Analysis of Tritium and Heat Generation in an Ni/H/K System by Notoya, et al.

H. Kozima, K. Arai and M. Fujii
Department of Physics
Shizuoka University
836 Oya
Shizuoka 422-8517, Japan

Synopsis

Experimental data of tritium and excess heat generation from an electrolytic system of porous Ni electrodes, potassium carbonate and light water obtained by Notoya, et al. are analyzed using the TNCF model. The data are consistently explained using the model, with the adjustable parameter n_n of 1.2×10^9 cm^{-3} for the tritium data. This value gives an expected excess heat of 0.26 J/s (= 1.6×10^{12} MeV/s), assuming the decay constant of ^{40}K in the surface layer, largely shortened to ~ 1 d from 1.3×10^9 y in the free state, compared with the experimental value 0.88 J/s (= 5.5×10^{12} MeV/s) described in the paper. The accordance of two values by a factor 3.4 for the excess heat is very good in the range of a usual discrepancy of a factor 3 ~ 5 obtained in our previous analyses and shows the ability to give a consistent explanation of the cold fusion phenomenon.

1. Introduction

In papers[1,2] given at ICCF4 and published later, Notoya, et al. have shown the simultaneous generation of excess heat and tritium in a light water electrolytic system using porous Ni cathodes and K_2CO_3.

Tritium is a nuclear product found fairly frequently in cold fusion experiments from the first stage of investigation and we have many reports[3-8] on it in various systems. Some of them have been analyzed by the TNCF model[9-15], giving a consistent explanation with other events. It is a fairly common obsession that tritium and neutrons should be observed evenly according to the presumption of the pertinent reactions for them as follows with almost the same cross sections:

$$d + d = {}^3\mathrm{He}\,(0.82\,\mathrm{MeV}) + n\,(2.45\,\mathrm{MeV}), \quad (1)$$

$$= t\,(1.01\,\mathrm{MeV}) + p\,(3.02\,\mathrm{MeV}). \quad (2)$$

In reality, tritium has been observed more frequently with a factor of up to 10^8 than neutrons and the situation is expressed as "tritium anomaly." This fact is explained by the TNCF model,

using a single parameter n_s, in terms of conventional physics.

In this paper we again show the agreement of the experimental data with the model, and also with other data in the cold fusion phenomenon.

2. Experimental Facts Obtained by R. Notoya, et al.

The measurement[1,2] of tritium was performed with the same experimental system as previous one[16] where a transmutation of potassium ^{39}K to potassium ^{40}K was analyzed using the TNCF mode[17]. The cathode was made of a porous Ni plate with 58% Ni having a size of 1.0 x 0.5 x 0.1 cm^{-3} in 0.5 M K_2CO_3 light (or heavy) water electrolyte. The amount of tritium in light (or heavy) water electrolysis was measured using a liquid scintillation analyzer.

2a) In the series of experiments with light water[1], the excess heat was constant about 68 ~ 82% of input energy. It is shown in Fig. 1 (Fig. 5 of the paper[1]) shows that the generation rate of tritium ($^3H = t$) expressed as Bq/24 h in 20 ml electrolyte used for electrolysis increases with the electrolytic current I or the input power W_{in}. In the paper[1] we see a general tendency for the amount of produced t to be proportional to the excess heat, if the excess heat was very large.

In the case of heavy water, on the other hand, the amount of tritium produced by electrolysis of 0.5 M K_2CO_3 solution was found to be 10 ~ 100 times larger than that observed in the light water experiment. The author suggests that the cause of the tritium generation in light water system be a small effect of the deuterium content in the electrolyte.

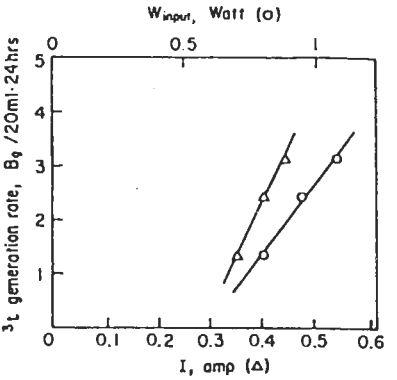

Fig. 1: Relationships between amount of tritium in 20 ml electrolyte during 24 hours of electrolysis (Bq/20ml 24h) and current I (Δ) and input power W_{in} (O) observed in 0.5 M K_2CO_3 on a porous Ni electrode. (Fig. 5 of Reference 1.)

It is seen in Fig. 1 that there is a threshold value of the electrolyzing current I and the input power W_{in} for the tritium generation. This is one of the characteristics of the cold fusion phenomenon which has been noticed before in many events observed by experimenters.

2b) In another experiment with a worn and new cathodes, they observed an interesting difference in the results of tritium generation as shown in Fig. 2 (Fig. 1 of the paper[2]). The worn cathode in this experiment means that it was used for the electrolysis more than 100 h before the experiment. The worn cathode generated twice as much tritium and excess heat as the new one.

The experiment number in the figure caption denotes the order of execution of the experiments. The experiments from 1 to 3 with the worn cathode and those from 1 to 4 with the new cathode were continued one after another without interruption except for

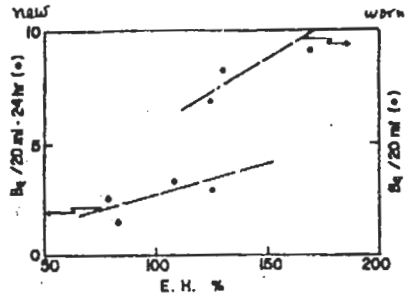

Figure 2: Relations between generation rate of tritium and evolved Q during electrolysis concerning the results of experiments 1, 2, 3 with a worn cathode (right ordinate) and experiments 1 through 4 with a new cathode (left ordinate). (Fig. 1 of Reference 2.)

renewing the electrolyte.

It can be seen from Fig. 2 that the history of the cathode has a large effect on the cold fusion phenomenon occurring in the cathode.

3. Theoretical Investigation and Conclusion

We analyzed the experimental data of tritium generation in the light water system explained above using the TNCF model, as done in a previous paper[17]. The nuclear reactions relevant with the present observation are written down as follows:

$$n + p = d + \gamma(2.22\ \text{MeV}), \quad (3)$$

$$n + d = t + g\ (6.25\ \text{MeV}), \quad (4)$$

$$n + {}^{39}\text{K} = {}^{40}\text{K} = {}^{40}\text{Ca}^{*} + e^{-} + \nu_e. \quad (5)$$

The cross sections of these reactions for a thermal neutron are 3.32×10^{-1}, 5.50×10^{-4} and 2.09 b, respectively.

In the second reaction, the deuteron is supplied by the first reaction in addition to the original content in light water less than about 0.015%. The third reaction occurs in the layer of thickness 1 μm on the surface of Ni metal used as the cathode. The surface area of the Ni metal of the porous cathode is taken as $10^3\ S$ where S is the macroscopic surface area of the cathode according to the information from R. Notoya, i.e. $S = 1.3\ \text{cm}^2$.

In the following calculation, it is assumed that H/Ni ratio = 1 and whole energy carried by the gamma rays in the reactions (3) and (4) is thermalized in the system and also that the reaction cross sections of (3) and (4) are 1% of those in vacuum (i.e. the factor $\xi = 0.01$) in NiH and NiD sample. However, the parameter ξ is taken as 1 for the reaction (4) between the trapped neutron and an impurity deuterium in NiH; $\xi = 1$. This assumption is based on the following reason: The constant ξ is defined to express stability of the quasi-stable trapped neutrons in a solid and takes a value 0.01 for the neutron - lattice nucleus interaction in volume and 1 for that in the surface layer to explain experimental data[18,19]. The interaction of the trapped neutrons with the minor isotope deuterons is intensified by the irregularity of the distribution of the deuterons in the lattice. A similar effect on the magnitude of ξ has been noticed[10] for the neutron - deuteron interaction in a solid at high temperature (~3000 °C).

Another assumption made in the analysis is about the life time of ^{40}K, which is known as 1.28×10^9 y by nuclear physicists. As was shown in the previous paper[20,21], analyzing the nuclear transmutation (NT) from ^{103,107}pd into $^{64\sim70}$Zn, the decay constant of 10^9 y seems to be shortened in the cold fusion material by a factor of 10^{-9}. An assumption we use in the following analysis to interpret experimental data

consistently is the same one that the decay time of ^{40}K becomes a small value t(s) comparable to the duration of the experiment (24 h).

The rate P_f of the reactions (3) ~ (5) per unit time is expressed by the following relation:

$$Pf = 0.35 n_n v_n n_x V \sigma_{nx} \xi , \qquad (6)$$

where $0.35 n_n v_n$ is the flow density of the thermal neutrons per unit area and time, n_n is the density of protons (neutrons, ^{39}K) in the reaction region with volume V and σ_{nx} is the cross section of the reaction. At room temperature, we can use $v_n = 2.2 \times 10^5$ cm/s. The factor ξ expresses an order of stability of the trapped neutron in the trapping region; As explained above, we take $\xi = 0.01$ for reactions (3) in NiH and (4) in NiD and $\xi = 1$ for the reaction (4) with a minor deuteron in NiH and reaction (5) in the surface layer according to the recipe of the TNCF model[18,19].

Using this relation we can calculate number of deuterons generated by the reaction (3) and ^{40}K by (5) as functions of n_n. On the other hand, the main part of the excess heat is generated in the reaction (3) (denoted as Q_{np}) and that of tritium is in the reaction (4).

3a) Assuming that the measured amount of tritium[1] introduced in 2a) is generated by the reaction (4) with the deuterons included in the light water by 0.015% as a first step of calculation, we can determine n_n as follows, using the experimental generation rate of tritium $\Delta N_t/\Delta t = 3.1$ Bq/20 ml · 24h = 2.0×10^4 t/s · 20 ml (1 Bq ≙ 5.6×10^8 t):

$$n_n = 1.2 \times 10^8 \eta \text{ cm}^{-3}. \qquad (7)$$

In this expression η is a ratio of tritium generated in the cathode to that which goes out into the electrolyte. (A measurement was performed only for the latter.)

Using this value for n_n, we can calculate amounts of deuterons in a cathode (with a volume 2.9×10^{-2} cm^3) and ^{40}K in the surface layer (with a volume $10^3 \times 1 \times 10^{-4} = 0.1$ cm^3) generated per unit time as follows:

$$\Delta N_d/\Delta t = 8.1 \times 10^8 \eta \text{ s}^{-1}, \qquad (8)$$
$$\Delta N_K/\Delta_t = 3.1 \times 10^{11} \eta \text{ s}^{-1}. \qquad (9)$$

This result shows that the amount of deuterons generated in the sample per unit volume in 24 h is $8.6 \times 10^4 \times 8.1 \times 10^8 \eta + 0.03 = 2.4 \times 10^{15} \eta$ cm^{-3}, which is three orders of magnitude smaller than the impurity deuterons in the sample $1.5 \times 10^{-4} \times 9.04 \times 10^{22} = 1.4 \times 10^{19}$ cm^{-3} if $h = 10$. Therefore we use the latter value for the density of deuterons in the following calculation, allowing an ambiguity of a factor 2 in the result.

It is difficult to estimate the amount of ^{40}K dissolved into the electrolyte which contributes to the liquid scintillation analysis where the amount of tritium in the electrolyte after the electrolysis was determined. It is obvious, therefore, that the amount of tritium determined by Notoya, et al. is overestimated by a factor of one order of magnitude due to the possible existence of ^{40}K in the electrolyte with a decay constant shortened to t, or an order of 1 day. This ambiguity is only pointed out here without being taking into the calculations.

The value n_n determined above can also give an expected amount of the excess heat generated by the reactions (3) ~ (5) assuming that the energy of the gamma rays emitted in the reactions

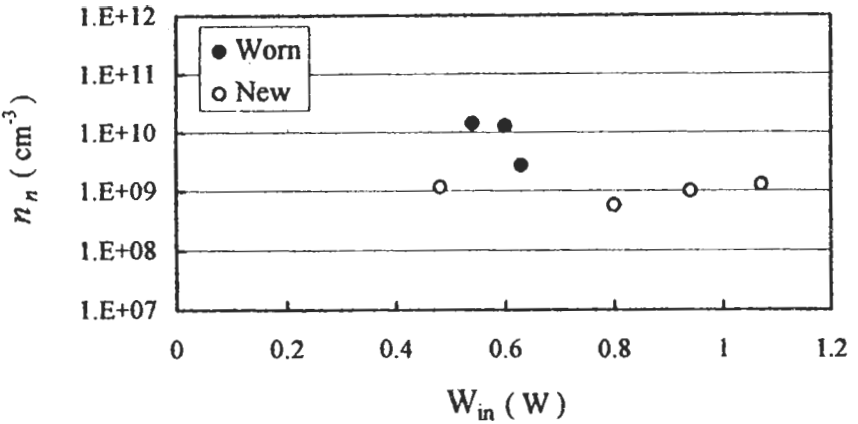

Figure 3: The dependence of n_n calculated from the generated amount of tritium on the input power W_{in} assumes $\eta = 10$.

(3) and (4) are wholly thermalized in the system. The main part of the excess energy is given by the reaction (5) and the resultant heat (when $\eta = 10$) becomes

$$Q_K = 0.26 \text{ W}. \qquad (10)$$

This value is compared with the experimentally determined value

$$Q_{exp} = 0.88 \text{ W}. \qquad (11)$$

The value η (the ratio of tritium generated to that in electrolyte) can be taken as 1 ~ 10, depending on the experimental procedure from electrolysis to liquid scintillation analysis and the discrepancy of the theoretical value 0.026 η W and the experimental one 0.88 W is by a factor 3.4 for $\eta = 10$. This is in accordance with the general tendency of higher excess heat recognized in the earlier analyses and is a tolerable discrepancy, considering the qualitative assumptions made in the calculation.

The experimental fact described at the end of Section 2 that the amount of tritium in Ni/D/K system is about 10 ~ 100 times larger than that in an Ni/H/K system is consistent with our result above. Taking the parameter $\xi = 1$ for the reaction (4) in the latter system, we obtain a theoretical ratio of generated tritium in D and H system as (1 x 0.01) + (0.00015 x 1) = 1/0.015 = 67. This value is the theoretical factor compared with the experimental one 10 ~ 100. The threshold values of I and W_{in} shown in Fig. 1 can be explained using the TNCF model as follows: The occurrence of the cold fusion phenomenon necessitates an existence of the trapped neutrons and nuclei to react with it. The current I (or W_{in}) produces occluded protium (in Ni/H/K system) in the cathode and also surface layer of NiK. alloy and/or K metal on the surface of Ni metal. Thermal neutrons can be trapped by this surface layer with a thickness more than a definite threshold value by the band structure mechanism[22]. This is a cause of the threshold value of W_{in} for the cold fusion phenomenon using the TNCF model.

3b) The same analysis is applicable

to the data introduced in 2b) and gives a similar result. A relation of the density of the trapped neutron n_n calculated with $\eta = 10$ for the experimental data shown in Fig. 2 to the input power W_{in} (from Tables 1 and 2 of Reference 2) is shown in Fig. 3. In the calculation, following values are assumed; H/Ni = 1 and D/H = 1.5×10^{-4}.

One fact we want to point out in this case is the difference in worn and new cathodes shown in Figs. 2 and 3. The amount of the generated tritium in the worn cathode is higher than that in the new for the same excess heat; in other words, more tritium is generated for an excess heat in a worn cathode. This fact is explained by our model as follows: there are more deuterons in the worn cathode due to the reaction (3) than in new ones; then, tritium generation is larger in the sample with larger deuterium content, i.e. the new cathode generates less tritium than in worn one for the same excess heat.

In Fig. 3 we also notice the following facts. Looking at the abscissa, we see that there exists a threshold value of W_{in} about 0.4 W in this system for the cold fusion phenomenon discussed at the end of Section 3a). On the other hand, the ordinate of Fig. 3 shows an existence of the optimum values of n_n about $10^8 \sim 10^{12}$ cm^{-3} in this system to produce the cold fusion phenomenon. The fact of the existence of the minimum and the maximum values of n_n for the cold fusion phenomenon has been noticed already in the results of analyses given as tables in the previous papers[19,23]. Therefore, it is necessary to have an optimum density of the trapped neutrons in materials with hydrogen isotopes to realized the cold fusion phenomenon. It is impossible to produce the phenomenon, not only with no thermal neutrons, but also with too many thermal neutrons. The latter condition will explain the absence of the phenomenon in the reactor commonly used now for electric power generation. (We have no evidence of this point, though.)

This figure shows clearly the existence of the threshold value of W_{in} for the cold fusion phenomenon discussed at the end of Section 3a).

As a conclusion, the analysis of the experimental data obtained in a Ni/H/K system gives a consistent picture of events, tritium and the excess heat generation and the nuclear transmutation from ^{39}K to ^{40}Ca, belonging to the cold fusion phenomenon. These events considered separately can not give any unified physics occurring in the material occluding hydrogen isotopes. One point should be especially remarked: that nuclei in the surface layer of a material with trapped neutrons becomes unstable and shortens a decay constant or induces nuclear fission. The change of the decay constant noticed in the papers[20,21] cited before is again shown in this analysis. From our point of view that the cold fusion phenomenon is a probe of the solid state - nuclear physics, the stabilization of trapped neutrons against beta decay, shortening of the decay constant of radioactive nuclei and the destabilization of stable nuclei in the crystal are the effects induced by the neutron - lattice nuclei interaction through the nuclear force which hasn't been noticed until now.

The analysis given above is still more evidence showing the ability of the TNCF model to explain the cold fusion phenomenon. As a next step of our program to explore the cold fusion science, we have to take up the confir-

mation of fundamental postulates of the model seriously together with people who have an adventurous spirit.

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References:

(1) R. Notoya, "Alkali-Hydrogen Cold Fusion Accompanied by ^3H Production on Ni," *Trans. Fusion Technol. (Proc. ICCF4)* **26**, 205 (1994).
(2) R. Notoya, y. Noya and T. Ohnishi, "Tritium Generation and Large Excess Heat Evolution by Electrolysis in Light and Heavy Water-Potassium Carbonate Solutions with Nickel Electrode," *Fusion Technol.* **26**, 179 (1994).
(3) M. Fleischmann, S. Pons and M. Hawkins, "Electrochemically Induced Nuclear Fusion of Deuterium," *J. Electroanal. Chem.* **261**, 301 (1989).
(4) M. Srinivasan, R.K. Rout, S.C. NEsra, M. Lai, A. Shyam, P.S. Rao and P.K. Iyengar, "Observation of High Tritium Levels in Aged Deuterated Titanium Targets as Possible Evidence of Cold Fusion," *Fusion Technol.* **18**, 88 (1990).
(5) E. Storms and C. Talcott, "Electrolytic Tritium Production," *Fusion Technol.*, **17**, 680 (1990).
(6) T.N. Claytor, D.G. Tuggle and S.F. Taylor, "Evolution of Tritium from Deuterided Palladium Subject to High Electrical Currents," *Frontiers of Cold Fusion (Proc. ICCF3)* p.217, ed. H.Ikegami, Universal Academy Press (Tokyo), 1993.
(7) T. Itoh, Y. Iwamura, N. Gotoh and I. Toyoda, "Observation of Nuclear Products under Vacuum Condition from Deuterated Palladium with High Loading Ratio," *Proc. ICCF5* (1995) p.189.
(8) V.A. Romodanov, V.I. Savin and Ya.B. Skuratnik, "Tritium Generations at Transfusion of Hydrogen Isotopes Through Target in Plasma of Powerful Glow Discharge," *Progress in New* Hydrogen Energy *(Proc. ICCF6)*, 585 (1996)..
(9) H. Kozima, M. Nomura, K. Hiroe and M. Ohta, "Analysis of Tritium and Neutron Generation in Pd + LiOD/D_2O System," *Cold Fusion* **19**, 4 (1996).
(10) H. Kozima, "Tritium Generation in Mo/D Cathode in Glow Discharge with D_2 Gas," *Cold Fusion* **20**, 28 (1996).
(11) H. Kozima, K. Hiroe, M. Nomura and M. Ohta, "Analysis of the First Cold Fusion Experiment on TNCF Model," *Cold Fusion* **21**, 6 (1997).
(12) 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).
(13) H. Kozima, H. Kudoh, M. Ohta and K. Kaki, "TNCF Analysis of Tritium Generation from Ceramics in Glow Discharge with D_2 Gas," *Cold Fusion* **23**, 42 (1997).
(14) H. Kozima, K. Yoshimoto, M. Ohta and K. Kaki, "TNCF Analysis of Tritium and Excess Heat Generations in Pd/D/Li System," *Cold Fusion* **23**, 24 (1997).
(15) H. Kozima, M. Ohta and K. Kaki, "TNCF Analysis of Excess Heat, Tritium and He4 Generation in a Pd/D/Li System" *Cold Fusion* **24**, 51 (1997).
(16) R. Notoya, "Cold Fusion by Electrolysis in a Light Water - Potassium Carbonate Solution with a Nickel Electrode," *Fusion Technol.* **24**, 202 (1993).
(17) H. Kozima, M. Nomura, K. Hiroe and M. Ohta, "Nuclear Transmutation in Electrolysis with Porous Ni Cathode and H_2O + K_2CO_3 Electrolyte," *Cold Fusion* **21**, 58 (1997).
(18) H. Kozima, "The TNCF Model -A Phenomenological Model for the Cold Fusion Phenomenon," *J. New* Energy **2-2**, 43 (1997): *Cold Fusion* **23**, 18 (1997).
(19) H. Kozima, K. Kaki and M. Ohta, "Anomalous Phenomenon in Solids Described by the TNCF Model" *Fusion Technology* **33**, 52 (1998).
(20) H. Kozima, K. Yoshimoto and K. Kaki, "A Qualitative Explanation of Nuclear Transmutation as a Whole," *Cold Fusion* **24**, 4 (1997).
(21) H. Kozima, H. Kudoh and K. Yoshimoto, "Nuclear Transmutation by Fission in Cold Fusion Experiment Analyzed by TNCF Model," *Cold Fusion* **25** (1998).
(22) H. Kozima, "Neutron Band, Neutron Cooper Pair and Neutron Life Time in Solid," *Proc. Third Russian Conf. Cold Fusion and Nuclear Transmutation (RCCFNT3)* 224 (1995):*Cold Fusion* **16**, 4 (1996).
(23) H. Kozima, "How the Cold Fusion Occurs (2)," *Report of Fac. Science, Shizuoka* Univ. **32**, 1 (1998).

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