ER-16
GCC
GCCarter/ses
12/2/91

ER-16
DLB
DLBarney
12/2/91

ER-16
WPolansky
12/3/91

DEC 3 1991

Dr. Frederick J. Mayer
Mayer Applied Research Inc.
1417 Dicken Drive
Ann Arbor, MI 48103

Dear Dr. Mayer:

This is in response to your letter dated November 11, 1991, that transmitted your hypothesis regarding charge-neutral "particles" embedded in solids, in a scenario involving their nuclear reactions.

I appreciate your interest in evaluating this hypothesis in the context of the cluster fusion experiments supported by the Division of Advanced Energy Projects (AEP), that are being performed by Buehler, Friedlander, and Friedman at the Brookhaven National Laboratory. While interesting results have been published on this subject, the present understanding of the processes attributed to cluster impact fusion, nevertheless, provides no compelling reason for this Division to expand its support of research in this area. Consequently, I cannot encourage you to submit a research proposal to develop your theory.

Let me emphasize that this evaluation only considered the proposed research in relation to funding priorities within AEP. It represents no judgement in terms of the scientific merit of the hypothesis.

However, you do have the option to seek funding from other sources. In this regard, I would encourage you to make sure that the members of the Brookhaven cluster-beam fusion research team are aware of your ideas.

Thank you for taking the time to inform me of your idea.

Sincerely,

Walter M. Polansky, Director
Division of Advanced Energy Projects
Office of Basic Energy Sciences, ER-16

DIVISION OF ADVANCED ENERGY PROJECTS, ER-16

OFFICE ROUTING SLIP

th regard to the attached: _____

Comments on this preproposal? (see comment below)

AEP

① W. M. Polansky Wm 11/15

② D. L. Barney _____

③ G. C. Carter _____ → then discuss

S. E. Stottlemyer _____

SBIR

S. J. Barish _____

S. H. Toms _____

P. Washington _____

K. I. Etzler _____

REMARKS:

Check out the Cold Fusion File. We've had some past correspondence with Mayer.

Please Indicate: File X Destroy _____

Name of File: Preproposal

Mayer
Applied
Research
Inc.

Applying Physics to Industry

1417 Dicken Drive Ann Arbor, MI 48103 313/662-3841

November 11, 1991

Dr. Walter M. Polansky, Director
Division of Advanced Energy Projects
Office of Basic Energy Sciences, ER-16
Department of Energy
Washington, D. C. 20585

Dear Dr. Polansky:

As you may remember, my colleague John Reitz and I had done some theoretical research in cold fusion. Recently, we have considered other anomalous experiments according to our hypothesis regarding charge-neutral "particles" that we have called hydrons. Enclosed is a preprint copy of our recent paper, "On Very-Low Energy Hydrogenic Nuclear Reactions", for your review. We believe that it contains important implications for the cluster-impact fusion program which we understand your office has helped to support. As you no doubt realize, we are in need of some support for our research (the previous work was privately funded). Because it is potentially very important, we would like to submit a proposal for some support to further our theoretical efforts and to suggest experiments for the Brookhaven group that could either prove or disprove our hypothesis. I am writing this letter as a pre-proposal, and to inquire whether you would encourage our submitting a proposal for model calculations and experiments design.

We think that there is some interesting new physics in these low-energy experiments; we hope that we might assist your office in an effort to understand it. I look forward to hearing from you soon.

Sincerely,

Fred Mayer

Frederick J. Mayer, PhD
President

ON VERY LOW ENERGY HYDROGENIC NUCLEAR REACTIONS

COLD FUSION

TECHNICAL NOTE

KEYWORDS: *hydrons, cluster-impact fusion, cold fusion*

FREDERICK J. MAYER *Mayer Applied Research Inc. 1417 Dicken Drive, Ann Arbor, Michigan 48103*

JOHN R. REITZ *2260 Chaucer, Ann Arbor, Michigan 48103*

Preprint - Fusion Technology 20 367, (1991)

Received May 30, 1991
Accepted for Publication June 27, 1991

Some results are described that derive from the assumption that very low energy (≈ 1 eV) electron-proton, electron-deuteron, and electron-triton resonance particle systems (denoted π-, δ-, and τ-hydrons) are created in various materials and experiments. Information regarding the resonance width and lifetime is extracted from the data of cluster-impact fusion experiments, and these experiments are discussed in connection with other anomalous experiments, including cold fusion experiments, which are examples of a new class of hydron-mediated nuclear reactions—resonant direct nuclear reactions.

INTRODUCTION

In recent years, numerous experiments have been performed that, in one way or another, appear to be associated with nuclear reactions but in an energy regime so low as to make them, in effect, seemingly impossible. Some of these experiments have led to substantial controversy, as in the case of the Fleischmann and Pons[1] experiments; some, such as the experiments of Buehler, Friedlander, and Friedman[2] (BFF), have led to astonishment; while others, such as the experiments of Lochte-Holtgreven,[3] have gone largely unnoticed. This technical note attempts to tie all of these seemingly disparate experiments together under one straightforward and basic theory of low-energy hydrogenic nuclear reactions.

Although these experiments are characterized by widely differing material configurations, they have a common thread—they all incorporate heavy hydrogen (deuterium) as one species in their active media. In the case of the Fleischmann-Pons experiments, deuterium is electrolytically loaded into a room temperature metal (e.g., palladium); deuterium is one component of a near-solid, heated plasma in the BFF experiments; finally, deuterium is a gaseous component in a lower density, low-temperature plasma in the Lochte-Holtgreven experiments. It is well known that to obtain finite, i.e., measurable, deuteron-deuteron (*d-d*) nuclear reactions, a plasma temperature of the order of 1 keV or higher is required to overcome the Coulomb barrier. Since, in all of these experiments, the temperatures do not exceed about a few tens of electron-volts, it is often stated that no nuclear reactions are possible because the *d-d* reaction would be expected to have the lowest Coulomb barrier, hence the highest reaction rate. We hope to show that this reasoning is only partially correct because it assumes that the incoming particles (deuterons) *always* have a charge of +1. If a short-scale screening mechanism exists, then barrier penetration is readily achieved, with much higher attendant nuclear reaction rates. That such screening does, indeed, lead to very strongly increased reaction rates has been clearly demonstrated in the case of muon-catalyzed fusion,[4] in which a muon of mass ~200 times that of an electron effectively screens out the electrostatic field of a hydrogen nucleus down to a dimension of ~260 F, giving rise to the strongly increased reaction rates observed in such experiments.

Recently, Benesh, Spence, and Vary[5] (BSV) suggested that an electron continuum bound state (resonance) is to be expected in electron-hydrogenic scattering systems. These resonances or "virtual-state" particles may exist long enough to charge neutralize a hydrogenic nucleus and, in a manner similar to that of muon-catalyzed fusion, allow for easy Coulomb barrier penetration and hence nuclear reactions of the hydrogenic system and its charged collision partner. On the basis of their quantum electrodynamic (QED) calculations, BSV estimated that the electron scattering resonance energy is only of the order of a few electron-volts, but perhaps most interesting is the fact that the virtual particle (*e-p*) is an extremely compact object of the order of a few fermis.[a] Furthermore, Benesh, Vary, and Spence[8] (BVS) applied the virtual particle concept in an attempt to understand the astonishing results of the "cluster-impact" fusion experiments of BFF, albeit with limited success. We believe that the large number of "strange" apparently nuclear reactions in these experiments, as well as other anomalous observations, may all be attributable to the existence and interactions in matter of

[a]Although QED calculations of the BSV type are expected to be the most accurate method for determining the properties of this compact "particle" resonance, we mention that its formation depends on a strong attractive interaction of short range. Our preliminary calculations[6] indicate that the magnetic dipole-dipole interaction (believed to be the important interaction governing compact e^+e^- resonance formation; see, for example, Wong and Becker[7]) is large enough to make the resonance particle size ~1 to 2 F.

these electron-hydrogenic resonance systems. We consider the resonance energy E_R to be ~1 eV (because of our fits to some data), but the derivations given here are more general and E_R can be considered a parameter.

For convenience, we give these compact particles a name: *hydrons*. We denote these electron continuum bound-state resonances as follows: the *e-p* resonance as the π-hydron, the *e-d* resonance as the δ-hydron, and the *e-t* resonance as the τ-hydron. Note that during their brief lifetimes, the π-hydron behaves very much like a neutron, the δ-hydron like a dineutron, and the τ-hydron like a trineutron, except that their nuclear reactions are different from their "real" neutron counterparts. It is very important to determine the characteristics of such particles, and in particular, their lifetimes. BVS made a fit to the BFF data to extract an estimate of the δ particle's lifetime, arriving at a value of the order of tens of milliseconds, an extremely long time on the atomic scale. Furthermore, to have important implications, it is only necessary that the resonance particles live for times that are long compared to typical atom-atom collision times of $\approx 10^{-14}$ s.

We present a set of calculations for estimating the nuclear reaction rates and characteristics of this new class of hydrogenic objects. We then connect our results to some available data that we believe demonstrates that these neutral, virtual particles (the hydrons) play the major role in the "strange" experiments. A detailed explanation of the so-called "cold fusion" experiments (e.g., the Fleischmann-Pons experiments) has been presented elsewhere.[9]

THE SCREENED COULOMB PENETRATION CALCULATION

Because it is the dominant process limiting nuclear reactions at low energies, we estimate the effect of screening on the barrier penetration with a simple model. We use a modified Wentzel-Kramers-Brillouin approximation and assume a sharp cutoff type of screening; i.e., the Coulomb barrier potential is unaffected for $R_n < r < r_s$, and it is zero for $r > r_s$, where R_n and r_s are the nuclear radius and the screen length, respectively. It is easy to show that in the limit $r_s/r_c \ll 1$, the penetration exponent Γ goes as [remembering that the barrier penetration factor is $P \approx \exp(-\Gamma)$]

$$\Gamma = \Gamma_c[(4/\pi)r_c^{-1/2}]\,(r_s^{1/2} - R_n^{1/2}) \ , \qquad (1)$$

where

$\Gamma_c = \pi[(2\mu)^{1/2}/h]\,(Z_1 Z_2 e^2/E^{1/2})$ = usual unscreened penetration exponent

$r_c = Z_1 Z_2 e^2/E$ = distance of closest approach in the unscreened Coulomb potential.

Substituting numbers, this equation becomes

$$\Gamma = 1.06(Z_1 Z_2 \mu_a)^{1/2}(r_s^{1/2} - R_n^{1/2}) \ , \qquad (2)$$

where

μ_a = reduced mass (amu)

R_n, r_s = nuclear radius and screen length (F).

With $R_n \approx 1.3A_2^{1/3}$ F, note that if the screen length is roughly a few fermis, the penetration exponent is still about zero; i.e., almost complete penetration to the nuclear surface can take place. Hence, the penetration factor $P = \exp(-\Gamma) \approx 1$. Therefore, the cross section for the resonance particle (π, δ, or τ) interaction with another nucleus may be approximately taken to be (in astrophysical notation)

$$\sigma(E) = S(E)/E \ , \qquad (3)$$

where $S(E)$ is the usual astrophysical S factor (keV·b) and E is, in the present case, in the range of only a few electron-volts.

THE NUCLEAR REACTION RATES

In the following, the notation refers to the case of a δ-hydron reacting with a partner, but it should be clear that all of the formulas are easily generalized to the other hydron interactions.

We follow the calculation outlined by Rolfs and Rodney.[10] The relevant formula for the reaction of δ-hydrons is Rolfs and Rodney's Eq. (4.17) with complete screening, that is, taking $b = 0$. The average of the cross section over a Maxwell-Boltzmann energy distribution (at temperature T) is

$$\langle \sigma v \rangle_s = (8/\pi\mu)^{1/2}(kT)^{-1/2}S(0)$$
$$= 1.5 \times 10^{-15}(\mu_a T)^{-1/2}S(0)\ \text{cm}^3/\text{s} \ , \qquad (4)$$

with $S(0)$ in kilo-electron-volt-barns and T in electron-volts. The usual unscreened *d-d* rate is given by

$$\langle \sigma v \rangle_u = 7.2 \times 10^{-19}\zeta^2 \exp(-\zeta)S(0)\ \text{cm}^3/\text{s} \ , \qquad (5)$$

with $\zeta = 197T^{-1/3}$. The total reaction rate (per cubic centimetre) of a mixture of δ and d particles would then be given by

$$r = n_\delta n_d \langle \sigma v \rangle_s + (n_d n_d/2)\langle \sigma v \rangle_u \ , \qquad (6)$$

where n_d is the deuteron number density. An example of the effect of the δ particles on the total *d-d* nuclear reaction rate is shown in Fig. 1, where we plot $r10^{19}/n_d^2$ as a function of temperature for three different fractional numbers of δ particles ($n_\delta/n_d = 10^{-13}$, 10^{-11}, and 10^{-9}), and we have taken $S(0) = 55$ keV·b. These curves show that substantial reaction

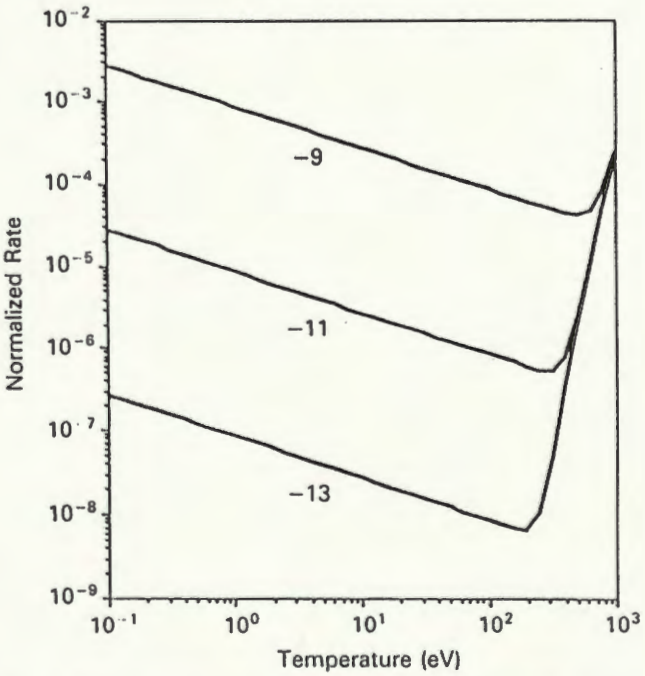

Fig. 1. The normalized *d-d* nuclear reaction rate ($r\ 10^{19}/n_d^2$) as a function of temperature. The parameter on the curves indicates the value of $\log_{10}(n_\delta/n_d)$.

rates are therefore possible even with relatively small numbers of δ-hydrons. This is, of course, the result of the electron scattering resonance providing easy Coulomb barrier penetration. Clearly, the number of δ particles produced under various conditions is a most important consideration.

RESONANCE PARTICLE PRODUCTION

To calculate the rate at which the resonance particles are created, we again follow the Rolfs and Rodney derivation[10] for sharply peaked resonance reactions. These authors display the velocity-averaged integration over the strongly peaked cross section of the (approximately) Breit-Wigner type. In the present case, Rolfs and Rodney's Eq. (4.56) becomes

$$\langle \sigma v \rangle_R = (2\pi/\mu kT)^{3/2} h^2 \omega \gamma_R \exp(-E_R/kT) \ , \qquad (7)$$

where

$\mu = m_e m_d/(m_e + m_d) \approx m_e$ = reduced mass

E_R = electron scattering resonance energy

T = electron temperature

ω = spin factor of order one

$\gamma_R = \Gamma_a \Gamma_b (\Gamma_a + \Gamma_b)$

Γ_a, Γ_b = energy widths for elastic and resonance scattering, respectively.

Substituting numbers, we have

$$\langle \sigma v \rangle_R = 3.12 \times 10^5 T_e^{-3/2} \eta \exp(-E_R/T_e) \ \text{cm}^3/\text{s} \ , \qquad (8)$$

where E_R and T_e are now in electron-volts, and $\eta = \omega\gamma_R$. Note that the resonance particle lifetime τ_n, and the resonance energy width are related by $\Gamma_b \tau_n = h$, so that with $\Gamma_a \gg \Gamma_b$,

$$\langle \sigma v \rangle_R \tau_n = 3.3 \times 10^{-22} \omega T_e^{-3/2} \exp(-E_R/T_e) \ \text{cm}^3 \ . \qquad (9)$$

Equation (9) relates the reaction rate to the δ-hydron lifetime. However, in general, mechanisms other than spontaneous decay of the δ particles are important, thereby reducing the δ particle's lifetime below that given by Eq. (9). We now look at some interesting time-dependent effects controlling the δ-particle population. Notice that the peak δ-particle production rate occurs for an electron temperature of $T_e = (\frac{2}{3})E_R$.

RESONANCE PARTICLE POPULATION DYNAMICS

The number of δ-hydrons present under specific circumstances depends on various time scales and whether steady state has been achieved. Here we derive the population density of δ particles for the important case in which we assume that the electron temperature remains constant (to make $\langle \sigma v \rangle_R$ a constant). The δ particles decay by either collisional decay with nuclei (or possibly electrons) or by natural decay after a lifetime τ_n. We refer to collisions with nuclei in the following. The population equation may be written as

$$dn_\delta/dt = n_e n_d \langle \sigma v \rangle_R - n_\delta (\tau_n^{-1} + \tau_{coll}^{-1}) \ , \qquad (10)$$

where

n_e, n_d = electron and deuteron (ionized deuterium atoms) densities, respectively

$\langle \sigma v \rangle_R$ = reaction rate per pair per cubic centimetre.

The collisional decay time is given by $\tau_{coll}^{-1} = n_n \langle \sigma v \rangle_n$, where n_n and $\langle \sigma v \rangle_n$ are the nuclear density and velocity-averaged collisional decay rate, respectively. If the collisions between δ particles and the nuclei are like "hard spheres," we might expect $\langle \sigma v \rangle_n \approx \pi R_n^2 v_n \approx 5 \times 10^{-20} A^{2/3} (T/\mu_a)^{1/2}$ cm^3/s. The solution to Eq. (10) is

$$n_\delta = [n_e n_d \langle \sigma v \rangle_R \tau_n / (1 + \tau_n/\tau_{coll})][1 - \exp(-t/t_s)] \ , \qquad (11)$$

with

$$t_s = \tau_n/(1 + \tau_n/\tau_{coll}) \ . \qquad (12)$$

If the source producing the ionization is removed, the first term in Eq. (10) goes to zero, and the δ-particle density falls exponentially. If we go to the steady state ($t \gg t_s$), then the δ-particle density is given by

$$n_\delta = n_e n_d \langle \sigma v \rangle_R \tau_n/(1 + \tau_n/\tau_{coll}) \ . \qquad (13)$$

If the collisional decay time is short compared to the natural decay time (high densities), then the steady-state δ-particle density is independent of the lifetime:

$$n_\delta = n_d n_e \langle \sigma v \rangle_R \tau_{coll} \ . \qquad (14)$$

Now, at early time ($t \ll t_s$), the δ-particle density from Eq. (11) is given by

$$n_\delta = n_e n_d \langle \sigma v \rangle_R t \ . \qquad (15)$$

We use this result later after estimating an important parameter in the resonance particle system—the line width Γ_b.

A CLUSTER-IMPACT FUSION MODEL

Important experiments were recently reported by BFF in Ref. 2. In these experiments, clusters of heavy water molecules were accelerated to a few hundred kilo-electron-volts and allowed to impact on deuterated targets (TiD, ZrD, deuterated polyethylene-CD_2). These researchers found that *d-d* nuclear reactions were induced in the cluster impact, yet the expected maximum reasonable numbers of such reactions based on high-energy deuteron barrier penetration was some ten or more orders of magnitude smaller than those observed. We believe that the production of a relatively small number of highly reactive δ-hydrons during the cooling of the target and cluster material to only a few electron-volts is the likely explanation of these experiments, as we show later. As mentioned earlier, this possibility has already been put forward in a different cluster impact model[8] by BVS, who attempted to extract the resonance energy and line width from both the BFF data and from some more recent data from Buehler et al.[11] After describing our cluster-impact fusion model, we compare our results to those of BVS.

We propose a model of the impact fusion process based on the following physical processes. A cluster of heavy water molecules (≈200) carrying kinetic energy of the order of a few hundred kilo-electron-volts deposits its energy into a target material by both electron conduction heating along the slowing-down path and direct nuclear scattering of some of the target nuclei encountered. This process spreads the initial cluster kinetic energy among numerous dissociated target atoms, ions, and electrons of the cluster material and a larger amount of target material. It is simple to show that the power deposition from the clusters must be of the order of 10^{14} W/cm^2. At these power levels and with temperature gradient lengths of approximately the cluster radius, the electron's heat conduction is saturated (or "flux limited"), and an electron thermal wave moves outward from the deposition region at a characteristic velocity $v_{ch} = f_L c_e = f_L (kT/m_e)^{1/2}$, where the

so-called "flux limit" parameter f_L has been estimated to be about $f_L \approx 0.4(2/\pi)^{1/2} = 0.32$. A good discussion of saturated electron heat conduction can be found in, for example, Ref. 12.

The kinetic energy deposition time lasts only a short time ($\approx 10^{-14}$ s), approximately the time it takes the cluster to travel a distance of its own radius. During this period, the energy is thermally conducted into a volume larger than the initial cluster size, and because of the high density and relatively high temperature, pressure gradients then hydrodynamically accelerate some of the target material outward, creating a crater.

A fully consistent plasma model for this complex interaction must take account of the cluster kinetic energy deposition of both cluster and "knock-on" nuclei, the ionization of the cluster and target atoms, the thermo- and hydrodynamic expansion of the deposited energy, and the nonequilibrium effects that may be important because of the short time scales and high energy densities involved in these experiments. This complex model is outside the scope of this technical note. We instead approximate the cluster-impact events with a model in which the incoming cluster deposits its kinetic energy as thermal energy in a conduction-heated zone extending some to-be-determined distance into the target material. This is clearly a very simplified model, but it does show the effects of target heating on the cooling of the cluster particles in a way that is, at least, straightforward, and it conserves energy; furthermore, it is similar in spirit to a model presented in Ref. 13.

It is useful to list some of the quantities of interest in our model and to be specific about the cluster and target numbers for better understanding. The notations and definitions that we adopt follow. The cluster radius and volume are given by $R_{cl} = 2 \times 10^{-8} N_{cl}^{1/3}$ cm, and $V_{cl} = 4\pi R_{cl}^3/3$ cm^3, where N_{cl} is the number of water molecules in a cluster. The velocity of the cluster is $V_0 = 9.78 \times 10^6 (E_{cl}/N_{cl})^{1/2}$ cm/s, where E_{cl} is the cluster energy in kilo-electron-volts, $n_w = 3.3 \times 10^{22}$/cm^3 is the D_2O density, and $n_t = 4.1 \times 10^{22}$/cm^3 is the CD_2 density.

We consider the plasma created by the slowing-down nuclei to be in thermal equilibrium to determine the number of electrons and ions among which the deposited kinetic energy is distributed. We used an ionization equilibrium model of the Saha type[14] to self-consistently determine the ionization level and the ionization energy that is expended to produce this level of ionization. We then curve fit the results of these calculations for both heavy water and deuterated polyethylene (CD_2). The curve fits take the following form (normalized quantities are per water molecule):

Electrons:

$$x_e = n_e/n_w = \exp(-6.4/T)\,[T^{2/3}/(1 + 0.12T^{2/3})] \ ,$$

Deuterons:

$$x_d = n_d/n_w = \exp(-6.4/T)\,[T^{2/3}/(1 + 0.5T^{2/3})] \ ,$$

and

Ionization Energy:

$$E_i = x_e(12 + 0.07T) \text{ eV} \ , \tag{16}$$

where T is in electron-volts. The curve fits are accurate only to $\sim 20\%$. We used these curve fits (x_e, x_d, and E_i) to determine the average temperature of the heated zone in the target.

We distribute the cluster kinetic energy over the total number of particles (neutrals, ions, and electrons), the ionization energy, and ~ 9 eV per molecule of dissociation energy to self-consistently find the temperature and the number densities of each species. We define the energy (in electron-volts) deposited to cluster and target material as

$$E_{dep} = N_{cl}[(\tfrac{3}{2})(3 + x_e)T + E_i + 9]f \ , \tag{17}$$

where we have introduced a constant f, which is the ratio of the total number of molecules heated (cluster plus target) to the number of cluster molecules. This result, Eq. (17), should be a good approximation for the higher energy (300-keV) clusters. For the lower energies, the cluster molecules are probably not completely dissociated. The time scale for the heating (and cooling) should be quite closely given by the cluster-impact "collision" time $t_c = R_{cl}/V_0$, which is of the order of 10^{-14} s. Since the electron thermal conduction is saturated, the heated volume increases during the collision time to a value of approximately

$$V = (4\pi/3)(R_{cl} + v_{ch}t_c)^3 = V_{cl}f \quad \text{with } f = (1 + f_L c_e/V_0)^3 \ . \tag{18}$$

We use the flux limit parameter as a fitting parameter although we expect its value to be ~ 0.32, as mentioned earlier. The energy balance is now written

$$1000E_{cl} = E_{dep} \ , \tag{19}$$

with E_{cl} in kilo-electron-volts and E_{dep} in electron-volts. Equations (17), (18), and (19) are iteratively solved using the temperature-dependent Saha parameters, Eqs. (16), for the self-consistent temperature. Once the temperature has been determined, we use Eq. (15) to determine the number of δ particles created during the cluster-impact heating time.

Therefore, taking $S(0) = 55$ keV·b and $t = t_c$ in Eq. (16) and using Eq. (4) in Eq. (7), we calculate the number of reactions that should be observed for given values of f_L and $\eta = \omega\gamma_R$. For example, the number of protons generated during the cluster-impact collision time can be shown to the given by

$$N_p = 2N_{cl}x_e x_d\{n_t\langle\sigma v\rangle_s t_c\}\{n_t\langle\sigma v\rangle_R t_c\} \ , \tag{20}$$

and this expression can be evaluated once the self-consistent temperature has been determined. Further, note that f enters the temperature estimate but not the reaction estimate.

Using this simple heat conduction and energy balance model, we fit the Beuhler et al. data[11]; the results are shown in Fig. 2. We adjusted f_L and $\eta = \omega\gamma_R$ to bring the model calculations and the data into agreement. The value of f_L that produces the full curve in Fig. 2 is $f_L = 0.38$, fairly close to the expected value of 0.32. The shapes of the yield curves versus N_{cl} are quite sensitive to the value of f_L because of the cubic dependence indicated in Eq. (18). This sensitivity is shown by the dashed curves in Fig. 2 for $f_L = 0.33$ and 0.43. The ratio of the total number of heated molecules to the number of cluster molecules is ~ 42 over the range of cluster sizes in the data of Fig. 2. The self-consistent temperatures for the best-fit solid curve is also shown in Fig. 2. Both the number of heated molecules and the temperatures so obtained are in good agreement with those estimated in Ref. 13. Although the fit to the data is reasonably good for a simple model, other effects mentioned earlier (e.g., incomplete molecular dissociation) may come into play and thus require additional study.

Our model, although inexact in the sense that it only approximates the thermo-, hydro-, and ionization dynamics, has already approximately the correct behavior as far as the

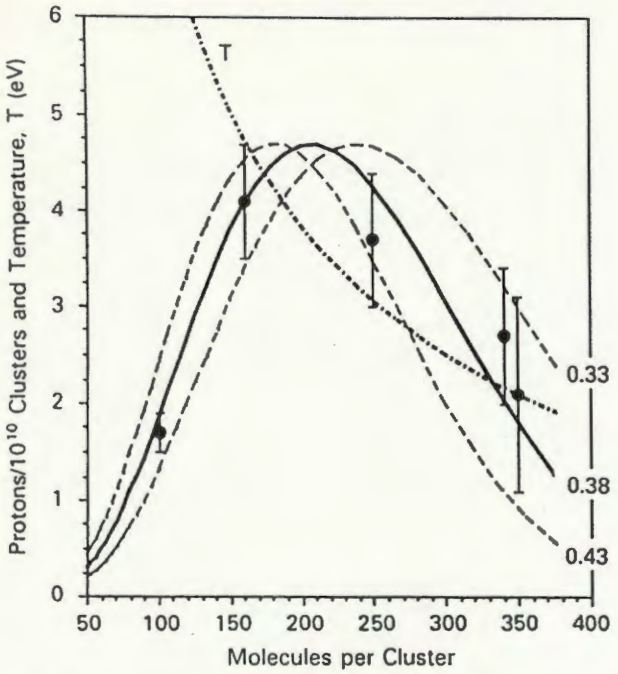

Fig. 2. The proton yield data (points) produced in the Beuhler et al.[11] experiments (with $E_{cl} = 300$ keV) versus the number of water molecules in a cluster. The solid and dashed curves are the model results and have f_L as a parameter. The dash-dotted curve is the temperature corresponding to the $f_L = 0.38$ curve.

reaction rates are concerned. Not only is it difficult to see how the ordinary d-d term [the second term in Eq. (7)] could be made to yield sufficient numbers of reactions, it is even more difficult to see how this term could be made to agree with a decrease of yield with the smaller cluster impacts. The model we have presented is to be viewed as schematic, although we believe that, for the extraction of the effective resonance width η, it is reasonably close.

THE LINE WIDTH AND MODEL RESULTS AND COMPARISON TO BVS

We now have an estimate (from the curve fit) of the natural line width of the δ resonance as approximately $\omega\gamma_R = 4.4 \times 10^{-8}$ eV. If $\omega = 1$, then $\gamma_R = 4.4 \times 10^{-8}$ eV; therefore, the natural lifetime is in the range 1.2×10^{-8} s $< \tau_n < 1.9 \times 10^{-8}$ s, with a best-fit value of 1.5×10^{-8} s. Of course, this value must still be considered an estimate because of the thermo-, hydro-, and ionization dynamics physics uncertainties.

Finally, a few other numbers are worth noting. The δ-particle density at the peak reaction rate in Fig. 2 is $\sim 10^{14}/\text{cm}^3$; i.e., only a few parts per billion of the available deuterons are converted to δ particles in the interaction. We note here that in steady state and under similar plasma conditions, the reaction rate would be increased by a factor of $n_d/n_\delta \approx 5 \times 10^8$. This increase, if realized at the same cluster kinetic energy, would increase the nuclear energy gain $G = E_{out}/E_{in}$ from $G \approx 10^{-5}$ in the present experiments up to a maximum gain of $G_{max} \approx 5000$, a very large gain indeed.

Note from Fig. 2 that the temperature at the peak cluster reaction point is ~4 eV. Target materials with ionization energies different from that of carbon will change the number of electrons produced at a given temperature (Saha equilibrium), and this would change the temperature for a peak in the reaction rate. The shape of the reaction rate curve, therefore, will be determined more from the ionization physics than from the resonance physics if, as expected, $E_R \ll E_I$. Therefore, it is probably not possible to extract the resonance energy from this sort of data as easily as the resonance width. Clearly, more work is required to obtain precision values for these important δ-hydron data. The lower temperatures (below $\approx$ 2eV) of Fig. 2 clearly require a more accurate model involving partial dissociation and other atomic and molecular physics processes that are not necessary for the higher temperature experiments. We now compare of our results to those of BVS.

Our results are substantially different from those of BVS because of our quite different models. BVS were able to extract a resonance energy of between 0.16 and 0.67 eV. Our model does not allow us to extract the value of E_R (we have simply assumed $E_R = 1$ eV) if it is small compared to the ionization levels of most materials. BVS find a line width of between 2×10^{-13} and 2.5×10^{-15} eV, giving a very long lifetime ($\tau_n \approx 3$ to 300 ms) to the δ resonance. On the other hand, we find $\gamma_R = 4.4 \times 10^{-8}$ eV for a rather shorter lifetime of $\tau_n \approx 1.5 \times 10^{-8}$ s. Although our model gives substantially different results, we do agree with BVS that the δ resonance is probably responsible for the observed nuclear reactions in BFF and Ref. 11.

OTHER EXPERIMENTS

There may be many experiments that can be explained by the existence of the δ particle and/or its cousins, the π and τ particles. The most controversial of these has been the observation of "excess" heat, tritium, and neutrons in cold fusion experiments. We have explained,[9] in some detail, how the production of the δ and τ particles in a metal lattice immediately removes the conflicts between theory and experiments in deuterated metals, by showing how barrier penetration takes place and by recognizing a new class of resonant nuclear reactions that give rise to the excess heat and very low neutron production. The new class of nuclear reactions is a resonant analog of the direct nuclear reactions in which a transfer of a neutron occurs between a projectile and target nuclei with positive Q with only charged particles in the exit channel. These resonant reactions are also analogous to low-energy neutron absorption resonances. An example of such a resonant direct nuclear reaction (RDNR) is $^{238}\text{U}(d,t)^{237}\text{U}$ with $Q = 0.106$ MeV. Both (d,t) and (t,d) reactions may be operable in the cold fusion experiments, allowing for both tritium production and consumption in these experiments but without release of neutrons or gamma rays in the reactions. There is direct evidence in experiments that these RDNRs are responsible for the excess heat, tritium production, and neutron production. Only because of formation of the charge-neutral δ- and τ-hydrons are such RDNRs made possible through barrier penetration of the higher Z target nuclei. It is outside of the scope of this technical note to present the details of these arguments; instead the reader is referred to Ref. 9 for details.

Although the cold fusion experiments have received wide attention, their association with nuclear reactions has been poorly understood. A number of other experiments, less widely publicized and also poorly understood, appear to be connected to both cluster-impact fusion and cold fusion by the resonance particle interaction hypothesis. These experiments

and their theoretical connection to cluster-impact and cold fusion experiments provide additional evidence that such resonances do exist.

The first of these is the experiment of Klyuev et al.,[15] where a LiD crystal was fractured by a shock wave produced by the impact of a 0.2 km/s projectile. In an experiment of this type, shock waves may produce temperatures of <1 eV but can produce both ionization and dislodged deuterons. These conditions are favorable to the production of some small number of δ-hydrons which can react, producing a small number of *d-d* neutrons, as these experiments did show. In these experiments, there are certainly no "high"-energy deuterons; hence, there can be no ordinary *d-d* reactions at all.

Arzhannikov and Kezerashvili,[16] in another Soviet experiment, recently reported observing small numbers of neutrons produced in a chemical reaction. In this work, LiD pellets were simply dropped into a test tube of heavy water, the entire assembly having been embedded in a neutron detector. Statistically significant numbers of neutrons were observed to be emitted during the exothermic chemical reaction of the LiD and D_2O. As in the previous experiment, there could not have been any conceivable method for producing kiloelectron-volt deuterons in a chemical reaction, but some neutron-producing δ particles could have been created with the small amount of ionization that accompanies chemical energy release.

Still another experiment with remarkable results is that of Lochte-Holtgreven,[3] where a capacitor bank was employed to explode a thin wire of LiD and lithium. The slow-discharge capacitor bank added thermal energy to the exploding plasma, but only to a few hundred electron-volts. After a short period, pulses of neutrons were observed, along with some indications of alpha particles emitted in the *d*-^{6}Li reaction. These reactions presumably take place in a low-temperature plasma where there should be very few particles energetic enough to produce the observed reactions by energetic particle barrier penetration.

DISCUSSION AND CONCLUSIONS

We have extended our theory for nuclear energy release in various very low energy systems involving hydrogen isotopes and other nuclei by the production of charge-neutral, resonance states in the electron-proton (π), electron-deuteron (δ), and electron-triton (τ) systems. The data in cluster-impact fusion experiments have been analyzed to extract important information about the resonance width and the natural lifetime of the δ resonance. We expect the lifetimes of the π and τ particles to be comparable, although this has yet to be determined. Most important is the fact that numerous experiments in which it is impossible to believe that high-energy particles have been present can be readily explained given that the resonance particles have been formed and survived long enough to allow barrier penetration and subsequent nuclear reactions. Both fusion reactions and a new type of reaction, RDNRs, have been identified in these various experiments. The RDNRs have a unique characteristic—they do not release neutrons, potentially important for the development of these reactions in nuclear reactors.

Of course, many experiments are required to understand the details of the operable nuclear reactions, including the details of resonance particle creation, scattering, reaction, and destruction. Optimization of these reactions in various materials and devices may allow the development of nuclear reactors of a new character compared to the concepts in magnetically confined and inertially confined fusion reactors. If sufficient energy release can be realized, the advantages provided by the aneutronic nature of some RDNRs will be very significant.

REFERENCES

1. M. FLEISCHMANN and S. PONS, "Electrochemically Induced Nuclear Fusion of Deuterium," *J. Electroanal. Chem.*, **261**, 301 (1989).

2. R. J. BUEHLER, G. FRIEDLANDER, and L. FRIEDMAN, "Cluster-Impact Fusion," *Phys. Rev. Lett.*, **63**, 1292 (1989).

3. W. LOCHTE-HOLTGREVEN, "Research on Nuclear Reactions in Exploding (Li + LiD) Wires," *Z. Naturforsch.*, **42a**, 538 (1987).

4. J. D. JACKSON, "Catalysis of Nuclear Reactions Between Hydrogen Isotopes by μ^- Mesons," *Phys. Rev.*, **106**, 330 (1957).

5. J. R. SPENCE and J. P. VARY, "Electron-Positron Scattering Resonances from Two-Body Wave Equations," *Phys. Lett. B*, **254**, 1 (1991); see also C. J. BENESCH, J. R. SPENCE, and J. P. VARY, "Cluster-Impact Fusion by the Formation of Compact Electron-Deuteron Resonances," *BAPS*, **35**, 1673 (1990).

6. F. J. MAYER and J. R. REITZ, "Formation of Charge-Neutral, Continuum Bound State Resonances in the Electron-Proton System," submitted to *Phys. Lett. B*.

7. C. Y. WONG and R. L. BECKER, "Scalar Magnetic (e^+e^-) Resonance as Possible Source of an Anomalous e^+ Peak in Heavy-Ion Collisions," *Phys. Lett. B*, **182**, 251 (1986).

8. C. J. BENESCH, J. P. VARY, and J. R. SPENCE, "Cluster-Impact Fusion by the Formation of Compact Electron-Deuteron Resonances," Private Communication (Sep. 18, 1990).

9. F. J. MAYER and J. R. REITZ, "Nuclear Energy Release in Metals," *Fusion Technol.*, **19**, 552 (1991).

10. C. E. ROLFS and W. S. RODNEY, *Cauldrons in the Cosmos*, University of Chicago Press, Chicago, Illinois (1988).

11. R. J. BEUHLER, Y. Y. CHU, G. FRIEDLANDER, L. FRIEDMAN, and W. KUNNMANN, "Deuteron-Deuteron Fusion by Impact of Heavy-Water Clusters on Deuterated Surfaces," *J. Phys. Chem.*, **94**, 7667 (1990).

12. L. L. COWIE and C. F. McKEE, "The Evaporation of Spherical Clouds in a Hot Gas. I. Classical and Saturated Mass Loss Rates," *Ap. J.*, **211**, 135 (1977).

13. M. W. MATTHEW, R. J. BEUHLER, M. LEDBETTER, and L. FRIEDMAN, "Large, Energetic Cluster Impacts on Surfaces," *Nucl. Instrum. Meth. Phys. Res.*, **B14**, 448 (1986).

14. D. L. BOOK, in *Physics Vade Mecum*, p. 271, American Institute of Physics, New York (1981).

15. V. A. KLYUEV, A. G. LIPSON, Yu. P. TOPOROV, B. V. DERYAGIN, V. I. LUSHCHIKOV, A. V. STRELKOV, and E. P. SHABALIN, "High-Energy Processes Accompanying the Fracture of Solids," *Sov. Tech. Phys. Lett.*, **12**, 551 (1986).

16. A. V. ARZHANNIKOV and G. Ya. KEZERASHVILI, "First Observation of Neutron Emission from Chemical Reactions," Preprint, Institute of Nuclear Physics, Novosibirsk, USSR.

FEB 6 1991

ER-16
WPolansky
2/6/91

Dr. Frederick J. Mayer
FJM Associates
1417 Dicken Drive
Ann Arbor, MI 48103

Dear Dr. Mayer:

This is in response to your January 29, 1991, letter to me that outlined a proposed agreement between the Department of Energy (DOE) and your company, FJM Associates, to expedite a cold fusion research program based on your theoretical model. Although technical details of the proposed activities were not provided, you did estimate the funding levels needed to perform the research.

The DOE has been receptive, at a modest scale and through its regular funding process, to high-quality research proposals aimed at understanding physical phenomena attributed to cold fusion. If your theory is based on sound, scientific principles and the proposed research effort would be within the Department's policy on cold fusion, then you should consider submitting a research proposal for evaluation. However, as occurs with research proposals submitted in other areas, the evaluation process for your idea would include a comprehensive, technical peer review.

I can appreciate that you are anxious to test your cold fusion theory and that you would be frustrated with our evaluation process. On the other hand, there has been no compelling evidence provided on cold fusion to date that would justify a revision of present DOE policy, such as the acceleration of review procedures.

Please accept my best wishes in your future endeavors.

Sincerely,

Walter M. Polansky, Acting Director
Division of Advanced Energy Projects
Office of Basic Energy Sciences, ER-16

ER-16:WMPolansky:SueEllen:3-5995:2-6-91:C:\POLANSKY\Mayer.91:wp5.1

FJM ASSOCIATES
APPLYING PHYSICS TO INDUSTRY

1417 Dicken Drive
Ann Arbor, MI 48103
313/663-0627

January 29, 1991

Dr. Walter M. Polansky
Basic Energy Sciences, ER-16
Department of Energy
Washington, D. C. 20545

Dear Dr. Polansky:

This letter is a follow-up to my telephone conversations with you and Dr. Barney last week.

First of all, let me apologize for the tone of these conversations. I hope that you will understand that I feel some urgency in trying to quickly get the appropriate discussions underway on these new developments.

As I mentioned on the telephone, we(myself and Dr. John R. Reitz) now have in hand a rather complete theoretical understanding of not only the gross features of "cold fusion" experiments but also some very detailed data from at least two quite competent experimental groups. Furthermore, our model points a very clear path to increasing the nuclear reaction level, almost certainly up to the power producing level. Our ideas are <u>not</u> generalities; they are directly testable. In addition, there <u>is</u> over-arching physics that has allowed us to understand, with precision, the data of the cluster impact fusion group (Brookhaven), as well as other anomalous experiments with evidence of nuclear reactions. Our first paper entitled, "Nuclear Energy Release in Metals" is scheduled for publication in May, at which time, we expect a substantial change in the success rate and reproducibility in a variety of experiments with nuclear observations.

I have suggested collaborations with LANL (Damon Giovanielli) and LLNL (Alex Glass). Both labs indicated either no interest or no funds, at least for purchasing completed research. This is the reason for contacting you. I would like to propose the following arrangement for your consideration, as a vehicle to get some experiments going as soon as possible.

The proposed agreement would have the following components: 1.) DOE and/or its designees will receive a confidential briefing on our work after having signed non-disclosure agreements. 2.) If you wish to make use of the work in beginning experiments, DOE will make a one-time payment to FJMA of $100K, during 1991, for the use of the information prior to publication. 3.) If the experiments derived from this work are successful, as I clearly expect them to be, I would be the lead author on the experimental paper. 4.) DOE will

consider negotiating a follow-on (1992) contract of about $1M with FJMA, for extending our joint experiments and beginning development work on some (to be disclosed) FJMA proprietary concepts for the reduction to practice of our physics concepts. Of course, there is no implied commitment of funds until you have decided that it is in your interest to proceed with such a joint program.

I realize that this proposal sounds rather presumptious, but please consider that we have some very important information that bears on the energy problem and there is not enough time to go through a contract proposal preparation, review, etc. In fact, we do not even have much time to get collaborative agreements in place, before the information is broadly distributed.

I trust that you will give our proposal a fair reading, even given the present negative climate in this controversial area. We are convinced that things in this area will be changing. Please contact me as soon as possible on how you wish to proceed. I have enclosed a vita for your information.

Very truly yours,

Frederick J. Mayer

Frederick J. Mayer, PhD
President

FREDERICK J. MAYER
1417 Dicken Drive
Ann Arbor, MI 48103
313-663 0627

Employment Background and Responsibilities

Mar.1988-Present **President, FJM Associates.** Consulting in Applied Physics. Technical and management consulting for large and small industrial corporations and national laboratories.

1984-Feb.1988 KMS Fusion, Inc. **Director of Advanced Research.** Directed an "entrepreneurial" group of eight scientists and engineers to develop new business areas using high-power lasers. Responsible for technical, personnel and financial performance. Responsibilities included product and process development, marketing, and securing internal and external funding. Directed employee graduate research. Acted as technical program spokesman at government research meetings.

1980-1988 University of Michigan. **Adjunct Research Scientist**, Department of Nuclear Engineering. Research program development and graduate theses supervision.

1980-1984 KMS Fusion, Inc. **Primary Scientist.** Staff research position reporting to the President. Responsible for new technical program assessments and new program development. Directed graduate research theses. Acted as technical spokesman at government research meetings.

1978-1988 KMS Fusion, Inc. **Director,** Fusion Experiments Division. Led a group of twenty scientists, engineers and technicians in executing a DOE laser-fusion experimental program. Responsible for technical personnel, and financial performance. Acted as technical program spokesman at government research meetings.

1975-1978 KMS Fusion, Inc. **Manager,** Target Diagnostics Group. Managed a group of ten scientists and engineers in developing diagnostic instrumentation for laser plasma interaction experiments. Responsible for technical personnel and financial performance. Acted as technical program spokesman at government research meetings.

1971-1975 KMS Fusion, Inc. **Senior Research Scientist.** Developed diagnostic instrumentation for laser plasma interaction experiments, performed experiments and supervised technicians.

1968-1971 Case Western Reserve Univ., Division of Applied Physics, **Senior Research Associate.** Designed, built, and conducted plasma physics experiments on a high-current, plasma focus device. Prepared funding proposals and prepared technical papers on the research; supervised two technicians.

Organizational Affiliations:
American Association for the Advancement of Science
American Physical Society, Division of Plasma Physics, Forum on Physics and Society
Collegiate Institute of Values and Science, The University of Michigan
Committee of Concerned Scientists
Michigan Technology Council
Inventors Council of Michigan
Materials Research Society
New York Academy of Science
Sigma Xi
International Society of Optical Engineering
MERRA

Honors: Fellow of the American Physical Society

Committees:
Associate Editor, Encyclopedia of Applied Physics,1987-Present
Corporate Associates Committee, AIP, 1986-1988
Publications Committee, APS Division of Plasma Physics,1985-1986
Associate Editor, Physical Review Letters (Plasma Physics) 1985-1986
Program Committee, APS Division of Plasma Physics, 1980-1982
Fellowship Committee, APS Division of Plasma Physics, 1982-1983
Program Committee, CLEOS/ICF Meeting, San Diego, CA, 1980
Program Committee, Anomalous Absorption Conference, Tucson,AZ,1980
Chairman, Third Annual Conference on Transport Phenomena in Laser Plasmas, Traverse City, MI 1978

Theses Supervised: (University of Michigan, Dept. of Nuclear Eng.)

"Hydrodynamic Simulation of Cold, Dense Objects Evaporating in a Hot Tenuous Plasma", Michael J. Dunning, May 8, 1987.

"Laser Driven Micro-Explosive Bonding", Dale Alexander, February, 1986.

"PICLE: A 2-D Code for Laser Beam - Gas-Jet Interaction Studies", Michael J. Dunning, January, 1982

Research Interests:
Applied Physics
Microwave Breakdown in Gases
Laser Plasma Interactions
Experimental and Theoretical Plasma Physics
Laser Fusion Diagnostics Instrumentation
Dynamic High-Pressure Physics
Similarity Hydrodynamics
Laser Ignition of Explosives
Plasma Focus Research
R&D Funding and Economics

Personal: Born May 24, 1940; married, two children

Clearances: DOE Q, DOD Top Secret

Education:
1985 "Workshop in Technical Writing and Editing," Shipley Associates.

1982 "Effective Technical Presentations," L. Gottlieb, LLNL.

1976 "Basic Management for the Newly Appointed Manager", Graduate School of Business Administration, The University of Michigan.

1968 Ph.D. degree, Case Western Reserve University, Research Area: Plasma Physics, Thesis: "Two Aspects of Transverse ChargedParticle Diffusion in the Positive Column"

1965 M.S. degree, Case Institute of Technology, Major: Plasma Physics

1962 B.S. degree, Pennsylvania State University, Major: Physics

Invited Participant:
Second U.S./U.S.S.R. Workshop on Dense Plasmas, Tucson, Az, March 1983.

CECAM Conference on Theory and Simulation of Laser-Plasma Interactions, Chateau du Gue' Paeu, France, September 1980.

First U. S. /U.S.S.R. Workshop on Laser-Matter Interactions, U.S.S.R., August 1978.

European Conference on Laser-Matter Interactions, Oxford, England, September,1977.

Gordon Research Conference on Laser-Matter Interactions, Tilton, New Hampshire, July, 1977.

International Plasma Diagnostics Conf., Karkov, U.S.S.R., October 1977

International Conference on Laser Interaction with Matter, Paleiseau, France, October, 1976.

1976 I.A.E.A. Conf. on Plasma Physics and Controlled Nuclear Fusion, Berchtesgaden, Germany, October, 1976.

I.A.E.A. Committee on the Technology of Inertial Confinement Experiments, Dubna, U.S.S.R., July, 1976.

Gordon Conf. on Plasma Physics, Santa Barbara, CA, June, 1976.

U.C.L.A. Short Course on Laser Induced Nuclear Fusion, October 16, 1975.

Patents:

"Method and Apparatus for Reducing Coherence of High Power LaserBeams"; F. J. Mayer and N. K. Moncur; (U. S. Patent #4,116,542-Sept. 26, 1978).

"Materials Processing Using Chemically Driven Spherically Symmetric Implosions; F. J. Mayer; (U. S. Patent #4,552,742-Nov.12,1985 and U. S. Patent #4,790,735-Dec. 13,1988).

"Pulsed Laser Microfabrication"; F. J. Mayer; Application SN 867,078, filed May 27, 1986.

"Microwave Oven Devices Incorporating Gas Chambers for Generating Plasmas"; F. J. Mayer, Patent Pending, March 20, 1989.

Technical Publications:

D. E. Alexander, G. S. Was, and F. J. Mayer, "Laser-driven Micro-explosive Bonding of Aluminum films to Copper and Silicon", J. Mat. Sci., Vol. 23, pg. 2181, (1988)

F. J. Mayer, W. B. Fechner, R. L. Maynard, N. W. Schmerberg, and M. R. Wixom, "Shock Processing of Materials with Laser Initiated Spherically Convergent Detonations," J. Appl. Phys., Vol. 64, pg. 4896 (1988).

F. J. Mayer, R. L. Maynard, D. L. Musinski, N. W. Schmerberg, and M. R. Wixom, "Recent Developments in Microshell-Tipped Optical Fibers as High-Pressure Shock Detectors," Shock Waves in Condensed Matter, Plenum Pub. Corp., (ed.) Y. M. Gupta, pg. 547-551 (1986). KMSF-U1586.

F. J. Mayer, "Comments on 'Energy Transduction in Pellet-Injected Plasmas," Phys. Rev. Lett 56, (12) pp. 1310-1311, March 24, (1986).

F. J. Mayer, "Energy Transduction in Pellet-Injected Plasmas," Phys. Rev. Lett. 55, (16) pp. 1673-1676, October 14 (1985); Bull. Am. Phys. Soc., 30 (9), 1586, October (1985). KMSF-U1544.

F. J. Mayer, "Energy Transduction in Pellet-Injected Plasmas," Phys. Rev. Lett. 55 (16), 1673 (1985).

F. J. Mayer, H. L. Ber[illegible]and D. W. Forslund, "A Laser-Ini[illegible]ted Energetic Ion, High Beta Mirror Plasma," Comments on Plasma Phys. and Controlled Fusion 9(4), pp. 139-147, August (1985).

F. J. Mayer and Gar. E. Busch, "Plasma Production by Laser-Driven Explosively Heated Thin Metal Films," J. Appl. Phys. 57 (3), pp. 827-829, February 1 (1985).

R. F. Benjamin, F. J. Mayer and R. L. Maynard, "Microshell-Tipped Optical Fibers as Sensors of High-Pressure Pulses in Adverse Environments," Fiber Optics in Adverse Environments II, Roger A. Greenwell,(ed.), Proc. SPIE 506, pp. 116-121, August 22-24 (1984). KMSF-U1493.

W. B. Fechner and F. J. Mayer, "Analysis of Flux-Relaxed Heat Waves," Phys. Fluids 27 (6), pp. 1538-1544, June (1984). KMSF-U1388

R. W. Lee, D. L. Matthews, L. Koppel, Gar. E. Busch, G. Charatis, M. J. Dunning and F. J. Mayer, "The Laser Irradiated Gas Jet: A Spectroscopic Experimental and Theoretical Study," J. Appl. Phys. 54 (9), pp. 4 September (1983).

F. J. Mayer, J. F. McGrath and J. W. Steele, "A Class of Similarity Solutions for the Nonlinear Thermal Conduction Problem," J. Appl. A.: Math Gen. 16, 3393 (1983).

F. J. Mayer, J. T. Larsen and J. W. Steele, "A Simple Ablative Implosion Model-Shell Dynamics," Phys. Fluids 26(3),pp.830-834, March (1983). KMSF-U1111.

F. J. Mayer, "Evaporation of Pellets Injected into Tokamak Plasmas and the Classical Flux-Limit Parameter," Phys. Rev. Lett. 48 (20),1400 (1982).

J. A. Tarvin, F. J. Mayer, D. C. Slater, Gar. E. Busch, G. Charatis, T. R. Pattinson, R. J. Schroeder, D. Sullivan and D. L. Matthews, "Absence of Fast Electrons in Laser-Irradiated Gas-Jet Targets," Phys. Rev. Lett. 48 (4), 256 (1982).

D. C. Slater, Gar. E. Busch, G. Charatis, R. R. Johnson, F. J. Mayer, R. J. Schroeder, J. D. Simpson, D. Sullivan, J. A. Tarvin and C. E. Thomas, "Absorption and Hot-Electron Production for 1.05 and 0.53 μm Light on Spherical Targets," Phys. Rev. Lett. 46 (18), 1199 (1981).

D. C. Slater, R. L. Berger, Gar. E. Busch, G. Charatis, R. R. Johnson, F. J. Mayer, D. Mitrovich, R. J. Schroeder, J. D. Simpson, D. Sullivan, D. J. Tanner and J. A. Tarvin, "Interaction of Short-Wavlength Laser Radiation with Spherical-Shell Targets," Nucl. Fusion Suppl. 2, 249 (1981).

G. Charatis, D. C. Slater, F. J. Mayer, J. A. Tarvin, Gar. E. Busch, D. Sullivan, D. L. Musinski, D. L. Matthews and L. Koppel, "Laser Heated Gas-Jet - A Soft X-ray Source," Proc. of the Topical Conf. on Low-Energy X-ray Diagnostics, Monterey, CA (1981).

D. C. Slater, R. L. Berger, Geo. E. Busch, C. M. Kinzer, F. J. Mayer, L. V. Powers and D. J. Tanner, "Simulated Brillouin Scattering Experiments," Laser Interaction and Related Plasma Phenomena 5, H. Schwartz, H. Hora, M. Lubin, and B. Yaakobi (eds.), Plenum Pub. Co. (1981).

F. J. Mayer and D. J. Tanner, "Explosively Heated Gaussian Objects," Annals of the New York Academy of Sciences 373, 68 (1981).

B. Ahlborn, W. Liese, and F. J. Mayer, "Ablative Acceleration of Thin Foils Driven by Thermal Power Fluxes," Can. J. Phys. 59 (2), pp. 262-265 (1981).

F. J. Mayer, Geo. E. Busch, C. M. Kinzer and K. G. Estabrook, "Measurements of Short-Pulse Backscatter from a Gas Target," Phys. Rev. Lett. 44 (23), 1498 (1980).

F. J. Mayer, R. L. Berger and C. E. Max, "Effect of Flux-Limited Thermal Conduction on the Jump Conditions of Laser-Plasma Critical Surface," Phys. Fluids 23 (6), 1244 (1980).

F. J. Mayer, A. H. Bennish, G. Charatis, G. E. Busch, R. A. Grandey, R. R. Johnson and D. C. Slater, "Implosion Experiments with Low Intensity, Nanosecond Laser Pulses," Technical Digest from Topical Meeting on Inertial Confinement Fusion Conf., 52 (1980).

F. J. Mayer with KMSF Technical Staff, "Laser Experiments at KMSF", UKAEA Culham Lab., Abingdon, England XVIII, 131 (1979).

F. J. Mayer, R. K. Osborn, D. W. Daniels and J. F. McGrath, "Electromagnetic Structure Resonances in Inhomogeneous Plasma Layers," Phys. Rev. Lett. 40 (1), 30 (1978).

F. J. Mayer with KMSF Technical Staff, "Laser Fusion Experiments at KMS Fusion," Proc. of the Ninth European Conf. on Controlled Fusion and Plasma Physics, Oxford, September (1979); Proc. of the I.A.E.A. Technical Committee Meeting on Advances in Inertial Confinement Systems, Takarayuka Hotel, Osaka, Japan, October (1979).

R. A. Cover, J. J. Kubis, F. J. Mayer and D. C. Slater, "Tamper Temperature and Compression from Simultaneous Proton and Alpha-Particle Measurements in Laser Fusion Experiments," Appl. Phys. Lett. 33 (3), 222 (1978).

R. L. Berger, P. M. Campbell, G. Charatis, J. G. Downward, T. M. Henderson, R. R. Johnson, T. A. Leonard, F. J. Mayer, D. Mitrovich, N. K. Moncur, G. R. Montry, D. L. Musinski, R. L. Nolen, L. V. Powers, S. B. Segall, L. D. Siebert, R. J. Simms, D. C. Slater, D. C. Slater, D. E. Solomon and C. E. Thomas, "The KMSF Laser Fusion Programme," Plasma Phys. and Controlled Nucl. Fusion Res. 3 pp. 3-15 (1978). KMSF-U767.

P. M. Campbell, R. R. Johnson, F. J. Mayer, L. V. Powers and D. C. Slater, "Fast-Ion Generation by Ion-Acoustic Turbulence in Spherical Laser Plasmas," Phys. Rev. Lett. 39 (5), pp. 274-277, August 1 (1977). KMSF-U643.

D. C. Slater, F. J. Mayer and J. S. Pearlman, "Fast Ions from Laser-Irradiated Layered Targets," Bull. Am. Phys. 22, 1128 (1977).

D. C. Slater and F. J. Mayer, "Two New Charged-Particle Diagnostics for Laser-Fusion Experiments," Laser Interaction and Related Plasma Phenomena 4B, (ed.) H. Schwartz and H. Hora, Plenum Pub. Co., 603 (1977).

R. R. Johnson, P. Hammerling and F. J. Mayer, "Laser Fusion Experiments Using Spherical Shell Targets," Laser Interaction and Related Plasma Phenomena 4A, H. Schwartz and H. Hora (eds.), Plenum Pub. Co., 421 (1977).

P.
M. Campbell, P. Hammerling, R. R. Johnson, J. J. Kubis, F. J. Mayer and
D. C. Slater, "Laser-Driven Compression and Neutron Generation with Spherical Shell Targets," Plasma Phys. and Controlled Nucl. Fusion Res. 1, pp. 227-243 (1977); Proc. of the Sixth Intern. Conf. I.A.E.A., Berchtesgaden, 6-13 October 1976.

P. M. Campbell, P. Hammerling, R. R. Johnson, J. J. Kubis, F. J. Mayer and D. C. Slater, "Laser-Driven Compression and Neutron Generation with Spherical Shell Targets," Proc. of the U.S.-Japan Seminar on Laser Interaction with Matter, C. Yamanaka (ed.), Institute of Laser Engineering, Osaka University, 134 (1977).

H. Brysk and F. J. Mayer, "Fast-triton Detector for Laser Fusion, Appl. Phys. Lett. 28 (11), pp. 688-690, June (1976). KMSF-U466.

R. R. Goforth, F. J. Mayer, H. Brysk and R. A. Cover, "Measurements of Alpha Particles and Protons in Laser-Driven Fusion Studies," J. Appl. Phys. 47 (11), 4850 (1976).

F. J. Mayer, R. R. Johnson and D. J. Tanner, "Neutron Yield Calculations From Self-Similar Spherical Compressions," Phys. Fluids 19 (12), 2049 (1976)

R. K. Osborn and F. J. Mayer, "Elementary View of Fusion Implosions," Am. J. Phys. 47 (2), 149 (1976).

F. J. Mayer and W. B. Rensel, "Plastic Bubbles and Tamper <pR> Measurements for Laser-Driven Fusion Experiments," J. Appl. Phys. 47 (4),1491 (1976).

R. K. Osborn and F. J. Mayer, "An Elementary Analysis of Fusion Implosions," Proc. of the U.S./Japan Seminar on Laser Interaction with Matter, C. Yamanaka (ed.), (1976) .
F. J. Mayer, "Recent Laser-Driven Implosion Measurements at KMS Fusion," I.A.E.A.-200, Technology of Inertial Confinement Experiments, Proc. Advisory Group Meeting, I.A.E.A. (Dubna, U.S.S.R., 1976) 107-140.

T. A. Leonard and F. J. Mayer, "Helium Blast-Wave Measurements of Laser-Heated Microshell Targets," J. Appl. Phys. 46 (8), 3562 (1975).

F. J. Mayer and H. Brysk, "Neutron Detection Efficiency of Silver Counters," Nucl. Instrum. & Methods 125, 323 (1975).

F. J. Mayer, G. R. Montry and E. Benn, "X-ray Diagnostics of LaserProduced Plasmas Using CaF2(Dy) Thermoluminescent Dosimeters," Advances in X-ray Analysis, 18, 169 (1975). W. Pickeles, C. Barrett, J. Newkirk and C. Rudd (eds.), Plenum Publ. Co.,

New York.

J. G. Downward, R. A. Grandey, F. J. Mayer and D. Mitrovich "Absorption of Spherically Convergent 1.06 μm Laser Light by Glass Microshells," 17th Meeting of the Div. Plasma Phys., Am. Phys. Soc., St. Petersburg, FL (1975).

G. Charatis, J. G. Downward, R. R. Goforth, B. Guscott, T. M. Henderson, S. Hildum, R. R. Johnson, N. K. Moncur, T. Leonard, F. J. Mayer, S. B. Segall, L. D. Siebert, D. E. Solomon, C. E. Thomas, "Experimental Study of Laser-Driven Compression of Spherical Glass Shells," Plasma Phys. and Controlled Nucl. Fusion Res., I.A.E.A. Vienna II, pp. 317-335 (1975). KMSF-U219.

F. J. Mayer, "The Blast Probe: An Inexpensive Laser-Blast Wave Energy Monitor," Appl. Phys. Lett. 25 (12), 733 (1974).

F. J. Mayer, "Exact Non-Linear Transverse Diffusion in the Low-Density Positive Column," Trans. Am. Nucl. Soc. Student Conf., (invited paper), Gainsville, FL, 94 (1968).

F. J. Mayer, "Stark Effect Produced Frequency Shifts in the Helium-Neon Laser," J. Quan. Elec. QE-3, 690 (1967).

Published Abstracts:

M. R. Wixom, W. B. Fechner, R. L. Maynard, N. W. Schmerberg, and F. J. Mayer, "Shock Processing in Spherical Geometry," The 1987 American Institute of Physics Topical Conference on Shock Waves in Condensed Matter, July 20-23, 1987.

F. J. Mayer, R. L. Maynard, D. L. Musinski, N. W. Schmerberg, M. R. Wixom, and R. F. Benjamin, "Recent Developments in Microshell-Tipped Optical Fibers as High-Pressure Shock Detectors," Bull. Am. Phys. Soc., 30, 1290 (1985).

M. J. Dunning, F. J. Mayer and J. T. Larsen, "Investigation of Thermal Flux Inhibition Effects on X-ray Emission in Gas Jet Targets," Bull. Am. Phys. Soc. 28 (8), 1145 (1983); 25th Annual Meeting Div. Plasma Phys., Los Angeles, CA; 7-11 November 1983.

F. J. Mayer, "The Flux-Relaxation Equation and Classical Electron Heat Waves," Bull. Am. Phys. Soc. 27 (8-II), 963 (1982); 24th Annual Meeting Div. Plasma Phys., New Orleans, LA, 1-5 November 1982.

F. J. Mayer, "Tokamak Pellet Evaporation Experiments and the Classical Flux Limit Parameter," Proc. 12th Annual Anomalous Absorption Conf., Santa Fe, NM, May 10-13, 1982.

F. J. Mayer and J. D. Simpson, "Bubble Calorimetry for Absorbed Energy Measurements in Spherical Laser-Target Interaction Experiments," Bull. Am. Phys. Soc. 22 (9), 1078 (1977).

F. J. Mayer, "Absorption and Transport Experiments at KMSF," Seventh Annual Symposium on the Anomalous Absorption of Intense High-Frequency Waves, Ann Arbor, MI, May 18-20, 1977.

G. Charatis, J. G. Downward, R. R. Johnson, T. A. Leonard, F. J. Mayer, S. B. Segall, J. D. Simpson and D. C. Slater, "Diagnostics for Laser-Driven Implosion Experiments at KMS Fusion, Inc." Second Conf. on Hot Plasma Diagnostics, Kharkov, U.S.S.R., 22-27 September 1977.

F. J. Mayer R. R. Johnson, D. C. Slater, P. M. Campbell, P. Hammerling, T. A. Leonard and S. B. Segall, "Recent Absorption, Transport and Implosion Experiments at KMSF," 11th European Conf. on Laser Interaction with Matter, Oxford, U.K., 19-23 September 1977.

F. J. Mayer, R. A. Cover, J. J. Kubis and D. C. Slater, "Temperature and Compression Determination of Laser-Driven Microshell Tamper," Bull. Am. Phys. Soc. 22 (9), 1204 (1977).

F. J. Mayer, R. K. Osborn, D. W. Daniels, J. F. McGrath and G. R. Montry, "Electromagnetic Wave Interaction with a Rigid Collisional Two-Step Plasma Boundary," Bull. Am. Phys. Soc. 22 (9), 1061 (1977).

F. J. Mayer, H. Brysk and S. B. Segall, "The Hard X-ray Tail from Laser Plasmas," Bull. Am. Phys. Soc. 21, 1046 (1976).

F. J. Mayer, G. Charatis and S. B. Segall, "Thermoluminescent X-ray Dosimetry of Laser Fusion Plasmas," Bull. Am. Phys. Soc. 21, 1084 (1976).

F. J. Mayer and D. C. Slater, "Fast-Ion Velocity Spectra from Laser Driven Microshell Implosions," Bull. Am. Phys. Soc. 21, 1120 (1976).

F. J. Mayer and D. C. Slater, "A Magnetic Spectrograph for Laser Fusion Studies," Bull. Am. Phys. Soc. 21, 1194 (1976).

F. J. Mayer, R. R. Johnson and G. Charatis, "Laser Fusion Measurements of Neutron Production and Pellet Compression," Third Intern. Conf. on Plasma Sci., I.E.E.E. Conf. Abstracts, 67 (1976).

F. J. Mayer, R. R. Goforth, H. Brysk and R. A. Cover, "Alpha and Proton Measurements in Laser Driven Fusion Experiments at KMSF," Third Intern. Conf. on Plasma Sci., I.E.E.E. Conf. Abstracts, 67 (1976).

F. J. Mayer, L. D. Siebert and J. Simpson, "Plastic Bubble Calorimetry for Laser Target Interaction Experiments," Third Intern. Conf. on Plasma Sci., I.E.E.E. Conf. Abstracts, 68 (1976).

F. J. Mayer and W. B. Rensel, "Plastic Bubbles and Tamper <rR> Measurements for Laser Driven Fusion Experiments," Conf. on Diagnostics of High Temp. Plasmas, Oak Ridge National Laboratory, January 7-9, 1976.

J. G. Downward, R. A. Grandey, F. J. Mayer and D. Mitrovich, "Absorption of Spherically Convergent 1.06 mm Laser Light by Glass Microshells," Bull. Am. Phys. Soc. 20, 1247 (1975).

R. R. Johnson, G. Charatis and F. J. Mayer, "Neutron Production and Compression Measurements from Laser Driven Implosions," Bull. Am. Phys. Soc. 20, 1318 (1975).

F. J. Mayer, "Laser Fusion Diagnostics at KMS Fusion," I.E.E.E. Conf. Record-Abstracts Second Intern. Conf. Plasma Sci., University of Michigan, Ann Arbor, MI, May 14-16, 1975, IEEE, Piscataway, NJ, 40 (1975).

R. R. Johnson, F. J. Mayer and G. Charatis, "Temperature Measurements of Laser Compressed Spherical Glass Shells," IEEE Conf. Record-Abstracts of the Second Intern. Conf. on Plasma Sci., University of Michigan, Ann Arbor, MI, May 14-16, 1975, IEEE, Piscataway, NJ, 122 (1975).

R. A. Grandey, P. Hammerling and F. J. Mayer, "Comparison of Theory and Experiment in Laser Driven Fusion Experiments," Bull. Am. Phys. Soc. 20, 68 (1975).

H. Brysk and F. J. Mayer, "A Search for High Energy Tritons from Laser Driven DT Microshell Implosions," Bull. Am. Phys. Soc. 20, 1237 (1975). KMSF-U366.

F. J. Mayer, R. R. Goforth, R. R. Johnson and T. A. Crispin, "Yield Scaling in Laser-Driven Target Experiments," Bull. Am. Phys. Soc. 20, 1237 (1975).

F. J. Mayer, "The Blast Probe: An Inexpensive Laser-Blast Wave Energy Monitor," Proc. IEEE First Intern. Conf. on Plasma Sci., University of Tennessee, Knoxville, TN, May 15-17, 1974, IEEE, Piscataway, NJ, 25 (1975).

F. J. Mayer, C. K. Cheng and J. G. Downward, "Mass and Energy Recovery Measurements of Laser Heated Spherical Glass Targets," Bull. Am. Phys. Soc.19, 910 (1974).

F. J. Mayer, "The Spindle Focus-Preliminary Considerations of Locational Stability," Bull. Am. Phys. Soc. 15, 1962 (1970).

F. J. Mayer, "A Variational Solution for the Positive Column Characteristic Curve," Bull. Am. Phys. Soc. 15, 431 (1970).

F. J. Mayer, "Ambipolar Diffusion Frequency Shifts in the Helium-Neon Laser," Bull. Am. Phys. Soc. 13, 207 (1968).

<u>Non-technical Publications:</u>

"A Simple Economic Catastrophe - A Physicist's Look at the Effect of Oil Cost," with Thomas Speziale, Forum on Physics and Society (APS) II (1), (1982).

"Party was Affirmation of Sakharov's Ideals," The Ann Arbor News, May 30,1981.

"Some comments on 'Accounting for Slower Economic Growth,' Ann Arbor, 1981.

"The University as Incubator," Ann Arbor, 1981.

Co-Chairman, Moscow Sunday Scientific Seminar: In Exile, Honoring Victor Brailovsky and Soviet "refusenik" scientists, April 5, 1981, University of Michigan.

"U.S. Fusion Researchers Conduct a Seminar for Soviet 'refuseniks,'" Laser Focus, November 1978.

F. J. Mayer and E. Yablonovitch, "Soviet Visits," letter to the editor, Laser Focus, November 1978.

ER-16
WPolansky
5/31/91

MAY 31 1991

Dr. Frederick J. Mayer
President
Mayer Applied Research, Inc.
1417 Dicken Drive
Ann Arbor, MI 48103

Dear Dr. Mayer:

This is in response to your May 22, 1991, letter regarding possible support from the Department of Energy (DOE). There has been no change in the Department's policy on cold fusion research since my February 6, 1991, letter to you. We continue to monitor developments in cold fusion throughout the world and we believe that we are aware of all recent reports, including your publication in Fusion Technology. However, we have yet to detect whether these reports are having any impact on the substantial air of scientific skepticism that has surrounded claims attributed to cold fusion.

In reply to the question raised in your letter, a proposal on cold fusion submitted to the DOE would be evaluated in accordance with the guidelines described in the enclosed booklet entitled, "Application and Guide for the Special Research Grant Program, 10 CFR Part 605." You should note that the evaluation procedures for research proposals include a comprehensive, peer review. Recognizing the present state of affairs in cold fusion, it is difficult to envision a research proposal submitted in this area would be able to withstand the scrutiny of such a review.

Thank you for taking the time to inform me of your research activities in cold fusion.

Sincerely,

Walter M. Polansky, Director
Division of Advanced Energy Projects
Office of Basic Energy Sciences, ER-16

Enclosure

DIVISION OF ADVANCED ENERGY PROJECTS, ER-16

OFFICE ROUTING SLIP

[redacted] regard to the attached: _____

FYI

AEP

(5) W. M. Polansky _____

(1) D. L. Barney DB 3/29

(2) R. R. Silbar RRS 5/23 — "yes"

(6) S. E. Stottlemyer last

SBIR

(3) S. J. Barish SJB 5/23

(4) R. S. H. Toms RS 5/23

[redacted] ~~. Washington~~ _____

~~M. A. Wilson~~ _____

REMARKS:

Any suggestions for Dr. Mayer?

Please Indicate: File X Destroy _____

Name of File: ~~Proposa~~ Cold Fusion

Mayer
Applied
Research
Inc.

Applying Physics to Industry

1417 Dicken Drive • Ann Arbor, MI 48103 • 313-662-3841

FACSIMILE TRANSMISSION SHEET

To:	Dr. Walter M. Polansky	
Company:	Department of Energy	FAX: 301 353 6594
From:	Dr. Frederick J. Mayer	FAX: 313 662 3920
Pages:	9 (including this one)	Date: 5/22/91 a.m.

Dear Dr. Polansky:

Appended is a copy of our first paper, "Nuclear Energy Release in Metals", which recently appeared in Fusion Technology. It goes a long way to removing the conflicts in the "cold fusion" effect. As I mentioned in my letter to you of January 29, we have in hand a rather complete understanding of the anomalous effects in deuterated metals. Our second paper (presently under review) is entitled, " On Very-Low Energy Hydrogenic Nuclear Reactions". A third paper with more of the basic physics of the new resonance particles, (we now call them "hydrons") is also out for review.

We are interested in finding some support for our experimental program. Is there a chance that a proprietary proposal to DOE could be processed fairly quickly? With our publications, we are pointing the direction for the experimentalists, and we expect some rather spectacular results quite soon. However, we also think that we are in a unique position to most directly attempt the development

of an energy source from our present understanding and designs. In fact, we would hope to lead a national program for the research and development of this energy source for DOE and industrial partners.

We have learned that a number of other countries are funding substantial programs in the area known (incorrectly) as "cold fusion". We have been approached by one Japanese company already, yet we don't seem to be able to get out of the "Pons and Fleishmann potential well" in our own country.

We would be happy to give you a briefing about our propietary concepts, if that would help. Please let us know if you have any suggestions on how we might proceed.

Sincerely,

Fred Mayer

Frederick J. Mayer, PhD
President

NUCLEAR ENERGY RELEASE IN METALS

FREDERICK J. MAYER
Mayer Applied Research, Inc.
1417 Dicken Drive, Ann Arbor, Michigan 48103

JOHN R. REITZ *2260 Chaucer*
Ann Arbor, Michigan 48103

Received October 16, 1990
Accepted for Publication December 13, 1990

COLD FUSION

TECHNICAL NOTE

KEYWORDS: *cold fusion, direct nuclear reactions, "virtual" particles*

A scenario for nuclear energy release in metals produced through resonant direct nuclear reactions of low-energy "virtual" dineutrons and trineutrons is proposed. These reactions produce heat, tritium, and only low levels of penetrating radiations. The proposed scenario is shown to be consistent with some detailed data from "cold fusion" experiments. Furthermore, the possible connection of the proposed scenario with some other previously recognized, but anomalous, nuclear observations of geophysical interest is suggested.

I. INTRODUCTION

In early 1989, the reports by Fleischmann and Pons[1] and of Jones et al.[2] led to a flourish of activity to determine if nuclear energy release at near-ambient conditions was indeed occurring in deuterium-loaded metals. Many experiments did not observe evidence of nuclear reactions, while others did. This disparity led to rather polarized debate in the scientific community as it became quite clear that, without straining credulity, the positive observations could not be explained by the well-studied, and most probable, *d-d* nuclear reactions. However, while the debate proceeded, so did other experiments; there are currently some 60 laboratories[3] around the world that have reported evidence of nuclear reaction activity and/or excess heat from electrochemical cells or other deuterium-loaded metal systems.

Numerous theoretical suggestions have been put forward to explain the experimental observations (excess heat, tritium generation, neutron generation, and charged-particle generation), but many are not completely consistent with the observations. It is *not* the purpose of this paper to discuss all the experimental observations, nor to critique the various theoretical models that have been proposed. The interested reader is referred to the review article of Bockris et al.[3] for a summary of the experimental situation and to the paper by Miley et al.[4] for a summary of the proposed nuclear physics models. Rather, it *is* the purpose of this paper to propose a new scenario that may be responsible for the experimental "cold fusion" observations and to suggest some clear directions for modifications of the current experiments that could test our proposal. We also suggest that the scenario proposed here may explain some previously recognized anomalous nuclear observations of geophysical interest.

For the sake of completeness, we list here some average observations in cold fusion experiments, not all of which are found by all observers, nor during all of their experiments. The positive results appear to be sporadic in nature and to depend in some unknown way on the materials used. Experimentally, the observations are roughly as follows:

1. neutron generation rate up to 10^3/s
2. tritium generation rate up to $\sim 10^{11}$/s
3. excess heat generation rate up to ~ 10 W/cm^3
4. little or no ^{3}He or ^{4}He detected
5. no deuteron-triton (*d-t*) neutrons or energetic gamma rays detected
6. all observables seem to be produced in bursts (microseconds for neutrons to a few hours for excess heat).

It is the lack of energetic secondary nuclear particles that is most revealing. As others[4,5] have pointed out, the absence of the easily detected *d-t* neutrons, which would have to be created at a rate of $\sim 10^{-5}$ times the tritium generation rate (the triton has 1.01 MeV of kinetic energy in the exit channel) in the deuteron-deuteron (*d-d*) reaction, apparently eliminates this reaction as the source of both the tritium and excess heat. On the other hand, the relatively small rates of *d-d* neutron production could be the result of secondary nuclear reactions in a situation where the primary reactions had very low energy deuterons in the exit channel.

We return to the comparison of the experimental observations and our proposed reaction scenario after a discussion of some relevant nuclear physics.

II. RESONANT DIRECT NUCLEAR REACTIONS

The mass-energy difference between the deuteron and a triton is quite small, $|\Delta_{dt}| = 1.8141$ MeV. So, in the well-studied direct reactions,[6] i.e., stripping (t,d) or pick-up

(d,t) reactions, the energy increment transferred can be small. Contrast this value with the classic direct reactions, (d,p) and (p,d), with a transferred energy increment of 5.8469 MeV. The latter energy increment often results in substantial energy being carried away as kinetic energy of the exiting light particle or nuclear excitation (and, therefore, gamma emission) in positive-Q reactions. On the other hand, the heavy hydrogen direct reactions may result in relatively low exit channel kinetic energies in reactions that are close to resonant with this energy increment. We believe that these reactions may be the primary operative nuclear reactions taking place in cold fusion experiments.

With such reactions, tritium is produced or consumed with no other light nuclei involved. Tables I and II list[a] the most closely resonant reactions on stable nuclear isotopes with the heavy hydrogen isotopes.[7] We designate these reactions *tritium producers* and *tritium consumers*. The list is incomplete, as we have chosen to display only those reactions that are within 10% of being "on" resonance, $Q/|\Delta_{dt}| < 0.1$. Notice in Table I that for most of the tritium producers, the heavy product nuclei are stable. For the t-^{238}U reaction, the resulting ^{237}U decays with a half-life of 6.75 days, and the product radiations are a soft beta and low-energy gamma rays.

Notice that the product heavy nuclei are either stable or have relatively low energy radioactivity. Also, the deuterons (and tritons) carrying away the excess Q are of low energy and, therefore, will not interact strongly with the ambient medium. There are numerous other reactions that could be off-resonance further than the 10% criterion above, especially in the (t,d) reactions; however, they would not be expected to have cross sections as large as the more closely resonant reactions listed, i.e., the zero-energy resonances. Of course, the resonant character of these reactions might be expected to yield cross sections many orders of magnitude above the nonresonant background reactions as in neutron absorption resonances (e.g., in indium). Without detailed measurements, however, it is not possible to know if these reactions actually possess very large resonant cross sections at zero energy. Such experiments are made nearly impossible at the extremely low

TABLE I

Positive-Q, Tritium-Producing Reactions (on Stable Isotopes) for Which $Q/|\Delta_{dt}| < 0.1$

Tritium Producers	Product Radiation (MeV)	Q (MeV)	$Q/\lvert\Delta_{dt}\rvert$
1. ^{238}U$(d,t)^{237}$U	β^-, low-energy gammas	0.1059	0.0583
2. ^{201}Hg$(d,t)^{200}$Hg	Stable	0.0259	0.014
3. ^{195}Pt$(d,t)^{194}$Pt	Stable	0.1259	0.070
4. ^{187}Os$(d,t)^{186}$Os	Stable	0.0459	0.025
5. ^{183}W$(d,t)^{182}$W	Stable	0.0759	0.042
6. ^{176}Lu$(d,t)^{175}$Lu	Stable	0.0859	0.047
7. ^{163}Dy$(d,t)^{162}$Dy	Stable	0.0059	0.0032
8. ^{143}Nd$(d,t)^{142}$Nd	Stable	0.1559	0.086

Note: Reaction 1 conserves spin and parity.

[a]Compiled from data from Ref. 7. More recent compilations of the nuclide mass levels differ from those used in the computations by as much as a few tens of keV.

TABLE II

Positive-Q, Tritium-Consuming Reactions (on Stable Isotopes) for Which $Q/|\Delta_{dt}| < 0.1$

Tritium Consumers	Product Radiation (MeV)	Q (MeV)	$Q/\lvert\Delta_{dt}\rvert$
1. ^{192}Pt$(t,d)^{193}$Pt	IT, iridium L X rays	0.0241	0.0175
2. ^{176}Hf$(t,d)^{177}$Hf	Stable	0.1141	0.063
3. ^{169}Tm$(t,d)^{170}$Tm	β^-(0.97), e^-, X rays	0.1641	0.09
4. ^{166}Er$(t,d)^{167}$Er	Stable	0.1841	0.10
5. ^{165}Ho$(t,d)^{166}$Ho	β^-(1.84), e^-, X rays	0.0741	0.060
6. ^{159}Tb$(t,d)^{160}$Tb	β^-(1.74), e^-, X rays	0.1341	0.074
7. ^{156}Gd$(t,d)^{157}$Gd	Stable	0.0941	0.05
8. ^{153}Eu$(t,d)^{154}$Eu	β^-(1.85), e^-, X rays	0.1341	0.07
9. ^{151}Eu$(t,d)^{152}$Eu	β^-(1.48), e^-, X rays	0.0341	0.02
10. ^{126}Te$(t,d)^{127}$Te	β^-(0.7), gamma rays	0.033	0.018
11. ^{123}Sb$(t,d)^{124}$Sb	β^-(1.48), gamma rays	0.1701	0.094
12. ^{106}Pd$(t,d)^{107*}$Pd	Palladium X rays, e^-	0.0641	0.035
13. ^{88}Sr$(t,d)^{89}$Sr	β^-(1.46), gamma rays	0.1441	0.08
14. ^{50}Ti$(t,d)^{51}$Ti	β^-(2.14), gamma rays	0.1231	0.068
15. ^{26}Mg$(t,d)^{27}$Mg	β^-(1.75), gamma rays	0.1831	0.10

Note: Reactions 3, 10, 12, and 15 conserve spin and parity.
*The asterisk in reaction 12 refers to an excited nuclear state.

d (or *t*) kinetic energies due to the very high Coulomb barrier. Of course, this is the obvious major objection to such reactions having *any* finite probability. The Coulomb barrier for these reactions is much larger than that of the *d-d* reaction because the barrier penetration factor scales approximately as

$$P \approx \exp[-989 Z_1 Z_2 (A_{12}/E)^{1/2}] ,$$

where

Z_1, Z_2 = atomic numbers of the reacting nuclei

A_{12} = reduced mass (amu)

E = center-of-mass kinetic energy (eV).

Considering deuteron kinetic energies of, at most, a few electron-volts, these reactions *could not* take place at finite (i.e., measurable) rates. Some reactions of the (d,t) type have been suggested by Rafelski et al.,[8] with screening of the deuteron charge provided by a massive negatively charged particle, supposedly a remnant of the early universe. Alternatively, we propose a different screening mechanism.

III. "VIRTUAL" NEUTRONS, DINEUTRONS, AND TRINEUTRONS

There is now reason to speculate on the existence of what we will call a "virtual" neutron, "virtual" dineutron, and "virtual" trineutron. (This nomenclature is used here for convenience, not precision.) These virtual particles may form as a result of continuum resonance scattering of an electron and a proton, deuteron, or triton. The latter resonance states are now expected, based on an extension of some recent work by Spence and Vary.[9] These authors describe a quantum electrodynamics calculation that yields quite narrow (i.e., long-lived) resonances in the electron-positron system. The continuum resonances so predicted appear to agree very well with data from certain heavy-ion experiments, where an apparently long-lived electron-positron pair is left behind in heavy-ion collisions. Furthermore, Benesh, Vary, and Spence[10] (BVS) have proposed an extension of the quantum electrodynamics calculations to the electron-deuteron (*e-d*) case, finding resonances in this system that might explain the much-higher-than-classical fusion rates in recent cluster impact fusion experiments.[11]

From these experiments and their theoretical calculations, BVS estimate a line width in the *e-d* system of $<10^{-11}$ eV, which would correspond to a lifetime of up to 60 μs—a very long time indeed. Furthermore, the electron energies of the resonances are contained in a region between a few tenths of an electron-volt and ~5 eV, just the range of electron energies that are to be found in certain metal lattices. From their theory, BVS also calculate that the virtual particles will be very small—only a few fermis. The compact size of these virtual particles allows them to penetrate the Coulomb barrier easily, with the much higher probability that they will undergo a nuclear reaction.This situation is quite similar to barrier penetration in the well-studied case of muon catalyzed fusion.[12] The Coulomb interaction of the virtual particle and a collision partner is screened out in regions larger than the virtual particle size—in the present case, down to the fermi scale. These virtual or resonance particles, therefore, will behave as though they were charge-neutral protons, deuterons, or tritons of very low energy; and if resonant direct nuclear reactions (RDNRs) are available, these reactions are then expected to be very strongly dominant,[13] a result[b] important to the discussion below.

We think it important to point out that there is a long-standing anomaly in the studies of the diffusivity of interstitial atoms in metals. It is well known that hydrogen isotopes have an extremely high diffusivity in metals,[14] as much as 20 orders of magnitude higher than other interstitials such as oxygen or nitrogen. This anomaly could be the result of the extreme smallness of the hydrogen isotope virtual particles giving rise to the rapid diffusion through the metal lattices. For example, the cross section should scale roughly as the approximate size of the interstitial atoms or particles. The charge-neutralizing radius of a hydrogen isotope dissolved in a metal is ~1 Å, but the size of the virtual neutron (*e-p*) or its heavier counterparts (*e-d* and *e-t*) is a few fermis, which then gives a projected area ratio of 10^9, not as large a factor as the observed increase, but large nonetheless. Clearly, compact virtual particles could be part of the explanation for the hydrogen-in-metal diffusivity anomaly.

We suggest that although there has yet to be direct evidence for the existence of compact, charge-neutral resonance particles (virtual neutron, dineutron, and trineutron), the indirect evidence (see below) for their existence does seem to be increasing. The possibility of generating and selectively reacting these virtual states of singly charged nuclei (and singly charged only!) could, in fact, open up a whole new class of low-energy nuclear physics experiments and applications.

Lastly, we mention that there has been speculation[15,16] that low-energy resonance reactions may have potential for nuclear fusion. However, the (d,t) and (t,d) reactions described in this paper were not suggested by McNally; more importantly, neither was the enabling screening mechanism provided by virtual particle formation. If our scenario does, indeed, explain the current cold fusion experiments, then it would be, of course, useful to search out additional resonant reactions.

IV. RDNRs, VIRTUAL PARTICLES, AND COLD FUSION EXPERIMENTS

IV.A. Electrochemical Experiments

The resonant direct nuclear reactions of the (d,t) and (t,d) type mentioned above have the important characteristic that the released nucleons all have very low energies (on a nuclear scale); hence, they do not react strongly with the surrounding medium to create secondary nuclear products, but deposit their energy as heat in the medium. Additionally, only very low energy gamma rays from low-lying excited states are present. Furthermore, neither ^{3}He nor ^{4}He are created in the reactions. All these characteristics are in agreement with observations (or, actually, the lack thereof) in cold fusion experiments. The observation of tritium production would be consistent with the tritium producer reactions listed in Table I, if the relevant nuclides were present as impurities in the metals or electrolytes in the electrochemicals cells. For

[b]Reactions on high-Z nuclei are expected to be much larger than for *d-d*, even without a resonance, as may be seen from extracting the $S(0)$ value from reaction cross-section data. Note that $\sigma(E) = S(E)P(E)/E$, where $S(E)$ is the astrophysical S factor. With screening down to the fermi scale, $P(E) \approx 1$, similar to the case of deuterons with energy "above the barrier." Based on data from Ref. 13, we find that $S(0) \approx 770$ keV·b for (d,t) on ^{238}U, but $S(0) \approx 55$ keV·b for (d,t) on deuterium.

the virtual dineutron and trineutron states, the resonant-electron may enter the exit channel reaction kinematics so as to carry away some fraction of reaction energy, further reducing the observable secondary nuclear reactions.

Impurities may be playing a very substantial role in the cold fusion experiments both in the metals and in the deuterium supply. In particular, the tritium that is found in D_2O water and deuterium gases could be contributing strongly to the evolved excess heat produced. Furthermore, if the tritium and metal impurities are indeed significant, then we expect the following:

1. The reactions should be sporadic (in bursts) as the various interaction partners are brought together in the electrochemical loading process, e.g., by cracking the lattice or by phase changes giving rise to drifting nuclei.

2. The experimental reproducibility should be poor due to probable widely varying levels of impurities in the different cell materials.

These erratic observations in cold fusion experiments are expected by our proposed scenario.

Determining which reactions in Tables I and II are allowed depends on the spin and parity of the nucleons in the reactions. In the case of the virtual particles, these quantum numbers are not known. One is tempted to use the spin and parity assignments of the corresponding charged particles (d and t); doing so results in only reaction 1 of Table I and reactions 3, 10, 12, and 15 of Table II being allowed. Note that for the tritium producers, only the uranium reaction remains. Of course, there is a possibility that a uranium impurity is present in some cell materials, but it is more likely that platinum (an anode material in some cell designs) is present as an impurity. In the case of the tritium consumers, the obvious allowed reaction is $^{106}Pd(t,d)^{107*}Pd$, reaction 12 of Table II, but other impurity nuclides involved in reactions 2, 10, and 15 of Table II could also be present. However, it is not clear that these spin/parity assignments are correct for the virtual particles, so these selection criteria may be in error. Further experiments should help resolve this issue.

There is some recent evidence that the $^{106}Pd(t,d)^{107*}Pd$ reaction may be taking place. In the following, we analyze the new results presented by Appleby, Murphy, and Srinivasan[17] (AMS). This group presented depth profile data of palladium isotopes taken from cathodes that were electrolyzed in both H_2O and D_2O. The experiments described by these authors are of the standard electrolytic cell type using a palladium disk cathode and a nickel mesh anode. Some of their data, reproduced in Fig. 1, shows the isotopically resolved data from a 0.63-cm-diam × 0.5-cm-long palladium disk in both heavy and light water electrolytes as a function of depth. The natural palladium isotopic abundances are $^{102}Pd = 0.96\%$,

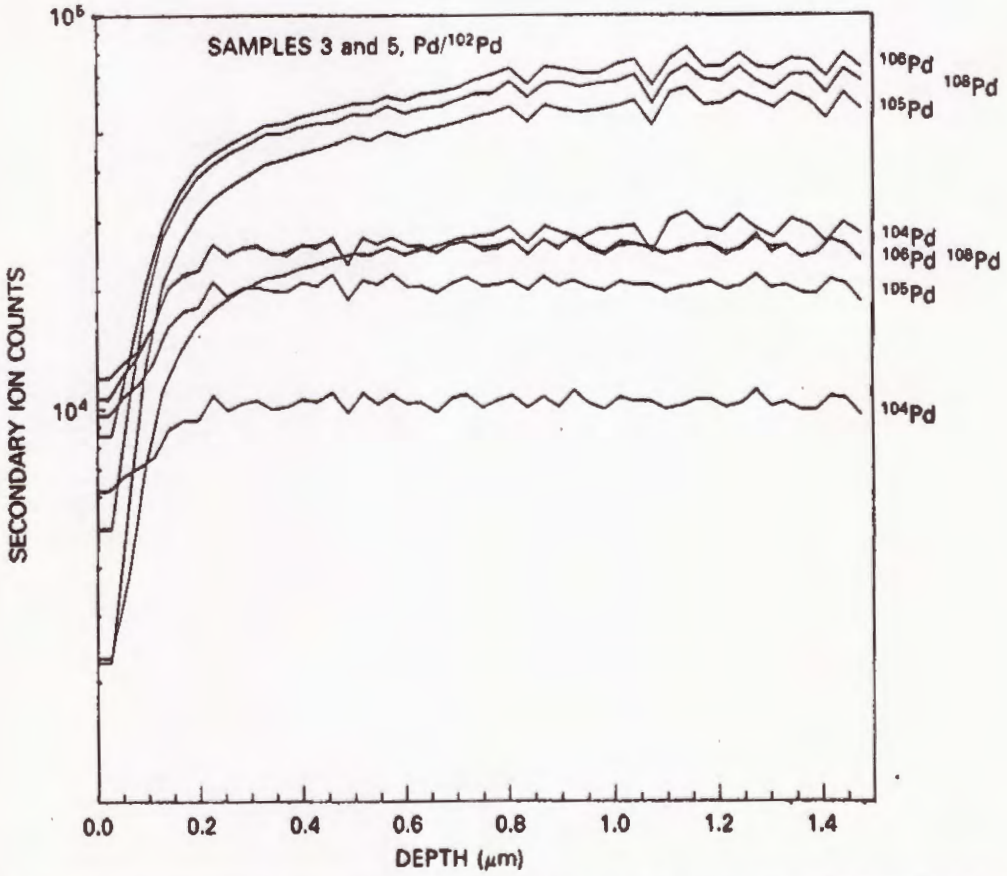

Fig. 1. Palladium isotope data versus depth in two experiments of Appleby et al.[16] The upper set of curves (sample 3) was obtained with a palladium cathode electrolyzed in H_2O; the lower set of curves (sample 5) was obtained with a palladium cathode electrolyzed in D_2O. Note that the ^{106}Pd curve in sample 5 has decreased a small amount relative to the other isotopes in this sample when compared with those in sample 3.

^{104}Pd = 10.97%, ^{105}Pd = 22.2%, ^{106}Pd = 27.3%, ^{108}Pd = 26.7%, and ^{110}Pd = 11.8%. In Fig. 1, the upper curves are the data from the light water electrolyte run, and the lower are from the heavy water run. The important observation here is that the ^{106}Pd of the light water run appears to have been depleted to a level about equal to that of the ^{108}Pd in the heavy water run at least to a depth of 1.4 μm. Other data show that this depletion extends into at least 8 μm. The candidate resonant direct nuclear reaction, as mentioned above, is ^{106}Pd$(t,d)^{107*}$Pd with Q = 0.0641 MeV, and the ^{107*}Pd then undergoes a radiative transition yielding a 0.115-MeV gamma ray.

The ^{106}Pd depletion[18,c] amounts to ~0.6% of the palladium in the first 8-μm layer, which corresponds to roughly 4×10^{17} atoms, and the energy released to ~4 kJ (not counting the gamma-ray energy); over a time of ~1700 h, this gives a released power of only ~7 mW. However, the heat may have been released in a much shorter time burst (≈12 h). In any case, the important result here is that the excess power deduced from this candidate reaction is within reasonable agreement with the observed excess power levels of AMS's experiments.

Clearly, if this is the operative nuclear reaction, then an equal number (4×10^{17}) of tritons would need to have been consumed. However, it is easy to estimate that there could not have been this many tritons available from the tritium in the heavy water (which typically contains ~10^9 atom/ml). The electrolyte had a volume of 100 ml, which converts to ~10^{11} tritons, but there is also fresh heavy water added to make up water lost in the electrolysis at a rate of ~4 ml/h for a replacement time of ~25 h or 68 replacements in their 1700-h run. This gives a total number of tritons available of ~6.8×10^{12}, which is down 6×10^4 from the total required to account for the ^{106}Pd depletion. So either there was additional tritium introduced, or it must have been produced in a tritium-producing reaction of the type listed in Table I.

There is no (d,t) RDNR on the palladium isotopes, so we are forced to look for reactions with contaminants. The nickel anode itself also has no RDNR candidates. However, platinum is a known contaminant (up to hundreds of parts per million) of palladium. Therefore, a candidate RDNR is ^{195}Pt$(d,t)^{194}$Pt(gs) with Q = 0.126 MeV. Uranium (reaction 1 of Table I) might also be present in smaller concentrations, although this has not been measured (as far as we know). The highly nonreproducible and sporadic (burstlike) character of the observed nuclear effects in cold fusion experiments might be traced to the amount of tritium (a contaminant in the deuterium) present and/or the amount produced (through metal contaminants) in RDNRs. This hypothesis can clearly be tested with controlled contamination of the palladium cathodes and by addition of tritium while measuring the excess power generated.

Before leaving our discussion of typical electrochemical experiments (with palladium cathodes), it is useful to mention a point of possible experimental confusion regarding tritium production in these electrodes. If the (t,d) reaction on ^{106}Pd (reaction 12 in Table II) is active in these experiments, then ^{107}Pd is created. This palladium isotope is beta radioactive with a very long half-life, but, more importantly, the beta end-point energy is only 40 keV. This is to be compared with the tritium beta end-point energy of 18.5 keV. If care is not taken to discriminate between these two nuclides by their energy spectra, it is possible to confuse ^{107}Pd for tritium. It is not clear whether this confusion has or has not occurred in cold fusion experiments up to now.

IV.B. Charged-Particle Beam Experiments

Next, we consider another very interesting and important recent experiment that has been described by Chambers, Hubler, and Grabowski[19] (CHG). This group has directly measured charged particles emitted from a thin deuterium-loaded 1-μm titanium foil using charged-particle detectors located directly behind the titanium foil. This group has observed the emission of 5.08-MeV charged particles. It is not known whether the particles were protons, deuterons, or tritons, but the energy measurement resolution was excellent at 17 keV. The CHG experimental result is inconsistent with the charged-particle branch of the d-d reaction that produces a 3-MeV proton and a 1-MeV triton. However, a candidate RDNR that might be responsible is ^{47}Ti$(t,d)^{48}$Ti with Q = 5.3701 MeV into the ground state of ^{48}Ti. Assuming zero incident energy in the center of mass, the exiting deuteron would then have kinetic energy of $E_d = (48/50)Q = 5.155$ MeV. The comparison with the measured charged-particle energy is even closer if the source energy is corrected for coming through the 1-μm foil. (Energy loss of ~88 keV/μm can be estimated from other data of CHG.)

A straightforward calculation of the number of tritons required if this RDNR is producing the CHG data suggests that, as in the case of the electrochemical cells, a tritium supply in excess of the tritium contaminant (~1 part in 10^{14}) in the deuterium would be required to observe their count rates. Since there are no (d,t) RDNRs on titanium, another contaminant metal (see Table I) would again be necessary.

Finally, we mention the quite extraordinary results of the Bhabha Atomic Research Centre[20] (BARC) group. After bombarding a titanium disk with energetic (hundreds of kiloelectron-volts) deuterons from a plasma focus device, the BARC group found no evidence of tritium production on two successive days; however, after 5 weeks they observed very large tritium activity. This group also measured the production of excess tritium by simply loading D_2 gas into palladium metal for a number of days. These results may be consistent with the RDNRs on contaminants taking place during some buildup time, due to a small reaction rate. However, experiments are needed to confirm this conjecture.

Our proposed scenario for explaining the observations in cold fusion leads us to suggest specific experiments that can be performed to test its validity. These include introducing excess amounts of tritium into palladium or titanium, along with measurements to observe enhancement of the nuclear effects. Also, palladium and titanium metals may be doped specifically with measured amounts of metals chosen from the list in Table II and then examined for production of additional tritium and heat.

V. DISCUSSION

In this paper, we proposed a scenario that appears to have characteristics that agree, in large part, with cold fusion experimental data. The scenario consists of RDNRs and electron-resonance-created virtual dineutrons and trineutrons.

[c]Contrary to these results, Ref. 18 reports data indicating an enhancement of the ^{106}Pd isotope during electrolysis; however, the authors in Ref. 18 also suggested that a contaminant species may have compromised their ^{106}Pd data.

The resonance screening hypothesis (without the RDNRs) may also explain observations of strongly increased nuclear reaction rates in "cluster-impact" fusion experiments.[10] Furthermore, it would appear that our scenario could also be an explanation for other anomalous observations apparently requiring nuclear reactions at near-ambient conditions. These include the observation of tritium being released from volcanos and other geothermal vents, as noted by Jones et al.,[2] and the observation of an anomalously large $^3He/^4He$ ratio in chemical-grade metals[21]; this latter observation might occur in a tritium-producing RDNR from deuterium introduced in water during melt processing of the metals, followed by subsequent beta decay of the tritium. Finally, the observation of excess ^3He compared with ^4He in geologically evolved gases[22] could have a similar reaction scenario as its source. Along with the excess ^3He from these reactions, there would be the associated additional source of heat, possibly contributing to the earth's anomalous heat production.[22]

Of course, our hypotheses will require many laboratory experiments of different types before the processes can be fully understood or extended to the geophysical problems mentioned above; however, the direction for further study of these virtual particle low-energy nuclear reactions has been made explicit and should be examined in the near future.

And finally, if the virtual particle hypothesis is borne out, there will undoubtedly be, in addition to the resonant direct nuclear reactions, other interesting virtual particle reactions to examine, such as the virtual-neutron-to-real-neutron transformation reaction that frees a neutron. Some of these reactions have been identified and would be worth examining later, as the two neutron transfer reactions would be.

Our scenario, if proven accurate, could indicate a very important new direction to access nuclear energy release with moderate effort and capital investment, compared with the present fission or fusion technologies.

ACKNOWLEDGMENTS

The authors wish to thank O. Murphy, A. J. Appleby, and S. Srinivasan for the use of their data before its publication. We also thank D. J. Nagel (Naval Research Laboratory) for his interest and support. F. J. Mayer thanks his family for their continuing support and J. Stuck for an important insight into the progress of technology.

REFERENCES

1. M. FLEISCHMANN and S. PONS, "Electrochemically Induced Nuclear Fusion of Deuterium," *J. Electroanal. Chem.*, **261**, 301 (1989).

2. S. E. JONES et al., "Observation of Cold Nuclear Fusion in Condensed Matter," *Nature*, **338**, 737 (1989); also see S. E. JONES et al., preprint submitted to *Nature* (Mar. 23, 1989).

3. J. O'M. BOCKRIS, G. H. LIN, and N. J. C. PACKHAM, "A Review of the Fleischmann-Pons Phenomena," *Fusion Technol.*, **18**, 11 (1990).

4. G. MILEY, M. H. RAGHEB, and H. HORA, "On Aspects of Nuclear Products," *Proc. 1st Ann. Conf. Cold Fusion*, Salt Lake City, Utah, March 28-31, 1990, p. 202, National Cold Fusion Institute (1990).

5. P. L. HAGELSTEIN, "Status of Coherent Fusion Theory," *Proc. 1st Ann. Conf. Cold Fusion*, Salt Lake City, Utah, March 28-31, 1990.

6. G. R. SATCHLER, *Introduction to Nuclear Reactions*, John Wiley & Sons, New York (1980).

7. C. M. LEDERER, J. M. HOLLANDER, and I. PERLMAN, *Table of Isotopes*, 6th ed., John Wiley & Sons, New York (1967).

8. J. RAFELSKI, M. SAWICKI, M. GAJDA, and D. HARLEY, "How Cold Fusion Can Be Catalyzed," *Fusion Technol.*, **18**, 136 (1990).

9. J. R. SPENCE and J. P. VARY, "Electron-Positron Scattering Resonances from Relativistic Two-Body Wave Equations," *BAPS*, **35**, 1677 (1990), in *Physics Letters B* (in press).

10. C. J. BENESH, J. P. VARY, and J. R. SPENCE, "Cluster Fusion by Formation of Compact Electron-Deuteron Resonances," *BAPS*, **35**, 1673 (1990), submitted to *Phys. Rev. Lett.*

11. R. J. BUEHLER, G. FRIEDLANDER, and L. FRIEDMAN, "Cluster-Impact Fusion," *Phys. Rev. Lett.*, **63**, 1292 (1989).

12. J. D. JACKSON, "Catalysis of Nuclear Reactions Between Hydrogen Isotopes by μ^- Mesons," *Phys. Rev.*, **106**, 330 (1957).

13. W. H. WADE, J. GONZALAZ-VIDAL, R. A. GLASS, and G. T. SEABORG, *Phys. Rev.*, **107**, 1311 (1957).

14. J. VOLKL and G. ALEFELD, "Diffusion of Hydrogen in Metals," in *Hydrogen in Metals*, Vol. 1, p. 321, G. ALEFELD and J. VOLKL, Eds., Springer, Berlin (1978).

15. J. R. McNALLY, Jr., "Cold Fusion and Graser Prospects," *Fusion Technol.*, **7**, 331 (1985).

16. J. R. McNALLY, Jr., "Nuclear Fusion Resonance Reactions of Possible CTR Interest," ORNL/TM-3233, Oak Ridge National Laboratory (1970).

17. A. J. APPLEBY, O. MURPHY, and S. SRINIVASAN, "Palladium/Hydrogen Isotope Systems: Microcalorimetric Measurements and Surface Analysis," *Proc. 1st Ann. Conf. Cold Fusion*, Salt Lake City, Utah, March 28-31, 1990, p. 32, National Cold Fusion Institute (1990).

18. D. R. ROLLISON, W. E. O'GRADY, R. J. DOYLE, Jr., and P. P. TRZASKOMA, *Proc. 1st Ann. Conf. Cold Fusion*, Salt Lake City, Utah, March 28-31, 1990, p. 272, National Cold Fusion Institute (1990).

19. G. P. CHAMBERS, G. K. HUBLER, and K. S. GRABOWSKI, "Observation of MeV Particle Emission from Ti Charged with Low-Energy Deuterium Ions," Private Communication (1990).

20. P. K. IYENGAR and M. SRINIVASAN, "Overview of BARC Studies in Cold Fusion," *Proc. 1st Ann. Conf. Cold Fusion*, Salt Lake City, Utah, March 28-31, 1990, p. 62, National Cold Fusion Institute (1990).

21. B. A. MAMYRIN, L. V. KHABARIN, and V. S. YUDENICH, "Anomalously High Isotope Ratio $^3He/^4He$ in Technical-Grade Metals and Semiconductors," *Sov. Phys. Dokl.*, **23**, 581 (1978).

22. E. R. OXBURGH and R. K. O'NIONS, "Helium Loss, Tectonics, and the Terrestrial Heat Budget," *Science*, **237**, 1583 (1987).

Mayer Applied Research Inc. (MARI)
Mayer Applied Research Inc. (MARI) is a consulting and research company started by Dr. Frederick J. Mayer in January 1991. The Ann Arbor, Michigan company specializes in applying physics for small and large companies, and national laboratories in the areas of plasma physics, nuclear physics, lasers, and inertial and magnetic fusion.

MARI has applied for several patents on practical nuclear reactor systems and processes that make use of the new research on hydrogenic nuclear reactions. In addition, MARI scientists have been collaborating with scientists at other laboratories to explore both the energy production and scientific implications of the research. And, joint R&D programs with industrial partners are being negotiated by the company.

Dr. Frederick J. Mayer is the principal scientist
Dr. Frederick J. Mayer has over twenty years of experience in magnetic and inertial fusion research. He received his PhD in plasma physics in 1968 from Case Western Reserve University. Before founding MARI, he directed laser-fusion experiments, plasma diagnostics, and advanced research programs at KMS Fusion in Ann Arbor.

Dr. John R. Reitz is the primary collaborator
Dr. John R. Reitz received his PhD in theoretical physics in 1949 from the University of Chicago. He was a professor of physics at Case Western Reserve University from 1954 to 1965 and Manager of the Physics Department at Ford Motor Company from 1965 to 1987. He has consulted for Los Alamos Scientific Laboratory and is presently a self-employed consultant.

For further information contact:

Mayer Applied Research Inc. (MARI)
1417 Dicken Drive
Ann Arbor, MI 48103

Telephone: 313-662-3841
FAX: 313-662-3920

May 23, 1991 -- on Mayer pre-preproposal

1) Any theory involving "hydrons" is unlikely to hold water.

2) Not clear **who** the experimentalists would be. Or just what the experiments themselves would be. (But I bet it'd be easy to disprove, probably an afternoon in somebody's lab, not a whole project at big $.)

3) The paper is unconvincing:

a) Uses Vary as evidence, but we didn't credit that work.

b) They also ignore fact neutrons are 100,000 times less frequent than tritons (when they should be nearly equally frequent). This, while explaining why there are "no" heliums.

c) Other things in my notes I found unconvincing or doubtful but won't go into here.

4) Would recommend to Mayer **not** to make a *proprietary* proposal. No proposal to AEP is processed quickly because it is reviewed. And, in present climate, *any* proposal having to do with cold fusion would likely fair badly. (Even the Admiral says it's "bad science".)