The 2011 Cold Fusion/Lattice-Assisted Nuclear Reactions Colloquium at the Massachusetts Institute of Technology—Part 2

(Report prepared by staff of JET Energy, Inc.)

The 2011 Lattice-Assisted Nuclear Reactions/Cold Fusion Colloquium at the Massachusetts Institute of Technology (Cambridge, Massachusetts) was held on Saturday, June 11 and Sunday, June 12, 2011. The meeting focused on the science and technology of cold fusion (CF) and lattice-assisted nuclear reactions (LANR). In 1989, the initial failures of cold fusion resulted from bad experiments, bad paradigm, materials issues, poor loadings and a poor appreciation of the requisite metallurgy and engineering. Today, those issues are resolved, and particle emission, excess energy, excess power gain and commensurate linked helium-4 production with excess heat are undeniable, along with increasing power gains and total energies achieved since 1989. Together, these herald an important new, clean form of energy production, fusion assisted by highly loaded metal hydrides—cold fusion or LANR.

At this year's CF/LANR Colloquium at MIT there were 23 presentations. LANR nanomaterials headlined the talks, only to be surpassed by patent issues, Rossi's contribution and recent high technologic developments in LANR. Plenary lectures in LANR were delivered by Dr. Mitchell Swartz (JET Energy), Prof. Peter Hagelstein (MIT), Dr. Brian Ahern (Vibronics), Prof. Xing Zhong Li (Tsinghua University), Dr. Francis Tanzella (SRI International), Prof. George Miley (University of Illinois-UC) and Robert Smith (Oakton International Corporation). Another eight presentations were given, followed by group discussions of the Rossi matter, present LANR/CF business opportunities and the U.S. Patent Office quagmire. This year's event proved successful, according to the 70+ attendees who gathered for the two-day conference.

Part 1 (*IE* #98, http://www.infinite-energy.com/images/pdfs/LANR2011Colloq.pdf) focused on the background of the colloquia and highlighted three plenary talks from Saturday's session (two by Swartz and one by Hagelstein). In this second report, the remainder of the plenary talks and shorter presentations will be discussed.

Saturday, June 11

Prof. Xing Zhong Li presented "A Clean Nuclear Energy Using Hydrogen and Condensed Matter Nuclear Science." Conventional nuclear energy systems are accompanied by nuclear radiation, consisting of neutron and gamma radiation and potential nuclear contamination.

Li has focused on pioneering work in LANR/CF over the past twenty years because it can transform hydrogen into nuclear energy and avoid potential nuclear contamination. Theoretically, he notes that both nuclear fission and nuclear fusion are heavily reliant upon nuclear resonance involving thermalized neutrons, precisely because the resonance enhances the cross-section of the nuclear reactions.

Li has focused on six reactions (d+t, d+d, d+^{3}He, t+T, t+^{3}He and p+D) used as examples of resonant tunneling through a thermalized proton model. He reasons that, indeed, the resonance of thermal protons might play a similar, key role in enhancing the cross-section of nuclear reactions in LANR/CF. There, a greatly enhanced tunneling through the Coulomb barrier, due to the resonance involving thermal protons, results because of the wave nature of the thermal protons inside the metal-hydrides.

Li began with the identification of low-lying nuclear energy levels which might be in possible resonance with thermal protons inside the loaded metal-hydrides. He notes that lithium-6 has a large cross-section with thermal neutrons, making it a likely candidate for possible resonant tunneling via thermal proton in a p+^{6}Li fusion reaction. The primary calculations of the proton resonant tunneling are shown to overlap the p+^{6}Li fusion cross-section data. Furthermore, Li noted that there is indeed a low lying energy level for p+^{6}Li, which may match the energy levels inside the metal-hydride. This suggests fusion products of p+^{6}Li reactions should be sought inside the loaded, active metal-hydrides. Consistent with this, experimental data indicates that the ratio of isotopic abundance (^{7}Li/^{6}Li) in the palladium hydrides deviates from the natural ratio beyond the expected experimental error.

In conclusion, Li noted that there is good evidence of a possible p+^{6}Li fusion reaction due to resonant tunneling of thermal protons inside active palladium hydrides, without neutron or gamma radiation.

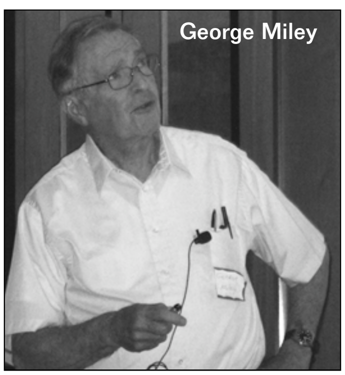
In his first lecture at the Colloquia at MIT, Dr. Francis Tanzella [with Dr. Michael McKubre] reported on their "Helium Progress and Energy Measurements from Exploding PdD_x Wires at 77°K." These studies use a thin palladium wire and an applied axial voltage similar to the Celani and Tripodi experiments. The studies are done in liquid nitrogen at 77°K, and the heat produced is related to the amount of liquid nitrogen that is converted into gaseous nitrogen. Only small, safe samples of palladium are used because of the possibility of explosive release of deuterium fusion energy. A large pulse of current (10 A) causes the thin Pd wire to either break at a weak point or to disintegrate ("explode"). The calorimetry has an accuracy of about 0.06 J; excess energies as large as 1.26 J have been measured. Excess energy in every experiment was observed when palladium was codeposited at high loading onto a thin palladium wire. Positive results were seen in the case of NiH experiments with codeposited Ni. Measurements of helium-3 and helium-4 are planned for future experiments.

Prof. George Miley presented "Next Generation Nuclear Battery Using D-Clusters in Nano-materials." Nuclear batteries using radioisotope sources have a long history of development for special uses where ultra long life, maintenance free, low power batteries are needed, such as space travel. Miley is developing a radical new nuclear battery termed a low-energy nuclear reaction (LENR) power cell based upon LANR/CF technology.

Observations of low levels of MeV particle emission, combined with nuclear transmutations and excess heat generation, provide basic evidence for nuclear reactions occurring in multi-layer thin palladium (Pd) films after deuterium (D) loading. These results, combined with recent observations of localized D/H condensation sites, have pointed the way for Miley to this remarkable new type of nuclear battery. The localized D condensation sites in Pd, actually D condensed in dislocation loops, are achieved by cyclically loading and unloading D in thin film Pd. SQUID measurements plus temperature programmed desorption show that localized D clusters are condensed in defects with densities ~10^{24}/cc. Once trigged, these D clusters lead to large local nuclear reaction rates. The "side" radiations emitted (protons, alphas and X-rays) are low level and not very penetrating (do not escape the cell structure) and no long-lived radioactive reaction products are observed.

Miley's design offers a "green" nuclear battery technology if material issues such as attaining a very high defect packing fraction can be achieved.

Miley also noted the connection of the "D-cluster LENR nuclear battery" to his earlier Ni-light water LENR work and the Rossi Ni-H_2 cell. The work Miley did some years ago with the late Jim Patterson (and others in Jim's cold fusion company, CETI) involved the then widely publicized 2 kW "Patterson Cell" which used light water-Ni or Ni-Pd composite electrodes. When Patterson asked Miley to study this cell, Miley found in his lab tests that it produced 2 kW as advertised (at that time there were doubts and much speculation in the cold fusion community about Patterson's claims since, like Rossi, Patterson did not disclose details because CETI was privately funded). In view of his duplication of Patterson's impressive excess heat results, Miley went on to study the reactions involved. He carried out a detailed study of the trace elements formed in the electrodes after many hours of run time. This disclosed that much of the energy released was associated with nuclear reactions (transmutations) versus conventional fusion reactions, the latter being hard to understand with light water. [These results are well documented in papers given at a number of ICCF meetings.] Miley then told how he used a plasma sputtering method to make "improved" thin film Ni and also Pd/Ni electrodes with minimum defects and voids versus Patterson's "rough" electroplated electrodes (void riddled when viewed under a scanning electron microscope). However, to Miley's surprise, electrodes did not produce nearly the power Patterson's did. Later, Patterson tried to make more of his electroplated electrodes when his original batch ran out. Unfortunately the new ones did work well—due to some mysterious uncontrolled metallurgy involved. (Similar to what Martin Fleischmann said about his thick Pd electrodes—if one from a batch from a supplier worked, all from that batch would. But if one didn't, the others would not either. Therefore, some "uncontrolled" factor in the manufacturing process seemed to cause different batches from the same company to behave differently in Fleischmann's cells despite use of strict protocol to maintain similar run conditions. However, despite Fleischmann's prodding, the manufacturers could never uncover what caused the "random" behavior. At the time some critics accused Fleischmann of not telling the truth about this—trying to hide the secret of his electrodes.) As time went on Miley said he concluded that the problem was that most reactions came from small local sites—probably associated with defects and voids in the materials. He concluded that these local voids and defects were the key to the non-reproducibility problem (in Patterson's this would explain why the "void riddled" electrodes worked so much better than Miley's minimum defect version, and in Fleischmann's case, the cause for the random production of "reactive" thick electrodes). In addition, other evidence of localized reaction sites was mounting in Miley's view, *e.g.* small crater-like hot spots and localized charged-particle traces in CR-39 film that he (and many others) observed in various LENR experiments. These observations then led Miley to an extensive search to find ways to create local defects of the type that could "host" D-clusters (local reactive sites) as described in the main part of the presentation about the D-cluster battery.


George Miley

Miley also noted that in addition to the creation of LENR reactions, MeV D beams can be created from the D-cluster electrodes when they are hit with a Petawatt laser, as demonstrated in recent experiments at the TRIDENT laser at LANL. This provides an important route to fast ignition of inertial confinement fusion targets. Fast ignition using energetic MeV electrons or protons is a popular approach to laser fusion reactors (hot fusion) under study at all major laser fusion labs worldwide. The D-beam version would have some advantages, including added fusion as the D ions interact with the target fuel in the process of heating up a central "hot spot" where the fusion burn starts in the fast ignition approach. He noted that hydrogen clusters (much like D-clusters) are also a potentially attractive approach to hydrogen storage in metals. Thus Miley believes that the cluster technology offers "triple usage"—LENR power, hot fusion and hydrogen storage.

In his second lecture on Saturday, Prof. Peter Hagelstein presented "Progress in Modeling Excess Heat in the Fleischmann-Pons Experiment." He detailed his most recent results, garnered from his long term efforts, of modeling the nuclear-phonon-lattice energy and momentum transfer processes in cold fusion/LANR experiments. His approach derives from an examination of many different experimental results, such as the two-laser experiment of Letts and Cravens. His presentation, like his analysis, began by focusing on aspects of excess heat production in the basic Fleischmann-Pons experiment, with the goal of developing a consistent model for the observed excess heat without commensurate energetic particles.

Hagelstein noted that ^{4}He is produced in amounts commensurate with the excess energy in Fleischmann-Pons experiments, and has been observed repeatedly in the off-gas. Dividing the excess energy produced by the number of ^{4}He atoms measured leads to an estimate of the reaction Q-value in the range of 20 MeV to 50 MeV in different experiments. The interpretation suggested for the large variation in Q-value is that the reactions occur at different distances from the surface (in the 100-500 nm range), so that different fractions of the helium produced diffuse to the surface to enter the gas phase. In two measurements (one done at SRI and one done at ENEA Frascati) substantial efforts were 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 ^4He atoms is 24 MeV, within <10%. This is significant since the mass difference between two deuterons and ^4He is 23.85 MeV, which is consistent with candidate proposed reaction mechanisms based on two deuterons combining somehow to make ^4He. This is in contrast to the situation in hot fusion, where two deuterons are observed to react to produce primarily p+t, and n+^3He, in roughly equal amounts.

Now, if the ^4He is produced in a new kind of reaction, it seems reasonable to ask the question how much energy is the ^4He (also called an alpha particle in connection with a nuclear reaction) born with? In conventional nuclear reactions one can learn important aspects of how a reaction occurs from the kinetic energy of the products. In the case of the final state p+t channel of the conventional d+d reaction, the p has about 3 MeV and the t has about 1 MeV. This is consistent with a Rutherford (billiard ball) picture reaction involving two particles, where conservation of energy and momentum results in the energy being divided up according to the inverse mass. If we can determine the energy of the alpha particle in the Fleischmann-Pons experiment, then we might be able to determine what recoil partner is present in a Rutherford picture reaction.

As it turns out, the deuterium in the PdD can serve as a serendipitous detector of alpha particle energy. If the alpha were to have an energy near 10 MeV, then some significant fraction of the time it would disintegrate a deuteron, leading to an observable energetic neutron. Even if the alpha has on the order of 10 keV, a collision with a deuteron can give the deuteron enough energy to cause a subsequent d+d reaction, resulting in an observable 2.45 MeV neutron. So, if you measure the number of neutrons produced when an energy burst occurs, then you can know how much energy the alpha particle is born with. From a survey of a great many experimental papers, it is possible to estimate an upper limit for the yield of about 1 neutron per 100 J, which is a very low neutron yield. The best estimate for the upper limit of the alpha energy is about 7 keV, but to be conservative the upper limit for the alpha energy is reported as bounded by 20 keV.

This is interesting for a number of reasons. One reason is that there is no two-body final state reaction channel in the Rutherford picture that can lead to such a low alpha energy for a reaction Q-value of 24 MeV. One can even go further and rule out all Rutherford picture reactions with three or four final state products. In essence, this result tells you that whatever is going on, it produces a very slow ^4He, and in doing so works in a way that we have never seen before in any nuclear reaction.

Given that all proposed conventional Rutherford picture reaction mechanisms can be faulted as inconsistent with experiment by the arguments above, Hagelstein next discussed ideas about what new kinds of mechanisms might work. The big problem is that a large reaction energy quantum must be dealt with, and if not converted into kinetic energy, then where does it go?

The general approach followed by Hagelstein has been to seek mechanisms that result in the fractionation of the large nuclear quantum into a great many smaller quantum, such as optical phonons or plasmons. The basic phenomenon is well known in the literature, at least qualitatively. In the spin-boson model (which has been widely studied, with applications in NMR and cavity QED), identical two-level systems are linearly coupled to an oscillator. In the multiphoton regime of this model, coherent energy exchange between the two-level systems and oscillator is found, consistent qualitatively with the effect being sought. If we try to use this model to fractionate a large nuclear quantum, we find that we can in principle exchange energy coherently with an oscillator as long as less than 50 oscillator quanta make up the two-level system transition energy. Of course, since there is no oscillator in the physical system that can satisfy the constraint, we conclude that the spin-boson model cannot do the job.

This leads to the question of why coherent energy exchange in the spin-boson model is limited to only a modest level of fractionation. If one analyzes the model in the weak coupling limit where perturbation theory can be applied, one finds that coherent energy exchange is limited by massive destructive interference between the different paths through which coherent energy exchange can take place. If this destructive interference could somehow be broken, then the effect could be much stronger.

By ICCF9 in 2002, a solution had been found to the problem. The addition of oscillator loss near the two-level transition energy to the spin-boson model eliminates the destructive interference, resulting in a new kind of model that describes coherent energy exchange under conditions of fractionation. An explicit computation in perturbation theory shows this effect most cleanly, as the loss modifies pathways going through intermediate states with an energy less than the initial energy, but has little effect on the intermediate states with an energy greater than the initial energy. In recent years, approximations have been found that allow for the estimation of coherent energy exchange rates in the strong coupling regime, and the results show that efficient energy exchange is possible even under conditions of extreme fractionation. An examination of the physical system shows that many loss channels are present in PdD that satisfy the requirements of this new model. In the strong coupling limit, a scaling law was found in which the rate of coherent energy exchange is inversely proportional to the square of the number of quanta exchanged, which is a slow and favorable scaling.

Now that a model has been developed that is capable of accounting for the most basic aspect of energy production in the Fleischmann-Pons experiment, Hagelstein turned his attention to the development of models to describe the effect explicitly. The simplest model of this kind might be one in which the $D_2/^4He$ system is thought of as an equivalent two-level system that is coupled to optical phonon modes. If we attempt the development of a lossy spin-boson model for this system alone, we quickly find that we are unable to get into a regime of sufficiently strong coupling to fractionate the 24 MeV quantum. The first and most straightforward approach to develop a model for the excess heat effect fails.

To remedy this, Hagelstein described more complicated models in which two different sets of two-level systems are coupled to a common highly excited phonon mode (there are many phonon modes present in the physical system, which is bad for the models generally, but if one is highly excited then the system can behave as if only one mode is present). One is weakly coupled, representing the $D_2/^4He$ system as a donor of excitation; and one is strongly coupled, representing a second nuclear system, that receives the excitation, fractionates the large quantum and exchanges energy coherently with the oscillator. This donor and receiver model has been analyzed, and it seems to meet all of the requirements mathematically to model new reactions of the kind needed to account for excess heat in the Fleischmann-Pons experiment. The reaction rate is found to be linear in the coupling matrix element for the $D_2/^4He$ system, as opposed to quadratic in the coupling matrix element as occurs for incoherent reactions. Since the associated matrix element is very small because of tunneling through the Coulomb barrier, having it appear in the reaction rate only once, instead of twice, results in the possibility of the associated reaction rates being tens of orders of magnitude larger.

Hagelstein related that a reviewer last year wanted to know precisely which transitions and what matrix elements were involved, because he was certain that the effects under discussion were too weak to produce the effects needed. Now, most of the research effort over the past few years has been spent on analyzing the lossy spin-boson and related models to understand how they work, while earlier efforts at identifying the receiver system had not been successful. Optical phonon modes in the THz region are implicated in the two-laser experiment of Letts and Cravens. But the receiver transition had not been identified. Motivated by the comments of the reviewer, a major effort was put into sorting through a large number of candidate receiver transitions to see if any of them could do what was required in the model. Several hundred transitions were assayed, and in the end, none of them were found to work. An unfortunate result, but a result nonetheless; which meant that the donor and receiver model based on two-level systems was not going to account for excess heat in the Fleischmann-Pons experiment, in spite of the fact that it was capable of doing the job mathematically.

The issue of what transitions can be good receiver transitions was seemingly settled recently based on a number of observations. One observation is that in the donor and receiver model with two-level systems, it was found that the receiver was capable of a subdivision effect as well as a fractionation effect; the receiver transition energy didn't need to be matched to the donor energy, instead many (identical) receiver transition energies needed to add up to be roughly the donor energy. Hence, the receiver transitions could be at much lower energy. Another observation is that the receiver lifetime must be long in order for the overall system to be efficient, consistent with experimental results generally showing the absence of (any) gamma emission commensurate with energy production. Weak gamma emission from long-lived metastable transitions seems possible, such as the 12 J of near-90 keV gamma emission from 109 Ag observed by Gozzi *et al.* in connection with 9 MJ of energy production, which would be consistent if the rate of fractionation were roughly one million times faster than the rate of decay of 40 second half-life metastable level. The big issue is that the obvious candidate receiver transitions do not couple to the lattice as two-level systems. Instead, lossy three- or more-level systems are needed to describe the receiver transitions.

Hagelstein summarized recent work showing that the lossy three-level model was capable of efficient coherent energy exchange under conditions of fractionation. This opens the door to a new set of models that are much more closely matched to the physical system. Receiver systems that have the best energy match to the $D_2/^4He$ transitions were presented for the PdD system, as well as receiver systems best matched to the $HD/^3He$ transition for the NiH system. It was proposed that the coherent energy exchange effect might be observable by itself in a different kind of experiment. For example, oscillator excitation might be most easily converted to nuclear excitation in nuclei with the smallest transition energy from the ground state, the lowest energy transition of which occurs among the stable nuclei in 201 Hg at 1565 eV. One could imagine a controlled experiment in which mercury is encorporated near the surface of a metal sample, and then compressional vibrational excitation imposed. If coherent energy exchange occurred, the lowest level of 201 Hg would be excited, and X-ray emission near 1565 eV could be observed. If the nuclear excitation were phase coherent near the surface, which could occur with specific highly excited vibrational modes (such as the lowest compressional mode), then the X-rays could be collimated (due to a phased array dipole radiation effect). Hagelstein noted that Karabut had reported precisely such an effect at recent ICCF conferences, and that Karabut's X-rays might well be a fundamental experimental demonstration of vibrational-nuclear coherent energy exchange. To prove it, the effect would need to be replicated under conditions where mercury was controlled.

Robert Smith, Jr. presented "Concept for Design and Simulation of a Gas Cooled Cold Fusion Reactor (GCCFR)." His major focus has been to develop a conceptualization of the necessary steps between laboratory experiments and implementation of that theory to the research, development, test and evaluation (RDT&E) of a GCCFR that utilizes deuterium coolant as fuel and that would replace a fission nuclear reactor in the primary loop of a nuclear power plant. A secondary purpose is to discuss the procedures required to develop a gas pressurized reactor versus an electrolytic reactor to provide a system that would have reliable potential applications for the U.S. military and space organizations.

Smith focused on specific objectives of these advanced CF/LANR systems which would include developing a closed gas primary loop, preventing quenching of fusion reactions and producing controlled, long endurance power levels equivalent to fission reactors. This is required to produce a safe, radiationless, commercial nuclear reactor without significant radioactive waste.

To accomplish this task, Smith taught what was required. First, his criteria begins with an estimated required energy production rate necessary for the task being a fusion reaction rate ten times the reaction rate of a fission reactor. This is because of the Carnot (in)efficiency in converting excess heat to electricity. Second, in the core, palladium and other LANR materials are used as LANR plates in sufficient number to provide adequate host energy as excess heat to produce the required heat, to be converted to electricity, for the primary loop. Therefore, the design of an LANR core must prevent degradation of all core materials because the reactor core is the key component of a primary loop. Smith continued by teaching the need for the host LANR configuration to be maintained, and the importance of avoiding quenching of the desired reactions. Third, he discussed in general how heat from cold fusion/LANR reactions must be removed to prevent melting of the core. Smith has pioneered the suggestion of the use of the deuterium fuel for the reactor to also be used as coolant. In that mode, coolant flow must not interfere with diffusion of fuel deuterium through the host metal lattice.

Smith presented his design, where holes are placed strategically within the fuel elements so that they will provide sufficient gas cooling to prevent melting of core LANR materials. This is a potentially serious matter since eddy currents of gas might increase the probability of the LANR fusion reactions or their quenching. Therefore, LANR bulk materials and structures must be carefully designed to provide adequate diffusion conditions for both fusion and cooling, through engineering of the coolant flux tube diameters, angles, number and length.

Smith showed that a complex computer simulation is required for understanding practical core design, consistent with the fact that there are many variables that must be considered simultaneously in order to optimize the system. The simulation requires partial differential equations describing required conditions within the reactor core. He suggested utilizing the extensive computer codes that have already been developed for fission reactors that could be modified for a gas cooled LANR reactor.

Robert Smith, Jr.

Smith concluded with final observations about the need for verifying the predictions of this engineering for RDT&E of reactors and for using them to predict possible LANR reactor quenching mechanisms, which can be identified and eliminated by using the computer simulations. Centrally important is the need for significant funding to enable engineering design and computed simulations of GCCFR, but funding opportunities might be enhanced by simulation models that meet operational requirements.

Dr. Brian Ahern presented on "LANR Nanomaterials and Anharmonic Systems." Such 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. He believes the LANR excess heat results from energy localization produced by nonlinear (anharmonic) motions and forces in nanometer sized materials. He said these kinds of effects produce bursts of energy and he again showed unusual behavior.

Ahern has identified and focused on a novel energy exchange mechanism that results in a new form of energy that was demonstrated in three Japanese laboratories in 2009. Last year, he demonstrated this mechanism at the 2010 CF/LANR Colloquium at MIT with a multiple pendulum to illustrate the effect. This year he demonstrated it with slides of anomalous anharmonic behavior. The anharmonic, newly-discovered vibrational modes at the nanoscale release nuclear binding energy from hydrogen. Hydrogen nuclei dissolved in certain metals initially undergo large amplitude, low frequency oscillations that bring the nuclei into close proximity. By nanostructuring such metals at the 3-12 nm size regime, those vibrational modes are further increased to a chaotic level where this new class of "nuclear-inspired" LANR reactions result. The energy released can be amplified by external excitation methods such as ultrasonic agitation and/or high voltage discharges and other methods.

Ahern believes that a theory proposed by retired MIT Prof. Keith Johnson helps to explain both CF/LANR and the superconducting properties of PdD, which are related to each other through anharmonic effects that are present in both PdH and PdD and which create what is referred to as a "Jahn-Teller" effect and the anomalous isotope shift in the critical superconducting temperature T_c, and the anomalous diffusivity of D over H, that both occur in PdD.

Dr. Mitchell Swartz gave his third talk on "Deuteron Flux (flow), Optimal Operating Point Manifolds, and LANR Metamaterials." He emphasized the importance of understanding the underlying role of hydrogen/deuteron flow in materials like palladium and the solutions around it (for loading), and showed how the hydrogen/deutron (H/D) fluxes (flows) could be analyzed by a quasi-one-dimensional (Q1D) model—the Q1D model of hydrogen/deuteron flow in CF/LANR. In particular, in this session, he showed how such proton and deutron flux (flow) in cold fusion explains historical past CF failures, and how it will enable future control of LANR/CF systems. He showed how the Q1D model of H/D flow led directly to codeposition, and to the discovery of optimal operating point manifolds (OOPs) which control excess heat and helium-4 production, and to the discovery that there are two overlapped optimal operating point manifolds (OOPs) coupling excess heat and helium-4 production, and to the development of HAD ("heat after death") control, and to understanding CF/LANR quenching and acceleration.

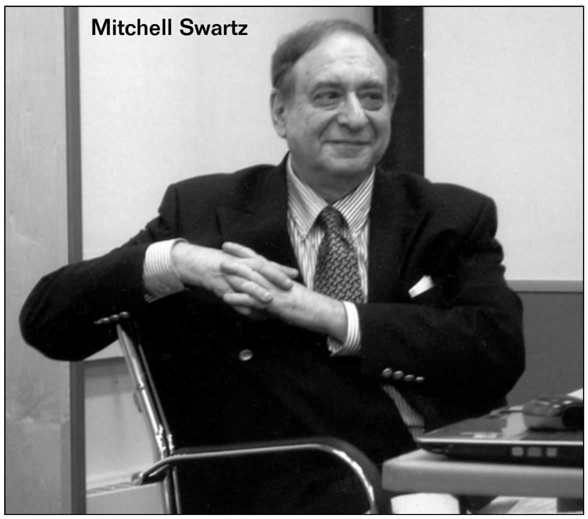
Starting with the Q1D equations of CF/LANR, he discussed how the development of hugely successful, quantitatively accurate, Q1D models of deuteron (and hydrogen) flow in LANR begins with an equation including the influence of electric fields and concentration gradients that influence their flux through metals like palladium and nickel. This is a one-dimensional "flux equation" relating deuteron flow to the diffusion gradient and the applied electric fields. This technique is more powerful than the Nernst equation approach because these equations actually apply in situations that involve non-equilibrium conditions. By deriving flow rates, Swartz derived a hydrogen flow equation which he then demonstrated, using experimental data, explains much in LANR. He began by demonstrating that the equations actually show which LANR experiments have no chance of working, and then show which experiments will quench LANR systems.

Then, using those equations, and adding the transport equations for palladium, Swartz showed that there are three distinctive types of LANR. There is the conventional FP-type, and two types of codeposition, pioneered by SPAWAR and by

JET Energy (Swartz). There are physical differences in the deep diffusion, where Pd is deposited either on palladium (like Swartz) or upon non-loading materials such as copper, gold, silver or platinum (like SPAWAR). 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 then explained how the Q1D equations predict CF/LANR quenching. He used photographs of electrode CF/LANR processes from JET Energy LANR systems along with the Q1D flux equations to demonstrate, in several cases, the key role of solution electrical conductivity in quenching LANR success. Continuing with the same equations, he showed the impact of cathodic irradiation by lasers (incremental LANR/CF power gain goes down even as the excess heat goes up), the impact of applied static magnetic fields, and the result of improved deuteron flux within the palladium of an already highly loaded (D/Pd) LANR system.

Swartz then explained how the Q1D equations led to the discovery of OOP manifolds and OOP operation of CF/LANR systems, one of the richest spin-offs of the Q1D model. The OOP is the location of the maximum value of output power (or other product of CF/LANR, such as helium-4) produced in an LANR experiment in a curve plot of the output power of the CF/LANR device/system as a function of input power. The OOP manifold is the curve which represents all the possible locations of outputs for the CF/LANR system for all possible input powers. OOPs are important because they control CF/LANR output. OOPs are important for several reasons in CF/LANR. First, when excess power is generated from an active LANR sample, these OOP-output graphs in V*I space demonstrate very large increases in output as the input power is varied over a relatively small range. Second, OOP manifold behavior is a general property of most, if not all, CF/LANR systems and is seen on plots of output power, or *de novo* helium-4 or tritium production, as a function of electrical input power. Third, such OOPs and OOP manifolds can be used to compare the responses of heat-producing samples. Swartz explained that OOP operation has engineering use, including distinguishing between system settings where excess heat is produced from CF/LANR inactive settings where this does not occur, finding ways to maximize both reproducibility and LANR output of quantities such as excess heat, and driving propulsion devices in the 1-20 W input electrical power range using CF/LANR. JET Energy systems use that peak LANR performance which occurs for production of heat and other products. Swartz showed how the reality of CF/LANR became indelible to him when he discovered in the data of Dr. Mel Miles that for D in Pd, the two OOPs for the maximum values of the excess power and the amounts of helium that were produced both occur at the same input power. That was followed by more evidence of the importance of the Q1D model of LANR and OOP operation when he showed experimental data which demonstrated that it was that effect which enabled him to develop systems to maximize and control "heat after death" and to observe non-thermal near-IR emission from LANR devices when they were operated at their OOP.


Mitchell Swartz

Using those Q1D CF/LANR equations, Swartz showed the impact of cathodic optical irradiation by lasers, the impact of static applied magnetic fields, and how the experiments bore out the predictions. Swartz showed the results from an LANR experiment where there were applied high intensity magnetic fields in different orientations. The magnetic field caused a 10-15% increase in the resistance of the solution, largest when the applied electric field that is used to create the electrolysis was perpendicular to the magnetic field.

Using those Q1D CF/LANR equations and adding terms for diffusion within the metal, Swartz briefly covered CF/LANR metamaterials (see *IE* #90). Metamaterials have properties that have not been previously observed or expected, but have been observed after the metamaterials are created artificially by structurally shaping the constituents of a material in particular ways. With these metamaterials, shape augments normal material properties. Metamaterials have been used to create electromagnetic cloaking devices, a negative phase and group velocity of light, anomalous reflections and excitations of surface waves, and isotropic lenses. With these LANR metamaterials, a specific shape creates an intrapalladium deuteron flow in the steady state.

Swartz showed how using OOP operation to standardize peak CF/LANR operation, he developed successful CF/LANR cathodes with a particular metamaterial shape, the spiral Phusor®-type LANR cathode. These cathodes have a distinctive open helical geometry and are used in a special high impedance solution to create a unique electric field distribution. That unique E-field results in deuterons being loaded both from the solution and within the palladium, under equilibrium conditions. Unlike other types of LANR devices, in this case there continues a deuteron flux through the metal. He demonstrated how the metamaterial shape and orientation play a decisive role and augment normal material properties by creating an intrapalladium deuteron flow in the steady state. This is requisite for excess power gain.

Swartz closed this talk with the results of two experimentals tests of additional predictions of the Q1D model of isotope flow in LANR. In the first with Larry Forsley, they had successfully investigated the reason for the success of the "superwave" input waveforms that Dr. Irving Dardik has developed in initiating a non-linear LANR excess heat. The Q1D/OOP model did show that the "superwave" creates a transitory variation in input power that appears to activate an LANR-induced OOP peak. In the second with Dr. Bob Bass, they had investigated whether implementing an "Empirical System Identification (ESID) Control" procedure might be predictful in LANR experiments. They discovered that, under certain conditions, the accuracy of the ESID Control procedure varies between 92 to 97.7%.

Edward Tsyganov (University of Texas Southwestern Medical Center at Dallas) closed Saturday's session with his talk on "Cold Nuclear Fusion." His accelerator experiments of various elements have demonstrated that the effective cross-sections of these reactions, in part, depend on what material the target particle is placed within. A significant increase in the probability of interaction occured when target nuclei were imbedded in a conducting crystal. Although Tsyganov feels that observation explains the mystery of CF/LANR, more likely it is spot-on consistent, and the question remains as to why, and how, the lattice changes everything.

Sunday, June 12

Opening the second day of the Colloquium on Sunday, Dr. Mitchell Swartz's fourth talk was on "Early LANR Efforts at MIT," including the Alibagli *et al.* paper which reported their early 1989 experiments at MIT's Plasma Fusion Center. This was later exposed to contain a proven-shifted curve for the heavy water sample. He reviewed the significant flaws in this so-called "negative" paper upon which so many in HeavyWatergate rely and shared new material not seen publicly, previously.

Prof. Peter Hagelstein's final presentation, "Electrochemistry and LANR," was concerned at a high level with the practical issues of developing a simulation model for the Fleischmann-Pons experiment. On the one hand, one needs a microscopic description of the new physical process responsible for the excess heat and helium production (which was discussed in a previous talk); and on the other hand, one needs an understanding of the applied physics, physical chemistry, and electrochemistry of the PdD cathode in the Fleischmann-Pons cell for modeling. The basic message in the presentation is that there are issues associated with the conventional physics part of the problem.

One such issue concerns the formation of D_2 inside the PdD lattice. It has been known since at least 1989 that molecular D_2 cannot form in bulk PdD, because the electron density is too high (which results in the occupation of anti-bonding orbitals, which pushes the two deuterons apart). Hagelstein showed the electron density along the [111] direction, which showed that the background electron density due to the Pd is lowest at the O-site, with a value from a simple superposition model near 0.081 e/Angstrom^3. The background Pd electron density in PdH at the H position is 0.069 e/Angstrom^3, which explains in a simple-minded way why O-site occupation is preferred, since the background electron density is close to what H or D wants to see from Pd. The electron density at the T-site is higher, over 0.12 e/Angstrom^3, which is why H or D prefers the O-site over the T-site. The background electron density of Pd in molecular PdH_2 is much lower at the position of the sigma-bonded dihydride ground state, 0.033 e/Angstrom^3, which is much lower than what is present in bulk PdD.

To arrange for D_2 to form then, it seems one simply needs a way to lower the electron density. One way to do this is to look near a Pd host atom monovacancy as the simplest example. The electron density is lowest at the vacancy site, and goes down to 0.016 e/Angstrom^3 at the vacancy site. Hence, in the absence of any other considerations, one would expect vacancies to play an important role in the Fleischmann-Pons experiment since they provide sites with lower electron density. Dr. Lou Dechiaro carried out some sophisticated DFT calculations and found that D_2 formation was aided by a cage effect near the monovacancy. In a recent set of calculations by Russian researchers, it was shown that H_2 formation near a monovacancy is prevented if one of the other O sites is open.

Hydrogen and deuterium loading is known to stabilize vacancies in Pd. At low loading, the vacancy is unstable by nearly 1 eV (but the associated kinetics that might quench the vacancy is slow below the vacancy saturation concentration near 0.001). At room temperature, one needs a D/Pd loading of about 0.95 to stabilize vacancies sufficiently so that they become thermodynamically preferred. Fukai and coworkers used a high temperature version of this effect in the mid-1990s to form PdH with super-abundant vacancies (one vacancy for every four Pd, to make $Pd_{0.75}H$). When loaded at 0.95 or above, the PdD would like to form super-abundant vacancies as in the Fukai material, but unfortunately the Pd self-diffusion is sufficiently slow that essentially no vacancy diffusion occurs over the duration of the experiment. The highly loaded PdD would like to make vacancies, but it can't.

Hagelstein has conjectured that a small amount of Pd present in the electrolyte, having been dissolved earlier in the experiment, can codeposit when the loading is above 0.95 to produce a massive concentration of vacancies. This seems consistent with the requirement seen at SRI that cathodes needed to be loaded above 0.95 sometime during the loading history to produce excess heat at all. It seems also to be consistent with the Szpak experiment, which in some recent experiments by Letts showed excess heat when the codeposition was done at high current density (consistent with high surface loading), but not at low current density.

This argument underscores the need for high loading in the Fleischmann-Pons experiment, which motivated a discussion of issues involving the modeling of the electrochemistry. One can find in the literature the use of what is termed the "hydrogen evolution reaction" model applied to the Fleischmann-Pons experiment. This model itself constitutes one of the real success stories in electrochemistry over the years, and one can find it described in electrochemistry textbooks. According to this model, deuterium atoms are brought to the surface in the Volmer reaction in connection with the electrochemical current, one deuteron per electron. The deuterium so deposited is adsorbed, meaning that it is on the surface, and it can move to the bulk through an (adsorbed/absorbed) exchange reaction. Deuterium leaves the cathode through molecular D_2 formation, where the molecule exits to the electrolyte. Finally, at high loading the Heyrovsky mechanism provides a route for the deloading of deuterium from the cathode, one atom per electron.

Hagelstein described his efforts to apply this model to published data, and to unpublished data from SRI loading experiments. What was found was that the basic model did not seem to be particularly closely related to the experimental data in important ways. For example, the Heyrovsky mechanism has been proposed in the literature as responsible for the loss of loading observed at high current density in the Fleischmann-Pons experiment. However, in the experimental work of Green and Britz, there is no evidence that the Heyrovsky route occurs in this system. Models that Hagelstein studied that included the Heyrovsky mechanism showed that if one invoked the mechanism to account for a loss of loading in one experiment, then that same model would not permit a substantially higher loading to occur in any other experiment. As a result, if the Heyrovsky reaction occurs in the system, it would have to kick in at a loading above 1.0, since people have observed such high loadings in Fleischmann-Pons loading experiments.

To simplify things, Hagelstein described reduced models relevant to low current density where only the Volmer and Tafel reactions occur, which is termed the Volmer-Tafel regime in the literature. It is possible to extract Volmer-Tafel model parameters from careful experimental results, such as those published by Green and Britz. A headache arises when those same model parameters are used for different experiments in which the same current density and electrolyte molarity is observed to produce much higher loading. It would be possible to develop a new Volmer-Tafel model then for each new cathode and each new experiment, but this seems to defeat the purpose of developing a physics-based model. The question such experiments raise is why should the loading be so different in experiments that seem to be so alike? This effect simply is not described by the hydrogen evolution reaction model taken as a predictive model. Something is missing.

After much consideration, Hagelstein came to the conclusion that this effect could be accounted for by a difference in the internal leak rate. As Dr. Michael McKubre has explained in many public lectures, loading a Pd cathode with deuterium is like blowing up a balloon. If the balloon is leaky, you don't get much air in it. The difference in loading observed in the various experiments is consistent with an internal leak rate that can vary by three orders of magnitude between the best and worst cathodes. The conjecture is that the very best loading is seen in Pd cathodes that have no internal leaks. Such cathodes might have a characteristic grain size that is on the order of the cathode thickness in the case of foil cathodes. More normal cathodes such as that used by Green and Britz would then have a large amount of internal surface where gas formation could occur, with transport routes to the outer surface.

There are more issues in the electrochemical modeling that need to be better understood, including the effect of Li surface adsorption, which is observed experimentally, and the impact of surface contamination at high current density which is thought to be responsible for the observed decrease in loading.

Finally, Hagelstein talked about the need to understand deuterium diffusion in PdD. One can find results for diffusion coefficient for the alpha phase at low loading, and also for the beta phase at higher loading (which is larger). But it seems that the diffusion coefficient in the miscibility gap is very low, and not known particularly well in the literature. To make progress on modeling, this problem will have to be understood better in the future.

Some preliminary results were presented comparing the model results with loading data. In the case where a steady-state version of the model was used, agreement was seen after many hours, but the loading transient was not described well. To accurately model the transient, one requires improved hydrogen evolution reaction models that are more relevant than what is in the literature. Hagelstein indicated that some progress had been made on this problem.

"Experiments in LANR Nanomaterial Systems" was presented by Dr. Brian Ahern, reporting on several of his experimental breakthrough discoveries in metal nanopowders based on Yoshiaki Arata's work using gas loading. Ahern discussed size-related material studies including some of his Air Force and MIT work. He reported his first efforts to demonstrate the new nanoscale energy production by replicating the earlier, more primitive, work of Arata. These are advanced materials which followed the more primitive materials in the Arata LANR/CF system. They are composite materials constructed from 3-12 nm size Pd powders and ZrO_2, similar to those which Arata pioneered to create excess heat, in gas-loading LANR/CF experiments. Uncoated Pd particles tend to agglomerate into larger sizes, and for this reason, the ceramic coating in the $PdZrO_2$ materials is needed to prevent agglomeration of the nanoparticles. Ahern pointed out that he has been using PdNi alloys in order to save money.

To form these materials, a Zr_2Ni alloy ribbon is heated to produce nano-particles of Pd-doped Ni that is coated with ZrO_2. These composite structures have PdNi nanoparticles circa 4% Pd, 65% Zr and 31% Ni. 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).

In these LANR/CF systems, hydrogen/deuterium gas cause the particles to heat up and remain warm indefinitely. The energy production is believed to be related to the proton motion inside the nanoparticles, but it does not produce proliferation materials or long-lived radiation hazards. The exact energy release mechanism remains undetermined at this time, but the energy release is not ambiguous. Five to eight watts of continuous excess power has been observed at 530° Centigrade. These systems are significant but presently believed to be of little commercial value due to its lack of scalability, power gain and other factors.

Ahern has repeated gas-loading experiments that were performed by Arata (using similar materials) and has been successful in creating excess heat six times in a row. Ahern believes that increases in vacancies help to spawn the effect. He said that another factor might be important: diffusion (which is related to loading). He pointed out, in particular, that the diffusivity in the nano-particle Pd powders is nine orders of magnitude greater than in larger Pd crystals.

Dr. Mitchell Swartz's final lecture, entitled "JET Energy Experiments and Research with LANR Nanomaterials," provided an overview of the process of working with nano-structured materials and discussed the nature, behavior and operational domains of LANR nanostructured materials, including those irradiated with ultrasound and incorporated into devices. He presented research results from JET Energy, Inc. which have been successful in producing excess heat using nanomaterial palladium, nickel and newer alloys such as ZrO_2PdNi. He noted 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. However, 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.

Swartz showed photographs and performance data of a number of LANR electronic devices that have CF/LANR nanostructured material positioned at the core of the device. When the nanostructured material is 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. Swartz explained theoretically that this sudden reduction can be attributed to an "avalanche effect" that is typical of the current-voltage behavior that occurs in Zener diodes, and noted that this NANOR device, in principle, could be used in similar applications where Zener diodes have been used (for example, for stabilizing circuits against potential surges in applied power).

Swartz next shared his and Gayle Verner's discovery that certain nanostructured LANR/CF materials are very sensitive to acoustic energy as sound or ultrasound. He developed 2D NANORs which show a delayed, persistent signal of heat secondary to sound, even after the ultrasound is turned off. In contrast to this situation he pointed out that the temperature in normal materials (in control situations, in which there is no heat) drops after the ultrasound is turned off.

Swartz also reported that NANORs in a LANR transistor configuration, driven by two applied electric field intensities, demonstrate LANR heat associated with low level near-infrared emission, controlled by two optimal operating point manifolds.

Jeff Driscoll reported on Dr. Randell Mills' (BlackLight Power) theory on hydrino atoms in LANR. By describing 3D wavefunctions in a more limited 2D wavefunction configurations (so that the 2 π circumference is sort of a "waveguide" with the associated boundary conditions), Mills' predicted levels of hydrogen below the well known ground state, and developed a plethora of secondary mathematical results. Driscoll presented information from his website www.zhydrogen.com, which has demonstrated that those results are close to known important values known in conventional "3D wavefunction" physics.

Keith Owens (Cold Fusion Energy) gave a short talk entitled, "Proposing a Solution on Cold Fusion." He briefly focused on resonance penetration of the Coulomb barrier, and then grounded the theory with experimental observations in metal deuterides and hydrides. He surveyed his interest in the molecular aspects of LANR, from the Rossi E-Cat, to zeolites and his proposed dilithium crystal. Zeolites have a hydrated framework with water in structural pores enabling a variety of applications, including abatement, catalysis, cations exchange and gas separation.

Abd ul-Rahman Lomax (Lomax Design Associates) presented, "Why an Image of the Chimera Heats Up Researchers and Leaves Skeptics Cold," on his analysis of one group of LANR experiments. These were conducted by Michael McKubre and Fran Tanzella at SRI International, for the Electric Power Research Institute. SRI measured the excess power of two paired cells driven in a series electrical circuit, to compare heavy water and light water [the cells known as "P13" and "P14"]. In one of the three runs, the deuterium cell did show a clear excess heat, well above noise, sustained for three days. Lomax concluded that the full experimental record demonstrates highly loaded palladium deuteride can yield a difficult-to-control, but experimentally clear, heat effect. The "chimera" nature of cold fusion is his term for the "poorly understood conditions."

Lomax offered his opinion regarding the response to the paper by Hagelstein *et al.*, presented to the U.S. Department of Energy in 2004. Like many, Lomax noted that positive LANR should have been considered, such as the SRI experiments P13/P14. In fact, the reviewers generally failed to adequately review the underlying published record. Furthermore, the DOE 2004 review panel allowed misconceptions to persist because there was a failure to communicate. One failure may have been the absence at the DOE meeting of LANR scientists who had done open demonstrations at ICCF10 (Dash and Swartz).

Ludwik Kowalski (Montclair State University) presented, "Rossi's Reactor: Nuclear or Not?" His focus was the Rossi system demonstrated at the University of Bologna, which reportedly had excess heat at ~12 kW power levels. Rossi claims that the energy was produced via nuclear fusion of individual hydrogen and nickel nuclei (p+Ni→Cu). Taking the side of the skeptic, Kowalski cited the Coulomb barrier argument that a barrier height of several MeV would appear to make the probability of such fusion negligible. He also stated that the reported accumulation of copper is not consistent with the normal half-lives of such radioactive copper byproducts. The ^{59}Cu half-life is 3.2 s. The ^{61}Cu half life is 3.3 hrs. Their daughter products, the result of their rapid decay, are ^{59}Ni and ^{61}Ni. He noted that only ^{63}Cu and ^{65}Cu would be stable, and then stated, but did not prove, that the natural abundant isotopes of nickel, 3.63% and 0.92%, respectively, is too low to be consistent with the claimed accumulation of 30% of copper. Assuming his own theory is correct, Kowalski purported that the byproducts of Rossi systems should be highly radioactive. But Rossi has noted [as have many others in LANR] that the reaction products are not radioactive several hours after the systems are shut down.

Doug Yuill, from Canada, showed a portion of his gas phase calorimeter and briefly described his work; he introduced his colleague David French.

David French (Second Counsel Services) is a Canadian patent attorney who contributed his guidance, understanding and managing of patents in the LANR field. He treated the Sunday attendees to key points in identifying patent document errors regarding claims and scope of protection. Many sat in rapt attention to his discourse. French recently expanded that with commentary on the forthcoming revision to the U.S. patent law (www.CanadaPatentblog.com).

Bob Weber (Patent Kinetics, LLC) contributed to the patent session beginning with his list of CF/LANR related patent applications (http://www.patentkinetics.com/lenr-patents-and-applications.html). He has been tracking LENR activities beginning with the ICCF10 conference (2003), and later in the discussions involving the U.S. Patent and Trademark Office, and its persistent cover-up of cold fusion patent applications. His diligence is only overshadowed by the fact that some applications have not yet been published, or might be in unexpected "art" categories.

Memorials

Near noon Saturday, the meeting stopped for a memorial session beginning with a moment of silence in honor of Dr. Scott Chubb and Dr. John "Alf" Thompson, who had both passed away this year after contributing so much to both the CF/LANR community and to these colloquia. Both had planned to give presentations to the colloquium this time, too.

During the memorial session, an announcement and presentation was made by Dr. Swartz in memory of Dr. Eugene Mallove. An honorarium of $125 was given as a gift to his son, Ethan Mallove, from the use of a JET Energy photograph of Gene which is to be used in an upcoming new documentary, entitled "Thrive," a feature length documentary that takes a comprehensive look at energy and the state of the world. The movie will show Dr. Mallove as one of the great pioneers having tread in the territory of free energy. The picture selected was taken by Mitchell Swartz just after his experiment, set up to show Gene and *Popular Mechanics* a CF/LANR experiment. It worked. They successfully got excess heat. This was Gene's first time of actually achieving excess heat in cold fusion, so a picture was taken of him next to the aquarium. Gene was so excited that he brought a cake with an inscription and candles to memorialize the moment. During that experiment, Gene convinced Dr. Swartz to take it to MIT for a demonstration. The experimental set-up would be seen thereafter at ICCF10 for the week (http://world.std.com/~mica/jeticcf10demo.html), by *Popular Mechanics*, and later by Brian Josephson. Unfortunately, Gene never lived to see the last two. But with his help, the pursuit of cold fusion has continued, as have the CF Colloquia at the Massachusetts Institute of Technology.

❑ ❑ ❑ ❑