Overview of the 21st International Conference on Condensed Matter Nuclear Science

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The subject of this review was initially called "cold fusion" when it was announced in 1989. It now goes by the name of Low Energy Nuclear Reactions (LENR), although there are about 20 other names for the topic.[1] Condensed Matter Nuclear Science (CMNS) is the more comprehensive name given to the field.

The central empirical feature of LENR is the ability to release nuclear energies (MeV) with chemical energies (eV). That enables the achievement of high energy gains, defined as the ratio of thermal energy from an LENR system divided by the electrical or other energy needed for stimulation of LENR. Gains of over 25 have been measured in strong experiments. A gain of 800 was reported in one paper by a good scientist in Japan, but it has not been verified or repeated.

LENR produce heat, which can be used directly or employed to generate electricity. With sufficient gain, such reactions offer the possibility of sustained power generation. That is, some of the electrical energy produced from LENR thermal energy can be used to generate further nuclear reactions. Naturally, both thermal and electrical energy from LENR can be used for many other purposes.

The current scientific study of LENR is complex and challenging for two kinds of reasons. The first is the number of involved disciplines. The study of LENR requires attention to physics, chemistry, biology, materials science, electrical engineering and nano-technology, among other disciplines. The second is the fact that LENR involves multiple levels of the natural world. That is indicated schematically in Figure 1. Knowledge and exploitation of theories germane to those levels are necessary for development of an understanding of LENR. The focus has to be on the nuclear level if Low Energy *Nuclear* Reactions are to be understood. The nuclear level is also the scale on which it is necessary to consider both Quantum Chromodynamics (the strong force) and Quantum Electrodynamics (the electromagnetic force).

The practical realization of a new clean commercial energy source might prove to be historic. However, it will require substantial investments in research in the coming years. Two primary goals for such research are understanding of the mechanisms that cause LENR and the reliable generation of thermal energy from LENR systems.

About three decades of experimentation have revealed the likely characteristics of commercial LENR generators. The experiments have shown that LENR do not produce significant dangerous radiation during operation. Further, unlike current fission reactors and hypothetical fusion reactors, LENR do not produce significant radioactive waste. Operation of LENR does not generate greenhouse gases.

There is guarded, but reasonable, expectation of commercial distributed LENR generators in the kilowatt range. They would be widely used in homes, offices and factories. Consumers with such sources would have control over, and responsibility for, their energy generation, just as they now have control over their energy usage, for example, their HVAC systems. Distributed LENR generators would avoid brown outs and black outs, and would have the further advantage of being insensitive to cyber or other attacks on the grid.

There are many sources of information on LENR. Several websites are devoted to the topic. One has a library with thousands of articles, many of which can be downloaded.[2] There have been months when the average rate of *downloading* LENR papers from that one site was about one per minute, with over four million downloads to date. A 2009 tally of papers by Rothwell, the keeper of the website, is available.[3] Many papers are available from the International Society for Condensed Matter Nuclear Science.[4] Other websites are also useful resources on LENR, including the New Energy Foundation's *Infinite Energy* magazine,[5] the *New Energy Times*,[6] *Cold Fusion Times*[7] and Cold Fusion Now.[8] Note that some authors and publishers continue to use the original term "cold fusion," rather than LENR or alternatives. Whatever the terminology, a large amount of experimental literature is available, and is open to discussion and criticism. Scientific interest in such information should be more widespread than it is now.

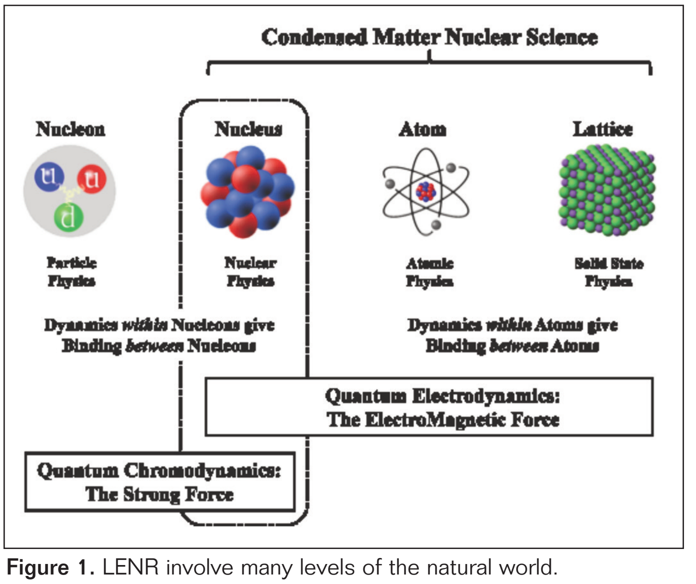

Figure 1. LENR involve many levels of the natural world.

LENR Organizations

LENR is both a challenging scientific problem and a promising new source of clean energy. Hence, it has two major international organizations, one devoted to scientific understanding and the other to exploitation.

The International Society for Condensed Matter Nuclear Science (ISCMNS) was founded by Bill Collis in 2003. It serves as the primary intellectual and scientific group for the field. As noted above, the Society has a useful website with many papers available for downloading (iscmns.org). It also publishes a well-refereed electronic *Journal of Condensed Matter Nuclear Science*. The 21 volumes published since 2007 are available from two locations.[9] The ISCMNS also sponsors workshops on LENR. Information on many of the twelve International Workshops on Anomalies in Hydrogen Loaded Metals organized by the ISCMNS is online.[10]

The LENR Industrial Association (LENRIA Corporation)[11] was founded by us (authors Katinsky and Nagel) in 2015, mainly to advocate for the field and to encourage funding of research on LENR. It publishes annual calendars that feature the people and laboratories from around the globe working on research or commercialization of LENR. The conference reviewed herein was organized by LENRIA. The LENR industrial association is presently focused on improving the scientific, media and public perception of field, with a long view on commercialization.

Both of the two major organizations just noted are global in character. There are also a few national organizations. The oldest of them is the Russian Conference on Cold Nuclear Transmutation and Ball Lightning. The 24th meeting was held in September 2017 in Sochi. The Japan Cold Fusion Research Society (JCFRS) is also continually active.[12] The 18th meeting of that Society was held in November 2017 in Sendai. Programs and abstracts for many of the JCFRS are available,[13] as are proceedings of 14 of the annual meetings of the JCFRS.[14] In 2014, the French Society on Condensed Matter Nuclear Science was founded.[15] It held its first meeting in Avignon during March 2016. The proceedings of that meeting are published in Volume 21 of the *Journal of Condensed Matter Nuclear Science*. All the materials are available online.[16] A second meeting of the French Society (RNBE-2018) was held in Paris during March 2018.

The ICCF Conferences

There have been sessions on LENR at conferences of the American Physical, Chemical and Nuclear Societies, in addition to the national meetings just noted. However, the primary outlet for presentations on LENR has been an international series of conferences held in various countries. The International Conferences on Condensed Matter Nuclear Science have been the main global forum for the field over the decades since 1990. The meetings were initially known as the International Conference on Cold Fusion, with the abbreviation of ICCF, which has been retained. The numbers of participants for the various ICCF meetings are given in Figure 2. Those numbers have some uncertainty due to different ways in which participants were counted in various years. However, they are probably correct to within 10%. They show that the participation numbers declined sporadically for the first 13 conferences, and then leveled out, again erratically, for the past eight conferences in the series. Links to the proceedings of many of the ICCFs are on the web.[17] Proceedings of the recent ICCF conferences are published by the *Journal of Condensed Matter Nuclear Science*.[18]

Organization of ICCF21

While interest in LENR has remained fairly stable, and may soon increase, the money available for support of an ICCF meeting is less than it was earlier. Hence, it was not possible to rely on levels of previous subsidies by various individual, institutional and government supporters in planning ICCF21. Due to this diminished funding trend, the organizers decided to look at alternatives to holding ICCF21 in a big city hotel conference center, as has usually been the case. Many universities offer affordable rates during the summers, when their facilities are underutilized and their student residences are largely vacant. The meeting capabilities of dozens of universities were researched and 15 universities were contacted to learn what they offered for meeting rooms, residences, dining and organizational support. Colorado State University (CSU) stood out among all those that were considered. CSU was found to offer rooms with air conditioning and private baths, outstanding facilities and a very good organization for planning and execution of a conference and its ancillary activities. Further, CSU is located near a major airport hub that features affordable airfare, the Denver International Airport. A contract with CSU was signed in September 2017 for holding ICCF21 during June 3 to 8, 2018 on the CSU Fort Collins main campus.

To control costs, and to provide the greatest cost predictability for attendees, the organizers of ICCF21 endeavored to offer a turnkey conference fee. A single, relatively low registration fee was offered to include the conference, residence, dining, excursions, conference banquet, and transportation from and to the Denver airport. An off-campus option was also provided. To encourage the building and renewal of relationships, and to foster the exchange of ideas between those attending, an evening lounge was also provided as part of the registration package. It gave conference participants a convenient and pleasant place for discussions.

The preparations for ICCF21 involved interacting with two main groups, the staff at CSU and the people who would come to the conference. There were also several third party vendors.

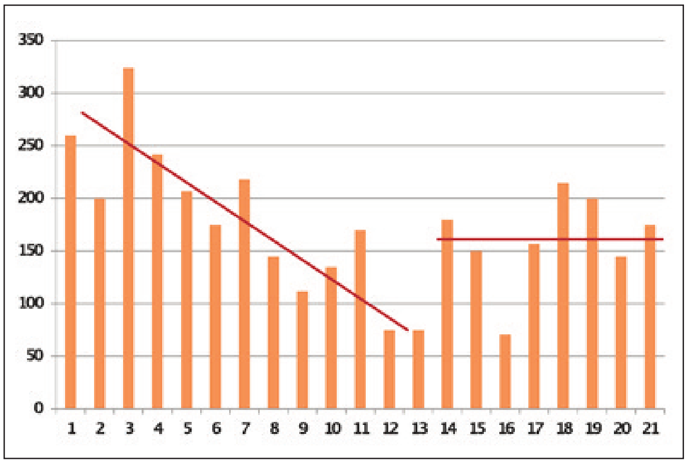

Figure 2. History of the numbers of participants in the 21 ICCF conferences.

CSU has a very good organization to assist in arranging and conducting conferences and events. Our primary contact was Briana Russell, who handled or assigned a wide range of the activities leading up to the conference. Registrations and funding from participants were handled by CSU using their facilities, which were linked from the conference website.

Interactions with potential conference participants started with set up of the conference website (iccf21.com). Once launched, the website was announced on the GoogleGroup devoted to CMNS. The website evolved continually up to the time of the conference. All of the work on the site was done by one of us (SBK) using a commercial website development platform. One of the earliest actions was the Call for Papers. It ultimately resulted in submission of 104 abstracts. That number is typical for recent ICCFs. The content of the abstracts varied widely, as usual, from advances in topics that were already part of the field to ideas and work that were new to the field.

There were two classes of participants in ICCF21. The first was the normal mix of scientists, technologists, engineers and business people. There were 147 such people at the conference, plus a dozen companions. In addition, there was a set of participants who had won scholarships to attend the meeting without cost other than their travel to and from the Denver airport. There were 21 such people, mostly students from the U.S. and six other countries, including three high school science teachers.

The Scholarship Program was the idea of one of us (SBK) motivated by two goals. The first was to introduce new young people to the field, which has an age distribution skewed toward older people, many already retired. The second thought was to enliven the conference by the presence of the young people. The Scholarship Program was announced on the conference website, which also had information on how to apply. There were about 50 applications, of which 42 were approved for funding, and 21 attended. Scholarship Committee Chairman Dana Seccombe screened the applications, with assistance from Florian Metzler and Mathieu Valat. Participants in the Scholarship Program had the opportunity to significantly enhance their knowledge and understanding about LENR. Those who had little prior exposure to LENR were introduced to the field. They also saw how a scientific conference works, as results are presented and discussed. They were asked to complete a survey after the conference. For more details, see the story about the Scholarship Program on p. 9.

Introductory Short Courses have been held on the day preceding some of the recent ICCFs. They serve to provide an overview of the field, which is useful for newcomers to the topic. That was especially germane for ICCF21, which had the Scholarship Program for the first time at an ICCF. One of us (DJN) organized the speakers, topics and times for the short course. They are shown in Table 1. The organization of the Short Course was very straightforward. After the introduction, there were two talks on the primary means of bringing together either protons or deuterons onto or into metals. That process is called "loading." Then, there was another pair of talks on the two most important measurements in LENR experiments, namely heat and elemental products. The field has two main challenges, materials and understanding, so a third pair of talks dealt with them. Finally, there was a presentation on the state of commercialization of LENR energy generators, a part of the field that has widespread interest. As many as 78 people were in attendance, substantially more than usual.

Table 1. The schedule, topics and speakers for the Short Course held on June 3.

Time	Minutes	Topic	Speaker
1000-1040	40	Introduction and Issues	Nagel
1040-1120	40	Electrochemical Loading	McKubre
1120-1200	40	Gas Loading	Biberian
1200-1330	90	Lunch	
1330-1410	40	Calorimetry and Heat Data	Letts
1410-1450	40	Transmutation Data	Srinivasan
1450-1510	20	Break	
1510-1550	40	Materials Challenges	Imam
1550-1630	40	Theoretical Considerations	Hagelstein
1630-1700	30	Commercialization	Seccombe

Keynote Talks

There were two keynote presentations at the start of ICCF21. The first gave a larger perspective, and the second was a technical overview of the field.

Thomas Darden is the Founder and CEO of Cherokee Investment Partners LLC, a private equity and venture capital firm specializing in the acquisition, remediation and sustainable redevelopment of brownfield real estate properties. He became interested in the possibilities of LENR as a new source of clean energy. Hence, he founded Industrial Heat LLC in 2012, and is the Chairman and CEO. He gave a keynote talk at ICCF19 in April 2015, which resonated with the LENR community.[19]

At ICCF21, Darden contrasted his position and activities with those of scientists working on LENR: "I'm not a scientist. I'm an entrepreneur. But we share a common inspiration in our endeavors. Business guru Peter Drucker once noted that entrepreneurship is intended as a manifesto and as a declaration of dissent. We see things that ought not to be, or we see things that ought to be but aren't. And then we go to work." Darden focused on the energy challenges that motivate many of the people trying to understand and advance LENR: "Our mission, like yours, remains focused on solving one of the biggest challenges of our time. We need energy alternatives that don't add to our pollution problems. Marginally reducing pollution by being less bad is not good enough; we need to turn back the clock. We need a gestalt shift, with 7.5 billion people facing increasingly catastrophic, existential threats." Next, Darden posed some key questions: "Why have some of you been chasing these elusive phenomena for almost 30 years? What drives that dedication, curiosity, risk-taking and willingness to sacrifice in pursuit of what remains an evanescent and intriguing effect? Meanwhile, why are we so isolated? And has this isolation played a positive role in these early stages of the paradigm shift?" Most of the rest of Darden's address dealt with social, cultural, scientific, financial and political factors relevant to LENR. He ended with a call for increased openness and collaboration within the LENR field. His last words were, “Humanity needs for us to succeed.”

Michael McKubre is an electrochemist who did his postdoctoral research with Martin Fleischmann, and then worked at SRI International from 1978 until 2016. During that time, he did research on the palladium-deuterium system for four decades, and led a large and productive research program on LENR since 1989. McKubre was also instrumental in the initiation and continuation of this series of conferences. So, it was most appropriate for him to give a “Technical Perspective” at the beginning of ICCF21.

McKubre and his group did hundreds of thousands of hours of quantitative parametric electrochemical experiments with precision calorimetry that produced leading results. They made major contributions on loading diagnostics, and measurements of nuclear products. The latter evidence included production of tritium and two isotopes of helium, and emission of neutrons and both X-rays and γ-rays. They produced the best data on the correlation of heat production with helium generation.

Rather than review those many results, McKubre gave a perspective on what is needed for LENR to progress and realize its promise for the benefit of mankind. He emphasized five “ation” words: verification, replication, correlation, demonstration and utilization. McKubre noted, as he has done in the past, the need for collaboration, cooperation and communication within the field. He stated that “Scientific proof without practical reality hasn’t worked to convince the world of the reality/importance of cold fusion.” He, like many of us, would like to see “something simple that makes net power and thus energy preferably in electrical form that is easily measured and can be used to display and improve the conditions needed for control and self-sustainment.” The key characteristics of the desired prototype are power level, energy gain and temperature. McKubre emphasized the value of high gain, especially with reduced input power levels. Other features of a demonstration prototype—like cost, safety and even reliability—are less significant now. McKubre gave three candidates for a prototype, including the electrochemical Pd-D system, the gas phase metal-hydrogen approach and metal-plasma system involving glow discharges.

Background on Experiments

All LENR experiments have some necessary components: the scientist(s), equipment, materials, methods and measurements. Hence, it is possible to organize descriptions of experiments in several ways. In the following sections, we will first review reports on heat measurements from ICCF21. Then, we turn to papers on transmutation products. A separate section treats other experiments before we survey the papers on materials and instrumentation presented at the conference.

Heat Measurements Supported by Industrial Heat

Support for LENR research comes from public and private sources. The public sources are in the governments of a few countries with an interest in the science and applications of LENR. The private sources include some individuals and a few companies. One of the most prominent companies with major programs in LENR is Industrial Heat LLC. The name of the company indicates its target market, which is large and peopled by professionals who operate equipment for many processes. As noted above, the company was instituted in 2012 by Thomas Darden of Cherokee Investment Partners. He serves as the Chairman and CEO. J.T. Vaughn is the Vice President and General Manager of the company. They support a few experimental programs, which are making serious contributions to the advancement of LENR. Results from three current or former researchers and groups supported by Industrial Heat were the focus of the first technical session at ICCF21.

Dennis Letts from Texas and Dennis Cravens from New Mexico have been making major experimental contributions to LENR for decades, both individually and as a team. They are now funded by Industrial Heat. Together, they presented a paper at ICCF21 on “Building and Testing a High Temperature Seebeck Calorimeter.” Their first graphic carried the statement: “The IH standard for official confirmation of any excess heat claims requires verification by a major independent lab with recognized, credible and skeptical researchers.”

The design features of their calorimeter and reactor system were given as: Operating Temperature 200-300°C; Air cooled; Copper block is 3 x 3 x 15 inches; Catalyst plated on inner wall of reactor; Loaded by high voltage discharge; Seamless switching D_2 to H_2; Calibrated with resistance heaters; Seamless switching from heaters to discharge; Constant total power operation. The core of the reactor has the following features: 316 stainless steel with Swagelok VCR fittings; Case is grounded cathode; Central anode rod is Molybdenum; Clamshell motor magnets surround the tube; 230 gauss on the inner wall, good to 350°C; Typical gas pressure is 10-20 torr; Pressure decline can be monitored to indicate gas loading into the catalyst; Typical operating conditions are 200°C, 10 torr, 350 V, 200 mA. Thermoelectric modules 56 mm square from Tecteg Manufacturing in Ontario, Canada, provide the signal from the Seebeck Calorimeter. Two coils outside of the calorimeter permit the application of magnetic fields to the experiment. The system is surrounded by a thermal enclosure clamped at 28°C to within +/- 0.05°C. It is typically operated from somewhat less than 200 to as much as 320 W. An image of the setup, including instrumentation and ancillary equipment, is in Figure 3. The inner wall of the reac-

Figure 3. The setup in Letts lab, showing the instrumentation rack on the left, the thermal enclosure with the reactor in the center, and vacuum and other instrumentation on the right.

tor is plated electrochemically with hydrogen-absorbing metals (0.35 g, 7 microns). Details on the composition, structure and preparation of the materials were not reported.

Letts and Cravens observed excess heat only if the high voltage was on to produce a plasma inside of the reactor *and* deuterium gas was present in the reactor. The resistive heater is in the system for calibration. Power balances are achieved with either or both energy inputs, the plasma or the heater. Power to the box heater is decremented during the production of LENR power. That gives a second means of excess power measurements, and it agrees with the output values of the calorimeter.

Letts and Cravens measured a sustained average LENR power of 7 W with a maximum of 10 W with a Standard Deviation of 0.74 W. A power ratio of 10% was obtained during the longest run (7 W excess for 70 W high voltage input power). The power density was 20 W/g of Pd, with 2.7 MJ generated during one long run. Details of that run are given in Figure 4. The responses of the excess power production to the variation of input conditions (both power and pressure) are noteworthy.

Tadahiko Mizuno of Hydrogen Engineering and Application Development Company has been a major contributor of experimental results on LENR for most of the time since 1989. He could not attend ICCF21 to give his most recent data, so Jed Rothwell graciously presented his paper "Excess Heat Generation by Simple Treatment of Reaction Metal in Hydrogen Gas." It included two major types of experiments, both performed in an air-flow calorimeter. The experiments were conducted in two types of stainless-steel reactors, one a cross-shaped chamber and the other a cylindrical chamber, each of which had overall largest dimensions about half of one meter. In both cases, the reactors were lined with nickel mesh at the walls, and had a central Pd rod 250 mm long wound with Pd wire. That rod was the anode, and the mesh and chamber were grounded. Pressures in the range of one to several kPa were employed. During runs, two identical reactors were placed in the large air-flow calorimeter, one (the active cell) was heated by application of voltages to produce the internal glow discharge and the other (the control) was heated at the same power level with an insulated resistive wire wound on the outside of the chamber. The roles of the two reactors could be swapped during runs.

Rothwell reported on two kinds of experiments done by Mizuno. The first involved *in situ* preparation of the surfaces of the electrodes by the glow discharge. In the words of the authors, "The method sometimes produced spectacular results, but it was too difficult and it took too long." Those results were indeed remarkable, as shown in Figure 5 for an experiment that spanned 3.2 years. As in Figure 4, both the applied power and pressure were varied during the course of the experiments to give the data in Figure 5. Power gains near a factor of 2 were realized. One of the graphics from this presentation showed data for an input power of 248 W and a maximum output power of 480 W.

In order to speed up the experimental cycle, Mizuno recently switched to another method of surface preparation. Rather than doing it in the reaction chamber using a glow discharge, he rubbed the nickel mesh cathode with a palladium rod before inserting it into the chamber. The author's

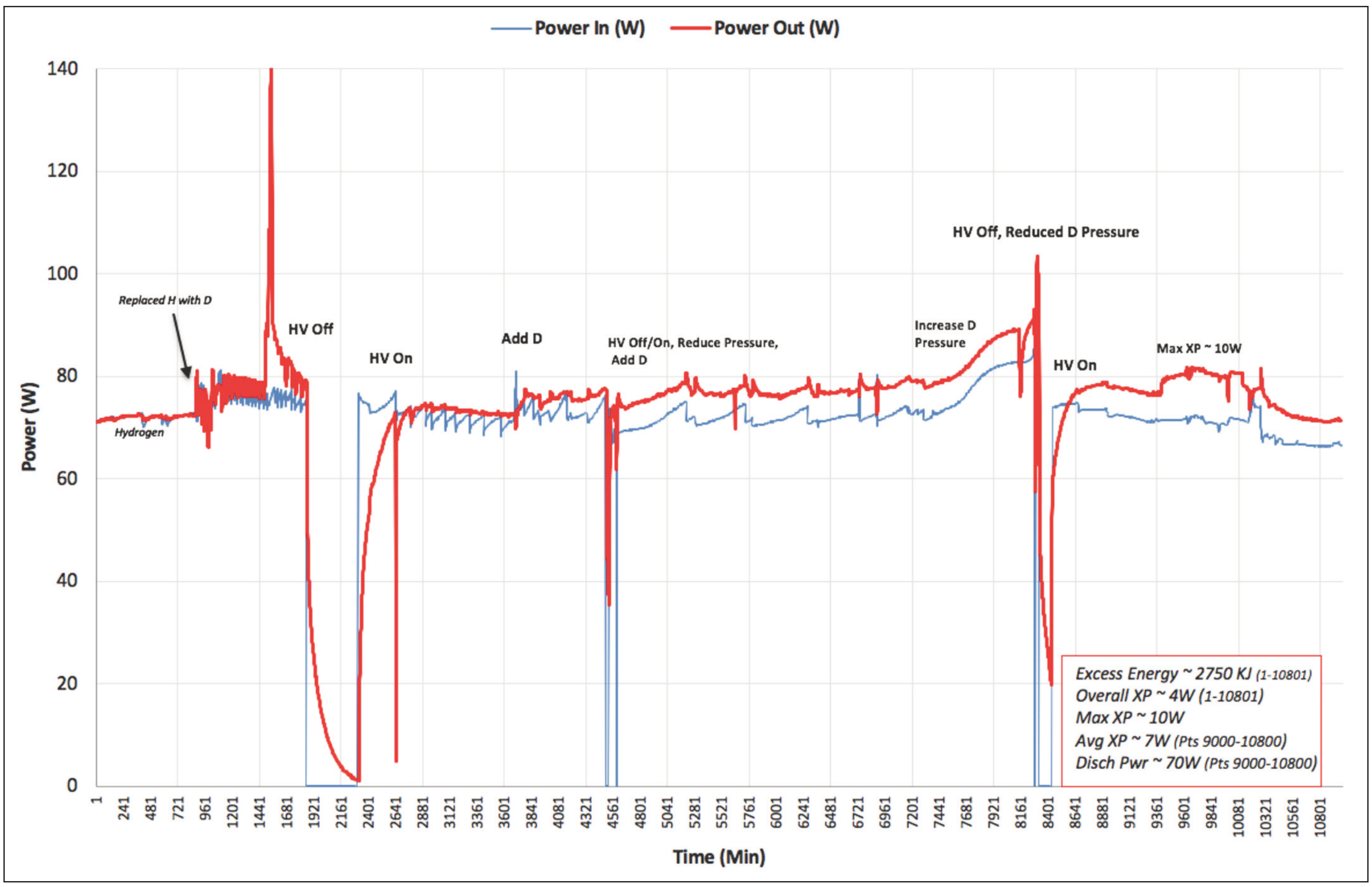

Figure 4. Results from the Letts-Cravens calorimeter during a 7.5 day run.

description of this approach follows: "With the new method, excess heat is more easily generated. However, it seldom exceeds ~5% excess. That is, 10 to 30 W absolute power. Still, it is surprising that significant excess heat can be obtained so easily." A tabulation of runs with this approach to surface preparation was presented by Rothwell. It contains 16 entries, some only controls. The maximum excess energy for an active run was 12%.

George Miley is a professor at the University of Illinois (Champaign-Urbana) and former editor of the journal *Fusion Technology*. He now heads a team funded by Industrial Heat LLC, which includes Dr. Kyu-Jung Kim and students Shriji Barot, Matthew Bergschneider, Jacob Meyer, Tapan Patel and Erik Ziehm. The group is also affiliated with the company Lenuco LLC. In his presentation on the Monday morning of the conference entitled "Progress in Cluster Enabled LENR," Miley gave an overview of the activities and results of the group. Details were given in four posters, which are discussed in the appropriate sections below.

Miley first gave some background on the "ultra-high density cluster" concept, which envisions hydrogen densities in the cores of dislocations near those of metallic hydrogen. Magnetic moment data was offered in support of that view. Work by the group primarily involves study of excess heat from pressurized nano-particles designed to achieve LENR reactions from ultra-dense hydrogen or deuterium clusters. A "reference" alloy using ~30% Pd and 70% zirconia was used to provide an interface that produces a high density of dislocations, and hence sites for cluster formation. Dislocations are created during milling, and also by expansion during pressurization of particles. High purity Pd was used in addition to the zirconia-containing materials. Both types of materials were subjected to pulsed pressurization and depressurization conditions with thermocouples as diagnostics.

In experiments with all materials, heating during pressurization exceeded cooling during depressurization, "suggesting an 'excess' energy due to LENR." Dozens of runs gave excess energy values that peaked near 40 J per gram of material. A water bath calorimeter was also employed by the Illinois group. The gas chamber was pressurized repeatedly at 2.5 minute intervals. That resulted in data indicating an excess heat of 20 mW for a five hour run.

Miley also presented data from the analysis of reaction products using Inductively Coupled Plasma Mass Spectrometry. The elements studied included Cr, Mn, Fe, Co, Ni, Cu, Pd, Ag, Rh and Ru. ^{107}Ag was constant while ^{109}Ag decreased for two different nanoparticle batches. Miley also presented early data on the use of CR-39 to record energetic particles produced by the pressurization and depressurization runs. He concluded by presenting the design of a low-power (few watt) prototype reactor system.

Heat Measurements in the Japanese Program

A large LENR program involving many institutions and people was funded from October 2015 to October 2017 by the Japanese New Energy and Industrial Technology Development Organization (NEDO).[20] The program was called "Phenomenology and Controllability of New Exothermic Reaction between Metal and Hydrogen." It was characterized by the high quality of the experiments, and by the detailed attention to production and characterization of nano-structured materials, as well as by experiments being done at different locations. Three papers on what was done

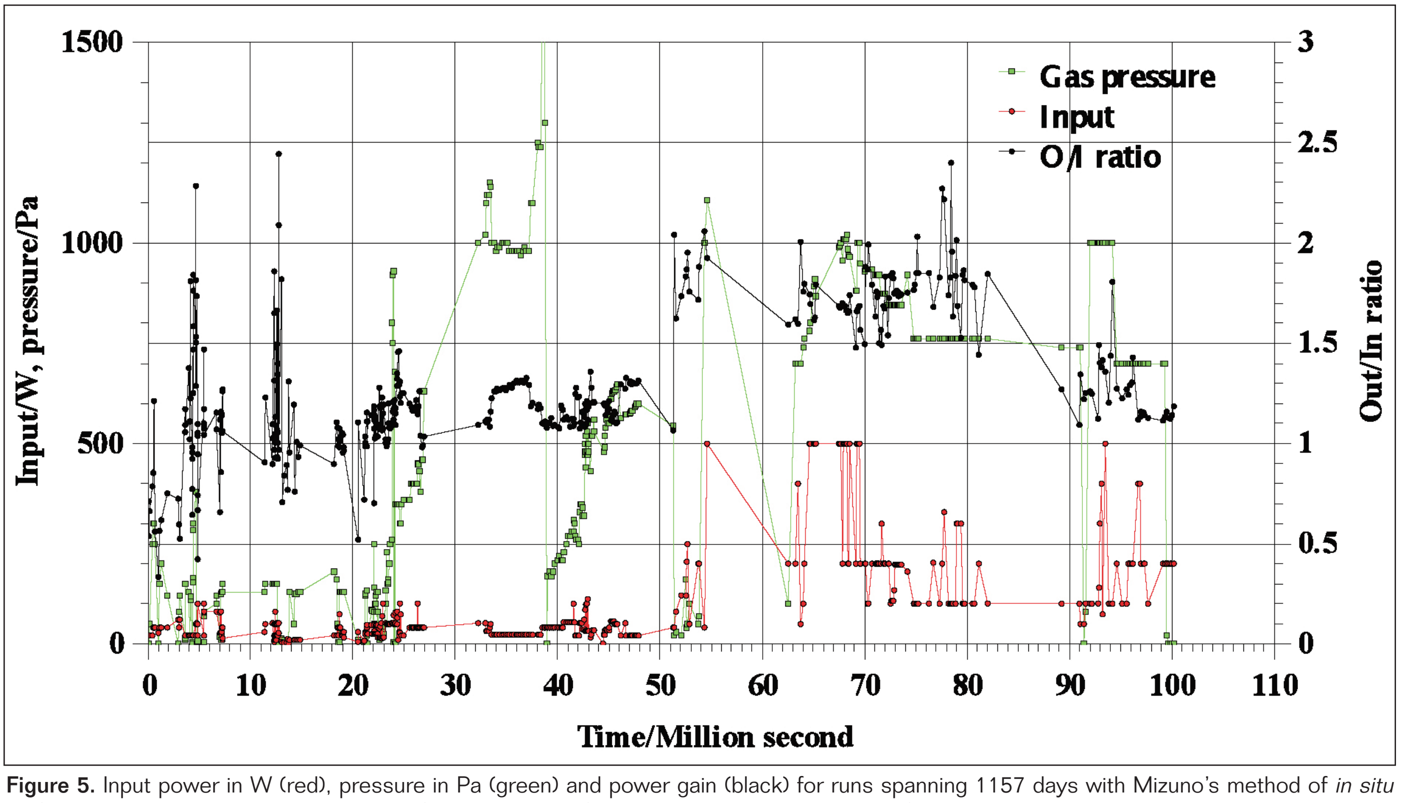

Figure 5. Input power in W (red), pressure in Pa (green) and power gain (black) for runs spanning 1157 days with Mizuno's method of *in situ* surface preparation. The cell was in an air-flow calorimeter for the entire experiment except for the period near 50 to 53 mega-seconds, when a water-flow calorimeter was used. At 55 mega-seconds, helium gas was introduced into the cell. At 64 mega-seconds, new D_2 gas was introduced. At 92 mega-seconds, air was introduced into the cell, which deactivated the reaction.

and found in that program were presented at ICCF21.

Akito Takahashi and 16 co-authors from Technova Inc., Nissan Motors Co., Kobe University, Kyushu University, Nagoya University and Tohoku University presented the first paper on the NEDO program entitled "Research Status of Nano-Metal Hydrogen Energy." The first part of the presentation involved a comparison of the performance of Metal Hydrogen Energy (MHE) compared to chemical and conventional nuclear energy densities. Takahashi also addressed possible applications of MHE. He then provided a high-level summary of the activities and results of the program: (a) Installation of new MHE calorimetry facility and collaborative tests were completed; (b) Sixteen collaborative experiments that verified the existence of MHE with Pd-Ni/ZrO_2 and Cu-Ni/ZrO_2 materials; (c) Generation of 10,000 times more heat than bulk PdH-absorption heat (about 200 MJ/mol-D in a typical case) and (d) Confirmation of MHE by a Differential Scanning Calorimeter (DSC) apparatus with small samples. Illustrations of the equipment and materials preparation methods were shown, along with a very detailed tabulation of all the collaborative experiments and their results. Excess power in the range of 2 to 8 W lasted for a week at elevated temperatures with H_2 gas and a $CuNi_7/ZrO_2$ material. In another run, 10 - 20 W of excess power was measured for one month. The highest measured excess power was 24 W. The DSC measurements with a $PdNi_7$/zirconia sample showed that a maximum of 80 mW per gram was obtained at 450°C.

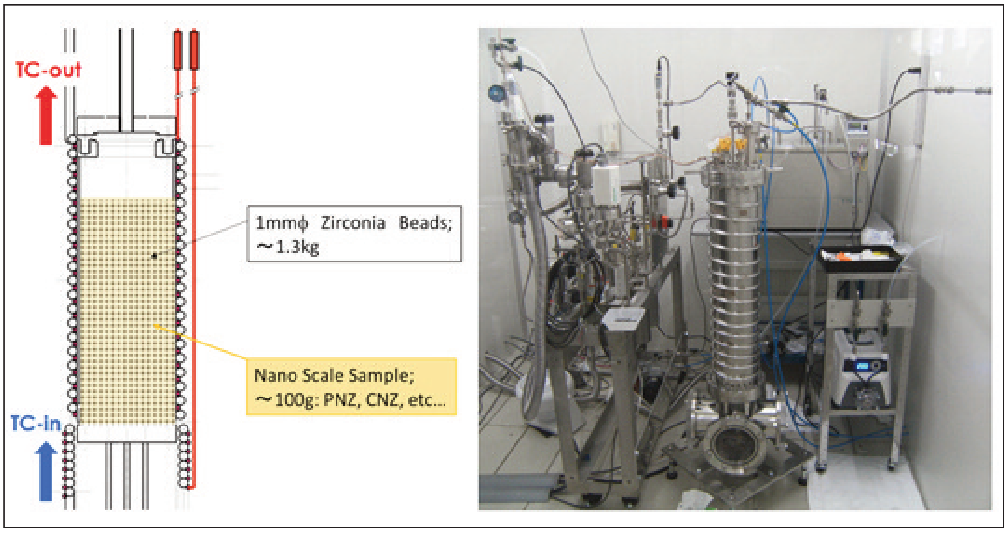

Figure 6. Schematic of the chamber and image of the overall LENR apparatus at Tohoku University.

Yasuhiro Iwamura from Tohoku University presented the second of the NEDO program talks, "Anomalous Heat Effects Induced by Metal Nanocomposites and Hydrogen Gas." It was co-authored by 16 researchers from seven organizations. The goal of the work was to "verify the existence of the Anomalous Heat Effect in nano-metal and hydrogen-gas interactions and to seek controllability of the effect." The focus of this talk was on seven of the 16 experiments, which had been run at Tohoku University, and the comparison of runs with the same materials at Tohoku and Kobe Universities. Figure 6 is a schematic of the reaction chamber in the heart of the apparatus and a photo of the overall experiment. These images show the sophistication of both the design and construction of the experiments. The measurements and calculations of excess powers were equally advanced. The excess power results from three runs with $CuNi_7Zr_{15}O_x$ samples and H gas at temperatures in the 150 - 350°C range varied from 2.5 to 5 W. Interestingly, increases in system pressure coincided with spikes in the temperature in the top of the reaction chamber. In one of the experiments, the integrated energy release was 67.8 eV per H atom, far beyond what can be explained by chemistry. The same samples of $PdNi_7Zr_{15}O_x$ were run with D_2 gas at both Tohoku and Kobe Universities, with very similar results. Excess powers in the range of 2 to almost 5 W were measured for about 150 hours in both locations. These results are significant, because they confirm the reproducibility of LENR for a particular material in two different, but similar, experiments in two different laboratories.

Tatsume Hioki and 18 colleagues gave the third NEDO-funded presentation "XRD and XAFS Analyses for Metal Nanocomposites Used in Anomalous Heat Effect Experiments." He began with a summary of the 16 experiments, including their location at Kobe or Tohoku Universities, the materials and gasses used, and the excess powers measured. His focus was on the preparation and characterization of the diverse materials used in the Japanese program. They ranged from nano-meter pore-size zeolites to TaiyoKagaku Mesoporous Silica (TMPS) materials with few nano-meter pores. Hioki discussed the use of Transmission Electron Microscopy (TEM), X-Ray Diffraction (XRD) and X-Ray Absorption Fine Structure (XAFS) to determine the shape of the nano-materials and their lattice structure as a function of annealing temperatures. The sample that gave the largest excess power (PNZ6) in the range 200 - 350°C was found to dominantly consist of $NiZr_2H_5$ and ZrO_2.

Both the thoroughness of the NEDO program regarding materials and measurements, and the remarkable results, are noteworthy. It will be most interesting to learn more about the durability of the nano-materials for use at elevated temperatures, and to observe attempts to scale the excess powers to higher levels.

Other Heat Measurements

In addition to the major programs just reviewed, many LENR researchers have performed electrical and calorimetric measurements using diverse setups and materials. Papers from some of them were given at ICCF21.

Francis Tanzella of SRI International presented a paper with Robert Godes and Robert George of Brillouin Energy Corporation on that company's large LENR development program. It was titled "Nanosecond Pulse Stimulation in the Ni-H_2 System." Their program focuses on the use of a complex cylindrical reactor tube consisting of layers of nickel and alumina, which are excited by electrical pulses. A cartridge heater inside the core permits operation in the temperature range of 200 to 600°C with either H_2 or D_2 gas at pressures up to 15 bar. The input pulse and heater powers are measured electrically. Output thermal power is measured with an isoperibolic calorimeter. The values of 57 parameters are measured every 10 seconds. Figure 7 shows the sophisticated computer interface for the reactor and calorimeter.

Tanzella began the talk by summarizing past Brillouin results. Over 100 experiments were performed with ten tubes. Excess power seen in a Ni-H_2 gas phase system has been shown to be reproducible and transportable. Axial pulses gave excess power in this system, which depends on the pulse repetition rate. Changing pulse parameters yield 25 - 100% excess power, and allows for switching power production on and off. The results were very dependent on material chemistry and morphology. After showing details of the experimental setup, data curves gave power in and power out values for a 40 hour run, during which the input power was increased five times for a few hours to 15 to 20 W, and energy gains near 30% were measured. The isoperibolic calorimeter was operated in power compensation or constant power modes. Overall, more than 500 experiments were performed with 100 different Ni-coated tubes in six different reactors. Energy gains from 1.0 to 2.0 were measured depending on stimulation conditions without measurable consumables. Currently, tube composition and metallurgy, and pulse generation, are still being optimized.

Mitchell Swartz is the principal in the company JET Energy Inc. He has been performing a wide variety of experiments on what he calls LANR (Lattice Assisted Nuclear Reactions) for most of the history of the field. Swartz had three papers at ICCF21. The one on his many experiences in the laboratory is reviewed below. Here, we summarize his papers on heat production and related topics. The first was an oral presentation "Aqueous and Nanostructured CF/LANR Systems Each Have Two Electrically Driven Modes." The thrust of the paper was that there are three possible states or LENR experiments. The third involves situations where the experimental material is irreversibly damaged and will remain inactive. The phrase "two electrically driven modes" refers to operation in either of two states that will produce LENR energy, one of them desirable and the second not optimum. Swartz likened the two states to the operation of an airfoil, like an airplane wing, which can experience either lift or be in a no-lift (stall) condition, depending on the angle-of-attack to the airstream. In the case of LENR, Swartz asserts that the relevant parameter is the power input to an experiment. He showed data where the LENR power increased with input power (analogous to increasing airfoil lift with increasing angle-of-attack) up to a point, beyond which the performance decreased (similar to the beginning of an aerodynamic stall).

Swartz invented and has been working with two primary types of LENR devices. The first is a high-impedance electrolytic system with a spiral Pd cathode, which he named the PHUSOR™. The other is a dry two-terminal device containing nano-scale materials, termed the NANOR™. Swartz typically makes redundant electrical and thermal measurements on his systems. To prove his view of two different operational states, Swartz showed four types of data: electrical conductivity, calorimetry, phase changes and changes in Raman spectra. The last technique involved his designing, making, calibrating and using a Raman spectrometer. He showed that, for the NANOR™ devices, an Anti-Stokes line appeared in the spectrum when excess heat was being produced. The appearance and intensity of that line depend on the presence of many phonons in the material. Overall, Swartz identified two modes for operation of LENR systems that "may explain why some systems fail to create 'excess heat.'" The requirement to achieve the proper operational state "must be added to the other pitfalls involving metallurgy, electrochemistry, isotopic loading, contamination and quenching." What Swartz calls the "Optimal Operating Point" is the input power that maximizes the LENR power (equivalent to maximum aerodynamic lift), but still short of wasting input power by producing too much electrolysis (equivalent to a plane stalling).

During this presentation, Swartz also reviewed his "Quasi-One-Dimensional Model of Electrochemical Loading of Isotopic Fuel into a Metal," which was published in 1992. The first order deuteron loading rate equation from that model shows that the deuteron gain by the lattice depends on the applied electric field minus the loss of deuterons from gas evolution and fusion.

The second paper on LENR heat production by Swartz and three colleagues was a poster

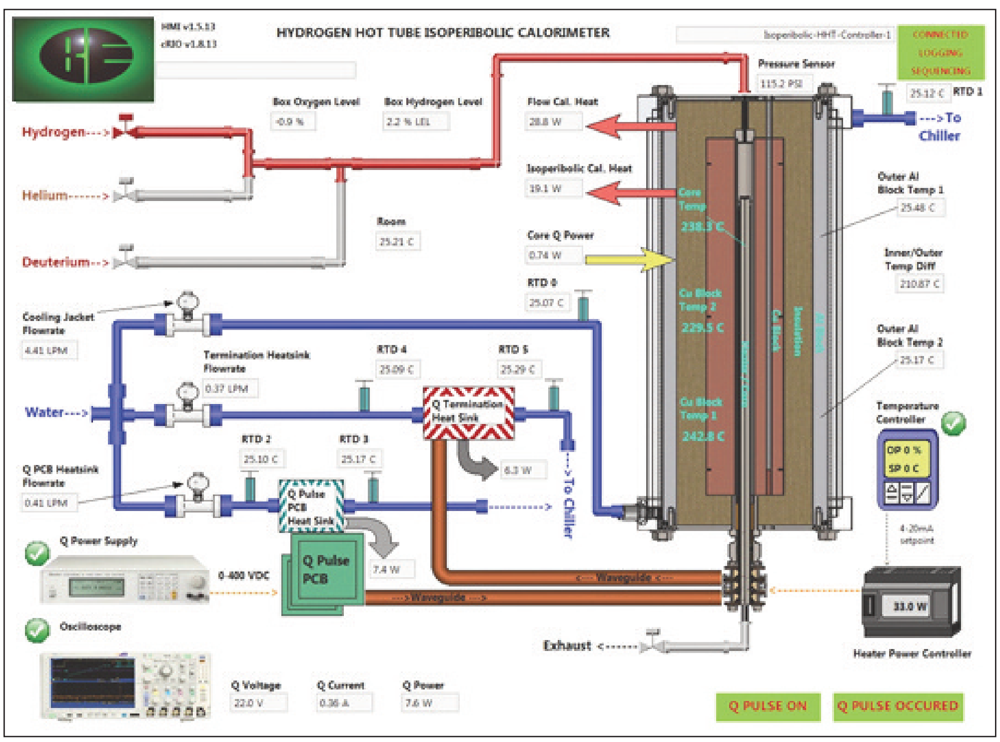

Figure 7. Schematic of the computer interface developed and used by Brillouin Energy Corporation.

entitled "Excess Heat is Linked to Deuterium Loss in an Aqueous Nickel CF/LANR System." The results were obtained at Lincoln Laboratory between 1993 and 1996, and augmented by recent measurements by JET Energy Inc. Quoting the abstract, "These results indicate a loss of deuterium from ordinary water when excess heat is observed in an aqueous Ni system using a very large cathodic area. The MIT Lincoln Laboratory Electrolytic Cell system had a 3 liter capacity [cathode 4.7 pounds made from #46 hard drawn smooth nickel wire (0.041 mm diameter, area ~240,000 cm^2)], anode platinized sheets of titanium (~3,200 cm^2), 0.6 M K_2CO_3 in laboratory distilled deionized 'ordinary' water, and two internal ohmic controls. When using V*I as electrical input power, the maximum incremental power gain was ~4 times the electrical input. At lower electrical input power, the maximum excess power was ca. 5 watts. Isotopic analysis was made by mass spectrometer (INFICON Quadrapole-102 Volt Energy). The HD/H_2 isotopic ratio [3/2 ratio] was less for gas leaving the cell, with some recovery in the recombiner water. This result heralds deuterons as the fuel. Importantly, deuterons and their isotopic flow, including in ordinary water systems, must be considered as the fuel for active aqueous nickel CF/LANR systems." The authors did not compute the energy available from the deuterium content of light water for comparison with the measured excess energy.

Francesco Celani, who is now a Guest Researcher at the INFN (Italian National Institute for Nuclear Physics), has led a remarkable and productive collaboration of Italian scientists at four institutions for many years. He presented their latest activities and results, "Steps to Identify the Main Parameters for AHE Generation in Sub-Micrometric Materials: Measurements by Isoperibolic and Air-Flow Calorimetry." AHE refers to the Anomalous Heat Effect.

The specific program, which began in 2011, is focused on the study of Constantan, an alloy of Copper and Nickel ($Cu_{55}Ni_{44}Mn_1$), instead of metals such as Pd, Ni and Ti that have been widely studied by other scientists. Celani cited the reasons for their interest in Constantan. It started with the idea that the "real and main catalyst or initiator" of the reaction with gaseous hydrogen was the thermocouple inserted within the Ni nano-powders, and not the Ni itself. They referred to the J-type (Fe-Constantan) thermocouple, particularly suitable for the temperature range of most experiments (<750°C). Furthermore, they had reason to believe that these thermocouples could be partially damaged after several tests, leading to activation of its surface. That led to the view that the insulating and protective material covering the thermocouple (a kind of glass) may contribute to the observed phenomena. They learned that Cu-Ni alloys, such as Constantan, may provide a large energy for the catalytic dissociation of hydrogen from the molecular to the atomic state. The value of energy is as large as 2 - 3 eV, in comparison to the most used material, *i.e.*, Pd, which provides only 0.424 eV from H_2 disassociation. They chose to use Constantan in the form of long and thin wires, treated with high peak power electric pulses, in order to obtain a sub-micrometric surface texture of Constantan, SrO, Fe_xO_y, K and Mn.

In almost all the experiments since 1989, Celani and his colleagues advocated having non-equilibrium conditions as a key factor to induce, and possibly increase, the AHE. That is one reason for their use of pulsed excitation. On the basis of such observations, in 2015 they introduced a new type of wire geometry, aiming to increase local thermal and, possibly, concentration gradients, without additional power. They developed simple procedures to get thermal gradients along the wire, including fiberglass sheaths that provide a step-discontinuity to heat transfer from the wire to local gaseous environment. After various attempts, they realized that the simplest approach was to introduce several knots in the Constantan wire. The procedure worked very well, and the AHE value is positively correlated with the number of knots. The optimal distance between knots is still under investigation. They are also currently developing and testing a new knot topology, aimed to enhance the non-equilibrium region in the wire and, overall, local temperature differences among hot and cold sections, with the hottest section at local temperature larger than 700°C. At such temperatures, the Fe, largely added at the Constantan wire surfaces, absorbs measureable amounts of H (or D). In such a way, geometric non-equilibrium of H (or D) concentration is achieved. Further enhancement is obtained by electro-migration along Constantan wires. The voltage drop is in the range of 400 - 1000 mV/cm, depending on wire section and temperatures.

The best results from the Celani team to date are the following: (a) with a 100 µm Constantan wire in 1 bar of D_2, an internal reactor temperature 500°C and 90 W of input power, the AHE was over 12 +/- 2 W, *i.e.*, over 150 W/g, but the wire broke after one day, and (b) with a 200 µm diameter Constantan wire, a Xe-D_2 mixture (each 0.1 bar) and the AHE was 6-7 W stably for weeks with 120 W of input power.

Michael Staker of Loyola University Maryland did LENR research starting in 1989, and is still active in the laboratory. He presented a paper at ICCF21 with the title "Coupled Calorimetry and Resistivity Measurements, in Conjunction with an Amended and More Complete Phase Diagram of the Palladium-Isotopic Hydrogen System." The presentation was essentially two papers in one, the first on the materials science of the Pd-H or D system and the second on LENR experimental results. The first part of the presentation was a thorough review of the literature on vacancies in the Pd-H or D systems. It included results from many measurement and imaging techniques and from Monte Carlo simulations. Staker is particularly interested in the production of super-abundant vacancies by dislocation production and motion. He considered both equilibrium and metastable phase diagrams in several metallurgical systems, including Pd with H or D.

Staker next reported on the results of his experimental program. He used a Fleischmann-Pons type cell with three power supplies, one for electromigration in the Pd cathodes in each of the two cells (one cell with H_2O and the other with D_2O), and one for electrolysis in both cells in series. The D to Pd ratio was measured *in situ*. The electrolyte level was held constant in both cells by the use of syringe pumps. The thermal time constants were 34.5 minutes for the cells and 116 hours for the constant temperature enclosure containing both cells. The measurement precisions were +/- 0.0005 W for the electrical Power In and +/- 0.015 W for the thermal Power Out. The D_2O cell showed an excess power of 0.32 Watts, which was 9.6% at 3.3 W input power. That cell had two episodes of a "run away," one of which gave 100% excess power with 2.4 W out for 1.2 W input. Total excess heat over a 46 day period was 0.775 MJ, which is 150

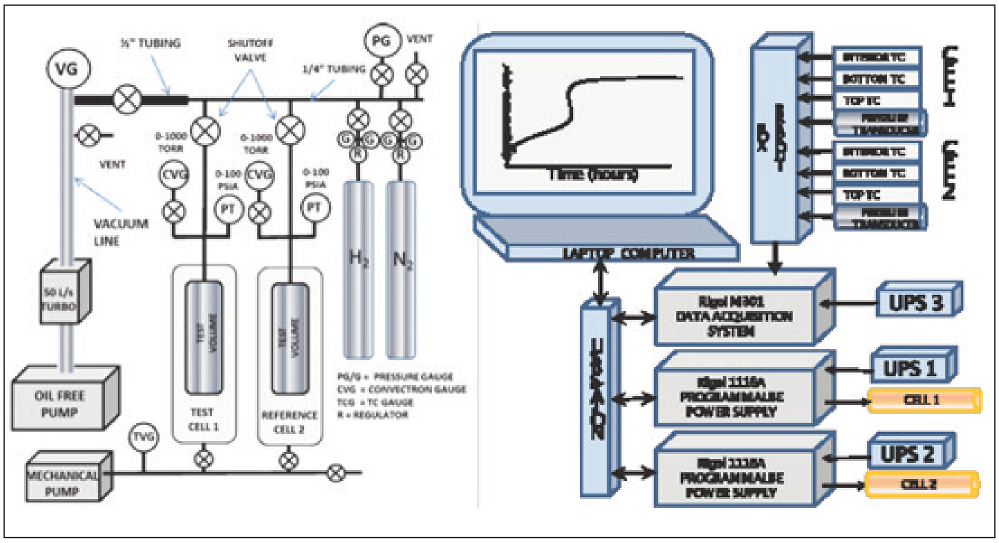

Figure 8. The setup and computer system for the Aerospace LENR experiments.

MJ/cm^3 of Pd or 14,000 eV/Pd atom. Staker found that during excess heat events, the resistance of the Pd cathode dropped as the temperature of the cell increased. He attributed that to the occurrence of a phase change. That motivated him to consider three Pd phases, γ, δ and δ'. He ended the experimental and analytical part of his talk by wondering if the δ phase is the "nuclear active environment."

Edward Beiting gave another presentation of work that had been done earlier, but not reported. He worked for The Aerospace Corporation, and had roughly one man-year of funding over two years to perform a LENR experiment. If a LENR power generator could be developed for space applications, it could eliminate solar panels, and provide energy for propulsion, communications, radar and other applications. Mating such a generator to NASA's Advanced Stirling Converter could provide 38% efficient thermal-to-electrical conversion at 850°C, which is four times better than current RadioThermal Generators. Figure 8 shows the experimental setup for the Aerospace experiment. It involved the use of ZrO_2NiPd nanoparticles with thermal triggering and thermometry as the diagnostic. Given reports of the beneficial influence of magnetic fields, $SmCo_2$ particles were added to one of two cells in a preliminary experiment which used deuterium gas. Although this test had several deficiencies compromising its results, the cell containing magnetic particles showed greater excess heat. Based on this tentative result, the follow-on main experiment added $SmCo_2$ particles to both cells. This main experiment involved ten week runs with two cells, one with hydrogen and the other with nitrogen. The experimental steps (days) were: bake (2), calibration (6), gas loading (2), heating for triggering (4), excess power integration (42) and step-down (13). During 950 hours of the integration period, the N_2 cell gave an apparent excess energy of 0.12 MJ and the H_2 cell 3.5 MJ. The difference was a net excess power of 7.5%. The H_2 cell had a specific excess energy of 635 MJ/kg, which compares to the similar value of 55 MJ/kg for methane, the most energy dense hydrocarbon fuel.

Given the strong results obtained in the Aerospace experiments, Beiting and his colleague Dean Romein are now working in the company TrusTech to further develop LENR technology. Their poster at ICCF21 was entitled "Generation of High-Temperature Samples and Calorimetric Measurement of Thermal Power for the Study of Ni/H_2 Exothermic Reactions." They are building a gas-phase Ni-H reactor that will go to 1200°C and seven atmospheres. A mass-flow water calorimeter will be employed with a data acquisition system to monitor more than 20 physical parameters.

Zhan Dong and four colleagues from Tsinghua University in Beijing offered a paper with the title "Temperature Dependence of Excess Heat in Gas-Loading Experiments." The paper was presented by Xing Zhong Li, one of the collaborators. In 1996-1999, a series of gas-loading experiments was conducted at Tsinghua University in order to detect the temperature dependence of excess heat. A thin and long Pd-wire (0.34 mm diameter by 250 mm long) was immerged in deuterium gas. The Pd-wire was heated to specified temperatures (50, 95 and 100°C) by a computer-controlled DC power supply. Two more data points (at 35 and 16.5°C) were obtained using cooling curves and temperature cycling methods without pumping. The experiments permitted the group to obtain an activation energy for the production of LENR energy of 0.55 eV. That value is substantially higher than activation energies from the temperature-dependent excess heat experiments of Fleischmann and Pons (0.40 eV) and of Storms (0.14 eV), both of which were obtained from electrochemical experiments. The production of excess heat was observed to be influenced by the cycling of the air conditioning unit in the laboratory, another indication of LENR temperature dependence. The dependence of LENR rates on temperature remain a central concern. It is discussed further in the Theory Section below. See Figure 10 in that section.

Recently, the Tsinghua group has performed a very different type of LENR experiment. They had seven palladium tubes that went into a chamber such that either vacuum or deuterium gas pressure could exist inside or outside of the tubes. The tubes were 2 mm in diameter and 400 mm long with a wall thickness of 80 µm. The pressure differences drove deuterons through the walls of the tubes. Excess heat of 2 to 3 W was observed to be correlated with the deuterium flux.

Prahlada Ramarao and three colleagues from S-VYASA Centre for Energy Research in Bangalore submitted an abstract entitled "Observation of Excess Heat in Nickel-LAH System." While they were unable to attend ICCF21, what they did and found is noteworthy. They sought to replicate the high temperature experiments of Alexander Parkhomov, which were themselves attempts to reproduce experiments and results reported by Andrea Rossi. The Indian group has performed about 50 runs. For a "couple of experiments," the temperature in the core of the experiment rose significantly after about 10.5 hours of heating starting from room temperature. The graphic in the abstract shows that, when the input power was maintained at 846 watts, the core temperature rose autonomously from 1272 to max of 1475°C for about 15 minutes, while the second thermocouple outside of the core continued to read about 1246°C. Before the rise in core temperature, the two thermocouples were within about 20°C of each other for over 10.5 hours. Based on the relationship between power input and realized core temperature, from the previous measurements over the last ten hours, and the realized temperature in this anomalous situation, it was inferred that the system generated excess power of 310 - 350 watts over this duration.

Hang Zhang and Yang Pei from the Qiran Lab in Xian submitted an abstract with the title "Experiment on Hydrogen Carrying Metal Glow Discharge." They could not attend the conference, but their work should still be noted. They performed calorimetry measurements from glow discharge excitation of the Ni-D system. They characterized the experiment as safe (no dangerous radiation) and reproducible (due to multiple successful runs). They achieved about 2 W of excess power with 30 W of input power during two four-hour long runs.

Summary of Heat Generation Papers

Since the production of thermal power is the primary driver behind commercial interest in LENR, and it is significant for both scientific and practical reasons, there were some strong reports on excess heat at ICCF21. Most of them were just reviewed, but some others will be summarized in later sections where they seem to fit best. There are two old graphics on excess heat production in the section below on Laboratory Experiences. Table 2 is a summary of the reported results already reviewed above.

The experiments and results shown in Table 2 vary widely. Both electrolytic experiments (mainly with D_2O), and gas phase experiments (with D_2 and H_2) were conducted. The excess powers ranged from well under 1 W to 350 W. Run times varied from a few hours to 3.2 years. Power gains varied from less than 10% to a factor of 2.3. All of those gain values were substantially lower than some of the power gains reported in past experiments.[21] The results in Table 2 can be compared with the compilation by Cantwell of heat results presented at ICCF17 in 2012.[22] That more-detailed compilation was qualitatively similar to the one in Table 2. It included a wide variety of experiments, uneven reporting of results by the scientists who obtained them, and wide variations in the excess powers, durations of runs and power gains.

While progress on heat production is slower than desired, the sophistication of current LENR experiments should be noted. The schematics and images in the figures above evidence great care in the design and fabrication of experiments. Calibrations of equipment and operations of experiments are similarly thorough.

Transmutation Measurements

Measurements of power and energy production are of greatest interest in the field, since they are the prelude to the development of commercial generators. However, from a scientific viewpoint, the products that result from LENR are also of great interest. They offer the possibility of understanding the mechanism(s) that cause LENR. Put another way, transmutation data might be more important scientifically than data on the production of energy, even though the latter drives the high interest in commercialization. There were a few papers at ICCF21 on the transmutation of elements during LENR. As usual, some of them had to do with the production of elements and some dealt with changes in isotope ratios.

Jean-Paul Biberian is a retired professor from the Aix-Marseille University in Marseilles. He presented a paper entitled "Anomalous Isotopic Distribution of Silver in a Palladium Cathode." Biberian gave the following background: "During their stay in France at IMRA, Stanley Pons and Martin Fleischmann did a number of very successful experiments with the ICARUS 9 calorimeter. Stanley Pons gave me this cathode in 2001. I kept it many years, and last year I started SIMS analysis to detect possibly silver." He listed possible fusion reactions between deuterons and six isotopes of palladium. Mass spectrometry of the interior of the old cathode showed only Pd. However, analysis of the surface gave spectral lines due to silver. Biberian concluded (a) that either silver is produced with only Ag-107, or there was formation of Pd-107 with its long half-life, (b) the reaction is a surface reaction in a layer one micrometer thick, (c) the reaction happens only in hot spots and (d) mass 112 must be checked to validate the measurements.

Nuclear reactions induced by the action of live biological entities have a very long history, which includes some strong data. But, like LENR in general, they remain controversial. Vladimir Vysotskii from the Kiev National Shevchenko University and Alla Kornilova from Moscow State University have been leaders in the field of bio-transmutations. At ICCF21, they and two other Russian colleagues gave a paper on "Experimental Evidence and Possible Mechanism of

Table 2. Reports of excess power production at ICCF21. The order is the same as in the text. NM stands for NanoMaterials.

Lead Author	Materials & Loading Method	Maximum Excess Power	Longest Run Duration	Power Gain (W/W)
Letts-Cravens	D_2 or H_2	10 W	7.5 days	77/70 = 1.1
Mizuno	Ni + D_2	232 W	3.2 years	480/248 = 1.9
Miley	NM + D_2	20 mW	5 hours	
Takahashi	NM + D_2 or H_2	24 W	1 month	
Iwamura	NM + D_2 or H_2	5 W	150 hours	
Tanzella	Ni + D_2 or H_2	5 W	40 hours	21/16 = 1.3
Swartz	Pd + D_2O	4 W	67 hours	2.3
Celani	Constantan + D_2	12 W	1 day	102/90 = 1.1
Staker	Pd + D_2O	1.2 W	46 days	2.4/1.2 = 2.0
Beiting	NM + D_2 or H_2		950 hours	7.5 %
Dong	Pd + D_2	2-3 W		
Ramarao	Ni + $LiAlH_4$	310 - 350 W	12 hrs	1.3 - 1.4
Zhang	Ni + D_2	2 W	4 hours	32/30 = 1.1

Biological Transformation of Stable and Radioactive Isotopes (Prehistory, Experiments, Theory, Perspectives).” It began, as the title indicates, with a brief review of the history of the field going back to publications by Kervran in the 1960s. The authors then provided details of experiments on fusion of iron-region stable isotopes in “one-line” growing microbiological cultures containing D_2O for one, two and three days in different growth modes. They used Mossbauer Spectroscopy and Laser Time-of-Flight analytical methods. The data indicate the production of ^{57}Fe from ^{55}Mn. The authors also reported on experiments that showed transmutations of other intermediate weight and heavy isotopes in a wide variety of cultures. Still other experiments involved deactivation of radioisotopes from nuclear reactor waste. The data show that metabolically active microorganisms increase the rate at which radioactivity decreases. Remarkably, ^{137}Cs was found to decrease 35 times faster than the normal physical decay rate. The authors then went on to discuss “The Possible Theoretical Model of Coulomb Barrier Suppression in Dynamical Physical and Biological Systems.”

Gongxuan Lu from the Chinese Academy of Sciences in Lanzhou was among the few scientists who submitted abstracts, but could not make it to ICCF21. He and Wenyan Zhang from the Jinling Institute of Technology in Nanjing offered a poster paper on “Photocatalytic Hydrogen Evolution and Induced Transmutation of Potassium to Calcium via LENR Driven by Visible Light.” They were motivated by the studies of Kervran on the transmutation of potassium to calcium in biological systems, specifically types of seeds. The authors achieved the transmutation of potassium to calcium during photochemical reaction of hydrogen evolution (HER). It is a bionic system which simulates the behavior of plants in nature when they absorb and convert solar energy for hydrogen production. Inspired by a recent discovery of the group, deuterium and helium were generated from protons by LENR during 90 minute runs. They noted, “Mass spectrometric and calorimetric analyses were used in this work. It was found that the concentration of calcium elements increased during the photochemical HER reaction in the presence of potassium. The results indicated that the increase of calcium might be closely related to H ions (H-) generated in the reaction system.” They also showed that a similar transmutation could be achieved by H- in $NaBH_4$ under dark conditions.

At ICCF21, Alexsander Nikitin and five colleagues from Belarus and Japan reported on “Impact of Effective Microorganisms on the Activity of ^{137}Cs in Soil from the Exclusion Zone of Chernobyl Nuclear Power Plant.” Their work sought to (a) research the behavior of natural and man-made radioisotopes in natural and agricultural ecosystems, (b) explore the processes of spatial redistribution and transformation of the physical and chemical forms of man-made radionuclides in the soil and water of the exclusion zone of Chernobyl power plant and (c) develop combined biologically active soil-improving additives for the rehabilitation of contaminated and disturbed soils. They worked with three organisms: Lactic Acid Bacteria, Photosynthetic Bacteria and Yeast. They found that the microorganisms reduce the transfer of ^{137}Cs to barley, and lessened transfers of ^{90}Sr to different crops. They also found that use of the microorganisms reduced the amount of ^{137}Cs in treated soils. Given that observation, they designed experiments to quantify reduction in ^{137}Cs activity in treated soils. Specifically, ^{137}Cs activity was measured both before and after 6, 12 and 18 month exposures to particular microorganisms. Gamma-ray spectra were measured with a Canberra coaxial germanium detector. Activity reductions averaging 3.5% were found after the 18 month experiments, higher values than from normal radioactive decay. The team also measured soil samples from Fukashima, Japan. The reductions in activity were as high as 14.8%, while the normal decay rate would give only a 4.3% decrease.

George Egely of Egely Research Co. (Hungary) and two colleagues dealt with transmutations in their paper “Change of Isotope Ratios in Transmutations.” They have been concerned with “dusty plasmas” in which nano- and micrometer sized particles are in equilibrium with the electrons and ions in plasmas. Positive ions that interact with the surfaces of the particles are thought to induce nuclear reactions. The authors experimented with a nano-dust fusion system from greentechinfo.eu and other electromagnetic resonant cavities. They were concerned with nuclear reactions involving carbon, nitrogen and oxygen. Energy dispersive X-ray analyses of ten samples of treated materials showed the production of Ca, Fe, K, Cu, Zn, Mg, Ti, S and Si.

Summary of Transmutation Data

The products from LENR are more indicative of the mechanisms that lead to such reactions than is the production of heat. Hence, data on elemental and isotopic changes have generally been presented at past ICCFs. Production of tritium, ^3He and ^4He have commonly been reported, but there was little on the generation of those isotopes at ICFF21. It is useful to summarize the reports of transmutations of medium weight elements at this conference. The five papers, one on an old electrochemical cathode, three on bio-transmutations and one on dusty plasma experiments, contributed to the two main riddles about transmutations. They are: (a) How is it possible that low energy effects can cause nuclear reactions in medium and heavy-weight elements, with their high Coulomb barriers? (b) Does fission occur in any LENR experiments? These two questions provide LENR theoreticians with stern challenges.

Old and New Diverse Experiments

There are two types of what can be called “old experiments.” The first are experiments done before, often long before, the announcement by Fleischmann and Pons in 1989. Some of these were presented at ICCF21. They are reviewed first in this section. The second type of old experiment involved work done in the first one or two decades after the 1989 announcement. Such experiments have been part of the LENR field already for many years. More recent work on such experiments was presented at the conference, and will also be surveyed in this section. Beyond such “old” experiments there are really new LENR and LENR-related experiments, a few of which were presented at the conference. They are summarized at the end of this section.

George Egely has worked for decades on very old experiments that appear to involve LENR. He has both done many experiments and written several reviews. Four of his papers were published in this magazine.[23] A recent book is a good summary of such experiments.[24] At ICCF21, Egely gave a paper entitled "Direct Electricity Generation by LENR (Forgotten Effects and Inventions)." Early in his presentation, he listed nine inventors and their inventions. All of them were put forward in one way or another, by reports, papers or patents, long before 1989. The ICCF21 presentation included dozens of circuit and other diagrams, as well as images from the old inventions. Several of the images were from experiments in Egely's laboratories over many years, which sought to replicate and understand the early reports.

Egely reported on some old experiments that involved transmutations. But, his main focus was his title, the direct production of electricity from LENR. So, he dwelt on three cases: Moray (rush-backrush), Correa (autogenous bursts) and Chernetzky (self-oscillations). Egely described the factors that those experiments have in common, including the geometries, materials, fuel and current pulses. The study enabled Egely to list the "Essentials of Direct Electric Energy Production." He then went on to compare the similarities and differences of LENR production of heat and electricity. During his presentation, Egely gave a list of reasons for (a) why these old discoveries were made and (b) why they did not get more attention. His last graphic stated, "Change is inevitable. Progress is optional." The prospect of production of electricity directly from LENR is very attractive. It seems that the old experiments, which Egely has studied, deserve much more detailed consideration and new attempts at reproduction with modern instrumentation and methods.

Max Fomitchev-Zamilov from Maximus Energy Corporation is an independent researcher also interested in replication of experiments reported long ago. He gave a paper "Neutron Formation, Lanthanide Synthesis on Nickel Anode." He sought to reproduce with modern instrumentation and methods an experiment on neutron production published by Sternglass in 1951. His initial objectives were to: (a) conduct faithful replications of neutron formation claims that are often referenced by LENR community, (b) produce conclusive proof of LENR that could withstand the most skeptical peer-review and (c) publish in a major scientific journal. Fomitchev-Zamilov conducted over 300 experiments during 18 months of full-time research after typing 208 pages of notes that were handwritten by Sternglass. He discovered and highlighted errors in statistical analyses made by the original experimenter. Fomitchev-Zamilov eliminated those errors and also some systematic and interpretive errors. He concluded that Sternglass was definitely in error due to poor neutron detection techniques and complete lack of statistical analyses. Fomitchev-Zamilov stated that he did not disprove a possibility of synthesis of neutrons out of protons and electrons, but did show that neutrons were not formed in the Sternglass experiment. In the course of the work, he developed state-of-the-art neutron and gamma detection techniques and hardware of great potential benefit to the LENR community. Now, he is in the process of devising a robust methodology for Scanning Electron Microscopy and Energy Dispersive Spectroscopic analysis of possible transmutation products on a solid surface, another useful tool for LENR research. The work by Fomitchev-Zamilov is a good example of the thoroughness with which some LENR experiments have been designed, conducted and analyzed.

Roger Stringham of First Gate Energies has long contributed papers to ICCF conferences on experiments that use ultrasound to produce cavitation bubbles, which interact with thin foils. Frequencies of 20 to 2000 kHz are employed. Stringham had two papers at ICCF21. The first was a poster entitled "A Deuteron Plasma Driven to Neutrality and ^{4}He." In it, he reviewed the basics of the cavitation and subsequent process, and his ideas on what is happening in the experiments. Stringham envisions something he called a "mesa cluster" of two to 100 deuterons. The neutralization of implanted deuterons in the cluster produces a pulse on the order of 10 femtoseconds. That, in turn, leads to D-D fusion. 10^{13} events per second in the target foil produce LENR power of 40 W. The poster included details on the reactor and radio-frequency driver. Data on helium concentration and images of target foils were also provided.

An oral presentation by Thomas Claytor (High Mesa Technology), with Roger Stringham and Malcolm Fowler (McFarland Instruments Services), also focused on the ultrasound LENR experiments. The title was "Stringham Sono-Cell Replication." The goals of the work were to verify the reported heat results of Stringham and look for other anomalies. Claytor and Fowler have several tools relevant to those goals. The paper began with a review of several ultrasound and related experiments, and the cavitation process. In contrast to Stringham's flow system, a new static ultrasound system was designed, fabricated and tested. A Seebeck calorimeter was used for this work. Eleven different foil compositions were examined with 22 W of power to the transducer at 1.7 MHz. Evidence for cavitation, and damage to target foils, was obtained. Many factors were found to affect the cavitation, including the foil composition, geometry and surface modifications; the H_2O or D_2O liquid and its gas content; the presence of micro-sized particles in the liquid; boiling; the transducer-to-foil distance; the composition and efficiency of the transducer; and the distance to an ultrasound reflector. A maximum excess power of 3 W was reported. The foils were imaged by optical and Scanning Electron Microscopy, and analyzed by Inductively-Coupled Mass Spectroscopy after being insonified. Various unusual compositions and structures were seen on the foils. The analyses showed nine elements near or significantly above their detection thresholds. Searches for tritium, and for X- and γ-ray emission, were inconclusive. The authors noted that Stringham's type of experiment provides a quick way to screen materials, and to produce modifications of surface morphology, with only small samples needed for testing.

William McCarthy gave the paper "Light Hydrogen LENR in Copper Alloys." He began with a list of common LENR characteristics and, from them, gave a list of "working principles." Based on them, he used light hydrogen with Li and B in Cu for (a) ease of processing and fabrication, (b) the use of common materials without deuterium or Pd, and (c) the possibility of generating substantial energy per reaction. To do so, McCarthy asserted that it was necessary to have moving charges (either electrons or ions). His experiments involved three phases. The first included attempts to react Li and B with H in Cu. Those static experiments had "little success." The second phase involved the use of a new capacitor configuration in which H was added before the reactions in a Seebeck calorimeter. Dynamic graphite particles substitute for bubbles in conventional electrochemical LENR experiments. There was immediate energy release, with the output often exceeding the 3σ calorimeter variation. Far infrared radiation was also measured. The third, planned phase is to reduce the input while increasing the power output, presumably due to self-heating of the capacitor arrangement.

Brian Roarty, another independent researcher, gave a presentation entitled "A Method to Initiate an LENR Reaction in an Aqueous Solution." His paper reported a protocol that enables one to initiate an apparent LENR reaction in a specific solution and under specific conditions. It consists of a series of steps taken in a sealed reactor, involving heating an aqueous solution of a soluble polyhedral silsesquioxane, which hosts lithium ions in a cubic cage, to within 5°C of the solution's boiling point. Then, radio-frequency and photonic stimuli are applied between conductive electrodes immersed in that solution over an extended period. After that stimulation, the temperature of the solution is raised above the boiling point. The pressure is then reduced in an impulse, thereby driving a phase change in the solution. That phase change initiates an expected exothermic reaction. However, within a very short time after the pressure drop, the temperature rises in both the solution and the headspace above it. That temperature rise is evidence of an exothermic reaction. Examination of the surface of the gold electrodes showed evidence of melting and small "volcanic sites" that suggested to the author some kind of chain reaction. There were hundreds of smaller sites, which might result from reactions involving 5 - 20 atoms each. This was taken as evidence of sustained reactions. Roarty describes successful replication as "routine."

David Daggett of Phonon Energy Inc. provided an abstract, but was not able to participate in the conference. His title was "Positive Result of a Laser-Induced LENR Experiment." He performed 37 tests over three years, and observed a single apparent excess heat result. Daggett used an infrared laser to stimulate heated nickel powder, which was conditioned under vacuum and pressurized in 99.995% pure hydrogen gas. An excitation laser was used at increasing step-levels of power as part of a test procedure. After some 4.5 hours of testing, four temperature sensors within the Ni powder recorded a sudden increase of temperature at a rate of about 19.5°C per hour, while constant background heater and laser power settings were maintained. The background heater in the test chamber was maintained at a constant power setting when the laser was switched off. The rate of temperature rise continued for about 45 minutes until the test was terminated.

Yuta Kitagawa and four colleagues from Kyoto University presented a paper "Direct Joule Heating of D-Loaded Bulk Pd Plates in Vacuum." They prepared planar layered specimens by first annealing palladium plates in a nitrogen atmosphere at 1000°C, and then depositing a 100 nm thick gold film on the palladium by electron beam evaporation. Next, the combination was loaded with deuterons by a ten hour exposure to D_2 gas, which started at 1 atmosphere. Finally, a bias voltage was applied directly across the Pd sample to provide a current injection into the Pd, to stimulate the nuclear reactions by Joule heating. The scientists anticipated strong electrodiffusion or electromigration, in addition to the conventional deuterium diffusion caused by pressure-induced mass-concentration and thermal gradients. Excess heat, usually around 0.5 W (5 W/mol-Pd), was observed for more than ten hours with a peak value of 1.5 W. Anomalous heat generation was inconsistent with known chemistry. Neutron emission was temporally coincident with onset of excess heat, where the neutron peak intensity was about 200 times the environmental background.

Vladimir Vysotskii and two colleagues from Moscow State University made a presentation on "Generation, Registration and Application of Undamped Temperature Waves at Large Distance in LENR Related Experiments." The group impinged high speed cavitating water streams onto heavy metal plates, and observed the production and propagation of X-rays and undamped thermal waves. High frequency (80 - 85 MHz) waves were measured 10 to 20 cm from the target. Vysotskii drew attention to an explanation of the thermal waves, which he and other colleagues published four years earlier. He then went on to discuss the possible application of the undamped thermal waves with direct distant stimulation of LENR. He reported on an experiment in which the thermal waves were directed to a Ti target 70% loaded with deuterons, with nearby track detectors. It was found for such a setup that controlled quasi-continuous LENR occurred, as evidenced by the generation of alpha particles.

Erik Ziehm and five colleagues in Miley's group had a poster on "Detecting Charged Particles in LENR Applications using CR-39." Their abstract read, in part: "CR-39 was used in LENR nanoparticle experiments to investigate the emission of energetic charged particles. The experiments utilized hydrogen (or deuterium) absorption in palladium-zirconium nanoparticles with cyclic pressurization and vacuum cycles. A direct relationship was found between track density and number of absorption-desorption cycles. Trends between track density and other parameters are also being investigated, *e.g.*, pressure, gas type and the location in nanoparticle vessel."

V.G. Plekhanov from the Fonoriton Science Laboratory of Garon Ltd. in Estonia was another scientist who provided an abstract, but was unable to participate in the conference. His title was "A Possible Signature of Neutron Quarks: Lepton Interaction in Solids." By adding one neutron (using LiD crystals instead LiH ones), there was an increased exciton energy at 103 meV, seen both in reflection and luminescence spectra. Since the gravitation, electromagnetic and weak interactions are the same in both kinds of crystals, the addition only changes the strong interaction. The author concludes that the renormalization of the energy of electromagnetic excitations (excitons, phonons) is due to the strong nuclear interaction. That indicates to him the necessity of consideration of the strong nuclear interaction to interpret the spectral results.

Thomas Prevenslik from QED Radiations in Hong Kong was yet another person who could not attend, even though he sent an abstract titled "X-ray Emission in LENR by Zero Point Energy or Simple QED?" His abstract dealt with X-ray bursts seen in the glow discharge LENR experiments of Karabut. He treats the zero point energy (ZPE) of the atom as a temporary state between quantum levels and not a quantum state of the atom. The X-ray bursts are explained by another mechanism. Prevenslik considered heat from the glow discharge into atoms, and invokes collective effects for both the excitation of atoms to X-ray relevant levels and the subsequent de-excitation by X-ray emission. He concludes that "Simple QED with super-radiance explains X-rays in LENR without the ZPE or nuclear reactions." QED is

Quantum Electrodynamics.

Florian Metzler and two colleagues from the MIT Energy Production & Conversion Group gave a paper that was new to the ICCF series of conferences. The title was "Experiments to Investigate Phonon-Nuclear Coupling and Related Effects." The experiment was borne of the theoretical work by Peter Hagelstein on the conversion of energy between phonon (meV) and nuclear (MeV) levels in solids. Conversion in either direction is of theoretical interest. Metzler began with a review of the literature relevant to phonon-nuclear coupling (PNC) and the theoretical work of Hagelstein for either excitation or de-excitation of nuclear levels or for transfer of nuclear excitations between atoms.

The MIT experiment described at ICCF21 dealt with the potential influence of mechanical (phonon) vibrations on nuclear transitions. Two hundred microCuries of ^{57}Co were placed in an area of about 50 mm^2 on the surface of a 3 x 6 inch steel plate. The plate was clamped in place with wooded supports. Three radiation detectors viewed the experiment, two above and one below. They registered radiation from the beta decay of the ^{57}Co to ^{56}Fe, which results in radiation at 136, 122 and 14.4 keV. It was expected that PNC can lead to changes in photon emission with a coupling strength stronger for 14.4 keV state and weaker at 136 keV state. Data taken immediately after applying a 2000 pound compressional stress to the clamps for the first time showed a strong enhancement in the 14.4 keV emission which lasted for about one week. The higher-energy emissions were found to be anisotropic due to the stress applied to the plate. The 14.4 keV and Fe Kα emission intensities were seen to be affected by warming of the ^{57}Co region with a 50 W heating pad. Increases in the rates were synchronized with times when the heat was applied. The author's interpretation is that the applied mechanical stresses produced dislocations and friction, which led to THz phonons. They in turn caused excitation transfer, which produced the observed effects. The presentation ended by the authors stating their belief in seeing PNC mechanisms and effects. They stated that the observations are consistent with the following picture: (a) delocalization of 14.4 keV photon emission (non-resonant excitation transfer involving the lower nuclear transition), (b) angular anisotropy of 122 and 136 keV photon emission (resonant excitation transfer involving the higher nuclear transitions) and (c) different ratios of Fe Kα and 14.4 keV nuclear peaks in different configurations (due to variation in phonon-nuclear coupling strengths). This work is clearly of great importance for nuclear and solid-state physics, in addition to its potential impact on understanding of LENR.

Materials Considerations

It is widely thought that materials hold the key to both the understanding and exploitation of LENR. This view has two bases. One is the apparent necessity for a solid, commonly a lattice, to be involved in LENR. The other is empirical. Many experimenters have found that some types and samples of materials do produce LENR, while others that seem to be similar never work. Given the importance of materials to LENR, there were several papers on various aspects of materials at ICCF21. They are reviewed in this section. Some of the papers in other sections also had a strong materials component. The paper by Staker, summarized above, is a prime example.

Edmund Storms provided two related abstracts on LENR materials entitled "The Enthalpy of Formation of PdH as a Function of H/Pd Atom Ratio and Treatment" and "The Loading and Deloading Behavior of Palladium Hydride." His oral presentation covered both of those topics. The first paper described a new method to directly measure the bond energy between the PdH structure and the contained H atoms in real time as a function of H/Pd ratio from zero to the maximum H content. This was done by using the electrolytic method with H_2SO_4 and H_2O to react Pd with H. A unique and very accurate calorimeter (±5 mW) is used to measure power during the loading reaction. This method is applied to three types of Pd, including commercial Pd sheet, extra pure Pd and a zone refine single-crystal of Pd after each is subjected to several treatments. The treatments include repeated loading-deloading cycles, annealing at 900°C and reduction in thickness.

The bond energy was measured by Storms from H/Pd = 0 to 0.8. It was found to be sensitive to purity, treatment and H/Pd ratio, with good agreement with published measurements being achieved after certain treatments. Three methods to measure the average H/Pd ratio are described and compared by Storms. These methods use weight gain, orphaned oxygen and recombiner temperature. The plots of bond energy versus the H/Pd ratio showed apparent phase boundaries near H/Pd values below 0.2 and near 0.35 to 0.4, in addition to the known α-β boundary near H/Pd = 0.6. These discontinuities in the enthalpy of bond formation showed up in some of the measurements made as a function of sample treatment. The graphic on the left in Figure 9 is an example. Repeated loading and deloading had a dramatic

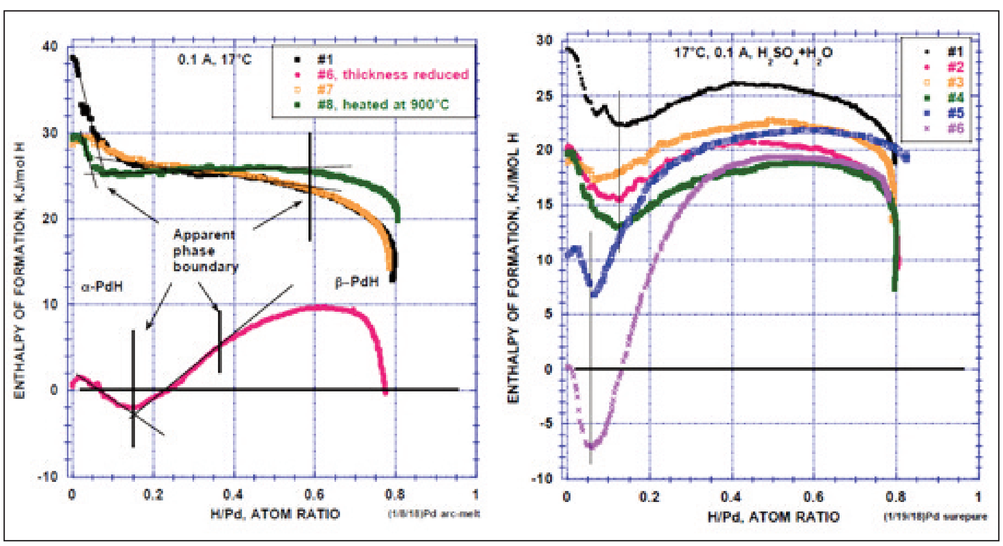

Figure 9. Left: Effects of sample treatment on the bond energies of H in Pd at various loading ratios. Right. Variations in bond energies for a sample that was loaded and deloaded six times.

effect on the bond energy as a function of the H/Pd ratio. This is illustrated on the right of Figure 9 for six loading cycles. The graphics in Figure 9 are representative of the many plots, each rich with measured data, which were shown by Storms.

Storms' loading-deloading study noted that H or D can be lost by surface reactions anywhere on the metal or from cracks. In both cases, diffusion is the rate-limiting step. So, Storms measured weight loss from loaded samples as a function of time. That enabled him to determine both the loss rate during electrolysis and, by extrapolation of the data back to zero time, the maximum loading of the sample. He noted that repeated loading and deloading causes a plate of Pd to change toward having the shape of a cube, as the volume of the sample increases. Samples that do not readily change like this are more likely to produce LENR. Storms made the point that samples do not remain unchanged during LENR experiments. This fact has clear scientific and practical implications. It begs understanding, and it is germane to LENR generators in which fuels will change during use.

Han Nee and two colleagues from Target Technology Company LLC presented the paper "Lattice Confinement of Hydrogen in FCC Metals for Fusion Reactions." They started by noting three LENR requirements: Fuel (from high H isotope concentration), Ignition (with the required energy) and Sustainability (with H isotope inward mobility and outward energy escape). The group anticipates that the fuel will be clusters of H isotopes in Ni (Pd) segregated to vacancies and di-vacancies, and vacancy-impurity complexes. Their report began with presentation of the results of many vacancy configurations in nickel. They were made using the Quantum Espresso Density Functional software. Plots of the formation energies as a function of the number of vacancies for both mono- and di-vacancies were shown. For ten protons in a divacancy in nickel, they computed a local density comparable to that in the sun. The vacancy clusters that resulted from the calculations are thought to be stable. They are considered to be the "nuclear active environment." Paired H states showed smaller distances between H atoms in divacancy clusters due to dipole-dipole, not Coulomb, repulsion. This was termed a "supercapacitor effect," equivalent to an anomalously large screening potential at any surface.

The Target Technology group also did experimental studies of the charging of nickel and a nickel catalyst at 83 atmospheres and 250°C for 24 hours. H or D concentrations up to 8 atomic percent were achieved. They then performed temperature programmed desorption to obtain bonding energies. The team computed absolute LENR reactions rates. For D concentration in a charged vacancy in Ni, they obtained a rate of 3×10^{13} Hz. Their comparable rate for D in Pd was 5×10^{14} Hz. At the end of their talk, both ignition and self-sustained reactions were considered. Their final statement was: "LENR can be implemented within standard solid state and nuclear physics theories."

Peter Hagelstein of MIT has studied the distributions of H isotopes and vacancies in metals for many years. One of his papers at ICCF21 was entitled "Statistical Mechanics Models for PdH_x and PdD_x Phase Diagrams with both O-site and T-site Occupation." He characterized PdH_x as "perhaps the best studied metal hydride" and listed reasons for that viewpoint. The situation is not as strong for PdD_x. Hagelstein wrote, "Simulation of the Fleischmann-Pons experiment requires a model for chemical potential." That provided motivation to assemble the isotherm data, estimate the phase diagram and develop a mean field theory for PdD_x. Hagelstein's inability to fit the high temperature data for the Alpha phase of PdD required him to consider tetrahedral (T) site occupation, in addition to the octahedral (O) site occupation. The T site energy obtained by fitting the data agreed closely with the results of density functional calculations. The difference between the T and O site energies was obtained as a function of loading. That enabled comparisons of the model with isotherms in the literature and the published phase diagram. Hagelstein concluded that a "Simple statistical mechanics model provides reasonable fit to the phase diagram." He went on to consider the Beta phase for the Pd-D system.

Ashraf Imam of The George Washington University, Melvin Miles from Dixie State University and one of us (DJN) had a presentation on "Fabrication, Characterization and Evaluation of Palladium-Boron Alloys Used in LENR Experiments." These were materials employed in several experiments by Miles, which will be described next. Those were excess energy experiments, which are also relevant to the sections on energy production above. Imam began by noting the many parameters related to the composition and structure of materials, most of which are possibly related to the outcome of LENR experiments. His work from the early days of LENR experimentation has dealt with high-purity and commercial-purity palladium and its alloys with boron, cerium and silver, among other elements. Imam described the arc-melting and swaging or rolling operations, which he used for alloy preparation.

As the title indicates, the focus of Imam's paper was on Pd-B alloys. Materials with compositions near 0.25, 0.5 and 0.75 weight percent of B were prepared. The results of annealing the alloys for various times (up to 20 hours) at different temperatures (as high as 1100°C) were shown as optical micrographs. The addition of B to Pd within solubility limit creates two Face-Centered Cubic phases with different lattice parameters, one phase being distributed as fine particles within the other phase. The creation of those two phases makes the material harder and less susceptible to cracking. That helps ensure retention of deuterium within the metal lattice. Another beneficial effect of the added boron is that it minimizes the activity of dissolved oxygen in the palladium by converting it to B_2O_3 during processing. The low density B_2O_3 floats to the surface, and is removed during the molten phase during the palladium-boron alloy preparation. Data from X-ray diffraction and glow discharge mass spectroscopy of the Pd-B alloys was provided. Miles and Imam have two U.S. patents on these alloys.

Melvin Miles presented a paper entitled "Excess Power Measurements for Palladium-Boron Cathodes." He started by reviewing a U.S. Navy cold fusion program that ran from 1992 to 1995. Late in that effort, seven of eight experiments by Miles with the Pd-B alloys made by Imam produced excess heat. Most runs lasted several weeks, the longest being 4.5 months. The highest excess power measured was 0.42 W. The one run that gave very little excess power had a cathode that was flawed, which might have prevented effective loading. Miles continued work with the Pd-B alloys at the New Hydrogen Energy Laboratory in Japan in 1997-98. Using a Fleischmann-Pons calorimeter, he obtained excess heat. Miles' analysis of the data from that run gave an excess power near 0.25 W. Fleischmann's analysis of the same run produced a curve with a maximum near 0.4 W. Unpublished data from the Naval Research Laboratory using the same Pd-B material was also presented by Miles. It showed only a few mW of excess power. Miles again ran a Pd-B experiment in his home in 2017, which gave a maximum of 0.12 W of excess power very early in the run. Overall, Miles obtained excess powers in nine of ten experiments with three different calorimeters in three laboratories. His successes are the main reason for the planned use of the Pd-B alloys in the LENRIA Experiment and Analysis Program (LEAP). That program is described below in the section on Other Topics.

It is widely known that there are two main approaches to obtaining palladium for LENR experiments. One is to procure and prepare it in advance and then insert it into experiments. The second is to produce the palladium metal *in situ* during a LENR experiment. The latter method goes by the name co-deposition, since the palladium that is electroplated out of solution is already loaded with deuterium. Both approaches have advantages and disadvantages. The papers on LENR materials reviewed above in this section were obtained by the first method. There was one paper on co-deposition at ICCF21 called "Overview of Pd/D Co-deposition." It was by Pamela Mosier-Boss, one colleague from Global Energy Corporation and another retired from the U.S. Navy Systems Center in San Diego. Their poster paper reviewed almost three decades of activities and results. A summary of the experiments and the diverse results constituted the bulk of the paper. The group has published about four dozen refereed papers since 1991, which are listed on the internet.[25]

Jacob Meyer and five colleagues from the Miley Industrial Heat LLC team had a poster "On the Oxidation of Palladium." Their research deals with palladium-zirconium alloys that are used to produce nanoparticles with composite Pd-ZrO_2 structures having length scales on the order of 10 nm. The role of oxidation is critical to the production of those nano-materials. This paper provided a review of the literature on the conditions necessary for the oxidation of palladium to produce the nano-scale materials. The group reported on recent thermogravimetric and X-ray diffraction experiments. Models for the oxidation of palladium were also presented.

Rydberg Matter

The materials and related processes reviewed in the last section involved more-or-less normal materials science. There is another class of materials, which appears to be related to LENR, that is relatively new and unconventional. Those substances go by the name Rydberg matter. It consists of a collection of hydrogen atoms with their electrons in highly-excited and large orbits, which can form an ordered collection by the actions of electron delocalization. This state was predicted theoretically in 1980 by Manykin and detected by Holmlid in 1989. In 2002, Holmlid published a means to produce Rydberg matter experimentally in the form of two-dimensional hexagonal arrangements by the use of condensation on suitable surfaces. An oxide catalyst is used to facilitate production of Rydberg matter. There were nine papers or abstracts on Rydberg matter at ICCF21. Some dealt with the relationship between Rydberg matter and LENR.

Sveinn Olafsson from the University of Iceland had one oral and four poster presentations. He began by reviewing the physics of Rydberg matter and the work of Holmlid, who performed laser-induced time-of-flight spectroscopy on Rydberg matter. The data indicate that the H atom separations can be as small as 2.3 picometers, compared to the 72 picometer bond distance in H_2. The new form of matter was termed UltraDense Hydrogen (UDH). In 2015, Holmlid published a paper that indicated the decay of UDH into various mesons.[26] That is a remarkable observation and interpretation. Also in 2015, he reported energy generation from laser irradiation of UDH.[27] That is a part of the possibility that there is common physics in both Rydberg matter and LENR. Olafsson then described the work in his laboratory on the production and study of Rydberg matter. His four posters can be summarized briefly:

- "Rydberg Matter Experimental Setup in Iceland." Olafsson described the Rydberg matter experimental setup that has been under construction for the last four years at Science Institute University of Iceland. It now has four operational cells with different functions. Some are specialized for vibrational excitation, ultra-high vacuum pressure and laser excitation. Laser experiments are expected to become functional in mid-2018.
- "Conductivity of Rydberg Matter." Olafsson reported measurements with deuterium Rydberg matter, which showed indications of electrical conductivity of such phases. He has measured the resistance of Rydberg matter and found quantized resistance values.
- "Adler-Bell-Jackiw Anomaly in Electroweak Interactions: The 3p+→3L+ Process and Links to Spontaneous UHD Decay and Transmutation Process." The author wrote, "One very recent interpretation is disintegration of the proton into lighter particles in a process of 3N-proton → 3N-anti-lepton process. This process is driven by the Adler-Bell-Jackiw anomaly in electroweak interactions in the Standard model. The process has never been observed, since it would need post Big Bang high temperature conditions to occur in a laboratory. If validated, it might solve one of the biggest remaining mysteries in cosmology, namely Baryogenesis."
- "Volcanism in Iceland, Cold Fusion and Rydberg Matter." Olafsson notes a "strange link" between positive electrochemical LENR experiments and areas with active volcanoes or hot geothermal areas. He asked, "Is it a coincidence that most active countries in cold fusion research are volcanic countries such as USA, Japan and Italy? This link has not been noted strongly by the LENR research community."

Sindre Zeiner-Gunderson has a Rydberg matter laboratory in Norway and is completing his Ph.D. with Olafsson at the University of Iceland. He had one oral presentation and two posters at ICCF21. The first paper with Olafsson and Holmlid was "Experimental Hydrogen Reactor for Rydberg and Ultra Dense Hydrogen States for Energy Applications." The abstract read: "Ultra dense hydrogen has until now never been detected outside the research group of Gotenborg University led by Professor Leif Holmlid. We hereby present a reactor setup that converts hydrogen to Rydberg matter, dense and ultradense state of hydrogen to be used in energy systems. Ultra dense hydrogen is releasing particles which can be one of the experimental possibilities to explain

LENR." The UDH state described by Olafsson in his oral paper is of particular interest since it is of "extreme importance for fundamental reasons, but also as fuel with the highest energy content of any combustion fuel, target material for laser initiated inertial confinement fusion and for the production of high energy particles." Zeiner-Gunderson described his new system for the production and study of Rydberg matter and UDH. With it he succeeded in making and measuring ultra dense deuterium, pi mesons and muons. His future research will include a search for annihilation radiation. It has high potential energy density: chemical reactions 10 MJ/Kg, nuclear fission of U-235 80 TJ/Kg, nuclear fusion of D 2300 TJ/Kg and annihilation 3000 TJ/Kg.

There were two posters from Zeiner-Gunderson, both with Olafsson, which gave details on his work. The first was on the experimental setup in Norway. The title was "Hydrogen Reactor for Rydberg Matter and Ultra Dense Hydrogen: A replication of Leif Holmlid." The second poster was "Distance Dependency of Spontaneous Decay Signal from Ultra Dense Hydrogen Source." It dealt with data as a function of the length of the time-of-flight tube out to a distance of 16 meters.

Mike Taggett of Tern Research provided an abstract on "Using Laser Ablation of Metals to Evaluate a Proposed Formation of Ultra Dense Deuterium." In it, he describes work over five years in three laboratories to produce and measure UDD. When his catalyst is working, the time it takes for the 10 Hz laser to burn through the 1.5 mm thick stainless steel target increased by 30% to 200%. UDD is believed to be primarily located on the surface, but current work is trying to determine if it is also interstitial.

Simulation and Instrumentation for LENR

Modeling and measurement capabilities are critical to LENR experiments. So, there were several presentations at ICCF21 on software, instruments and procedures for their use.

Bob Higgins (Acuiti Science and Engineering) and Dennis Letts (Industrial Heat LLC) presented a way to simulate the experiments by Letts and Cravens, which were described earlier in this review. The paper was on "Modeling & Simulation of a Gas Discharge LENR Prototype." Well-known software for simulation of electrical circuits was used. Specifically, they employed the free Simetrix version of PSPICE. It enables the exploitation of analogs between circuit elements and processes, on one hand, and thermal models, on the other. This method runs much faster than either behavioral or finite-element approaches to thermal modeling. This new model was written to include relevant hardware elements, and then calibrated against experiment. The final version of the equivalent circuit required about 30 components. Iterative runs of the model can be used to extract excess power waveforms from measured time histories. Use of the model also permitted the team to determine additional sources of heat storage and movement.

There were other ICCF21 papers on calorimetry. Melvin Miles has been a major contributor to LENR experimentation for a long time. In addition to his presentation on calorimetry of Pd-B cathodes, reviewed above in the section on Materials Considerations, Miles had two posters on calorimetry at ICCF21. One was based on his correspondence with Martin Fleischmann between 1992 and 2008, which was entitled "Calorimetric Insights from Fleischmann Letters." While the letters were dominantly on calorimetry, more general topics relating to cold fusion were also discussed. Recently, Jed Rothwell posted these letters on the internet.[28] Miles' poster provided details on cell size, equations and calibrations. His second poster went into details on the equations for isoperibolic calorimeters of the type used by Fleischmann and Pons. The title asserted that there is "No Steady State for Open Isoperibolic Calorimetry." The presented differential equations were compared with experimental data to make the point that there is no steady state for open isoperibolic calorimetry, save for special conditions that are not generally applicable in a laboratory.

There were two posters on calorimetry from Miley's group. Matthew Bergschneider *et al.* provided the paper "Study of a Calorimeter Apparatus Utilizing Radiation-Based Heat Transfer." The poster discussed a radiation-based heat transfer approach for a calorimetry device. The calorimeter was placed in a vacuum to mitigate heat transfer via conduction or convection to the environment. This new calorimeter was used to investigate metal hydride formations, and to compare the expected thermodynamic output to actual results. The design, instrumentation and calibration methods of the calorimeter were presented. In addition, COMSOL Multiphysics models were used to investigate accuracy of the system.

Shriji Barot *et al.* had a poster on "Flow Calorimetry Design for Elevated Temperature Experiments with Deuterium and PdZr Nanoparticles." Results from pressurization of chemically reactive nanoparticle metal hydrides with hydrogen gas have shown consistent production of a net anomalous heat. Hence, the team made efforts to analyze their experiments with deuterium gas at higher temperatures. A high temperature calorimetry setup with water flow was designed to allow for proper heat transfer measurements of the system. The change in the water temperature from inlet to outlet can be integrated over time to calculate the total heat released from the reaction. The poster gave the design of the system and the results obtained with it.

Malcolm Fowler and Thomas Claytor presented a paper titled "Development of a Sensitive Detection System for the Measurement of Trace Amounts of He-4 in Deuterium or Hydrogen." Their motivation was the fact that many LENR systems generate He-4 from deuterium, but there are few systems that can detect trace amounts of He-4 in the presence of D_2. As an alternative to commercial magnetic sector mass spectrometers, they developed a lower cost and compact system that permits measurement of He-4 down to sub-100 ppb levels in D_2. The heart of their system utilizes a column of activated carbon at LN_2 temperature that effectively absorbs everything but helium. The design, calibrations and use of that system were described in detail. A typical sample size required to achieve low ppb sensitivity to He-4 is 50 cc at 50 torr. More recently, the pair started to consider the analysis of samples other than gas phase materials. So, they implemented a tube furnace to heat samples to desorb He-4 from metal foils. They are also developing a system to electrically heat metal samples to desorb He-4.

Jirhota Kasagi and two colleagues from Tohoku University provided a paper on "Search for γ-Ray Radiation in NiCuZr Nano-Metals and H_2 Gas System Generating Large Excess Heat." The study was motivated by the observation of gamma radiation from a few earlier LENR experiments. The authors stated the advantages of such an approach: (a) discreet γ-rays identify nuclear reactions currently occurring, (b) delayed γ-ray lines identify nuclei generated in the reaction, (c) if 511 keV radiation is seen, it gives evidence of annihilations that occur during or as a result of LENR and (d) continuum γ-rays due to Bremsstrahlung indicate the motion of fast charged particles in experimental materials. The experimental setup for this work included a Ge detector added to the arrangement shown in Figure 6. It recorded spectra from 50 keV to 2.7 MeV. Spectral peaks obtained during production of excess power agreed with those measured without power production. The authors concluded: "There were no γ-ray transitions down to 50 keV during the heat generation of 1.3 MJ. Only upper limits of γ-ray emissions were obtained."

Max Fomitchev-Zamilov was motivated to develop better radiation diagnostics by the research he did, which is described above in the section on Old and New Diverse Experiments. He detailed the equipment and software developments in a poster "Reliable Neutron and Gamma Radiation Detection." His tutorial started with a summary of the best practices for multi-mode neutron and gamma detection. He then described his turn-key hardware and software solution, which offers exceptional sensitivity to the desired signals while being virtually impervious to electromagnetic noise. The system allows monitoring, auditing, aggregation and statistical analysis of neutron and gamma counts and spectra that originate from multiple devices, which communicate wirelessly via WiFi.

Fabrice David from the Laboratoire de Recherches Associatives in France and John Giles of DeuoDynamics in the UK had a paper on "Alternatives to Calorimetry." They listed many candidate LENR materials, and were seeking "fast and reproducible tests to sort all these alloys and select the most promising samples." The team listed three approaches, and discussed each. The first was to use their earlier development, a "Fusion Diode." It consists of powdered deuterated alloys in contact with a semiconductor powder, which cause the appearance of an easy-to-measure electrical voltage. Such diodes can be fabricated and measured more quickly than most calorimetric LENR experiments. Their second method was based on the Reifenschweiler effect. That effect is the apparent temperature sensitivity of the beta-decay of the tritium absorbed into titanium. The authors offered an explanation of the effect, and envisioned its application to LENR experiments. They wrote, "It is therefore possible to use the Reifenschweiler effect to sort the new alloys containing hydrogen according to their capacity to house Bose-Einstein Condensates." The last of the alternatives considered in this paper was based on the postulated, but not yet observed, "magnetic cancellation of the tritium pairs." They outlined an approach that might produce such an effect.

Frank Gordon and Harper Whitehouse from Inovl Inc. presented a paper entitled "Real-time Instrumentation and Digital Processing for LENR Characterization." They were motivated by earlier work, which showed that LENR phenomenon take place on time-scales short relative to the response times of calorimeters. They described their development of a number of real-time measurement techniques that simultaneously gather and process multi-channel data on a 24/7 basis. Details were provided on the sensors and systems for data acquisition, storage, processing and display. Measurements included temperature, magnetic fields, X- and γ-rays, neutrons, RF and acoustic radiation, and cell operating characteristics.

Edmund Storms submitted an abstract that was not presented at ICCF21. However, his subject is significant and deserves attention. The topic and measurements are broadly relevant to electrolytic experiments that use recombiners to convert D_2 and O_2 gases back to D_2O. The title of the abstract was "The Strange Behavior of Catalysts Made from Pd or Pt Applied to Al_2O_3." Graphics in the abstract showed cyclic changes in the temperature of the recombiner, which produces synchronous changes in the measured excess power and open circuit voltages. This happened with either D or H in the electrolyte. It was attributed to the production of some radiation that could escape the cell, as well as changes in the surface of the cathode after escape of that radiation.

LENR Theoretical Developments

Understanding and exploitation are the two primary goals of current global research and development on LENR. Hence, there is continuous high interest in theoretical work on the topic. Almost 20% of the papers at ICCF21 were on some aspects of LENR theories. They were contributed by two classes of scientists, those who have long been working on the topic and some scientists new to the struggle to understand LENR. We will review presentations by scientists in the first group, and then summarize the new ideas given at the conference.

After his presentation on experiments done under the NEDO program, reviewed above in the section on Heat Measurements in the Japanese Program, Akito Takahashi provided an Appendix on "Brief View of Theoretical Models." He was first concerned with the Sub-Nanometer Holes (SNH) in the palladium coating of nickel nano-particles. He believes that they are the sites for Tetrahedral Symmetric Condensation (TSC) of four deuterons to a point in space and time. TSC is the first step in a theory of LENR that Takahashi has been advancing for many years. The role of SNH in producing TSC is a relatively new tact for his theory. Takahashi provided computed rates and characteristics for TSC-based LENR in both hydrogen and deuterium systems.

Peter Hagelstein has also pursued a long theoretical campaign to understand LENR. His approach is focused on Phonon-Nuclear Coupling (PNC). In earlier work, he showed that it is necessary to consider relativistic effects for PNC to occur. At ICCF21, he presented an oral paper entitled "Phonon-Mediated Nuclear Excitation Transfer." The focus of this paper was on the transfer of excitations from one nucleus to another via phonons. Hagelstein listed several applications of phonon-mediated excitation transfer: angular anisotropy experiments; delocalization experiments; up-conversion including collimated X-rays and γ-rays; low-level nuclear emission; the first step in excess heat production, and energy exchange through many sequential excitation transfers. He provided the equations for PNC in condensed matter.

Focusing on excitation transfer, Hagelstein noted that an excited nucleus can radiate one photon, but not one

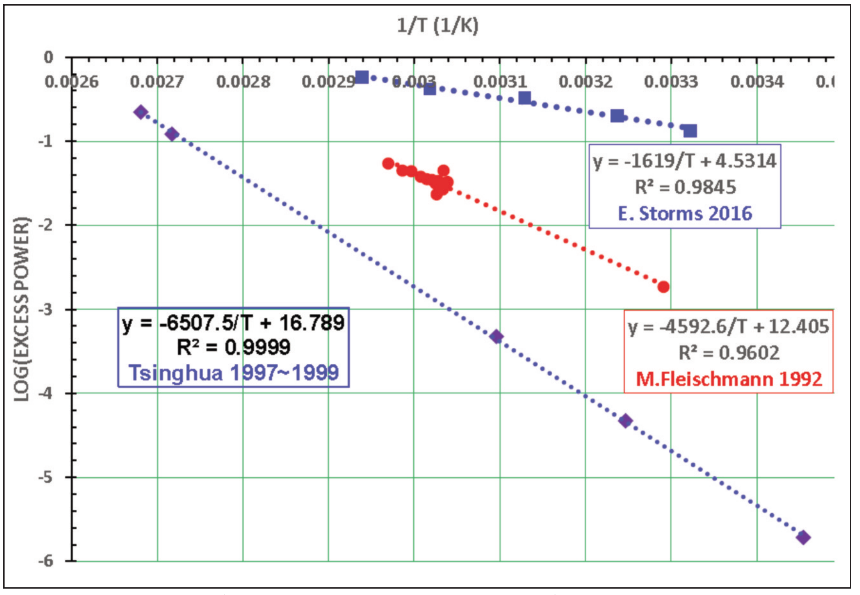

Figure 10. Variation of excess power with temperature from three LENR experiments. The activation energies in eV shown by each curve. (Courtesy of Xing Zhong Li.)

phonon. It is necessary to deal with a two-phonon process when considering excitation transfer. Hagelstein found that single Electric Dipole (E1) transitions in a monoatomic crystal suffer destructive interference for molecular and lattice excitation transfers. In contrast, two E1 transitions can provide the needed coupling. And, the common Magnetic Dipole (M1) and Electric Quadrapole (E2) transitions are free of destructive interference. Hence, they can provide the basis for PNC and excitation transfer. So, Hagelstein has been concentrating on those two multipolarities in Fe-57. He seeks to explain the observations of energetic alpha particles, protons and neutrons in LENR experiments by use of the incoherent excitation transfer process. He briefly described the experiment with Metzler, reviewed above, in which excitation transfer and angular anisotropies of decay emissions from Co-57 were observed. Delocalization of emitted radiation gave evidence of excitation transfer, 10 nm per step over distances of several hundred micrometers. They also observe an excess of Fe Kα emission, which is consistent with the excitation transfer mechanism. Hagelstein ended by using the PNC and excitation transfer models to explain excess heat in LENR experiments. He wrote, "Simple down-conversion is most straightforward conceptually…but numbers don't work out. Numbers much better for multi-step scheme based on excitation transfer, subdivision, and down-conversion…Model works for $D_2/^4He$ on same footing as $HD/^3He$ for light water reactions with evidence for ^4He as product from heavy water experiments and weaker D_2/HT mechanism for tritium production."

Hagelstein also had a poster at ICCF21 with the title "Phonon-Nuclear Coupling Matrix Element for the Low Energy E1 Transition in Ta-181 and Applications." The work was motivated by several observed oddities in LENR and other experiments. He wrote: "Such effects seem anomalous, especially since what goes on inside of a nucleus is generally thought to be only weakly impacted by the local condensed matter environment, or by the associated relatively slow center of mass dynamics." This paper provided the results of "a computation of the interaction matrix element in the case of Ta-181, which has a low-energy E1 transition at 6237 eV." The work is closely related to what Hagelstein described in his oral presentation.

Xing Zhong Li has also been a long time contributor to the theory of LENR. He and three colleagues from Tsinghua University presented a paper at the conference on "Resonant Surface Capture Model." They wrote: "The essence of resonance is to put the peak of wave function at the nuclear edge; thus, the deuteron would deliver a neutron to the surface of target nucleus, then, cause the capture of neutron by the target nucleus. When this resonance is at very low energy, the resonant elastic scattering (diffusion process) is maximized; and the consequent capture (excess heat) is maximized as well. Both are featured by an exponential factor, which leads to the straight line in temperature (T) dependence of excess heat in semi-logarithmic plot." Figure 10 was presented to illustrate the exponential dependence of LENR excess power on T. It is significant that two electrochemical LENR experiments (Fleischmann and Storms) and one gas-loading LENR experiment (Tsinghua) all exhibit an exponential variation with temperature. The group wrote that such exponential behavior "implies this resonant surface capture model," and "is created by this resonant elastic diffusion process, which generates the mother state of nuclear transition. This transition probability is maximized by this resonance as well. A deuterium flux is necessary to create this mother state in terms of resonant elastic scattering." They then presented equations for the average rates of diffusion and excess heat production. Reactions between protons and deuterons and ^6Li were analyzed. The abstract for this paper ended with this prediction: "More fuels are available for this resonant surface capture reaction provided that the target nucleus has an energy level very close to the thermal energy (*e.g.* d+Li6, p+B10, etc.). High electric charge number Z is no longer a problem. The best candidate would be gadolinium, which has the largest capture cross-section of thermal neutron."

Vladimir Dubinko and four colleagues are affiliated with three organizations, Quantum Gravity Research in the U.S., and the Kharkov Institute of Physics and Technology and the B. Verkin Institute for Low Temperature Physics and Engineering, both in the Ukraine. They had another paper in which activation energies play a central role. In earlier research, Dubinko and colleagues have shown that "in a crystalline matrix, the activation energy may be reduced due to localized anharmonic vibrations (LAVs) of atoms, LAV can be excited thermally or by irradiation, resulting in a drastic acceleration of chemical reaction rates driven by thermally-activated 'jumps' over the reaction barrier due to the time-periodic modulation of the barrier height in the LAV vicinity." They extended the model to excitation by Zero Point Vibrations (ZPV) as an alternative to thermal fluctuations. They wrote, "Large amplitude atomic motion in LAVs may result in time-periodic driving of adjacent potential wells occupied by hydrogen ions (protons or deuterons) upon hydrogenation. This driving is shown to result in the increase of amplitude and energy of ZPV. Based on that, we demonstrate a drastic increase of the D-D or D-H fusion rate with increasing number of modulation periods. That takes into account suppression of the Coulomb barrier due to ZPVs, which is further enhanced by LAVs. In this context, we present numerical solution of Schrödinger equation for a particle in a non-stationary double well potential, which is driven time-periodically imitating the action of a LAV. We show that the rate of tunneling of the particle through the potential barrier separating the wells can be enhanced enormously by the driving in a certain frequency range." The authors presented "atomistic simulations of LAVs in the crystal lattice of Ni, Pd, Ti-Zr-Ni" and in their quasicrystalline nanoclusters." They also provided "experimental results on the interaction of the Ni, Pd and Ti-Zr-Ni crystals and quasicrystals with hydrogen and deuterium under thermal equilibrium and under gamma irradiation, which is introduced as an efficient tool for the athermal production of LAVs."

Jean-Luc Paillet from University Aix-Marseille and Andrew Meulenberg of the Science for Humanity Trust, Inc. provided a paper in their series on deeply (strongly) bound electrons within femtometers of the nuclei of atoms. It was titled "On Highly Relativistic Deep Electrons." They started by showing that relativistic effects are both the source of the deep electron orbits, and the solution for an apparent problem due to application of the Heisenberg Uncertainty Principle to the tightly confined orbits. Then, they made the case for existence of a local minimum in energy very near the nucleus. The high kinetic energy of the localized electron is attributed to dynamics within the nuclear proton. This is another instance of concern about the content of nucleons affecting what is happening in LENR experiments. That is one reason the internal structure of nucleons was shown in Figure 1. Paillet and Meulenberg concluded by citing their advances in understanding relativistic effects and localized binding of electrons very near nuclei. They looked ahead as follows: "Relativistic corrections of spin should be taken into account. QED effects on highly relativistic electrons must be studied" and "LENR features, such as energy transfer with neither gamma radiations nor energetic particles, requires enhanced internal conversion. So, we study possible connections between deep, highly-relativistic electrons and nuclei, quarks, hadrons."

Vladimir Vysotskii has addressed the understanding of LENR for many years. He and another colleague from Kiev National Shevchenko University, and a collaborator from the INFN-Laboratori Nazionali di Frascati, had an oral presentation at ICCF21. It included material from two papers, the first of which was "Using the Method of Coherent Correlated States for Realization of Nuclear Interaction of Slow Particles with Crystals and Molecules." This paper began with a review of earlier work on "general and universal mechanism for LENR optimization based on the application of coherent correlated states (CCS) of interacting particles. This mechanism provides a high probability of LENR and can be applied with the same efficiency to different experiments. It should be noted that the CCS method makes it possible to explain different LENR paradoxes on the basis of standard quantum mechanics and modern nuclear physics without involving fantastic heuristic models." The motion of a proton relative to the atoms in a crystal induces a harmonic perturbation, which results in "giant fluctuations" in transverse energy. The authors use this mechanism to explain the reaction ^7Li + proton to 2 ^4He. Their mechanism also explains the absence of MeV alpha particles from that reaction.

The second paper presented by Vysotskii was entitled "Effective LENR in Weakly Ionized Gas Under the Action of Optimal Pulsed Magnetic Fields and Lightning (Theory and Experiments)." Usually the effects of CCS "are considered in condensed systems with controlled interaction between guest particles and matrix nuclei that is similar to non-stationary oscillator. Another alternative method of CCS formation is connected with a pulsed change of the frequency of an equivalent harmonic oscillator under the action of a pulsed magnetic field on free charged particles. A typical example of such external action is an electric discharge in a gas or liquid. The current of the discharge is accompanied by the formation of a pulsed azimuthal magnetic field in which the motion of the ions corresponds to tunable cyclotron resonance, and the system itself is a complete (formal) analog of the nonstationary harmonic oscillator with the same Hamilton operator, wave functions and energy spectrum." The authors found that the optimum pulse lengths were 100 nanoseconds with magnetic fields of 600 Gauss (0.06 Tesla)." They ended with, "These results explain the realization of LENR both in laboratory experiments with pulse discharge and in processes stimulated by lightning."

Konrad Czerski of Szczecin University and IFK Berlin is another experimentalist who is working on theory. He provided the paper "Influence of Crystal Lattice Defects and the Threshold Resonance on the Deuteron-Deuteron Reaction Rates at Room Temperature" even though he could not attend. Jirhota Kasagi graciously gave the presentation at ICCF21. A few groups have reported for many years that deuteron-deuteron fusion cross sections are significantly enhanced at low (few kilovolt) energies. Both Czerski and Kasagi have been leaders in that research. The enhancements can be interpreted in terms of screening potential. This paper began with a review of the physics and data of the cross section increases. Scatter in the data from different laboratories might be due to surface oxidation or non-uniform distributions of deuterons in targets. Still, there is no issue that the cross section enhancements do occur. They are not yet understood theoretically. Czerski had investigated the possibility that the core reason for enhancements is a resonance condition involving a level in the ^4He compound nucleus. Calculations based on that idea agree well with the branching ratio and angular distributions for neutrons and protons from experiments. Czerski stated that a balance between the resonance and electron screening explains ^4He production and increases in reaction rates at room temperature up to seven orders of magnitude and changes in the branching ratio.

Katsuaki Tanabe from Kyoto University presented a paper at ICCF21 on "Plasmonic Field Enhancement on Planar Metal Surfaces." His earlier work had showed optical energy enhancement on spherical metal nanoparticles of as much as 1000 times for noble metals and ten times for Pd, Ni and Ti. His new paper dealt with such enhancements on planar surfaces, which are commonly used for cathodes in LENR experiments. The enhancements represent how much energy can be concentrated from the incident electromagnetic power. Quantitative field enhancement factors were computed for Pd, Ni and Ti as a function of wavelength and the medium surrounding the metals. Values obtained for Pd beyond 1500 nm are in excess of 30 in vacuum or gases, and larger than 20 for immersion in light or heavy water. Conversion of the incident electromagnetic energy into localized and propagating surface plasmons is the reason for the enhancements. The author discussed the role of surface roughness in the coupling and field enhancements. He wrote, "the enhancement of the supplied energy density around the nuclear-reaction sites would increase the reaction rates by providing a larger opportunity and a larger amount of energy to be absorbed and then utilized for the excitation."

Gennadiy Tarasenko and a colleague from Caspian State University of Technologies and Engineering had a poster on "The Mechanism of Formation of LENR in Earth's Crust." It was a development of Tarasenko's presentations at earlier ICCFs. They envision this process: "Rotation of sub-surface geospheres generates electricity and is responsible for the dynamo effect of planet Earth." The large-scale currents are viewed as the source of the earth's field with associated discharges that can cause earthquakes and various geological formations. They wrote, "This LENR process is possible because of the presence of plasmas of various forms, which possess both gravitational and magnetic fields and are able to process the surrounding material into geological bodies of different types." The team conducted laboratory experiments to simulate geophysical conditions. These were described: "Inside a simple reactor chamber, a pressured environment was created in the presence of a magnetic field and electric discharges. After the initial excitation of electrical discharges, a voltage appeared on the stator, which suggests the formation of a condenser-like structure inside the reactor." That structure is thought to be similar to what occurs in the earth.

Several participants, most of whom are relatively new to LENR, discussed their ideas at ICCF21. They are reviewed in the rest of this section.

Anthony Zuppero and Thomas Dolan of Tionesta Applied Research Corporation had one oral and one poster presentation at ICCF21. The first was titled "Electron Quasiparticle Catalysis of Nuclear Reactions." Their new model of how LENR occur started with a chemical physics process in which electron bonding between fuel and reactant molecules leads to ejection of an electron from the system. The electron that enables the process must have an effective mass above a threshold. The authors focused on the extension of the mechanism from the molecular to the nuclear levels. The model "uses heavy electrons to facilitate nuclear reactions, similar to muon catalysis. The heavy electrons have lifetimes ~10 fs, during which some of them may facilitate nuclear transmutations." The authors provided a means to compute the required effective masses for their mechanism to work at the nuclear level. They then considered diverse nuclear reactions with associated required effective masses in the range from 8 to 64 times the normal electron mass. One of the attractive features of their model is that the reaction products are not in excited states, so that the common deexcitation problem with LENR theories is avoided. That is, this new model is compatible with the dearth of radiations from LENR experiments. The poster by Zuppero and Dolan was on "Transmutations by Heavy Electron Catalysis." It applied their model to nine experimental observations. The authors ended by noting that "Heavy electron catalysis may be useful for neutralizing Cs-137 and Sr-90."

Cheryl Stevenson and a colleague from Illinois State University and PragmaChem LLC presented a paper entitled "Isotope Effects beyond the Electromagnetic Force: ^{1}H and ^{2}H in Palladium Exhibiting LENR." An electron-catalyzed mechanism was presented for the electrolysis of deuterated water with a palladium cathode, which is infused with deuterium. As a result, there is the formation of small amounts of radioactive tritium, excess energy and the concomitant liberation of ^{4}He. An influx of electrons into the Pd-D lattice results in a deuteron capturing an electron to form a di-neutron. The newly described mechanism involves that very important and almost forgotten intermediate. The di-neutron interacts with D or H "via phonon enforced quantum tunneling" to produce ^{4}He or ^{3}He. The authors wrote, "These reactions involve the weak force, but they take place in simple electrochemical systems that are normally thought of in terms of the electromagnetic forces only."

Serge Afanasev from Saint Petersburg provided a poster with the title "Cold Fusion: Superfluidity of Deuterons." He wrote: "It is supposed that the reaction of deuteron merger takes place due to one deuteron, participating in the superfluidity motion, and one deuteron, not participating in the superfluidity motion. The Coulomb barrier is overcome due to the kinetic energy of the Bose condensate motion being very large. The Bose condensate forms from delocalized deuterons by taking into account that the effective mass of delocalized deuteron is smaller than the free deuteron mass." Further, he asserted: "It can be understood why CF reactions occur in palladium and titanium only. This fact is connected with the effective masses of delocalized deuterons in palladium and titanium being small."

Simon Brink from Subtle Atomics in Australia presented a paper entitled "LENR Catalyst Identification Model." He focused on the role of catalysts in many types of past LENR experiments. His ideas meld the characteristics of Rydberg atoms (not Rydberg matter) with the "below ground state" ideas of Randell Mills from about 1990. Brink is conducting testing to validate his model. Details can be found at subtleatomics.com.

Martin Gibson is an independent researcher in the U.S. He had a poster paper at the conference on "A Geometric Understanding of Low Energy Nuclear Reactions in the Palladium-Deuterium Lattice." He began by making the case for the central role of geometry in physics by writing, "Current physical theory tends toward the wave/field model as a means of explaining and calculating all physical object interactions. A result of this development in physical thinking is that the interaction of all properties and their elaborations are localized in their objective perception according to well-defined, multi-dimensional geometric constraints." Gibson then discussed a geometrical interpretation of LENR in deuterium-loaded palladium lattices.

Toshihiko Yoshimura and three colleagues from the Tokyo University of Science provided a paper on "Estimation of Bubble Fusion Requirements during High-Pressure, High-Temperature Cavitation." Cavitation bubbles on surfaces are central to the work of Stringham, already described above in the section on Old and New Diverse Experiments. Such bubbles in liquids can produce what is called "bubble fusion." It is hot fusion, rather than LENR. In this paper, the authors wrote, "a new cavitation method termed multifunction cavitation (MFC), which combines the characteristics of both ultrasonic cavitation and water jet cavitation, was applied to the study of bubble fusion. The cavitation velocity and the pressure and temperature inside a bubble in deuterated acetone when employing MFC were estimated theoretically and compared to the values required for fusion." The authors showed images of their new setup for MFC experiments.

Farzan Amini from Iran could not participate in ICCF21, but he provided a poster on "Warp Drive Hydro Model for Interactions between Hydrogen and Nickel." There was no evident connection between this work and LENR.

The diversity of the ideas on the mechanisms behind LENR, as presented at ICCF21, is both noteworthy and challenging. The wide variations in the status of the development of the various theories is also significant. Some theories are just ideas, but others have resulted in sophisticated calculations. In only a few cases, it is possible to make contact with LENR experimental results.

Nuclear Structure Theory

At ICCF17 in Daejeon in 2012, a group of relatively young newcomers to the field met, and soon afterward began the Martin Fleischmann Memorial Project. The group specializes in Open Science. They post their work and give access to ongoing experiments on the Quantum Heat website.[29] At ICCF21, a group devoted to the study of nuclear structure was nucleated due to the leadership of Norman Cook and Bob Cook. The two Cooks are not related biologically, but they share a strong interest in the interactions between the sciences of nuclear structure physics and LENR. Their evening meeting during ICCF21 attracted about 20 participants. Figure 11 shows Norman Cook leading that active and interesting discussion. The core group of nuclear theorists continues to communicate on various topics, especially the reconciliation of the various nuclear structure models. Those ideas include the Lattice, Structured Atom, Alpha Particle, Quantum Spring, Cluster and Deep Orbit nuclear models. The models are being compared to the widely studied and more accepted, albeit unreconciled, Liquid Drop, Fermi, Cluster and Shell models of the nucleus. The group has compiled a list of Purposes and Principles for their ongoing discussions. The self-assembly and emergence of this Nuclear Structure Group was one demonstrable benefit of ICCF21.

Norman Cook of Kansai University and Paolo Di Sia of Padova University gave a paper with the title "The 'Renaissance' in Nuclear Theory: Low-Energy Nuclear Reactions and Transmutations." Their presentation started with the case for the acceptability of lattice models of the nucleus in opposition to the historical view of their impossibility. Specifically, they state, "Nuclear Lattice Effective Field Theory (NLEFT) has been developed by Ulf Meissner *et al*. so that conclusions at a new level of spatial detail concerning nuclear structure have become possible. Because NLEFT entails specification of individual nucleon positions within a lattice of nucleons, it explicitly contradicts the dominant 'Copenhagen' interpretation of quantum mechanics." The authors then noted the two main competing lattice nuclear models, the Simple Cubic and Face-Centered Cubic (FCC) versions. They made the case for the FCC model, which is treated in detail in Cook's book.[30] A strong point was made that all the symmetries of the Independent Particle (Shell) Model of the nucleus are present in the FCC lattice model. The talk included numerous graphics on lattice simulations of LENR. Such computations can be done using a simulation tool written by Cook, which is available on the internet.

Cook and Di Sia noted the energy ranges of fundamental theories of matter: QED (quantum electrodynamics) 10 - 100 eV (for chemistry), QND (quantum nucleodynamics) 100 keV - 3 MeV (for nuclear physics) and QCD (quantum chromodynamics) 100 - 1000 MeV (for particle physics). QND is described as appropriate to LENR in addition to nuclear physics. The authors suggest to LENR theoreticians that they "develop ideas that conventional nuclear theorists can relate to," given the increasing acceptance of lattice nuclear models.

Philippe Hatt is an independent researcher from France. His poster was entitled "Cold Nuclear Transmutations Light Atomic Nuclei Binding Energy." He postulates that the "nuclei of the various elements are constituted out of α particles and other nucleons grouped in order to form sub nuclei bound together by four types of bonds that involve neutrons N and Protons P, called NN, NP, NNP, NPP." Hatt showed that "the hypothesis of α structures in the n-α nuclei can indeed describe the binding energy systematics. In such an approach, the system in its ground state behaves like a crystal, with stationary configuration and shape and with defined bond values between the various α particles."

Nancy Bowen of Colorado Mountain College provided a paper that also dealt with nuclear binding energies, but at the sub-nucleon level. It was entitled "A Simple Calculation of the Inter-Nucleon Up-to-Down Quark Bond, and Its Implications for Nuclear Binding." The paper described "an interesting and potentially significant phenomenon regarding the properties of up and down quarks within the nucleus, and how the possible inter-nucleon bonding of these quarks relates to the bonding energy of the nuclear force. A very simple calculation is used, which involves a bond between two inter-nucleon up and down quarks. The calculation does not depend on the type or mechanism for the bond; furthermore, this simple calculation does not specify the shape or structure for the nucleus. This calculation only examines the energy of all possible up-to-down inter-nucleon bonds that may be formed within a quantum nucleus. A comparison of this energy is made to the experimental binding energy with excellent duplication of experimental results, using only one parameter (instead of five, as in the

Figure 11. Norman Cook leading the session on the intersection of Nuclear Structure and LENR.

semi-empirical formula). The binding energies are calculated for a representative sample of stable nuclides, going up to uranium U-238. The resulting errors of this calculation are on the order of a few percent (the average error from A=12 to A=50 is 1.68%)."

Russ Blake from Quantum Spring Technology Pty Ltd. in Australia had two presentations at ICCF21. The first was a talk on "Understanding LENR Using QST," where QST stands for Quantum Spring Technology. In his abstract, Blake wrote that "QST maintains that normal physics does apply at subatomic scale; it is space that has properties but which are only observable at that scale." The paper aimed to evaluate the extent to which the QST can or cannot explain the diverse experimental results observed in LENR experiments. Blake asserted that "As QST places the LENR phenomenon on a classical physics foundation, it becomes clear there are only a few basic conditions that must be present for LENR to occur: (1) a physically stable target nucleus experiencing minimal phonon motion, (2) an impact nucleus with sufficient speed (*i.e.* energy) to overcome the opposing Coulomb forces, and (3) a trajectory, possibly guided by the lattice, encouraging the impact nucleus to collide with the target." "Aiding or impeding" one or more of these conditions leads to explanations of LENR observations. Blake's poster presentation was "Further Foundations of Fusion." In it, he cited the improved computations of binding energies from the QST, compared to the FCC and Liquid Drop nuclear models. Blake's "models of protons and neutrons, combined with electromagnetic forces, duplicate the binding energy of 12 isotopes from deuterium through carbon with correlation 0.99893." In this poster, he summarized previous results, then presented some new evidence that the model is plausible. Blake included images of the models of isotope nuclei from deuterium through carbon which yielded these results.

Edo Kaal and James Sorenson are both independent researchers, the former from The Netherlands and the latter from the U.S. Their paper at ICCF21 was "The Structured Atom Model-SAM." They wrote that the SAM "postulates that the nucleus has a precise, fixed, geometric structure based on two of the platonic solids, the tetrahedron and icosahedron. The nucleus grows predictably and its structure determines the properties of the elements which in turn defines the organization and periodicity of the periodic table of elements. The larger elements are built from clusters of 12 nucleons in the shape of an icosahedron." They applied their concepts to explain why LENR occur without γ-ray mission.

All of the nuclear structure models presented at ICCF21 need further work on their applicability to LENR. The work by Cook and his colleagues is most advanced in this regard. The eventual understanding of LENR might contribute to the trend toward conceptual unification of the basic levels of matter, as indicated in Figure 1. Currently, there is increasing interaction between High Energy Physics and Nuclear Physics, as forces within nucleons are being related to forces between nucleons. In a somewhat similar fashion, understanding of LENR could lead to a closer intellectual relationship between the nuclear and atomic levels of matter. It is appropriate that Nuclear Physics, with its multiple models, is in the middle of the current attempts to understand LENR. The new subject raises old and unresolved issues in Nuclear Physics. Could understanding of LENR lead to a more integrated and mature theory of the nucleus?

Integrated LENR Research Programs

LENR will be understood and commercialized fastest and best by a combination of experimental and analytical research. There are a few programs in the field that involve such combinations. One of them is the work at MIT led by Peter Hagelstein. His theoretical work, and new experiments with Metzler that are based on the theoretical and computational work, were already reviewed above. A few papers from other programs involving both theory and experiment are reviewed next. An academic program with experiments, advanced data analyses and simulations is summarized at the end of this section.

There were a few papers at ICCF21 that involved a combination of theory and experiments. Three of them have already been reviewed above, calculations and measurements of vacancies in nickel by Nee and his colleagues, the Rydberg Model work of Brink and the bio-transmutation research of Vysotskii and Kornilova. Other papers on integrated research efforts are reviewed in this section. Some of the papers are combinations of theory and experiments. Others have to do with experiments and simulations.

Dimeter Alexandrov from Lakehead University in Canada gave a presentation on "Nuclear Fusion in Solids: Experiments and Theory." He has experimented with Pd, Ni, Zn and Mo, but presented data on Pd only. His setup has the following components and capabilities: vacuum chamber, mass-flow analyzer, plasma source operating with a gas flow, heater for the sample holder, stainless metal grid acting as anode for additional plasma measurements, and detectors for both neutrons and γ-rays. The initial vacuum environment is about 10^{-6} Torr, and contains H_2 at about 10^{-7} Torr. The concentrations of both ^3He and ^4He in the flow of gas (4.5% D_2 and 95.5% N_2) are less than 10^{-11} Torr. Alexandrov presented data on the production of ^3He and ^4He as a function of temperature and time. Both mass and optical spectroscopy were used to monitor those isotopes. The measured temperature increases scaled with the amount of helium produced. No γ-ray and neutron radiation greater than that of the normal background was detected during the experiments. Alexandrov's theory is based on a solid-state increase in effective mass, and quantum tunneling to cause fusion reactions. He notes that "The released energies of the fusion reactions partially destroy the crystal lattice making the corresponding regions not able to participate in immediate further reactions. It corresponds to the cyclic change of the temperature that was observed experimentally, *i.e.*, the time for recovery of the crystal lattice is needed in order for fusion reactions to be re-established again."

Andras Kovacs and Dawei Wang from Fiskarsin Voima Oy in Finland had a poster entitled "Electron Mediated Nuclear Chain Reactions." They proposed that (a) there is a class of nuclear reactions that is initiated by the nuclear capture of energetic electrons and (b) such reactions may generate a higher number of energetic electrons as the output. In an earlier publication, they investigated alloys containing ^{58}Ni and ^6Li-^7Li mixtures as possible fuels for electron-mediated nuclear chain reactions. They showed experimental evidence for an exothermic nuclear reaction in which the observed experimental details are consistent with the electron-mediated chain reaction model. In this paper, the authors presented evidence from relevant experiments in literature, as well as their own experiments. The work implies the possibility of sustainable energy production from metallic nickel or lithium. Gamma-ray and radio-frequency data was shown to make the case.

An academic LENR research program is led by one of us (DJN) at The George Washington University (GWU) in Washington, DC. The long-range goal is to reproduce, control and understand LENR. The near-term aim is to reproduce, control and understand LENR experiments. Our program includes parametric experiments, sophisticated data analyses, and simulation of the electrical and thermal behavior of the electro-chemical cells. The focus is on experiments with nickel cathodes in light water electrolytes. Such experiments in the early 1990s resulted in reports of significant energy gains, some as high as 37.

There were three posters from the GWU program at ICCF21. The first by Emma Gutzmann *et al.* was titled "Parametric Experimental Studies of Ni-H Electrochemical Cells." It provided electrical and thermal data as a function of electrolytes (Li, Na, K and Rb carbonates) and applied voltages (1.5 to 4.0 V in half-volt increments). Thermometry and Impedance Spectroscopy were the main measurements. No evidence of LENR was obtained.

The second GWU poster was by Felix Scholkmann of the Research Office for Complex Physical and Biological Systems in Zurich. It was titled "Complex Current Fluctuations in Ni-H Electrochemical Experiments: Characterization using Linear and Non-linear Signal Analysis." The paper presented results of detailed analyses of the current fluctuations as a function of time in potentiostatic experiments. We determined (a) how the fluctuation magnitude and the fractal dimension of the time series depend on the electrode potential, and (b) if the complexity of the signals can be captured by analyzing the multiscale time irreversibility (MTI). It was found that the fluctuation magnitude follows a power law, that is, depends non-linearly on the electrode potential. The fractal dimension usually increases with electrode potential. The MTI is able to quantify the scale-dependent complexity of the electrochemical signals, and large fluctuations in the data follow generalized extreme value distributions. The analyses provide information on current fluctuations caused by formation and release of bubbles on the cathode of the electrochemical cells. They provide the background beyond which LENR might be measured.

The last poster from the GWU program was by Gabriel Papadatos *et al.* entitled "Electrical, Thermal and Chemical Simulations of Ni-H Electrochemical Cells." We are using COMSOL software because of the completeness of the included physics, and its ability to handle diverse geometries, materials and processes. Specifically, we employ the Electrical (AC/DC) and Heat Transfer modules of COMSOL. Spatial and temporal distributions of temperatures were obtained, again as a function of electrolyte and applied voltage. The computed temperatures were higher than those measured, possibly because the simulations to date have yet to include the energy going into electrolysis. The experiments in the GWU program are straightforward, similar to much other laboratory work on LENR. The data analysis and simulation components of the program are as good as any in the field.

Potential Applications for LENR

Most of the contemplated uses for LENR involve the output heat. It can be used for home and industrial heating, and for production of electricity, if the generator temperatures are high enough. ICCF21 did not have any papers on thermal applications of LENR. There are other uses of LENR that are based on the changes in elemental composition, which inevitably accompany the nuclear reactions. Some people are attracted by the possibility of producing valuable elements, like platinum. Others focus on the prospect of turning severely radioactive waste from fission reactors into benign elements, and obtaining additional energy in the process. There was one paper at ICCF21 on waste remediation, which is reviewed next. An application that gets little attention is the use of the neutrons from LENR. That is mainly due to the fact that these reactions produce very few neutrons. However, there were two papers at the conference on the use of those neutrons in hybrid fusion-fission reactors. They are summarized at the end of this section.

Andrew Meulenberg and Jean-Luc Paillet provided a presentation on "Nuclear-Waste Remediation with Femto-Atoms and Femto-Molecules." Their earlier theoretical work on deep relativistic electron orbits included predictions of hard-radiation-free transmutations. An implication of that work is "relativistic long-range electromagnetic forces of the deep-orbit electrons that can draw a femto-atom or femto-molecule through a lattice to an excited or unstable nucleus. The selective attraction of the mobile femto-atoms or femto-molecules to radio-nuclides means that, not only transmutation products but, all radioactive materials in the vicinity are preferentially made to decay by multi-particle, but fast, processes." Femto-atoms and femto-molecules are compact entities containing the computed deep electron orbits, which are highly mobile in a lattice. The paper included suggestions for testing of the theoretical transmutation model. Such experiments, and especially the determination of potential reaction rates, are on the long list of needed LENR measurements.

Pamela Mosier-Boss and two colleagues presented a concept new to this series of conferences. The paper was on a "Hybrid Fusion-Fission Reactor Using Pd/D Co-deposition." In earlier experiments, they measured the production of neutrons with energies in excess of 9.6 MeV. They can induce nuclear fission in uranium. In this work, electrolytic co-deposition of Pd-D materials was performed in a cell with a composite cathode of gold and uranium wires. Neutron fluxes sufficient to damage the Ge detector were observed. The interactions were modeled and gave neutron energies of 6 - 7 MeV. CR-39 track detectors were used to verify the production of energetic neutrons. X-ray analysis of the post-run materials showed evidence of new elements (Fe, Zn, Al, Si, Mg, Cr and Na), apparently fission fragments. The authors wrote, "The results of these experiments show that a hybrid fusion-fission reactor is feasible that would not produce greenhouse gases, could be easily shut-off, and could potentially be used to dispose of long-lived radioactive fission products produced by conventional nuclear power plants."

Lawrence Forsley and Pamela Mosier-Boss from Global Energy Corporation next gave a sequel to the paper just reviewed entitled "Space Application of a Hybrid Fusion-Fission Reactor." Almost all deep space missions past Mars have been powered by RadioThermal Generators, which provide less than 1 kW of power. Such unmanned probes, and also human travel beyond the earth-moon system, need greater powers. The authors wrote, "Various electrical power needs range from tens of kilowatts for instruments to over 20 megawatts for human spacecraft electric propulsion and planetary power." Global Energy Corporation has an agreement with the NASA Glenn Research Center to develop a launch-compatible design, operating at the Plum Brook Station. That facility has vacuum, acoustic and shake table systems to certify space launch capabilities. The presentation by Forsley described the activities of that program.

Other Presented Topics

Not all of the ICCF21 oral and poster presentations fall into the categories listed above. Five such papers are summarized in this section.

Jacques Ruer, an independent researcher from France, and two colleagues from Canada had a presentation on "Chemical Heat Generation in LENR." Over the decades, there have been a few reports of meltdowns or explosions in LENR experiments. Sometimes they were attributed to LENR. Whether or not that was the case is important both scientifically and practically. This paper dealt with two types of phenomena in which chemical (non-LENR) effects might have contributed to what happened. One was self-heating of H-loaded Pd exposed to air. The burning of escaping H heats the metal, which accelerates the out-diffusion. The authors modeled the process as a function of loading and Pd geometry. They found that a 5 mm rod, which was initially loaded to H/Pd = 0.9, would reach a temperature near 1100°C in about three minutes, if the surface was catalytically active.

The second phenomena of interest were explosions, one of which was reported by Biberian. Ruer performed experiments to see if there could be a chemical explanation of what happened. He induced subsonic deflagration and supersonic detonation events in hydrogen-oxygen mixtures. His experiments considered production of detonations by shock wave amplification by coherent energy release. Ruer attributed Biberian's explosion to that effect. The work is a good example of thorough examination of odd effects seen in various LENR experiments.

At the end of the presentation, Ruer offered a scenario for the 1985 experiment by Fleischmann and Pons, which destroyed an experiment, burned through the supporting bench and produced significant damage in the concrete floor. He ended by making the case for renaming LENR as QEE for Quantum Effects Energy, partly to avoid the word nuclear, which can be a source of needless concern to non-scientists.

Steven Katinsky and three of us had a poster entitled "LEAP: The LENRIA Experiment and Analysis Program." It reviewed the plans and status for a multi-laboratory experimental program aimed at reversing the negative scientific and public perceptions about the legitimacy and promise of LENR. LEAP is designed to reduce the number of variables associated with achieving LENR reproducibility by delivering a turnkey experiment to a group of well-regarded laboratories and experimentalists. Institutionalizing the engineering, construction, programming, testing and materials phases of the experiments is expected to reduce the introduction of unknowns, while permitting participants to focus on operating and vetting the experimental regime, and reporting their results. The plan is to use the Pd-B alloys prepared by Imam in modernized experiments, similar to those of Miles. Those materials and protocols gave highly reproducible results, as reviewed above in the section on Materials Considerations.

There were two posters at ICCF21 having to do with the archiving and use of information on LENR from past research. The first of them by Thomas Grimshaw (University of Texas at Austin) and Edmund Storms (Kiva Laboratories) described a large effort to ensure that the records of Storms are properly archived. Their paper was "Documentation and Archive of 29 Years of LENR Research by Dr. Edmund Storms." The abstract read: "Storms' LENR publications include about 125 items. They include his two books, published in 2007 and 2014. Unpublished progress reports, mostly to sponsors of his work, include more than 110 documents. His ten lab notebooks document LENR research from 1995 to 2015. A work history prepared by Dr. Storms from these notebooks consists of about 2750 entries. The electronic files are on current and legacy media, including an active computer, CDs, DVDs, ZIP disks, VHS tapes, an external hard drive, and 3½-inch floppy disks. A dozen hanging file tubs of hard-copy records were assembled. The LENR library contains more than 6000 papers and similar items. It is one of the largest collections of materials on the topic in existence." Ordering and archiving all these records is a service to both LENR scientists and to future historians of LENR.

The second paper on LENR information was by Abd ul-Rahman Lomax on "Correlation and Cold Fusion." He started with a brief review of the early history of LENR (then "cold fusion"). Lomax wrote, "Just as premature rejection led to a widespread belief that cold fusion was found to be a mistake 'long ago,' so too, reaction to that belief damaged our own work. We believed that it was necessary to produce 'better' results to convince skeptics, 'better' usually meaning substantial and reliable heat. Yet the most significant missing evidence from the original work was not heat, it was the reaction product, and especially a correlated nuclear product." He ended with a call for better interactions with mainstream scientists: "We need the interest of genuine skeptics, those who will actually investigate and sanely criticize what is claimed."

One contributed abstract did not result in an ICCF21 presentation. However, it is on a topic of interest in the field, so it is mentioned here. Ryan Wood from Frontline Aerospace Inc. asked this question in his title "Joseph Papp Noble Gas Engine Shows Early LENR?" His interest was to "cover the history, experiments and technical insights of the inventor Joseph Papp and his noble gas engine and connect them to the LENR paradigm." Wood has examined "historical science, witness testimony, film evidence, patents, official interviews and one historical certified power-in power-out controlled test." A solid connection between the Papp engine and LENR waits for future experimental work.

Laboratory Experiences

Several of the ICCF series have had unusual sessions for specific purposes. At ICCF14, there were two sessions devoted to the work of LENR pioneers, specifically Stanislaw Szpak and Yoshiaki Arata. The intention of those sessions was to review and highlight the many contributions to this field by those people, and to honor them for their work and results. Something similar was tried at ICCF21. A session on Friday morning was devoted to talks by three long-time contributors of experimental results about LENR. The intent was again to honor them and their contributions. The talks also gave them a chance to emphasize results that they obtained over the decades, which they think are most important. Many of the results were presented at earlier ICCFs, but it was useful to have key results pulled together in one presentation by each of three scientists.

Edmund Storms did his initial LENR experiments at Los Alamos National Laboratory, and then continued research in his home laboratory for more than the past two decades. Storms gave the first review of his Laboratory Experiences, which primarily involved electrochemical loading of deuterons from heavy water into Pd and related materials. He showed very early measurements of tritium. Detection of tritium during and after LENR experiments is very significant, since it is not in the environment and is relatively easy to detect. Storms then went on to show excess heat results, up to 6 W in some cases.

Two experimental facts were emphasized by Storms. One is the changes in Pd and related materials due to loading and deloading. The other is the complex nature of the surface of Pd materials. The surfaces are very unlike textbook concepts. Storms has spent a lot of effort on the development, calibration and testing of Seebeck calorimeters. He showed several results from using such instruments. One of these experiments resulted in unusual data. He employed a Pd anode and a Pt cathode, the opposite of what is normally done. Operation of the cell in a heavy water electrolyte resulted in a thin deposit of Pd and other elements (probably Li and Si) on the cathode. Substantial excess heat was measured, as shown in Figure 12. This is a relatively simple experiment that deserves much more attention.

The second speaker in the session on Laboratory Experiences was Jean-Paul Biberian. He now serves as the Editor of the *Journal of Condensed Matter Nuclear Science*, and also works in his home laboratory. Like Storms, he has spent decades on measuring the results of a wide variety of LENR experiments. His presentation covered both science and technology. The scientific research included heat production in electrolysis experiments and transmutations (nuclear reaction products) in both electrolytic and plasma experiments. The latter kind of experiment was done with graphite (carbon and impurities) in a kitchen microwave generator. Inductively-Coupled Plasma Auger Electron Spectroscopy was used to analyze for 30 elements. Some of the results are: B (+1900%), Ba (+364%), Mg (+88%), Mn (+42%), Fe (+38%) and Na (+11%).

Biberian reported on four types of technological LENR experiments. They included the use of nickel nano-powders, Ni-Pd-ZrO_2 materials, solid-state electrolytes and biological transmutations. He employed heat-flow calorimetry with the first two types of materials. Figure 13 shows that Biberian measured about 5.5 W of excess thermal power, which was about 12% above the input electrical power. He also presented data on excess heat from proton conductor samples, and the production of boron, sodium and manganese by the algae Spirulina. Biberian concluded by noting three goals: scientific demonstration of cold fusion, application for energy production and the use of biological transmutations for nuclear waste remediation.

The final speaker in the Laboratory Experiences session was Dr. Mitchell Swartz. He has a Doctorate of Medicine from Harvard Medical School and is Board-Certified as a Therapeutic Radiologist. In addition, Swartz also has a Sc.D. in Electrical Engineering from the Massachusetts Institute of Technology. He simultaneously continues his medical practice and does leading research on LENR. Swartz uses the term LANR for Lattice Assisted Nuclear Reactions. He began his presentation at ICCF21 by listing four goals for LANR: (a) demonstration of excess heat, (b) reproducible production of excess heat at high gain, (c) electricity production and (d) electricity production at breakeven. The last of these would permit self-sustained operation of LENR power generators, where some of the produced electricity would be used to sustain and control continued energy production.

Swartz provided a history of his activities and results in three graphics, which are reformatted as Table 3. It shows that he has used a variety of devices, and achieved strong results over the years. Not shown in the table are the redundant diagnostics, which he has used to ensure that his calorimetry and other measurements are correct.

After providing the history, Swartz went on to show images and results from the different experiments. Most of his graphs are noteworthy because they contain data from both controls and active devices. He also reviewed the early improper handling of their LANR data by MIT; the character and implications of his Quasi-One-Dimensional model for deuteron fluxes; the importance of what he calls Optimal

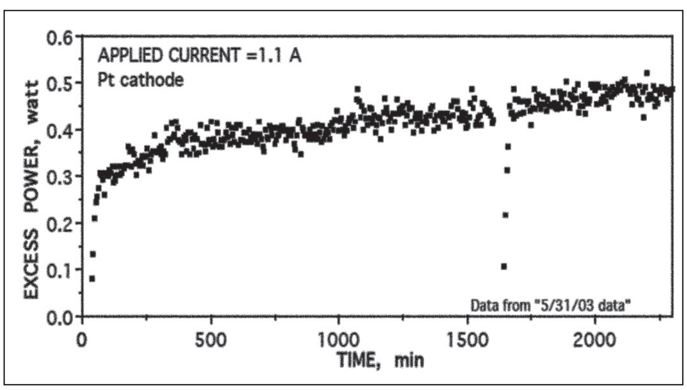

Figure 12. Plot of excess power vs. time from an experiment by Storms in which the active material was a thin layer of Pd deposited on a Pt cathode.

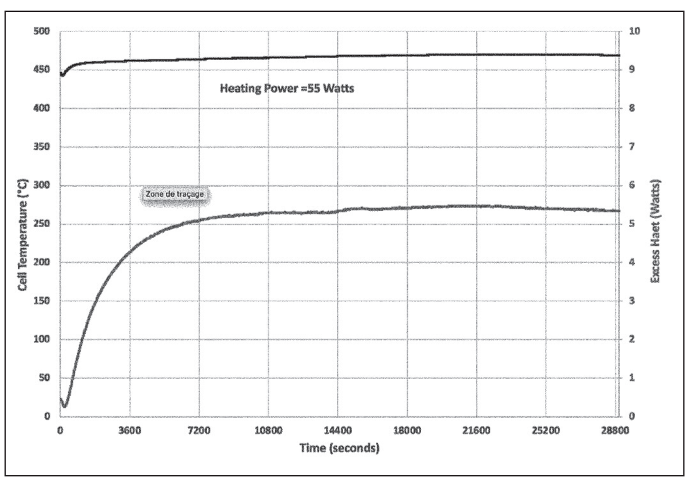

Figure 13. Input power (top curve and left scale) and output power (bottom curve and right scale) measured by Biberian.

Table 3. History of the Activities and Results obtained by Dr. Mitchell Swartz.

Year	Device	Excess Energy	W/cm3	Public Activities	Comments
1989	F+P type ElChem Cells	115%	7		Not Reproducible
1992	Varied ElChem Cells	140%	80		More Reproducible
1996	Phusor®-type Cells	200%	700		Near Reproducible
2003	Phusor®-type Cells	230%	1000	Public Demo #1	
2005	Phusor®-type Cells	300%	1500		LANR Engines
2008	Phusor®-type Cells	500%	2000		
2009	NanoMaterials	~140%			Some Excess Energy
2010	NANO®R-type comp	~300%			More Reproducible
2011	NANOR®-type comp	~900%			Near Reproducible
2012	NANOR®-type comp	~2000%		Public Demo #2	19,000 W/kg
2013	M NANOR®-type comp	~8000%			Good electrical control
2014	M NANOR®-type comp			IAP Colloquium	
2015	G NANOR®-type comp				
2016	MOAC #1	~400%			Very Low Input Power
2017	MOAC #2	~900%			50 W Input
2018	MOAC #3	~3000%			>150 W Input
2019	Phusor®-type Cells			Advanced Course	
2020s	NANOR®-type 10th and 11th Generation				NanorSats?

Operating Manifolds (regions of input power correlated with high gain); his work with Stirling engines and a fuel cell/LANR car; the recent use of coherent Raman Spectroscopy for characterization of active NANOR devices and aqueous components; his use of 3D printing to make experimental components; and his long-term publication of *Cold Fusion Times*.

The three talks on Laboratory Experiences by three leading experimenters on LENR were interesting, and should have been instructive to Scholarship Program participants in ICCF21. For example, these three major contributors to this field did most of their significant work in home laboratories. Determined scientists will find a way to pursue their objectives.

Other Relevant Experiences

The struggle to understand and exploit LENR has precedents in other areas of science and engineering. The several decades between the discovery of superconductivity and its understanding is a well-known example in science. Experience with the development of semiconductor chips is an example from engineering. Both cases, and others, are potentially relevant to the current science and early engineering of LENR devices.

The complexity of LENR involves two types of challenges. One is the large number of diverse observations that have been made in LENR experiments during the past three decades. The second involves the many parameters that need to be explored, especially in regard to materials. This abundance of variables is similar to the early days of the development of semiconductor devices.

Because of the apparent similarities between current LENR research and the early days of chip making, ICCF21 included a presentation on experiences from making computer and memory chips. Dana Seccombe presented a talk entitled "Experience with Semiconductor Technology Development Potentially Relevant to LENR." He cited his leadership of a major and innovative semiconductor development program. That experience is relevant to the commercialization of LENR generators. Fifteen lessons learned for semiconductor yield improvement included these five: (a) Small teams can deliver dramatic results, if they stay focused, (b) Cycle time through experiments is directly related to convergence rate on solutions to problems, (c) Unit process control, and both cradle-to-grave and chemical tracking, are essential, (d) Easy-to-use, comprehensive, automatic diagnostic tools and special test structures greatly simplify otherwise difficult problems, and (e) Intermediate gains are important to maintain team morale and funding for continuing development. Yield in semiconductor production is conceptually equivalent to success (reproducibility) in LENR experiments. If funding of LENR development were adequate, it would be possible to use the iterative, focused practices from the massive semiconductor industry to speed knowledge, commercialization and exploitation of LENR. Materials are central to LENR, as they are in the semiconductor industry. Systematic parameter-variation experiments with diverse materials, using robust experimental setups with multiple monitors and serious data analysis would require team efforts and significant funding. But, they have the potential to bring LENR to market sooner and with greater confidence, compared to the current diverse, and usually-disconnected and widely-distributed, experimental efforts in the field.

Social Aspects of the Conference

Personal interactions are as important parts of conferences as are technical discussions. So, this conference was planned to promote easy and leisurely discussions separate from the technical sessions. Three activities contributed to the collegiality.

Lounge: ICCF21 had an evening lounge, which promoted interactions among participants. About 80% of the participants lived in the nice dormitory rooms on campus. But, the campus is not near the center of Fort Collins. The co-location and relative isolation meant that the participants were close to each other for most of the conference. They needed a place to meet. So, the conference included a lounge in the same nearby building as the dining area from 7:00 to 11:00 p.m. daily. Beer, wine and snacks were provided in the lounge as part of the registration fee. The lounge served its intended purpose, with many of the participants spending their evenings there discussing science and other topics.

Excursions: As has been usual for the ICCFs, Wednesday afternoon was devoted to going to some place interesting in the region. Normally, all of the conference participants would go to the same location. The difference for ICCF21 was having multiple destinations. The proximity of several attractions in the region around Fort Collins made that possible. Hence, separate tours were arranged for the National Renewable Energy Laboratory in Golden, and the National Institute of Standards and Technology, the National Oceanographic and Atmospheric Administration and the National Center for Atmospheric Research, all in Boulder. Visiting those U.S. government facilities required prior approval, and the number of visitors permitted at each location was limited. About half of the conference attendees went to Rocky Mountain National Park.

Banquet: The traditional Thursday evening banquet was held in a very unusual location for ICCF21. Colorado State University has a football stadium that is only a year old. The banquet was held in a large room on the third level of that stadium, which had a very nice view of the sunset behind the Rocky Mountains. Prior to the banquet, many of the participants were permitted to go onto the field for an unusual perspective of the stadium. A social hour preceded dinner. A pair of pianists provided the entertainment during and after dinner.

Preparata Medal for Dr. Mitchell Swartz

In addition to the tour of the field, conversations, dinner and entertainment, a highlight of the banquet was the presentation of the Preparata Medal of the International Society for Condensed Matter Nuclear Science. Bill Collis, who instituted the award and had the medals minted, started the ceremony by announcing that Dr. Mitchell Swartz would be the 2018 recipient. He introduced Professor Peter Hagelstein, who gave some interesting and humorous background on Dr. Swartz. After the actual award, the recipient expressed his appreciation and made other remarks.

Press Coverage of ICCF21

Ideally, the occurrence, participants and contents of an ICCF conference would attract the attention of reporters from broadcast and print outlets on all levels from local to national and even global. However, that has not been the case during most of the conferences in the series. Unfortunately, that was also the situation for ICCF21.

There were two attendees at ICCF21 with an interest in writing about the conference and its activities. One was Ruby Carat from Cold Fusion Now. She provided flash drives to all participants with her podcasts,[31] all of the conference abstracts, the contents of the *Current Science* Special Issue on LENR from February 2015 and various articles. The other reporter was Marianne Macy, who writes for *Infinite Energy*; her coverage of ICCF21 will appear soon on the *IE* website.

Technical Resources from ICCF21

Scientific conferences produce a large volume of information, which is of interest to people who could not participate in a conference, as well as to the participants. That was certainly the case for ICCF21. Here is a summary of such information, and the status or plans for making it available. It is planned to pay in advance for maintenance of all the following ICCF21 web-based information for the next ten years.

1. Abstracts. The 104 Abstracts were posted on the conference website several days prior to the conference (https://www.iccf21.com/submit-abstract).
2. Graphics from Presentations. Adobe Acrobat versions of all the presentation graphics will be posted on the conference website.
3. Posters. Adobe Acrobat versions of all the posters will also appear at iccf21.com.
4. Papers. Authors of both oral and poster presentations were asked to submit their manuscripts to the Editor of the *Journal of Condensed Matter Nuclear Science*.
5. Photographs. A conference photographer took hundreds of images during ICCF21, which will be posted on the website.
6. Videos. The presentations were videotaped. After editing, they will be posted on the iccf21.com website.

Ruby Carat has posted recordings of most of the ICCF21 presentations and many photographs of conference participants on the Cold Fusion Now website.[32] Abd Lomax is providing detailed discussions of some of the ICCF21 presentations. His review of Takahashi's paper is available.[33]

ICCF22

The chairman and location, and sometimes the dates of the next conference, are decided at each ICCF by the International Advisory Committee (IAC). That group is made up of the past Chairmen and Co-Chairmen of a conference in this series. The IAC met on the evening of June 6 to consider a proposal from Bill Collis to hold ICCF22 at Lake Bled in Slovenia in the fall of 2019. That proposal was accepted. Subsequently, Bill Collis determined that the conference could be held in Assisi, Italy, at a more favorable cost. The IAC concurred with this possibility. So, ICCF22 is slated to occur in the center of Assisi during September 8-13, 2019. The location will be the Hotel Domus Pacis.[34]

Summary of ICCF21 and LENR

Oral and poster presentations at ICCF21 covered a very wide variety of topics, tools and materials. Both the science of LENR, and progress toward commercialization were well represented at the conference. In particular, high quality work and results on heat production were featured. Responses to the conference were highly favorable. That was undoubtedly due in part to the nice venue, excellent weather and outstanding support provided by Colorado State University during the conference. However, the content of the conference was its core, and that was widely appreciated.

It is worth noting the large and increasing role of computational science in advancing LENR now, which was evident at this conference. Nee did sophisticated Quantum Espresso calculations of vacancy configurations in nickel, Hagelstein and Vysotskii computed matrix elements and rates, Scholkmann performed complex data analyses, Papadatos and his coworkers used COMSOL to simulate the three-dimensional motion of currents and heat in cells, and Higgins used SPICE to simulate the thermal behavior of the cells used by Letts and Cravens. These are only some of the ICCF21 papers with substantial computational character.

There is a great and growing global need for more energy due to both increasing population in most of the world and increasing per capita use of energy in developing countries. New energy sources must be clean for multiple reasons, including both human and environmental health, as well as to slow the negative impacts of global climate change. Research on LENR actually dates from at least 1985, when the meltdown experiment occurred in the laboratory of Fleischmann and Pons. In one-third of a century, many experiments have shown that it is possible to cause nuclear reactions by use of chemical energies. That bodes well for energy gains, which have already been well established. Experiments have shown that LENR occur without significant prompt radiation or radioactive waste, or the emission of greenhouse gases. This combination of factors, as well as the need for new sources of clean energy, make LENR very attractive commercially. More than 20 companies in many countries are seeking to commercialize LENR generators now, even though the basic mechanisms that cause LENR remain to be understood. Much investment and development work is needed to successfully commercialize LENR. Generators must be fully reproducible, controllable, safe and reliable, with regulatory and consumer acceptance. The field of LENR is a rare and fascinating combination of a major scientific riddle and a serious commercial prospect.

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The authors served as reporters and not critics in writing this overview of ICCF21.

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