

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

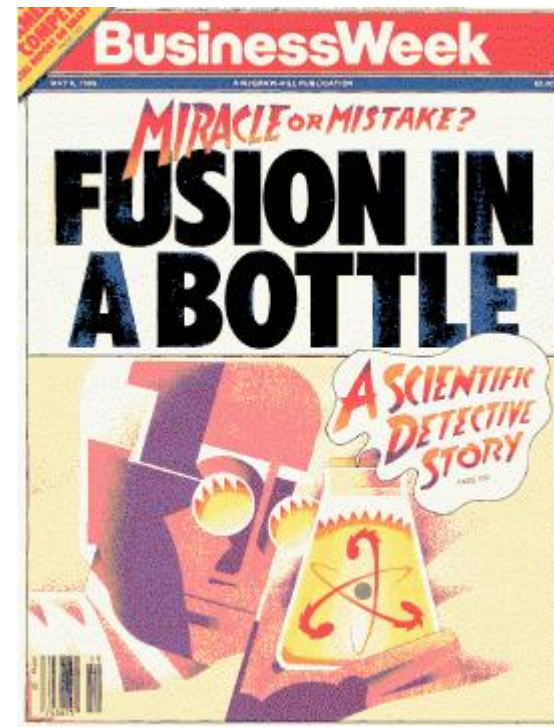
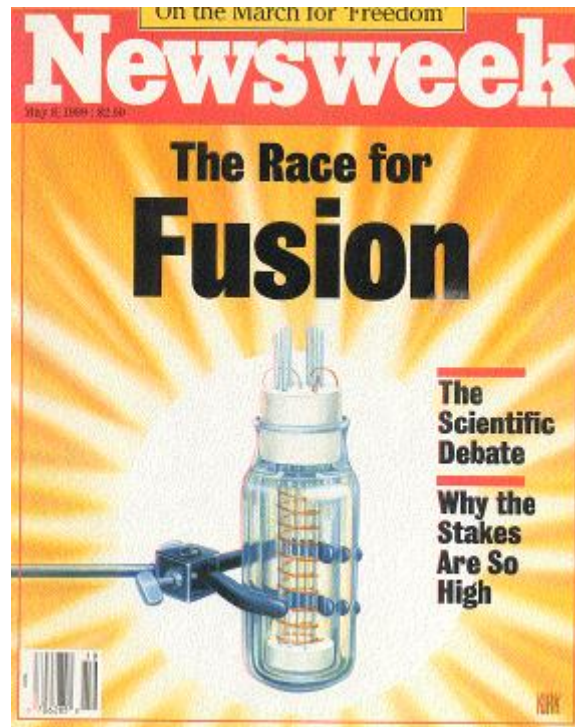
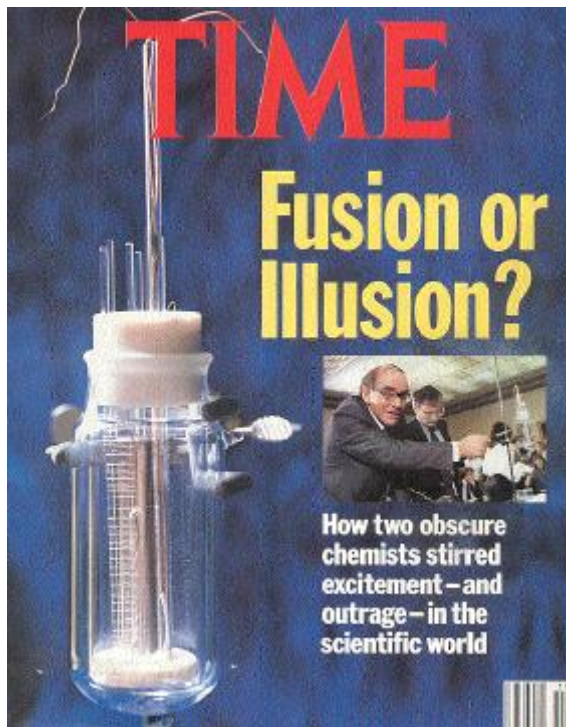
Francesco CELANI

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

**CERN Colloquium
Geneva, March 22nd, 2012**

(by D. Nagel-USA, 2011; partially revised/modified by C. Cavallero & F.C.)=> \$€

**Magazine Cover Stories (May 8, 1989)
about March 23 1989 presentation by M. Fleischmann and S. Pons**

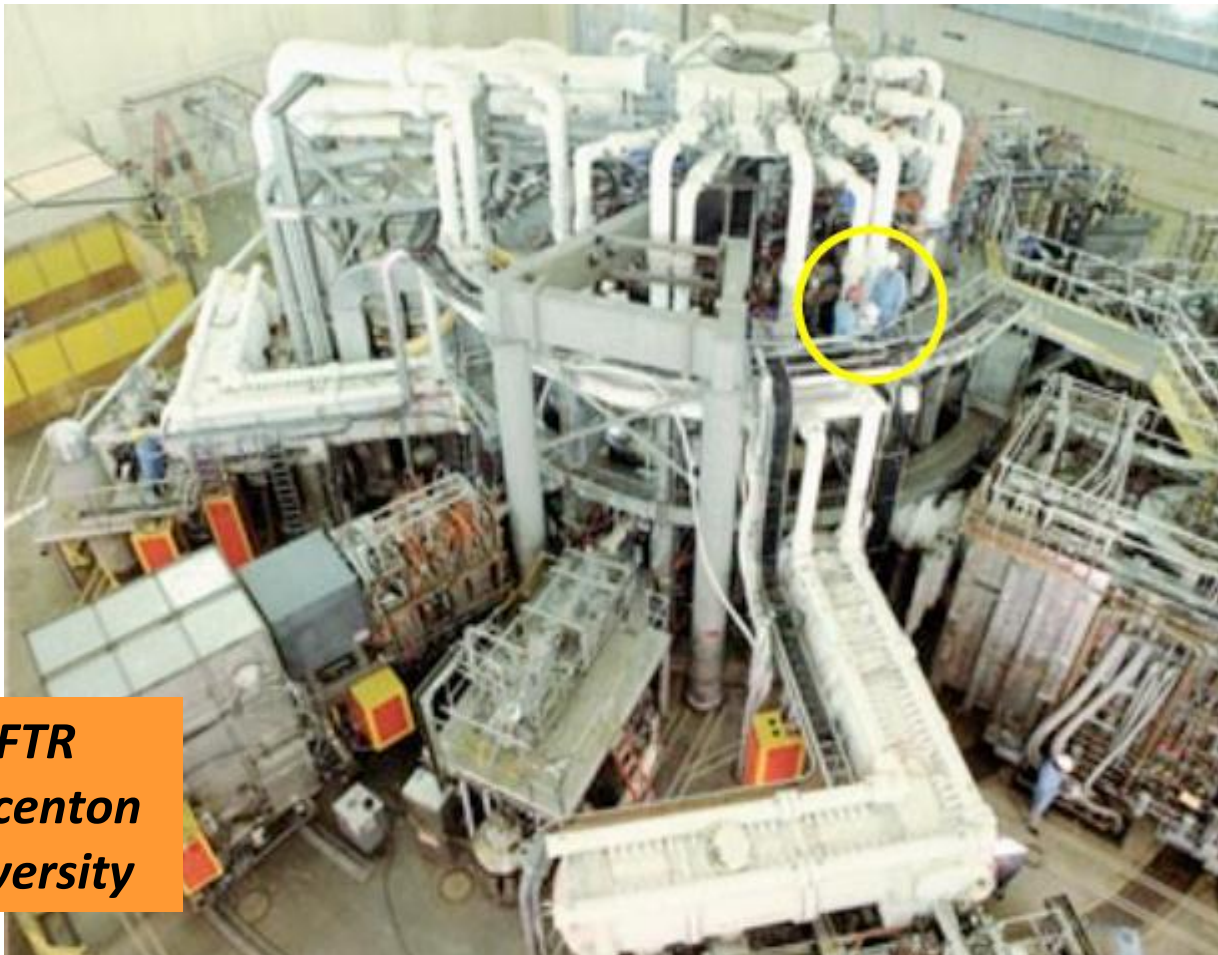


TRULY EXTRAORDINARY INTEREST!

§€ The Fleischmann-Pons effect

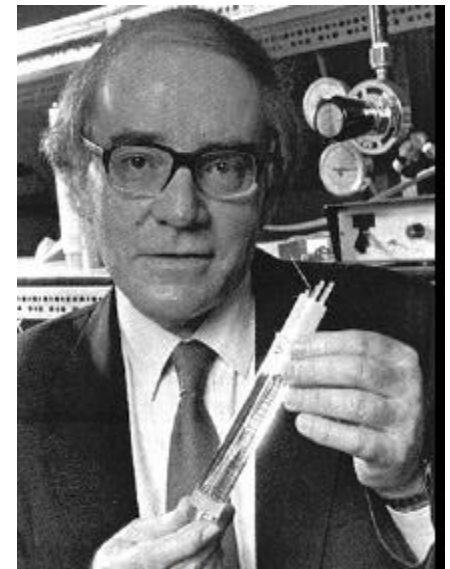
Cold Fusion generated a lot of enthusiasm when announced as well a large derision when scientists realized the difficult reproducibility in the laboratory.

The main interests were not only temperature but also the size compared with the traditional fusion experiments.



**TFTR
Princeton
University**

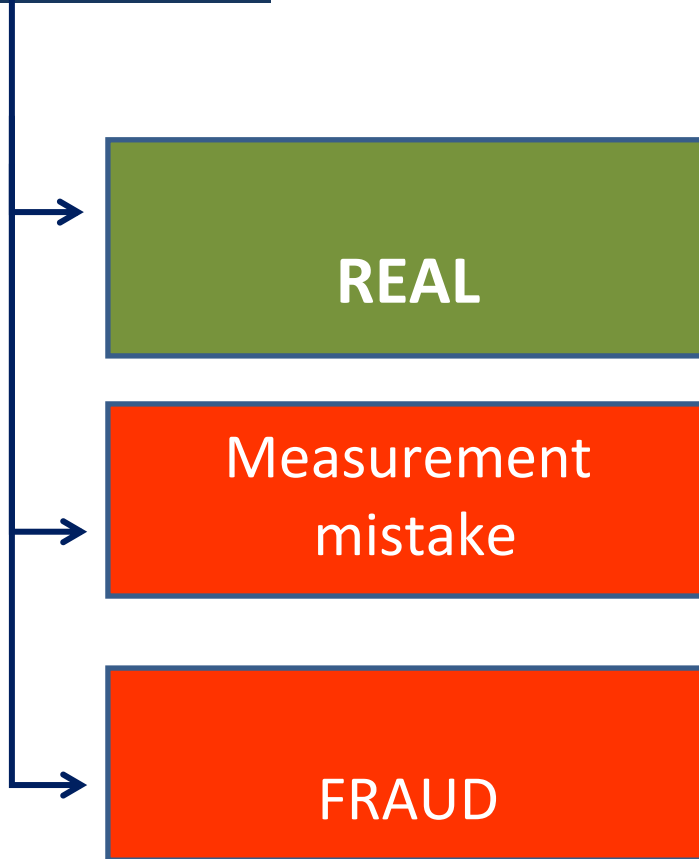
VS.



Martin Fleischmann

§€ The Progress of the Evidence

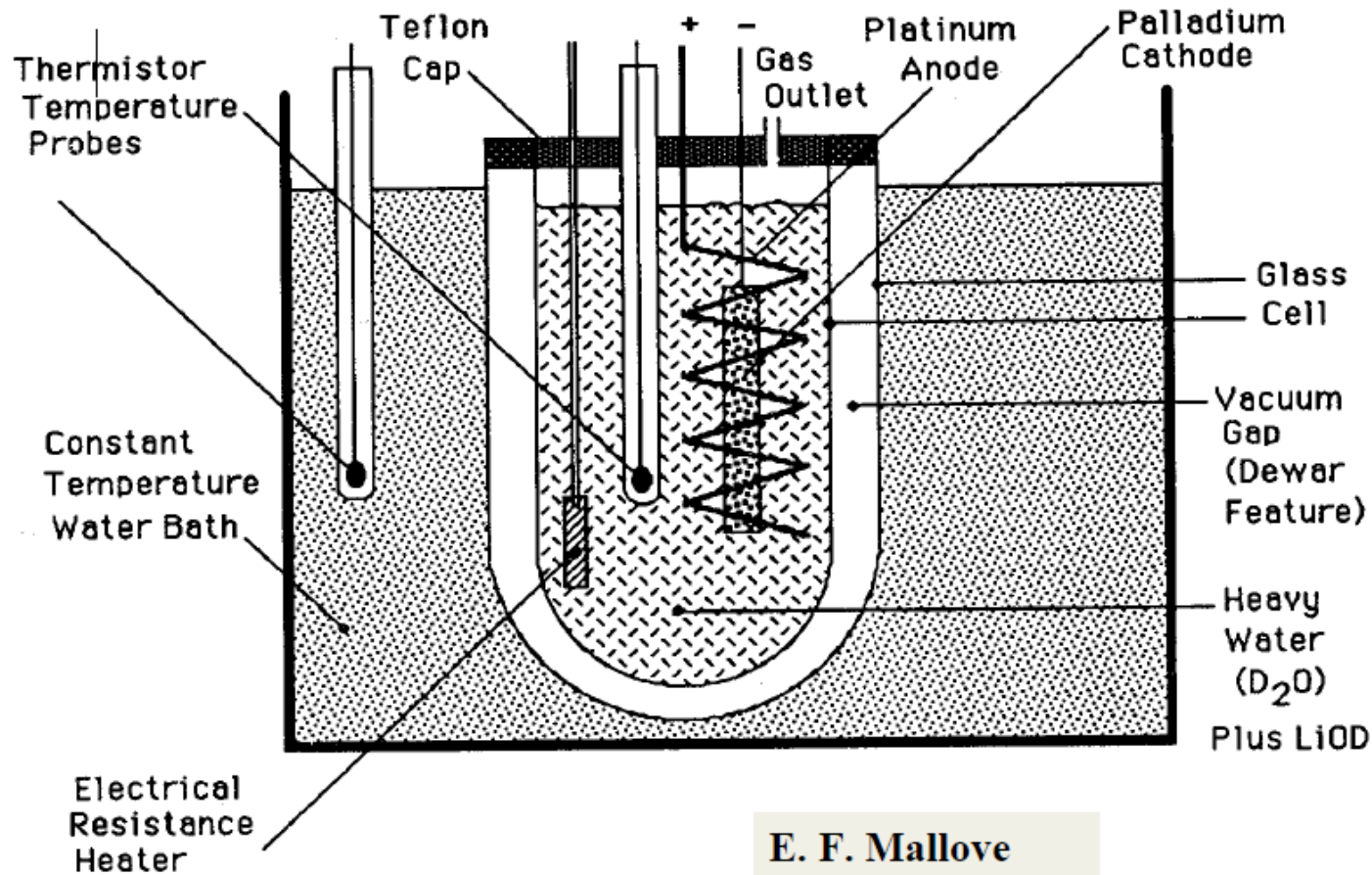
**Fleischmann &
Pons effect**



€ Electrochemical Loading & Heat

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

[Most simple calorimeter: bath calorimeter. Most reliable, and user-oriented: flow calorimeter]



Selected results, mainly on heat generation. (#1)

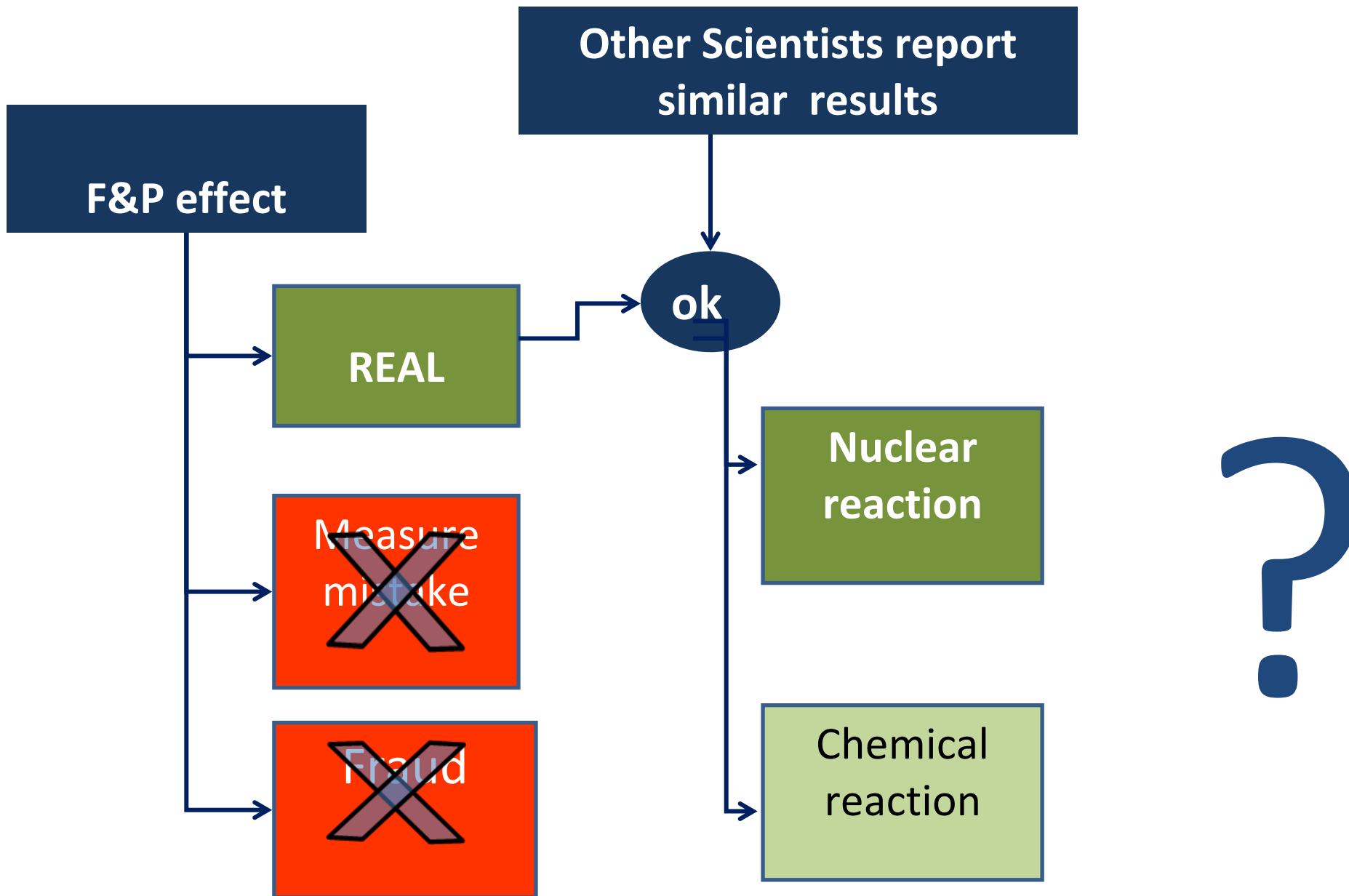
Authors Affiliations	Year	Ex.Power(W) Gain%	Temp. (°C)	Experiment type	Notes
Fleisch.&Pons Univ. SLC USA	1989	.01-1W 2-5%	30°	Electrolysis Pd/Pt LiOD .1M	Rod Isoperibolic Calorimetry
Mc. Kubre SRIL, USA	1990	.1-3W	30°	Electrolysis Pd/Pt LiOD .1M	Rod Flow Calorim
A. Takahashi UNIV. Osaka Japan	1991	5-60W 25%	30°	Electrolysis Pd/Pt LiOD .1M	Plate (25x25x1mm) Flow Calorim

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.

§€ 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**)

Each of the types of results individually indicates that **NUCLEAR REACTIONS** occur in diverse experiments at modest temperatures.

The database is robust

Progresses in anomalous heat generation (#2)

Celani-I De Ninno-I Mellove-USA	1992	1-8W 2-8%	30°	Electrolysis Pd/Pt LiOD .1M	Plate Flow Calorim Batch probl. Part. replic.
Piantelli Univ. Siena Italy	1993	5-40W 10-50%	350°	Gas H ₂ Press. <1bar	Rod Therm. emission
Arata Univ. Osaka Japan	1993	2-20W 20%	40°	Ibrid. DSC Elettr&press (1000bar)	Sub-micro Pd Powder Flow Calorimetry
Kunimatsu Toyota-Japan	1994	1-10W	40°	Electrolysis Pd/Pt LiOD 1M	Rod Isoperibolic Calorimetry

*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.*

Preparata Leda-Italy	1995	1-20W 5-50%	50°	Electrolysis Pd/Pt LiOD 0.005M	Long and thin Pd wires Isoperibolic Calorimetry
Celani INFN-Italy	1995	2-20W 5-60%	40°	High Power Pulsed Electr. J>150kA/cm²	Pd wires, thin Isoper. and Flow Calor.
Miley Univ. Chicago- USA	1997	1-10W 200%	40°	Electr. H2 Nano-beads: Plastic-Ni-Pd multilayer	Isoper. and Flow Calor.
DeNinno- Violante-Prep ENEA-Italy	2000	0.05-0.5W 100%	40°	Electr. Pd/Pt LiOD	Thick film, l=1m self-destruc.

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.

Arata Univ. Osaka Japan	2002	2-20W 5-20%	30°	Ibrid. DSC Elettr&press (1000bar)	Nano-particle ZrO ₂ -Pd 2 months
Arata Repl.					
McKubre SRII-USA	2003	1-10W 4-15%	30°	Ibrid. DSC Elettr&press.	Confirmed
Celani INFN-Italy	2004	10-20W 200%	300°	Pd thin wire; surface nano-coated, H ₂ , 6bar	Isop. Calor. Only 30minutes later self destroyed.
Arata Univ. Osaka Japan	2005	10-30W 15-25%	180°	Nano-particl. ZrO ₂ -Pd D ₂ , 60bar	12 hours

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?

=>phenomenon of **Energy Localization** at 3-20nm dimensions, following/revising the Fermi-Pasta-Ulam paradox (1954 LANL-USA: code LA1940, pp.977-988).



Investigation of Anomalous Heat Observed in Bulk Palladium

Gustave C. Fralick (Project Lead),
John D. Wrbanek, Susan Y. Wrbanek,
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



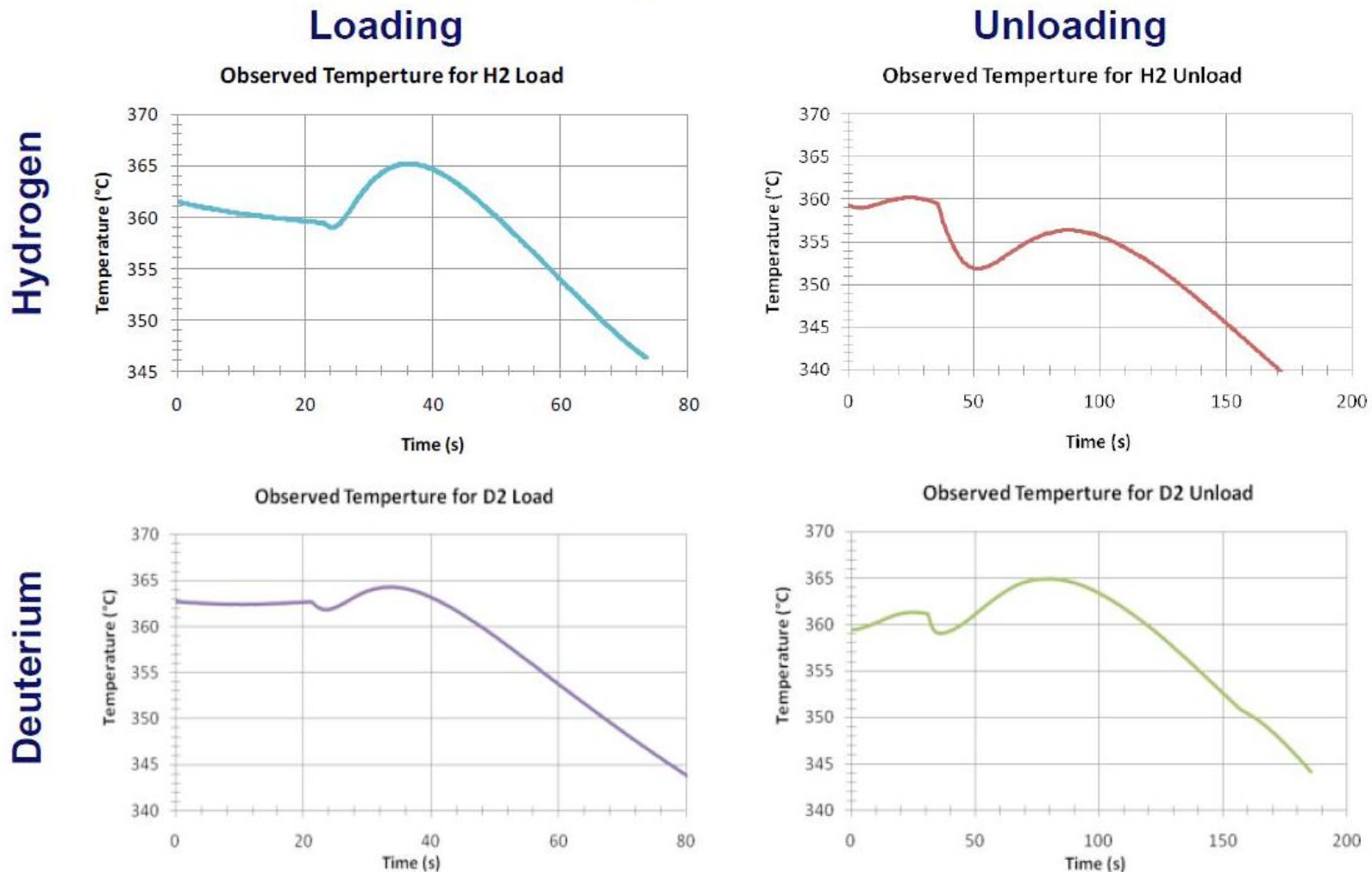
Reconfirmation, on Oct. 2009, of the first high-quality proof of anomalous production of heat (Dec. 1989, TM 102430) during deloading of D_2 gas from Pd-Ag membrane at $350^\circ C$. Conventional results with H_2 .

Both the experiments, very important, were not made public at that time.

National Aeronautics and Space Administration



RESULTS (Preliminary): Temperatures vs. Time



Arata Univ. Osaka Japan	2008	.2-1W infinite (no power input)	25°	Nano-particl. 3-20nm ZrO ₂ -Pd D2, 60bar	Differential Calorimeter
Celani INFN-Italy	2008	1-5.5W 5-10%	550°	Pd wire nano-coated D2, 6Bar	Diff. Calor. In-situ 400W/g Pd 12hours
Arata Repl.					
Takahashi, Kitamura Toyota, Univ. Osaka Japan	2008	.1-1W infinite (no power input)	25°	D2, 60 bar	Confirmed, Industrial material by Santoku KK (Japan)

* *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.

Ahern Ames Lab. USA	2009	.5-3W infinite	25°	D2, 60 bar	ZrO₂-Ni-Pd nanoparticles
Celani INFN-Italy	2010	2-26W 3-15%	900°	H₂-Ar, (D₂), 6 bar Ni wire, nano-coated,	6 days. Power density 1800W/g Ni.
Rossi EFA-Italy	2011	10kW 600%	>100°	Ni nano- powders+X? H ₂ , 25bar	Flow calorim. NO ind. test >6months??
Defkalion Greece	2011	10kW, 2500%	>200°C	Ni nano- powders+Y? H ₂ , 25bar	Flow calorim. NO ind. test >1month??

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.

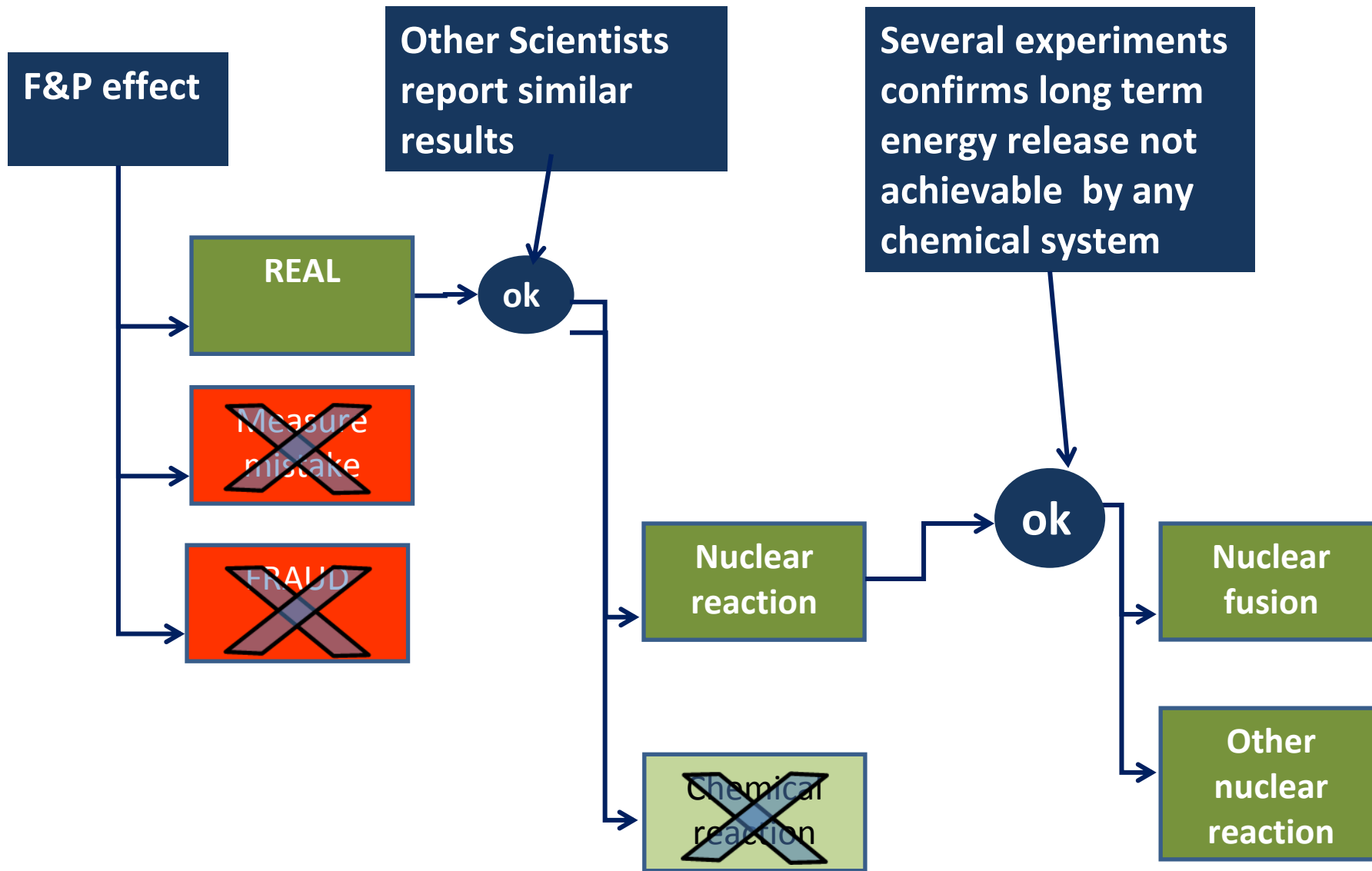
\$€

Experimental summary: overall organization.

***The database
is robust !***

- **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 Progress of the Evidence



§€ The International Society for Condensed Matter Nuclear Science

organizes the:

INTERNATIONAL CONFERENCE ON CONDENSED MATTER NUCLEAR SCIENCE and ICCF series

THE ICCF Series of Conferences

North-AMERICA

- 1. Salt Lake City**
- 4. Maui-Hawaii**
- 7. Vancouver
(Canada)**
- 10. Cambridge**
- 14. Washington DC**

EUROPE

- 2. Como (Italy)**
- 5. Monaco**
- 8. Lerici (Italy)**
- 11. Marseilles (France)**
- 15. Rome (Italy)**

ASIA

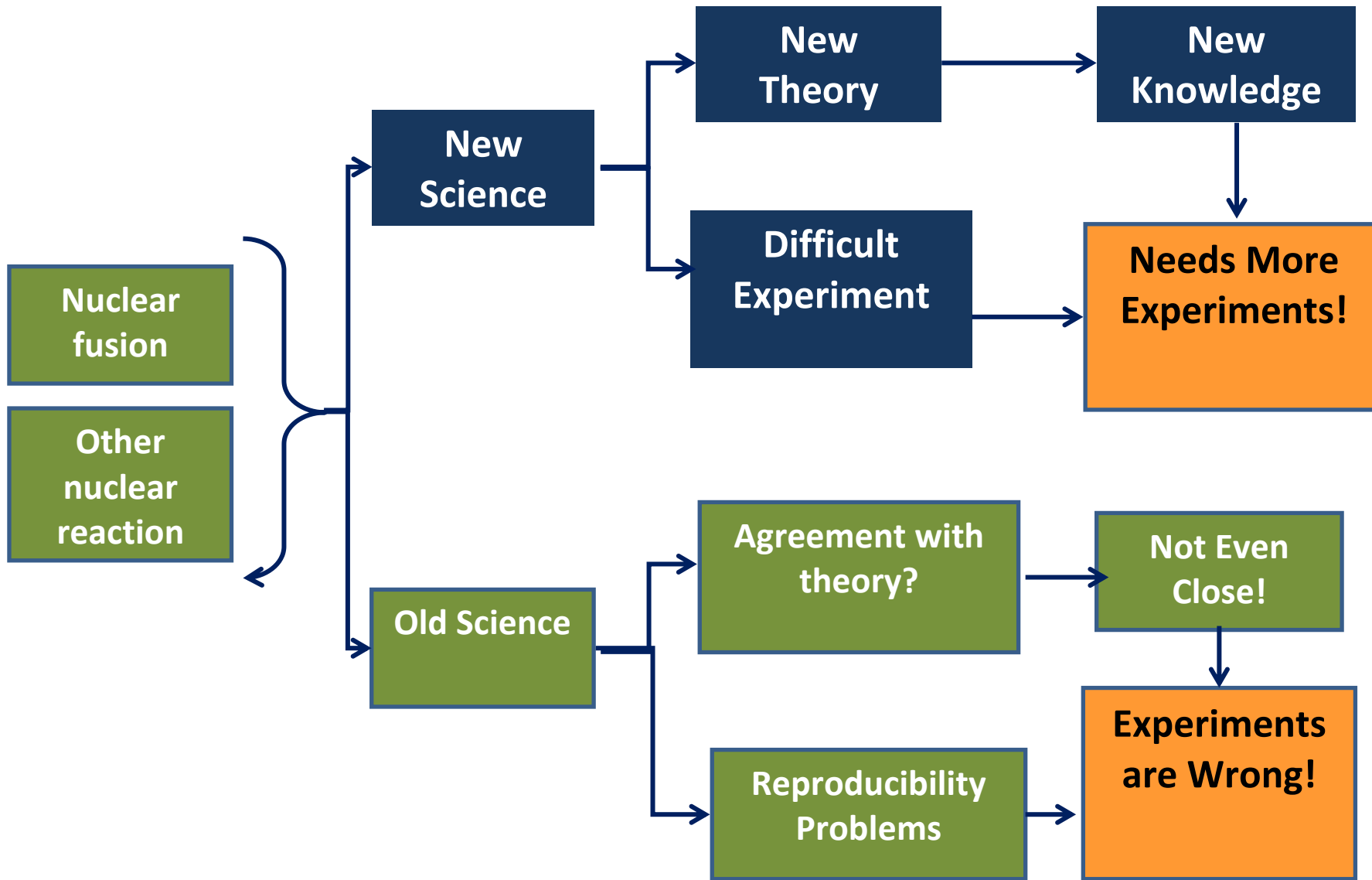
- 3. Nagoya (Japan)**
- 6. Sapporo (Japan)**
- 9. Beijing (China)**
- 12. Yokohama (Japan)**
- 13. Sochi (Russia)**
- 16. Chennai (India)**
- 17. Korea (Aug 2012)**

OTHER International Conferences/Workshops:

18 in Russia, 11 in Japan, 10 in Italy, 8 in USA.

Dedicated sessions at National Society Conference/Workshops

§€ The Progress of the Evidence



§€ 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.

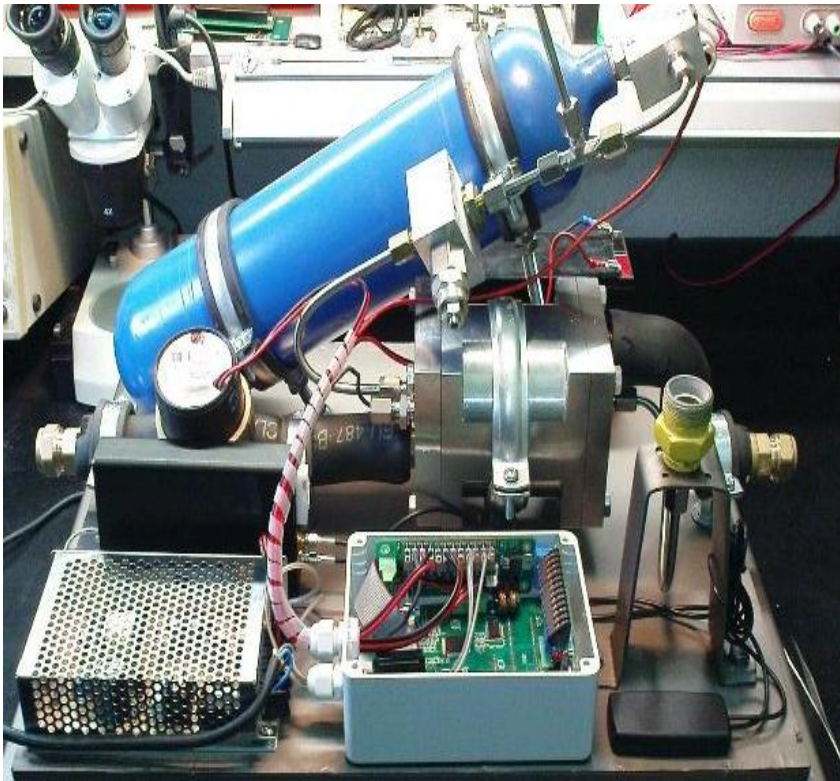
Some well-respected physicists attended to the demos and, according to them, there is no evidence of fraud. Anyway, the thermal balance in this reactor is not totally convincing.

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.

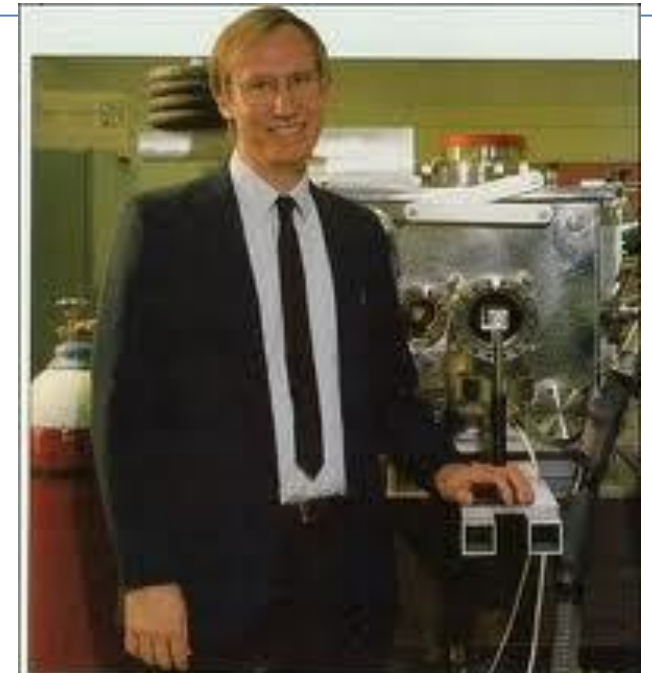


Recent Developments



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.



<p>Celani INFN-Italy</p>	<p>Nov. 2011 Reconfirmed Jan. 2012</p>	<p>10W 15%</p>	<p>>260°</p>	<p>Cu-Ni-Mn alloy Micro-Nano coated</p>	<p>Flow-calorim. Wire resist. from PTC to NTC related to thermal anomalies</p>
<p>Takahashi& Kitamura Toyota&Univ.Kobe</p>	<p>March 2012</p>	<p>2-3W eV/Ni_atom>>300 i.e.>>100Chem.</p>	<p>300 in progress</p>	<p>Cu8%Ni32%- -Zr60% Nano-powder H2, D2</p>	<p>Twin calorimeter Calibr.:He EndoT<100°C ExotT>200°C</p>

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

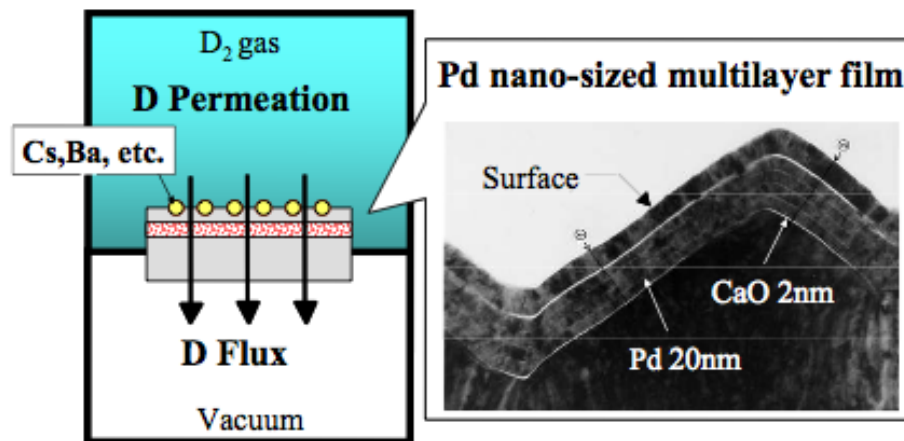
F. Celani's presentation at CERN Colloquium

On March 22, 2012

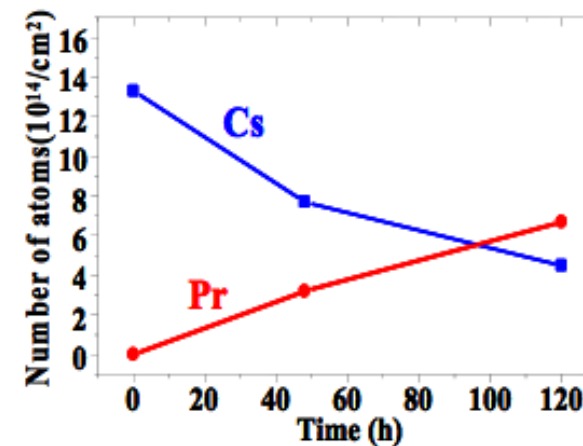
Innovative Low Energy Nuclear Transmutation Method

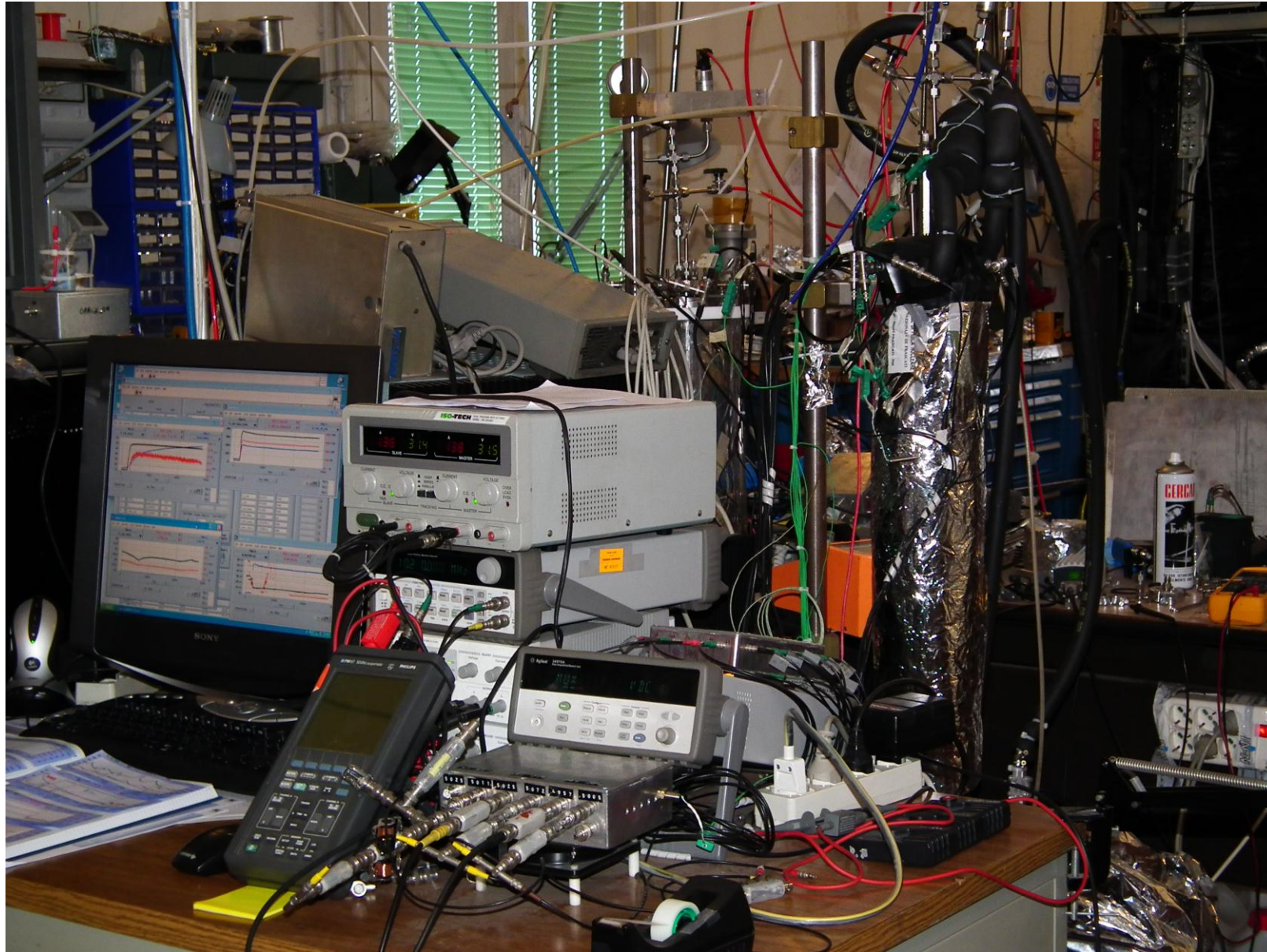
D₂ gas permeation through **nano-structured Pd multilayer** film makes it possible to induce **nuclear transmutation** under **low pressure and low temperature** condition.

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 H₂ or D₂, 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?**

§€ Key Features of Low Energy Nuclear Reaction

All experiments confirm that LENR:

- Produces little dangerous radiations **SAFE**
- Generates little Residual Radioactivity **CLEAN**
- Not production of Greenhouse Gases **GREEN**
- The Energy source is very small **DISTRIBUTED**

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

CAN LENR BE COMMERCIALIZED?

Conclusions

The quality of the research - Reproducibility

- 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.

Conclusions

The gas environment

- Thanks to Yoshiaki Arata (*Emperor Prize*), it began evident the role that specific nano-materials (e.g. $\text{ZrO}_2\text{65\%}-\text{Pd35\%}$) 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.