Szpak, S., et al. *LENR Research Using Co-Deposition*. in *ICCF-14 International Conference on Condensed Matter Nuclear Science*. 2008. Washington, DC.

LENR Research using Co-Deposition

S. Szpak [1], P. A. Mosier-Boss [1], F. Gordon [1], J. Dea [1], M. Miles [2], J. Khim [3], L. Forsley [3]
[1] *SPAWAR Systems Center-Pacific, San Diego, CA 92152*
[2] *Dixie State College, St George, UT 84770*
[3] *J W K International, Annandale, VA.*

ABSTRACT

The Pd/D co-deposition process was developed by Stan Szpak at the Naval Laboratory in San Diego as an alternative means of initiating LENR. Besides heat, other nuclear products that have been measured using Pd/D co-deposition include tritium and the emission of γ- and X-rays, neutrons, and energetic particles. This communication summarizes 19 years of LENR research that has focused on the Pd/D co-deposition process.

In March 1989, two chemists in Utah, Fleischmann and Pons, announced that they had performed electrochemical experiments that produced more excess energy than could be accounted for by chemical reactions. Therefore they speculated that the source must involve nuclear reactions and the effect became known as "Cold Fusion." The claims of Fleischman and Pons caused a global sensation. Much of the uproar was due to the fact that their observations disagreed with the accepted theory of nuclear reactions. Within days scientists around the world had started work on duplications of the experiments. Many of these efforts failed. Reasons for the failures varied. Many researchers used palladium cathodes whose past histories were unknown. Others used improper cell configurations that precluded achieving the high D/Pd loadings necessary to initiate the effect. Still others did not realize that, with bulk electrodes, long incubation times were necessary to produce the effect. However, despite the large number of failures, there were other scientists who did observe anomalous behaviors that could not be explained. These other scientists continued to investigate the effect, which is now called Low Energy Nuclear Reactions (LENR).

Stan Szpak, an electrochemist at the Naval laboratory in San Diego, developed the Pd/D co-deposition process as a means of initiating LENR that greatly reduces the incubation time and gives reproducible results. In this process, working and counter electrodes are immersed in a solution of palladium chloride and lithium chloride in deuterated water. Working electrode substrates that have been used include Cu and Au foils and Ni mesh. Palladium is then electrochemically reduced onto the surface of the working electrode in the presence of evolving deuterium gas. SEM analysis of electrodes prepared by Pd/D co-deposition exhibit highly expanded surfaces consisting of small spherical nodules.[1,2] Cyclic voltammetry[2,3] and galvanostatic pulsing[4] experiments indicate that, by using the co-deposition technique, a high degree of deuterium loading (with an atomic ratio D/Pd>1) is obtained within seconds. These experiments also indicate the existence of a D_2^+ species within the Pd lattice. Because an ever expanding electrode surface is created, non-steady state conditions are assured, the cell geometry is simplified because there is no longer a need for a uniform current distribution on the cathode, and long charging times are eliminated.[5] Using a Dewar-type electrochemical cell/calorimeter, it

was shown that the rates of excess enthalpy generation using electrodes prepared by the Pd/D co-deposition technique were higher than that obtained when Pd bulk electrodes were used.[6] Positive feedback and heat-after-death effects were also observed with the Pd/D co-deposited electrodes. In one experiment that was done in the open air, boil off of the electrolyte occurred as well as melting of the Pd deposit, Figure 1a (Note Pd melts at 1554.9°C).[1] Infrared imaging of electrodes prepared by Pd/D co-deposition, Figures 1b and 1c, show that the working electrode is hotter than the solution indicating that the heat source is the Pd/D co-deposited electrode and not Joule heating. As shown in Figure 1b, the heat generation is not continuous, but occurs in discrete spots on the electrode. The steep temperature gradients of the hot spots, Figure 1c, indicate that the heat sources are of high intensity and located very close to the contact surface.

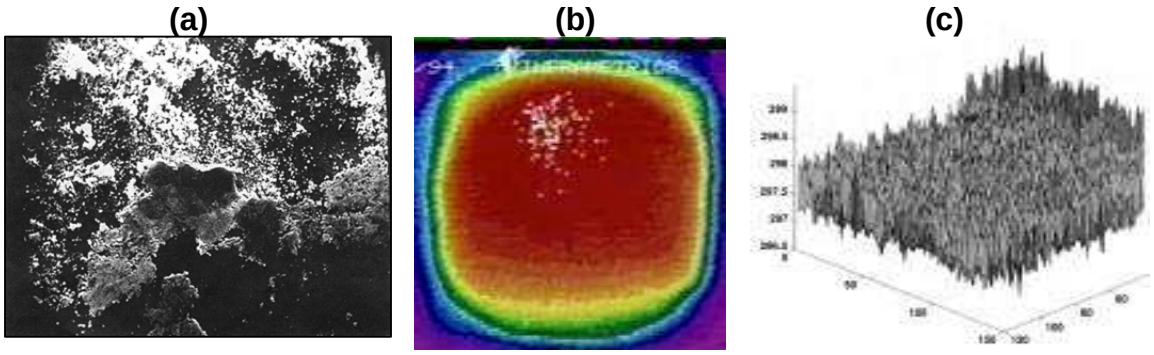


Figure 1. (a) SEM of the Pd film showing features consistent with Pd melting under water. Infrared images of the electrode surface prepared by Pd/D co-deposition. (b) View of the obverse side of the cathode showing the distribution of hot spots ranging from <29°C (purple) to >49°C (white). (c) Temperature gradients on the back side of the cathode.

The 'hot spots' observed in the infrared imaging experiments are suggestive of 'mini-explosions' (Figure 1b[7]). To verify this, the Ag electrode on a piezoelectric transducer was used as the substrate for the Pd/D co-deposition. If a mini-explosion occurred, the resulting shock wave would compress the crystal. The shock wave would be followed by a heat pulse that would cause the crystal to expand. In these experiments, sharp downward spikes followed by broader upward spikes were observed in the piezoelectric crystal response. The downward spikes were indicative of crystal compression while the broader upward spikes are attributed to the heat pulse and the consequent crystal expansion following the explosion.

After confirming the Pd/D co-deposition process produces heat, experiments were conducted to detect the resulting nuclear ash. Measurements of X-ray emission,[8] tritium production,[9] transmutation,[10] and particle emission[11,12] were explored. In early experiments, exposure of photographic film was observed that was indicative of the emission of soft X-rays.[5] Using Si(Li) X-ray and HPGe detectors, it was shown that the cathodically polarized Pd/D system emits X-rays with a broad energy distribution with the occasional emergence of recognizable peaks due to Pd K_α and Pt L peaks.[8] Furthermore, the emission of X-rays was sporadic and of limited duration. The evidence of tritium production was based on the difference between the computed and observed concentration of tritium in the liquid and gaseous phases. It was shown that the tritium production was sporadic and burst-like. During bursts, the average rate of tritium production ranged between 3000-7000 atoms sec^{-1} over a 24 hr period.[9]

Both the radiation emission and tritium production indicated that the reactions were nuclear in origin and occurred in the subsurface. To enhance these surface effects, experiments were conducted in the presence of either an external electric or magnetic field. SEM analysis showed that when a polarized Pd/D electrode was exposed to an external field, significant morphological changes were observed.[13] These changes ranged from minor, e.g. re-orientation and/or separation of weakly connected globules, through forms exhibiting fractal and molten-like features, Figures 2a and 2b respectively. It has been reported that the micro-volcano like features shown in Figure 2b are consistent with damage that has been observed in materials such as Californium which undergo spontaneous nuclear fission. EDX analysis of a blister-like such feature, Figure 2c, showed the presence of additional elements (Al, Mg, Ca, Si, and Zn) that could not be extracted from cell components and deposited on discrete sites. [10]

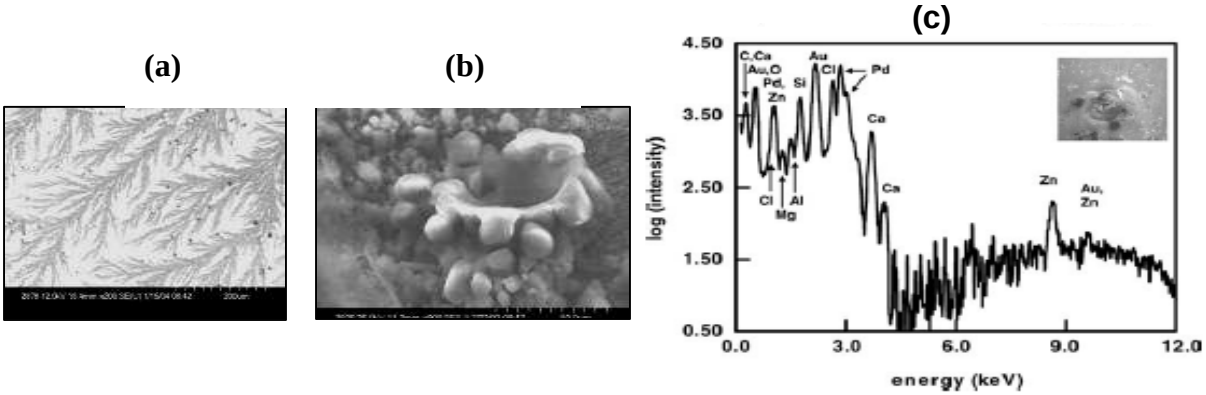
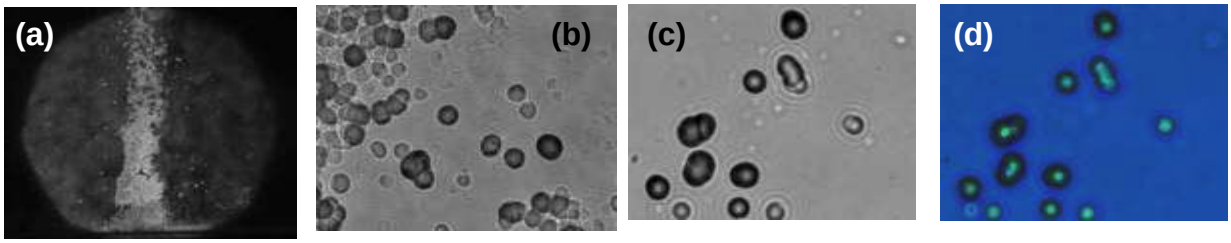


Figure 2. SEM of (a) fractal and (b) micro-volcano-like features formed when Pd/D co-deposition has been conducted in an external electric field. (c) EDX of blister-like (insert) structure formed after exposure of the Pd/D film to an electric field.

More recently, Pd/D co-deposition experiments have been conducted using "CR-39" polyallydiglycol carbonate polymers that have widely been used as a solid state nuclear track detectors.[14] These detectors have been used to detect energetic particles such as alphas, protons, deuterons, tritons and neutrons. CR-39 is the detector of choice in Inertial Confinement Fusion (ICF) as it is not affected by the electromagnetic pulse that disables electronic detectors. When traversing a plastic material such as CR-39, charged particles create along their ionization track a region that is more sensitive to chemical etching than the rest of the bulk. After treatment with an etching agent, tracks remain as holes or pits and their size and shape can be measured.

Pd/D co-deposition experiments were conducted using an Au wire, that was in direct contact with a CR-39 chip, as the substrate.[12] After the Pd was completely plated out, the cell was exposed to an external magnetic field. The experiment was terminated after two days and the CR-39 chip was etched using standard protocols. After etching, the chip was examined under a microscope. Figure 3a shows an image of the CR-39 detector, at 20X magnification. Damage to the detector is observed where the cathode was in contact with the surface of the detector. This indicates that the source of the damage is the palladium that had been plated on the Au wire. Figure 3b shows a higher magnification image taken near the edge of the cathode where there was less damage to the CR-39 detector. The image shows both small and large, dark pits as well as what look like double and triple pits. Figure 3c is an image of the CR-39 surface while Figure 3d is an overlay of two images taken at two different focal lengths (one focal length is at the

surface of the CR-39 detector and the other focal length is at the bottom of the pit). On the surface image, the pits are either circular or elliptical in shape and dark in color, Figure 3c. When focusing deeper into the CR-39 detector, bright points of light are observed in the center of the pits, Figure 3d. These bright points are due to the bottom tip of the conical track. The pits also exhibit a high optical contrast. The optical contrast, shape, and bright spot in the center of the pit are used to differentiate between real particle tracks (which tend to be dark) from false events



(which are often lighter in appearance and irregular in shape).

Figure 3. (a) 20X magnification of a cloudy area observed where the Au/Pd cathode was in contact with the CR-39 detector during an external magnetic field experiment. (b) 500X magnification taken near the edge of the Au/Pd cathode where less damage to the CR-39 detector is observed. 1000 X image of pits in CR-39 created during Pd/D co-deposition: (c) the focus is on the surface of the CR-39. (b) Overlay of two images taken at two different focal lengths (surface and the bottom of the pits).

The CR-39 detectors used in the Pd/D co-deposition experiments also show evidence of neutrons. A neutron generated during the Pd/D co-deposition has a probability of 10^{-5} of encountering a proton, carbon, or oxygen atom inside the plastic. Depending upon the energy of the neutron, it can elastically knock an atom out of place. Further etching of a CR-39 detector exposed to neutrons reveals "knock-on" tracks inside the CR-39. Figure 4a shows an image obtained for a CR-39 detector that had been used in a Pd/D co-deposition experiment after additional etchings. The large pit was first observed on the surface and was 10 μm in diameter. After longer etching, the pit on the surface gets larger in size (50 μm in diameter) and is shallower. However, on the left hand side of the large pit, a new elliptical track attributed to a knock-on is observed. Microscopic examination of the CR-39 detectors after a Pd/D co-deposition experiment also shows the presence of what appear to be triple tracks, Figures 4b and 4c. Microscopic examination of the bottom of the triple track pit shows that the three lobes of the track are splitting apart from a center point. The presence of three α-particle tracks outgoing from a single point is diagnostic of the $^{12}C(n,n')3\alpha$ carbon break up reaction and is easily differentiated from other neutron interactions occurring within the CR-39 detector.[15] In order to shatter a carbon atom into three α-particles, the energy of the neutron needs to be ≥9.6 MeV.

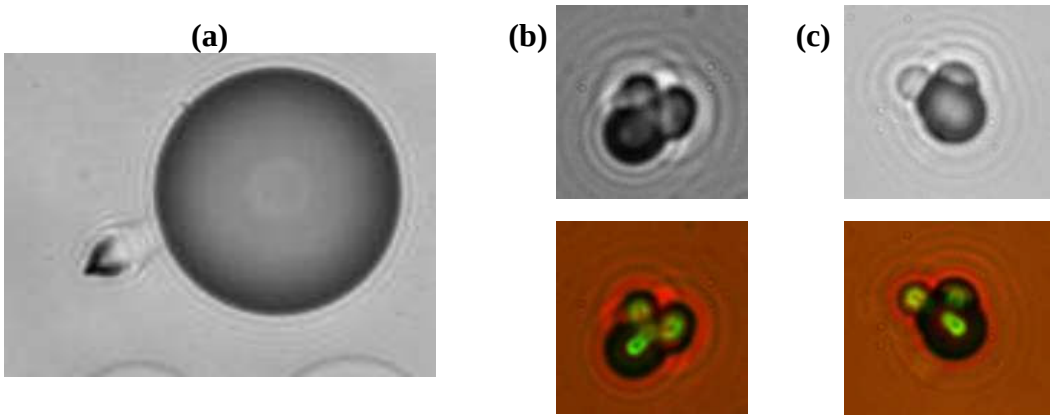


Figure 4. Images obtained at 1000X magnification. (a) Image of CR-39 detectors taken after longer etching times showing a track due to a knock-on. (b) and (c) Images of triple tracks. In the top images, the focus is on the surface of the CR-39 detector. Bottom images are an overlay of two images taken at two different focal lengths (top and bottom of pit).

In conclusion, the Pd/D co-deposition process, that was developed by Stan Szpak, has proven to be a versatile tool to explore LENR activities. Research efforts using Pd/D co-deposition are ongoing. Collaborations have been established with Energetics to explore coupling the Super-wave charging protocol to Pd/D co-deposition and with Dr. Mitchell Swartz of Jet Energy, Inc. to apply his optimum operational points (OOPs) analysis to the co-deposition process.

References

1. S. Szpak and P.A. Mosier-Boss, 'On the Behavior of the Cathodically Polarized Pd/D System: a Response to Vigier's Comments', *Phys. Letts. A*, Vol. **221**, pp. 141-143 (1996).
2. S. Szpak, P.A. Mosier-Boss, S.R. Scharber, and J.J. Smith, 'Charging of the Pd/^{n}H System: Role of the Interphase', *J. Electroanal. Chem.*, Vol**. 337**, pp. 147-163 (1992).
3. S. Szpak, P.A. Mosier-Boss, S.R. Scharber, and J.J. Smith, 'Cyclic Voltammetry of Pd+D Codeposition', *J. Electroanal. Chem*., Vol. **380**, pp. 1-6 (1995).
4. S. Szpak, P.A. Mosier-Boss, and J.J. Smith, 'Deuterium Uptake During Pd-D Codeposition', *J. Electroanal. Chem.*, Vol. **379**, pp. 121-127 (1994).
5. S. Szpak, P.A. Mosier-Boss, and J.J. Smith, 'On the Behavior of Pd Deposited in the Presence of Evolving Deuterium', *J. Electroanal. Chem*., Vol. **302**, pp. 255-260 (1991).
6. S. Szpak, P.A. Mosier-Boss, M.H. Miles, and M. Fleischmann, 'Thermal Behavior of Polarized Pd/D Electrodes Prepared by Co-Deposition', *Thermochim. Acta*, Vol. **410**, pp. 101-107 (2004).
7. P.A. Mosier-Boss and S. Szpak, 'The Pd/^{n}H System: Transport Processes and Development of Thermal Instabilities', *Il Nuovo Cimento*, Vol. **112A**, pp. 577-585 (1999).
8. S. Szpak, P.A. Mosier-Boss, and J.J. Smith, 'On the Behavior of the Cathodically Polarized Pd/D System: Search for Emanating Radiation', *Phys. Letts. A*, Vol. **210**, pp. 382-390 (1996).
9. S. Szpak, P.A. Mosier-Boss, R.D. Boss, and J.J. Smith, 'On the Behavior of the Pd/D System: Evidence for Tritium Production', *Fusion Technology*, Vol. **33**, pp. 38-51 (1998).
10. S. Szpak, P.A. Mosier-Boss, C. Young, and F.E. Gordon, 'Evidence of Nuclear Reactions in the Pd Lattice', *Naturwissenschaften*, Vol**. 92**, pp. 394-397 (2005).

11. S. Szpak, P.A. Mosier-Boss, and F.E. Gordon, 'Further Evidence of Nuclear Reactions in the Pd/D Lattice: Emission of Charged Particles', *Naturwissenschaften*, Vol. **94**, pp. 511-514 (2007).
12. P.A. Mosier-Boss, S. Szpak, F.E. Gordon, and L.P.G. Forsley, 'Use of CR-39 in Pd/D Co-Deposition Experiments', *European Physics Journal-Applied Physics*, Vol. **40**, pp. 293-303 (2007).
13. S. Szpak, P.A. Mosier-Boss, C. Young, and F.E. Gordon, 'The Effect of an External Field on Surface Morphology of Co-Deposited Pd/D Films', *J. Electroanal. Chem*., Vol. **580**, pp. 284-290 (2005).
14. F.H. Séguin, J.A. Frenje, C.K. Li, D.G. Hicks, S. Kurebayashi, J.R. Rygg, B.-E. Schwartz, R.D. Petrasso, S. Roberts, J.M. Soures, D.D. Meyerhofer, T.C. Sangster, J.P. Knauer, C. Sorce, V.Y. Glebov, C. Stoeckl, T.W. Phillips, R.J. Leeper, K. Fletcher, and S. Padalino, 'Spectrometry of Charged Particles from Inertial-Confinement-Fusion Plasmas', ***Rev. Sci. Instrum***., Vol. 74, pp. 975-995 (2003).
15. A.M. Abdel-Moneim and A. Abdel-Naby, 'A Study of Fast Neutron Beam Geometry and Energy Distribution Using Triple-α Reactions,' *Radiat. Meas*., Vol. **37,** pp. 15-19 (2003).