Scientific and Commercial Overview of ICCF19

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ICCF is the abbreviation for International Conference on Cold Fusion. It is the historic identifier of a series of conferences that started in 1990. The 19th conference had the full title of International Conference on Condensed Matter Nuclear Science (CMNS). It was held from April 13 to 17, 2015 in Padua, Italy, about 40 kilometers west of Venice. This was the fourth conference in this series that was held in Italy. The General Chairman of the conference was Anthony La Gatta, who is the Founder and President of the company TSEM. He opened the conference with an interesting theme on the melding of mathematics and music. The Co-Chairmen were Michael C.H. McKubre from SRI International and Vittorio Violante of Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA).

This conference occurred in a remarkable venue, the Palazzo della Ragione. The building was begun in 1172. It has one great hall on the second floor that is over 260 feet long and about 70 feet wide. Thirty-two oral presentations were given in that hall. There are 66 posters listed on the ICCF19 website.[1] They were on display in that same grand space throughout the conference. The attendance at ICCF19 was comparable to recent conferences in this series, about 200 scientists, engineers, business people and students. Contributions to the conference were made by authors from about one dozen countries, and there were attendees from another dozen countries. These figures attest to the global interest in LENR.

Conference Chairman Anthony La Gatta toasting the members of the International Advisory Committee.

Photo courtesy of TSEM.

The next section provides a short summary of the status of the entire field. It is very similar to the synopsis given at the start of my overview of ICCF18. That is because the overall status of LENR has not changed qualitatively in the past two years, despite significant progress on several fronts. Due to the great global interest in commercialization of LENR, an early section will review aspects of the conference about or related to development of practical generators of heat and electricity. The bulk of this review will deal with scientific aspects of the field. Sections are provided on the production of heat by various means, transmutations, particle and radiofrequency experiments, materials, theoretical and computational studies, data analysis, engineering and applications.

It should be noted that this overview addresses all of the work presented at ICCF19. Such completeness serves as a thorough summary, essentially an intellectual history, for the entire conference. The author has restrained his critical habits in providing all of the summaries. Were they freed, some of the works included in this overview would have been sternly criticized or entirely ignored.

Status of the Field

Before considering ICCF19 in detail, it is useful to give a brief summary of the three major parts of the field, namely science, engineering and business. The two parts of the science of LENR, experimental and theoretical, are very different in their state of development. In over a quarter-century since the announcement by Fleischmann and Pons, excess heat has been observed hundreds of times in very different experiments in laboratories in several countries. The data shows that it is possible to produce nuclear reactions at ordinary temperatures. The major experimental problems are production of materials with the properties needed to cause LENR, and related lack of reproducibility and controllability. Although the experimental situation is very solid, the theoretical side of the science remains quite wide open. There are very roughly three dozen theories on the mechanisms behind LENR. But, none of these has been adequately tested, and there is no consensus on the theoretical aspects of LENR.

The engineering side of the field also has two parts, experiments and prototypes of products. The design, fabrication and testing of experimental LENR systems is very well developed. Inspired by over two decades of attacks by critics, and good laboratory practices by experienced and skilled researchers in the field, some very sophisticated and well-engineered laboratory systems have been built and employed. Their use has also been first-rate in many cases. In contrast, the prototypes revealed by a few of the companies seeking to develop products for a large market are sometimes relatively crude. This is due to the haste with which these companies are seeking to develop commercial products and limited funding.

The business of LENR has yet to develop. That is, no one is making money now by mass marketing of products based on LENR. There are two types of companies involved in the field to very different degrees. Small companies, mostly start-ups, are devoted entirely to the development and commercialization of LENR. These companies vary widely in their size, funding and approaches to selling LENR heat or electrical generators. Some large companies are monitoring very closely progress in LENR science, engineering and business. A few are actively involved in the field, but most of the big companies are watching and waiting until it is clear that LENR generators will be adequately controllable, safe and reliable to receive serious market acceptance.

Start of the Conference

The first morning of ICCF19 was devoted to welcoming and related presentations, three by local and national representatives, one from a university, one from a law firm and one by the Minister of Brazil Economic Development. Professor Robert V. Duncan, Chairman of ICCF18 and President of the ICCF19 Scientific Committee, gave his views on the need for high quality scientific research on LENR.

The first technical presentation at ICCF19 was by Michael C.H. McKubre of SRI International. He gave a summary of the state of the field. McKubre asserted that this year and conference marked a transition for the field of condensed matter nuclear science from being "resource limited" to "talent limited." That is an interesting statement since, when resources for research on LENR do become adequately available, there will be many talented and relevant scientists now outside of the field who will become involved. McKubre noted that time has been harder on the band of vocal critics of LENR than on the larger group of people interested in its study and advancement. That is especially true because the ranks of critics are essentially static while young people are increasingly interested in the study of LENR.

McKubre attributed much of the growing interest in LENR to the activities of Andrea Rossi. Specifically, he said "with combined showmanship and operational scale, Rossi brought to the attention of a new generation of innovators the possibility that 'cold fusion' might not only be real but also practical." Continuing, McKubre noted that the possible use of nickel and hydrogen has shown, in contrast to the palladium and deuterium approach of Fleischmann and Pons, that LENR might be both useful and "not so difficult to achieve." McKubre asserted that the possibility "accomplished more than the thousands of published papers on CMNS."

This background serves to explain the setting for ICCF19 and many of its characteristics. So, now we can focus on aspects of the conference related to commercialization of LENR.

ICCF19 Activities on LENR Commercialization

It was interesting that this conference, organized by a company at a time of great interest in commercialization of LENR, had relatively little information on the business side of the field. Part of that situation was due to the reluctance of some companies active in the field to participate in the conference. Fortunately, there were some significant presentations and posters having to do with development of products based on LENR. They are summarized in this section. There is great interest, at the conference and in the overall field, in possible commercialization of the combination of nickel with hydrogen.

The talk in the opening session that dealt directly with commercialization was that of Thomas Darden, the CEO of the Cherokee Investment Firm in North Carolina. According to their website, it is a "private equity firm investing capital and expertise in Brownfield redevelopment. Cherokee has invested in more than 525 properties worldwide. The firm has nearly $2 billion under management and is currently investing its fourth fund." Darden and others formed a company, Industrial Heat LLC, which announced in January of 2014 that it "acquired the rights to Andrea Rossi's low energy nuclear reaction (LENR) technology, the Energy Catalyzer (E-Cat)."[2] The choice of the company name is interesting, since it implies that the early E-Cat products will be targeted for industrial applications, rather than residential utilization. That makes sense since the E-Cat generators in industry will be run by process professionals, rather than by a large number of homeowners of diverse capabilities.

Darden is strongly motivated by the promise of LENR for reduced environmental impacts, even beyond its expected value as a source of energy. His presentation concentrated largely on his background and motivations. Notably, it did not include an update on the status of E-Cat development. A video of his presentation[3] and the text of his speech[4] are on the web. An interview of Darden by Marianne Macy was published in Issue 121 of this magazine.[5]

Tyler van Houwelingen presented a poster entitled "LENR Market: Update and Opportunities." It largely summarized the activities of two sister companies, LENR Invest SA in Switzerland and LENR Invest LLC based in the United States.[6] The companies were founded in 2013, and performed diligence on most LENR firms globally. They have invested in four companies to date. Their focus is on three investment areas: (a) core LENR reactors technologies, (b) vertically integrated industries and (c) intellectual property. LENR Invest stated their belief that the first LENR product could arrive on the market over the next 12 to 36 months.

Robert Godes, the CTO of Brillouin Energy Corporation, presented a poster on test results that support their Controlled Electron Capture Reaction hypothesis. The company has two types of LENR systems. The first is a WET™ boiler containing Pd and ordinary water, which has produced tritium without neutrons, and 180 kJ of excess heat. That level "exceeds chemical potential of reactants by orders of magnitude." The second has a nickel coated rod in a hydrogen gas system run at 600°C, called a Hydrogen Hot Tube (HHT™) system. Both are driven by the company's proprietary Q-Pulse™ control system. Godes reported energy gains (thermal output divided by electrical input) of 2.25 for the WET™ technology and 4 for the HHT™ system.

A significant milestone in the commercialization of LENR was presented by Steven Katinsky. He and this author recently founded an industrial association for LENR called LENRIA, with a website at lenria.org. That action is timely because progress toward a change in the perception of the science and business of LENR is gaining momentum. This is occurring both through scientific study and commercial research, and because of early engineering of systems based on LENR to produce thermal and electrical power. Several small companies are conducting experiments, and are designing, building and testing prototypes of LENR-based devices. A few large companies are known to be watching developments, with some having their own programs in the field. There will be growing needs for provision of information, organization of commercial conferences or expositions, professional communications to counter opponents and negative propaganda about LENR, and representation of LENR before government bodies, regulators and the public. LENRIA will advocate for both scientific study and, especially, commercial advancement of the field. There will be various member services to dues-paying individuals and companies. LENRIA serves the global community of involved and interested persons and organizations.

Michel Vandenberghe of LENR Cities SA in Switzerland presented an overview of that relatively new organization entitled "Society and New Technologies." They are "creating and managing an innovative business and management ecosystem to develop LENR technologies." LENR is viewed as a "clean, abundant and cheap and decentralized source of energy that will be a major disruptive technology and a source of massive innovation in all industries." Vandenberghe believes that it will be very disruptive with unpredictable effects on markets, and that minimizing risks for all involved parties is important. According to him, a standard business plan does not make sense. A compromise is required between established companies and innovators. More detail about LENR Cities can be found on their website: lenr-cities.com.

Thomas Grimshaw of the University of Texas Energy Institute presented a paper entitled "Integrated Policy Making for Realizing Benefits and Mitigating Impacts of LENR." He noted that improved LENR prospects are indicated by the significant numbers and varied locations of researchers in several countries, a large body of accumulated scientific evidence, major advances in theory development, and recent activities, including a plethora of proposed energy-producing devices. In Grimshaw's view, policymaking opportunities are emerging for LENR to realize its potential benefits, and to deal with anticipated adverse secondary impacts due to the disruptive nature of practical LENR heat and electrical generators. He touted an integrated approach to policy formulation for both positive and negative aspects of LENR.

Some of the other presentations and posters at ICCF19 contained material relevant to commercialization of LENR. They will be discussed in the following technical sections, starting with excess heat measurements based on electrochemical, gas and plasma loading of diverse materials.

Excess Heat with Electrochemical Loading

Melvin Miles gave a historical and technical talk entitled "Excerpts from Martin Fleischmann Letters." It mostly dealt with calorimetric methods to measure heat produced in electrochemical cells. The letters were from the period 1992 to 2010. They included discussions of major early experiments at CalTech, MIT and Harwell. Many technical points were also considered, including the effects of impurities, surface blocking, current densities and various alloys of palladium. Fleischmann considered details of isoperibolic calorimetry, including changes over time in the heat transfer and heat capacity of a cell due to the changing electrolyte level. The point is that there is never a static situation in a LENR cell, so that full (mathematical) understanding of such calorimeters is a time-dependent problem. Miles noted that Fleischmann wrote him that the first indication of ^{4}He in their cells occurred in December 1988.

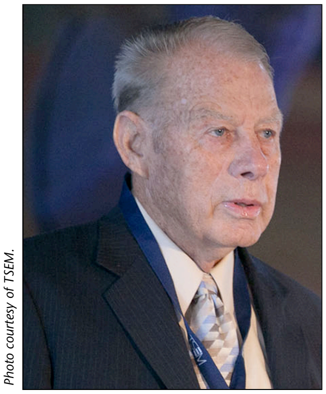

Photo courtesy of TSEM.

Melvin Miles

Two new papers at ICCF19 on production of excess heat by electrochemical means came from the Sidney Kimmel Institute for Nuclear Renaissance (SKINR) at the University of Missouri. Orchideh Azizi and a team of eight others took creative approaches to production of cathode materials with surface structures on the scales of micrometers and nanometers. In the first paper, they produced Pd nanoparticles and then suspended them in an electrolyte of D_2O and 0.1 M LiOD prior to electrolysis. This yielded cathodes having particles uniformly distributed on the Pd substrates, which achieved high loading with deuterons. Both a closed cell with a recombiner and an open cell were employed. The closed cell did not yield excess heat, but the open cell gave excess heat for "several days" with a gain of 1.15 to 1.65. Low cell currents favored excess heat production. The SKINR team also studied the effects of proton or deuteron absorption into and diffusion through foils in a permeation double cell.

The second method used by Azizi and her team involved single-walled carbon nanotubes (SWCNT). An aqueous suspension of SWCNT was drop cast onto the surfaces of "pretreated" Pd foils at a density of 0.1 mg/cm^2. Graphene coated Pd foils were also prepared and decorated with Pd nanoparticles. Cyclic Voltammetry and Impedance Spectroscopy, as well as both Scanning Electron and Atomic Force Microscopies, were used to characterize the materials. Twenty such cathodes were run over two years, only one of which (with SWCNT) showed excess heat in a pair of separate bursts. In the first, 75 kJ was obtained during three hours for an energy gain of 55. During the second, 13 kJ appeared in 1.5 hours, giving an energy gain of 27. Only the heat producing cathode showed Sn and Pb surface impurities after the run.

Excess Heat with Gas Loading

Scientific studies using gas loading were more numerous than electrochemical approaches at ICCF19. Nine papers dealt with this approach, mainly involving hydrogen and nickel-containing materials, but also some with deuterium and palladium.

Francesco Celani and a group of ten other scientists from three laboratories in Italy reported on their progress with experiments they have pursued since 2011. They used a copper-nickel-manganese alloy Constantan in wire form 100 cm long and 100 to 200 micrometers in diameter. The samples are treated in a variety of ways to produce diverse surface structures. At temperatures exceeding 120°C, the surface micrometer and nanometer structures catalyze the dissociation of H_2. This approach had yielded 5-10 W of excess power for input powers of 50 W, as reported at ICCF17. The team found that the following conditions are conducive to production of excess power: temperature as high as possible (but avoiding sintering), sufficient hydrogen adsorbed or absorbed by the catalytic material (which leads to nanomaterial production), a large and fast as possible flux of hydrogen (from a region of high concentration to a lower one), addition of elements that have hydrogen concentration increasing with temperature (like Fe) and non-equilibrium conditions (as large as possible). The wires that have good performances from the point of view of LENR showed surprising spontaneous voltages.

In related work, the SKINR group sought to replicate results reported by Celani at previous ICCFs. They did sensitive mass flow calorimetry on eight Cu-Ni-Mn wires, six from Celani and two others from Mathieu Valet. The group employed a stainless steel cell, in contrast to the glass cell of Celani, in order to be able to perform the calorimetry. But, they followed closely the set-up, operation and heating protocols that earlier gave excess heat for the Celani group. Beyond the initial protocol, they tried pulsed and highly-modulated (SuperWave) driving voltages. Neither the original nor the new protocols gave excess heat during about 200 days of testing, with a calorimetric sensitivity of less than 10 mW.

Two groups reported on experiments involving nanomaterials containing nickel and other materials. Mitchell Swartz and his colleagues have been developing and testing NANOR®-type devices for several years. In recent work, they employed nickel nanoparticles coated with ZrO_2 in a deuterium atmosphere. The oxide serves to prevent aggregation of the nanoparticles during experiments. The two-terminal NANOR®-type devices suffer avalanche breakdown if driven too hard. So, Swartz and his co-workers measured the power gains on both sides of breakdown. They found power gains of about 20, which decreased as the drive voltage was increased. After breakdown, the calorimetry gave unity "gain," that is, the measurements above the avalanche voltage show that the calorimeter was properly calibrated.

Another ongoing series of experiments involving nickel nanoparticles is being done in a collaboration between Technova Inc. and Kobe University. Akira Kitamura, Akito Takahashi and four others reported on work with a wide variety of materials in a new chamber ten times larger than what they had been using. The materials included Al_2O_3 powder (for calibration), nano-nickel (mixed with alumina), nickel particles (supported by mesoporous SiO_2), and three nickel-containing materials $Pd_{0.016}Ni_{0.070}$, $Cu_{0.022}Ni_{0.092}$ and $Cu_{0.011}Ni_{0.077}$ (again on mesoporous SiO_2 and mixed with alumina), all exposed to both hydrogen and deuterium atmospheres. Oil flow calorimetry is employed by the group, with sample temperatures up to 350°C. The research is motivated by the expectation that surface adatoms of the minority component serve to catalyze the decomposition of the hydrogen or deuterium molecules to enable adsorption and then absorption by the bulk material. The binary nano-composite $Cu_{0.011}Ni_{0.077}$ sample showed a catalytic effect of the minority Cu atoms on excess heat evolution, with a long-lasting temperature increase, excess power of 10 W (0.8 W/g-Ni) at around 300°C, and excess energy of 15 keV/atom-H or 0.38 keV/atom-Ni, implying a nuclear origin of the heat.

A pair of papers dealt with gas loading of deuterium into sub-nanometer and nanometer particles of Pd on zeolites or alumina. In the first, David Kidwell and two colleagues at the Naval Research Laboratory sought to understand the earlier observation that loading of deuterium gas into sub-nanometer particles of Pd gives more heat than did similar loading of hydrogen gas. Their concern was that the exchange of D for H in –OH radicals or H_2O might be the source of the measured difference. Kidwell and his group wondered if the potential H-D exchange can account for excess heat, since all other chemistry has been eliminated. That is, the effect might be purely chemical and not nuclear in origin. Mass spectra of the gases obtained during pumping out the samples could be measured. But, that method could not be applied to the pressurization phase of the experiments. So, Nuclear Magnetic Resonance (NMR) was used to obtain the kinetics of the H-D exchange process during both pressurization and pump-out phases. For some samples, the measured amount of heat could be explained by the exchange kinetics. However, in other preparations, the NMR showed that the exchange kinetics were too slow to explain the measured heat. Since NMR did not match the calorimetry results, some other source must be the cause. The authors opined that gas loading is the ideal experiment for studying LENR. It is very reproducible, and has many variables and diverse conditions without being commercially interesting.

The second paper on gas loading of Pd nanoparticles was by Iraj Parchamazad and Melvin Miles of the University of LaVerne. Zeolites have very large (10^{10} V/m) fields in the cavities in which the Pd particles exist, which might be important for the production of LENR. Zeolites made of Na and Y, and containing Pd nanoparticles, were exposed to both deuterium and hydrogen gases. The authors prepared the materials by subjecting the Na-Y zeolites to solutions of $PdCl_2$, and then heating them to drive off the solvent. The presence of Pd was verified by the use of Scanning Electron Microscopy and Energy Dispersive X-Ray Spectroscopy. Exposing the samples to deuterium gas produced two effects that were absent when hydrogen gas was used. First, "significant temperature increases" were observed with D_2 and not with H_2. Second, the presence of Cu and "several other metals" was observed after the use of deuterium gas, but not when hydrogen gas was employed. Based on their results, the authors estimated that the observed excess power was about 10 kW per gram of Pd. However, given the relatively dilute concentration of Pd in the zeolites and the low thermal conductivity of zeolites, it is unclear if such a high power density could be made into a practical power generator.

An innovative new approach to gas loading of Pd was reported at ICCF19 by Jean-Paul Biberian of Aix-Marseilles University. He made a capacitor 2 cm^2 by sputtering Pd onto the surface of a silicon wafer that had been oxidized in air. That device was placed into a heat flow calorimeter with deuterium atmosphere at a pressure of 2 bars. DC and AC voltages were applied to the device. A sine wave with a peak of 0 to 30 V was used from 0 to 1 MHz. Excess heat was measured as a function of the frequency and amplitude of the

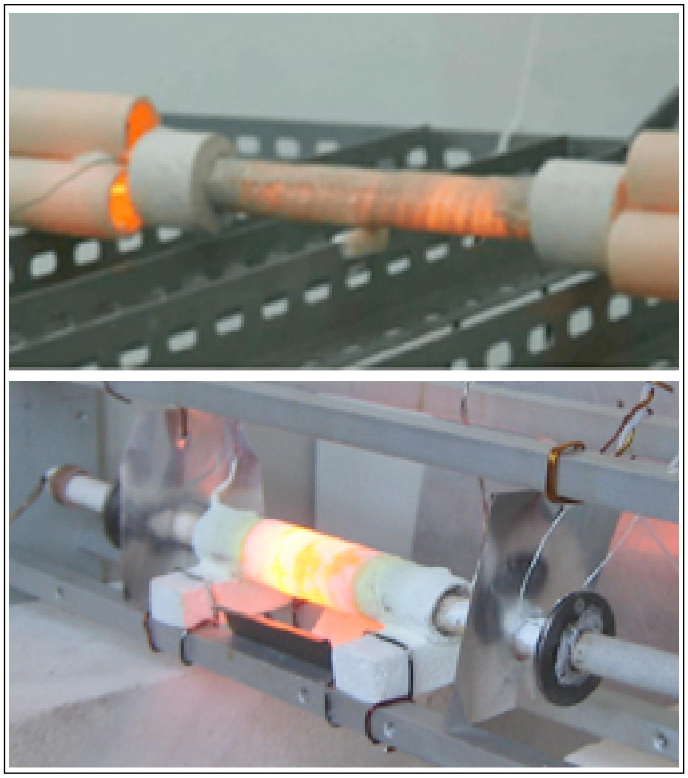

Figure 1. The top image shows an E-Cat made by Rossi, which was tested by Levi and his team. At the bottom is a photograph of the replica of the E-Cat as made and tested by Parkhomov.

applied signal. The values ranged from 0 with DC voltages to 60 mW with 30 V and the 1 MHz sine wave.

It is widely known that Andrea Rossi is now working for Industrial Heat LLC to produce another MW-level E-Cat system.[7] It will consist of a large number (about 100) of smaller LENR units, which use the combination of nickel and hydrogen. Rossi's original E-Cat units used gaseous hydrogen from a pressurized cylinder. In recent years, the protons in his systems have been obtained by employing a compound rich in H, specifically $LiAlH_4$, with the nickel, and no gas bottle. Presumably, the H freed from that compound at elevated temperatures provide a hydrogen gas atmosphere needed during power production. However, H dissolved in any liquid within the experiment at high temperatures may also play a role.

The two reports by Levy and his colleagues on the performance of the Rossi E-Cat units resulted in broader and greatly increased interest in the practical possibilities of LENR.[8,9] They also stimulated multiple attempts to replicate the E-Cat configuration imaged in the second of the reports, the so-called Lugano Report. That device is shown in the top of Figure 1.[8] About a half dozen individuals and groups are seeking to replicate the reported performance of the E-Cat using similar configurations.

One of the leading individuals attempting such replications is A.G. Parkhomov of the Lomonosov Moscow State University. He and a colleague from the same university had a poster presentation at ICCF19. Late in the conference, Parkhomov fielded questions through interpreters in front of his poster. His system is shown in the bottom of Figure 1.[10] It contained about 1 gm of nickel powder of unspecified characteristics, and about 100 mg of $LiAlH_4$. The device was submerged in water, and the amount of water that was evaporated was used to compute the thermal energy output. A correction was made for heat loss through surrounding insulation. Experiments with a Type 1 device showed that, for operating temperatures of 1100°C and higher, the device produced more energy than it consumed. The ratio of the output thermal energy to the input electrical energy was given as 0.99 at 970°C, 1.92 at 1150°C and 2.74 at 1290°C, each for 90 minute runs. "The Type 2 apparatus worked continuously for more than three days, producing more than twice as much as the applied electrical energy. More than 40 kWh or 150 MJ were produced in excess of the electrical energy consumed." The results of these experiments have generated a great deal of discussion on the internet since the conference.

One other experiment aimed at replicating the work by Rossi and Parkhomov was reported in a poster paper at ICCF19. Jean-Paul Biberian employed 500 mg of nickel and 50 mg of $LiAlH_4$ inside of stainless steel and alumina tubes in a mass flow calorimeter. He obtained excess powers as high as 12 W at 1000°C. It is hoped that Biberian will continue this line of research, and that at least a few of the several current replications of the E-Cat device will prove conclusive.

Excess Heat from Plasma Experiments

Seven papers at ICCF19 reported on production of thermal energy with plasma loading and excitation. Three dealt with plasma discharges in gaseous or liquid media, three with plasma electrolysis in liquids and one with ultrasonic excitation of metal foils in a liquid medium.

Chongen Huang and four others from Xiamen University reported on two approaches to replicating the experiments and results published about two years ago by Defkalion Green Technologies. Both Defkalion and the Chinese group used gas discharge systems containing nickel and hydrogen. Two set-ups were described in the ICCF19 poster. A spark plug cell, similar to what Defkalion used, gave no excess heat for a range of pressures and temperatures. However, a high voltage cell produced 20 W of excess heat with a H_2 pressure of 0.2 MPa. That represented 14% of the input power. When D_2 was used instead of H_2, "heat after death" was observed. The performance of these experiments was not reproducible.

Anatoly Klimov was lead author of two papers at ICCF19. Both of them dealt with plasmoids. They are defined as coherent structures of both plasmas and magnetic fields. The first, single-author paper listed Klimov's affiliation as the Joint Institute of High Temperatures RAS in Moscow. It was a review of about 20 years of research on energy production, transmutations and ball lightning involving "cold heterogeneous plasmoids." Klimov stated that energy gains in the range from 4 to 10 were reported in papers dated 1985 and 1994. In an experiment with energy gains of 2 to 4, the concentrations of Li and Ca were increased by factors of 100 to 1000. That determination was based on Optical Spectroscopy. Infrared, Atomic Absorption, Ion Mass and X-Ray Spectroscopies were also used in the research.

The second paper by Klimov was co-authored with six others, all authors affiliated with the company New Inflow LLC.[11] According to their website, the company has a broad program spanning experiments, theory and numerical simulations in seven listed organizations of Russian universities and the Russian Academy of Sciences (RAS). The website also states that LENR effects have been confirmed in several laboratories with energy gains of 6 to 8 and evidence of transmutations was obtained. They assert that devices from the company can use a wide variety of materials as fuels, not just Pd or Ni. The paper by the group at ICCF19 reported energy gains from plasmoid vortex reactors in the range of 2 to 10, supposedly due to LENR. They recorded "intensive" X-ray emission in the 1-10 keV range. Numerical simulations of the plasmas and their emissions were performed. The poster from this paper is available from the New Inflow LLC website www.newinflow.ru.

Photo courtesy of TSEM.

Anatoly Klimov

The three posters on plasma electrolysis were from Russia, Germany and France. Yuri Bazhutov and three colleagues had a poster on "Plasma Electrolysis as Foundation for Russian E-Cat Heat Generator." Their E-Cat stands for "Erzion Catalyzer." The group tried to reproduce Rossi's system. They measured neutrons and X-rays, but not excess heat. Then, they returned to plasma electrolysis experiments, which had earlier produced both excess heat and nuclear radiations. They modernized their apparatus, which uses electrodes in ordinary water. With it, they "regularly demonstrated" energy gains up to a factor of 7, as well as evidence for nuclear reactions.

A paper by A. Gromov, and two others affiliated with one German and one Russian institution, dealt with low-voltage plasma electrolysis. They used voltages up to 300 V and currents as high as 3 A. Electrolytes with alkaline, acidic and salt solutions were employed, with electrodes of Al, Cu, Mo, Pb, a Fe-Zn alloy and stainless steel made by sintering of powders. The authors reported, "The heat released from such water boiling system is up to 2500% more efficient compared to Ohm boiling." They also report the production of copper and iron in experiments that used "very pure" reagents and materials. Interestingly, the team asserted that the presence of Mg in porphyrin rings in chlorophyll and the presence of iron in similar molecules in hemoglobin are both the result of biotransmutations due to LENR.

Jean-Paul Biberian and two other French colleagues reported in a poster on results from pressurized plasma electrolysis experiments. They used a tungsten cathode surrounded by an anode of stainless steel. A relief valve maintained a pressure of 5 bars inside the cell. Heat produced was computed from the weight loss of the cell, which was positioned on a balance during operation. Both tungsten and nickel anodes have been tested, and different types of magnetic fields were tried, including permanent magnets on the anode, and a coil with 250 turns around the cell in series with the current. Excess heat of up to 12% was measured with both the permanent magnets and the coil.

Roger Stringham of First Gate Energies in Hawaii gave a poster entitled "Single DD Fusion Event." He produced bubbles that collapse rapidly on the surfaces of materials using ultrasound frequencies of 20, 46 and 1600 kHz. The size of the bubbles decreases with increasing frequency. Stringham presented Scanning Electron Micrographs of the surfaces of foils from his experiments. They showed craters consistent with single fusion events at depths of 25 to 50 nanometers under the foil surface. He estimated that 400,000 lattice atoms were ejected from each crater into the circulating D_2O.

Transmutations

At ICCF19, as at earlier conferences in this series, there were several papers on the results of LENR other than heat production. Chemical analysis methods were used before and after experiments to gain evidence for transmutation reactions. They are summarized in this section, starting with two poster papers related to radioactive isotopes.

Vladimir Vysotskii from the Kiev National Shevchenko University and three colleagues from Russia studied experimental transmutation of ^{133}Cs to ^{134}Ba in media supporting the growth of methanogenic bacteria from sea sludge. The microorganisms were cultivated under anaerobic conditions at 30°C in an aqueous nutrient medium. Controls had no sea sludge, that is, none of the bacteria thought to add a proton to the Cs to produce Ba. Samples from the cultures were drawn and analyzed at 48, 94, 144 and 192 hours. The data showed a monotonic decline in Cs and monotonic growth of Ba. The rate of transmutation was computed from the data to be about 10^{-6} synthesized Ba nuclei per second per ^{133}Cs nucleus. That value is two orders of magnitude greater than the team's earlier experiments with the same system. It is comparable to the rate for conversion of Mn to Fe obtained previously by the group. We note that the transmutation work described at ICCF19 with a non-radioactive isotope of Cs does not guarantee that biological transmutations, presumably due to LENR, can be used to remediate the radioactive isotope ^{137}Cs. However, earlier experiments by this group showed the rate for bio-transmutation of ^{137}Cs to be 10^{-6} synthesized ^{138}Ba nuclei per second and ^{137}Cs atom.

Leonid Urutskoev and four co-workers from the Moscow Institute of Physics and Technology and the Prokhorov General Physics Institute reported on the possibility of induced alpha decay in heavy nuclei due to the deformation of electron shells caused by strong magnetic fields. They produced high-current electrical explosions of titanium foils in solutions of uranium salts. Mass, Gamma and Alpha Spectroscopies were used to monitor the results. Depletion of ^{238}U was found to exceed depletion of ^{235}U. ^{4}He was measured in the gas phase, and "significant thermal heating of the explosion chamber was observed." The authors stated that their results confirmed other experiments at the General Physics Institute in which laser ablation of ^{197}Au nanoparticles suspended in a solution of uranium salts produced similar depletion of ^{238}U. They attribute both results to the strong magnetic fields due to the high currents that exploded the foils. In their view, those fields "significantly distort the atomic shell and thereby initiated the α-decay."

There were six additional poster papers that reported experimental results on transmutations. They vary widely both in the methods used and the isotopes produced. In one, Ubaldo Mastromatteo from A.R.G.A.L. in Italy irradiated thin films of Pd on a Cr adhesion layer on a Si wafer in an H_2 atmosphere with low power lasers. A 1 mW 633 nm laser and a 3 mW 403 nm laser were employed for the two-week irradiations. The samples were examined before and after the runs with a Scanning Electron Microscope having an X-ray analysis capability. The virgin samples had a few defects due to the evaporation process that produced the Pd films, and showed mainly X-ray peaks due to Pd and Cr. After the runs, the samples exhibited cavities around which "significant percentages" of light elements were observed. Strong X-ray lines from O, Al, Si and K were measured. The results were said to be similar to those of other researchers in "different contexts and with different materials." If not due to contamination, the "nuclear fission hypotheses will have to be seriously considered."

Max Fomitchev-Zamilov posted a paper entitled "Apparent Synthesis of Nitrogen and Oxygen from Heavy Hydrocarbons: The Case for LENR." He used 5.6 kg of the oil Kendex 0842, and degassed it at 80°C at 50 μHg for 5 hours to eliminate the possibility of atmospheric contamination. Then, the oil was subjected to "extreme hydrodynamic cavitation" for some unstated time. That caused the production of 5 gm of N, which out-gassed to form 3.6 liters of gas. The 22 gms of O reported to be formed reacted with the oil to form resins. The author surmised that the production of N and O was due to LENR with addition of protons to carbon and nitrogen, respectively. No radiation or heat production was observed during the experiments.

A. Gromov and colleagues from Russia and Italy reported on the formation of Ca in reactions between Al and N in Al-Fe_2O_3 thermites. The combustion products from three types of experiments in which Al and N reacted showed "abnormally high concentrations of Ca (up to 0.5 mass %) as determined by Energy Dispersive X-Ray and Inductively-Coupled-Plasma Mass Spectroscopies. In an experiment in which molten Al was jet sprayed into a N_2 atmosphere, the increase in Ca content averaged 600% compared to the starting materials. The authors posited a nuclear reaction and compared it to the chemical reaction of Al and N. $^{13}Al + {}^{7}N$ gives ^{20}Ca and about 5 x 10^{28} MeV per mole. This is about 10 million times the chemical energy of burning Al in nitrogen.

Renzo Mondiani from Italy reported on transmutations by an electrolytic cell having copper electrodes. With a "low to medium" concentration of K_2CO_3, he reported the formation of $^{32}S_{16}$ by fusion of two $^{16}O_8$. However, in a "high concentration" of the solution, he determined that a fission reaction occurred, namely $^{39}K_{19} - {}^{16}O_8 \rightarrow {}^{23}Na_{11}$. For intermediate concentrations, which reaction dominated depended on the size of the anode. The first reaction was primarily for small anodes and the second for large anodes. The results of the first reaction could be determined visually due to gas volume changes. In both cases, unstated types of chemical analyses were used to establish the reaction products. Those analyses also showed production of Mg, presumably by a fission reaction: $^{39}K_{19} - {}^{14}N_7 \rightarrow {}^{25}Mg_{12}$.

F. Ridolfi from the Universita degli Studi di Urbino "Carlo Bo" reported on the results of ultrasound irradiation of iron and steel bars. Damage to the sample surfaces, neutron bursts and observation of unexpected elements resulted from the ultrasound. The cavities were less than or about 10 μm in diameter. K, Cl and Cu were found, and the $^{63}Cu/{}^{65}Cu$ ratio was in the range of 0.3 to 1.7, rather than the normal value of 2.2.

D.S. Baranov and O.D. Baranov from a private laboratory INLEAS in Moscow did experiments on application of "strong" electric fields to bismuth salts. They gave the following summary of results, but did not cite the analytical methods employed to determine these values: "The elemental composition of substances emitted from the sample was radically different from that of the initial bismuth salts. There were found some different elements: carbon (up to 90%), zinc (up to 6%), potassium (up to 2%), calcium (up to 2%) and aluminum (up to 5.5%)," plus tin and titanium in unspecified amounts. The authors interpret these results as evidence for "giant long-lived nuclear molecules" and state further that "It is assumed that in nuclear molecules some nucleon transfers are possible."

This completes the review of reports at ICCF19 on the appearance of new elements in LENR experiments. Such work remains relatively controversial within the field. Some scientists prefer data on the emission of energetic particles from LENR experiments. Chemistry simply cannot generate neutrons or particles with MeV energies. We turn to such experiments next.

Particle Emission and Impact Experiments

At this conference, as in its predecessors, there are two types of experiments involving particles. In the first, measurements of neutrons or fast particles emitted by LENR experiments are made. Such data clearly shows that nuclear reactions can occur due to stimulation with chemical energies. In the second, energetic particles are employed to bombard samples and the results of fusion events are measured. It was and remains unclear that such measurements will elucidate the mechanisms behind LENR, since the incident energies involved are much higher than energies equivalent to room temperature.

There were three very detailed papers on neutron emission from experiments reported at ICCF19. The first two were from the same group of four researchers at four institutions in Rome—Emilio Santoro, Andrea Petrucci, Alberto Rosada and Fabio Cardone. Both papers had to do with sonicated steel. For several years, the group has measured transmutations and neutrons due to piezonuclear effects, but has consistently been unable to register gamma rays above backgrounds. In the current experiments, a cylindrical steel bar was insonicated with 330 W at 20 kHz for three minutes. Sixteen CR39-BA passive neutron detectors surrounded the cylinder, and two active detectors were also used. The boric acid (BA) served as a neutron-to-alpha converter. One active detector recorded a neutron spectrum with a peak at 0.7 MeV and a dose of 0.024 μSv. That dose was 40 times larger than the background neutron intensity. Tracks in the CR39-BA detectors were compared with tracks in similar detectors exposed to two "thoroughly known" neutron fluxes from TRIGA and TAPIRO reactors.

The second paper from the Roman group provided more details on their results. It discussed the anisotropic and asymmetric character of the neutron bursts during the sonic runs. The paper reported that the PTFE material that supported the steel cylinder "shows clear signals of melting and burning." It is noted that those effects might be due to the "possible and likelier suspect" for the damage, rather than deposition of energy from emitted neutrons. The authors stated that their observations "have nothing to do…with the 'classical cold fusion,' at least in its initial and straighter meaning, conversely they hint at the existence of new physics."

The third paper on neutron emission was by Yu. Kurilenkov and two colleagues from the Joint Institute for

High Temperatures RAS in Moscow. It is unclear that this paper is closely related to LENR because high temperatures are involved. A nanosecond discharge was triggered across two electrodes in a vacuum, one of them deuterium-loaded Pd. The authors performed particle-in-cell (PIC) simulations using a fully electrodynamic code. They divided the time history of the fast discharges into two phases. During the first 1-2 nsec, electrons interact directly with the D-loaded Pd. Neutrons are emitted during this first phase, although the mechanism of their origin is not understood. Later, a virtual cathode forms within the inter-electrode gap. The PIC computations indicated that a potential well of depth 50-60 keV developed between the electrodes during the second phase. Deuterons in that well can accelerate up to a few tens of keV and undergo conventional D-D fusion reactions with the deuterons in the anode.

There was a poster by Dennis Pease and nine others from the SKINR that reported on the results of a search for particle and X-ray emission from a special electrochemical cell. That cell was outfitted with a thin cathodic structure consisting of either (a) 1 μm silicon nitride with 200 nm of Pt and Pd or (b) a 30 μm Pd foil. The first combination cathode would be able to pass MeV alpha particles or soft X-rays with energies of 1 keV or greater. The X-ray detection capability was able to detect photons at rates less than 1 Hz. That corresponds to a heat sensitivity of less than 0.2 femto-Watts. Data was collected for over one year. No X-rays were observed above background levels for the energy range 1-35 keV.

Two groups reported on the results of incident-ion experiments at ICCF19. Jirohta Kasagi and a student measured the screening energy of D-D reactions in an electron plasma due to cooperative colliding reactions. In past work, Kasagi and others have found enhanced cross sections for D-D fusion in a variety of targets at bombardment energies as low as and even below 1 keV. The challenge of such work is to know the density of accessible deuterons in the target. In the current work, the experimenters used beams of molecular deuterium. One of the deuterons in an incident molecule can be scattered by a target atom and fuse with its partner D. This means that "the number of target deuterons is unambiguously determined." Measurements were made for liquid metals of In, Sn, Pb and Bi with D_3+ beam energies in the range of 15-60 keV. The screening energies computed from the reaction cross sections were found to be larger than those determined earlier from experiments with solid targets. The average screening energy of 570 eV is more than ten times larger than the Thomas-Fermi screening prediction.

Z.S. Rusetskiy and seven colleagues from three institutions in Moscow also did measurements of D-D fusion yields at relatively low beam energies. They bombarded Pd/PdO:D_x and Ti/TiO:D_x heterostructures with deuterons in the 10-25 keV range. Neutron and proton fluxes were measured with ^{3}He active and CR-39 passive detectors. Yields much higher than those expected from theory were obtained. The group performed two other related experiments. They bombarded the heterostructures with H^+ and Ne^+ ions and observed "appreciable" D-D stimulation. They also studied the neutron yield from polycrystalline D-saturated diamonds prepared by chemical vapor deposition. A significant anisotropy in the neutron emission was measured. This careful work in the Japanese and Russian particle impact papers presents two challenges: (a) understanding of the enhanced D-D reaction cross sections and (b) relating them to LENR studies at much lower effective energies.

Radio Frequencies in LENR Experiments

In the mid-1990s, two groups applied RF to electrochemical LENR experiments and saw increases in the production of excess power. John Bockris, Dennis Letts and their group, and Dennis Cravens separately, used coils around the cells to apply the RF fields without contact with the cells. Much later, the inverse experiment was done at the Naval Research Laboratory in collaboration with ENEA. RF were sought within the basic electrochemical drive circuitry. A pickup coil was used, and RF frequencies were observed, sometimes but not always coincident with the power production. That work was presented at ICCF17 and published much later in the issue of *Current Science* devoted to LENR. Violante and his team at ENEA performed similar measurements, also observed high frequencies and published their results in a long paper in 2014.

There were three papers at ICCF19 which dealt with RF. Interest in the topic is driven by the questions of (a) whether or not RF frequencies within electrochemical circuits are real and not an artifact of the power supply or its interactions with the cell, and (b), if real, what can the RF data reveal about the fundamental mechanism behind LENR? The NRL team of Kidwell and four collaborators detailed some of their earlier observations, in particular three bursts in two experiments, which produced excess energies in the range from 2.4 to 44.3 kJ. RF frequencies were measured coincident with those bursts. They varied from 450 kHz into the MHz range. The authors state that a "common signal near 5 MHz could be frequency shifted and its intensity increased (Cathode #60) or decreased (Cathode #54) by excess heat production." By contrast, another cell that showed low levels of thermal power in the range of 1-7 mW exhibited RF that was not correlated with the energy production. The group is still wrestling with concerns that the RF frequencies on the electrochemical voltage are due to the power supply or its interaction with the cell, that is, an artifact.

Vittorio Violante and the ENEA group had an oral presentation "Heat Production and RF Detection during Cathodic Polarization of Palladium in 0.1 M LiOD." The paper reported excess heat values 50 times greater than could be explained chemically. Electrochemical impedance spectroscopy was performed from 4 to 200 kHz without and with excess power production. The cathode interface varied with the appearance of LENR. The equivalent circuit was dominantly resistive without LENR, but had a resonant component during generation of excess power. A National Instruments spectrum analyzer good from 20 kHz to 3.5 GHz was used with an 80 GHz down-converter for RF measurements. Pulsed magnetic stimulation was applied to the cell. It produced both an increase in cell temperature and the appearance of RF. Smith plots from a network analyzer showed very different characters depending on whether or not RF frequencies were being measured. The ENEA group presented a table of 23 experiments with two steel and the rest Pd cathodes, some in light water but most in heavy water. All four combinations of the appearance or not of excess power and RF were obtained.

Felix Scholkmann and two colleagues provided a poster paper that surveyed the papers on RF and LENR experiments that were available before ICCF19. Those papers fall into two categories. The first contains the two reports from the mid-1990s on the ability to increase excess power production by the application of RF from a coil around the cell. The second includes more recent observations of RF within the basic electrochemical circuit. The authors gave a summary of reported frequencies in the range from 450 kHz to 83 GHz. The group also discussed possible mechanisms for generation of such frequencies within LENR cells. Esaki and Gunn diodes are semiconductor devices with areas of negative resistance that are used to generate RF in many systems. It can be asked if semiconductors might be deposited on the surface of cathodes to create such devices. The authors give four reasons why that scenario is unlikely. Relatively low carrier velocities (0.1 to 100 cm/sec) across the double layer on a cathode surface are consistent with the observed frequencies, but the driver for such charge motions is unknown.

It remains to be determined whether or not the high frequencies within LENR electrochemical circuits are due to the mechanism of power production or some kind of an artifact.

Materials Studies

The two primary gaps in knowledge of LENR involve materials and theory. Many of the experimental papers at ICCF19 reported on studies of materials, some of which have already been reviewed. There were nine papers that were dedicated almost solely to issues about materials. They are summarized in this section.

Before turning to the ICCF19 papers, it is timely to make a larger point. In more than a quarter of a century of attacks by critics, scientists studying LENR have improved their experiments dramatically. Calorimetry of electrochemical cells can now be performed with precision and accuracy at or below the 10 mW level. That threshold is very much smaller than the excess powers reported in dozens of LENR experiments. Many improvements in the ability to produce and characterize the materials that go into LENR experiments have also been realized. Simply listing all of the methods that were employed in the several ICCF19 papers makes the point.

The following techniques and processes were used to produce materials for electrochemical and other LENR experiments. Some materials processes were cited in only a single paper, however, many of them were used in multiple laboratories.

► Materials production methods include: Melting, Rapid Cooling, Heat Treatment and Annealing, Cold Rolling, Strong Acid Etching, Electrochemical Oxidation or Reduction, Oxidation in Air, Exposure to Impurities, DC Sputtering, Galvanostatic Electro-Deposition, Electrochemical Cycling, Electrochemical Loading, and Gas Charging.

► Diverse experimental methods were used to characterize the composition and structure of materials that were part of laboratory studies reported at ICCF19. They are: Confocal, Scanning, Transmission and Atomic Force Microscopes, X-Ray Diffraction without and with Rietveld Refinement, Electrochemical Impedance Spectroscopy, Cyclic Voltammetry, Chrono-Amperometry, Chrono-Potentiometry, Electrochemical Permeations, Potential Decay Transients, and Differential Scanning Calorimetry.

► Several parameters were exercised or determined in the course of the materials preparation and characterization measurements. They include: Temperatures, Times, Applied Voltages, Hydrogen Active Surface Areas, Double-Layer Capacitance, Charge Transfer Resistances, and Reaction Rates.

► A wide variety of materials parameters were obtained and reported by use of various combinations of processes and characterization methods. They are: Chemical Composition, H or D Loading, Sub-Surface H or D loading, H Diffusion Coefficient, Surface Crystallographic Texture, Surface Patterns and Morphology, Grain Size Distribution, Rate of Recrystallization, Grain Boundary Morphologies such as Grooving, Activation Over-Potentials, Deuterium Kinetics for Loading, Desorption and Escape of H or D, and Surface Power Spectral Distribution.

The diversity and depth of the materials studies just noted is further evidence of the maturity of the experimental study of LENR. We now turn to summaries of specific papers on materials at ICCF19.

Coolescence LLC had three detailed papers on the production and characterization of materials for LENR experiments and measurements of their loading. David Knies and four colleagues from that company based their work on previous material studies at ENEA and SRI International. The earlier work had identified surface texture and morphology, in addition to a high loading (ratios of deuterons to Pd atoms in the material), as favorable to the production of LENR. The new work by Coolescence sought to learn the factors that promote high loading of Pd. Annealing, oxidation and etching procedures were used to produce Pd foils with desired crystallographic orientation, surface morphology and strong grain boundary grooving. The results can be summarized as follows: There is a disconnect between high loading and metallurgical treatment. As-deformed (non-annealed) foils just as likely meet or exceed the loading threshold as highly textured foils. The primary predictor of high loading was determined to be the presence of non-uniform thin (< 10 nm) coatings of various surface promoters (Cu, Pb, In, Bi, etc.). Copper was chosen as a promoter impurity for further analysis because numerous experiments indicate Cu is beneficial for high loading, and it is easy to deposit.

S. Hamm and the four others from Coolescence reported on the electrochemical analysis of Pd cathodes in relation to their ability to achieve high loadings with D/Pd > 0.9. The team described and employed multiple electrochemical techniques. Methods, including Electrochemical Impedance Spectroscopy and Chrono-Potentiometry, were very useful for investigating the surface reactions and effects of impurities. They yielded information on hydrogen-active surface area, charge transfer resistances and reactions rates. Parameters included details of annealing and different surface impurities in various concentrations. They were correlated with loading performance, with these conclusions: Surface impurities clearly affect the total H adsorption coverage, H_2 evolution rate, and rate of absorption and desorption. A thin film or some amount of surface coverage of impurities appears to be a simple answer to the question, "How do you reproducibly achieve high D/Pd loading ratios?" Whether or not it is the only way is another issue.

Olga Dimitriyeva led the Coolescence group in a closely-related computational study of the role of dopants for deuterium loading into Pd. Density Functional Theory (DFT) was used to obtain explanations of how the presence of surface dopants changes the activation over-potential and alters the deuterium escape kinetics during loading. The authors concluded the following: DFT simulations explain the energetics of adsorption and desorption processes on modified surfaces and provide the framework for screening additional materials, including Fe, Ag, Zn, Bi, Ti, W, In, Mo, Sn, Si and Al (including oxides).

The group at ENEA has performed many leading materials studies over the years. It ICCF19, they had a pair of papers on the topic. S. Lecci and six others used a diversity of materials preparation and characterization methods in relation to the ability of Pd to not only load, but also produce excess heat. They measured composition with Energy Dispersive X-Ray Analysis and Secondary Ion Mass Spectrometry. Electron Backscatter Diffraction was used to get crystallographic structure. Both Atomic Force and Scanning Electron Microscopies were employed to assess surface structure. Electrochemical Impedance Spectroscopy and Cyclic Voltammetry were used to obtain information on surface properties of materials in cells. Despite use of all of these tools, the authors conclude that the parameters controlling the Fleischmann-Pons Effect (FPE) might still be "out of our reach." The authors expect that better, and possibly not-yet-available instrumentation, is needed to understand the FPE.

Francesco Sarto and four others from ENEA gave a presentation on the morphology and electrochemical properties of Pd-based nanostructures made by different deposition techniques. Electro-deposition and DC sputtering were used to put Pd over carbon-based nano-porous substrates. Hydriding the samples produced a wide variety of morphologies, as seen with a Scanning Electron Microscope. The authors note the following: Surfaces can change during electrolysis, and microscopic techniques used before or after experiments are unable to follow surface evolution. Hence, *in-situ* techniques are necessary to characterize surface changes during electrolysis. They employed Cyclic Voltammetry (CV) as a primary tool because it reveals surface changes during loading. Simultaneous R/R_0 data acquisition allows direct correlation of loading kinetics with surface status. The effect of CV treatment was found to be less important than changes produced by loading.

Four other groups reported on detailed studies of materials preparation and characterization. Orchideh Azizi and four colleagues from the SKINR described the results of experiments on the use of various pretreatment methods and chemical additives for 50 µm thick Pd foils. Four different pretreatment methods were used, and six electrochemical methods and Scanning Electron Microscopy were applied to the resulting samples. Combinations of chemical and electrochemical pretreatment were found that improved the loading of protons into Pd. However, that was not the case for deuteron loading, the controlling parameters for which are "still largely unknown."

Photo courtesy of TSEM.

Orchideh Azizi

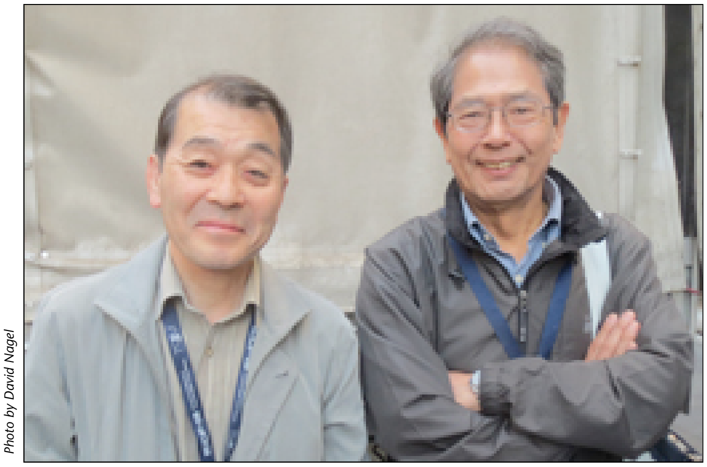

Photo by David Nagel

Akira Kitamura and Tatsumi Hioki

Emanuele Marano and two colleagues from the University of Turin reported on the synthesis and characterization of Pd-Ni-ZrO_2 composite materials for LENR experiments. They followed the procedure reported about six years earlier by Arata and Zhang. Master alloys were prepared by arc melting of elemental materials to give $Pd_{35-x}Ni_xZr_{65}$ where $0 < x < 35$. The molten alloys were rapidly cooled to produce amorphous materials, which were ground into a powder that was heated in air at 553 K for 24 hours. That resulted in Zr being oxidized, which formed a coating over nanometer-sized particles of Pd or Pd-Ni. X-Ray Diffraction was used to characterize the materials. It is planned to study the materials by Transmission Electron Microscopy and to investigate the thermal behavior of the materials calorimetrically in atmospheres of H_2 and D_2 at various pressures.

Tatsumi Hioki and five others from two groups in Nagoya University and the Toyota Central Research and Development Laboratories also studied hydrogen absorption in complex materials. They dealt with meso-porous silicas (MPS) with controllable pore sizes of a few nanometers. Pd atoms "are expected" to occupy the pores, and grow due to the heat released by the process of hydrogen loading. Hydrogen storage capacity in weight % was measured for pressures up to 8 MPa. In samples with the higher Pd concentrations, the H/Pd ratios obtained were similar to Pd bulk values. However, samples with lower Pd concentrations gave H/Pd = 0.4, much lower than that for bulk Pd.

Another paper, dominantly on materials for LENR, was from the new Center for Emerging Energy Sciences (CEES) at Texas Tech University led by Robert Duncan. The lead author was student Tara Scarborough, with Duncan, McKubre and Violante as co-authors. One of the current thrusts of the new Center is to be able to correlate images of cathode materials before and after experimental runs. To achieve this, Confocal, Scanning Electron and Atomic Force images at various resolutions are being stitched together. The result is a data set that can be viewed on any level from the macroscopic (centimeter) to the nanoscopic (nanometer) scales. Examples of such images were shown at ICCF19. The Center is in the process of acquiring three analytical instruments, a Pfeiffer ASM 340 leak detector for detection of H and He isotopes, a Jeol GCMate double-focusing mass spectrometer for gas chromatography (GC-MS) and a Quantra Fourier transform ion cyclotron mass spectrometer (FT-ICR).

The Center will also have a cryogenic calorimeter for measurement of energy released by explosion of fine wires of hydrided materials.

Theoretical Papers: Introduction & Major New Ideas

It is noted that some of the experimental papers reviewed above include theoretical musings on the causes of the measured effects. One example is the attribution of the results of plasma electrolysis to Erzion catalysis by Bazhutov *et al.* Another is the association of transmutation results by Ridolfi to ideas on "deformed space time." We will not double back in this section to review those theories, but rather review theoretical articles not already summarized. Hence, the total body of theoretical work presented at ICCF19 exceeds the contents of this and the next two sections, similar to the case for the section on Materials just above.

As usual at an ICCF, theory was the single category with the greatest number of papers. This time, one-third of the almost 100 papers were on theory or related computations. And, as before, such papers represent the greatest challenge to understanding. Most of the experimental papers involve materials and methods that are broadly intelligible. However, many of the theoretical papers require knowledge of concepts and techniques of advanced physics for their understanding. This challenge notwithstanding, summaries of the many theoretical papers are provided in this and the following two sections. A few of the ICCF19 papers introduced noteworthy new ideas into the field.

One of the theoretical papers was by Norman Cook of Kansai University and Andrea Rossi of Industrial Heat LLC "On the Importance of Nuclear Structure Theory for Understanding the E-Cat." Rossi was not present at ICCF19, but this paper represented his first involvement in any way in one of the ICCFs. The paper was based on published transmutation results. The approach follow's from Cook's lattice theory of nuclear sub-structure. It is built on the "unambiguous geometry of the mean positions of nucleons in nuclei that is analogous to the geometry of the electron orbitals in atoms." Further, "each and every nuclear state (ground and excited-states for any combination of Z and N) has a unique 3D structure." Cook and Rossi note that addition of a proton to the first excited state of ^{7}Li allows for direct formation of an excited state of ^{8}Be. That state decays to two alphas with momentum of about 17 MeV and no gamma rays. The authors assert that the reaction accounts for about 90% of the excess heat from an E-Cat system, with the rest being due to nickel transmutations that "remain more difficult to explain."

Graham Hubler, the Scientific Director of SKINR, gave a theoretical paper entitled "On a Possible Cosmological Explanation of the Anomalous Heat Effect." He feels that the experimental evidence for nuclear reactions being responsible for the AHE is "not compelling," but is still exploring a nuclear explanation. Hubler views the lack of neutron and gamma ray emission commensurate with the heat produced, and the lack of activation of materials, as evidence that the AHE may not involve nuclear physics. His new idea is based on a combination of solid-state physics and cosmology. Hubler hypothesizes that very strong (hyperfine) magnetic fields exist in materials in LENR experiments, and that the materials have resonances driven by the current in electrochemical cases. A phonon resonance provides a photon flux in the lattice and drives an electronic phase transition at about 10^{13} Hz. The core of the idea is the Primakoff effect, hypothesized in 1951. It is resonant production of neutral mesons by high-energy photons interacting with an atomic nucleus. Hubler considered the non-uniform distribution of dark matter, and estimated powers in the range from 0.5 to 500 mW. He states that his concept "gives plausible explanations for the difficulty in reproducing the AHE, the appearance of AHE in bursts, the necessity for D/Pd > 0.9, why D works and H does not, the lack of detectable particle and gamma emission, the quadratic dependence of excess heat on D loading > 0.9, and provides a rationale for why NiH may produce excess heat." Hubler states that the hypothesis does not require new physics, does not violate any physical laws and is testable.

Graham Hubler

Theoretical coupling of LENR to astronomical, geological and other regimes is not new. But, the ideas of Hubler are significant. Explaining LENR would lead to its faster exploitation commercially. But, coupling LENR to cosmology is also potentially very important scientifically. Astronomical studies of the motion of large structures have led to the current viewpoint that 73% of the mass in the university is "dark energy," which pushes galaxies apart, and 23% of all mass is in the form of "dark matter," which otherwise influences galactic motions.[12] Of the remaining 4% of the universe, 3.6% is not luminous and only 0.4% is visible. Particles called axions with unknown masses between 10^{-6} and 1 eV are prime candidates for the composition of dark matter. Currently, there are no reliable detectors for dark energy or dark matter. If it turns out that what we call LENR experiments can serve as detectors for dark matter, both our field and cosmology will benefit greatly.

Mark Davidson gave a presentation on another theoretical topic new to the field of LENR, something that he introduced in a pair of refereed publications during the past two years. It was entitled "Off-Mass-Shell Particles and LENR." Configurations of a physical system, particularly in quantum field theory, which satisfy classical equations of motion, are called *on shell*, and those that do not are called *off shell*.[13] Ordinarily, physicists treat the masses of elementary particles such as neutrons, electrons, protons and other ions as constant during the course of collisions. That is, they are "on shell." Davidson reviewed the 80 year history of theories in which particle masses are treated as variable, that is, "off shell." He noted that theories that have dealt with "off shell" effects have solved many problems in covariant relativistic quantum wave mechanics. His theory is that the "off shell" approach provides a mechanism for rest-mass variation of particles, which "can explain a large number of observed anomalous effects in LENR." He seeks modifications that follow from the standard model of particle physics, "the parent field for both condensed matter and nuclear physics." Davidson aims to use his variable mass theory of LENR to engage the mainstream physics community. It must be noted that full understanding of his approach requires knowledge of advanced and sophisticated techniques in modern theoretical physics.

The three papers just summarized illustrate part of the breadth of the ideas now in play to explain the mechanism(s) that cause LENR. It remains possible that the explanation of LENR will originate (or has already arisen) from a field of science well outside of condensed matter nuclear science. But, it is also possible that the desired and needed understanding will come from one of the ideas that have already been considered for years and are still undergoing development. Updates on some of those ideas were presented at ICCF19. They are summarized in the next section.

Theoretical Papers: Continuing Studies

Several competent theoreticians have pursued ideas about the mechanism(s) of LENR for many years. Some of them were at ICCF19 and presented or posted their latest thinking. Summaries of their papers follow.

Theories about LENR can be grouped into classes of related ideas. One of those categories includes theories in which so-called "compact objects" play a central role. They are combinations of either protons or deuterons with electrons that are intermediate between atoms and nuclei in both size and binding energy. Their small size means that they can approach nearby nuclei much closer than ordinary atoms. That reduces the distance required for tunneling and, hence, greatly increases the probability of tunneling and nuclear contact with subsequent reactions. The situation is analogous to muon-catalyzed fusion. In that process, an atom or molecule in which a muon has replaced an electron is much smaller than the same entity without the muon. The fusion rate is substantial and well verified, even though it is not high enough for practical production of energy.

Several authors have dealt with the formation and reaction of compact objects to explain LENR. Andrew Meulenberg is one of the more persistent among that group. J. Paillet, his new collaborator, and Meulenberg had three papers at ICCF19 on such work. The first was a review of the arguments against and for the existence of deep Dirac levels (DDLs), solutions of the relativistic Dirac equation in quantum mechanics, discussed in two earlier papers by Meulenberg. A primary problem is the existence of a singularity at the origin of the wave functions associated with the DDL, that is, at the center of the nucleus. The authors examined each of the four primary arguments against accepting certain solutions of the Dirac equation as physically realistic. Next, they provided a summary of the essential elements of Dirac theory. Then, they reviewed three papers that give the most complete elaboration of the infinity of DDL solutions. Paillet and Meulenberg analyzed methods for and properties of solutions of the Dirac equation that include a "corrected potential" inside of the nucleus. The extent of the resulting wave functions is on the scale of femtometers.

The above review of the literature and their ideas provided the background for two posters by Meulenberg and Paillet. In the first, a more detailed examination of the DDLs was provided. The quantum numbers of the DDLs "appear to be those of the hyperfine structure related to spin-spin interaction between the nucleus and orbiting electrons." Binding energies of up to 511 keV are found. The authors state that "the existence of these deep levels provides a ready explanation for the mechanism for penetration of the Coulomb barrier and the means of D-D fusion." The author's view cold fusion results as providing an experimental basis for understanding DDLs and the "proposed new fields of femtophysics and femto-chemistry." The last of the three papers dealt with the possibility and nature of femto-molecules, and with the nature of the forces that create them.

Xing Zhong Li from Tsinghua University and his colleagues have provided theoretical ideas and their elaboration for many of the ICCFs. Their formula for the fusion cross section is based on selective resonant tunneling. In the past, they fitted experimental cross sections for several nuclear reactions over wide energy ranges using a model with only three parameters. In their current paper, they showed that the model fits the (p + ^{6}Li) reaction, and that it has the required resonance. Their expectation is that this reaction is the basis of LENR observations, not only of excess heat, but also of electromagnetic radiation from LENR experiments.

Akito Takahashi is affiliated with both Technova Inc. and Osaka University. He has been studying for years the character and results of what he calls the tetrahedral symmetric condensation (TSC) of four deuterons to small region in space and time within a Pd lattice. His paper at ICCF19 dealt with a very important topic in LENR, namely reaction rates. Those rates, that is, the number of LENR per second per either the surface area or the volume of fuel materials, are central to the practical application of LENR. Rates obtained from theory are needed for comparison with experimental results on heat production or transmutations. It is noted that such comparisons are challenging because most experimental LENR results exhibit unpredictable and sometimes wild variations of the reaction rate with time during an experimental run.

Takahashi asserted that "the application of collision cross section formulas which treat instantaneous interactions is not proper for our CMNS nuclear reactions." That is, his view is opposite to that of Li and colleagues. Due to the finite lifetime of the trapped particles, Takahashi employs the Fermi Golden Rule to compute rates. He shows that the D-D nuclear separation within a molecule or cluster of deuterons must be smaller than one picometer for the resulting theoretical fusion rates to match "experimentally claimed" thermal power levels.

Peter Hagelstein of MIT has been working on models of LENR mechanisms for most of the history of the field. His paper at ICCF19 was "Current Status of the Theory and Modeling Effort Based on Fractionation." The focus of his work is on two reciprocal processes. The first is the down-conversion or division (fractionation) of MeV-level energies from nuclear reactions into meV-level energies associated with phonons within solids. The second is up-conversion of low energy quanta associated with a vibrating copper foil into more energetic quanta, which might manifest as charge emission or electromagnetic radiation. Both processes are based on a "lossy spin-boson" model, in which a two-level quantum mechanical system is coupled to a "bath" of a large number of harmonic oscillators. The model allows coherent energy exchange between the two involved sub-systems. It is embodied in a physical situation where there are numerous vacancies near the surface of a cathode which contain two deuterons. Rates of excess heat generation that follow from the model are consistent with the Piantelli NiH work and Swartz's NANOR®. The model gives an interpretation of the

Letts two-laser THz experiment. The up-conversion possibilities are being pursued experimentally with Francis Tanzella and Michael McKubre at SRI International. A copper foil vibrated at different frequencies has given "preliminary evidence of charge emission effect correlated with the vibrational excitation."

Vladamir Vysotskii is another theoretician who has been studying coherent phenomenon to understand LENR. His ICCF19 paper with M.V. Vysotskyy was "Spontaneous Formation of Coherent Correlated States in Changing Nanowells and Nanocracks: The Universal Way for LENR Realization." The paper reviewed and extended work on the topic to explain LENR, which spanned 25 years. In their view, "the most universal, optimal and natural method of satisfaction of the strict requirements of LENR realization is connected with the self-similar formation of CCS (coherent correlated states) of interacting particles during both increase (expansion) or decrease (compression) of nanowells in condensed matter." Other changing defects, including nanocracks, nanobubbles and dynamical nanovacancies in biomolecules, are embraced by the CCS approach. The authors consider the action of a stochastic force due to a stationary random process that causes collisions between a particle (nucleus, ion or atom) with atoms of gas in the various defects. Fast changes in defects in the surfaces of materials, or the formation of molecules during growth of biological systems, leads to LENR. Critical concentrations for different speeds of growth or compression of defects have been computed for an "optimal LENR condition."

V.I. and A.V. Dubinko's paper was on "Quantum Tunneling in Breather 'Nano-Colliders.'" A "Discrete Breather" or DB is a localized large-amplitude anharmonic lattice vibration in a solid. Papers published by these authors in mainstream journals showed that these entities can result in amplification of chemical reaction rates in their vicinity. Last year they published a paper in the *Journal of Condensed Matter Nuclear Science*, which applied the same methodology to nuclear reaction rates. That work, extended at ICCF19, shares with Hagelstein a focus on lattice vibrations and with Vysotskii an interest in correlated effects. The authors argue that DBs provide the "most efficient way to produce" the action envisioned by Vysotskii. They analyzed the effects of temperature (relevant to E-Cat reactors) and of knocking atoms out of position (by electrolysis or plasma loading). Their results showed an exponential dependence on temperature and a linear dependence on electron (ion) current, consistent with experiments. They attribute observed long electrochemical loading times and the requirement of high loading to the need to prepare metal-hydride clusters in which DB occur "more easily." Their conceptual work interests the authors in the value of atomistic simulations of DBs in metals and ionic crystals by molecular dynamics, as discussed below in the section on Computational Material Science.

Yuri Bazhutov postulated the existence of a particle called an Erzion in the early 1980s to explain some cosmic ray anomalies. A decade later, he employed the concept to explain LENR. He believes that catalytic Erzion nuclear reactions are the basis for LENR, and that they explain the generation of excess heat, new chemical elements and isotopes, and X-ray and neutron bursts seen in LENR experiments. Erzions contain a pair of stable heavy mesons, each the combination of a quark and anti-quark. They are thought to have come to earth in cosmic radiation. The Erzion cannot be captured directly by nucleus. However, it can form a stable bound state with a baryon containing three quarks to form a five-quark entity that Bazhutov calls an Enion. The latter can bind to nuclei with low (1-100 eV) energies. At high temperatures, Enions are freed in LENR experiments, such as the Ni-H devices. They then trigger "catalytic chain Erzion exothermic nuclear reactions." In his ICCF19 paper, Bazhutov provided estimates of reaction rates for power production of about 10 kW, that is, a power level in the range of what is produced by the E-Cat. He states that the Erzion model also explains the results of their plasma electrolysis experiments discussed above in the section on Excess Heat from Plasma Experiments and their light stimulation experiments described below in the section on Miscellaneous Topics.

Fulvio Frisone has presented his ideas and calculations based on them at earlier conferences in this series. He views deuterium loaded palladium as three different plasmas, electrons, deuterons and Pd ions. He proposed a "general model for the effective local time-dependent deuteron-deuteron potential that takes into account the electron and ion plasma oscillations." Phonon exchange is said to produce an "attractive component between two deuterons," which reduces their inter-nuclear separation to 0.16 A. That increases the probability of tunneling and nuclear reactions.

Additional Theoretical Models

Half of the theoretical papers presented at ICCF19 were entirely or mostly new to this series of conferences. They are briefly summarized in this section.

Edward Tsyganov and five colleagues presented a poster on "Cold DD Fusion in Conducting Crystals." The central idea of their model is that the deuteron atoms in a crystal have an electron excited into a p-orbital. When two of these entities occupy a single octahedral site, the "distance between these two deuteron nuclei may be less than 1/10 of the nominal size of the unexcited atom." Then, the "quantum vibrations" of the two nuclei give an immense "60-65 orders of magnitude" increase in the fusion probability with the reaction energy being discharged into the lattice by "virtual photons."

Magnetism played a central role in two theoretical papers at ICCF19. Valerio Dallacasa from Verona University considered magnetic forces that arise from phase differences between motions within the structures of both neutral and charged particles. He stated that for charged particles, such as the proton, the magnetic force can overcome the Coulomb repulsion. A medium is needed in order to stabilize a phase difference. If the medium is a crystal with magnetic domains, the phase is determined by the localized magnetic moments in the domains. Pd, Ti, Ni and their nanoclusters, used in LENR experiments, reportedly have localized magnetic domains. "Fairly accurate" values of the magnetic binding were derived by using polarizability data and the experimental distributions of charge in the proton and neutron.

The second paper invoking magnetic effects was by Andrea Calaon. It is based on earlier work by Dallacasa and Cook, which said that nuclei are held together by magnetic attraction. Calaon assumes that the Zitterbewegung of electrons can generate attractive forces between an electron and nucleon or nucleus. Zitterbewegung is a circulatory motion within an electron presumed to be the basis of the electron spin and magnetic moment. The attractive force creates an "almost neutral pseudo-particle, called here Hydronion." Calaon addresses both the formation of these entities and the dissipation of energy when they cause LENR.

There were two papers based on the theory of deformed space-time (DST) and its implications at ICCF19. The DST theory has been developed by Fabio Cardone and his collaborators during about the past 15 years. It involves a new geometrical structure of space-time, based on a generalization of the usual Minkowski space, taken to be endowed with a metric whose coefficients are energy dependent. The first paper was by Gianni Albertini of UNIVPM and Domenico Bassani of SIDOM S.A.S., both in Italy. It claims to unify "all observed phenomena in a unique general phenomenology." The second paper by Bassini included experimental evidence of transmutations, which was "obtained in conditions of local Lorentz invariance breakdown in a metal." He used DST theory to explain the results. The abstracts of these two authors provided numerous references to earlier work by Cardone and others.

Daniel Szumski contributed two papers to ICCF19. The first was an overview of his least action nuclear process (LANP) theory of cold fusion. It posits two heat reservoirs, each with its own temperature. The first is the ordinary thermodynamic temperature. The second is the "domain of heat radiation" describing the system's radiation temperature. The latter includes both the free radiation content and "the radiation locked in chemical bonds between atoms." These lead to a "quantum electrodynamic (QED) description of Mössbauer resonant bonding between nuclei," similar to the QED model of covalent bonding. In Szumski's picture, gamma ray exchanges are what provide the nuclear bonding. The gamma energy increases during a LENR experiment, bringing the nuclei into closer proximity. He asserts that "even without excess heat, nuclear transmutations occur." The second paper is entitled "The Atom's Temperature." It deals with the deterministic and reversible limit of statistical mechanics for a system with a small number of participating units. The reversible process is found to give "enormous energy efficiencies." Szumski states that "treating cold fusion as a reversible process is five orders of magnitude more efficient than achieving the equivalent fusion energy in a Tokamak."

David Davidyan and three colleagues from Armenia provided a poster paper on "Theoretical Prerequisites for Creating Cold Fusion Reactors." They proposed a model to explain fusion reactions involving Ni and Cu, to which a proton is added to give Cu and Zn, respectively. They cite experiments by Rossi and a chemical experiment as evidence of cold fusion. The authors wrote, "Currently work is underway to create an industrial power station."

George Umarov is a Russian theoretician. He presented a theory based on a many-body solution involving discovery of "a hierarchy of small parameters." The basis of the approach was described in a paper by Umarov in 1981, when he and his colleagues were using the formalism for chemical reactions. Now, he has applied the methodology to nuclear reactions. He stated, "We can prove that such reactions can take place not only as fusion, but also as transmutations..."

N.A. Magnitskii from the New Inflow LLC in Moscow provided the paper "A Possible Explanation for the Results of Experiments with LENR." His approach is based on the ether theory of elementary particles. He cites a six-step process starting with the production of hydrogen atoms at a cathode and ending with production of thermal energy.

Max Fomitchev-Zamilov based his ideas about the mechanisms behind LENR on a "model of a nucleus as a system of tightly bound proton and electron states." That is, he takes a fundamentally different approach to nuclear physics after expressing his unhappiness with the current state of the subject. That malcontent is not his alone, but is also shared by Norman Cook and many others. Fomitchev-Zamilov attempted to "offer a glimpse of such an intuitive theory of what the electron, proton and neutron actually are and how they collectively hold the nucleus together." He details the structure of each of these entities. And, he notes that there is a finite number of electron states in a solid, and asks what happens when more electrons are put into a solid than there are states to accept them. His answer is that the electrons go into nuclear states to form "excess transient neutrons," which can lead to LENR.

Philippe Hatt had two related papers at ICCF19. He wrote, "the purpose of my theory is to represent the structure of the neutron, the proton and hence the atomic nucleus at a quantic level in line with the three interactions at the level, *i.e.*, the electromagnetic and the two nuclear forces." Hatt states that "the nucleon is composed of mass and electromagnetic quanta" and explains how a proton is transmuted into a neutron via a cold process featuring the weak interactions. He wrote, "Mass as well as anti-mass put in motion are much more important than the final detected mass of a nucleon." He notes that anti-mass is different from anti-matter, and explains the difference. Hatt computes binding energies, which "explains the possibility of cold fusion and fission processes." His work can be found at this link and the links it contains: http://www.philippehatt.com/

T. Toimela from the Vaasa University of Applied Sciences in Finland had a paper at ICCF19 entitled "Theoretical Study on the Transmutation Reactions." The author seeks to explain the variation of the transmutation rates for different elements, knowledge that might be used to increase such rates. In the process, he hopes to restrict the class of possible explanations for the mechanism of LENR. His one assumption is that the mechanism behind transmutations does not depend on the nuclear charge. Toimela proposes ways to experimentally verify his explanation and to enhance transmutation rates.

Frederic Henry-Couannier of the Centre de Physique des Particles de Marseilles entitled his paper "Dark Gravity and LENR." He explained that dark gravity (DG) theories are "extensions of general relativity having a stable-anti-gravitational sector." They were developed, and succeeded, in explaining "several well-known enigmatic cosmological discoveries." The author states that only his version of DG theory, published in 2004 and 2013, naturally lead to the "likely existence of genuine field discontinuities." Those discontinuities are said to be "all we need to explain in a unifying and very simple way many if not all of the well known so-called 'LENR miracles.'"

Uwe Wettin of LCD-Solutions s.a.r.l. in France wrote that "the easiest way to explain cold fusion is to use the rules dark matter follows." But, he admits that such rules are not known yet. In fact, he states that the first necessary step is to show that dark matter exists on earth. Wettin notes that the gravitational constant is the most inaccurate measured fundamental constant by a factor of 1000. His paper deals with the question of whether "simple experiments" can elucidate the nature of the interaction of known and dark matter.

Farzan Amini from Iran had a poster paper entitled "The Effects of Gravitational Field on Nano Bubble-Nickel Interactions in Nano IBN Cell." He described the structure of the cell with "main parts such as two enclosed channels with cantilever plates, pulsed plasma jet actuator and nano-centrifugal rotating machine," plus a nano bubble injector system consisting of four main parts, and pulsed-plasma jets, an electrolyzer and two outer magnets. Forces in the system "act as a gravitational field which gives rise to spacetime distortion." He observed "various tiny volcanoes" on the surface of a hydro turbine in the system. They are attributed to the interactions of hydrogen atoms that are inside of nickel nanoparticles in the flow.

As usual at an ICCF, there were a few papers that seemed to have nothing to do with LENR. D.V. Filippov and L.I. Urutskoev from the Prokhorov General Physics Institute of the Russian Academy of Sciences had a paper entitled "Increase in the Probability of Electron Beta Decays in Superstrong Magnetic Field." The problem is that the fields of interest to them are not accessible in LENR experiments. Richard Amorosa focused on the "Future of Particle Physics: Unified Field Alternatives to 100 TeV, PeV Colliders."

Before leaving the topic of theoretical papers about LENR, the wide variety of ideas now being touted should be considered and appreciated. This author does not know if such a situation is common or not for radically new experimental topics in physical and biological sciences. However, the variety certainly does complicate the search for the key ideas that will lead to understanding of LENR.

It is possible, maybe even likely, that some of the theoretical papers reviewed in this and the preceding two sections contain ideas that seem surprising, amazing or even far-fetched to some readers. It should be noted that several of the bold concepts were put forward by scientists with records of earlier refereed publications in good journals. In some of the cases, the ideas were earlier applied to other fields, such as chemical reactions, and are now being used in attempts to understand LENR.

It seems likely that the one or few ideas that will ultimately prevail for understanding the mechanisms underlying LENR have a long way to go before they succeed and are accepted. Equations based on those ideas, and production of numbers from evaluation of the equations, are needed, but generally unavailable now. Those numerical results will have to be compared with data from past experiments or used to predict the outcome of new experiments. It seems more probable to this reviewer that the ultimately successful idea(s) will survive and be widely accepted because (a) they are useful in the design of new experiments to test them and (b) the results of the new experiments are consistent with the quantitative predictions of the winner(s).

Computational Material Science

Experimentation and theory have been major parts of the field since its beginning. Computational science was also significantly involved from the early days, mostly for the analysis of the performance of calorimeters. However, significant work on computational materials science started only in the past few years, and has been increasing steadily. That type of research was a part of some papers already reviewed, such as those by Kurelinkov on neutron emission and Dimitriyeva on Density Functional Theory calculations of surface energies. A few papers at ICCF19 were specifically on calculational methods for materials and their results. They are now reviewed.

Volodymyr Dubinko from the Ukraine and three colleagues from Belgium, Russia and France had a poster paper on "Atomistic Simulations of Discrete Breathers in Crystals and Clusters: A Bridge to Understanding LENR." This paper is a companion to the other paper on Discrete Breathers reviewed above in the section on Continuing Theoretical Studies. As noted there, discrete breathers (DB) are localized vibrational modes in which the amplitude of atomic oscillations greatly exceeds that of ordinary phonons. In this second paper, the authors performed molecular dynamic simulations in materials, diatomic crystals and nanoclusters. In Pd loaded with protons or deuterons, DBs arise at frequencies in the gap in the ordinary phonon density of states. They report on "a striking site selectiveness of energy localization in the presence of spatial disorder at high loading ratios. As a result of the disorder, the energy for excitation of DBs can go to zero, producing nuclear active sites and LENR."

D. Burov and four colleagues from New Inflow LLC in Moscow reported on "Kinetic Calculations of Element Transformations in the Presence of a Cold Neutron Flux." They assume the availability of a flux of low energy neutrons. Their code takes a distribution of chemical elements initially present and computes the rates of neutron capture and decay of newly formed radioactive isotopes. The initial distribution of elements can be adjusted to give the numbers of new elements that have been found in several past transmutation experiments. Particular attention is given to the results of Klimov on the use of plasmoids to produce transmutations. Two of his papers are reviewed in the section above on Excess Heat from Plasma Experiments.

Jacques Ruer continued his analytical study of small craters, which appear in the cathodes of electrochemical LENR experiments. His ICCF19 paper dealt with the lifetimes of the hot spots that produce craters. He computed the kinetics of heat flow following the deposition of a given amount of energy in a specified volume of a material. Thermal conduction was the dominant process. A characteristic cooling time A was calculated for crater diameters of 2 μm (A = 13 nsec) and 10 μm (A = 345 nsec). Relative peak temperatures were obtained as a function of the duration of the energy release events.

Dmitry Terentyev used atomistic kinetic Monte Carlo and molecular dynamics methods to study the interactions of dislocation loops in materials. His paper on "Hardening and Embrittlement of Fe-Based Alloys for Nuclear Applications" did not deal explicitly with LENR. However, dislocations are thought by some to play an important role in the production of energy by LENR. Hence, Terentyev's methods might be useful for study of nuclear active regions involving dislocations.

Data Analysis

Sometimes, raw data from measurements suffices to give key information on the outcome of LENR experiments. However, most of the time, it is useful to apply various analysis methods to the captured data to wring additional information out of it. There is a wide variety of such possibilities. Often, making simple arithmetic estimates of parameters based on measurements are instructive. Common tools like Fast Fourier Transforms applied to experimental time series yield spectra of various frequencies involved in LENR experiments. Other more sophisticated data analysis tools can show whether or not two data streams are correlated. Recently, techniques more advanced than those of classical data analysis have appeared. They are part of the field of Data Mining, which is itself now a subset of the field of Predictive Analytics. There were a few papers at ICCF19 that exploited various levels of data analysis. They are summarized in this section in reverse order from the most to the least sophisticated.

Olga Dimitriyeva and three colleagues from Coolescence gave a presentation on "Machine Learning to Analyze Deuterium Loading Patterns During Electrochemical Experiments." The goal of machine learning is to "generalize from the observed data to predict the behavior of the system and recognize the correlations and patterns." The methodology uses a table of data, namely sample numbers and their characteristics, to train algorithms to recognize patterns. In their work, the authors employed the MongoDB relational database and an open-source Python-based algorithm. During the years 2012 to 2015, Coolescence performed electrochemical experiments on 350 cathodes for 35,000 hours, which produced 6,300,000 data points on temperature, current, voltage, power, pressure, resistance ratio, and annealing and etching regimes. They plan to obtain data from over 1000 cathodes during 100K hours of experiments. The machine learning work to date has involved only data generated within Coolescence. However, in principle, the data used in such work could involve information from other LENR laboratories. Increasing the size and diversity of the data available to the algorithm might significantly increase the value of the data mining results.


Photo by David Nagel

Olga Dimitriyeva

Melvin Miles and Iraj Parchamazad of the University of LaVerne provided a paper on "Thermodynamic and Kinetic Factors Concerning the D + D Fusion Reaction in the Pd/D System." They computed the changes in internal energy, the enthalpy, the entropy and the Gibbs free energy for the reactions D + D goes to ^{4}He. The results showed that the reaction is thermodynamically possible at room temperature. But, the thermodynamic approach cannot provide information on LENR rates. The authors note that the rate of the D-D fusion reaction might be controlled by physical or chemical processes, the speeds of which are described by Eyring rate theory. Using the LENR energy production rate of 100 mW and the Eyring equation, an activation energy of 0.19 eV was obtained. This is close to the reported activation energy for diffusion of 0.21 eV. The authors take this to suggest that the rate at which LENR occur is limited by diffusion into the regions just outside of or just inside of a cathode .

This author did some simple calculations for a paper on "High Energy and Power Density Events in Lattice-Enabled Nuclear Reaction Experiments and Generators." He analyzed the 1985 meltdown of a cubic Pd cathode 1 cm on a side in an experiment of Fleischmann and Pons, and reviewed several reports of explosions in LENR experiments. Such rapid releases of energy raise the question of whether or not chain LENR reactions can occur. The power density within the small craters formed on LENR cathodes was found to be greater than the power density of TNT. That raises questions about the safety of commercial LENR generators, and possible weaponization of LENR. Military use of LENR is an unpopular topic, but it has been considered since soon after the 1989 announcement by Fleischmann and Pons.

Engineering and Applications

Scientific study of LENR is a vigorous activity, as the reviews above attest. However, there is simultaneous work on the engineering of LENR generators and their applications. The few papers in those arenas at ICCF19 are reviewed in this section.

Dmitry Baranov and Valeriy Zatelepin from the private laboratory INLEAS in Moscow provided a poster on "The Concept of Propulsion with a LENR Heat Source for Aircraft and Ground Application." They note that LENR generators are "characterized by a certain range of parameters of thermal energy." Based on such expected performance characteristics, the authors presented a concept for converting LENR thermal energy into mechanical energy in an air-jet engine. They provide a baseline design for the "overall weight and dimensional characteristics of an engine power of 500 kW."

Igor Goryachev from the Kurchatov Institute in Moscow and V. Kuznetsov of the Center for Applied Physical Investigation in Dubna contributed four papers to ICCF19. The first was a "'Road Map' for Developing Engineering Applications of LENR Technologies." They envision the following characteristics of LENR units, in their words:

- Generating ecologically clean and safe heat.
- Generating ecologically clean and safe electricity.
- Complete neutralization of radioactive waste and spent nuclear fuel.
- Cheap and ecologically clean desalinated sea water.
- Neutralizing war gases and toxic hazardous waste products.
- Producing precious and rare metals out of cheaper materials.
- Producing new special materials and alloys.
- Using LENR-radiation for technical and medical needs.

The authors developed the "technical and commercial" parameters for 11 projects. Among them were a 100 kW water heater, a 120 kW "fuelless" electrical generator, a 5 MW electric power generator and a 10 MW power installation.

Goryachev and Kuznetsov then considered specific applications in their other papers. The first deals with the destruction of solid waste at sea by use of a "sea cleaning" ship. It would have three 10 MW generators "each based on new physical principles." Electricity would be generated as "the result of low energy transmutations of water oxygen under the impact of specially formed electromagnetic radiation (analog of LENR technology)." The ability to process materials at the rate of 3000 kg per hour, with ashes that can be dumped at sea, was projected.

The same two authors also offered a poster on "Low Cost Desalinating Sea Water Based on Low Energy Transmutations of Chemical Elements." Their concept involves using low energy transmutations to convert salts into silica and gases, both of which are easily separated from water. They wrote, "Transmutational radiation is generated by special beam generators." They estimate the input electrical power to be in the range from 500 to 2000 kW, the productivity as 1312 cubic meters per day and the cost of desalinated water as 0.47 € per cubic meter.

The last paper by Goryachev and Kuznetsov is entitled "Technology of Environmentally Clean Remediating Radioactive Waste Based on Low Energy Transmutation of Radioactive Nuclides." They are concerned with two processes. One is the pyrolysis of organic materials and melting of inorganic materials in fission waste, which must capture of 90-95% of the radioactive isotopes in the slag. Since that process does not remove radioactivity, they also deal with a second process from the Center in Dubna. A means is described to use low energy transmutations to produce exothermic reactions to transform unstable isotopes into stable ones. The authors believe that a combination of the pyrolysis method and the transmutation technique is best. They stated that "the design of such a reactor has been developed."

Miscellaneous Topics

The topics of a few papers did not fit the above categories, which is not a pejorative statement about them. They are reviewed here.

In past ICCFs, there were often many papers on instrumentation, especially calorimetry. In Padua, there was only one report specifically on calorimetry. E. Castagna and three colleagues from ENEA had a paper "The Significance of a Properly Conceived and Instrumented Calorimetry." They noted that both mass flow and isoperibolic calorimetry have been used to study the production of power by LENR. Such devices can be instrumented to give electrochemical conditions as well as deuterium concentration within Pd cathodes, gas pressure in the cells and coolant flow rate for the mass flow method. The authors were concerned with designing measurements to insure that there are checks on the onset of LENR. They wrote, "The approach described paves the way to conceive updated experiments that could require specifically designed and realized instruments."

Vladimir Vysotskii and Anton Vasilenko from the Kiev National Shevchenko University and Alla Kornilova from Moscow State University continued their study of effects due to high-speed cavitating flow. Earlier, they reported on the production of external soft X-rays. At ICCF19, they discussed "Observations and Study of Undamped Thermal Waves in LENR-Related Systems." The waves were generated by impact of the high-speed flow on a tungsten target, and measured with a piezoelectric detector at distances from the target up to 21 cm. Their frequencies were in the range of 80-85 MHz. Such acoustic frequencies will not penetrate that far in air, so the authors conclude that they measured undamped thermal waves. They solved the heat transfer equation to obtain values for frequency and time delay that were consistent with their experimental results.

Yuri Bazhutov and five colleagues from in and near Moscow made heat and transmutation measurements on an experiment with unusual excitation. They performed optical irradiation of solutions with light emitting diodes (LEDs) and lasers of unspecified intensities and wavelengths "in the red irradiation region." No X-ray or gamma ray signals were obtained, but small neutron bursts (100 neutrons in a few milliseconds) were obtained. Tritium was measured at some unstated level with a liquid scintillation system after LED irradiation of water solutions of LiOH and Na_2CO_3. No excess heat was detected with calorimeters.

Gennady Tarasenko and Yelena Demicheva from the Caspian State University offered a paper on "Tarasenko Generator on the Basis of the Model of the Earth." They provided an electrical circuit that models several geophysical phenomena, including ball lightning, as well as electromagnetic phenomena associated with "seismic, meteorological and biophysical phenomena." This paper was built on earlier work that related geological phenomena to cold fusion.

LENR Academic Research Programs

There are various signs of the maturation of the field of LENR. One of them was the formation of an industrial association for the field, namely LENRIA. The ICCF19 paper on that new organization is reviewed above in the section on Commercialization of LENR. Another indicator is the appearance of university programs for research and teaching of LENR. In the past few years, three such programs have been formed.

The Sidney Kimmel Institute for Nuclear Renaissance was set up at the University of Missouri in 2012. It hosted and was thoroughly described at ICCF18 in the middle of 2013. Robert Duncan was the leader of that action, and Graham Hubler is the Scientific Director. Duncan moved to Texas Tech University early in 2014, and founded the second academic institute focused on LENR. It is the Center for Emerging Energy Sciences (CEES). One paper on that Center was presented at ICCF19 by Tara Scarborough, a Ph.D. student at that university. The paper was on materials, so it was reviewed in the section on Materials above. Both of those LENR groups in the U.S. are now addressing basic scientific questions about LENR, rather than developing engineered generators of heat or electricity. However, they can be expected to evolve into more engineering-oriented work as the field further matures.

The third academic research program was also described at ICCF19. Yasuhiro Iwamura left Mitsubishi Heavy Industries (MHI) to join the faculty of Tohoku University in Sendai. His presentation with Jirohta Kasagi and Hideki Yoshino described the new Division of Condensed Matter Nuclear Reactions. It includes those three leaders and Takehiko Itoh, also formerly of MHI. That organization will start with basic research on LENR, but it has a goal of developing a LENR-based generator by the year 2020.

The three academic programs have been started with funding in the $2-6M range, which spans periods of about five years. That is, it is taking roughly $0.5-1M annually to run an academic research program. This is a relatively small burn rate compared to the costs of industrial research. However, production of results in a university is generally much slower than in a company due to course work by students and the pace of their degree programs.

Beyond the university programs just described, there was another related development at ICCF19. The creation of the

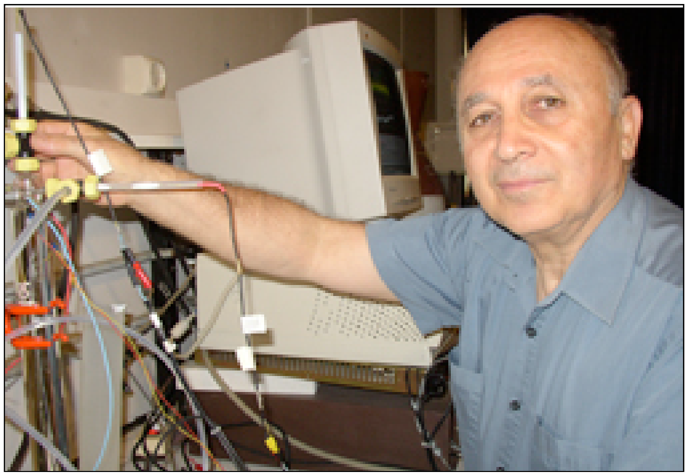
Photo courtesy of Jean-Paul Biberian.

Jean-Paul Biberian in his laboratory.

French Society of Condensed Matter Nuclear Science was announced by its president, Mathieu Valat. He can be reached at info@sfsncm.org. The goal of the group is "catalyzing interest in cold fusion in France and French speaking countries." The other national society in this field is the Japan Cold Fusion Research Society. It has existed since 1999. The website for that group is http://jcfrs.org/indexe.html. The International Society for Condensed Matter Nuclear Science is at http://www.iscmns.org/.

Other Aspects of ICCF19

The General Chairman of the conference, Anthony La Gatta, was able to enlist support from many organizations. Patrons of ICCF19 included the Office of the Prime Minister of the Republic of Italy, the Presidency of the Council of Ministers, the Italian Ministry of Economic Development, the National Research Council of Italy, the Italian National Agency for New Technologies, Energy and Sustainable Economic Development, the Chamber of Commerce of Padua, the Padua Convention and Visitor's Bureau, and the International Society for Condensed Matter Nuclear Science. Sponsors included the New Energy Foundation and the Sidney Kimmel Institute for Nuclear Renaissance.

One of the enduring features of conferences in this series is the awarding of the Preparata Medal of the International Society for Condensed Matter Nuclear Science (ISCMNS). The recipient at ICCF19 was Professor Jean-Paul Biberian of the Aix-Marseille Université in Marseille. He plays two major continuing roles in the field. Since 1993, Professor Biberian has been a very active and versatile experimental scientist with many contributions to the science of LENR. His three papers at ICCF19, which involved very different experiments, are recent evidence of his experimental versatility and virtuosity. This photograph of him in the laboratory from his website is a reflection of that role.[14] Secondly, Professor Biberian has served as the Editor-in-Chief of the *Journal of Condensed Matter Nuclear Science* since 2007. It is a free refereed on-line journal published by the ISCMNS, which is devoted to LENR. Recently, he published a book entitled *Fusion in All Its Form*s, which is available in English.[15] An article on the award of the Preparata Medal to Professor Biberian is in this issue.

ICCF19 had some unusual characteristics compared to earlier conferences in the series. The unavailability of abstracts at the conference was an example. Fortunately, the abstracts, graphics from oral presentation and the full posters were made available to all attendees two months later. Overall, the conference was very successful, bringing together the international scientific community with diverse interests in LENR. In terms of location and meals associated with the conference, it was among the more pleasant of the ICCF series.

The Proceedings of ICCF19 will be published in the *Journal of Condensed Matter Nuclear Science*.[16] It is hoped that the papers will provide very thorough documentation of what was done and found experimentally, theoretically or computationally.

Conclusion

There were some themes in the 32 oral presentations and 66 poster papers at ICCF19. As usual, theory and related papers were the dominant topic at the conference. The diversity of ideas and their wide range of developments are noteworthy. There have been a few papers in the LENR literature and at ICCFs linking the topic to geophysical ideas. There was one such paper at this conference. Similarly, relating LENR to astronomical and cosmological notions is not new. But that arena got unusually great attention at ICCF19. Presented theories ranged from only concepts to numerical comparisons with experiments or the design of experiments.

One of the dominant topics at the conference involved experimental study of materials and their loading with deuterons. Outstanding materials research was reported by Coolescence, ENEA, SKINR, and a few other laboratories. The way to achieve high loading is now much clearer. However, that alone does not translate into reliable production of excess power.

There were lesser threads within the papers at ICCF19. Electrochemical and gas loading, and plasma excitation, got much attention, as usual. Ultrasonic excitation was used in several experiments, many times to produce cavitation. There was remarkably little discussion of instrumentation at ICCF19.

Growing interest in and activity about LENR were clear even before ICCF19. The involvement of many companies and organizations is part of that evidence.[17] The same can be said of the dozens of websites and blogs now dealing with LENR,[18] and the numerous government organizations that are similarly involved or else watching the field.[19] The participation in ICCF19 by scientists, engineers and business people from two dozen countries is evidence of the global nature of interest in LENR.

ICCF19 came at a good time, not long after the formation of the LENRIA Industrial Association and the LENR Cities consortium. The institution of two more academic research programs, one in Texas before and another in Japan just after ICCF19, is additional evidence of the ferment in the field now.

ICCF20 will be organized by Professors Jirohta Kasagi and Yasuhiro Iwamura of Tohoku University, and held in Sendai, Japan, during October of 2016. A satellite conference might be organized in China about that time.

Acknowledgements

Graham Hubler provided useful insights on papers from this conference. He and Steven Katinsky offered helpful comments on the manuscript of this overview.

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