The History of Cold Fusion from my Perspective

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INTRODUCTION

The concept of cold fusion can be likened to a Greek tragedy in three acts. It is a tragedy because this potential source of clean, cheap, and accessible energy could have replaced CO_2 emissions from fossil fuels and the dangerous radioactive byproducts of nuclear power before they led to the end of civilization. Instead, the idea was dismissed for misguided reasons.

The first act involves an active rejection of cold fusion. This rejection was justified on the grounds that the proposed process conflicted with established scientific understanding and posed a threat to the financial interests tied to oil, as well as the significant efforts to apply the hot fusion method. These justifications are elaborated in the paper in Appendix 1.

The second act centers on internal conflicts within the field regarding the explanations for the observed phenomena. Everyone had their own theories, which they defended vigorously, often without considering the growing body of new observations. In the absence of a common framework, these ideas can not be evaluated in standard ways. Instead, the acceptance of an idea depended on the social standing of the advocate.

The third act is still unfolding. During this phase, the process is expected to be accurately explained and effectively applied. Because a complex and hazardous machine is not required, this type of energy could potentially power individual homes and factories, with fuel obtained at very low cost from local water supplies. Only the will to pursue this innovation stands in the way.

This paper summarizes my efforts to pursue this goal and includes many of my experimental results that have not been published. I will also attempt to explain, in plain language, how I believe this process works and can be made useful. Having reached the age of 94.5 with declining health, I no longer have the energy to combat the ignorance. Instead, I offer this document to future efforts aimed at addressing the need for clean energy.

SCIENTIFIC BACKGROUND

Before I describe my life with cold fusion, I need to tell you about my unique scientific experience because it has allowed me to see the behavior of cold fusion in new ways.

Education

After graduating from Penn State with a degree in chemistry, I enrolled in the radiochemistry program at Washington University (WU) in St Louis at the PhD level with Prof. Kennedy as my major professor. Dr Kennedy was the head of the metallurgy division at Los Alamos National Laboratory (LANL) during WWII and co discovered plutonium. He created a program at WU to train people about such knowledge, with future employment at LANL as a possibility.

He was interested in creating the super heavy nuclei that are claimed to be stable as an island of stability near an atomic number of 112. To this end he proposed to isolate a source of Sr^{90} in vacuum, allowing the voltage to increase to 2 MeV as the isotope lost energetic electrons by beta decay. An alpha emitter would be placed on the high positive voltage, which would add energy to the emitted helium ions. These energetic helium nuclei would be used to bombard a target of U^{238} at ground potential. The process was expected to continue unattended for many years, during which time mass and atomic number would be added to the target nuclei and the nuclei resulting from their radioactive decay. The expected stable nuclei were expected to slowly accumulate.

This method proved unworkable because the vacuum would not sustain the required high voltage. I contributed to the project by designing and constructing a mass spectrometer that was used to measure the voltage on the Sr^{90}. This tool was also used to study the nature of the discharge mechanism from the high voltage, which became the subject of my thesis. Ironically, the transmutation process caused by cold fusion is expected to result in the same stable nuclei if the process were continued long enough at a large enough rate.

Experience at LANL

My understanding of how a mass spectrometer worked led to my being hired at LANL by a program that was studying the high melting materials used in a nuclear reactor designed to provide electrical and propulsion power in space. I was given the task of designing a mass spectrometer that could be used to measure the vapor pressure of these materials. My studies eventually involved all of the chemical properties exhibited by such materials, which resulted in a book and the papers and presentations listed in Appendix 1.

These materials all have the chemical structure and basic chemical properties similar to PdD, which was the material used initially to support cold fusion. This gave me a unique insight into the nature of the chemical environment in which the fusion process is claimed to occur.

At the time cold fusion was announced in 1989[1], the design of the nuclear reactor being explored at LANL was having difficulty. Everyone realized that if the discovery announced by Profs. Fleischmann and Pons (F-P) were correct; their method for generating energy would solve many problems. In addition, LANL at that time was filled with creative energy, which was stimulated by this new discovery. Prof. Pons was invited to the lab to give a lecture, which had standing room only. I was involved in having Prof. Fleischmann invited to provide his complex explanation for the process.

I suggested an explanation to my group and a willingness to test the claim. This resulted in the DOE providing the money for this and many other studies, and for Carol Talcott, who was an expert in the chemistry of palladium hydride, to join me in the replication effort. Since we worked in a group having expert knowledge about the properties of tritium, an expected nuclear product of cold fusion, we set about trying to make tritium using the electrolyte method, as used by F-P. Other people in laboratories all over the world were also looking for tritium as well as neutrons and heat, the other expected nuclear products.

While tritium was found by researchers in India[2] and at LANL by Dr Thomas Claytor [3] using different methods, our effort was viewed by Prof. John Bockris[4] at Texas A&M as competition for the first to detect tritium in the US by using the F-P method. He won the prize with his ability to make large amounts of tritium while our efforts produced only rare success. Our work was eventually published.[5] Later, I realized that his success resulted from using D_2O that contained a lot of H_2O while we tried to used nearly hydrogen-free D_2O. This experience provided the first clue that tritium (^3H) resulted from the fusion of D+H with an electron being captured by the resulting nuclear product. I assumed that this same electron-capture process occurred when D+D fused to produce ^4H and when H+H fused to produce D (^2H). Justification for this idea has accumulated, as I explain in several papers including in an unpublished paper attached as Appendix 3. However, acceptance by other researches has been slow for reason I will explain below.

Eventually all studies at LANL were terminated by the DOE based on a very faulty evaluation.[6] This error was repeated in 2004.[7, 8] Because my group leader realized that the cold fusion reaction was real and important, I was allowed to continue my study as part of a program that had funding for a different study. This program to produce nuclear power using the fission reaction was later canceled before it was successful. At least some of the money was not wasted.

My effort was expanded to measure the heat energy using a calorimeter that I designed. This design was the isoperibolic type with the D/Pd ratio determined using the pressure of the orphaned oxygen in an electrolytic cell. The first sample was a piece of Pd supplied by Prof. Takahashi in Japan. He had acquired a sheet of Pd, most samples from which were shown by other independent studies to support the claimed cold fusion reaction. Our study also found excess energy to result from two different samples and no energy to result from Pd that other people also found to be dead. We also identified a property of the material that was related to the ability to make this extra energy.[9, 10] Consequently, as early as 1991, proof of independent replication was available as published results.[11] However, the rejection was so effective that the DOE ignored this demonstration. Nevertheless, a growing number of successful studies continued in the US and in other countries. I summarized these studies in my first book, "The Science of Low Energy Nuclear Reactions", published in 2007.[12]

At about that time, because the laboratory was short of funding, people were encouraged to retire early by being given a bonus. In addition, the DOE had taken over control of the laboratory, resulting in much frustration. As a result, so many people retired, including myself, that the laboratory could no longer function. So, we all were hired back as consultants, during which time I continued my study of cold fusion, which was possible because the laboratory briefly retained a little independence.

BUILDING THE HOUSE AND LABORATORY

Carol and I had fallen in love, planned to marry, and then move to Santa Fe. So, we married in a private and unique ceremony at our rustic house in the wilds New Mexico. We then retired and used our time to build a house of our design on a steep lot overlooking the city at 8000 feet, with Los Alamos in the distance. We did much of the physical work ourselves, including the survey of the foundation location, the electrical, the plumbing, and interior framing. Carol laid the many tiles in interesting patterns while we hired a crew and subcontractors to do the rest. We avoided much paper work by paying for the work from our retirement income and savings. The result was a home having very unusual features that contained a laboratory for my continued studies of cold fusion and a place where Carol could make world-class stained glass windows for the house. She eventually created a company to sell her original beaded earrings through local stores. These earrings are still available (2025). We never had so much fun, while some of our friends were suing their contractors.

EXPERIENCE TESTIFYING BEFORE CONGRESS

While Carol and I were building the house, in 1993, I was asked by Rep. Swett of New Hampshire to testify before the Committee on Science, Space, and Technology, US House of Representatives in Washington DC about the status of the cold fusion research. The lab was very unhappy about an ordinary citizen speaking about this subject, but they were forced to comply. So Carol and I flew to Washington where I joined two other scientists to give our support to our respective claims for energy production.[13]

The hot fusion program, which had promised success for the last 40 years, was once again asking for money based on more promises. Congress wanted them to worry that other possibilities were available. However, this event caused no change in the general rejection of cold fusion by the DOE or the repeated support of the failed hot fusion efforts. Nevertheless, it was a fun experience to see how the government actually operates, with appearance being more important than actions. Nevertheless, I was able to put much supporting detail about the subject in the public record.

EXPERIENCE DURING PRIVATE RESEARCH

With the house finished and my laboratory operational, Lewis Larsen hired my services to test the claims being made by Prof. George Miley[14]. Lewis thought that the studies by Prof. Miley violated the IP he was promoting. I found that the claims by Prof. Miley were based on the wrong value for the neutral potential, which he used to correct his measurements of power obtained using the electrolytic method. Consequently, he was not producing extra energy by his process. As is typical of the behavior by people in this field, he refused to accept my claim. This correction is explained in detail in my first book.[12]

Lewis continued to fund my studies, eventually buying an electron microscope for me to examine the material in more detail. This tool was useful to shown the complex nature of the surface produced by the electrolytic process. With his support, I explored the use of all kinds of calorimeter designs, tested the effects of the suggested sources of error, and measured the behavior of many different materials. Eventually, we had a dispute because he chose to support a theory created by Prof. Widom[15] that was so wrong it was an embarrassment.[16, 17] However, this theory was accepted by many people and tested. Of course, all the tests failed because the description was not based on reality. Nevertheless, I was allowed to keep the scanning electron microscope. This tool was later given to Dr Thomas Claytor when my laboratory had to close.

Next Brian Scanlan took an interest in my work and agreed to fund my studies with the goal of creating a useful source of energy. Brian is a self-taught scientist with an interest in exploring new ideas. He created his own laboratory in the basement of his pool house. Our collaboration was both fun and very productive. Without his support and encouragement, I would not have been able to achieve my present understanding of how cold fusion actually works. Eventually he realized that cold fusion would not provide the investment return that other possibilities would provide. We parted with mutual respect and friendship.

LARGE LABORATORY EXPERIENCE

A well equipped laboratory was created in Lubbock Texas with a plan to replicate the methods used by McKubre[18] and Violante[19] who claimed a 75% success rate. The studies were done with the goal of proving by many very careful replications using duplicate cells that the claim for fusion was valid.

The D/Pd ratio was determined using the resistance ratio[20] [21] as pioneered by McKubre[22]. This method caused the first major problems because it required welding fine wires to the Pd cathode. These wires were used to measure the electrical resistance of the cathode, from which the D/Pd ratio was calculated. These wires proved very difficult to attach. In audition, the cathode could not be removed and periodically examined during a study. Eventually, the many cells that had been constructed using this method were later redesigned to use the pressure of orphaned oxygen generated in each electrolytic cell to determine the final D/Pd ratio of each cathode. This method proved difficult because the cells had to be sealed, which created a danger because they would occasionally explode and self-destruct.

I also choose to use the orphaned oxygen method but I measured the volume of oxygen rather than its pressure. This allowed the use of simple glass cells that popped open when they exploded without harm or danger. I found that the temperature of the recombiner catalyst could also be used to determine the D/Pd ratio in real time.[23, 24] When combined with the weight gain, I had three methods to determine the D/Pd ratio that could be compared.

The heat produced by each electrolytic cell in the Lubbock laboratory was measured using a Seebeck-type calorimeter designed by the Navel Research Lab.[25] This calorimeter design was found to have hidden errors. As a result, many cells and calorimeters had to be destroyed and again redesigned. This repeated expense combined with the habit of having equipment shipped from Italy made the study very expensive.

I used a Seebeck calorimeter of my design that had a demonstrated uncertainty of ±0.005 watt. This design allowed all aspects of the cold fusion process to be studied using the same calorimeter. This calorimeter is described in many of the cited studies in the reference section.

With the ability to measure heat at the Lubbock laboratory being uncertain, the helium generated by the fusion reaction was measured. A box containing pure nitrogen surrounded each cell to prevent contamination by the helium in the air. Although this precaution eliminated a possible error, it involved a large additional expense because the nitrogen gas was obtained as boil off from a very large container of liquid nitrogen.

The efforts were unsuccessful in producing useful energy or even to suggest a better understanding because the material was not treated so as to discover the required information. Instead the approach suggested by McKubre was followed[26]. He insisted that only a high D/Pd ratio was required. In addition, the cost was high because many cells had to be destroyed and rebuilt after errors were discovered in their design. Eventually, the lab was shut down.

I was asked to solve several technical problems during several visits to the laboratory but a different approach was never implemented. At the time, my understanding was not good enough to change the accepted understanding provided by McKubre. His explanation was based on the idea later described by Prof. Staker[27, 28]. This description is in direct conflict with well-documented studies about the PdH phase relationship that exists at temperatures and pressures used to cause the fusion reaction.[29]

This failure by well-funded "experts" provided additional evidence that cold fusion has no future.

NASA STUDY

Dr Bruce Steinetz at NASA Glen laboratories asked me to design a calorimeter for their use. I provided a basic design and expected to work with them to implement the many details. Instead, I was asked to visit the laboratory about a year later when I discovered that they had made the calorimeter but with many flaws. The apparatus was much too large, which created a problem because increased size makes a calorimeter more sensitive to changes in the environmental temperature. What was worse, as a safety precaution because H_2 gas was used, the calorimeter was placed in a separate room that did not have environmental temperature control. So, even though the apparatus worked, it did not give stable results. This approach was typical of the NASA style. Their studies were done using very large and complex equipment, with an engineering design suitable for a trip to Mars.

Bruce then asked me to study a sample that had been made years ago by the method used by Dr. Takahashi[30, 31] in Japan. This sample consisted of an alloy of Pd-Zr that had been oxidized to produce isolated particles of Pd in ZrO_2. This approach continues to be explored by Dr Takahashi[32] using a variety of alloys.

Batches of the material he sent had been tested previously with one batch giving excess energy. Unfortunately, the apparatus failed and the money ran out before the test could be repeated. Bruce wanted to know whether this apparently successful test was correct or not. I studied the active batch in detail and found that, indeed, it produced excess energy. I also discovered information about how its chemical behavior influenced energy production. The reports are attached as Appendix 4.

My support by NASA continued until they lost interest in the subject because their efforts to replicate the behavior failed to produce useful power. Nevertheless, important information was discovered about the nature of the nuclear process[33], but without my contribution being acknowledged.

GOOGLE STUDY

Mat Trevithick invited Carol and I to visit the Google campus to discuss funding for me to study some ideas he had about the subject. He was interested in exploring various alloys to determine if they were able to support cold fusion. To this end, he provided a new data acquisition system to make my calorimeter completely automatic and several samples made by commercial sources. Some samples were found to produce fusion energy but not at a useful level. Unfortunately, the studies were not done in a way that could identify the reason for success or failure. The resulting reports are attached as Appendix 5

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TOYOTA AWARD

The field has two awards that are used to honor good work. The first is the silver Preparata Award, which was given to many people over the years, including myself. The second is the gold Toyota Award. This Award was intended to honor Martin Fleishmann and Stanley Pons for their discovery. The Award was given to Martin but it was refused by Stan because he no longer wanted to have any relationship to the subject. Bill Collis, who was instrumental in the creation of this Award, proposed that it be given to me as recognition of my contribution. This was done at a ceremony during ICCF24 in Mountainview, CA. While I was grateful for the recognition, this award did not result in any change in the rejection of my ideas. Carl Page, who organized the conference and provides financial support for several ongoing studies, did not show any interest in my work or its recognition, even to ignore my e-mails. In addition, the lack of any publicity made the event unknown except to people who actually attended the ceremony. So from my perspective, this was a useless nonevent with a value equal only to the gold content of the coin.

HISTORY OF MY UNDERSTANDING OF THE FUSION PROCESS

My approach to research is to work on a small scale and not reach a firm conclusion until the process is fully explored. Because I could make all the required apparatus including machining, programming, and glass working, I could make changes quickly as the need arose. Using trial and error, I eventually designed and built a calorimeter that could be used to study all aspects of the process. The design was replicated by studies supported by Google and by NASA, but without attribution.[34]

Over the years, an effective explanation became clear to me. This description is not only consistent with all of the observed behaviors but also with the laws of Nature. In addition, the approach could be used to design a source of practical energy. Unfortunately, by the time I could use this explanation to describe the process, everyone else in the field had become certain about their own personal understanding. I also discovered that identifying the flaws in the other explanations was a thankless job that did not result in any change. Instead, many people chose to attack my explanation with insults rather than examine their own flaws. As a result, I eventually withdrew from interaction with most people in the field.

Furthermore, the nature of scientific publication has changed. Two types of publication are available. Either the author pays the cost (at the thousands of dollars level) for making the information freely available on the internet to everyone or the reader pays the cost (at $40/download) for access to the paper. Many journals will accept almost any paper when the author pays the cost. In contrast, a journal is encouraged to accept papers paid for by the reader only when a large readership can be expected. Cold fusion does not have a large readership and I do not have the personal money to waste paying for publishing ideas that are ignored.

Events on the way to a full understanding of the operational process.

1.Evidence that the production of heat and transmutation products occur only in very isolated locations and not throughout the material.

2.Evidence that helium 4 is the final nuclear product.

3.Evidence that tritium results from D+H fusion.

4.Evidence that gaps were produced in the material with their number being related to the amount of heat produced.

5.Evidence that metal atom vacancies are not present at the temperature and physical pressure used to cause cold fusion.

6.Evidence that cold fusion and hot fusion resulted from two entirely different mechanisms

7.Realization that the process that causes fusion must not cause detectable chemical changes in the material and must be consistent with all the know rules of chemical behavior.

8.Realization that the rate at which the D can enter the active location, to replace the D after He forms, must be a rate determining process.

9.Evidence that ^4H is emitted with unusual energies.

10.Evidence that all of the transmutation reactions can be explained by the reaction of ^4H with other nuclei in the material. Evidence that the observed neutron emission and occasional radioactivity results from this process.

Operational description of the cold fusion process

The fusion reaction occurs only in special sites, called the nuclear active environment (NAE), These are created as small gaps or voids in a physical structure as the result of treatment. The treatments include forming the NAE in a sintered mixture of small particles and by adding small particles of CaO or SiO_2 to Pd, after which the material is caused to expand as the result of its reaction with D_2 or H_2. The only unknown is the optimum size of the particles. The small gaps can also be manufactured using nanomachining technology.

The random sintering process is proposed to be the accidental source of NAE that is many times attributed to the high surface area of small particles or a condition imagined to be present within the chemical structure. The addition of CaO is proposed to replicate the method J-M used to make active palladium for F-P, which resulted from the purification process used at the time.[35] This method was described by Fleischmann to involve the addition of CaB_6, which formed the particles of CaO when it reacted with dissolved oxygen.

The NAE has the ability to make local electrons available that can lower the Coulomb barrier between two nuclei of hydrogen within the void space. This fusion process adds one electron to the emitted nuclear product along with the emission of other electrons having an energy and direction sufficient to conserve momentum. These electrons can be detected as an emitted current.[36] The nuclear product has enough energy to cause a transmutation reaction when it encounters another nucleus in the surrounding structure, which accumulates in the NAE. When ^4H is emitted, it has a series of individual energies that appear to be separated by multiples of the mass-energy of the electron.[37]

The fusion of D+H produces the occasionally detected tritium, fusion of H+H produces deuterium, and fusion of D+D results in the emission of ^4H. The ^4H decays rapidly to ^4He by beta emission with the release of energy. Before its decay, the energetic ^4H has enough kinetic energy to cause the reaction $^{A}A_{Z} + {}^{4}H \rightarrow {}^{(A+2)}A_{(Z+1)} + 2n$ when another nucleus is encountered. This reaction is the source of the occasionally observed neutrons and transmutation products. The amount of power added by this transmutation process is only a very small fraction of the power produced by the fusion process because of its very low reaction rate.

The total amount of power is determined by the number of NAE present in the material and the rate at which the hydrogen fuel can replace the resulting fusion product in the NAE for the fusion events to continue. The fuel is present in the surrounding lattice structure. The rate of replacement is determined by the diffusion rate, which is sensitive to temperature, applied current, concentration of the fuel in the structure, and laser radiation. Consequently, samples that have too little NAE to produce detectable power have been found to produce detectable power simply by being heated, even when the D/Pd ratio is as low as 0.1.[38]

The role of the fuel/Pd ratio is complex because the measured value is the average throughout the sample, not the value near the NAE. Only the fuel/Pd ratio near the NAE will determine the probability of a fuel nuclei entering the NAE. Furthermore, the fusion process will reduce the concentration near the NAE as the fuel is converted to the nuclear product, thereby creating a concentration gradient between this site and the surrounding lattice. This gradient would be reduced by an increase in the diffusion rate, thereby causing the local concentration to increase with the measured average fuel/Pd ratio having a greater effect on the amount of observed power. Consequently, the diffusion rate would have two effects; one that supplies fuel to the fusion site and the other that causes the local fuel/Pd ratio to have a larger effect that depends on the temperature. This behavior has not been seen because the effect of the D/Pd ratio has been determined mainly at a constant temperature near 20°C.[26]

The nuclear mechanism occurring in the NAE does not have to be understood for the process to be made useful because the fusion reaction is essentially instantaneous without the need for additional treatment after two hydrogen nuclei enter the NAE. Nevertheless, this process is so unusual that it can be expected to reveal a new understanding about the nuclear process.

The total amount of power is described by the following equation. The effect of current is expected to be increased by an applied magnetic field. The effect of laser radiation is too complex to address here.

$$P(\text{watt}) = N * \exp(-E/(RT)) * I^2 * H * C$$

P – fusion power
T – temperature, K
N - number related to the concentration of NAE
H - number related to the D/(D+H) ratio with the smallest value being produced when 100% H is present and the largest value when 100 % D is present in the material.
C - number related to the (H+D)/Pd ratio. This number is complex as described above.
E - activation energy for diffusion
I - number related to the electron current passing through the source of fuel.
R - gas constant

The process has the potential to self-destruct when the temperature can increase without control, as has been observed on a few occasions.[39-41] However, this process would not be dangerous when D_2 gas is used as the source of fuel.

A METHOD TO PRODUCE PRACTICAL POWER

The explanation can now be applied effectively to produce a source of useful power, even above the MW level.

The two most important variables are the number of nuclear active sites and the temperature. The use of pure deuterium creates more power/event compared to the use of normal light hydrogen and avoids the creation of tritium.

Consequently, a method needs to be discovered to make the NAE in a large and very reproducible concentration. The creation of these sites by using a random chemical treatment, as has been done in the past during the laboratory studies, will not result in the required high concentration. Instead, the gaps must be made on purpose using nanomachining or nanoetching methods. This method can be optimized by trial and error after the need for this approach is accepted.

The best materials can also be explored by trial and error with emphasis on the use of Ni and Pd. These can be applied as suitable layers followed by rolling to optimize the size of the gaps as the thickness is reduced. These materials can be effectively recycled so that their cost is not a factor in the design. The resulting transmutation products can be harvested for additional economic benefit. The addition of U^{238} to the nuclear active material can increase the amount of power and produce super heavy nuclei that can have additional applications, but at the cost of additional shielding to stop the resulting neutron radiation.

After a sheet of the activated material is made, it can to be placed in a mixture of D_2 and helium gas having a suitable concentration such that the heat can be carried away by gas transport. The concentration of D_2 gas in the helium gas would be too low to create a risk of an explosion should a leak occur. Loss of gas would quickly stop the production of energy, making the method very safe. A conventional method can be used to convert the heat to electric power.

The temperature of the gas needs to be held in a range that maximizes efficiency, with higher temperatures producing more power but a shorter lifetime for the active material. A current can be caused to pass through the activated metal sheet to rapidly change of the amount of fusion power to match the load and keep the temperature constant. The design needs to allow easy replacement of the active material as it slowly degrades. Suitable shielding is required to stop the radiation produced mainly by transmutation and its radioactive products. The role of transmutation is explained in the paper in Appendix 3

The amount of power delivered by the generator can be matched to the load simply by increasing the number of separate reactors connected in parallel or by changing the temperature and the current applied to each reactor. The control system needs to be designed to prevent thermal runaway.

The generator design is so simple that it can be used to produce local energy at any level and in any environment. The waste heat can be used to separate the D from the H in ordinary water to produce even greater savings. The fusion process produces helium at the rate of 2.8×10^{11} atoms/watt-sec or 0.04 mol He/day to produce 1 MW of heat energy. The loss of D_2 gas would equal this rate. This very small amount of easily available and inexpensive fuel needed to produce a large amount of energy demonstrates the huge cost saving that can result from using this nuclear reaction.

ACKNOWLEDGMENT

The published work of many people made this understanding possible. This information is available in the library at www.LENR.org, This library has been made useful by the efforts of Jed Rothwell, without whose skill and dedication much of the information would have been lost.

APPENDIX 1

Unpublished paper describing the consequence of using cold fusion power.

Cold Fusion,
A new kind of energy and a new threat to civilization

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11/1/25

ABSTRACT

The so-called Cold Fusion process provides a source of inexpensive and safe nuclear energy using isotopes of hydrogen as the fuel without the need to apply high energy. The history and consequences of this important discovery are examined with respect to the political consequence of applying this source of clean energy and how
the fusion process needs to understood to achieve this goal.

Keywords: cold fusion, energy, LENR, nuclear reaction, tritium,

1.0 INTRODUCTION

Thirty-six years ago, a groundbreaking source of energy was discovered that could replace most others now used by industry. Two professors working at the University of Utah, Martin Fleischmann and Stanley Pons,[42] found that nuclear energy could be generated using electrolysis when deuterium, an isotope of hydrogen extracted from ordinary water, was reacted with palladium. This energy was later found to result from the formation of helium.[43] This process, commonly known as cold fusion or low energy nuclear reaction (LENR), is now understood to occur simply by heating certain materials in D_2 or H_2 gas after they have been subjected to special treatment.[37, 44-46] Initially, the claim was met with great interest because it offered a potential solution to the energy shortages in many countries and would allow the elimination of dangerous and expensive sources of energy.[47] However, because skeptics were unable to replicate the claim, further work in the U.S. was stopped and a belief that the claim was not valid was promoted[6, 7]. Huizenga[48] has described the scientific reasons behind this rejection, while Krivit[49] has detailed the political factors that contributed to this process.

This paper will address a series of critical questions, beginning with: Why should anyone take an interest in cold fusion and its troubled past? The answer is urgent and vital: we are faced with one of the greatest challenges of our time. For humanity's survival, we must urgently innovate and develop technologies that do not produce additional greenhouse gases, which are contributing to the alarming rise in global temperatures. (https://science.nasa.gov/climate-change/evidence/)

2.0 DISCUSSION

Hundreds of studies listed in the library at LENR.org have demonstrated that energy can be produced by the cold fusion reaction without creating harmful radiation or radioactive waste, with helium being produced as the main nuclear product when deuterium, obtained from ordinary water, is the fuel. So, why isn't this source of ideal energy being embraced with enthusiasm?

2.1 THE PROBLEMS

Two major problems stand in the way.

First, the ability to achieve fusion without the need for external energy input was once deemed impossible by conventional science. Some skeptics have even suggested that the reported energy outputs resulted from errors or fraudulent claims. However, this skepticism is increasingly baseless. A multitude of studies from diverse laboratories across the globe have consistently observed similar results, with power levels occasionally reaching the kilowatt range. Many of these laboratories can now replicate this effect with remarkable ease[45, 50], though they have yet to achieve commercial viability. Moreover, the amount of helium generated corresponds with the energy released based on the mass change caused by a fusion reaction involving deuterium.[43] Other nuclear products, such as tritium[12] and transmutation products[51], have been documented. This substantial and expanding body of evidence necessitates the acceptance of these claims, even as the underlying nuclear processes may appear improbable. A detailed proposal of how the process might function and be applied is outlined later in this paper.

Second, if this very inexpensive and readily available energy were to become widely accessible, many existing sources of energy could be abandoned, leading to chaos in the energy markets. For example, certain countries, especially China, Japan, and countries in the EU would benefit from this energy by reducing their dependency on costly oil and natural gas imports. Additionally, the reliance on expensive and hazardous fission power could also be eliminated. Such a shift could lead to economic losses for those countries that supply these fuels, diminishing their political influence.

On the other hand, if we do not curtail the burning of coal, natural gas, and oil, the resulting impact on the climate could threaten the very survival of civilization.[52] Furthermore, a reliable source of electrical energy is becoming essential for the functioning of modern civilization. Thus, we are faced with a difficult choice. So, what can be done to reduce the consequences of doing nothing?

The future of civilization will depend on whether countries can collaborate to develop and implement this new form of energy without causing economic disruption in time to stop the predicted change in the climate. Enough understanding about how cold fusion works is available in the published literature to achieve this goal.

2.2 THE SOLUTION

The solution requires a change in how the observed behavior is evaluated and how this information is applied.

Currently, many conflicting and competing explanations have been proposed.[17] These conflicts need to be resolved by effective discussions. The first requirement is to correctly apply the principles that influence a chemical environment. A nuclear reaction is likely an accidental outcome of conventional conditions, rather than a result of a unique mechanism specifically created to initiate a nuclear process.

Furthermore, every condition that would affect the nuclear process would also influence any potential chemical change in the structure. It is important to remember that the local energy in a chemical structure is typically less than a fraction of an electron volt (eV) while a nuclear process involves energy levels greater than many keV, both as a cause and a result. These factors greatly limit the mechanisms capable of facilitating a nuclear process within a chemical environment. Fortunately, after 36 years of study, a clear path addressing this problem has emerged.[53]

The cold fusion process is now known not to use local energy to overcome the Coulomb barrier between the fusing nuclei. Instead, electrons offset the positive charge that keeps the hydrogen nuclei apart. These electrons can assemble in unknown ways in a special physical environment in a solid material, identified as the nuclear active environment (NAE). This environment is proposed to occur naturally in certain materials but at too small concentration to produce evidence of its existence unless a special effort is made.

The generation of the power required for a practical energy source requires the correct identification and the creation of these unique and rare sites. We now know that these sites can be created by several conventional mechanisms consistent with normal chemical behavior[37, 53] and that they are observed to form only in certain locations. We need only to identify and create these sites on a large scale with total control. Nothing in Nature stands in the way of achieving this goal.

These sites are crucial because the electrons present reduce the Coulomb barrier between hydrogen nuclei, allowing their nuclear energy states to interact and potentially form a new element. However, because this critical electron environment is small and rare, identifying it poses significant challenges. As a result, the relationship between cause and effect is often based on speculation. Additionally, since this process occurs within a chemical structure, certain unique rules of this environment are frequently overlooked, leading to explanations that lack connection to accepted physical laws. Consequently, a large and conflicting array of explanations can distract from an effective search for the truth, making it difficult to justify the reality of the claimed energy to skeptics. How can we discover and gain acceptance for the correct explanation?

The challenge now is to increase the amount of the NAE on purpose. Nothing else is required to make energy at useful levels. The amount of power is then determined by how rapidly the fuel is able to diffuse to each of these sites and replace the hydrogen lost to the fusion process. Increased temperature[38, 54-56] and a current caused to pass though the material [37, 57-59] can be used to further increase the amount of power after some NAE has formed. Laser radiation applied to a surface will also amplify the nuclear process.[60-63] Each of these conditions is proposed to increase the local diffusion rate of the hydrogen nuclei, which would make them more accessible to the NAE. In short, the answer to the question asked above is very simple, without the need to propose complex mechanisms justified by complex equations.

The nature of the nuclear process itself remains a mystery, leading to several important questions. How can electrons be assembled in a physical void? How can they lower the Coulomb barrier? How is momentum conserved when only one nuclear product, helium, seems to be formed? The answers are expected to reveal an understanding about electron behavior that is new to science. However, an answer to these questions is not required to create a useful energy generator.

3.0 CONCLUSION

While finding answers to many complex questions is crucial for scientific understanding, they are not necessary for designing an effective energy generator. This is because the nuclear process occurs spontaneously after the NAE has formed and populated with two hydrogen nuclei. The amount of power generated depends solely on the number of NAE present in the material and the rate at which hydrogen nuclei can diffuse from their normal positions within the crystal structure to enter the NAE.

The application of this clean source of energy with a readily available fuel is essential for civilization to continue at its present level. In addition, this energy is critical to support human space travel.

4.0 SUMMARY

The cold fusion effect has been demonstrated numerous times as a potential source of nuclear energy. This process involves applying a specific treatment to a material during which unique conditions are formed where fusion can occur when isotopes of hydrogen are present. The hydrogen nuclei can be made available using methods such as electrolysis, low-voltage gas discharge, or direct reaction with gas.

Increasing the temperature, passing an electric current through the material, or exposing the surface to laser radiation can enhance the power output. Various nuclear reactions can be triggered, leading to the production of ^{4}He, tritium, and transmutation products, depending on the hydrogen isotopes present in the material. Some of these nuclear products have significant economic value. Practical power generation can be achieved when the concentration of nuclear-active sites is sufficiently high. Heat energy is released without producing harmful radiation or dangerous nuclear byproducts. Additionally, energetic electrons are emitted, which could potentially be harnessed to directly generate useful electrical energy.[36]

Success in creating a practical source of energy using this very inexpensive and easily available fuel has significant political and economic consequences that need to be considered. Detailed information about the observed behavior can be found at the www.LENR.org.

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The author has no conflict of interest.
Copies of the papers can be found at www.LENR.org.

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This paper was rejected by the International J. Hydrogen Energy on the bssis of the following comments by the reviewers. The comments demonstrate that the reviewers missed the main point of the paper and showed a profound ignorance of what is known about the fusion process and the intent of the paper.

Reviewer #1: The manuscript presents a view of the cold fusion matter. It is written by an expert in the sector and shortly summarizes the main events and related results of the research in this field. The author is requested to address the following comments before publication.

1) The claim that cold fusion is an inexpensive energy source is too generic. Does any economic analysis exist? If so, it should consider the cost of materials (deuterium, metals used) and their preparation and operation (gas uploading, electrolysis, etc.) and compare the cost of electricity produced via cold fusion

with that of emergent renewable energies (e.g., wind and PV solar are approaching the LOE of 5 cents per kWh!).
2) An important aspect to be discussed is the stability of the hydrogen/metal systems used and then the power density limit of generators based on cold fusion. When the cold fusion occurs, the heat released does increase the temperature of the system and this effect can be exploited to produce useful energy (electricity or some else). On the other hand, we know that the cold fusion in the condensed matter occurs when a high hydrogen concentration is achieved in the metal lattice. The temperature increase following the heat excess is expected to alter the hydrogenation of the metal lattice (e.g., it involves the hydrogen desorption) and then stop the cold fusion event. Could we expect that cold fusion systems are stable only if the power released is well controlled and is limited below a certain value avoiding significant increase of temperature of the hydrogenated metal? If so, actual cold fusion systems will be characterized by low power density and operation at relatively modest temperatures (namely, below 150-200 °C).
3) The references related to conferences papers and reports could not be easily available: is it possible to give a web link to these references?

Reviewer #2: The manuscript presents a perspective on cold fusion as a potential energy source, emphasizing its historical context and societal implications. While the topic is of high interest, the paper lacks original experimental data, rigorous theoretical analysis, or a critical review of recent advances, which limits its scientific contribution in its current form. The specific opinions are as follows.
1. As a Short Communication, the manuscript should offer new insights or data. However, it primarily summarizes known literature and the author's prior work without presenting novel findings or experimental validation.
2. The author proposes that electrons assemble in a "nuclear active environment (NAE)" to lower the Coulomb barrier, but no quantitative model, simulation, or experimental evidence is provided to support this mechanism.
3. The description of methods to enhance NAE concentration (e.g., laser irradiation, electric current) is vague and lacks specific parameters, making it difficult to assess or reproduce.
4. The manuscript ignores comparisons with mainstream fusion approaches (e.g., tokamaks, laser inertial confinement), which are necessary to contextualize cold fusion's claimed advantages.

APPENDIX 2

Publications while working at LANL

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APPENDIX 3

Unpublished paper describing the nature of transmutation reactions

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

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Santa Fe, NM

Topics: transmutation, cold fusion, nuclear mass of $^4H^+$, 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 ^4H particle with enough kinetic energy to produce the reaction $^AA_Z + {}^4H \rightarrow {}^{(A+2)}A_{(Z+1)} + 2n$ 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[37] 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.[12] Profs. Fleischmann and Pons (University of Utah) first described the events in 1989[42] to occur in PdD when electrolysis was used. Since then this nuclear reaction has been replicated many times using other treatments[51, 64, 65], 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.

$$P(watt) = N*f/t*F$$

Where P is the total fusion rate express as measured power, N is the number of NAE in the sample, f/t is the rate at which the fuel enters the NAE, and F is related to the 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 f/t is determined by the temperature and other conditions that can increase the diffusion rate of the fuel.

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[12, 37]. The measured values for the He/energy ratio are compared in Fig. 1 as a histogram. The plotted helium/energy ratio is obtained from two separate and independent measurements made during each study. Neutrons are not produced by this reaction because all of the p and n supplied by the d are in this product.

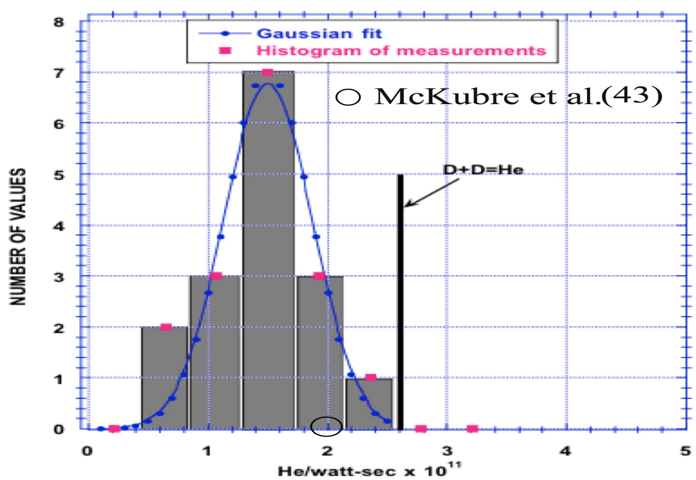

FIGURE 1. Histogram of measured He/energy values compared to the ratio obtained using the mass change when the fusion reaction d+d=He occurs using electrolysis. [17, 43] The vertical line represents 23.85 MeV/He. The value by McKubre et al.[66] is obtained when charcoal+Pd are heated in D_2 gas, demonstrating that the method does not affect the result of the fusion process.

The displacement of the average measurement from the calculated value obtained from the mass change is proposed to result from some helium being trapped in the PdD structure and 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 energy is dissipated. This problem is explored in greater detail by Storms[53] in another paper.

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[67]. These two studies are compared in Fig 2. Both measurements show a linear relationship that extrapolates to zero. An accidental process or an error is unlikely to produce such nearly identical behaviors. A typical spectrum obtained using a silicon barrier detector (SBD) on which the values in Fig. 2 are based in shown as Fig. 3. Storms and Scanlan[68] demonstrated that the emissions are an isotope of hydrogen, not helium. Later Storms suggested that the observed helium could be explained if these emissions are actually $^4H+$, with the observed ^4He gas being formed by beta decay after most of the hydrogen isotope has diffused out of the material in which the fusion reaction had occurred. This idea is explored below.

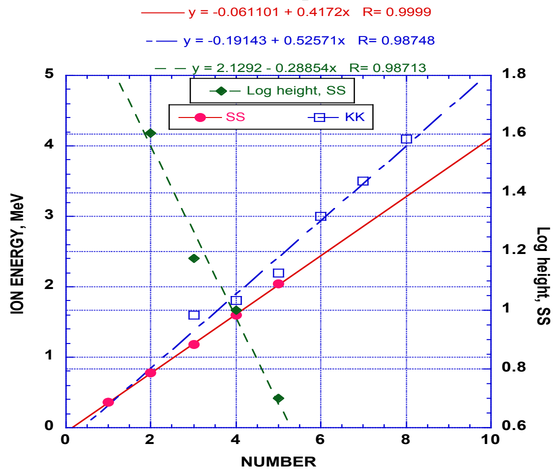

FIGURE 2. A comparison between the measurements of Karabut et al. (KK)[67] and Storms and Scanlan (SS)[68] showing the kinetic energy of the claimed $^4H^+$ emissions resulting from the fusion of deuterium. The NUMBER identifies each value in a series of energy sets that are separated from each other 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.

This claim for the emission of ^4H has created 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 4H ery energetic deuterons. The resulting generation of energetic particles is claimed to be caused by the brief formation of the unstable ^4H nucleus, instead of by the fragmentation of d or t.[69-73] In contrast, if ^4H were to form with less applied energy, Gurov et al.[73] 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 ^4H. For example, the $^4H+$ 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.

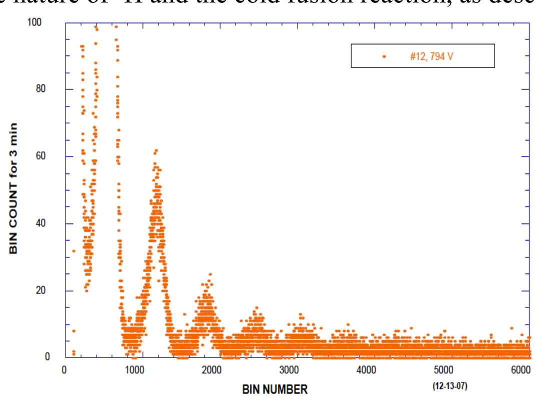

FIGURE 3. Typical spectrum produced when cold fusion occurred during gas discharge in D_2+H_2 gas. [68] The BIN calibration is MeV = 0.000657*BIN.

Although many researchers have attempted to explain the process, this paper will not address this literature.[17] Instead, only the model proposed by the author is discussed.

II. DISCUSSION

II.1 Justification for ^{4}H involvement

The proposed role of ^{4}H is supported by four observed behaviors, with each being logically consistent with each 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 ^{4}He forms, an emission that might have been detected by Holmlid[74, 75]. However, the observed energetic electron emission was attributed to muon decay rather than to beta decay. How a muon could form in a chemical environment is hard to understand. Mosier-Boss et al.[76] also noted the observation by Holmlid and provided further evidence for energetic emissions using CR-39. The question discussed here involves the true nature of these emissions.

First, a single assumption can be used to explain several independent behaviors, which leads to the conclusion that ^{4}H results from the fusion of d. The logic starts with the observed formation of tritium (^{3}H) 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, ^{3}He 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 ^{2}H (deuterium). This deuterium can then accumulate and result in d-d fusion with the production of ^{4}H, 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 significantly less ^{4}H produced with a much smaller energy along with the production of tritium and deuterium. Observations supporting this result are gradually accumulating, although more evidence is needed.[37] Why this electron capture occurs will be the subject of a future paper.

Second, the formation of ^{4}H can account for 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.[77] 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.

Third, Storms and Scanlan(SS)[68] measured the behavior of the ion emission resulting from the fusion reaction 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. This emission 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 would produce D, as described above.

Fourth, 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 used 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. The decay of the resulting radioactive nuclei will create additional uncertainty. These variables are frequently uncontrolled or not even acknowledged, making the results difficult to compare. Further difficulty is created because fusion occurs only in certain isolated locations with only 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 Pd deposited on plastic or glass beads subjected to electrolysis in D_2O, as reported by Miley et al.[78-81]

Many other studies[51] 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.

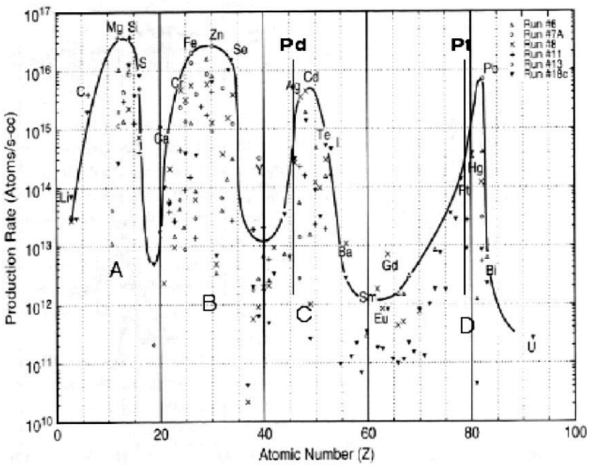

FIGURE 4. The results reported by Miley as summarized by Srinivasan et al.[81] and modified by Storms[17].

Region C is proposed to result from the reaction between ^{4}H and Pd with additional elements being formed as the ^{4}H reacts with the resulting transmutation products. This reaction is described in greater detail in the next section. Region D results from the reaction between ^{4}H 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 ^{4}H 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[82, 83]. For example, the Mg might instead result from the transmutation of Na and the Zn from transmutation of Cu, which are common impurities.

In other words, transmutation can result in a complex assortment of elements and isotopes, all of which are proposed to result from the same kind 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.[84] 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 ^{2}H but did not identify how the momentum could be conserved when the resulting energy was dissipated. Dash and Wang[85, 86] 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. [87] 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 ^{4}He. On the other hand, the behavior can be fully explained if ^{4}H is emitted as Storms[17] suggested. The reaction then becomes Pd + ^{4}H = Ag + 2n, with a deuteron being added to the Pd. The two emitted neutrons are proposed to be emitted separately, not as a dineutron.[88] 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	b+	5.2		Pd
104	11.14	106	24 m	b+	5.5		Pd
105	22.33	**107**	stable		7.96	4.0	
106	27.33	108	2.4 m	B-	5.7	2.8	Cd
108	26.46	110	24 s	b-	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 is allowed to continue for a longer time and examined before some nuclei are lost to radioactive decay. Notice 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 when d-d fusion occurs is expected to be the result of secondary nuclear processes.

In summary, the calculated isotope distribution of Ag in Table 1 is consistent with the observations of Biberian et al.[84] The presence of silver with radioactive isotopes is consistent with the observations of Dash and Wang[85], 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.[87], 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.

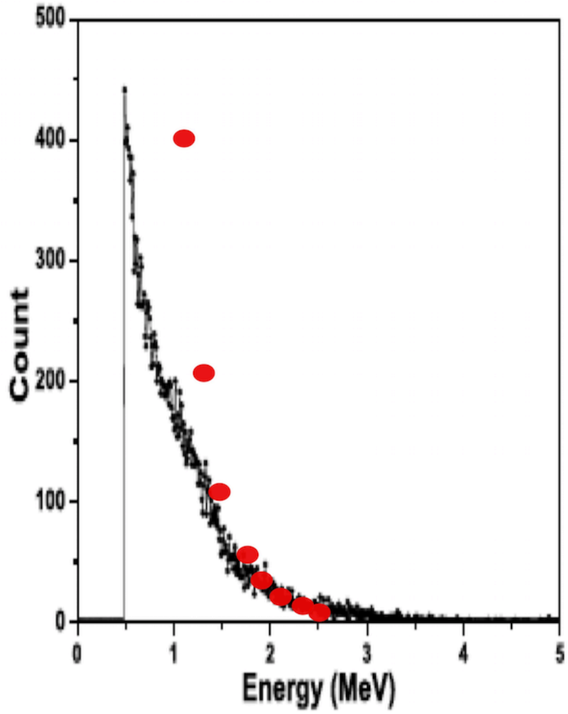

FIGURE 5. Energy spectrum of emitted neutrons produced when the fusion of deuterium occurred in Pd.[87] The calculated values shown as solid O are based on the kinetic energy of the ^{4}H emission resulting from the fusion of deuterium reacting with Pd to produce Ag^{107}. Neutrons resulting from the formation of other elements would add to the number of detected neutrons. The missing neutrons at the lowest energy are proposed to result from a reduced efficiency for the reaction between the ^{4}H and the Pd as the energy of the ^{4}H decreased even as the number of emitted ^{4}H increased.

According to the values 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 calculated amount of mass-energy depends on the mass chosen for the $^4H^+$ ion, which has to be estimated. Although the mass-energy change resulting from Ag formation is constant, the kinetic energy added by the $^4H^+$ is not constant, which results in the neutron emission having a range of energies, which are plotted as solid circles (O) on Fig. 5. This process is explained next.

Figure 2 illustrates the energy and flux of each 4H 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. The 4H 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 minimal that the efficiency of the resulting transmutation reaction is expected to be lower than anticipated based solely on the number of 4H present, leading to fewer neutrons being produced from this emission energy.

The individual neutron energies blend into a smooth curve due to the small kinetic energy range of each emitted ^{4}H, causing some overlap in the measured energies. Additionally, all of 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 a range of measured neutron energies for each ^{4}H. The overlap of these energies contributes to the smooth behavior of the measured curve shown in Fig. 5. However, this range of neutron energies is not represented in the calculated values.

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 is taken into account. 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 ^4H 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 ^4H 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 ^4H and the Pd nucleus. For ^4H 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 ^4H 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 ^4H. 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 ^4H decays by beta emission to produce ^4He. Consequently, more than half of the heat energy measured during the formation of ^4He might be attributed to the beta decay of ^4H. 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.

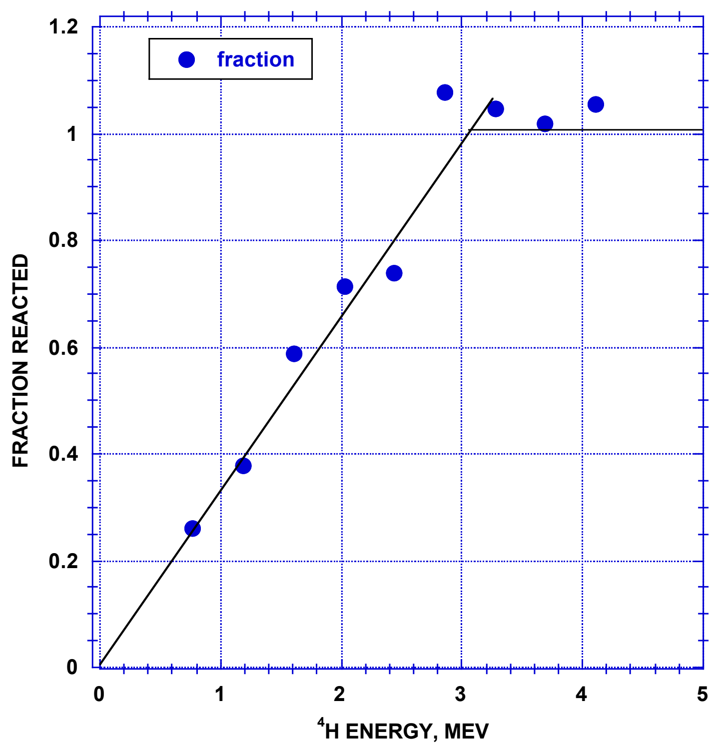

FIGURE 6. Fraction of the emitted ^4H that reacts with the Pd to cause the formation of Ag as a function of the ^4H energy.

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.[76, 89, 90]

Because the resulting nuclear product remains at the fusion site, repeated reactions involving ^4H 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.[91, 92] 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.[93] [91, 94]

$$^{133}_{55}Cs \xrightarrow{4d(2\alpha)} {}^{141}_{59}\mathrm{Pr}$$

$$^{88}_{38}Sr \xrightarrow{4d(2\alpha)} {}^{96}_{42}Mo$$

$$^{138}_{56}Ba \xrightarrow{6d(3\alpha)} {}^{150}_{62}Sm$$

$$^{137}_{56}Ba \xrightarrow{6d(3\alpha)} {}^{149}_{62}Sm$$

$$^{44}_{20}Ca \xrightarrow{2d(\alpha)} {}^{48}_{22}Ti$$

$$^{184}_{74}W \xrightarrow{2d(\alpha)} {}^{188}_{76}Os$$

$$^{182}_{74}W \xrightarrow{4d(2\alpha)} {}^{190}_{78}Pt$$

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 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.[95].

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	
		Additional product			
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 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.[96, 97] Addition of D results in neutron emission.[98] The resulting neutron emission might also cause the uranium isotopes to fission, thereby releasing even more neutrons.[99] The behavior has been presumed to result from cold fusion occurring at suitable sites within the material to produce nuclear products with enough energy to further interact with the uranium nucleus.

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 suggested by Cartwright[100], 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 removed by heating in NaOH solution, resulting in pits that could 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 a 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. This conclusion was not consistent with the measured flux being too small to account for the measured power.[67] These results need to be reexamined in light of this new mechanism.

Kowalski[101] observed that the pit size measured by Mosieer-Boss et al.[102-104] 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 ^{4}He. Although the explanation provided by Mosier-Boss et al. might be valid, these larger pits might be caused by the emission of ^{4}H that creates an increased distortion of the local chemical bonds when it decays by beta emission in the plastic to form energetic ^{4}He. 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[105-107]. 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.

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 ^4H 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.[108]The proposed emission of ^4H 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 $^{A}A_Z + {}^4H = {}^{(A+2)}A_{(Z+1)} + 2n$. 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,[109, 110] 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 ^4H 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 ^4H 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 when ^4H is produced by the application of high energy from the t+t and d+t transfer reactions.[69]

Use of this mass to calculate the energy resulting the fusion of deuterons reveals that most of the resulting energy is released when the ^4H forms ^4He by beta decay. 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 ^4H 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 ^4H and the resulting rest mass change between the reactants and products, based on the equation $E=mc^2$. The kinetic energy of the ^4H is obtained using the equation in Fig. 2 that resulted from the measurements of SS.

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

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

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 ^4H 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 ^4H is 4.01841 instead of 4.02588. (https://www.chemlin.org/isotope/hydrogen-4).

The total kinetic energy of the two neutrons is $½M_n*V^2_n$ and the kinetic energy of the Ag is $½M_{Ag}*V^2_{Ag}$ 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 ^{4}H energy and flux.
^{4}H energy: Value calculated using the equation in Fig. 2.
^{4}H 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.

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APPENDIX 4

Reports sent to NASA

APPENDIX 5

Reports sent to GOOGLE

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