

20th International Conference on Condensed Matter Nuclear Science

Part 1: Introduction and Experiments

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The scientific study of Low Energy Nuclear Reactions (LENR) remains a vibrant global activity with ongoing research in about a dozen countries and evident interest in roughly as many other countries. And, there are numerous small startup companies in several countries, including at least Finland, Italy, Japan, Russia, Switzerland and the U.S. They are motivated by the possibility of LENR being the basis for a new type of clean, distributed and safe energy source. But, the center of the field remains in the scientific realm because of experimental challenges, notably experimental reproducibility and controllability, and the theoretical requirement for understanding.

This series of meetings started with the name International Cold Fusion Conferences (ICCF). It now goes by the name in the title, but retains the original ICCF numbering. It is the primary series of scientific conferences in the field, but far from the only type of conference on or related to LENR. The First Meeting of the French Society for Condensed Matter Nuclear Science was held in Avignone in March 2016. The 12th International Workshop on Anomalies in Hydrogen Loaded Metals will be held during June 5-9, 2017 in Costigliole d'Asti, Italy. The 16th meeting of the Japan Cold Fusion Research Society happened on December 11-12, 2015 in Kyoto, Japan. The 22nd Russian Conference on Cold Nuclear Transmutation and Ball-Lightning (RCCNT&BL-22) was held from September 27 to October 4, 2015 in Sochi, Russia.

There are many other conferences relevant to LENR. One example is the World Hydrogen Energy Conference, the 16th of which was in Zaragoza, Spain, on June 13-16, 2016. Conferences on materials are certainly germane to LENR. One series is by the TMS (The Minerals, Metals and Materials Society), which will have its next meeting in February and March 2017 in San Diego, California. Another is the Materials Research Society, which is planning its next meeting for April 2017 in Phoenix, Arizona. And, there are sometimes sessions on LENR at meetings of the American Physical, Chemical and Nuclear Societies. However, despite all these activities and possibilities, the ICCF meetings remain the most important series of conferences on LENR.

ICCF20 was hosted by the Condensed Matter Nuclear Reactions Division within the Research Center for Electron Photon Science of Tohoku University. Professors Jirohta Kasagi and Yasuhiro Iwamura of that University served as the

Chairmen of the conference. The website for the conference (iccf20.net) lists committees and several sponsors, including Tohoku University, the Thermal and Electrical Energy Foundation, Clean Planet, Inc., Technova, Nissan Motor Corporation and the Sendai Tourism, Convention and International Association. The conference was held during October 2-7, 2016 in a very modern mixed-use facility in the heart of Sendai, conveniently located near the railroad station, with many nearby hotels. There were 145 attendees at ICCF20 from 19 countries. We were treated to 47 oral presentations and 36 posters, in addition to several ancillary activities to be discussed below. Figure 1 shows the attendees in the room where the conference was held.

One unusual characteristic of this conference involved the organizations and individuals who were not at ICCF20. Very unfortunately, there were no participants from Russia, probably due to lack of funding. There were also significant academic and commercial absences. No one from the Center for Emerging Energy Sciences at Texas Tech University was at ICCF20. It is reportedly a well-funded university center with a major effort on LENR, which participated in ICCF19. Neither Robert Duncan, the CEO, nor Michael McKubre, the Manager of new LENR company Seashore Research LLC, were at ICCF20. Anthony LaGatta, who chaired ICCF19 and is the principal behind the Italian company TSEM, was absent. And, Tadahiko Mizuno of Hydrogen Engineering Application and Development Company in Japan could not make the conference. Despite these key players not being in Sendai for ICCF20, it was an outstanding conference in all respects, scientifically and in terms of pleasant activities.

Michael McKubre gave the opening talk despite not being able to attend. It consisted of his comments delivered by Matt Trevithick, and a video prepared by McKubre. The presentation included a list of observations by McKubre, which are worth noting:

- Collectively we have the answer; individually none of us does.
- We need a reasonable trajectory towards problem resolution.
- We must learn from the past.
- We need fresh data.
- There exists no consensus around an agreed set of facts.
- We must work together to finish what has not yet been done.
- Our future is our youth. Let them learn and do. Watch them win.



Figure 1. Photograph of the ICCF20 attendees.

- Our field is not limited by money.
- This effort and its benefits must be multi-national.

McKubre concluded with a set of recommendations:

- Identify what we consider to be the best three or four experiments.
- Recruit multiple laboratories to work on them.
- Write clear scientific papers, including multiple authors from the multiple labs.
- Do our own peer review first.
- Publish these papers in the *Journal of Condensed Matter Nuclear Science (JCMNS)* or other peer-reviewed scientific journals.
- Present the work at ICCF21 in a special session focused on these replications.

In the video, McKubre urged ICCF20 participants to practice scientific communication, cooperation and collaboration. That is usual for the pre-competitive phase of a field, which is the situation now for LENR. However, it does not happen when proprietary plans, information and rights are in play. Such is now the case for Seashore Research LLC, which McKubre joined recently after retiring from SRI International.

Almost all of the following sections are reviews of the contents of the oral and poster presentations at ICCF20. The subjects are common to most of the ICCFs, with attention to energy production, transmutations and other experimental topics. Reviews of papers on theoretical concepts and developments, and other subjects, such as applications, will constitute the second part of this report on ICCF20. That will appear in the next issue of this magazine. The material on heat production spans the following three sections because of both its volume and the diverse types of experiments that focus on energy generation.

1. Heat Production Using Nano-Materials

There has been strong interest in the use of nanometer-scale materials in LENR experiments for about a quarter of a cen-

tury. This line of research started with Arata and Zhang, who used fine scale particles of palladium, first without and later with ceramic coatings. The composite materials are prepared by producing thin films of palladium, sometimes alloyed with nickel, which are also alloyed with zirconium. Oxidation produces nano-scale particles of Pd or Pd-Ni alloys coated with ZrO_2 . The ceramic coating prevents sintering together of the metals, but is thin enough not to impede movement of protons or deuterons into the alloys. Many LENR experiments have been performed using such materials, and reported in the past. At ICCF20, a few papers dealt with this approach to bringing together Pd or Pd-Ni with hydrogen isotopes.

Akito Takahashi has long been a major contributor to LENR research, both experimentally and theoretically. He is now one of the principals leading a seven-person collaboration between Technova and two universities in Kobe and Osaka. His title at ICCF20 was “Anomalous Heat Effects by Interaction of Nano-Metals and H(D)-Gas.” The talk began with a review of research in that arena by the team during the years 2008 to 2015. That work is distinguished by use of two similar experimental systems in parallel, one with hydrogen gas and the other with deuterium gas, and by the use of many different nano-materials. Zirconia and mesoporous silicon coatings of elemental and alloy samples were used in the past research. Recent work with samples of mixed Pd and Zr oxides gave excess heat of about one-quarter of a watt when exposed to deuterium gas. Hydrogen gas exposure also produced excess heat, but at levels somewhat lower than with deuterium gas.

The Technova-Kobe-Osaka team had been doing mass flow calorimetry with water. They changed to using oil in order to work at higher temperatures. Recent work was done at 200-300°C using nickel-based alloys. Anomalous heat production was measured for several days in some runs, giving values as high as “several tens of eV per atom of H.” Use of diverse materials and ceramic coatings resulted in LENR energy generation. Takahashi showed many Transmission Electron Microscope images of the materials, and time histories of experimental temperatures. Some data were evi-

dence of excess powers of 1 and 8.3 W. Both neutron and gamma ray detectors were employed, but they showed only background values during the experiments.

The second presentation on the type of research just described was given by Akira Kitamura. His collaborators include some of the same scientists as contributed to the work described by Takahashi. There were 15 authors on Kitamura's presentation from Technova, Nissan Motor Company and four universities in Japan: Tohoku, Nagoya, Kobe and Kyushu. The title of this presentation was "Collaborative Examination on Anomalous Heat Effect Using Nickel-Based Binary Nanocomposites Supported by Zirconia." The experiments used equipment at both Kobe and Tohoku Universities. A variety of nano-materials was exposed to both hydrogen and deuterium gases at temperatures up to 300°C. They included $\text{Pd}_{0.044}\text{Ni}_{0.31}\text{Zr}_{0.65}$ and $\text{Cu}_{0.044}\text{Ni}_{0.31}\text{Zr}_{0.65}$. Inductively Coupled Plasma-Atomic Emission Spectroscopy and X-Ray Diffraction analyses of the samples were done at three of the participating laboratories. Scanning Tunnelling Electron Microscopy and Energy Dispersive Spectroscopy were also performed. The samples were found to have uniform mixtures of Pd, Ni, Zr and O before absorption experiments, and crystallites of Pd and Ni about 100 nanometers in size after the experiments. The mass flow calorimetry showed excess heat of about 0.5 eV per D atom in experiments at room temperature. With the same types of samples, experiments at the elevated temperatures gave excess powers as high as 10 W after corrections for flow rate and heater power. Excess powers of 8 W were also obtained with two other samples. The authors state that they attained excess power of "5-10 W for several days."

The Condensed Matter Nuclear Reactions Division (CMNRD) was founded at Tohoku University in May 2015. It is allied with numerous organizations in Japan for research and development on LENR. A diagram showing the activities and relationships was published in Issue 130 of this magazine. It is in the report on the Satellite Symposium to ICCF20, which was held in Xiamen, China, in the week before this conference.¹ At ICCF20, Yasuhiro Iwamura from the CMNRD presented a paper entitled "Replication Experiments at Tohoku University on Anomalous Heat Generation Using Nickel-Based Binary Nanocomposites and Hydrogen Isotope Gas" with five other scientists from Kobe University, Technova and Clean Planet, Inc. The work sought to replicate observations of excess heat reported by Takahashi and Kitamura, and to develop a new energy source. Like the work described in the earlier paragraphs in this section, the research reported by Iwamura involved sophisticated materials science, equipment and procedures. Similar nano-materials of $\text{Pd}_{0.044}\text{Ni}_{0.31}\text{Zr}_{0.65}$ and $\text{Cu}_{0.044}\text{Ni}_{0.31}\text{Zr}_{0.65}$ were produced, characterized and exposed to both H_2 and D_2 gas at both Tohoku University and Kobe University.

There are two noteworthy aspects of the report by Iwamura. The experiments were excellent in design and execution and the results are, in themselves, very significant. Figure 2 shows the layout of the

apparatus, which includes an oil flow calorimeter for measurements up to a few hundred degrees C. There are four Resistance Temperature Detectors (RTDs) in the chamber with the nano-materials. The sophistication of the experimental setup sketched in Figure 2 is worth reflection. Excess heat up to 10 W was seen with the Pd-containing material, and up to 5 W with the Cu-based material. One of the runs with the latter material is shown in Figure 3. The significant power levels and long duration of the experiment are noteworthy.

Results obtained at Tohoku University (0.57 eV/D) were very near those gotten at Kobe University (0.56 eV/D) with materials from the same preparation procedure and batch. Historically, most replications of LENR experiments have been done sequentially. The near-simultaneous replication of a LENR experiment at two major Japanese universities is significant. In addition, coincident increases in the pressure and temperature in the gas within the reaction chamber were measured in the experiments in Sendai.

A study that combined materials and heat measurements was reported on by E. Marano and two colleagues from

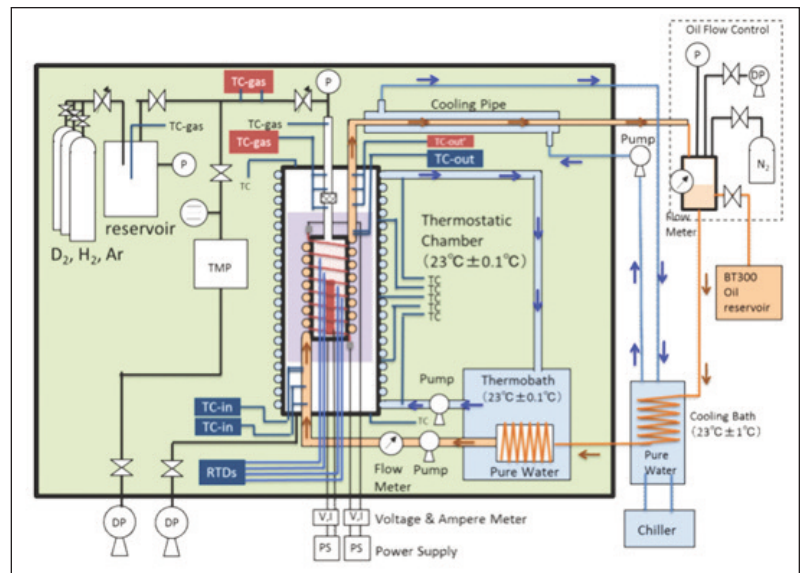


Figure 2. Schematic of the LENR experimental apparatus at Tohoku University, which is similar to that at Kobe University.

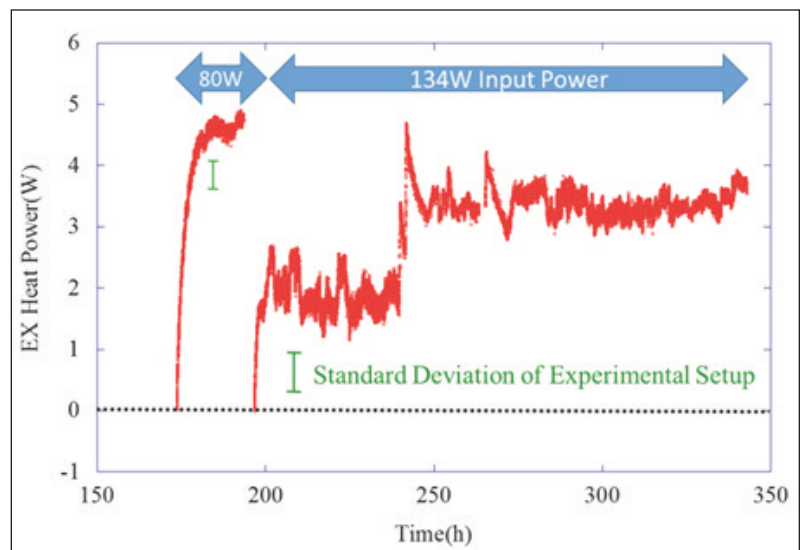


Figure 3. Time history of excess heat production for one run at Tohoku University.

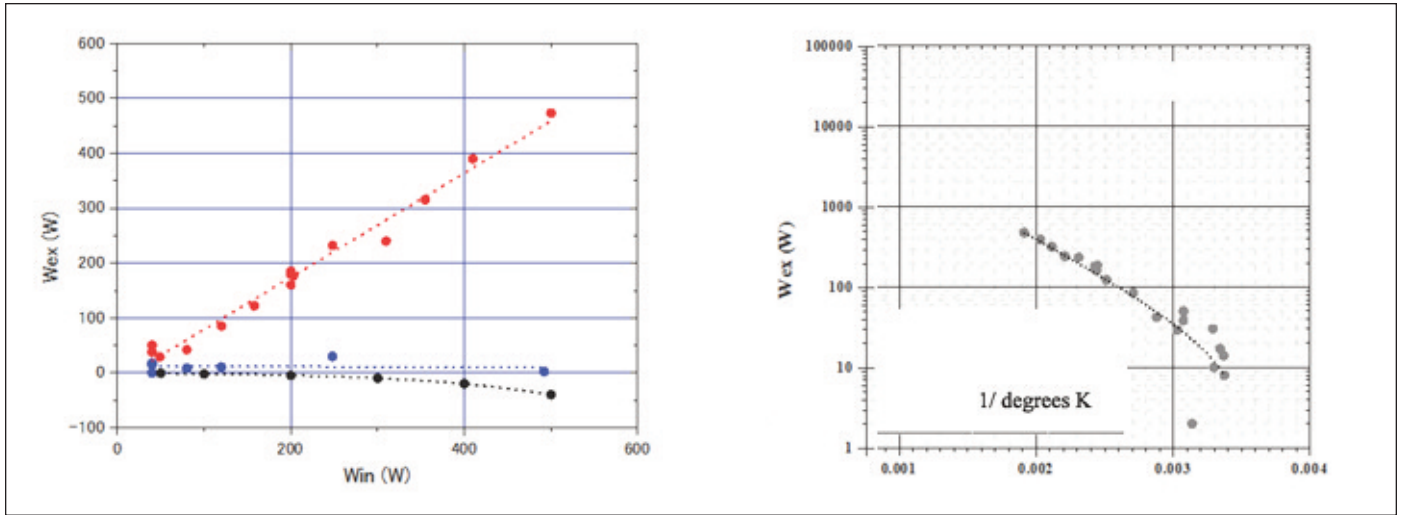


Figure 4. Left: Excess power as a function of input power for (bottom to top) the heater, evacuated reactor and the reactor when producing excess power. Right: Excess power vs. inverse absolute temperature. The dashed line is an exponential fit to the temperature variation.

Università degli Studi di Torino. Their title was “Calorimetric Study of Hydrogen Absorption in Nano Composite Materials Prepared from Pd_xNi_{30-x}Zr₆₅ (0<X<35) Amorphous Alloys.” They described their nine-step process for synthesizing nano-materials similar to those used in the Japanese studies described above. The samples contained 0, 5, 15 and 20% Pd. Thermal Gravimetric Analysis and Differential Scanning Calorimetry analyses up to 800°C were used to study the oxidation of the amorphous alloys. Different oxidation procedures were tested, with the resulting materials monitored with X-Ray diffraction. Exposure to H₂ was performed in a commercial high-pressure micro-calorimeter. Enthalpies for hydrogenation were gotten from the literature to compute expected heats of reactions. The authors concluded that the oxidation process is critical for determining the phase composition of the final material. Their bottom line was, “Observed heat in H₂ and D₂ can be explained by expected chemical reactions.” This study invites comparisons with the results reported by the researchers in Japan, who are employing similar materials.

A study of nano-materials closely related to those described above was reported by Hioki and two colleagues. It is described in the later section on Materials.

Nano-scale materials can have many different forms regarding their composition, internal and external structures, and coatings. And, they can be produced on the surface of bulk materials. Tadahiko Mizuno of the Hydrogen Engineering Application and Development Company and Hokkaido University has been working with nano-materials on surfaces. He treats materials with glow discharge plasmas to generate such materials. That approach has the long-term prospect of making it possible to renew the materials in LENR generators *in situ*, without opening the fuel chamber or putting new materials into a generator from the outside.

As noted in the Introduction, Mizuno was unable to participate in ICCF20. However, he graciously provided the graphics he planned to present. The title of his report was “Heat Generation by Metal Nanoparticle and Hydrogen Gas.” The experimental reactor is a stainless steel cylinder 110 mm in diameter and 500 mm long. It is lined with a number 50 nickel mesh, and has a central nickel rod 3 mm

in diameter and 350 mm long. The reactor was placed in a sealed box that served as an air flow calorimeter. A DC fan moved air through the box. A heater in the calorimeter was used for calibration of the system. The reactor itself was heated by an external resistive coil around the steel cylinder. When 500 W were supplied to the calibration heater, the difference between the outlet and inlet temperatures was about 18°C. When the reactor was powered with 500 W, the increase in temperature was 35°C. One of the plots from this work shows that an excess power near 470 W was achieved with an input power of 500 W. It, and another graph showing increased excess power with increased temperature, are in Figure 4. Mizuno summarized the experimental results as follows: “We confirmed the heat-generating reaction by the activated nickel and deuterium gas and found that the output heat exceeds 100% of the input power.” The key to Mizuno’s success is the pre-run “activation” of the nickel by use of plasma discharges in D₂ gas. Micrographs in Mizuno’s graphics of the surface after such treatment showed granular structures with features of size less than 100 nanometers. Mizuno stated that having pure gases and removing the gas released from the surface treatment were important. His presentation ended with images of housings for a 5 kW house heater, a 5 kW boiler heater and a 10 kW greenhouse heater.

A detailed paper seeking to replicate Mizuno’s findings was presented at ICCF20 by Takehiko Itoh and three colleagues from Tohoku University. Itoh works for both Clean Planet, Inc. and the CMNRD in Tohoku University. Their title was “Anomalous Excess Heat Generated by the Interaction between Nano-Structured Pd/Ni Surface and D₂/H₂ Gas.” The presentation began with a brief review of one of Mizuno’s earlier experiments that gave 78 W of excess power. Their apparatus, and the Ar glow discharge means of activating the Pd rod and Ni mesh, were very similar to what Mizuno demonstrated. Experiments in a D₂ atmosphere were done at 300°C with 7 W input and at 700°C with 40 W input. Excess powers of about 5.5 and 6.5 W were obtained, respectively, for times near 1.5 hours. In another experiment, a gas circulation capability was added to the system. Then, higher gas pressures could be used for long runs. The temperature in the system rose by about 25°C over a D₂ run

somewhat longer than 180 hours, and about 10°C for an H₂ run of similar duration. Radiative heat transfer was estimated using COMSOL, which is a commercial multi-physics simulation software.

Francesco Celani has contributed many papers to the ICCF conferences on experiments with wires having nano-structured surfaces in gas environments. At ICCF20, he and 14 colleagues from three Italian organizations presented a paper entitled “Improved Stability and Performance of Surface-Modified Constantan Wires, by Chemical Additions and Unconventional Geometrical Structures.” Their 100 cm long wires had a concentration of Cu₅₅Ni₄₄Mn with a diameter of 200 micrometers. The material was chosen for its excellent ability to catalyze the disassociation of H₂ and D₂. “Electric thermal” treatments of the wires produced surface structures with typical feature sizes of 100 nm. Pt wires nominally 100 cm long and 100 micrometers in diameter were used with the Constantan wires. They provided power calibration of the system, could heat the Constantan wires and served as resistive temperature sensors. The Constantan wires were knotted. One had 41 knots, and another had 71 knots nominal. The wires were inserted into borosilicate flexible sheathes, followed by various chemical treatments. Those processes added Fe, Mn and K oxides to the wires. After drying, the glass sheathes were put into an alumina sheath able to withstand operation continuously at 1200°C. Three of those assemblies were braided and inserted into another glassy sheath 4 mm in diameter. Then, that grouping was wound around a stainless steel tube that had type K thermocouples inside. Three wires are connected to the outside of the chamber by using a MACOR cylinder. Experiments were conducted at 0.2 and 2 bar of D₂ gas and input powers in the range from 10 to 90 W. The authors concluded, “The addition of Fe-Mn-K mixed oxides, to our experimental setup, has shown a significant increase of the AHE in respect to our previous similar experiments.” AHE stands for the Anomalous Heat Effect. No numbers were given for either excess powers or energies. The authors proposed “a simplified model of the experiment where atomic hydrogen/deuterium is firstly formed by exothermic adsorptive dissociation on the surface of Constantan (Ni/Cu), migrates through the Fe-Mn-K impregnated fiberglass sheath, and exothermically recombines on MACOR ceramic.”

Professor George Miley has been a central actor in the LENR field for a long time in several roles. Now, he is pursuing commercialization of LENR in the company LENUCO, which is funded in part by Industrial Heat LLC. His paper was titled “LENR Reactions Using Clusters.” The presentation covered four topics. First, he reviewed earlier work on thin-film electrolytic experiments. That part included Secondary Ion Mass Spectra taken before and after electrolysis. Then, Miley went on to discuss pressure loading of composite nano-particles of Pd in a ZrO₂ matrix. He showed time histories of temperature differences due to first pressuring the 47 g samples and then pumping out the D₂ gas. Results from about 200 runs were shown. Data on characterization of the samples was also given. The third part of this presentation dealt with hydrogen clusters produced by plasma treatment of materials. The idea is to produce large numbers of lattice defects that can trap hydrogen to form clusters. Finally, Miley provided a concept for a LENR-based reactor. A group photo showed seven members of the LENUCO team.

The diversity and quality of the LENR experimental work with nano-particles reported at ICCF20 deserves reflection. Many experiments are being performed by skilled scientists in well-equipped laboratories, especially in Japan, but also in Italy and the U.S. Very good procedures are employed, notably absolute calibrations, which are needed to convincingly demonstrate production of power. The absolute powers are not large, but they are measured with good signal-to-noise ratios. Diverse materials preparation procedures and materials characterization tools are being used. The work results in detailed publications. This class of LENR experiments is indistinguishable from real science in other arenas involving energy and materials sciences.

Another line of experimental research in LENR is related to what was described above in this section. It also involves bringing together nickel materials with hydrogen gas, but at significantly higher temperatures with different approaches. That work started with Piantelli and was continued by Focardi, Rossi, Parkhomov, Jiang and the Martin Fleischmann Memorial Project, among others. Reports on that type of LENR research at ICCF20 are the subject of the next section.

2. Heat Production Using High Temperature Ni-H

For many years, it has been widely accepted in the field that the first commercial LENR generators would not involve electrochemical loading of deuterons into palladium. The materials are expensive. The process is generally slow, and usually results in low powers. Also, it is limited in temperatures due to the boiling point of ordinary and heavy waters. Electricity cannot be produced efficiently at those temperatures. Hence, it is thought that use of nickel materials loaded with hydrogen at high temperatures would be the first LENR generators to market. Those products could involve nano-materials, such as discussed in the last section. However, they are generally expensive to produce and difficult to maintain at high temperatures. So, many of us expect that the first commercial LENR products will be heaters based on the interaction of nickel powders with larger (micrometer and up) sizes with hydrogen at high temperatures. Experiments aimed at this possibility are summarized in the rest of this section.

The Martin Fleischmann Memorial Project (MFMP) has been designing, conducting and measuring hot Ni-H experiments using their Live Open Science approach. The results, status and plans of the combined efforts of the MFMP group and their collaborators were summarized by Robert Greenyer. The presentation was entitled “MFMP *GlowStick* Series, a High Temperature Experiment Platform.” The MFMP reported on several efforts. One was to check the results published by Giuseppe Levi and his colleagues in what is termed the “Lugano Report,”² which was a test of one of Rossi’s high temperature Ni-H systems. A finned replica of the Rossi device was made and run without fuel to check on the energy measurements reported by Levi *et al.* Two thermocouples and two infrared temperature sensors, one an imager, were employed by the MFMP. They concluded that “Excess heat estimated to be much smaller, but still possible.” Specifically, they inferred 103 W vs. 1668 W from the Lugano report, with a revised COP = 1.13, and 290 W vs. 2313 W in the Lugano report, with a revised COP = 1.32, for

lower and higher electrical inputs, respectively.

Greenyer then went on to describe both their in-house hot Ni-H experiments using what they call a "Glow Stick" and similar experiments by at least six other researchers. The MFMP cell design is among the best conceived and instrumented of the many hot Ni-H experiments. It has two sections in one system, one with fuel and the other with alumina powder as a control. The fuel is 1.18 gm of Ni powder (Hunter AH50), 0.16 gm of LiAlH_4 and 0.11 gm of Li (NanoShell). Performance was reported as "Possible small excess heat of ~70 W after 48 hours of heating." The MFMP experiments can be monitored with two types of X-Ray detectors, one Gamma-Ray detector, two kinds of neutron detectors and a radio frequency probe good from 300 kHz to 40 GHz. Greenyer outlined future plans using various types of stimulation and variations in the fuel, including the use of ^{62}Ni . That isotope has been reported to be "more active" in hot Ni-H experiments.

There were three posters at ICCF20 on hot Ni-H experiments. Each will be reviewed in the following three paragraphs. Activities and results varied greatly.

A group of six scientists from the Sidney Kimmel Institute for Nuclear Renaissance (SKINR) had a poster entitled "Final Report on SKINR Replication Experimental Program to Seek Excess Heat Using Nickel Powders Mixed with LiAlH_4 and Free Li under High Temperature Hydrogen Gas." The team worked with temperatures up to 1350°C and pressures up to 7 bars. Two different nickel powders, various amounts of LiAlH_4 and different temperature profiles were employed. The goal of the project was to reproduce the results reported in such experiments by Parkhomov. The authors concluded by stating that "No indications of excess heat were observed during any of SKINR's twelve experimental trials."

Another poster on hot Ni-H experiments was by Chongen Huang and five colleagues from Xiamen University. The title was "A Pilot Study of the Ni-H High Temperature Systems." Their reaction tube was connected to a pump, hydrogen bottle and pressure gauge. Temperature was measured with a type K thermocouple and contact thermography. No excess heat has been observed to date. However, Inductively-Coupled Plasma Mass Spectrometry indicated an isotope shift in Li in some experiments, without any change in the isotopic distribution of Ni. ^6Li increased by 5%, with a corresponding decrease in ^7Li . This group acknowledged support from the National Natural Science Foundation of China.

A poster serving as a progress report on a hot Ni-H experiment was given by this author (Nagel) and four colleagues. The title was "High Temperature Gas-Phase Nickel-Hydrogen Experiments in Nickel and Stainless Steel Tubes in a Furnace." The experiments were similar to those summarized above. Rather than building a furnace around a sample tube, we put sample tubes into an existing furnace. Powders of carbonyl nickel with rough surfaces and average grain sizes of 2.4 micrometers were used. The time dependence of the pressure from decomposition of LiAlH_4 reached values as high as 5 bars. Nickel tubes were used first to reduce the number of elements in the experiment. But, at 1200°C, they absorbed all of the hydrogen from the LiAlH_4 , and produced a vacuum inside of the sample tube. Using stainless steel tubes also resulted in loss of hydrogen. Future experiments will include a H_2 gas bottle to maintain the gas pressure around the nickel powders. Scanning Electron Micrographs

of the materials after the experiments showed porous structures of melted and fused grains, with dimensions on the order of 10 micrometers. Energy Dispersive X-Ray Analysis gave the composition of the post-run residues as dominantly nickel with a few percent of aluminum and carbon, and some oxygen. The amount of oxygen was highly variable.

3. Heat Production with Other Methods

A wide variety of LENR experiments beyond those summarized in the last two sections were reported at ICCF20. They are reviewed in this section.

Jean-Paul Biberian retired as a Professor at Marseilles University. But, he remains active in the field by doing experiments in his home laboratory, and by serving as the Editor of the *Journal of Condensed Matter Nuclear Science*. In his presentation at ICCF20, he gave a status report on two of several different experiments he is currently performing. The title of his presentation was "ICARUS 9 Replication and Proton Conductors." The goal of the experiment was to measure excess heat using a Fleischmann-Pons type calorimeter. Electrochemistry in an ICARUS-9 type calorimeter with a palladium cathode in $\text{D}_2\text{O} + \text{LiOD}$ electrolyte was performed up to the boiling temperature. Data on the temperature of the cell and three sensors in the calorimeter was given as a function of power up to 65 W input power. Above that power, "the condenser is not effective and water vapor escapes." The first experiment was run with a 12 mm long cathode for 60 days loading time at 200 mA, and then current was increased to 500 mA. No excess heat was observed, "similar to a 1996 report." A new experiment with a 100 mm cathode, and 30 days loading time, was running at the time of ICCF20.

The second type of LENR experiment described by Biberian involved solid-state electrolysis using LaAlO_3 as electrolyte in hydrogen or deuterium gas. In that experiment, the material conducts protons or deuterons, with vacancies playing an important role. The experiments are being done in a heat flow calorimeter with the sample clamped between the two electrodes. Excess power of 2 to 4.5 W was observed in deuterium experiments, but not with hydrogen. The experiments are "totally reproducible." Biberian has been using large crystals of the LaAlO_3 . But, they are hard to procure and tend to disintegrate. He is about to perform such experiments with powders of the material. If the powders work, higher temperature experiments are attractive due to increased conductivity of protons or deuterons.

A paper entitled "Effects of D/Pd and Cathode Pretreatment on Excess Heat in $\text{Pd}|\text{D}_2\text{O}+\text{D}_2\text{SO}_4$ Electrolytic Cells" was presented by Wu-Shou Zhang in memory of Professor John Dash. He showed electrochemical loading data indicating that pre-electrolysis in an open cell is an effective way to activate a cathode. Data he presented at ICCF20, obtained by using that procedure, gave excess power values of 120 and 220 mW. Interestingly, Zhang showed data for a "stable" excess power of 96 mW over 5 to 7 hours with a relatively small loading ratio of $\text{D}/\text{Pd} = 0.62$. In another run, he got excess power of 120 mW for 8 to 10.5 hours with a loading ratio of only 0.58. A very useful summary of the success rates with four different pre-run treatments was provided. For those four processes, excess heat was obtained as follows (success/attempts): 5/21, 11/22, 21/37 and 3/6. The large

number of runs (86) is noteworthy. Post run analyses of cathodes with an Energy Dispersive Analysis X-ray detector in a Scanning Electron Microscope indicated some appearance of silver. In summary, Zhang noted that temperature and surface roughness are significant for excess heat production, but there is "no clear correlation with D/Pd or current density." Zhang then showed the activities and results obtained in many hot Ni-H experiments. Calorimetric results for 15 runs were given. The excess heat values scattered about zero, ranging from -0.23 % to 0.45%. The breadth and depth of the LENR research being done by Zhang's group is significant.

Michael Halem is an investor in Brillouin Energy Corporation (BEC). According to their website,³ the company has two technologies:

1. A low temperature system operating up to 150°C based on an electrolytic (wet) process. Brillouin Energy's WET™ Boiler systems can supply low temperature thermal energy for space and water heating, and other common low temperature industrial purposes, such as food processing or health-care applications.
2. A high temperature system operating at 500°C to 700°C based on applying high-pressure hydrogen gas to the core. Brillouin Energy's Hydrogen Hot Tube (HHT™) Boiler systems can supply high temperature process heat and can also be used to generate electricity in much the same way as fossil or nuclear fuels generate electricity.

Halem is also a very capable technologist, who has been making measurements on the BEC HHT™ system at both the company's location in Berkeley, California, and the SRI International laboratory in Palo Alto, California, and then analyzing the resulting data. His presentation at ICCF20 provided the results of his ongoing assessment of the high temperature system. Halem's abstract stated that the "results show with very high confidence excess energy output above chemical" reactions. He stated that nuclear reactions yielded "12 to 20 watts over an 18 to 20 hour period several times during the spring and summer of 2015." The power input was stated to be 80 W.

A second presentation on the LENR development work by Brillouin Energy Corporation was given by Francis Tanzella from SRI International and three colleagues. The title was "Controlled Electron Capture (CEC): Enhanced Stimulation and Calorimetry Methods." He began with a review of the CEC process envisioned by Robert Godes, the CTO of Brillouin. Tanzella also presented the following points to summarize experimental results obtained with the BEC electrolytic approach:

- Excess power >100% seen in Ni/H₂O electrolysis system
- Pulsed axial and cathode voltages gave excess power in this system
- Excess power depends on pulse repetition rate
- Other proprietary pulse parameters necessary to give 25 - 100% excess power
- Experimental conditions and results are consistent with CEC hypothesis
- Changing pulse parameters allows for switching power production on and off

The bulk of this paper was on results measured using the

HHT™ system. The fourth generation hot tubes have hollow cores containing a heater, on top of which are applied layers of copper, alumina and nickel. The number of layers is variable. Pulses sent into the outer nickel layer return through the inner copper layer. Detailed diagrams of the associated computer system and the calorimeter were presented. The core temperature was varied from 200° to 600°C, but held constant during runs. The operational sequence was detailed, and equations governing the calorimetry were presented. Experimental energy gains from 1.01 to 1.44 were presented with the associated core temperatures. In all, over 100 experiments were performed using eight different cores. The optimum temperature was near 300°C. At the end of his presentation, Tanzella showed a photograph of the scientists and engineers involved in this work, which included 14 people.

A poster paper entitled "A Study of Excess Heat Generation in Ni-H Gas Discharge Systems" was presented by Zhong-Qun (ZQ) Tian and his colleagues from Xiamen University. It was a summary of two posters that were presented at the Satellite Symposium in Xiamen, China, the week before ICCF20.¹ The following two paragraphs review those papers.

Gas discharge experiments were reported in China by researchers from the College of Chemistry and Chemical Engineering of Xiamen University. In one of them, Chongen Huang and four collaborators discussed "A Preliminary Study on Ni-H Gas Discharge Systems." Following work by the company Defkalion Green Technologies, they constructed two Ni-H gas discharge systems. In a cell with a spark plug, they did not observe any excess heat. However, in a "high voltage" cell, 20 W of excess power was recorded, when the cell contained H₂ at a pressure of 0.2 MPa. That value was about 14% of the input power. With D₂, the Heat After Death (HAD) phenomenon was observed. But, the authors state "we cannot reproduce these phenomena."

The second poster in China on the gas discharge experiments at Xiamen University was by Miaohong He and Wei Hang with the title "The First Exploration of the Discharge Reaction between Ni-Foam and H₂ via Mass Spectrometry and Optical Spectrometry." These researchers used both DC (19.5 mA) and pulsed high-voltage (5 keV) discharges between nickel foam and a counter electrode in an atmosphere of H₂. Optical Spectrometry showed that hydrogen was excited to Rydberg States. Electro Spray Ionization Time-of-Flight Mass Spectrometry and Residual Gas Analysis were used to monitor the gas in the experiment. No new species were found during the runs. The EI TOF MS was also used to measure the nickel foam before and after the experiments, and no differences were noted. The authors plan to reduce the surface oxide of the nickel foam before future runs.

It is noted that there were few reports of electrochemical loading of deuterons into Pd at ICCF20. In the earlier conferences in this series, results from that type of experiment were frequently reported. This change is probably due to the hot Ni-H systems being most likely to make it to market before the electrochemical Pd-D approaches.

4. Transmutations

Production of thermal energy by LENR is of great interest both scientifically and for its practical potential. However, the new elements that result from LENR are also of interest

scientifically. Based on available experimental and theoretical reaction rates, it now seems unlikely that LENR will be of use for either production of valuable elements or neutralization of radioactive waste from fission reactors. However, research on those possibilities continues in a few laboratories. We now turn to measurements of transmutations and reports of studies of the residue of LENR which were presented at ICCF20.

Takehiko Itoh and four colleagues from the CMNRD, Clean Planet, Inc., Mitsubishi Heavy Industries and Technopro R&D, Inc. offered a poster paper on "Pd, Se, Zr Transmutation Experiments Induced by D₂ Gas Permeation with the Nano-Sized Pd Complexes." This paper is a continuation of earlier work, in which foils of Pd containing CaO layers were permeated with deuterium. Their current objective is to develop a new method of nuclear waste decontamination for ⁷⁹Se, ⁹³Zr, ¹⁰⁷Pd, ¹³⁵Cs and ¹³⁷Cs, using this deuterium permeation method. As a step toward that goal, they are first seeking transmutations of stable isotopes of some of those elements, Se, Zr and Pd. They produced the permeations at a temperature of 70°C. Mass spectra showed an enhancement of mass 114 about 100 times the background. But, it remains unclear whether that peak is due to transmuted Pd or else Cd.

Overall, the excess heat experiments by the Condensed Matter Nuclear Reaction Division of Tohoku University are going well, but the transmutation experiments there have yet to attain the strong results reported by Mitsubishi Heavy Industries, when Iwamura was a scientist there.

Another paper on transmutations was due to the work of K.P. Rajeev from the Indian Institute of Technology in Kanpur. Mahadeva Srinivasan gave the paper for Rajeev, entitled "Transmutation of Nickel by Electrolysis." A 0.75 mm diameter nickel cathode was electrolyzed for 100 hours in a K₂CO₃ electrolyte with 100 V applied and currents ranging up to 5 A. Energy Dispersive X-Ray Spectrometry was used after the run to determine the elemental composition of specific spots on the cathode. One spot showed the appearance of new elements, including Cu (20%), Rh (10%), Zr (6%) and Fe (2.5%). That location had only about 3% nickel. The author commented that "Spectra obtained from different regions of the sample differ." He also had the sample analyzed with Time-of-Flight Secondary Ion Mass Spectrometry. That method indicated the presence of other elements, including "K, Si, Ca, Zn, Mg, Mn, Rh, Zr and Pb." Data on the nickel isotopic makeup of two of the 10 μm

spots on the sample showed significant differences in the three isotopic ratios compared to the natural abundances: (a) ⁵⁸Ni was enriched, 74.4% and 75.5% rather than 68%, (b) ⁶⁰Ni was depleted, 22.4% and 21.6% rather than 26% and (c) ⁶²Ni was depleted, 3.2% and 2.8% rather than 3.6%.

A poster with the title "Influencing Radioactivity via Transmutation" was given by George Egely from Hungary. He worked with a salt of natural uranium, specifically U₂SO₄. The material was ground to a fine dust, mixed with carbon particles and treated in a microwave-induced plasma for 3-4 minutes. The author reported that "this treatment changed the γ radiation level of the mixture...The radiation reduction was more marked when stable but heavy elements like lead oxide were added to the treated mixture." Electrical powers of 1 to 1.2 kW were used in the experiments. The author envisions both energy recovery and the treatment of spent fission reactor fuels to reduce their radioactivity.

Vladimir Vysotskii from the Ukraine and five colleagues from Russia presented a paper on "Biotransmutation of ¹³³Cs and Biodeactivation of ¹³⁷Cs by Aerobic Syntrophic Microorganisms and Micro-organisms of Methanogenic Sea Ooze." This is a contentious subject, as the authors stated, "The hypothesis about the possibility of nuclear transmutation of chemical elements and their isotopes in biological systems is one of most mysterious in the natural history and has been frequently discussed during the last decades." This is another in a long series of biotransmutation experiments by Vysotskii and his colleagues. The talk began with a short review of earlier work. The paper had three parts. The first two were experimental studies of proton addition to ¹³³Cs and ¹³⁷Cs. They are summarized here. The third part was on the application of the lead author's theory of correlated states to explain the results. It will be reviewed in a section on theory in Part 2 of this review.

The first set of experiments dealt with transmutation of ¹³³Cs, which was expected to become ¹³⁴Ba by proton addition. A sophisticated experimental protocol, including a control without the bacteria present, was outlined by Vysotskii. He provided details on how the experiment was run and sampling accomplished. Samples were taken and measured after 2, 4, 6 and 8 days. Analysis of ¹³³Cs was done with a high-resolution continuum source Atomic Absorption Spectrometer. An Atomic Emission Spectrometer with an Inductively Coupled Plasma source was used to quantify the ¹³⁴Ba. Figure 5 shows the results for the decrease in ¹³³Cs and increase in ¹³⁴Ba, along with data from the control. A

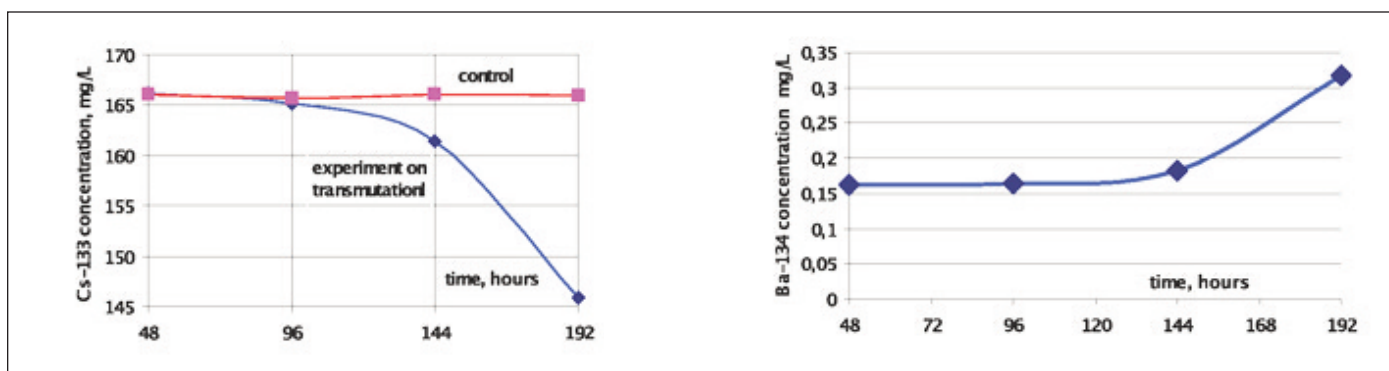


Figure 5. Left: Constancy of the ¹³³Cs concentration in the control, and decrease in ¹³³Cs in the sample with the microbes. Right: Increase in ¹³⁴Ba concentration in the bio-active sample.

nuclear reaction rate was derived at the eight day mark from these data, specifically 6×10^{-7} per Cs atom per second.

In the second experiment, Vysotskii and his team measured the gamma ray activity of ^{137}Cs . It was expected to transmute by proton addition to ^{138}Ba . The ^{137}Cs emission at 661.65 keV was measured with a NaI scintillation detector with 1% accuracy. The decline in the gamma-ray emission intensity was 70% over 21 days. A rate of 2×10^{-7} per Cs atom per second was computed.

Another paper by some of the same people doing the bio-transmutation experiments used a very different means to cause LENR and assess the resulting products. This paper at ICCF20 by Vladimir Vysotskii and Mykhailo Vysotskyy from the Kiev National Shevchenko University in Kiev and Alla Kornilova from Moscow State University was on the use of shock waves to cause nuclear reactions. Their title was "Experimental Observation and Theoretical Explanation of Effective Transmutation of Target Nuclei under Action of Shock Waves." The experimental setup involved forcing water through a small aperture to create cavitation bubbles. The fast moving water then impacted a silver bar of 99.99% purity during a five hour exposure. Afterwards, craters approximately 300 microns in size were found on the front surface of the target, arranged in a few overlapping patterns of circular and concentric rows of varying diameters. Energy Dispersive X-Ray Analysis of the craters on the front surface in a Scanning Electron Microscope showed the presence of many elements. They included silicon, aluminum and titanium, which were not seen in analyses before the long run, as well as an increase in the concentration of magnesium. The electron beam energy, and with it the depth of X-ray analysis, was varied to prove that the elements were not only on the surface of the silver. That was taken to rule out contamination from the incident water stream. The authors considered these nuclear reactions as possible sources of the elements they measured: $\text{C}^{12} + \text{O}^{16} = \text{Si}^{28}$, $\text{C}^{12} + \text{C}^{12} = \text{Mg}^{24}$ and $\text{Mg}^{26} + \text{p} = \text{Al}^{27}$. Nuclear reactions between two heavy elements would ordinarily require tremendous kinetic energies. The authors attribute them to the existence and action of coherent correlated states. Again, that theory will be discussed in Part 2 of this review in the section on theories about the mechanisms of LENR.

Early in the field, there was a great deal of research on LENR (then "cold fusion") in India. Over 50 scientists worked on the topic at the Bhabha Atomic Research Center (BARC) in the months following the Fleischmann-Pons announcement in 1989. One of the leaders of that effort was Mahadeva Srinivasan. He has continued to contribute to the field over the years, even though the BARC program was terminated in 1990. This year, Srinivasan organized a meeting on LENR of a dozen Indian laboratories.

At ICCF20, Srinivasan gave evidence of an extraordinary possibility, namely the daily production of tons of transmutation products by LENR. His presentation was entitled "Observation of Anomalous Production of Si and Fe in an Arc Furnace Driven Ferro Silicon Smelting Plant at Levels of Tons per Day." It was authored by C.R. Narayanaswamy, former owner and Managing Director of Silcal Metallurgic Ltd. in Tamil Nadu, India. The plant run by the author produced about 25 tons of Fe-Si steel daily by use of a very large electric arc furnace operating at 12 kVA and 30-60 kA to melt steel scrap, wood charcoal and quartz. Srinivasan reminded

the Symposium attendees of past reports of transmutations induced by arc experiments. An accounting of the masses of input and output materials at the Silcal Metallurgic Ltd. plant indicated that the operation produced about three tons of excess Si and one ton of excess Fe daily. Such production would have been accompanied by release of massive amounts of energy, which was not observed. That obviously casts doubt on the reported transmutation rates. The plant no longer operates. Unfortunately, the author of this paper did not retain samples for isotopic analysis. Srinivasan expressed interest in contacting operators of any currently-active electrolytic ferro silicon plants to obtain samples for testing, and to do detailed accounting of their materials and energy flows.

5. Bombardment

Electrochemical and thermal loading of hydrogen isotopes onto and into metallic materials have been the two dominant approaches to producing LENR. However, there have been many experiments over the years where ion beams were employed to produce the interactions needed to trigger LENR. The ion beams can produce kinetic loading of either protons or deuterons into metallic targets. And, they can induce nuclear reactions. In general, beam energies of about and somewhat below 1 keV are used to produce D-D fusion in LENR-related experiments. At lower beam energies, the fusion cross section is so low that the measurements cannot be done in reasonable times. The good news is the numerous observations of D-D fusion cross sections much higher than expected because of electron screening. The enhancement is quantified in terms of a "screening potential energy." The bad news is that impact energies of 1 keV are still much higher than the energy equivalent to room temperature, namely 0.025 eV, typical of most electrochemical LENR experiments. Connecting the two energy regimes has been a challenge. The reports on ion beam experiments at ICCF20 are summarized in this section.

There are only a few centers globally where ion beams are used to cause LENR. There were papers at ICCF20 from three of them. Conrad Czerski gave one of two such presentations. Experimental work on enhanced cross sections was published by Czerski and colleagues as early as 1998. Presentations on this line of research were given at ICCF11 (2004), ICCF14 (2008) and ICCF15 (2009). The 2004 paper dealt with screening due to three sources, the bonding and core electrons and the ion cores in the lattice. The latter is termed "cohesion screening." Consideration of all three contributions to screening gave the mass dependence of the screening energy with the correct trend, but with absolute values about half of measured data. Agreement with the low neutron rates available at that time could be achieved by assuming that the deuterons in electrochemical cathodes moved "quasi freely." In the 2004 paper, the authors noted that, while screenings could account for most of the differences between experiments in solids and gas phase D-D fusion reactions, they could not explain the magnitude of excess heat production. That required reaction rates 10^7 higher than for neutron production. They considered a "thin resonance in the ^4He nucleus lying close to the D + D reaction threshold." Cross section enhancement due to such a resonance might explain excess heat at energies equivalent

to room temperature, and also some of the variability in LENR experiments.

The paper by Czernski at ICCF20 was titled "Enhancement of the DD Fusion Yield: Experimental Evidence for Interplay between the Threshold Resonance and the Electron Screening Effect." That report has six co-authors from two of the centers for the study of low-energy D-D fusion reactions, the University of Szczecin in Poland and the Institute for Solid-State Nuclear Physics in Germany. It provided experimental evidence for the coupled roles of screening and the resonance near the threshold for D-D fusion. Czernski began by reviewing the basics of both screening and the energy levels of ^4He . He showed D-D fusion data as a function of incident deuteron energy. The graphs indicated that it is necessary to consider both screening and the threshold resonance, and their coupling, to explain the measurements. The authors wrote "balance between the resonance and electron screening explains ^4He production and increases reaction rates at room temperature up to seven orders of magnitude." They also noted "electron screening locally enhanced by impurities and crystal defects" and "nuclear reaction rates at room temperature can change dramatically." At the end of the presentation, Czernski showed graphics of a new facility and a new concept. The Laboratory of Nuclear and Medical Physics in Germany has an accelerator coupled to an ultra-high vacuum chamber. The accelerator will deliver a few mA of low-energy light ions into the chamber with a vacuum of 10^{-11} torr. A conceptual diagram was shown for a "Dual Fluid Reactor," which is "an environmentally friendly nuclear concept for cost-efficient electricity and fuel with no need for geological waste storage." It will be interesting to see if this concept is developed.

Yuki Honda and Jirohta Kasagi are from Tohoku University, another center for study of enhanced low-energy D-D cross sections. They presented a paper on "Low-Energy Cooperative DD Collision in Liquid Metal and Electron Screening Effect." This work is an extension of many years of such research by Kasagi. The talk began with a review of screening effects on D-D fusion cross sections. As noted above, reductions in the Coulomb barrier due to electron screening of incoming ions are expressed as potential energies. Data from experiments have shown screening energies as high as 310 eV for Pd and 600 eV for PdO. Kasagi found earlier that discrepancies in data from low-energy collision experiments could be rationalized by a Cooperative Collision Mechanism (CCM). In it, one of the two deuterons in an incident molecular ion D_2^+ scatters from a target atom and then reacts with the second deuteron from the same incident ion. Calculations of D-D fusion probabilities based on that model were presented. In their experiments, the authors bombarded liquid indium and lead with D_3^+ ions and measured reaction products with a silicon detector. Deuterons do not accumulate in the liquid targets as they do in solid targets. Hence, D (beam)-D (embedded) collisions are eliminated, leaving only reactions due to the CCM. Good agreement was obtained between the measurements and calculations based on the CCM model. Screening potentials of 220 ± 110 eV for the indium and 290 ± 100 eV for lead were computed from the data. They are much larger than the potentials calculated with a simple Thomas-Fermi model.

Ion beams are used for analysis of materials as well as for production of LENR. Jirohta Kasagi also presented a paper of

this type. The title was "Observation of ^{141}Pr by ^{40}Ar Scattering (RBS) on Cs Implanted Pd/CaO Multi-Layer Foil with D_2 Gas Permeation." The goal was confirmation of the presence of ^{141}Pr by use of Rutherford Back Scattering (RBS). That element was reported in earlier work to be a transmutation product from the operation of LENR on Cs. In the current work, ^{40}Ar was used for RBS measurements of ^{141}Pr . The existence of the Pr isotope was reported with a small statistical significance. This research is being done at Tohoku University, and will continue.

6. Stimulation

The production of LENR is sometimes considered to be a multiple-step process. First, conditions conducive to LENR are produced, for example, the loading of deuterons to high levels in palladium. Then, some means of stimulating (triggering) LENR are considered, such as application of an electrical current to the loaded material. Those two steps are not to be confused with discussions of the mechanisms for LENR. Most theories are thought to involve a single reaction, but some concepts invoke two sequential reactions. They will be part of the section on theory. In this section, we consider experiments presented at ICCF20 that used a variety of means to stimulate the production of nuclear reactions.

Hitoshi Soyama from Tohoku University presented a paper on "Spectroscopy Analysis of Laser Abrasion and Laser Cavitation Induced by Pulse Laser." Cavitation is the production of small bubbles in a liquid that collapse quickly to produce plasmas with relatively high temperatures and pressures. Soyama began by reviewing the three means of producing cavitation, namely high speed hydrodynamic flow, laser absorption and ultrasonic excitation. The author was concerned with the first two of these means, especially laser generation of cavitation bubbles. The next paper reviewed below involves ultrasonic production of cavitation. The results of laser initiation of cavitation came from a well-instrumented laboratory equipped with a high speed intensified charge-coupled imager. A Nd:YAG laser with a wavelength of 532 nm, pulse energy of 0.2 J and pulse width of 4-6 ns was used to irradiate duralumin, titanium and nickel targets in "water." The dynamics of the shock wave from the laser pulse absorption were captured by the fast camera. A piezoelectric sensor recorded the pressures produced by the process. The techniques used in this work are probably applicable to study of the dynamics of cavitation produced by ultrasound, as in the next paper.

Roger Stringham has done experiments on LENR for over 20 years, using cavitation induced by ultrasonic frequencies. He has given papers at many of the conferences in this series. His early work employed kHz frequencies. Then, he moved to using higher frequencies, still using an oscillator to drive the experiment. In his ICCF20 paper, Stringham reported on the use of frequencies near 2 MHz generated by a tuned radio-frequency (RF) source. The RF signals were used to drive a piezoelectric transducer 2 mm thick, which was spaced a quarter of a millimeter away from a target foil. The gap was filled with light water, heavy water or mixtures of the two. One experiment was done with a copper foil in light water. After the run, it showed evidence of heavy oxidation on both surfaces. Another experiment employed a 100 μm palladium foil with 10% D_2O in H_2O . Seven runs

were made with similar palladium foils in 99.8% pure D_2O . The heavy water was saturated with argon, which is used to pressurize the system. Because the RF from the source introduced too much noise into the measurement equipment, Stringham recorded temperatures during 5 seconds when the source was turned off, and then turned it on for 30 seconds without any measurements. The system contained 100 g of water. Its temperature was kept low and relatively steady with a heat exchanger that served as a mass flow calorimeter. A 60Ω heater was in the system for calibration. Stringham reported production of 13.3 W of excess power after 47 minutes of one run. The temperature had been increasing steadily for over half an hour prior to that point in the run. Then, the system was allowed to cool for 20 minutes prior to calibration with the resistive heater.

There are two additional aspects of these experiments that are noteworthy. Thomas Claytor of High Mesa Technology has contributed very significantly to experimental data on LENR over the years, especially tritium measurements. Now, he is giving support to Stringham by providing Scanning Electron Microscopy of the target foils after runs, and by analysis for tritium and helium in samples of the argon atmosphere in the system. Stringham showed one of the micrographs. It exhibited numerous small craters, some as small as 50 nm in diameter. They were thought to indicate an energy release of 4 pJ, about the energy equivalent to the formation of one helium atom from two deuterons. Many substantially larger craters are also visible in the micrograph of the target foil surface. No data on either tritium or helium production were provided in the ICCF20 paper.

Secondly, as usual, Stringham discussed the process by which the production and collapse of cavitation bubbles leads to nuclear energy generation. The waves from the piezoelectric transducer interact resonantly with the target foil, producing cavitation bubbles on the target's surface. Collapse of those bubbles leads to production of an interior plasma containing both electrons and deuterons. The asymmetry of the bubble collapse, due to having the foil on one side, causes a jet toward the target surface. That jet directs both electrons and deuterons onto the solid surface, causing nuclear reactions and surface craters. Stringham introduced a new concept into his consideration of mechanisms in his paper at this conference. He referred to work by N.M. Lawandy published in 2009 on the interaction of charged particles with surfaces. The core idea of that work is the possibility of two like charges above a surface binding to each other through their image charges inside of a material. Specifically, the presence of an electron above a surface will produce a positive image charge in a material, which can attract another electron above the materials. It is not clear how that effect applies to experiments involving cavitation bubble collapse, since both negative (electron) and positive (deuteron) charges are present in the jet of the collapsing bubbles. This reviewer remains uncertain if the heat Stringham is measuring is due entirely to hot fusion or "conventional" LENR, or maybe even a mix of the two mechanisms. The temperatures in the jets of collapsing bubbles may not be high enough for hot fusion, and neutrons have been sought and not found from such experiments. But, the temperature in the collapsing bubble is probably much higher than the melting temperatures of metallic targets, so the usual picture of loading deuterons into a solid does not seem certainly germane. Evidence of surface melting is seen

in the foils of Stringham's targets. It seems that this experiment needs a full three-dimensional modeling of all the material and energy dynamics on the relevant spatial and temporal time scales. That would be a challenging task, but might be the only way to understand what is happening in Stringham's cavitation experiments.

Max Fomitchev-Zamilov from Quantum Potential Corp. had two related papers at ICCF20. Both of them were replications of old experiments and involved neutron production. The oral presentation was "Helium Production in Plasma Arc Discharge: Successful Replication of Wendt & Irion Tungsten Wire Explosion." The experiment referenced in the title was reported in 1922. The author closely replicated the physical and electrical characteristics of the old experiment. Tungsten wires 35 microns in diameter were exploded in an evacuated Pyrex vessel with 30 kV pulses. A modern residual gas analyser (RGA) was used to monitor the atmosphere in the vessel before and after explosion of the fine wires. Mass spectra from that instrument showed no helium or deuterium before the discharge. However, occasionally, helium was detected after an explosion. More commonly, peaks in the mass spectrum associated with deuterium were observed, in particular a peak at mass 3, which was attributed to the molecule HD. Varying the voltage on the RGA showed that the peak could not be due to 3He . A bubble detector near the experiment gave direct evidence of neutron emission. Neutron production was also inferred from the production of helium, possibly by neutron capture by boron in the Pyrex. Experiments with BF_3 in the vessel are planned to check on that idea. A simple electrical circuit analysis led to the conclusion that decelerating electrons are subject to an electromagnetic force due to the circuit's inductance. Uses of neutrons produced by this type of experiment were cited. Engineering a system that could replace the tungsten wires quickly and produce higher fluxes of neutrons would be needed to enable the applications.

The poster by Fomitchev-Zamilov reported on an experiment to replicate the results of Ernest Sternglass, which were published in 1951. The title was "Neutron Synthesis in Plasma Arc Discharge: Successful Replication of Earnest Sternglass' Experiment." The plasma in the discharge contained H_2 and HCl. It was excited by a 30 kV and 30 mA current. Again, bubble detectors gave evidence of neutron production, which was substantially stronger than in the exploded wire experiment. It was attributed to acceleration by the field due to the inductance of the circuit by use of a one-dimensional analytical model. Currently, it is possible to model computationally the three-dimensional kinetics and dynamics of plasmas produced by electrical discharges. This experiment is a good candidate for such modelling. It is noted that in both of the papers by Fomitchev-Zamilov plasmas and not lattices were the active medium. The tungsten wires were exploded with pulses during the experiments to produce plasmas, and the H_2 atmosphere in the steady state discharge was also turned into a plasma. Hence, the connection between those experiments and the occurrence of LENR in or on a lattice remains to be established.

Peter Hagelstein has designed two experiments to test the coupling between vibrational and nuclear levels. One such proposal is already being tested in an MIT laboratory by Florian Metzler, Hagelstein and Suyuan Lu. Metzler is a Ph.D. student in the business school at MIT, who works with

Professor Hagelstein on that experiment. He presented a paper with the title "Experimental Effort at MIT to Study Phonon-Nuclear Coupling," with the sub-title of "Seeking X-ray Emission from Ultrasound-Induced Nuclear Vibrations." That experiment aims to measure energetic radiation from the up-conversion of many small vibrational quanta. Metzler reviewed four earlier LENR experiments that gave evidence, which might be due to such up conversion, and reviewed Hagelstein's theory relevant to that process. The experiment seeks to measure X-rays with energy of 1.5 keV due to decay of an excited nuclear state in ^{201}Hg that is pumped by the phononic up-conversion. Work to date has included the design of vibrating plates, computation of their modes of vibration and associated frequencies, development of a system to measure frequencies, and matching of the plate resonances to the resonant frequency of the ultrasound transducer. The necessary overlap between the frequencies of plate vibrations and the transducer frequency has been achieved, and the efficiency for coupling of transducer energy into the plate vibrations was measured. The MIT group built and tested an energy-dispersive X-ray detector that is responsive from 1 to 20 keV. The system will be used in coming weeks to seek correlations between mechanical vibrations and emission of energetic radiation.

7. Techniques

Over the years, scientists have presented many papers at ICCF conferences on experimental methods. That was also the case at ICCF20. The several papers of this type are reviewed in this section.

The use of Hg additions to the electrolyte in LENR experiments was the subject of a poster by Orchideh Azizi and five colleagues from the Sidney Kimmel Institute for Nuclear Renaissance at the University of Missouri. Their paper was on "Effect of Mercury on the Kinetics and Mechanism of Hydrogen/Deuterium Loading into Palladium in Alkaline Solution." High loading of D into Pd is known from many experiments to be a favorable, and possibly necessary, condition for production of LENR. Four point resistance measurements and *in situ* X-ray diffraction were used to assess the degree of loading in this work. They achieved loading values as high as $\text{D/Pd} = 0.96$ by the addition of 200 ppb of Hg to an electrolyte of 0.1 M LiOD in heavy water. Hg in relatively high concentrations is known to seal H or D into loaded Pd. In this work, small additions of Hg were studied. Five different types of electrochemical measurements were made. The Hg additions were found to increase loading, permeation rates and reproducibility. Twenty experiments gave 95% reproducibility for the loading. That high degree of reproducibility was achieved when the Pd cathode was fully transitioned from the α phase to the β phase at low currents prior to addition of the Hg salt. The measurements indicated that Hg at the levels added did not fully cover the Pd cathodes. The authors suggest that the presence of superficial Hg has two beneficial effects, acting as a discharge site and inhibiting recombination of deuterium.

Sangho Bok and nine colleagues from Southern Utah University (now his home institution) and the University of Missouri gave a paper with the title "Fluorescence Based Temperature Sensor for *in situ* Sub-Micron Heat Detection on D/H-Loaded Palladium Electrode Surfaces." The motivation

for the research was to develop an optical means for assessing temperature at spots on cathodes in LENR experiments. Such a capability would be very useful for determining non-uniform energy production, as some theories postulate. It could also be applied for temperature measurements in micro-fluidic devices, which are on the market for medical and other diagnostics. The key to the methodology is the fact that the quenching of fluorescence from some materials is temperature dependent. One example is an oligo (ethylene glycol) methacrylate (OEGMA) based copolymer. Unwanted processes, such as photobleaching and oxidation, challenge use of this approach. Using Rhodmine 6G (R6G), the authors measured a decrease in fluorescence intensity of 17% by changing temperature from 28°C to 60°C. They obtained a linear variation in fluorescence intensity over this temperature range. The authors expect the method to be useful up to 250°C, when R6G starts to decompose. They then did experiments with Pd in a heavy water electrolyte of 0.1M LiOD. Loadings as high as $\text{D/Pd} = 0.92$ were achieved by using 100 to 400 ppb of Hg in the electrolyte, as described in the preceding paragraph. Images in the fluorescence intensity were obtained. Variations in fluorescence intensities were measured at two grain boundaries and within one grain over periods as long as 48 hours. Temperature differences as large as 193°C were reported from regions as small as 0.3 μm . The authors expect to be able to monitor the spatial and temporal characteristics of excess heat in future experiments.

Another important optical method was the subject of a paper by Mitchell Swartz of Jet Energy Inc. and Peter Hagelstein of MIT. Their title was "Increased Anti-Stokes Peaks in Raman Measurements Correlated with Excess Heat Mode." Raman scattering is due to the interaction of incident light with the short-range vibrational and rotational transitions of the bonds between nearest-neighbor atoms. The incident photons (usually from a laser) can lose energy to the lattice, producing a lower-energy spectral line called the Stokes peak, or even gain energy from the lattice to yield a higher-energy Anti-Stokes peak. Raman scattering can provide information on the chemical composition or molecular structure of a sample. We note in passing that similar interactions of light with the longer-range deformations of a lattice due to phonons are termed Brillouin scattering. Information on the phonons in a material or their long wavelength limit, the elastic properties, can be gotten from Brillouin scattering. The authors of this paper note, "If nanostructured material (is) present on a metal surface, then (one) can get a large enhancement of the electric field (which is termed) Surface Enhanced Raman Spectroscopy." Fleischmann is credited with the discovery of that effect, which is called by its acronym SERS.

In this paper, phonons in what Swartz terms a NANOR™ were probed by a method called CMORE for Coherent Multi-wavelength Optical Reflection Electric-driven spectroscopy. The NANOR™ contains Pd and Ni, as well as ZrO_2 , so the authors first measured the Raman spectra of that oxide. They then measured samples without and with Pd and without and with electrical currents, both without and with production of excess heat. Spectra were obtained in three modes of operation, with the NANOR™ off, with the device in an "avalanche mode" due to application of 1 keV and in the desired LENR state. The high-energy Anti-Stokes peak in the

Raman spectrum was strongest in the LENR active state. Ratios of intensities in the Anti-Stokes peaks to the intensities of the Stokes peak were given for controls and for NANORS™ in their three modes. They varied significantly. The authors found that, at the highest scattered intensity, the central peak in the spectrum at the 532 nm wavelength of the incident radiation from a laser was absent. This caused them to suggest that they might be observing a phonon laser effect. That, by itself, is very interesting.

Melvin Miles gave a paper entitled "Features of the Fleischmann-Pons Isoperibolic Calorimetry." He started by noting that the measurement and analytical methods used by the originators of the field are still important today. They were part of the early controversy, and are still poorly understood by most scientists. When correctly applied, the methods are very accurate, and they have potential applications to other electrochemical studies. Miles emphasized that poor temperature measurements limit the accuracy of calorimetry, which is part of the reason Cal Tech, MIT and Harwell made negative reports of their early, publicized and damaging studies. He detailed the terms in the equations needed to understand quantitatively the performance of an isoperibolic calorimeter, and gave many graphics with data showing their variations. Miles went on to describe the setup and results of a recent 13 day run he made with a Pd cathode in a 0.1 M KNO₃ electrolyte. The experiment produced excess heat after four days, which later peaked at about 72 mW. Cooling rates were obtained after the experiment was terminated. At the end of his presentation, Miles listed 11 factors that are important in attaining calorimetric accuracy with Fleischmann-Pons methods. He asserted that calorimetric errors as low as 0.01% (0.1 mW) can be achieved.

Jinghao He and eleven collaborators from nine institutions in Brazil, France, Germany, Italy, Portugal, Switzerland and the U.S. presented a paper on "Hyperfine Interactions in Palladium Foils during Deuterium/Hydrogen Electrochemical Loading." It began with his showing a "wiring diagram" of the collaboration, indicating who did what where in which order. The collaboration was organized by Graham Hubler, a complex arrangement to deal with a complex topic. The subject is not widely familiar and requires an extensive introduction. It constitutes the next two paragraphs.

What the authors call "Hyperfine Interactions" are the cause of "Hyperfine Structures" in the spectra of ions, atoms and molecules. They are referenced to what is called the "Fine Structure" of such spectra. The splittings of energy levels that leads to the spectral fine structure are caused by the interactions of the magnetic moments due to intrinsic spin of electrons with the orbital angular momentum of electrons. That is, the fine structure is entirely on the electronic level in an ion, atom or molecule, independent of the nuclei. The energy level splitting that causes the hyperfine structure is due to interactions of the nuclei with the internal electric or magnetic fields. There are two main classes of such splitting. In one, the nuclear electric quadrupole moment (dependent on the charge distribution in a nucleus) interacts with the electric field gradient due to the distribution of charges within or near the atom. The other is caused by interaction of the nuclear magnetic dipole moment (dependent on the numbers of protons and neutrons in a nucleus) with the magnetic field caused by nearby electrons.

The overall situation can be summarized as follows: (a)

electrostatic interactions between nuclei and electrons lead to orbitals with energies dependent on the principal quantum number, which cause the K, L, M, etc. shells in ions and atoms; (b) electrostatic and other interactions among the electrons within each of the major shells cause splitting in the energies of the primary orbitals, which are described by three additional quantum numbers, and produce the sub-shell structure of atoms and fine structure in spectra; and (c) interactions between the electron orbitals and characteristics of nuclei, which cause further level splitting, produce the hyperfine structure of spectra. But, what does all of this have to do with LENR?

Most theoretical ideas about the mechanisms that cause LENR deal with conditions and interactions on the scale of atoms within materials. The fact that LENR occur in or on solids is one of their most salient features. Hence, it is desirable to probe conditions within, or near, the surface of solids at the atomic level. The essential point of this research is that atoms themselves can serve as monitors of conditions inside of solids. The authors of this paper asked, "What is correlation between the local environment and electromagnetic fields in the PdD_x/PdH_x?" They stated, "This work is a fundamental physics...approach, trying to determine the microscopic environment of Pd and D in the lattice." If the distribution of deuterons in a material is in equilibrium, the electric field gradient will not change. But, if the deuteron distribution is changing, so also will the electric field gradient.

This study used a technique called Perturbed Angular Correlation (PAC) in which an isotope that can emit two gamma rays in sequence is employed. The angular correlation between the emission directions of the two gamma rays can be related to the nuclear moment, or if a nucleus with known quadrupole moment is used, the electric field gradient can be determined. In this work, ¹⁸¹Hf was used, which first isotropically emits a 133 keV gamma ray, and then emits an anisotropic 482 keV gamma ray. Precession of the nuclei in the solid-state fields enables angular information to be determined from measurements of the times between the two gamma ray emissions. The ¹⁸¹Hf isotope was produced in Missouri and implanted in Germany into palladium foils prepared in Italy. The implantation energy was 80 keV, and the dose was 10¹¹ ions/cm². The foils were vacuum annealed at 550°C for 1 hour to remove defects caused by the implantation process. The electrolytic loading of either protons or deuterons was done at CERN to a level of H/Pd = D/Pd = 0.9. The PAC were measured at the ISOLDE-CERN SSP Laboratory. Electric field gradients gotten by fitting the PAC data were obtained for both of the hydrogen isotopes as a function of loading. There were no field gradients for the annealed material, which suggests that the annealing effectively removed implantation-induced defects. It was found that, in the palladium Beta phase, the gradients were higher for PdD_x than for PdH_x by about 50%. This was attributed to the larger lattice distortion of the D material, compared to the H material, in the Beta phase. Strong dynamic effects on the field gradients were seen with D, but not H.

This paper also included the results of first-principles computations of electrical field gradients, which considered the effects of defects. The WEIN2k code was used. The calculated gradients compared well with those of materials in the Alpha and Beta phases. Different distributions of the H or D, and the assumption of various vacancy configurations,

resulted in significant increases of the computed electric field gradients. In the end, the authors of this paper were not able to fully understand the two differences they measured between the H and D loaded materials. However, their analysis of the experimental results is continuing.

This reviewer presented a paper entitled "Another Approach to Reproducing Reported LENR Excess Heat." The essence of that methodology is to repeat experiments that have reportedly resulted in significant excess heat with a substantially improved suite of measurement equipment and analytical techniques. The author and student colleagues are performing electrolytic experiments with nickel cathodes in light water electrolytes. Such experiments were done in the early 1990s, some with very strong excess heat results. In addition to thermometry and planned calorimetric methods, this group is using several diagnostics not common to LENR experiments. They include Impedance, Optical, Radio-Frequency, Acoustic and Electrical Noise Spectroscopies, each over broad frequency ranges. The last of these methods is very sensitive. It might be able to detect the occurrence of LENR at levels far below what can be measured with a calorimeter. The Lattice Enabled Nuclear Reaction (LENR) Energy and Spectroscopy Laboratory in The George Washington University in Washington, DC has been in operation for only six months.

Electrical noise on analog signals is unavoidable due to thermal fluctuations and the discrete character of electrical carriers. The spectrum of such noise can reveal information on the system through which a current is flowing. Gleidson Roque and three others from The George Washington University gave a poster paper on "Electrical Noise Spectroscopy of LENR Electrochemical Cells." They measured noise spectra over two ranges by using different instruments. First, the BioLogic SP-300 power supply and monitoring system gave the cell current for a platinum anode and nickel cathode in 0.5 M Na₂CO₃ electrolyte at 2.5 V. With a sampling rate of 1 kHz, Fourier transformation of the current-time series produced a spectrum from a frequency (F) below 1 Hz to 500 Hz. Two variations in the slope of the spectra were measured, 1/F^{0.5} below 10 Hz, and approximately 1/F above that frequency. The minimum noise level in these data is about 0.1 μA. Second, a system developed at that university was employed to obtain noise spectra from 1 Hz to 100 kHz. It has a noise floor with the input shorted of 10⁻¹⁸ V²/Hz. This is equivalent to a thermal noise power of 10⁻²¹ W. When an electrochemical cell with two platinum electrodes was measured, the noise increased by a factor of 1000 for 2 V applied, and increased monotonically with applied voltages of 3, 4 and 5 V. At 5 V, the noise power was still only 10⁻¹⁷ W. If 1 nanowatt of LENR power goes into producing electrical noise, it will be possible to detect the occurrence of LENR at levels roughly one million times lower than can be measured with calorimeters.

Dennis Pease and five colleagues from the Sidney Kimmel Institute for Nuclear Renaissance at the University of Missouri addressed an important topic, namely the identification of artifacts in LENR experiments. Recognition of erroneous signals is fundamental to experimental science. It is especially true for LENR because of the contentious nature of the field. Their poster was entitled "Measurement Errors and Artifacts in AHE and LENR Experiments." They addressed four types of problems with Pd-D electrolytic experiments.

The first was the appearance of false peaks in X-ray spectra due to radio-frequency, magnetic or acoustic simulations. The second was anomalies in radio-frequency spectra. Sampling problems during the measurement of pulsed AC electrical power measurements constituted the third class. Finally, this poster dealt with uncertainties in near real time Fourier transforms of current and voltage signals. Making their experiences available to the broader LENR community was a useful service.

8. Materials and Unusual States

It is widely thought that some subtle, and currently unknown and uncontrollable, aspect of materials in LENR experiments is responsible for the variability and lack of control of LENR results. Materials of diverse composition and structures have been employed in LENR experiments. Some are bulk materials, the surfaces of which are given great consideration. That is because protons or deuterons that are loaded into such materials must transit the surface. And, there is considerable experimental evidence that LENR occur on or near the surfaces of materials. Nanometer scale materials have long been used in LENR experiments. They have high surface area-to-volume ratios. And their small size means that high loading of such particles can be accomplished quickly.

Particles with sizes in the range of nanometers can be produced by a variety of means. One technique was described in the section above on heat production using nanomaterials. It involved producing amorphous alloys of Pd, Ni and Zr by very fast cooling of melts of those elements. Oxidation of such amorphous materials then produces nanoparticles of Pd-Ni alloys embedded in ZrO₂. In the work described in this section, nanoparticles are made by growing them in materials with very small pores. The first three papers reviewed here take that approach. The fourth paper uses other means of making small scale materials. The last paper in this section deals with a highly unusual state of matter.

Hioki and two colleagues from Nagoya University presented a paper at ICCF20 with the title "Stabilization of Nano-Size Pd Particles under Hydrogen Atmosphere." They provided a schematic showing the structures of two types of materials with nanometer-scale voids. Such small openings can be used to produce nanoparticles of palladium for LENR experiments. Figure 6 is a modification of one of their figures. The authors began with a review of previous work on the preparation of nanomaterials and their use in gas loading LENR experiments at room temperature and temperatures greater than 200°C. They also expressed two common concerns about the use of nanomaterials in LENR experiments, their optimum size and the structural stability of such materials during exposure to H₂ or D₂ gases. So, their goal was to develop means to produce nanoparticles with well-defined particle sizes and good stability. Their approach involved precipitation of palladium particles in the openings of materials with small voids, such as those shown in Figure 6.

The focus of the study at Nagoya was on use of Meso Porous Silicon (MPS) with voids of three different sizes, 1.5, 2.7 and 4 nanometers. Their "conventional impregnation" method involved putting the MPS into a solution of Pd(NO₃)₂, drying the result, heating it to 400°C for two hours and then exposing the result to H₂. Transmission

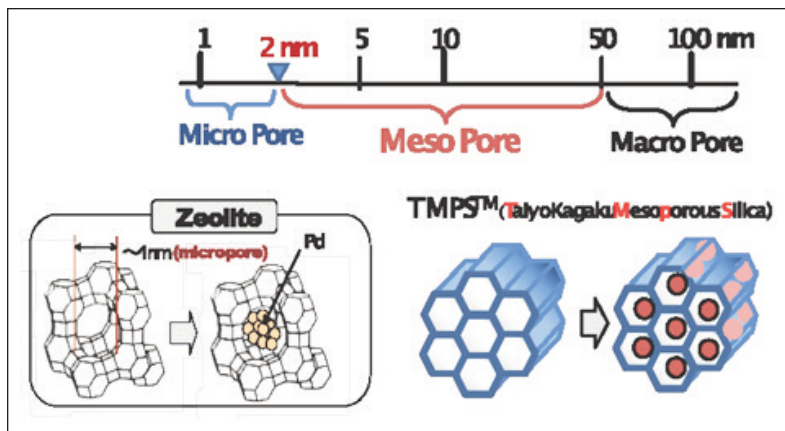


Figure 6. Schematic showing a nanometer scale with the size ranges of three types of materials. Zeolites are examples of “micro pore” materials, and the TMPS materials fall in the “meso pore” range.

Electron Microscope (TEM) images of the materials showed that palladium particles smaller than the pore sizes were inside the material, but larger Pd particles were on the surface of the MPS. Hioki and his colleagues then developed a “modified impregnation” technique. It introduced an additional step, namely washing in n-octane after immersion in the nitrate solution and before drying. That prevented the formation of superficial palladium particles on the MPS. The broadening of X-ray diffraction lines was used to determine the palladium particle sizes. One hundred and fifty particles in the TEM images were analyzed to produce a palladium particle size distribution. The Pd nanoparticles were found to be stable up to 500°C and loading ratios of H/Pd = 0.5 were obtained. The authors are planning to do flow calorimetry measurements with the materials, which they can produce on the basis of this study.

There were two papers at ICCF20 on the use of zeolites for production of palladium nanoparticles. The first was by Iraj Parchamazad and Melvin Miles from the University of LaVerne in California with the title “Investigations of Pd/D₂ in Zeolite Systems.” The lead author wrote, “Our efforts for more than 10 years was to create a sound background for zeolite-assisted Cold Fusion and other novel Zeolite technology.” This paper began with a review of the characteristics of zeolites, notably their internal fields as high as 7 V/nanometer. Because of these voltages, and pore sizes often less than one nanometer, the authors wrote, “Generally zeolites act as a nanoreactor and all the chemistry, photochemistry, and photophysical processes are very different from classical approaches.” The paper concentrated on a particular material out of the 200 known substances of this type, something called Na-Y zeolite. The catalytic and electron transfer characteristics of this zeolite with guest molecules were noted. The authors used an organo-palladium compound dissolved in ether, which enabled them to avoid chemical exchange processes that result in the formation of unwanted materials. The process resulted in 1.5 mg of Pd in 1 g of the zeolite. Scanning Electron Microscopy and X-Ray Fluorescence Analysis have been employed so far to characterize the produced materials. Seven other analytical tools are now being used to determine the location and numbers of Pd atoms in the zeolite cavities.

The third paper on LENR materials within materials with

open pores was by Frank Dodd (Tony) Smith, Jr. The poster was entitled “Cold Fusion: Deuterium in 147-atom Pd Nanoclusters Embedded in Zeolite Cages.” It began with a useful graphical summary on related work from the LENR and materials literature. Relevant theoretical work by Schwinger, Takahashi and Hagelstein was reviewed. The abstract of the poster reads: “147-atom palladium clusters embedded in zeolite cavities enable cold fusion when exposed to deuterium gas by Klein Paradox Tunneling of D+D+D+D producing He+He+47.6 MeV. Cold fusion energy goes to optical mode phonons in the Pd clusters and then to the zeolite where it is stored as heat that is released by D₂O heavy water to produce useful energy. Ejection of He+He and reloading of D+D+D+D is done by Jitterbug transformation between icosahedral ground state and cuboctahedral metastable state of

147-atom Pd clusters. Based on prior results of Arata and Zhang (replicated by McKubre at SRI) and of Parchamazad, the expected energy production is on the order of kilowatts per milligram of palladium.” The paper summarizes experimental production of Pd clusters with 147 Pd atoms, which was published by the Sandia National Laboratory and the University of New Mexico. Starting with the production of Be from four deuterons, a decay scheme was postulated by Smith to account for energy production. The paper ends with interesting information on mining of palladium, and on comparison of global energy production.

Jacques Dufour has made many experimental and theoretical contributions to the science of LENR for more than a quarter of a century. His presentation at ICCF20 was titled “A 100 W Pilot to Study the Synthesis of an Iron Pico-Hydride (Fe-pH).” The co-authors included his son Xavier, also from Paris, and Jenny Vinko from Rome. The paper dealt with synthesis and characterization of a particular material, processes that might not include LENR. The material of interest is called Fe-pH, which is thought to be a permanent electric dipole on an atomic scale. It has a high enthalpy of formation, about a thousand times higher than usual chemical reactions. The authors wrote, “The synthesis of an iron pico-hydride is a very slow reaction: the conversion (rate) is some thousand ppm/day.” In their process, iron powder and lumps of sodium (to provide free electrons) were heated in a hydrogen atmosphere to 1100°C. A calorimeter was used to measure an enthalpy of formation of 390 MJ/mole Fe. This corresponds to 4.5 keV per molecule! The measurement was done in a calorimeter of the author’s design, which can go to 1200°C and stand up to 7 bars of pressure. Details of the radiative and conductive heat transfer associated with their calorimeter were given.

Dufour reported the results of five experiments. One of the Fe-pH synthesis runs spanned nine days. The post-run materials were analyzed with a Thermo ELEMENT 2XR Inductively-Coupled Plasma Mass Spectrometer. The material showed a significant decrease of ⁵⁴Fe and a significant increase of ⁵⁷Fe, compared to natural iron. The spectra showed a strong peak at the mass of 55. It was taken to be Fe-pH. They state that the “positive charge is complex: a positive nucleus with charge 26 and some 10 fm diameter, and a positive charge 1 at a few picometers, bound to the Iron nucleus by an oscillating electron, resulting in ⁵⁴Fe-pH being

a permanent electric dipole." Given the above results, the authors set an objectives to (a) process 200 g of iron under above conditions, thus producing 100 W, (b) have a stable device able to operate for long periods of time (weeks), (c) control the atmosphere of calorimeter chamber to avoid corrosion of heating resistors and thermocouple (with argon) and (d) have a reliable measurement of the water flow and of the water temperatures in and out. The design of their system to accomplish these objectives was detailed. Initial temperature vs. time curves were presented.

There are some instances of LENR intersecting, at least conceptually, with unusual states of matter or energy. One of them was the subject of a presentation at ICCF20. The paper by Sveinn Ólafsson of the University of Iceland and Leif Holmlid from the University of Gothenburg was titled "Rydberg Matter and Low Energy Nuclear Reactions." It began with a review of the characteristics of Rydberg matter. According to Wikipedia, "A Rydberg atom is an excited atom with one or more electrons that have a very high principal quantum number. These atoms have a number of peculiar properties including an exaggerated response to electric and magnetic fields, long decay periods and electron wave functions that approximate, under some conditions, classical orbits of electrons about the nuclei." Some alkali metals and hydrogen can form Rydberg matter, usually by using the surface of a material to provide a means for the excited atoms to interact with each other. Generally, Rydberg matter contains clusters of less than about 100 atoms, in which the delocalization of the electrons in Rydberg states provides the interaction and binding energy for the cluster. The lifetime and size of the cluster both depend on the principal quantum number N of the constituent atoms. The lifetime of a cluster with $N = 12$ is 25 seconds.⁴ Destruction of Rydberg matter clusters with short-pulsed lasers permits time-of-flight determination of the velocities with which the atoms leave the cluster. Such measurements enable estimates of the proximity of the atoms while they were in the Rydberg matter. Remarkably, interatomic distances of 2.3 picometers are obtained. This is about 32 times smaller than the separation of hydrogen atoms in an ordinary hydrogen molecule. A list of a dozen publications by Holmlid in refereed journals on Rydberg matter was provided in the presentation at the conference.

The Olafsson-Holmlid paper showed their laboratory setup in which Rydberg matter is stabilized on a laser target by use of a Styrene catalyst Fe_2O_3 with K atoms on the surface. Both spontaneous and laser-induced decay of the Rydberg clusters are observed from the light emission due to impact of the fast fragments of the cluster on a catcher foil. The evidence permits inference of the presence of nuclear constituents in the decay products, indicating the involvement of nuclei in the breakup of Rydberg matter and subsequent flight of the cluster constituents. Six reasons for the appearance of muons in the decay products were given. Another calorimetric setup was used to obtain data that indicated the release of energy under laser stimulation at levels

greater than the energy of the laser pulse. The authors also discussed quantum entanglement of atoms. They suspect that Rydberg matter might form on the surfaces of cathodes in LENR experiments. This conjecture clearly needs further study both theoretically and experimentally.

Conclusion

The introductory material and experimental summaries given above show the great diversity of laboratory work on LENR. Some strong heat production and transmutation results were given at ICCF20. Even more important, a large volume of such results from earlier LENR conferences in this and other series is readily available.⁵ The care with which many experiments are planned, conducted, analyzed and documented should be noted and appreciated. The study of LENR is demonstrably a scientific field, even though it is not widely recognized as such.

This completes the introductory discussion of ICCF20 and review of most of the experimental papers given at the conference, either orally or as posters. The rest of the report on ICCF20 will appear in the next issue of this magazine. It will survey almost 20 theoretical papers, which cover a very wide range of ideas. Then, papers on applications, a few diverse topics and policies relevant to LENR will be reviewed. Other activities associated with ICCF20 will be noted, prior to some general comments on the field.

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