Excess Energy and Nuclear Products

FROM "COLD FUSION" TO "HYDREX" AND "DEUTEX" STATES OF HYDROGEN

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Abstract

Based on experimental results, the possibility of formation of new bound states between an electron and a proton (deuteron) is discussed. These bound states (HYDREX and DEUTEX) result from the equilibrium between the attractive Coulombic force and the repulsive weak electro-nuclear force. These species could account for all data obtained in field of Cold Fusion".

Introduction

Seven years ago, the announcement [1], that nuclear fusion of deuterium had been obtained at room temperature by electrolysing heavy water with a palladium cathode, raised much interest but also much controversy. Although the phenomenon is now denied by most scientists, a number of more and more reliable experimental data, point to a real phenomenon, but still very surprising and difficult to explain.

A number of those puzzling experimental data have been obtained by striking sparks or ozonizer discharges through an hydrogen isotope [2,3] (hydrogen and deuterium were used), in contact with a palladium electrode :

- excess energy production, in amounts far above any known chemical reactions that could take place in the systems used [4,5,6].
- unexplained disappearing of hydrogen [6,7].
- emission of ionizing radiations (X Rays, γ Rays ?) that can be observed even after the electrical current is cut off [4].
- production of exceedingly small amounts (if any) of the known ashes of the classical fusion reactions between hydrogen isotopes, which cannot explain the amount of excess energy observed (by several powers of ten) [6].
- possible nuclear synthesis of lithium from helium and deuterium.

The last experimental results obtained with an ozonizer type of discharge are presented. A description is then given of possible bound states of a proton and an electron, resulting from the combined action of the attractive Coulombic force and the repulsive weak electro-nuclear force. These hypothetical bound states will be called HYDREX (when a proton is involved) and DEUTEX (in the case of a deuteron). It will be seen that the properties of these hypothetical species can account for all experimental data observed in the field of so-called "Cold Fusion" [1], including transmutations [8,9]. The existence of HYDREX and DEUTEX, when proven, is likely to be the actual reason why the TNCF phenomenological model gives a very approximate description of the phenomenon [10].

Experimental results

The most interesting results obtained when an ozonizer (or a spark) discharge is struck through hydrogen isotopes, contacting a palladium electrode, will now be summarised. The experimental devices used have been previously described [4,5,6,7].
Emphasis will be laid on results obtained with pure hydrogen (ALPHAGAZ quality U $H_2 > 99.995$ %) and pure palladium (Johnson Matthey quality Puratronic, metal impurities less than 20 ppm weight) (see table 1 in annex for detailed compositions of the palladium), as this system is the most simple and clean.

Excess Energy and Nuclear Products

Excess energy

Very significant excess energy production have been observed, on long periods.

⇨ excess power up to 10 W (representing 7 % of the input power) have been obtained [6,7]. The standard deviation of the calorimetric system being 1W, this result is very significant. This excess power production has been obtained on long periods ($3x10^6$ to $10x10^6$ s) and increases when the input power is increased. Fig.1 in annex, gives the evolution with time of this excess power for the system hydrogen/palladium (note that for deuterium, the excess power is higher : 14 W, representing 10 % of the energy input).

⇨ unexplained disappearing of hydrogen (deuterium) which cannot be explained by leakage, diffusion through the walls of the reactor or combination with elements present in the reactor [7]. The loading ratio of the palladium after experiment (measured by heating the electrode and measuring the volume of hydrogen -deuterium- recovered) is 0.85 to 0.9. Fig.2 in annex, gives the evolution with time of the "apparent" loading ratio of the palladium during the experiment (calculated from the amount of palladium present in the reactor and the quantity of hydrogen injected in this reactor to keep its pressure constant). It can be seen that this "apparent" loading ratio reaches values up to 5, which is impossible. Hydrogen is thus lost in the experiment.

⇨ very high excess energy per atom : Fig.3 in annex, is a plot of the cumulative excess energy ($\int_0 E_P(t)dt$, $E_P(t)$ being the excess power in Watt at time t) as a function of the cumulative quantity of hydrogen lost ($\int_0 F_H(t)dt$, $F_H(t)$ being the flow of hydrogen into the reactor, in mMole H per second at time t), for the above mentioned experiment with hydrogen and palladium. The slope of the curve is the overall excess energy per mMole H (W/mMole H). It can be seen from Fig.3, that :

① the mean value of the overall excess energy is very high ; expressed in eV/atom H : 7,100 eV/H (to be compared to 1 eV/H for the combustion of hydrogen). This value is shown on Fig.3 by the straight line.

② this value increases with time as can be seen from the curvature of the curve Fig.3.

Table 2 below summarises the results obtained with the system hydrogen/palladium :

Table 2 Period	Duration (second)	H consumed (mMole H)	Excess energy on period (J)	Mean excess power (W)	Exc.Ene. eV per atom H	Power input (W)
CAL	230 000	0	0			Calib.
INC	695 000	9.88	1 737 500	2.5	1 800	Increasing
I	1 390 000	9.63	5 838 000	4.2	6 300	115
II	342 000	1.41	1 846 000	5.4	13 600	150
III	767 000	5.44	6 596 000	8.6	12 600	150
Total	3 424 000	26.36	16 018 300	4.7	9 000	

Note that the combustion of all the hydrogen used in the experiment (26.36 mMole H) would have yielded 6,400 J, to be compared with 16,018,300 J actually obtained.

Emission of low energy radiations

During the experiments carried out with sparks [4], observations were made, that can be related to the emission of low energy X Rays :

⇨ light tight films placed in the reactor were found completely blackened after experiments with hydrogen and deuterium. In contrast, experiments carried out in the same conditions, but using nitrogen as sparking gas yielded no blackening of the film.

⇨ after cut-off of the spark a strange phenomenon was observed : by polarising the electrodes gap (100 V for a gap of 1 cm), **after an experiment**, the gap being filled with the hydrogen that had been submitted to the sparks (hydrogen pressure round 900 mbar), a current was measured with values up to

25 nA for hydrogen experiments 700 nA for deuterium ones. The current was observed on periods of several days, with a fast decrease for deuterium (hours) and a slower one for hydrogen (days). Similar measurements carried out with hydrogen and palladium **before sparking**, yielded current values lower than 10 pA. Fig.4 in annex, shows the evolution of this unexplained current with time (for a D_2/Pd experiment).

These two sets of observations can be explained by the production of low energy X Rays, the intriguing thing being the long persistence (several days) of the phenomenon after cut-off of the discharge.

Possible synthesis of new elements in the palladium matrix (transmutation)

A complete analysis of the palladium electrode used for the experiment with hydrogen above mentioned (ozonizer discharge), was carried out. The **palladium electrode** was a wire (diameter 0.25 mm) **weighing 120 mg**.The electrode was completely dissolved and the following analysis were carried out (sample 3H06):

- atomic emission spectrometry with plasma torch (ICP/AES) for Fe, Ru , Rh and Ag.
- mass spectrometry with plasma torch (ICP/MS) for the other impurities and for the isotopic composition of the palladium.

Similar analytical procedure was carried out on a virgin palladium wire from the same batch, the same roll of wire and of the same weight as sample 3H06 (sample Blank) .

The complete results of the analysis are given in annex (Table 1). From Table 1 it can be seen that variations from sample Blank to sample 3H06 are observed for the elements :
Li, Mg, Al, Cr, Mn, Fe, Ni, Cu, Zn, Ir, Pt and Au. Table 3 gives the variations of these elements (expressed in number of atom) :

Table 3 :

Element	3H06	Blank	3H06 - Blank
Li	5.2×10^{14}	1.0×10^{14}	4.2×10^{14}
Mg	2.5×10^{17}	2.2×10^{16}	2.3×10^{17}
Al	7.2×10^{16}	2.7×10^{15}	7.0×10^{16}
Cr	1.1×10^{16}	1.3×10^{15}	9.7×10^{15}
Mn	3.9×10^{14}	2.6×10^{14}	1.3×10^{14}
Fe	2.8×10^{16}	1.3×10^{16}	1.6×10^{16}
Ni	3.3×10^{15}	2.5×10^{15}	8.6×10^{14}
Cu	4.7×10^{15}	1.8×10^{15}	2.8×10^{15}
Zn	4.8×10^{16}	4.8×10^{15}	4.3×10^{16}
Ir	2.3×10^{14}	1.9×10^{14}	3.8×10^{13}
Pt	3.0×10^{14}	5.2×10^{14}	-2.2×10^{14}
Au	2.9×10^{14}	4.0×10^{14}	-1.1×10^{14}

From table 1 (annex) it can also be seen that there is no significant variation of the isotopic composition of the palladium. This table also shows that the precision on the measure of Ag is low (1.3×10^{16} atoms), so any nuclear generation of Ag lower than this quantity are not detectable.

From these data, following conclusions can be drown :

- the total amount of new atoms that appear in the sample (some 2.4×10^{17}) is much higher than the total amount of atoms that disappear from the sample (some 3.3×10^{14}). No nuclear reaction, either fusion or fission, can explain this fact. So the bulk of the new atoms in sample 3H06 comes from contamination and indeed all the new elements found (except Li), can be traced back in the various components of the reactor. The case of Li will be discussed below.
- assuming that all new elements found in sample 3H06 originate from a nuclear reaction with an exothermicity of 5 MeV, it can be calculated that the total amount of energy produced would have been 3×10^{5} J, which represents only 1.9 % of the total amount of excess energy produced in the experiment (some 16×10^{6} J).

o case of Li : a contamination of sample 3H06 by Li could not be found obviously. Although the precision of the analysis carried out to trace it back, cannot completely rule it out, a nuclear origin of Li found, is plausible. The detailed nuclear reaction proposed to account for that will be discussed below (*Reactions of HYDREX with nuclei of the metal*). The overall reaction could be written :

$$ {}^{4}_{2}He + {}^{2}_{1}H = {}^{6}_{3}Li + 1.4 \text{ MeV} \qquad (0) $$

The origin of ${}^{4}_{2}He$ in the palladium could be ionic implantation of ${}^{4}_{2}He$ from the hydrogen gas phase of the reactor : during the search for fusion ashes [6], the amount of ${}^{4}_{2}He$ in the gas phase (H2 bottle) was found to be 4.4×10^{13} atoms per cm^3, which, for the experiment reported (26.36 mMole H) , gives a total of 1.3×10^{16} atoms. The amount of lithium formed (4.2×10^{14}) can thus originate from ${}^{4}_{2}He$ present in the experiment. The data gathered [6] allows an evaluation of the order of magnitude of the reaction rate of reaction (0). The equilibrium amount of ${}^{4}_{2}He$ in the metal was found to be 10^{13} atoms. From the deuterium content of the H2 used, we can assume that the amount of deuterium in the palladium is 2.5×10^{19} atoms. Given the volume of the palladium wire (1.3×10^{-3} cm^3), the concentration of the reacting nuclei are thus: for ${}^{4}_{2}He$ 7.69×10^{15} and for ${}^{2}_{1}H$ 1.92×10^{22} atom.cm^{-3} . The total duration of the experiment being $3{,}4 \times 10^{6}$ s, the average formation rate of lithium is : $9.5 \cdot 10^{10}$ atom.s^{-1}. cm^{-3} . The average first order reaction constant for (0) is thus :

$$ k_0 = 6.4 \cdot 10^{-28} \quad (s^{-1}) \cdot (\text{atom} \cdot cm^{-3})^{-1} $$

which expressed in $(s^{-1}) \times (\text{Molexcm}^{-3})^{-1}$ yields 3.85×10^{-4}, which is the order of magnitude of the fastest nuclear reactions occurring in the sun.

Conclusion on the experimental results

Three main conclusions can be drown from the experimental results :

① a sizeable amount of excess energy is produced, and hydrogen is lost.

② if a small part of this excess might come from nuclear reactions, the bulk cannot have this origin, but is much higher than any known chemical reaction.

③ ionizing radiations (X Rays ?) are produced during the experiment. They are persistent (for periods of hours to days) after cut-off of the experiment.

All this is extremely puzzling and a **strong and simple lead is necessary** to order all these data.

Theoretical arguments have thus been developed to show the possible existence of **new bound states between a proton** (deuteron) and **an electron**, resulting from the **equilibrium** between the **attractive Coulombic force and the repulsive weak electro-nuclear force**. The properties of these bound states, when there existence is proven, can account for all data obtained in the field of "Cold Fusion".

Physical basis of the model

A good overall description of the hydrogen atom is given by the Bohr model that quantifies the interaction between the Coulombic force and the resulting kinetic energy of the electron. Another interaction is possible between the proton and the electron, the endothermic synthesis of a neutron :

$$ p^+ + e^- = n + \nu - Q \ , \quad \text{with } Q = \left(M_n - M_h\right)c^2 \qquad (1) $$

M_n and M_h being respectively the masses of the neutron and of the hydrogen atom and c the velocity of light. $Q = 1.2583 \times 10^{-13}$ J. No (or extremely small amounts) of neutrons are produced in "Cold Fusion" experiments. (1) is thus likely to yield only virtual states of the neutron.

Contrary to the Coulombic force or the centrifugal force, the weak electro-nuclear force has no macroscopic description. Nevertheless a very broad description of its possible interaction with the Coulombic force can be achieved by using the basic principles of quantum mechanics.

To start with, it can be noted that the Bohr model deals with a system consisting of a single proton and a single electron in vacuum. Considering the electron starting from infinite, the formation of the hydrogen atom can be described as the electron approaching the proton, with a kinetic energy ruled by the intensity of

the Coulombic force and successively meeting the various excited states of the hydrogen atom to finally end up in the ground state of this atom.

In a metallic hydride forming metal, the hydrogen is partly in the form of protons. Conduction electrons could interact with these protons in a way which is likely to be very different from the previous one. It is well known [11] , that the behaviour of the conduction electrons in a metal can be precisely described by the void cation model, where the Coulombic potential from the cation is replaced by a much lower "pseudo potential" (with practically 0 value) in the close vicinity of the cation (from 0 to 1.66 Bohr radius / see Fig.5 in annex). This is due to the periodic character of the cation lattice and means that the conduction electrons can move in the vicinity of the cations without feeling their Coulombic attraction. Note that this model is not meant to describe the very close vicinity (some fm) of the cation, where the real Coulombic potential should apply. In a metallic hydride, if all the sites available are occupied by hydrogen, a similar phenomenon could occur, between the conduction electrons and the lattice formed by the hydrogen cations (which is a "moving lattice", because it is known that protons can migrate across the metal lattice under the influence of an electrical field).

A model of the hypothetical interactions between protons trapped in a metallic lattice and the conduction electrons of this "proton lattice" can thus be obtained by considering the system formed by one proton and one electron, **the electron starting its motion** towards the proton at **a very short distance** from it (some fm) **with 0** (or very low) **kinetic energy**, this very short distance being the distance beyond which the void cation model is valid and the pseudo potential very low.

The HYDREX (DEUTEX) model

As usually the proton is considered to be fixed. Let R_0 be the distance from the center of the proton, from which the electron starts its motion towards it and R_a the distance at which the electron impacts the proton. R_0 being supposed very small, the interaction between the spins of the 2 particles should favour "head on" collisions.

The exchange of energy between the 2 particles can be described in 3 steps :

❶ - acceleration of the electron towards the proton. At the impact R_a , the kinetic energy of the electron is :

$$E_c = \frac{e^2}{4\pi\varepsilon_0}\left[\frac{1}{R_a} - \frac{1}{R_0}\right] \qquad (2)$$

❷ - nuclear interaction between the electron and the proton to yield a virtual neutron, that reverts into an electron and a proton according to the scheme :

$$p^+ + e^- = n + \nu = p^+ + e^-$$

Theoretical arguments to justify the possibility of such a reaction have already been proposed[12]. Note that they suppose a very small mass of the neutrino (10^{-3} to 10^{-1} eV).

The life time of the virtual state of the neutron is limited by Heisenberg uncertainty relations :

$$\Delta T \cdot \Delta E \geq \hbar$$

ΔE being equal to $(Q - E_c)$, ΔT can be expressed as :

$$\Delta T = \frac{k\hbar}{(Q - E_c)} \qquad (3)$$

with $k > 0$ and integer and $(Q - E_c) > 0$, reflecting the virtual state of the neutron.

❸ - ejection of the electron from the neutron, when the neutron reverts to the proton, with a kinetic energy $E_c^{'}$ given by the energy balance of step 2 :

$$E_c^{'} = Q - (Q - E_c) = E_c$$

The electron is then back to its initial state (distance R_0 from the proton, kinetic energy very low) and steps ❶,❷ and ❸ repeat indefinitely, yielding the HYDREX bound state of hydrogen.

A very broad description of the various levels of this bound state can be obtained by considering step ❷ as an elastic collision between the electron and the proton, with duration ΔT and impact energy E_c. The quantification of the product $E_c.\Delta T$ gives :

$$E_c.\Delta T = n\hbar \quad , \quad \text{n being an integer} \qquad (4)$$

Replacing E_c and ΔT by (2) and (3) and Q by its value (1) in (4), yields :

$$\frac{1}{R_a} - \frac{1}{R_0} = \frac{n}{n+k} \frac{4\pi\varepsilon_0 c^2}{e^2} \left(M_n - M_h\right) \qquad (5)$$

(5), with the condition that R_0 is positive, gives a broad estimation of the values of the radii of the different states of HYDREX, provided an hypothesis is made on the values of k, that is on the actual duration of the virtual state of the neutron (note that this value could be k' different from k in the case of DEUTEX where a virtual di-neutron is formed, and that the quantity Q' corresponding to Q is also different - see below for an estimation of Q' -).

Discussion. Possibilities and limitations of the model

To choose the above mentioned values of k, we have to take into account the limitations set previously :

$k > 0$ integer , (virtual state of the neutron) (6)

$\left(Q - E_c\right) > 0$, (virtual state of the neutron) (7)

$1/R_0 > 0$, $(R_0 > 0)$ (8)

Combining (3) and (4) shows that (7) is satisfied for all values of $k > 0$:
Combining (5) and (8) yields the condition :

$$k > \text{n} . \left[R_a \frac{4\pi\varepsilon_0 c^2}{e^2} \left(M_n - M_p\right) - 1 \right] \qquad (9)$$

For R_a = 1.2 (radius of the proton), (9) yields $k > -0.4372$. n. This is always true if n and k are positive integers, which are the only 2 conditions left.

Description of the HYDREX state of hydrogen

To describe HYDREX, an hypothesis has to be made on the value of R_a. It is commonly admitted that the radius of the free proton is 1.2 fm. This value has been taken for R_a (parametric calculations have shown that the basic description of HYDREX is not much modified when R_a varies from 1 to 1.5 fm).

The ground state is obtained for n = 1. As mentioned above, nothing is known on k, which describes the life of the virtual state of the neutron (note that for k infinite, the radius of HYDREX is $R_0 = R_a$, and the model is no longer valid).

A parametric calculation yields the following values for the ground state :

k	1	2	3	4	5
R_0 (fm)	1.78	1.53	1.43	1.38	1.35

The highest excited state (end of the continuum) is obtained for n infinite, where the influence of low values of k are negligible. The radius of this state is :

$$R_0^{\infty} = 3.47 \text{ fm}$$

Given the physical way HYDREX is supposed to be formed, **these highest excited states are likely to be the first obtained.** To analyse the way they deexcite, the energies of the various transitions have to be calculated. Let $\Delta E_{n,k}^{n+1,k}$ and $\Delta E_{n,k}^{n,k+1}$ be the transitions for k fixed and n fixed respectively. The way the binding energy of HYDREX is disposed of will be discussed later. The transition energies can be calculated from the values of the potential energies of the electron at R_0, $E_p\left(R_0\right)$:

$$E_p(R_0) = \frac{e^2}{4\pi\varepsilon_0}\left(\frac{1}{R_a} - \frac{n}{n+k}\right)(M_n - M_h)c^2 \qquad (10)$$

From (10) :

$$\Delta E_{n,k}^{n+1,k} = \frac{k}{(n+1+k)(n+k)} \cdot (M_n - M_h)c^2 \qquad (11)$$

$$\Delta E_{n,k}^{n,k+1} = \frac{-n}{(n+k+1)(n+k)} \cdot (M_n - M_h)c^2 \qquad (12)$$

(12) shows that transitions $\Delta E_{n,k}^{n,k+1}$ are forbidden. This means that once HYDREX is formed with a given duration quantum of the virtual neutron state, this duration is kept constant during all the deexcitation process. This reduces the limitations of the model and allows a representative description of HYDREX to be made, by taking k = 1 (it should be kept in mind that k could differ from 1 and be different for HYDREX and DEUTEX).

Three other quantities have to be taken into account to describe HYDREX :

- the life time of the virtual state of the neutron. Replacing $(Q - E_c)$ by its value (5) and (1) in (3) yields :

$$\Delta T = (n+k)\frac{\hbar}{(M_n - M_h)c^2} \qquad (13)$$

- the endothermicity of this virtual state, obtained from (1) and (5) :

$$(Q - E_c) = \frac{k}{n+k}(M_n - M_h)c^2 \qquad (13')$$

- the velocity on the electron at the impact with the proton. The electron being relativistic, its velocity v_e is , by combining (2) and (5) (with M_e the rest mass of the electron) :

$$v_e = c\sqrt{1 - \frac{1}{\left(1 + \frac{n}{n+k}\frac{M_n - M_h}{M_e}\right)^2}} \qquad (14)$$

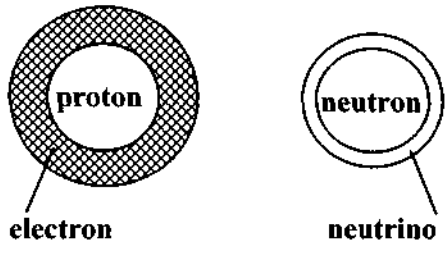
Table 4 gives the main features of HYDREX, for $k = 1$ and for n varying from 1 to infinite.

Table 4 n	R_0 (fm)	$\Delta E_{n,1}^{n+1,1}$ (keV)	Virtual neutron life (10^{-21}s)	Time for 1 electron oscillation (10^{-23} s)	Ratio Neutron/ (p+e) states (s/s)	Binding energy (keV)
1	1.78	130.90	1.67	2.10	80	392.69
2	2.13	65.45	2.51	2.87	85	261.79
3	2.36	39.27	3.35	3.38	100	196.35
4	2.51	26.18	4.19	3.74	110	157.08
5	2.63	18.70	5.03	4.01	125	130.90
6	2.73	14.02	5.87	4.22	140	112.20
7	2.81	10.91	6.70	4.39	150	98.17
8	2.86	8.72	7.54	4.53	165	87.26
9	2.92	7.13	8.38	4.64	180	78.54
20	3.20	1.70	18.40	5.23	350	35.69
100	3.41	0.077	84.62	5.73	1475	7.77
500	3.46	3.1×10^{-3}	419.90	5.87	7150	1.56
1000	3.47	0.8×10^{-3}	838.9	5.87	14290	0.078
10^6	3.47	7.8×10^{-7}	8.4×10^5	5.87	1.42×10^7	7.8×10^{-4}

It can be seen that :

- the radius R_0 of HYDREX increases from 1.78 to 3.47
- the transitions between levels are in the order of tens of keV for the first values of n and decrease to values of a few eV when n increases.
- in all cases, HYDREX is more often in the form of a virtual neutron + virtual neutrino than in the form of a proton + electron. This is shown in column (Neutron/(p+e) states) which gives the ratio of the duration of the virtual state of the neutron (ΔT) to the duration of the motion of the electron to and from the proton (calculated from the velocity of the electron, considering that its average velocity is half its velocity v_e at the impact of the electron on the proton).

At that stage, HYDREX can be described as an oscillation between two states : one is the proton, surrounded by an electron cloud at very short distance (few fm) and the other a virtual neutron state surrounded by an oscillating virtual neutrino.



$$H\left(\left|{}^{e}_{p}\right.\right) \quad \Leftrightarrow \quad H\left(\left|{}^{\nu}_{n}\right.\right) \qquad (15)$$

HYDREX can thus be noted as $H\left(\left|{}^{e}_{p}\right., \left|{}^{\nu}_{n}\right.\right)$, resulting from the oscillation between the two states written in (15)

This scheme gives a clear understanding of what is the binding energy of the system. This binding energy, given in the last column of table 4, is equal to $(Q - E_c)$. It is the amount of energy that has to be given to the system either in the form $H\left(\left|{}^{\nu}_{n}\right.\right)$ to yield a real neutron and neutrino :

$$H\left(\left|{}^{\nu}_{n}\right.\right) + (Q - E_c) = \mathrm{n} + \nu$$

or in the form $H\left(\left|{}^{e}_{p}\right.\right)$, to yield a proton and an electron at a distance beyond the stability limit of HYDREX :

$$H\left(\left|{}^{e}_{p}\right.\right) + (Q - E_c) = \mathrm{p} + \mathrm{e}$$

The description of the way HYDREX may deexcite and may react with nuclei will give more insight on its properties and shed light on the field of "Cold Fusion".

Before this description is given, two limitations of the model should be emphasised :

- **no indication are available on the value of k. This is due to the lack of knowledge on the weak electro-nuclear force**. The situation might be improved if the models proves to represent an actual new combination of a proton and an electron.
- the second is more fundamental : **the existence of a virtual neutrino implies that the neutrino has a mass**. The order of magnitude of the required mass can be evaluated by writing the momentum and energy conservation equations. It can thus be calculated that this mass should be in the order of $\mathbf{10^{-1}}$ **to** $\mathbf{10^{-3}}$ **eV**.

Excess Energy and Nuclear Products

Deexcitation of HYDREX and possible nuclear reactions

Deexcitation of HYDREX

As previously mentioned, HYDREX is formed in its higher excited states. The way the binding energy is emitted, is very similar to classical electron capture : emission of a neutrino, with the difference that the neutrino is virtual. The electron which is bound, comes from the conduction band of the palladium. If ΔE_f is the energy of the Fermi level of palladium + hydrogen (deuterium), HYDREX is formed in a state n such that :

$$\Delta E_n^{\infty} \geq \Delta E_f$$

A photon of energy ΔE_f is emitted when a new electron replaces the HYDREX bound electron in the conduction band (UV range) and this emitted energy can be small compared to ΔE_n^{∞}.

Further deexcitation can occur when HYDREX, in its $H\left(\left|{}^{v}_{n}\right.\right)$ state, collides with an electron e_L more energetic than the conduction band electrons (deeper levels of the electronic structure of the atom). If ΔE_L is the energy of the corresponding level of the electron, a transition of HYDREX from level n to level m (m<n), can occur if :

$$\Delta E_m^n \geq \Delta E_L$$

and the only visible energy production is the emission of a photon (or a cascade of photons) of energy ΔE_L. Note that, here again, ΔE_m^n can be much higher than ΔE_L and that unknown selection rules can limit some HYDREX transitions. The deexcitation process can be written as :

$$H\left(\left|{}^{v}_{n}\right.\right) + e_L \Rightarrow H\left(\left|{}^{e_m}_{p}\right.\right) + e_n + \text{X photon}$$

The formation and deexcitation of HYDREX should thus be visible, first through emission of **UV photons characteristic of the Fermi level of the metal used** and through **emission of X photons characteristic of the atoms present in this metal**.

This can explain X Ray emission during the formation and deexcitation of HYDREX and also the fact that the X Ray emission can go on even after the discharge has been cut-off.

Furthermore, the very small dimension of HYDREX explains that it readily diffuses through any material and is thus very quickly lost from the reactor.

Reactions of HYDREX with nuclei of the metal

When sufficiently stable, HYDREX in its $H\left(\left|{}^{v}_{n}\right.\right)$ state could react with a nucleus to yield neutron induced transmutations, provided that the endothermicity of the virtual neutron state is lower than the exothermicity of the neutron induced transmutation. It should be noted that the cross sections of these reactions should be in the order of magnitude of those occurring with real neutrons, which combined with the high diffusivity of HYDREX, should limit transmutation reactions in currently used experimental set-up.

The endothermicity of the virtual neutron state is equal to the binding energy of HYDREX. Equation (13') shows that this energy is always lower than 784 keV. Thus all neutron induced transmutation having an exothermicity higher than this value are possible. Put in an other way, it can be said that any reactions implying the addition of an atom of hydrogen (or deuterium) to a nucleus and that would be impossible (for Coulombic barrier reason), are possible with HYDREX (DEUTEX), provided this reaction is exothermic. As an example, the reaction with deuterium should yield tritium according to the scheme :

$$^{2}_{1}H + H\left(\left|{}^{v}_{n}\right.\right) \Rightarrow {}^{3}_{1}H + \nu \qquad (16)$$

because the reaction :

$$^{2}_{1}H + n \Rightarrow {}^{3}_{1}H + \nu \qquad (17)$$

has an exothermicity of some 6260 keV, higher than the highest binding energy of HYDREX. But this reaction (16) should have a rate severely limited by cross section and diffusion reasons.

Another example is the production of lithium that may have been observed in our experiments. Reaction (0) can be written :

$$ {}^{4}_{2}He + D\left(\left|{}^{\nu}_{2n}\right.\right) \Rightarrow {}^{6}_{2}He + \nu \Rightarrow {}^{6}_{3}Li + \beta^{-} + \bar{\nu} \qquad (0') $$

$D\left(\left|{}^{\nu}_{2n}\right.\right)$ being the virtual (di-neutron,neutrino) state of DEUTEX - $D\left(\left|{}^{e}_{d}, \left|{}^{\nu}_{2n}\right.\right.\right)$ -.

In the case of DEUTEX, Q' is equal to :

$$ Q' = \left(M_{2n} - M_d\right)c^2 = \left(2M_n - M_d\right).c^2 $$

assuming that the di-neutron has no binding energy (M_d being the mass of the deuterium atom, M_{2n} the mass of the di-neutron and M_n the mass of the neutron). Q' is thus equal to 3.11 MeV. The radius $R_a^{'}$ of the deuteron is taken as 2.5 fm. It can be seen from the relations (5) to (15), that stable states of DEUTEX, with values of $R_0^{'}$ in the order of 25 fm (that is still meeting the condition that head-on collisions between the electron and the deuteron are dominant), can be found for $k' \approx 10^2$ (for DEUTEX relation (9) implies $k \geq 4.4.n$). This means that DEUTEX is likely to be easier to form than HYDREX. Moreover the bound states thus formed have a much higher binding energy than HYDREX, and their first deexcitation steps are also more energetic. All this might explain that more positive results are obtained with deuterium than with hydrogen and could account for the production of lithium in our experiment, according to (0'), because reaction (0) is exothermic (1.40 MeV) .

Conclusion

The model described in this paper, based on experimental results, can account precisely for all results obtained in the field of "Cold Fusion". It is hoped that it will be a strong guidance for further progress in the field.

Tables and figures in annex

Table 1 : Composition of virgin and activated palladium sample.
Figure 1 : Excess power generation as a function of time.
Figure 2 : Apparent loading ratio as a function of time.
Figure 3 : Excess energy per atom hydrogen as a function of time.
Figure 4 : Ionizing radiations after cut-off as a function of time.
Figure 5 : The pseudo-potential in the void cation model.

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Ref.3 J. Dufour Patent **WO 94/10688** "Energy source system and process", Filed 26 October 1992, International publication date 11 May 1994

Ref.4 J. Dufour "Cold Fusion by sparking in Hydrogen Isotopes", *Fusion Technology*, **24**, p. 205 (1993)

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Ref.7 J. Dufour, J. Foos, J.P Millot, X. Dufour "Interaction palladium/hydrogen and palladium/deuterium. Measurement of the excess energy per atom for each isotope" *Accepted for publication in Fusion Technology.*

Ref.8 I.B. Savvatimova, Ya.R. Kucherov, A.B. Karabut "Cathode material change after deuterium glow discharge experiment". *Proceedings : fourth international conference on cold fusion.* **Vol. 4 : Nuclear measurement papers**, p 16-1 (1993)

Ref.9 D. Tuggler, T. Claytor, S. Taylor "Tritium evolution from various morphologies of palladium". *Transactions of Fusion Technology : fourth international conference on cold fusion.* **Vol. 26**, p 221 (1994)

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Annex

FIGURE 5

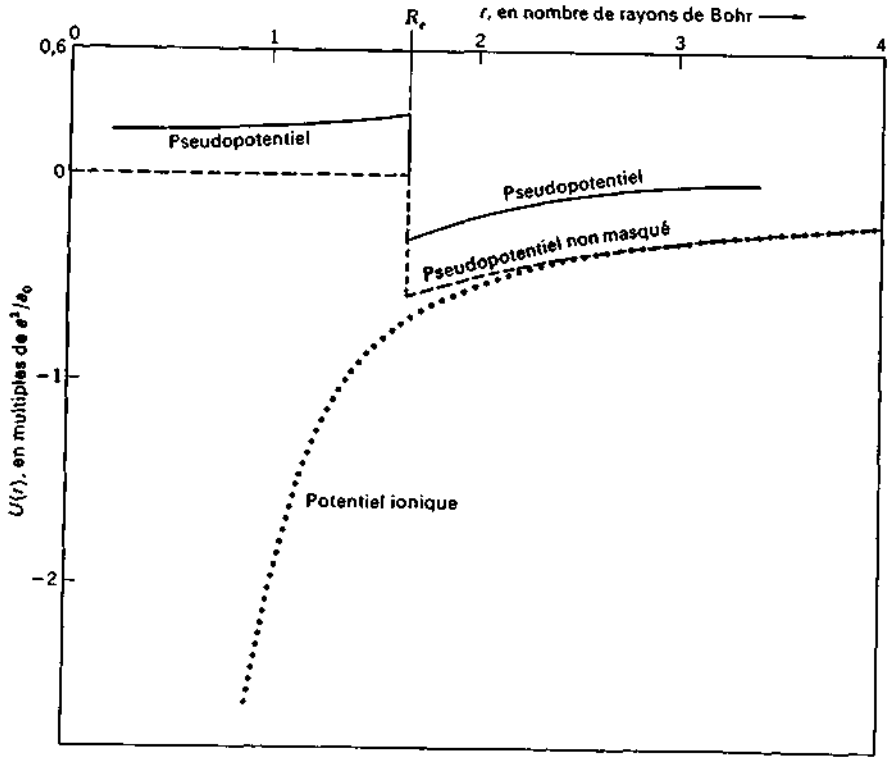


Figure 22 Pseudopotentiel du sodium métallique, basé sur le modèle du cation vide et masqué par la fonction diélectrique de Thomas-Fermi. Les calculs ont été réalisés pour un rayon $R_c = 1{,}66\,a_0$, où a_0 est le rayon de Bohr, et pour un rayon d'écran $\lambda a_0 = 0{,}79$. La courbe en tirets représente le potentiel non masqué, d'après l'équation [21]. La courbe en pointillés est le potentiel réel du cation ; en-dessous de $r = 1$, ce potentiel $V(r)$ prend les valeurs $-4{,}6$, $-11{,}6$ et $-50{,}4$ pour $r = 0{,}7$, 0,4 et 0,15 respectivement. Par conséquent le potentiel réel de l'ion (ajusté pour correspondre aux niveaux d'énergie de l'atome libre) est bien plus grand que le pseudopotentiel, dans un rapport 200 pour $r = 0{,}15$.

TABLE 1 *Chemical composition of 3H06 Pd sample and virgin Pd sample (amount expressed in ppm per mass)*

Element	Pd of 3H06	Virgin Pd sample
H	***43 ± 7***	***28 ± 10***
Li	***0.05 ± 0.02***	***≤ 0.01***
Be	≤ 0.01	≤ 0.01
B	≤ 0.08	≤ 0.08
Na	nm	nm
Mg	***85 ± 9***	***7.3 ± 0.8***
Al	***27 ± 3***	***≤ 1***
Si	nm	nm
P	nm	nm
K	nm	nm
Ca	*	*
Ti	≤ 0.1	≤ 0.1
V	≤ 0.2	≤ 0.2
Cr	***7.9 ± 0.8***	***0.9 ± 0.3***
Mn	***0.3 ± 0.1***	***≤ 0.2***
Fe	***22 ± 10***	***≤ 10***
Co	≤ 0.05	≤ 0.05
Ni	***2.7 ± 9***	***≤ 2***
Cu	***4.1 ± 0.4***	***1.6 ± 0.2***
Zn	***43 ± 5***	***4.3 ± 1.5***
Ga	≤ 0.05	≤ 0.05
Ge	≤ 0.7	≤ 0.7
As	*	*
Se	≤ 8	≤ 8
Rb	≤ 0.15	≤ 0.15
Sr	≤ 0.15	≤ 0.15
Y	≤ 0.05	≤ 0.05
Zr	≤ 0.1	≤ 0.1
Nb	≤ 0.1	≤ 0.1
Mo	≤ 0.6	≤ 0.6
Ru	≤ 80	≤ 80
Rh	≤ 10	≤ 10
Pd	bulk	bulk
Ag	≤ 20	≤ 20

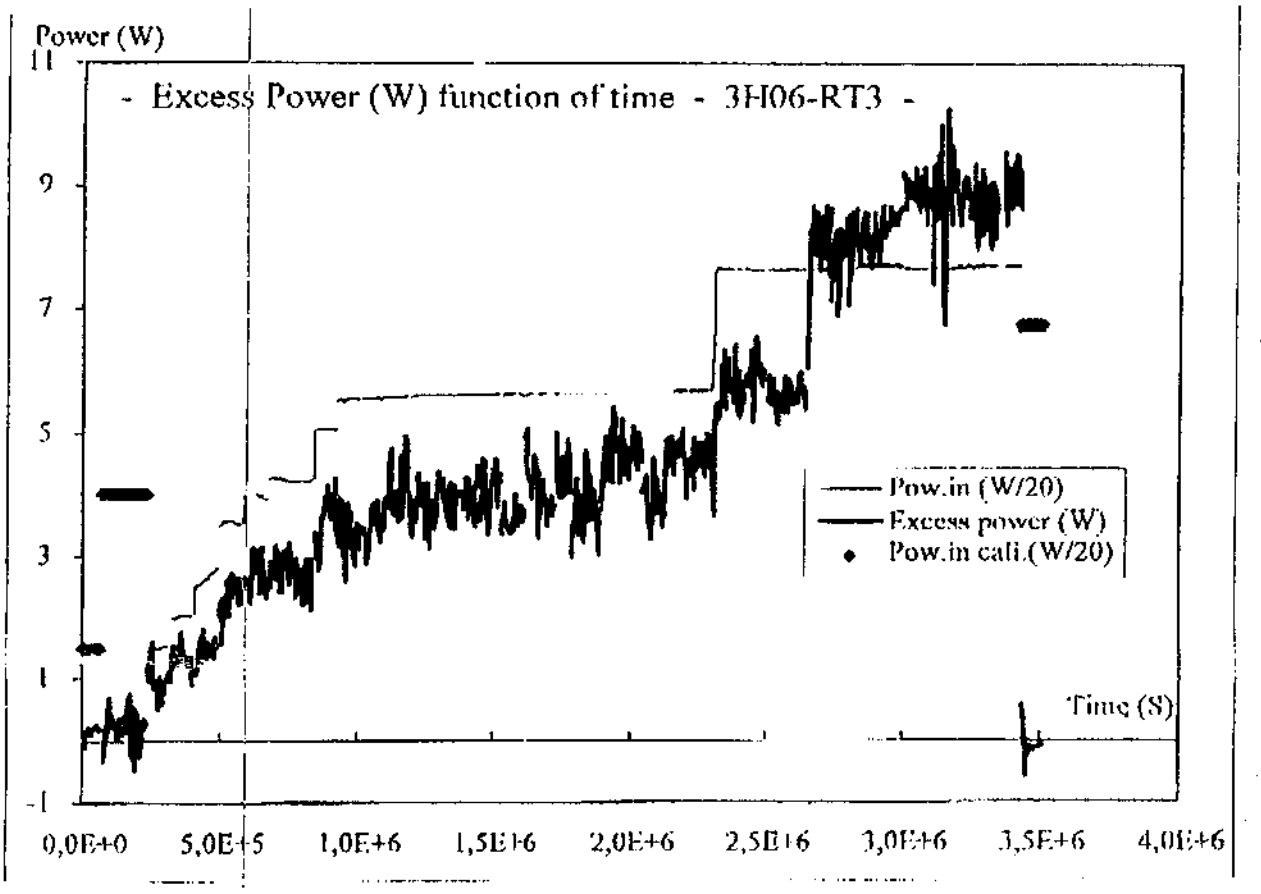
Element	Pd of 3H06	Virgin Pd sample
Cd	0.7 ± 0.2	0.7 ± 0.2
Sn	*	*
Sb	*	*
Te	*	*
Cs	≤ 0.05	≤ 0.05
Ba	≤ 0.07	≤ 0.07
La	≤ 0.15	≤ 0.15
Ce	*	*
Pr	≤ 0.07	≤ 0.07
Nd	*	*
Sm	≤ 0.4	≤ 0.4
Eu	≤ 0.01	≤ 0.01
Gd	≤ 0.1	≤ 0.1
Tb	≤ 0.02	≤ 0.02
Dy	≤ 0.08	≤ 0.08
Ho	*	*
Er	≤ 0.05	≤ 0.05
Tm	≤ 0.01	≤ 0.01
Yb	≤ 0.08	≤ 0.08
Lu	***0.05 ± 0.02***	***0.02 ± 0.01***
Hf	≤ 0.15	≤ 0.15
Ta	≤ 2	≤ 2
W	≤ 0.15	≤ 0.15
Re	≤ 0.1	≤ 0.1
Ir	***0.6 ± 0.2***	***0.5 ± 0.2***
Pt	***0.8 ± 0.1***	***1.4 ± 0.2***
Au	***0.8 ± 0.1***	***1.1 ± 0.1***
Hg	0.4 ± 0.1	0.4 ± 0.1
Tl	≤ 0.04	≤ 0.04
Pb	≤ 0.08	≤ 0.08
Bi	≤ 0.05	≤ 0.05
Th	≤ 0.15	≤ 0.15
U	≤ 0.05	≤ 0.05

* not measured ⇨ interference ; **nm** : not measured

Isotopic composition (expressed in atomic %)

Pd isotopes	Pd of 3H06	Virgin Pd sample	* Natural Pd
Pd 102	0.86 ± 0.10	0.87 ± 0.10	0.96
Pd 104	10.2 ± 1.0	10.2 ± 1.0	10.97
Pd 105	21.4 ± 1.5	21.5 ± 1.5	22.23
Pd 106	27.5 ± 2.0	27.5 ± 2.0	27.33
Pd 108	29.0 ± 2.0	28.9 ± 2.0	26.71
Pd 110	11.0 ± 1.0	11.0 ± 1.0	11.81

* Handbook of Chemistry and Physics - David R. Lide - 1994 - 1995 - CRC Pres


Power (W)
- Excess Power (W) function of time - 3H06-RT3 -
Pow.in (W/20)
Excess power (W)
Pow.in cali.(W/20)
Time (S)
11
9
7
5
3
1
-1
0,0E+0
5,0E+5
1,0E+6
1,5E+6
2,0E+6
2,5E+6
3,0E+6
3,5E+6
4,0E+6

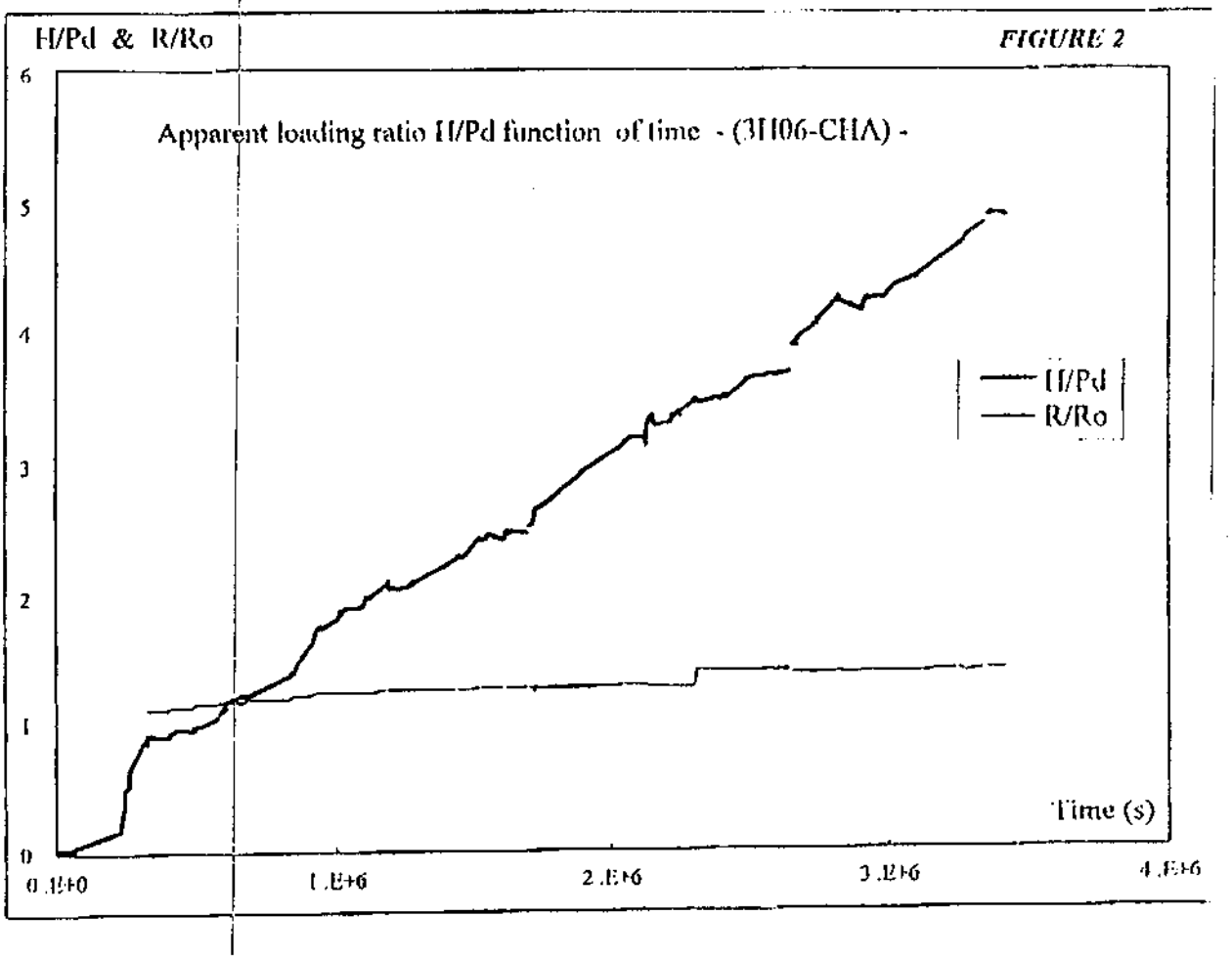

H/Pd & R/Ro
Apparent loading ratio H/Pd function of time - (3H06-CHA) -
H/Pd
R/Ro
Time (s)
6
5
4
3
2
1
0
0.E+0
1.E+6
2.E+6
3.E+6
4.E+6

FIGURE 2

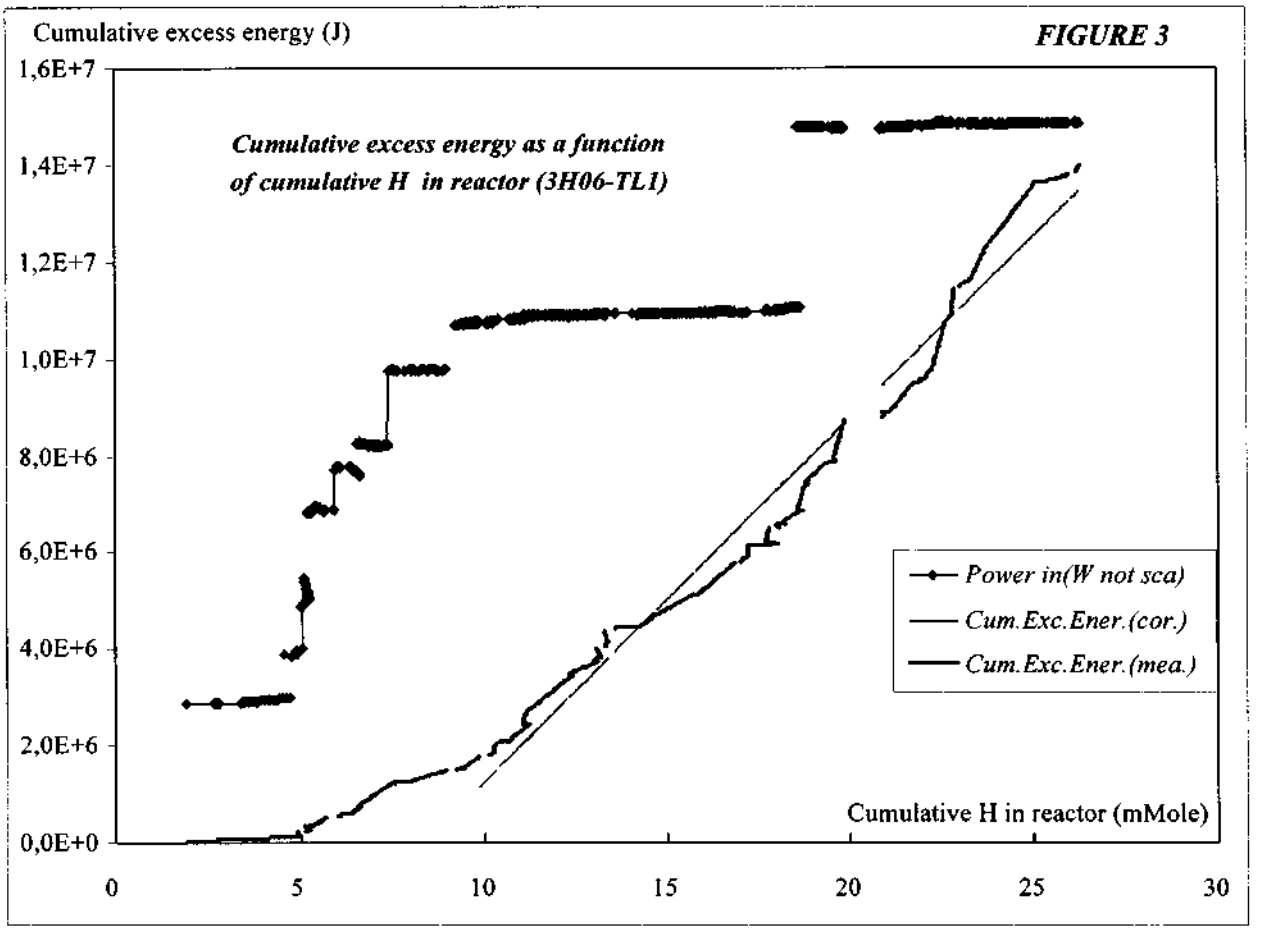


FIGURE 3

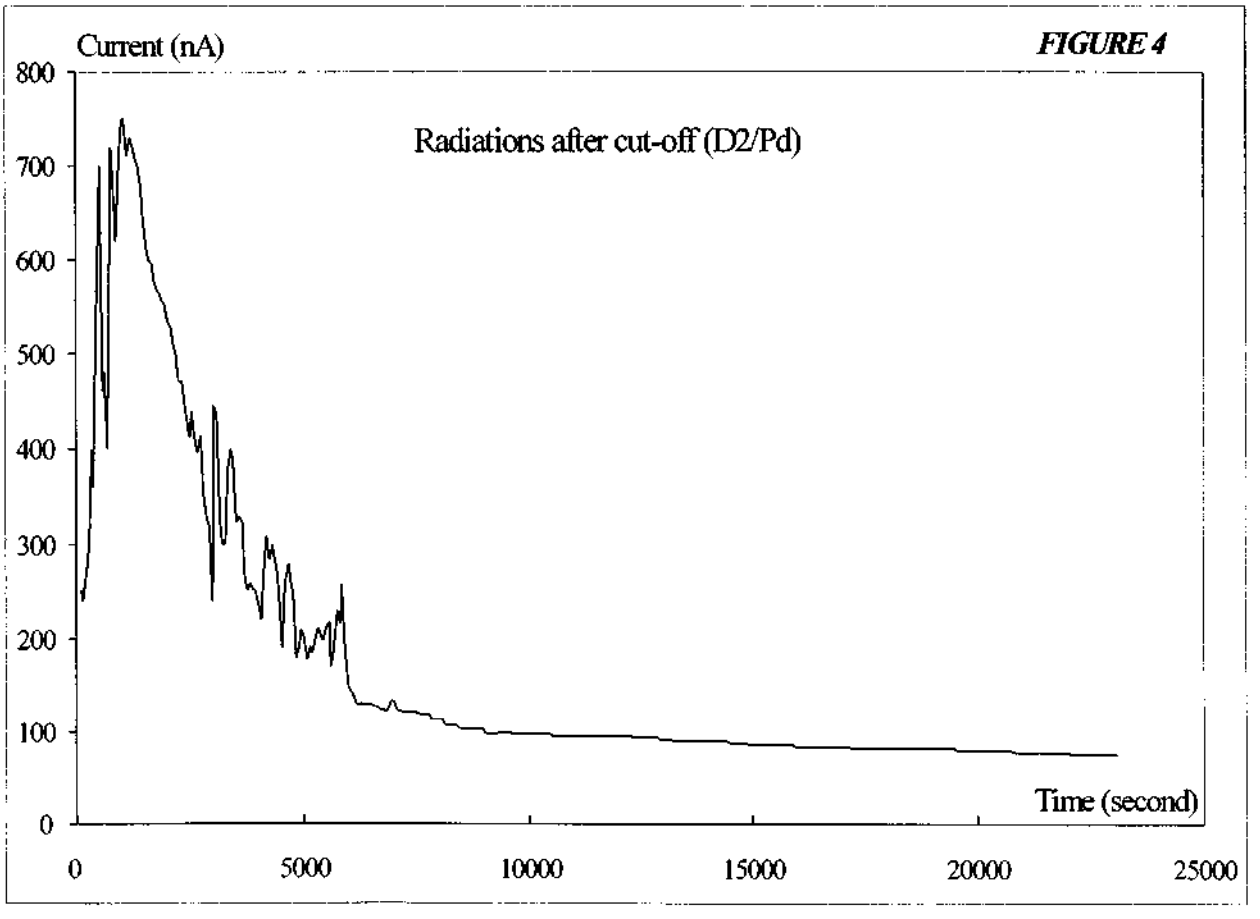


FIGURE 4