

## Chapter 13

# Radiochemical Comparisons on Low Energy Nuclear Reactions and Uranium

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The discovery of nuclear fission by Otto Hahn and Friedrich Strassmann was based on a very rare microanalytical result that provided the first realization that neutrons could fission uranium. However, this was only the beginning of many discoveries about this complex process. An analogy related to the discovery of low energy nuclear reactions (LENRs) is noted here. It is remarkable that the reaction product distribution measured in LENR experiments using thin-film palladium/nickel electrodes heavily loaded with either hydrogen or deuterium has a strong similarity to the element distribution from uranium fission. Thus, the LENR reaction process is hypothesized to pass through a heavy complex nucleus similar to the fission process in uranium. Further, a detailed structure is observed in the LENR distribution corresponding to the Maruhn-Greiner local maximum of the distribution within the large-scale minimum of the fission product distribution curve. This observation leads to the proposed explanation that the fissioning compound nucleus in the LENR case is element  $^{306}\text{X}_{126}$  with double magic numbers. A major difference, however, is that in uranium fission the compound nucleus arises after single-neutron absorption, whereas in LENR a multi-body process is needed to create the heavy complex nucleus. Indeed, subsequent analysis of the various observations associated with these LENR experiments

suggests that the multi-body reaction involved follows from the formation of Bose-Einstein condensed clusters formed in dislocation void regions in the electrode. Consequences and proposed future studies based on this cluster conjecture are discussed.

## Introduction

Large numbers of indications have been reported from laboratories worldwide supporting the claim of nuclear reactions occurring at low temperatures in solids loaded with a very high concentration of hydrogen isotopes (1). Most early observations attributed this to D-D cold fusion reactions. However, some years after the original cold fusion announcement, a startling but reproducible result indicated that another type of reaction can occur: transmutation reactions involving the loaded deuterium (or in some cases hydrogen) and the electrode metal atoms themselves (2,3). Here, we concentrate on a specific class of that type of reaction where a large array of transmutation products appears, suggesting that a fission-like process is involved (2, 3). Such reactions involving transmutation have been termed low energy nuclear reactions (LENRs). Note, however, that this term includes direct reactions involving transmutations to single isolated products as well as the product array reactions discussed here.

The product array experiments exhibit a number of important characteristics that will be discussed here. For example, the array of products generally has a distribution of heavy nuclei vs. proton number  $Z$  which has maxima that correlate with a Boltzmann distribution (4). As discussed later in detail, analysis of this distribution allowed a derivation of the magic numbers of the nuclei involved (5) that shows a threefold multiplication of the shell structure, consistent with a quark property within the nuclei (4,5).

Another distinctive feature found in this product array is the observation of a local maximum in the large-scale minimum of the element distribution (4,5) near the nucleon number  $A = 153$ . This unique feature is similar to the distribution of the fission products of uranium around  $A = 119$ . In uranium, this important detailed structure is attributed to the Maruhn-Greiner process where the intermediate compound (or complex) nucleus in the fission process is excited to energies in the MeV range. Thus, it has been postulated that an excitation of the intermediate compound nucleus may occur in the LENR array experiment where a fission reaction via an excited nucleus with  $A = 306$  appears to be involved (4, 6). However, in this case, as stressed later by Akita Takahashi (7), the excitation energy of the intermediate compound nucleus in LENR is much less than in uranium fission. The reason is that the multi-body formation of the compound nucleus builds up less internal energy than the neutron absorption reaction in uranium. This leads to a "soft" fission in LENR, explaining the very low level of emission of energetic radiations such as gamma rays (vs. low energy beta and x-rays) during the process.

We recall next that the uniqueness of the chemical analysis of extremely low quantities of barium (8) was the observation that led to the discovery of fission. The first view was that the uranium fission process simply generated nuclei of medium atomic weight. With time, it was eventually realized that the detailed process is much more complicated, often including radioisotopes that decay with beta emission. This is the basis for proposing that the LENR process is similarly a process in combination with beta decays or, as initially explained, a deuterium cluster reaction process (4) with a reaction branch yielding  $^3\text{He}$ . We discuss these various reaction processes in more detail next.

## The Hahn-Strassmann Discovery of Nuclear Fission

It is remarkable that the discovery of nuclear fission was based only on the chemical detection of small quantities of alkaline earth elements, especially barium. The uranium sample before neutron bombardment had a concentration of barium far below the minimum detection limit. However, a clearly detectable barium concentration was observed after the neutron bombardment. It is understandable that, only weeks before the Hahn-Strassmann publication (8), the radiation physicist Lise Meitner (9) could not believe the data showing traces of barium. She requested a repeat of all experiments before drawing a conclusion that nuclear fission must have occurred.

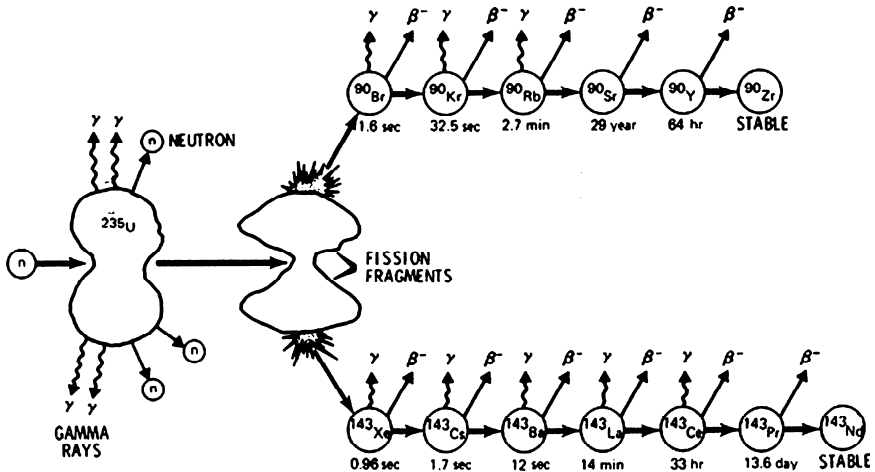
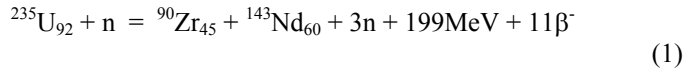


Figure 1. Reaction of a neutron with  $^{235}\text{U}$  leading to a branch with 11 beta decays until stable nuclei are produced (8).

The very complicated details about what was happening in the uranium fission process were only explained later, leading to recognition that the neutron reaction with  $^{235}\text{U}$  leads to neutron multiplication and the possibility of achieving a critical mass fission assembly. One of the numerous explanations offered for these reactions is shown in Fig. 1, where eleven additional beta decays (10) are required to arrive at the reaction:



In this reaction branch, the only alkaline earth elements products are radioactive,  ${}^{143}\text{Ba}$  (12s) and  ${}^{90}\text{Sr}$  (29y), which can be sufficient for detection immediately after completion of the experiment. In other branches, longer lifetime barium appears, but it too undergoes radioactive beta decay. If Hahn and Strassmann (8) had waited to check their samples much later after the experiment, the barium would have dropped below detection limits, and they would not have discovered fission. At that time, this could not have been understood without knowing the very complicated reaction branches, such as those given in Fig. 1. Thus, all kinds of suspicions might have arisen about the initial experiments with the barium detection.

With so many possible problems with the measurements, it was not surprising that Emilio Segre stated later that the way fission was discovered is really a miracle. The only method of detection was based on the tedious measurement of barium, not any other elements. But still, this turned out to be sufficient to conclude that the uranium nuclei were split into two fragments, i.e. reaction products. This history appears relevant now in the sense that early workers doing LENR array transmutation studies were also faced with experiments fraught with possible errors and giving a maze of complicated reaction product data. Now, very distinctive features, some coming from analogy with uranium fission, have been recognized, and the mystery of this reaction mechanism is being unraveled.

## Uranium Fission and the LENR Transmutation Array

The distribution of the nuclei after fission of uranium or plutonium shows a minimum at the half-nucleon mass  $A$  of the initial nuclei, i.e. at a nuclear mass of 119, see Fig. 2 (11). This distribution with the absolute minimum, however, refers to fissioning nuclei having very low excitation energy. If the fissioning nuclei are excited to a higher energy in the MeV range, a local maximum appears within the absolute minimum of the fission products. An analysis based on a liquid drop model of the nucleus reproduces this local maximum with the physics added by Joachim Maruhn and Walter Greiner (12). Their calculations are based on collective mass parameters from the BSC formulation, where the key parameter  $\lambda$  is the scale length in the Schrödinger equation for the splitting of heavy nuclei. This follows the models of nuclear molecules (13) but uses an adjustment fit according to the theory of fragmentation dynamics in nucleus-nucleus collisions (12).

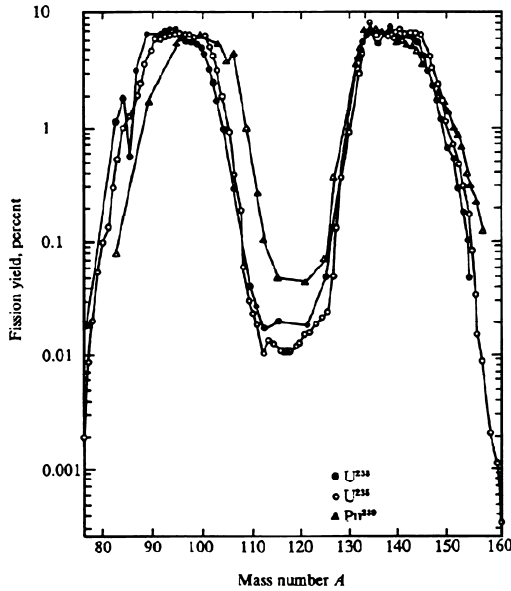


Figure 2. Fission mass distribution curves as measured for  $^{233}\text{U}$ ,  $^{235}\text{U}$  and  $^{239}\text{Pu}$ , from (11).

Fig. 3 shows the resulting fission mass distribution for  $^{236}\text{U}$  for the elongation  $\lambda = 1.8$  at different excitation temperatures of the splitting nucleus. As seen, the initial absolute minimum near  $A = 119$  contains a distinctive local maximum if the nucleus is excited to 1 - 7 MeV before fission.

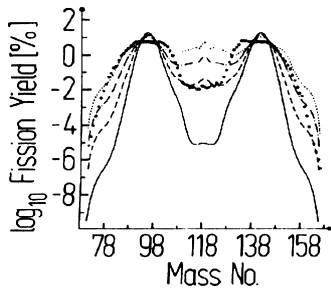


Figure 3. Fission mass distribution curves for  $^{236}\text{U}$  calculated if the nucleus at the time of fission is excited to a temperature 0, 0.5, 1.0, and 7.0 MeV (upward sequence of plots) for the length parameter  $\lambda=1.8$  in the Schrödinger equation (12).

As discussed later, this feature has also been observed in the LENR distribution and thus provides an additional very important point of agreement between LENR and uranium fission.

The LENR product distribution shows other important features that suggest the basic nuclear physics involved. Figure 4 shows the generation of nuclei after several weeks' reaction period (2) in multi-layer, thin-film palladium highly loaded with hydrogen.

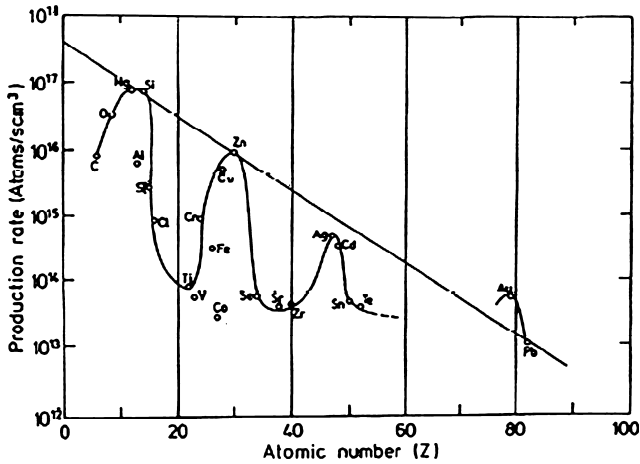


Figure 4. Measured production rates for reaction products from thin film LENR experiments vs. proton number (2,3). The solid line represents a Boltzmann distribution, Eq. (2).

The line drawn in the figure follows a Boltzmann distribution of the measured maxima (14). This gives the relation:

$$N(Z) = N' \exp(-Z/Z') \quad (2)$$

where  $Z'$  is found to be 10. Other numbers for  $Z'$  (e.g. 9 or 11) do not fit. This is especially important in that it provides a unique evaluation of magic numbers. This same distribution, cf. Eq. 2, can be seen in the standard abundance distribution (SAD) of the elements in the Universe (13) for elements above iron, as seen from Fig. 10 of Ref. 15.

Returning to the Maruhn-Greiner effect, we now focus on detailed measurements of the minimum in Fig. 4 for  $Z$  between about 50 and 80 shown in Fig. 5 (16).

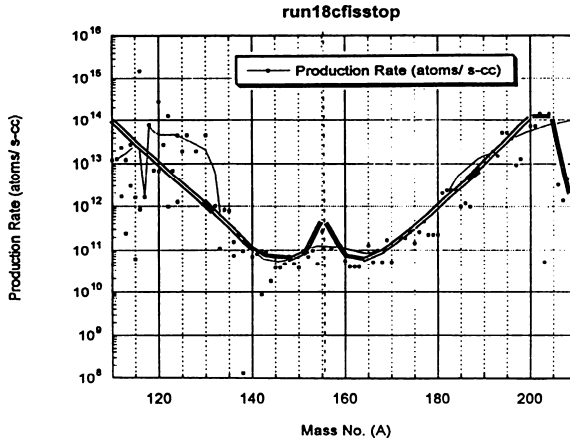


Figure 5. Detailed nuclear mass spectrum of the LENR reaction products generation probability at the highest- $Z$  minimum of Fig. 4.

It is most significant that the minimum near  $A = 155$  is amazingly similar to the uranium fission of Fig. 2. The distribution clearly shows an additional local maximum which appears to represent a Maruhn-Greiner local maximum (cf. Fig. 3). This strongly suggests that this LENR data results from a fission process from an excited short-lived compound nucleus corresponding to  $A = 306$ . Although this state is excited, the soft-fission aspect noted earlier suggests the excitation energy is much less than that of the uranium in Fig. 2.

### Magic Numbers From LENR Data

From evaluation of Eq. 2 based on the LENR measurements and from the SAD measurements in the Universe, the following **bold** magic numbers can be identified (14):

$$M_{an} \in \mathbf{2, 8, 20, 40, 70, 112}, \quad (3)$$

$$M_{bn} \in \mathbf{2, 6, 14, 28, 50, 82, 126}, \quad (4)$$

Erich Bagge (17, 18) originally derived the sequences 3 and 4 from numerical speculations needed to achieve agreement with various nuclear measurements. But he could not explain the jump from one sequence to the other. We outline here the numerological procedure of Bagge (17, 18) as used before (14) to interpret magic numbers in terms of the maxima that occurs within the broad minimum of the distribution of the LENR products.

First, we consider the number sequences:

2 3 4 5 6 7 8.....being the difference to:

1 3 6 10 15 21 28.....again after the difference:

1 4 10 20 35 56 84.....times two arrives at the final series:

$$2 \quad 8 \quad 20 \quad 40 \quad 70 \quad 112. \quad (3')$$

Next, using the same procedure, we obtain the following sequence:

1 2 3 4 5 6 7.....

1 2 4 7 11 16 22.....

1 3 7 14 25 41 63.....

$$2 \quad 6 \quad 14 \quad 28 \quad 50 \quad 82 \quad 126. \quad (4')$$

The resulting sequences (3') and (4') here correspond directly to the prior (3) and (4). Thus, this procedure, based on the observed LENR Boltzmann distribution, Eq. 2, can be used to directly explain the jump in the sequence that so concerned Bragge. Previously, to explain this jump, J. Hans Jensen and Maria Goepfert-Mayer had to involve the change from spin to spin-orbit properties within the nuclei (see ref. 18).

A further consequence of the LENR-SAD evaluation (14) leads to the ratios  $R(n)$  ( $n = 1, 2, 3, \dots$ ) of the Boltzmann probabilities, Eq. 2, namely

$$R(n) = 3^n. \quad (5)$$

This suggests a threefold property of stable configurations at magic numbers in nuclei, consistent with a quark property. Based on sequence (4), the previously uncertain magic number 126 was included along with new magic numbers 180, 246 and 324. However, this result was viewed as quite uncertain. Thus, the intermediate, very short-lived compound nucleus  $^{306}\text{X}$  identified in the LENR transmutation experiments becomes extremely significant for having the magic numbers of 126 protons and 180 neutrons, fitting well this proposed sequence. This is analogous to the double magic numbers 82 and 126 in the very stable nucleus  $^{208}\text{Pb}$ .

This identification of the sequence of (4) and the conjecture of the magic number 126 illustrate how LENR research has unexpectedly led to important new basic nuclear physics data. As more LENR data is obtained, further insights into nuclear structure should emerge.

## LENR Transmutation Experiment Issues

Not all workers in cold fusion accepted the observation of the "miracle" of the broad array of transmutation products when it was first presented in ICCF meetings and published in Refs. 2 and 3. They had anticipated a conventional cold fusion  $\text{D} + \text{D} \rightarrow {}^4\text{He}$  reaction of the Pons-Fleishmann type. However, almost from the beginning, cold fusion critics had disputed the possibility of this

reaction because of the need for anomalous tunneling through the Coulomb barrier, plus its deviation from the traditional D-D reaction channels and the need for a massive collective mechanism to quickly transfer the energy of the excited reaction products to the lattice. Possible answers to these issues were just beginning to emerge when this new claim came forth implying that reactions involving the very high Z metal atoms in the lattice and D (or, in some cases, H) could occur under appropriate conditions. The immediate reaction by many in and out of the cold fusion field was simply to pass this claim off as experimental error. The easy accusation was that impurities in the cell were being confused with the reaction products. Impurities are, of course, an obvious potential pitfall in such experiments where, like the early barium detection studies of uranium fission, reaction product levels approach impurity limits. However, the experimentalists doing this work were well-aware of that issue and had taken extreme precautions to minimize impurity levels. The electrolytic cell and support system (pump, piping, etc.) was designed with high-purity plastics and glass to eliminate corrosion products from metal parts. Two exceptions were the metallic electrodes, which used high-purity metals, and the electrolytic salts. Still, despite such precautions, there will always be some level of various impurity elements in the apparatus components and electrolytic solution. Thus, great attention was devoted to precision measurements of key impurities in these materials in order to clearly define background limits. Ultimately, all components were analyzed using neutron activation analysis (NAA) for nine key elements (having the highest concentration and offering reasonably high neutron cross sections) identified in the reaction products. NAA provides a volumetric identification of elements as opposed to other probe analysis which interrogates local volumes. This provided a very accurate measure of background impurities of the elements that were of paramount interest as potential reaction products. And, as it turned out, many elements observed were well above the maximum background limits. This precision background purity measurement allowed a definitive identification of these transmutation products. To study other elements not amenable to NAA, a novel method, "combined NAA/SIMS," was developed for a quantitative measure of the full reaction product array. This technique has been documented in detail in a publication in the *Journal of Radioanalytical and Nuclear Chemistry* – see Ref. 19. In this procedure, the nine key elements that were amenable to NAA were analyzed, using a NIST calibration to obtain absolute weights. NAA provides a positive identification of elements, avoiding the possible molecular species error that can plague SIMS (also avoiding the difficulty of obtaining overall mass yields with SIMS because of the localized characteristic of the probe beam involved). On the other hand, SIMS can identify many more elements than NAA because a usable neutron reaction cross section is not needed. Thus, the SIMS measurements were used to fill in missing elements. Consequently, that data (which included SIMS identification of the nine NAA elements) was normalized to the key NAA element measurements. This procedure then allowed assignments of approximate mass yields to the non-NAA elements observed with SIMS. The SIMS element data then had much more uncertainty associated with it than the NAA measured elements, but it still provided a reasonably accurate estimate of the full spectrum of reaction products. An independent check of these results was done at the Illinois State

Water Survey Laboratory with Inductively Coupled-Plasma Mass Spectrometry (IC-PMS) for one sample, and reasonable agreement was found.

Additional data that supports the identification of transmutation elements vs. natural-element impurities was the measurement of isotope ratios of key product elements. These ratios showed deviations from natural isotope ratios in key cases. The most accurate isotope ratio measurements used NAA on Cu and on Ag, where a definitive deviation from the natural element ratios was found. Other ratios relied on SIMS measurement.

Other supporting evidence includes subsequent measurements for electrodes using metals other than Pd, e.g. Ni and Ti (20). These showed a pattern similar to the Pd case but, as anticipated, some systematic differences occurred because of mass differences. In addition, product density profiles were measured using SIMS across the thickness of the thin-film electrodes. As anticipated for products created internally (vs. external impurities), peaks were found near the multi-layer interfaces. In several cases, electrodes removed from the cell after operation were placed on photographic film, and the long time exposure (several days) showed a distinct pattern over the electrode area, attributed to beta emission or possibly soft x-rays (2).

Another important issue that was investigated is whether the energy balance for the reaction giving these products is consistent with excess heat observed in these experiments (21). The mass yield of the reaction product array was used to calculate the mass defect between the products and the reacting Pd and D (or H). This then was used to calculate energy release rates which compared favorably with the excess heat observed in these experiments (22). Although the uncertainty limits in these calculations were large, the rough agreement with excess-heat measurements provides added confidence in the experimental observations.

Finally, it was emphasized in the original paper disclosing this data that others (T. Mizuno, and John Bockris, sees Refs. 2, 3) had previously measured product arrays with somewhat similar product array patterns. However, their analysis had not provided absolute mass yield data like the new results, nor did they have much of the added supporting data noted above.

As time has gone on, many other amazing transmutation experiments have been done with LENRs, but most have focused on specific transmutations giving isolated products rather than a broad array. A review of all results up to a few years ago is presented in Ref. 23.

In view of this overwhelming data, many former skeptics (but not all) now accept transmutations in LENR. But, of course, the accuracy and details of given reactions can always be debated. The point is that this battle to gain respectability for transmutations has been in many ways analogous to the early days, when the fission of uranium was first reported. In retrospect, it can be realized how difficult it was for chemists like Otto Hahn et al. (8) to convince physicists such as Lise Meitner that fission could occur. In the case of uranium fission, however, the massive inflow of money and scientists during the Manhattan Project moved the uranium fission field ahead much more rapidly than has happened in the underfunded, undermanned field of transmutations in LENR. Also, the early bitter controversy after the original much-publicized announcement of cold fusion resulted in many unethical behaviors by scientists

(both proponents and critics) that hurt progress in the field in general, e.g. see Ref. 24 and related papers in that journal.

It is interesting to note that even hot-fusion research encountered a similar unexpected anomaly. It was initially thought that, to overcome the Coulomb repulsion, it was necessary for nuclear reactions to use energies much higher than MeV per nucleon. But it was discovered by James Cockroft and Ernest Walton (25) that 150 keV protons could disintegrate boron nuclei and, finally, that deuteron interaction energies of less than 10 keV led to the fusion reactions (26). These nuclear reactions of nearly 1,000 times lower energies than expected were indeed an extreme anomaly, and perhaps because of this, not much attention was given to these results discovered in routine studies at the then Mecca of nuclear research, the Cavendish Laboratory. At the time, there was no physics theory to understand this anomaly, and this added to the temptation to ignore the data. Gradually, various fits with numerous parameters were employed to describe the measured cross sections, see e.g. (27). Later, tunneling theory was applied, and as late as 2000, a theory using Schrödinger potentials with imaginary parts led to improved basic understanding (28).

As an aside, it is interesting that there appears to be another tie between fission and LENR history. It has been pointed out by M. Shaheen, et al. (29) that data from samples take at the famous Oklo natural fission reactor in Africa indicate that some simultaneous LENR reactions may have occurred. If this hypothesis can be confirmed, the frequently asked questions about where cold fusion occurs in nature would be answered.

## **Bose-Einstein Deuteron Clusters**

Thus far, we have stressed the amazing resemblance between measurements of the LENR product distribution on the proton number  $Z$  (or the nucleon number  $A$ ) and the corresponding product distribution from the fission of uranium. An additional consistent pattern in the LENR data is that it follows the Boltzmann distribution with  $Z_0 = 10$  as noted earlier in Eq. 2, leading to the derivation of the magic numbers and the quark-like 3<sup>rd</sup> law for the probability ratios for magic numbers.

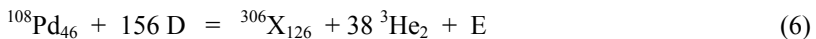
We now turn to consider the obvious question of how the multi-body reactions needed to form the compound fissioning nucleus can occur in a low-temperature solid. Based on the early measurements of Prelas et al. (30), it was concluded earlier (31) that the deuterons absorbed in the palladium have a Coulomb screening factor of 14 compared with a factor of 5 for screening in high-temperature plasmas. Also, by comparing with the very anomalous long-distance reactions for hot fusion and with the short distances for muionic fusion, it can be concluded that the reactions in palladium occur at distances of 2 to 3 pm with a reaction time in the range of Ms (megaseconds). Similar distances and times are also known from the K-shell electron-capture radioactivity. Thus, the estimates appear not necessarily unreasonable.

As transmutation array data accumulated and associated features of the experiments (localized volumes with large concentrations, spotty exposure patterns seen on x-ray film exposures, etc.) were found, workers began to

associate the reactions with localized regions where condensed matter states (termed “clusters”) of D (or H) were postulated to have formed (32-34). In his book, Ed Storms (35) calls such sites “nuclear-reactive,” but at that time, he did not have sufficient data to identify their structure or how to purposely create them.

The cluster conjecture eventually led to a series of SQUID-type electromagnetic measurements at the University of Illinois that indicated such clusters formed a type II superconducting state (36). The hypothesis then is that this superconducting cluster state represents the nuclear-reactive site such as envisioned by Storms (35). However, the volume associated with these clusters is only a small fraction of the total electrode volume, so recent work has focused on developing ways to nano-manufacture electrode structures that lead to a larger volume density of cluster regions in the electrodes (33, 34). If the cluster volumetric density can be increased, a significant increase in the overall reaction rate in the electrode should be possible. Thus, this insight into the existence of cluster states provides a road map for developing a high-performance LENR cell (34).

The mechanism for forming the cluster and its subsequent reaction is under study. The deuterons can be viewed as moving as electric neutral particles like a Maxwellian plasma within the palladium. If their interaction distance is less than 2 pm, this solid-state plasma is reactive. It is calculated (4) that the 2 pm distance between the electrically neutral deuterons arrives at gravitational attraction or Casimir attraction in the range of an energy density of 0.1 eV/cm<sup>3</sup>. This attractive force is competitive against thermal motion. If clusters of about 150 neutral deuterons are produced, their diameter is in the range of 10 pm. Because the DeBroglie wave length of each deuteron at room temperature is in the >10 pm range, the cluster can assume a Bose-Einstein quantum state with non-distinguishable deuterons. (Recently, Yeong Kim (37) also proposed the formation of Bose-Einstein states in LENR electrons). This state is thought to correspond to the superconductivity regions measured by SQUID, as previously noted. During a time of less than 1 Ms, such a cluster can move within 2 pm distance to a palladium nucleus. Then, for example, the following illustrative reaction may occur:



expressing the mass per nucleon  $m_X$  by proton masses in X to arrive at

$$m_X = 1.004946 \text{ minus the relative part of E.} \quad (7)$$

This mass is not necessary excessive, as seen by comparing the very low value  $m_{\text{Fe}}=0.9988376$  with the value of  $m_{\text{U}} = 1.0001868$  when splitting into  $^{121}\text{Sb}$  with  $m_{\text{Sb}} = 0.99824$ . A comparable value can be seen from the splitting of the compound nucleus X of Eq. 6 into  $^{153}\text{Eu}$ . This gives  $m_{\text{Eu}} 0.9988375$ . Based on the energy per nucleon in  $^{306}\text{X}_{126}$  of 5.73 MeV minus the contribution going into the reaction energy E. Based on these analogies, the energies involved in the LENR process appear to be reasonable in magnitude for such a compound nuclear reaction process (6). If the lifetime of the double magic number

intermediary compound nucleus  $^{306}\text{X}_{126}$  is in the range of seconds, it should be detectable from very energetic K-shell x-ray emission. Indeed, that could explain the x-ray film exposure observed following long-run, thin-film electrode experiments noted earlier. There are also other possibilities, including reactions that are similar to Eq. 6 but which involve multi Pd nuclei. Indeed, some of the earlier experiments that used light water (i.e. H clusters) were postulated to involve a variety of multi-body reactions between H and Pd (2, 3, 38, 39).

Another observation from the experiments (2) should be noted in view of the speculations about a compact nucleus X generation. The postulate of fissioning through an excited state that produces the local maximum at the broad minimum of Fig. 5 via Eq. 6 suggests that  $^3\text{He}$  should be detected in these experiments. Prior studies did not attempt its detection. Thus, future work might focus on that issue. Another future direction is to further investigate whether the fission into the elements around  $A = 153$  proceeds by a similar process.

Because the clusters have an enormous specific weight from their very high density, other measurements to directly confirm them might be pursued. One possibility is to check whether the reaction is favored by surface plasmas, because the clusters would be drawn down by gravitation.

Some added comments should be included here about the previously derived (5, 14) magic number 180 from the  $3^n$ -law, Eq. 5. The theory of confining the nucleons in a nucleus by a Debye layer mechanism and the identification of a quark structure for preferred shells because of the  $3^n$ -law was evaluated in detail for the first time by Nader Ghahramany et al. (40, 41). Using this data, they observed the details of the predicted quark-gluon statistics with a very convincing result. However, they arrived at a magic number 184 instead of 180. However, Fig. 5 indicates that the local maximum for the LENR-generated elements is not at 153 (which would indicate a compound nucleus  $^{306}\text{X}_{126}$ ); instead, the peak appears to be clearly at 155. This indicates very convincingly that the compound nucleus  $^{310}\text{Y}_{126}$  (not X) is involved, indicating the magic number for the neutrons of 184 in the Y-nucleus. Thus, because of the very accurate measurement of Fig. 5, there is strong proof of the Debye layer model for nuclei (31, 36,40). This LENR data mutually confirms the compound nuclear assumption of Eq. 6, as well as the result of very weak forces between quarks. It is also consistent with the 2 pm deuterium cluster hypothesis.

Finally, we note that the Coulomb screening effect (19, 20, 22-24, 31,42) for the deuterons in solid-state plasma in highly loaded metals has been gaining more attention as its importance is recognized. Indeed, recent measurements have confirmed anomalous screening in a variety of substrate metals. An illustration is the estimated effective screening potential of 470 eV (15, 31) of D in a highly loaded hydride which roughly agrees with recent direct measurements of  $> 320$  eV (42).

## Conclusion

The distribution minima for LENR and for uranium fission at  $A = 153$  and  $119$ , respectively, plus the local Maruhn-Greiner maxima in both have been shown to exhibit strong similarities. Based on this strong similarity, we have suggested that the reaction product array from LENR occurs by fission of a heavy compound nucleus. The question remains, however, whether the LENR process proceeds by reactions similar to that of Eq. 1 for uranium with inclusion of sequent beta decays or whether LENR proceeds without the beta processes as given by Eq. 6. The reason may be that the LENR processes are many orders of magnitudes slower than uranium type fission processes so that there is sufficient time to generate lower energy stable isotopes.

It was noted that photographic film exposures tend to support the beta decay route, but much more work is needed to be definitive. In any case, it is remarkable that the LENR soft-fusion process results in nearly stable nuclei with only a low level of energetic emission of nuclear particles or of low-energy radiation.

Still, it has to be taken into account that some measurements, e.g. Mark Prelas et al. (30), show a very low intensity of gamma lines of very high energies. This may indicate that the LENR generation of an array of heavy nuclei from the very high density screened deuterons in palladium is much more complicated than expressed by Eq. 6. The point is emphasized by the identification by various researchers of other selective LENR reactions that lead to individual transmutation products (unlike the array discussed here). These results clearly show that a variety of nuclear reactions can occur that do not involve fission. Along those lines, it should be stressed that nonfission (individual) product patterns were noted to occur in the prior thin-film experiments along with the fission-like pattern (see discussion in the early studies cited here (2, 3)).

The ability to fully control the type of transmutation reaction (fission-type array vs. single-product production) has not been achieved, although this is possible to some extent through the selection of the electrode construction and electrolyte solution (or gas) using results reported in the literature as a guide.

A most important concept proposed here is the possible role of a Bose-Einstein condensed matter cluster that has strong implications for control of reactions. As described, this provides a road map for improving the overall reaction rates in LENR cells. If achieved, that would significantly enhance our ability to study LENR reactions and at the same time potentially lead to practical units for either energy production or transmutation applications.

## References

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