December 1, 2004

Report of the Review of Low Energy Nuclear Reactions

The Department of Energy's (DOE) Office of Science (SC)

Introduction

The Department of Energy's (DOE) Office of Science (SC) was approached in late 2003 by a group of scientists who requested that the Department revisit the question of scientific evidence for low energy nuclear reactions. In 1987 Pons and Fleischmann first reported the production of "excess" heat in a Pd electrochemical cell, and postulated that this was due to D-D fusion (D=deuterium), sometimes referred to as "cold fusion." The work was reviewed in 1989 by the Energy Research Advisory Board (ERAB) of the DOE. ERAB did not recommend the establishment of special programs within DOE devoted to the science of low energy fusion, but supported funding of peer-reviewed experiments for further investigations. Since 1989, research programs in cold fusion have been supported by various universities, private industry, and government agencies in several countries.

Review and Process

In response to the above request, the Office of Science agreed to a peer review of the experimental data and supporting theory since the 1989 ERAB review. The scientists who made this request were asked to generate a review document that identified the most significant experimental observations and publications, and those areas where additional work would appear to be warranted. This document, entitled "New Physical Effects in Metal Deuterides," was prepared by Professor Peter Hagelstein of MIT, Dr. Michael McKubre of SRI International, Professor David Nagel of George Washington University, Dr. Talbot Chubb of Research Systems Inc., and Mr. Randall Hekman of Hekman Industries (hereafter referred to as the proposers). Together with supplemental material, said document was submitted to DOE in July 2004 (Attachment 1).

The Basic Energy Sciences and Nuclear Physics Offices in the DOE Office of Science conducted a peer review of the submitted material in a manner typical for a DOE sponsored university or laboratory research program. The review had two components. First, the review document received by DOE was sent out for peer review by mail. Nine scientists with appropriate scientific backgrounds in experimental and theoretical nuclear physics, material science, and electrochemistry were identified by DOE, and were given approximately one month to review the report and supplementary material. The second part of the review consisted of a one-day review conducted on August 23, 2004. The reviewers consisted of nine additional scientists chosen by DOE for their expertise in relevant fields. Anonymous comments from the mail peer review referred to above were provided to members of the reviewers prior to the

presentations. Oral presentations were made to the reviewers by research scientists, chosen by the authors of the review document. Six research groups gave approximately one-hour presentations on the work being performed in their laboratories. Individual comments from reviewers were requested following the presentations.
In total, 18 individual reviewer comments were received by DOE.

Review Criteria

Reviewers were asked to respond to the following charge in their evaluation of the written and/or oral material: (1) To examine and evaluate the experimental and theoretical evidence for the occurrences of nuclear reactions in condensed matter at low energies (less than a few electron volts). (2) To determine whether the evidence is sufficiently conclusive to demonstrate that such nuclear reactions occur. (3) To December 1, 2004 determine whether there is a scientific case for continued efforts in these studies and, if so, to identify the most promising areas to be pursued. Copies of the charge letter and accompanying instructions regarding conflict of interest and confidentiality are attached (Attachment 2).

Review Document and Presentations

The review document submitted (Attachment 1) focused on "a subset of research from two areas" in the field of low energy nuclear reactions: (1) "selected issues associated with excess heat production in deuterated metals" and (2) "some aspects of nuclear emissions from deuterated metals." According to the review document, D-D fusion has been demonstrated to occur spontaneously when D is introduced into Pd metal at very high concentrations (D/Pd ~ 0.95). According to the review document, these demonstrations include purported production of anomalous energy, helium, tritium, and a variety of elements not initially present in the experimental container.
The material presented in the review document and oral presentations focused on electrochemical reactions in the Pd/D_2O system, evidence for excess heat and nuclear reaction products, and the current theoretical framework that has been used to describe the observations. Data were also presented on the use of ion beams and glow discharge systems used to study the Pd, Ti/D and Pd, Ti/H systems. The review only addressed "light element" experiments, namely H or D fusion.
The proposers state that the results from the research provide evidence for effects in three categories, as summarized in the review document's Conclusions Chapter:
1. "The existence of a physical effect that produces heat in metal deuterides. The heat is measured in quantities greatly exceeding all known chemical processes and the results are many times in excess of determined errors using

several kinds of apparatus. In addition, the observations have been reproduced, can be reproduced at will when the proper conditions are reproduced, and show the same patterns of behavior. Further, many of the reasons for failure to reproduce the heat effect have been discovered."

2. "The production of ^4He as an ash associated with this excess heat, in amounts commensurate with a reaction mechanism consistent with D+D $\rightarrow$ ^4He + 23.8 MeV (heat)".

3. "A physical effect that results in the emission of: (a) energetic particles consistent with $d(d,n)^3He$ and d(d,p)t fusions reactions, and (b) energetic alphas and protons with energies in excess of 10 MeV, and other emissions not consistent with deuteron-deuteron reactions."

The material presented can be found at http://www.sc.doe.gov. Following the oral presentations, reviewers requested additional documentation from the presenters. This supplemental material can also be found at the indicated link.

Detailed Summary of Reviewer Response to Charge Elements Since the 1987 report by Pons and Fleischmann, scientists have continued to investigate the conditions responsible for the anomalous heat production in an attempt to establish reproducible conditions for the generation of excess energy, quantify the amount of energy being released, and confirm the hypothesis that the energy is a consequence of nuclear fusion by detecting the expected nuclear reaction products.

Below is a summary of the reviewer responses to the three charge elements, written by DOE program managers and intended to give an overall sense of the reviewers' comments. The entire charge letter is December 1, 2004 enclosed as Attachment 2. The redacted reviewer comments (only their names and institutions were removed) have been sent to the proposers.

Charge Element 1: Examine and evaluate the experimental evidence for the occurrences of nuclear reactions in condensed matter at low energies (less that a few electron volts).

The experimental evidence presented by the review document and oral presentations for the occurrences of nuclear reactions consisted of two general types: excess power production from an electrolytic cell containing metal electrodes (palladium is the typical metal) with a deuterated electrolyte; and measurement of expected fusion products such as ^4He in electrolytic cells, or any of the other expected products observed in hot fusion, proton + triton (the nucleus of tritium, consisting of two neutrons and one proton) or neutron + ^3He, in a variety of experiments.

The excess power observed in some experiments is reported to be beyond that attributable to ordinary chemical or solid state sources; this excess power is attributed by proponents to nuclear fusion reactions.

Evaluations by the reviewers ranged from: 1) evidence for excess power is compelling, to 2) there is no convincing evidence that excess power is produced when integrated over the life of an experiment. The reviewers were split approximately evenly on this topic. Those reviewers who accepted the production of excess power typically suggest that the effect seen often, and under some understood conditions, is compelling. 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 of 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. Most reviewers, including those who accepted the evidence and those who did not, stated that the effects are not repeatable, the magnitude of the effect has not increased in over a decade of work, and that many of the reported experiments were not well documented.

The hypothesis that excess energy production in electrolytic cells is due to low energy nuclear reactions was tested in some experiments by looking for D + D fusion reaction products, in particular ^{4}He, normally produced in about 1 in 10^{7} in hot D + D fusion reactions. Results reported in the review document purported to show that ^{4}He was detected in five out of sixteen cases where electrolytic cells were reported to be producing excess heat. The detected ^{4}He was typically very close to, but reportedly above background levels. This evidence was taken as convincing or somewhat convincing by some reviewers; for others the lack of consistency was an indication that the overall hypothesis was not justified. Contamination of apparatus or samples by air containing ^{4}He was cited as one possible cause for false positive results in some measurements.

Beam experiments not involving electrolytic cells were reported in the review document and oral presentation, purport to provide evidence for low energy nuclear reactions. These experiments involved low energy deuterium beams impinging on deuterium loaded metal foils such as titanium. 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.

A similar line of investigation involved counting deuterium loaded foils to observe the products for the standard fusion reaction channels, proton + triton or neutron + ^{3}He, with particle detectors and coincidence techniques. Indications of purported detection of proton-triton coincidences at a low level were presented. Even skeptical reviewers cited this work as one line of investigation that could be pursued to a clear conclusion. However, the results were not convincing to some reviewers in regard to the occurrence of low energy nuclear reactions. Experts noted many deficiencies in the techniques, methods, and interpretation of the data presented. The present state-of-the-art for tracking coincidences and the methodology for low data rate experiments is far advanced beyond methods used in the experiment contained in the review document and oral presentations.

Two-thirds of the reviewers commenting on Charge Element 1 did not feel the evidence was conclusive for low energy nuclear reactions, one found the evidence convincing, and the remainder indicated they were somewhat convinced. Many reviewers noted that poor experiment design, documentation, background control and other similar issues hampered the understanding and interpretation of the results presented.

Charge Element 2: Determine whether the evidence is sufficiently conclusive to demonstrate that such nuclear reactions occur.

Reviewers expert in nuclear physics noted that the cold fusion mechanism put forward by proponents is not in accord with presently accepted knowledge of D + D fusion. Specifically, D + D fusion is accompanied by the production of protons, neutrons, tritons, ^{3}He, ^{4}He and high energy gamma rays, all in well known proportions. The fusion channel resulting in ^{4}He and high energy gamma rays occurs approximately only once for every 107 D + D fusion reactions. These characteristic proportions for the production of the fusion products are found for every energy of the incident deuteron measured so far, down to the lowest that has been measured.

The review document and oral presentations made the argument that the branching ratios are different at low energies and that in cold fusion, ^{4}He fusion channel is predominant. According to the review document, no high energy gamma rays appear to accompany the ^{4}He, as is observed in D-D fusion reactions. Instead, the approximately 24 MeV in energy resulting from D-D fusion was purported to appear as heat in the material lattice. To explain these unusual characteristics, the reviewers were presented with a theoretical framework that purported to describe how collective energy from the material lattice couples to a deuteron pair to induce fusion, how the only fusion reaction channel that occurs would be the production of ^{4}He, and how all the energy is coupled back into the material in the form of heat instead of high energy gamma-rays. The reviewers raised serious concerns regarding the assumptions postulated in the proposed theoretical model for the explanation for ^{4}He production.

The preponderance of the reviewers' evaluations indicated that Charge Element 2, the occurrence of low energy nuclear reactions, is not conclusively demonstrated by the evidence presented. One reviewer believed that the occurrence was demonstrated, and several reviewers did not address the question.

Charge Element 3: Determine whether there is a scientific case for continued efforts in these studies and, if so, to identify the most promising areas to be

pursued.
The nearly unanimous opinion of the reviewers was that funding agencies should entertain individual, well-designed proposals for experiments that address specific scientific issues relevant to the question of whether or not there is anomalous energy production in Pd/D systems, or whether or not D-D fusion reactions occur at energies on the order of a few eV. These proposals should meet accepted scientific standards, and undergo the rigors of peer review. No reviewer recommended a focused federally funded program for low energy nuclear reactions.
Reviewers identified two areas where additional research could address specific issues. One is the investigation of the properties of deuterated metals including possible effects of alloying and dislocations. These studies should take advantage of the modern tools for material characterization. A second area of investigation is the use of state-of-the-art apparatus and techniques to search for fusion events in thin deuterated foils. Several reviewers specifically stated that more experiments similar in nature to those that have been carried out for the past fifteen years are unlikely to advance knowledge in this area.

Conclusion

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.
The current reviewers identified a number of basic science research areas that could be helpful in resolving some of the controversies in the field, two of which were: 1) material science aspects of deuterated metals using modern characterization techniques, and 2) the study of particles reportedly emitted from deuterated foils using state-of-the-art apparatus and methods. The reviewers believed that this field would benefit from the peer-review processes associated with proposal submission to agencies and paper submission to archival journals.

Attachment 1: Review document submitted by requesters, "New Physical Effects in Metal Deuterides."
Attachment 2: Charge letter to reviewers

Reviewer's Comments

2004 U.S. Department of Energy Cold Fusion Review
Reviewer Comments (Selected Comments) from Reviewers of the 2004 U.S. Department of Energy Cold Fusion Review.

1) Review #6

To begin a review of "Cold Fusion" it is useful to remind oneself of the quote by Dr. Gordon Baym from his article in *Phys. Rev. Lett* **63**,191(1989).
"We are searching for new experimental phenomena in an area in which theory must be supported by consistent, systematic data. Any search for 'anomalous phenomena' is, in its early stages an experimentally, not theoretically driven field. It is necessary to stay as close as possible to conventional physics for as long as one can hold out, and only when driven up the wall should theorists invoke new physics."
Clearly the data described in the position paper is not consistent and systematic. Furthermore the scientists quoted do not spend enough effort searching for conventional causes of the phenomena claimed or for systematic errors in the measurements. Little has changed in Cold Fusion from the publication of John R. Huizenga's book "Cold Fusion: The Scientific Fiasco of the Century", U. of Rochester Press, Rochester, New York (1992). Cold fusion is inconsistent with a huge body of knowledge about nuclear processes developed over the past 70 years. Three miracles are required for "Cold Fusion" as described to occur. These are:
1. **The Fusion Rate miracle.** The inter-atomic distance of deuterium adsorbed onto palladium is larger than deuterium gas, 0.28-0.17 nm. The estimated tunneling rate for that distance is $3 \times 10^{-64} s^{-1}$.
2. **The Branching Ratio miracle.** When deuterium atoms fuse a compound nucleus with an excitation energy of 23.85 MeV is formed. This is a well studied reaction because it is commonly used as a source of 3 MeV neutrons. The excited nucleus is known to decay with a 50 percent probability by neutron emission 50 percent probability by proton emission. No significant production of neutrons has been observed in "Cold Fusion" studies.
3. **The Concealed Nuclear Products miracle.** Neutrons, tritium, or gamma rays are not observed in quantities consistent with fusion, see table 1.

Hagelstein Theory

This theory was apparently developed to explain Huizenga's miracle number 3, concealed nuclear products. The mathematics presented in the paper is sound. But, the devil is in the conjectures. The most implausible being conjecture II. While it is possible for nuclei to be coupled a two different sites as demonstrated

by Terhune and Baldwin in the 1960's. That coupling occurs through the Mössbauer effect.
There is no crystal lattice that could produce a recoilless transition of a 23.8 MeV gamma ray. Converting all of that energy in to phonons (heat) must have negligible probability of then reassembling into the narrow width of another nuclear level. I was somewhat puzzled by Hagelstein's discussion of phonons being mediated by the strong force. The reaction he conjectures is amusing because one of the reaction products from equation 8 is 106Ru produced by alpha emission from 110Pd (11 % natural abundance). The anomalous heat claims suggest 10 18 to 10 19 fusions if this reaction were at all probable the 106Ru activity would be at the Curie level, quite hazardous.

Conclusion

I find nothing in the articles that I've read that convinces me that the new anomalies reported are not experimental artifacts. Exposing or disproving experimental artifacts is far more difficult than generating them. Better experiments could be done, however. For example, a time projection chamber trace showing a proton and triton originating from the same point in a TiD foil with the correct energy would be convincing. Certainly the weight of the evidence present thus far is not strong enough to overcome the three miracle requirement.

2) Review #7

I. General Comments.

I have spent the past few weeks reading the papers sent to me by the Office of Science, DOE, including many of those that are referenced in the overview paper by Hagelstein et al. (cited in this review as reference DoE31). I find it fascinating that, as noted by these latter authors in their Introduction, "thousands of papers" on this topic have been written since the initial cold fusion claims of 1989.
Compared with the early work on cold fusion with which I am familiar (e.g., I was a participant in the 1989 cold fusion evaluation workshop at Erice), I find the large number of different experimental methods that have been applied to the cold fusion problem to be very impressive. However, one aspect of cold fusion studies has not changed, namely that the field crosses the boundaries of several rather different scientific areas, such as chemistry, electrochemistry, thermodynamics, solid state physics, hydrogen storage in solids, and nuclear physics. It is difficult to find scientists who are knowledgeable in all of these areas – either cold-fusion practitioners or peer reviewers. As I note in a few examples in section II below, I have the impression that in some instances, cold-fusion experimenters are not as expert as they should be in the methods that they have chosen to use.

II. Detailed Comments and Questions About Searches for Nuclear-Reaction Products in Cold Fusion.

In this section, I will focus on several topics that I am knowledgeable about, related to searches for evidence of nuclear processes occurring in cold fusion experiments. I must note that, because of constraints on my time and because of the large number of relevant papers, I have selected papers that seemed important and/or sparked my interest. My review necessarily does not cover all of the work referenced by DOE.

I also will not discuss the electrochemistry, calorimetry, and thermodynamics issues involved in cold fusion experiments, since these are outside my areas of expertise.

In the first case, section A below, I will present the results of my analyses that I believe are contradictory to the claims of a paper that has been cited as providing particularly strong experimental evidence for nuclear fusion, namely the paper on charged-particle detection of Jones et al., which was one of the additional papers distributed by DOE (cited in DoE31 as Ref. 94).

A. "The Jones Experiment" Concerning Charged-Particle Emission.

This paper by Jones et al. was presented at the Tenth International Conference on Cold Fusion. The paper shows data obtained with nuclear particle counters, and claims direct evidence for the fusion reaction, d + d → 3.02-MeV protons + 1.01-MeV tritons, from the observation (a) of protons in a solid scintillator array, and (b) of protons and tritons in silicon particle-detectors.

In summary of this part of my review, I believe that my analyses and comments about the data by Jones et al. raise serious doubts about the so-called definitive identification of protons from cold fusion.

2) Review #10

Preamble

It has been about 15 years since the first ERAB report appeared and it is appropriate to examine the work in the area of cold fusion (or LENR) that has been carried out in the interim. A fair appraisal can be clouded by the cultural problems in this field. There are "true believers," whose judgment may be clouded by a confirmed belief in the reality of chemically driven nuclear events and the perceived need to defend the field. There are also the "confirmed disbelievers," who are so bothered by the fact that the results do not follow the established nuclear paradigm that they won't even examine the results, a position that is equally dangerous. Many papers (~3,000) have appeared during this time period, making a complete evaluation very difficult, especially in the limited time available. However, a reasonable picture can be obtained from the review by Hagelstein, McKubre, Nagel, Chubb, and Hekman (HMNCH) and some of the references therein, indicated in what follows as (ref. x) and the presentations at our meeting. Nevertheless, there are real difficulties in assessing the work. As Antoine Lavoisier wrote in 1784, when faced with an analogous task, "The art of concluding from experience and observations consists of evaluating probabilities, in estimating if they are high or numerous enough to constitute proof. This type of calculation is more complicated and more difficult than one might think."

My comments focus on the calorimetry and electrochemical aspects, which are closest to my area of expertise.

Response to the Charges

Is the evidence sufficiently conclusive to demonstrate that such nuclear events occur? At this stage, I think the evidence suggests the possibility of such events, by cannot be considered conclusive beyond a reasonable doubt, for reasons alluded to above.

Is there a scientific case for continued efforts in these studies? Identify promising areas. I don't think there is a case for focused funding in this area. After 15 years and at least $60M spent on this area, it is doubtful whether there is much to be learned from more of the same type of research. However there remain interesting unanswered questions about these systems and DOE should be willing to entertain novel proposals in this general area. For example calorimetry with anodes that can oxidize D_2 (fuel cell anodes), if they can be made to operate in closed cells at the needed current densities, especially with a cell resistance minimized by close spacing of anode and cathode, would be interesting. These experiments they would eliminate O_2 evolution and possible attendant reactions and also probably decrease side reactions like Li deposition.