Excess Heat, Tritium and Neutron Measurements by Iwamura et al. Analyzed Using the TNCF Model

H. Kozima, K. Arai and M. Fujii
Department of Physics
Faculty of Science
Shizuoka University
836 Oya
Shizuoka 422, Japan

Synopsis

Experimental data of the excess heat and nuclear products from a Pd-D system with electrolytic and gaseous loading done by Iwamura et al. are analyzed using the TNCF model, assuming quasi-stable thermal neutrons in cold fusion materials. The adjustable parameter n_n in the model was determined by the observed amounts of the excess heat and neutrons at their high times as about $10^7 \sim 10$ cm^{-3} for all samples with positive results. This value of n_n is in the range of values determined hitherto in more than 50 systems analyzed using the TNCF model and shows again validity of premises assumed in the model.

1. Introduction

The cold fusion phenomenon discovered in 1989 by M. Fleischmann and S. Pons has been left as an unsolved, undetermined, sustaining phenomenon in many of the established institutions in the world — except several countries, including Italy, Russia, China, India and others. On the other hand, some applications of this phenomenon are becoming popular with the commercial appearance of research kits for generating excess heat and radioactivity remediation from CETI and the Cincinati Group. Some stories of the origin of the cold fusion phenomenon remind us of attempts to construct perpetual motion in the beginning of 19th century before (and even after) the establishment of thermodynamics.

It is therefore necessary to treat the cold fusion phenomenon from the scientific point of view in order to clarify this unknown factor. We must apply present physics to this until now unexplored area, using experimental data as our basis. The TNCF model is an approach to this, based on our present theories of quantum mechanics and the structures of matter and the nucleus.

Events in the cold fusion phenomenon could be accepted as signals sent from complex systems composed of hydrogen isotopes (protium, deuterium, and possibly tritium) in some characteristic solids caught by probes as explained in our previous papers[1-3]. The events are classified into two categories: 1) direct and 2) indirect information of the physics of the cold fusion phenomenon.

1) Direct events.

Energy spectra of product particles, mainly neutron and gamma photon. Spatial distributions of product particles, namely heavy nuclei by the nuclear transmutation belong this category.

2) Indirect events.

Statistical average of products in the cold fusion phenomenon, i.e. the excess heat, generated amount of charged particles, tritium (triton), helium(^{4}He and ^{3}He) and various transmuted isotopes (transmuted nuclei) without spatial distribution.

Our efforts by now using the TNCF model have revealed some features of the cold fusion phenomenon such as the value of the adjustable parameter of $n_n = 10^8 \sim 10^{13}$ cm^{-3} in situations where remarkable events were observed, the irreproducibility of the events, trapped neutron - nuclear reaction in the surface layer, ratios of numbers of events generating excess heat, tritium, helium and neutron, and others. The unexplained features include a general lack of simultaneity of some events anticipated by the model, a scarceness of gamma ray observations, and others.

We do not take the all-or-nothing point of view, so we continue to analize the experimental data using the TNCF model with the hope of accomplishing a final theory for the cold fusion phenomenon. At present there are still several events unexplainable using the TNCF model, as illustrated above. In this paper, we take up the fine experimental data obtained by Iwamura et al. of Mitsubishi Heavy Industries over the last several years. The data show the general characteristics of the cold fusion phenomenon clearly and the analysis is only of those data showing excess heat and neutrons at their peaks, i.e. data where these quantities were observed with sufficient confidence.

2. Experimental Results of Iwamura et al.

Scientific efforts by Iwamura et al. using a PdD$_x$ system have been going on for several years and have produced th following results, which have not always been consistent. We consider them as data faithfully reflecting the physics of the cold fusion phenomenon in PdD$_x$.

In this section, the experimental data of Iwamura et al. are introduced according to their papers[4-8].

2-1. Neutron and tritium measurements in a gas loaded PdD$_x$ system[4] ($x \sim 0.66$)

Heating experiments of anomalous nuclear effects in a vacuum chamber had been performed for deuterated alloys with gas loading. Neutron emission and tritium production were observed in some cases when deuterium gas was released from the PdD$_x$ samples by heating.

Palladium sheets (25 x 25 x 1 mm^3) were heated to 573 K and cooled down to room temperature (~ 298 K) in D$_2$ gas. After loading deuterium to D/Pd ratio ~ 0.66 in more than a week, the samples were kept in liquid N$_2$ temperature (77 K) for several hours. The samples were brought back to room temperature environment and then gold or aluminum thin-film was vapor deposited onto both surfaces of the samples in order to reduce the rate of deuterium gas release.

The samples were then introduced into a vacuum chamber and heated up to about 400 K by a heater located in it to force the deuterium out of the samples. In this heating process, neutron, tritium and charged particles emissions were observed several times.

1) Neutrons. A clear and prominent neutron emission peak was observed for a sample with D/Pd = 0.66 and Au film using a ^{3}He neutron detector. The emission rate was estimated at 4.0 x 10^2 *n/s* or 3.0 x 10^{-20} events/s·d-d pair.

2) Tritium. Tritium production from a sample with D/Pd = 0.65 and Au film was observed by a high-resolution quadrupole mass spectrometer. Quantitative data were not obtained, however.

3) Simultaneous neutron and tritium observations were obtained in a sample with D/Pd = 0.66 and Al film. Coincidence of neutron and tritium production with deuterium gas release had been observed several times.

As a whole, reproducibility of tritium production was better than that of neutron emission.

2-2. Neutron, tritium and X-ray production in electrolysis loaded PdD_x system[5] (x = 0.7 ~ 0.83)

Observation of nuclear products from deuterated Pd heated under vacuum condition had been performed. Neutron and X-ray emission were observed in some cases and also observed DT gas breeding with high reproducibility correlated with D/Pd ratio and degassing rate of deuterium gas.

A Pd rod sample (25 x 3 mmø) were set in a D_2O - LiOD electrolysis cell which was operated at constant current (0.1 A) for 24 to 48 hours to load deuterium up to about D/Pd = 0.8. The sample was then electroplated with Cu in a Cu_2SO_4 electrolysis to maintain a high D/Pd ratio.

The sample was introduced into a vacuum chamber and set on a heater located in it. Nuclear products were observed in the process of evacuation and then heating up to 393 K by the same methods as those used in the previous work[4].

1) Neutrons. A neutron emission peak with 22 cpm (which corresponded to 458 *n/s*) was observed in the process of sample heating about 16 minutes after its start.

2) Tritium. Watching the behavior of gas with a mass number 5 (DT molecule) by a quadratic mass spectrometer, the authors could demonstrate the production of triton (*t*) in the process of heating with high reproducibility (~ 80 %) but did not determine the quantity of produced tritium. The relative amount of the produced tritium is higher for a higher D/Pd ratio.

3) X-rays. An X-ray emission with a peak at around 21 keV was observed in a sample five minutes after the beginning of evacuation. It was pointed out that this peak corresponds to Ka characteristic X-ray of palladium (21.2 keV).

2-3. Neutron and X-ray observation from a PdD_x cathode (x ~ 0.8) in electrolysis[6].

Neutron and characteristic X-ray emissions had been observed during electrochemical loading of deuterium in Pd metal. A Pd rod sample (25 x 3 mmø) was preloaded in deuterium gas to about D/Pd ~ 0.66 and was set in a closed type electrochemical cell with 1M LiOD + D_2O solution.

The electrolysis lasted from one to several days. X-ray and neutron counts increased during the process. Also, neutron emissions were observed several hours after the end of electrolysis in some samples. A peak of neutron emission corresponded to 620 cpm, which means 2067 n/s by the counting efficiency of 0.5%.

X-ray spectra had clear peaks at an energy of about 75 keV, which corresponded to the K_α characteristic line of Pb (74.2 keV). No correlation between X-ray and neutron emissions was observed.

2-4. Simultaneous measurement of the excess heat and X-ray in electrolytic PdD_x system[7] ($0.8 \le x$).

A new type of experimental apparatus was constructed to measure the excess heat and nuclear products simultaneously. The excess heat and X-ray spectrum were measured in PdD_x ($0.8 \le x$) system.

1) The excess heat was measured in the system with a Pd plate cathode (25 x 25 x 1 mm^3). The maximum value was 4 W and the average 1.1 W for a event of excess heat generation which lasted more than 25 minutes when the input power was 40 W.

2) The X-ray spectrum extended continuously to 200 keV was measured with a count rate 10 times larger than that of background. X-ray emission lasted for more than a day. No correlation was observed between the excess heat and X-ray emission. The numbers of events were largely different for the two events; 10^{12} for the excess heat (assuming a few MeV per event) and $10^2 \sim 10^4$ for X-rays.

Tritium was observed[8] qualitatively with similar characteristics to the data obtained in the previous experiments.

3. Analysis of the Data of Iwamura et al. using the TNCF Model

The quantitative data obtained by Iwamura et al. introduced in the preceding section are analyzed using the TNCF model in this section. The adjustable parameter n_n of the model is determined by the experimental values of the excess heat and the nuclear products at their high times.

The TNCF model is based on several premises common for all events in the cold fusion phenomenon. The fundamental premise is the quasi-stable existence of trapped neutrons in materials with a finite density which we denote as n_n. Supplementary premises are explained in following paragraphs in the explanation of nuclear reactions in the material.

A trigger reaction between the trapped neutrons and the ^{6}Li nucleus in the electrolytic system is assumed to occur in the surface layer of alkali metals on the cathode;

$$n + {}^6\mathrm{Li} = {}^4\mathrm{He}\ (2.1\ \mathrm{MeV}) + t\ (2.7\ \mathrm{MeV}). \quad (1)$$

A trigger reaction in a deuterium system without the surface layer is assumed to be a reaction between the trapped neutrons and deuterons in the material;

$$n + d = t\ (6.98\mathrm{MeV}) + \gamma\ (6.25\ \mathrm{MeV}). \quad (2)$$

Relations between quantities in the trigger reactions are summarized as follows (P_f = the number of the reactions between the trapped neutrons n_n and a nucleus ^A_ZM in unit time, ξ = a numerical factor of a value 1 ~ 0.01);

$$P_f = 0.35 n_n v_n n_M V \sigma_{nM} \xi \qquad (3)$$

where $0.35 n_n v_n$ is the flow density of the neutron per unit area and time, n_M is the density of the nucleus, V is the volume where the reaction occurs, σ_{nM} is the cross section of the reaction. ξ is taken as 1 for the reaction (1) in the surface layer and 0.01 for (2) in the volume.

The thickness of the surface layer will be assumed as 1 μm throughout the following analysis (allowing one order of magnitude uncertainty in the determined value of n_n) though it has been determined as 1 ~ 10 μm in experiments . Also, the abundance of the isotope ^{6}Li will be assumed as the natural one, i.e. 7.4 % except otherwise described. An average velocity of the trapped neutrons is $vn = 2.2 \times 10^5$ cm/s ($T = 300$ K).

It was noticed that the number of tritium atoms generated by the reaction (1) is also the number of events generating the excess heat of 4.8 MeV;

$$N_t = N_Q \equiv Q\,(\mathrm{MeV})/4.8\,(\mathrm{MeV}).$$

Breeding reactions are expected to occur between the energetic particles generated in the trigger reactions and another nucleus in the material.

The tritons with an energy of 2.7 MeV generated in the reaction (1) can pass through the crystal along the channeling axis on which is an array of occluded deuterons or can proceed a finite path with a length ($l_t \simeq 1 \sim 10$ μm) determined by the interaction with charged particles in the crystal. In the process of penetration through a crystal, a triton can react with a deuteron on the path with a length 1 μm with a cross section ~ 1.4×10^{-1} barn (b);

$$t\,(2.7\ \mathrm{MeV}) + d = {}^4\mathrm{He}\,(3.5\ \mathrm{MeV}) + n\,(14.1\ \mathrm{MeV}). \qquad (4)$$

Not trying to detect higher energy neutrons up to 15 MeV, which are expected to be generated in this reaction, has been a defect in experimental research. In the following analysis, we assume $l_t = 1$ μm throughout this paper.

The neutron with 14.1 MeV generated in this reaction can interact with particles in the crystal, especially with a deuteron, elastically giving a large amount of energy to it or inelastically dissociating it;

$$n + d = n' + d', \qquad (5)$$

$$n + d = n' + p + n''. \qquad (6)$$

In these reactions the original high energy neutrons will be thermalized or will generate other low energy neutrons to be trapped in the sample (breeding process).

When a neutron becomes thermal, it can fuse effectively with a deuteron in volume by the reaction (2) with a cross section 5.5×10^{-4} b or with a ^{7}Li nucleus in the surface layer by a following reaction with a cross section 4.5×10^{-2} b;

$$n + {}^7\mathrm{Li} = {}^8\mathrm{Be} + \gamma = 2\,{}^4\mathrm{He} + e^- + \nu_e + 16.2\ \mathrm{MeV} + \gamma. \qquad (7)$$

The deuteron, having an energy up to 12.5 MeV accelerated elastically in the scattering (5) by the neutron with 14.1 MeV, can fuse with another deuteron in two modes with a fairly large cross section of the order of 0.1 b;

$$d + d = t\,(1.01\text{ MeV}) + p\,(3.02\text{ MeV}), \quad (8)$$
$$= {}^{3}\mathrm{He}\,(0.82\text{ MeV}) + n\,(2.45\text{ MeV}). \quad (9)$$

Depending on the situation in a cold fusion system, the trapped thermal neutrons can induce trigger reactions like the reactions (1) and (2) and the generated energetic particles can sustain breeding chain reactions (4) ~ (9) producing a lot of the excess heat and the nuclear products.

The photons generated in the reactions (2) and (7) can induce photo-disintegration of deuterons and nuclei if they have more energy than the threshold energies of following reactions, (which is 2.22 MeV for the reaction (10));

$$\gamma + d = p + n, \quad (10)$$
$$\gamma + {}^{A}_{Z}\mathrm{M} = {}^{A-1}_{Z}\mathrm{M} \quad (11)$$

In samples with deuterons, this reaction (10) with a cross section ~ 2.5 x 1^{-3} b can work as a neutron breeder.

A relation between N_n and N_t in a D/Li system is writen down as follows. When the n – ^{6}Li reaction (1) is predominant in a electrolytic system with D_2O, neutrons are generated by the reaction (4). The number of this reaction is given by

$$N_n \sim N_t l_t n_d \sigma_{t-d}, \quad (12)$$

where $l_t \sim 1$ µm, $n_d = 6.88 \times 10^{22}\, x$ (x = D/Pd) and $\sigma_{t\text{-}d} \sim 1.4 \times 10^{-1}$ b. The neutrons generated by the reaction (4) with 14.1 MeV will lose energy by reactions (5) and (6) and some of them will be measured by the counter in the experiment. In the following analysis, we assume the number of neutrons measured in the experiment as those calculated by the equation (12).

Using the relations (3) and (11), we can determine the parameter n_n by the experimental values of the excess heat, neutrons and tritium generations.

3-1. Analysis of data given in Subsection 2-1.

Using the maximum value of the observed neutron N_n = 7.67 cpm = 4.0 x 10^2 n/s and the relations (3) and (11), we can determine the value n. at the time where the neutron was generated as follows;

$$n_n = 3.7 \times 10^8\ \mathrm{cm}^{-3}.$$

We can calculate gneration rate of tritium in the reaction (2) using the relation (3) and this value of n_n as follows;

$$N_t = 4.4 \times 10^6\ \mathrm{s}^{-1} = 7.8 \times 10^{-3}\ \mathrm{Bq}/s.$$

This value can be used as a measure of quantitative determination of the generated tritium, though only the relative value of tritium was measured experimentally.

3-2. Analysis of data given in Subsection 2-2.

Using the experimental value of neutron generation N_n = 22 cpm = 458 n/s, we can determine n_n as follows;

$$n_n = 9.6 \times 10^6\ \mathrm{cm}^{-3}.$$

This value of n_n gives the generation rate of tritium when this amount of neutron is generated;

$$N_t = 8.0 \times 10^9\ \mathrm{s}^{-1} = 1.4 \times 10\ \mathrm{Bq/s}.$$

3-3. Analysis of data given in Subsection 2-3.

Using the observed number of neutron of 620 cpm = 2067 *n/s*, we can determine the parameter n_n as follows (D/Pd = 0.8 is assumed);

$$n_n = 4.3 \times 10^7 \text{ cm}^{-3}.$$

3-4. Analysis of data given in Subsection 2-4.

Using the excess heat of 4 W and assuming the reaction (1) for the excess heat generation, we can determine n_n as follows;

$$n_n = 3.3 \times 10^{10} \text{ cm}^{-3}.$$

If we use the average value of the excess heat 1.1 W for a event which lasted about 25 minutes, the value becomes 9.5×10^9 cm^{-3}.

Results of the analyses are tabulated in Table 1.

4. Discussion

The precise experimental data obtained by Iwamura et al. in these more than four

years has been analyzed using the TNCF model and the parameter n_n in the model was determined by the quantitative data of events (neutrons and the excess heat) in the experiments. Using the value of n_n we could estimate the generation rate of relevant quantities, e.g. tritium, which were observed, but not determined by the quantitative rate of generation in the experiments.

One of the positive results of the analysis given above is a consistency of the value n_n determined above (n_n = $9.6 \times 10^6 \sim 3.3 \times 10^{10}$ cm^{-3}) with those determined for various events in various materials before. It is remarkable that the parameter n_n determined by different events like the excess heat, tritium, neutrons, helium and nuclear transmutation in various systems are in a range of values from $10^8 \sim 10^{13}$ cm^{-3}. This fact, in our opinion, reflects a new phase of physics for the cold fusion phenomenon.

The premises of the model used commonly in these analyses should be the themes of scientific research. Higher reproducibility of triton generation than that of neutrons shown in the experiments analyzed above is even more evidence supporting the model, where the former is generated by the reaction (1) and the latter is by (4) successively (and therefore with low probability).

There remain, however, some problems unexplained by the model. The experimental lack of simultaneity expected in the model, i.e. the generation of tritium and ^{4}He in the trigger reaction (1), together with the excess heat of 4.8 MeV, is a question to be explained experimentally or theoretically. The efficiency of measurement for unobserved events should be a key ele-

Authors	System	S/V cm^{-1}	Measured Quantities	n_n cm^{-3}	Prediction
Iwamura et al.[4]	PdD$_x$plate(x= 0.66)	20	n(400/s)	3.7×10^8	$N_t = 4.4 \times 10^6$ /s
Itoh et al.[5]	PdD$_x$rod(x= 0.8)	13.3	n(458/s)	9.6×10^6	$N_t = 8.0 \times 10^9$/s
Itoh et al.[6]	PdD$_x$rod(x= 0.8)	13.3	$n(2.1 \times 10^3$/s)	4.3×10^7	
Iwamura et al.[7]	PdD$_x$plate(x= 0.8)	20	Q(4 W)	3.3×10^{10}	

Table 1: Results of analyses of the data obtained by Iwamura et al. using the TNCF model. The neutron density n_n is calculated from the Number N_x of events x ($N_Q \equiv Q$ (MeV) /4.8 (MeV)). Typical value of the surface vs. volume ratio S/V(cm^{-1}) of the sample is tabulated, also.

ment in the investigation of this problem.

The difference of number of events, e.g. the excess heat N_Q and tritium N_t is another question to be explained; N_Q is, in general, larger than N_t by a factor of 3 ~ 5, suggesting there may be some extra reactions generating energy other than (1) in electrolytic system. Nuclear transmutation is a candidate for this discrepancy.

There are many mystical phenomena in this world which reject a simple explanation using the established principles of physics. The scientific effort should be to clarify them using the principles first, then to find out new principles revealed by them. Our effort using the TNCF model belongs to the first, with a successful step to develop a new perspective of the cold fusion phenomenon as the physics of trapped thermal neutrons in solids.

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References

(1) H. Kozima, K. Kaki and M. Ohta, "The Physics of the Cold Fusion Phenomenon", *Cold Fusion* **22**, 58 (1997).

(2) H. Kozima, S. Watanabe, K. Hiroe, M. Nomura, M. Ohta and K. Kaki, "Analysis of Cold Fusion Experiments Generating Excess Heat, Tritium and Helium," *J. Electroanal. Chem.* **425**, 173 (1997).

(3) H. Kozima, K. Kaki and M. Ohta, "Anomalous Phenomenon in Solids Described Using the TNCF Model," *Fusion Technology* **33**, 52 (1998).

(4) Y. Iwamura, T. Itoh and I. Toyoda, "Observation of Anomalous Nuclear Effects in D_2-Pd Systems," *Proc. ICCF4* (Dec. 1993, Lahaina, Maui Vol.3, p.12, EPRI TR-104188.

(5) T. Itoh, Y. Iwamura, N. Gotoh and I. Toyoda, "Observation of Nuclear Products Under Vacuum Conditions from Deuterated Palladium with High Loading Ratio," *Proc. ICCF5* (April. 1995, Monte-Carlo, Monaco) p.189 (1995).

(6) T. Itoh, Y. Iwamura, N. Gotoh and I. Toyoda, "Characteristic X-ray and Neutron Emissions from Electrochemically Deuterated Palladium," *Proc. ICCF5* (April. 1995, Monte-Carlo, Monaco) p.197 (1995).

(7) Y. Iwamura, T. Itoh, N. Gotoh and I. Toyoda, "Correlation Between Behavior of Deuterium in Palladium and Occurrence of Nuclear Reactions Observed by Simultaneous Measurements of Excess Heat and Nuclear Products," *Progress in New Hydrogen* Energy *(Proe. ICCF6)* (Oct. 1996, Hokkaido, Japan) p.274 (1996).

(8) T. Itoh, Y. Iwamura, N. Gotoh and 1. Toyoda, "Observation of Nuclear Products in Gas Release Experiment with Electrochemically Deuterated Palladium," *Progress in New Hydrogen Energy (proc. ICCF6)* (Oct. 1996, Hokkaido, Japan) p.410 (1996).

Free Energy

At the Tesla Society Conference and others like it, we see the promoters of free energy devices — above unity machines. What we don't see are good explanations of where the energy is coming from.

So I've seen and ridden the Takahashi scooter, supposedly powered by a magnetic motor. It was an illusion. we have Dennis Lee selling distributorships in his amazing products, which are apparently just another illusion.

Neither the Newman engine nor the Griggs water heater have proven to be above unity in performance. I suspect that the fabled Swiss generator will also fail any careful test.

Then there's zero point energy. I'm still waiting to see the first proof that there is such a thing.

......*Wayne*