Cs and Sr seed elements placed on the outermost surface
  - $_{55}Cs^{133}$ target transmuted to $_{59}Pr^{141}$; $_{38}Sr^{88}$ transmuted to $_{42}Mo^{96}$
  - In both cases* the nuclei grew by 8 nucleons
- W-L theory postulates the following plausible nucleosynthesis pathway:



- $^{133}_{55}Cs + 1\,ulm\,n \rightarrow {}^{134}_{55}Cs + \gamma$ (Q = 6.9 MeV; 2.1 yrs; $\sigma_{thermal}$ = 140b)
- $^{134}_{55}Cs + 1\,ulm\,n \rightarrow {}^{135}_{55}Cs + \gamma$ (Q = 8.8 MeV; hl = 2.3 x 10^6 yrs; $\sigma_{thermal}$ = 8.9b)
- $^{135}_{55}Cs + 1\,ulm\,n \rightarrow {}^{136}_{55}Cs + \gamma$ (Q = 6.8 MeV; hl = 13.2 days; $\sigma_{thermal}$ = ?)
- $^{136}_{55}Cs + 1\,ulm\,n \rightarrow {}^{137}_{55}Cs + \gamma$ (Q = 8.3 MeV; hl = 30.1 yrs; $\sigma_{thermal}$ = 0.25b)
- $^{137}_{55}Cs + 1\,ulm\,n \rightarrow {}^{138}_{55}Cs + \gamma$ (Q = 4.4 MeV; hl = 33.4 min; $\sigma_{thermal}$ = ?)
- $^{138}_{55}Cs + 1\,ulm\,n \rightarrow {}^{139}_{55}Cs + \gamma$ (Q = 6.6 MeV; hl = 9.3 min; $\sigma_{thermal}$ = ?)
- $^{139}_{55}Cs + 1\,ulm\,n \rightarrow {}^{140}_{55}Cs + \gamma$ (Q = 4.4 MeV; hl = 64 sec; $\sigma_{thermal}$ = ?)
- $^{140}_{55}Cs + 1\,ulm\,n \rightarrow {}^{141}_{55}Cs + \gamma$ (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)

- $^{88}_{38}Sr + 1\,ulm\,n \rightarrow {}^{89}_{38}Sr + \gamma$ (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)
- $^{89}_{39}Y + 1\,ulm\,n \rightarrow {}^{90}_{39}Y + \gamma$ (Q = 6.9 MeV; hl = 64hrs; $\sigma_{thermal}$ = 6.5b)
- $^{90}_{39}Y + 1\,ulm\,n \rightarrow {}^{91}_{39}Y + \gamma$ (Q = 7.9 MeV; hl = 59 days; $\sigma_{thermal}$ = ?)
- $^{91}_{39}Y + 1\,ulm\,n \rightarrow {}^{92}_{39}Y + \gamma$ (Q = 6.5 MeV; hl = 3.5 hrs; $\sigma_{thermal}$ = ?)
- $^{92}_{39}Y + 1\,ulm\,n \rightarrow {}^{93}_{39}Y + \gamma$ (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)
- $^{93}_{40}Zr + 1\,ulm\,n \rightarrow {}^{94}_{40}Zr + \gamma$ (Q = 8.2 MeV; stable; $\sigma_{thermal}$ = 0.05b)
- $^{94}_{40}Zr + 1\,ulm\,n \rightarrow {}^{95}_{40}Zr + \gamma$ (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)
- $^{95}_{41}Nb + 1\,ulm\,n \rightarrow {}^{96}_{41}Nb + \gamma$ (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)

- Neutron-rich isotopes build up via neutron captures interspersed with β-decay
- Neutron capture on stable or unstable isotopes releases substantial nuclear binding energy, mostly in gamma emissions, which convert to IR

* Iwamura noted that it took longer to convert Sr into Mo than Cs into Pr. W-L argue that this is because the neutron cross section for Cs is vastly higher than for Sr

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Slide #28 of Ulrich & Toton presentation re Widom-Larsen

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W-L Theory Insights Cont'd

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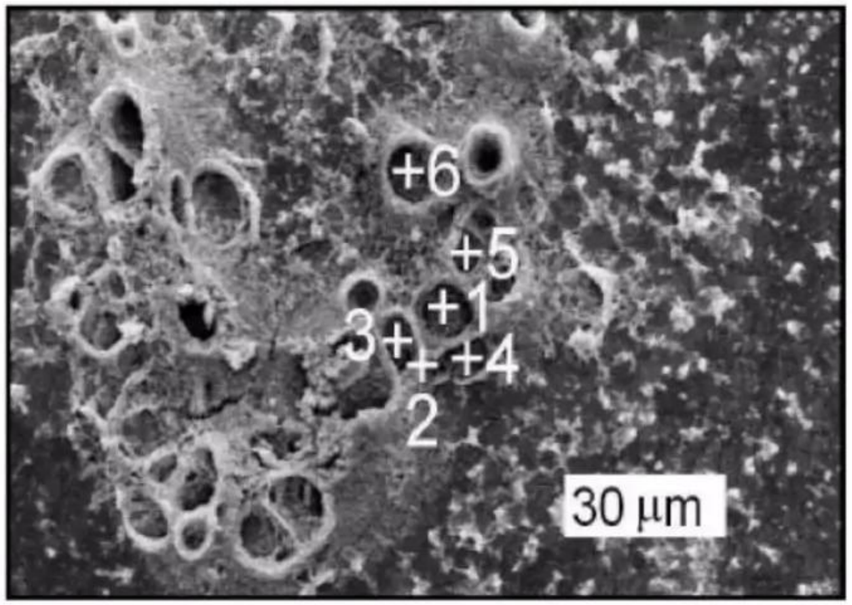
Insight 5: Transmutation sites correlate with surface damage

- With Pd as the target element in an electrolytic cell, silver (Ag) is observed at the location of microcraters on the Pd cathode
- W-L theory suggest this is the result of ULM neutron captures on Pd with β-decays to Ag isotopes, resulting in locally high heat fluxes
- Feature size is consistent with theoretical scale of oscillating patches of protons, deuterons and tritons

Scanning electron microscope image of Pd cathode



W. Zhang and J. Dash, "Excess heat reproducibility and evidence of anomalous elements after electrolysis in $Pd/D_2O + H_2SO_4$ electrolytic cells," 13th Intl. Conference on Condensed Nuclear Matter, Sochi, Russia 2007

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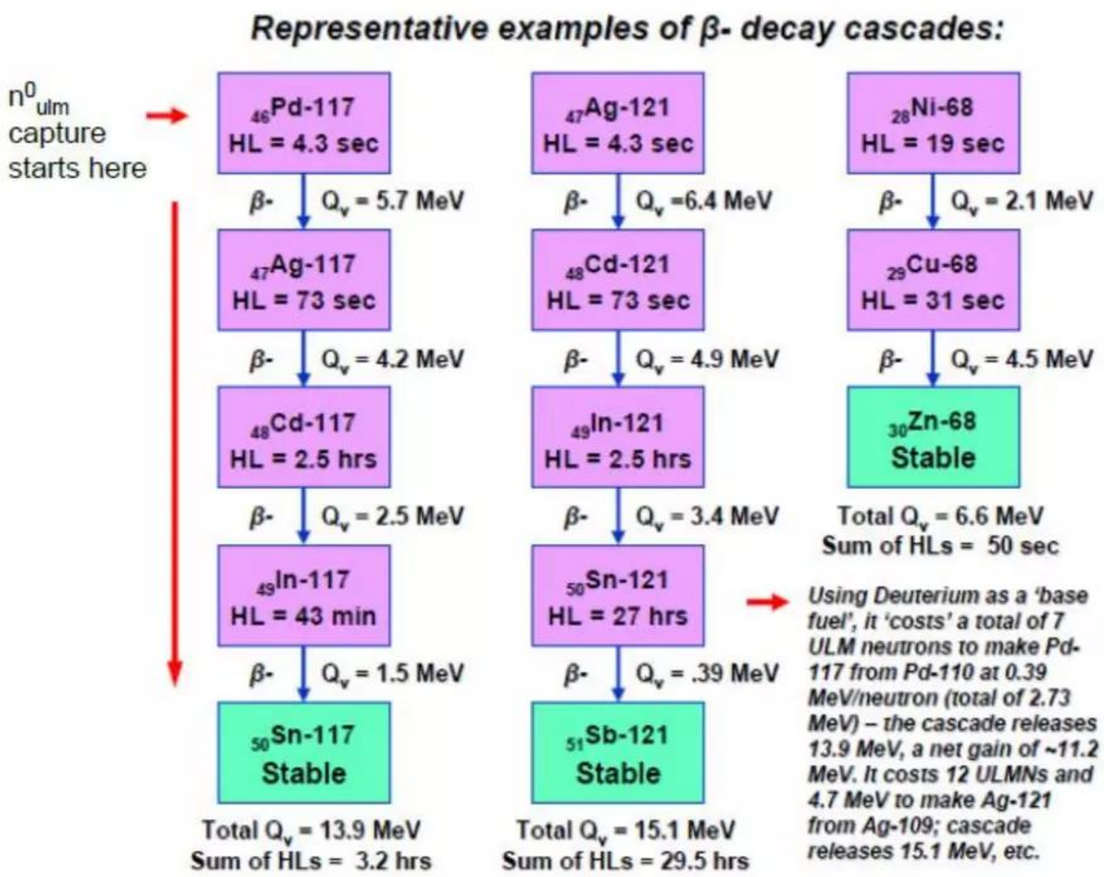
W-L Theory Insights Cont'd

From Science to Solutions™

Insight 6: "Weak nuclear interactions"are not weak in terms of energy release

- Neutron-rich isotopes* will decay, mainly by a series of rapid β cascades
- β particles create heat by transferring kinetic energy to surrounding matter
- Energy released is comparable to D-D and D-T fusion reactions
- Decay cascades terminate in production of stable higher Z elements



* In condensed matter LENRs, neutron-rich "halo" isotopes continue to absorb ULM neutrons as long as capture Q values remain favorable and as long as they are unable to decay or shed neutrons

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W-L Theory Insights Cont'd

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Insight 7: LENR experiments produce few long-lived radioactive isotopes

- In surface patches that experience large fluxes of ULM neutrons, populations of very neutron-rich "halo" nuclei will build up
- The half-lives of these nuclei are longer than they would be if isolated because they are unable to emit β electrons or shed neutrons into unoccupied states in the local continuum
- The cessation of ULM neutron production will trigger serial cascades of fast β-decays from neutron rich into stable isotopes
- Few long-lived radioisotopes remain after this process has run its course

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W-L Theory Insights Cont'd

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Insight 8: Production of Helium

- Several LENR researchers (e.g., McKubre, Miles, Arata and Zhang, Lipson, Karabut) have reported detectable levels of He-4 and He-3 in some of their experiments
- Considered by many to be a telling signature of the D-D nuclear fusion reaction, He^4 can be produced by other nuclear reactions, including minor alternative branches of neutron captures and various alpha particle decays (e.g., when using lithium* as the fuel)

$$Li^6 + n^0 \rightarrow Li^7$$
$$Li^7 + n^0 \rightarrow Li^8$$
$$Li^8 \rightarrow Be^8 + e^- + \nu_e$$
$$Be^8 \rightarrow He^4 + He^4$$

- Many isotopes have minor (n,α) decay channels with small cross sections that would result in at least one alpha (He^4) particle
- Unstable isotopes of elements with atomic number > 83 commonly decay via α-decay

* In a Pons and Fleischman-type electrolytic cell, any lithium present in the electrolyte will invariably accumulate in intimately alloyed admixtures with Pd on the surface of the cathode

Slide #32 of Ulrich & Toton presentation re Widom-Larsen

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Possible Pathway to He^4 Production using Palladium as Seed Nucleus

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- Besides serving as the medium for producing ULM neutrons, Pd can also potentially capture ULM neutrons
  - All stable Pd isotopes have large ULM neutron capture cross sections
- ULM capture on PD isotopes can release significant amounts of binding energy
- Alpha decays of Pd isotopes have small cross section but positive Q values

$^{102}_{46}Pd$, $^{104}_{46}Pd$, $^{105}_{46}Pd$, $^{106}_{46}Pd$, $^{108}_{46}Pd$, $^{110}_{46}Pd$ 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 10^6yrs; 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 $^{106}_{46}Pd \rightarrow {}^{102}_{46}Ru + He^4$

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14

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β-Delayed Isotopic Decay Branches

- LENR systems exhibit a very dense occupation of local fermionic states which can delay the β-decay (a fermion) of neutron-rich intermediate isotopes compared to that of isolated nuclei
- This provides a much richer variety of decay channel possibilities, such as beta-delayed emissions of gammas, neutrons, alpha particles, tritons and deuterons
  - Production cross-sections for such emissions are typically small, but certain isotopes have substantial β-delayed branches e.g., 12% of N^{18} decays emit alphas
  - Over 100 isotopes are known to exhibit β-delayed decay pathways
- Depending on the LENR nucleosynthetic pathways, target seed nuclei may produce significant quantities of He^4 without any lithium present or the need to invoke D-D "cold fusion" processes

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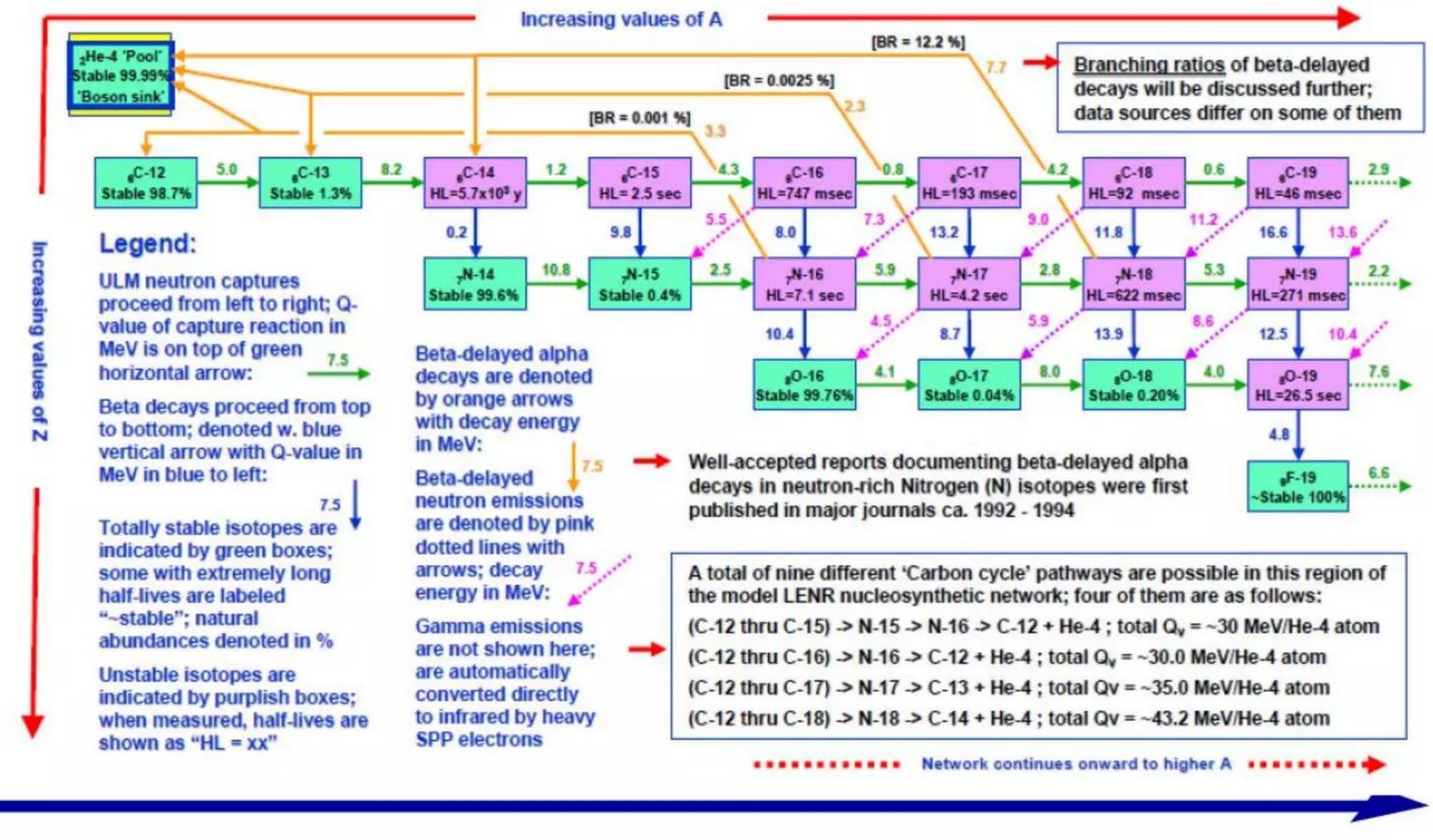
ULM Neutron Catalyzed LENR Network

Starting from $_6C^{12}$ (Lattice Energy LLC)

From Science to Solutions™

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



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The Widom-Larsen Theory Summary

- The Widom-Larsen (W-L) theory of LENR differs from the mainstream understanding in that the governing mechanism for LENR is presumed to be dominated by the weak force of the standard theory, instead of the strong force that governs nuclear fission and fusion
  - Assumption of weak interactions leads to a theoretical framework for the LENR energy release mechanism consistent with the observed production of large amounts of energy, over a long time, at moderate conditions of temperature and pressure, without the release of energetic neutrons or gamma radiation
- W-L theory is built upon the well-established theory of electro-weak interactions and many-body collective effects
- W-L theory explains the observations from a large body of LENR experiments without invoking new physics or ad-hoc mechanisms
  - So far, no experimental result fatally conflicts with the basic tenets of the W-L theory
  - In fact, an increasing number of LENR anomalies have been explained by W-L
  - In one case, W-L theory provided a plausible explanation for an anomalous observation of transmutation in an exploding wire experiment conducted back in 1922
- Could the W-L theory be the breakthrough needed to position LENR as a major source of carbon-free, environmentally clean source of source of low-cost nuclear energy??

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LENR State of Play

From Science to Solutions™

- The Widom-Larsen theory has done little to unify or focus the LENR research community
- If anything, it appears to have increased the resolve of the strong-force D-D fusion advocates to circle the wagons
- LENR is an area of research at the TRL-1 level but the community is already jockeying for position to achieve a competitive TRL-8 position, which further impedes the normal scientific process
- Without a theory to guide the research, LENR will remain in a perpetual cook-and-look mode, which produces some tantalizing results to spur venture capital investments but does little to advance the science
- DTRA needs to be careful not to get embroiled in the politics of LENR and serve as an honest broker
  - Exploit some common ground, e.g., materials and diagnostics
  - Force a show-down between Widom-Larsen and Cold Fusion advocates
  - Form an expert review panel to guide DTRA-funded LENR research

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18

Recent books about LENRs and the Widom-Larsen theory

Three volumes in series titled "Explorations in Nuclear Research"

Provides overview of entire field at level of *Scientific American* article

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

"Fusion Fiasco" (Volume 2)
Steven B. Krivit
Pacific Oaks Press, San Rafael, CA, November 11, 2016 (531 pages)
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99
https://www.amazon.com/dp/0976054523

PowerPoint synopsis of book with additional commentary:
http://tinyurl.com/z6fsbn2

"Lost History" (Volume 3)
Steven B. Krivit
Pacific Oaks Press, San Rafael, CA, November 11, 2016 (380 pages)
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99
https://www.amazon.com/dp/0996886419

Publications about the Widom-Larsen theory of LENRs

Index provides comprehensive guide to available online information

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

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

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

"Index to key concepts and documents" all hyperlinks in document are live
v. #21 updated and revised through Sept. 7, 2015
L. Larsen, Lattice Energy LLC, May 28, 2013 [133 slides] download is enabled
http://www.slideshare.net/lewisglarsen/lattice-energy-llc-hyperlinked-index-to-documents-re-widomlarsen-theory-and-lenrs-september-7-2015

Key conclusion of theoretical paper published in Pramana

Journal is peer-reviewed publication of Indian Academy of Sciences

"A primer for electro-weak induced low energy nuclear reactions"

"The analysis presented in this paper leads us to conclude that realistic possibilities exist for designing LENR devices capable of producing 'green energy', that is, production of excess heat at low cost without lethal nuclear waste, dangerous γ-rays or unwanted neutrons. The necessary tools and the essential theoretical know-how to manufacture such devices appear to be well within the reach of the technology available now. Vigorous efforts must now be made to develop such devices whose functionality requires all three interactions of the Standard Model acting in concert."

Widom-Larsen enables commercialization of LENRs

Applied nanotechnology and LENRs are mutually joined at the hip

Development risks can be reasonable thanks to Widom-Larsen and nanotech

Guided by physics of the Widom-Larsen theory, an opportunity to commercialize LENRs as truly green CO_2-free nuclear energy source has been enabled by a unique juxtaposition of very recent parallel advances in certain very vibrant areas of nanotechnology (esp. plasmonics), quantum entanglement, new innovations in nanoparticle fabrication techniques, as well as an array of new discoveries in advanced materials science.