The nature of transmutation and its relationship to low-energy fusion of deuterium

Edmund Storms
Santa Fe, NM

Topics: transmutation, cold fusion, nuclear mass of $^{4}H^{+}$, neutron emission, low-energy nuclear fusion, LENR

ABSTRACT
Elements that are absent in a material have been found to form during the low-energy fusion of deuterium. This transmutation process can be explained by assuming the fusion reaction involving deuterium emits a ^{4}H particle with enough kinetic energy to produce the reaction $^{A}A_{Z} + {}^{4}H \rightarrow {}^{(A+2)}A_{(Z+1)} + 2n$ when it encounters a nucleus in the surrounding chemical environment. This proposed mechanism is examined in light of several published studies.

I. INTRODUCTION

The fusion of hydrogen isotopes is found to occur spontaneously within specific sites[1] in certain materials, a process that is commonly called cold fusion. This reaction produces measured energy and observed nuclear products consisting of helium and occasional tritium.[2] Profs. Fleischmann and Pons (University of Utah) first described the events in 1989[3] to occur in PdD when electrolysis was used. Since then this nuclear reaction has been replicated many times using other treatments[4-6], with the production of other elements not initially present in the material. This additional nuclear process is called transmutation, which is proposed to result from the energetic fusion product causing a nuclear reaction when it encounters nearby nuclei such as the Pd nucleus in the surrounding PdD crystal structure. This paper explores the relationship between these two types of nuclear reactions through the involvement of ^{4}H, an unstable isotope of hydrogen containing three extra neutrons.

But first, some background information is required. The fusion reaction takes place in small physically isolated sites, called the nuclear active environment (NAE), with each site operating as an independent process. The amount of energy and nuclear products depends on the number of these sites in a sample and the rate at which the fuel, either D or H, can enter the NAE. This process can be described by the following equation. No other equation is required to describe the operational behavior of the process.

$$P(watt) = N*D*F$$

Where P is the total fusion rate expressed as measured power, N is the number of NAE in the sample, D is the rate at which the fuel enters the NAE, and F is related to the D/(D+H) ratio in the material, with the largest value resulting when 100% D is used. The value of N is determined by the treatment of the material. The value of D is determined by the temperature and other conditions

that can increase the rate at which the fuel is transported through the structure, which includes the concentration of the fuel in the structure.

Helium-4 (^{4}He) gas is an observed nuclear product resulting from the fusion reaction when deuterium is used, with the mass change resulting in the calculated energy release of 23.84 MeV/He[1, 2]. The measured values for the He/energy ratio are compared in Fig. 1 as a histogram. The plotted helium/energy ratio results from two separate and independent measurements made during each study involving the amount of helium in the gas and the amount of energy measured using a calorimeter. Neutrons are not produced by this reaction because all of the p and n supplied by the d are in this product.

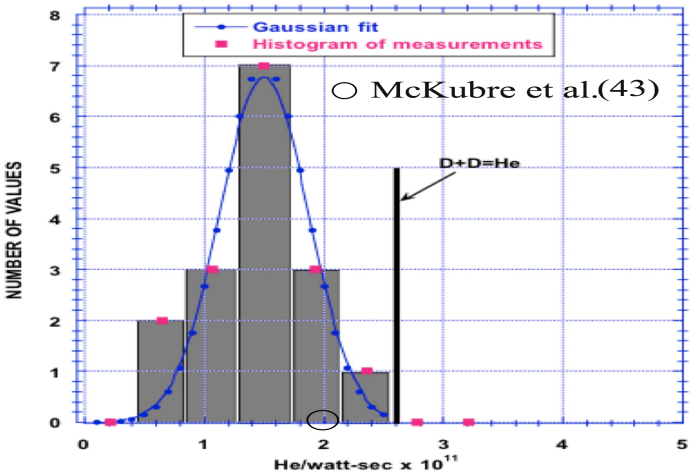

FIGURE 1. Histogram of measured He/energy values compared to the ratio obtained using the mass change when the fusion reaction d+d=He occurs using electrolysis. [7, 8] The vertical line represents 23.85 MeV/He. The value by McKubre et al.[9] was obtained when charcoal+5%Pd was heated in D_2 gas, demonstrating that different methods and materials can produce the same ratio as obtained using electrolysis.

The displacement of the average measured ratio from the calculated value obtained from the mass change is proposed to result from some helium being trapped in the PdD structure along with a smaller amount lost during the transmutation reactions. Some energy may also be lost, as described later in this paper. Nevertheless, the good agreement between the measured values and the value based on the mass change indicate that helium is the major fusion product. How the resulting energy is dissipated is the next problem requiring a solution because another emission is required to conserve momentum as the nuclear energy is dissipated. This issue was explored by Storms[10] who showed that the emission of electrons could not account for the behavior. A solution to this problem will be explored in a future paper.[11]

When the kinetic energy of the emitted fusion product is measured, an unusual feature is observed. Two independent studies described the emission of ions having a series of energies, with each having a consistent value from one to the next in the series[12]. These two studies are compared in Fig 2. Both measurements show a linear relationship between the energy and the number in the sequence that

extrapolates to zero. An accidental process or an error is unlikely to produce such nearly identical behaviors shown by two independent studies.

A typical spectrum obtained by Storms and Scanlan[13] using a silicon barrier detector (SBD) on which the values in Fig. 2 are based, is shown as Fig. 3. They demonstrated that the emissions are an isotope of hydrogen, not helium, by the behavior when the emission passed through absorbers. Later Storms suggested that the observed helium could be explained if these emissions are actually $^{4}H+$, with the observed ^{4}He gas being formed by beta decay after most of this emitted hydrogen isotope had diffused out of the material in which the fusion reaction occurred. This idea is explored next.

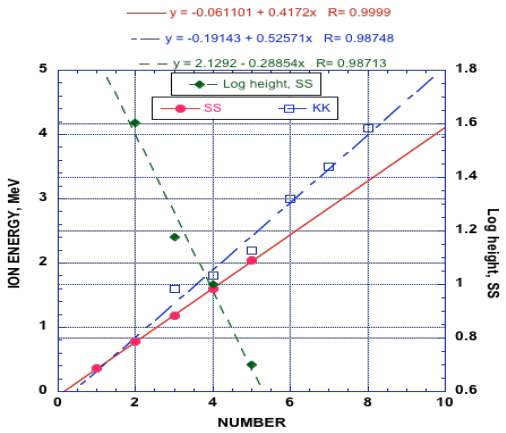

FIGURE 2. A comparison between the measurements of Karabut et al. (KK)[12] and Storms and Scanlan (SS)[13] showing the kinetic energy of the claimed $^{4}H^{+}$ emissions resulting from the fusion of deuterium. The NUMBER identifies each value in a series of energy sets that are separated from each other by the same amount of energy. Also shown is the log of the relative intensity (labeled log height) as a function of the number in the sequence using the SS values. The difference between the two studies could result from the ions having passed through a different amount of material before they were emitted and detected.

This claim for the emission of ^{4}H has attracted many objections because this isotope is thought to be very unstable: decomposing by the emission of a neutron to form tritium in 10^{-22} sec. This behavior is observed when the tritium in PdT is bombarded by very energetic deuterons. The resulting energetic particles are claimed to be caused by the brief formation of the unstable ^{4}H nucleus, instead of by the fragmentation of d or t.[14-18] In contrast, if ^{4}H were to form with less applied energy, Gurov et al.[18] speculate that metastable states may exist in its nuclear structure with the ability to support unexpected behavior.

A variety of observed behaviors described below invite further conclusions about the nature of ^{4}H, its mode of decay, and its atomic mass. For example, the $^{4}H+$ emitted by the fusion of d has enough kinetic energy to cause nuclear interaction when it encounters a nearby nuclei. Consequently, such a secondary nuclear process

can reveal important information about the nature of ^4H and the cold fusion reaction, as described in this paper.

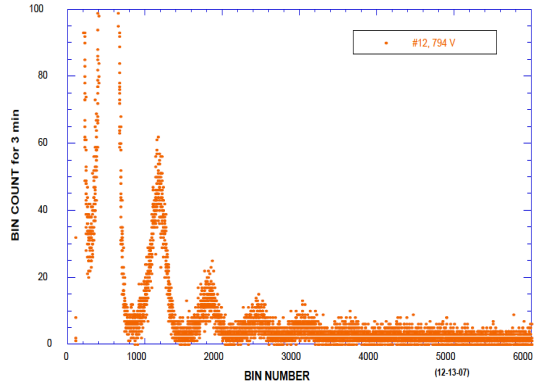

FIGURE 3. Typical spectrum produced when cold fusion occurred during gas discharge in D_2+H_2 gas.[13] The BIN calibration is MeV = 0.000657*BIN. A similar spectrum was observed by KK when a more intense flux was produced using only D_2.

Although many researchers have attempted to explain the transmutation process, this paper will not address this literature.[8] Instead, only the model proposed here by the author is discussed.

II. DISCUSSION

II.1 Justification for ^4H involvement

The proposed role of ^4H is supported by four observed behaviors, with each being logically consistent with the other. Although these patterns of behavior are not proof, they suggest that $^4H^+$ is the initial emission resulting from the low-energy fusion of two deuterons in a material. This process would predict the emission of very energetic electrons as ^4He forms, an emission that might have been detected by Holmlid[19, 20]. However, the observed energetic electron emission was attributed to muon decay rather than to beta decay. Mosier-Boss et al.[21] also noted the observation by Holmlid and provided further evidence for such energetic emissions using CR-39. Mastromatteo[22-24] observed an unusual emission using photographic film. Many other efforts to detect unusual particle emission have been reported, both successful and unsuccessful. While this literature is important, the question discussed here involves only the secondary nuclear reactions caused by the emission of energetic ^4H. The relationship between possible muon formation and cold fusion will be explored in a future paper.[11]

The explanation of ^4H emission starts with the observed formation of tritium (^3H) when both deuterium (D) and hydrogen (H) are present. The formation of tritium can be explained by the capture of an electron during the fusion process. Without this capture, ^3He would result, which is not observed. This capture mechanism is proposed to operate regardless of which hydrogen isotope is involved. As a result, fusion of hydrogen (proton) is expected to produce ^2H (deuterium). This deuterium can then accumulate and result in d-d fusion with the production of ^4H, even when only normal hydrogen is initially present. As a result,

the use of normal hydrogen is expected to exhibit the same behavior as pure deuterium, but with ^{4}H being produced at a lower rate. The production of tritium and deuterium would also be predicted. Observations supporting this result are gradually accumulating, although more evidence is needed.[1] This electron capture is proposed to occur because the process removes energy from the fusion process and converts it to mass in the ^{4}H nucleus. This mass converts to energy when the ^{4}H forms ^{4}He by beta decay within the calorimeter, thus accounting for the consistent He/energy ratio (Fig. 1).

A second consideration involves why all of the helium produced by d-d fusion is not trapped in the PdD lattice, which is a well-known characteristic of helium atoms.[25] Instead, the initial formation of ^{4}H, which behaves chemically like hydrogen, would allow some of this nuclear product to rapidly diffuse out of the PdD. The observed ^{4}He is then formed by beta decay after most of the ^{4}H has escaped into the surrounding gas.

Storms and Scanlan(SS)[13] provided direct evidence for the formation of ^{4}H by measuring its behavior as it passed through absorbers. This behavior, when compared to the known behavior of energetic hydrogen and helium radiation, indicated the emission is an isotope of hydrogen, not helium. which is assumed to be ^{4}H+. As noted above, this fusion product would be expected to result when either D or H is present at the fusion site because the fusion of H+H+e would produce D, as described above.

Transmutation reactions involving the addition of deuterons to produce elements that were not previously present in the material add further evidence supporting the formation of ^{4}H, which is the main focus of this paper.

For a transmutation reaction to occur, three conditions must be met. First, the fusion product must have enough kinetic energy to overcome the Coulomb barrier between it and the target, with the reaction probability being sensitive to its kinetic energy and the charge on the target nucleus, as determined by the atomic number. Second, the resulting nuclear reaction must be exothermic. Finally, something else must be emitted in the opposite direction from the transmutation product to conserve momentum when the resulting mass-energy is dissipated. The creation of many observed transmutation products with the emission of neutrons is consistent with these requirements when ^{4}H is assumed to cause transmutation, as described next.

The ^{4}H+ appears to be emitted with a series of unique energies, shown in Figs. 2 and 3, some of which might have enough kinetic energy to overcome the Coulomb barrier at an observable rate. The resulting transmutation reaction is exothermic, as noted below, and the proposed reaction emits neutrons as the required second nuclear product. Thus, all of the requirements have been satisfied. Furthermore, a series of transmutation products can be expected to form as the fusion product reacts with the elements formed by the previous transmutation reaction, thereby adding additional deuterons to the target, as is observed and described below.

Because these reactions occur at a low rate, the kind and concentration of the resulting elements and isotopes will depend on how long the fusion process occurred and its rate as the products slowly accumulate. The decay of the resulting radioactive nuclei

will create additional uncertainty. These variables are frequently uncontrolled or even acknowledged, making the reported results difficult to compare. Further difficulty is created because fusion occurs only in certain isolated locations with nuclei very near the fusion site being transmuted. Thus, the examined location and the duration of the study will both determine the observed result. With these limitations in mind, what do the reported behaviors reveal?

As an example, Figure 4 summarizes a collection of elements measured throughout a thin layer of Pd deposited on plastic or glass beads subjected to electrolysis in D_2O, as reported by Miley et al.[26-29] Many other studies[4] show a similar relationship between the amount and kind of the transmutation products, with the formation of many similar elements being favored. Of course, some of these elements might be normal impurities in the material and some transmutation products might be produced by unexpected impurities. Nevertheless, this study provides a useful example of a typical behavior, with four different regions being identified. These regions are proposed to result from the presence of certain target elements having a sufficiently high concentration for their transmutation products to be detected.

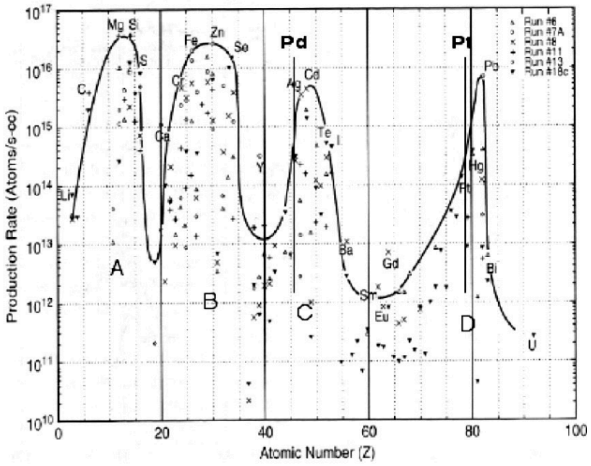

FIGURE 4. The results reported by Miley as summarized by Srinivasan et al.[29] and modified by Storms[8].

Region C is proposed to result from the reaction between ^4H and Pd with additional elements being formed as the ^4H reacts with the resulting transmutation products that accumulate in the NAE. This reaction is described in greater detail in the next section. Region D results from the reaction between ^4H and the Pt impurity normally present in or deposited on the cathode surface as it is transferred from the anode. The regions A and B are proposed to result from the reaction between ^4H and other impurity atoms and their transmutation products in the active material, not as the result of the fission of a transmutation product as is commonly believed[30, 31]. For example, the Mg might result from the transmutation of Na and the Zn from transmutation of Cu, which are common impurities in an electrolytic cell.

In other words, transmutation can result in a complex assortment of elements and isotopes, all of which are proposed to result from the same type of nuclear reaction. Because the concentration and kind of the impurities are frequently unknown, the

resulting transmutation products cannot be clearly related to the source. This problem is eliminated when the target can be clearly identified, as described next.

II.2 Formation of silver

The reaction involving the transmutation of Pd to produce Ag and Cd is used as the first example of how the transmutation mechanism might function.

Biberian et al.[32] studied the transmutation of palladium to silver using a Pd cathode in an electrolytic cell containing D_2O. They found the stable Ag^{107} to be present in greater abundance than the other stable isotope of Ag^{109}, but only in certain locations that had become abnormally hot. The transmutation reaction apparently occurred near the surface in only certain locations with mainly one stable isotope of silver being the result. They proposed that the Pd fused with ^2H but did not identify how the momentum could be conserved when the resulting energy was dissipated. Dash and Wang[33, 34] observed the presence of silver on a Pd cathode after electrolysis using light water (H_2O). This material changed its shape over time, suggesting that it contained radioactive isotopes. Gadly et al. [35] observed a correlation between Ag production and neutron emission, with a range of neutron energies measured below about 3.5 MeV (Fig. 5). These studies provide a good test for the proposed mechanism.

In order for Ag to form, one proton needs to be added to the Pd nucleus. This cannot happen if the fusion product is ^4He. On the other hand, the behavior can be fully explained if ^4H is involved as Storms[8] suggested. The reaction then becomes $Pd + {}^4H = Ag + 2n$, with a deuteron being added to the Pd. The two emitted neutrons are proposed to be emitted separately, not as a dineutron.[36] Table 1 summarizes the resulting nuclear products. The Ag^{107} results as the first stable product with a smaller amount of stable Ag^{109} being produced as a secondary product that would increase as the Cd^{109} decays.

TABLE 1
Isotopes of silver created when Pd is transmuted by reaction with ^4H.
$Pd + {}^4H = Ag + 2n$

Pd atomic weight	Pd abundance %	Ag atomic weight	Half life	decay	Mass-energy change, MeV*	Neutron energy, MeV	Decay product
		first product					
102	1.02	104	69 m	β+	5.2		Pd
104	11.14	106	24 m	β+	5.5		Pd
105	22.33	**107**	stable		7.96	4.0	
106	27.33	108	2.4 m	β–	5.7	2.8	Cd
108	26.46	110	24 s	β–	5.9	2.9	Cd
		second product					
Ag^{107}		Cd^{109}	461 d	electron capture	8.1		Ag^{109}

* Kinetic energy of the ^4H is not added to mass-energy change.
https://en.wikipedia.org/wiki/Isotopes_of_silver.
https://en.wikipedia.org/wiki/Isotopes_of_palladium
https://en.wikipedia.org/wiki/Isotopes_of_cadmium
Nuclear Mass of ^4H used to calculate the reaction energy is assumed to be 4.0258814 amu. (https://www.chemlin.org/isotope/hydrogen-4).

Some Cd has been detected along with the Ag, which would result from the radioactive decay of the unstable isotopes of Ag and the further addition of ^4H to the resulting stable Ag^{107}. Additional elements would be expected if the fusion reaction were allowed to continue for a longer time and examined before some nuclei are lost to radioactive decay. Notice from Table 1 that positrons, beta emission, and the resulting annihilation gamma ray would be expected as well as X-rays.

Because many studies are made with Pd in the material, a similar series of nuclear reactions should happen during all such studies regardless of which isotope of hydrogen is used. However, the transmutation rate is too small to add detectable energy to that produced by the fusion reaction itself. Nevertheless, the occasional reports of weak neutron emission can be explained as being the result of this transmutation process, as described below. Some neutrons are also expected when tritium fuses with deuterium and when hot fusion occurs after the energetic ^4H encounters a d nucleus. Consequently, all observed neutron emission is expected to be the result of secondary nuclear processes, not from d+d fusion. This paper provides evidence supporting this conclusion.

To this end, the calculated isotope distribution of Ag is provided in Table 1. This distribution is consistent with the observations of Biberian et al.[32]. In addition, the presence of silver with radioactive isotopes is consistent with the observations of Dash and Wang[33], which would be true, as explained above, even when light water is used as was the case. The neutron emission energy observed by Gadly et al.[35] when silver is made, plotted in Fig. 5, is examined in greater detail next. However, this study was retracted because the authors could not replicate the results, perhaps because the fusion reaction could not be initiated once again. Nevertheless, the behavior shows consistency with the measurements of the ^4H energy (Figs. 2 and 3).

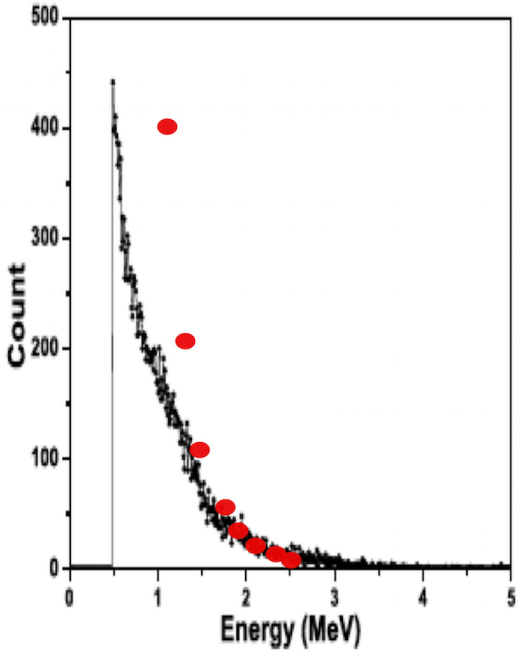

FIGURE 5. Energy spectrum of emitted neutrons produced when the fusion of deuterium occurred in Pd.[35] The calculated values shown as solid O are based on the ^{4}H emission reacting with Pd to produce Ag^{107}.

According to values of neutron energy calculated using the chosen mass of ^{4}H (Table 1), the neutron spectrum would be expected to have a broad maximum between 3 and 4 MeV. In contrast, the neutron spectrum reported by Gadly et al. (Fig. 5) shows a rapid decrease in the number of neutrons as the energy is increased from 0.5 MeV, with no neutrons reported above about 4 MeV. How can this conflict be resolved?

The amount of energy that has to be dissipated would result from the sum of the mass-energy released when Ag formed and the kinetic energy of the ^{4}H. The best fit for the calculated neutron energy depends on a mass chosen for the $^{4}H^{+}$ ion, which can be estimated. Although the mass-energy change resulting from Ag formation is constant, the kinetic energy added by the $^{4}H^{+}$ is not constant, which results in the neutron emission having a range of energies, which are plotted as solid circles (O) on Fig. 5.

Figure 2 illustrates the energy and flux of each ^{4}H emission. Each of these energy sets interacts with the Pd to produce Ag, resulting in varying energy levels that predominantly dissipate as neutron emissions. Consequently, the neutron spectrum exhibits a broad range of values, as observed, but with distinct values. The ^{4}H with the smallest kinetic energy (NUMBER 1 in Fig. 2) yields the lowest energy for emitted neutrons but with the highest flux. However, this emission's energy is so small that the efficiency of the resulting transmutation reaction is expected to be lower than anticipated based solely on the number of ^{4}H present, leading to fewer neutrons being produced by this emission energy. The efficiency of the nuclear reaction would increase as the energy of the ^{4}H increased.

The individual neutron energies blend into a smooth curve because both the neutrons are not always emitted directly opposite to the Ag nucleus, which results

in an unequal distribution of energy between the two emitted neutrons. This variation leads to the apparently smooth behavior over the range of measured neutron energies. In contrast, the calculated values result from using the exact energy of each ^{4}H.

Two variables are used to calculate neutron energy: the sensitivity of the detector and the amount of mass-energy produced by the mass change during the transmutation reaction. These variables are adjusted to achieve the best fit between the calculated and measured values. The loss of reaction efficiency at the lowest energy levels becomes apparent when the calculated values are compared to the measured values, as shown in Fig. 6. The resulting best-fit values of neutron energy are plotted in Fig. 5 for each numbered data set of SS obtained from Fig. 2. The equations used for this calculation are provided in the APPENDIX.

A perfect fit is not expected due to several factors. An unknown fraction of low-energy neutrons may be absorbed, the efficiency of ^{4}H reacting with the target nucleus might not reach 100% at the lowest energies, and additional neutrons could be produced through other nuclear reactions aside from the formation of silver. Nevertheless, the general shape of the measured spectrum aligns well with these calculations, while meeting the three essential requirements for transmutation to occur, without the need for additional assumptions. The fraction of ^{4}H that reacts to produce neutrons is determined by its kinetic energy. Figure 6 illustrates the relationship between the ratio of measured to calculated neutrons and the neutron energy shown in Fig. 5. This ratio corresponds to the effective probability of a nuclear reaction occurring between ^{4}H and the Pd nucleus. For ^{4}H energies below approximately 3 MeV, the effect of kinetic energy on this fraction is found to be linear, with the expected zero reaction probability at zero energy. This relationship arises from two compensating processes: the ability to overcome a reaction barrier decreases rapidly as energy decreases, while the number of available ^{4}H increases quickly as energy decreases. These two factors combine to create a linear relationship in the overall process.

The best fit between the calculated and measured values is achieved using a mass of 4.01841 amu for ^{4}H. Using this mass, the resulting energy release for the other transmutation reactions can be calculated. This mass indicates an energy release of 14.2 MeV when ^{4}H decays by beta emission to produce ^{4}He. Consequently, more than half of the heat energy measured during the formation of ^{4}He might be attributed to the beta decay of ^{4}H, with only 10.6 MeV being emitted with the ^{4}H, to which momentum had to be matched by another emission. Some of this energy may not be measured as heat energy, as the expected emission of an antineutrino would carry away some kinetic energy. This expectation necessitates that measurements of energy and helium resulting from fusion be conducted with greater precision in order to properly understand this reaction and the resulting He/energy ratio.

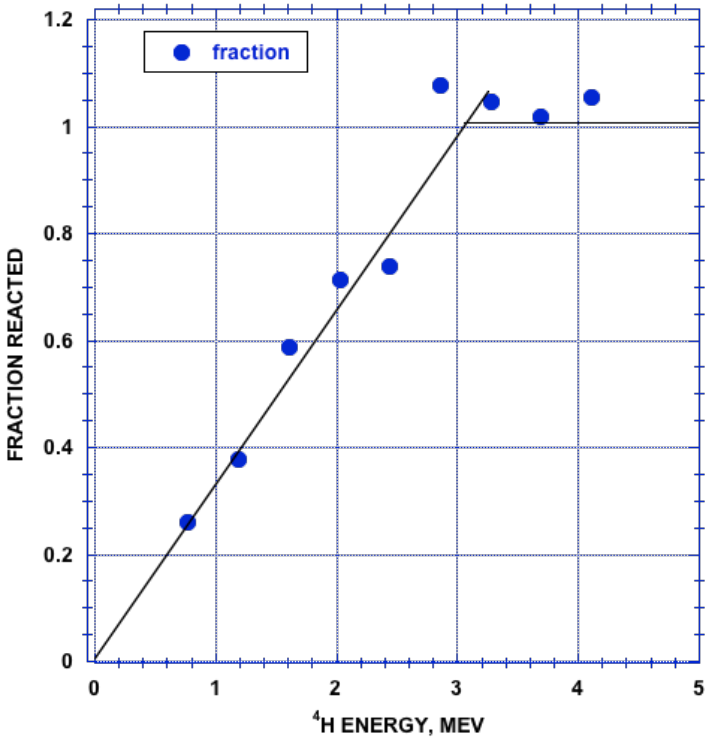

FIGURE 6. Fraction of the emitted ^{4}H that reacts with the Pd to cause the formation of Ag as a function of the ^{4}H kinetic energy.

As shown by the formation of Ag from Pd, the transmutation process adds a deuteron to the target nucleus, which results in the general formula of $^{A}A_{Z} + {}^{4}H = {}^{(A+2)}A_{(Z+1)} + 2n$. This reaction is proposed to be one of the several sources of the low-level neutron emission that is occasionally reported.[21, 37, 38] Because the resulting nuclear product remains at the fusion site, repeated reactions involving ^{4}H can result in a series of transmutation products or their radioactive decay products. As a result, a series of new elements with many deuterons being added to the final product should be observed. When radioactive elements are produced, various kinds of radiation, including gamma rays, electrons resulting from beta decay, and positrons with the annihilation radiation can be expected. These emissions will create a rich assortment that must be carefully evaluated. In addition, the resulting radiation will depend on the duration of the study and the length of time until measurements are made. Because the transmutation rate is so low, the resulting nuclei will normally not accumulate to detectable levels and the neutron emission rate will be too low to detect unless special efforts are made. Because the resulting isotopic abundance will not be normal, the correct identification of the element can be challenging when a mass spectrometer is used. These variables and limitations make the correct interpretation more difficult and have caused much conflict in the understanding.

II.3 Formation of transmutation products with extra deuterons added

Several other examples of this process can be examined to test the validly of the proposed mechanism. Iwamura et al.[39, 40] studied the transmutation resulting from the multiple addition of deuterium (d) to certain target elements in a nuclear active environment containing D_2. Table 2 describes a few examples of the reported nuclear products, which were concentrated only at certain locations in the material. In this case, the targets could be identified because many deuterons were added to an identified target nucleus to produce an easily identifiable nuclear product. The emission required to conserve momentum was not identified.

TABLE 2
Examples of transmutation reactions reported by Iwamura et al.[41] [39, 42]

$$^{133}_{55}Cs \xrightarrow{4d(2\alpha)} {}^{141}_{59}Pr$$
$$^{88}_{38}Sr \xrightarrow{4d(2\alpha)} {}^{96}_{42}Mo$$
$$^{138}_{56}Ba \xrightarrow{6d(3\alpha)} {}^{150}_{62}Sm$$
$$^{137}_{56}Ba \xrightarrow{6d(3\alpha)} {}^{149}_{62}Sm$$
$$^{44}_{20}Ca \xrightarrow{2d(\alpha)} {}^{48}_{22}Ti$$
$$^{184}_{74}W \xrightarrow{2d(\alpha)} {}^{188}_{76}Os$$
$$^{182}_{74}W \xrightarrow{4d(2\alpha)} {}^{190}_{78}Pt$$

Cesium was added to a material that was able to support the d+d fusion reaction. The sequence of elements produced by a serial addition of deuterons is shown in Table 3. Of the several predicted reaction products (shown in red) that should have been present in sufficient concentrations to be detected, only the Pr and La were observed. The concentration of Pr^{141} would be increased, hence made more easily detected, by it having been produced both by the decay of Ce^{141} and by the addition of ^4H to Ce^{139}. As noted in Table 2, four deuterons were found added during the process. Nuclei containing additional d would be expected to form in the material if the reaction had been studied for a longer time. However, the increased nuclear charge on the target would be expected to reduce the reaction rate as additional ^4H is added. Consequently, these targets would be expected to react with only the most energetic emissions of ^4H as was found to occur when ^4H reacted with Pd (Fig. 6).

TABLE 3
Transmutation reactions resulting from Cs as the target

Element	Mass-abundance	Product	Mass	Half-life	Decay product	Mass-Energy, MeV
Cs-added	133 100%	**Ba**	135	stable		6.5
Ba	135	**La**	137	$6x10^4$ y		6.1
La	137	Ce	139	137 d	La^{139}stable	
La	139	Ce	141	32 d	Pr^{141} stable	

Ce	139	***Pr-finish***	141	stable		
		Additional product				
Pr	141	**Nd**	143	stable		

Natural strontium containing its three stable isotopes, as shown in Table 4, was added to a nuclear active material containing deuterium. Table 4 shows that Mo would be expected to result with an isotopic concentration similar to that of Sr, which was observed.[43].

TABLE 4
Sequence of reactions when natural Sr is the target.

Element	Mass-abundance	Product	Mass	Half-life	Decay product
Sr-added	88 82%	Y	90	64 h	Zr^{90}
Sr-added	87 7%	Y	89	stable	
Sr-added	86 10%	Y	88	106 d	Sr^{88} stable
Y	90	Zr	92	stable	
Y	89	Zr	91	stable	
Y	88	Zr	90	stable	
Zr	92	Nb	94	$2x10^4$ y	
Zr	91	Nb	93	stable	
Zr	90	Nb	92	$3x10^7$ y	
Nb	94	Mo-finish	96	stable	
Nb	93	Mo-finish	95	stable	
Nb	92	Mo-finish	94	stable	
Mo	96	Tc	98	$4x10^6$ y	

Isotopes of Zr and Nb should also be detected. The concentration of each of the elements in the sequence should be less than the preceding stable transmutation product.

The radioactive elements with a short half-life will gradually disappear and be replaced by their decay products. As a result, the observed composition will depend on the duration of the study. In each case, Ca and O were both present in the nuclear active site along with the added elements. These two elements should produce Ti (Table 5), with the resulting Sc, V, and F decaying away before measurements can be made.

When the uranium nucleus is added, it is found to be transmuted when either H or D are present during the fusion process. For example, the alpha decay rate is increased when normal hydrogen is present.[44, 45] Addition of D results in neutron emission.[46] The resulting neutron emission might also cause the uranium isotopes to fission, thereby releasing even more neutrons.[47] The behavior has

been presumed to result from cold fusion occurring at suitable sites within the material to produce nuclear products with enough kinetic energy to further interact with the uranium nucleus to produce other elements.

According to the model proposed here, the use of deuterium would result in the addition of deuterium to the uranium nucleus to form neptunium followed by the emission of neutrons. The use of H would result in the same reaction but at a lower rate as D accumulates by the fusion of H+H+e. These predictions need to be tested

TABLE 5
Sequence of reactions when Ca or O is the initial target

Added element	Mass-abundance	Product	Mass	Half-life	Decay product
Ca-added	40 97%	Sc	42	680 ms	Ca^{42}
Ca-added	44 2%	Sc	46	84 d	Ti^{46}
Ca-added	42	Sc	44	4 h	Ca^{40}
Sc	46	Ti	48	stable	
Ti	46	V	48	16 d	Ti^{48}
O-added	16	F	18	1.8 h	

The plastic identified as CR-39, first used by Cartwright[48], has been used by many studies in an attempt to detect the expected emission of alpha particles and neutrons from electrolytic cells when cold fusion is expected. The emissions, as they pass through the material, cause a local change in the chemical stability of the plastic that can be made visible by heating in NaOH solution, resulting in pits that can be counted and measured to determine the kind of radiation and its estimated energy. Because the events are accumulated in the plastic, a very small flux can be detected by using long exposure. Must of the early studies failed to detect reliable emissions while later studies showed reproducible particle emission of various kinds. However, the emitted flux was assumed to be the nuclear products resulting from the fusion reaction itself rather than the result of the transmutation reaction.

Kowalski[49] observed that the pit size measured by Mosieer-Boss et al.[50-52] was too large, on average, compared to the pit size known to be produced by alpha particles. Consequently, these pits must result from something else that is emitted by the fusion process, not ^4He. Although the explanation provided by Mosier-Boss et al. might be valid, these larger pits might be caused by the emission of ^4H that creates an increased distortion of the local chemical bonds when it decays by beta emission in the plastic to form energetic ^4He. Similar pits were produced when H_2O was used in the electrolyte but in far fewer numbers. These are proposed to have resulted after D had been made by the fusion of H, not, as suggested, as the result of the small amount of D impurity in H_2O.

Neutrons were also detected[53-55]. These are proposed here to have resulted only from the various transmutation reactions as described above, with a

spectrum of energy similar to that shown in Fig. 5, but displaced to high energies because of the added contribution by the reaction with lithium when electrolysis is used, as described next.

In addition, when Li is present in the system, as is common when electrolysis is used with LiOD in the electrolyte, the following sequence (Table 6) resulting from the transmutation process is predicted. Repeated transmutation would cause an accumulation of ^{9}Be, ^{11}B, and ^{13}C with additional neutron emission resulting from each reaction. Because these elements have a lower nuclear charge than Pd, the transmutation reaction is expected to occur with greater probability when the lower energy ^{4}H encounters a Li nucleus and its transmutation products. With enough time, the frequently observed iron isotopes could be produced at detectable concentrations at some sites because the transmutation products are all stable, hence available for further transmutation. The transmutation of ^{6}Li would add ^{4}He and extra energy to the He/energy ratio.(Fig. 1)

This sequence is on a path of stability, which does not produce radioactive isotopes until ^{37}Ar is produced, thus accounting for the frequent failure to detect radioactive products. In other words, the absence of radioactivity is a natural consequence of the isotope being produced, not a unique characteristic of the transmutation reaction itself.

TABLE 6
Sequence of reactions when Li is the initial target

Added element	Mass-abundance	Product	Mass	Half-life	Decay product
Li	6 7.5%	Be	8	10^{-17} sec	He^{4}
Li	7 92.5%	Be	9	stable	
Be	9	B	11	stable	
B	11	C	13	stable	
C	13	N	15	stable	
N	15	O	17	stable	
O	17	F	19	stable	

III. IMPLICATIONS TO CONSIDER WHEN HIGH FUSION RATES ARE CREATED

The transmutation mechanism is so inefficient that only a small fraction of the emitted ^{4}H will encounter a nucleus before losing its kinetic energy as the result of unproductive encounters. However, when the fusion rate is increased enough to generate practical power, these transmutation reactions will occur at a significant rate. As a result, the material will become radioactive and undergo modifications as the created elements accumulate in each nuclear active environment. Some of the isotopes may have economic value, making the initial atomic composition of the material important. For example, addition of U^{238} would allow the production of Pu^{242} and other transuranium elements. Perhaps this method might even allow the

island of stability near Z=112 to be accessed when the fusion rate using deuterium is sufficiently large. (https://en.wikipedia.org/wiki/Island_of_stability)

Additionally, neutron, positron, electron, and photon radiation will be emitted at rates that would justify shielding. These consequences will require the generator to be shielded and the nuclear active material to be replaced periodically. The use of light hydrogen is expected to produce tritium. These predictions need to be considered when a practical energy generator is designed.

IV. CONCLUSIONS

This paper expends on the explanation of cold fusion proposed first by Storms in 2012.[56]The proposed emission of ^{4}H as the result of the low energy fusion of deuterium is supported because its emission can account for the reported transmutation products as well as identifying the source of the reported neutron emission. Transmutation can be explained without any additional assumptions being made while the required exothermic behavior and the conservation of momentum are satisfied. The proposed mechanism can be described as $^{A}A_{Z} + {}^{4}H = {}^{(A+2)}A_{(Z+1)} + 2n$. All nuclei located close to the site of the fusion reaction can be expected to transmute to other elements as fusion of the hydrogen isotopes takes place, with each site having a different assortment of elements because each site operates independently of the other sites. This secondary reaction cannot be avoided and would result in weak neutron emission, which is detected when suitable measurements are made. The decay of the resulting radioactive nuclear can be expected to produce other unexpected radiation.

The transmutation products formed by the energetic d or t emitted when H fuses have yet to be fully explored. This reaction is proposed to result in the nuclear products found created in living systems,[57, 58] with the required NAE being created in the living cell. This conclusion is based on the assumption that a single universal condition and mechanism causes all transmutation reactions regardless of the material.

A new value of 4.01841 amu for the mass of ^{4}H is calculated based on the measured neutron energy when Pd is transmuted to produce isotopes of Ag. The use of this value would make the decomposition of ^{4}H into tritium and a neutron endothermic, hence not spontaneous. In other words, the observed formation of silver is in direct conflict with the claimed behavior resulting if ^{4}H were produced by the application of high energy from the t+t and d+t transfer reactions.[14]

Use of this mass to calculate the energy resulting from the fusion of deuterons reveals that most of the resulting energy is released when the ^{4}H forms ^{4}He by beta decay, with an energy release near 14.2 MeV, leaving only about 10.6 MeV to be dissipated within the material at the site of the each fusion reaction. This may explain why the kinetic energy of the emitted nuclear product measured by KK and SS is so small compared to the energy released by the fusion reaction. This also reduces the amount of momentum and kinetic energy required of the accompanying electron emission after fusion has occurred.

In view of these conclusions, the behavior shown in Fig. 1 needs to be reexamined. The displacement of the average data set from the value calculated from the mass change indicates that some helium is missing, which is proposed to be trapped in the PdD. The behavior described here suggests that some energy

would also be missing when the proposed beta decay occurs with the emission of an antineutrino. This loss would cause the data set to be plotted at a larger He/energy ratio than would represent the correct value. The resulting ambiguity needs to be resolved by measuring the amount of helium retained in the PdD with greater precision.

The emission of ^{4}H as a fusion product reveals important information about the nature of the fusion reaction. In addition, the implications have a direct consequence to predicting how a practical source of such energy would behave. This behavior includes the production of useful elements and the need to protect the environment from the emission of dangerous radiation as the fusion and transmutation rates are increased to industrial levels.

V. APPENDIX

When transmutation occurs, the momentum is conserved by the emission of 2 neutrons in one direction and the nuclear product, here assumed to be Ag, in the other direction. This event is described by the following equation.

$$2* M_n * V_n = M_{Ag} * V_{Ag} \qquad 1$$

where M is the atomic mass and V is the velocity with M_n=2.017329 for 2 neutrons and M_{Ag107}=106.90509.

The energy released by the overall reaction into the kinetic energy of the products is equal to the sum of the kinetic energy added by the ^{4}H and the resulting rest mass change between the reactants and products, based on the equation $E=mc^2$. The kinetic energy of the ^{4}H is obtained using the equation in Fig. 2 that resulted from the measurements of SS.

$$\text{Energy } (^4\text{H}) \text{ (MeV)} = -0.0611 + 0.4172*N \qquad 2$$

$$\text{Log Flux} = (0.28854 - 0.28854*N) \text{ normalized to } N=1 \qquad 3$$

where N is the number in the sequence of the energy values.

The energy resulting from the mass change, E(delta mass), is obtained by choosing a value that allows the calculated energy of the neutron to best fit the curve shown in Fig. 5. This approach is necessary because the mass of the ^{4}H used to calculate this value is too uncertain. The best fit between the calculated and measured values of the neutron energy is obtained when the mass of ^{4}H is 4.01841 instead of 4.02588. (https://www.chemlin.org/isotope/hydrogen-4).

The total kinetic energy of the two neutrons is $\frac{1}{2}M_n*V^2_n$ and the kinetic energy of the Ag is $\frac{1}{2}M_{Ag}*V^2_{Ag}$ with their sum equal to $E_t = E(^4H)+E(\text{delta mass})$. The goal is to calculate the kinetic energy of the neutrons that has the required consistently between the momentum and energy. The following equation is the result.

$$\text{The energy of the 2 neutrons} = E_t/((M_n/M_{Ag}) + 1) = E_t * 0.9815 \qquad 4$$

The neutron flux produced by the lowest energy of ^4H, assuming the reaction efficiency is 100%, is adjusted to give the best fit to the measured values. The equation based on the measurements of SS (Equation 3) is used to calculate the flux at each of the other ^4H energies. The calculated values are listed in Table 7.

TABLE 7
Calculated values

$$E_2 = E/(m_2/m_1+1)$$

Equation used to calculate amount of total energy (E) in the emitted neutrons (E_2).

m_2	2.017329832	2n
m_1	106.90509	Ag
m_2/m_1	0.018870288	2n/Ag
m_2/m_1+1	1.0189E+00	
1/	9.8148E-01	

Fraction reacted	measured count	peak number	^4H energy MeV	^4H flux	normalized	Neutron energy MeV	Total energy MEV	Calculated count
		1	0.36	69.29	1.00	0.67	1.36	1500.0
0.259	200	2	0.77	35.65	0.51	0.87	1.77	771.9
0.378	150	3	1.19	18.35	0.26	1.08	2.19	397.2
0.587	120	4	1.61	9.44	0.14	1.28	2.61	204.4
0.713	75	5	2.02	4.86	0.07	1.48	3.03	105.2
0.739	40	6	2.44	2.50	0.04	1.69	3.44	54.1
1.077	30	7	2.86	1.29	0.02	1.89	3.86	27.9
1.047	15	8	3.28	0.66	0.01	2.10	4.28	14.3
1.017	8	9	3.69	0.34	0.00	2.30	4.69	7.4
1.054	4	10	4.11	0.18	0.00	2.51	5.11	3.8

Fraction reacted: Ratio of measured neutron count to calculated count. Plotted on Fig. 6.
Measured count: Values obtained from Fig. 5.
Peak number. Number of peak used to calculate the ^4H energy and flux.
^4H energy: Value calculated using the equation in Fig. 2.
^4H flux: Value calculated using the equation in Fig. 2.
Normalized: The flux normalized to 1 for peak #1.
Neutron energy: The calculated energy of a single neutron.
Total energy: The total of the mass energy change and the applied kinetic energy.
Calculated count: The calculated neutron count. Plotted on Fig. 5 as red dots.

Edmund Storms reports financial support was provided by NASA. Edmund Storms reports a relationship with Google LLC that includes: funding grants. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Submitted to J. Appl. Phys. on 26-Dec-2025, The manuscript is assigned the Manuscript #JAP25-AR-07223. The paper was rejected for the following reason:
Unfortunately, the manuscript is not acceptable for publication in Journal of Applied Physics because it does not meet the journal's acceptance criteria. Journal of Applied Physics considers for publication full-length manuscripts that significantly advance understanding in applied physics and closely related disciplines and are likely to have a noteworthy impact on the relevant scientific communities. Your manuscript addresses a fundamental physics topic, and would find a more engaged readership in a journal where such work is published.

REFERENCES

The papers cited here are found in the library of papers available at www.LENR.org.

[1] E. Storms, Cold Fusion Explained, JCMNS 39 (2025) 249-85.
[2] E.K. Storms, The science of low energy nuclear reaction, World Scientific, Singapore, 2007.
[3] M. Fleischmann, S. Pons, M. Hawkins, Electrochemically induced nuclear fusion of deuterium, J. Electroanal. Chem. 261 (1989) 301-8 and errata in Vol. 263, 187-8.
[4] D. Nagel, Potential Correlations between Apparent Peaks in LENR Transmutation Data and Deuteron Fusion Screening Data, JCMNS 39 (2025) 2095-321.
[5] M. Srinivasan, Introduction to isotopic shifts and transmutations observed in LENR experiments, Current Science 108 (2015) 624-7.
[6] P.A. Mosier-Boss, A Review on nuclear products generated during low-energy nuclear reactions (LENR), J. Cond. Matter Nucl. Sci. 6 (2012) 135-48.
[7] E.K. Storms, The status of cold fusion (2010), Naturwissenschaften 97 (2010) 861.
[8] E.K. Storms, The explanation of low energy nuclear reaction, Infinite Energy Press, Concord, NH, 2014.
[9] M.C.H. McKubre, F.L. Tanzella, P. Tripodi, P.L. Hagelstein, The emergence of a coherent explanation for anomalies observed in D/Pd and H/Pd system: evidence for ^{4}He and ^{3}He production, in: F. Scaramuzzi (Ed) 8th International Conference on Cold Fusion, Italian Physical Society, Bologna, Italy, Lerici (La Spezia), Italy, 2000, pp. 3-10.
[10] E. Storms, A New and Improved Understanding of Cold Fusion Based on the Observed Behavior, ICCF26, Morioka City, Japan, 2025.
[11] E. Storms, Role of the muon in the cold fusion process, To be published (2026).
[12] A.B. Karabut, Y.R. Kucherov, I.B. Savvatimova, Nuclear product ratio for glow discharge in deuterium, Phys. Lett. A 170 (1992) 265-72.
[13] E.K. Storms, B. Scanlan, Detection of radiation from LENR, in: D.L. Nagel, M.E. Melich (Eds), 14th International Conference on Condensed Matter Nuclear Science, www.LENR.org, Washington, DC, 2008, pp. 263-87.

[14] G.M. Ter-Akopian, Y.T. Oganessian, D.D. Bogdanov, A.S. Fomichev, M.S. Golovkov, A.M. Rodin, S.I. Sidorchuk, R.S. Slepnev, S.V. Stepantsov, R. Wolski, V.A. Gorshkov, M.L. Chelnokov, M.G. Itkis, E.M. Kozulin, A.A. Bogatchev, N.A. Kondratiev, I.V. Korzyukov, A.A. Yukhimchuk, V.V. Perevozchikov, Y.I. Vinogradov, S.K. Grishechkin, A.M. Demin, S.V. Zlatoustovskiy, A.V. Kuryakin, S.V. Fil'Chagin, R.I. Ilkaev, F. Hanappe, T. Materna, L. Stuttge, A.H. Ninane, A.A. Korsheninnikov, E.Y. Nikolski, I. Tanihata, P. Roussel-Chomaz, W. Mittig, N. Alamanos, V. Lapoux, E.C. Pollacco, L. Nalpas, Hydrogen-4 and Hydrogen-5 from t+t and t+d transfer reactions studied with a 57.5-MeV triton beam NUCLEAR PHYSICS IN THE 21st CENTURY, AIP Conference Proceedings, Volume 610, pp. 920-924 (2002). 2002.
[15] D.R. Tilley, H.R. Weller, Energy Levels of Light Nuclei, A = 4, Nucl. Phys. A541 (1992) 1.
[16] V.K. Jain, B.B. Srivastava, Energy Level Calculations of 4H in the Cluster Model, Prog. Theor. Phys. 55 (1976) 1653-954.
[17] S. Fiarman, W.E. Meyerhof, Energy levels of light nuclei A=4, Nucl. Phys. A 206 (1973) 1-64.
[18] Y.B. Gurov, M.N. Behr, D.V. Aleshkin, M.V. Tel'kushev, Spectroscopy of superheavy hydrogen isotopes 4H and 5H, EUR PHYS J A 24 (2005) 231-6.
[19] L. Holmlid, S. Zeiner-Gundersen, Ultradense protium p(0) and deuterium D(0) and their relation to ordinary Rydberg matter: a review, Phys. Scr. 94 (2019) 075005.
[20] L. Holmlid, S. Olafsson, Spontaneous ejection of high-energy particles from ultra-dense deuterium D(0), Int. J. Hydrogen Energy 40 (2015) 10559-67.
[21] P.A. Mosier-Boss, F.E. Gordon, L.P. Forsley, D. Zhou, Detection of high energy particles using CR-39 detectors part 1: Results of microscopic examination, scanning, and LET analysis, International J. Hydrogen Energy 42 (2017) 416-28.
[22] T. Matsumoto, Observation of new particles emitted during cold fusion, Fusion Technol. 18 (1990) 356.
[23] T. Matsumoto, 'Nattoh' model for cold fusion, Fusion Technol. 16 (1989) 532.
[24] T. Matsumoto, Comments on "Evidence of micrometre-sized plasmoid emission during electrolysis cold fusion, Fusion Sci. & Technol. 40 (2001) 108.
[25] W.J. Camp, Helium detrapping and release from metal tritides, J. Vac. Sci. Technol. 14 (1977) 514-7.
[26] G.H. Miley, G. Narne, M.J. Williams, J.A. Patterson, J. Nix, D. Cravens, H. Hora, Quantitative observations of transmutation products occuring in thin-film coated microspheres during electrolysis, in: M. Okamoto (Ed) Sixth International Conference on Cold Fusion, Progress in New Hydrogen Energy, New Energy and Industrial Technology Development Organization, Tokyo Institute of Technology, Tokyo, Japan, Lake Toya, Hokkaido, Japan, 1996, pp. 629.
[27] G.H. Miley, J.A. Patterson, Nuclear transmutations in thin-film nickel coatings undergoing electrolysis, J. New Energy 1 (1996) 5.
[28] G.H. Miley, Product characteristics and energetics in thin-film electrolysis experiments, in: F. Jaeger (Ed) The Seventh International Conference on Cold Fusion, ENECO, Inc., Salt Lake City, UT, Vancouver, Canada, 1998, pp. 241-51.

[29] M. Srinivasan, G. Miley, E.K. Storms, Low-energy nuclear reactions: Transmutations, in: S. Krivit, J.H. Lehr, T.B. Kingery (Eds), Nuclear Energy Encyclopedia: Science, Technology, and Applications, John Wiley & Sons, Hoboken, NJ, 2011, pp. 503-39.
[30] H. Hora, J.A. Patterson, The d and p reactions in low-energy nuclear fusion, transmutation, and fission, Trans. Amer. Nucl. Soc. 76 (1996) 144.
[31] I.B. Savvatimova, A.B. Karabut, Nuclear reaction products detected at the cathode after a glow discharge in deuterium, Poverkhnost(Surface) (1996) 63 (in Russian).
[32] J.-P. Biberian, Anomalous Isotopic Distribution of Silver in a Palladium Cathode, J. Cond. Matter. Nucl. Sci. 29 (2019) 211-8.
[33] J. Dash, Q. Wang, Anomalous Silver on the Cathode Surface after Aqueous Electrolysis, in: V. Violante, F. Sarto (Eds), 15th International Conference on Condensed Matter Nuclear Science, ENEA, Italy, Rome, Italy, 2009, pp. 38-41.
[34] J. Dash, Q. Wang, D.S. Silver, Excess Heat and Anomalous Isotopes and Isotopic Ratios From the Interaction of Palladium With Hydrogen Isotopes, in: J. Marwan, S. Krivit (Eds), Low-Energy Nuclear Reactions Sourcebook Volume 2, Oxford University Press, 2009.
[35] T. Gadly, S. Phapale, S. Gamre, P. Jain, H. Kumar, S.K. Poudel, S. Desai, A.K. Pathak, A. Srivastava, A. Kumar, P. Pal, P. Chandwadkar, C. Acharya , A.K. Bakshi, 8,, S. Varma, B.S. Patro, D. Goswami, Experimental and theoretical validation for transmutation of palladium at electrochemical interfaces, Scientific Reports, https://doi.org/10.1038/s41598-024-70597-y 14 (2024).
[36] B. Monteagudo, Mass, Spectroscopy, and two-neutron decay of 16Be, Phys. Rev Lett. 132 (2024) 082501.
[37] P.J. Smith, R.C. Hendricks, B.M. Steinetz, Electrolytic co-deposition neutron production measured by bubble detectors, J. Electroanalytical Chem. 882 (2021) 115024.
[38] T. Schenkel, A. Persaud, H. Wang, P.A. Seidl, R. MacFadyen, C. Nelson, W.L. Waldron, J.L. Vay, Q. Ji, G. Deblonde, B. Wen, Y.-M. Chiang, B.P. MacLeod, Investigation of light ion fusion reactions with plasma discharges, J. Appl. Phys. 126 (2019) 203302.
[39] Y. Iwamura, T. Itoh, N. Yamazaki, H. Yonemura, K. Fukutani, D. Sekiba, Recent advances in deuterium permeation transmutation experiments, J. Cond. Matter Nucl. Sci. 10 (2013) 63-71.
[40] Y. Iwamura, T. Itoh, N. Yamazaki, J. Kasagi, Y. Terada, T. Ishikawa, D. Sekiba, H. Yonemura, K. Fukutani, Observation of low energy nuclear transmutation reactions induced by deuterium permeation through multilayer Pd and CaO thin film, J. Cond. Matter Nucl. Sci. 4 (2011) 132-44.
[41] Y. Iwamura, T. Itoh, M. Sakano, N. Yamazaki, S. Kuribayashi, Y. Terada, T. Ishikawa, Observation of surface distribution of products by X-ray fluorescence spectrometry during D_2 gas permeation through Pd cathodes, in: A. Takahashi, K.

Ota, Y. Iwamura (Eds), Condensed Matter Nuclear Science, ICCF-12, World Scientific, Yokohama, Japan, 2005, pp. 178-87.
[42] Y. Iwamura, S. Tsuruga, T. Itoh, Increase of transmutation products in deuterium permeation induced transmutation, in: A. Kitamura (Ed) Proc. JCF13, Japan CF-Research Soc, WincAichi, Jap, 2012, pp. 196-213.
[43] Y. Iwamura, M. Sakano, T. Itoh, Elemental analysis of Pd complexes: effects of D_2 gas permeation, Jpn. J. Appl. Phys. A 41 (2002) 4642-50.
[44] J. Dash, D. Chicea, Changes In the radioactivity, topography, and surface composition of uranium after hydrogen loading by aqueous electrolysis, in: P.L. Hagelstein, S.R. Chubb (Eds), Tenth International Conference on Cold Fusion, World Scientific Publishing Co., Cambridge, MA, 2003, pp. 463.
[45] J. Dash, I. Savvatimova, S. Frantz, E. Weis, H. Kozima, Effects of glow discharge with hydrogen isotope plasmas on radioactivity of uranium, in: X.Z. Li (Ed) The Ninth International Conference on Cold Fusion, Tsinghua University, Beijing, China, 2002, pp. 77.
[46] S.-S. Jiang, X.-M. Xu, L.-Q. Zhu, S.-G. Gu, X.-C. Ruan, M. He, B.-J. Qi, Anomalous Neutron Burst Emissions in Deuterium-Loaded Metals: Nuclear Reaction at Normal Temperature, Chin, Phys.Lett. 29 (2012) 112501.
[47] P.A. Mosier-Boss, L.P. Forsley, P. McDaniel, Uranium Fission Using Pd/D Co-deposition, J. Cond. Matter. Nucl. Sci. 29 (2019) 219-29.
[48] B.G. Cartwright, E.K. Shirk, P.B. Price, A nuclear-track recording polymer of unique sensitivity and resolution, Nucl. Instrum. Meth. 153 (1978) 457-60.
[49] L. Kowalski, Comment on “The use of CR-39 in Pd/D co-deposition experiments” by P.A. Mosier-Boss, S. Szpak, F.E. Gordon and L.P.G. Forsley, Cur. Phys. J. Appl. Phys. 44 (2008) 287.
[50] P.A. Mosier-Boss, S. Szpak, F. Gordon, L. Forsley, Reply to comment on “The use of CR-39 in Pd/D co-deposition experiments”: a response to Kowalski, Eur. Phys. J. Appl. Phys. 44 (2008) 291.
[51] P.A. Mosier-Boss, S. Szpak, F.E. Gordon, L.P.G. Forsley, Use of CR-39 in Pd/D co-deposition experiments, Eur. Phys. J. Appl. Phys. 40 (2007) 293-303.
[52] P.A. Mosier-Boss, L. Forsley, F. Gordon, Comments on Co-deposition Electrolysis Results: A Response to Kowalski, J. Cond. Matter Nucl. Sci. 3 (2010) 4-8.
[53] A.S. Roussetski, A.G. Lipson, F. Tanzella, E.I. Saunin, M.C. McKubre, Evidence for fast neutron emission during SRI’s SPARWAR/GALILEO type electrolysis experiments #7 and #5, based on CR39 track detector record, in: V. Violante, F. Sarto (Eds), 15th International Conference on Condensed Matter Nuclear Science, ENEA, Italy, Rome, Italy, 2009, pp. 231-6.
[54] P.A. Mosier-Boss, S. Szpak, F.E. Gordon, L.P.G. Forsley, Triple tracks in CR-39 as the result of Pd/D co-deposition: Evidence of energetic neutrons, Naturwissenschaften 96 (2009) 135-42.
[55] P.A. Mosier-Boss, F.E. Gordon, F.P.G. Forsley, Characterization of neutrons emitted during Pd/D co-deposition, J. Cond. Matter Nucl. Sci. 6 (2012) 13-23.
[56] E.K. Storms, An Explanation of Low-energy Nuclear Reactions (Cold Fusion), J. Cond. Matter Nucl. Sci. 9 (2012) 85-107.

[57] J.-P. Biberian, Biological Transmutations: Historical Perspective, J. Cond. Matter Nucl. Sci. 7 (2012) 11-5.
[58] J.-P. Biberian, Biological transmutations, Current Science 108 (2015) 633-5.