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SURVEY

Survey of the Observed Excess Energy and Emissions in Lattice Assisted Nuclear Reactions

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Abstract—Lattice assisted nuclear reactions (LANR) are real, and offer a clean, efficient potential new source of energy production. Two decades of LANR R&D have confirmed excess heat production, and other clearly nuclear phenomena, using electrolysis and other gas loading techniques. Requirements for success include incubation time, high loading of $>90\%$ PdD_x, and other requisite conditions difficult to achieve. Several types of LANR now exist, as well as LANR metamaterials, and several types of triggering and control methods. In LANR, excess heat and helium-4 are the usual products, but charged particles, tritium, and the sequelae of neutrons can be sometimes detected. Excess power gains up to 200–400%+ have been reported. Given the prevalence of the fuel, and the incredible efficiency, LANR could be an important revolutionary technology.

Keywords: palladium—excess heat—lattice assisted nuclear reactions—deuterium—deuterons—loading—flux—excess power gain—optimal operating point

1. Background: Brief Survey of Lattice Assisted Nuclear Reactions (LANR)

LANR [1–44] enable deuterium fusion. They are incredibly clean and free of pollution, all toxic emissions, all carbon footprints, all greenhouse gases, and radioactivity, while obviating fossil fuel. The deuterium is plentiful in the oceans. But the problem with this new technology is that the first published LANR reaction involved the 1989 Pons-Fleischman (Drs. Martin Fleischmann [Southampton, UK] and Stanley Pons [Utah]; P-F) experiment which was called "cold fusion" [1, 2]. Before that, the term was originally introduced by Benjamin Franklin for fulgurites, created by atmospheric lightning discharging into sand. Rather than agglomerating sand, LANR's core is quite different, involving a metal, like palladium, loaded fully with heavy hydrogen [45–51], obtained either from deuterons from heavy water or gaseous deuterium.

Cold fusion was widely, but not deeply, investigated in March 1989. P-F announced that the "electrochemical experiments" they had conducted had produced more energy ("excess energy") than could be accounted for, either by input energy or by available chemical reactions. They speculated that nuclear reactions were involved. Attention was directed to cold fusion which savaged its messengers for global sensation and to benefit special interests. Was there a substantive basis for this attack? Fusion had not been explored, and was not known to occur, at low temperatures or in solids in a lattice. High energy theoretical physics never involved a lattice in the nuclear calculations. And yet, in favor of LANR, this was not the first time a lattice was involved with coupling to nuclear effects. Mossbauer effects [52–54] preceded cold fusion, as did other physics and engineering calculations which would eventually prove cold fusion is consistent with physics. Although the Mossbauer effect involves nuclear decay, it also shows a coherent momentum coupling to the lattice as a whole. The relevance to LANR is not the nuclear decay versus nuclear fusion, but the fact that the Mossbauer effect actually heralds one real existing case of nuclear lattice coupling. It is an example of a coherent linkage between the nuclei and electronic s-orbitals bathing them, coupling them to the entire solid state lattice. It demonstrates that the lattice is important in this branch of nuclear physics and must be considered, even if it was not previously.

In 1989, most efforts failed because of flawed paradigms, cracked inactive palladium cathodes, contamination (including from ordinary water), and most often, improper cell configurations, inadequate or questionable loadings, and incubation times. The patterns of failure have been many and have been discussed in detail elsewhere [1, 38], although in 1989 the physics community did not believe the initial P-F experiments since fusion was not known to occur at low temperatures or in solids. Today, the experimental facts rule. The initial failures, some which took years to understand, involved bad paradigms, questionable materials and loadings, but that is now resolved. Particle emission, excess energy, power gain, commensurate linked helium-4 production, increasing power gains and total energies achieved since 1989, all pave the way to an important, new, clean form of energy production: LANR.

Two decades of R&D, *sub rosa*, have investigated LANR phenomena ranging from excess heat production (far above the input), very low level but measurable emissions, thin films, and coupling to motors and electricity production systems. A few hundred credentialed scientists with diverse backgrounds continued to conduct careful experiments as they performed detailed data analyses using improved instrumentation, equipment, calibration, and controls. No single error or combination of errors on the part of all of the scientists can explain the developing results. They have been reported in over 3000 papers [55]. This paper will review a small, but worthwhile, fraction of the worldwide experimental work which saliently provides much compelling evidence that nuclear reactions can be assisted by a metallic lattice, PdD_x.

As will be discussed in Section 8, LANR (cold fusion) is consistent with conventional physics. The LANR-derived “excess energy” begins at high energy, in the excited state of helium, which is obtained from reactions between deuterons within the lattice. That helium-4 excited state is either the first excited state, or one energetically located above it, all at least 20 million electron volts (20 to $\sim 23^+$ MeV) above the ground level. This is significant in magnitude and clearly

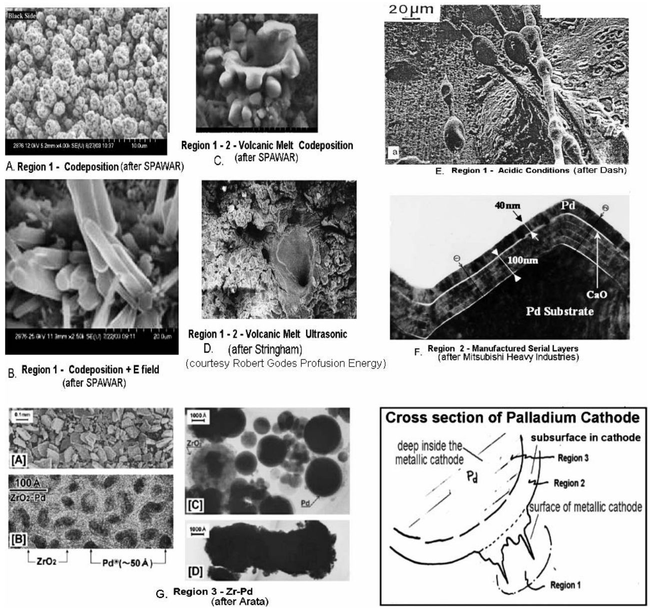

Fig. 1. Diversity of palladium LANR sites and nanostructures.

not "low energy", as often (mis)claimed. As such purported "low energy nuclear reactions (LENR)" are a misnomer, a paradoxical description of what is actually not observed. Furthermore, if these are low energy reactions, why even bother? Fortunately, they are high energy reactions.

Today, LANR research involves electrolytic (with solution resistance ranging from conventional to "high impedance" devices in the range of 200,000 ohms), gas loading, gas permeation, ion beam, and glow discharge loading techniques and devices. They run in both open and closed systems, at pressures up to 10,000 psi, and driving motors, with on-line monitoring, redundant, high precision, time-resolved semiquantitative calorimetry.

What has been learned? That LANR is real and generated in one of three different sites within the solid state, deuteron-loaded, metallic palladium lattice [42] (Figure 1). Each location has its own, differing, rate of excess heat, tritium, and helium production and appears to be linked to a different group of optimal operating point (OOP) manifolds characterizing active LANR samples and devices [39–44].

The fuel for LANR is the deuteron. It is driven into the metal by the applied electric field intensity or by gas pressure applied. In most cases, the product is an extraordinary amount of heat. Commensurate with the amount of excess heat is the "ash", usually *de novo* helium-4. The important point is that from those high energy levels of He^{4*} made in LANR come the observed excess energies in those difficult-to-achieve loaded lattice conditions, under some conditions.

These reactions are complex, and under some conditions, tritium and other emissions result. Some of the variety of regions involved both within, and upon, the metallic lattice is shown in Figure 1 [42]. Like hot fusion, the keys are containment, time, and density, but with flux substituted for temperature [1, 37, 43, 44, 56, for example]. This first key for LANR is that the PdDx alloy must be driven, usually electrically, to extremely high loading, until it is filled and almost bursting like a sponge with water. The electrode must accept and maintain high loading for excess heat ($>90\%$), for a sufficient incubation time, up to several hundred hours. Why? Vacancies must drift into the bulk from the surface, slightly facilitated by the loading itself [7, 56–58].

The additional keys for LANR are that there must be integrity of the loaded alloy; a condition difficult to achieve, although it is circumvented to some degree by the codeposition methods, albeit with their limitations [5, 7]. As the lattice loads, it swells. Too much swelling yields irreversible failure, just like a swollen, burst balloon. Another requirement is that deuteron flux must continue, within and through the already highly loaded lattice.

LANR success is rewarded by "excess heat", which means that the energy producing reactions have generated *de novo* helium into the lattice ($\sim 10^{12}$ for every watt-second), and those conditions were adequate to enable energy transfer to the lattice. LANR success also means that significant energy (think, $E = mc^2$ from the tiny difference between D_2 and He^4) is released rather than the low energy released by "burning" the deuterons into heavy water. There is more heat released than if the entire cathode were substituted for an equivalent quantity of TNT, but in this case it is safe, clean, and efficient.

2. Varieties of LANR

The LANR method which P-F first taught in March 1989 had problems, including inefficient reproducibility, and a requirement for very high loading with long incubation time. This created havoc for those inexperienced in metallurgy, electrochemistry, and physics. Today, briefly, there are several types of LANR; conventional (F-P), two types of codeposition (JET Energy, SPAWAR), dual cathode (Arata) systems, and a variety of other loading systems.

On one hand, development for high power has led to today's high electrical solution resistivity LANR systems (very low levels of electrolysis yield superior excess heat levels pioneered by JET Energy) and then LANR metamaterials (JET Energy [59]). Metamaterials use shapes engineered to control deuteron flux, even at equilibrium, and even after loading, such as shown in Figure 2. The Phusor® spiral cathode system, with its open helical cylindrical geometry, in a high electrical resistance solution, creates a unique and unusual electric field distribution [59]. There is an anomalous effect in those portions of the cathode closest to the anode. This results in both deuteron loading flux from the solution to the electrode, and intra-palladium deuteron flux [59].

This configuration is a new kind of $Pd/D_2O/Pt$ and $Pd/D_2O/Au$ engineered LANR structure with impressive energy gain and fairly good reproducibility [4, 7,

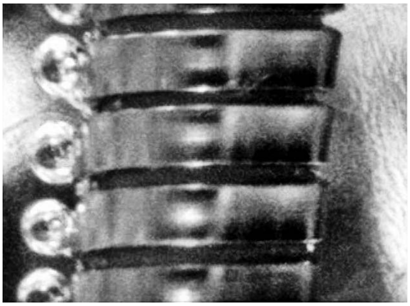

Fig. 2. Phusor LANR cathode in high electrical resistance solution. (Left) 2-D vector E-field distribution for two parallel, infinitely long, wire electrodes (anode at the top, and cathode wire). (Middle) 2-D vector E-field distribution for the wire-PHUSOR®-type LANR system. (Right) Close-up of cathode showing asymmetric bubbling. This heralds flux through the loaded metal, which differs from how others approach the problem.

10, 60]. These contain low paramagnetic content heavy water creating a unique, distinguishing electric field distribution quite different from customary wire-wire and plate-plate systems. LANR metamaterials, and high loading systems (included those explored by IENA, Energetics) and metallurgically engineered electrodes (NRL, SPAWAR, JET Energy), all point the way to high output powers and efficiencies.

On the other hand, codeposition LANR systems point the way to speedy onset for some of the reactions. Codeposition yields faster results without the prolonged incubation times. In codeposition systems, fresh Pd and D plate out together on the cathode. Highly expanded surfaces, nanoscale spherical nodules dominate on the growing surface. Cyclic voltammetry and galvanostatic pulsing experiments indicate, and excess heat measurements herald, that a high degree of deuterium loading (with an atomic ratio $D/Pd > 1$) is obtained within seconds. The results to date indicate nuclear reactions which occur very near the surface of the electrode (within a few atomic layers). In the original JET Energy Pd/D codeposition process, working and counter electrodes are immersed in a solution of palladium solution with neither chloride nor lithium, deposited on palladium. In the SPAWAR Pd/D codeposition process, working and counter electrodes are immersed in a solution of palladium chloride and lithium chloride in deuterated water, deposited onto silver, gold, or copper. There are physical differences in the two types involving deep diffusion [5], where Pd is deposited either on palladium (like Dr. Swartz) or upon non-loading materials such as copper, gold, silver, or platinum (like SPAWAR).

SPAWAR and JET have investigated the physical changes, the excess heat generation, hot spots with calibration showing near- and far-infrared (IR) emission (Figure 3). JET Energy's and SPAWAR's (near- and medical IR imaging) have revealed that in LANR there are cathodic hot spots, and not just Joule heating in the solution (IR drop). The desired reactions producing excess energy

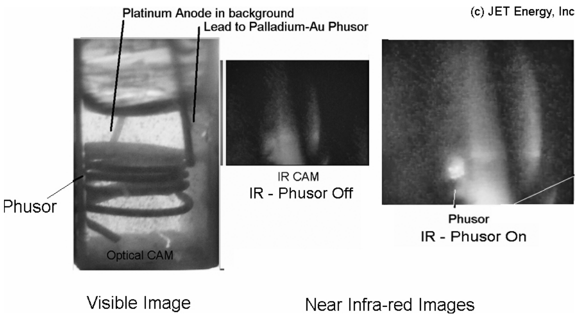

Fig. 3. Visible and near-IR images of a DAP Phusor® type LANR device in heavy water before and after activation.

yield localized hot spots (Szpak). The calibrated imaging of these localized hot spots, using an IR camera, reveal non-thermal near-IR emissions correlated with excess heat (Swartz) in active LANR devices by in situ monitoring [11] (Figure 3). This discovered non-thermal IR is linked, and specific, to the presence of excess heat production and not their physical temperature. This confirms the Swartz-Verner hypothesis that in LANR, unlike hot fusion, bremsstrahlung emission, under increasingly lower temperatures, shifts from penetrating ionizing radiation toward skin-depth-locked infrared radiation [61].

3. The Products of LANR

In LANR, excess heat and helium are the usual products, but charged particles, tritium, and the sequelae of neutrons can be sometimes detected. Excess heat and helium production are the dominant reactions. Melvin Miles of China Lake with Johnson-Matthey Pd rods was the first to show the correlation of heat and helium-4 production. Arata and Zhang reported *de novo* He^4 with LANR, including with Zr_2O_4/Pd powder exposed to deuterium gas, but not with hydrogen gas. Les Case ([28]; NH), using LANR with platinum group metals on carbon catalysts, reported He^4 production from deuterium gas. As a result of these findings, but ignoring the impact of the lattice for the moment, the reaction is something like

$$D + D \rightarrow He^4 + \sim 22 \text{ MeV (lattice)}$$

Energy and momentum are conserved in LANR [49, 62, 63], and because of the unique relationship to the lattice, the helium generated is moving slowly, at low velocity, very unlike hot fusion (discussed below). The He^4 which appears is retained in the cathode, until very high temperatures (~850C). The peak energy is consistent with the relatively low energy, but penetrating, ionizing radiation. Miles (China Lake, USN) and M. Srinivasan (Bhabha Atomic Research Center [BARC]) independently used dental x-ray films on the outside of this apparatus; they became fogged indicating low energy x-ray production.

In rare conditions, tritium production has been seen. In India, M. Srinivasan from BARC reported tritium in 1989. John Bockris (Texas A&M) reported tritium in bursts but the tritium was not accompanied by measurable heat, which he measured in other experiments. Szpak (SPAWAR) in open cells reported 3000 to 7000 atoms per second for a 24 hour period. Ed Storms (LANL) reported excess tritium in 10% of his cells.

Some experiments have detected very low number neutrons and charged particles with short range. M. Srinivasan (BARC) reported neutrons in 1989. As the current increased beyond 100 amperes, neutron signals, in bursts, resulted in 6 of 11 cells. X. Z. Li (Tsinghua U) first used CR-39 in his 1990 Pd gas loading experiments to detect energetic charged particles [64]. CR-39 is a polyallydiglycol carbonate polymer, widely used as a time-integrating, solid state, nuclear track detector. Larry Forsley (JWK International) and Mosier-Boss (SPAWAR) have reported D-D and D-T possible reaction pathways capable of generating the observed charged particles, neutrons, etc. Their CR-39 tracks indicate possible neutron interactions, including carbon shattering. Some tracks herald D-D and DT reactions. Etching suggests uniformity in the 2–8 MeV range. The triple tracks, found in ~5–10 of their experiments, indicate energetic neutrons having shattered a carbon atom. Also observed in LANR systems are post LANR mini-explosions, ionizing radiation, and neutron production, and tritium production. These observations of significant quantities of high energy charged particles, and emissions, in LANR systems, suggests that there is accumulating, near overwhelming, evidence that nuclear reactions in, and assisted by a lattice, are initiated at low energies.

4. Megajoules of Excess Energy

P-F reported excess energies of 4 megajoules in 80 hours. Similar amounts are seen in Figures 4 and 5. Several LANR devices show excess power gains from 25% to several times input electrical power, beyond the controls. High impedance LANR devices have shown power gains 200% to 400%, and one has yielded 8000% power gain for a short time. JET Energy has shown that some electrodes, of specific shape, are metamaterials which produces excess heat of a superlative magnitude, successfully driving Stirling engines at the 1–19+ watt level [3, 4, 6, 7, 39–41]. In 2003, JET demonstrated a working LANR high impedance PHUSOR-type LANR systems for 5 days at MIT at ICCF-10, producing ~230% excess energy at the 1–2 watt level.

Representative time histories (Figures 2 and 3) show both input and output electrical powers and energies. The input electrical power was switched manually between the LANR device and the resistor ("Control"). Integrated total energy for electrical input (solid red line) and thermal output (dashed blue line) are shown. The data marked by "PHUSOR" heralds electrical power supplied to it. The input electrical power is taken as V ∗ I, so the excess heat measured was a lower limit to what occurred. An excess heat is induced at low power with a gain near 200%, after which the system is taken to higher input power, where the

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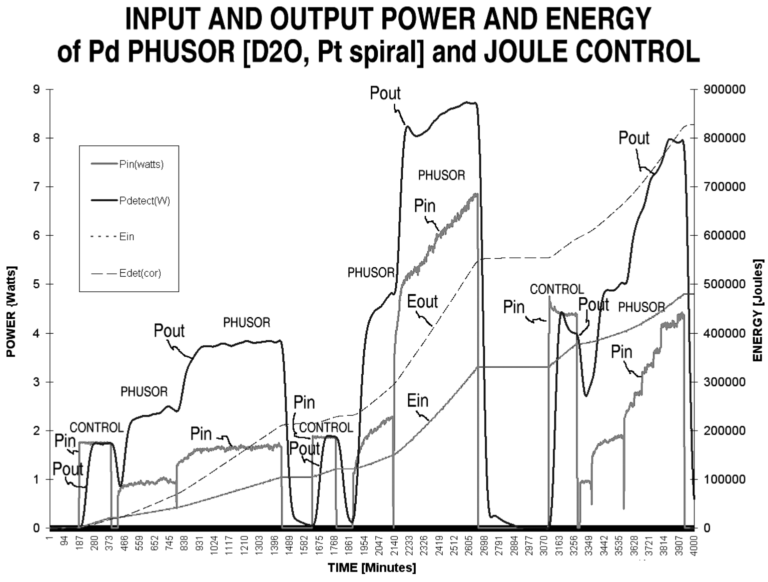

Fig. 4. Input electrical power (solid red line) and output thermal power (solid blue line) of a single ohmic calorimeter as a function of time.

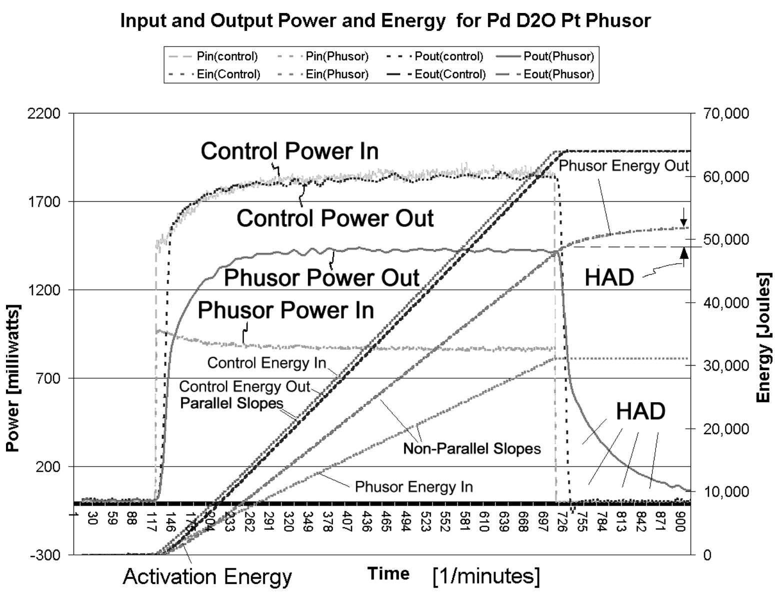

Fig. 5. Input electrical power (solid red line) and output thermal power (solid blue line) as a function of time for a Dual Ohmic Control (DOC) Calorimeter showing and activation energy, power gain, excess heat, and "heat after death" (HAD) which occurs after the termination of input electrical power.

power gain is lower, near 130%, followed by another calibration pulse. After this, the cell produces excess heat under varying conditions. The total input energy over 4000 minutes is illustrated by the solid red line, giving a result near 480 kJ. The total output energy over 4000 minutes is illustrated with the dashed blue line, giving a result of about 820 kJ. One observes in this run an energy gain of 1.7.

It can be seen in Figure 3 that the observed output power is much greater for the deuteron-loaded system as compared to the joule control and thus, there is excess heat. Two additional curves, the result of time-integration, on Figure 3 support the excess heat of the deuterium-loaded palladium system compared to the control. Figure 3 also has the integrated energy curves. It can be seen that for the ohmic joule (thermal) control the integrated energies of the input and output arise in parallel. By contrast, in the deuterium-loaded heavy water systems, there is an expanding gap which is not parallel but which increases over time, corroborating that there has been excess heat generated; more than 50,000 joules compared to the control.

The most important point is that even if one were to replace the entire cathode with TNT, one would only get 1.2 kilojoules on explosion. The excess energy observed with LANR is greater than any known chemical reaction. The second most important point is that the excess energy brings heat and changes wrought upon the electrode. SPAWAR, JWK, Stringham, Dash and others have reported volcano looking pits in electrodes. These induced pits are important for two reasons.

First, these features require a lot of local heat to produce the focal melting of the Pd, require substantial energy expenditure in order to form, again consistent with a nuclear source, not chemical. Second, SPAWAR [12, 20, 22, 23], Mitsubishi Industries (Japan) [37], George Miley (U of Illinois) [65], and others have shown elements appearing only at these unusual sites, which are consistent with nuclear, possibly even fission, products, some of which could not be extracted from cell components.

The heat diffuses away from the cathode, the site of LANR activity. Szpak, Mosier-Boss and Frank (SPAWAR) have shown that the temperature of the cathode is greater than the solution for codeposition. Swartz has shown how the temperatures change between anode and cathode as the OOP is reached. Modern calorimetry systems routinely employ calibration including thermal ohmic, metallic controls, and thermal waveform reconstruction. JET Energy measures the background noise, displaying it in "thermal power spectrograms" showing both input and output power, and energy by time-integration (Figures 4 and 5). These are supplemented calorimetry with up to five corroboratory measurements including heat flow measurements, electricity production, and paired, LANR-coupled Stirling motors.

5. Triggering LANR

There are two ways to control LANR—triggering and maintaining one OOP. Successful LANR requires critical control of input power, the OOPs of the driven

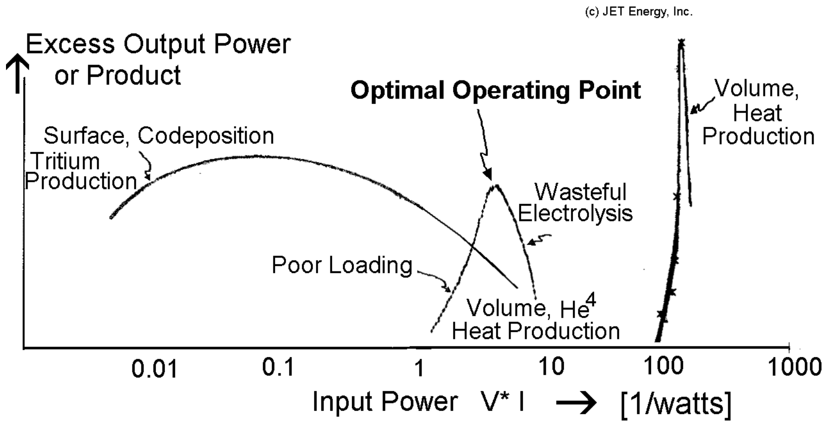

Fig. 6. Three LANR OOP manifolds.

systems, loading (> 85–90%), and loading flux. Worse, the driving and loading fluxes needed for the reactions have a side effect. They can easily destroy a Pd specimen making it never work again. This occurs because there are complex metallurgical problems which involve swelling grain size and changing orientations, occurring at increased loadings, deforming the lattice. More than 1 gigapascal pressure produces stress, strain, cracks, deloading, and the usual "fatal" cracking.

JET Energy has examined the impact of laser irradiation on LANR cathodes, and reported in 2003 that part of the impact is due to reflection off of the cathode back into the double layer. There, deuteron injection into the palladium increases (activation energy of ~14 kilocalories per mole) from microwave rotation and IR vibration for the intermolecular transfer of deuterons to the Pd [10]. Hagelstein, Letts, and Cravens [29, 66] have reported both single and dual photon impacts on cathodes.

The important point is that several types of experiments have revealed that input energy levels of less than 10eV (involving the applied electric field, with or without additional visible light irradiation) can successfully stimulate production of excess heat of megajoules and, on occasion, stimulate nuclear by-products, including neutrons which have been detected at energies exceeding 12 MeV [23].

6. OOP LANR Operation

JET Energy reported that anomalous energy gain in metal deuterides became a more reproducible phenomenon as system operation was guided using continuum electromechanics. It revealed that there are narrow regions of optimal excess power generation, and peak helium-4 or tritium production, each when viewed as a function along the electrical input power axis (Figure 6). In Figure 6, the three

OOP manifolds show LANR systems response for excess power gain, *de novo* helium and tritium production, for several LANR systems, including codeposition and palladium-black nanomaterials. The peak of each of these relatively narrow biphasic functions is the OOP. The OOP peak is only one operating point at which the LANR system can be driven. The other possible operating points at which the system can be driven are not "optimal", but are within the OOP manifold.

OOPs are complex, often more than one, and they can change shape and size over time. During situations in which excess power is generated from an active LANR sample or device, large changes in LANR output, such as excess power gain, are observed as the input power is varied over a relatively small range. Over the years, the OOP approach to LANR has been quite successful (JET Energy [38–41]; JWK [67]; Innoventek [68]). The development of OOP technology has been one of our most useful assets in this research. Most importantly, OOP operation allows control and better understanding of LANR systems. For example, there are the corresponding matched peaks for heat production and helium production in the Pd-D2O system, in an entirely different regime for tritium production and Pd nanomaterials.

Second, OOP behavior is a general property of most, if not all, LANR systems. OOP manifolds appear to be universal, describing a large group of LANR systems and their generated excess heat, incremental helium-4, and tritium production. OOPs characterize output for heavy water helium production, for excess heat production from general LANR systems and devices, for high impedance LANR devices, for codeposition systems and codeposition PHUSOR LANR devices, for tritium generated from codeposition and "P-F"–type heavy water systems, and for excess heat and helium production in palladium-black systems (Figure 6).

Peak LANR performance occurs with production of heat and He^4, or tritium, at their two OOPs which exist at two different locations in electrical input power space. As a result, OOPs explain a vast set of experimental data, not otherwise explicable.

Third, when the data is thus organized, it formidably dispels any arguments that LANR research is not reproducible. Fourth, OOP operation enables researchers to "standardize" samples and devices, which has led to several discoveries, including those which only occur when the LANR sample or device is driven at the OOP (including maximizing and controlling "heat after death", the response to incident coherent optical radiation, and non-thermal near-IR emission).

7. Transmutations from LANR

The production of helium-4 *de novo*, making the excess heat, when a LANR device is driven at its OOP is a transmutation. Other transmutations do not produce heat, such as when tritium is produced. Iwamura (Japan, Mitsubishi Industries) reports transmutation by deuterium gas permeating through palladium which has barriers of cesium and calcium oxide. The cesium content drops, and praseodymium appears (also strontium to molybdenum). George Miley (U of

Illinois), John Dash (Portland State), Takahashi (Osaka U), Karabut (Russia), DeNinno (ENEA Rome), Claytor (LANL), Arata and Zhang (Osaka), and Stringham (HI) have all reported shifts in isotopic ratios, although most have not semiquantitatively corrected for electrophoretic mobility (ie electrodeposition).

8. Theories Involving Portions of LANR

It cannot be true that only one single "theory" will fit all the solid state, nuclear physics, and requisite electrical engineering. They involve a complex non-linear, time-variant system including an overloaded metal lattice, stirring with flux, and electrical currents involving both electrons and deuterons and their holes. In time, also formed are low dielectric constant layers appearing spontaneously in electrical series (bubbles). There are second order applied fields. This is in addition to the electric fields, magnetic fields, and electromagnetic fields including optical, terahertz, and other irradiations, which LANR experimentalists use, which result from the drifting electrons, deuterons, and their holes. The bottom line is that no one theory can ever cover it all. Instead, there are several, and they fit conventional physics quite well [31, 44, 56, 58, 62, 63, 69–74].

The quasi-one-dimensional (Q1D [39–44]) model of loading, based on continuum electromechanics, has led to the discoveries of OOPs and the key roles of D-flux, solution conductivity, and cathodic irradiation by laser in LANR systems. Recently, coupling this with Laplace's law has uncovered the need for deuteron flux within the palladium in an already highly loaded (D/Pd) LANR system. The Q1D models most important insight is that the first order D-flux equation, with the substitution of the Einstein relation, shows that the ability to load D depends on the ratio of ordering energy (the applied electric field) to thermal disorder ($k_B * T$) minus what goes up into the gas. The latter is perhaps most important because it reveals why so many have failed to generate successful LANR, because the name "fusion by electrolysis" is a misnomer.

How is fusion achieved? Are there "expected products"? In hot fusion without a lattice, the kinetic energy of 23.8 MeV charged particles (alphas) yields ionizations, Pd knock-off atoms, low energy X-rays, and heat. Secondary neutrons (by D[α,n]) have a small cross-section. Most physicists are more aware of the ionization and X-ray production of D + D impact physics without a lattice. In this hotter fusion, the products are fast moving helium (23.8 MeV α-particles) which yields 22 keV Pd K shell X-rays and bremsstrahlung below ~4 keV. Conventional bremsstrahlung is ionizing penetrating radiation well-associated with hot fusion. In D + D impact physics without a lattice, neutrons and charged particles (fast moving helium ions, α particles) are seen.

In summary, in hot fusion, the production ratios are about 50% neutrons with He^3, 50% tritium and a proton, and a tiny fraction (less than 1/1,000,000) as nuclear gamma rays. By incredible contrast, the production ratios observed for LANR reactions is mainly He^4, and negligible He^3, neutrons, and gammas of very low energies. Why is it different from hot fusion?

Historically, since1989, cold fusion was ignored, along with the scientific facts, generally speaking. The basic truth is that the temperature of cold fusion, lattice, and the nuclear isospin control which products are observed. The physics in LANR appears conventional, but band energies, lattice and isospin issues, and temperature dependences must be addressed. First, not all emission branches from the excited state of He^{4*} are even spin-available. The gamma emission branch from the excited state of He^{4*} is actually spin-forbidden for both hot and cold fusion [62, 63]. However, at higher hot fusion temperatures the restriction is lifted slightly. This is consistent to what is seen for both hot and cold fusion.

Second, the relative absence of neutron and hard gamma-ray penetrating radiation in cold fusion appears to be due to the lack of availability for two different, but thermally linked, reasons. The first thermally linked reason is that the only nuclear branches available are those whose band gaps are surmountable by the available activation energy (limited by the ambient temperature and incident radiation). The neutron emission branch is more than 1 MeV above the first excited state (He^{4*}). Hot fusion has large activation energies available (it is "hot"), whereas LANR (cold fusion) does not. In LANR, given the actual much smaller amount of thermal energy, $k_B * T$, available for cold fusion (~1/25 eV), absence of adequate activation energy decisively means that that branch is NOT available, as it is for hot fusion. Neutrons are not observed, helium production is in its stead.

The second thermally linked reason is that in the analysis for LANR, with the explicit incorporation of temperature into the bremsstrahlung equations, reveals that ionizing penetrating radiation by bremsstrahlung is not expected at low temperature. The bremsstrahlung shift (secondary to temperature and lattice availability) alters from what is expected at room temperature with the forward deposition of energy dropping by 18 orders of magnitude. Instead, at cold fusion temperatures, the penetrating ionizing radiation shifts to lower frequencies (to the near-IR) where the radiation is not longer ionizing, and where it is trapped in the palladium by the "skin-depth" effect. In fact, this shift to near-IR was later observed (and reported) in LANR devices when they were operated at their OOP. The result is non-thermal near-IR emission [11].

It is the lattice which is key to the final products. It controls the de-excitations to produce He^4 in the ground state if there is coupling to though phonons. In hot fusion, the lattice—and therefore the coupling—are not there. In LANR/cold fusion, the fast moving He^4 (as charged particles, alphas) are not seen because the phonons, each about 35–43 millieV, help the He^{4*} state shed ~20+ MeV to return to the He^4 ground state [7, 38, 57, 58, 71]. However, in a coherent lattice, there are enough phonons to enable transfer in the nanoseconds required. Hence the "excess heat". Ergo, it is the lattice that opens up the new pathway. The many-spin, spin boson model [58, 61] has led to discoveries of how exchange energy between oscillator quanta enables coherent energy exchange. One *sine qua non* is that there be enough phonons (lattice vibrations) [7, 38, 57, 58, 71, 75]. If they act coherently, and if there are enough Frenkel defects, then the lattice appears to be "oiled" enough for coherent energy transfer (this is from where the excess heat arises) from the very high energy nuclear state consisting of the nuclear helium excited state to the lattice [7, 58, 62, 70]. This unusual coupling in LANR, occurring from nuclear states to the lattice, is rare, requiring s-orbital interactions. It was first seen in momentum transfer to lattices (Mossbauer-type) experiments.

Other theories which improve nuclear state-lattice interactions are those involving Bose-Einstein condensates, poly neutrons clusters, and loosely coupled oscillators; each give a view to electron screening, an important physical factor in metals, astrophysics, and LANR. The catastrophic active media [56] theory models the unusual change in deuteron solubility that Pd demonstrates with temperature.

9. Advanced LANR Technology—Revolutionary Apps Just Around the Corner?

LANR could become the energy multiplier saving the planet. The energy density of LANR reactions is 10 million times that of gasoline. The fuel is heavy water, obtainable from the sea which is already one part in 6000 a heavy hydrogen. Given the prevalence of the fuel, and the incredible efficiency, LANR could play a critical role in all future technologies with potential revolutionary applications to all energy issues—robotics, transportation, electricity production, space travel. Larger LANR power devices will fit into a hybrid car and offer methods to power in vivo medical devices such as the artificial heart. JET Energy, Inc. has already reported on thermal and efficiency issues of the electrical feedback loop, and has connected the excess heat to Stirling engines.

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