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CFP (Cold Fusion Phenomenon) stands for
"Nuclear reactions and accompanying events occurring in open (with external particle and energy supply), non-equilibrium system composed of solids with high densities of hydrogen isotopes (H and/or D) in ambient radiation" belonging to Solid-State Nuclear Physics (SSNP) or Condensed Matter Nuclear Science (CMNS).

This is the *CFRL News* (in English) No.95 for Cold Fusion researchers published by Dr. H. Kozima, now at the Cold Fusion Research Laboratory, Shizuoka, Japan.
This issue contains the following items:

1. ***Proc. JCF15* was published and posted at JCF website**
2. **From the History of CF Research (9) — Qualitative Reproducibility and Complexity in the Cold Fusion Phenomenon –**

1. *Proc. JCF15* was published

Proc. JCF15 held in Hokkaido, Japan on Nov. 1 – 2, 2014, was published and posted at JCF website;
http://www.jcfrs.org/proc_jcf.html

The Contents of the Proceedings is cited below;

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2. From the History of CF Research (9) — Qualitative Reproducibility and Complexity in the Cold Fusion Phenomenon —

2.1 Introduction

We have developed for about 20 years the science of the cold fusion phenomenon (CFP) phenomenologically using the TNCF model [Kozima 1994, 2006, 2014]. In the course of the development, we have noticed existence of regularity in the events of the CFP formulated in three laws; (1) The First Law: the stability effect for nuclear transmutation products, (2) the Second Law; the inverse-power dependence of the frequency on the intensity of the excess heat production, and (3) the Third Law: bifurcation and chaos of the intensity of events (neutron emission and excess heat production) in time [Kozima 2011].

About the general $1/f^{\delta}$-divergencies ($0.8 < \delta < 1.4$), the above explained second law in the CFP is an example, Schuster has shown that a class of maps (difference equations or recursion relations) which generates intermittent signals displays $1/f^{\delta}$-noise [Schuster 1984 (Sec. 4.3)].

The characteristics of the CFP including the Three Laws mentioned above suggest that the physics of the CFP should be investigated as a complexity in terms of the nonlinear dynamics [Kozima 2012, 2013]. In this paper, we take up this phase of the CFP using the controversial concepts of the irreproducibility and unpredictability as key words.

It should be mentioned a word on the general trend of contemporary science to look into the probabilistic nature of the whole world, the cold fusion phenomenon is a part of it as discussed in this paper, as explained by I. Prigogine in his excellent book [Prigogine 1996]. For the benefit of readers, we posted the *Introduction* of the book at this CFRL site next to the News No. 95;
http://www.geocities.jp/hjrfq930/News/news.html

It should be kind for the readers, to explain some words and concepts used in this paper before the discussion of the main theme.

(1) The cold fusion phenomenon (CFP)

The cold fusion phenomenon (abbreviated sometimes as "the CFP") is the name used in our papers to express *"Nuclear reactions and accompanying events occurring in open* (*with supplies of external particles and energy*)*, non-equilibrium system composed of solids with high densities of hydrogen isotopes* (*H and/or D*) *in ambient radiation" belonging to Solid-State Nuclear Physics (SSNP) or Condensed Matter Nuclear Science (CMNS).*

There are very many events observed by sophisticated experiments which are, however, not explained using physical principles established by the end of 20th century. And therefore, the CFP is not necessarily recognized as a part of science by scientists in the established branches of science and the accomplishment obtained in the field has been published in a limited small circle of specific publications.

One of the many reasons induced such a situation is the extraordinary difficult conditions to get positive results in the CFP which are inexplicable from known principles of science. The most controversial condition of the CFP will be the irreproducibility or unpredictability of experimental results which is the theme we take up in this paper to bridge the abyss between pros and cons of this phenomenon making the nature of events in the CFP clear logically.

To start the investigation of the essential points of the CFP, it is useful to arrange the processes occurring in the experiments of the cold fusion phenomenon.

(2) CF material and cf-matter

The field where the CFP occurs may be a special one because there occur events incredibly different from those occurring in other fields of established sciences, we have to use specific terminology which does not have civil right in other branches of science.

We define "the *cf-matter*" as the necessary condition (or state) for occurrence of the CFP in a "*CF material*" or "*CF substance*" (a solid material composed of a host element (e.g. C, Ti, Ni, Pd, etc.) and a hydrogen isotope (H or/and D)).

(3) Construction and Destruction of the cf-matter

Construction and destruction of the "cf-matter" (a state in a "CF material" where the cold fusion phenomenon (CFP) takes place) occur according to the atomic processes (microscopic processes) in a CF material arranged by an experimental setup (macroscopic processes) in a dynamical, non-equilibrium system composed of multi-component inhomogeneous materials (CF materials).

The construction is governed by essentially stochastic (or statistical) atomic processes occurring in inhomogeneous materials composed of a solid (transition metals or carbon) and hydrogen atoms H (and/or deuterium atoms D). The atomic processes include adsorption of H (D) on the surface of solids, absorption of H (D) into the solids, occlusion of H (D) in the solids, formation of an intermetallic compound (e.g. PdD, NiH, etc.), or formation of a regular array of a hydrocarbon (e.g. XLPE, microbial cultures, etc.) where exist stochastic processes (diffusion) and/or self-organization of a stoichiometric compound in local area from non-stoichiometric solution.

The macroscopic arrangement of an experimental initial condition does not completely determine the microscopic initial condition at all and there is a vast freedom not determined by the arrangement which results in variety of CF materials. The variety itself may produce different effects after nuclear reactions between components of the CF material (cf-matter).

Furthermore, the self-organization is not controlled by the macroscopic initial condition at all and therefore the resulting cf-matter is not controllable from outside.

(4) Unpredictability and Irreproducibility

There have been a long history of unresolved disputes between pros and cons about the reality of the CFP since the first stage of the investigation when the paper by Fleischmann et al. [Fleischmann 1989] and the *DOE Report 1989* [DOE 1989] were published in 1989. However, it seems there is a misunderstanding of the meaning "irreproducibility" in science which will be resolved by consideration of the relation of cause and effect in proper concepts.

It will be possible to say that the concept "unpredictability" in theoretical context corresponds to the "irreproducibility" in experimental situation. We say the effect is unpredictable when we cannot predict the result (effect) for a definite initial condition (cause) for a system. In this case, a cause does not give a definite effect. We say the effect is irreproducible when we cannot obtain the same result (effect) for a (supposedly) the same experimental condition for a system.

The cause-effect correspondence (relation) for a physical process is divided into three cases: Effect with (1) "one-to-one" correspondence between them, (2) "one-to-several" correspondence with a probability, (3) "one-to-none" (or "one-to-some" effects) correspondence with by chance (or without any definite probability).

These cases are expressed by the predictability with (1) a quantitative probability with a definite value, (2) a qualitative probability with statistical values, and (3) zero probability for the effect.

Correspondingly, the cases are expressed experimentally by (1) a quantitative reproducibility, (2) a qualitative reproducibility, and (3) irreproducibility.

Here, in the CFP, are two causes of unpredictability (and therefore irreproducibility), the first is the stochastic processes in the formation of CF materials and the second is the self-organization of cf-matter in the CF materials including enough amount of hydrogen isotopes in solids.

Destruction of the cf-matter is induced by the CFP itself that makes the components of the CF material shift from the optimal ones for the CFP and also destroys the structure of the CF material by heat and dynamical impact by particles produced by nuclear reactions. The destruction of the cf-matter is another cause of irreproducibility and unpredictability.

2.1.1 Qualitative Reproducibility or Statistical Reproducibility

Unpredictability in theoretical context means irreproducibility in experimental context. We use these words interchangeably in following discussions.

2.1.1a Macroscopic States and Microscopic States

It is impossible to control microscopic states by defining macroscopic states in principle. Furthermore, it is impossible to determine exact states by an experiment without any error. This situation is described clearly in relation to the unpredictability due to instability or chaotic nature of the system in a text on the nonlinear dynamics.

In the linear dynamical systems we have mainly treated in classical physics, we can say following expression for the cause-effect relation:

"*Measurements could never be perfect. Scientists marching under Newton's banner actually waved another flag that said something like this: Given an approximate knowledge of a system's initial conditions and an understanding of natural law, one can calculate the approximate behavior of the system.*" [Gleick 1987 (p. 14-15)].

The expression has to be altered by a following sentence when there is nonlinearity in the system;

"*The often repeated statement, that given the initial conditions we know what a deterministic system will do far into the future, is false. Poincaré (1892) knew it was false, and we know it is false, in the following sense: given infinitesimally different starting points, we often end up with wildly different outcomes. Even with the simplest conceivable equations of motion, almost any non-linear system will exhibit chaotic behaviour. A familiar example is turbulence.*" [Cvitanovic 1989 (p. 3)]

The problem in the predictability is expressed in the above sentence by Gleick as "*one can calculate the approximate behavior of the system.*" which is only correct in the deterministic system with a negative Lyapunov exponent explained in Sec. 1.1.1c (and also [Strogatz 1994 (Sec. 10.5)]). It is shown that there are systems in which this is not true as explained there.

2.1.1b Averaging of Measured Results on an Effect Observed by an Experiment

Effects are sometimes summed up to make them measurable by macroscopic apparatus which is handled macroscopically (e.g. pressure gauge for gas pressure – induced by extravagant number of molecular impacts on a wall).

For events where we satisfy with their effects averaged over time and space, we do not care about their exact initial condition (which is impossible to get by our limited imperfect ability of measurement) but approximate one which results in approximate behavior and in the same average effect irrespective of their initial condition. Irrespective of minor differences in the initial condition, we can reproduce the almost the same result by averaging over approximate results – attaining reproducibility.

However, there are other cases where we meet an individual event but not the averaged one.

The alpha-decay of Radium-226 ($^{226}_{88}Ra$) is statistical and its average behavior is described by an equation

$$N(t) = N(0) \exp(-t / \tau), \qquad (1.1)$$

where $N(0)$ and $N(t)$ are the numbers of the nuclei at time 0 and t, respectively. The real decay process is not described by the relation (1.1) but stochastic; the signals of a Geiger counter amplifying the discharge caused by alpha-particles reflect the decay process of the $^{226}_{88}Ra$ placed near the counter.

In this case, the signal of a Geiger counter is not described by a differential equation (1.1) but by a difference equation. Suppose that each signal of the Geiger counter gives a tremendous amount of water that we have to treat as fast as possible, we cannot wait several signals to be averaged over them. Then, the averaging of the signals is nonsense and the individual event is meaningful. The situation we met in the CFP may correspond to the latter example described above. And averaging and therefore reproducibility has nothing with the CFP.

Another example of the statistical or qualitative reproducibility is the famous $d-d$ fusion reactions at low energy as discussed by Huizenga in his book;

"$D + D \rightarrow [^4He]^* \rightarrow {}^3He$ (0.82 MeV) + n (2.45 MeV), (1.2a)

$\rightarrow T$ (1.01 MeV) + p (3.02 MeV), (1.2b)

$\rightarrow {}^4He$ (0.08 MeV) + γ ray (23.77 MeV), (1.2c)

The reactions (l.2a) and (1.2b) have been studied over a range of deuteron kinetic energies down to a few kilo-electron volts (keV) and the cross sections (production rates) for these two reactions have been found experimentally to be nearly equal (to within ten percent). Hence, the fusion of deuterium produces approximately equal yields of 2.45 million-electron-volts (MeV) neutrons (with an accompanying ^{3}He atom) and 3.02–MeV protons (with an accompanying tritium atom). This near-equality of the neutron and proton branches (production rates) is expected also on the basis of theoretical arguments. The cross section (production rate) for reaction (1.2c) is several orders of magnitude lower than reactions (l.2a) and (1.2b)." [Huizenga 1992 (pp. 6 – 7)]. (Numbers of the equations are renumbered at citation.)

The fusion reaction of two deuterons with energies down to a few keV occurs with probabilities for three channels given in Eqs. (1.2) as explained in the above sentence by Huizenga [Huizenga 1992]. If the results are averaged over many events, then we will obtain the products according to the probabilities determined by the branching ratios. The individual product, however, shows an unexpected value not described by the probability in a short term measurement where we observe only few reactions. This is another example of the qualitative (or probabilistic) reproducibility in nuclear physics where it is usual laws in microscopic processes.

It should be noticed another phase of truth in the sentence by Huizenga cited above. We know a doubt expressed by M. Fleischmann in his first paper on the mechanism of the CFP;

"*The most surprising feature of our results however, is that reactions (v) and (vi) are only a small part of the overall reaction scheme and that the bulk of the energy release is due to an hitherto unknown nuclear process or processes (presumably again due to deuterons).*"[Fleischmann 1989]. (The reactions (v) and (vi) in this sentence correspond to reactions (1.2a) and (1.2b) written above in this paper.)

The point we want to notice is the different reactions of Huizenga and Fleischmann to the experimental fact: Huizenga pointed out only the contradiction between the fact and the scheme of existing science while Fleischmann noticed something new in the same contradiction as Huizenga noticed.

Here, we remember a parable about our recognition told by ancient

Chinese saint:
"*When you are angry, you cannot be correct. When you are frightened, you cannot be correct; when there is something you desire, you cannot be correct; when there is something you are anxious about, you cannot be correct. When the mind is not present, we look, but do not see. We listen, but do not hear; we eat, but don't taste our food. This is the meaning of "the cultivation of the person lies in the correction of the mind.*"[Great Learning (9. The cultivation of the person lies in the correction of the mind.)].

We see that the cause of the difference in the responses of two scientists to the same fact is based on the desire they had in their mined; "*when there is something you desire, you cannot be correct;*" From my point of view, the desire in the mind of Huizenga disturbed his sight into the truth through the experimental facts.

Evidence of stochastic occurrence of events (at least the emission of neutrons) in the CFP is clearly shown in Fig. 2.1.1 by an excellent experiment by Gozzi et al. [Gozzi 1991]. As is well known, the Poisson distribution is a discrete probability distribution that expresses the probability of a given number of events occurring in a fixed interval of time and/or space if these events occur with a known average rate and independently of the time since the last event. One of examples in physics that may follow a Poisson is the number of decay events per second from a radioactive source, as cited above the alpha-decay of $^{226}_{88}$Ra.

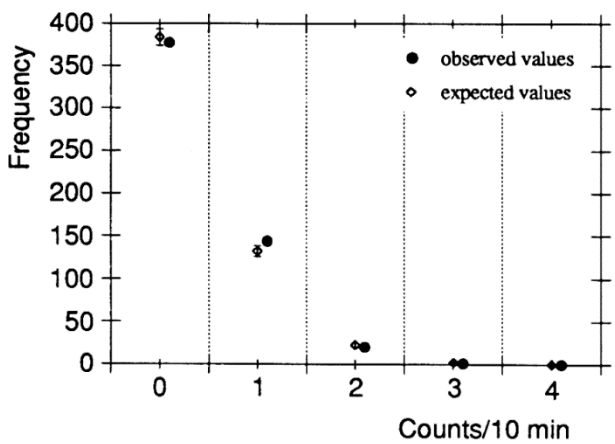

Fig. 2.1.1 Frequency count of neutrons as observed in 5421 intervals of ten minutes acquisitions and as expected in a Poisson distribution. The

variability of the expected values obtained allowing the measured mean value to vary between $\mu - \sigma = 0.32$ and $\mu + \sigma = 0.37$ counts/10 min. is also reported [Gozzi 1991 (Fig. 13)].

2.1.1c Self-organization and Chaotic Behavior of a Microscopic State in Non-equilibrium Condition beyond Control by Macroscopic Conditions

As we have discussed already in a paper published in 2013 [Kozima 2013], there is a possibility that the optimum microscopic state, e.g. the superlattice of a host element and a hydrogen isotope, is constructed by self-organization in the non-equilibrium CF materials. It is, of course, the process governed by nonlinear dynamics and is not controllable macroscopically. This characteristic is discussed by many in terms of the complexity as cited below:

"*The constructive role of irreversibility is even more striking in far-from-equilibrium situations where non-equilibrium leads to new forms of coherence.*" [Prigogine 1996 (p. 26)]
"*Nonequilibrium leads to concepts such as – self-organization and dissipative structures*, - - - ." [Prigogine 1996 (p.27)]

"*Could unpredictability itself be measured? The answer to this question lay in a Russian conception, the Lyapunov exponent. This number provided a measure of just the topological qualities that corresponded to such concepts as unpredictability. The Lyapunov exponents in a system provided a way of measuring the conflicting effects of stretching, contracting, and folding in the phase space of an attractor. They gave a picture of all the properties of a system that lead to stability or instability. An exponent greater than zero meant stretching—nearby points would separate. An exponent smaller than zero meant contraction (stability). For a fixed-point attractor, all the Lyapunov exponents were negative, since the direction of pull was inward toward the final steady state. An attractor in the form of a periodic orbit had one exponent of exactly zero and other exponents that were negative. A strange attractor (chaos), it turned out, had to have at least one positive Lyapunov exponent.*" [Gleick 1987 (p. 253)]

The stability of a system is determined by the sign of the Lyapunov exponent of the system described by a difference equation. As explained in our paper [Kozima 2013], the Feigenbaum's theorem tells us a various kind of systems obeying a single hump distribution of the recursion function show the chaotic behavior, and therefore unpredictability or irreproducibility.

2.1.2 DOE Reports on the Consistency and Reproducibility

As we have pointed out in the first issue of this series (*From the History of CF Research* (1)), the critiques of the Reviewers of the *DOE Reports* published in 1989 [DOE 1989] and in 2004 [DOE 2004] are valuable to take up seriously to develop the science of the CFP recognizing their limits imposed by the conditions the Reviewers had to suffer in their work. We pick up several problems pointed out by the Reviewers in relation to the reproducibility we are discussing in this paper.

2.1.2a Consistency between Observables in Theoretical Expectation

"*Those who claim excess heat do not find commensurate quantities of fusion products, such as neutrons or tritium that should be by far the most sensitive signatures of fusion. Some laboratories have reported excess tritium. However, in these cases, no secondary or other primary 3 nuclear particles are found, ruling out the known D+D reaction as the source of tritium.*" [DOE1989 (Summary)]

"*Neutrons near background levels have been reported in some D_2O electrolysis and pressurized D_2 gas experiments, but at levels 10^{12} below the amounts required to explain the experiments claiming excess heat.*" [DOE1989 (Summary)]

2.1.2b Reproducibility or Predictability

Unpredictability in theoretical context means irreproducibility in experimental context.

"*Some experiments have reported the production of tritium with electrolytic cells. The experiments in which excess tritium is reported have not been reproducible by other groups. These measurements are also inconsistent with the measured neutrons on the same sample. Most of the experiments to date report no production of excess tritium. Additional investigations are desirable to clarify the origin of the excess tritium that is occasionally* *observed.* " [DOE1989 (Summary)]

"*- - they have been unable (a) to completely solve the nagging problem of the non-reproducibility (irreproducibility) of the experimental results, or (b) to elucidate and/or nail down all the important parameters involved in the proposed cold-fusion phenomena (plural nuclear mechanisms have been proposed) or (c) even to convince the broader scientific community that cold fusion is real.*" {DOE2004 (Reviewer #7)}

"*In a general summary of the calorimetric results, the observation of sudden and prolonged temperature excursions (bursts of excess heat), has been made a sufficient number of times that, even if not totally reproducible, still have not been explained in terms of conventional chemistry or electrochemistry (a conclusion also made in the 1989 ERAB report). However the systems are sufficiently complicated, the measurement sufficiently difficult, and the effects sufficiently small, that it is difficult to conclude from these effects alone that nuclear processes are involved. Even with all of the careful work that has been done on electrochemical cells and calorimetry, the system is still not under experimental control, in the sense that one knows exactly the materials needed and the operating conditions to get the same results, even semi-quantitatively, every time.*" [DOE2004 (Reviewer #10)]

"b) *Experiments involving excess power/heat. More careful experiments have been done in recent years (e.g. SRI work). There seem to be increasing evidence for the production of excess heat, even though the reason is totally unknown. Reproducibility has been improved, but it still has not reached a satisfactory level. Yes, it is likely that an unknown process (in materials physics or in nuclear physics) is responsible. However, the link to nuclear reaction is still not strong enough at the present time.*" [DOE2004 (Reviewer #12)]

"In spite of the lack of reproducibility and predictability, positive observations have been made a number of times and by several different groups under what seem to be credible experimental conditions." [DOE2004 (Reviewer #13)]

"2) *Reproducibility*

The lack of reproducibility continues to be a serious problem. None of the important phenomena can be duplicated reliably. This has made it impossible to obtain a quantitative understanding of what is taking place. [DOE2004 (Reviewer #14)]

2.1.3 Responses to the Critiques on the Irreproducibility in the CFP

There are several explanations for the lack of reproducibility in the CFP based on the inherent incompleteness to arrange microscopic initial conditions in experiments. One of such explanations was given by McKubre et al.:

"*An apparent irreproducibility in the production of an, as yet, anomalous excess power from Pd cathodes electrochemically loaded with D can be associated with irreproducibility in the attainment of several necessary starting conditions. Of these, the threshold loading (D/Pd atomic ratio) has received the most attention. A statistical analysis is presented of the results of 176 experiments intended to test the means of establishing reproducible control over D/Pd loading. A set of variables are examined, and procedures identified which permit the attainment of loading above the threshold necessary for excess heat production.*" [McKubre 1995 (Introduction)]

The "*irreproducibility in the attainment of several necessary starting conditions*" mentioned by McKubre et al. in the above sentence cited from their paper is an expression universally true in experimental science as noticed in Section 2.1.1a.

2.2 Qualitative Reproducibility in the Cold Fusion Phenomenon (CFP)

Even if we could not reproduce our measurements in the CFP quantitatively, we have obtained the similar (qualitatively the same) experimental results as shown in the next subsection 2.2.1; i.e. the result is qualitatively the same from a null to some maximum value for the same macroscopic arrangement for an experiment.

2.2.1 Experimental Evidences

There are many examples showing the qualitative reproducibility of the effects in the CFP for the same macroscopic setup of experiments. (We give a list of very many papers where are shown mainly the experimental results of qualitative reproducibility on the end of this subsection until 1996 (ICCF6) omitting all papers published afterwards.)

"(b) *Enthalpy generation can exceed 10 W/cm³ of the palladium electrode; this is maintained for experiment times in excess of 120 h, during which typically heat in excess of 4 MJ/cm³ of electrode volume was liberated.*" [Fleischmann 1989 (p. 304 – 305)].

This sentence means that the numbers tabulated in Table 1 of their paper [Fleischmann 1989] are averaged over some experimental times but not the instantaneous values which fluctuate with very large amplitudes.

We cite here several experimental data showing temporal evolution of excess powers and disintegration numbers as illustrations of the qualitative reproducibility in Figs. 2.2.1 – 2.2.7.

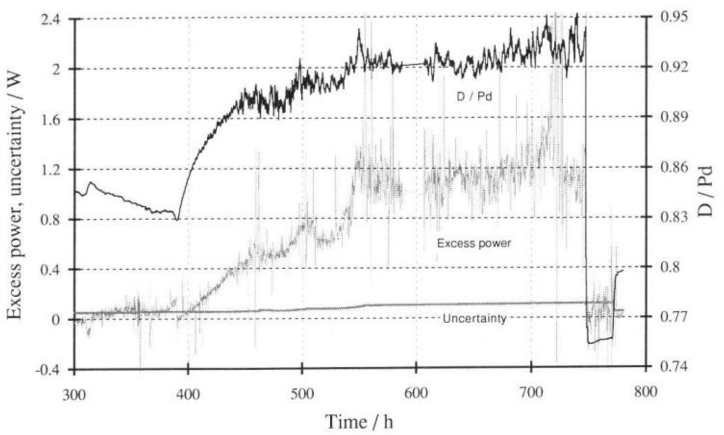

Fig. 2.2.1 Variation of excess power, uncertainty and loading [McKubre 1993 (Fig. 5)]. Shows temporal variations of the loading ratio D/Pd and the excess power. The former is out of control by macroscopic experimental setup and the latter is the effect caused by the cf-matter constructed in the CF material (PdD_x).

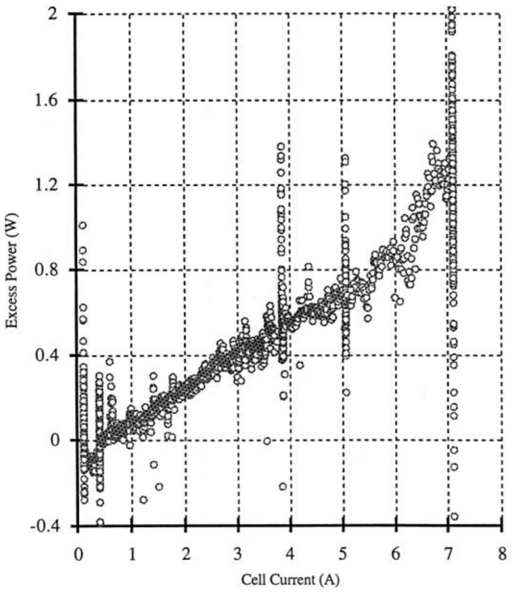

Fig. 2.2.2. Variation of excess power with cell current [McKubre 1993 (Fig. 6)]. The excess power is qualitatively reproduced for a definite cell current.

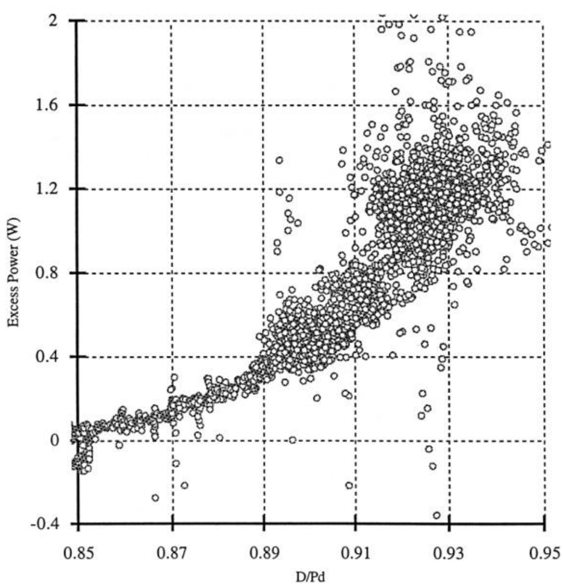

Fig. 2.2.3. Variation of excess power with loading ratio [McKubre 1993 (Fig. 7)]. The excess power is qualitatively reproduced for a definite value of D/Pd ratio.

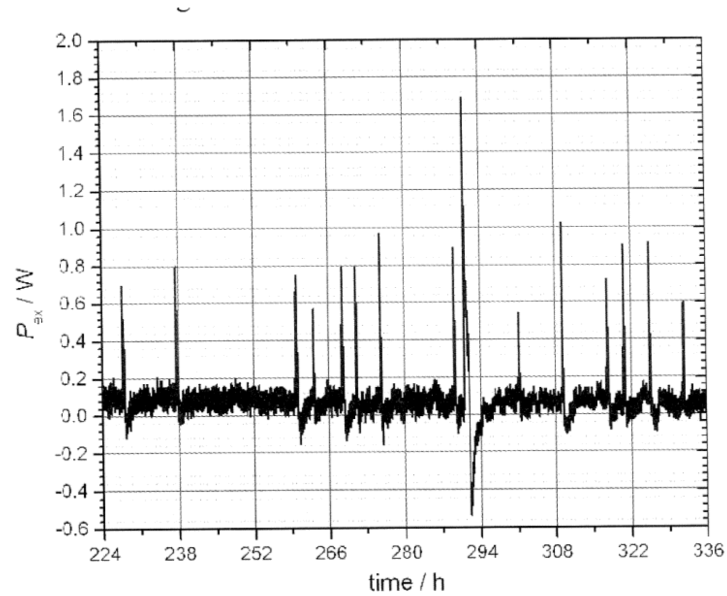

Fig. 2.2.4 Excess Power pulses and bursts curing a 112 hour period of an experiment (061026) which lasted 14 days as a whole [Kozima 2008 (Fig. 2)]. The excess power is qualitatively reproducible but uncontrollable as shown in this and the next figures.

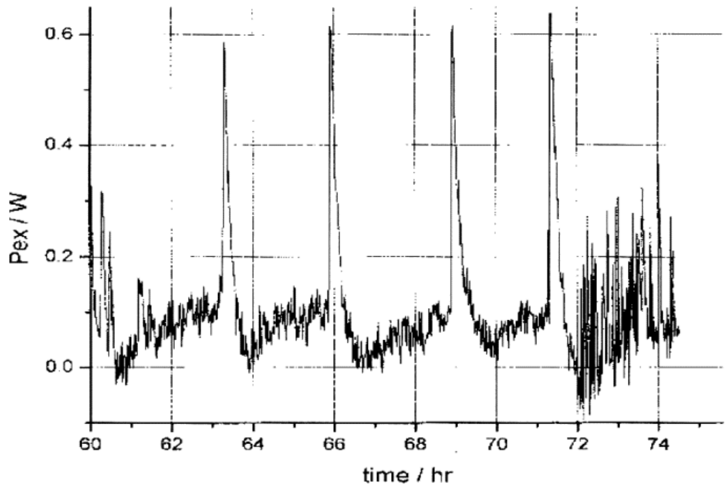

Fig. 2.2.5. Excess power pulses during a 14 hour period of an experiment (070108) which lasted 12 days as a whole [Kozima 2008 (Fig. 3)].

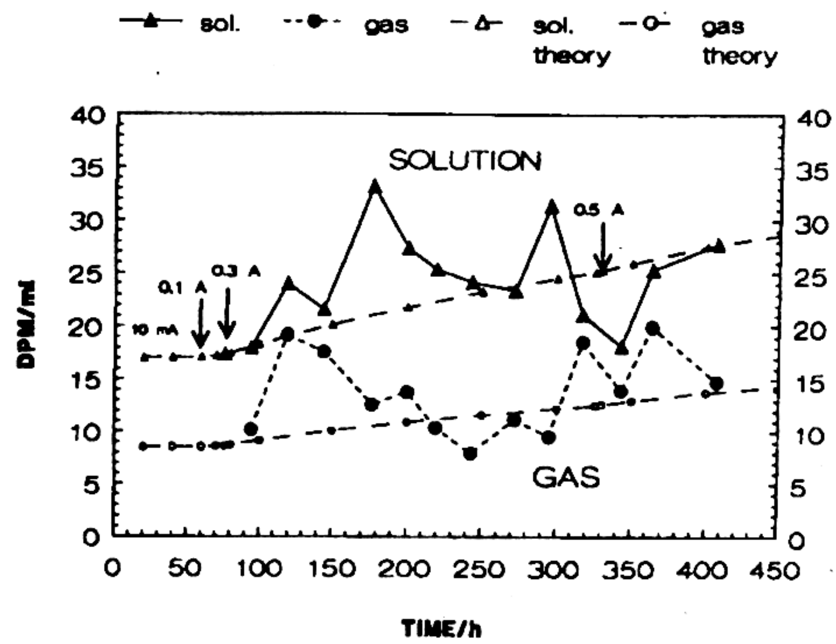

Fig. 2.2.6. DPM (disintegrations per minute)/ml of tritium vs. time (hour) in the liquid and gas phases during 2 weeks of electrolysis in 0.05 M PdCl2/0.3 M LiCl; dashed lines – theoretical values. [Bockris 1993 (Fig. 6)]

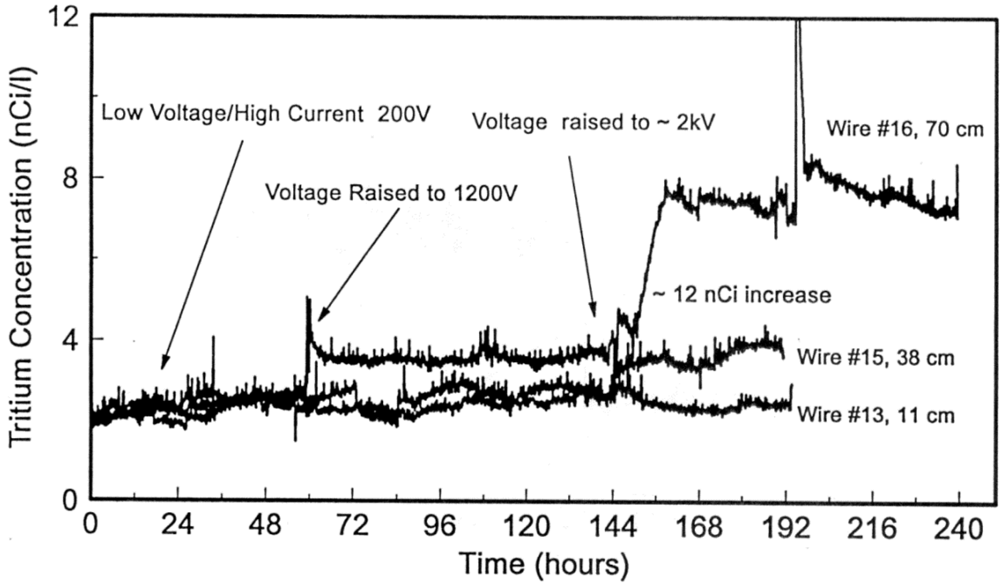

Fig. 2.2.7 Tritium evolution (nCi/l) vs. time from three power wire cells. The conditions that produced the large, sudden increase in tritium level in wire cell 16 have not been reproduced. [Tuggle 1994 (Fig. 5)]

The largest result in powder wires in the experiments by Tuggle et al. [Tuggle 1994] is shown in Fig. 2.2.7 which occurred when an arc was apparently formed in the track. The rate of tritium production (~ 5 nCi/h) during this episode far exceeds anything they had seen from the other types of cells.

References for Subsection 2.2.1

[Bertalot 1995 (Figs. 2 and 3)], [Bockris 1993 (Fig. 6)], [Celani 1993 (Figs. 7 – 9)], [Cellucci 1996 (Figs. 3 – 5)], [Claytor 1991 (Fig. 8)], [Dufour 1995 (Fig. 7)], [Fleischmann 1989 (Table 1 and its explanation), 1993 (Fig. 6), 1995a (Figs. 4 and 8), 1995b (Fig. 5)], [Gozzi 1991 (Fig. 5)], [Iwamura 1994 (Figs. 2, 5)], [McKubre 1991 (Figs. 7, 8, 14), 1993 (Figs. 5 – 7), 1995 (Figs. 1 – 4)], [Mengoli 1991 (Figs. 1 and 3)], [Menlove 1991 (Fig. 5)], [Miles 1996 (Figs. 1 – 5)], [Miyamaru 1994 (Fig. 5)], [Kozima 2008 (Figs. 2 and 3)], [Numata 1991 (Fig. 5)], [Okamoto 1994 (Figs. 6, 8)], [Ota 1993 (Fig. 1)], [Pons 1994 (Figs. 4, 7, 14)], [Sevilla 1993 (Fig. 3)], [Shyam 1995 (Figs. 3 and 5)], [Szpak 1993 (Fig. 1)], [Takahashi 1991 (Fig. 5), 1993 (Figs. 4 – 7)], [Tazima 1991 (Fig. 2 – 4)], [Tuggle 1994 (Figs. 4, 5, 6, 7)],

2.2.2 Theoretical Justification

As shown in the preceding section by several from very many experimental results cited as References there, we have experimental evidence showing that the CFP shows characteristics of the complexity investigated thoroughly by nonlinear dynamics.

It is, however, difficult to give a mathematical analysis for the events in the CFP based on the nonlinear dynamics due to the complex nature of the mechanisms working in the CF materials. We have given phenomenological approach to this problem and formulated a tentative scheme for the analysis of the CFP with the nonlinear dynamics [Kozima 2012, 2013]. We give an outline of our trial in this Section.

2.2.2a Formation of CF Materials with Sufficient Conditions for the CFP

The most important mechanism for the CFP may be the formation of the optimal structure (e.g. PdD and NiH superlattice) in the CF materials. In this formation, we supposed the self-organization in complexity is working

(Local hydridation of Ni (formation of NiH in localized regions, e.g. at surface regions) or local deuteridation of Pd (formation of PdD in localized regions, e.g. at surface regions) by self-organization in complexity) [Kozima 2012, 2013].

Emergence of the localized optimum structure (state) PdD (NiH) in the CF material with an average composition PdD_x (NiH_x) (x = 0.85 – 0.95) by self-organization is one of features described by complexity in nonlinear dynamics.

2.2.2b Change of CF Materials due to Nuclear Reactions of the CFP

The optimum state for the CFP formed by the self-organization or other mechanisms does not last long by the change of environment due to the nuclear reactions causing the CFP. The change will result in the positive feedback for the CFP in favorable situation (as discussed by Fleischmann [Fleischmann 1995a]) or in the destruction of the optimum state to terminate the reactions.

We have given a trial to explain the positive feedback of nuclear reactions in the CFP based on the TNCF model in a former paper [Kozima 2012 (Sec. 3.2)] where the parameter n_n in the model is used as the variable of the logistic difference equation. When the CF reaction causes a change of n_n in the direction favorable for the reaction, then the CFP receives a positive feedback.

While the case is positive for the CFP in the above case, the opposite case is also possible. When there occurred a nuclear reaction in a CF material, the physical parameters, temperature, composition and so forth, around the site where the reaction occurred would change and the necessary condition for the CFP satisfied before the reaction could be not satisfied anymore. This is the case probably occurs rather frequently where the CFP terminates rapidly than the case of positive feedback favorable for the CFP considered above.

2.3 Complexity

As is now common sense to accept the concept of complexity for systems with nonlinear interactions among components noticed in Introduction, we have to investigate the CF materials from the viewpoint of nonlinear dynamics accepting the statistical reproducibility for the events in the CFP.

One of the concepts we have to take into our consideration is the formation of the optimum state for the CFP by the self-organization as discussed before [Kozima 2013]. Self-organization of the regular superlattice composed of sublattices of a host element and a hydrogen isotope, e.g. NiH, PdD, and HC_6 (or HC_8) gives a chance to form the neutron bands in a CF material [Kozima 2013 (Sec. 3.3)]. In the neutron band, we can expect formation of the cf-matter corresponding to the trapped neutron with a density n_n assumed in the TNCF model.

Another concept suggested for the CFP by the complexity is chaotic behavior of the events such as bifurcation and chaos [Kozima 2012 (Sec. 2.3)].

One of many examples showing the chaotic behavior of physical systems is shown in Fig. 2.3.1 for laser [Strogatz 1994].

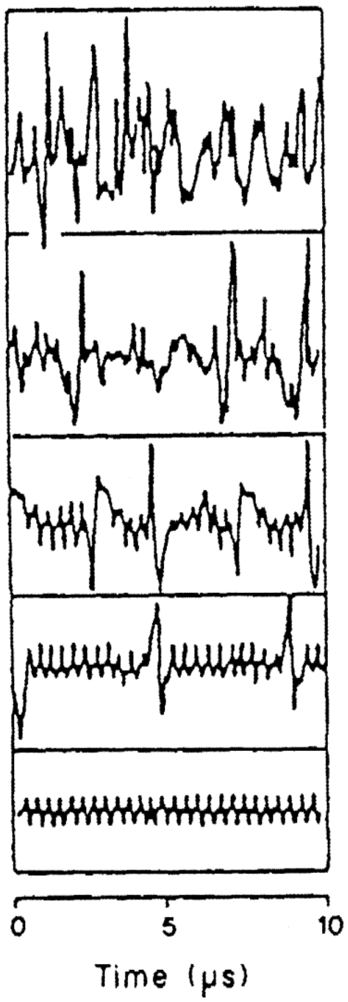

Fig. 2.3.1 Intensity of emitted laser light vs. time [Strogatz 1994 (Fig. 10.4.5)].

In Fig. 2.3.1, an experimental example of the intermittency rout to chaos in a laser is shown [Strogatz 1994 (Fig. 10.4.5)]. In the lowest panel of Fig. 2.3.1, the laser is pulsing periodically. A bifurcation to intermittency occurs as the system's control parameter (the tilt of the mirror in the laser cavity) is varied. Moving from bottom to top of Fig. 2.3.1, we see that the chaotic bursts occur increasingly often.

We can compare the figures in Fig. 2.3.1 with examples from the CFP (Figs. 2.2.1 – 2.2.7) cited above in Sec. 2.2.1. It is impressive to recognize the close similarity of temporal behaviors of a laser in Fig. 2.3.1 and those observed in the CFP, even if it is only an analogy between a well-known laser emission and an unknown phenomenon called the CFP.

In a former paper, we have given a trial for the explanation of applicability of Feigenbaum's theorem to the events in the CFP. In the trial, we identified the parameter n_n of the TNCF model (assumed to be the density of trapped neutrons in a CF material) with the parameter λ in the logistic equation [Kozima 2012 (Sec. 3.2)]. The treatment is legitimated qualitatively by the general discussions cited below from Strogatz's book [Strogatz 1994].

"*How can the theory work, given that it includes none of the physics of real systems like convecting fluids or electronic circuits? And real systems often have tremendously many degrees of freedom—how can all that complexity be captured by a one-dimensional map? Finally, real systems evolve in continuous time, so how can a theory based on discrete-time maps work so well?*" [Strogatz 1994 (Section 10.6)]

"*Now we can see why certain physical systems are governed by Feigenbaum's universality theory—if the system's Lorenz map is nearly one-dimensional and unimodal, then the theory applies. This is certainly the case for the Rössler system, and probably for Libchaber's convecting mercury. But not all systems have one-dimensional Lorenz maps. For the Lorenz map to be almost one-dimensional, the strange attractor has to be very flat, i.e., only slightly more than two-dimensional. This requires that the system be highly dissipative; only two or three degrees of freedom are truly active, and the rest follow along slavishly. (Incidentally, that's another reason why Libchaber et al. (1982) applied a magnetic field; it increases the damping in the system, and thereby favors a low-dimensional brand of chaos.)*" [Strogatz

1994 (Section 10.6)]

2.4 Conclusion

The various phases of the CFP, some of them have been investigated in this paper, make the science of the CFP very difficult to understand and construct it in the ordinary manner of natural science developed by the 20th century which treated mainly simple linear systems. We have tried to construct an image of the science of the CFP phenomenologically based on the experimental facts even if they did not fit into the frames of existing sciences [Kozima 1998, 2006, 2014]. Our trial developed by 2014 has revealed several important phases of the science which are, of course, only a part of the true image of the science of the CFP.

One of the important features of the CFP noticed in this paper is shown experimentally in Fig. 2.1.1 (Poisson distribution of neutron pulses) supplementing the complexity nature of the CFP by bifurcation and chaos of events discussed in Sec. 2.2. The CFP shows sometimes a simple independent event as revealed in Fig. 2.1.1 and also shows temporal developments revealed by Figs. 2.2.1 – 2.2.7 which might be described by nonlinear dynamics.

The regularity found in the CFP, formulated in the Three Laws [Kozima 2011], shows also a phase of the CFP closely related to the complexity as explained briefly in Sec. 2.1 referring to the work by Schuster [Shuster 1984].

The experimental data obtained in these more than a quarter of the century show clearly the CFP is closely related to the physics of neutrons in CF materials as our phenomenological approach revealed. The physics of neurons in CF materials is in turn governed by nonlinear dynamics and therefore the CFP is destined to be complexity. This characteristic of the CFP explains the controversial problem of reproducibility of events in this field.

The characteristics of the CFP reviewed in this series of "From the History of Cold Fusion Research" and also in the books and papers published before (e.g. [Kozima 1998, 2006, 2014]) surely related with phenomena in nuclear physics and solid state physics. We hope the researchers in these fields will pay attention to the CFP in proper researches which must be really useful for their works.

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