Journal of Fusion Energy, Vol. 25, No. 3/4, December 2006 (© 2006)
DOI: 10.1007/s10894-006-9023-8

Progress in Condensed Matter Nuclear Science

**Xing Z. Li,[1,*] Qing M. Wei,[1] Bin Liu,[1]
Shu X. Zheng[2] and Dong X. Cao[2]**

The progress of the Condensed Matter Nuclear Science reported during ICCF-12 is summarized with emphasis on reply to the DOE review in 1989 and in 2004. The 18 reviewers might not be aware of the new achievement in the Advanced Technology Research Center, Mitsubishi Heavy Industries; hence, their conclusion should have been more positive towards this research. Arata's DS-reactor, NASA's early experiment, and the"heat after death" experiment should change the conclusion about the "excess heat" and its prospect. Various fundamental researches have shown the consistent nature in understanding. A cost effective and comprehensive study is mentioned.

KEY WORDS: condensed matter nuclear science; nuclear transmutation; super-lattice complex; deuterium flux; excess heat.

FROM 1989 DOE REVIEW TO 2004 DOE REVIEW

Sixteen years have past since the DOE 1989 review (the famous Blue Cover Book written by DOE 1989 ERAB [1]). There was a second DOE review in 2004. Eighteen reviewers gave their comments on the report [2] and presentations provided by Professor Hagelstein of MIT, Dr. Mckubre of Stanford Research Institute, International and other scientists from Naval Research Laboratory and Frascati INFN Laboratory.

ICCF-12 is a good chance to check the progress in the past 16 years and compare with reviewers' comments. In the Blue Cover Book, the fifth point in conclusion was "Nuclear fusion at room temperature, of the type discussed in this report, would be contrary to all understanding gained of nuclear reactions in the last half century; it would require the invention of an entirely new nuclear process." It is true that 16 year study has confirmed that there is *an entirely new nuclear process*. The title of Mckubre and Hagelstein's report was just "New Physical Effects in Metal Deuterides". Among the 18 reviewers, one half of them recognized that "evidence for excess power is compelling" [3]; however, only one of them recognized that the occurrence of low energy nuclear reactions is demonstrated by the evidence presented. If DOE allowed more time for the reviewers to become acquainted with the nuclear transmutation work, the other 17 reviewers might recognize also that the occurrence of low energy nuclear reactions is demonstrated, because in the past 10 years Dr. Iwamura just did what they recommended, i.e. "the use of state-of-the-art apparatus and techniques to search for fusion events in thin deuterated foils" [4].

NUCLEAR TRANSMUTATION IN SUPER-LATTICE COMPLEX

Dr. Iwamura's constant pursuing led to his great success. He started his research when Japanese NHE

[1] Department of Physics, Tsinghua University, Beijing, 100084, China.
[2] Department of Engineering Physics, Tsinghua University, Beijing, 100084, China.
* To whom correspondence should be addressed: E-mail: lxz-dmp @tsinghua.edu.cn

(New Hydrogen Energy) Project was initiated in 1993; however, he did not stop when NHE project stopped. He did not insist to use neutron as the only one signal for nuclear reaction. He tried tritium, X-rays, and excess heat. He tried both electrolysis and gas-loading method. Eventually, he found that deuterium flux, cesium coating on the surface, and the super-lattice complex were the three key elements to reproduce his discovery, i.e. the nuclear transmutation induced by deuterium flux. He found that XPS (X-ray photoelectron spectroscopy) was the most suitable *in-situ* diagnostic tool to monitor the nuclear transmutation. His supervisor was so judicious to allow him traveling between Yokohama and Kobe in every week in order to continue his study. Indeed he was so brave to try the high Z element as a candidate to interact with the low energy deuterium gas; and he was so patient to wait for weeks in order to observe the nuclear transmutation. When his methodology was established, he was able to send his sample to France for the SIMS (time-of-flight) analysis; and send his sample to SPring-8 for micro-beam analysis. Moreover, Professor Takahashi of Osaka university was able to use his method to make sample, and use the NAA (Neutron Activation Analysis) to verify the product of the nuclear transmutation (Pr) [5]. Now Mitsubishi Heavy Industries is collaborating with NRL (Naval Research Laboratory) in US in order to use NRL's TEAMS (Trace Element Analysis Mass Spectroscopy) equipments. The Disclose Agreement between MHI and NRL restricted the information flow before the publication; however, we might still learn from Drs. Iwamura, Narita, and Yamada's presentations [6, 7]. The unidentified peak was discovered using the micro-beam. Possibly, it was lanthanum (La). It was just the element between Cs and Pr. It might imply that Cs was added a deuteron first; then, one more deuteron was added to reach the Pr. Moreover, if we look at the natural abundance of lanthanum, there is only one stable isotope for lanthanum with a little mixture of long life-time isotope (0.09%, 1.05×10^{11} years). This is very similar to the praseodymium which has only one stable isotope as well. Indeed, terbium (Tb) and thulium (Tm) were discovered in the early EPMA (Electron Probe Micro-Analysis) experiment also when we tried to identify any new elements in the sample of palladium hydride [8]. To my surprise, Tb and Tm have only one stable isotope as well (see Table 1).

HYDROGEN INDUCED LOW ENERGY NUCLEAR REACTIONS

It was a new step for Iwamura to select high Z material (Cs, Sr, Ba etc.) as his test sample. It was also a great step for Professor G. Miley to study the hydrogen (H_2) induced low energy nuclear reaction [9]. In the early days, H_2 was just selected as a control in comparison with D_2, because most of scientists (including the members of ERAB of DOE) were thinking of the d + d fusion reaction only. Even Professor M. Fleischmann was not ready to accept such new phenomena. In ICCF-7 (Vancouver, 1998), Miley asked a question during a plenary session. He would like to know what are Martin's comments on nuclear transmutation. Fleischmann replied with humor "I am a conventional chemist". However, the most impressive results are the four peaks in the distribution of nuclear products which appeared in various experiments in the world (Mizuno *et al.* [10], Ohmori and Enyo [11], Bockris [12] etc.). The organizer of ICCF-12 made a good program to arrange a minicourse presentation by Miley. It should be emphasized that both Miley and Iwamura used thin film samples and used super-lattice complexes in their experiments.

FROM DS-CATHODE TO DS-REACTOR

Professor Arata has been a very successful and innovative scientist in his career (welding etc.); however, he switched to condensed matter nuclear science early in 1990's with an innovative double-structure palladium cathode for electrolysis. This time Professors Arata and Zhang switched from electrolytic cell to gas-loading experiment while keeping his double-structure characteristics of palladium [13]. He is happy with this new structure because "Sauna-bath" is better

Table 1. Isotope Abundance of the Rare Earth Series of Elements

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
99.91	4*	100	7*	0*	6*	2*	6*	100	7*	2*	6*	100	5*	2*

*The integer shows the number of the stable isotopes.

than the "hot-water-bath". More energy output would be available from the newly designed DS-reactor. It is quite clear qualitatively to show that the temperature reverse (i.e. the temperature of heater (T_{out}) is lower than that of the heated object (T_{in})) appeared when the H_2 was replaced by D_2, and the vacuum vessel was filled with Pd-black or Nano Pd. The most interesting point was the temperature setting. $T_{out} = 140°C$ was just same as that appeared in the early experiment in China where a correlation between the deuterium flux and abnormal heat flow was found [14] (Figure 1, right-hand-side).

The DOE reviewers in 2004 asked the frequently asked questions in those excess heat experiments: "The reviewers who did not find the production of excess power convincing cite a number of issues including excess power in the short term is not the same as net energy production over the entire time of an experiment; all possible chemical and solid state causes of excess heat have not been investigated and eliminated as an explanation; and production of power over a period of time is a few percent of the external power applied and hence calibration and systematic effects could account for the purported net effect."

As a supplement to against those criticisms, we may add two more experiment: NASA's 1989 work [15], "Heat after Death" work in 1993 [16].

Early in 1989, G. Fralick of NASA, USA utilized the hydrogen purifier as a D/Pd system to search the neutron emission, while H_2 was used as a control. Excess heat was found unexpectedly when deuterium gas was pumped out from the hot palladium tube. The temperature of Pd tube increased from 383 to 400°C in 15 s while heating power was fixed. Usually, one would expect the temperature drop when the pumping started, because both the adiabatic expansion of D_2 gas and the endothermic nature of the degassing should lower the temperature. On the other hand, one might suspect also the change of the heat conductivity, because heat conductivity would be smaller when the D_2 pressure was much lower than the Knudsen limit. However, when H_2 gas was pumped out from the same system, Fralick had never observed such temperature rising. Hence, the heat conductivity could not explain the Pd temperature rising from 383 to 400°C in 15 s. We might estimate how much power was necessary to make this temperature rising. The mass of palladium tube was about 78 g. It needs 22 W to heat 78 g palladium from 383 to 400°C in 15 s adiabatically. It corresponds to 440 J per mole of Pd as the most conservative estimate. This power density was even greater, when Fralick switched off the heating power and pumped out the deuterium gas again at 370°C. It clearly showed that deuterium flux might induce "excess heat" without any neutron radiation.

M. Fleischmann's "Heat after Death" experiment in 1993 provided a compelling estimate with even much higher "excess heat". His electrolytic cell was boiled to dry in 10 min. The vaporization heat was so large (102.5 kJ) that all uncertainties in the other effects might be ignored (e.g. 22.5 kJ for input from electrolysis, 6.7 kJ for heat transfer to ambient). The volume of the palladium cathode was only 0.0392 cm^3 which is about 4.6×10^{-3} mol. Hence, the most conservative estimate would be 18.8 MJ per mole of Pd (i.e. 195 eV per Pd atom). Even if this

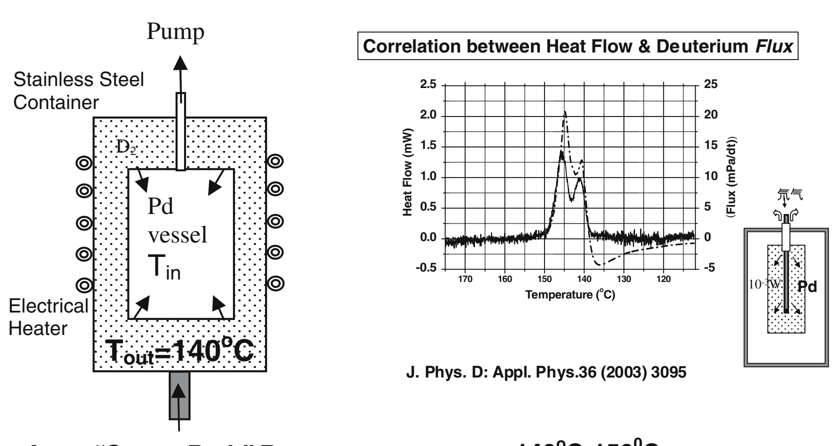

Fig. 1. 140°C as a characteristic temperature was discovered in both Arata's Sauna bath and an early Chinese correlation experiment where D_2 gas was permeating Pd thin wall.

amount of energy had have been stored in the palladium due to some unknown mechanism during the long period of electrolysis, this would have still be an anomalous "chemical" effect (if it is not a nuclear effect). Would the reviewers still say "While significant progress has been made in the sophistication of calorimeters since the review of this subject in 1989, the conclusions reached by the reviewers today are similar to those found in the 1989 review", if they had paid attention to this calculation.

NHE (NEW HYDROGEN ENERGY) PROJECT AND LOADING RATIO

Dr. Matsui kindly appeared in ICCF-12 again. His announcement about NHE project in ICCF-4 was a great impetus to Condensed Matter Nuclear Science research. At that time a program was established to aim at the high loading using electrolysis method. Adding something (e.g. thiourea etc.) in the electrolyte was found effective to enhance the loading ratio, but the excess heat was not as great as expected [17]. The failure in helium detection and the argument on "excess heat" were partially compensated by the successful nuclear transmutation [18] and the deuterium flux effect [19]. Particularly, the deuterium flux effect appeared both in the "excess heat" and in the nuclear transmutation experiments. It turns out to be the key issue to *reproduce* the effects of the condensed matter nuclear science instead of the high loading ratio. If the 18 reviewers had chance to review this issue, they might not be so pessimistic that "Most reviewers, including those who accepted the evidence and those who did not, stated that the effects are not repeatable,..."

FUNDAMENTAL RESEARCH IN CONDENSED MATTER NUCLEAR SCIENCE

"...use of reasonably well characterized materials, exchange of materials between groups, and careful estimation of systematic and random errors" was recommended in DOE 1989 review. Then, what is the important characteristic of material for this condensed matter nuclear science? The resistance ratio of palladium sample was widely used as an important characteristic in electrolysis and gas-loading experiment. Mckubre of SRI group [20], and Spollane and Celani of Frascatti group [21] presented very careful measurement with close collaboration. Eight methods of measurement were summarized to relate this resistance ratio to the loading ratio of the palladium sample. It was found that the relationship between resistance ratio and loading ratio was very complicated because there was no good calibration for the high loading region where the sample was supposed to work, and because the resistance depended on temperature while the temperature coefficient depended on loading ratio also. The recommendation is that resistance ratio might be still a good characteristic if we specified the temperature at which this ratio was measured. The significance of the high loading is possibly due to its relation with deuterium flux.

The careful study on the temperature coefficient of the resistance of the palladium hydride revealed a possible phase transition in the high loading region which might be just the region of interests for Condensed Matter Nuclear Science.

LONG LIFE-TIME STATE IN CONDENSED MATTER NUCLEAR SCIENCE

What is the important basic research for the condensed matter nuclear science? The reviewers might have very different guide line in their mind. Three deuteron reaction was unexpectedly discovered while the branching ratio of the d + d fusion was measured at low energy. It was first discovered in 1993 by Professor Kasagi at Tohoku University in terms of $d + (d + d) \rightarrow p + n + \alpha$ reaction [22]. Kasagi's experiments at low energy was very reliable that even Dr. Morrison of CERN, the famous opponent of the "cold fusion", stood up to praise Kasagi's experiments for anomalous screening effect at low energy as the best experiment in ICCF-7 (Vancouver, 1998). Indeed, Professor Takahashi tried to verify this three deuteron reaction in terms of $d + (d + d) \rightarrow T + {}^3He$ as well at Osaka University [23]. This three deuteron reaction implied that two deuterons were kept in a *Long Life-Time State* before two deuterons saw the third deuteron. During the ICCF-12, Kasagi proposed further the evidence of the motion of the deuteron before d + d interaction, and Takahashi proposed further the assumption of Bosonized Condensates [24].

If we look at the Bockris' paper in ICCF-11 proceedings [12] about the tritium production and the β-decay, we may believe that this *Long Life-Time State* might be essential in order to understand the mechanism of the condensed matter nuclear science. If the reviewers could be aware of those facts; then, they might not say: "The studies were designed to investigate screening effects in materials that would be relevant to fields such as nuclear astrophysics. Those reviewers who commented on these studies generally viewed them favorably, but to many reviewers these studies were somewhat peripheral to the main thrust of this review."

DOLAN'S COMMENTS AND ITALY–JAPAN JOINT PROJECTS

Dr. Thomas Dolan was an officer at IAEA (International Atomic Energy Agency) to co-ordinate the fusion research in the world for United Nations (1995–2001). He was mainly working for plasma fusion projects; however, he visited some of the "cold fusion" laboratories, and even took part in the ICCF-9 (2002, Beijing) as a retired scientist. He suggested that we should establish an international society, an international journal, and an academic award in order to enhance the credit of our research, and break the bad cycle to obtain both the credit and the research fund. Now he attended ICCF-12 again. We have the International Society for Condensed Matter Nuclear Science, have the International Journal for Condensed Matter Nuclear Science, and have the Preparata Medal. Professor Takahashi announced that there would be a Joint Project between Italian and Japanese scientists to explore the possibility of processing the nuclear waste using the nuclear transmutation induced by deuterium flux. The first phase would be supported by 13 Million Euros and followed by second phase with 12 Million Euros.

A COST EFFECTIVE STUDY

Dr. Thomas O. Passell, the Co-Chairman of the ICCF-4, proposed further his results in using discharge tube for excess heat detection [25]. He intended to use the small size gas discharge tube to make a wide-range survey on various materials for electrodes and gases while keeping the sensitivity and efficiency high enough. When the government support is still a long way to go, he used his retirement money to keep the project running. As a retired manager from the EPRI (Electrical Power Research Institute), he has been optimistic towards the future of the Condensed Matter Nuclear Science.

Israel group represents an excellent private company to achieve constant progress in excess heat with the best international collaboration (Mckubre of SRI, Violante of INFN) [26]. DOE's recommendation, "Emphasis should be placed on calorimetry with closed systems and total gas recombination, use of alternative calorimetric methods, use of reasonably well characterized materials, exchange of materials between groups, and careful estimation of systematic and random errors. Co-operative experiments are encouraged to resolve some of the claims and counterclaims in calorimetry", has been realized there already.

PROSPECTS

The situation is changing gradually towards favorable to Condensed Matter Nuclear Science. The Journal of Fusion Energy, decided to accept the submission from the Condensed Matter Nuclear Science [27]. It has been mainly a hot fusion journal edited by the former DOE officer (Dr. Steve Dean), and published by the famous Springer Verlag. Springer Verlag even decided to publish an academic book about the Condensed Matter Nuclear Science as well. This "New Physical Effects in Metal Deuterides" would be disseminated eventually, and lead to a clean and sustainable energy resource for the world.

ACKNOWLEDGEMENTS

This work is supported by the Natural Science Foundation of China (#10475045), Ministry of Science and Technology (Division of Fundamental Research), and Tsinghua University (985-II, Basic Research Funds).

REFERENCES

1. "Cold Fusion Research", DOE/S-0073, A Report of the Energy Research Advisory Board to the United States Department of Energy (November 1989)
2. P. L. Hagelstein, M. C. H. McKubre, D. J. Nagel, T. A. Chubb, and R. J. Hekman, *New Physical Effects in Metal Deuterides*, private communication (November 2004)
3. U.S. Department of Energy Cold Fusion Review Reviewer Comments, http://www.newenergytimes.com/DOE/DOE.htm (2004)
4. Y. Iwamura, *et al.*, Observation of surface distribution of products by X-Ray fluorescence spectrometry during D_2 gas permeation through Pd complexes, Presentation in ICCF-12, Nov. 27–Dec. 2, 2005, Yokohama, Japan

5. T. Higashiyama, A. Takahashi, *et al.*, in P. Hagelstein and S. R. Chubb (eds) Proceedings of ICCF-10, Cambridge, USA, 24–29 August, 2003, World Scientific (New Jersey, 2006), p. 447
6. S. Narita, *et al.*, Discharge experiment using Pd/CaO/Pd multi-layered cathode, Presentation in ICCF-12, Nov. 27–Dec. 2, 2005, Yokohama, Japan
7. H. Yamada, *et al.*, Producing transmutation element on multi-layered Pd sample by deuterium permeation, Presentation in ICCF-12, Nov. 27–Dec. 2, 2005, Yokohama, Japan
8. G. S. Qiao, X. Z. Li, *et al.*, Proceedings of ICCF7, Vancouver, Canada, April 19–24, 1998, ENECO, Inc., Salt Lake City, UT (1998), p. 314
9. G. H. Miley, Overview of light water/hydrogen-based low energy nuclear reactions, Presentation in ICCF-12, Nov. 27–Dec. 2, 2005, Yokohama, Japan
10. T. Mizuno, T. Ohmori, and M. Enyo, *J. New Energy*, **1**(1), 23 (1996)
11. T. Ohmori and M. Enyo, *J. New Energy*, **1**(1), 15 (1996)
12. J. O.-M. Bockris, in J.-P. Biberian (ed) Proceedings of ICCF-11, Marseilles, France, 31 Oct.–5 Nov. 2004, World Scientific (New Jersey 2006), p. 562
13. Y. Arata, M. J. A. Y. C. Zhang, Development of "DS-Reactor" as the practical reactor of cold fusion based on the "DS-Cell" with the "DS-Cathode", Presentation in ICCF-12, Nov. 27–Dec. 2, 2005, Yokohama, Japan
14. X. Z. Li, J. Tian, *et al.*, *J. Phys. D Appl. Phys.* **36**, 3095 (2003)
15. G. C. Fralick, A. J. Decker, and J. W. Blue, Results of an attempt to measure increased rates of the reaction $^2D + {}^2D \rightarrow {}^3He + n$ in a nonelectrochemical cold fusion experiment, NASA Technical Memorandum 102430, Lewis Research Center Cleveland, Ohio, Dec., 1989
16. M. Fleischmann, and S. Pons, Calorimetry of the Pd–D_2O system: from simplicity via complications to simplicity. *Phys. Lett. A*, **176**, 118 (1993)
17. A. Kubato, *et al.*, in M. Okamoto (ed) Proceedings of ICCF-6, Toya, Japan,13–18 Oct., 1996, Vol. 1, p. 52
18. G. H. Miley, *et al.*, in M. Okamoto (ed) Proceedings of ICCF-6, Toya, Japan,13–18 Oct., 1996, Vol. 2, p. 629
19. Y. Iwamura, *et al.*, in M. Okamoto (ed) Proceedings of ICCF-6, Toya, Japan,13–18 Oct., 1996, Vol. 1, p. 274
20. M. C. H. Mckubre, *et al.*, Using resistivity to measure H/Pd and D/Pd loading: method and significance, Presentation in ICCF-12, Nov. 27–Dec. 2, 2005, Yokohama, Japan
21. A. Spallone, F. Celani, *et al.*, Measurements of the temperature coefficient of electric resistivity of hydrogen overloaded Pd, Presentation in ICCF-12, Nov. 27–Dec. 2, 2005, Yokohama, Japan
22. J. Kasagi, *et al.*, *J. Phys. Soc. Japan*, **64**(3), 777 (1995)
23. A. Takahashi, *et al.*, in P. Hagelstein, S. R. Chubb (eds) Proceedings of ICCF-10, Cambridge, USA, 24–29 August, 2003, World Scientific (New Jersey, 2006), p. 657
24. A. Takahashi, Time-dependent EQPET analysis of TSC, Presentation in ICCF-12, Nov. 27–Dec. 2, 2005, Yokohama, Japan
25. T. B. Benson and T. O. Passell, Glow discharge calorimetry, Presentation in ICCF-12, Nov. 27–Dec. 2, 2005, Yokohama, Japan
26. I. Dardik, *et al.*, Progress in electrolysis experiments at energetics technologies, Presentation in ICCF-12, Nov. 27–Dec. 2, 2005, Yokohama, Japan
27. X. Z. Li, *et al.*, *J. Fusion Energy*, **23**(3), 217 (2004)