Overview of Theoretical and Experimental Progress in Low Energy Nuclear Reactions (LENR)

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National Institute of Nuclear Physics, Frascati National Laboratories. Vice-President of International Society for Condensed Matter Nuclear Science

CERN Colloquium
Geneva, March 22nd, 2012
Magazine Cover Stories (May 8, 1989) 
about March 23 1989 presentation by M. Fleischmann and S. Pons

TRULY EXTRAORDINARY INTEREST!
Cold Fusion generated a lot of enthusiasm when announced as well as a large derision when scientists realized the difficult reproducibility in the laboratory. The main interests were not only temperature but also the size compared with the traditional fusion experiments.
Fleischmann & Pons effect

REAL

Measurement mistake

FRAUD

$\text{The Progress of the Evidence}$
Electrochemical Loading & Heat

(Power X Time=Heat Energy --> Temperature Increases)

[Most simple calorimeter: bath calorimeter. Most reliable, and user-oriented: flow calorimeter]
After only 3 years from the original announcement of F&P, some experiments, with excellent quality, confirm the thermal effect in electrolytic environment. Some key results not made public. In red are emphasized the improvements in respect to previous experiments.
F&P effect

Other Scientists report similar results

REAL

Measure mistake

Fraud

ok

Nuclear reaction

Chemical reaction

$€ \text{ The Progress of the Evidence}$
Experimental summary: results

- Measurements of Large Excess Heat
- Systematics Seen for Heat Production
- Helium can be Produced (Miley, Gozzi, Preparata, Arata)
- Heat-Helium can be Correlated
- Tritium can be Produced (India->Srinivasan; LANL->E. Storms)
- Neutrons Measured in Bursts (LANL; INFN-LNF; BYU-USA; ....)
- Observations of X-and γ-Rays
- MeV-Energy Particles Measured (NRL)
- Observations of Sound Impulses
- Craters in Cathodes Measured
- Hot Spots Measured on Cathodes
- New Elements Measured (Miley; Iwamura; 3 pages report; Mizuno; ....)
- Enhanced Electron Screening (Armin Huke, PRC 78, 015803_1-20, 2008; J. Kasagi; Lipson)

The database is robust

Each of the types of results individually indicates that NUCLEAR REACTIONS occur in diverse experiments at modest temperatures.
### Progresses in anomalous heat generation (#2)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Year</th>
<th>Power</th>
<th>Temperature</th>
<th>Electrolyte</th>
<th>Plate Flow Calorimetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Celani-I De Ninno-I Mellove-USA</td>
<td>1992</td>
<td>1-8W 2-8%</td>
<td>30°</td>
<td>Electrolysis Pd/Pt LiOD .1M</td>
<td>Partially replicated</td>
</tr>
<tr>
<td>Piantelli Univ. Siena Italy</td>
<td>1993</td>
<td>5-40W 10-50%</td>
<td>350°</td>
<td>Gas H2 Press. &lt;1bar</td>
<td>Rod Therm. emission</td>
</tr>
<tr>
<td>Kunimatsu Toyota-Japan</td>
<td>1994</td>
<td>1-10W</td>
<td>40°</td>
<td>Electrolysis Pd/Pt LiOD 1M</td>
<td>Rod Isoperibolic Calorimetry</td>
</tr>
</tbody>
</table>

*International trial (USA, Italy) to Takahashi experiment=> Partially replicated.*

Experiments in different conditions (even the 350°C temperature with Pd-D₂ at NASA on 1989, NOT diffused) and the first Piantelli’s H₂ gas environment with Ni, confirm the F&P effect with heat generation of non-chemical origin.
<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Power</th>
<th>Temperature</th>
<th>Process Details</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparata</td>
<td>1995</td>
<td>1-20W</td>
<td>50°</td>
<td>Electrolysis Pd/Pt LiOD 0.005M</td>
<td>Long and thin Pd wires</td>
</tr>
<tr>
<td>Leda</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Isoperibolic Calorimetry</td>
</tr>
<tr>
<td>Celani</td>
<td>1995</td>
<td>2-20W</td>
<td>40°</td>
<td>High Power Pulsed Electr. J&gt;150kA/cm²</td>
<td>Pd wires, thin</td>
</tr>
<tr>
<td>INFN-Italy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Isoper. and Flow Calor.</td>
</tr>
<tr>
<td>Univ. Chicago-USA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DeNinno-Violante-Prep</td>
<td>2000</td>
<td>0.05-0.5W</td>
<td>40°</td>
<td>Electr. Pd/Pt LiOD</td>
<td>Thick film, l=1m self-destruct.</td>
</tr>
<tr>
<td>ENEA-Italy</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

The use of thin and wires, thanks to Preparata’s model, become more frequent since 1996. G. Miley was the first to confirm the Patterson’s multilayer plastic nano-beads procedure, although very difficult.
The use of nano material (powder and thin wires) makes evident the importance of increasing the surface exposed to the gas environment to enhance the effect. Arata fully replicated by Mc Kubre (SRII-USA).

**Nano-dimensionality important by itself, as claimed by Y. Arata and B. Ahern?**


<table>
<thead>
<tr>
<th></th>
<th>Year</th>
<th>Power</th>
<th>Angle</th>
<th>Methodology</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arata Univ. Osaka Japan</td>
<td>2002</td>
<td>2-20W 5-20%</td>
<td>30°</td>
<td>Ibrid. DSC Elettr&amp;press (1000bar)</td>
<td>Nano-particle Zr02-Pd 2 months</td>
</tr>
<tr>
<td>Arata Repl.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>McKubre SRII-USA</td>
<td>2003</td>
<td>1-10W 4-15%</td>
<td>30°</td>
<td>Ibrid. DSC Elettr&amp;press.</td>
<td><strong>Confirmed</strong></td>
</tr>
<tr>
<td>Celani INFN-Italy</td>
<td>2004</td>
<td>10-20W 200%</td>
<td>300°</td>
<td>Pd thin wire; surface nano-coated, H2, 6bar</td>
<td>Isop. Calor. Only 30 minutes later self destructed.</td>
</tr>
<tr>
<td>Arata Univ. Osaka Japan</td>
<td>2005</td>
<td>10-30W 15-25%</td>
<td>180°</td>
<td>Nano-particl. Zr02-Pd D2, 60bar</td>
<td>12 hours</td>
</tr>
</tbody>
</table>
Investigation of Anomalous Heat Observed in Bulk Palladium

Gustave C. Fralick (Project Lead),
John D. Wrbaneck, Susan Y. Wrbaneck,
Janis M. Niedra (ASRC) and Marc G. Millis
with
David J. Spry, Roger Meredith
and Jim Mazor (TFOME/Sierra Lobo)

NASA Glenn Research Center
Cleveland, Ohio
Reconfirmation, on Oct. 2009, of the first high-quality proof of anomalous production of heat (Dec. 1989, TM 102430) during deloading of $\text{D}_2$ gas from Pd-Ag membrane at $350^\circ \text{C}$. Conventional results with $\text{H}_2$.

Both the experiments, very important, were not made public at that time.
<table>
<thead>
<tr>
<th>Experimenter/Institution</th>
<th>Year</th>
<th>Power Input</th>
<th>Temperature</th>
<th>Reagents</th>
<th>Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arata, Univ. Osaka, Japan</td>
<td>2008</td>
<td>0.2-1W infinite (no power input)</td>
<td>25°</td>
<td>Nano-particle 3-20nm ZrO₂-Pd</td>
<td>Differential Calorimeter</td>
</tr>
<tr>
<td>Celani, INFN-Italy</td>
<td>2008</td>
<td>1-5.5W 5-10%</td>
<td>550°</td>
<td>Pd wire nano-coated D2, 6Bar</td>
<td>Diff. Calor. In-situ 400W/g Pd 12hours</td>
</tr>
<tr>
<td>Arata Repl.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Takahashi, Kitamura, Toyota, Univ. Osaka, Japan</td>
<td>2008</td>
<td>0.1-1W infinite (no power input)</td>
<td>25°</td>
<td>D2, 60 bar</td>
<td>Confirmed, Industrial material by Santoku KK (Japan)</td>
</tr>
</tbody>
</table>

* The first experiment self-sustained (without power input), by Arata, confirms that LENR, in proper conditions, could offer opportunity for energy generation.

* Some test with industrial material (Santoku) in Japan (by Toyota): they fully reconfirmed the original results of Arata. Later, the results were even improved.

* The “psychological barrier” of transferred irreproducibility, in CMNS experiments, broken once for ever.
Anomalous excess heat: last 2 years results. Mainly nano-materials.

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Power Output</th>
<th>Temperature</th>
<th>Pressure</th>
<th>Main Material</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahern Ames Lab., USA</td>
<td>2009</td>
<td>0.5-3 W infinite</td>
<td>25°</td>
<td>D2, 60 bar</td>
<td>ZrO$_2$-Ni-Pd nanoparticles</td>
<td></td>
</tr>
<tr>
<td>Celani INFN-Italy</td>
<td>2010</td>
<td>2-26 W 3-15%</td>
<td>900°</td>
<td>H2-Ar, (D2), 6 bar Ni wire, nano-coated,</td>
<td>6 days. Power density 1800W/g Ni.</td>
<td></td>
</tr>
<tr>
<td>Rossi EFA-Italy</td>
<td>2011</td>
<td>10 kW 600%</td>
<td>&gt;100°</td>
<td>Ni nano-powders+X? H2, 25bar</td>
<td>Flow calorim. NO ind. test &gt;6months??</td>
<td></td>
</tr>
<tr>
<td>Defkalion Greece</td>
<td>2011</td>
<td>10 kW, 2500%</td>
<td>&gt;200°C</td>
<td>Ni nano-powders+Y? H2, 25bar</td>
<td>Flow calorim. NO ind. test &gt;1month??</td>
<td></td>
</tr>
</tbody>
</table>

Recently Rossi and Defkalion claimed high power output (10kW), suitable for an industrial application.

During Rossi demonstrations were not allowed any independent, third part, scientific verification of the results.

Defkalion test and demonstrations already promised but not yet scheduled.
Experimental summary: overall organization.

- Better Instrumentation, Calibration and Controls
- Some Systematics Found & Verified for Heat Generation Experiments
- Nuclear Ash Measured & Correlated with Heat Production
- Many New Experiments Performed
- More Attention to Materials
- Improved Inter-Lab Reproducibility
- Continuous Activity & International Conferences

The database is robust!
The Progress of the Evidence

- F&P effect
  - Measure mistake
  - Fraud
  - Real

Other Scientists report similar results

Several experiments confirms long term energy release not achievable by any chemical system

- Nuclear reaction
  - Ok
  - Nuclear fusion
  - Other nuclear reaction
**THE ICCF Series of Conferences**

<table>
<thead>
<tr>
<th>North-AMERICA</th>
<th>EUROPE</th>
<th>ASIA</th>
</tr>
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<tbody>
<tr>
<td>1. Salt Lake City</td>
<td>2. Como (Italy)</td>
<td>3. Nagoya (Japan)</td>
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<tr>
<td>7. Vancouver (Canada)</td>
<td>8. Lerici (Italy)</td>
<td>9. Beijing (China)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16. Chennai (India)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17. Korea (Aug 2012)</td>
</tr>
</tbody>
</table>

**OTHER International Conferences/Workshops:**
18 in Russia, 11 in Japan, 10 in Italy, 8 in USA.

Dedicated sessions at National Society Conference/Workshops
$\S$ The Progress of the Evidence

New Science

New Theory

Difficult Experiment

Needs More Experiments!

Agreement with theory?

Not Even Close!

Experiments are Wrong!

Reproducibility Problems

New Knowledge

Old Science

Nuclear fusion

Other nuclear reaction
The three Major Streams of Research

1) Electrochemical loading of Deuteron into Palladium
   • It is the initial Fleischmann–Pons approach
   • Most of the research were in this field.

2) Gas Loading of Deuterium into Pd (also Ni, alloys) nanoparticles (Arata; Takahashi&Kitamura; Ahern), and/or wires nano-coated (Celani).

3) Gas Loading of Protons into Nickel.
   • Research initiated by F. Piantelli in 1991, rods.
   • This is the Rossi and Defkalion choice more recently (and claims of large power, 10 kW range), but no independent tests up to now. Nano/micro-particles+secret catalyser???
   • Several new groups worldwide.
Recent Developments

In January 14, 2011 Andrea Rossi, a chemical engineer, and Sergio Focardi a well known physicist who worked with Piantelli, showed in Bologna, to a restricted public, a LENR device called E-Cat capable to generate some kW of excess thermal power. During 2011 similar demonstrations occurred three times always without a strict scientific control. On my request, at November 2011, to perform a scientific validation (request even boosted, using an Italian science magazine, by the Nobel Laureate Brian Josephson), A. Rossi refused. Some well-respected physicists attended to the demos and, according to them, there is no evidence of fraud. Anyway, the thermal balance in this reactor is not totally convincing. Rossi announced, on October 2011, the intention to produce and market a device for house heating by end 2012 early 2013 in USA.

In January 2012, just before my presentation at WSEC2012 in Geneve, NASA released on its website a short video claiming the exciting opportunities to use LENR for aviation, space and in general for energy generation. Few days later, the author of one of most promising experiments at NASA (Joe Zawodny), specified that some of the opinions expressed in the video come of himself and were not approved by NASA.
In 2011 Defkalion, a Greek Company former partner of Andrea Rossi, announced it had developed independently a thermal device similar to Rossi’s E-cat capable of generating 10 kW at high temperatures (650 °C). No demonstration available at the moment but the Company claimed, also to me, to be available for independent testing in the near future.

In February 2012, at Massachusetts Institute of Technology, during the Cold Fusion Course held by Prof. Peter Hagelstein (DoE Lawrence award), a new device, based on electrochemical environment by Mitchell Swartz, was successfully tested.
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</tr>
</thead>
<tbody>
<tr>
<td>Takahashi&amp; Kitamura Toyota&amp;Univ.Kobe</td>
<td>March 2012</td>
<td>2-3W eV/Ni_atom&gt;&gt;300 i.e.&gt;&gt;100Chem.</td>
<td>300 in progress</td>
<td>Cu8%Ni32% -Zr60% Nano-powder H2, D2</td>
<td>Twin calorimeter Calibr.:He EndoT&lt;100°C ExotT&gt;200°C</td>
</tr>
</tbody>
</table>

The Cu-Ni alloy, independently (and secretly) studied by both groups (Japan, Italy), gives qualitatively similar results although using powders or surface coated wires. Using nano-coated wires, it was discovered that the alloy changes from usual Positive Temperature Coefficient (PTC) of resistance to NTC and the effect was related to anomalous heat production.
Preliminary Report on CNZ-I D(H)-Gas Results

Akira Kitamura, Kobe University
Akito Takahashi, Osaka University
Prepared for F. Celani’s presentation at CERN Colloquium
On March 22, 2012
Innovative Low Energy Nuclear Transmutation Method

D₂ gas permeation through nano-structured Pd multilayer film makes it possible to induce nuclear transmutation under low pressure and low temperature condition.

Mitsubishi Transmutation Method

Transmutation of Cs into Pr

Over-view of experimental set-up at Frascati Laboratories
LENR - the State of the Art

- The effect described by Fleischmann & Pons in 1989 is confirmed.
- These reactions, called LENR, occurs in the Condensed Matter normally in the crystal lattice of metals.
- Some radiation emissions, not stable during experiments, confirm the nuclear nature of LENR.
- The reactions are surface sensitive, increasing the surface increases reaction rate.
- The lattice where reaction occurs shows changes in some physical properties.
- The complex reaction environment offers few opportunities for a strict control of the conditions. In the most productive experiments lattice saturation, with H$_2$ or D$_2$, is governed by a chemical environment with many similar to chemical process based on heterogeneous catalysis.
- The most productive experiments, performed without an independent scientific control, claim to use secret catalysts to enhance the reaction rate and thermal effects.
Big Unresolved Questions about LENR

- Are the reactions only nuclear, only atomic or both?
- Is there one mechanism active or are there multiple processes?
- Do the reactions occur only on the surface of materials or also in the bulk (volume) of the materials?
- What, if anything, is common to electrochemical and gas loading experiments that have exhibited excess power and heat?
- What is the root cause of experimental irreproducibility?
- Which external factor could be used to initiate and control LENR?
All experiments confirm that LENR:

- Produces little dangerous radiations
- Generates little Residual Radioactivity
- Not production of Greenhouse Gases
- The Energy source is very small

Separately all these attributes are important. Together they might be an historic breakthrough.

CAN LENR BE COMMERCIALIZED?
• After very turbulent beginning, due to poor reproducibility, the Researchers involved in the Science field of Condensed Matter Nuclear Science improved, step-by-step, the quality and reproducibility of the results obtained.

• The most innovative experiments, since 1992, were cross-controlled by other groups, with enough specific experience and, overall, not linked to the Scientists that claim extraordinary results.

The specific procedures adopted are in full agreement with both the highest standards of Scientific methods and ethics.
Thanks to Yoshiaki Arata (*Emperor Prize*), it began evident the role that specific nano-materials (e.g. ZrO$_2$65%-Pd35%) play in absorbing large amounts of Deuterium, even under mild pressure (60 bar, recently only 10 bar).

*Thanks to gas environments, instead of initial electrolysis, the possibility to increase the temperature become evident and possible practical applications were planned.*

Under gaseous atmosphere, mixture of H$_2$-Ar, it was possible to detect anomalous excess heat even at local wire (Ni, nano-coated at the surface) temperature as large as 900°C. The experiment lasted up to 6 days and other expert Scientists, external to the (Celani) group, made any kinds of test they wished.
Conclusions
Need for an International Research Program

- Apart from the Rossi and/or Defkalion claims (in principle very interesting but never, up to now, independently reconfirmed by third parts), the quality of experiments worldwide performed is so high and the results obtained so widespread/reproduced, that I believe it is the time to start an International Research Program to boost the results.

- This Program, well funded and based on multidisciplinary approach, shall have the objective to design and test “working devices” able to generate heat and, later on, electricity.

- Clearly, this Program shall not stop the research on the theory side, aimed to define a general theoretical architecture of the whole phenomena we are discussing today.

- If successful, this Program should also launch an economic and industrial roadmap to define the guidelines of future investment and regulations.