Summary of the 2010 Colloquium on Lattice-Assisted Nuclear Reactions at MIT

Scott Chubb and Thomas Dolan

An abbreviated version of this summary appears in Infinite Energy #93. (Photos courtesy of Cold Fusion Times.)

The 2010 Colloquium on Lattice-Assisted Nuclear Reactions (LANR) at MIT was held on July 18 in the Hermann Haus Room of the Electrical Engineering Department. Approximately 35 scientists and observers gathered to hear a number of presentations about cold fusion (CF) and related processes and effects. Dr. Mitchell Swartz (Chief Technology Officer of JET Energy, Inc., http://world.std.com/~mica/jet.html) hosted and organized the event. There were 14 presentations. These were given by Dr. Mitchell Swartz, Professor Peter Hagelstein (MIT), Dr. Brian Ahern and Dr. Scott Chubb. Dr. Swartz has organized CF Colloquia at MIT since 1991. The event was sponsored by JET Energy and the *Cold Fusion Times* (http://world.std.com/~mica/cft.html).

Colloquium Overview

Dr. Swartz opened the meeting by presenting an overview, "LANR for Clean, High-Efficiency Energy Production," in which he summarized some of the more important facts about CF and reasons that research is needed. He pointed out that there is a profound need for more efficient energy production, as a result of increasing energy demand. He illustrated this using a concrete example: energy consumption in the city of Boston. He estimated that in Boston alone, there is an average power demand of 6 gigawatts, which leads to daily energy consumption (5.2×10^{14} Joules) that requires the energy equivalent of 54,000 tons of coal. He emphasized that CF offers a potentially revolutionary, clean energy source that would dramatically reduce the consumption of fuel. In particular, the equivalent amount of energy that is consumed on a daily basis in Boston could be obtained from 6 pounds (three quarters of a gallon) of heavy water. Even more astonishing are the environmental implications. Each day, burning the amount of coal associated with consuming this energy would create 180,000 tons of CO_2, 3,600 tons of SO_2 and 480 tons of NO_2. In contrast, CF is "ultraclean": To produce the same amount of energy each day, CF would create 24 garbage size bags of an entirely pollution-free product, ordinary helium gas.

Dr. Swartz noted that, besides creating heat, CF-related processes are motivating scientists to develop new materials and devices. These kinds of processes can potentially alter the behavior of radioactive materials (including waste products from nuclear power plants). He also emphasized that although CF, historically, has been difficult to reproduce, key factors associated with loading, materials and contamination are now being understood.

It was requested that speakers focus on work and effects that are related to new materials and devices, including nanomaterials. Swartz stated that at JET Energy they are particularly interested in creating devices; they have developed a procedure for creating electricity (at a very low level) directly from a CF process (without using the excess heat to do this). In the remainder of this article, we summarize the talks that were presented at this conference.

Summary of Presentations

Dr. Swartz also gave the second talk, "Deuteron Flux and Optimal Operating Point Manifolds Control LANR." He emphasized the importance of understanding the role of deuteron flux, J_D, in cold fusion. J_D is the product of deuterium concentration, D, with its velocity. He wrote down a one-dimensional version of what he referred to as the "flux equation." This equation relates J_D to deuteron concentration gradient $\frac{\partial D}{\partial z}$, the variation of the applied voltage (Φ) with respect to changes in position (the electrostatic potential gradient) $\frac{\partial \Phi}{\partial z}$, the diffusion constant (B), and the electrophoretic mobility μ : $J_D = -B \frac{\partial D}{\partial z} - \mu_D D \frac{\partial \Phi}{\partial z}$.

In practice, a slightly modified equation (the first order deuterium flux rate—or flow rate—equation) is used to model the experiments. This equation is constructed by dividing J_D by the deuterium concentration D. This leads to $k_e = \mu_D E - (k_g + k_f)$, where E is the electric field, k_g represents the rate of loss from gas emission and k_f represents the rate of loss (which is miniscule) from fusion, and $k_e = \frac{J_D}{D}$ is the rate that deuterium is "lost" as it flows into the interior of the material.

Swartz emphasized that these equations are more general than the Nernst equation, which is frequently cited in the electrochemical literature, because they apply in situations that involve equilibrium as well as non-equilibrium conditions, while the Nernst equation only applies when the system is in equilibrium. The approach that he and his colleagues use is unique because they use very pure heavy water

and their electrolysis is carried out in a high impedance (high Z) solution.

He also emphasized that to create excess heat it is necessary to have sufficiently high loading (the value of x in PdD_x) and that this has to occur before additional flux of deuterium through the loaded material is introduced. In particular, he cited work by SRI (McKubre and Tanzella)[1] that shows that to achieve excess heat, values of x must be greater than 0.85.

Swartz discussed what he refers to as Optimal Operating Points (OOPs) and OOP manifolds. An OOP refers to the location of the maximum value of a particular parameter (output power, loading, or the amount of helium-4 or tritium that is produced) that is important in LANR phenomena, in a plot of the parameter as a function of input power. The OOP manifold refers to the locations of the values of one (or more) of these parameters when they are plotted (in a 2-dimensional plot) as a function of input power.

By construction, OOP manifolds provide important information about system response as input power is changed. Swartz pointed out that because of this fact, OOP manifolds are useful for developing procedures for reproducing excess heat. Near an OOP, the variations in excess heat and the amounts of ^{4}He that are produced can be directly correlated, which provides significant evidence that the heat is created through the d + d → ^{4}He reaction. Swartz discovered this using unpublished data provided by Melvin Miles. He found in plots of the amounts of ^{4}He that were produced as a function of input power and in comparable plots involving excess power, that both the excess power and the amounts of ^{4}He are maximized at the same values of the input power. (Using a different data set, involving tritium production, he found a similar correlation in which the maximum values of the excess power and the amounts of tritium that were produced both occurred when the input power had the same value.)

Swartz said that OOP manifolds can be used to compare the responses of heat-producing samples because, effectively, they provide a visual tool for aligning the response of each sample (as a function of electrical input power) at the same location in a situation in which the underlying input information induces changes in the internal structure (and the very complicated kinematical "phase space" associated with the available momentum and energy in LANR).

Swartz also pointed out that the value of the input power where the OOPs occur, and the magnitude of their height, both change as the age of the materials that are used changes. He speculated that a potential reason for this could be the result of vacancy migration. He suggested that a particular trend in which the curves associated with the OOP manifold appear to "grow" (*i.e.*, the peaks rise and broaden) and shift "to the right" (towards greater values of the input power) might be the result of an inward diffusion of vacancies that occurs as the age of the sample increases. In nanometer-scale materials, he has found that the OOPs occur over even higher values of the input power. He suggested that vacancies may be responsible for this fact.

In heat-producing experiments, at lower values of input power, Swartz said the reaction rates of the desired reactions vanish or are low (usually because the loading rate is inadequate). At higher values of input power (associated with the region located to the right of any of the OOP manifold peaks), the output power is reduced for several reasons. These include losses in output energy from a reduced number of reactions, a secondary effect associated with gas bubble formation and the combined effect of both sources of energy loss on the system.

In additional studies, Swartz has found that the values of the input power where OOPs occur have a range that varies from low power for tritium-producing experiments to higher (1-20 W) input electrical power in heat-producing experiments. He concluded with a number of qualitative remarks:

1) With increased input electrical power beyond the value of the power where the OOPs occur, increases in bubble formation occur. He showed a series of slides demonstrating the evolution of gas at specific locations leading to large accumulations of bubbles and decreases in excess power.
2) Bubble formation should be avoided since it competes with and reduces loading.
3) His most successful electrolytic experiments have involved "metamaterials" (which he discussed in a later talk). The experiments that produced excess heat most rapidly made use of a codeposition procedure (in which Pd and D are codeposited onto a substrate). He has conducted these experiments using a procedure that is similar to experiments that the SPAWAR group conducts. The difference between the two procedures involves the choice of substrate. In his experiments, the D and Pd are deposited onto a Pd substrate.In the SPAWAR experiments, a different substrate, (*e.g.*, Au) is used.
4) He pointed out that in his Dual Anode Phusor® (DAP) codeposition experiments, he found that as the (Pd) substrate thickness increases, the excess power increases.

Peter Hagelstein commented that the effects associated with the fact that the maximal values of excess power and ^{4}He production occurred with the same input power and the comparable correlation between input power and excess power and tritium production might also be related to observed differences in applied current density. He pointed out that in helium-4 producing experiments, applied current densities are on the order of 250 mA/cm^2, while they are significantly lower in cases involving tritium (70 mA/cm^2) and in cases involving neutrons (20 mA/cm^2).

Dr. Brian Ahern gave the third talk, "The Role of Anharmonic Oscillations in LANR." Ahern has been conducting gas-loading experiments based on Yoshiaki Arata's work. In December 2009, he started to use some of the samples (composite materials constructed from 3-12 nm size Pd powders and ZrO_2) that Yoshiaki Arata used to create excess heat. He has also been conducting similar gas-loading experiments involving $NiZrO_2$. To form these materials, a Zr_2Ni alloy ribbon is heated. This produces ZrO_2 with composite structures that contain PdNi nanoparticles, with 4% Pd, 65% Zr and 31%Ni. He said that the nano-particles can be visualized as being "like raisins in raisin bread" (the bread being the ZrO_2 that is used to embed the Pd-Ni structures). Ahern plans to apply a high voltage discharge (~30 kV) through the ceramic powder (discussed later in his second talk).

Ahern believes this form of discharge will create large amplitude oscillations at low, terahertz frequency and that these forms of oscillation play a fundamental role in creating excess heat. He cited early computational studies by

Fermi and Passar and Ulam that had been classified for many years, as a basis for his hypothesis. In particular, in these studies, when even a very small anharmonic perturbation (of the form k_2x^2) is added to the force F (= -kx) associated with a harmonic oscillator, a large effect involving energy localization is induced, in which the energy that is uniformly distributed between a large (countable) number of modes of oscillation, in the absence of the perturbation, becomes focused into a small number of modes. He showed a linked two-pendulum system that demonstrates this effect. Another example that he cited occurs when small metallic balls ("BBs") are placed on a vibrating plate. The anharmonic effect can create upward jets of BBs when energy localization occurs.

Ahern believes that energy localization evolves as a result of a feedback mechanism that enhances vibrational amplitudes in materials that have a characteristic dimension that varies between 3 and 12 nm. Arata uses materials that are 5-10 nm in size in his gas-loading experiments. He also mentioned that uncoated Pd particles tend to agglomerate into larger sizes and, for this reason, a coating (like ZrO_2) is needed. (Francesco Celani has pointed out that a ceramic coating involving ZrO_2 or other material in gas-loading experiments is necessary for preventing the materials from being destroyed during the loading process.)

Ahern also cited a theory (by retired MIT material scientist Keith Johnson) for explaining the anomalous isotope shift in the critical superconducting temperature T_c that occurs in PdD (where T_c = 11°K), relative to the situation in PdH (where T_c = 9°K), as an indication that anharmonic effects are at work in the PdD system, which he suggested are also related to CF. The anomaly is associated with the fact that in the Bardeen-Cooper-Schreiffer theory of superconductivity, the value of T_c should be lower when the isotope of a particular element possessing a higher mass is substituted for the initial element in a particular superconducting material. In Johnson's theory, the anharmonic effects that are present in both PdH and PdD create what is referred to as a "Jahn-Teller" effect and this effect is responsible for both CF and the anomaly in T_c.

Ahern also said he has been successful in creating excess heat six times in a row in gas-loading experiments involving the kinds of materials Arata used. He believes that increases in vacancies help to spawn the effect. He said that another factor might be important: diffusion (related to loading). He pointed out, in particular, that the diffusivity in the nanoparticle Pd powders is nine orders of magnitude greater than in larger Pd crystals. He concluded by pointing out he used PdNi alloys in order to save money.


Prof. Peter Hagelstein

Professor Peter Hagelstein gave the fourth talk, "Physical Chemistry of D_2 Formation Near Vacancies in PdD." He pointed out that in his theory, to account for d+d fusion reactions without high-energy particles, the formation of deuterium (D) molecules (D_2) (or a process that brings two D's closer together) is necessary. This fact has motivated him to investigate ways that this kind of effect might take place in PdD. He pointed out that we know from theoretical studies of molecular hydrogen[2] that a particular kind of molecular orbital (referred to as a symmetric orbital) leads to bonding (in which H-atoms are strongly attracted to each other), and a second kind of orbital (an antisymmetric orbital) leads to anti-bonding (in which H-atoms are weakly attracted to each other).

In these studies, anti-bonding orbitals become occupied as the electron density increases. To estimate the relevant electron density that is required for D_2 formation in Pd, he looked at a particular situation associated with a Pd-H_2 molecule, in which a molecule of H_2 bonds to a molecule of Pd in a molecular (as opposed to an atomic) form of hydrogen. He pointed out that the electron density resulting from the presence of Pd (in the regions where bonding occurs in this molecule) is ~0.03 electrons/Å^3, which is much lower than the lowest electron density (~0.08 electrons/Å^3) that is found in bulk PdD as a result of Pd being present. He suggested that this is the reason D_2 does not form in bulk PdD.

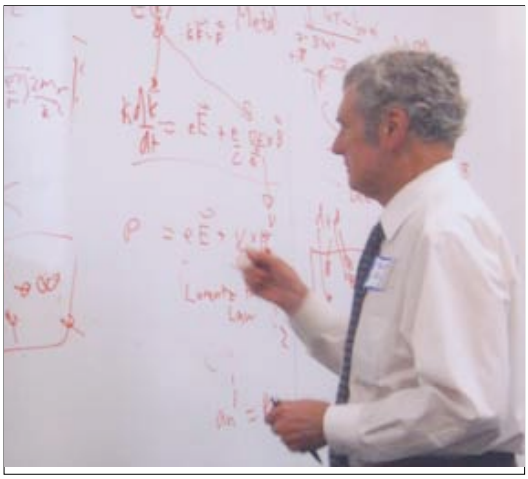
Hagelstein reasons, then, that for D_2 to form in PdD, it is necessary for the electron density to be lower, and he points out that in the vicinity of a Pd vacancy in PdD, the electron density is sufficiently low that it can provide an environment for a D_2 molecule to form. From simplified superposition models, he estimates that the appropriate electron density for this occurs at a distance ~1 Å from a mono-vacancy, in the direction of the nearest octahedral site. This hypothesis is consistent with information from a more sophisticated Density Functional Theory (DFT) calculation, performed by L. Dechiaro. This calculation shows an additional feature: A "cage effect" that allows the D_2 to stay together inside a region of higher electron density that has associated with it very strong binding. He said that since D_2 at high electron density becomes repulsive, this cage effect can be thought of as resembling a situation in which a husband and wife, who are not getting along, are confined within a small kitchen.

Hagelstein summarized:

- DFT calculations support the conclusion that "caged" D_2 forms near a mono-vacancy with a D-D equilibrium separation that is larger than for the case in which the D_2 is in free space because of the increased background electron density that occurs inside the solid.
- DFT calculations show a molecule forming near the Octahedral-site (the O-site), near a vacancy when the other O-sites are occupied, with a large (>1 eV) binding energy.
- Vacancies require ~1 eV to form in Pd and are stabilized by H or D loading.
- Vacancy formation becomes favorable since its formation energy approaches 0 as D/Pd loading values become ~0.95 (at T=300°K). The possible importance of their formation and stabilization, he is suggesting, at these values of loading is that if he is correct that they are needed for creating excess heat, increases in vacancies at higher loading could provide an explanation for the observation at SRI that positive excess heat results occur only in cathodes which have reached a D/Pd ratio ~0.95.
- Vacancies don't diffuse near room temperature; so the only way they can be formed in the Fleischmann-Pons (FP) experiments is through inadvertent codeposition of Pd at high loading.

• This last hypothesis is consistent with the fact that excess power in the FP experiment occurs only after a long time (involving weeks) has passed after the electrolysis has begun.
• The hypothesis is also consistent with the considerably shorter triggering time that appears to be required in the Szpak codeposition experiments (where excess power in successful experiments seems to be present in hours or minutes after Pd is codeposited with D). The codeposition is controlled in the Szpak experiment, and if the D/Pd ratio is at or above 0.95, then a high vacancy layer is formed by the process.
• Excess power versus loading curves (which show excess power when D/Pd > ~0.85) are consistent with the statistical mechanics associated with D_2 occupation near vacancies. (Statistical mechanics shows significant D_2 occupation as the D/Pd loading ratio approaches these values.)
• A preliminary calculation indicates that 1% of the D's are in D_2 molecules; since the new D_2 binding energy is so high, the expectation is this number will end up closer to 100%.

Dr. Scott Chubb presented his uncle, Talbot Chubb's, paper, "Interface Model of Cold Fusion in Nanometer Size Materials," concerning the nuclear effects that he believes are responsible for the excess heat and helium-4 results that Arata and others have observed in the nanometer $PdZrO_2$ composite structures that they have used in gas-loading and electrolysis experiments. He discussed observations that T. Chubb has made about the loading characteristics of this kind of structure in experiments by Arata and Zhang. In some of these experiments, it had been suggested that D/Pd loading values that are as high as three are possible.


Dr. Scott Chubb

T. Chubb cites curves of pressure versus loading that apply when D_2 is loaded and de-loaded into the $PdZrO_2$ composite structures that were used in the Arata-Zhang excess heat studies. These curves provide evidence of a hysteresis effect during the loading/de-loading process in the composite structure that appears to be similar to a comparable effect that occurs in bulk Pd where it results from the transition between the alpha+beta and beta phases. Since the effect tracks a change that is tied to loadings of ~1 in "bulk" Pd in PdD, it can be used to distinguish between loading that occurs at the interface between the ZrO_2 and Pd in the composite structures from loading that occurs in the interior of the Pd. T. Chubb suggests that because of this fact the situation where the loading value is claimed to approach 3 corresponds to a case in which loading in the interior region of the Pd has a value that approaches 1.1.

S. Chubb provided background information about the underlying theory that T. Chubb has used in his theory of how nuclear reactions occur in the $PdZrO_2$ composite structures. The initial theory, as formulated by S. Chubb and T. Chubb, is based on the assumption that in order to minimize the energy associated with deuteron (d)-d Coulomb repulsion, a small fraction of the d's that enter a fully-loaded PdD lattice can effectively dissociate from the electrons (that are bound to them when they enter the lattice) and occupy wave-like states (ion band states) that are similar to the kinds of wave-like (electron energy band) states that electrons occupy in ordinary metals. In this kind of situation, a complete quantum mechanical calculation, involving information about matrix elements, is used to calculate reaction rate. The relevant matrix elements are determined in a situation in which the momentum can change abruptly (without its magnitude actually becoming large). The usual Gamow formula does not apply in this limit because this formula only applies when the momentum does not vary appreciably over short length scales.

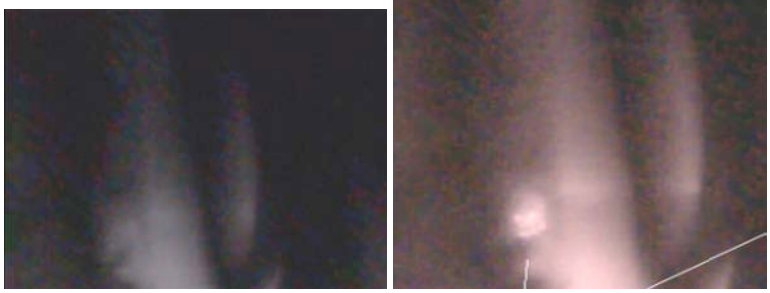
They model the situation using a periodic lattice (which is required in order for energy band theory to apply) with discontinuous momentum changes (through cusps in the wave function) at the locations where nuclear reactions are allowed to occur. As S. Chubb discussed in a later talk, the discontinuities lead to changes in the kinetic energy (in the Schrödinger equation) that cancel the large repulsive contributions from d-d repulsion that are conventionally associated with the Coulomb barrier.

This earlier theory applies to fully-loaded PdD. In situations involving the composite $PdZrO_2$ structures, T. Chubb believes that it is necessary to modify the initial theory by introducing forms of neutralization that alter the charge of the d's, so that they are not ions. He uses an idealized picture (that is not entirely rigorous) involving a "dressed" deuteron (D^+) that is neutralized by electrons in the metal, and he suggests it behaves like a fermion, not like a boson. In this picture, a dressed proton (H^+) on the other hand, behaves like a boson, not like a fermion.

S. Chubb views this idea as highly speculative because it is not consistent with how the "dressing" normally occurs in solids. Normally, "dressed particles" are thought of as having charge and the "dressing" affects the magnitude of the charge. Whether or not a particle possesses charge alters how it interacts with the lattice and also affects the nature of its spin-statistics, including how it behaves with respect to particle-exchange and whether or not it is a boson or a fermion.

In T. Chubb's view, at the interface between an insulator or dielectric and a transition metal, in a nm scale environment, each surface ion from an insulator sees a mirror image charge inside the metal. The deuterons are delocalized, and their wave function spreads out over large (many lattice-spacing) distances. Nanometer scale quasi-particles can move rigidly, and their oscillations can couple to phonons. The interface thins or thickens, depending on whether the d's are delocalized or are diffusing. There is a momentum jump at the interface.

An important point that S. Chubb emphasizes is that for a charged particle moving with velocity v, possessing momentum P and charge e, $P \neq mv$. The correct relationship is $P - \frac{e}{c}A = mv$, where A is the vector potential. When this more general relationship holds, P and A can both change abruptly either by the same amount (without altering the



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value of v) or in such a way that how v changes involves a non-local effect (that can be coherent). The possibility that nanometer scale quasi-particles can move rigidly is associated with this fact.

Dr. Swartz presented the sixth talk, "Near-IR Emission and Electrodynamic Behavior in LANR." He summarized experiments in which JET Energy made calibrated near-IR images of electrodes in high Z and codeposition experiments. He said they have observed near-IR radiation emissions when excess heat is near its maximum (at the OOP). This near-IR emission might be non-thermal because it appears to be correlated with excess heat production and not the physical temperature. None of the control experiments (in which heat is introduced in the electrodes resistively) produce a comparable effect even at higher temperature.

Swartz speculated that the IR might result from a shift of Bremmstrahlung radiation to lower frequencies. This is based on an analysis that he performed that suggests that in CF experiments involving excess heat, there is a temperature-controlled shift of potential electromagnetic emission that might be induced (through LANR) from penetrating, ionizing radiation, leading to IR radiation that would be constrained (through skin-depth effects) to remain in the lattice. As a result, in this earlier study, he concluded that penetrating, ionizing radiation would not be present in situations in CF.

Professor Hagelstein pointed out that if the heat is produced locally in an inhomogeneous fashion in the codeposition images, near-IR radiation might be created thermally through hot spots that would not be present in the images of the electrodes in the control (resistive heating) situation, where the heating would be created homogeneously.

Professor Hagelstein presented the seventh talk, "Electrochemical Models for the Fleischmann-Pons Experiment," which was motivated by the need to model SRI loading experiments, using the relevant electrochemistry. His initial thought was that constructing a model to accomplish this would be straightforward. It turned out not to be. As an example, he pointed out that the diffusivity D is given by $D = D_o \times (1 - x)(1 - \exp(-\Delta E/(kT)))$, where according to the values quoted in Yuh Fukai's book,[3] in PdD, $D_o = 1.7 \times 10^{-3}$cm^2/sec, and $\Delta E = 206$ meV. Unfortunately, this model over-predicts the diffusivity by a factor of 100 in the mixed phase region (0.03<D/Pd<0.6), and the model under-predicts it at high loading (D/Pd>0.6).

He found a similar problem in the existing electrochemical loading models. In these models, three reactions are used: the Volmer reaction, the Tafel reaction and the Heyrovsky reaction. In the Volmer reaction, D_2O molecules dissociate on the Pd surface, with D entering the metal and OD^{--} ions leaving the surface. In the Tafel reaction, two D atoms recombine on the surface and leave as a D_2 molecule. In the Heyrovsky reaction, as a D_2O molecule approaches the surface, it dissociates into an OD^- and D, but the D does not enter the solid; instead it combines with a second D, and both the OD^- and D_2 leave the surface.

Hagelstein emphasized that the predictive power of the model associated with these reactions (known together as the hydrogen evolution reaction—HER) constitutes one of the major successes of electrochemistry. He has found at low current density, a model that is based on combining the Volmer and Tafel reactions provides a satisfactory description of the loading behavior. At higher current density, the loading is observed to decrease, which is in qualitative agreement with the Heyrovsky model. Unfortunately, in the case of PdH and PdD, the combined Volmer-Tafel-Heyrovsky model gives results that are not in qualitative agreement with experiment in the high current density regime.

In the HER model, since the Heyrovsky mechanism effectively acts as a barrier that prevents higher loading, if one selects a particular data set as a reference, the model that results is incapable of achieving significantly higher loading under fairly general conditions. Since electrochemical D/Pd loadings as high as 1.04 have been reported, Hagelstein has concluded that probably the Heyrovsky mechanism does not play any role at lower loadings. He pointed out this is consistent with the absence of experimental evidence for the Heyrovsky mechanism at lower loading (where people have looked for the associated reaction).

These deficiencies have motivated Hagelstein to develop a modified electrochemical model. He initially began looking for an alternative mechanism that causes deloading at high current density. He found it was necessary to develop something more sophisticated. He observed that in the FP experiment, Li in the electrolyte is adsorbed onto the surface (he suggested this probably occurs at the same sites where H or D is adsorbed), and he concluded that the associated kinematical effects should be added to the model. He pointed out that to model the early SRI experiments, it is necessary to account for adsorption of what he referred to as "nonclassical poisons" (impurities, involving Al in some situations, and silica in others, at the 200 part-per-million level) in the electrolyte.

In the modeling, these impurities were initially thought to poison the Tafel reaction (and prevent it from occurring), while leaving the Volmer reaction unaffected. However, Hagelstein observed that when the surface coverage is high, these Al and silica adsorbents block the Volmer reaction in a manner that depends on the coverage in a linear manner; while they block the Tafel reaction in a manner that depends on the square of the coverage. He pointed out this difference implies a subtlety: just blocking a large number of the sites will naturally produce higher loading, without requiring a poison to block the Tafel reaction.

This observation motivated him to develop an electrochemical model, involving the following: 1) An increased role for internal Tafel losses in most cathodes, and an

increase in internal Tafel losses as the loading increases; 2) A reduction in the number of active surface sites, which would enhance the effect of Li and also other additives that are intended to block active sites; 3) An accumulation of electrolyte contaminants on the surface at high current density when the cathode over-potential becomes very negative.

He also pointed out that the affinity of Pd for H is about ten times higher than for D.

With respect to the problem of modeling electrochemistry and loading, the highlights of his presentation were:

—Diffusion of D in PdD is complicated and involves three-regions that show distinctly different behavior.
—Loading in the lower D-concentration (alpha) phase (where D/Pd < 0.03) can be explained using the textbook values of the diffusivity.
—The mixed alpha and beta phase region (0.03 < D/Pd < 0.60) has a low diffusivity, resulting from the fact that the chemical potential does not change as the loading is altered.
—The beta phase region (D/Pd > 0.60) has a high diffusivity.
—The low diffusivity in the mixed phase region implies that a discontinuous change in loading propagates through the cathode. This causes a lattice disruption due to a ~10% volume change.
—The hydrogen evolution kinetics (Volmer, Tafel, Heyrovsky) model, which is one of most successful models in electrochemistry for understanding hydrogen loading in many metals, does not work in PdD at high current density.
—The Volmer reaction is of the form, $H_2O + M + e^- \rightarrow M + H_{ads} + OH^-$ (H_{ads} refers to adsorbed H); it describes a loading process.
—The Tafel reaction describes a de-loading process; it is based on a reaction of the form, $M + 2H_{ads} \rightarrow M + H_2$ (this reaction depends only on the chemical potential of H, or how highly PdH is loaded).
—When low current density (less than 10 mA/cm^2) is used, the Volmer reaction leads to loading, and the Tafel reaction leads to deloading, but loading is a function of current density.
—When the current density is high (above 100 mA/cm2), the experiments show that de-loading takes place.
—The Heyrovsky reaction leads to de-loading: $H_2O + M + H_{ads} + e^- \rightarrow M + H_2 + OH^-$.
—Zhang and others had assumed that the Heyrovsky reaction is responsible for de-loading at high current density. This is incorrect, since the Heyrovsky reaction leads to limiting values of the maximum loading, under all conditions.
—Since electrochemical loading is observed with loadings as high as D/Pd ~1.04, the limiting loading value where the Heyrovsky reaction might apply begins with D/Pd ~1.04.
—New models are needed in order to describe loading in the FP experiments.
—One proposal is a two-electron transfer reaction: $2H_2O + M + 2e^- \rightarrow M + H_2 + 2OH^-$.
—Hagelstein developed a preliminary model involving the Volmer and Tafel reactions, Li adsorption, and deloading, using the two-electron reaction. This model has successfully reproduced loading versus current density curves in a reasonable way; but it did not successfully predict the loading dynamics since the loading current density consistent with the requirements of the model was too small.
—He developed a modified version that was outlined above: it includes Volmer and Tafel reactions, but with a much stronger and loading-dependent internal Tafel mechanism, Li adsorption kinetics, and a reduced number of active sites. This new model gives reasonable values of the loading as a function of current density, it improves the description of dynamical loading, and it is the first model to address the anomaly in the "Tafel lines" noted by John Bockris (where a slope change is seen near 100 mA/cm^2 in plots of the overpotential as a function of current density).
—The model in some cases predicts two possible values of possible D/Pd loadings for a particular value of the given current density, when the loading is high. This may be connected with the "breathing" mode instability that has been observed in some experiments.
—The loss of loading that occurs at high current density is most likely due to the accumulation of contaminants on the surface.
—Modeling the electrochemistry and diffusion to compute the D/Pd loading in FP experiments is much more difficult than was thought to be the case initially.

Dr. Scott Chubb began the eighth talk, "Importance of Crystal Size in Initiating Excess Heat," by emphasizing that CF occurs through a deuteron d+d$\rightarrow^4$He reaction, without high-energy particles or γ rays. He argued that a key reason this fact has not been accepted is the lack of a cogent argument, based on fundamental physical ideas, justifying it. In a new paper that he and Talbot Chubb are planning to submit to *Physical Review Letters*, they re-examine this question, based on a generalization of energy band theory that applies to finite (as opposed to infinitely-repeating) periodic solids, in which d's are allowed to occupy wave-like, ion band states, similar to the kinds of states that electrons occupy in ordinary metals.

Chubb pointed out that the basis of energy band theory traditionally has been viewed as being semi-phenomenological and imprecise. By generalizing band theory to finite solids, he has developed a more precise basis for the subject that actually can be applied to situations involving nanometer scale crystals. In the generalization, the lowest energy forms of scattering between charged particles are dominated by coherent, resonant effects, in which the solid, as a whole, moves rigidly. These forms of scattering can result in nonlocal forms of momentum and charge transfer, leading to nuclear fusion, without the emission of high-energy particles. Equivalently, the scattering processes can be viewed as involving waves and the associated "particles" are fractionally split-up into many different pieces that are present at many different locations at once. When the associated scattering takes place, the momentum and energy from the process is fractionally shared at many different locations, leading to a situation in which only a small amount of the energy is released at any particular location.

The associated wave effect is the result of a symmetry that results because it is impossible to determine the precise location of the boundaries of a lattice and, for this reason, it is not possible to determine if the center-of-mass of the lattice is in motion or at rest, and a form of Galilean relativity is involved. As a result of this symmetry, the energy of the particles in the solid is not altered when it is moved rigidly, in such a way that the separation between each pair of particles remains fixed. In the generalization of band theory to many-body, finite systems, this symmetry is used to identify the

lowest energy excitations. Reactions can become non-local, as a consequence. In this context, through the generalization of the theory, it is possible to predict the optimal crystal size for initiating CF.

Chubb noted that an important point is that momentum conservation can be violated at an isolated location (while globally it is required to be conserved), and the relative momentum between two particles can change abruptly (as Chubb mentioned in his first talk) over short distances without affecting their relative velocity. This is because implicitly there is a form of coupling between velocity, momentum and the electromagnetic field that occurs because when a charged particle moves with velocity v and possesses momentum P and charge e, $P \neq mv$. The correct relationship is $P - \frac{e}{c}A = mv$, where A is the vector potential. When this more general relationship holds, P and A can both change abruptly either by the same amount (without altering the value of v) or in such a way that how v changes involves a non-local effect (that can be coherent).

Chubb then provided some of the mathematical relationships that can be used to determine reaction rate through processes in which momentum is transferred from the reacting, wave-like deuterons, directly to the lattice through a process in which the lattice moves rigidly. The associated calculation provides a lower limit for reaction rate that is consistent with a situation in which energy is minimized inside the solid (but the reaction products, including the heat are distributed outside the solid). The particular case that he presented applies to a limiting situation where the mathematical expressions are sufficiently simple that a single process can be identified. Chubb pointed out that in general, many processes can be involved, and the relevant expressions, in fact, are sufficiently general that they can describe almost anything.

Next, Chubb summarized a number of predictions that he and Talbot Chubb had made, based on the ion band state theory, that were subsequently observed. These include the following predictions: ^{4}He should be produced at levels that explain excess heat; the ^{4}He should be found in an unanticipated location, outside and at the surface of heat-producing electrodes; the apparent requirement that high-loading ($x \rightarrow 1$ in PdD_x) is necessary to create excess heat; and excess heat is created without the emission of any high-energy particles or radiation.

Chubb concluded his talk by summarizing results of the theory that relate crystal size to the onset of excess heat. In particular, using an argument associated with energy and momentum dissipation, he suggested during ICCF11[4] that a lattice possessing a characteristic dimension a = 4 nm (3,000 unit cells) can trigger the excess heat effect in about 3 μs; while the same argument implies that a lattice with a = 30-60 nm (3-6 million unit cells) would trigger the excess heat effect in about 3 ms. The associated argument suggests that with each increase in a by a factor of 10, the triggering time increases by a factor of 1,000 (which provides a possible explanation for the fact that the time required for excess heat to be initiated can be weeks or even months). Previously, the Chubbs developed an approximate energy minimization argument that suggested the minimal size that is required for excess heat to be produced is ~6,000 unit cells.

This calculation did not include the requirement that the abrupt changes in momentum (associated with the lattice rigidly moving) lead to an explicit cancellation (associated with "cusps in the wave function") between large (negative) contributions from the kinetic energy with the large Coulombic repulsion terms in the Schrödinger equation that occur at each location where d-d overlap is allowed to take place. When this cancellation is explicitly included, a smaller lower bound for the crystal size is obtained. This calculation suggests that lattice sizes as small as 1-2 nm (700 unit cells) can trigger the excess heat effect. Boundary effects can further reduce the effective crystal size. The calculations assume an effective screening radius parameter r_{sc} = 0.156 Å can be used to define the region where appreciable nuclear overlap can take place.

Dr. Mitchell Swartz presented the ninth talk, "Metamaterials, Magnetic Fields, Hyperdrive and ESID Control in LANR." *IE* covered some of Swartz's ideas about metamaterials in Issue 90. Swartz emphasized that these metamaterials have properties that have not been previously observed or expected. Metamaterials are created artificially by structurally shaping the constituents of a material in particular ways. They are engineered to show characteristic behavior that is very unusual. For example, metamaterials have been created that have a negative index of refraction. They have been used to create electromagnetic cloaking devices, a negative phase and group velocity of light, anomalous reflections and excitations of surface waves, isotropic lenses, and soliton decoherence. Electrical permittivity ε and magnetic permeability μ are both positive in materials that are formed through natural processes. In these kinds of materials, what are referred to as "right-handed rules" for electromagnetic (light) propagation apply. A requirement of these rules is when light propagates through a medium in the forward direction, its energy, momentum and power travel in the same direction. However, if a material is a "left-handed material" (LHM), then it has a negative index of refraction, and it has unusual properties as a result of this fact. In a LHM, both ε and μ are negative, and the phase and group velocities of light propagate in opposite directions. This has been observed in meta-materials. Then, because of the different form of handedness, when the light is directed in the forward direction, the power and momentum actually propagate backwards. This behavior can be used to reverse the expected Doppler shift in a collision and to reverse the propagation direction of Cherenkov radiation (from the forward direction to the backward direction).

Swartz also talked about the unusual properties of a particular metamaterial cathode, which he calls the "spiral Phusor®-type LANR cathode." This cathode has a distinctive open helical geometry. When it is placed in a high impedance solution, it creates a unique electric field distribution that results in deuterons being loaded both from the solution and within the palladium, under equilibrium conditions. The associated effect appears to enhance the excess heat effect. Swartz uses the flux and flux rate equations (see p. 1, discussed in his second talk) to model how these materials perform during electrolysis.

Swartz then discussed results from experiments where he has applied high intensity magnetic fields. He said that magnetism can lead to a 10-15% increase in the resistance of the solution. He emphasized that this is very important because these increases in resistance appear to increase loading and minimize the negative effects of electrolysis. The effect is

largest when the applied electric field that is used to create the electrolysis is perpendicular to the magnetic field.

Swartz uses the terms "Hyperdrive" and "Empirical System Identification Control (ESID Control)" to describe two new procedures that he uses to facilitate the identification of OOPs and to influence the effects resulting from varying the input power in such a way that the effects of excess heat (and other phenomena associated with LANR) are enhanced. These procedures have resulted in significant improvements in his ability to create excess heat through a sampling procedure that alters the OOP manifold in ways that improve system performance.

With Larry Forsley and others, Swartz has also investigated reasons for the success of the "Superwave" forms of input wave-forms that Irving Dardik/Energetics has developed in initiating excess heat. They have shown that Superwaves create a transitory variation in input power that appears to activate an LANR-induced OOP peak. Hagelstein and others have suggested that the superwaves initiate non-linear effects that are responsible for triggering excess heat.

Swartz collaborated with Bob Bass in implementing the ESID Control procedure in his experiments. (Bass formulated the theory associated with the procedure in 1989; the work is documented in the Proceedings of ICCF1.[5]) They found that the "accuracy of the ESID Control procedure varies between 92 to 97.7%."

Dr. Brian Ahern presented the tenth talk, "Inverse Capillary Discharge for Amplifying LANR." Ahern has been very intrigued by the recent work by Rossi and Focardi (http://www.lenr-canr.org/acrobat/FocardiSanewenergy.pdf) involving Ni and normal hydrogen. He pointed out that they have used two important innovative steps: 1) The use of a composite material involving nanometer scale Ni and a ceramic; 2) The use of gas-loading to significantly raise the levels of excess heat that are observed in Ni-H systems. As in his first talk, Ahern emphasized the idea that energy localization, resulting from non-linear effects, might potentially play a key role in initiating excess heat.

He believes that the use of Pd or Ni nano-materials, in the presence of gas-loading, can provide a fundamental way to create large excess heat effects. He suggests that if a powder of nanometer-scale Pd or Ni in a cylinder in the presence of H_2 or D_2 is enclosed and an electrode rod is placed at the center of the powder and an electric discharge (on the order of 30 kV) is introduced between the rod and the cylinder, it can be expected that a very large excess effect will be created. He refers to this as an "inverse capillary discharge."

Ahern plans to perform an experiment that is based on this idea, using nm Pd. He suggested that by using a "Superwave" form for the discharge, the effect might be enhanced. With an input power of 15 W, Rossi reported 3,000 W output. Ahern will test this experiment soon. He believes anharmonic vibrations at very high loading (x > 4) in a NiPd alloy may lead to intense LANR. He will be using a pulsed power supply that has voltages that can be varied from 14 - 30 kV. The pulses give a Fourier spectrum not unlike the superwave approach.

Ahern also discussed other experiments, including capillary fusion experiments, associated with early fusion research (and the Sherwood project). He described experiments involving exploding wires and noted that when the wires break, neutrons are emitted.

Dr. Scott Chubb presented the eleventh talk, "Potential Importance of External Electromagnetic Fields in Enhancing/Triggering Excess Heat." He began by summarizing some of the ideas associated with his and Talbot Chubb's ion band state theory that motivated him to think that external electromagnetic fields might trigger or enhance excess heat. These included the following observations: 1) CF involves d+d $\rightarrow$ ^{4}He without high-energy particles; 2) This can occur from small fluctuations in loading $\delta <\sim 10^{-4}$ in $PdD_{1\pm\delta}$ through the occupation of ion band states; 3) How this occurs is intimately tied to the underlying electronic structure; 4) Fluctuations involving $\delta <\sim 10^{-4}$ are associated with a highly-polarized, anti-bonding situation in which each electron that enters the solid with each deuterium nucleus effectively dissociates from it; as a consequence, the lowest energy acoustical phonons in finite crystals of PdD actually are inadequately described as phonons (because they are the result of vibrations that do not conserve charge).

Chubb pointed out that in the limit involving $\delta <\sim 10^{-4}$, a very weak electric field (~10^{-8} V/cm) effectively is present that could couple to the d's that occupy ion band states. This fact provided motivation for his believing that external electromagnetic fields could help to trigger/enhance the excess heat effect. Through a generalization[6] of energy band theory to finite solids, the associated dynamics can be described, based on rates of reaction. In the generalization, the lowest energy forms of scattering are dominated by coherent, resonant effects, in which the solid, as a whole, moves rigidly. This can result in non-local forms of momentum and charge transfer, leading to nuclear fusion, without the emission of high-energy particles.

Chubb suggested that his key, new idea (associated with how electromagnetic interaction can lead to enhancements in excess heat) involves recognizing that forms of coupling to the lowest-lying excitations preferentially occur in a reference frame where the lattice is in "free fall" (and has vanishing net force, net energy and power from potential nuclear reactions). In this preferred reference frame, energy from a nuclear reaction preferentially is transferred to the kinetic energy of the center of mass of the lattice, in which the lattice moves as a whole (and the separations between all of the particles with respect to each other remain fixed). Effectively, the associated picture defines the lowest energy configurations that result from potential scattering processes involving the electromagnetic field.

When the power P is constant, the dot product of the local force F with the velocity v is constant. This fact has unusual implications associated with potential coupling to static fields—in which the orientations of the fields are important. In particular, when the solid moves rigidly, in its reference frame, as a consequence of the generalization of band theory that Chubb derived, $\frac{d\vec{k}}{dt} = 0$, where $\vec{k}$ is any one of the wave-vectors that is used to define an energy band state $\varepsilon_i \equiv \varepsilon\ (\vec{k}_i)$.

Then, by assuming the applied local force F is defined by the semi-classical electrodynamic equations associated with the Lorentz force law as it applies to band theory, $F = \hbar \frac{dk}{dt} = e\vec{E} + \nabla_k \varepsilon\ (k) \times \vec{B}$, Chubb derived a relationship (using the fact that $\frac{d\vec{P}}{dt} = \frac{q\hbar}{M}\frac{d\vec{k}\cdot F}{dt} = \frac{q\hbar}{M}\frac{\vec{k}\cdot\partial F}{\partial t} = 0$), between the rate of change of the electric field with respect to time $\frac{\partial \vec{E}}{\partial t}$ and the compa-

rable rate of change of the magnetic field with respect to time $\frac{\partial \vec{B}}{\partial t}$: $-q\,\frac{\partial \vec{k}\cdot\vec{E}}{\partial t} = q\cdot\vec{k}\cdot(\frac{\nabla_{\vec{k}}\varepsilon(\vec{K})}{c}\times\frac{\partial \vec{B}}{\partial t})$.

Using Faraday's law ($\nabla \times \vec{E} = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t}$), he then showed that in a particular situation, this last equation is related to a one-dimensional wave equation, which has solutions that can become localized or delocalized in a manner that depends on the behavior of the group velocity $\frac{\nabla_{\vec{k}}\varepsilon(\vec{K})}{\hbar}$ and the orientation of the applied fields. In a situation involving a thin film (which is relevant to the SPAWAR experiments) $\frac{\nabla_{\vec{k}}\varepsilon(\vec{K})}{\hbar}$ should vanish asymptotically in directions normal to the surface. When this occurs, the associated states can become localized within the film when an applied magnetic field is directed parallel to the film. The associated effect, Chubb suggested, can explain how the emission of high-energy particles can be triggered normal to the surface in a manner that appears to be counter-intuitive: by applying a static magnetic field parallel to the film.

Chubb also discussed the triggering mechanism[9] that he alluded to in his first talk, where he mentioned a relationship between a triggering time (3 ms) and crystal size (30-60 nm). The triggering mechanism involves a resonant condition that can occur as a result of the weak, effective electric field $\vec{E}$ that he suggests results from the strongly polarized bonding that occurs near full-loading. In particular, the associated mechanism involves an effect, referred to as a Bloch oscillation, in which values of $\vec{K}$ increase as a function of time when an applied force = $e\vec{E}$ is introduced (through the relationship $\vec{k}(t) = e\vec{E}\,t/\hbar$) until $\vec{k}(t)$ equals a reciprocal lattice vector: $e\vec{E}\,t_n/\hbar = \vec{k}(t_n) = \vec{G}_n$. When this happens, momentum is transferred to the lattice through a process in which the lattice moves rigidly. By estimating $\vec{E}$ ~10^{-8} eV/Å, Chubb has used this last relationship to estimate the time that is necessary to trigger a fusion reaction.[4]

Chubb also mentioned that an NMR type measurement of deuteron spin might actually trigger excess heat. The origin of this effect is associated with the fact that the d+d → ^{4}He reaction requires that the initial and final states have vanishing net spin. Because the presence of an applied magnetic field leads to a precession of the deuteron spins, the orientation of the field can induce vanishing spin in directions perpendicular to it. As a consequence of this fact, the field can induce a preferential direction (associated with vanishing spin) where ^{4}He is created. By orienting the field appropriately, the potential ^{4}He reactions can be directed along a path that minimizes potential disruptions in periodic order. This possibly can enhance CF.

He also pointed out that ion band states resemble phonons in a certain sense because they are de-localized and wave-like, and phonons and ion band states d's are both bosons. But ion band states carry charge. As a consequence, d's in ion band states can behave coherently in the way that is similar to the way that charged bosons (like Cooper pairs in a superconductor) behave and as a Bose Einstein Condensate (BEC). But he emphasized that fusion is initiated from a dynamical process that involves a small concentration of d's (in ion band states), and for this reason, effects associated with the fact that d's in the lowest energy band state occupy a BEC and are capable of providing superconductivity are not directly related to the fact that fusion occurs.

Dr. Swartz presented the twelfth talk, covering three topics: "Optimal Operating Point Control in Thompson LANR Radium Transmutation," "LANR Nanostructured Materials, Ultrasound and Devices" and "Direct Electricity from LANR Nanostructured NANOR Devices." The first portion of the talk summarized a continuation of ongoing experiments which have been directed by John (Alf) Thompson. Thompson is now conducting these experiments in collaboration with Swartz, Charles Entenmann, Ni Luo and George Miley. In these experiments (which Thompson has been conducting for quite awhile), radium is mixed with proprietary nanoparticles, containing palladium, and the composite material that results is loaded with deuterium. At last year's colloquium at MIT, Thompson discussed the procedures he used in these experiments and control experiments. At that time, Thompson presented preliminary results that suggested he discovered what appears to be an LANR-induced decrease in radioactivity. In particular, he observed a decrease, by several percent, in the count rate from a Geiger counter, over several hours, resulting from radioactive emissions from his samples. However, it appeared that some form of radioactivity (detected by the counter) partially returned after the apparatus had been turned off for several hours.

Swartz and Thompson are not sure if the decrease in radioactivity and its return are as important as potential variations in signals from the sample that would be attributable to the differences in penetration from radioactive emissions from the daughter products (decay channels) of radium. During the last year, Swartz and Thompson discovered that the rate of decrease of radioactivity appears to exhibit an OOP manifold behavior and may have a well-defined OOP. They have concluded that in order to assess the importance of the decrease in radioactivity that they have observed, they have to perform a new experiment, involving radioisotopes that do not have as many decay channels.

In the next portion of his talk, Swartz discussed "LANR Nanostructured Materials, Ultrasound and Devices." He first provided an overview of the process of working with nanostructured materials. He said at JET Energy, they have been quite successful in producing excess heat using nanometer scale samples of palladium, nickel and a new nanostructured ZrO_2PdNi material. He said that the reduced size of these materials appears to be playing an especially important role in initiating excess heat, which initially was surprising, just as shape was surprisingly important in initiating excess heat in situations involving metamaterials.

He then pointed out that the nanometer size particles can be potentially dangerous when they are inhaled or ingested. They can cause harmful effects that appear through renal, ophthalmic and arthritic manifestations. To avoid these kinds of problems, Swartz developed what he refers to as NANORs. These are LANR electronic devices that have a number of terminals and are designed in such a way that the nanostructured material is positioned at the core of the device. Positioned in this way, he has found that these LANR devices are affected by the presence of externally applied electric, magnetic and ultrasonic fields. These kinds of fields may be applied in the x, y and z directions.

The electrical impedance in one NANOR device was 3 megohm when lower voltages were applied, but then as the voltage was increased to ~24 V, the impedance suddenly

decreased to very low values. He said that this sudden reduction can be attributed to an "avalanche effect" that is typical of the current-voltage behavior that occurs in Zener diodes. This NANOR device, in principle, could be used in similar applications where Zener diodes have been used (for example, stabilizing circuits against potential surges in applied power).

Swartz and Gayle Verner shared their discovery that nanostructured LANR materials are very sensitive to sound. (Swartz said, "They pick-up sound.") JET Energy developed 2D NANORs which show that ultrasound can induce a delayed (he used "late-occurring"), persistent signal of heat, as a result of increases in the values of temperature (the temperature can even increase in magnitude after the ultrasound is turned off). In contrast, he pointed out that the temperature in normal materials (in control conditions in which there is no heat) drops after the ultrasound is turned off. He also mentioned that they have found evidence of a process that directly converts ultrasound into very low levels of electricity.

Swartz concluded this talk by presenting material associated with a similar discovery that he referred to as "Direct Electricity from LANR Nanostructured NANOR Devices." He performed the associated work in collaboration with Charles Entenmann. He reported that JET Energy was able to generate what he referred to as "ultra-small amounts of electricity," directly from NANOR-type nanostructured LANR systems. He emphasized that the significance of this discovery is the fact that although the effect is small, because it involves the production of electricity directly from an LANR-related process, the process avoids the inefficiency that is required when heat is converted into electricity. He pointed out that in addition to electricity, heat was generated as well.

Professor Hagelstein presented the thirteenth talk. In it, he consolidated two topics. The first topic was "Models for Excess Heat in Fleischmann-Pons Experiments," based on a recent paper.[7] The second topic was "Two-laser Experiments and Results," covered in papers he has prepared in collaboration with Dennis Letts and Dennis Cravens.[8]

Hagelstein began by suggesting that the calculations of conventional reaction rates, based on the low neutron yields that are found when excess heat is observed, indicate the alpha particles that are created have a very low (<20 keV) energy. He based this conclusion on the assumption that any neutrons that are produced occur through secondary d+d fusion processes that are initiated from the (dominant) d+d $\rightarrow$ ^{4}He reaction.

In particular, he emphasized that ^{4}He is the source of the excess heat: it has been observed in the off-gas in FP experiments in amounts that are correlated with the energy that is produced and that this means that the energy of the dominant reaction can be obtained by dividing the amount of excess heat that is produced by the number of ^{4}He atoms that are found. From this analysis, it is possible to infer that the energy of the reaction falls within a range of possible values.(Values have varied between 25 MeV and 50 MeV.) There is a range of values because observations of different reaction energies have been obtained in different experiments, and there have also been variations in the value of the energy per ^{4}He atom for different excess heat events in the same experiment. An interpretation proposed for this is that the helium is made in an active region near (within ~100 nm from) the cathode surface so that the helium can diffuse into regions outside the electrode, but that not all of it manages to do this because it becomes trapped.

He said this fact implies the amount of helium that actually reaches the gas depends on how close to the surface it forms. In two measurements (one at SRI and one at ENEA Frascati) an effort was made to scrub the retained helium from the near-surface region. In both of these experiments the ratio of energy produced to the number of ^{4}He atoms is 24 MeV, to within better than 10%. This is significant since the mass difference between two deuterons and ^{4}He is 23.85 MeV.

Hagelstein pointed out that if 24 MeV is produced in a conventional reaction, one would expect the reaction products to have energy distributed in a way that is consistent with local conservation of energy and momentum. But if this energy is responsible for triggering the low-level neutron emissions that have been observed, the ^{4}He that is created must have a low (<20 keV) energy. This fact, essentially, is impossible to reconcile with any conventional nuclear reaction mechanism.

He has inferred this 20 keV upper limit for the ^{4}He energy from an analysis of the different reaction mechanisms that are possible for an energetic alpha particle to be created in PdD. The one that is most sensitive to alpha particles occurs when the alpha collides with a deuteron, and then this deuteron collides with another deuteron to produce a neutron through a conventional d+d reaction. In essence, this requires that energetic alphas are present since they are necessary to produce measurable, secondary neutrons.

In an analysis of the early published experiments involving excess power measurements and neutron measurements, he has inferred that an experimental limit for the associated energy to be the result of neutrons requires ~0.01 neutron/Joule. Using the assumption that the secondary neutrons occur from the d+d reaction (initiated from an energetic alpha particle), he has found the upper bound: the ^{4}He can have no more than 6-20 keV of the 24 MeV reaction energy. This fact has important implications: it rules out all Rutherford-type, conventional binary nuclear reactions. It also rules out almost all mechanisms that have been put forth since 1989 for FP excess heat.

As an example, he pointed out there has been discussion over the years of a proposed 4-body reaction of the form d+d+d+d $\rightarrow$ ^{4}He + ^{4}He + 48 MeV, which is aneutronic, in which the two alpha particles each have a large, 24 MeV, energy. It was thought that such a process could be a candidate to account for excess heat in the FP experiment since the alphas would simply slow down, inside the cell, without being detected with high-energy. However, the same argument that was used to make the 20 keV estimate for the upper bound for the alpha particle energy can be used to show that the 24 MeV alpha particles associated with this last reaction would produce many more (orders of magnitude more) neutrons than have been observed in the experiments.

This fact has motivated Hagelstein's theoretical approach, which has been to focus on models that split up the large (MeV) nuclear quantum of energy associated with the reaction into many small (meV) phonon quanta. The first step in his approach is to identify a new, simplified mechanism that accompishes this. He believes that if it really is possible to "fractionate" (divide up) a large quantum into a very large

number of smaller quanta, then it should be possible to demonstrate this first in a simpler model, and later, in more complicated models.

He suggested that one of the simplest possible models of this kind involves a set of two-level systems that is coupled to an oscillator in a linear manner and that the "spin-boson" model, which is quite well-known (it has been used in studies of NMR, cavity quantum electrodynamics, and for other applications) accomplishes this. He pointed out the spin-boson model is capable of producing a version of the desired coherent energy exchange effect (associated with creating many small quanta) under conditions where the two-level transition energy is a reasonably large multiple of the oscillator quantum. Hagelstein considers the fact that such a well-known model exhibits a version of the basic effect that is necessary to be a positive feature of the approach but that the approach has a negative feature: the energy exchange rate becomes vanishing-ly small when one tries to "fractionate" a large quantum into more than ~50 oscillator quanta.

To obtain coherent energy exchange at a rapid rate, Hagelstein found that it was necessary to identify and understand the limitations of the spin-boson model and then to modify it in an appropriate way. Here, he identifed a key point: when a large number of quanta are involved, the ability of the spin-boson model to exchange energy is limited by destructive interference. To overcome this limitation, about ten years ago, he proposed the idea of adding a form of loss to the oscillator coupling, at the transition energy of the two-level systems. In the lossy spin-boson model, he has found that solving the problem of dividing the large quantum associated with the two-level system into millions of oscillator quanta is formidable. Recently, he has solved a simplified version of the model in the strong coupling limit, and he has established a scaling law that connects the coherent energy exchange rate to the number of oscillator quanta Δn, resulting from the fractionation process.

For this kind of problem, he finds that no energy exchange occurs until the coupling becomes extremely strong, but when this is assumed, coherent energy exchange occurs, the associated characteristic rate is on the order of the coupling matrix element divided by Δn^2 and reduced further by what he refers to as "modest hindrance factors." As a result, he has been able to estimate the time that is required for the energy of a large (~ MeV) quantum associated with a typical nuclear process (that is involved with the energy associated with excess heat) to be converted into a typical number (~30 million) of oscillator quanta that is required to dissipate the energy without high energy particles. Using the scaling law and by assuming an appropriate value M (~1 MeV) for the coupling matrix element, he finds that the rate of the initial nuclear process ($M/\hbar \sim 1.5 \times 10^{15}$/s) is reduced by the fractionation process to a value ($M/(\Delta n^2 \hbar) \sim 1.7 \times 10^6$/s) for an appropriate value of Δn. This shows that the model is capable of producing quanta that have characteristic lifetimes (~1-10 μs) that are sufficiently long that coupling to conventional solid state processes becomes possible and, as a consequence, it provides a way to understand energy production from a nuclear process without highly energetic particles.

To specifically apply the model to the excess heat problem, he pointed out that the simplest assumption, which is that the two-level system involves a nuclear transition from a D_2 molecule in the lattice (representing the excited state) to a ^{4}He nucleus (associated with the ground state), is not expected to work because the relevant matrix element associated with the coupling is reduced dramatically by Coulomb repulsion (as a result of Gamow tunneling factor, which he assumes applies). This has forced him to consider more complicated models, beginning with the initial two-level (D_2 molecule-^{4}He) system with its small coupling matrix element and possible exchange of phonons, and a second set of two-level systems that are strongly coupled to the lattice. The excitation from the $D_2/^4$He system can be transferred in these models to the second set of two-level systems, and the second set of two-level systems can coherently exchange energy with the lattice, fractionating the large nuclear quantum in the process.

In previous years Hagelstein has looked at a number of candidates for the "receiver" system (the second set of two-level systems that are strongly coupled to the lattice). After deriving lossy spin-boson models directly from a general physical model of the energy (the general Hamiltonian), he concluded that potential "receiver" systems can involve any process which can be excited through phonon exchange and that all of these systems are able to participate, but that systems with lower transition energy are favored since when this is assumed, the resulting number of oscillator quanta that are involved in the fractionation is smaller. He also concluded that the transition that is most favorable for creating the fastest rates for excess heat production is the dissociation of a deuteron through the d→n+p reaction, which has an (excitation) energy of 2.22 MeV. He pointed out that although the n+p state itself is free and for this reason seems unsuitable for this kind of model, the state only is used as a virtual state (a state that is never physically occupied) in the model, so that for the purpose of providing the necessary coupling to the lattice, it can be used.

Recently, he has also obtained a classical limit of what he refers to as "the donor-receiver model dynamics" in the strong coupling limit. Here, the donor system for heavy water experiments is the d+d → ^{4}He reaction; while the receiver refers to a particular form of nuclear interaction that can couple to the optical phonon modes with low group velocity.

He can also apply the same kind of picture to the light water system. Then, the donor system is p+d → ^{3}He. If this reaction accounts for excess heat in this situation, ^{3}He should be present in the off-gas in the light water excess heat experiments in amounts that account for the excess heat. He is waiting for experimental verification of this prediction.

Tritium in his model involves an excitation process: ^{4}He → p+t. He said that potential transmutation effects that he did not expect seem to be present in the model. For example, if Pd (or Ni) is excited in the scheme, there are a variety of two-nucleus states which become available as final products, and the model seems to favor them only when the residual kinetic energy is close to zero. Other predictions of the model include: 1) Excitation of the host lattice can be stimulated through acoustic phonon modes rather than optical phonon modes; 2) If there is insufficient deuterium in a lattice, then transitions in the host lattice can become the "receiver system," so that light water systems can become more likely to show the transmutation effect (and sufficient deuteration of the system should enhance cou-

pling to the d→n+p system, which would eliminate transmutation). He is in the process of documenting his work on these models for publication in the *Journal of Condensed Matter Nuclear Science* and elsewhere. Details about the spin-boson model are available online: http://www.lenr-canr.org/acrobat/Hagelsteinexcitation.pdf.

In the second part of his talk, Hagelstein spoke about his work with Letts and Cravens involving irradiating the surface of an electrode with lasers. Letts and Cravens measured the excess power that resulted when two red diode lasers (~685 nm) irradiated the electrode surface. The interfering laser beams created a signal that has a variable beat frequency (that was controlled by the temperature of a diode). As the beat frequency was varied from 0 to 30 THz, three clear peaks of excess power were found at about 8, 15 and 21 THz. The lower two peaks were predicted by Hagelstein's phonon theory, and the 21 THz peak may be associated with an H impurity in the D. This experiment suggests that there are important effects associated with the localized optical phonons (associated with zone-boundary values of the wave-vector) in PdD. In particular, Hagelstein's theory suggests that these kinds of phonons are important, and the enhancement can be explained as a resonant effect involving a transition associated with these particular phonons. The excess power continues after the lasers are turned off. The magnitude of the excess power is insensitive to the laser power, which is on the order of mW/cm^2.

Dr. Mitchell Swartz gave the final talk, "Excess Heat, Electricity Production and HAD Control in LANR." Swartz uses different materials, coatings, and a different approach than most of the other experimenters in the LANR field. Swartz uses what he referred to as "low-paramagnetic D_2O," which has high purity, and anodes that have 99.99% purity, along with cathodes that are constructed systematically using low-contamination materials. He pointed out that other experimenters in the field rely on lower purity materials and electrolytes; by adopting an approach in which purer materials are used, they have made discoveries that have had significant consequences. In particular, by using a pure electrolysis solution, empirically they have found that an extremely high electrical impedance of the solution in LANR is good for producing excess heat. An explanation for this is that solutions that have higher conductivity induce significantly higher rates of gas evolution, and this results in low (usually zero) excess power.

As opposed to the conventional FP electrolysis experiments, in which D is loaded into a Pd cathode, Swartz and the SPAWAR group have shown that codeposition techniques, in which Pd and D are simultaneously codeposited through electrolysis onto a substrate, are effective because these techniques lead to a rapid (<1 hour) rate for inducing excess power, albeit at a very low level. In particular, the time required for turning-on the effect (which can involve days and even weeks, or longer, in more conventional FP electrolysis experiments) is dramatically reduced.

Swartz has maximized the excess heat effect by using ultra-pure D_2O, using what he refers to as a "Dual Anode PHUSOR®" (DAP) system. He said he obtains an OOP associated with a ratio of output power to input power that is as high as 80, using the DAP [Pd/D_2O,$Pd(OD)_2$/Pt,Au] arrangement. He also pointed out the importance of coatings of Au or B, which can change the hydrogen/deuterium admittance, leading to enhancements (increases) in loading and excess heat production and reproducibility.

He reported that JET Energy has obtained excess power values that vary between 0.5 to 19 W and higher. The activation energy of the LANR Pd Phusor® system is ~60.7 kilojoules/mole. There is a critical input electrical current density ~1.5 mA/cm^2 in these systems. Swartz pointed out that during ICCF10, he demonstrated to an audience that it is possible to produce excess heat. In particular, he showed that if the open circuit voltage exceeds 0.7 V at the end of a particular run, then excess power probably would be created.

Swartz also reported results from some of his extensive "light" water nickel experiments. He has investigated the effect of adding small amounts of D_2O to ordinary H_2O in Ni LANR experiments. He has found that these additions increase the excess power. He reported this fact during ICCF9. He also demonstrated that when excess deuterium is added to light water experiments involving Ni, when sufficiently high current densities are applied or excessively high D_2O concentrations are used, changes in the metal's color and in its electrical properties take place, and the associated changes "flatten" the OOP manifold, irreversibly destroying the excess heat process. These destructive effects do not occur in Pd, where LANR involve more reversible processes.

Fleischmann and Pons observed an effect in the early 1990s which they referred to as "Heat After Death" (HAD). This occurs when excess energy is observed after the CF/LANR cell is turned off. Swartz has analyzed experiments that produce this effect closely. He refers to the excess power that is generated in this kind of situation as Tardive Thermal Power (TTP). He believes that, technically, TTP is a more precise term than HAD. (The integral of the TTP with respect to time over an interval of time is the HAD associated with the time interval.) Swartz has reported that this quantity decays initially with a short time constant, then it decays with a longer time constant. Swartz suggests that this may be the result of excess heat production from both shallow traps and deeper traps, both within the loaded cathodes.

Swartz has also reported that the TTP is proportional to the square of the voltage that initiates the effect, followed by a decay in its value until the open circuit voltage drops to 0.7 volts. He said that JET Energy has used TTP to run Stirling engines using high-Z PHUSOR®-type LANR systems. They have found power gains of 170-220% (with energy gains of 152%).

He also mentioned that JET Energy has been exploring alternative procedures for generating electricity directly from LANR processes. An example of one of these attempts involved experiments with fuel cells. But in these experiments, they found a number of complicating factors associated with heat loss from gas generation and water regeneration, and losses in creating electricity. For these reasons, they do not intend to repeate these fuel cell experiments.

Swartz concluded with some general comments about LANR experiments. He emphasized that it is important to consult with individuals who have experience in order to perform the experiments correctly and effectively, and to produce LANR effects successfully. He said that it is necessary to take precautions to avoid accidental explosions from (heavy and light) hydrogen and oxygen gas (that can be released during the experiments), and he advised that it is important to use small cathodes, minimize electrolysis, and

to avoid materials which generate chlorine.

Summary

At JET Energy, Swartz said they have emphasized the need for *in-situ* calibration controls, during experimental runs, and they have found conclusive evidence for substantial excess energy. Impedance matching and high electrolyte impedance are needed to avoid deuterium loss from bubble formation. Bubble formation severely reduces excess power. There is an optimal operating point (OOP) in applied power that maximizes excess power that can be identified from plots of output power as a function of input power.

Tardive Thermal Power occurs when the open circuit voltage at the end of a run is above a threshold value. Ultrasound, electric fields, and magnetic fields may be used to activate and control LANR. Scientists from JET Energy have experimented with electricity generation, fuel cells and Stirling engines.

Swartz has found that Thompson's discovery that radioactivity of radium can be decreased by LANR is controllable through optimal operating point control.

Brian Ahern believes excess heat results from energy localization that results from non-linear (anharmonic) forcing in nanometer materials. He said these kinds of effects can produce bursts of energy, and he used the unusual behavior of a multiple pendulum to illustrate this effect. He also believes that a theory proposed by retired MIT professor, Keith Johnson, that suggests both CF and the superconducting properties of PdD are related to each other, provides strong support for his view that these kinds of effects are important in initiating the excess heat effect.

He has repeated gas-loading experiments that were performed by Arata (using the same materials) and has found excess heat in six successive experiments. He has produced nano-particles of Pd-doped Ni that is coated with ZrO_2. He plans to use these materials, as well as pure Ni powders in inverse capillary discharge experiments. In these experiments, he will apply a 30 kV potential difference between a rod that he will place in the center of a cylinder, containing a composite Ni-Pd/ZrO_2 or pure Ni powder, and the boundaries of the cylinder, in the presence of hydrogen and/or deuterium gas. He believes the optimum particle size for creating excess heat is between 3 and 12 nm. He said that the ceramic coating in the $PdZrO_2$ materials that Arata uses is needed to prevent agglomeration of the nano-particles. He anticipates he will find very large gains in energy, similar to the gains that Rossi and Focardi have found, when he repeats their experiments.

The Chubb model shows how momentum discontinuities and ion delocalization may cause LANR. Nano-particle size determines the time required for triggering LANR. A 4 nm particle could trigger the onset of excess heat in about 3 μs, and a 30 nm particle could do this in about 3 ms. In recent calculations, the Chubbs have found evidence that excess heat can be produced in even smaller (1-2 nm) crystals. Chubb believes the effects of interfaces in the composite $PdZrO_2$ materials that Arata uses may further help to reduce the size requirements associated with the creation of excess heat.

Chubb has generalized conventional energy band theory (which applies to infinitely-repeating, periodic solids) to situations involving solids that have finite-size. This generalization provides a more rigorous way of understanding energy band theory. In the associated fusion model, the process of overcoming the Coulomb barrier is replaced by an aternative problem involving minimizing the energy, in a model that Chubb believes realistically applies to fully-loaded PdD. In the solution to this problem, nuclear overlap between deuterons that occupy wave-like ion band states becomes possible because at any specific location, the charge of each d that occupies such a state becomes a small fraction of the charge that is associated with a d in free space and because the relative momentum between two d's at locations where Coulomb repulsion occurs changes abruptly.

He believes when the energy is minimized, the kinetic energy that results from these abrupt changes in momentum becomes negative at the locations where Coulombic repulsion is maximized. When this happens, the repulsion is reduced. For sufficiently large crystals, an exact cancellation becomes possible.This cancellation effectively eliminates the requirement of overcoming the Coulomb barrier in order for significant overlap between two d's to become possible.

The origin of the abrupt changes in momentum that make this possible is the change in mass and momentum that results from the nuclear reaction. The resulting change in energy is fractionally split, in such a way that negligible accumulation of energy or momentum occurs at a specific location through a process in which the solid as a whole moves, by recoiling in response to the momentum that is imparted as a result of the reaction. He further suggested that a magnetic field may couple to deuteron spin precession, as in NMR, that this may further enhance fusion, and that a preferred orientation of such a field might optimize the excess heat effect.

Hagelstein has been thinking about the problem of D_2 in PdD for many years, and recently he has focused on the problem of D_2 formation in the reduced electron density region near a monovacancy. Recent DFT calculations provide support for his hypothesis that D_2 forms there. From these calculations, he suggests it is possible to identify a 7-deuteron configuration around a monovacancy, where a tightly bound D_2 molecule can exist. The existence of a D_2 molecule is required by his theory for nuclear reaction. Assuming that excess heat forms as a result, the possibility that a D_2 molecule is induced by vacancies suggests that the problem of vacancy formation plays an important role in creating excess heat and that this fact explains the requirement for high loading and a long charging time in the FP experiment, and the short charging time in the Szpak codeposition experiment. He also suggests that because D_2 initiates the excess heat, the statistical mechanics of D_2 occupation of the 7-deuteron configuration is connected to the dependence of excess power on loading.

Hagelstein has been interested in developing a numerical simulation model for the FP experiment, which involves both new nuclear process models and very applied electrochemistry and physical chemistry models. He outlined issues in modeling diffusion and electrochemistry, and has proposed new models in both cases. The new electrochemistry model includes Volmer and Tafel reactions, greatly enhanced internal Tafel loss in off-the-shelf cathodes, lithium kinetics, blocking adsorbed atoms, and surface contamination at high current density. He said that the new model seems to do much better in comparisons involving dynami-

cal loading data.

He also described new modeling efforts for the coupled nuclear and condensed matter process, involving the generation of energy in the FP experiment. He emphasized that the major theoretical problem that has to be addressed in this situation is the absence of energetic particles in processes that are responsible for excess heat. Hagelstein focused on models that "fractionate" (*i.e.*, divide or splinter) a large quantum of energy into many smaller energy quanta, through an efficient, coherent form of energy exchange between two systems (the nuclear system and optical phonon mode system) that have characteristic energy scales that are separated by many orders of magnitude. In essence, energy from a d+d → ^{4}He transition is transferred elsewhere, then converted into optical phonons, and finally thermalized.

Experiments by Letts and Cravens showed that the beat frequency of two diode lasers incident on the surface of PdD could be tuned to particular frequencies (8 and 15 THz) that enhance excess heat production. Hagelstein predicted this effect, using the lossy spin-boson type models that he has developed. In particular, in his theory, he uses coupling to the localized optical phonons in PdD to initiate excess heat. These phonons have specific energies that Hagelstein has identified that have the frequencies (8 and 15 THz) that were observed when excess heat was maximized. A third peak at 21 THz could be due to a hydrogen impurity.

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