LOW ENERGY NUCLEAR REACTIONS: TRANSMUTATIONS

by

Mahadeva Srinivasan George Miley and Edmund Storms

Preprint of review article distributed to participants of ICCF 16 Conference held in Chennai during Feb 2011

1st February 2011 Chennai

LOW ENERGY NUCLEAR REACTIONS: TRANSMUTATIONS

Mahadeva Srinivasan¹, George Miley² and Edmund Storms³

¹ 25/15, Rukmani Road, Kalakshetra Colony, Besant Nagar, Chennai 600 090, India ² Department of Nuclear, Plasma and Radiological Engineering, University of Illinois, Urbana Il, 61801; ³ Kiva Labs, 2140 Paseo Ponderosa, Santa Fe, NM 87501

1. Introduction:

This article describes different aspects of the phenomenon called "Low Energy Nuclear Reactions" (LENR) which investigate the occurrence of various types of nuclear reactions in certain "host" metals such as Palladium, Titanium, Nickel, etc when they are "loaded" or "charged" with deuterium (or hydrogen) to form the corresponding metallic deuterides (or hydrides).

Deuterium, a heavier isotope of hydrogen, is present in natural waters in minute quantities in the proportion of one deuterium atom to 6000 atoms of hydrogen. The nucleus of the deuterium atom is termed deuteron and is composed of a proton and a neutron. The chemical molecule composed of two atoms of deuterium and one of oxygen is called "heavy water", similar to light water which is primarily made of hydrogen and oxygen. Heavy water (and hence deuterium) is available plentifully in natural water bodies such as the oceans, rivers and lakes and indeed there are industrial level production plants in many countries which produce heavy water commercially in quantities of several tens of tons per annum, by separating it out from ordinary water. (Heavy water is used as a "neutron moderator" in the type of nuclear fission reactor developed originally in Canada known as the CANDU reactor. Detailed descriptions of the CANDU and other types of reactors are available elsewhere in this Encyclopedia.)

Ever since the announcement on March 23rd, 1989, by Martin Fleischmann and Stanley Pons of the discovery of the phenomenon which initially came to be known as "Cold Fusion" but later more appropriately described as "Low Energy Nuclear Reactions" (LENR), physicists have been speculating on the nature of the "anomalous nuclear reactions" that appear to be taking place in the near surface regions of deuterated metals and which often generate significant amounts of "excess heat". (Some times such devices which produce more energy than what they consume are referred to as "over unity systems".)

It has by now been confirmed that in excess heat producing LENR experiments a proportionate quantity of helium gas is released. Evidence accumulated over the last two decades has revealed that at times when the right experimental conditions are met, helium or at times neutrons and also a radioactive isotope of hydrogen known as tritium (in whose nucleus there are two neutrons attached to a proton) are generated. As well, in other carefully conducted experiments, energetic charged particles such as alpha particles (which are basically the nuclei of helium atoms stripped of their two orbiting electrons) and protons have also been detected.

Thus the extensive experimental evidence accumulated over the last two decades has led to the conclusion that when metals such as Palladium or Titanium or Nickel etc are loaded with deuterium to a sufficient degree (meaning high deuterium to metal atom ratios) and these deuterated metals are triggered appropriately, nuclear reactions take place involving the deuterons, catalyzed by the special lattice structure of the "host" metal. In all these inter deuteron

nuclear reactions the host metal appears to serve primarily as a facilitating agent, witnessing the nuclear reactions between the deuterons but not directly taking part in it.

Viewed from the perspective of the generally accepted understanding of nuclear physics, the occurrence of nuclear fusion reactions between a pair of deuterons at room temperatures as described above would be considered "impossible". The basic issue is the strong repulsion between two positively charged deuterons referred to as the "coulomb barrier" which has to be overcome before a nuclear reaction can take place. Theoreticians are raking their brains to explain in what manner the electronic properties and the geometrical arrangement of the ordered atomic lattice of the "host" metal and the possible presence of impurity atoms and/or lattice defect/vacancy sites could be playing an unexpectedly favorable role in enabling nuclear reactions to take place between deuterons embedded in the matrix of the atomic lattice.

Under these circumstances any suggestion or speculation of the possible occurrence of nuclear reactions between the deuterons and the nuclei of the "host" metal such as Palladium or Titanium or Nickel etc, resulting in the transformation of the host metal nucleus would be considered as totally unthinkable! This is because the magnitude of the repulsive coulomb barrier between deuterons and the nucleus of the host metal atom is enormously larger than that between a pair of deuterons.

Yet there were indeed some researchers who, right from day one of the "LENR saga", wondered whether such "magical" nuclear reactions might be occurring in deuterated metallic solids and devised experiments in quest of evidence for them. For if the deuteron could invade the nucleus of the host metal atom in simple laboratory experiments (of the type described later on in this chapter) and succeed in altering the nucleonic composition of the host metal nucleus, resulting in its isotopic composition changing or transmuting its elemental nature then it would imply that the age old claims of Alchemy has been effectively validated and it would have to be admitted that Nuclear Science is witnessing a silent revolution, with deep scientific implications.

However since the stakes are so high, before reaching such an extraordinary conclusion, *the phenomenon would have to be unequivocally confirmed to be true, meeting the highest standards of scientific rigor and scrutiny.* In this chapter we review the on going and fascinating quest for evidence of occurrence of nuclear transmutation reactions in simple experimental configurations.

Throughout the last 21 years, researchers have used an immensely broad variety of experimental and diagnostic approaches to seek and measure elemental and isotopic anomalies in LENR experiments. As a result of this variety, it is not yet practical to perform a full synthesis of the collective results. This chapter will instead provide the reader with an overview of some of the highlights of the work.

2. First Reports of Observation of Pd Isotopic Anomalies:

The first reports of the possible occurrence of nuclear reactions involving a "host" metal nucleus was discussed as early as October 1989 at the NSF/EPRI Workshop on "Anomalous Effects on Deuterated Materials" held at Washington D.C. Rolison and O'Grady of the US Naval Research Laboratory, presented results of their mass spectrometric measurements which hinted at the possibility of changes having taken place in the isotopic composition of the Pd in samples taken from near surface layers of Pd cathodes electrolyzed in D_2O [2.1].

The atomic number of Pd is 46 and its natural isotopic abundance is: Pd^{102} (1.2%), Pd^{104} (8.7%), Pd^{105} (20.5%), Pd^{106} (22.3%), Pd^{108} (15.6%), Pd^{110} (10.5%). Rolison and O'Grady reported that time-of-flight secondary ion mass spectrometry (TOF-SIMS) measurements had indicated that samples from two D₂O electrolyzed Pd cathodes had exhibited an increase of about 20% in the intensity of the (m/z) = 106 peak with a corresponding decrement in (m/z) = 105 peak intensity. Note that Pd^{105} is the only natural isotope of Pd which has an odd number of neutrons, namely 59, in its nucleus. The pre-electrolysis control Pd sample and H₂O electrolyzed "control" sample showed only natural Pd isotopic composition. This result elicited considerable excitement at the meeting as it implied a direct neutron transfer reaction between a deuteron and a Pd¹⁰⁵ nucleus.

However experts in mass spectrometric measurements were skeptic and cautioned that there could be experimental artifacts caused by molecular ions having an (m/z) close to 106 giving rise to false peaks. Indeed at the March 1990 ICCF 1 meeting held at Salt Lake City five months later, the authors did concede there might have been trace levels of ZrO on the Pd electrode as a surface contaminant in the LiOD experiments but emphasized that the Li₂SO₄ electrolyzed samples which did not have this impurity interference still indicated isotopic shifts near the expected (m/z) region. This result, the authors asserted [2.2, 2.3], could not be dismissed away as an artifact, but doubts still persisted in the minds of peers. The original authors too did not persist with their claims since they too could not replicate the results in subsequent measurements.

The Rolison – O'Grady exploratory work however played an important role in highlighting the challenges involved in carrying out such transmutation measurements. It is obvious that the quantity of new isotopes or new elements produced in LENR experiments would be in such low concentrations that skeptics would always dismiss the results as impurities possibly deposited on the electrode from the electrolytic solution or migrated to the surface of the cathode from the interior layers of the bulk cathode material, accumulating at selected hot spots on the surface.

Interestingly it has also been reported that nuclear reactions seem to be taking place even when no host metal is present at all, as in the so called Carbon Arc experiments or in the case of the phenomenon referred to as "Biological Transmutations" which are both discussed later in this review article. While reading this Chapter it is therefore advisable to be mindful of the fact that we are treading a very new and unexplored area of Nuclear Science.

As the story of the possible occurrence of nuclear transmutations in the LENR field unfolded over the years, periodic status reviews were carried out by Miley [2.5, 2.6]. Also Storms had painstakingly collected and compiled in tabular form (reproduced as Appendix A), for inclusion in his 2007 book titled "The Science of Low Energy Nuclear Reaction" [2.7] a large number of experimental reports on the occurrence of transmutation reactions. The present authors have taken advantage of these prior review papers and compilations while preparing this updated overview.

3. Miley-Patterson Thin Film Light Water Electrolysis Experiments:

The pioneering work of George Miley of the University of Illinois and James Patterson of CETI company and their collaborators which was first presented in September [3.1] and later again in October [3.2] 1996 has played a very seminal role in winning recognition for the possible occurrence of transmutation reactions in the LENR field. This work is therefore discussed first at the start of this review, although historically [3.3] during the interim period between 1989 and 1996 too there were many reports of observation of new elements on post run cathodes both in electrolysis experiments and in the impressive glow discharge experiments carried out by Russian groups which are discussed in later sections.

To place the Miley-Patterson work in perspective, one has to first discuss the so called Patterson Power Cell [3.1]. **Figure 1** is a schematic representation of Patterson's flowing packed bed electrolytic cell. The unique feature of this cell was that it used for cathode a packed bed of 1 mm dia plastic or glass microspheres (or beads) which were coated with thin films of Ni and/or Pd. Typically there were about 1000 microspheres in the cell forming a four or five layer bed which constituted the cathode. Both single and multilayer coated bead configurations were investigated, with coating thicknesses varying in the range of 500 A to 3000 A. Some had Ni only coatings, others Pd only and the rest multilayer coatings made up of alternating layers of Ni and Pd.





Miley's group developed a novel technique of producing robust thin film coated beads using a special sputtering process after appreciating the advantages of spherical substrates invented by Patterson, rather than the conventional flat plate support structures which he had been deploying in his earlier thin film electrolysis studies. The distinct advantage of using thin film cathodes is that whatever new reaction products are formed it would constitute a significant percentage of the host metal atoms rendering the results more trustworthy. The freshly generated products would no more constitute such minute levels that critics could readily dismiss the results as probable impurities deposited from the electrolyte. Besides, high deuterium or hydrogen loadings could be obtained with thin films in time durations as short as an hour or two compared to days or weeks required when conventional Pons-Fleishmann type thicker electrodes are used.

The electrolyte deployed in the Miley-Patterson studies was a light water solution of 1M Li_2SO_4 (Lithium Sulphate) which was circulated in a closed loop through a heat sink, for purposes of excess heat measurements. Knowing the mass flow rate and the temperature differential between outlet and inlet, the power output could easily be computed; the input power is the product of voltage applied and cell current. In several runs excess heat production was observed with multilayer coatings giving excess power values as much as 4 watts. Details of their calorimetry and excess heat results are discussed in References [3.1, 3.2].

Unlike their early excess heat oriented studies, for purposes of transmutation measurements, Miley and Patterson constructed a new system which eliminated metallic components to the extent possible, thereby minimizing possible sources of impurities. During the electrolysis runs the thin metallic films quickly get loaded to a high ratio of H-to-film metal atoms which is then believed to undergo nuclear transmutation reactions involving the hydrogen and host metal nuclei. After a couple of weeks of electrolysis, beads from the top layers of the packed bed cathode were carefully removed and analyzed for the presence of new elements not present in the "control" beads prior to electrolysis. In all more than a dozen experiments were carried out with cathode beads of various types of coatings described earlier.

A variety of measurement techniques such as Secondary Ion Mass Spectrometry (SIMS), Energy Dispersive X-ray (EDX) analysis, Auger Electron Spectroscopy (AES) and Neutron Activation Analysis (NAA) were employed. While EDX gave confirmatory data for the higher concentration elements AES was used for depth profiling of these elements. SIMS was used to obtain an overall picture of the various nuclides present and their relative isotopic ratios while NAA gave a quantitative measure of 8 key elements namely Al, Ag, Cr, Fe, Cu, V, Co and Zn present in a gross sample containing ten microspheres. In case of Cu and Ag NAA helped establish deviations of isotopic composition from their natural abundance values. NAA has the advantage that it circumvents the molecular ion interference problem that often plague mass spectrometric measurements. The University of Illinois Triga research reactor was used for these studies with calibration carried out using NIST standards. Since NAA typically gives an average value integrated over 10 beads it averages out the significant bead to bead variations in the reaction product yields which are known to be sensitive to the location of the microspheres in the packed bed. Other techniques helped probe a local area of coating on a single microsphere.



Fig. 2. Miley's Pd-Ni thin film light water electrolysis experiments: Log rate of reaction product yield as a function of its mass number.

The results of elemental analysis showed the presence of a wide range of new elements in the post run thin films. Surprisingly the reaction products had mass numbers ranging both below and above the atomic mass number of the host metal, spanning across the entire periodic table. Figure 2 shows a consolidated plot of the Reaction rate (yield) vs. Product mass number for the case of several Ni-Pd composite multilayer thin film cathode runs, reproduced from Ref. [3.2]. The raw experimental data from different analytical measurements were appropriately normalized prior to plotting. Data from several different runs are plotted in this figure. The outer envelope enclosing all the data points brings out the distinctive grouping of the high yield elements into four broad zones of mass numbers (A ~ 22 to 23, 50 to 80, 103 to 120 and 200 to 210).

Figure 3 shows the same data plotted as production rates against the atomic number (Z value) of the reaction product elements. The characteristic four humped yield spectrum is once again

evident with humps occurring at Z = 6-18 (peak at Mg-Si), Z = 22-30 (peak at Fe-Zn), Z = 44-50 (peak at Ag-Cd) and Z = 75-85 (peak at Au). In some of the runs as much as 40% of the initial metal atoms of the thin film coating was transmuted. It is speculated that each of these groups of elements is derived from one of the main elemental components used in the construction of the cell such as Sulphur, Nickel, Palladium and Platinum (anode material). Interestingly this type of grouped reaction product yield curve is found to be consistent with the results reported by other investigators too such as Mizuno, as will be seen in the next section.



Fig. 3. Miley's Ni-H₂O experiments: Reaction product yield vs. atomic number.

From the SIMS data which indicates the isotopic composition of the elements, it is observed that most of the elements showed substantial isotopic deviation from natural abundance whereas analysis of the control beads corresponded to natural isotopic ratios only. The NAA data for Ag and Cu also confirmed statistically significant deviations from natural abundance. However it was not possible to discern any systematics in the isotopic shift results since there was considerable scatter in the isotopic ratios depending on the location of the bead in the cathode bed as well as depth of the sample within the coated film layer. The original papers on these studies [3.1, 3.2, 3.4, 3.5] have dealt with the expected criticism namely the possibility that the observed post run reaction products could have arisen from impurity deposition from the electrolyte. The NAA quantitative comparisons of the levels of the key "transmutation elements" in pre vs post-run beads provide very strong support for the reliability of the transmutation results, since impurity deposition can not explain the isotopic shifts. The original papers have also discussed the differences in yield spectrum between different base metal coatings, differences in product yield between plastic beads and glass microspheres and differences between H₂O runs and D₂O runs.

There is considerable speculation on the nature of the mechanism that could be responsible for production of such a wide variety of elements. The similarity of these four humped yield curve with the well known double humped yield curve observed in the neutron induced fission process has led to speculation that there could be a similar proton or deuteron induced fission of the compound nucleus formed between a host metal nucleus and one or more deuterons in LENR configurations.

4. Mizuno and Ohmori: Transmutation Products on Pd Cathodes in D₂O Electrolysis Experiments:

At about the same time in 1996 when Miley and his team were performing the above experiments, Mizuno and his collaborators at Hokkaido University, in Sapporo started carrying out a systematic analysis of their post run Pd cathodes which had earlier been electrolyzed in heavy water solutions at high current density, high temperature and high pressure, in search of evidence for the presence of new elements not present in the virgin cathode material. They were inspired by the deliberations at the First International Conference on Low Energy Nuclear Reactions held at College Station, Texas in June 1995 under the leadership of Prof. Bockris who is considered a pioneer [4.1] in the field of LENR research . Using several different analytic methods, Mizuno, Ohmori and Enyo [4.2] found reaction products with mass numbers varying from 6 to 220, comprising a wide range of elements from hydrogen to lead.



Fig. 4. EDX Spectra from a Pd cathode rod before and after electrolysis.

Figure 4 reproduced from Ref [4.2] shows a semilog plot of the EDX spectrum of a Pd cathode rod before and after electrolysis as recorded by them. This rod had shown an integrated excess energy output of ~10 MJ. Peaks corresponding to Pt, Cr and Fe are seen to be comparable in magnitude to the bulk Pd peak while signals corresponding to Sn, Ti, Cu and Pb are relatively smaller in magnitude. EDX analysis performed at different locations on the cathode surface indicated that the counts corresponding to newly formed elements varied by as much as a factor of ten between different locations, bringing out the highly localized nature of the transmutations (indeed the entire LENR) phenomenon, a feature which has been highlighted by Miley and most other workers also.

Figure 5 reproduced from the same reference [4.2] shows the yield spectrum of the reaction products deduced from the SIMS count rates generated using O_2^+ ions to bombard the Pd sample. The data are plotted as a function of the atomic number of the detected isotope. (The explanation for labeling the X-axis as "counting correction RSF/cm⁻³" is discussed in detail in Ref. [4.2].) It is surprising that in the spectrum the maxima correspond to inert gases. The authors have speculated that perhaps during SIMS analysis the inert gas atoms may have been more efficiently ejected when bombarded by oxygen ions, giving false peaks corresponding to their atomic positions.



Fig. 5. Mizuno's Pd-D₂O experiments: Yield of elements formed on surface vs. atomic number

Figure 6 shows the reaction product yield spectrum plotted as a function of the mass number of the isotope. Note that this too shows a four humped spectrum remarkably similar to that of Miley et al, presented in Fig. 2.



Fig. 6. Mizuno's Isotopic Analysis of Pd cathode electrolyzed in heavy water solution: SIMS count rates vs. mass number

Mizuno also reports that the isotopic distributions of almost all of the newly produced elements are drastically different from their natural abundances. **Fig.7** shows one such example for the case of Cr isotopes detected on a Pd cathode which had shown excess heat. The left figure shows variation of atomic concentration of the Cr isotopes with depth while the right part shows depth profile of the isotopic ratios. Significant variatios are seen in the top 10 micron region.



Fig. 7. Depth Profile of Cr Isotopic Ratios on Surface of Pd Cathode which had shown Excess Heat

As emphasized already while isotopic shift measurements are notoriously subject to interference effects caused by molecular ions having m/z values in the region of the signal of the isotope under study, it is equally difficult to conceive of the presence of a plethora of interfering molecular ion species readily available in the cell components to give false peaks at every one of the mass spectrum locations observed by Mizuno and Ohmori.

5. Neutron Activation Analysis of Deuterated Pd Samples which had Produced Significant amounts of Excess Heat

Tom Passell of Electric Power Research Institute (EPRI) had arranged for samples of Pd cathodes which were known to have "exhibited episodes of excess heat beyond all inputs" during electrolysis in LiOD, to be analyzed for possible changes in trace element nuclide composition using Neutron Activation Analysis (NAA). He was clearly motivated to do this following reports of isotopic anomalies observed by other workers using the NAA technique which is more appealing to nuclear physicists than mass spectrometry which is subject to molecular ion interference issues. Also NAA gives an integrated overall global result and is not sensitive to local variations within a sample. Mo et al from China too had reported [5.1] at ICCF 7 in 1998 a 20 to 34% increase (Zn^{64}/Zn^{68}) activity ratio in samples of thin Pd wires exposed to gaseous hydrogen isotopes using NAA techniques.

Passel obtained his first samples for analysis by NAA from Stan Pons; these were thin slices from the 2 mm dia Pd cathode rods used in the Icarus 9 experiments conducted at IMRA, Europe, One was taken from an active Pd cathode (22.1 mg in weight) which had generated significant amounts of excess power during electrolysis while the second (29.3 mg) was a control taken from a similar but virgin rod. The NAA measurements were carried out by Bush and Logowski of the department of Chemistry, University of Texas, Austin campus. These measurements indicated [5.2] that the Pd¹⁰⁸ to Pd¹¹⁰ isotopic ratio of the active Pd sample was depleted by about 28% relative the virgin cathode sample. In addition the concentration of several trace elements were found to be higher relative to the control sample, the most noticeable being Fe (56 times) and Zn (12 times); The concentrations of Co, Cr, Cs and Eu too indicated an increase by a few times.

In a follow up series of measurements reported first at ICCF 8 [5.3] and again at ICCF 10 in Cambridge, Massachusetts [5.4], samples of Pd black powder, taken from the inner plenum of a double structured cathode provided by Arata of Osaka University, were analyzed at the University of Texas (UT), Austin. Three samples were drawn from cathodes which had shown tens of MJ of excess heat during electrolysis lasting several months at SRI International. A fourth sample was virgin Pd black powder from the same batch. Since the active powder samples were from the central hollow portion of the double structure cathodes they would not have had any possibility of getting contaminated from impurity elements during electrolysis.

The samples (5 to 15 mg each) were loaded in standard small Polythene vials and irradiated simultaneously in the University of Texas nuclear reactor facility for 80 mins. The 13.4 hr Pd¹⁰⁹ activity gave a measure of the Pd¹⁰⁸ content while the 7.45 day Ag¹¹¹ activity was taken as representative of the Pd¹¹⁰ content. All data were normalized to the corresponding gamma counts obtained for the virgin powder sample. The area under the respective gamma photo peaks were integrated using procedures routinely used at this NAA laboratory. The results clearly showed a statistically significant 8% decrease of the Pd¹⁰⁸ to Pd¹¹⁰ ratio for active cathode sample B. Interestingly this cathode sample also showed a corresponding increase in Zn⁶⁴ (~15 times) and Co⁵⁹ activity (~60% higher) implying anomalous production of Zn and Co as well during the electrolysis runs.

Passel suggests that Fe, Zn, Co and other elements which are found in the active Pd samples could have been fragmented products arising from deuteron induced fission of Pd nuclides, the depletion of Pd¹⁰⁸ being indicative of a relatively higher fissioning rate of the Pd¹⁰⁸ nuclide relative to the Pd¹¹⁰ nuclide. It may be pointed out that NAA gives information only about nuclides which get activated during exposure to a neutron flux and all isotopes of Pd do not respond in the same manner during NAA analysis.

6. Anomalies in Trace Element Composition of Newly Formed Structures on Cathode Surface in Co-deposition Experiments (Spawar Group)

The co-deposition protocol has been successfully developed into a very powerful technique for the investigation of LENR phenomena by Stanislaw Szpak, Pamela Boss and others at the Naval SPAWAR Systems Center in San Diego from the very beginning of the CMNS-LENR era [6.1]. In the work [6.2] reviewed here, the main innovation introduced was placing the co-deposition cell in an electrostatic field applied perpendicularly to the direction of flow of the electrolytic current, as illustrated in **Fig. 8**.

The Pd and deuterium atoms are simultaneously deposited onto the surface of the Au strip substrate, forming a thin cohesive layer of PdD. The experimental protocol arrived at after years of effort calls for the cell current to be initially maintained at 1 mA for the first 24 hrs after which it is stepped up to 3 mA; this is continued until the solution becomes colorless (implying Pd²⁺ is fully reduced). The current is then raised to ~ 40 mA for a few hours until vigorous D₂ gas evolution is observable; this indicates that the D/Pd atomic ratio has stabilized and become uniform.



Fig. 8. SPAWAR Co-Deposition Electrochemical Cell set up and Assembly of Au Cathode

Figure 9 shows the typical structure of the co-deposited PdD film at this time, as imaged by a Scanning Electron Microscope (SEM). The PdD is seen to have a "characteristic cauliflower" like structure made up of globules 3 to 7 μ m in dia. (see insert in Figure). The corresponding EDX scan of the PdD layer shows only the expected Pd and D, having composition of Pd (95.17 wt%) and O (4.83 wt %).



Fig. 9. Scanning Electron Microscope (SEM) Image in absence of Electric Field and EDX Scan of the Co-deposited PdD Film

At this point an external 6 KV cross electric field is switched on while simultaneously jacking up the current to 100 mA. This is maintained for about 48 h. At the end of this procedure the SEM scan of the electrode shows the appearance of several new structural forms having morphologies suggestive of localized melting. The researchers have characterized the newly produced morphologies as having "boulder like", "crater like", "blister like" etc features. What is interesting however is that the EDX scan of these new structures indicates the presence of a variety of trace elements such as Al, Ca, Mg, Si etc which were not present either in the electrolyte nor in the cauliflower like structure of the initial PdD deposit. The quantum of the newly formed elements is at times as high as several tens of percent. Equally intriguing is the fact that the composition and magnitude of the additional elements is different in the central and peripheral regions of some of these morphological structures.

The experimenters had confirmed that the concentration of all these newly appeared trace elements were below detection limit in the initial electrolytic solution. The total quantity of all impurities in the electrolytic solution was less than 0.5 mg and could not account for the total magnitude of the newly appeared elements. The authors have concluded that the only logical explanation is that these elements must have been generated by some type of nuclear transmutation reactions occurring in the PdD cathode structure. A comprehensive discussion of the various arguments that have lead the authors to such a conclusion are presented in their original paper [6.2].

7. Observation of Trace Element Distribution on Cathode Surfaces Following Electrolysis at Portland State University (John Dash):

John Dash of Portland State University, Oregon has been researching LENR phenomena ever since the Fleischmann Pons announcement, with the help of graduate students. A notable feature of his experiments is their simplicity since they are designed as student projects [7.1]. His main tools are open electrolytic cells and a Scanning Electron Microscope (SEM) equipped with an Energy Dispersive Spectrometer (EDS) with which he can measure surface morphology as well as elemental composition of cathode samples on a microscopic scale before and after electrolysis. He also has available a Secondary Ion Mass Spectrometer (SIMS) with which the mass spectrum of ionic species ejected from the surface during sputtering by Cs ions can be recorded. By peeling off layers one after the other, he has the capability to depth profile the mass spectrum of ejected ions.

In a recent review [7.2] of his two decade long pursuit of isotopic anomalies, Dash has highlighted the fact that after a mere 6 minutes of electrolysis (at a current density of 0.25 A/cm^2) he was able to detect changes in trace element composition on the surface of his cathodes, as well as isotopic anomalies using their quadrupole mass spectrometer of the SIMS instrument. He is of course fully seized of the pitfalls of mass spectrometry, namely possibility of interference caused by molecular ion species having m/e values very close to that of the nuclide being measured. These issues are addressed in detail in his papers.

Dash was among the earliest to report [7.2] presence of Au and Ag on the Pd cathodes after electrolysis in an electrolyte comprised of H_2SO_4 and D_2O or H_2SO_4 and H_2O , at ICCF 6 in Lake Toya, Hokkaido in 1996. (Note that Ag is the upper neighbor of Pd in the periodic table of elements and Au the higher mass neighbor of Pt which was the anode material in his cells.) Dash operated two identical cells in series - one containing acidified D_2O electrolyte and the other a control cell loaded with acidified H_2O electrolyte. The 40 µm thick Pd foils used for fabricating his 2 cm long, 0.8 cm wide cathodes, were cold rolled from 500 µm thick Pd metal sheets. A Pt lead wire was spot welded to the vertically suspended cathode foil at the upper edge. SIMS scan of the post electrolysis cathodes revealed isotopic inversion of Pd isotopes on the near surface layers of the foil which had been electrolyzed in acidified D_2O , as compared to the virgin foil. The (Pd¹⁰⁸/Pd¹⁰⁶) ratio was somewhat higher than the natural abundance value (which is close to unity). Sputtering exposed deeper layers and the isotopic ratio anomaly steadily decreased reaching natural abundance levels at a depth of 0.3 microns.



Fig. 10. Pd Isotopic Distribution - SIMS Counts after 6 Minutes of Electrolysis in Heavy water Electrolyte

Figure 10 which brings out this observation clearly indicates that whatever processes are responsible for nuclear transmutation phenomena are confined to the outermost layers of the cathodes. This type of behavior was noticed at ten different spots on the same cathode. For comparison the corresponding variation of the concentration of the Pd isotopes for the case of a foil electrolyzed in light water solutions is presented in **Fig. 11**. Isotopic ratio inversion is not seen here.



Fig. 11. Pd Isotopic Distribution - SIMS Counts after 6 minutes of Electrolysis in Light water Electrolyte

One very interesting observation reported by Dash was that a couple of days after the above mentioned SEM/EDS study was completed and the Pd foil which had been put away in storage at room temperature and ordinary atmosphere, was reexamined they discovered a new oval shaped structure had developed at a spot wherein significant amounts of Ag had been freshly generated; when this spot was again examined a month later, the additional presence of cadmium (upper side neighbor of Ag in the periodic table) was observed suggesting that the silver had been further transmuted to Cd during the intervening one month period when it was in the storage cabinet!

In a later paper Dash had reported that Vanadium concentration was found to have increased on the surface of Ti cathodes after electrolysis. Note again that the atomic number of V is 47, which is one unit higher than that of Ti which is 46.

8. Isotopic Shift Measurements of Violante and Collaborators in a Ni-H₂ System:

Violante and his collaborators have performed some very carefully planned experiments to confirm the occurrence of transmutation reactions in thin film $Ni-H_2$ electrochemical experiments. This work was carried out as part of a cooperative research effort between ENEA and Rome University in Italy and SRI International in Menlo Park, CA. The experimental approach was inspired by their prior theoretical prediction that nuclear phenomena in LENR are generated and controlled by plasmons-polaritons excitation [8.1, 8.2]. (Surface plasmons (or polaritrons) are quantified plasma oscillations created by the collective oscillation of electrons on a solid surface.)

The electrochemical cell for these studies was fabricated out of only two materials, namely pure polyethylene and 99.98% purity Pt. The cathode was a thin film of Ni (0.8 cm² in area) while the anode was made of Pt wire wound in the form of a flat spiral. The electrolyte was 1M Li_2SO_4 in pure H₂O.

Copper which is always present as an impurity in Nickel was selected as a "marker" for this experiment since it has only two natural isotopes, namely Cu^{63} and Cu^{65} and the masses of neither of these overlaps with that of other impurity elements in the cell. The natural isotopic abundance ratio of $[Cu^{63}/Cu^{65}]$ is 2.25. It was confirmed through prior analysis that there were no elements or isotopes in the mass range of 126 to 140 in the experimental assembly, thereby ruling out the possibility that during SIMS measurement of Copper isotopes, doubly ionized species of isotopes with mass 126 and 130 would give rise to false signals.

The thin film cathodes of Ni were made by a sputtering process during which the copper impurity also gets incorporated into the thin film. During sputtering two identical films were made, one to serve as a control while the other was used for electrochemical loading with H_2 or D_2 to form black colored Nickel Hydride. Electrolysis was performed for times varying from 4 mins to 20 hours.

To test the Plasmons-Polaritrons theory, the loaded black NiH₂ film was irradiated with a laser beam for 3 hours, as per their theory. The details of this so called Attenuated Total Reflection (ATR) method is described in Ref. [8.2]. The same optical treatment was given to the blank control Ni film also. After this both the blank and Nickel black were analyzed using SIMS. The results are shown in Figs. 12 and 13.

The results clearly show that after laser treatment and as predicted by their theory there is strong evidence for reversal of [Cu⁶³/Cu⁶⁵] isotopic ratio confirming that Cu⁶³ has got transmuted to Cu⁶⁵. Details of this neat experiment are presented in refs [8.3, 8.4].



Fig. 12. Peaks of Cu⁶³ and Cu⁶⁵ in the blank film of Expt # NiE (Before laser treatment)



Fig. 13. SIMS count peaks corresponding to Cu⁶³ and Cu⁶⁵ in the black film of Expt # NiE: (After laser treatment)

9. Russian Glow Discharge Experiments (Karabut, Savvattimova and others):

Karabut, Kucherov, and Savvatimova from Russia were among the earliest researchers in the LENR field to present experimental findings indicative of the occurrence of nuclear transmutation reactions and anomalous isotopic shifts in deuterided metals [9.1]. This group has been carrying out exhaustive studies for almost two decades using high current, high voltage glow discharge devices in a deuterium (or hydrogen) plasma to investigate LENR phenomena. Figure 14 is a schematic diagram of their glow discharge apparatus which is basically a double walled quartz vacuum chamber with a Mo anode and a cathode.



Fig. 14. Schematic Diagram of Glow Discharge Apparatus Used by Karabut et al

The design of the set up permits use of different cathode materials for study. The chamber is evacuated to about 10^{-3} Torr and filled with D₂ gas to a pressure in the region of 3 to 10 Torr. The region of the cathode bombarded by the plasma ions is typically ~ 1 cm² in area. The cathode, anode and the quartz chamber housing are each separately cooled by circulating water. Temperature sensors located at appropriate locations in the cooling circuits permit calorimetric measurements. The voltage applied is varied from 50 V to 1.2 KV while the discharge current is ~100 mA. The power dissipated, inclusive of excess heat if any that is generated, is removed by the three cooling water circuits.

While they have reported observing "excess heat" consistently with near 100% reproducibility, they did not detect the expected normal (d-d) fusion reaction products such as neutrons, tritium or even helium in quantities commensurate with the magnitude of the heat generated. (The details of excess heat measurements are discussed in the companion articles on LENR in this Encyclopedia.)

The studies reported in this review were mainly conducted with a Pd planchet (cathode) and deuterium plasma. In quest of the mystery of the missing reaction products, they carefully analyzed the surface of the Pd cathode after it had been subjected to several tens of hours of glow discharge in deuterium gas. The bulk impurity content of the virgin Pd cathode material (supposedly 99.99 % purity) was first analyzed [9.2, 9.3] using spark mass spectrometry at the GIREDMED mass spectrometry laboratory. The detection limit of the set up was 10^{-6} % (atom percent). The scan showed presence of the following impurity elements with concentrations above` 10^{-4} %: Mg, Ca, Fe, Rh, Ag, Ta, Pt, and Au. A few other elements were also present but with lower concentration. It was confirmed that the total impurity content of the virgin material was indeed under 0.01%.

The post discharge Pd cathode buttons were subjected to detailed investigations using the following techniques:

- * Surface topography by scanning electron microscopy.
- * Element and isotopic composition using spark mass spectrometry, SIMS and XRF.
- * Autoradiography for evidence of any remnant radioactivity.
- * Thermal Ionization Mass Spectrometry (TIMS).

Several different laboratories in the Moscow - Podolsk region were involved in carrying out these investigations.

As emphasized already presence of new elements after discharge alone cannot be taken as evidence of formation of new elements by transmutation processes. In the case of gaseous plasma experiments although there is no electrolytic solution involved and the possibility of impurity deposition from the electrolyte is absent, alternate routes of impurity migration from the discharge environment needs to be thoroughly examined and ruled out.

The Russian investigators hence carried out detailed isotopic composition measurements on the cathode samples at the Tomsk Polytechnik Institute using Secondary Ion Mass Spectrometry (SIMS). This study clearly indicated significant deviations from natural abundance values for most elements. **Table 1** reproduced from Ref. [9.3] brings out this feature elegantly. But this data can only be taken as representative since the reaction product yield is known to notoriously vary from spot to spot on the surface of the cathode, a feature that has been independently observed by several workers in the LENR field. At the Nagoya ICCF 3 meeting in 1992 Karabut et al

reported [9.3] finding as much as 0.1% of Na, Mg, Br, Zn, S, Mo and Si in the upper crust of the Pd and had speculated that these elements could in principle be explained through occurrence of multiple deuteron captures in one of the isotopes of the Pd cathode, followed by fission of the complex intermediate compound nucleus.

Table 1. (From Ref. [9.3]

An obvious question that bothered the investigators right from the beginning was the possibility of mass transport of impurity ions on to the cathode surface from various metallic components used in the discharge environment such as the silica and alumina insulators and the molybdenum anode. The top 1 μ m layer of the Pd sample was examined at several spots in the front portion, the back portion and shielded area with a spatial resolution of 1 μ m using an X-ray microprobe analyzer. It was found that the content of some elements increased by tens to hundreds of times relative to initial content in virgin Pd. **Table 2** reproduced from Ref. [9.4] for example, gives the concentration of many elements for discharge run times of 4 hours and 40 hours respectively.

Table 2 From Ref. [9.4]

The Russian groups have continued to report similar but fresh observations in almost every ICCF conference since 1992 refining and improving their experimental procedures. At ICCF 5 held in Monaco in 1995 [9.5] they again reported that the quantity of the newly appearing "impurity" products varied significantly from spot to spot as detected by X-ray microprobe analyzer. In some spots the Ag content was as high as 12 to 15 % and Mo about 5 to 7 %. The concentration of elements such as As, Br, Rb, Sr, Y and Cd which are not present in any of the construction materials used in the experimental apparatus, was in the range of 0.1 to 0.2 %. A new result reported at the Monaco meeting was that even with hydrogenous plasma they observed elements not present in the virgin cathode, but in general the products yield with deuterium gas was orders of magnitude higher.

At ICCF 9 held in Beijing in 2002, Karabut reported [9.6] new results obtained by subjecting the discharge device to an "impulsive periodical power source" (pulsed voltage) which led to generation of intense X-ray laser beams. Discussion of this discovery, though very interesting, is beyond the scope of this review. The difference in "impurity" elements content before and after the experiment is taken as the yield of nuclides produced in the experiment. The main impurity nuclides (with more than 1% content) registered in the top 100 nm thick surface layer are Li⁷, C¹², N¹⁵, Ne²⁰, Si²⁹, Ca⁴⁴, Ca⁴⁸, Fe⁵⁶, Fe⁵⁷, Co⁵⁹, Zn⁶⁴, Zn⁶⁶, As⁷⁵, Ag¹⁰⁷, Ag¹⁰⁹, Cd¹¹⁰, Cd¹¹¹, Cd¹¹², Cd¹¹³. It is apparent that one can identify two broad categories of impurity elements: Those with masses roughly half of that of Pd (probably caused by deuteron induced fission) and those with masses close to but above that of Pd (possibly caused by multiple deuteron captures). Karabut speculates that the excess heat measured in the glow discharge experiments must have been caused by these two categories of transmutation reactions leading to the production of the plethora of observed product nuclides. Details of his arguments are presented in his original paper [9.6].

At ICCF 12 held in Yokohama in December 2005 Karabut presented [9.7] further results from discharges carried out with V, Nb and Ta cathodes and in the inert gases of Xe and Kr besides D_2 . In general with cathodes other than Pd, "impurity" element yield was significantly lower. In these experiments Karabut measured the impurity content yield after peeling off some atomic layers using plasma etching and then again analyzed the elemental content using SIMS. Table III

presents the impurity nuclide yields for the discharge experiments with Pd cathode and D_2 plasma as a function of depth in the cathode sample.

At the same conference in Yokohama, Savvatimova presented [9.8] a very detailed and exhaustive account of her independently conducted glow discharge results with hydrogen, deuterium, argon and (argon-xenon mixture) plasmas. The influence of various experimental parameters such as nature of plasma gas, total dose of bombarding ions, discharge current density (mA/cm²) and type of applied voltage (direct or pulsed) on the yield of "additional" elements was studied systematically. This time she also used multilayer cathodes comprising several foils of 100 μ m thickness stacked one on top of the other to study differences in product yield characteristics with depth. In particular special attention was paid to the structural changes associated with the hot spot sites (especially grain boundaries) where the additional elements are generally found to be concentrated. The greatest changes in "additional" element content and isotope shifts were found in certain "hot spots", where a micro-explosion or plasma micro-discharges had appeared to have taken place. The author makes special mention of elements with mass numbers 59(C0), 55(Mn) and 45(Sc) which were always found in plenty in the post discharge samples but never in initial samples.

On the whole Savvatimova finds that the more deeply she investigates the LENR glow discharge phenomenon the more complex it is found to be, as brought out by her in the 13 Tables of results included in the Yokohama paper [9.8]. For example while investigating the effect of time duration of discharge, Savvatimova found that while a 30 minute run resulted in the content of Zr increasing by a factor of 570 to 340, that of V by a factor of 100 and Cr by 160, continued irradiation did not yield significantly more products, a behavior observed by them several years earlier also. On the other hand Mo which is an element used in the construction of some components of the discharge chamber showed an increase commensurate with total dosage of ions (current x time). The author speculates that with a fresh a cathode sample there may have been many defect sites which promote transmutation reactions but these might have all been consumed or destroyed on continued experimentation.

Table III: Depth wise Variation of Impurity Nuclide Content Obtained Using Plasma etching and SIMS Measurements Alternately (Example of Mass 99 to 111 Region)

| A | V-H | | | V-D | | | | |
|-------------------|-----------------------------------|-----------------------------------|------------------------------------|------------------------|-----------------------------------|-----------------------------------|------------------------------------|--|
| Impur. nuclide | 1 scan 10 nm, content, % | 2 scan 50 nm, content, % | 3 scan 700 nm, content, % | A Impur. nuclide | 1 scan 10 nm, content, % | 2 scan 50 nm, content, % | 3 scan 700 nm, content, % | |
| 99Ru | ND | ND | ND | 99Ru | 0.42 | 0.11 | 0.02 | |
| 102Ru | 0.66 | 0.73 | 0.4 | 102Ru | 0.74 | 0.51 | 0.4 | |
| 103Rh | 0.25 | 0.14 | 0.02 | 103Rh | 0.19 | 0.23 | 0.34 | |
| 104Pd | 0.16 | 0.04 | 0.3 | 104Pd | 0.22 | 0.2 | 0.37 | |
| 106Pd | 0.15 | 0.02 | 0.02 | 106Pd | 0.29 | 0.16 | 0.12 | |
| 108Pd | 0.45 | 0.04 | 0.06 | 108Pd | 0.21 | 0.24 | 0.12 | |
| 111Cd | 0.05 | 0.16 | 0.01 | 111Cd | 0.15 | 0.2 | 0.07 | |

If the additional elements appear as a result of cathode sputtering or redistribution one would expect a higher yield of "impurity" elements with bombardment by heavier ions such as Argon or Xenon as compared to Deuterium runs. But the results always show maximum quantity and maximum variety of additional elements with Deuterium discharges and much less with Hydrogen and least with Argon.

One intriguing new result reported at Yokohama was that the isotopic changes continued to occur for at least 3 - 5 months after glow discharge exposure, reminiscent of the "life after death" phenomenon reported by many authors in the LENR field. (Readers may recall that a similar observation made by Dash has been noted by us earlier in this review paper.) Several isotopes with masses less than those of W and Ta increased by factors ranging from five to 1000 times.

The exhaustive two decade long series of experiments [9.1 to 9.12] conducted by two separate Russian groups using the glow discharge technique clearly indicates that the plethora of observations pertaining to additional element production and their deviation from natural isotopic composition are indeed very complex in nature and strongly support the postulate that both fusion and fission type nuclear transmutation reactions seem to be occurring in Pd cathodes subjected to deuterium plasma bombardment. Besides the accumulated evidence also points to the occurrence of such reactions preferentially in certain selected sites or "hot spots" which appear to be associated with grain boundaries.

It is noteworthy that precisely the same conclusion was arrived at from the transmutation measurements in electrolysis experiments discussed in earlier sections.

10. Replication of Glow Discharge Transmutations by Yamada's Group at Iwate University, Japan:

The Glow Discharge apparatus employed by this group [10.1, 10.2] which was made of Pyrex glass to avoid contamination from metallic impurities, is shown in **Figure 15**. Yamada used a Pd plate (10 mm square and 1 mm thick) as cathode and a gold foil as Anode. Great care was taken to avoid contamination of the Pd sample (99.95% purity) prior to experimentation. The Pd samples were first the pre-loaded insitu by a gas loading procedure by evacuating the discharge chamber and filling it with D₂ or H₂ gas at 5 to 10 atmospheres for 2 days. Discharge runs (600 to 800 V and 2 mA) were then conducted for about an hour either with deuterium or hydrogen gas at 10^{-3} torr.



Fig. 15. Glow Discharge Apparatus used by Yamada's Group

The impurity composition of every sample was analyzed by high resolution TOF-SIMS both before and after discharge runs. Prior to discharge the following elements were found to be present in the Pd samples: B, Na, Al, Mg, Si, Ca,K and Mn and to a lesser extent Li, Fe, Cr and Cu. The post run samples were analyzed for those elements which were not present prior to discharge. Be and Ni whose masses are less than that of Pd was invariably found in the post run samples, both in case of D_2 and H_2 but never in pre run samples. The quantity of Li, an element whose mass is substantially smaller than that of Pd, increased in 3 out of 10 runs while the presence of Ba whose mass is heavier than that of Pd was surprising.

Ni and Ba were also found in Pd samples discharged in hydrogen plasma. The authors have pointed out that the TOF SIMS measurement system used by them for isotopic analysis could easily distinguish between Ba¹³⁸ and Pd-Si molecular ion species (both ¹⁰⁸Pd-³⁰Si and ¹¹⁰Pd-²⁸Si). The details of their results are presented in the Tables given in Ref 10.2. The authors speculate that appearance of elements such as Li and Ni lighter than Pd could indicate occurrence of some type of fission of Pd while presence of Ba which is heavier than Pd could indicate a fusion type reaction.

11. Iwamura (MHI): Transmutation Reactions Observed During D₂ Gas Permeation Through Pd Complexes:

Yasuhiro Iwamura and his colleagues at the Mitsubishi Heavy Industries (MHI) Laboratories of Japan have been systematically investigating the occurrence of nuclear reactions during the loading and diffusion of deuterium in Pd foils since 1993. At the beginning they used a simple gas loading/deloading method and reported detecting neutrons and tritium [11.1]. The problem with gas loading however is that in general it is very difficult to obtain loadings > 0.8. Subsequently they employed electrolytic loading from one side of the foil and looked for charged particles on the other side [11.2]. In the next phase they loaded the Pd foil electrolytically, then deposited a thin copper layer on the surface to seal the loaded foil to prevent deuterium degassing. This loaded and sealed foil was then transferred to a vacuum chamber where, on heating , the loaded deuterium gas was released and during this process they observed nuclear reaction products such as neutrons and tritium [11.3], like so many other workers in the field the world over.

Iwamura's group had thus independently arrived at the conclusion that to cause nuclear reactions one needs both a decent loading as well as some method to cause the deuterons to rapidly diffuse within the Pd. At this point they intuitively speculated that perhaps impurities play an important role in enhancing the nuclear reaction processes and decided to incorporate a third entity such as CaO which has a very low "work function" (1.60 to 1.86 ev) into the PdD, inspired by their "Electron Induced Nuclear Reaction" (EINR) model [11.4,11.4a]. Accordingly they prepared a new multilayer cathode comprised of a 1 mm thick Pd sheet, followed by 10 alternating layers of CaO (20A) and Pd (180A) and topped off with a 400A Pd over layer. This was carried out at room temperature using an Ar ion beam sputtering apparatus. Details of preparation of this multilayer complex as well as the calorimetry measurements performed by them to measure excess heat production are described in Ref. [11.4].

Figure 16 shows a sectional view of their "electrolytic continuous diffusion apparatus". The electrochemical cell made of Teflon is separated from a vacuum chamber by an O ring gasket. 1M LiOD was used as the electrolyte. Deuterium was loaded by electrochemical potential on one side of the Pd complex and released from the vacuum side, the rate of diffusion of deuterons

through the complex being controlled by the cell current as well as gas pressure on the vacuum side.



Fig. 16. Iwamura's electrolytic continuous diffusion set up

Using an Electron Micro Probe Analyzer (EPMA) they detected an anomalously large $(20 \ \mu g)$ amount of Ti as well as extra amounts of Fe and Cu on the inner electrolyzed surface of the post run Pd complex. These results were perhaps Iwamura's first hints of observation of transmutation reactions in LENR devices. SIMS measurement of the isotopic composition of iron isotopes showed that (Fe⁵⁷/Fe⁵⁶) ratio varied in the region of 0.24 to 0.66, which is over an order of magnitude higher than its natural abundance ratio value of 0.023. Later at ICCF 8 held in Lerice, Italy in May 2000, Iwamura's group reported [11.5] measuring (Fe⁵⁷/Fe⁵⁶) values even as high as 1.8 at some spots on the post electrolyzed cathode. Such high ratios, in comparison to the natural abundances, is indeed a clear indication of the occurrence of nuclear transmutation processes.

At Lerici, Iwamura also presented details of their improved gas diffusion apparatus [11.5], which had facilities for insitu measurements of the surface concentration of selected elements and isotopes using X-ray Photoelectron Spectroscopy (XPS). These new elements are thought to be generated through transmutation reactions during the simple process of diffusion of deuterium through Pd complexes. In this experiment "permeation" of D₂ gas is solely due to the gas pressure differential of 1 atmosphere between the two faces of the Pd complex. Maintaining the foil temperature at 70 C is found to facilitate permeation. Since no electrochemistry is involved it is a clean experiment with less scope for impurities to enter. **Fig. 17** depicts their gas diffusion apparatus comprising two SS vacuum chambers separated by the Pd foil complex; on one side is D₂ gas while the other side is evacuated by means of a turbo molecular vacuum pump.



Fig. 17. Iwamura's gas diffusion apparatus with insitu XPS analyzer and Quadrupole mass spectrometer

The system incorporates an X-ray gun and electrostatic analyzer for XPS, a mass spectrometer and a Ge semiconductor detector for charged particle measurements. The great advantage of this set up is that the surface of the Pd sample can be analyzed without taking the sample out of the experimental chamber, thereby avoiding the possibility of contamination. Prior to introduction of D_2 gas into the system the Pd surface was first analyzed. After filling the gas, diffusion was permitted to take place for a period of about a week or two. At the end of the permeation period XPS measurement was carried out, after evacuating the deuterium gas for a short while. As is well known to surface scientists, carbon is always present as an impurity on the Pd foil complex even under high vacuum conditions. In the initial experiments when a pure Pd foil was used for permeation studies, there was no change in C content before and after permeation. But when the permeation was carried out with the Pd-CaO-Pd multilayer complex, after 40 hours the carbon content had decreased to almost zero, but the levels of Mg, Si and S increased. Mg, Si, and S have never been detected in their samples before permeation commenced. Fig. 18 depicts these results. Further permeation (after 116 hrs in all) resulted in the amount of Mg decreasing marginally while Si and S went up correspondingly.



Fig. 18. XPS measurement of time dependence of C, Mg, Si, and S on the surface of multilayer Pd samples after D_2 gas permeation.

Iwamura explains these results using his EINR theoretical model [11.4] which suggests that ${}_{6}C^{12}$ somehow captures (may not be a direct reaction) 6 deuterons to become ${}_{12}Mg^{24}$ as follows:

$${}_{6}\mathrm{C}^{12} + 6({}_{1}\mathrm{d}^2) \rightarrow {}_{12}\mathrm{Mg}^{24}$$

Likewise the **right part of Fig. 18** is explained by postulating the following reactions:

$$_{12}Mg^{24} + 2(_{1}d^{2}) \rightarrow _{14}Si^{28}$$

 $_{12}Mg^{24} + 4(_{1}d^{2}) \rightarrow _{16}S^{32}$

and

In all these reactions deuterons seem to be getting captured in multiples of 2 or 4 or 6 etc. In a repeat experiment (his expt. No. 4) wherein the initial C content was somewhat higher, the time variation of the C, Mg, Si and S content, shown plotted on the **right part of Fig. 18**, further corroborates the possible occurrence of the above sequential nucleo synthesis reactions scheme, through multiple "even number of deuterons captures" hypothesis.

SIMS analysis of the isotopic composition of sulphur isotopes on the multilayer complex after D_2 gas permeation showed that the ratio (S^{33}/S^{32}) was anomalously large (0.25) as compared to the corresponding natural isotopic abundance ratio of 0.0079, once again confirming the occurrence of nuclear phenomena.

In further studies, Iwamura and his colleagues electrolytically deposited Li as a dopant on the surface of the multilayer complex and then carried out the D_2 gas permeation experiment. Insitu XPS analysis showed (see Fig.19) the production of Fluorine first, which then appears to have gotten transmuted to Al during the second half of the permeation process as follows:



$$_{3}\text{Li}^{7} \rightarrow _{9}\text{F}^{19} \rightarrow _{13}\text{Al}^{27}$$

Fig. 19. Time Dependence of F, Mg, Al, Si detected on the Pd, Li/CaO/Pd samples

In each step either 6 deuterons or 4 deuterons seem to have been effectively added to the nucleus.

For Iwamura's group these results were possibly the first taste of reliable and trustworthy transmutations effected during the simple process of D_2 gas permeation. The reactions investigated so far involved mainly light elements, upto mass number 27. As a next step they

decided to attempt transmutations with higher mass nuclides. During the last decade Iwamura's group have laboriously carried out [11.6 to 11.12] a series of systematic experiments using essentially the same experimental procedure described above and investigated the occurrence of nuclear transmutation reactions with nuclides having Z values upto 56 and mass values upto 138 during D₂ gas permeation. The D₂ molecule appears to undergo "dissociative chemisorption" and diffuses through the solid complex in the form of deuterons. They have experimentally confirmed that permeation induced transmutation reactions do not occur either on pure Pd foils nor with complexes wherein MgO is used as a dopant instead of CaO. Thus the presence of CaO in the environment seems to be absolutely essential. In all these experiments deuterons are effectively captured always in multiples of 2, namely either 4 or 6 or 8. It has also been established that the phenomenon occurs only at certain "hot spots" and that too within the top 100 μ m layer of the surface. Iwamura's group have presented regular updates on their spectacular results at every one of the consecutive ICCF conferences held during the last decade. Since the experimental methodology and analytical techniques were essentially the same we summarize below only the highlights of their more recent experiments and observations.

It was at Beijing in 2002 that Iwamura first presented [11.6, 11.7] their Cs to Pr and Sr to Mo transmutation results which has been hailed as one of the turning points in the history of transmutation research in the LENR field. In these studies a very thin layer of Cs or Sr was first deposited on the Pd complex by an electrolytic method. (It took only 10 seconds for the Cs or Sr layer to be formed when electrolyzed in a very dilute solution of either $CsNO_3$ or $Sr(OD)_2$.) Fig. 20 presents the time variation of the concentration of Cs and Pr during D_2 gas permeation. The decrease of Cs concentration and increase of Pr atom density is plainly visible. Note that there was no Pr present prior to permeation. The results of two runs are shown plotted in Fig. 21, suggesting that the reproducibility of such experiments is reasonably good.



Fig. 20. Time variation of Cs and Pr atomic density during D₂ gas permeation

Ref [11.6] which gives the time variation of the XPS spectra for Cs, Pr and Pd shows that while the Cs peaks decrease and Pr peaks increase that for Pd remains steady with time. They have also experimentally established that in these permeation experiments the reaction rate correlates linearly with the flux of flowing deuterium atoms. (See Fig 21).



Fig. 21. Correlation Between D₂ Permeation Rate and Conversion Rate

Similar results for Sr to Mo transmutation are presented in Fig. 22. The only difference is that the permeation time for this study was 14 days since the transmutation rate was lesser for this reaction.



Fig. 22. Time Variation of Sr and Mo Atomic Density During D₂ Gas Permeation

The following transmutation reactions corresponding to the above measurements are thought to occur:

$$_{55}Cs^{133} \rightarrow _{59}Pr^{141}$$
 and $_{38}Sr^{88} \rightarrow _{42}Mo^{96}$

In each of these reactions 4 deuterons are "effectively captured" by the initial test nuclide. Interestingly the authors themselves do not specifically claim, anywhere in their papers, that the 4 deuterons are directly captured; As per their EINR theory, this reaction happens through an intermediate step of dineutron formation following electron capture by deuterons. But a detailed description of the theoretical conjectures of how such a complex reaction may be taking place is beyond the scope of this review.

The energy released in the above reactions, based on mass deficit calculations, works out to 50.3 MeV and 53.5 MeV respectively per reaction. This translates into an excess power of a few milliwatts for the amounts of new elements generated in their measurements and was well below the detection sensitivity of their calorimetry method. So they could not state whether any excess

energy could have been generated or not. Iwamura has also categorically stated that they did not detect any X rays or gamma rays during the permeation experiments, since they did in fact have an appropriate detector kept switched on and monitoring the set up during permeation.

As controls they repeated the experiments with H_2 gas permeation and also with D_2 gas but with a Pure Pd foil with no CaO-Pd multilayer complex present. In both cases the Cs level did not change, nor was any Pr observed on the post permeation samples.

For isotopic composition studies the samples were taken out and analyzed using a secondary ion mass spectrometer (SIMS) using O_2^+ ions for bombardment of the sample. The mass resolution of the measurements was about 300. SIMS typically scans an area of 150 µm dia as compared to XPS which analyzes a spot 5 mm in size. The authors have emphasized [11.6] that their SIMS analyses was performed by the "offset voltage technique" to suppress the effects of molecular ions on mass spectra. Thus while the isotopic composition of the initial Cs as well as the bulk Pd corresponded to that of their natural abundances, the isotopic spectrum of the newly produced Mo was significantly different from natural abundance. In fact it had a huge peak at mass number 96, exactly where one would expect it if it was generated from Sr⁸⁸ capturing 4 deuterons.

At ICCF 10 conference held in Cambridge, MA in 2003, Iwamura presented [11.8] an yield vs. deuterium gas flow rate (or flux) correlation curve for the Cs to Pr transmutation reaction. The maximum gas flow rate achieved was close to 4 cm³ per min. To obtain adequate permeation rates the sample is maintained at an elevated temperature of 70 C. Although there was considerable scatter in the data, one could fit an approximate linear correlation, from which an estimate for the reaction cross section was derived as 1 barn. Also, in the newer work, the Cs and Pr levels in the samples were measured by ICP-MS as well, making it the fifth technique of quantification of concentration levels, besides XPS, TOF-SIMS, XANES and XRF.

However the main innovation introduced this time was depth profiling of the Cs and Pr on the samples using TOF-SIMS. To facilitate this the Cs layer deposition on the Pd foil complex was carried out by an ion implantation technique in order to obtain a controlled depth profile of Cs atoms in the target sample prior to permeation. Fig. 23 presents the results of one such depth profile measurement before and after permeation. (In this figure the X-axis scale is indicated as sputtering time but it was translated into depth through auxiliary calibration measurements. Thus as shown at the top of the figure 1000 secs corresponds to a depth of about 500A.)



Fig. 23. Depth profiles of Cs and Pr before and after permeation

It is seen that before permeation the depth profile of Pr is flat at zero level while Cs concentration steadily decreases with depth. The maximum penetration of the Cs ions into the sample was 500 A. After permeation the levels of Pr increases with depth reaching a maximum at about 50 or 60 A and then falls back to zero beyond 100 A. Correspondingly the Cs level has decreased but only in the top 50 A or so. Beyond this depth there is no change in Cs concentration levels. This confirms that the transmutation of Cs into Pr takes place only on the top near surface layers within a depth of 100 A.

At ICCF 11 held at Marseilles, France in 2004, Iwamura presented results of the transmutation of ₅₆Ba into ₆₂Sm during which reaction 6 deuterons are effectively captured by Ba resulting in the Z number increasing by 6 units and mass number increasing by 12 units. Barium has seven natural isotopes having masses varying from 130 to 138. But the most abundant Ba isotopes are Ba¹³⁷ (11.3%) and Ba¹³⁸ (71.7%). Sm too has seven natural isotopes ranging in mass from 144 to 154. This makes the interpretation of the results quite complicated. Inspite of this, Iwamura's group carried out permeation studies with natural Barium as well as with enriched Ba¹³⁷ and Ba¹³⁸ respectively. While the interpretation of SIMS data from natural Ba was somewhat complicated as expected, they did find strong evidence to indicate that Ba¹³⁷ yielded Sm¹⁴⁹ while Ba¹³⁸ produced Sm¹⁵⁰. Fig.24 reproduced from Ref. [11.9] shows the mass correlation between the starting and final elements on the surface of the foil complex. When Ba¹³⁷ was used to start with Sm¹⁴⁹ was obtained and when Ba¹³⁸ was used Sm¹⁴⁹ was obtained; in each case the atomic number increased by 6 units while the mass increased by 12 units.



Fig. 24. Mass correlation between the elements in the before and after permeation samples

At ICCF 12 held in Dec 2005 at Yokohama, Iwamura presented results obtained using a significant improvement in the measurement technique. They used the powerful Spring 8 Synchrotron light source facility at Hyogo for carrying out insitu two dimensional X-ray Fluorescence (XRF) Spectrometry of the permeated samples for studying the surface distribution of the transmuted elements. **Fig. 25** shows the experimental set up. The test micro X-ray beam from the synchrotron is seen to enter the set up from the left side. Fresh Pd complex samples with either Cs or Ba layer on top were prepared and permeation was carried out in situ at the Spring 8 facility. The X-ray beam was filtered by a pair of rectangular slits to produce a square cross section beam of 1 mm square. The Pd sample was mounted on an X -Y motion table operated by stepping motors. A microscope with camera permitted taking surface topography photographs of

the portion being scanned by the XRF spectrometer. With this arrangement it was possible to correlate the distribution of elements with the corresponding surface images.



Fig. 25. Experimental setup used by Iwamura at Spring 8 Synchrotron facility for *in situ* measurement of spatial variation of new element production during D_2 gas permeation

The main observation to emerge from these studies was that Cs to Pr conversion does not take place all over the entire surface but only at highly localized "hot spots", something which has been observed by other LENR researchers also using diverse experimental procedures as described already in the present review paper.



Fig. 26. Mapping of Surface Distribution of Pr Using 100-micron X-ray beam within a 500 micron square zone



Fig. 27. XRF Spectrum of Cs and Pr at three selected points on Surface using 100 micron X-ray probe of Spring 8 Facility

The exhaustive decade long experimental studies conducted by Iwamura's team under "clean conditions" employing sophisticated analytical methods, has confirmed that complex multibody elemental transmutations do seem to be taking place when deuterons interact with certain metallic lattices. The observation that these reactions take place during the simple act of permeation of D_2 gas through specially prepared Pd multilayer complexes is a remarkable discovery. The fact that these reactions seem to occur only in selected spots on the near surface region corroborates similar observations of other researchers also. Their finding that for these reactions to occur certain special additives such as CaO (and not MgO)) besides the bulk metal Pd are required is a very significant hint regarding the nature of the Nuclear Active Environment (NAE).

12. Replication of MHI Permeation Experiment by other groups

Higashiyama and others of Osaka University were amongst the first groups to replicate the MHI D_2 gas permeation transmutation experiment [12.1]. The Osaka group started with multilayer Pd complexes (comprising substratum bulk Pd plate over which 1000 A thick alternate layers of CaO and Pd had been formed, topped off with a 400 A thick Pd film) supplied by the MHI group. They then deposited a thin Cs layer on the top surface by performing rapid electrolysis in 1 mM CsNO₃ solution by applying 1V electric field for 10 seconds. Prior to this the top surface of the foil complex was pre-cleaned to get rid of any likely surface hydrocarbon contamination.

The Osaka group then carried out the D_2 gas permeation studies following the protocol provided by the MHI group. The Cs side of the foil complex was subjected to a D_2 gas pressure of 1 atm and the bulk Pd side was evacuated by a turbo molecular pump. The foil complex was maintained at a temperature of 70 C as recommended in the protocol. The MHI group had indicated that for obtaining successful results the gas flow rate has to be maintained at a level of atleast 1 sccm (cm cube per min under standard conditions). To attain this the temperature of the Pd foil complex had to be adjusted appropriately. To avoid moisture in the set up they had to bake the chamber and flush it with N₂ gas. As they had not taken this precaution earlier, the gas flow rate in the first two runs was less than optimal.

It was only in the third attempt which lasted over 120 hours, that they succeeded in obtaining the requisite gas flow rate of over 2 sccm. But unfortunately by then they started running out of D_2 gas whose pressure steadily decreased resulting in the flow rate falling to below 0.5 sccm. Inspite

of the experimental conditions not being ideal production of Pr on the surface was confirmed in all three runs.

Elemental analysis was performed by two independent techniques namely ICP-MS and Neutron Activation Analysis (NAA). The results of the ICP-MS analysis carried out at the MHI Labs is summarized in **Table IV** below: The amounts of Cs and Pr measured after the permeation runs are given in the Table. When there was more Cs present initially more Pr was produced and there was also more left over Cs.

| | Pr(ng) | Cs(nq) | Max flow(sccm) | Average(sccm) | Minimum (sccm) |
|------------------------|--------|--------|-------------------|---------------|-------------------|
| 1 st run | 18 | 180 | 173 | 0.93 | 0.43 |
| 2 nd run | 5.1 | 141 | .61 | .35 | 0.29 |
| 3 rd run | 36 | 330 | 2.17 | 0.76 | 0.27 |

Table IV. Transmutation of Cs into Pr: Replication by Higashiyamam et al - ICP-MS Results

The NAA analysis which was performed at the Japan Atomic Energy Research Institute's 14 MeV Fusion Neutron Source facility also confirmed presence of Pr in all three runs. For details the original paper of Higashiyama et al [12.1] may be referred to.

The replication experiment confirms that Cs^{133} is transmuted to Pr^{141} with mass number increasing by 8 and atomic number by 4. Takahashi, who is a co-author of this replication paper, has proposed a multibody resonance fusion model via formation of energetic Be⁸ nuclei as an intermediate step for explaining this transmutation reaction [12.2].

13. Carbon Arc Experiments

In this very simple experiment the claim is that when an arc is struck between a pair of carbon rods dipped in water, by applying a voltage of some tens of volts, the powder debris that falls from the arcing region to the bottom of the vessel would contain significant amounts of iron as well as other metals in the Fe, Co, Ni region [13.1]. It was speculated by these early researchers that the basic reaction involved is could be a multibody heavy ion fusion reaction involving 2 carbon nuclei and 2 oxygen nuclei as follows:

$$2\{{}_{6}C^{12} + {}_{8}O^{16}\} \rightarrow \text{(intermediate compound nucleus)} \rightarrow {}_{26}Fe^{56}$$

or alternately $2\{{}_{6}C^{12} + {}_{8}O^{18}\} \rightarrow {}_{26}Fe^{56} + {}_{2}He^{4} + 56.55 \text{ Mev}$

As an intermediate step an atom of oxygen and an atom of carbon may combine to generate ${}_{14}Si^{28}$, since in some experiments presence of silicon in the debris has also been reported.

Historically the credit for the "invention" of this process is attributed to George Oshawa [13.1] of Japan who was a close friend of Michio Kushi, and both were admirers of Louis Kervran during the early 60s. The word "invention" is used here as it was not an accidental discovery but rather a carefully crafted experiment with the objective of producing iron. It is reported that the first successful synthesis was carried out in 1964 and the mixture of elements which was so

generated was found to contain some Ni and Co also and so the product was called "George Oshawa Steel". Arcing between the carbon rods is reported to have been successfully performed both in air and under water with comparable end results. Thus the origin of this very simple transmutation experiment goes back almost a quarter of a century prior to the Fleischmann-Pons announcement, and was inspired by the "Biological Transmutation" (discussed in the next section) works of Louis Kervran.

Roberto Monti has reported that he has independently verified the production of iron and other elements during the arcing of carbon several times [13.2]. It was after listening to a talk given by Monti at the Bhabha Atomic Research Centre (BARC) in Mumbai in 1992 that a group at BARC set up the experiment disbelieving and challenging Monti to demonstrate production of iron. But in the end they confirmed finding iron in the debris [13.3]. Simultaneously Sundaresan of BARC who was a post doctoral fellow at the Texas A & M University (TAMU) at that time and Prof. Bockris also independently set up the carbon arc experiments and confirmed production of Fe at College Station [13.4]. (Both the BARC paper and TAMU paper were peer reviewed simultaneously and published in same issue of Fusion Technology in 1994.) At ICCF 7 held at Vancouver in 1998, Jiang et al of the Beijing University of Aeronautics and Astronautics reported finding Fe⁵⁸ content increasing from its natural value of 0.3 % to 0.5% and other elements such as Cr, Co and Zn in the debris [13.5]. The enrichment of Fe⁵⁸ isotope was deduced through Neutron Activation Analysis.

As an illustration of this simple experiment we describe below the Carbon Arc studies conducted by Sundaresan and Bockris [13.4]. **Fig. 28** gives a schematic diagram of the experimental set up. The 6.14 mm dia, 300 mm long spectroscopically pure carbon rods were procured from Johnson Mathey and were certified to have an initial iron impurity content of \sim 2.0 ppm. (This was independently also verified by the experimenters.) The rods were mounted in a Pyrex glass trough as shown in the figure, with the tips being about 5 cm below the surface of the water. The voltage applied was typically ~10 V. The current drawn to strike the arc was initially higher but quickly settled to a steady value of between 5 and 15 A depending on various experimental factors. A simple manually operated screw driven arrangement as depicted in the figure, permitted re-adjustment of the gap between the tips in order to keep the arc sustained as the rods got consumed.



Fig. 28. Schematic of Carbon Arc Experimental Set up

The ultra pure distilled water was additionally passed through an ion exchange column to attain a resistivity of 13 M Ω . It was then further purified by percolating it through finely crushed carbon powder (made from same stock of carbon rods), so as to minimize the iron content of the water prior to commencement of the transmutation experiments.

Arcing under water was performed for a few hours until adequate quantity of detritus accumulated at the bottom of the vessel. For each new run, a fresh set of carbon rods was deployed. In a second series of experiments with a given pair of rods the collected powder was taken out every few hours for analysis and at this time the vessel water too was replaced. This way it was possible to study the variation of the quantum of iron formed with time duration of arcing.

The Fe content in the detritus powder was measured by a standard spectrophotometer method using a Perkins Elmer Lambda instrument. This technique measures the optical density of a solution of a colored complex of iron thiocyannate at 470 nm wavelength. Calibration was done using standard solutions having known iron content. The results of the first series of 14 runs are summarized in **Table V**.

| | | | · · · · · · · · · · · · · · · · · · · |
|-------------------------------------------------|--------------------------------------|----------------------|---------------------------------------|
| Experiment Number | Weight of Carbon Detritus (mg) | Iron Content (µg) | Iron in Carbon (ppm) |
| 1 2 3 4 ^a 5 ^a | 269 116 167 361 103 | 45 45 15 | 167 125 146 |
| 6 7 8 9 | 231 192 183 163 143 | 11 5.5 13.5 | 57 30 80 |
| 11 12 13 ^a 14 ^b | 138 130 471 477 | 5.5 53 196 | 42 112 410 |

| Table | V: | Spectrophotometric | Measurement | of | Quantum | of | Iron | in | detritus | of |
|--------|-----------|-----------------------|-------------|----|---------|----|------|----|----------|----|
| carbor | ı po | wder at the bottom of | f the tank | | | | | | | |

^aSame rod.

^bThis value and the last value in Table I are abnormally high, and the analyses were performed on the same day; it is possible that an instrument malfunction might have caused the error.

It is seen that the iron concentration in the detritus powder varies in the range of 30 to 167 ppm which translated to several tens of μg of total Fe production in each run or an average the rate of about 4 to 5 μg of Fe per hour of arcing. The second series of runs indicated a nominally linear correlation between duration of arcing and total quantity of iron generated. Electrode pair No. 3 which was subjected to arcing for a total of 10 hours yielded altogether about 40 μg of Fe.

Before concluding that nuclear transmutation reactions were indeed responsible for the generation of iron, the authors did consider other possible modes of "adventitious" entry of iron into the system. Firstly ingress of iron from the water was ruled out since the total content of iron in the entire inventory of water in the trough was calculated to be well below the amounts detected in the debris. Alternately it may be suggested that the entire initial content of iron in the carbon rods could have diffused to the tips of the rods and accumulated in the powder debris collected at the bottom of the vessel. Since the rods are immersed in water their

temperature is well under 100 C, except for the very small portion near the tips which could have been close to say a 1000 C. ("The rods were cool to touch at distances beyond 2 cm from the tip.") Even at 100 C the diffusion coefficient of iron in carbon is so low $(10^{-26} \text{ cm}^2 \text{ sec}^{-1})$ that diffusion-concentration mechanism cannot be attributed to be the source of the iron measured in the debris.

Interestingly the authors found that when the arcing was carried out with nitrogen gas dissolved in the water in place of oxygen no additional Fe was detected in the debris. This experiment thus not only ruled out the diffusion-concentration theory but also supported that oxygen is indeed necessary for the generation of iron as suggested by the multibody transmutation reaction proposed by the original proponents of this experiment.

Sundaresan et al have also pointed out in their paper that the average rate of iron production namely 5 μ g/hr implies a nuclear heat production of 135 watts assuming 55.65 Mev per atom of Fe generated. This is to be compared with an electrical power input of between 50 to 150 W, depending on the steady current level. Following simple external heating calibration they did have indication of detectable "excess heat". The authors have recorded that in general over heating of the water was indeed a problem requiring them to periodically stop the arcing in order to allow the water to cool down and thereby avoid reaching near boiling temperatures.

14. Vysotskii's Microbial Transmutation Studies

This section discusses the remarkable "Microbial Transmutation" experiments conducted during the last decade by Vladimir Vysotskii and his collaborators at Kiev, Ukraine which confirm that certain Biological entities such as microbes are able to catalyze nuclear transmutation reactions [14.1, 14.2] under certain special conditions. Vysotskii's experiments have a great bearing on the prospects of converting radioactive nuclear waste into stable products and so deserves careful scrutiny.

The origin of the concept of "Biological Transmutations" in fact goes back to the 60s, decades before the Fleischmann & Pons effect became known, when Louis Kervran of France published three books pertaining to this topic. An English version of Kervran's books became available in 1972 [14.3]. In his works Kervran had exhaustively compiled previous experimental publications and scientific reports which indicated that non radiative elemental transmutations might be occurring in plants, animals and indeed even human beings. Over a century ago keen observers had been puzzled by the fact that hens lay dozens of eggs which contain a lot of calcium but the food eaten by the hens (mostly mica) did not appear to contain the requisite amount of calcium content. During 1799 to 1815 Vauquelin analyzed the excreta of hens and found that there is more Ca in it than in the oats fed to them. In 1822 an English physiologist by the name of Prout reported incinerating and analyzing freshly hatched chicks to find that the ash contains more Ca than present in the eggs from which the chicks hatch out. These reports suggested that the following nuclear reaction possibly takes place in these biological systems:

$$_{14}\text{Si}^{28} + {}_{6}\text{C}^{12} \rightarrow {}_{20}\text{Ca}^{40}$$

During the second half of the 19th century several workers, notably Herzeele, reported through carefully conducted experiments that while seeds germinate there is a change in their trace element composition through elemental transmutations. Prof. Baranger of the Ecole Polytechnic in Paris has claimed [14.4] that he has independently repeated and confirmed Herzeele's experiments. Baranger states that seeds of "cerdagne vetch" growing in distilled water showed no

change in phosphorous or potassium content, but when germinated in calcium chloride solution showed increase of phosphorous or potassium content by over 10%.

Kervran himself repeated the germinating seeds experiments and has reported [14.3], from analysis of 840 seeds and 403 sprouts, finding strong evidence for ${}_{19}K^{39}$ (potassium) absorbing a proton to yield ${}_{20}Ca^{40}$ during germination.



Fig. 29. Changes in K and Ca content following Sprouting of seeds

It is seen from Figure 20 that the decrease in the amount of potassium (33mg) is approximately equivalent to the increase in quantity of calcium (32 mg).

In a another experiment Kervran placed "tench" fish in a tank of water containing 1.4 % sodium chloride (NaCl) solution for 4 hours and found that the concentration of KCl in the blood of the fish increased by 66% and that in the tank from 3.95 g/l to 5.40 g/l suggesting the occurrence of the following transmutation reaction:

$$_{11}\mathrm{Na}^{23} + {}_{8}\mathrm{O}^{16} \rightarrow {}_{19}\mathrm{K}^{39}$$

Kervrans book is full of such very interesting examples. Unfortunately many of the quoted experimental studies were not published in mainstream peer reviewed Physics journals and the scientific community, especially the nuclear physicists, never took these "claims" seriously since occurrence of such transmutation reactions is not possible as per contemporary knowledge of nuclear physics.

During the period 1967 to 1992 Komaki of Japan had conducted several experiments, some of them jointly with Kervran, [14.5 and cross references therein] which indicated the occurrence of nuclear transmutation reactions in nutrient cultures in which certain micro-organisms thrive. These investigators determined the amounts of potassium, magnesium, iron and calcium in the dried cells of selected micro-organisms such as Aspergillus Niger, Penicillium Chrysogenum etc, cultured in normal media as well as media deficient in one of the test elements such as potassium, magnesium, iron or calcium. Komaki has specifically mentioned [14.4] that these experiments which were carried out under more controlled conditions than previously were quite reproducible.

Vysotskii was inspired by the experiments of Kervran and Komaki but was unhappy that they had not analyzed the isotopic composition of the newly formed elements as this would have partly answered the criticisms of the skeptical Nuclear Physicists. By the time Vysotskii entered the field, in the early 90s, high resolution mass spectrometers capable of identification of individual nuclides became more commonly available. He therefore set about conducting a fresh set of meticulously planned experiments, aimed at measuring the isotopic composition of the newly formed chemical elements.

To begin with Vysotskii identified the following nuclear reaction for investigation [14.6]:

$$_{25}Mn^{55} + _{1}d^{2} \rightarrow _{26}Fe^{57}$$

He categorizes this reaction as an example of transmutation of "light and intermediate" isotopes. He selected Fe⁵⁷ isotope not only because iron is an integral part of most living organisms but it is a rare isotope whose abundance in natural iron is only 2.2 %. More importantly the detection of Fe⁵⁷ isotope can be carried out very simply and elegantly using the Mossbauer technique. Vysotskii proceeded to attempt synthesis of Fe⁵⁷ through the above reaction in biological systems. He selected several different bacterial cultures as well as a culture of yeast for initial tests. One culture in which he was particularly interested was *Deinococcus radiodurans* M-1 because this culture is known to withstand high radiation doses. (The motivation for choosing this will become apparent later in this write up.) Other micro-organisms were selected because of their known ability to multiply in cultures containing heavy water.

After preliminary treatment the cultures were placed in a dish containing standard salt-sugar nutrient medium, incorporating various salts such as Mg, S, Ca, K, etc and heavy water. Control studies were initially done in a medium containing only light water. For transmutation $MnSO_4$ salt was added. Natural Manganese comprises of only one stable isotope, namely Mn^{55} , and so it renders the interpretation of the results unambiguous. Before commencement, the Fe⁵⁷ content of all the dry ingredients used in the cultures were analyzed using Mossbauer spectroscopy; and it was confirmed that the initial Fe⁵⁷ content in all cases was below detection limit. There were in all four experimental flasks, three of which served as controls. The culture growth periods were 24 or 48 or 72 hours. The temperature of the flasks was maintained at 32° C by a thermostat and the flasks were kept continuously stirred.

At the end of the growth period the biological substances were separated in a centrifuge, rinsed in distilled water, dried and then ground to powder. A small portion (~0.3 g) of this was tested in the Mossbaur spectrometer using standard Mossbauer spectrometry procedures. It was found that only the fourth flask which contained both Mn and D₂O indicated presence of Fe⁵⁷.

Vysotskii then selected the following transmutation reaction representing "middle range atomic numbers" for study, deploying the microbiological culture known as *Bacillus Subtilis*.:

$$_{11}\text{Na}^{23} + {}_{15}\text{P}^{31} \rightarrow {}_{26}\text{Fe}^{54} + 22.4 \text{ Mev}$$

Both the reacting nuclides occur in nature as single isotopes while the reaction product is a low natural abundance (5.8%) isotope of iron. He placed the microbial culture in a nutrient medium which was deficient in iron an then added controlled quantities of sodium in the form of NaNO₃ and phosphorous in the form of K₂HPO₄. There were two identical flasks in which all ingredients were same except that in one there was no phosphorous additive. The quantity of Fe⁵⁴ generated was measured using mass spectrometry. The isotopic ratio of (Fe⁵⁴/Fe⁵⁶) increased

from its natural value of 0.06 to about 0.20 to 0.25 in various repeat experiments. The details of the experiment and results are described in Ref [14.7].

Vysotskii has performed a large number of auxiliary experiments to determine how the yield of these Biological transmutation reactions can be improved. His new 2009 book [14.2] discusses the biotechnology approaches adopted by him for this purpose in great detail. The main lesson learnt by him was that instead of using "one-line' cultures, if a mixture of a large variety of cultures are deployed, the transmutation yield improves substantially. To achieve this he has invented what he calls a "Microbial Catalyst Transmutator" (MCT). The MCT is composed of special granules of concentrated biomass of metabolically active micro-organisms, sources of energy and nutrients such as N,C,P etc bound together by a gluing substances which keep all compounds in the granules stable in water solutions for long times under any external conditions. The basis of the MCT are microbes syntrophin associations that contains thousands of varieties of micro-oganisms that are in a state of complete symbiosis. These organisms represent different physiological groups displaying a very wide variety of microbe metabolism and accumulation mechanisms. According to Vysotskii the state of complete symbiosis of the syntrophin associations is the key feature that is responsible for maximum adaptation to external environment.

Vysotskii has repeated the Fe^{57} generation experiment using MCTs in place of the single species microbes use by him earlier. Fig. 30 shows the Mossbauer spectrum of the Fe^{57} so generated.





The quantum of Fe^{57} present was also independently confirmed using Thermal Ion Mass Spectrometry (TIMS). The results of the TIMS measurement are summarized in **Table VI**. The decrease in the amount of Mn⁵⁵ approximately matches the increase in amount of Fe⁵⁷ in the powder of the transmutation flask. Also it may be seen that the (Fe⁵⁶/Fe⁵⁷) isotopic ratio has decreased from the natural iron value of 41.7 to 19.5. These results clearly confirm the occurrence of nuclear processes in these microbiological cultures.

Table VI: Mass Spectrometric Measurements of Fe⁵⁶/Fe⁵⁷ Isotopic Ratios in Control and Transmuted Cultures

| Isotope (natural concent- ration) | Natural isotopic ratio (in relation to Fe ⁵⁶) | Concentration in dried biological substance in control experiment: $H_2O +$ $MnSO_4 +$ nutrient medium | Isotopic ratio in control biological substance | Concentration in dried biological substance in experiment on transmutation: $D_2O + MnSO_4$ + nutrient medium, (normalized) | Isotopic ratio in the experiments on transmutation |
|--------------------------------------------|--------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|
| Mn ⁵⁵ , 100% | | 0.15 ± 0.01 | $Mn^{55}/Fe^{57} = 6.6$ | 0.13 ± 0.01 | Mn ⁵⁵ /Fe ⁵⁷ = 7.7 |
| Fe ⁵⁶ , 91.7% | 1 | 1 | 1 | 1 | 1 |
| Fe ⁵⁷ , 2.2 % | Fe^{56}/Fe^{57} = 41.7 | 0.024 ± 0.002 | Fe ⁵⁶ /Fe ⁵⁷ = 42.5 | 0.051 ± 0.003 | Fe ⁵⁶ / Fe ⁵⁷ = 9.5 |

Vysotskii then turned his attention to the possibility of transmutation or "accelerated deactivation" of a "heavy mass" radioactive nuclide such as Cs^{137} using the MCT approach. But prior to tackling radioactive Cs^{137} , he first developed the procedures using Cs^{133} and verified that the following reaction does take place in microbial cultures [14.2]:

$$Cs^{133} + p^1 \rightarrow Ba^{134} + 8.3 Mev$$

However details of this study are not discussed in this review. Instead the Cs^{137} study [14.8] is discussed in more detail as it has great relevance to the problem of deactivation of radioactive waste for the nuclear industry.

 Cs^{137} decays with a half life of ~30 years emitting a 661 Kev gamma ray in the process. Vysotskii started with 20 Kbq of Cs^{137} dissolved in distilled water. 10 ml each of this active water was transferred into each of 8 thin walled closed glass vials. The 8th vial served as a control and no other ingredient was added into it. In each of the other seven vials he added the same quantity of MCT granules. The 7th vial also served as control as no nutrient salt was added in it. In the remaining 6 vials one of the following 6 six salts was added into the active water: K, Ca, Na, Fe, Mg and P. These additive elements are vitally necessary for the cultures to grow. According to Vysotskii's hypothesis "each of these specific additives completely blocks all transmutation channels in which any of the biochemical analogs of the specific chemical element can be used [14.2]; this blockage is a consequence of the need to attain an optimal balance of micronutrients."

The cultures were grown at a temperature of 20° C for 45 days. Every 7 days the activity of the closed flasks was counted in a low background Ge gamma counting system sitting on the 661 kev peak. **Fig.31** displays the results of this experiment.



Fig. 31. Accelerated decay of Cs¹³⁷ isotope in "biological cells" in presence of different chemical elements

It is seen that the activity of the 7^{th} vial which contains only active water and MCT (no salts) follows the natural 30 year half life decay rate whereas the fastest decay corresponding to a half life of 310 days occurs for the vial containing CaCO₃ as additive. This means the decay rate has been speeded up by a factor of 35 times. However it is to be noted that all the 6 salts did result in speeding up the decay to a greater or lesser extent.

Vysotskii hypothesizes that the following exhothermic proton capture reaction occurs in all 6 vials where there was some "nutrient salt" besides the MCT granules, resulting in stable Ba¹³⁸:

$$Cs^{137} + p^1 \rightarrow Ba^{138} + \Delta E (5.58 \text{ Mev})$$

In References [14.2 and 14.8] the author has offered his explanation as to why the speed up rate for transmutation is better when the concentration of Ca is increased.

In general Vysotskii theorizes that for optimal growth of microbial cultures, a balanced mix of trace elements is essential. A deficiency of even one of the required elements hinders the growth of the entire biological object. According to Vysotskii the phenomenon of occurrence of transmutation of chemical elements and isotopes in Biological systems is based upon the heuristic proposition that if some of the essential elements are not present in the environment (in this case the nutrient medium) then, *provided certain pre-requisites are met*, these elements will be synthesized through appropriate nuclear transmutation reactions. Vysotskii has arrived at such a proposition following more than a decade of experimental investigation of the topic of Biological Transmutations. His new book [14.2], presents a detailed exposition of his experimental findings and theoretical conjectures.

Needless to emphasize Vysotskii's works are of great relevance to the urgent task of dealing with the problem of radioactive waste generated by nuclear power stations. His Microbial transmutation technique appears to have great promise and deserves study and replication.

15. Summary and Conclusions:

A brief summary of the major experimental investigations and results of the LENR field pertaining to the occurrence of a gamut of nuclear transmutation reactions in simple experimental configurations has been presented. There are in fact many more such studies which could not be covered in this review due to space constraints. For purposes of completeness we reproduce as Appendix A an exhaustive updated tabulation of 101 transmutation experiments compiled by Storms and given initially in his book [2.7] which includes most of the major studies that we have discussed so far.

The sheer variety of experimental approaches in which transmutations have been reported rules out the probability that experimental artifacts could be responsible for erroneous interpretation of the observations and compels us to take serious note of the results, not withstanding the fact that the presently accepted understanding of nuclear phenomena does not provide any scope at all for such reactions to take place. However in view of the deep implications of the claim that nuclear transmutation reactions can and do occur in simple experimental configurations (almost validating the age old claims of Alchemy!) it is absolutely imperative that some of these very simple experiments be replicated by groups outside of the limited LENR community, enabling critical evaluation by a wider section of the scientific community and leading to eventual publication and endorsement by mainstream journals. The purpose of the present review paper is precisely to encourage such an effort.

A careful scrutiny of the reported results brings out some insightful features [15.1,15.2]. During transmutation the atomic weight and atomic number of some of the nuclides present in the reaction environment appear to have increased in "multiples of several deuterons". In addition, isotopes having a fraction of the atomic weight (and atomic number) of the initial nuclei present in the experimental zone are detected in post experimental samples, suggesting that perhaps some large sized nuclei may have "fissioned" into smaller nuclear fragments. These features are evident in **Figure 32** which illustrates the number of occasions where in various elements have been observed on the surface of the Pd cathode following electrolysis in a D₂O based solution. Also the presence of Au (Z = 79) and Pb (Z = 82) at the higher atomic number end appears to be attributable to multiple deuteron captures in Pt (Z = 78) which is obviously sourced from the anode material.



Fig. 32. Frequency of observation of elements on surface of Pd cathodes after electrolysis in D₂O based electrolytes

Figure 33 gives the Z vs. A representation of the stable isotopes of elements (shown as dots) in the Z = 46(Pd) to Z= 55(Cs) region, extracted from a standard periodic table of elements. The

x - axis represents the atomic weight while the y - axis gives the atomic number. All combinations of Z and A, other than that shown as dots, are unstable and would imply radioactive nuclides. Since in LENR experiments radioactive products have seldom been observed, only the stable isotopes represented by the dots are relevant to our discussions. The three straight lines emanating from the dot corresponding to Pd^{110} nuclide indicate how the Z vs. A plot will vary if a series (or clusters) of protons, deuterons or neutrons are captured by Pd^{110} nucleus.



Fig. 33. Isotopic compositions of stable elements with $Z \ge 46$ (Pd) shown as dots and the effect of adding one or more protons, deuterons or neutrons to Pd¹¹⁰ nucleus.

Addition of a single neutron to Pd¹¹⁰ would lead to formation of radioactive Pd¹¹¹ which is a beta emitter with a 23.4 min half-life. Further addition of neutrons would result in beta emitters with even shorter half-lives. Decay of these isotopes would lead to other radioactive species until the decay chain terminates in a stable end product nuclide. Because this type of behavior has not been observed in LENR experiments, neutrons are not likely to be the cause of the observed transmutation reactions.

If we next follow the line marked "add proton" in **Fig. 33** we note that sequential addition of several protons to Pd^{110} can lead only to a few stable elements with tin (Sn) being the heaviest. Beyond that one again ends up in radioactive isotopes which are not observed.

It would thus seem that only addition of one or more deuterons enables the full range of observed *stable elements* to be synthesized, at least in $Pd-D_2$ experiments. Note also that in general stable isotopes are produced only when even numbers of deuterons are added. In this context the remarkable observations of Iwamura et al during D_2 gas permeation studies discussed earlier, are relevant. It may be recalled that these authors had found, during transmutation studies involving single nuclides, always only even numbers of deuterons, namely 4, 6 or 8 deuterons, were added and that too in such a manner that radioactive isotopes were not formed. However we do recognize in electrolysis experiments Palladium is not the only target nucleus available; Platinum, Lithium, Silicon, Oxygen and possibly a few impurity atoms also are present on the surface of the cathode where transmutation products are formed. This complicates the task of theoretical interpretation of these processes.

The newly emergent Science of Low Energy Nuclear Reactions (LENRs) is thus wide open and indeed offers exciting challenges and opportunities to the future generation of nuclear scientists!

REFERENCES:

2.1 Rolison, D.R. and O'Grady, W.E., Proc. NSF/EPRI Workshop, Washington D.C., USA October (1989)

2.2 Rolison, D. R. and O'Grady, W. E. (1991) "Observation of elemental anomalies at the surface of palladium after electrochemical loading of deuterium or hydrogen", Anal. Chem. 63 (1991) pp.1697–1702.

2.3 Rolison, D., O'Grady, W., Doyle, Jr, R., Trzaskoma, P., "Anomalies in the surface analysis of deuterated palladium", *Proc. 1st International Conference on Cold Fusion*, March 28-31, 1990, Salt Lake City, Utah. National Cold Fusion Institute: University of Utah Research Park, Salt Lake City, Utah, 1990; p 272.

2.4. Miley, G.H. and Shrestha, P.J., "On Transmutation Reactions and Associated LENR Effects in Solids." In Condensed Matter Nuclear Science: *Proc.10th International Conference on Cold Fusion*, Aug. 24-29, 2003, Cambridge, MA,; Hagelstein, P. L.; Chubb, S. R., Eds.; World Scientific Publishing Co.: Singapore (2006) pp.361-378.

2.5. Miley, G.H.; Shrestha, P.J., "Overview of light water/ Hydrogen-base low energy nuclear reactions." *Proc. 12th Int. Conf. on Cold Fusion,* Yokohama, Japan, Nov. 27- Dec. -2, 2005. Eds., Takahashi, A., Ota, K., Evamura, Y., World Scientific (2006) pp. 34-43.

2.6. Miley, G. H. and Shrestha, P. J. "Transmutation Reactions and Associated LENR Effects in

Solids," Low Energy Nuclear Reactions Sourcebook, Eds, Marwan, J. and Krivit, S.

B., American Chemical Society, Washington D.C, Oxford Univ. Press, (2008)

2.7. Storms, E., "The science of Low Energy Nuclear Reaction", World Scientific (2007)

3.1. Miley, G.H. and Patterson, J., "Nuclear Transmutations in Thin-Film Nickel Coatings Undergoing Electrolysis", J. New Energy, 1(3) (1996)

3.2. Miley, G.H., Narne, G., Williams, M J., Patterson, J., Cravens, D., Hora, H. "Quantitative Observations of Transmutation Products Occurring in Thin-Film Coated Microspheres During Electrolysis", Proc. 6th Int. Conf. on Cold Fusion, Hokkaido, Japan, Oct. 13-18, 1996, Ed., Okamoto, M., New Energy and Industrial Technology Development Organization: Tokyo, (1996) pp 629-644.

3.3 Bockris, J.O.M., Mallove, E.F. "The Occurrence of Cold Nuclear Reactions Widespread Throughout Nature?" Infinite Energy, 27, (1999) pp. 29–38

3.4. Miley, G. H., "Product characteristics and energetics in thin-film electrolysis

experiments", Proc. 7th Int. Conf. on Condensed Matter Nuclear Science (1998), Vancouver,

British Columbia, Canada, Ed. ENECO, Salt Lake City, Utah USA, (1998) pp 241-246.

3.5. Miley, G. H., Heinrich, H., Lipson, A., Kim, S. O., Luo, N., Castano, C. H.,

Woo, T. "Progress in Thin-Film LENR Research at the University of Illinois" Proc. 9th Int. Conf. on Cold Fusion: Beijing, China, May 19-24 2002, Ed. Xing Z. Li, Tsinghua Univ. Press, Beijing, China (2002) pp 255-260.

3.6. Storms, E. and Scanlan B., "Role of Cluster Formation in the LENR Process", Proc. 15th Int. Conf. on Condensed Matter Nuclear Science, Roma, Italy, Oct. 5-9, 2009, Eds, Violante, V., and Sarto, F., ENEA Publications, Frascati, Rome, Italy (2010)

3.7 Storms, E. and Scanlan, B., "What is Real about Cold Fusion and What Explanations are Possible?" AIP volume (2011)

4.1. Bockris, J. O. M. "History of the Discovery of Transmutations at Texas A & M University", Proc. 11th Int. Conf. on Condensed Matter Nuclear Science ,Oct.31-Nov. 5, 2004, Marseilles, France, Ed, Biberian, J. P., World Scientific (2006) pp. 562-586.

4.2 Mizuno, T., Ohmori, T. and Enyo, M., "Isotopic changes of the reaction products induced by cathodic electrolysis in Pd" J. New Energy, 1(3), (1996) p. 31.

4.3 Mizuno, T., "Transmutation Reactions in Condensed Matter", Low Energy Nuclear Reactions Sourcebook, Eds, Marwan, J. and Krivit, S. B., American Chemical Society, Washington D.C, Oxford Univ. Press, (2008)

5.1 Mo, D.W. et. al., "The Evidence of Nuclear Transmutation Phenomena in PdH System Using NAA (Neutron Activation Analysis)", Proc. 7th Int. Conf. on Condensed Matter Nuclear Science, April 19-24, 1998, Vancouver, Canada (1998), pp 259-293

5.2 Bush, B.F. and Lagowski, J.J., "Trace Elements added to Palladium by Electrolysis in Heavy Water", EPRI Report TP-108743 (1999), Electric Power Research Institute, Palo Alto, CA, USA (Unpublished)

5.3 Passel,T.O. and George,R., "Trace Elements added to Palladium by Exposure to Gaseous Deuterium", Proc. 8th Int. Conf. on Cold Fusion, Lerice, (La Spazia), Italy, May 21-26, 2000 Ed., Scaramuzzi, F., Society Italiana Fisica, Bologna, Italy, (2000) pp 129-134
5.4 Passel, T.O., "Pd¹¹⁰/Pd¹⁰⁸ Ratios and Trace Element Changes in Particulate Palladium Exposed to Deuterium Gas", Proc.10th Int. Conf. on Condensed Matter Nuclear Science, Aug. 24-29, 2003, Cambridge, MA,,USA, (2003), Hagelstein, P.L.; Chubb, S. R., Eds.; World Scientific Publishing Co.: Singapore (2006) pp 399-404

6.1 Szpak et. al., "LENR Research Using Co-Deposition", Proc. 14th Int. Conf. on Condensed Matter Nuclear Science, August 10-15, 2008, Washington D.C, USA
6.2 Szpak, S., Boss, P.A.M., Young, C. and Gordon, F.E., "Evidence of Nuclear Reactions in the Pd Lattice", Naturwiss., 92(8), (2005) pp 394 -397

7.1 Dash, J.J., Noble, J.J., and Diman, J., "Surface Morphology and Microcomposition of Palladium cathodes After Electrolysis in Acidified Light and heavy Water: Correlation with Excess Heat", Transactions in Fusion Technology, 26, (1994) p 299

7.2 Dash, J., Wang, Q and Silver, D.S., "Excess Heat and Anomalous Isotopes and Isotopic ratios From the Interaction of Palladium with Hydrogen Isotopes", ACS Low Energy Nuclear Reactions Sourcebook, Vol 2, Oxford University Press, (2010)

8.1 Violante, V., Torre, A., Miley, G. H. and Selvaggi, G., "Fusion Technol.", 39, (2001), p.266 **8.2** Violante, V., Sibilia, C., Gioacchino, D. Di., McKubre, M., Tanzella, F., Tripodi, P., Proc. 8th Int. Conf. on Cold Fusion, Lerice, (La Spazia), Italy, May 21-26, 2000 Ed., Scaramuzzi, F., Society Italiana Fisica, Bologna, Italy, (2000) p. 409.

8.3. Violante, V., Mazzitrlli, G., Capobianco, L., "Search for Nuclear Ashes in Electrochemical Experiments", Proc. 10th Int. Conf. on Condensed Matter Nuclear Science, Cambridge, MA, USA, Aug. 24-29, 2003, Eds., Peter, L. H. and Scott, R.C., World Scientific (2006) pp. 405 - 420.

8.4. Violante, V., Castagna, E., Sibilia, C., Paoloni, S., Satro, F., "Analysis of Ni-hydride thin film after surface Plasmon generation by laser technique", Proc. 10th Int. Conf. on Condensed Matter Nuclear Science, Cambridge, MA, USA, Aug. 24-29, 2003, Eds., Peter, L. H, Scott, R. C., World Scientific, (2006) pp. 421-434.

9.1. Karabut, A. B., Kucherov, Ya. R., Savvattimova, I.B., "The Investigation of deuterium Nuclei Fusion at Glow Discharge Cathode", Fusion Technology, 20, No. 4, Part 2, (1991) pp. 924.

9.2. Karabut, A. B., Kucherov, Ya. R., Savvattimova, I.B. "Nuclear Product Ratio for Glow Discharge in Deuterium", Physics Letters A, 170, (1992) pp. 265.

9.3. Karabut, A. B., Kucherov, Ya. R., Savvattimova, I.B. "Possible Nuclear Reactions Mechanism at Glow Discharge in Deuterium", Proc. 3rd Int. Conf. on Condensed Matter Science, October, 21-25 (1992) Nagoya, Japan, Ed. Ikagami, H., University Academy Press Inc. Tokyo, Japan (1992) pp. 165-168.

9.4. Savvatimova, I. B., Kucherov, Ya. R., and Karabut, A. "Cathode Material Change after Dehuterium Glow Discharge Experiments", Proc. 4th Int. Conf. on Condensed Matter Nuclear Science, Maui, Hawaii, Dec. 6 - 9 (1993), Transactions of Fusion Technology, V 26, American Nuclear Society, (1994) pp. 389 – 394.

9.5. Savvatimova, I. B and Karabut, A, Nuclear Reaction products registration on the Cathode after Glow Discharge", Proc. ICCF 5, pp 213 -222

9.6. Karabut, A.B. "Excess heat power, nuclear products and X-ray emission in relation to the high current glow discharge experimental parameters", Proc. 9th Int. Conf. on Cold Fusion: Beijing, China, May 19-24 2002, Ed. Xing Z. Li, Tsinghua Univ. Press, Beijing, China (2002) pp. 151 – 154.

9.7 Karabut, A.B., "Research Into Low Energy Nuclear Reactions In Cathode Sample Solid With Production Of Excess Heat, Stable And Radioactive Impurity Nuclides". The 12th International

Conference on Condensed Matter Nuclear Science. 2005. Yokohama, Japan.

9.8. Savvatimova I.B. "Reproducibility of Experimental and Glow Discharge and Process accompanying Deuterium Ions Bombardment", Proc. 8th Int. Conf. on Condensed Matter Nuclear Science, Lerici (La Spezia), Italy, May 21 - 26 (2000) Ed. Scaramuzzi, F., Societa Italiana Di Fisica, Bologna, Italy, (2000) pp. 277.

9.9 Karabut, A.B. "Analysis of Experimental Results on Excess Heat power Production, Impurity Nuclides Yield in the Cathode Material and Penetrating Radiation in Experiments with High Current Glow Discharge", Proc. Iccf 8 (2000) pp 329 -334

9.10. Savvatimova, I.B. and Gavritenkov, D.V., "Influence of the parameters of the Glow Discharge on Change of Structure and the Isotope Composition of the Cathode Materials", Proc. 12th Int. Conf. on Condensed Matter Nuclear Science, 27 Nov. to 2nd Dec. 2005, Yokohama, Japan 2005 World Scientific, Singapore, (2006) p. 231.

9.11. Savvatimova, I., Savvatimov, G., Kornilova A., "Decay in Tungston Irradiated by Low Energy Deuterium Ions", Proc. 13th Int. Conf. on Condensed Matter Nuclear Science, Sochi, Russia (2007)

9.12. Savvatimova, I. Proc.13th Int. Conf. on Condensed Matter Nuclear Science, June 25 –July 1st, 2007, Sochi, Russia, (2008) p. 505

10.1 Yamada, H., et al, C. Fusion Technology, Vol 39, p253 (2001)

10.2 Arapi, A., et al, Proc. 9th Int. Conf. on Condensed Matter Nuclear Science, May 24-29, 2002. Tsinghua Univ., Beijing, China: Tsinghua Univ. Press. Beijing, China (2002) p 1

11.1 Iwamura, Y., Itoh,K., Toyoda, I., "Observation of Anomalous Nuclear Effects in D₂-Pd System", 1ccf4 pp.160-164

11.2 Itoh, T., Iwamura,Y., Gotoh, N., and Toyoda, I., "Observation of Nuclear products under vacuum condition from deuterated palladium and High Loading ratio", 1ccf 5, pp 189-196. **11.3** Iwamura,Y. et al iccf6, (1996) p 274

11.4 Iwamura, Y. et. al., "Detection of anomalous elements, x-ray, and excess heat in a D_2 -Pd system and its interpretation by the electron-induced nuclear reaction model", Fusion Technology, 33, (1998) p. 476

11.4a Iwamura,Y. et al, "Detection of Anomalous Elements, X-Ray and Excess Heat Induced by Continous Diffusion of Deuterium through MultiLayer Cathode (Pd/Cao/Pd), Proc. 7th Int. Conf. on Cold Fusion, April 19-24, 1998, Ed., Jaeger, F., Published by Eneco Inc., Salt lake City, Utah, USA (1998) pp 167-172

11.5 Y. Iwamura, T. Itoh and M. Sakano, "Nuclear Products and Their Time Dependence Induced by Continuous Diffusion of Deuterium through Multi-layer Palladium Containing Low Work Function", Proc. of ICCF8, 21-26 May 2000 Lerici (Italy), SIF Conf. Proc.Vol.70, pp.141-146.

11.6. Iwamura, Y., Sakano, M. and Sakai, S., "Elemental analysis of Pd complexes: Effects of D₂ gas permeation", Jpn. J. Appl. Phys., 41, (2002) pp. 4642 - 4648

11.7. Iwamura, Y. et. al., "Observation of Low Energy Nuclear reactions induced by D2 gas permeation through Pd complexes" iccf9 2002 pp 141 - 146

11.8. Iwamura, Y.,T. Itoh, M. Sakano, S. Sakai and S. Kuribayashi, Proc. ICCF10, Cambridge, USA, Aug.24-29 (2003), World Scientific, pp.435-446

11.9 Iwamura, Y.,T. Itoh, M. Sakano, S.Kuribayashi, Y. Terada, T. Ishikawa and J.Kasagi, Proc. ICCF11, Marseilles, France, Oct.31-Nov.5 (2004), World Scientific, pp.339-350.

11.10 Iwamura, et.al., "Observation of surface distribution of products by x-ray fluorescence spectrometry during D_2 gas permeation through Pd complexes", iccf 12 Yokohama, Nov 27-dec 2, (2005) pp. 178 – 187.

12.1 Higashiyama, T., Sakano, M., Miyamaru, H. and Takahashi, A., "Replication Of MHI Transmutation Experiment By D₂ Gas Permeation Through Pd Complex", ICCF 10 Cambridge, MA (2003) pp 447-454

12.2 Takahashi, A., "The Basics of Deuteron-Cluster Dynamics as Shown by a Langevin Equation," ACS Low-Energy Nuclear Reactions and New Energy Technologies Sourcebook, Vol. 2 (2010) pp 193-217

13.1 "Kushi Institute Study Guide", Issue No. 10 (1980) Ed. Hugus, C., Published by Kushi Institue, Brooklyn Village, MA

13.2 R. A. Monti, Cold Fusion and Cold Fission: Experimental Evidence for the Alpha Extended Model of the Atom. ICCF-2, Como, Italy 1991 (J. N. E.).

13.2a R. A. Monti, "Low Energy Nuclear Reactions: The Revival of Alchemy",

13.3 Singh, M., Saksena, M.D., Dixit, V.D. and Kartha V.B., "Verification of the george Oshawa experiment for Anomalous Production of Iron from Carbon Arc in Water", FusionTechnol., 26, (1994) pp 266 - 270

13.4 Sundaresan, R., and Bockris, J. O.M., "Anomalous Reactions during arcing between carbon rods in water", Fusion Technol. 26.,(1994) pp 261 - 265

13.5 Jiang, X. L., Han, L. J. and Kang, W., "Anomalous Element Production Induced by Carbon Arcing under Water", Proc. 7th Int. Conf. on Cold Fusion, April 19-24, 1998, Ed., Jaeger, F., Published by Eneco Inc., Salt lake City, Utah, USA (1998) pp 172 -179

14.1 Vysotskii, V. I., Kornilova, A. A, "Nuclear Fusion and Transmutation of Isotopes in Biological Cultures", Mir Publishers, Moscow (2003)

14.2 Vysotskii, V. I., Kornilova, A. A., "Nuclear Transmutation of Stable and Radioactive Isotopes in Biological Systems", Pentagon Press, New Delhi, India, (2009)

14.3 Kervran, L. C., "Biological Transmutations", Swan House Publishing Co., N.Y., (1972). **14.4** Bahrangar, P., J. Biol. Sciences, 3(2), (1960) pp 57-85

14.5 Komaki, H., "Observations on the Biological Cold Fusion or the Biological Transmutation of Elements", Proc. 3rd Int. Conf. on Condensed Matter Science, October, 21-25 (1992) Nagoya, Japan, Ed. Ikagami, H., University Academy Press Inc. Tokyo, Japan (1992) pp 555-558 **14.6** Vysotskii, V. I., Kornilova, A. A. and Samoylenko I.I., "Experimental discovery of the phenomenon oflow-energy nuclear transmutation of of isotopes (Mn55 \rightarrow Fe57) in growing biological cultures", Proc. 6th Int.Conf. on Cold Fusion, Toya, Japan (1996) pp 687-693 **14.7** Vysotskii, V. I., Kornilova, A. A. and Samoylenko I.I., "Experimental Observation and study of controlled transmutation of intermediate mass isotopes in growing biological cultures, Proc.8th Int. Conf. on Cold Fusion, 21-26 May 2000 Lerici (Italy), SIF Conf. Proc.Vol.70 (2000) pp 135-140

14.8 Vysotskii, V.I., Tashyrev, A.B. and Kornilava A.A., "Experimental Observation and Modelling of Cs137 isotope deactivation and stable isotopes transmutation in biological cells", American Chemical Society Sourcebook vol 1 (2008) Oxford university Press pp 295-303

15.1 Storms, E.K. and Scanlan, B., "Role of cluster formation in the LENR process", in *15th International Conference on Condensed Matter Nuclear Science*. 2009. Rome, Italy: ENEA.

15.2 Storms, E.K. and Scanlan, B., "What is real about cold fusion and what explanations are plausible?", in *AIP Symposium Series*, J. Marwan, Editor. 2010, Am. Inst. of Phys.

APPENDIX A

SUMMARY OF EXPERIMENTAL STUDIES IN WHICH NUCLEAR TRANSMUTATION REACTIONS HAD BEEN REPORTED AS OF 2007 (Reproduced from Edmund Storms' book [2.7])

| Source | Substrate | Environment | Method | Detected |
|-----------------------|-----------|--------------------------------------------------------------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Wang et al.[1] | Pd | $H_2SO_4+D_2O$ | electrolytic | Ag,Ni,Fe,Ti,S,Pt |
| Wang et al.[1] | Ti | H ₂ SO ₄ +D ₂ O | electrolytic | Ag,Ni,Fe,Ti,S,Pt |
| Szpak et al.[2, 3] | Pd | LiOD+D ₂ O | electrolytic | Si,Mg,Zn,Ca,Al Al,Mg,Br,Sr,Rb,S,F,O,Ni,Cr, |
| Savvatimova et al.[4] | Ti | D_2 gas | plasma | Fe,Sn (isotope ratio change) |
| Mizuno et al.[5] | W | K ₂ CO ₃ +H ₂ O | plasma | Ca,Fe,Zn |
| Lochak and | | | | Na,Mg,Al,Si,K,Ca,V,Cr,Fe,Ni, |
| Urutskoev[6] | Ti | H_2O | fuse | Cu,Zn |
| | | | | Li,C,N,Ne,Si,Ca,Fe,Co,Zn, As, |
| Karabut[7, 8] | Pd | D_2 gas | plasma | Ag,Cd,In(isotope ratio change) |
| Focardi[9] | Ni | H_2 gas | ambient | Cr,Mn |
| Cirillo and Iorio[10] | W | $K_2CO_3+H_2O$ C_2H_5OD+ | plasma | Re,Os,Au,Hf,Tm,Er,Y |
| Celani et al.[11] | Pd | Th,Hg | electrolytic | Cu,Zn,Rb,Cs,Pb.Bi |
| Campari[12] | Ni | heated H ₂ gas | ambient | Na,A,Si,S,Cl,K,Ca,Fe,Zn |
| Yamada et al.[13] | Pd | H_2 gas | diffusion | Ti,Cr,Mn,Fe,Ni,Cu,Ag |
| Violante et al.[14] | Ni | D_2O | electrolytic | Cu (isotope ratio change) |
| Passell[15] | Pd | D_2 gas $K_2CO_3+D_2O_3$, | plasma | Pd isotope change, Co,Zn,Au,Ir |
| Ohmori et al.[16] | Re | H_2O C_2H_5OD+ | plasma | K (isotope ratio change) |
| Celani et al.[17] | Pd | Th,Hg,Sr | electrolytic | Sr→Mo(isotope ratio change) |
| Violante et al.[18] | Ti | D ₂ O+Li ₂ SO ₄ | electrolytic | Zn,Cu,Ag (isotope ratio change) Li,B,Mg,Al,K,Ca,Ti,Cr,Mn, Fe, |
| Vamada at al [10] | Ъ | $\mathbf{U} \cap \mathbf{N}_{\mathbf{a}} \subset \mathbf{O}$ | alaatualiitia | Co,N1,Cu,Zn,Ba,Pb(1sotope ratio |
| Vorman at al [20] | Pu Ti | $\Pi_2 O + Na_2 CO_3$ | electrolytic | And the second s |
| Wantel et al.[20] | 11 | $D_20+\Pi_230_4$ | biological | Au |
| Matsupaka at al [22] | Dd | | electrolytic | Da Fo Zn |
| watsullaka et al.[22] | ru | D_2O | electrorytic | C Ca Ti Fe Co Zn As Ag Cd |
| Karabut[23] | Pd | D. gas | nlasma | (isotope ratio change) |
| Iwamura et al [24 | 14 | D ₂ gas | Plasina | (isotope ratio change) |
| 25] | Pd | D ₂ gas | diffusion | Cs→Pr Sr→Mo |
| Gorvachev[26] | Ni | 27 MeV electron | bombard | Ni→Rh |
| 001 / 4010 / [20] | 1,1 | 2, 100, 000000 | comoura | 111 1111 |

| Di Giulio et al.[27] | Pd | PdD | laser | Ca,Fe,S,Zn,Ti,Cu,Cr |
|---------------------------------------|-------------|---------------------------------------------------|--------------|--------------------------------------|
| Arapi et al.[28] | Pd | D_2 gas | plasma | Li,Be,Fe,Ni,Cu,Ba |
| Yamada et al.[29] | Pd | D_2 gas | plasma | Fe.Cu |
| Warner and Dash[30] | Ti | $D_2O+H_2SO_4$ | electrolytic | Cr |
| Wang et al [31] | TiH | H ⁺ | bombard | He ⁴ |
| Vysotskii et al [32] | 1111 | No P | biological | Na+P→Fa |
| Passall and | | Iva, I | biblogical | Na+1 /1e |
| | ьı | | -1 | 7. |
| George[55] | Pa | D_2 or D_2O | electrolytic | Zn |
| Nassisi and | D.I. | D ID | | |
| Longo[34] | Pd | PdD | laser | Zn |
| | | | | Al,Si,Ca,Ti,Cr,Fe,Ni,Zn,Ge, |
| Mizuno et al.[35] | W | K ₂ CO ₃ +H ₂ O | plasma | Pd,Ag,In |
| Li et al.[36] | Pd | Pd+D ₂ O | | Ni |
| Iwamura et al.[37] | Pd | D_2 gas + C | diffusion | Mg,Si,S |
| Iwamura et al.[37] | Pd | $LiOD + D_2O$ | electrolytic | F, Al, Si |
| | | - | - | Si.S.Cl.K.Ca.Ti.Cr.Mn.Fe.Co. |
| Hanawa[38] | С | H ₂ O | plasma | Ni.Cu.Zn |
| Dufour et al [39] | Pd | H_2^2 gas | nlasma | Mg Zn Fe |
| | 10 | 112 Bub | plusinu | Na Mg Al P S Cl Ca Ga Fe |
| Castallano at al [40] | Dd | DAD | lacor | Ni Zn Cu Sn |
| Castenano et al.[40] | Tu | TuD | 14501 | EN-M-ALC: DCCLKC-C- |
| 0 | NT' | 1 (111 | 1 | F,Na,Mg,AI,SI,P,S,CI,K,Ca,Cr, |
| Campari et al.[41] | IN1 | heated H_2 gas | ambient | Mn,Fe,Cu,Zn |
| Bernardini et al.[42] | 11 | $K_2CO_3+D_2O$ | electrolytic | Sc (radioactive) |
| Ransford[43] | С | H_2O | plasma | Fe,Cr |
| Ohmori and | | Na_2SO_4+ | | |
| Mizuno[44] | W | H_2O | plasma | Cr,Fe,Ni,Re,Pb |
| | | | | C,O,Mg,Si,K,S,Cl,Al, |
| Focardi et al.[45] | Ni | heated H ₂ gas | ambient | Na,Fe,Cu |
| Klopfenstein and | | - 0 | | |
| Dash[46] | Ti | $D_2SO_4+D_2O$ | electrolvtic | Al.S.Ca.Fe (Ti isotope change) |
| O_{iao} et al [47, 48] | Pd | D_2 | ambient | Zn |
| Que et all 17, 10] | 10 | Na_2CO_2 or | uniorent | Hg Kr Ni Fe Si Mg (isotone |
| Ohmoi et al [40] | A 11 | $N_{2}SO_{1} \pm H_{2}O_{2}$ | electrolyte | change) |
| Ohmori and | Au | 112504 + 1120 | ciccuotyte | change) |
| Minumo[50] | W | | nlaama | Ni C Es Cr Dh (isstens shanse) |
| Mizuno[50] | w | $K_2CO_3 + H_2O$ | plasma | NI,C,Fe,CF,Pb (Isotope change) |
| Notoya et al.[51] | N1 | $K_2CO_3 + H_2O$ | electrolytic | Os,Ir,Pt,Au,K |
| | | | | AI,Au,C,Ca,Cl,Cr,Fe,K,Mg,Na, |
| Nassisi[52, 53] | Pd | H_2 , D_2 gas | XeCl laser | Nd,Ni,V,Zn,O,S, Si, delayed n |
| Jiang et al[54] | Pd | $NaOD + D_2O$ | electrolytic | Mg,Al,Si,Fe,Cu,Zn,Pt |
| Jiang et al.[55] | С | H_2O | plasma | Fe |
| Iwamura et al.[56, | | | | |
| 57] | Pd | $LiOD + D_2O$ | electrolytic | Ti,Cu,Fe (isotope change) |
| - | Ni. | $(NH_4)_2MoO_4+$ | - | |
| Nakamura et al.[58] | (C anode) | H ₂ O ⁷⁷ | plasma | radioactivity |
| | () | NasSO4 K2SO4 K2 | I | |
| | | $CO_{2} KOH_{+}$ | | |
| Ohmori et al [59] | Δ11 | H ₀ | electrolytic | Fe (isotone change) |
| Official $[57]$ | Au Dd | П ₂ О Ц | ambiant | Zn Th |
| Viao et al.[00] | Fu | Π_2 | amoient | ZII,10 |
| Kopecek and | т. | | 1 4 1 4 | OKO NO E N'Z |
| Dasn[61, 62] | 11 | $H_2SO_4 + D_2O$ | electrolytic | S,K,Ca,V,Cr,Fe,N1,Zn |
| Ohmori and Enyo | | | | - 4 |
| [63] | Au, Pd | $Na_2SO_4+H_2O$ | electrolytic | Fe (isotope change) |
| Yamada et al.[64] | Pd | D_2 gas | plasma | С |
| Karabut et al. [65] | Pd | D_2 | plasma | Na,Mg,Br,Zn,S, Mo.Si |
| | | | | Major elements: |
| | | | | Cr,Fe,Mn,Cu,Zn,Se,As,Cd, |
| Miley et al.[66-68] | Ni | Li ₂ SO ₄ +H ₂ O | electrolytic | Ag (isotope change) |
| Savvatimova and | | 2 7 2- | | |
| Karabut[69] | Pd | Ha. Da gas | plasma | As.Br.Rh.Sr.Y.Cd(isotone change) |
| Notova[70-72] | Ni | $H_0 + C_s + SO$ | electrolytic | Ra |
| 1.010ya[70-72] | 111 | solid | ciccuorytic | Pt(radioactive) Al Ca Ma Bi |
| Mizuno et el [72, 74] | Dt | alastrolyta | alastrolytic | Sm Cd Dy |
| 1 1 1 1 1 1 1 1 1 1 | Гι | electrolyte | electrolytic | SIII,OU,Dy |

| | | SrCeNbY | | |
|-----------------------|----|---------------------------------------------------|--------------|----------------------------------|
| Sundaresan and | | OXIC | | |
| Bockris[75] | С | H ₂ O | plasma | Fe |
| Singh et al. [76] | С | H ₂ O | plasma | Fe |
| 0 | | - | | Ti and Cr(isotope change), |
| | | | | Ca,Mn,Fe,Co,Cu,Zn,Cd,Sn, |
| Mizuno et al.[77, 78] | Pd | LiOH+D ₂ O | electrolytic | Pt,Pb |
| Dash et al.[79, 80] | Pd | H ₂ SO ₄ +D ₂ O | electrolytic | Ag |
| Matsunoto[81] | Pd | K ₂ CO ₃ +H ₂ O | plasma | Ni,Ca,Ti,Na,Al,Cl,Cd,I |
| Bush and | | | | |
| Eagleton[82, 83] | Ni | Rb ₂ CO ₃ +H ₂ O | electrolytic | Sr(radioactive) |
| | | | | Li,B,V,Cr,Fe,Ni,Cu,Sr,Zr,Na,Al, |
| Savvatimova et | | | | Si,Ti,Nb,Mo,Ag,In (isotope ratio |
| al.[84] | Pd | D_2 gas | plasma | change) |
| Notoya[85] | Ni | $K_2CO_3 + H_2O$ | electrolytic | K→Ca |
| | | | | Na→K, Na→Mg, K→Ca, |
| Komaki[86] | | H_2O | biological | Mg→Ca |
| Dillon and | | | | |
| Kennedy[87] | Pd | $LiOD + D_2O$ | electrolytic | Zn,Cu,Cr,Fe |
| Bush and | | | | |
| Eagleton[88, 89] | Ni | $Rb_2CO_3 + H_2O$ | electrolyte | Rd→Sr |
| Ohmori and Enyo[90] | Ni | $K_2CO_3 + H_2O$ | electrolytic | K→Ca |
| Rolison and | | $Li_2SO_4 +$ | | |
| O'Grady[91] | Pd | D_2O,H_2O | electrolytic | Rh,Ag |
| Williams et al.[92] | Pd | $LiOD + D_2O$ | electrolytic | Li,Cu,Zn,Fe,Pb,Si,Pt |
| Divisek et al.[93] | Pd | $LiOD + D_2O$ | electrolytic | Pb, Cu |
| Greber[94] | Pd | $LiOD + D_2O$ | electrolytic | Pb,Hg,Bi,Zn |
| | | | | |

The following are examples of observation of isotopic enrichment:

| Source | Method | Isotope Change | Remarks |
|------------------------|---------------------------------------------------|-----------------------------------------------------------------|-------------------|
| Donohue and Petek[95] | Electrolysis, D ₂ O | Pd | no change |
| Savvatimova et al.[69, | Plasma, Pd in D_2 | $+\mathrm{Fe}_{54}, +\mathrm{Fe}_{57}, +\mathrm{B}_{11},$ | Many elements |
| 84] | gas | $+V_{51}$, $+Cr_{53}$, $+Ni_{61}$, | produced |
| | | $+Cu_{63}, +Sr_{87}, +Zr_{90}$ | |
| Mizuno et al.[77, 78] | Plasma, Pd in D_2O | 100% Cu ₆₃ , +Fe ₅₇ , | Many elements |
| | | $-Fe_{56}$, $+Cr_{53}$, $-Cr_{52}$, | produced. |
| | | $-K_{39}$, $-Zn_{64}$, $+Ir_{91}$, | |
| | | $-Ir_{93}$, $+Re_{185}$, $-Re_{187}$ | |
| Ohmori and Enyo[59, | Electrolysis, Pd and | $+Fe_{54}$, $+Fe_{57}$ | Fe increased as |
| 63] | Au in H ₂ O | | excess energy |
| | | | increased. |
| Savvatimova et al.[96] | Plasma in Ar+Xe | $+Pd_{104}$ | Many elements |
| | gas | | produced. |
| Miley[97] | Electrolysis, Ni in | +Ag ₁₀₇ , -Ag ₁₀₉ , +Cu ₆₃ , - | Many elements |
| | H ₂ O | Cu ₆₅ | produced. |
| Iwamura et al. [98] | Electrolysis, Pd in | +Fe ₅₇ , | Pd-CaO-Pd |
| | D_2O | | cathode |
| Ohmori et al. [99] | Plasma, W in H ₂ O | +Fe ₅₆ , +Cr ₅₂ , +Pb ₂₀₆ , - | Cr and Fe found |
| | | Pb ₂₀₈ | together on the W |
| Karabut [23] | Plasma, Pd in D ₂ | +Fe ₅₇ , +Cd ₁₁₀ | Many elements |
| | gas | | produced |
| Celani et al. [17] | Electrolysis, Pd in | +Cu ₆₃ , +K ₃₉ , | Many elements |
| | D ₂ O+C ₂ H ₅ OD | | produced |
| Ohmori et al. [16] | Plasma, Re in | $+K_{41}$ | |
| | $H_2O/D_2O + K^+$ | | |
| Violante et al. [14] | Electrolysis, Ni in | +Cu ₆₅ | Laser light used |
| [100] | H ₂ O | | |
| Kim and Passell [101] | Various methods | +Li ₇ /Li ₆ | |
| Savvatimova and | Plasma, Ti in D ₂ | $+Ti_{40}$ | Many elements |

Electrolyte = solution through which current is passed to initiate a Faraday-type reaction.

Plasma = Sufficient voltage is applied to either a gas or liquid to form gaseous ions as an arc or spark.

Laser = Laser light is applied in order to stimulate nuclear reactions.

Diffusion = Deuterium or hydrogen is diffused through palladium from the gas phase.

Fuse = Metal is rapidly melted by high current while under water.

Ambient = Metal substrate is placed in the indicated gas.

Bombard = Substrate is bombarded with the indicated charged particle.

Biological = Transmutation products are made in the presence of living organisms.

+ = indicates increase in concentration: - = indicates decrease in concentration

References for Table of Appendix A

1. Wang, Q. and J. Dash. Effect of an additive on thermal output during electrolysis of heavy water with a palladium cathode. in 12th International Conference on Condensed Matter Nuclear Science. 2005. Yokohama, Japan. p. 2. Szpak, S., P.A. Mosier-Boss, and F. Gordon. Precursors and the fusion reactions in polarized Pd/D-D₂O systems: Effect of an external electric field. in 11th International Conference on Cold Fusion. 2004. Marseilles, France: World Scientific Co. p. 359. 3. Szpak, S., et al., Evidence of nuclear reactions in the Pd lattice. Naturwiss., 2005. 92: p. 394.

4. Savvatimova, I. and D.V. Gavritenkov. Results of analysis of Ti foil after glow discharge with deuterium. in 11th International Conference on Cold Fusion. 2004. Marseilles, France: World Scientific Co. p. 438.

5. Mizuno, T., et al. Generation of heat and products during plasma electrolysis. in 11th International Conference on Cold Fusion. 2004. Marseilles, France: World Scientific Co. p. 161.

6. Lochak, G. and L. Urutskoev. Low-energy nuclear reactions and the leptonic monopole. in 11th International Conference on Cold Fusion. 2004. Marseilles, France: World Scientific Co. p. 421.

7. Karabut, A. Excess heat production in Pd/D during periodic pulse discharge current in various conditions. in 11th International Conference on Cold Fusion. 2004. Marseilles, France: World Scientific Co. p. 178.

8. Karabut, A.B. Analysis of experimental results on excess heat power production, impurity nuclides yield in the cathode material and penetrating radiation in experiments with high-current glow discharge. in 8th International Conference on Cold Fusion, 2000, Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy, p. 329.

9. Focardi, S., et al. Evidence of electromagnetic radiation from Ni-H systems. in 11th International Conference on Cold Fusion. 2004. Marseilles, France: World Scientific Co. p. 70.

10. Cirillo, D. and V. Iorio. Transmutation of metal at low energy in a confined plasma in water. in 11th International Conference on Cold Fusion. 2004. Marseilles, France: World Scientific Co. p. 492.

11.Celani, F., et al. Innovative procedure for the, in situ, measurement of the resistive thermal coefficient of H(D)/Pd during electrolysis; cross-comparison of new elements detected in the Th-Hg-Pd-D(H) electroytic cells. in 11th International Conference on Cold Fusion. 2004. Marseilles, France: World Scientific Co. p. 108.

12. Campari, E.G., et al. Photon and particle emission, heat production and surface transformation in Ni-H system. in 11th International Conference on Cold Fusion. 2004. Marseilles, France: World Scientific Co. p. 405.

13. Yamada, H., et al. Analysis by time-of-flight secondary ion mass spectroscopy for nuclear products In hydrogen penetration through palladium. in Tenth International Conference on Cold Fusion. 2003. Cambridge, MA: World Scientific Publishing Co. p. 455.

14. Violante, V., et al. Analysis of Ni-hydride thin film after surface plasmons generation by laser technique. in Tenth International Conference on Cold Fusion. 2003. Cambridge, MA: World Scientific Publishing Co. p. 421.

15. Passell, T.O. Pd110/Pd108 ratios and trace element changes in particulate palladium exposed to deuterium gas. in Tenth International Conference on Cold Fusion. 2003. Cambridge, MA: World Scientific Publishing Co. p. 399. 16.Ohmori, T., et al., Enrichment of ${}^{41}K$ isotope in potassium formed on and in a rhenium electrode during plasma electrolysis in K_2CO_3/H_2O and K_2CO_3/D_2O solutions. J. Appl. Electrochem., 2003. **33**: p. 643.

17. Celani, F., et al. Thermal and isotopic anomalies when Pd cathodes are electrolyzed in electrolytes containing Th-Hg salts dissolved at micromolar concentration in C_2H_5OD/D_2O mixtures. in Tenth International Conference on Cold Fusion. 2003. Cambridge, MA: World Scientific Publishing Co. p. 379.

18. Violante, V., et al. X-ray emission during electrolysis of light water on palladium and nickel thin films. in The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science. 2002. Tsinghua Univ., Beijing, China: Tsinghua Univ. Press. p. 376.

19. Yamada, H., et al. Production of Ba and several anomalous elements in Pd under light water electrolysis. in The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science, 2002. Tsinghua Univ., Beijing, China: Tsinghua Univ. Press. p. 420.

20. Warner, J., J. Dash, and S. Frantz. *Electrolysis of* D_2O *with titanium cathodes: enhancement of excess heat and further evidence of possible transmutation.* in *The Ninth International Conference on Cold Fusion.* 2002. Beijing, China: Tsinghua University: Tsinghua University. p. 404.

21.Vysotskii, V.I., et al. Catalytic influence of caesium on the effectiveness of nuclear transmutation on intermediate and heavy mass isotopes in growing biological cultures. in The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science. 2002. Tsinghua Univ., Beijing, China: Tsinghua Univ. Press. p. 391.

22. Matsunaka, M., et al. *Studies of coherent deuteron fusion and related nuclear reactions in solid.* in *The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science.* 2002. Tsinghua Univ., Beijing, China: Tsinghua Univ., Beijing, China. p. 237.

23. Karabut, A.B. Excess heat power, nuclear products and X-ray emission in relation to the high current glow discharge experimental parameters. in The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science. 2002. Tsinghua Univ., Beijing, China: Tsinghua Univ. Press. p. 151.

24. Iwamura, Y., et al. Observation of low energy nuclear reactions induced by D_2 gas permeation through Pd complexes. in The Ninth International Conference on Cold Fusion (ICCF9). 2002. Beijing, China: Tsinghua University. p. 141.

25. Iwamura, Y., M. Sakano, and T. Itoh, *Elemental analysis of Pd complexes: effects of D₂ gas permeation*. Jpn. J. Appl. Phys. A, 2002. **41**(7): p. 4642.

26. Goryachev, I.V. Registration of synthesis of ₄₅Rh¹⁰² in media of excited nuclei of ₂₈Ni⁵⁸. in The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science. 2002. Tsinghua Univ., Beijing, China: Tsinghua Univ. Press. p. 109.

27.Di Giulio, M., et al., Analysis of nuclear transmutations observed in D- and H-loaded films. J. Hydrogen Eng., 2002. 27: p. 527.

28. Arapi, A., et al. *Experimental observation of the new elements production in the deuterated and/or hydride palladium electrodes, exposed to low energy DC glow discharge.* in *The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science.* 2002. Tsinghua Univ., Beijing, China: Tsinghua Univ. Press. p. 1.

29. Yamada, H., et al., *Producing a radioactive source in a deuterated palladium electrode under direct-current glow discharge*. Fusion Technol., 2001. **39**: p. 253.

30. Warner, J. and J. Dash. Heat produced during the electrolysis of D_2O with titanium cathodes. in 8th International Conference on Cold Fusion. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy. p. 161. 31. Wang, T., et al. Nuclear phemonena in $P+Ti_3H_3$ experiments. in 8th International Conference on Cold Fusion.

2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy. p. 317.

32. Vysotskii, V., et al. *Experimental observation and study of controlled transmutation of intermediate mass isotopes in growing biological cultures.* in 8th International Conference on Cold Fusion. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy. p. 135.

33. Passell, T.O. and R. George. *Trace elements added to palladium by exposure to gaseous deuterium*. in 8th International Conference on Cold Fusion. 2000. Lerici, Italy: Italian Physical Society, Bologna, Italy. p. 129. 34. Nassisi, V. and M.L. Longo, Experimental results of transmutation of elements observed in etched palladium samples by an excimer laser. Fusion Technol., 2000. **37**(May): p. 247.

35. Mizuno, T., et al. *Confirmation of heat generation and anomalous element caused by plasma electrolysis in the liquid.* in 8th International Conference on Cold Fusion. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy. p. 75.

36. Li, X.Z., et al. *Nuclear transmutation in Pd deuteride*. in 8th International Conference on Cold Fusion. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy. p. 123.

37. Iwamura, Y., T. Itoh, and M. Sakano. Nuclear products and their time dependence induced by continuous diffusion of deuterium through multi-layer palladium containing low work function material. in 8th International Conference on Cold Fusion. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy. p. 141.

38. Hanawa, T. X-ray spectroscropic analysis of carbon arc products in water. in 8th International Conference on Cold Fusion. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy. p. 147.

39. Dufour, J., et al. Hydrex catallyzed transmutation of uranium and palladium: experimental part. in 8th

International Conference on Cold Fusion. 2000. Lerici, Italy: Italian Physical Society, Bologna, Italy. p. 153.

40. Castellano, et al. Nuclear transmutation in deutered Pd films irradiated by an UV laser. in 8th International

Conference on Cold Fusion. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy. p. 287.

41. Campari, E.G., et al. *Ni-H systems*. in *8th International Conference on Cold Fusion*. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy. p. 69.

42. Bernardini, M., et al. Anomalous effects induced by D_2O electrolysis at titanium. in 8th International Conference on Cold Fusion. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy. p. 39.

43. Ransford, H.E., Non-Stellar nucleosynthesis: Transition metal production by DC plasma-discharge electrolysis using carbon electrodes in a non-metallic cell. Infinite Energy, 1999. 4(23): p. 16.

44. Ohmori, T. and T. Mizuno, Nuclear transmutation reaction caused by light water electrolysis on tungsten cathode under incandescent conditions. Infinite Energy, 1999. **5**(27): p. 34.

45. Focardi, S., et al. On the Ni-H system. in Asti Workshop on Anomalies in Hydrogen/Deuterium Loaded Metals. 1997. Villa Riccardi, Italy: Societa Italiana Di Fisica. p. 35.

46.Klopfenstein, M.F. and J. Dash. *Thermal imaging during electrolysis of heavy water with a Ti cathode*. in *The Seventh International Conference on Cold Fusion*. 1998. Vancouver, Canada: Vancouver, Canada. p. 98.

47. Qiao, G.S., et al. Nuclear products in a gas-loading D/Pd and H/Pd system. in The Seventh International Conference on Cold Fusion. 1998. Vancouver, Canada. p. 314.

48. Kong, L.C., et al., *Nuclear products and transmutation in a gas-loading D/Pd and H/Pd system.* J. New Energy, 1998. **3**(1): p. 20.

49. Ohmori, T., et al., Transmutation in a gold-light water electrolysis system. Fusion Technol., 1998. 33: p. 367.

50. Ohmori, T. and T. Mizuno, *Excess energy evolution and transmutation*. Infinite Energy, 1998. 4(20): p. 14.

51.Notoya, R., T. Ohnishi, and Y. Noya. *Products of nuclear processes caused by electrolysis on nickel and platinum electrodes in solutions of alkali-metallic ions.* in *The Seventh International Conference on Cold Fusion.* 1998. Vancouver, Canada: ENECO, Inc., Salt Lake City, UT. p. 269.

52.Nassisi, V., *Transmutation of elements in saturated palladium hydrides by an XeCl excimer laser*. Fusion Technol., 1998. **33**: p. 468.

53. Nassisi, V., Incandescent Pd and Anomalous Distribution of Elements in Deuterated Samples Processed by an Excimer Laser. J. New Energy, 1997. 2(3/4): p. 14.

54.Jiang, X.-L., et al. *Tip effect and nuclear-active sites*. in *The Seventh International Conference on Cold Fusion*. 1998. Vancouver, Canada: ENECO, Inc., Salt Lake City, UT. p. 175.

55. Jiang, X.L., L.J. Han, and W. Kang. *Anomalous element production induced by carbon arcing under water*. in *The Seventh International Conference on Cold Fusion*. 1998. Vancouver, Canada: ENECO, Inc., UT, USA. p. 172.

56. Iwamura, Y., et al., Detection of anomalous elements, X-ray and excess heat induced by continuous diffusion of deuterium through multi-layer cathode (Pd/CaO/Pd). Infinite Energy, 1998. 4(20): p. 56.

57. Iwamura, Y., et al., Detection of anomalous elements, X-ray, and excess heat in a D_2 -Pd system and its

interpretation by the electron-induced nuclear reaction model. Fusion Technol., 1998. 33: p. 476.

58. Nakamura, K., Y. Kishimoto, and I. Ogura, *Element conversion by arcing in aqueous solution*. J. New Energy, 1997. **2**(2): p. 53.

59. Ohmori, T., et al., *Transmutation in the electrolysis of light water - excess energy and iron production in a gold electrode.* Fusion Technol., 1997. **31**: p. 210.

60. Qiao, G.S., et al., Nuclear transmutation in a gas-loading system. J. New Energy, 1997. 2(2): p. 48.

61. Kopecek, R. and J. Dash, *Excess heat and unexpected elements from electrolysis of heavy water with titanium cathodes*. J. New Energy, 1996. **1**(3): p. 46.

62. Dash, J., R. Kopecek, and S. Miguet. *Excess heat and unexpected elements from aqueous electrolysis with titanium and palladium cathodes*. in 32nd Intersociety Energy Conversion Engineering Conference. 1997. p. 1350-1355.

63. Ohmori, T. and M. Enyo, Iron formation in gold and palladium cathodes. J. New Energy, 1996. 1(1): p. 15.

64. Yamada, H., et al., Carbon production on palladium point electrode with neutron burst under DC glow discharge in pressurized deuterium gas. J. New Energy, 1996. 1(4): p. 55.

65. Karabut, A., Y. Kucherov, and I. Savvatimova, *Possible nuclear reactions mechanisms at glow discharge in deuterium.* J. New Energy, 1996. 1(1): p. 20.

66. Miley, G.H., et al. *Quantitative observations of transmutation products occuring in thin-film coated microspheres during electrolysis.* in *Sixth International Conference on Cold Fusion, Progress in New Hydrogen Energy.* 1996. Lake Toya, Hokkaido, Japan: New Energy and Industrial Technology Development Organization, Tokyo Institute of Technology, Tokyo, Japan. p. 629.

67. Miley, G.H. and J.A. Patterson, *Nuclear transmutations in thin-film nickel coatings undergoing electrolysis.* J. New Energy, 1996. **1**(3): p. 5.

68. Miley, G.H., *Possible evidence of anomalous energy effects in H/D-loaded solids-low energy nuclear reactions (LENRS)*. J. New Energy, 1997. **2**(3/4): p. 6.

69. Savvatimova, I. and A. Karabut. *Nuclear reaction products registration on the cathode after glow discharge.* in 5th *International Conference on Cold Fusion*. 1995. Monte-Carlo, Monaco: IMRA Europe, Sophia Antipolis Cedex, France. p. 213.

70. Notoya, R. Nuclear products of cold Fusion caused by electrolysis in alkali metallic ions solutions. in 5th International Conference on Cold Fusion. 1995. Monte-Carlo, Monaco: IMRA Europe, Sophia Antipolis Cedex, France. p. 531.

71. Notoya, R., *Low temperature nuclear change of alkali metallic ions caused by electrolysis.* JNE, 1996. 1: p. 39. 72. Notoya, R., *Low temperature nuclear change of alkali metallic ions caused by electrolysis.* J. New Energy, 1996. 1(1): p. 39.

73. Mizuno, T., et al., Formation of ¹⁹⁷Pt radioisotopes in solid state electrolyte treated by high temperature electrolysis in D_2 gas. Infinite Energy, 1995. **1**(4): p. 9.

74. Mizuno, T., et al., *Excess heat evolution and analysis of elements for solid state electrolyte in deuterium atmosphere during applied electric field.* J. New Energy, 1996. **1**(1): p. 79.

75. Sundaresan, R. and J.O.M. Bockris, *Anomalous reactions during arcing between carbon rods in water*. Fusion Technol., 1994. **26**: p. 261.

76. Singh, M., et al., *Verification of the George Oshawa experiment for anomalous production of iron from carbon arc in water*. Fusion Technol., 1994. **26**: p. 266.

77. Mizuno, T., T. Ohmori, and M. Enyo, *Anomalous isotopic distribution in palladium cathode after electrolysis.* J. New Energy, 1996. **1**(2): p. 37.

78. Mizuno, T., T. Ohmori, and M. Enyo, *Isotopic changes of the reaction products induced by cathodic electrolysis in Pd. J.* New Energy, 1996. **1**(3): p. 31.

79. Dash, J. and S. Miguet, *Microanalysis of Pd cathodes after electrolysis in aqueous acids*. J. New Energy, 1996. **1**(1): p. 23.

80. Miguet, S. and J. Dash, Microanalysis of palladium after electrolysis in heavy water. JNE, 1996. 1(1): p. 23.

81. Matsumoto, T., Experiments of underwater spark discharge with pinched electrodes. JNE, 1996. 1(4): p. 79.

82. Bush, R.T. and R.D. Eagleton, Evidence for electrolytically induced transmutation and radioactivity correlated

with excess heat in electrolytic cells with light water rubidium salt electrolytes. Fusion Technol., 1994. 26(4T): p. 344.

83. Bush, R.T., *Electrolytic stimulated cold nuclear synthesis of strontium from rubidium*. JNE, 1996. **1**: p. 28. 84. Savvatimova, I., Y. Kucherov, and A. Karabut, *Cathode material change after deuterium glow discharge*

experiments. Trans. Fusion Technol., 1994. 26(4T): p. 389.

85. Notoya, R., *Cold fusion by electrolysis in a light water-potassium carbonate solution with a nickel electrode.* Fusion Technol., 1993. **24**: p. 202.

86. Komaki, H. An Approach to the Probable Mechanism of the Non-Radioactive Biological Cold Fusion or So-Called Kervran Effect (Part 2). in Fourth International Conference on Cold Fusion. 1993. Lahaina, Maui: Electric Power Research Institute 3412 Hillview Ave., Palo Alto, CA 94304. p. 44.

87. Dillon, C.T. and B.J. Kennedy, *The electrochemically formed palladium-deuterium system. I. Surface composition and morphology.* Aust. J. Chem., 1993. **46**: p. 663.

 Bush, R.T. and R.D. Eagleton. Experimental studies supporting the transmission resonance model for cold fusion in light water: I. Correlation of isotopic and elemental evidence with excess energy. in Third International Conference on Cold Fusion, "Frontiers of Cold Fusion". 1992. Nagoya Japan: Universal Academy Press, Inc., Tokyo, Japan. p. 405.
 Bush, R.T., Electrolytically simulated cold nuclear synthesis of strontium from rubidium. J. New Energy, 1996. 1(1): p. 28.

90. Ohmori, T. and M. Enyo. Excess heat production during electrolysis of H₂O on Ni, Au, Ag and Sn electrodes in alkaline media. in Third International Conference on Cold Fusion, "Frontiers of Cold Fusion". 1992. Nagoya Japan: Universal Academy Press, Inc., Tokyo, Japan. p. 427.

91. Rolison, D.R. and W.E. O'Grady, *Observation of elemental anomalies at the surface of palladium after electrochemical loading of deuterium or hydrogen*. Anal. Chem., 1991. **63**: p. 1697.

92. Williams, D.E.G., et al., *Upper bounds on 'cold fusion' in electrolytic cells*. Nature (London), 1989. **342**: p. 375. 93. Divisek, J., L. Fuerst, and J. Balej, *Energy balance of* D_2O *electrolysis with a palladium cathode. Part II. Experimental results*. J. Electroanal. Chem., 1989. **278**: p. 99.

94. Greber, T., et al. Cold fusion experiments in Fribourg. in Understanding Cold Fusion Phenomena. 1989. p. 95. Donohue, D.L. and M. Petek, Isotopic measurements of palladium metal containing protium and deuterium by glow discharge mass spectrometry. Anal. Chem., 1991. **63**: p. 740.

96. Savvatimova, I.B., A.D. Senchukova, and I.P. Chernov. *Transmutation phenomena in a palladium cathode after ions irradiation at glow discharge*. in *The Sixth International Conference on Cold Fusion*. 1996. Lake Toya, Japan: The Institute of Applied Energy. p. 575.

97. Miley, G. Characteristics of reaction product patterns in thin metallic films experiments. in Asti Workshop on Anomalies in Hydrogen/Deuterium Loaded Metals. 1997. Villa Riccardi, Rocca d'Arazzo, Italy: It. Phys. Soc. p. 77. 98. Iwamura, Y., et al. Detection of anomalous elements, X-ray and excess heat induced by continous diffusion of deuterium through multi-layer cathode (Pd/CaO/Pd). in The Seventh International Conference on Cold Fusion. 1998. Vancouver, Canada: ENECO, Inc., Salt Lake City, UT. p. 167.

99. Ohmori, T. and T. Mizuno. *Strong excess energy evolution, new element production, and electromagnetic wave and/or neutron emission in the light water electrolysis with a tungsten cathode.* in *The Seventh International Conference on Cold Fusion.* 1998. Vancouver, Canada: ENECO, Inc., Salt Lake City, UT. p. 279.

100. Violante, V., et al. Search for nuclear ashes In electrochemical experiments. in Tenth International Conference on Cold Fusion. 2003. Cambridge, MA: World Scientific Publishing Co. p. 405.

101. Kim, Y.E. and T.O. Passell. Alternative interpretations of low-energy nuclear reaction processes with deuterated metals based on the Bose-Einstein condensation mechanism. in 11th International Conference on Cold Fusion. 2004. Marseilles, France: World Scientific Co. p. 718.