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Cold Fusion Explained at the Operational Level
Edmund Storms
Santa Fe, NM, USA

ABSTRACT
All phenomena of nature create two separate questions needing an answer. The scientific question asks WHY a process occurs, and the engineering question involves HOW the process works and can be made useful. These two questions are only marginally related. Either question can be correctly answered without knowing the answer to the other. The cold fusion discovery has been handicapped by an overemphasis on the scientific question. Instead, this paper focuses on HOW cold fusion works and HOW it can be made useful. A successful answer would allow the creation of a material having an infinite ratio of created power to applied power (COP).

This is a proposed transcript of a future talk that is provided with the hope to encourage enlightened discussion about the subject at the time the talk is given. More details can be found in the paper "A New and Improved Understanding of Cold Fusion Based on the Observed Behavior", which will be published in CMNS vol 41 and is available at LENR.org as my talk at ICCF26.

1. Introduction

The science of cold fusion has a problem. Most of the explanations are not designed to show how this source of energy might be used to create a working generator. Worse, very little agreement exists between the many explanations, most of which have very little relationship to observed behavior or established knowledge. So, at the risk of being really annoying to those of you who have a favorite explanation, I will describe an understanding that I propose is required to create a source of practical energy using cold fusion.

I will address HOW cold fusion works, not WHY. The HOW focuses on the engineering variables and the physical conditions required to cause and modify the amount of energy being produced. In contrast, the WHY focuses on the mechanism, in this case the mechanism involving the fusion reaction itself. This reaction is not addressed here. Instead, this scientific understanding is best discovered starting with HOW. Then, based on this accepted understanding, work toward an understanding of WHY fusion occurs, rather than the other way around, which is how most explanations are structured

All explanations start with assumptions. These assumptions guide the thinking and determine the kind of measurements. In addition, the assumptions frequently determine how the measurements are explained. For example, if fusion were assumed caused by neutron formation, then the studies would be designed to detect neutrons and measure their energy. If neutrons were observed, their presence would be used as support for an explanation. Such an effort would give the wrong explanation if the assumption were wrong. In this case, the assumption is wrong because neutrons are not emitted by the fusion reaction. Instead, the transmutation reactions emit the detected neutrons. But, that is a subject for a different talk." The nature of transmutation and its relationship to low-energy fusion of deuterium", see LENR.org

Here, I will start by clearly identifying my assumptions.

2. Three assumptions
1. Ochham's razor- of two competing theories, the simpler explanation of an entity is to be preferred.

-This old classic should be applied to every theory.

2. A single universal mechanism causes the fusion event at a unique site regardless of the material or the treatment.

- This assumption is based on the belief that a behavior so unique and rare would not result from more than a single mechanism or occur frequently at the many normal sites in a material.

3. The mechanism and behavior are consistent with the rules that apply to a chemical environment.

-This condition is required because the process occurs in a chemical structure. The rules that apply to such an environment are well understood. In addition, such a structure is held together by energy at the eV level. Therefore, energy above this limit cannot be spontaneously localized or applied without it being absorbed by the structure before it can cause nuclear interaction. In other words, energy amplification caused by resonance, super heavy electrons, or energetic phonons cannot exist in such a structure.

These assumptions invalidate most explanations.

3. General requirement for energy production
All sources of energy involve the same general features. Here, I use the automobile engine as an example, as shown in Fig.1. In this case the Chemically Active Environment (CAE) is the cylinder where the energy is released. The fuel is stored in the fuel tank, and delivered to the CAE by the fuel pump. The number of cylinders and the rate at which the fuel is delivered to this CAE determines the power.
Likewise, in the case of cold fusion, the fuel is stored in the lattice structure and delivered to the site where energy is released by diffusion. The number of Nuclear Active Environment (NAE) and the diffusion rate determine the amount of power. Success in applying cold fusion as a source of energy involves the understanding and the control of these events.
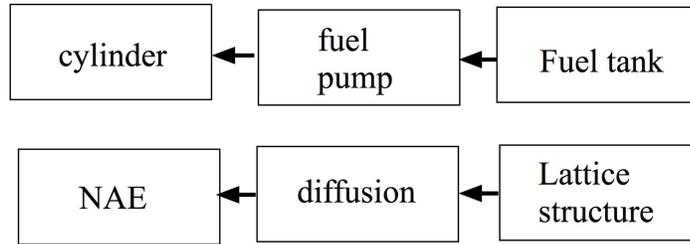
FIGURE 1. Relationship between the mechanisms operating in an automobile engine and during cold fusion.

We have only two problems to solve. A large number of NAE must be created and the rate at which the fuel enters the NAE must be controlled and increased.

5. Summary of Controlling Variables

The following equation identifies the variables that determine how much power can be produced by a material. Of these, the value of N, the number of NAE, is the most important. The maximum amount of power that can be produced by a sample is determined directly by the number of NAE present. The failure to produce cold fusion results ONLY from the absence of enough NAE to make detectable power or radiation.

The next variable of importance is the temperature because it has an increasingly larger effect on the amount of power as it is increased. This results in positive feedback as was identified by Fleischmann thirty-seven years ago. As a result, if the number of NAE is too great, the material will self-melt, as has been observed. Therefore, the number of NAE must be controlled.

And finally the applied current is important because it can be used to increase and rapidly change the amount of power. The other variables have less importance.

Equation describing the controlling variables.

$$P = N * \exp(-E/(RT)) * I^2 * H * f(T,p)*C * dC/dx$$

P – fusion power (watt)
T – temperature (K)
N - number of NAE in the sample being studied.
H - number related to the D/(D+H) ratio with the smallest value being produced when 100% H is present and the largest value when 100 % D is present in the material.
C - number related to fuel concentration ratio (D,H/Pd). The ratio is only important at very low and very high values. It has no effect on the power over most of the range.
dC/dx – concentration gradient. The motion of ions through the gradient would increase the chance of an encounter between a D or H and the NAE.
E - activation energy for the process. The value depends on the material.
I - number related to the electron current passing through the source of fuel. An applied magnetic field will increase the effect of this variable.
R - gas constant
p – effective gas pressure of H_2 or D_2.

6. Basic Nature of the Nuclear Active Environment ((NAE)

The first problem to solve is the correct identification of the nuclear active environment. This condition is observed to have several important features. These features limit how the NAE needs to be studied and explained

OBSERVED: The fusion reaction requires and occurs only at certain sites within the material. These sites are not unique to PdD.
OBSERVED: These sites are created by the treatment. They are normally not present.
OBSERVED: Several very different treatments can create the same kind of sites.

Requirement: The site must be consistent with the surrounding chemical environment.

7. Proposed Nature of the NAE

In order to create the NAE on purpose, it must be correctly identified as to its relationship to the chemical structure. Two different kinds of NAE are being considered, as shown as schematic cartoons in Fig. 2. The conventional understanding supported by Staker[1] describes the NAE as Pd atom vacancies that form a special kind of structure in the fcc PdD. The face-centered cubic structure is shown as the first figure.

On the other hand, for over 20 years, I have described the NAE as physical gaps or voids having no relationship to the fcc crystal structure, but with a critical size. These accidental flaws disrupt the electron relationship in certain locations so that the normal rules no longer apply. The second figure shows a typical flaw that is surrounded on all sides by Pd atoms and their electrons. This kind of flaw can be produced in any material.

Creation of these two different structures requires the application of entirely different treatments. Therefore, effective creation of the NAE requires it to be correctly described.

The following treatments have produced active material. The same NAE would be expected to be produced in each chemical structure. Other researchers have replicated several of these methods.

TABLE 1
Examples of successful treatments to produce nuclear active material

Researcher	Material	Treatment	Result
Fleischmann+Pons	Pd	Long electrolysis in D_2O +LiOD	Deposit of Li, many flaws
Takahashi et al.	Zr+Pd+Ni	Oxidation	Powder ZrO_2+metals
Storms	Pd + CaO particles	melting	Small particles of CaO imbedded in Pd metal
Zhao et al.	Small particles of Pd	Sintering	Porous structure
Dardik et al.	Pd	Superwave	Many flaws
Mizuno et al.	Ni mesh	Sanding+Pd deposit	Many flaws
Iwamura et al.	Pd on CaO	React with D_2	Stress cracks

fcc Lattice Structure

NAE

Cross Section View

○ D Atom

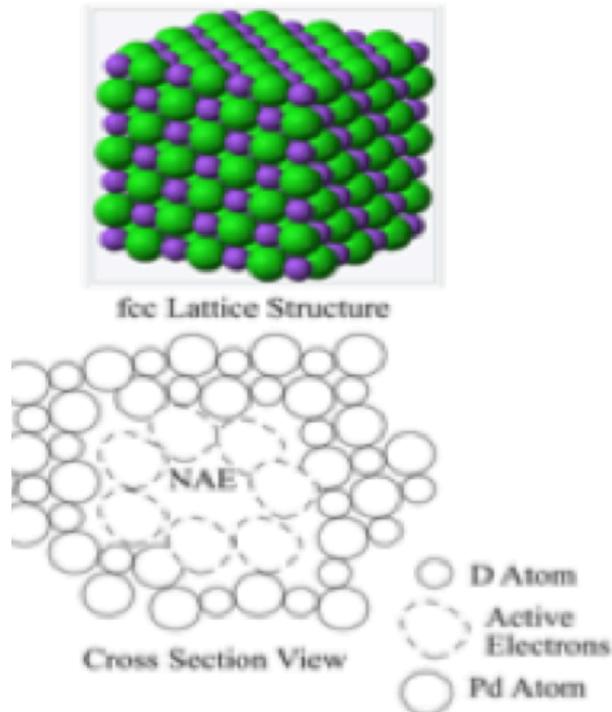◌ Active Electrons

○ Pd Atom

FIGURE 2. Comparison between the two proposed NAE, with the top drawing showing the structure in which the conventionally understood NAE is located. The lower drawing shows the proposed NAE as gaps or flaws in the atom arrangement. The gap is a three dimensional structure surrounded by metal atoms in a chaotic arrangement.

8. Popular understanding of the NAE

Let's examine the popular understanding in more detail. The main architects of the present accepted understanding are McKubre and Staker[2]. The phase diagram (Fig. 4) was created by Staker[1]. The effect of D/Pd (Fig. 3) was measured by McKubre et al.[3]

The phase diagram created by Staker has no justification based on accepted methods. Instead, he assumes that cold fusion requires a new phase, which he places on the diagram so as to be consistent with the values in Fig. 3. In other words, he assumes his conclusions. The other proposed phases are based only on his imagination and the studies by Fukai[4, 5], which could not be replicated when an attempt was made. The proposed phase behavior would apply to high physical pressure (5 Gp) at high temperature (600°C), conditions that are not required for fusion to occur. In other words, the vacancy explanation and the proposed phase diagram have no experimental justification. Many other reasons to reject the idea can be identified when the rules of chemical behavior are applied. Yet, these conclusions continue to guide the efforts to create the NAE. This is an example of a major flaw in this field where people pay very little attention to accepted knowledge.

In addition, the model only applies to PdH,D when a large (D,H)/Pd ratio has been achieved and maintained because the proposed metal atom vacancies are proposed to form only at a large D/Pd ratio. The repeated success in causing fusion when the D/Pd ratio is small and the sample is heated cannot be explained by this model.
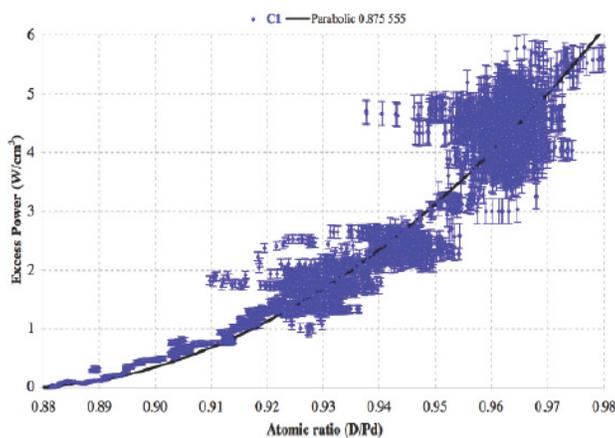
FIGURE 3. Effect of D/Pd ratio on the measured power at 20° C reported by McKubre et al. when using the electrolytic method. [3]
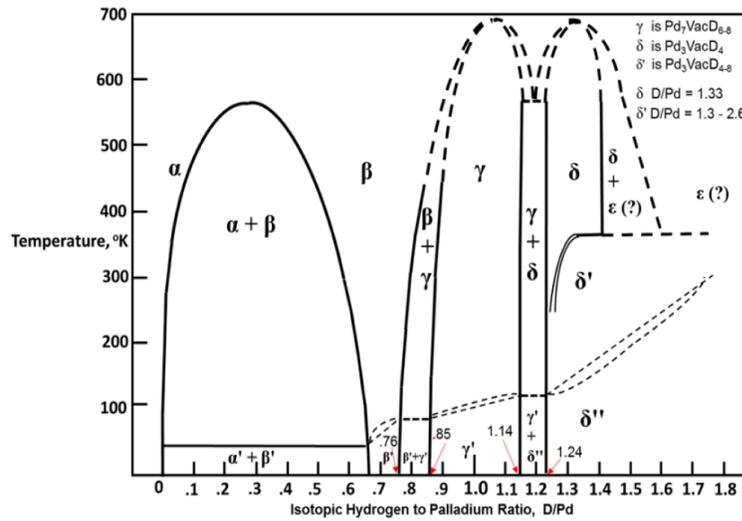

FIGURE 4. Phase diagram proposed by Staker. Fusion has been studied above 300K and at values of D/Pd less than 1.

No conventional method used normally to identify phase relationships, including the resistivity measaured by McKubre[6], supports this claimed phase relationship. The Staker-McKubre model is not consistent with observed behavior of cold fusion and cannot explain why fusion can occur at small D/Pd ratios and in other materials and structures.

9. Accepted phase diagram.
 The accepted phase diagram[7, 8] based on over 100 years of study is shown in Fig. 5. No phases have been identified above H/Pd = 1.0 when accepted methods are used.
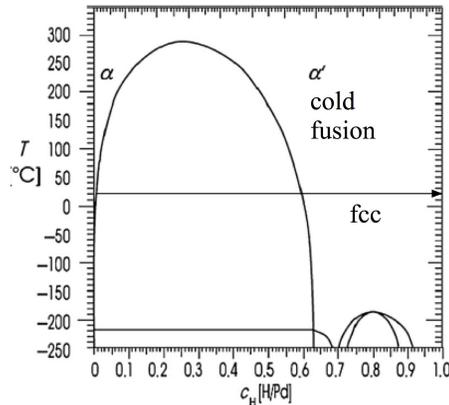
FIGURE 5. Accepted phase diagram.

The face centered cubic (fcc) structure exists throughout the system, with the upper boundary of the H/Pd ratio being near 1.0. The H or D vacancies form an ordered structure near -200° C. Random atoms are present in the tetrahedral sites, but this does not change the phase relationship. Pd atom vacancies are not observed to form in the fcc phase.

Cold fusion has been produced above the line shown at 20° C and over the composition range.

10. Less Popular Understanding of the NAE

The nuclear active flaw can be produced in any material by many very different methods, as summarized in Table 1. Each method is observed to produce many physical flaws in the material, which is the only feature they have in common.

A local disruption of the atom relationship frees the chemical electrons to achieve new relationships to the each other in the NAE. This allows the electrons to increase the local negative charge, which is proposed necessary for fusion to occur.

The challenge is to create the NAE at high concentration with high reliability using treatments known to produce such flaws. The critical requirement is the size of the flaw, with a required size between 1 and 10 nm being estimated.

This description is consistent with the observed behavior and conventional understanding. The Coulomb Barrier is real. It cannot be overcome by spontaneous local energy in a chemical system. The only other available method is for local electrons to reduce its magnitude. That cannot happen in a crystal environment because all of the electrons are in fixed energy states and therefore unavailable to interact with the barrier. So, we have to look elsewhere.

11. Operation of Fuel Transport
DIFFUSION

The diffusion rate can be described by the equation $R = A \exp(-E/(RT))$ where E is the activation energy, T is the temperature, R is the gas constant, and A is a variable that depends on other conditions.

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ELECTRO MIGRATION

When a voltage is applied across PdD, resulting in current flow, the D+ will respond to the voltage gradient and move to the negative electrode. This movement increases the probability of the D finding the NAE. Hence, the number of fusion reactions/sec is increased. A magnetic field will increase the effect of voltage (current) because it will increase the path length of the D+ as it moves to the negative electrode, thereby increasing the probability of encountering a NAE site. The local number of free electrons will also be increased.

12. Evidence for the effect of applied current

This process was called the Coehn effect[9] by Fleischmann[10]. Other people call the effect electromigration. The following studies showed evidence for the effect of applied current. However, each author explains the behavior in different ways. Because each describes a different mechanism, all cannot be correct according to Assumption #2. Nevertheless, these studies all demonstrate that the application of a current will increase the fusion rate.

The references to the studies are noted here. Staker[11], Celani[12] and Godes[13], Storms[14], Del Giudice et al.[15], Biberian et al.[16]

The effect of applied current has been observed by many studies but explained in many different ways, thereby creating confusion.

13. Observed Behavior

Figure 6 (B) compares various samples of solid Pd with different measured D/Pd ratios using electrolysis. All the lines are parallel, indicating that all samples have the same activation energy. The vertical position of the line is proposed to result from the number of NAE in each sample.

The results in Fig. 7 resulted from a solid piece of Pd subjected to electrolysis. The sample was first heated while electrolytic current was applied, resulting in an average measured D/Pd ratio above 0.8. The electrolytic current was then turned off. Measurements of power were made while the sample lost D. Finally, all of the D was removed and again heated in the cell without applied current. Notice that very little extra power was measured at 20°C and the D/Pd ratio had no effect on the power.

This sample and all the other examples shown here would have been considered dead if they had been studied only at room temperature using the calorimeter designs normally applied. In other words, cold fusion is easier to cause than the skeptics believe and many studies would demonstrate the reality of cold fusion if increased temperature had been used.
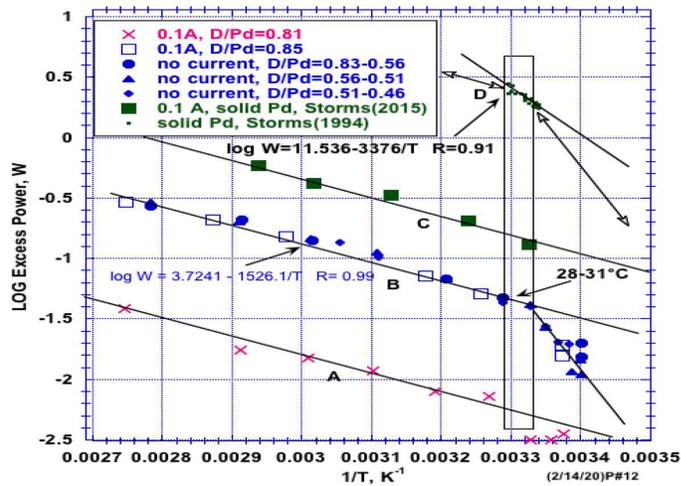
FIGURE 6. Various Pd samples heated in an electrolytic cell containing D_2O with and without applied current. Sample B was studied when different amounts of measured D were present.

Figure 7 compares the same sample when different D/Pd ratios are present. The D_2 was added using electrolysis. After the study, the D_2 was removed and the sample was again heated in the electrolytic cell using the same calorimeter. The cell is heated using external heaters.
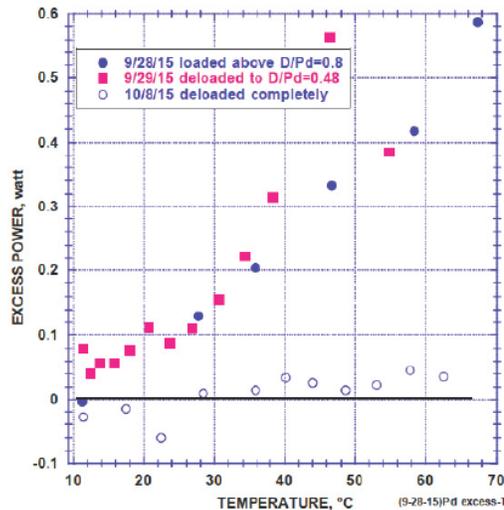

FIGURE 7. Pd plate heated in an electrolytic cell containing D_2O + LiOD.

The power in Fig. 8 resulted from pressing 325 mesh Pd powder into a compact solid. This treatment is proposed to produce the required active gaps between the small particles. The sample was first studied in an electrolytic cell with and without applied current. The sample was removed and then heated in a cell containing D_2 gas while using the same calorimeter. Notice that the D/Pd ratio has no effect and the same behavior occurs when either electrolysis is used and when the sample is heated in D_2 gas.
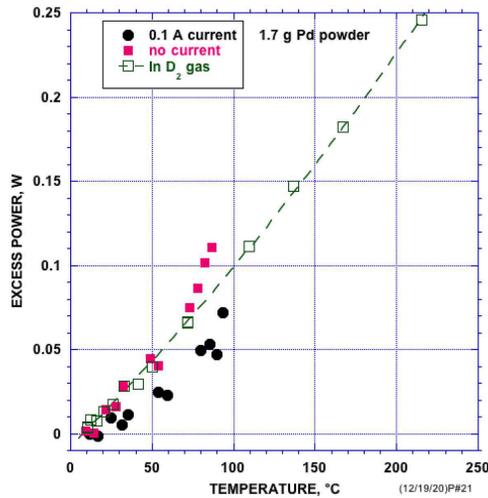
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FIGURE 8. Powdered Pd cold pressed to produce a solid and studied first in an electrolytic cell containing D_2O. The sample was then studied in D_2 gas. The D/Pd ratio changed with temperature when exposed to D_2 gas.

Figure 9 shows the effect of temperature when a sample of powdered Ni was cold pressed and heated in D_2 gas. Notice a change in activation energy at 60° C. This demonstrates how such a plot of the measurements can reveal important information about the process. Once again, the gaps between the sintered particles are proposed to be the NAE.
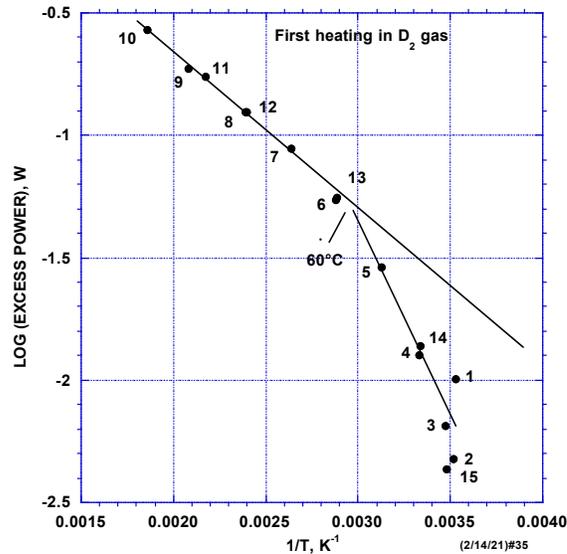

FIGURE 9. Powdered Ni cold pressed into a pellet and heated in D_2 gas. The numbers show the sequence in the measurements.

14. Observed Behavior

Figures 10 and 11 show the behavior of a powder created by heating an alloy of Ni-Pd-Zr in oxygen when heated in H_2. Notice that the absence of power at 20°C would identify this sample as dead if it had not been heated. Also, the activation energy for

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diffusion is smaller than for PdD. Note that otherwise, this material behaves exactly like the other examples.

This method of activation has been used in Japan by Takahashi et al.[17] The sample was provided by NASA.
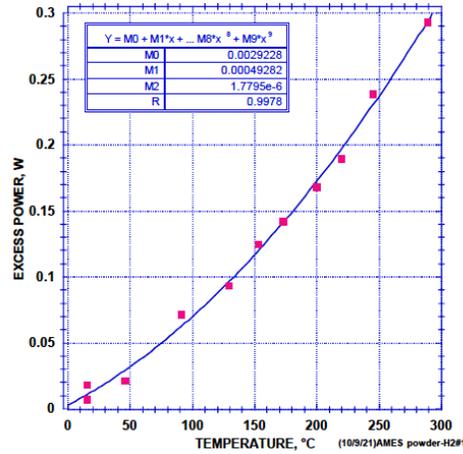

FIGURE 10. Powdered ZrO_2+(Pd-Ni-Zr-O) alloy heated in H_2 gas. The sample was first heated in intervals and then cooled. The calorimeter was allowed to reach steady state for 110 min between each temperature change.
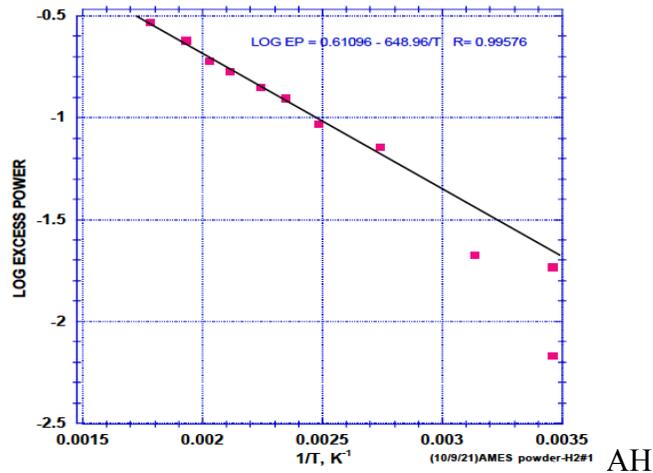

FIGURE 11. Plot of log power vs 1/T for the values plotted in Fig. 10.

These behaviors all demonstrate the following conclusions:
1. The D/Pd ratio is not important over most of the composition range.
2. The temperature is a critical variable to increase the number of fusion reactions/sec.
3. Many conditions and materials cause the same behavior.
4. Both D and H cause the same behavior.
5. The general behavior of cold fusion is the same for all materials and treatments.

15. Summary of Suggested Design Requirements

Here are a few suggested design requirements for a practical source of energy.

1. The material should contain enough NAE to self-heat to a temperature near 550° C when exposed to D_2 gas and when the external demand for energy is zero. Too much NAE can result in melting of the material.

2. The power can be dissipated from the active material through the surrounding gas by using a mixture of D_2 in He, with a low partial pressure of D_2 used to limit the fusion rate.

3. Current is applied to maintain a constant temperature as the energy demand changes. This method is effective because the effect of current is instantaneous.

4. The active material will have to be replaced as the NAE is destroyed by the accumulation of nuclear products. This important issue needs to be studied.

5 The transmutation products need to be extracted. Certain elements can be added in the active material to maximize the economic value of the transmutation product. For example, the use of Pd favors the production of silver.

6. Radiation protection, including neutron protection, will be required when high power is produced.

7. Use of D_2 that is free of H_2 is preferred to reduce the production of tritium.

16. Nature of the fusion process

So as not to ignore the theoreticians, the understanding of the nuclear process requires different questions and answers. These answers require the use of different behaviors and requirements. But this is the subject of a different talk for another time. At the very least, the following questions need to be answered.
 •These are:
1. How is the Coulomb barrier reduced?
2. Why is ^4H produced with a series of equally spaced energies?
3. How is momentum conserved?

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Copies of most papers listed here can be found at LENR.org.

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