Lattice White Paper

LENRs enable green radiation-free nuclear power and propulsion

Lewis Larsen

President and CEO, Lattice Energy LLC

May 16, 2019

Chicago, IL USA
1-312-861-0115
lewisglarsen@gmail.com

Pdf download from SlideShare is enabled
All embedded hyperlinks in document are live

History of LENRs dates back nearly 100 years and even includes Albert Einstein

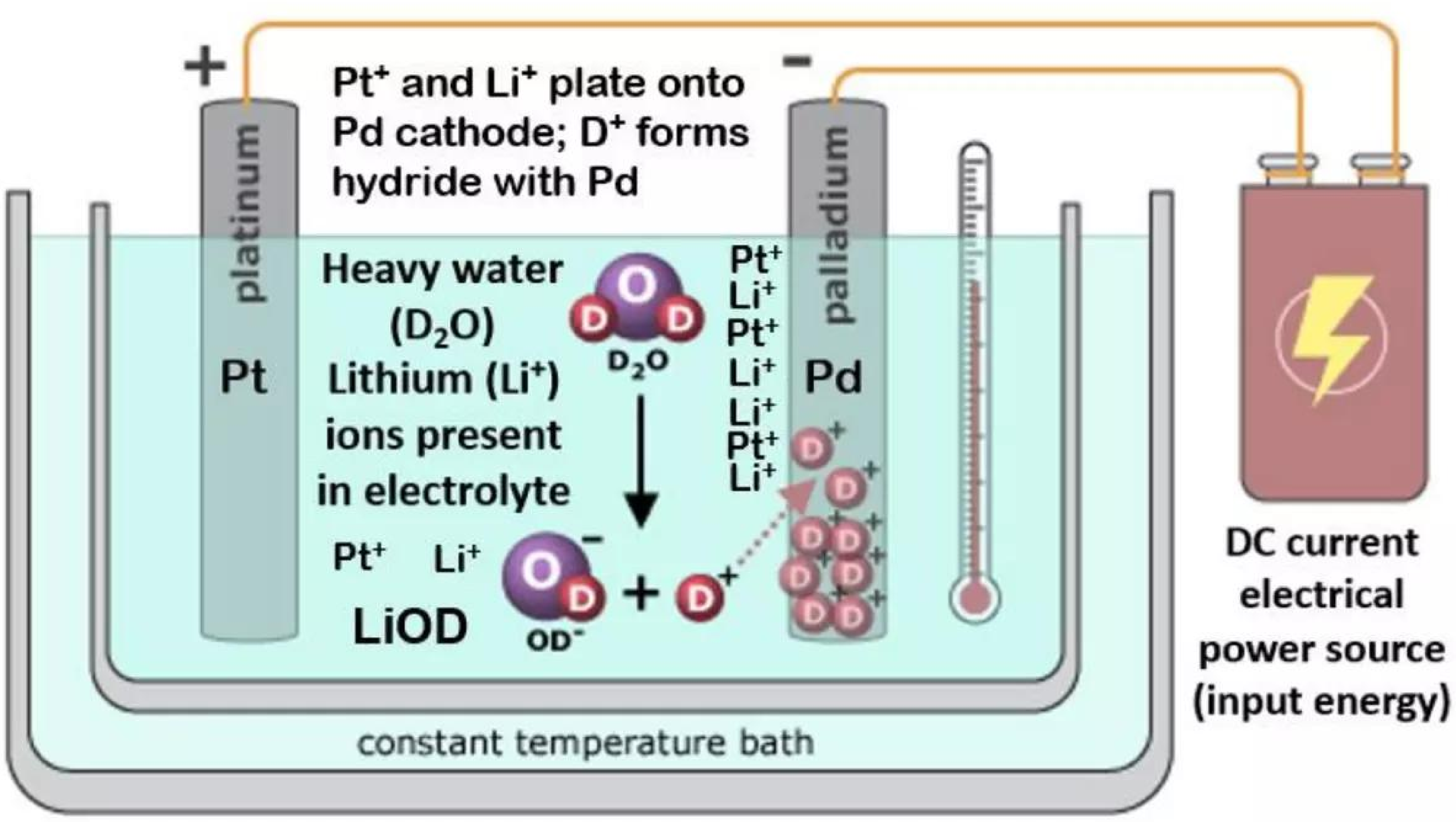
History of ultralow energy neutron reactions (LENRs) is surprisingly long; researchers have episodically and unknowingly encountered LENR-related effects since the early 1900s. Most did not realize they were observing nuclear processes because energetic neutron and/or gamma radiation emissions that characterize known fission and fusion reactions were absent.

In 1951, then Cornell Ph.D. candidate Ernest Sternglass and Albert Einstein had an incredible encounter with LENRs [1]. After reading a 1920s theoretical paper by C.G. Darwin, Sternglass believed neutrons could potentially be created by directly reacting protons with electrons at low energies in tabletop experiments. He and Prof. Lyman Parratt constructed a Hydrogen-filled X-ray tube to test this radical idea. Shockingly, Sternglass did find clear indirect evidence for low-energy neutron production. No one at Cornell, including legendary physicists Hans Bethe and Richard Feynman, could understand why these experiments worked. Bethe suggested that Sternglass travel to Princeton and discuss his inexplicable results directly with Einstein.

After examining Sternglass' data, Einstein thought it could be explained by collective quantum effects with electrons; he strongly encouraged Sternglass to conduct more experiments and publish his work. Sometime after returning to Cornell, rumors circulated around the physics department that Sternglass was pursuing very dubious research. Fearing controversy that might delay or derail granting of his Ph.D., Sternglass stopped his experiments on neutron production, finished his thesis work on a 'safer' topic, and never published the neutron data in a journal. Ironically, Einstein's stunning intuitive hypothesis was effectively incorporated in the many-body collective Widom-Larsen theory of LENRs published 54 years later in 2005.

Unaware of Sternglass' experiments, in ~1985 respected University of Utah electrochemists Profs. Stanley Pons & Martin Fleischmann (P&F) had privately speculated that Deuterium + Deuterium (D+D) fusion reactions might be electrochemically triggered by gigantic effective pressures thought to exist inside Deuterium-loaded bulk metallic lattices of Palladium cathodes immersed in room temperature heavy water (D_2O) electrolyte. This idea was heretical because physicists presume that nuclear fusion requires star-like temperatures such as the 150 million degrees C needed to ignite ionized plasmas in the ITER project's D+T Tokamak fusion reactor.

Conceptual overview of P&F's aqueous electrochemical cell reactor

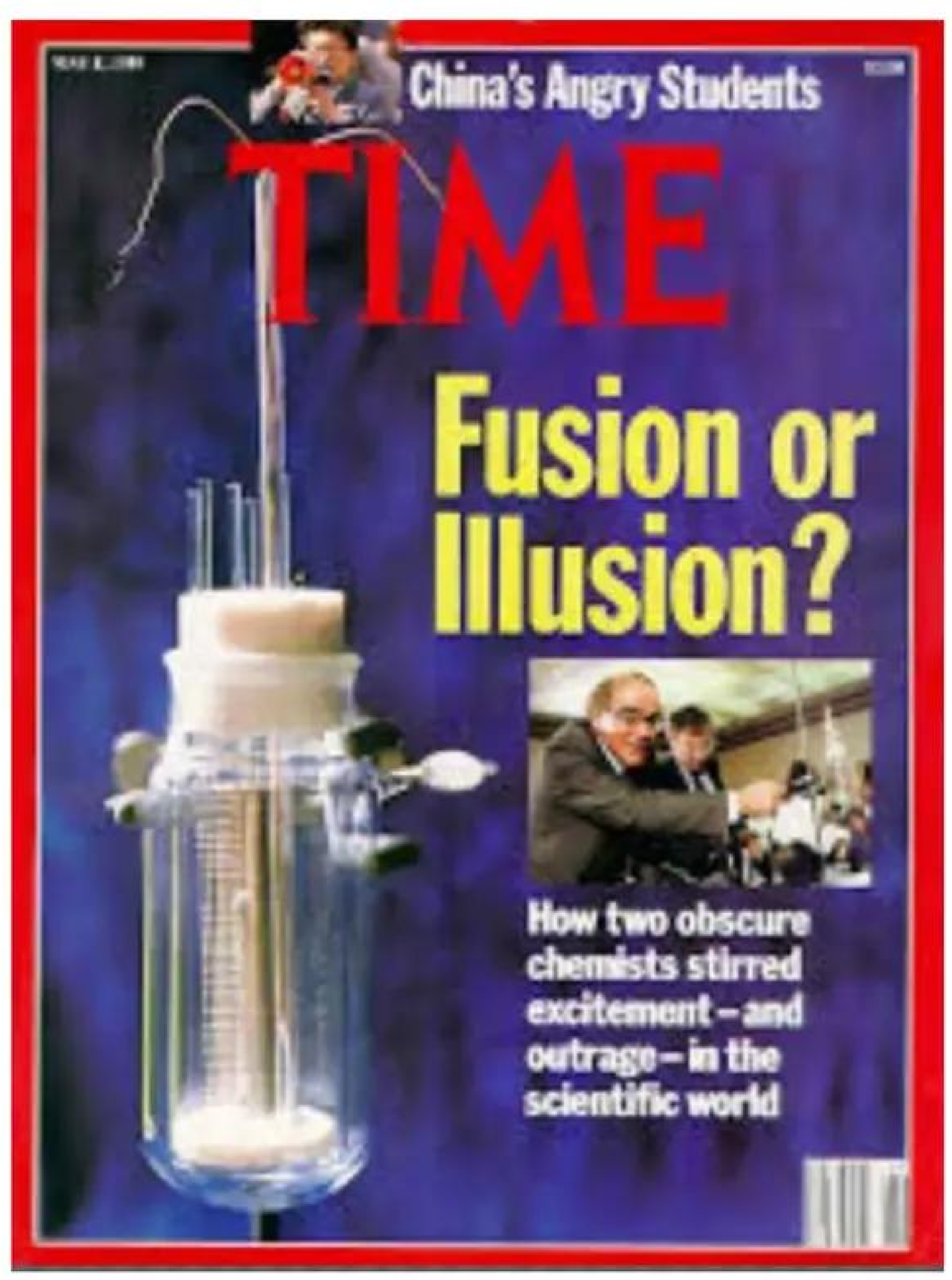


During years of secretive self-funded experimentation testing their idea, P&F sometimes observed production of calorimetrically measured excess heat in anomalously large quantities inexplicable by known chemical processes. They also thought they had detected occasional production of radioactive Tritium (T, unstable Hydrogen isotope) and small bursts of neutrons. Untrained in nuclear physics, P&F believed this data confirmed their speculative hypothesis. If these heretical results were confirmed by others, it would be a revolutionary advance. Emboldened, they informed the University, filed patents, submitted a journal paper, and agreed to announce their experimental results at a Univ. of Utah news conference on March 23,1989.

While preparing for their fateful news conference, P&F had no idea that a "cold fusion" firestorm would ruin their reputations. Lacking today's knowledge, they were unaware that nuclear reactions producing anomalous excess heat measured in their calorimeters were many-body radiation-free LENRs, not the few-body D+D fusion reactions postulated in their hypothesis.

Post news conference, scientists worldwide raced to confirm P&F's excess heat claims. Vexingly, repeatability was poor and successful experiments were rare. Worse yet, even when significant anomalous excess heat production was observed, it was not accompanied by commensurately large, *lethal* emissions of energetic neutron and gamma radiation. This anomaly conflicted with physicists' understanding of D+D fusion reactions. If heat data was correct, then radiation should have killed the experimenters. Existing theory could not explain such results. This array of gnarly problems doomed Pons & Fleischmann: their claims were immediately ridiculed by the scientific community and widely regarded as discredited by 1990.

***Time Magazine* cover shows P&F electrochemical reactor and electrodes - May 8, 1989**



Reputations battered, in January 1991 P&F left the U.S. to continue their controversial research in France at a private laboratory owned by Institute of Minoru Research Advancement (IMRA), founded by Minoru Toyoda of the Japanese family that controls Toyota. Technova, Inc., a research management company controlled by Toyota, operated this laboratory until 1998, when it closed due to inconclusive excess heat results. Martin Fleischmann died in 2012; Stanley Pons still lives quietly out of the media limelight in a rural location near Nice, France.

Besides not having non-fusion theory that could explain anomalous excess heat and mystifying dearth of energetic radiation, researchers in 1989-90 lacked other key puzzle pieces. First, they didn't know that radiation-free LENRs existed and occur in discrete nm- to μ-scale active sites located on surfaces or at interfaces, not inside bulk metallic lattices as P&F had believed. Second, they didn't have today's vastly increased base of knowledge about nanotechnology, plasmonics, quantum entanglement, and materials science --- which didn't exist in 1989-90 --- that provides critical technical know-how required to engineer and fabricate LENR thermal device nanostructures that can reliably produce significant amounts of excess heat.

LENRs in years following the "cold fusion" fiasco of 1989-90

By 1990, overwhelming majority of scientists, governments, and large companies had lost interest in "cold fusion" worldwide. P&F's fiasco gradually faded from memory. That wasn't true in Japan. After 1991, only the Japanese government maintained serious interest in LENRs and provided programmatic support beyond token R&D funding. On the corporate side, Mitsubishi Heavy Industries, Toyota Central Research Laboratories, and Technova still pursued modestly funded experimental R&D programs in LENRs. Publishing results at conferences and in some peer-reviewed journals, they made slow, meticulous incremental progress and occasionally filed patents for the past 29 years.

Besides small R&D groups at Mitsubishi and Toyota, under 200 researchers worldwide continued to work full-time on LENR experiments and theory. They mostly comprised professional scientists and some amateurs who conducted their R&D at a variety of universities, government & non-profit laboratories, small startup companies, and private home laboratories located in U.S., Japan, Russia, France, Italy, China, India, and Israel.

Apart from legitimate scientists, some dubious players have also been involved in LENRs. Most episodically surfaced out of nowhere, promoted unsupported claims about devices that could produce huge amounts of excess heat, attempted to raise money, and eventually disappeared. Recent example of this phenomenon involved a Nickel-Hydrogen gas-loading reactor that supposedly produced a megawatt of excess heat; this claim was never independently verified.

By mid-1990s, LENR researchers had split into two main factions worldwide. While both groups experimented with DC current-driven aqueous electrochemical cells, one faction continued with P&F's original set-up using heavy-water (D_2O) electrolyte containing Lithium (Li) salts, Platinum (Pt) anodes, and Palladium (Pd) cathodes. Other group used either light-water (H_2O) or D_2O electrolyte containing various other salts, Pt or other anodes, and Nickel (Ni), Titanium (Ti), Pd, or other cathode compositions, and certain types of gas-loaded Nickel-Hydrogen reactors.

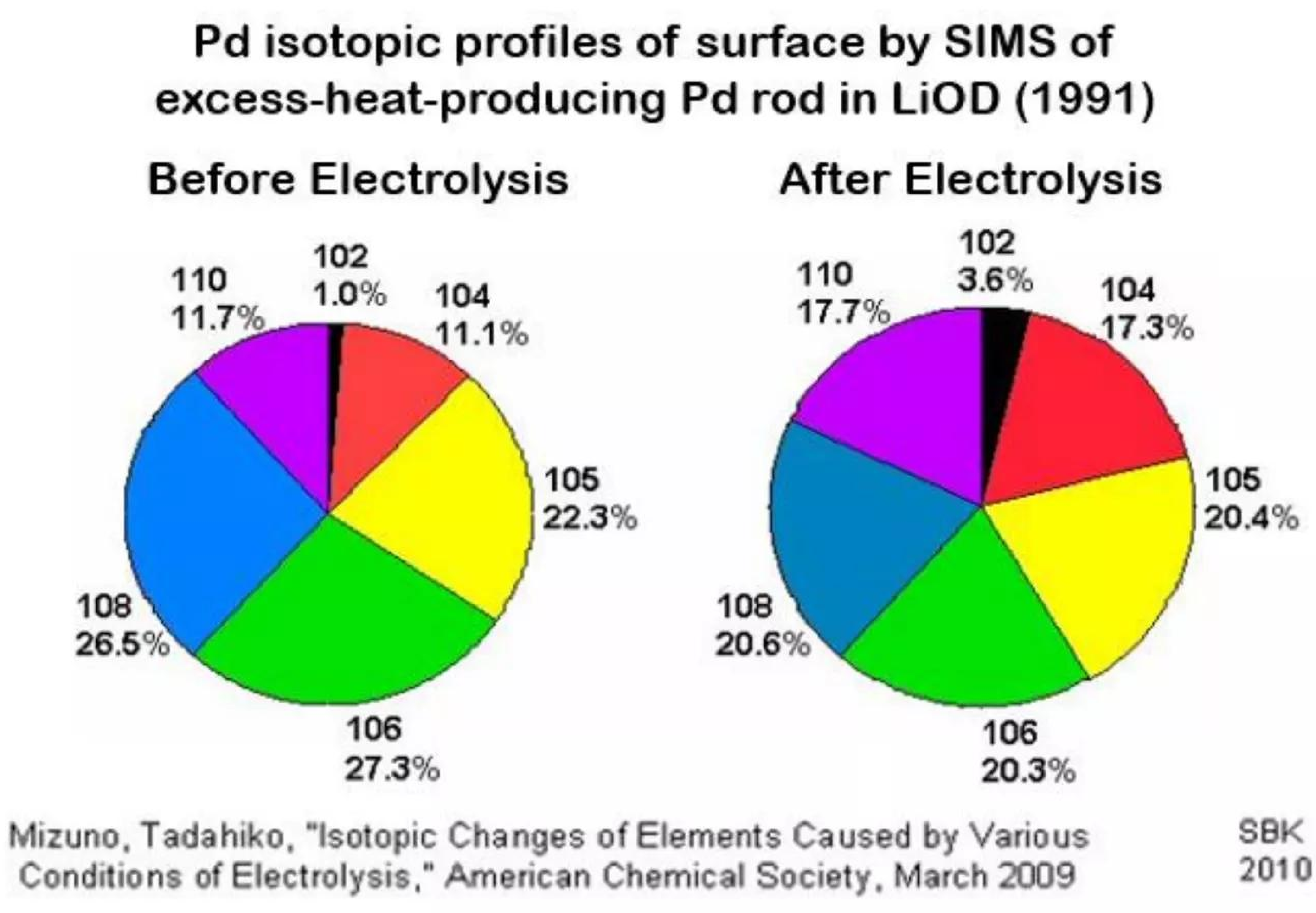
Heavy-water faction was certain that only D+D "cold fusion" could be producing anomalous excess heat that was measured with thermal calorimetry in P&F-type electrochemical cells. Consequently, they only attempted to also measure a few of 6 products produced by all 3 branches of the D+D fusion reaction. They used solid-state detectors for neutron and gamma radiation; a few also used mass spectroscopy for gaseous Helium (He-4, He-3) and Tritium (H-3) production. No one ever tried to measure all 6 D+D reaction products during one experiment.

Light-water LENR faction did not share mistaken belief that only D+D fusion was possible in their experiments. Knowing that nuclear reactions readily cause transmutation of elements, besides obligatory neutron and gamma detectors they also utilized a variety of analytical techniques, including EDX, ICP mass spectroscopy, and SIMS, to measure whatever chemical elements and isotopes might be present on surfaces or in bulk metal of cell cathodes before and after experiments. These researchers were much less concerned about producing excess heat than detecting nuclear transmutation products. Unlike heat that could also be produced by exothermic non-nuclear chemical processes, transmutations are indisputable evidence for nuclear reactions if external contamination of analyzed samples can confidently be excluded. Chemical processes cannot radically change values of isotopic ratios or produce elements different from what were initially present in experimental cells at the beginning of experiments.

Heavy water “cold fusioneers” were never able to detect commensurately large emissions of energetic neutrons or gammas in parallel with significant production of anomalous excess heat. Reliable reports documenting production of Helium and Tritium along with heat were rare; results were inconsistent and inconclusive. Convincing experimental data indicating presence of D+D fusion reactions in room-temperature aqueous electrochemical cells remains absent.

By contrast, more open-minded light water researchers reported numerous extremely well-documented experiments wherein large-scale isotopic shifts and anomalous production of many different chemical elements had clearly occurred. All of this data unquestionably confirmed the presence of nuclear processes in electrochemical cells. Yasuhiro Iwamura, Tadahiko Mizuno, and Hideo Kozima in Japan then argued that such data were consistent with neutron-catalyzed transmutation processes. Anomaly in their results was that energetic neutrons and prompt or delayed neutron capture gamma emissions were not detected in parallel with transmutation. If neutrons were really causing transmutations, then how were they created and why weren’t deadly energetic gammas and/or neutrons also being produced?

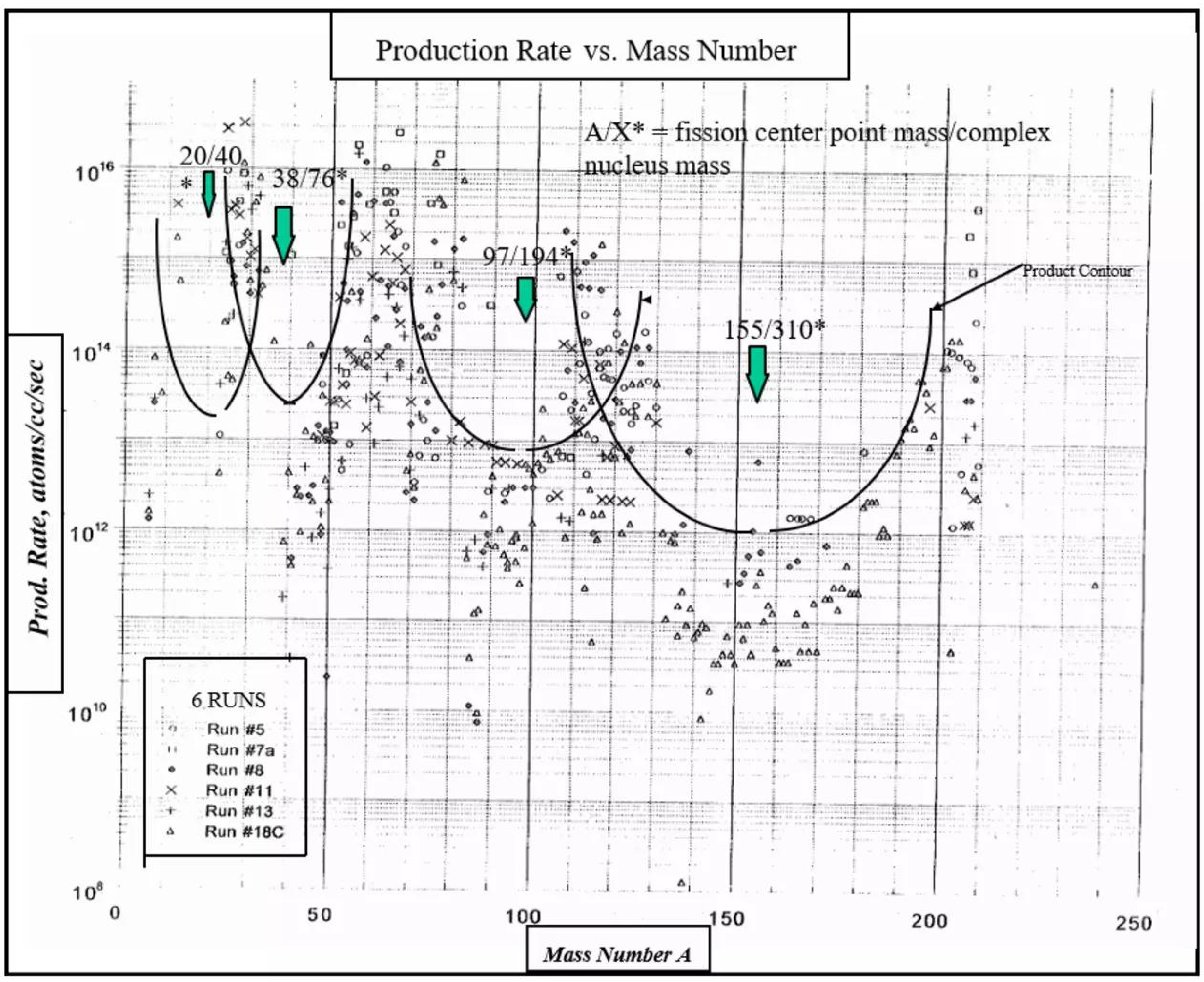
Following data reported by Mizuno (1991) illustrates very large changes in relative percentages of stable isotopes found on the surface of a Palladium cathode that are way too large to be explained by any type of chemical fractionation process. That being the case, neutron capture on Pd is the only reasonable explanation for these major changes in Pd isotope abundances.



In 1995-97, George Miley (USA) and Tadahiko Mizuno (Japan) conducted a series of definitive electrochemical cell experiments with exhaustive analyses to detect as-many-as-possible nuclear transmutation products. Mizuno used P&F-type D_2O cells with Pt anodes and Pd cathodes; Miley used H_2O cells with Pt anodes and Nickel (Ni) cathodes [2]. Both researcher's experiments produced bewilderingly large arrays of different lighter --- as well as heavier --- elements and isotopes ranging from Silicon (mass = 28.1 amu) up to Lead (mass = 207.2 amu).

Miley and Mizuno both observed roughly the same complex 5-peak transmutation product mass spectrum. Miley mistakenly believed fission processes produced his data: he tried to explain the results with an *ad hoc* hypothesis that 4 types of unstable compound nuclei with masses of 40, 76, 194, and 310 amu fissioned to create the observed peaks in production rate. In fact, these results are inconsistent with fission, which does create complex 2-peak mass spectra but invariably emits copious energetic gamma and neutron radiation. Such results are also inconsistent with the D+D fusion reaction, which only produces 6 different nuclear products. However, five distinctive peaks in this electrochemical transmutation data are fully explained by ultralow energy neutron optical absorption model of the Widom-Larsen theory.

Miley's 5-peak transmutation product mass spectrum of inferred production rate (y-axis) vs. atomic mass of observed products in amu (x-axis) – 1997 paper



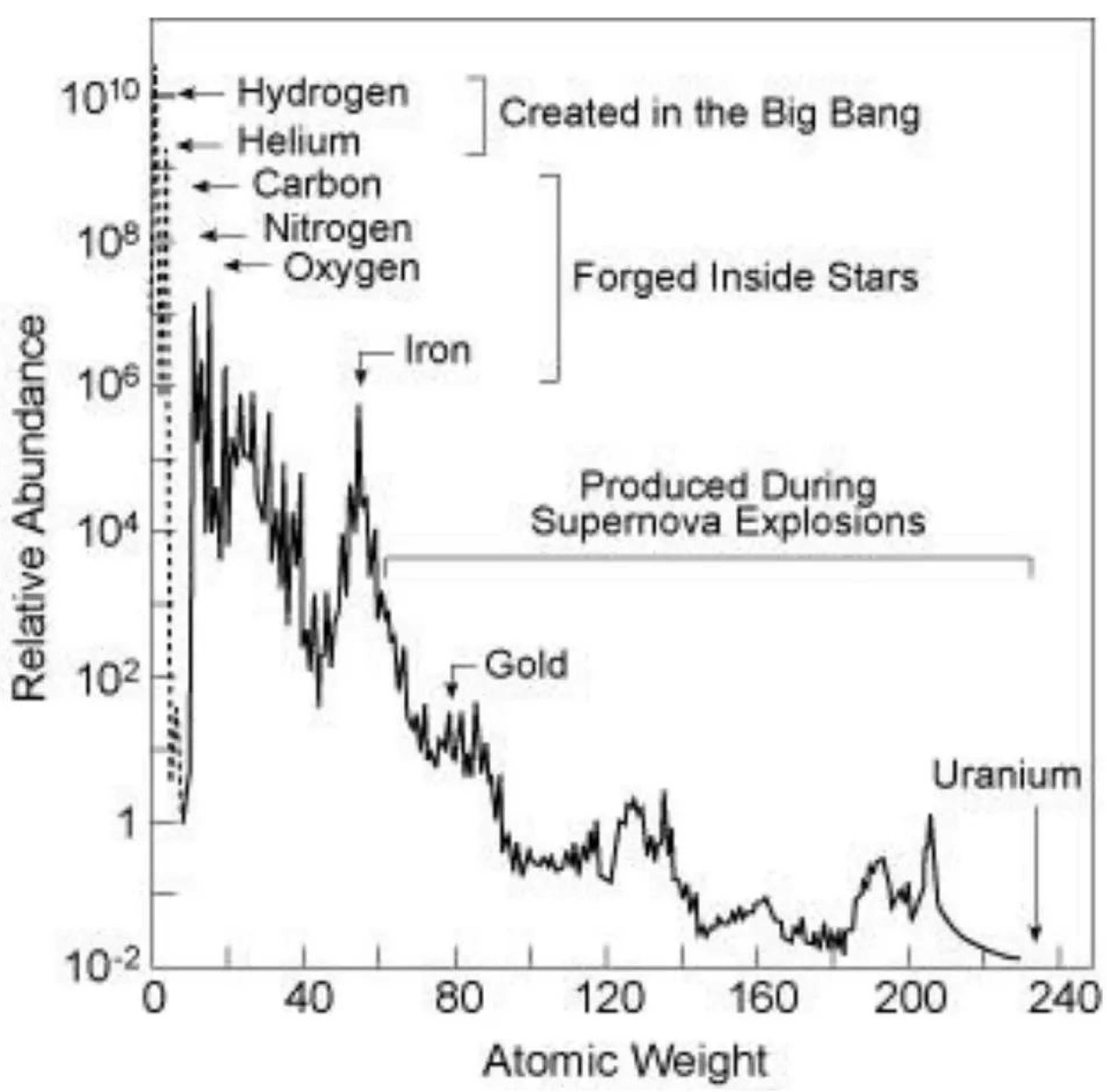
Unexpected similarity of 5-peak mass spectra in both light- and heavy-water systems posed a major dilemma for "cold fusion" advocates. If D+D fusion were the only nuclear process creating transmutations in P&F-type heavy water electrochemical cells, then Miley should never have observed extremely complex arrays of transmutation products in light water experiments because Deuterium is effectively absent in such systems. So either D+D fusion is not the only type of nuclear process responsible for producing observed transmutations, or as critics have argued since 1989, perhaps no fusion of any kind is occurring in such experiments.

By 1990-96, breadth of high-quality data on transmutation products prompted development of several neutron-based theories of LENRs. Peter Hagelstein and others proposed "neutron-hopping" mechanisms whereby neutrons were somehow separated from Deuterium nuclei and then "hopped" onto nearby nuclei of other elements which captured the freed neutrons and were transmuted by them. However, such theories could not explain transmutations in light-water experiments deficient in Deuterium. Iwamura and Mizuno independently theorized that neutrons and benign neutrinos were created in electrochemical cells by direct electroweak reactions between protons and electrons or deuterons and electrons. This mechanism could readily explain transmutations in light- and heavy-water experiments. However, Japanese were unable to articulate detailed rigorous physics that explained how electroweak 2-body $e + p$ and $e + d$ neutron-producing reactions would be able to proceed at high rates in room-temperature electrochemical cells. None of these earlier theories could explain absence of deadly energetic neutron and gamma radiation that uniquely characterizes LENR transmutation experiments.

Larsen encountered LENRs in 1997 and formed Lattice Energy LLC in 2001

My first encounter with LENRs occurred in July 1997 because of questions about future energy "wild cards" posed by a paying client of a small strategic technology consulting business I was involved in. After finding George Miley, we met to discuss whether "cold fusion" was real and, if so, his thoughts about current research and key players. During that meeting, Miley presented his 5-peak mass spectrum chart for light water and mentioned Mizuno's data for heavy water electrochemical cells showed very similar spectral peaks. Recalling astrophysics from college, I realized Miley's 5-peak mass spectrum closely resembled multi-peak elemental abundance patterns created by nuclear fusion and neutron-catalyzed transmutation reactions in stars.

Relative elemental abundance (y-axis) vs. atomic weight in amu (x-axis)
Note multiple distinctive peaks in relative abundance data



In 2001, I along with other partners and angel investors formed Lattice Energy LLC to develop LENRs for power generation. We initially funded experiments at the University of Illinois in the Dept. of Nuclear Engineering under Prof. Miley's direction. Around 2002, I privately theorized that if ultralow energy (ULE) neutrons could instead be produced via many-body collective processes rather than simpler, high temperature 2-body supernova $e + p$ "neutronization" reactions, large neutron production rates might be possible in room temperature electrochemical cells. I was unaware of Sternglass' 1951 work and his interaction with Einstein until months after we uploaded our first theory preprint to the Cornell arXiv in May 2005. Unwittingly, we followed the same conceptual pathway Einstein had suggested 54 years earlier

It was plausible that ULE neutron-catalyzed transmutation processes could produce complex spectra of stable elements/isotopes reported by Miley, Mizuno, and others. However, that possibility required articulation of physics capable of producing large fluxes of extremely low-energy neutrons at moderate temperatures and pressures in electrochemical cells. Such theory must also be able to explain absence of deadly energetic radiation, a common feature across many experiments wherein anomalous transmutations and/or heat have been reported. It was therefore an opportune time to involve very experienced academic physicists as outside consultants to help develop and publish a new, rigorous theory of LENRs.

Widom-Larsen many-body collective theory of LENRs (2005)

In September 2004, I recruited Prof. Allan Widom (Northeastern University) --- and 2 years thereafter, Prof. Yogendra Srivastava (University of Perugia) --- to join Lattice's theoretical effort. We succeeded in developing a rigorous theoretical physics framework that explains all key features of LENRs and formerly inexplicable experimental data. Two peer-reviewed journal papers summarized our joint work from 2004 - 2008: *European Physical Journal C - Particles & Fields* (2006) [3] and lengthy review paper in *Pramana – Journal of Physics* (2010) [4].

In Widom-Larsen theory of LENRs in condensed matter, ULE neutrons and benign neutrinos are produced via collective electroweak reactions between many quantum mechanically (Q-M) entangled (p_n^+ protons, d_n^+ deuterons, or t_n^+ tritons) and electrons (e_n^- surface plasmon electrons on metal hydrides or delocalized π electrons on aromatic Carbon rings and graphene). In case of protons (Hydrogen: 1 proton) the $e_n^- + p_n^+$ reaction produces 1 neutron and 1 neutrino; for deuterons (Deuterium: 1 proton + 1 neutron) the $e_n^- + d_n^+$ reaction produces 2 neutrons and 1 neutrino; and for tritons (Tritium: 1 proton + 2 neutrons) the $e_n^- + t_n^+$ reaction produces 3 neutrons and 1 neutrino.

Neutron production, capture, and decay-driven transmutation of isotopes and elements

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

Induces safe hard-radiation-free nuclear transmutation processes

Neutrons + atomic nuclei → heavier elements + decay products

Neutron capture $n + (Z, A) \rightarrow (Z, A+1) + \gamma_{\text{gamma}} + Q_{\text{energy}}$

Beta⁻ decay $(Z, A) \rightarrow (Z + 1, A) + e_\beta^- + \bar{\nu}_e + Q_{\text{energy}}$

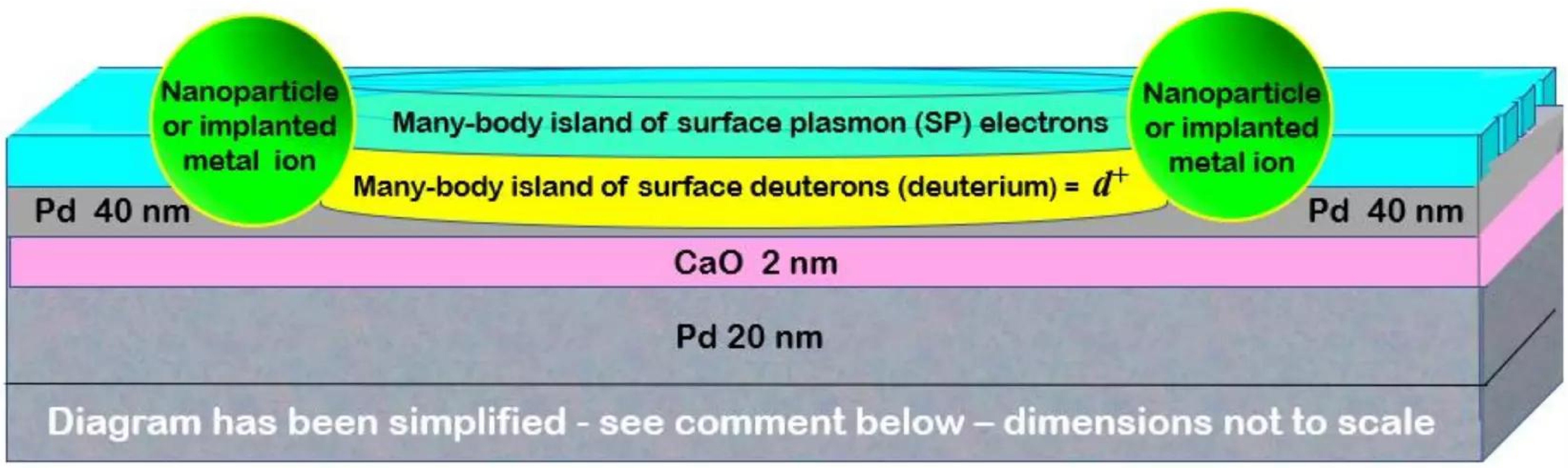
Alpha decay $(Z, A) \rightarrow (Z-2, A-4) + \alpha_{\text{He-4}} + Q_{\text{energy}}$

These many-body collective electroweak reactions between electrons and protons are endothermic; external sources of non-equilibrium input energy are obligatory to drive neutron production. These include electric currents, ion currents, and fluxes of coherent or incoherent electromagnetic (E-M) photons. Coherent photons can be supplied by lasers emitting at resonant frequencies. Incoherent photons can be provided by various types of light sources and broad-spectrum blackbody radiation emitted from interior wall surfaces of heated reaction chambers functioning as resonant E-M cavities, e.g. many types of gas-loading reactors.

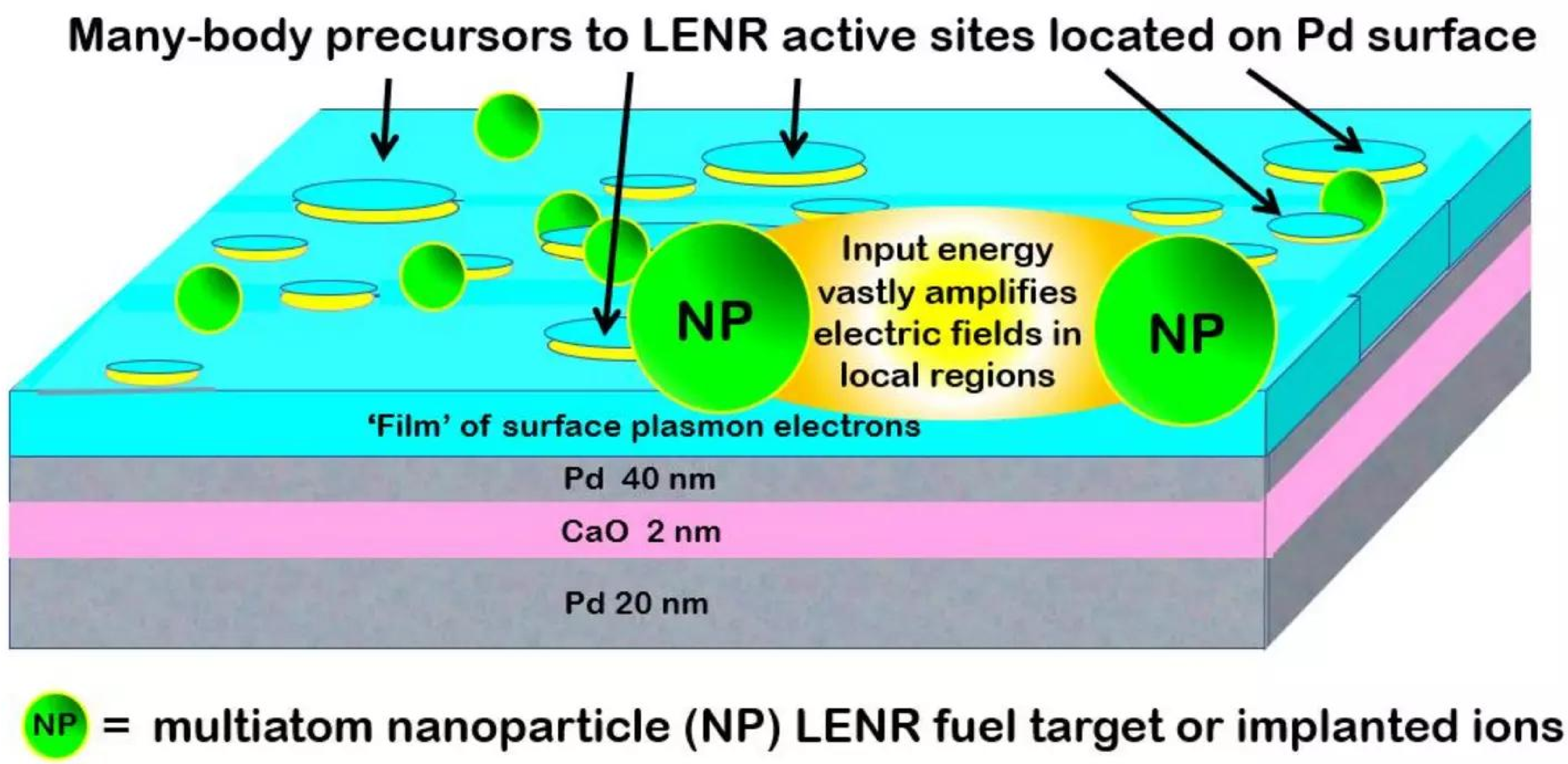
Widom-Larsen theory provides detailed description of nm-scale active sites

LENRs require input loading of Hydrogen isotopes to create many-body ‘islands’ of protons or deuterons with dimensions from 2 nanometers up to ~100 microns that are precursors to LENR active sites. Such islands form spontaneously on surfaces of fully loaded metallic hydrides and at interfaces: e.g. metal/air, metal/oxide, metal/H_2, etc. In metal hydrides, Hydrogen/metal atomic ratio in bulk metal hydride must exceed 0.80 for surficial islands to form. Loading can be accomplished with DC currents in H_2O/D_2O cells or heating and pressure in H_2/D_2 gas-loading reactors. Other types of loading methods can also be utilized.

Conceptual overview of micron-scale precursor to a single many-body Widom-Larsen active site. Very similar to devices fabricated by Mitsubishi Heavy Industries (Japan)



Multiple inactive precursor sites with one active site (yellow) and multiple target fuel NPs. Input energy boosts local electric fields to >10^{11} V/m to produce ULE neutrons



Surface plasmons absorb incident input energy and transport it to precursor proton/electron 'islands.' Active site formation is caused by input energy injection and breakdown of Born-Oppenheimer approximation which enables loose E-M coupling between entangled active site electrons and protons. Altogether, this creates nuclear-strength local electric fields > 1.4 x 10^{11} V/m within active sites. High-field-mediated energy transfer in active sites increases effective masses for subset of active site electrons above threshold values that permit $e_n + p_n$ reaction to proceed at substantial rates in aqueous electrochemical cells and various types of gas-loaded reactors, among others. Active site lifetimes thought to be 200 - 400 nanoseconds.

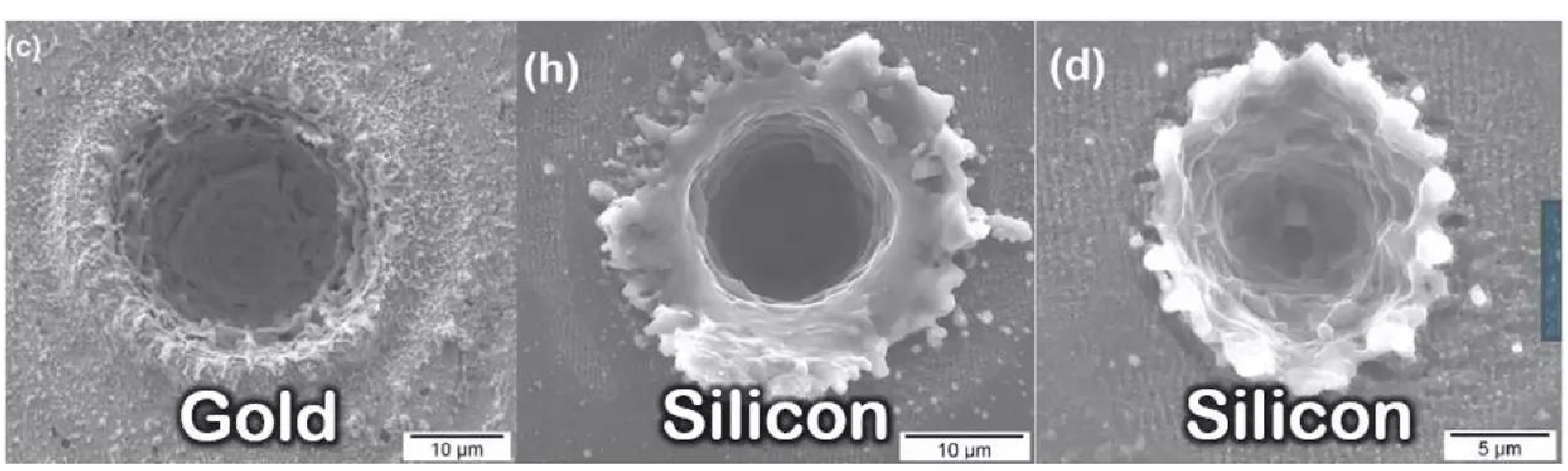
Post-experiment images show key features of LENR active sites on surfaces

In Section D of [5] in our first-principles calculations of ULE neutron production rates in electrochemical cells, we calculated a predicted theoretical peak "noise temperature" for LENR active sites of roughly 5,000 ^{o}K (4,727 ^{o}C). In reality, it is really a range of ~4,000 - 6,000 ^{o}C. This prediction was confirmed by presence of micron-scale 'crater' structures that are visible in many post-experiment SEM images of LENR device surfaces:

Post-experiment SEM images: electrochemical cell; Palladium cathode surfaces
Pd MP = 1,828 ^{o}C BP = 2,963 ^{o}C Credit: P. Boss, U.S. Navy SPAWAR

Above distinctive crater-like structures exhibit morphologies that are consistent with extremely rapid vaporization followed by thermal quenching and solidification of metal or metal-oxide substrates at temperatures of thousands of degrees. In fact, SEM images of active site craters closely resemble those produced by femtosecond (fs) high-energy laser ablation (see below).

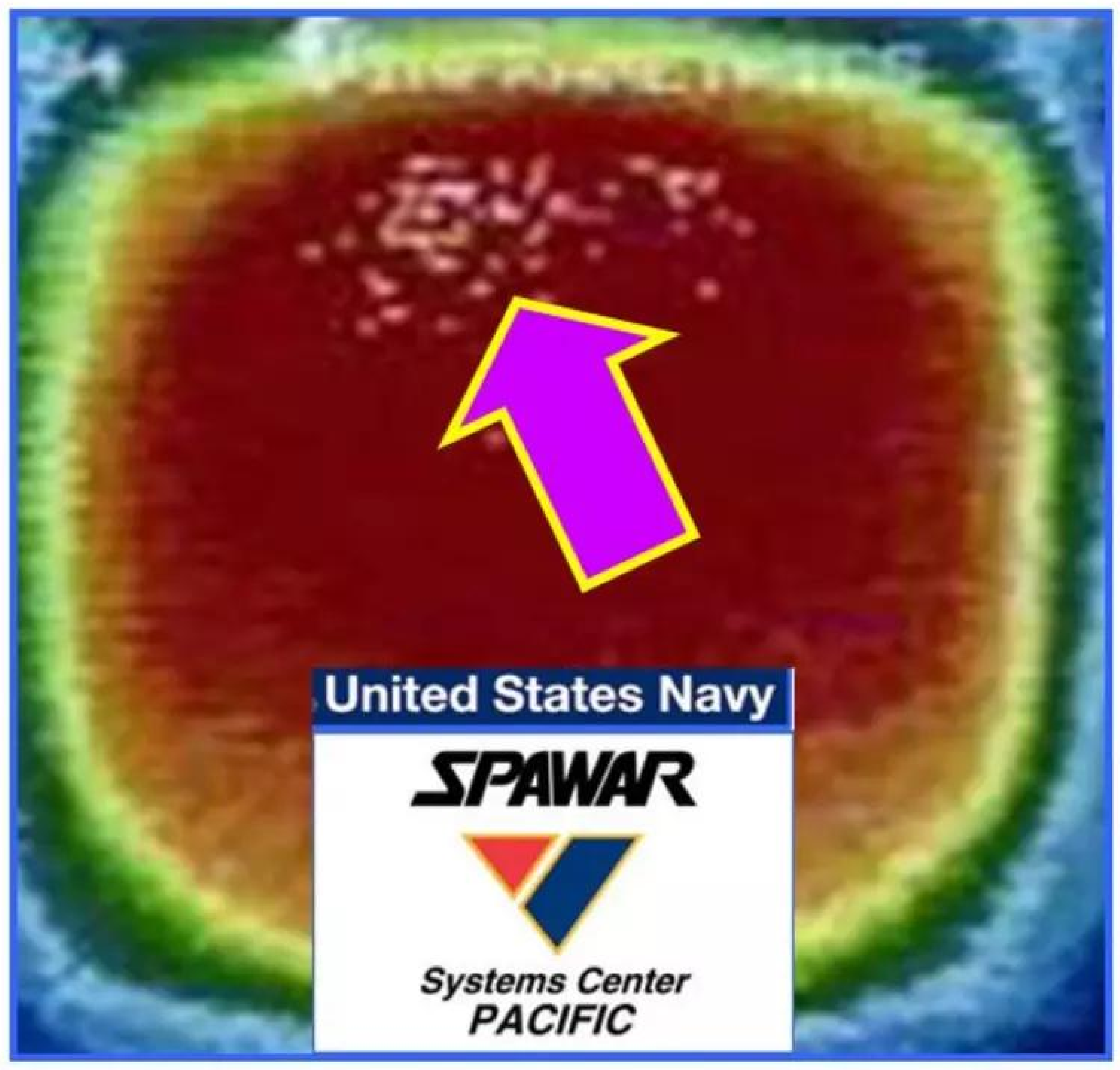
Post-experiment SEM images: fs laser ablation of Gold and Silicon surfaces
Gold MP = 1,064 °C BP = 2,807 °C ; Silicon MP = 1,414 °C BP = 3,265 °C
Figs. 2 and 4 in M. Shaheen et al, *Laser Physics* 24 pp. 106102 (2014)



Identification of such craters as LENR active sites was further confirmed by multiple researchers' EDX and SIMS analyses of locations in and around such craters that clearly indicated local presence of nuclear transmutation products. Note that only larger and more energetic LENR active sites will form crisply defined craters with smooth interior walls; smaller, less energetic sites simply rework and significantly roughen surrounding substrate surfaces.

U.S. Navy infrared video of Pd cathode surface in operating electrochemical cell

In 1994, U.S. Navy used high-speed digital infrared (IR) video camera to image a planar ~cm-scale Palladium (Pd) cathode surface while operating inside an aqueous electrochemical co-deposition cell. Tiny IR 'hotspots' form spontaneously, flicker across cathode surface like fireflies in nighttime field, and then die-out, just as we described in our 2006 rates preprint [5]. See URL to SPAWAR YouTube video at: http://www.youtube.com/watch?v=OUVmOQXBS68



Credit: P. Boss, U.S. Navy SPAWAR (1994)

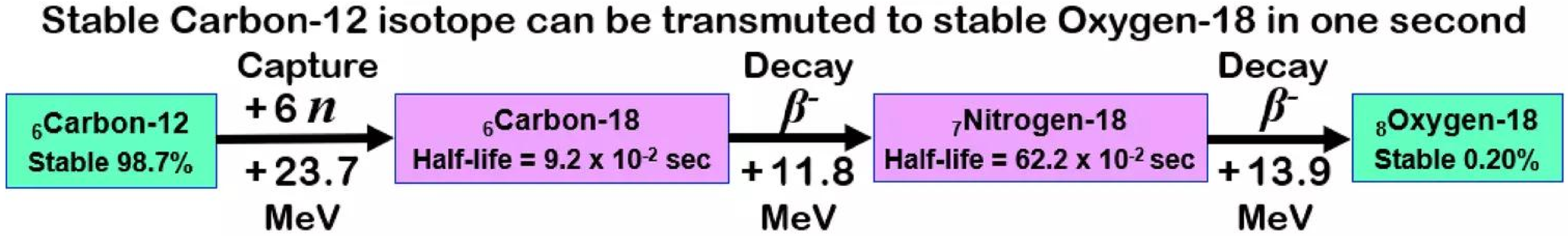
Widom-Larsen explains absence of deadly radiation and sources of excess heat

Neutrons produced collectively in active sites have ultralow energies and nearly all are captured locally by nearby atoms; energetic neutrons are not emitted externally. Locally produced or incident gamma photons are converted directly into safe infrared (IR) photons by unreacted heavy electrons present in active sites per Lattice patent US# 7,893,414 B2 [6]; MeV-energy gamma radiation is not emitted. Widom-Larsen posits LENR excess heat is produced by direct gamma-to-IR conversion plus scattering of β^- and α particles off atoms in device materials.

Widom-Larsen explains why LENRs do not produce long-lived radioactive wastes

LENR transmutation of elements occurs in and around active sites via ULE neutron capture and subsequent β^- and some α-particle decays of unstable neutron-rich products. These transmutation processes typically proceed from left-to-right across rows of the Periodic Table. They can rapidly create complex, branched nuclear reaction networks that follow very neutron-rich pathways and create vast arrays of different unstable intermediate isotopic products and stable elements as end-products. Being very neutron-rich, unstable intermediates typically decay rapidly, so long-lived radioactive waste production is not a problem as in U-235 fission.

Stable Carbon-12 isotope can be transmuted to stable Oxygen-18 in one second

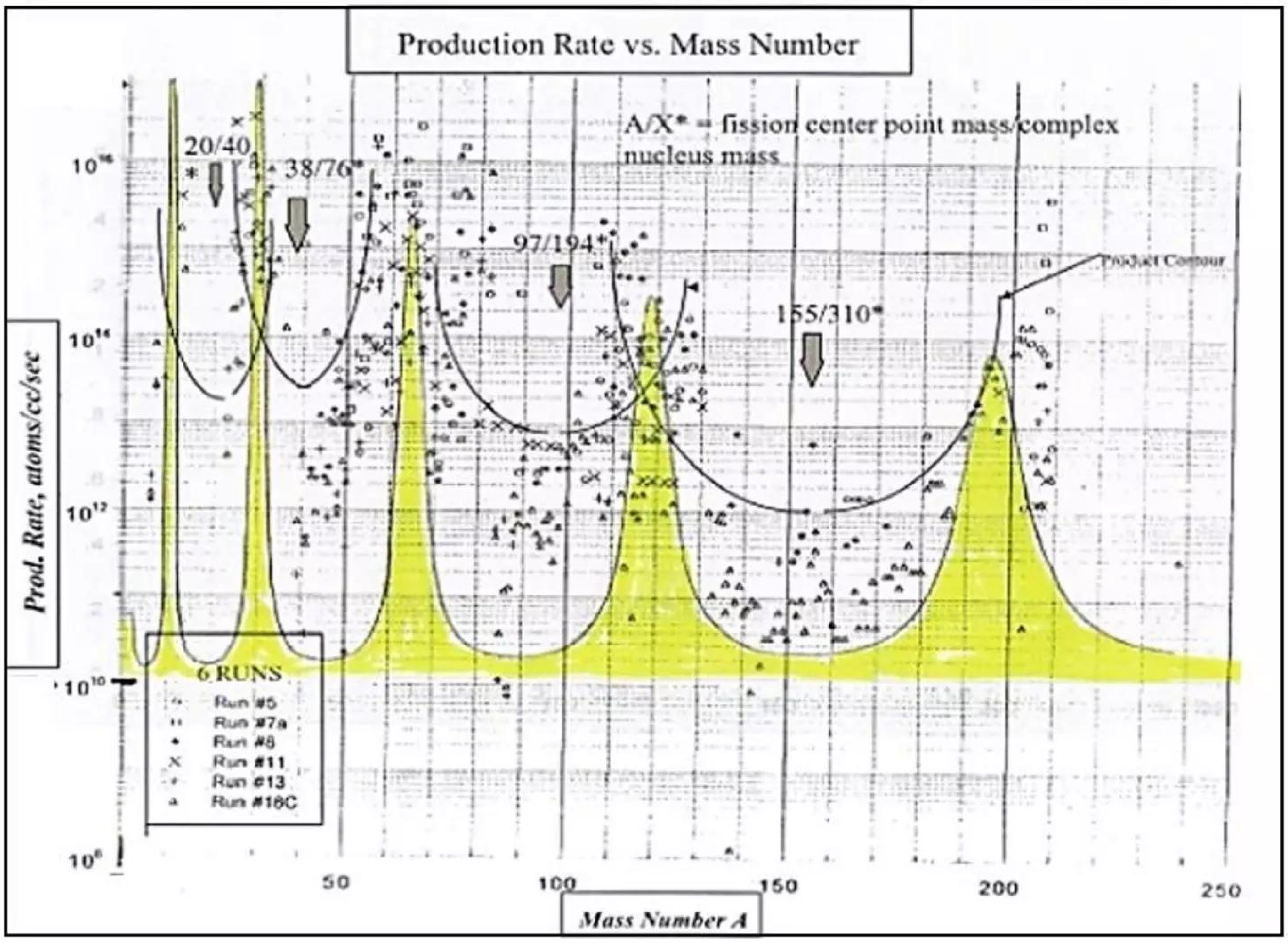


Exothermic LENR network pathway releases 49.4 MeV of nuclear binding energy

Widom-Larsen optical model explains Miley and Mizuno's 5-peak mass spectrum

Published Widom-Larsen optical model of ULE neutron absorption by atomic nuclei (arXiv 2006) [7] provides definitive experimental confirmation of theory. LENR transmutation product abundances predicted by our simple 2-parameter theoretical model (shaded yellow; no fitting) are in reasonable agreement with Miley and Mizuno's reported data. Model's predicted 5-peak product mass spectrum represents unique 'signature' for capture of ULE neutrons by nuclei; higher-energy neutrons produce different abundance patterns not seen in LENR experiments.

Miley's 5-peak transmutation product mass spectrum of inferred production rate vs. atomic mass – predictions of Widom-Larsen optical model shaded in yellow



Once neutrons are produced, what occurs in and near LENR active sites is long-established nuclear physics. Involves ULE neutron captures on local atoms and eventually mostly beta- and some alpha-decays of unstable isotopes. LENRs produce nuclear transmutation products akin to a stellar *r*- or *s*-process that operates in condensed matter at STP and can create simple or complex nucleosynthetic networks, depending on rates and total duration of neutron production, i.e. effectively, local neutron dosage.

Widom-Larsen calculations of neutron production rate are consistent with data

We published rigorous first-principles theoretical calculations in 2007 [5] predicting ULE production rates in electrochemical cells under specified conditions. Predicted rates are in satisfactory agreement with best-available published experimental data; confirms many-body collective $e_n^- + p_n^+$ and $e_n^- + d_n^+$ reactions can occur at high rates on the order of ~10^{12} - 10^{14} neutrons/cm^2/sec. on cathode surfaces in well-performing, DC current-driven chemical cells.

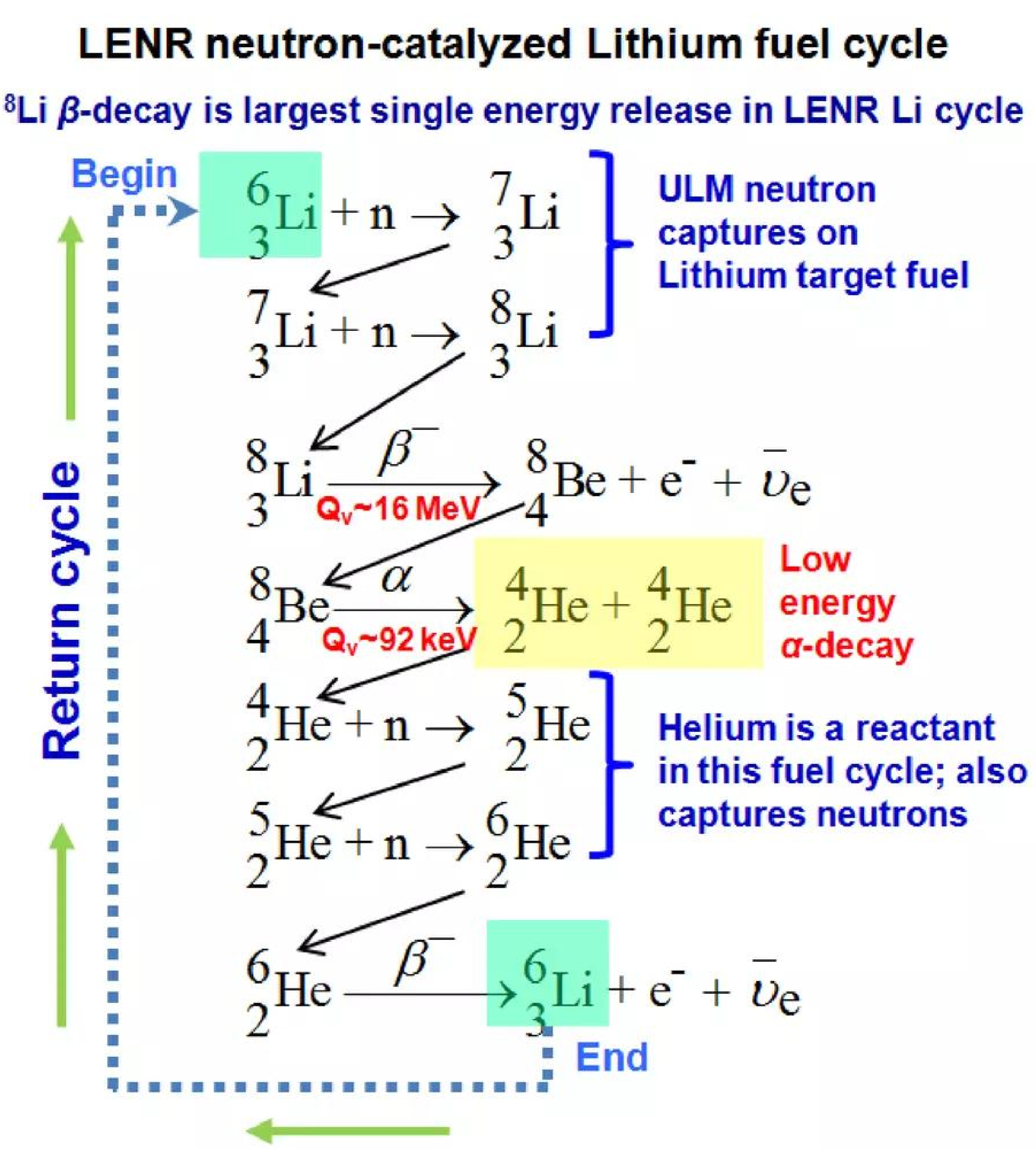
Widom-Larsen explains why Tritium is rarely detected in LENR experiments

Neutron capture on Hydrogen produces Deuterium. Tritium is produced when Deuterium captures one ULE neutron. Tritium β-decays into He-3, which transmutes into He-4 by capturing one ULE neutron. All three Hydrogen isotopes are readily converted into ULE neutrons and neutrinos during operation of LENR active sites, so Tritium rarely accumulates in local concentrations large enough to be detected.

Widom-Larsen explains He-4 production and predicts a Lithium fuel cycle

Helium-4 (identical to α-particle) can be produced via LENR transmutation pathway that begins with ULE neutron capture on Lithium (Li), which automatically plates onto Pd cathodes in aqueous electrochemical cells that contain Lithium salts. He-4 is also produced by neutron capture on Pt that plates from Platinum anodes onto Pd cathodes in some types of electrochemical cells. Widom-Larsen theory shows how He-4 can also be a reactant that captures ULE neutrons in LENR active sites.

W-L theory also predicts existence of a 'leaky' Lithium LENR fuel cycle that can ultimately lead to production of heavier elements in LENR reactors. It is disclosed in our 2006 *EPJC* paper [3]:



LENR Lithium fuel cycle releases more nuclear energy than D+T fusion reaction

Net of total input energy 'cost' required to create ULE neutrons that drive this relatively simple LENR transmutation network, entire Lithium target fuel cycle pathway has a Q value = 26.9 MeV, released mainly in the form of easy to convert excess infrared heat. This Q value is larger than the D+T fusion reaction's Q = 17.6 MeV, which is released mainly in the form of hard to convert 14 MeV neutrons. A much less costly LENR Lithium fuel cycle at modest temperatures can release more energy than D+T fusion without emitting MeV-energy neutron and γ radiation.

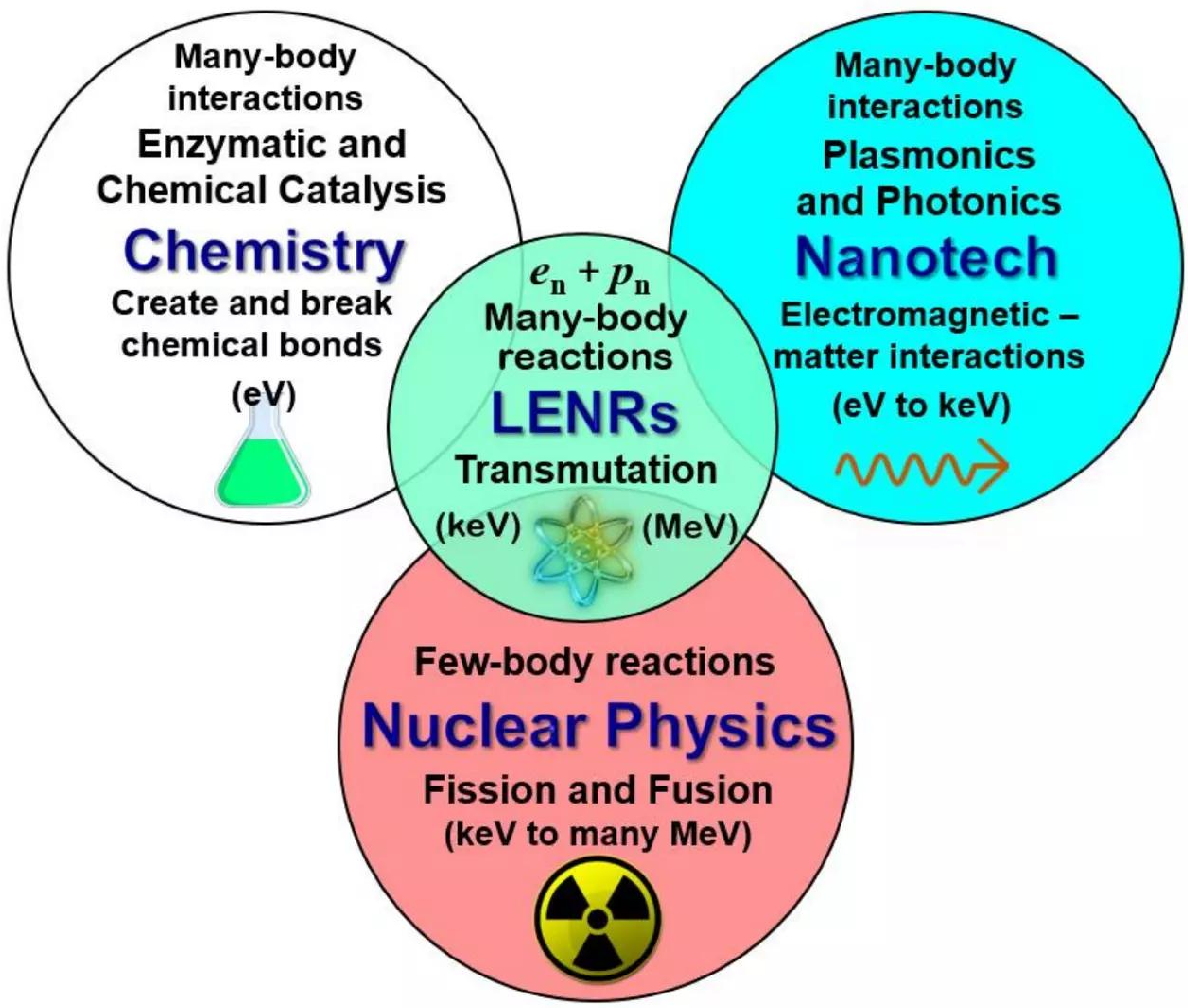
Widom-Larsen is the only theory providing comprehensive explanation of LENRs

Widom-Larsen is only peer-reviewed theory which articulates detailed physics that rigorously explain entire body of good transmutation and excess heat data reported by heavy- and light-water LENR researchers since 1989. It is also only theory that proposes plausible mechanisms that can explain heretofore inexplicable absence of energetic neutron and gamma radiation that uniquely characterizes LENRs. It can also guide engineering of power generation devices. According to W-L theory, LENRs are *intrinsically* nanoscale phenomena because LENR active sites will have dimensions ranging from 2 nm on aromatic rings to maximums of ~100 microns.

Widom-Larsen theory reveals connections to chemical catalysis and plasmonics

Venn diagram below indicates there are surprising interrelationships between nuclear physics, chemistry, nanotechnology, and LENRs. Surface plasmons' key role in Widom-Larsen theory in condensed matter also suggests strong interconnections between LENRs and plasmonics, which is the intersection between photonics and electronics on nanometer (nm) length-scales.

Theory shows that green nuclear LENRs have deep connections to abiotic and enzymatic chemical catalysis, plasmonics, photonics, and nanotechnology



W-L theory also informs characteristics of local nanostructures needed to facilitate formation of ultrahigh local electric fields > 10^{11} V/m required for many-body collective ULE neutron production. Altogether, this suggests that thermal device engineering progress could be greatly accelerated by judicious data mining from knowledge bases in plasmonics and nanotech.

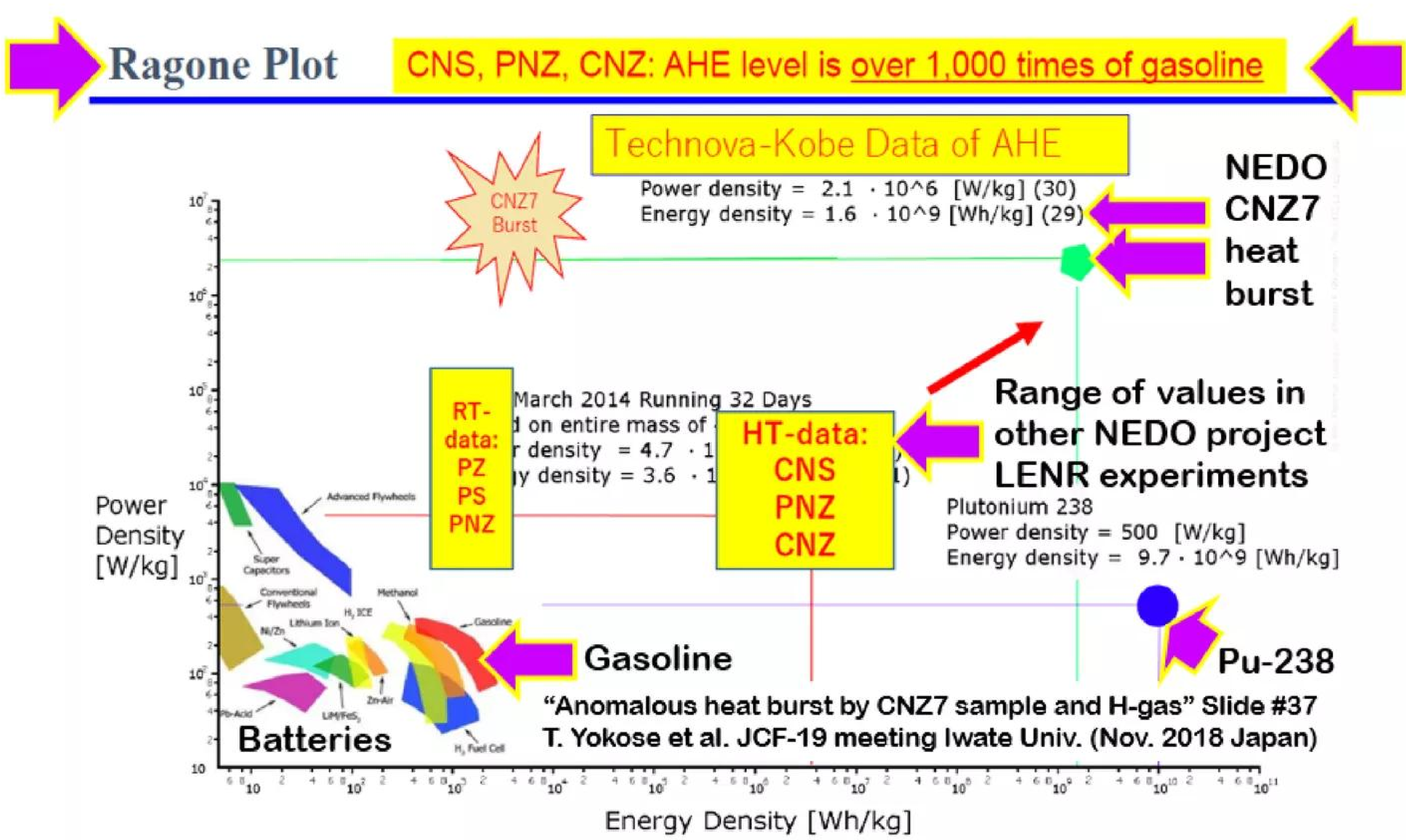
Technology readiness level of LENRs stagnated at TRL-3 for over fifteen years

From 2000 to 2015, LENR technology stagnated at Technology Readiness Level TRL-3 (European Commission definitions). During that time, typical best-performing LENR experimental systems were DC current-driven H_2O or D_2O electrochemical cells with bulk metal ~ cm^2 99% pure Pd metal cathodes, 99% pure Pt anodes, and various salts in electrolytes. Calorimetrically measured excess heat production in such systems typically ranged from several milliwatts to 0.5 Watts; values over 1 Watt were rare. Experimental repeatability and duration of excess heat production varied enormously. In "successful" experiments, heat was often erratic at milliwatt levels and only lasted for several days. Excess heat production of 100s of milliwatts for several days and no better than 10 - 20% repeatability for given batch of fabricated electrodes were considered state-of-the-art results.

Japanese NEDO LENR project recently advanced readiness from TRL-3 to TRL-4

Directly applying today's state-of-the-art nanotech, corporate and academic scientists working in Japanese government-funded NEDO project have recently made major progress toward overcoming previously intractable experimental problems in developing LENRs as a new, breakthrough source of 'green' radiation-free nuclear power. In 2015, Japanese government New Energy and Industrial Technology Development Organization (NEDO) organized and funded an LENR thermal device nanofabrication and testing project managed by Technova. Participants: Mitsubishi Heavy Industries, Toyota, and Nissan Motors; universities were Tohoku, Nagoya, Kobe, and Kyushu [8].

NEDO project researchers increased typical LENR device excess heat production from milliwatts to Watts. This improvement is 1,000x better thermal performance versus prior best-practices results. Repeatability of excess heat production increased from under 10 - 20% beforehand to >70 – 80%. These achievements advanced LENR technology readiness from TRL-3 to TRL-4 in 2.5 years at cost of < US$54 million. Researchers recently published Ragone Plot claiming that LENR device thermal performance already exceeds 1,000x that of gasoline:

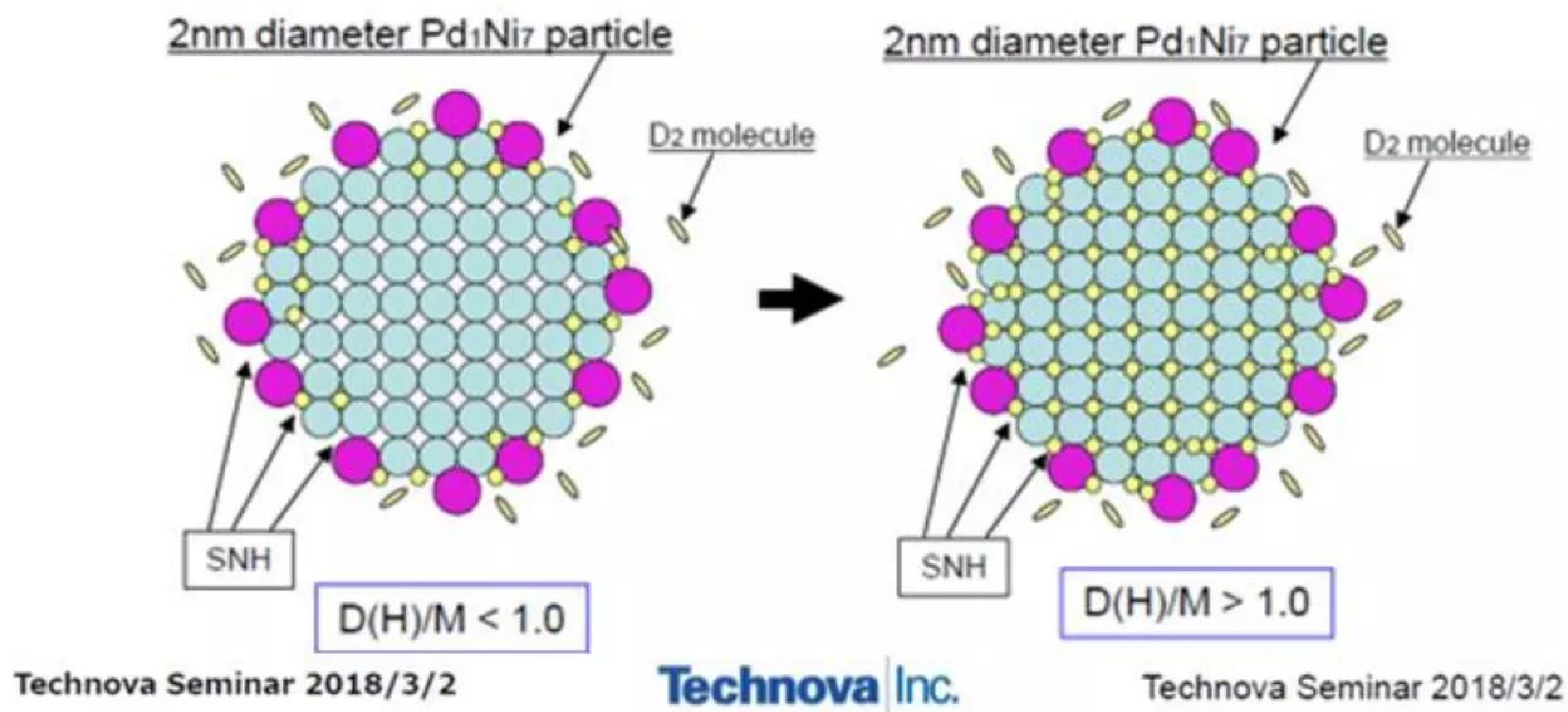


Source: Yokose et al. Technova JCF19 Nov, 9-10, 2018 (Lattice annotated chart)

NEDO project used nanoparticle fuels in H_2 or D_2 gas-loaded LENR reactors

NEDO project designed and fabricated nanoparticulate LENR devices that produced 3 - 24 Watts (average ~ 5 Watts) of excess heat for periods ranging from several to 45 days with repeatability >70 - 80%. Recently, a 90-gram device produced 130 Watts for 100 seconds. LENR devices consisted of 90 - 120 grams of ~2 nm Ni/Pd nanoparticles capable of hosting precursors to LENR active sites intermixed with ~1 kilogram of 1 mm ZrO_2 or SiO_2 "filler beads."

NEDO project fabricated ~2 nm Ni/Pd nanoparticles used as LENR fuel targets



Ni/Pd target fuel nanoparticles and filler bead mixtures were poured into cylindrical stainless-steel 500 cc reaction chambers, then sealed and filled with 99% pure Hydrogen (H_2) or Deuterium (D_2) gas. Gas-loaded reactors were heated to device working temperatures of 200 - 400^o C, after which excess heat production above input power was measured with sensitive integrated calorimetry. Substantial excess heat was produced in both H_2 and D_2 experiments. Relative percentages of Nickel vs. Palladium had substantial impacts on excess heat production and strongly resembled behavior of certain types of bimetallic chemical catalysts.

Schematic diagram of NEDO project LENR reactor (credit: Technova)

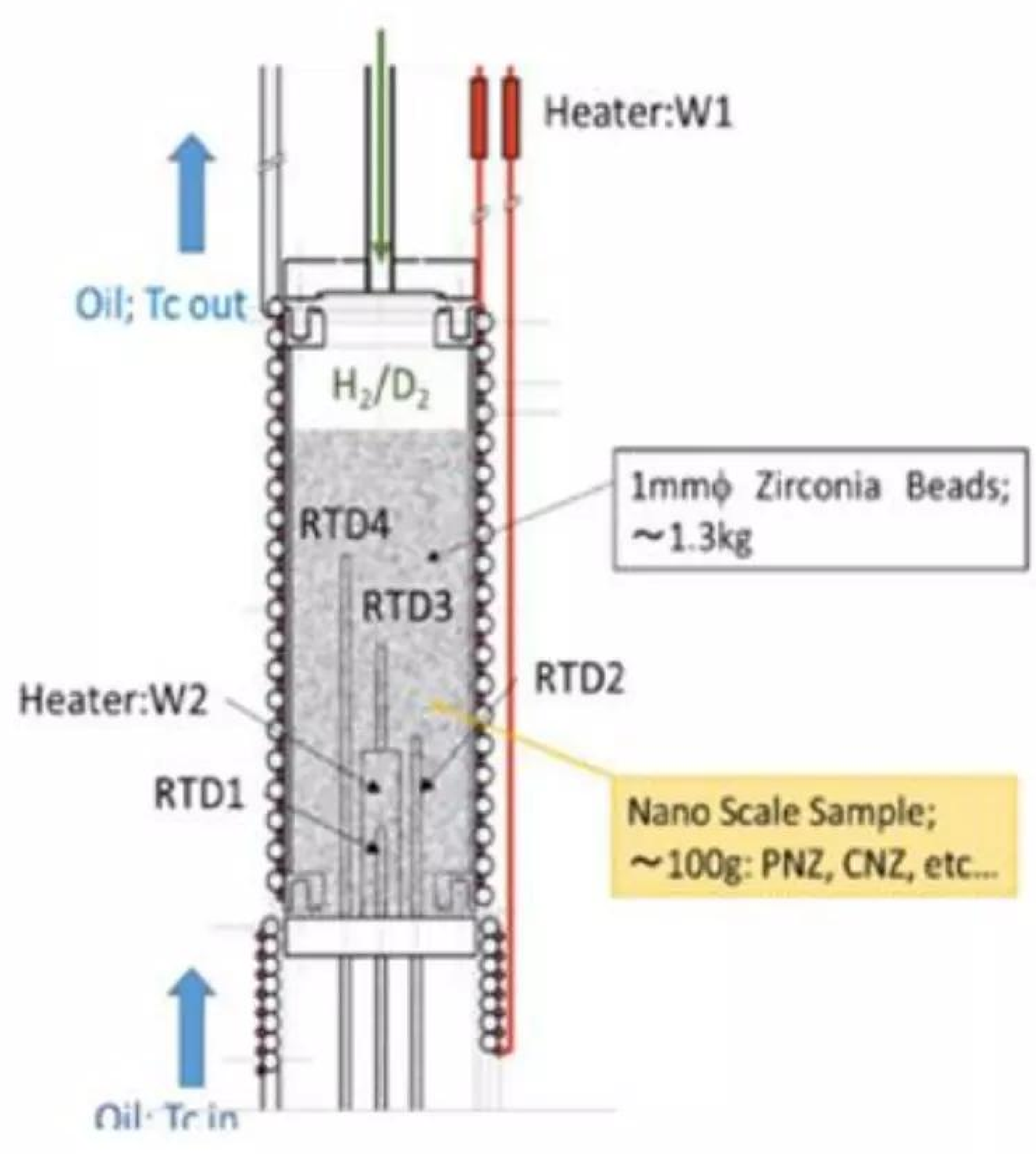
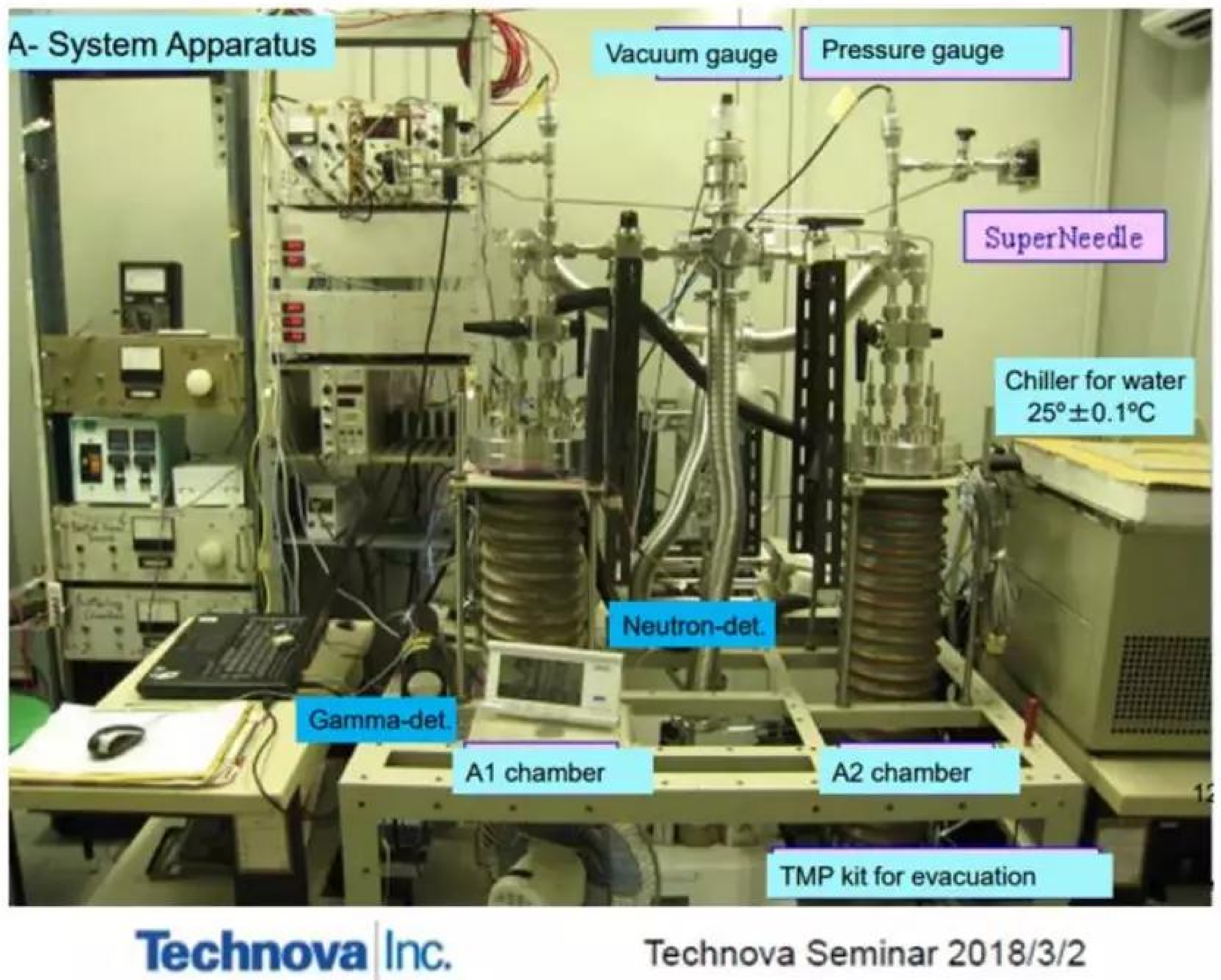


Image shows two NEDO project gas-loaded reactors in university laboratory



Theoretical energetics for LENR transmutation of stable Nickel (Ni) target fuels

NEDO PNZ Ni/Pd nanoparticulate LENR target fuels with highest molar ratios of Ni produced largest amounts of excess heat. Theoretical Specific Energy (MJ/kg) of Ni target fuel is roughly 3 million x larger versus than that for combustion of H_2 as fuel. Chart below shows theoretical energy gain of ~12x for LENR transmutation of Nickel target fuels. This suggests that, even with energy conversion inefficiencies and various types of unavoidable losses, well-engineered LENR power systems could likely operate at good multiples of breakeven.

Nickel target fuel: estimated energy gain ratio = 12.14x
Avg. energy release per capture (MeV) / cost to make one neutron (MeV) = 9.47/0.78

Isotope Capturing ULM Neutron or Beta decaying	Natural abundance of stable isotope	Neutron capture Q-value in ~MeV (all are + values)	Contribution to weighted average based on natural abundance
Ni-58	68.0%	9.0	6.94
Ni-59	Nil	11.4	
Ni-60	26.2%	7.8	2.04
Ni-61	1.14%	10.6	0.12
Ni-62	3.63%	6.8	0.30
Ni-63	Nil	9.7	
Ni-64	0.92%	6.1	0.07
Ni-65 (decay)	Nil	2.1	
Weighted average energy release (MeV) per neutron capture on Nickel fuel target			**9.47 MeV**

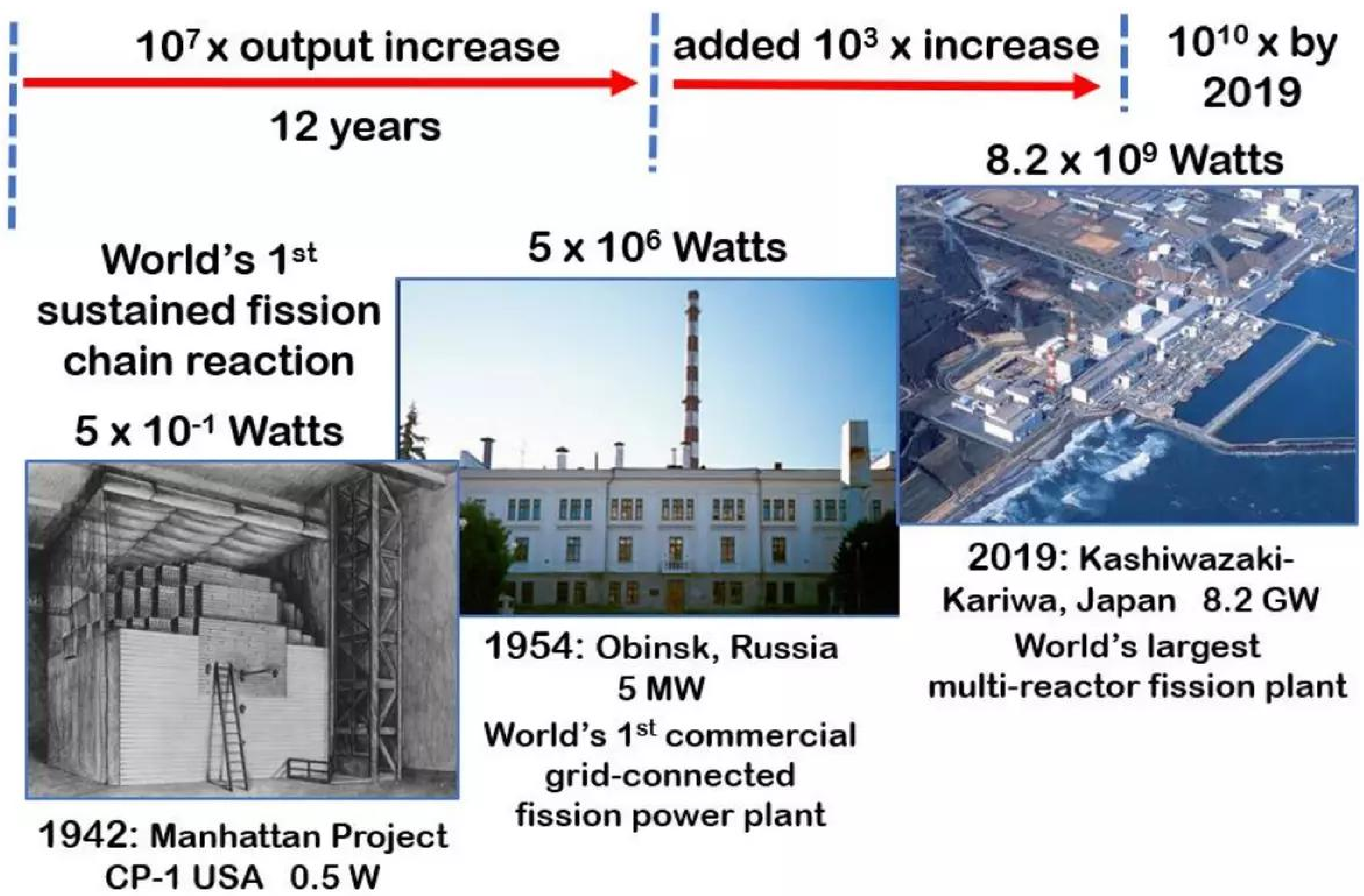
Further steps in commercializing LENRs for future power and propulsion

Further nanotech engineering is necessary to advance from today's small-scale TRL-4 laboratory protype reactors to TRL-9 commercial LENR thermal power generation systems. Technologists must achieve high-volume/low-cost fabrication of rationally designed nanostructures hosting large numbers of LENR active site precursors. These nanostructures must then be emplaced on working surfaces of LENR reactors in close proximity to target fuels such as Lithium, Nickel, aromatic Carbon (Benzene), etc.

Once cost-effective, high-yield device fabrication, triggering, and extended longevity have been achieved, total output of LENR reactors can be scaled-up by: (1) increasing designed area-densities of precursors to LENR active sites on fabricated nanostructures; and/or (2) injecting larger quantities of target fuel nanoparticles hosting precursors into larger-volume reaction chambers containing Hydrogen gas. Off-the-shelf energy conversion subsystems suited for particular applications can be selected and integrated with commercial LENR heat sources to create standalone power generation systems.

First fission reactor was 400 tons and produced 0.5 Watts of heat for 28 minutes

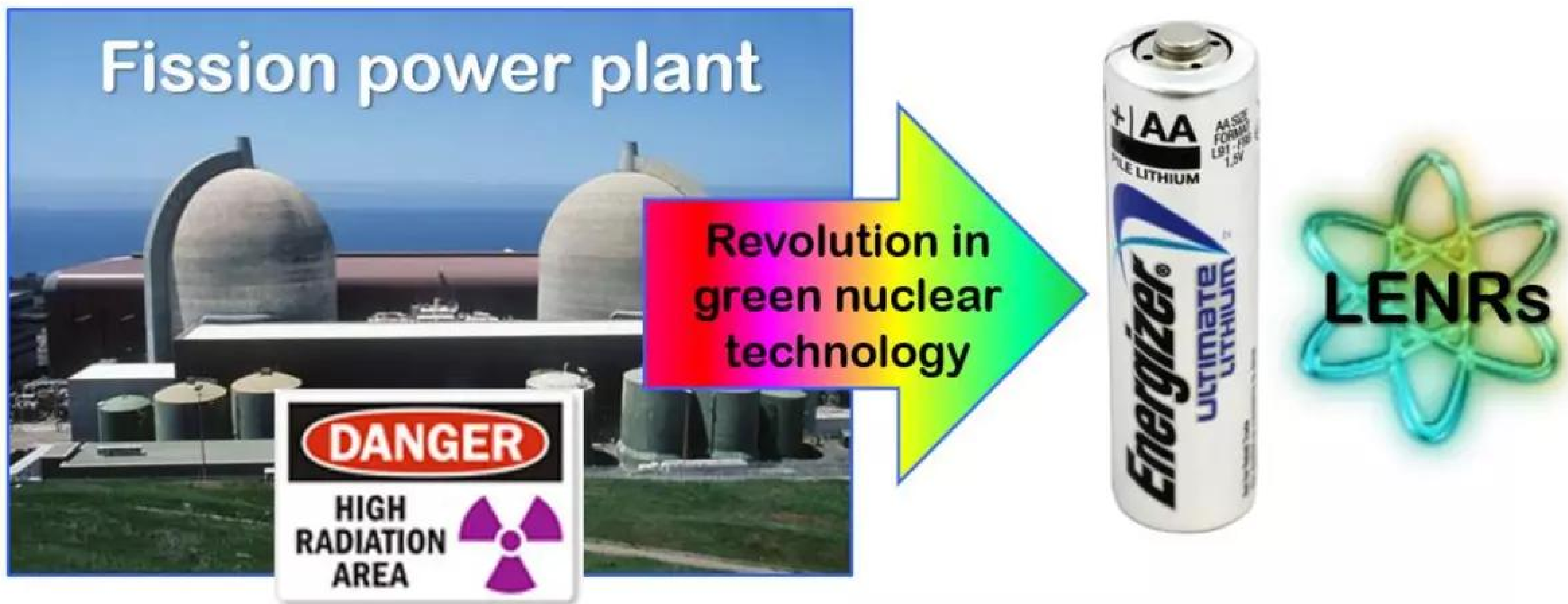
Enrico Fermi's original Manhattan Project CP-1 Uranium fission reactor at the University of Chicago weighed ~ 400 tons and only produced 0.5 Watt (thermal) for 28 minutes went it first went critical in 1942. By 1954, USS Nautilus submarine had been launched with a 93% enriched ^{235}U pressurized water reactor that produced power output of ~ 10 megawatts (13,400 hp thermal); first fueling powered Nautilus until 1957, after voyaging 62,562 miles. By 1954, USSR had commissioned world's first commercial nuclear power plant in Obinsk, Russia with power output of 5 MW (net electrical) produced from 30 MW (thermal). Both of these early ^{235}U reactors were operational 12 years after CP-1 which achieved TRL-4 back in 1942.



No *a priori* technical reason why LENRs could not scale-up as fast as fission did

Vs. CP-1, NEDO project's TRL-4 LENR devices presently average 5 Watts thermal and weigh ~100 grams. Entire NEDO reactor system apparatus weighs < 1,500 pounds. These facts argue that future commercial versions LENR power generation systems, which would not require radiation shielding or containment subsystems, could have higher effective system power densities than ^{235}U fission reactors. W-L theory supports this possibility: we estimate that local power density inside *μ*-scale LENR active sites could briefly reach peak values as high as $E_{(J)} = 1.0 \times 10^{21}$ Joules/sec·m^3. Given generous programmatic funding at ITER's present US$125 million/yr., there is no *a priori* technical reason why thermal output of LENR power systems could not be scaled-up just as rapidly as fission reactors increased from 1942 - 1955. Investments in developing LENRs have been miniscule compared to fission and fusion.

Absence of hard radiation allows development of portable LENR power sources



LENR fuels and power sources: vastly higher energy density vs. chemical power

Fuel	Energy Type	Specific energy (MJ/kg)	Applications
Uranium (breeder) U-235 fission	Nuclear fission	80,620,000	Nuclear reactors: grid electric power generation plants and submarine propulsion
Thorium (breeder) Th-232 → U-233 fission	Nuclear fission	79,420,000	Thorium reactors under development for grid electric power generation plants
Electrons, protons (Hydrogen), and LENR target fuels such as Ni, Li, and aromatic Carbon	LENRs: neither fission nor fusion; transmutation of target fuels	Nickel target fuel est. ~3,817,235	Stationary, mobile, and portable power generation systems; electric power plants
Hydrogen (compressed to 70 MPa)	Chemical combustion	142	Rocket and automotive engines; grid storage and conversion
Diesel/Fuel oil	Chemical combustion	48	Automobile engines; certain types of power generation systems, e.g. diesel gensets
LPG (including Propane, Butane)	Chemical combustion	46.4	Cooking, home heating, auto engines, lighter fluid
Jet Fuel	Chemical combustion	46	Aircraft
Gasoline (Petrol)	Chemical combustion	44.4	Automotive engines; other types of power generation systems

LENR fuels could boost range performance and collapse fuel logistics pipelines

Energy densities of future commercial LENR fuels would be > 5,000x larger than gasoline (Japanese NEDO project's LENR laboratory devices have already achieved 1,000x gasoline); this unprecedented competitive advantage would have important future implications:

- **Revolutionary range performance**: automobiles, trucks, aircraft, or ships powered by LENRs could travel around entire world on quantity of nanoparticulate fuel that would fit into a large FedEx box. LENR fuels would be inert and benign and could safely utilize existing overnight package delivery systems and drones for resupply of end-users
- **Size of fuel logistics pipelines would collapse:** typical gasoline or diesel tanker trucks as shown below carry ~ 5,000 to 12,000 US Gallons of liquid fuel. LENR fuels producing same number of BTUs would fit into one FedEx box

LENR power and propulsion would possess substantial competitive advantages

LENR-based power systems could be extremely competitive across broad range of markets and applications because system and fuel energy densities would be orders of magnitude larger than any competing chemical combustion and battery energy storage technologies.

Radiation-free LENR power generation systems would not require heavy, expensive radiation shielding and containment systems for safe operation. Consequently, LENR-based systems could be vastly smaller and less expensive than fission or fusion reactors, and safe-enough to be utilized in unshielded systems suitable for motor vehicles, ships, aircraft, and spacecraft. Lack of radiation would also permit development of battery-like portable LENR power systems that directly compete with batteries and fuel cells. Possible future nanoparticulate LENR target fuels include Nickel, Lithium, and aromatic Carbon molecules, among many other possibilities.

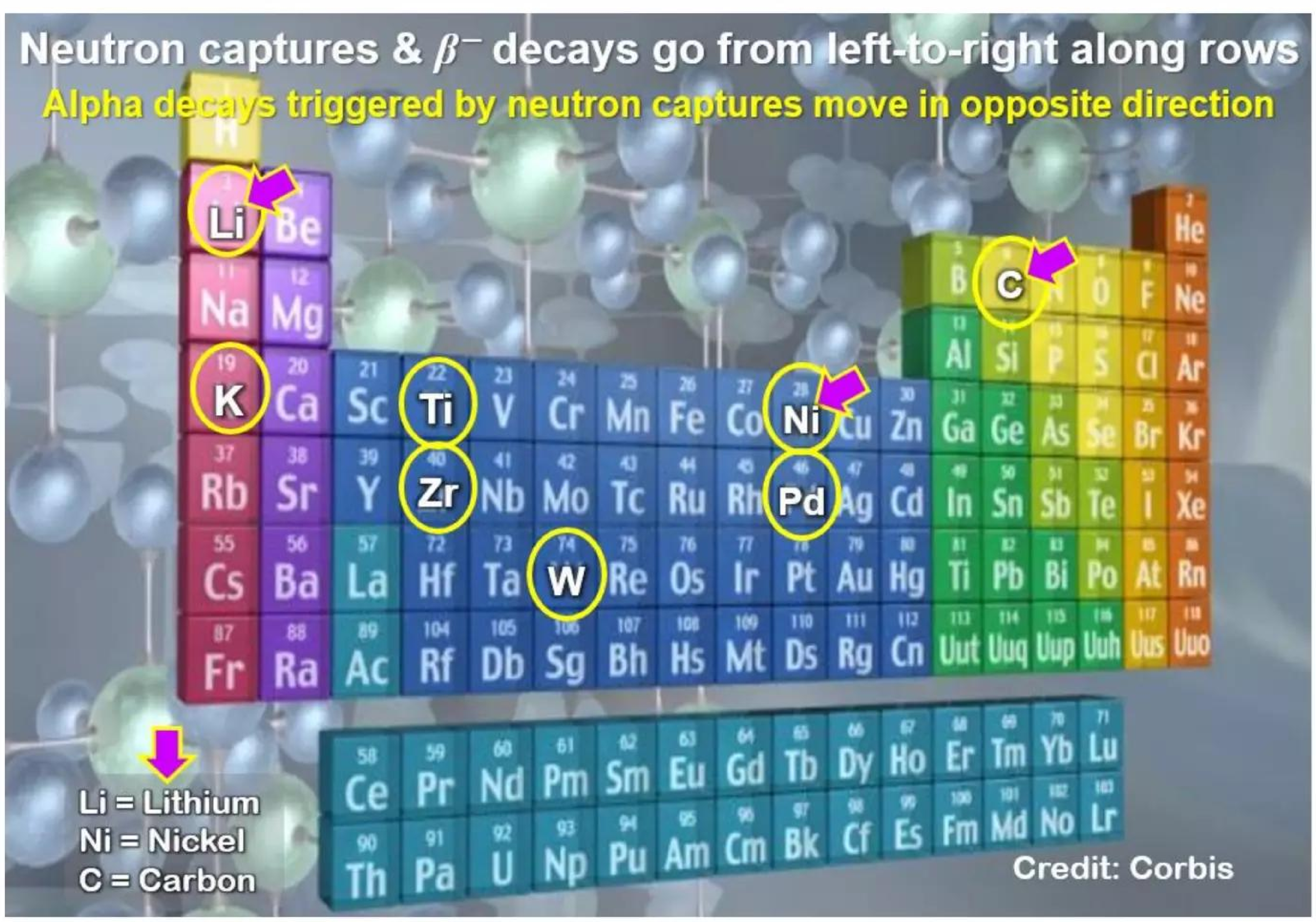
LENR energy density: game-changing impact on aircraft and spacecraft design

Commercialization of LENRs would enable expansion of nuclear power and propulsion into huge range of land vehicles, aircraft, watercraft, and spacecraft. Aerospace propulsion systems based on use of ultra energy-dense LENR fuels would be a game-changer.

Development of high-performance LENR propulsion systems with power outputs on order of 50 - 100 megawatts or more is needed for mission-critical applications in larger military and passenger aircraft, cruise missiles, large spacecraft, and even surface ships and submarines. Key advantage of LENR propulsion technology is that energy densities of LENR fuels would be >5,000x gasoline or jet fuel. Such high fuel energy density would enable onboard fuel fractions at vehicle takeoff to be slashed by 90% or more --- a revolutionary advance. In practice, it means that enough nanoparticulate LENR fuel needed to complete a 3,250-mile SR-71 Blackbird mission --- producing same number of BTUs as combusting 12,000 gallons of jet fuel --- would fit into a FedEx box.

Fuel fractions for aircraft, missiles, and launch vehicles presently range from 27 - 96%

Many different elements are LENR fuel candidates but some are much better than others



Large increases in global R&D spending on LENRs are definitely warranted

Over 26 years prior to NEDO funding its Japanese LENR nanofabrication and device testing project, total cumulative worldwide R&D spent on LENRs was probably at most ~US$250 million; LENRs nevertheless advanced from TRL-1 to TRL-3.

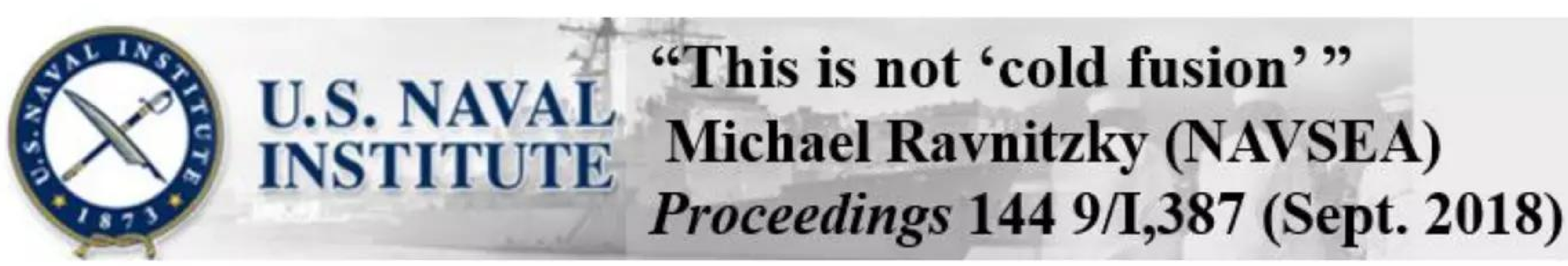
In ensuing three years from 2015 - 2018, total NEDO LENR project spending probably did not exceed US$ 54 million. Importantly, its reported results have advanced LENR development from TRL-3 to TRL-4. Total global R&D funding of LENRs since 1989 thus likely to have been less than ~US$ 300 million.

Today, total number of researchers working full-time on R&D in LENR technology is probably still less than 200 people worldwide. Given that LENRs are now at TRL-4 and technology's huge intrinsic advantages vs. fission and fusion for power generation, large increases in R&D spending are definitely warranted. Present R&D on LENRs is ridiculously underfunded given its incredible future potential as a new green energy source. Thousands of scientists could be profitably working on developing this promising new technology.

By comparison, Sagara et al. (2015) believe that successful operation of the ITER D+T fusion demonstration reactor in 2025 would only advance D+T fusion power technology to TRL-5/6 after cumulative spending of more than US$ 22 billion on that project alone.

Given results to date, it is time for government and private sectors to up the ante on funding.

Provocative article about LENRs published in *Proceedings* of U.S. Naval Institute



Article begins by saying: "LENRs offer the first opportunity since the advent of fission reactors to change fundamentally the way the Navy powers its ships, systems, and weapons" and goes on to say, "Once relevant LENR scientific and engineering parameters are more broadly understood and harnessed, LENR energy sources … could power underwater, surface, or airborne vehicles or stationary nodes."

And also notes, "Since the European Organization for Nuclear Research (CERN) held a 2012 colloquium on LENRs, the prevailing explanation of the phenomenon has been the Widom-Larsen theory. Peer-reviewed experimental research reported in the *Japanese Journal of Applied Physics*, for example, has given support to this theory."

Key conclusion from our *Pramana* W-L theory review paper published in 2010

"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." [4]

Future potential of commercialized LENRs for power generation and propulsion

If commercialized, LENRs could become one of the world's preeminent energy technologies. At system electrical power outputs of just 5 - 10 kwh, modular LENR-based distributed power generation systems providing combined heat and electricity (CHP) could satisfy energy requirements of a majority of urban and rural households as well as smaller businesses worldwide. Much lower-output, revolutionary *portable* LENR power sources could displace chemical batteries in applications where ultrahigh performance and longevity are needed.

At electrical outputs of 60 - 200 kwh, LENR-based integrated power generation systems would be able to power vehicles, drones, as well as smaller aircraft and watercraft. This would break oil-based fuels' 150-year stranglehold on internal combustion engines and decisively decarbonize the entire transportation sector. High-performance LENR thermal sources could also provide high-quality heat for many types of industrial processes.

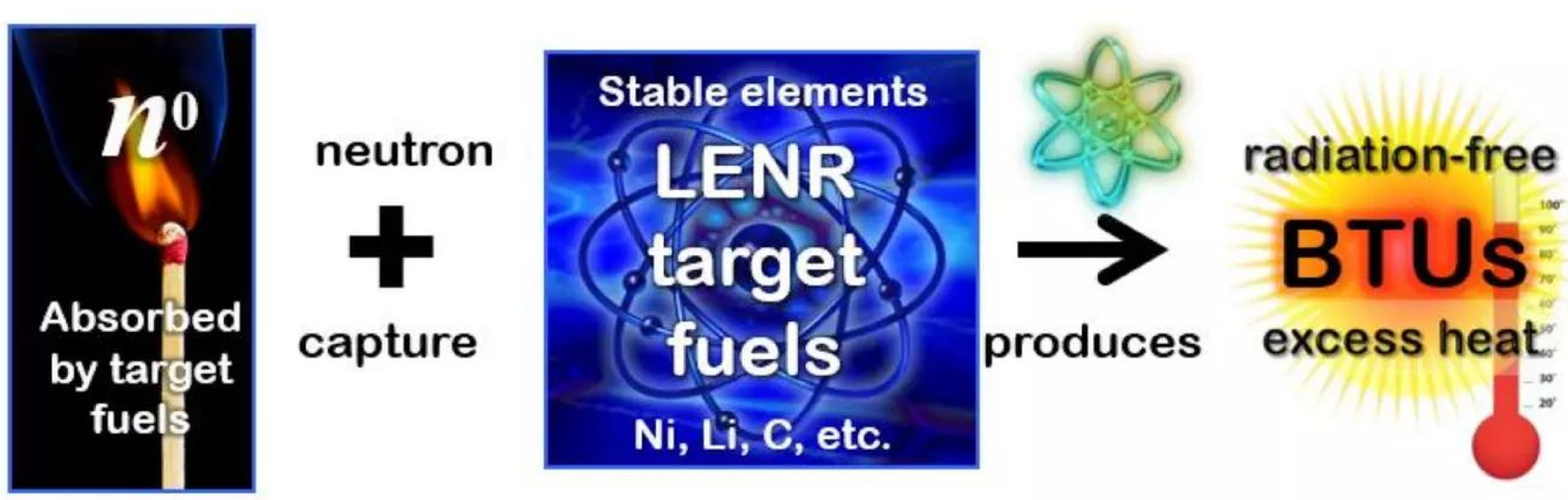
Although they could very likely be designed and built, development of megawatt-output LENR systems are not mandatory to disrupt the world of energy for the better. If wide deployment of small-scale, low-cost LENR CHP distributed generation could be achieved, large numbers of fossil-fired and/or fission power plants would not have to be built to supply competitively priced, uninterruptible electricity to regional grids serving urbanized areas. Under that scenario, centralized grid power generation would be gradually displaced by vast numbers of smaller, price-competitive distributed LENR power systems inside homes and businesses.

LENRs could potentially 'green' the world's fossil fuel industry – here's how

Contrary to what many might assume, LENRs are synergistic with oil & gas as well as intermittent renewable energy sources. LENR technology provides a compelling strategic opportunity for fossil fuel companies because it could enable future processing and conversion of aromatic molecules found in oil and coal into green CO_2-free nanoparticulate LENR fuels that have >5,000x the energy density of gasoline. In fact, existing refineries could eventually be upgraded to produce revolutionary LENR fuels in parallel with traditional industry products.

Gradually replacing today's age-old Carbon combustion technology with LENR *transmutation* of aromatic Carbon could green the world's fossil fuel industry over time. Such a technological shift would also be very synergistic with renewable energy sources like wind and solar because renewables could supply electricity that provides input energy for LENR systems that would in turn effectively amplify input power by 5x - 10x.

Think of LENR technology as potentially being an integrated power amplifier for low-energy-density wind or solar systems. In such a future, fossil energy producers, solar and wind power industries, energy consumers, and the Earth's environment would all win.



References with live URL hyperlinks

1. "Einstein's lost hypothesis: is a third-act twist to nuclear energy at hand?"
   Mark Anderson, *Nautilus* magazine, pp. 21 - 29 Winter 2013-14 issue Nov. 28, 2013
   http://nautil.us/issue/7/waste/einsteins-lost-hypothesis

2. "Possible evidence of anomalous energy effects in H/D-loaded solids - Low Energy Nuclear Reactions" G. Miley et al. *Journal of New Energy* **2** No. 3 - 4 pp. 6 - 13 (1997)
   https://www.researchgate.net/publication/295652235_Possible_evidence_of_anomalous_energy_effects_in_HD-loaded_solids_-_low_energy_nuclear_reactions_LENRS

3. "Ultralow momentum neutron catalyzed nuclear reactions on metallic hydride surfaces"
   A. Widom and L. Larsen *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

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

5. "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 (2007) http://arxiv.org/pdf/nucl-th/0608059v2.pdf

6. US# 7,893,414 B2 "Apparatus and method for absorption of incident gamma radiation and its conversion to outgoing radiation at less penetrating, lower energies and frequencies" Lewis Larsen and Allan Widom - Issued: February 22, 2011 Assignee: Lattice Energy LLC https://www.slideshare.net/lewisglarsen/us-patent-7893414-b2

7. "Nuclear abundances in metallic hydride electrodes of electrolytic chemical cells"
   A. Widom and L. Larsen Cornell physics preprint arXiv:cond-mat/0602472 (2006)
   https://arxiv.org/pdf/cond-mat/0602472.pdf

8. "Widom-Larsen theory reveals many surprising similarities between LENRs and chemical catalysis" L. Larsen Lattice Energy LLC PowerPoint on SlideShare Nov. 4, 2018
   https://www.slideshare.net/lewisglarsen/lattice-energy-llc-widomlarsen-theory-reveals-surprising-similarities-and-connections-between-lenrs-and-chemical-catalysis-nov-4-2018

Only one authoritative popular science book has been published that provides an honest history of the field of LENRs and accurate high-level description of the Widom-Larsen theory:

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

As of today, Lattice has an online collection totaling 175 public presentations and documents uploaded to SlideShare; most are in MS-PowerPoint format. Overwhelming majority of them concern LENRs and the Widom-Larsen theory; many can be freely downloaded as pdf files. Embedded URL hyperlinks in documents are live; see: https://www.slideshare.net/lewisglarsen