Scientific Overview of ICCF15

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1. Introduction

The research topic which was first and poorly called "cold fusion" has been of international interest since its beginning in 1989. Hence, a series of International Conferences on Cold Fusion (ICCF) has been held on three continents during the past two decades. In recent years, the topic has come to be viewed as part of the larger field of Condensed Matter Nuclear Science; therefore conferences during the last few years have been called the International Conference on Condensed Matter Nuclear Science even though the moniker of ICCF has been maintained. At present, the key reactions are often called Low Energy Nuclear Reactions (LENR), with the main scientific website on the topic being www.lenr.org. But there remains confusion not only about what to call the field, but about the several scientific riddles at the heart of the field.

The dominant scientific question at the core of LENR is how input chemical energies (on the order of electron volts, that is, eV) can trigger nuclear reactions (with output energies of millions of eV). There is a great deal of published empirical evidence now that nuclear reactions can be initiated at much lower energies than previously thought possible. In most cases, either protons or deuterons are put into a solid, and some unexpected effects are observed, notably the generation of energies far beyond what is explicable chemically.

The wide diversity of LENR experiments makes it desirable to have some system for classifying them. One such taxonomy is given in Figure 1. On the left are the sources of the hydrogen isotopes, including liquids, gases, plasmas and beams. On the top are the classes of measurements made in the experiments, namely excess heat, nuclear reaction products, energetic particles or other low energy phenomenon. The topics in Figure 1 were used to organize much of this review, first by loading methods and then by measurement techniques. Other broader topics are also addressed, such as materials and theory.

The design and conduct of LENR experiments are very interdisciplinary, with many types of scientific and engineering skills needed to make defendable measurements. Electrochemical loading was the initial approach to LENR experiments and remains the most practiced. Gas loading is also widely performed and, in the minds of many scientists in the field, is the most likely approach for initial products. Plasma loading is also widely practiced. Papers on these three types of experiments are reviewed in the following three sections. Particle beam experiments are an important part of the field, so the reports on them are noted in the next section. Then, papers on three types of measurements are surveyed in the following sections. Most people in the field believe that materials issues are at the heart of current inabilities to fully reproduce and control LENR experiments. The growing importance of nanometer-scale materials is evidence that the nuclear reactions are occurring in domains with very small dimensions. New instrumentation and protocols are essential to advancement of the field, so the papers on these topics are also reviewed. Many attempts to understand the cause and character of LENR were presented at the conference, and these are summarized briefly in a separate section. Papers that do not fit in other sections are then summarized, along with two round table discussions. The following section deals with documenting rebuttals to critics of LENR. Finally, some of the author's opinions on what is needed in the field, after the reports given at ICCF15, are offered prior to the concluding section.

There were over 100 papers scheduled for ICCF15, actually 62 presentations and 41 posters. The scheduled presentations are available online at: http://iccf15.frascati.enea.it/program/programme.html. The oral presentations and order of presentation varied significantly from the published agenda. A listing of the papers and posters actually presented should be available soon at the same link. This review cannot survey all of the material either scheduled for or given at the conference. Full papers will be available later in the proceedings of the conference and, in many cases, on the web. This review is merely one person's view of the scientific reports at the conference. The categorization of the papers at ICCF15 is also subjective. Most experiments involve one means of loading protons or deuterons into solids and one

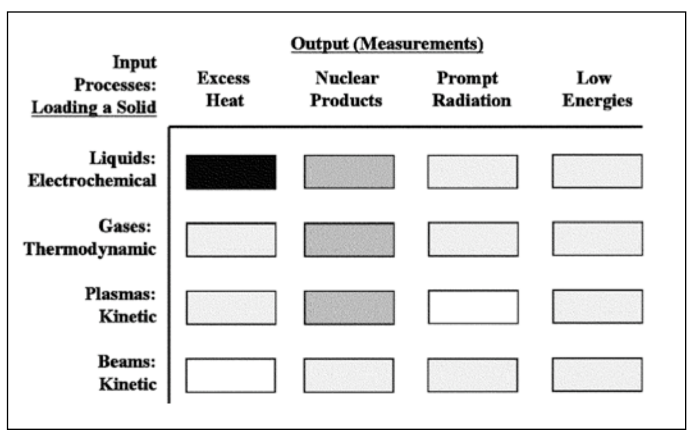

Figure 1. The types of inputs to and outputs from LENR experiments. The darker shading indicates combinations on which more work has been done. Studies of relevant materials and development of theories span this entire experimental space. While broad, this taxonomy does not include all the types of experiments on LENR.

or more measurement techniques. So, should they be classified by the type of loading process or by the primary class of measurement? Papers were put into the following sections in an attempt to recognize their dominant thrusts.

2. Electrochemical Loading

In past conferences in this series, there were usually several papers on the assessment of the fractional loading of hydrogen (H) or deuterium (D) into Pd or other materials, or the correlation of such loading with the production of heat and other effects. The experimental determination of loading was usually done by one of three methods: (1) measurement of resistance ratios, usually in electrochemical systems, (2) the reduction of pressure during gas loading experiments, or (3) the *in situ* measurements of lattice parameters by X-ray diffraction, which is applicable to any loading method.

At ICCF15, several papers reported the results of measuring loading ratios, that is, H/Pd or D/Pd, as a tool for understanding the conditions of materials during LENR experiments. They are cited in later sections. However, there was little attention given to the demonstration or testing of new methods to determine loading ratios in electrochemical or other experiments at this conference. It seems especially important to use electrochemical loading to determine the efficacy of putting more complex materials in LENR experiments. That is, the large base of equipment and knowledge built up in the field for electrochemical loading is a resource to be exploited.

3. Gas Loading

The loading of hydrogen isotopes from gases into solids has two motivations. Such experiments are useful scientifically, and they might lead to the first products based on LENR. There are two broad types of gas loading experiments. One is either static or else involves the flow of gas over and into, but not through, the materials. The interaction of hydrogen or deuterium gas with Pd and other materials in pressure vessels, commonly at elevated temperatures, often leads to LENR. The materials are frequently in the form of nanoparticles for the experiments in recent years. The second kind of gas loading experiment is dynamic, and involves the permeation (flow) of one of the hydrogen isotopes through thin foils of pure Pd or composites containing Pd and other materials. Both classes of gas loading experiments were represented at ICCF15. We review the gas pressurization of materials first, then the H or D permeation experiments.

Arata and Zhang (Osaka University) have performed gas loading of Pd nanoparticles in recent years. Their report dealt with the production of energy and helium in two types of materials—nanopowder ZrO_2Pd_{35} and powder $ZrO_2Ni_{30}Pd_5$. Specifics on the particle sizes were not given. Large samples (about 16 grams) and high pressures (near 15 atmospheres) were employed. Vacuum annealing was used to remove the oxygen prior to experimental runs. Temperature rises indicated the production of excess heat. Three types of cooling systems were employed. The ZrNiPd sample initially gave as much as 8 W per gm of Pd, which then declined to about 1 W per gm over the 800 minute experiment runs with air cooling of the pressure vessel. This was about ten times the output of the ZrPd material. With water cooling of the prototype reactor, there was a similar order of magnitude difference between the two materials, with a peak near 12 W per gm of Pd in ZrNiPd during a run of 400 minutes duration. The deuterium gas from the reactor was mass analyzed with an instrument capable of resolving He from D_2. Helium production was found for both types of materials. As with the heat measurement, the ZrNiPd sample gave more He than did the ZrPd material. That is, there is a qualitative correlation between the production of heat and He.

Gas loading experiments similar to Arata and Zhang's are being performed by a collaboration between Kobe University and Technova. Ten nanometer particles of Pd are being used. Sasaki (Kobe University) gave the first of their two reports. Two parallel experiments, one with hydrogen and the other with deuterium, use nano-sized powders of Pd and Zr oxides. The D_2 gas gave 20-90% excess heat. Excess heats near 2 kJ/gm were obtained with deuterium gas, while the outputs were near zero for hydrogen gas. Takahashi (Technova) then compared the heat production values per D or H atom to those for surface adsorption and bulk absorption. Their LENR experimental values were a factor of several above the chemical values. The experiments did not yield increased gamma ray or neutron detection rates.

Another Japanese collaboration, including the Toyota Central Research and Development Laboratories and Tokohu University, is also studying gas loading. Hioki and his colleagues have determined the loading of H or D into Pd-γAl_2O_3 dispersions. They found that the loading into Pd particles with diameters of 10-20 nm is similar to loading into bulk Pd, that is, the H or D to Pd ratios are 0.74 to 0.78. However, the use of smaller Pd particles with sizes in the 2 to 5 nm range gave remarkable apparent loading values of 2.6 to 3.2.

Kidwell and his colleagues (Naval Research Laboratory) prepared Pd particles about 1 nanometer in size in an aluminosilicate matrix. They performed hundreds of loading and deloading experiments with H and D gas. Use of D produced eight-fold more heat than the use of H. Reversibility, that is, absorption of heat during evacuation equal to the release of heat during pressurization was seen with H and not with D.

Celani (Laboratori Nazionali di Frascati) and many collaborators from Italy have been doing gas loading with samples having a more complex geometry. They coat 50 micrometer wires of Pd that are 60 to 70 cm long with a layer 1 to 3 micrometers thick of Pd-based nanomaterials. At ICCF14, they reported excess powers of 5 W in experiments at 2 to 8 atmospheres and temperatures in the range of 200 to 500°C. The excess power was steady for over five hours. At ICCF15, they presented experiments for which the cell volume was reduced from 3000 to 100 cubic centimeters. However, the change led to contamination problems, so they returned to the larger reactor. Despite problems, the group reported that they have found "a procedure that can be, in principle, the starting point for a CMNS high temperature engine."

Qing and his colleagues (Tsinghua University) gave the results of heating Pd tubes filled with deuterium gas. The tubes were inside of a stainless steel tube that could be heated. Twenty thermocouples were welded to the Pd tubes at 3 cm intervals. Some regions of the tube showed abnormal temperature rises for about 10 minutes, while nearby thermocouples gave normal readings. The amount of excess heat was estimated to be 70 J, corresponding to 13 eV per Pd atom.

Scaramuzzi (LNF/INFN) has long been studying the loading of D into Pd at low temperatures. He reported on an experiment performed at ENEA Frascati in 2002 and published in 2004. Loading ratios near unity were achieved in samples 3.6 micrometers thick at 150 K even with pressures lower than one atmosphere. At ICCF15, Scaramuzzi also proposed an experiment with lower dimensionality Pd materials at the temperature of liquid nitrogen (77 K).

There were also some reports and discussions of permeation experiments at ICCF15. A very interesting situation has developed. The permeation experiment described by Iwamura and his collaborators at Mitsubishi Heavy Industries (MHI) at ICCF9 in 2002 has gotten much deserved attention. They reported the ability to transmute one heavy element into another, notably Cs into Pr and Sr into Mo. That experiment and others by the group since 2002 appeared to be particularly simple and clean, although the Pd foils used for the permeation have a complex nanometer-scale layered structure. The group reported at an earlier ICCF the results of spatially resolved synchrotron radiation X-ray fluorescence measurements, which showed that Pr was localized on the surfaces of the permeation foils. There have been multiple attempts to replicate the results reported by the MHI group. At ICCF15, Iwamura and his colleagues presented new material on the use of nuclear analysis using the reaction $^{1}H(^{15}N,\alpha\gamma)^{12}C$ with a microbeam to quantify the deuteron density near the surface of their multi-layered foils. They also reported the initial results from first principles calculations of the electronic structure of the transmuted elements, specifically Pr.

Kitamura (Kobe University) and his collaborators from Technova gave results of their replication of the MHI experiment. They used both *in situ* and *ex situ* accelerator analyses to study the Sr to Mo conversion process. Apparently positive results were obtained in 8 of 14 runs. However, the Mo peak in proton-induced X-ray emission spectra was not definitive, and there were concerns about the loss of Cs being due to sputtering.

A thorough collaboration between the Naval Research Laboratory (NRL) and MHI also sought to replicate the transmutation results initially reported by Iwamura. Grabowski (NRL) gave the report of the multi-year effort. Many protocols and samples were prepared both in the U.S. and Japan, and analyzed with several techniques. The collaboration was unable to assert that replication had been achieved. After the presentation at ICCF15 by the NRL, Iwamura offered his perspective on what was done and found.

These conflicting reports on attempts to replicate the MHI results are important to the field. Both those reporting replication and those unable to replicate are experienced scientists, who work at well-equipped laboratories. It will be interesting to see if this collaborative line of research continues to be followed in the future, given the current stalemate.

Li and his collaborators (Tsinghua University) did some of the early permeation studies using simple Pd foils. At this conference, they gave two papers, both having to do with permeation of Pd foils, some without and some with nanometer-scale surface coating layers (Pd-TiC-Pd). The foils were inside of a cylinder that could be heated, with the temperature measured using thermocouples. The permeation rate was measured and found to be greater with the coated samples than with the bare Pd foils. In their second paper, the group offered a theoretical explanation of the observations. The model envisions a wave nature for the deuterium flux within the foils, including interference of scattering from the various layers in the coated samples. Afonichev (IMSP RAS) reported that he had permeated a membrane fixed inside of a cylinder. This geometry was similar to that used by the Tsinghua group. Measurements of tritium and helium, as well as metallographic examinations, were made by Afonichev.

Barbieri and his coworkers (Institute of Membrane Technology and University of Calabria) described a model for the purification ("polarization"), that is, the separation of H from a mixture of gases by permeation of self-supported Pd-based membranes. The model was evaluated as a function of many operating conditions, including the upstream molar fraction, the pressures upstream and downstream, temperature, membrane thickness and permeance, and the upstream Reynold's number. Both thin (1-5 micrometer) and thick (about 100 micrometer) membranes were considered.

Three other papers dealt with permeation or gas loading. Santucci and colleagues (ENEA) reported on the electrical resistivity and linear expansion of Pd-Ag permeation tubes 200 micrometers thick. They gave the temperature dependence for both parameters. Tsvetkov and Tsvetkov (Moscow State University) presented data on the excess heat from saturation of Ti with a mixture of deuterium and air. A neutron count rate of 1.7 exp(5)/sec was also reported. David and Giles (Deuo Dynamics) showed the design and results from diodes containing powders of Si and Pd that were pressurized with Ar (the control), H or D. A maximum cell voltage of 1.1 was reported, with the generation of a small amount of energy.

4. Plasma and Cavitation Loading

Besides loading of hydrogen isotopes into metals from liquids and gases, plasmas have been demonstrated to be effective sources of protons or deuterons. As usual, this ICCF included a report on plasma effects on materials within low temperature ionized gases. Applications of ultrasound have also been a staple at this series of conferences. In Rome, there were two papers on insonification of materials during LENR experiments. Since the interior of sonically-induced cavitation bubbles is commonly ionized, the technique represents a form of plasma loading of materials.

Baldi *et al.* (Universita di Roma La Sapienza) placed Pd wires under tension in hydrogen gas at pressures from 18 to 1800 mbar without and with low temperature coronal-discharge plasmas. They measured the loading ratios (H/Pd atoms), resistivity and elongation of the wires. The group demonstrated the ability of the electric field produced in the coronal discharge to perturb the thermodynamic state of the system. Data analysis gave the standard and excess chemical potentials for H in Pd.

Cirillo and his colleagues (Promete Srl, a spin-off company from CNR INFM) advanced a line of research on electrolytic plasmas begun by Mizuno and his coworkers a decade ago. They have data on reproducible production of excess energy. Fauvarque (CNAM Laboratoire des Electrochemie—Paris) and coworkers gave a paper that also reported excess heat in a Mizuno-type experiment. The French group fixed an error in one of their earlier papers, another example of care taken by scientists working on LENR.

Stringham (First Gate Energies) has long contributed results on cavitation loading in heavy water and other effects in various metals. His work, called "sonofusion," is not to be confused with "bubble fusion," in which no solid materials are directly involved. Stringham presented the results of measurements of tritium made in the mid-1990s. About 4exp(15) tritium atoms were produced after a run of 18 hours in a 200 W, 20 kHz reactor containing a Ti target. He also reported the production of thin Ti oxide coating of the target, which reflected the standing wave patterns of the ultrasound (giving colored optical images), and the appearance of long hollow 1 micrometer diameter tubules of Ti (seen in SEM photographs).

Toriyabe and his colleagues (Tokohu University) produced cavitation bubbles on the surface of liquid Li targets during deuterium ion bombardment (with 10 to 80 keV energies). Emission of α particles was measured with a solid-state detector. It was found that the $^6Li(d,\alpha)\alpha$ reaction showed small rate variations synchronized to the ultrasound frequency of 18.8 kHz.

5. Particle Beam Experiments and Associated Theories

The incidence of particle beams on targets is useful for loading the target with protons or deuterons, for probing these hydrogen isotopes that are already within the lattice and for studying the variations of deuterium reaction cross section at low beam energies. Kasagi (Tokohu University) has been one of the leaders in the study of cross sections for deuteron-deuteron reaction cross section at low energies, specifically energies in the range near 1 keV. His group and others found an increasing enhancement of the reaction probabilities as the beam energy is decreased. The results can be interpreted in terms of an effective screening potential, with values up to the remarkable level of 300 eV. Kasagi reported on the measurement of proton to tritium yield ratios that cannot be understood simply in terms of a screening potential.

Jiang and his colleagues (China Institute of Atomic Energy) employed α particles from U decay to bombard deuterium containing Ti targets. They found that the D-D cross sections for α-recoiled deuterons in the metal lattice were 6 to 7 orders of magnitude higher than the conventional cross sections.

There were two theoretical papers at ICCF15 on the subject of enhanced D-D reaction rates at low bombardment energies. Dufour (Laboratoire des Sciences Nucleaires) previously developed a model using a Yukawa potential between nucleons, plus screening by lattice electrons, to explain the enhanced D-D reaction rates. It was found insufficient to explain all of the larger cross sections, so a coupling between deuterons in the lattice was invoked. Dufour's paper at ICCF15 sought to explain cross section enhancements in the 0.5 to 1 keV range of incident deuteron energies.

Work by Czerski (University of Szczecin) and his colleagues in Berlin addressed both the enhanced D-D cross section at low impact energies and the basic mechanism responsible for LENR. Quoting from their abstract: "The enhanced electron screening effect observed in accelerator experiments for the $2H(d,p)^3H$ and $2H(d,n)^3He$ reactions in deuterized metallic targets can increase the fusion reaction rates at room temperature by a factor of 10^{40} compared to the value predicted for the deuterium molecule. However, the domination of ^4He production observed in cold fusion experiments requires a 0+ resonance which should exist in the compound nucleus ^4He very close to the D-D reaction threshold. Theoretical and experimental arguments for such a resonance, its spectroscopic structure and decay modes will be discussed in detail. The interplay between the electron screening effect and the resonant fusion reaction mechanism at room temperature offers a simple explanation of heavy-water electrolysis experiments, which will be illustrated by new theoretical calculations. Importance of proposed effects can also be studied in radioactive decays taking place in different hosting materials. The predicted increase of the decay constant of alpha decays in metallic environments agrees very well with results of the first experiments."

It should be noted that there are four orders of magnitude between the energy of room temperature (about 0.02 eV) and the energies of the lowest beam experiments (about 200 eV). Hence, it is not certain that the enhanced cross section in the beam experiments will connect in some manner with the very large "effective" cross sections needed to explain LENR. But, the work by Czerski and his collaborators is a significant attempt at closing that gap.

6. Heat Measurements and Thermal Effects

Calorimetry and craters provide two very different ways in which to study the effects of heat generation in LENR experiments. The use of calorimeters to measure temperature changes that are due to power production is a central activity in this field. Calorimeters provide time histories of excess power, which is the difference between electrically input powers and those produced by the experiment. The time integral of excess power over the duration of an experiment gives the excess energy.

Many researchers have also observed small craters in SEM photographs of their cathodes after LENR experiments. The craters have morphologies indicative of melting. Formation of such craters requires the brief release of significant energies on or near the surface of the materials. If the energy release rate (power) is too low, it will dissipate by conduction. If it is spatially extended, the very small (micrometer-scale) craters would not appear, that is, they would have to be larger in diameter.

These two lines of evidence for heat release in LENR experiments cannot be simply rationalized with each other. However, both indicate nuclear-level energy releases. Data on heat measurements and thermal (melting) effects were presented at ICCF15.

Mizuno (Hokkaido University) reported a confirmation of his earlier observations that heavy oil heated (T >about 500°C) at high pressure (>60 atmospheres) with hydrogen gas in the presence of a metal catalyst produced heat. Heat generation of up to 100 W was observed for several hours. The experiment is reproducible, but the heat production is not stable. Both X- and gamma radiations were observed, with a "weak" but "reasonably significant correlation between heat generation and radiation emission." Three reasons were given why the observed heat cannot be chemical in origin. At high temperatures, hydrogenation reactions are endothermic, there are virtually no chemical fuels (oxidizers included) in the cell and the excess heats are too large to explain chemically.

Zhang (Chinese Academy of Science) had been studying excess power production in the Pd and heavy water system during recent years. At this conference, he gave two conditions necessary for heat generation: (1) pretreatment of the Pd at high temperatures and (2) using temperature increases during the experiment. He observed that noise on the cell voltage decreased during excess heat generation in galvanostatic experiments.

Karabut and Karabut (FSUE "LUCH") have also been studying excess heat production, and other effects, for years. They gave reports on heat generation, transmutations and X-ray emission from both electrolytic cell (liquid loading) and glow discharge (plasma loading) experiments. In one paper, works on heat generation experiments were given for both Pd-D_2O and Ni-H_2O systems. Excess powers in the range of 5-8 W with 170% efficiency were reported for the glow discharge experiments. Work on transmutations reported at ICCF10 was noted again. The techniques used to assay impurity nuclides (some with isotope ratios varying from the natural values) included spark mass spectroscopy, and secondary ion and neutral mass spectroscopies. In the Karabuts' second paper, the results of X-ray measurements from glow discharge experiments were reported. Many gases and targets were employed in the various experiments. A crystal spectrometer was used to record specific emission bands from various materials in the experiments. X-ray spectra in the range from 0.6 to 10 keV were observed during and, remarkably, up to 20 hours after the glow discharge was extinguished. Beams with small angular divergence were sometimes observed. These results are on the long list of unusual observations in the field.

Turning now to craters seen in micrographs of cathode materials after LENR experiments, Srinivasan (retired from BARC) presented a paper with the title "Hot Spots, Chain Events and Micronuclear Explosions." He examined the possibility that heat generation in LENR experiments is due to very numerous and near simultaneous nuclear reactions, which release enough heat to form the small craters seen by many scientists globally. He estimated that 10^{12} to 10^{14} LENR reactions take place in small regions and short times. If there are 10^{13} nuclear reactions, each of which releases 24 MeV, 40 J would result in the postulated short time. The time constants of calorimeters are much longer, so such high instantaneous powers would not be observed using calorimeters. But, it is recalled that work with temperature sensitive infrared imagers, reported earlier and not at this conference, showed brief hot flashes on cathodes in operating cells.

7. Nuclear Reaction Products (Transmutations)

If the large excess heats that are well measured in many LENR experiment are indeed due to nuclear reactions, then the products of those reactions should be observable. If the key process is D-D fusion in heavy water experiments, then it is reasonable to look for He atoms in the experimental materials after runs that generated excess heat. The measurement of He and its correlation with heat production has a long history in the field. But, if there are nuclear reactions involving elements heavier than hydrogen isotopes, it should be possible to measure elements after experiments that were not there before the runs. Indeed, many laboratories have reported the creation of elements during LENR experiments, that is, the transmutation of one element into another. At ICCF10 in 2003, Miley (University of Illinois) listed 15 laboratories in six countries that had reported evidence for transmutations. Isotope ratios for specific elements, which deviate from natural abundances, have also been published in many cases.

The measurement of transmutations from LENR experiments is very challenging. First, the amounts of the elements that might be produced in such experiments are often small. Second, unexpected elements have often been observed to be spatially localized, with many reports of the new elements appearing in the vicinity of micro-craters that are indicative of both high temperatures and, presumably, large numbers of nuclear reactions in small regions. Hence, it is attractive to use analytical tools, which provide micrometer spatial resolution, such as scanning electron microscopy with an associated X-ray analysis capability. However, that technique does not provide low limits of detection due to its having a high X-ray background. The other problem with searching for the transmutation products of LENR is the possibility that some impurities were present but widely distributed prior to the experiment. Then, they might be below the measurement threshold of the analytical techniques employed to search for those elements in materials before an experiment. But, if the experiment concentrates the impurities spatially, they might be brought into the dynamic range, that is, above the minimum detectable limit of the assay methodologies. Having said all this, there have been reported observations of unexpected elements after LENR experiments that seem to be defendable.

The topic of transmutations was the focus of several papers and much discussion at ICCF15. Since many of the transmutation studies involved gas loading, in particular gas permeation of Pd-based foils, they are discussed in Section 3 above. But, there were other papers at the conference on transmutation measurements.

Dash and Wang (Portland State University) reported the results of scanning electron imaging and microanalysis of Pd cathodes from electrolysis experiments. Rimmed craters were observed and found to contain Ag. The Ag/Pd ratio in the spectra from within the craters varied from 0.04 to 0.23, with an average of 0.15. However, Ag was not detected on the rims of the craters. Neutron absorption by Pd, followed by beta decay to a form of Ag, was postulated.

Kornilova (Moscow State University) and Vysotskii (Kiev National Shevchenko University) gave a new report on a continuing line of investigation. They produce cavitation in oil transiting a small orifice at high speeds due to high pressures upstream from the aperture. Optical and X-ray emissions are measured. They also interact the supersonic cavitation jet with surfaces, such as Ag. X-ray analysis before and after exposure of the materials provides evidence for transmutations.

Many scientists in this field view the transmutation reports as important and worth further investigation, but not entirely convincing yet. When the amount of detailed (and expensive) work on transmutations approaches the large amount of work on heat measurements, then this part of the field might be on an even more solid footing.

8. Emission of Energetic Particles

One of the standard ways to measure the existence and results of nuclear reactions is to record the types and energies of particles emitted from the reactions. For example, in ordinary D-D (hot) fusion, energetic (MeV) neutrons and tritons are emitted in equal numbers, which are 10^7 times greater than the number of He nuclei produced. So, attempts to measure neutrons and energetic tritons have been a major part of the field since 1989.

We now know, in dramatic contrast to hot fusion, that the number of tritons produced in LENR experiments is a small fraction of the number of reactions, and the number of neutrons is another factor of one million or more times smaller. Helium nuclei are the dominant reaction product in many experiments. The numbers of He atoms have been correlated quantitatively with the amount of excess heat in several important past reports. Hence, it is natural to seek to measure alpha particles from LENR.

Lipson (Russian Academy of Sciences) has been one of the few scientists persistently measuring energetic particles in LENR experiments. At ICCF15, he reported the following activities and observations in a summary of results from various experiments:

• D-D reaction enhancement during low energy deuteron bombardment of metallic targets in accelerator and glow discharge experiments (see also Section 5 above).
• Low intensity emissions of D-D reaction products from metal cathodes after D-loading, including 3 MeV protons, 1 MeV tritons and 2.45 MeV neutrons.
• The observation of alpha particles with energies above 9 MeV.
• Measurements of soft (E < or = 1.5 keV) X-ray emission from metal cathodes in pulsed glow discharge and desorption experiments.

Lipson and a large group of colleagues also described in detail the results of desorption experiments in a second paper. Electron beam irradiation of samples of $Pd/PdO{:}D_x$ and TiD_x resulted in deuterium desorption. The widely-used CR-39 track detectors were employed to measure D-D reactions products, including 3 MeV protons and 1 MeV tritons. The samples had very unusual surface morphologies after the experiments. Scanning electron, atomic force and scanning tunneling microscopies were used. Deep craters with diameters of several micrometers and channels 100 to 500 nanometers in diameter were found on the surfaces.

Roussetski (Russian Academy of Sciences) is another longtime contributor to the measurement of energetic particles from LENR experiments, and to the calibration of the plastic detector CR-39. At this conference, he and his colleagues reported on calibration of CR-39 chips and the analysis of chips exposed during Pd deposition experiments at SRI International. They obtained evidence for the emission of neutrons with energies in the 2.0 to 2.5 MeV range.

Bazhutov (Ionosphere and Radiowave Propagation Institute IZMIRAN) and his coworkers had a paper scheduled for presentation at ICCF15 on the shallow pits in CR-39 chips exposed in space. Their earlier work with such detectors on satellites led to the hypothesis of neutral cosmic ray Erzions, which are hadrons with energies near 10 keV. The scientists ascribe the pits in CR-39 as being due to "catalytic cyclic nuclear exchange reactions, which create about 10^6 recoil nuclei of tritium and three carbon isotopes." These particles have been invoked to explain the LENR experimental results of Oriani (retired from the University of Minnesota). In the current research, further measurements of the production of tritium and ^{14}C effects in CR-39 were studied. Calibrations were also performed with beams of protons and nitrogen in the 0.1 to 5 MeV range.

Kowalski (Montclair State University) and his collaborators were also motivated by the results of Oriani. Their electrolytic experiments were done with Ni cathodes in light water, using CR-39 detectors. Preliminary results showed evidence of the emission of nuclear particles, maybe alpha particles. The experiments were not reproducible. Mastromatteo (STM Microelectronics) also sought to measure particle emissions from electrochemical cells. He gave a preliminary report on the use of CR-39 as particle detectors, but did not have positive results yet.

In summary, the reports of energetic particle measurements at ICCF15 added to the body of evidence for such emissions. However, as is the case for transmutations, a great deal of additional work is needed to quantify the types and energies of particles from the diverse kinds of LENR experiments.

9. Materials Challenges

Materials are at the heart of efforts to produce LENR reliably and to scale up their output to levels needed for various applications. But, materials have multiple problems. The most basic challenges are their production, modification and characterization, that is, the measurement of materials composition and structure before, during and after experiments. This is true whether materials are inserted into an experiment or deposited during an experiment. Given the central importance of materials, there was significant attention given to them at ICCF15.

Violante (ENEA), the conference Chairman, provided an overview of an international collaboration that seeks to correlate materials characteristics with excess heat production. His collaborators include scientists at two laboratories in the U.S. (Naval Research Laboratory and SRI International), another in Italy (Universita di Roma La Sapienza) and one in Israel (Energetics Technologies). Since multiple talents are needed to attack a topic which is as intrinsically interdisciplinary as LENR, such collaborations are both needed and likely to increase in numbers. The group employed X-ray diffraction to determine crystal orientation in Pd foils and atomic force microscopy to measure surface roughness. Then, they used the foils as cathodes in calorimetric electrolysis experiments. They find that foils which have (100) orientation crystal faces and particular roughness scales are more likely to produce excess heat. Lecci and his colleagues (ENEA) described the database used to keep track of the many foils and the results obtained from them.

To avoid problems associated with materials preparation and characterization before experiments, there has been continuing interest in LENR protocols that lead to materials deposition during an experiment. This approach is generally called co-deposition. At ICCF15, Miles reported on the investigation of co-deposition systems which he had used earlier in Japan to get excess energy. He is now doing detailed diagnostics on an ammonia-based Pd and heavy water system using cyclic voltammetry and electrochemical impedance spectroscopy. The goal is to measure the reproducibility of excess heat in co-deposited materials.

Most electrochemical LENR experiments involve metal electrodes in aqueous electrolytes. However, there has been some attention in past conferences to solid electrolytes. At ICCF15, Santucci and his collaborators (ENEA) described the production and characterization of a ceramic proton conductor. X-ray diffraction, scanning electron microscopy and electrochemical impedance spectroscopy were the primary experimental tools for characterization of the materials. An activation energy of 0.4 eV resulted from the work.

It seems very desirable to attempt to attract experts on hydrogen in metals to LENR conferences. There are many uses for hydrogen in metals, notably hydrogen storage. A great deal of research has been done on that topic separate from LENR. Much of that work involved complex alloys. It is unclear if the LENR community has adequately exploited the methods and knowledge already available for study of hydrogen in metals.

Much new work on materials for LENR experiments is also needed. The search for transmutation products deals with the composition of materials. The overall study of materials demands attention to both their composition and structure. Determination of these characteristics, especially on the nanometer size scale, is laborious and expensive. But, such measurements are critical to the achievement of understanding, reproducibility, control and maybe exploitation of LENR.

10. Instrumentation and Protocols

There are only a few categories of items needed for a LENR experiment. They include materials, instrumentation and protocols, which are the time sequence of actions taken by the experimenter. Now, we turn to some of the diverse types of instrumentation and protocols that were presented at the conference. The subjects of apparatus and procedures for LENR experiments are very diverse, as these papers evidence.

There were two papers at ICCF15 on calorimeters, a subject of continuous interest in the field. Miles (Dixie State College) and Fleischmann (retired from University of Southampton) described some new approaches to isoperibolic calorimeters. Their goal was to produce instruments that are relatively insensitive to normal changes in the electrolyte level in cells. Four prototypes were made from concentric copper cylinders, the inner one being separated from the outer one by insulation. Motor oil was employed for thermal coupling between the interior glass electrolytic cell and the inner copper cylinder. The design permits operation at high temperatures. The systems were thoroughly modeled. Early tests of the calorimeters gave excellent stability for the cell temperature measurements (± 0.002C) and high precision of ±5 mW (±0.6%) for power measurements up to 800 mW of input power, with a time constant of 40 minutes. The goal for these calorimeters is a precision of ±1 mW or better.

Knies (Naval Research Laboratory) and his co-workers reported on the design and testing of a low-cost, conceptually-simple and sensitive differential calorimeter. Identical sample and reference cells are connected to the same large thermal mass by thermoelectric modules. It is expected that these calorimeters can be replicated for costs of a few hundred USD. They have high sensitivity, linear response, short time constants of 14 minutes and long term stability of 2 mW, are relatively insensitive to ambient conditions and can be customized to diverse experimental conditions.

The report by Dufour (Laboratoire des Sciences Nucleaires) and two collaborators described development and testing of a source of low-energy deuteron beams for experiments on enhanced D-D reaction cross sections. The source is based on a glow discharge. Currents of 600 microamps have been obtained at energies as low as several hundred eV. Roussetski (Russian Academy of Sciences) and his coworkers described the characteristics of a new accelerator for LENR experiments called HELIS. It will produce beams of ions for atomic numbers 1 to 54 with energies of 0.5 to 50 keV and current densities up to 2 A/cm^2. The authors provided a long list of studies that are planned with the new ion source.

One paper dealt with neutron detection and another study addressed X-ray imaging. Angelone (EURATOM-ENEA) provided a review of the main physical laws and basic detection principles for measuring neutrons. Montereali and coworkers (ENAE) presented work on the use of LiF X-ray imaging detectors. These are based on the radiation production of color centers followed by thermally-induced optical readout of the materials.

There were a few papers on methods of materials characterization, including X-ray diffraction for structural measurements, and mass spectrometry, laser-based probes and neutron activation analysis for composition determinations, as well as a report on mechanical testing. Hubler and several colleagues (Naval Research Laboratory) described X-ray diffraction measurements of lattice expansion and phase transformations within active electrochemical cells containing Pd cathodes loaded with H or D. High energy synchrotron x-radiation was used to probe the cathodes with spatial resolution of 20 to 50 micrometers. While the alpha-beta phase transformation was seen clearly, no new phases at high concentrations were confidently determined.

There were three papers on chemical analysis. Apicella and colleagues (ENEA) presented a report on critical aspects of high resolution mass spectrometry for separate determination of D_2 and ^4He in LENR experiments. Caneve (ENEA) provided an overview of laser-based means for chemical characterization of materials. Laser-induced breakdown spectroscopy (LIBS) and Laser Induced Fluorescence (LIF) were featured. Rosada and collaborators (ENEA) presented their results on the use of Neutron Activation Analysis (NAA) for determination of the elements in and on Pd, Ni and Cu cathodes from electrolytic experiments. NAA has been used for several transmutation studies. Bemporad (University of Rome ROMA TRE) and his coworkers presented a report on the combined use of focused ion beams and both micro- and nano-mechanical tests for the characterization of the surfaces of materials in LENR experiment.

Protocols that can induce (trigger) the production of excess power are clearly important. Laser irradiation has been a staple in the field since Letts and Cravens showed six years ago that illumination can initiate or increase excess power. At ICCF15, there were two papers on systematic studies of triggering, one using lasers and the second using mechanical means. Tian *et al.* (CUST Changchun) reported on the results of thorough parametric triggering studies with a 532 nm laser and gas loading experiment. Eleven of their 60 experiments gave "obvious excess heat." The same group also sought to achieve triggering by mechanical changes, specifically altering the pressure in their gas experiments and the rotation (stirring) speeds in electrochemical experiments. They are applying for a patent on their techniques.

Dardik (Energetic Technologies) described the superwave protocol that is used to drive some of the most successful heat-producing electrolysis experiments in the field. The protocol was first employed in the company, and then used at ENEA and SRI International for successful replications. Superwaves have been applied to human health with success. Their applicability to physical and chemical laboratory experiments requires more theoretical understanding.

11. Theoretical Explanations

ICCF15 had more papers on theory than on any other topic. Over 30% of the papers were reports on concepts and subsequent theoretical developments. Some of the theory papers have already been reviewed in an appropriate experimental section above. The plethora of theoretical papers is understandable for two reasons, one a principle and the other practical. Understanding is so central to the progress in science and the exploitation of research results, that many scientists are concerned about the theory of LENR. There are over two dozen rather distinct concepts put forward since the field began in 1989. These are in widely different stages of development now. Few have been compared directly with the results of LENR experiments.

The practical reason for the disproportionate attention to theory is the fact that it requires little money compared to experiments. Computationally-intensive theoretical work does demand very good computer resources. However, that is not the case for most LENR theories at the moment. In the sequence from (1) developing a concept to (2) writing out its equations to (3) evaluating them numerically to (4) comparison with available data or (5) design of future experiments, most LENR theories are not past the third stage.

One of the oddities of this field is the wide variety of observations, some of them quite disparate. A few years ago, this author compiled a list of a dozen types of observations from LENR experiments that indicated the existence of LENR. Some of the classes, like heat measurements, were robust, with many strong reports. Others were quite weak, with only a single, and hence unverified, report, such as the observation of sound emission from cathodes in electrochemical loading experiments. At ICCF14, Hagelstein (MIT) and his collaborators listed five classes of experimental observations in LENR experiments, most of which have subcategories. At this conference, Kim gave the following list of observations, which must be quantitatively rationalized by one or more successful theories:

1. Coulomb barrier between two deuterons is suppressed
2. Excess heat production (the amount of excess heat indicates its nuclear origin)
3. ^{4}He production commensurate with heat production and no 23.8 MeV gamma-rays
4. Production of hot spots and micro-scale craters on metal surfaces
5. Detection of radiations
6. Production of nuclear ashes with anomalous rates
7. "Heat-after-death"
8. Requirements for deuteron loading and deuteron mobility (D/Pd > ~0.9, electric current, pressure gradient, etc.)
9. Requirement of deuterium purity (H/D << 1)
10. More tritium is produced than neutrons

Table 1. ICCF15 theory papers not otherwise reviewed in this paper.

Lead Author	Affiliation	Title or Topic
Hagelstein	MIT	Modeling Excess Heat in the F-P Experiment
Kim	Purdue U.	Bose-Einstein Condensation Nuclear Fusion
Huke	TU Berlin	Electron Catalyzed Fusion
Frisone	U Catania	Probability of Deuteron Fusion in Deformed Crystal Lattices and Micro-Cracks
Cook	Kansai U	FCC Substructure of the Nucleus and Magnetic Interactions Among Nucleons
S. Chubb	Inf. Energy Magazine	Why EM Dynamics Explain the F-P Effect
T. Chubb	Inf. Energy Magazine	Usefulness of Quasi-Particle Ion Band States
Dufour	CNAM	Evaluation of D-D Reactions Rates in Metallic Lattices as a Function of Deuteron Energy
Alexandrov	Lakehead U	Heavy Electrons in Nano-Structure **Clusters** in Solid Surfaces and Interactions with Positive Nuclei
Storms	Kiva Labs	Role of **Cluster** Formation in the LENR Process
Meulenberg	HiPi Consulting	Tunneling Beneath the ^{4}He Fragmentation Energy
Melich	Naval PostGrad School	Oscillatory and Directional Emission Properties of Transition Metal Catalysts
Tasker	LANL	Quantum Mechanical Study of the F-P Effect
Chernov	Tomsk Polytech. U	Plasmon Based Mechanism of Nuclear Reactions in Metal Deuterides
Vysotskii	ElectroDyn Lab. Kiev	Accelerated Low Energy Nuclear Synthesis on the Basis of Correlated States of Interacting Particles
Hora	U of New South Wales	**Clusters** with Picometer Distances of Deuterons
Bressani	U di Torino	Exotic Nuclear Physics: From Cold Fusion to Antikaonic Nuclear **Clusters**
Nagel	GWU	Diurnal Effects in LENR Experiments
Takahashi	Technova	Neutron Spectra in CMNS: Model Predictions & Past Data
S. Chubb	Inf. Energy Magazine	Procedure for Evaluating Theoretical Papers on LENR
Cook	Kansai U	Simulation of Palladium Transmutation Products
Gareev	Joint InstNucl Research	Isomorphism—Structural United Universe
Gareev	Joint InstNucl Research	New Mechanism for Cold Fusion Reactions
Menegus	CNR	Nuclear and Electronic Structure of Atoms
Meulenberg	HiPi Consulting	Characteristic Frequencies of CMNS
Miley	U Illinois	Bose-Einstein Type D **Cluster** Electrode Development
Moagar-Poladian	Nat'l Inst for R&D MicroTech	A Possible Mechanism for Cold Fusion
Tsuchiya	Tokyo Nat'l College of Technology	The Effects of Nuclear Reactions in Solids on Phonon Dispersion Relations
Vysotskii	Kiev Natl. Shevchenko Univ.	Supereffective Nuclear Synthesis on Condensed Targets with the Participation of Monochromatic Beams

It is almost inconceivable that a separate theory will be required to explain each of these observations. This is especially true since some of the observations are already correlated, notably heat and helium production. So, the challenge to theoreticians is to develop theories that will explain all or most of the observations. It remains possible that there is more than one mechanism active in LENR experiments. If so, some of the experimental irreproducibility might be understandable. That is, sometimes, materials or experimental conditions would favor one mechanism and other times, materials or protocols could activate another mechanism.

It would take much more space than is available for this overview of ICCF15 to properly discuss each of the 30+ theory papers. Hence, Table 1 merely lists the lead authors and the subjects of the theory papers at ICCF15 which are not discussed elsewhere in this review. The order of papers in the table is the order in which they appeared in the abstract book.

It would be satisfying to review each of the papers in detail. However, something can be gained by simply examining the table. For one thing, attempts to understand LENR span the globe. For another, there is a remarkable diversity of ideas abroad in the field. However, there is one new situation. Several of the papers deal with clusters of particles of one type or another. The word "clusters" is bolded in the table. Other theories, presented in the past, have also centered on clustering of particles. So, there now seems to be sort of a "wave" of attention to clusters, and also condensates. This is reminiscent of the many papers on coherent phenomena, which were given in the first ten years of the field. Whether these bursts of attention, first to correlations and now to clusters, turn out to be indicative of approaches to successful LENR theories, or else theoretical fads, remains to be seen.

12. Other Reports and Round Table Discussions

Some of the papers presented at ICCF15 do not fit the categories above, so they are reviewed in this section. They involve electromagnetic interactions with surfaces, piezonuclear reactions and emerging interest in fast reactions. Brief comments on the panel discussions are also provided.

A major issue in the field remains the location of LENR. Do they occur on the surface or the interior of materials, and is that distinction worthwhile, or even possible, for very small nano-particles? Since there is a significant body of evidence for surface reactions, attention to optical interactions with surfaces is natural. At this conference, Letts (LettsLab) and his collaborators sought to explain peaks in excess power generation observed as a function of frequency of incident THz radiation. Two lasers were heterodyned to obtain THz frequencies. They found that two of the measured peaks align with phonon frequencies in the PdD system.

Work on visible light interactions with cathode surfaces was also reported in four papers. Sibilia and Bertolotti (Universita di Roma La Sapienza) addressed light localization. Li Voti and others from that group provided both theoretical calculations and experimental results on light scattering. Sarto and coworkers (ENEA) discussed the role of surface morphology and roughness on light enhancement and localization. Castagna and his colleagues (ENEA) provided a model for such interactions.

Piezonuclear reactions result from the rapid deformation and cracking of materials. Their relation to the basic mechanism(s) in conventional LENR experiments is not yet clear. But, they share with usual LENR experiments the ability to trigger nuclear reactions at ordinary temperatures. The relationship was explored in a paper by Petrucci and his colleagues (LFN-INFN). Carpenteri (Politecnico di Torina) and his coworkers reported the results of compression tests of granite. They assert the occurrence of the reaction $^{56}Fe \rightarrow 2\ ^{27}Al$ and 2 neutrons. A great deal of work remains to be done on piezonuclear reactions using advanced instrumentation.

There is other interest in fast LENR reactions. At ICCF15, three other papers dealt with such cases. Papageorgiou (National Technical University of Athens) and Raptis (National Center for Science and Research) presented a paper on fragmentation of thin wires with high voltage pulses. Jiang (Beijing University of Aeronautica and Astronautics) and colleagues addressed the possibility of nuclear transmutation in electrical discharge systems due to the Casimir effect. Tanzella and McKubre (SRI International) gave a preliminary report on calorimetry of pulsed electro-melting of PdD_x wires.

Two round table discussions were held on Thursday, October 8. The first was on Theories and chaired by Dattoli (ENEA Frascati) and Hubler (Naval Research Laboratory). There was some attention to coherent processes, delocalizations, clusters (localizations), resonant tunneling, Bose Einstein Condensation, and superwaves. The needs for quantitative results from theories and experimental testing of theories were emphasized. The second round table dealt with Future Perspectives and was led by Bertilotti (ENEA Frascati) and Hubler. The discussion involved some specific suggestions about what needs to be done. It ranged from bemoaning the current lack of funding and attention to upbeat assessments of how the field is progressing and its prospects.

13. Refuting Critics Quantitatively

Criticisms of LENR are very diverse, ranging from assertions of theoretical impossibility to accusations of experimental errors. They are also communicated in varied manners, sometimes in normal published articles, but other times verbally, in either private conversations or in the media. Criticism is normal and fundamental to science, of course. Nonetheless, it is important for people who think that LENR are a real physical phenomenon to refute criticism, preferably quantitatively and in writing.

There have been only a few papers rebutting the many criticisms of LENR experiments and theories. The earliest was published by Bockris and his colleagues in the *International Journal of Hydrogen Energy* in 1989. It showed that the excess power densities reported from LENR experiments could not be explained by any of eight chemical mechanisms. Another paper, given at ICCF10, showed that energy stored in lattice defects cannot account for measured excess energy.

There were two papers at ICCF15 which addressed specific concerns of critics. Dardik and his colleagues (Energetics Technologies) showed that reported excess powers and energies are not due to errors in the measurement of energies input to their cells. That concern has long been raised by critics, most recently on a major U.S. television news show in April of this year. The group from Energetics Technologies employed fast oscilloscopes, and they increased sampling rates from operating electrochemical experiments. They also sought power spectral correlations between fluctuations in the input and output powers. None of their measurements and analyses indicated that there was any unobserved and unknown additional input power, which could account for their large excess heats and energy gains.

Al Katrib and Nagel (The George Washington University) analyzed published reports of excess heat. They computed the number of eV that would have to be extracted from each water molecule to explain observed excess heat values. The results showed that the energy generated in electrochemical experiments does not originate as some type of transition within the many water molecules in experimental cells, at least for several experiments that give high excess energies.

A review giving all types of criticisms of measurements made in the field, and citing all published rebuttals, would be useful.

14. What is Needed?

The study of LENR, both experimentally and theoretically, has several clear requirements. Some were already cited. In his talk at ICCF15, McKubre (SRI International) listed a set of questions that span both the laboratory and conceptual aspects of the field. They are:

1. What initial hypothesis was proposed?
2. What experimental methods were employed?

3. What results were obtained?
4. How were these results interpreted?
5. What new understanding was achieved?
6. How does this fit in the framework of modern physics?
7. What alternative explanations, or objections have been proposed?
8. How can the objections be countered or incorporated into an improved understanding?

Lipson believes that careful measurements of energetic particles from LENR experiments provide the best way to convince the rest of the physics community of the ability to trigger nuclear reactions with chemical energies. He offered the following list of approaches:

1. Perform complete experiments with simultaneous detection of excess heat, atomic ^{4}He, tritium, charged particles (D-D products and energetic alphas) and neutron emissions, as well as soft X-rays (E < or = 2.0 keV, not characteristic K X-rays from Pd)
2. Search for correlations between excess heat events and emissions of nuclear species and X-rays
3. Employ special electrolytic cells and appropriate state-of-the-art calorimetric and nuclear detection equipment.
4. Use (nanostructured or nanolayered) highly D-loaded cathode samples (Pd-SWCNT-Pd, Pd-Re-Pd and PdO-Pd-PdO) with both enhanced deuterium desorption flux and D-D reaction yield, where SWCNT = single-walled carbon nanotubes.

There are similar needs for theoretical papers in the field. In very general terms, theory has only two functions, to explain the past or to predict the future. Surprisingly, many of the LENR theories have not produced quantitative results yet. And, there have been very few direct comparisons of theoretical calculations with available data, and even fewer cases where an LENR theory was used to design experiments. S. Chubb (*Infinite Energy*) provided a procedure for evaluating theoretical papers on LENR for ICCF15. He listed the following questions, which should be answered in every theoretical paper:

1. What is the form of the reaction (if any) that is addressed?
2. How does the theory treat the Coulomb barrier?
3. Has the theory been written in a way that involves equations?
4. Have the equations been reduced to numbers for some cases?
5. Can anything be said about computational results associated with the theory?

Beyond these conceptual, experimental and theoretical desirata, there is a significant need for better documentation of experiments. Al Katrib reviewed over 300 experimental papers, most of which presented what was done and found in electrochemical heat measurements. The number of papers that provide all relevant information is disappointingly small. Factors that are needed include the time history of excess power production, the total output and input energies (and, by difference, the excess energy), the cell volumes, the material, size and shape of the electrodes, loading ratios, and the temperatures in and around the cells.

There are some additional major and widely-recognized needs in the field. An improved understanding of materials is high on the list. The composition and structures of key materials in LENR experiments must be better understood, certainly before and after experiments and, if possible, during their conduct. This is especially true for cathode materials in electrochemical experiments, whether they be prepared in advance and inserted into a cell, or else produced in the cell before or during experiments.

Diverse modern instruments are now available, which could produce useful data from LENR experiments and their materials. These include high energy synchrotron x-radiation, infrared imagers, various laser techniques, and many others. It should be particularly useful to perform *in situ* Atomic Force Microscope (AFM) measurements in electrochemical cells during experimental runs.

Many people think that nano-scale conditions are critical to the triggering of LENR. In fact, problems with reproducibility might be due to experimenters not using tools that have sufficient spatial or temporal resolution. Hence, the AFM and other tools of nano-technology, and a wide variety of nano-materials, are relevant to future work on LENR. Of course, the use of advanced instruments and materials is expensive, so the lack of funding in the field has been a major impediment to improvements in reproducibility, controllability and understanding.

There remains a major need for parametric studies, and for attempts to make correlations between products of LENR experiments. It has been recognized from the early days of the field that heat production from nuclear reactions will also result in nuclear products of the reactions. The several studies of heat and helium correlation reflect this fact. However, there are numerous other experimental parameters, especially those from the use of advanced instruments, which can be obtained and correlated with quantitative inputs and more conventional measurements. For example, ultrasound and the resulting cavitation are now part of several experiments. But, there do not seem to be any published correlations between the frequency and power of the ultrasound and the performance of LENR experiments.

In his opening talk, Robert Duncan (University of Missouri) stated, "There is ample experimental evidence that suggest that the excess heat effect is real. . .Experiments are needed now to determine if these excess heat levels may be scaled up and obtained at higher heat rejection temperatures." The results of scaling experiments will determine if LENR energy sources will reach levels of kilowatts or higher powers, and thus have wider utility. However, if they produce less than kilowatts, they could still be very useful for powering portable electronics, among many other appliances.

15. Conclusion

Many very high quality studies were presented at ICCF15. Work from laboratories ranging from Mitsubishi Heavy Industries in Japan to the Naval Research Laboratory in the U.S. to the ENEA in Italy, and many other global sites, made the conference scientifically exciting. There seems to be an increase in interest in the field, which parallels and might largely be due to the concurrent increase in the quality of research on LENR.

J. Robert Oppenheimer was quoted as saying, "When you

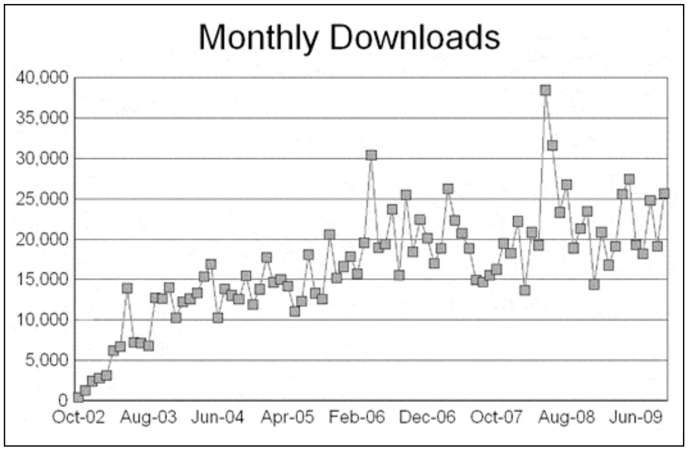

Figure 2. Number of Acrobat files (papers) downloaded per month at www.lenr.org since it began in 2002. The last point indicates October downloads through October 27, 2009. (Courtesy of Jed Rothwell.)

see something that is technically sweet, you go ahead and do it. . ." In the view of many people, probably the majority of participants at ICCF15, the mystery of how it is possible to use eV chemical reactions to trigger MeV nuclear reactions certainly qualifies as being "technically sweet." It is a scientific challenge, the solution of which will likely be recognized as historic. Currently, this is only a scientific problem, which may or may not result in commercial technologies. The empirical data base, now mostly public, shows that the nuclear power sources with the following characteristics might be developed:

• The generators do not have to be big or expensive. However, they might be scalable for larger applications, both mobile, like heavy trucks, and fixed for diverse installations.
• The sources could be distributed, even powering individual homes and, hence, relieving the electrical distribution grid of some load.
• The new sources would be safe during their operation because LENR do not emit dangerous prompt radiation.
• There is ample experimental evidence that LENR do not produce significant residual radioactivity, so generators based on these reactions would not provide dangerous waste.
• No green house gases are emitted during the operation of LENR experiments.

If commercial products exploiting these highly desirable characteristics do result, probably no sooner than 10 to 20 years, a whole new nuclear power industry might develop. The potential impact of LENR sources for production of clean water by distillation of either salt water or dirty river water, and the attendant health benefits, could be momentous.

There seems to be a growing interest in the results of LENR experiments in the broader scientific community. The number of visits to the Wikipedia article "cold fusion" is in the range of one to two thousand daily, or around half a million visits annually. Figure 2 shows the history of the monthly number of downloaded papers from the website www.lenr.org.

What Duncan (University of Missouri) said at the beginning of the conference is a fitting end for this review: "Science is fundamentally empirical, so scientists must always be prepared for surprises that challenge accepted thought. But the Scientific Method, which strives to disprove the hypothesis through experiment, must be followed always, with no exception."

Appendix: Terminology

The following gives a summary of the various names applied to what was initially termed "cold fusion," plus some comments on them and their utilization. [This Appendix is not available in the print version of the magazine.]

Terminology	Comments
Cold Fusion	Original and recognized name, but incomplete
Low Energy Nuclear Reactions	Low is a relative term and unclear
Lattice Enabled Nuclear Reactions	Clear and specific, but very new and little known
Lattice Assisted Nuclear Reactions	Also accurate, but little used
Chemical Assisted Nuclear Reactions	Many chemists like this
Condensed Matter Assisted Fusion	New and little used
Cold Fusion Nuclear Reactions	Little used
Cold Nuclear Transmutations	A Russian favorite
New Hydrogen Energy	A major past Japanese program
Metal Deuterium Energy	A current program in Japan
SANER	SAfe Nuclear Energy Release
Fleischmann-Pons Effect	Clear and encompassing

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