Energies **2009**, *2*, 1-x manuscripts; doi:10.3390/en20x000x

OPEN ACCESS

energies

ISSN 1996-1073

www.mdpi.com/journal/energies

Review (Type of Paper)

Potential Clean Energy by Condensed Cluster Fusion

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Received: / Accepted: / Published:

Abstract: Clean distributable energy source is expected to develop for the sustainable societies in the 21st century. Recent research development of condensed matter nuclear science (CMNS), which is the descendant new research filed of past controversial "cold fusion" saga, is now revealing the new possibility of potential clean nuclear energy in portable size devices, although the stage of research is still basic and fundamental. This review paper describes; 1) Brief experimental results of anomalous excess heat generation with ^{4}He ash without visible neutron and gamma-ray emission by the two methods of deuterium loading into Pd-nano-metal reactor samples based on D_2O electrolysis and the one method of gas-phase deuterium loading. Key issues for further engineering-phase development are discussed. 2) For the physical understanding of this "new phenomena", as new-type of deuteron-related fusion reactions in the ordering and constraint dynamics of deuterium clustering in condensed matter as PdDx lattice or surface, brief review on the theoretical progress of condensed cluster fusion, typically 4D multi-body fusion by the tetrahedral symmetric condensate (TSC), is given with easier physical explanations. Key issues as reproducibility and increment of power density are summarized.

Keywords: clean excess energy; metal deuterium system; ^{4}He ash without neutron; nano-structure sample; ordering and constraint; transient dynamics; tetrahedral symmetric condensate; 4D fusion; condensed cluster fusion; clean distributable energy; reproducibility; power density

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1. Introduction

The sustainable development is now widely regarded to be a way of human beings in the 21st century. To solve the energy problem, the idea of best mixing of various available energy sources may be a compromised solution. To mitigate the pollution of environment, cleaner energy resources are being looked for. Solar energy and windmills are seriously considered, but the author thinks these can merely cover a small portion of energy needs of the world. Extension of nuclear power plants is now again on the urgent construction phase as CO_2 free energy source. Development of thermo-nuclear fusion reactors (DT reactors) is also expected to serve in 50 years. These nuclear power systems are big concentrated power plants, from where we have net-work systems of electric power distribution to societies. However, some (and probably many) people are seriously dreaming the realization of portably small clean power sources based on some new principles, especially the idea of clean and small scale source of nuclear energy which can be distributed in private houses, offices and eco-vehicles. Such distributed type clean power sources should share needs for societies, while the big power plant systems will continue to share significant role. The emerging research field of condensed matter nuclear science (CMNS), which would provide a new way of clean portable nuclear energy devices, is therefore of great potential importance.

The new research field of condensed matter nuclear effect (CMNS) was born as a descendant research field of past controversial saga of "cold fusion" (CF). We cite the author's view in the reference-1. "In March 1989, S. Pons and M. Fleischmann at University of Utah announced "cold fusion" by D_2O/Pd electrolysis in test tube. The experimental system looked very simple. So many people in the world were involved in hurried trials of replication-experiments. In most trials, however, huge excess heat as claimed by Pons-Fleischmann was not observed. Parallel replication trials for the Nature paper by S. Jones on weak 2.45 MeV DD fusion neutron emission from D_2O/Ti electrolysis cell were not either successful. Very negative mood was seen in almost all scientific communities in the world[2]."

The same paper continues "In 1990-1992, some hopeful data on excess heat in D_2O/Pd cells were reported from research teams in USA, Japan and Italy. Although reproducibility was yet to be attained, great expectation was come back for the clean energy application based on 'new nuclear energy' process. In Japan, the New Hydrogen Energy (NHE) project was implemented for 1994-1998, at Shin-Sapporo Laboratory where about 20 researchers from major Japanese industries and several foreign scientists worked together to verify the excess heat effect in Fleischmann-Pons type systems. The NHE effort was concentrated in D/H absorption data in metal-samples and excess heat detection. In spite of energetic efforts by the NHE team, they made final report that excess heat effect was not confirmed. Few positive data on excess heat from foreign researchers and some positive data on nuclear products from Japanese University-teams were unfortunately not meaningfully evaluated by the NHE evaluation committee. The NHE project was terminated in 1998."

A faint but steady stream of CMNS/CF researches has continued in the world after 1990. ICCF-series conferences have counted 15 meetings (ICCF1 through ICCF15). The last ICCF conference (ICCF15) was held in Rome, October 2009. Other smaller international meetings have been held as Asti-series workshops, Russian cold transmutation conferences, sessions at American Chemical Society (ACS), American Nuclear Society (ANS), American Physical Society (APS), and so on. It is thought with rough statistics that about 300 researchers in the world have been continuing CMNS/CF studies. Accumulated research reports are piling up high, as published in books of *Condensed Matter Nuclear*

Science as ICCF Proceedings[3-6], *LENR Source-Book* Vol.1 and Vol.2 by ACS[7, 8]. Especially, ACS held a series of New Energy Technology Symposium at its fall and annual meetings since 2007. Unfortunately, publication of papers on CMNS/CF works has been rejected by many of highly-ranked magazines and journals as Nature, Science and Physical Review Letters, but many peer-reviewed papers have been published in Fusion Technology, Japanese J. Applied Physics (JJAP), Physics Letters A, J. Electro-Analytical Chemistry, Il Nuovo Cimento, Naturwissenschaften and so on.

We cite again the following sentences from the reference-1. "In frontiers of science pursuing new phenomena, combined actions between Experimentalism, Rationalism and Skepticism should support the progress. Aspects to application of the phenomena are also important.

1) Experimentalism: The effect should be reproducible with same conditions, qualitatively and quantitatively. Qualitative repeatability of phenomena by other methods and/or other groups is "broadened" reproducibility; the phenomenon with excess heat with ^{4}He production has cleared this criterion. To be perfect, quantitative reproducibility is required: The technological application is only possible by clearing this criterion.
2) Rationalism: Theoretical models should be created with original ideas. New theories should be compatible to established theories and should be self-consistent within own theoretical model. All contradictions should be cleared.
3) Skepticism: Defects and contradictions in experiments should be attacked. Mutual consistency between experimental results, new models and established theories should be checked to find contradictions.
4) Applicability: feasibility for R & D to distributed clean nuclear energy devices should be critically discussed. Remediation of radio-active wastes from nuclear plants should be also discussed.

Most essential consequences of latest CMNS studies may be summarized into the following three items:

1) Occurrence of deuteron-related clean fusion producing excess heat and ^{4}He.
2) Occurrence of selective transmutations of host metal nuclei and fission-like foreign elements.
3) New theoretical models to interpret qualitatively and quantitatively above results."

Processed metal (mostly Pd) test samples with nano-technology have recently been used for heavy-water electrolysis, D_2-gas permeation and gas-discharge experiments. Experiments with heavy water are no longer simple test tube-type, but various kinds of stimulation techniques have been tried as slow and fast pulsed electrolysis-current supply, ultra-sonic wave supply, laser-beam supply, plasma-mode-electrolysis, and so on.

The nano-modification of sample, especially surface modification is of current trend of experimental innovations as well as nano-particles, complex multi-layers, micron-size long wires, and so on[1].

In 2006-2009, we have had further progress for the item 1) in experimental efforts by two advanced methods of heavy water (D_2O) electrolysis, namely the super-wave electrolysis with ultrasonic wave Pd cathode surface conditioning (by Energetics Technologies Inc., SRI and ENEA)[9-11], and the co-deposition type D_2O electrolysis (SPAWAR)[12-14]. The super-wave experiment reported more than 20 times out-put power in 20 watt level for several tens hours. If this condition would be 100% reproducible and continue for many days, it must be already in the engineering phase of energy-producing devices. However the reported reproducibility in 2008 is about 70%. Secondly, in 2008-2009, a new deuterium-gas-loading method with nano-Pd/metal-oxide composite sample of reactor cell was demonstrated (by Arata-Zhang) to show long lasting heat power without nominal input power and nuclear ash of ^{4}He[15,16], and the anomalous heat power phenomena has been reproduced by the other

group (Kitamura et al)[17-19]. This nano-particle/gas-loading method is regarded to provide a highly reproducible heat power at higher temperature (than room temperature) to control more easily by using designed reactor material samples and their processing.

Here palladium is regarded as a kind of catalyst and deuterium is real fuel for producing heat-power. We know about 1/6700 of water on our planet is heavy water (D_2O). We should have huge nuclear energy source if the claimed phenomena can be applied for. We can regard the above three methods as mile-stones for starting R&D programs of engineering phase of developing clean portable energy devices. The former two are based on deuterium-loading (full loading is required as mentioned later in detail) into nano-fabricated metal cathodes by the liquid phase technique, namely electrolysis. The latter is based on the enhanced deuterium loading into nano-powders of palladium by the gas phase technique. The further development will be done in competition of two techniques. Attainment of high reproducibility of sustaining heat power and its controllability must be key issues of developments. In Chapter 2, key experimental results by the above three methods will be reviewed.

As commonly recognized, new theories are required to explain the claimed experimental results as clean heat power with ^{4}He ash without neutron and gamma-ray emission, since the usually known DD (d + d) fusion reaction should emit lethal amount of 2.45MeV neutrons and tritium (10^{12} neutrons per one joule heat, for instance) as criticized in the early debate in 1989[2]. Theories must *invent new nuclear mechanism*s to result in clean heat with ^{4}He ash without neutrons and gamma-rays. The new mechanisms must hold because of the ordering/constraint/self-organization process, probably in dynamic motion of particles, of deuterium-contained condensed matter, in contrast to the random stochastic mechanism of plasma fusion and accelerator-induced fusion reactions of deuterons.

Several theoretical models have been proposed and elaborated for interpreting possible mechanisms of "new fusion reactions" by deuteron behaviors under ordered (or equivalently constrained) conditions in the environment of metal-deuterium systems of condensed matter.

Typical theories have been proposed as categorized into 7 types as follows:

1) D-Cluster Fusion Models; EQPET/TSC: A. Takahashi[20-25],
2) Bose-Einstein Condensation Models: Y. Kim[26],
3) Resonance Tunneling: X.Z. Li[27,28]
4) Phonon-Coupled Gauge Theory: P. Hagelstein [29, 30]
5) Coherent Bloch-State Models: S. Chubb[31], T. Chubb[32]
6) Swimming Electron Layer Model: H. Hora and G. Miley[33]
7) SCS Fission Model: A. Takahashi and M. Ohta[34]

For modeling in every theory, we should treat and clear the following criteria A through D:

A) The new aspect how dynamic ordering or particle-constraint conditions in condensed matter (solid state) physics states can be linked or combined with new nuclear reaction channels. How is it possible?

B) We have to clarify how Coulomb repulsion between deuterons in low kinetic energies can be overcome.

C) We have to show how new nuclear channels of ^{4}He ash without neurons and gamma-rays are open.

D) We have to quantify theoretical models to give quantitative predictions for nuclear reaction rates, so as to meet the high reaction rate levels, corresponding to heat-power source, from experiments.

Criteria A), B) and C) are related to the so called *three miracles in cold fusion*[2].

One practical issue is how ^{4}He can be major ash without associating intense neutron emission.

The scenario: D + D → ^{4}He + lattice-energy (23.8MeV): does not have place to stand on, in the view of nuclear physics. Detailed discussions and theoretical view are given later in Chapter 3.

Only a few theories could have cleared the four criteria. The condensed cluster fusion theory - 4D/TSC theory by the author[20-25] is one of them and will be briefly explained in Chapter 3.

Summary and future problems for R&D towards engineering clean portable power devices are written in Chapter 4.

2. Review of Major Experimental Results on Anomalous Heat Generation

Processed metal (mostly palladium, Pd) test samples with nano-technology have recently been used for cathodes of heavy-water electrolysis. D_2-gas loading experiments have been also done with nano-meter size Pd particle powders dispersed in ceramics flakes. Very positive excess heat results, in some cases with observation of remarkable level of ^{4}He generation, have been reported recently[9-19].

Experiments with heavy water are no longer simple test tube-type as one first reported by Fleischmann and Pons[35], but various kinds of stimulation techniques have been tried as the slow and fast pulsed electrolysis-current supply, the ultra-sonic wave supply, the laser-beam supply, the plasma-mode-electrolysis, and so on.

The nano-modification of metal sample, especially surface modification is of current trend of experimental innovations as well as nano-metal-particles, complex multi-layers, micron-size long wires, and so on. Positive and convincing data have been reported from several groups as the Energetic Technologies (Israel) + SRI (USA) + ENEA (Italy) group[9-11, 37], Arata-Zhang[15-16], McKubre[10], Celani[36], NRL-San-Diego (SPAWAR)[12-14], and so on. Key issues in experiments are calorimetry, mass-analysis, nano-size-condition of sample, stimulation and triggering, diagnostics and detection.

2.1 Super-Wave Electrolysis

Dardik et al[9, 10] have reported clear excess heat data with 25 times output power lasting long time (17 hours typically) using super-wave electrolysis (see **Fig.1** illustrating cell design and operation). This method provided the most encouraging excess heat data (see **Fig.2**) they have obtained. They made processing of surfaces of sample Pd-cathodes by the argon or hydrogen plasma etching before mounting to the reactor cell. They suggested that the condition of surface processing would be relating to success of excess heat. They have made the in-situ surface conditioning of Pd cathode by irradiating ultrasonic wave (20 kHz). After this surface conditioning, they found the formation of fractal nano-meter scale surface structure (see **Fig.3**). Their Super-wave for electrolysis voltage was modulated with special wave forms programmed by computer (PC). Averaged fundamental frequency was 1/(20 minutes). Super-wave was generated by the superposition of its harmonics (this is a kind of fractal pattern in chaos theory). It is interesting how the highly fractal wave form by Dardik et al may effect on dynamic behavior of deuterons in PdDx lattice systems. One of their collaborators is asserting that the superposition of super-waves in microscopic limit can induce microscopic ordering of condensed matter systems and induce nuclear reactions. The effect of ordering/self-organization in atomic or

molecular size level should be interesting, but phonon or electromagnetic wave should not so easily induce directly nuclear reactions. We should find stages of mechanisms between electronic environments and nuclear force field.

In series of their experiments they reported large excess power reaching more than 10 times of input power for time-spans of more than several hours. Reproducibility for these remarkable cases is in 20-30 %. The best data they observed is shown in **Fig.2**, where 20 watts averaged output-power, with 0.74 watts input-power, lasted for 17 hours. Gain was 25! This excess power level is corresponding to 24.8 keV/Pd-atom-in-lattice, and is far greater (more than 1000 times) than chemically possible heat source level. Therefore, one has to seek theoretically possible nuclear mechanisms in deuterium-contained condensed matter; the author's theoretical model will be explained in Chapter 3.

This group is trying superposed stimulation with laser beam and ultrasonic wave. This is interesting trial. The group has obtained data for ^{4}He production in correlation with excess heat generation. When we irradiate laser on surface of Pd cathode, we can choose laser wave length in ultra-violet and EUV region due to the classical Drude formula for frequency dependence of dielectric constant of metal. They used a He-Ne laser (632 nm wave length). And they observed increase of excess power of several times of laser input power (33 mW). During the laser irradiation and excess power episode, D/Pd ratio kept more than 0.9. However, continuation of laser irradiation induced no excess power and decrease of D/Pd ratio (increase of resistance ratio). This is very interesting data showing relation between excess power and D/Pd ratio under the laser stimulation. Reproducibility for excess heat production including small gains is about 70% currently.

Fig.1: Illustration of experimental cell design and operation, by Energetics Technology[9,38] , for super wave electrolysis of heavy water with Pd cathode under ultrasonic conditioning

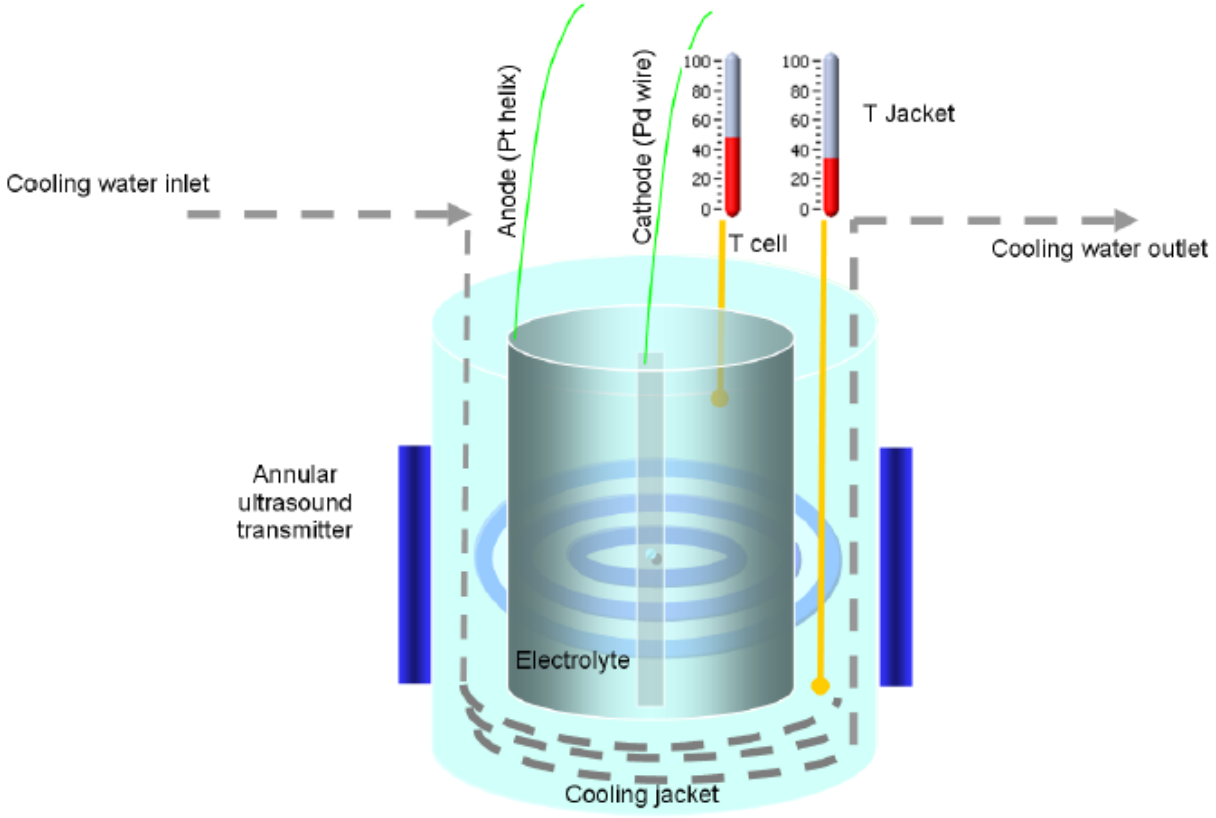
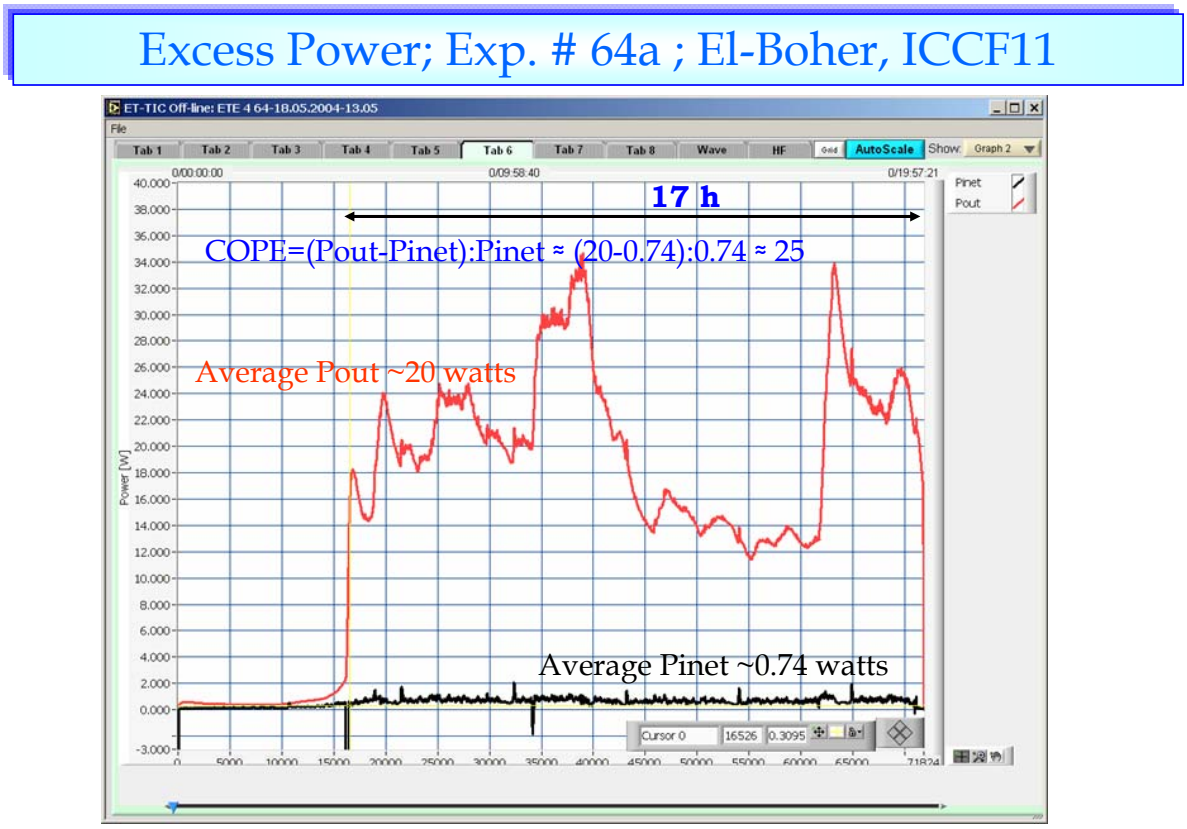
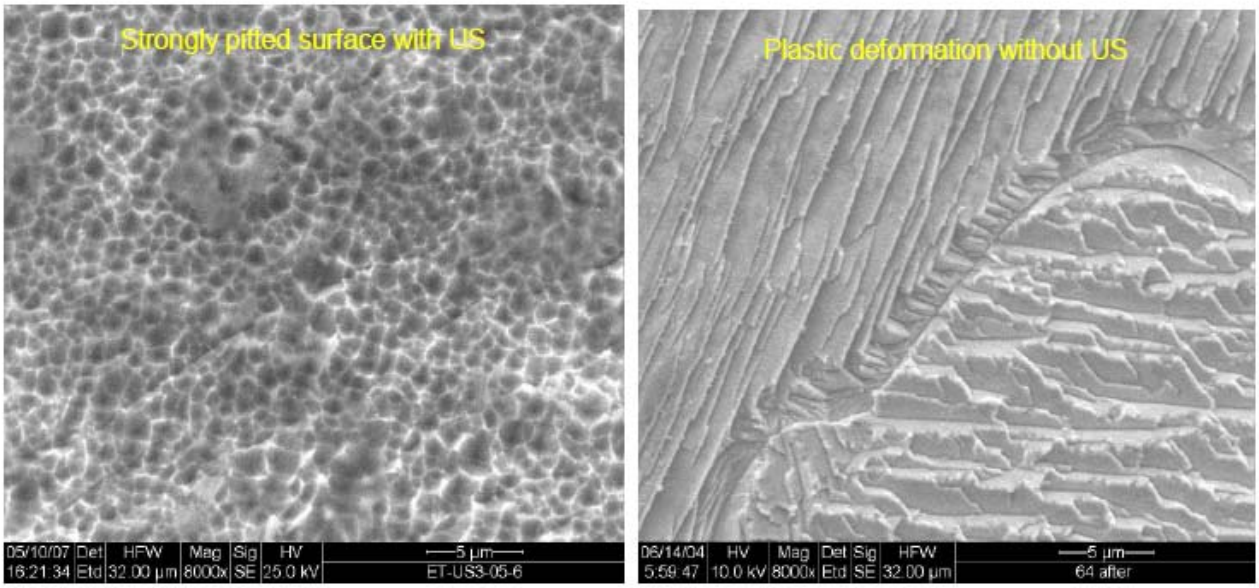


Fig.2: The best data of excess heat power evolution observed by Energetic Technologies[9], using the super-wave electrolysis method with ultrasonic conditioning of Pd-cathode in heavy water



Excess Power of up to 34 watts; Average ~20 watts for 17 h

Fig.3: SEM image of Pd-cathode surface under ultrasonic conditioning (left figure), compared with one without ultrasonic conditioning (right figure), SEM magnification = 8,000, by Energetics Technologies[38]



Arata et al[15,16] have made significant contribution to provide clear experimental data of ^{4}He production from their own double structure cathode of Pd in heavy water electrolysis cell[16]and from D-gas-phase absorption system of Pd nano-particles under laser or ultrasonic wave irradiation. Their ^{4}He analysis by QMAS (quadru-pole mass analysis system) is reliable. Detection of neutron emission was tried in-situ, but could not be observed in meaningful counting level of events, compared with natural neutron background. Tritium production in electrolyte liquid was checked periodically for sampled heavy-water by LSC to observe no significant increase of tritium level compared with BG sample. They observed great amount of ^{4}He from Pd powder by heating.

Arata et al also tried laser irradiation experiment on Pd nano-particles (5 nm in diameter) in ZrO_2 substrate, and observed clear ^{4}He generation. This experiment gave important hint to theoretical modeling[20-25] of CMNE in finite size PdDx lattice system. McKubre et al in SRI[39] have made great efforts in replicating experiments by Arata, Case and others. They were also involved in their own systems of closed-type heavy-water/Pd electrolysis to detect excess power and ^{4}He and their mutual correlations. Correlation of excess heat evolution and ^{4}He production rate was observed as typical data is shown in **Fig.4** for their heavy water electrolysis.

Data shown in **Fig.5** were taken in Case-type cell which employed PVC-deposited Pd layer on carbon. Produced ^{4}He goes out partially into gas-phase of cell, and other portion will be remained in Pd cathode. They collected both components and made helium analysis by mass spectroscopy (QMAS). They obtained correlation data as 31 MeV per He-atom with 13 MeV error bar. Their latest reevaluation of this correlation is 24 MeV per ^{4}He production with 10% error. This is important data indicating that ash of excess heat events was ^{4}He-nuclei produced as major nuclear product.

Arata-Zhang[15] have also reported clear results of ^{4}He production, on the level of 10^{17} atoms in their latest D-gas loading experiment, as explained more in detail in the next section, by using a high resolution QMAS system. If we assume energy production of 24 MeV per one ^{4}He production, 10^{17} ^{4}He atoms correspond to the order of 1 mega joules (1 MJ). Therefore, these experimental results are very seriously taken. As known in fusion and nuclear physics researches, deuterium fusion should mean, in usual sense, the DD (d + d) two body nuclear reaction which emits neutron (2.45MeV) and triton (1MeV) with same weights (50% branching ratios) . No ^{4}He as major reaction product should be produced by the known DD (d + d) fusion.

Many researchers have been asserting the working hypothesis: D + D → ^{4}He + Lattice-energy (23.8MeV).

However, this hypothesis has no support from nuclear physics theory as we discuss in the theory section Chapter 3.

Fig.4: Correlation of excess heat evolution and ^{4}He accumulation in heavy water electrolysis with Pd cathodes, observed by SRI group[39]

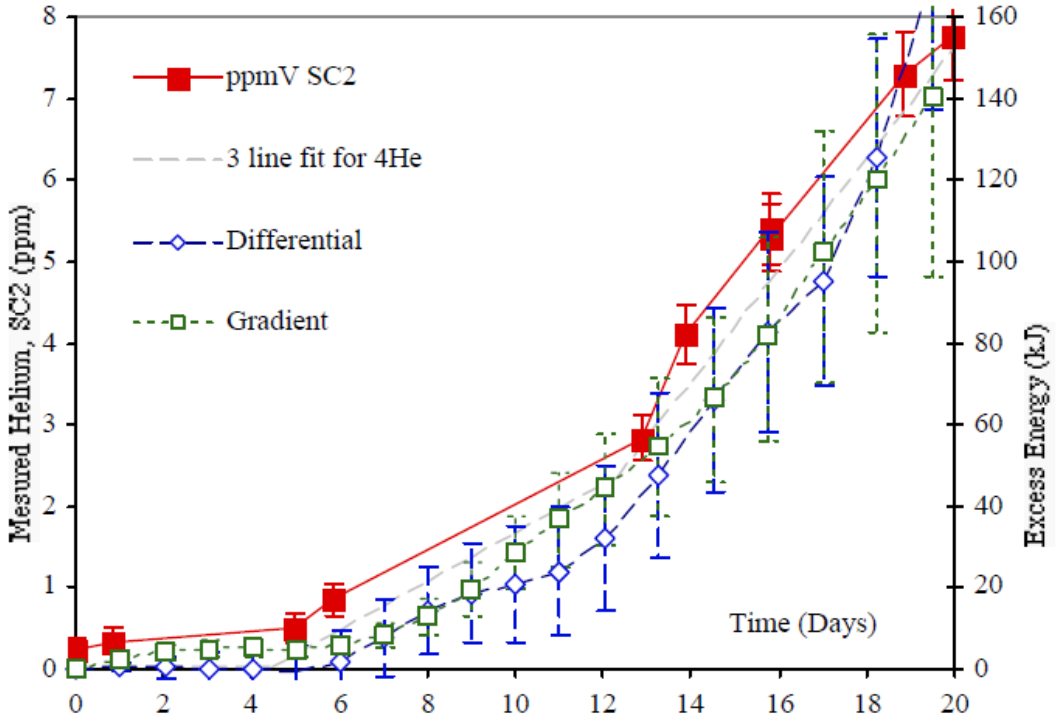
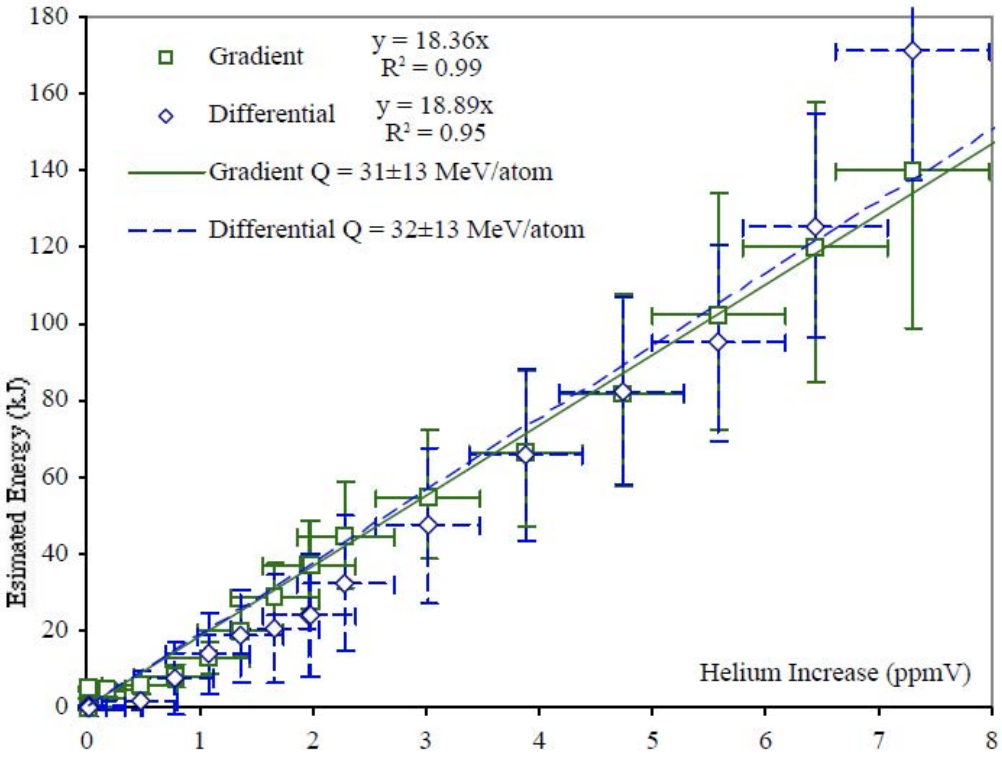


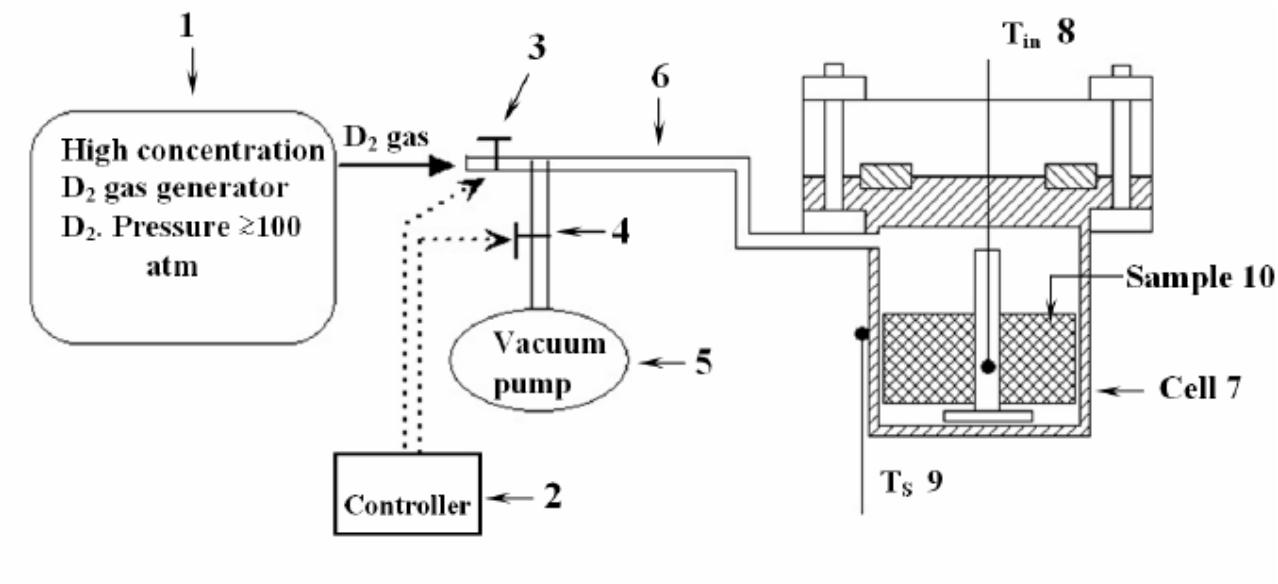
Fig.5: Estimated energy production rate per one ^{4}He generation in Case type cell, observed by SRI[39]



2.2 D-Gas Loading Method into Pd Nano-Particles

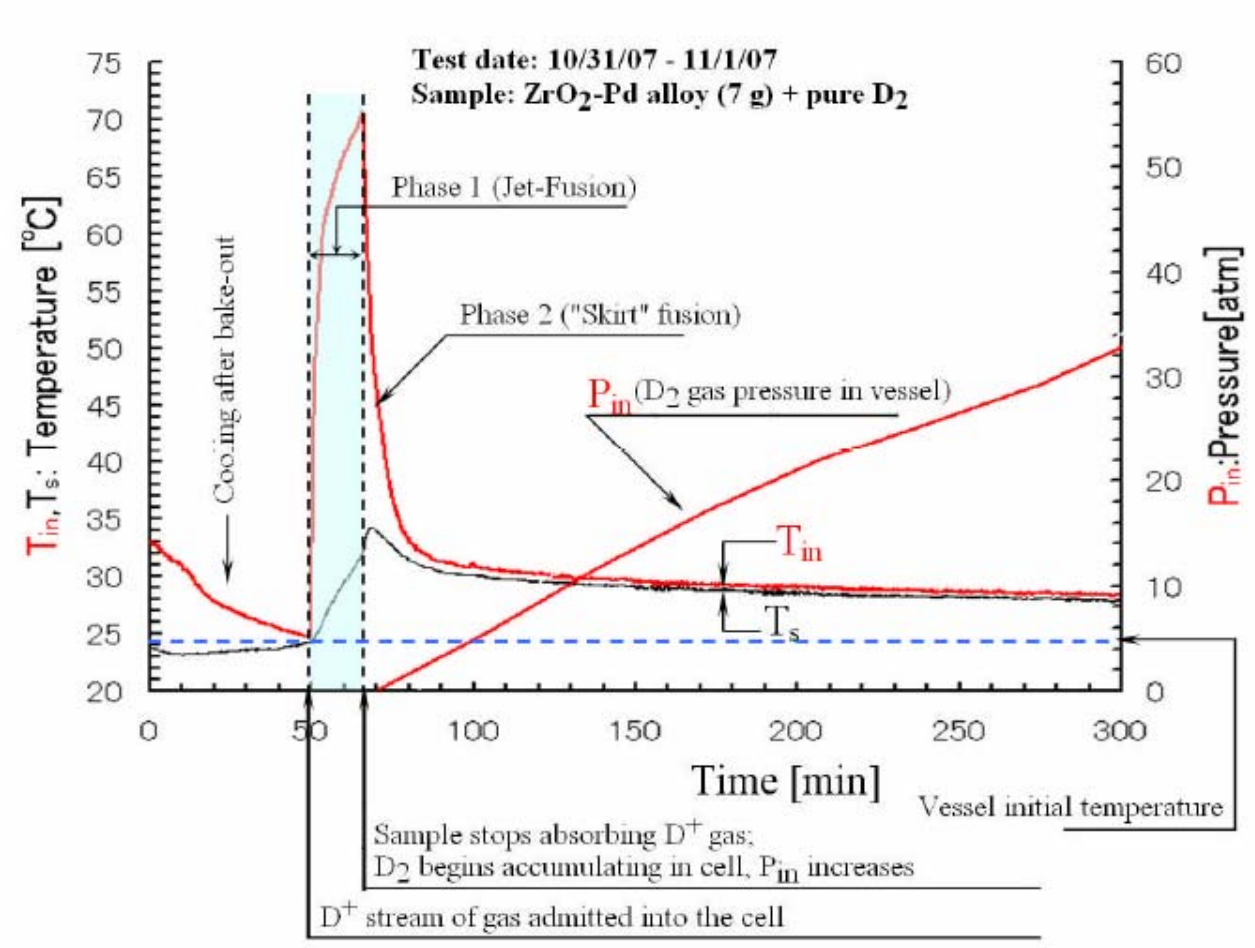
After a series of studies using the DS cathode system[16], Arata-Zhang employed a more simple system of deuterium-gas (D-gas) loading into Pd nano-particles dispersed in ceramics flakes (ZrO_2)[15]. The use of this nano-particle composite sample is now widely regarded as a promising method to induce the "anomalous condensed matter nuclear effect", presumably a new kind of clean fusion process specifically in condensed matter. A simplified schematic view of Arata-type gas-loading system is shown in **Fig.6**.

Fig.6: Schematic view of Arata-type deuterium (or protium)-gas loading system for "nuclear fusion" heat power evolution[15], 1; high concentration gas generator, 2; controller, 3, 4; valves, 6; gas feed line, 7; reactor cell, 8; inside thermocouple, 9; surface thermocouple, 10: Pd sample powder,



Arata-Zhang used a composite sample of Pd/ZrO_2 mixture. About 5nm diameter Pd nano-particles are dispersed in about 10 micron size flakes of ZrO_2. After mounting the sample in reactor cell, they evacuated the cell, baked the sample at about 180 deg C for degassing, and started the D(H)-gas loading through a membrane Pd filter which controlled gas-flow rate and in addition purified D(H)-gas. Typical pattern of cell-temperature evolution is shown in **Fig.7**. They made public demonstration of "solid nuclear fusion reactor", in May 2008. Many discussions and debates have been seen in several internet sites in 2008-2009. Replication of their results is now under way in several laboratories in USA, Japan, France, China and so on.

Fig.7: Typical evolution patterns of cell temperature and D-gas pressure, for earlier time interval of experiment with Pd/ZrO_2 sample and D-gas loading, by Arata-Zhang[15]



The evolution of data can be divided into two phases: Phase-I is the interval where Pd-composite powders absorb all of inlet D(H)-gas and keep the pressure nominal zero. After the absorption has reached at the saturation (we may think the formation of PdD or PdH), Phase-II starts with sudden increase of cell gas-pressure and long tail of increased cell temperature, compared with the room temperature (blue broken line). The inside temperature (Tin: red curve) is much higher than the surface temperature (Ts: black curve) in Phase-I, and slightly higher in Phase-II. Separate run with H-gas showed lower (about 70%) temperature peak in Phase-I and rapid drop to the room temperature in an hour or so.

Fig.8 shows the long lasting evolution of "higher temperature" for 3,000 minutes. Obviously, cell temperature (Tin) sustained "higher values" than outer (surface) temperatures for surprisingly long time interval of 3,000 minutes, while Tin data for H-gas run returned to the room temperature in about 500 minutes. One must consider that there was a long lasting heat source inside the reactor cell. Arata-Zhang concluded that the heat source should be "clean" fusion reaction producing ash of ^4He atoms, as they observed great amount of ^4He atoms inside Pd particles and smaller amount in cell gas, as shown in **Fig.9**. They sampled cell-gas and sent to a QMAS system in the same room for ^4He detection. After opening the cell, they sampled a used Pd/ZrO_2 sample and set it inside an oven to heat up to about 1,000 deg C to extract ^4He atoms to be detected by QMAS. Typical results of QMAS analysis (repetitive mass-scanned curves) are shown in Fig.9.

Fig.8: Long lasting "higher cell temperature" for Pd-composite samples with D-gas loading, compared with those with H-gas loading, for 300 to 3,000 minutes interval after Phase-I, by Arata-Zhang[15]

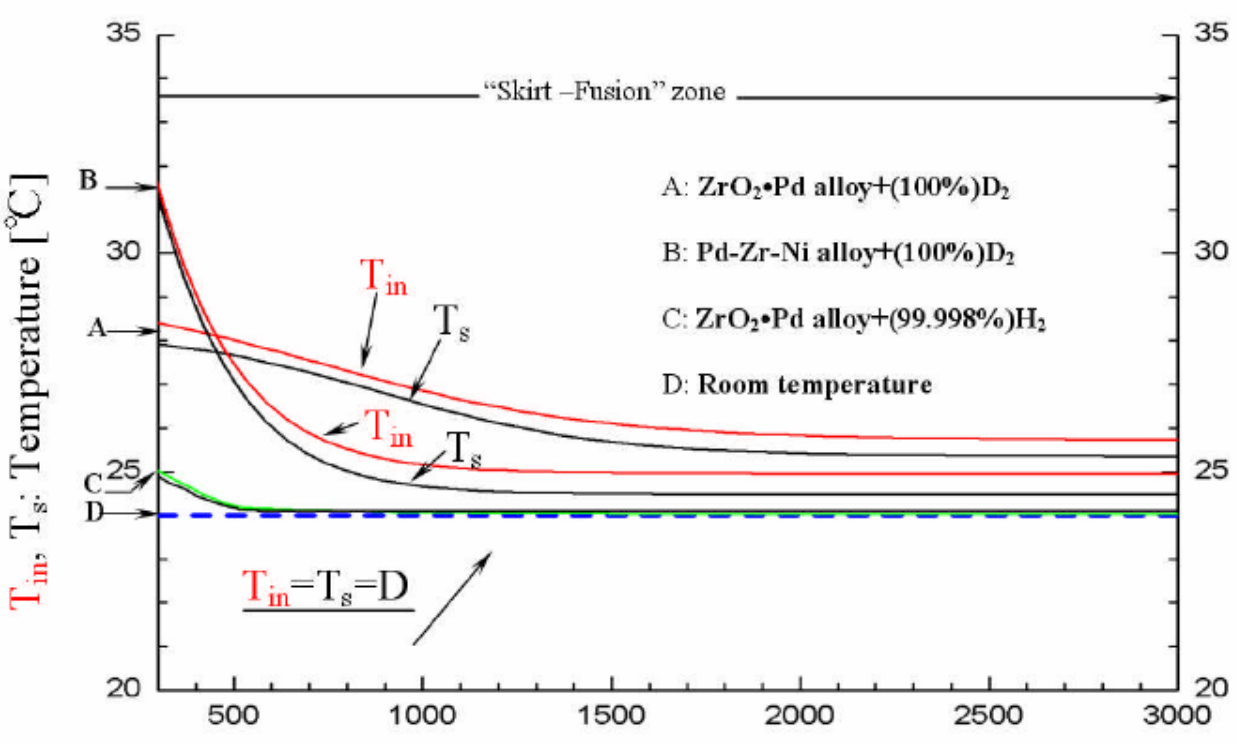
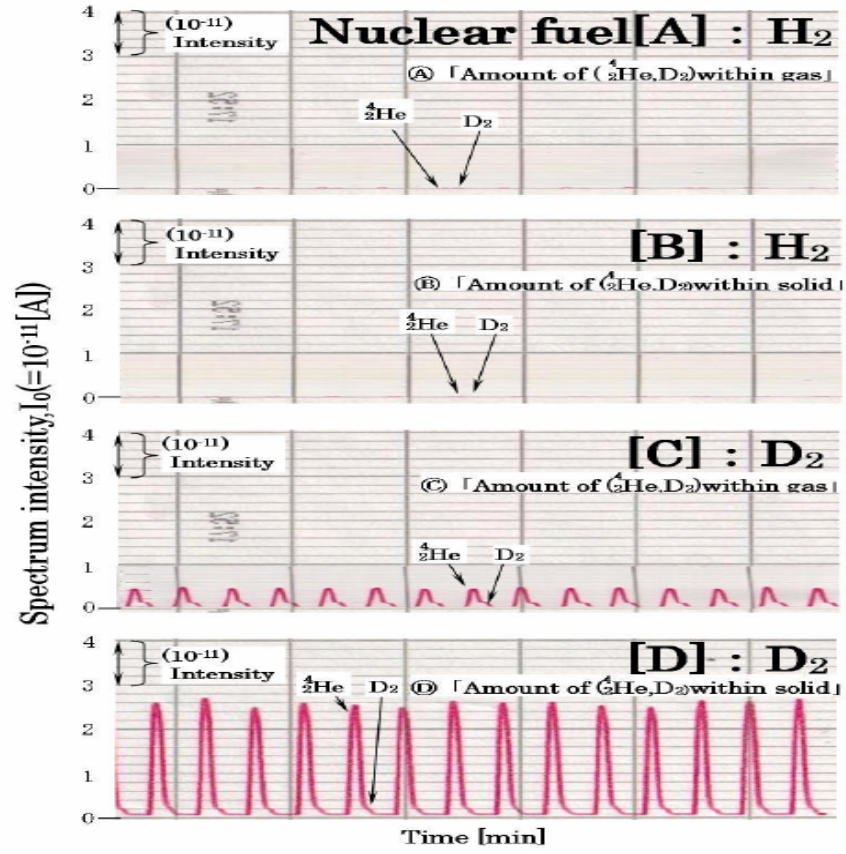


Fig.9: ^{4}He detection by QMAS, every peak shows a scan (sweep) of near mass-4 area intensity[15]



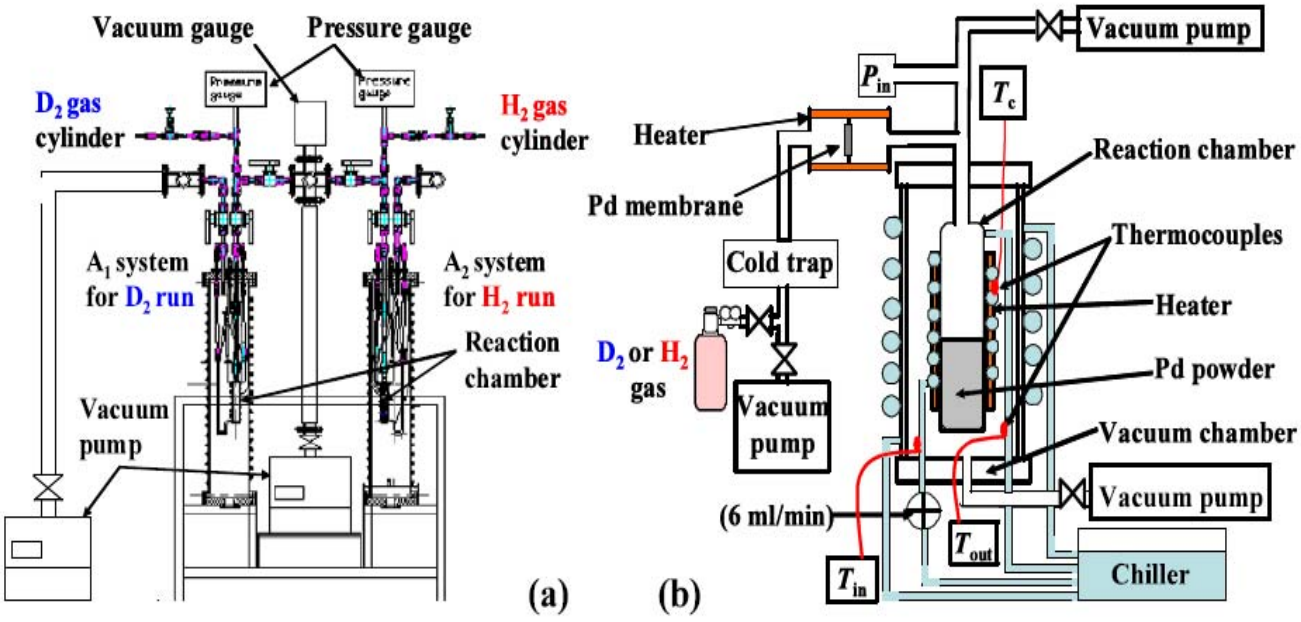
Obviously, most component of ^{4}He amount was retained inside Pd-nano-particles. Only a small portion of ^{4}He atoms was found in cell gas. Data by protium-gas (H_2) did not show any ^{4}He peaks. This fact suggests that "clean fusion" reactions took place mostly inside Pd-particles.

Arata-Zhang[15] did not make accurate calorimetry to evaluate heat power level and integrated heat amount. Therefore, the deduced data of energy/^{4}He value was not given.

Because of the simplicity of this Arata-type gas-loading experiment, researchers in CMNS feel that the reproducibility and controllability would be good if we do not have secretes in the nano-composite samples.

Kitamura-Takahashi group has started replication experiments of Arata-Zhang, using a sophisticatedly modified system to measure D(H)/Pd loading ratios and heat-power evolution[17-19]. They designed and constructed a twin cell system for gas-loading experiments, as shown in **Fig. 10**.

Fig.10: A twin D(H) gas-loading system for metal powder samples; (a) A_1 for D-gas run and A_2 for H-gas run, (b) functional illustration of a half of twin system[17-19].

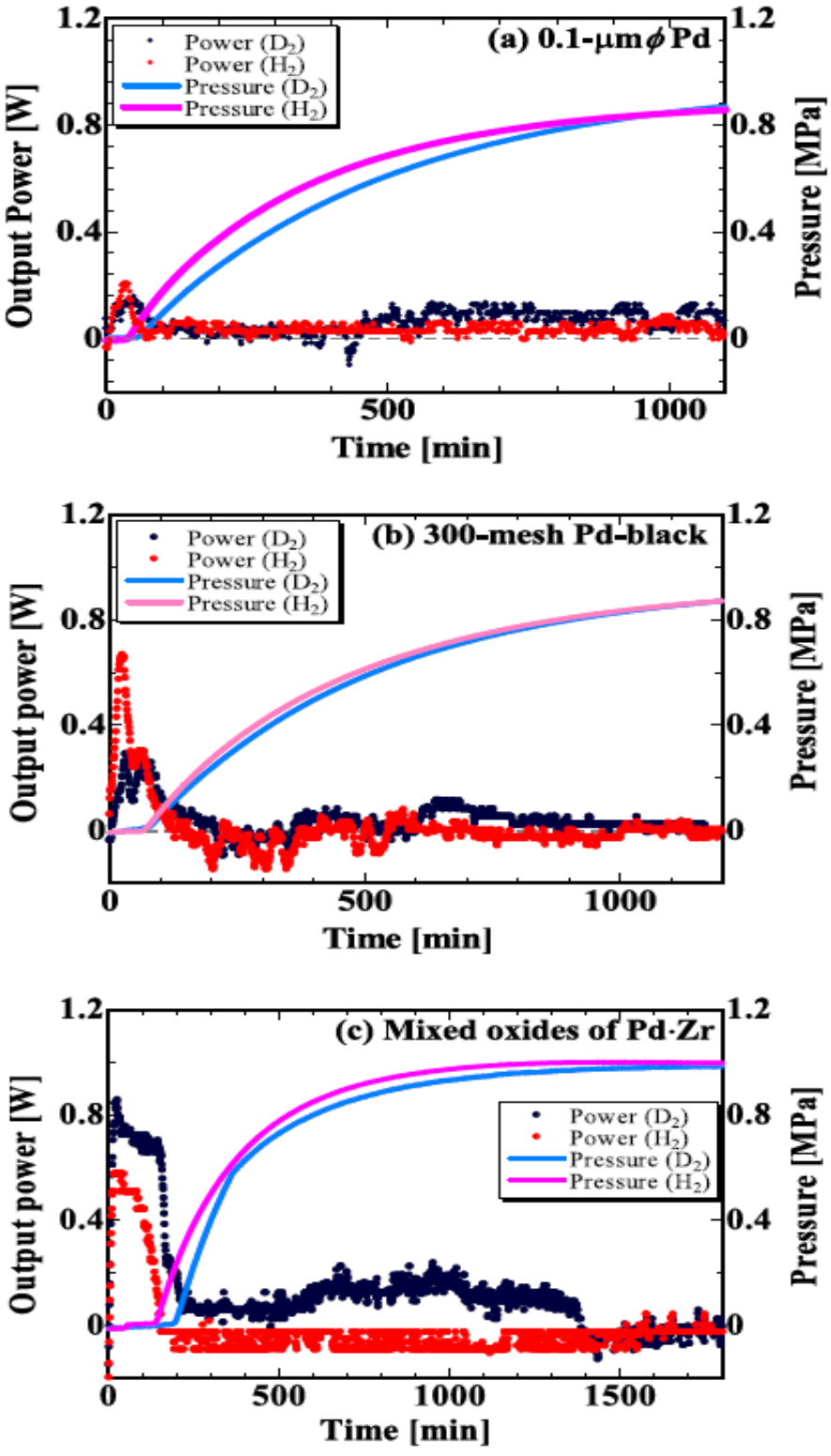


Their experimental procedure is similar to Arata-Zhang's for evacuation, baking sample, and gas-loading. Different points are; Kitamura group used a twin system to run simultaneously the D-gas run and the H-gas run, did active mass flow calorimetry (by constant temperature-regulated water flow) as high precision as possible and monitored neutron and gamma-ray levels. They also used various Pd particle and powder samples; 0.1 micron Pd particles (commercially available), Pd-black (300mesh) and Pd/ZrO_2 composite samples made by Santoku Co. (different company from Arata's). Size of Pd nano-particle for Kitamura et al was 10.5 nm in average, about twice larger diameter than Arata-Zhang's.

The main aim of Kitamura-Takahashi group is to understand the underlying physics of "anomalous heat generation" by D-gas loading into Pd-nano-particles. Their typical data of heat-power evolution

and gas-pressure change are shown in **Fig.11** for comparing results between Pd 0.1 micron powder, Pd-black and Pd/ZrO_2 composite powder, respectively and simultaneous comparison for D-gas and H-gas runs.

Fig.11: Results of D(H) gas loading experiments for three kinds of Pd powders, by Kitamura et al[17-19]



They found the trend that the finer was the surface nano-structure the larger heat-power levels were observed in Phase-I and Phase-II; namely the 0.1 micron Pd powder showed conventionally given trend of D(H)-absorption rate and heat emission level, the Pd-black sample gave much larger D(H)/Pd loading ratios in Phase-I and integral heat of Phase-I and the Pd/ZrO_2 sample gave anomalously large D(H)/Pd loading ratios in Phase-I and very large integrated heat (about 10 times of 0.1 micron Pd powder). Detail of integrated data is seen in **Table-1**.

Table-1: Integrated data obtained by D(H) gas loading experiments into various Pd powders, by Kitamura et al[17-19] ; PP denotes 0.1 micron Pd powder, PB denotes Pd-black (300mesh) and PZ denotes nano-Pd (10nm)/ZrO_2 composite. E1st is energy per one absorbed D (or H) in Phase-I.

Run #	weight of Pd [g]	Flow rate [sccm]	Output energy [kJ]		Specific output energy [kJ/g]		D/Pd or /Pd (1st ph.)	E1st [eV/D(H)]
			1st phase	2nd phase	1st phase	2nd phase		
D-PP1#1	5.0	2.7	0.5±0.4	2.5±4.1	0.10±0.07	0.52±0.83	0.43	0.26±0.14
D-PP1#2	5.0	3.8	0.5±0.2	4.0±4.4	0.10±0.05	0.79±0.88	0.44	0.25±0.09
H-PP2#1	5.0	5.4	0.4±0.2	2.6±3.9	0.08±0.03	0.53±0.80	0.44	0.20±0.07
D-PB1#1	3.2	3.6	1.7±0.3	8.3±4.5	0.54±0.10	2.60±1.40	0.88	0.67±0.12
H-PB2#1	3.6	4.2	1.6±0.3	(-2.2±4.6)	0.45±0.08	(-0.62±1.30)	0.79	0.62±0.11
D-PB3#1	20.0	2.9	9.3±1.1	1.1±0.5	0.47±0.06	0.06±0.02	0.79	0.65±0.08
D-PB3#2	20.0	0.9	3.3±0.5	3.4±2.6	0.17±0.03	0.17±0.13	0.23	0.79±0.05
H-PB3#3	20.0	2.1	3.2±0.2	14±4.6	0.16±0.01	0.68±0.24	0.24	0.74±0.05
D-PZ1#1	3.0	1.8	7.0±0.2	6.8±1.3	2.33±0.05	2.27±0.43	1.08	2.4±0.05
H-PZ2#1	3.0	2.3	3.6±0.1	(-5.1±1.4)	1.20±0.02	(-1.70±0.47)	1.00	1.3±0.02
D-PZ3#1	3.0	1.9	6.4±0.2	6.2±1.4	2.13±0.05	2.07±0.47	1.08	2.2±0.05
H-PZ4#1	3.0	3.6	4.8±0.1	1.9±1.4	1.60±0.02	0.63±0.47	0.86	2.1±0.03
D-PZ5#1	3.0	2.0	7.1±0.2	1.3±1.4	2.38±0.03	0.42±0.45	1.04	2.5±0.03
H-PZ6#1	3.0	5.9	7.1±0.1	(-0.2±1.4)	2.36±0.02	(-0.08±0.48)	1.34	1.9±0.02
Averagefor PZ		(D)	6.9±0.4	4.8±3.0	2.3±0.1	1.6±1.0	1.1±0.0	2.4±0.2
		(H)	5.2±1.8	(-1.1±3.6)	1.7±0.6	(-0.4±1.2)	1.1±0.3	1.8±0.4

In **Table-1**, the run number is designated by "G-PN#M", with G, P, N and M being the gas species, the powder species, powder ID, and the number of repeated use, respectively. The powder species include PP (Pd powder with particle diameter of 0.1 μm and a purity of 99.5 %), PB (Pd-black with a particle size of "300 mesh" and purity of 99.9 %), and PZ (mixed oxides of Pd·Zr). For example, "D-PB2#3" represents the third absorption run with D_2 using a Pd-black sample "2" following evacuation and baking after two cycles of evacuation-baking-absorption.

Kitamura et al wrote[17] concluding remarks for PZ runs as; "We notice the following four facts in the 1st phase (Phase-I): (1) very large output energies that are more than 3 times greater than those for the Pd-black samples, (2) very large D/Pd (H/PD) ratio of 1.1 ±0.0 (1.1 ±0.3) that are even higher than those for the PB samples, (3) surprisingly large E_{1st} = (2.4 ±0.2) eV (D) and (1.8 ±0.4) eV (H) on the average, and (4) larger isotope effect in E_{1st} compared with those for 0.1-μmϕ powder and Pd-black; the difference just exceeds the error range determined by standard deviations. We have anomalously

large absorption energies and loading ratios accompanied by a large isotope effect in the present mesoscopic system of Pd·Zr oxides. It is difficult to assume large contribution of ZrO_2 to these quantities. We have to consider reduction of PdO_x followed by production of xD_2O (xH_2O) and PdD_y (PdH_y). The reaction energies Q_D and Q_H are evaluated to be $(162.6\times x + 70.0\times y)$ kJ and $(156.6\times x + 58.0\times y)$ kJ, respectively. For assumed values of $x = 1 \sim 0$ and $y = 0 \sim 1$, Q_D and Q_H are 0.84 ~ 0.73 eV/D and 0.81 ~ 0.60 eV/H, respectively. These are too small to account for both the observed energy and the isotope effect. There might be a yet-unknown atomic/electronic process governing the phenomenon in the present mesoscopic system, or the concept of "atom clusters" might apply. However, it seems rather difficult to assume that such a large isotope effect is only in the electronic process of adsorption and/or hydride formation. Some nuclear process could be a candidate for the process responsible for the phenomenon. As for the 2nd phase (Phase-II), we have negative values for the specific output energy in two runs using H_2. This should be considered to be due to slight shift in the zero point of the thermocouple signal. In contrast to the runs with H_2, the second phase in the runs with D_2 has apparently positive output energy as typically shown in **Fig. 11(c)**. This implies that some nuclear process could be involved, although the values are only marginal in view of the negative value observed in H-PZ2#1. These points should be subjected to further investigation. Finally, it should be mentioned that we observed nothing other than steady background both in the neutron counter and the scintillation probe."

Arata-Zhang experiment[15] for anomalous heat-power evolution was thus replicated by Kitamura et al[17-19]in quantitatively similar results. Further replication studies and works towards engineering device development can be expected.

2.3 Co-Deposition Electrolysis and Nuclear Detection

The SPAWAR group[12-14] invented the co-deposition electrolysis method for CMNS study. They used electrolyte that solved PdCl in heavy water (D_2O). They claim that this technique provides very repeatable experiments for excess heat and nuclear products (tritium, neutron, X-rays, gamma-rays) observation. **Fig.12** shows a brief explanation of their method (presented at Missouri University Seminar, May 2009).

Deposited Pd layers on cathode showed cauliflower-like fractal nano-structure as seen in inserted figure of Fig.12.

They observed excess heat power level of 0.1-0.3 watts every time, although the power level is not so high as the super-wave electrolysis method of Energetics-SRI-ENEA joint team. They observed evolution of temperature distribution on Pd cathode surface using IVR camera, which demonstrated interesting behavior of time-varying high temperature heat spots on cathode surface. They used CR39 track detector for detecting possibly emitted charged particles and neutrons. They also monitored the change of tritium concentration in electrolyte by LSC (liquid scintillation counting) to find significant increase as a function of elapsed time.

The most striking claim they reported in ACS meetings (2008-2009) is that about 12-17 MeV energetic neutrons[12-14] were detected as triplet tracks in CR39. In **Fig.13**, we pick up a slide from their presentation (May 2009).

Fig.12: Explanation slide of SPAWAR co-deposition method (2009 at U. Missouri Seminar)

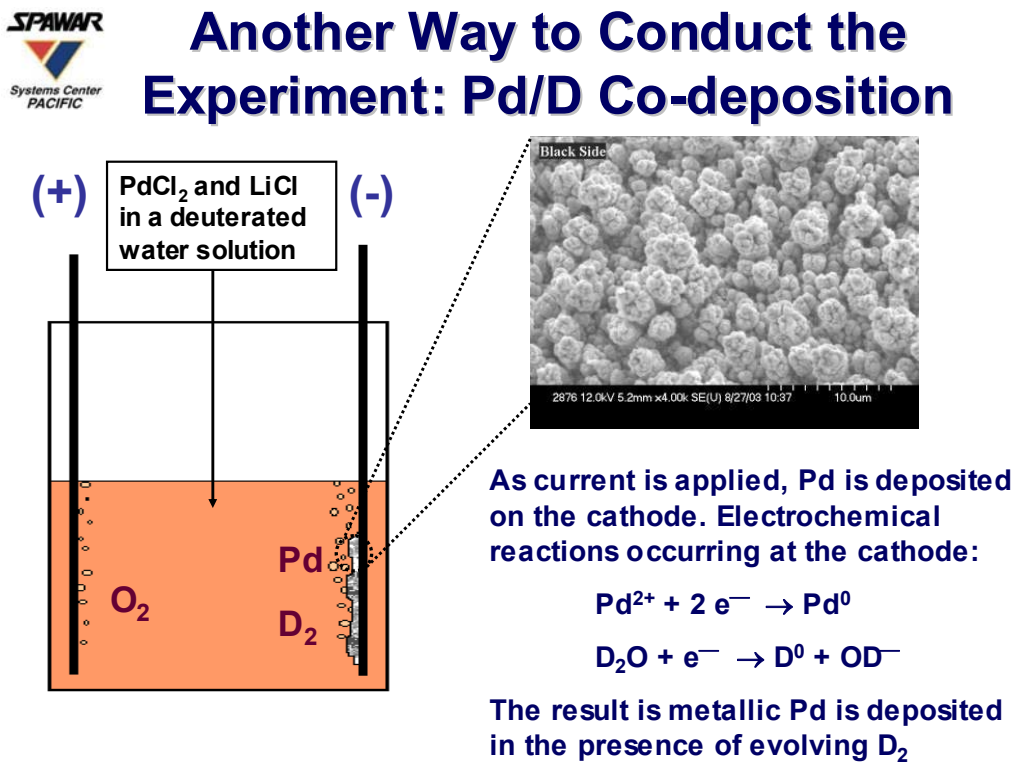
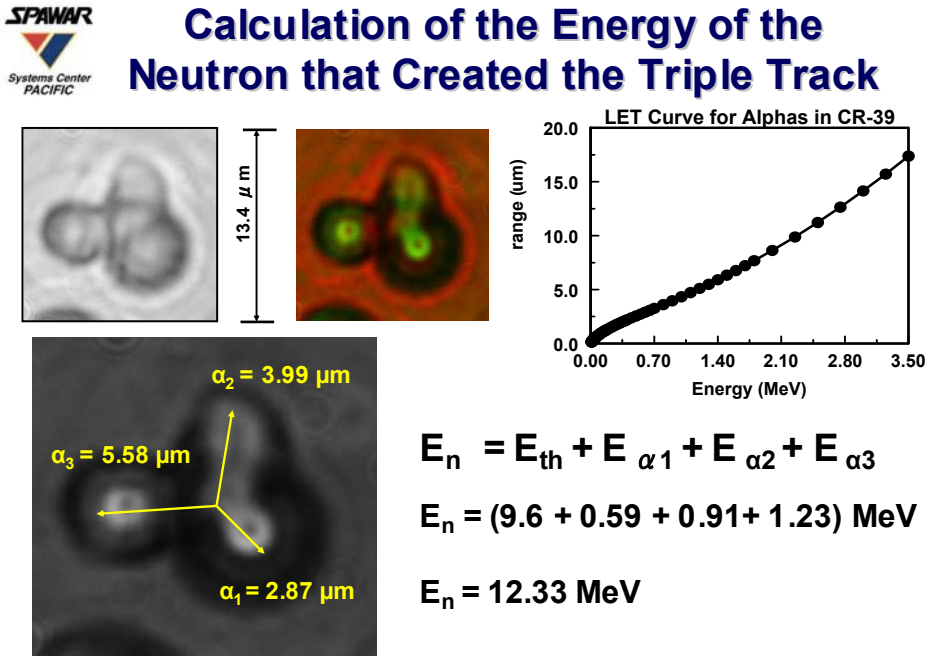


Fig.13; Triplet tracks observed in CR39 for co-deposition experiment of SPAWAR[12-14]



Since the detection of clear neutron signal means the occurrence of some "nuclear reaction in condensed matter", their reports[12-14] have been taken seriously. They explained that the energetic neutrons could be by DT (t + d) reactions. If the t + d reactions were secondary reactions of slowing down tritons after the primary DD (d + d) to p + t + 4.03 MeV reaction branch of two body d-d reactions, we should have detected one million times 2.45 MeV neutrons from the same weight branch of d + d to n + ^{3}He + 3.25MeV. Such big amount of tracks by 2.45 MeV neutrons was not detected in their CR39 detectors. What is the reason? We discuss possible theoretical scenarios in Chapter 3.

3. Theoretical Progress in Condensed Cluster Fusion Models

3.1 A summary of Conventional 2D Fusion Reaction

Major criteria of theoretically modeling the process of "radiation-less excess heat with ^{4}He ash" as condensed matter nuclear effects (CMNE) are:

A) How can the mutual Coulombic repulsion between deuterons be overcome at low deuteron energy, so as to reach at significant level of deuteron-related fusion rates?
B) How can ^{4}He generation channel be predominant?
C) How can hard radiations be suppressed?
D) What kinds of environments in/on condensed matter are incubating CMNE?

Many researchers have been concentrated in the criteria A and D, although controversial efforts were done for the criteria B and C. This section focuses on the criterion B.

"The major ash of helium-4 by two-body deuteron fusion reaction can not be expected." This comment is very true, as far as we concern about emitted particles in final state interactions by fusion reactions which are commonly data-based in nuclear physics. This means that we need to *invent* some new nuclear process in condensed matter for explaining ^{4}He production in correlation with excess heat[40]. The authors think that the direct coupling of excited nucleus in final state with lattice (e.g., metal-deuteride system) to transfer nuclear excited energy directly to lattice (vibration) is impossibly difficult[20, 25, 40].

To get to certain lower excited state (probably to be referred to assumed levels as 20.21 MeV by Swartz[41] or Schwinger-Preparata P-wave state[42] as shown in **Fig.14**) of ^{4}He*, we may have in principle various ways. See **Fig.14** for ^{4}He level charts and related reactions. One simple way is excitation by incident gamma-rays with energy more than 20.21 MeV, which may have resonance photon absorption at Eg =20.21 MeV with some narrow energy width (maybe on the order of several tens meV). One of other ways is usage of the p + t reaction with (20.21-19.814) = 0.396 MeV relative kinetic (beam) energy. Conventional d + d reaction can not go there since ^{4}He* excited energy with zero relative kinetic energy is 23.8MeV. So, Swartz[41] was assuming to take this 3.6 MeV difference – (23.8 minus 20.21) - by his hypothetical Phuson interaction, for which we are discussing below about its feasibility. Anyway his assumed 20.21MeV state of 'special d-d fusion' should reach at there through the d + d strong interaction, and therefore we need to consider the competition race among n-, p- and gamma-emission channels with own partial energy widths, because we have to start or compete with the <d-d> admixture state by d + d to ^{4}He*(E_x=23.8MeV) or some by-passed routes if invented. So, anyway we need to treat the competition among particle emission break-ups and gamma (or electromagnetic)

transitions. To treat photon channel only is therefore misleading. We stress that the p + t break-up channel, [t] channel, is dominant due to its large partial energy width, defeating the gamma-ray emission transition, [γ] channel, for the 20.21 MeV state of ^{4}He if this were attained in d-d interaction in condensed matter at all (We are however very pessimistic to this possibility).

We can not change branching ratios after the (virtual) intermediate compound state ^{4}He*(E_x = 23.8MeV + E_k) with very short life (on the order of 10^{-22} s), since no force-exchange bosons can transfer energy (or any information) from the intermediate compound nucleus to surrounding nuclei, atoms and lattices which are locating in distances larger than 0.1 nm. We need traveling time of force-exchange boson (photon for electro-magnetic interaction) more than 3×10^{-19} s which is very much larger than the life time 10^{-22} s of ^{4}He* (E_x = 23.8MeV +E_k). The branching ratios, [n]/[t]/[γ] of d-d fusion should keep therefore almost constant values, $0.5/0.5/10^{-7}$ for E_k = 0.025eV to about 100 keV. (See **Fig.15** for illustrating the feature of branching). Here E_k is the relative kinetic energy of d-d interaction.

To change out-going channels, namely branching ratios, we need the participation of *Third Interaction* into the d-d strong interaction process during the initial sate interaction stage. The third interaction should be effective enough quantitatively to change the virtual intermediate excited state of ^{4}He*(E_x), or other deuteron-related compound nuclei states.

Fig.14: DD (d + d) reaction and energy levels of ^{4}He

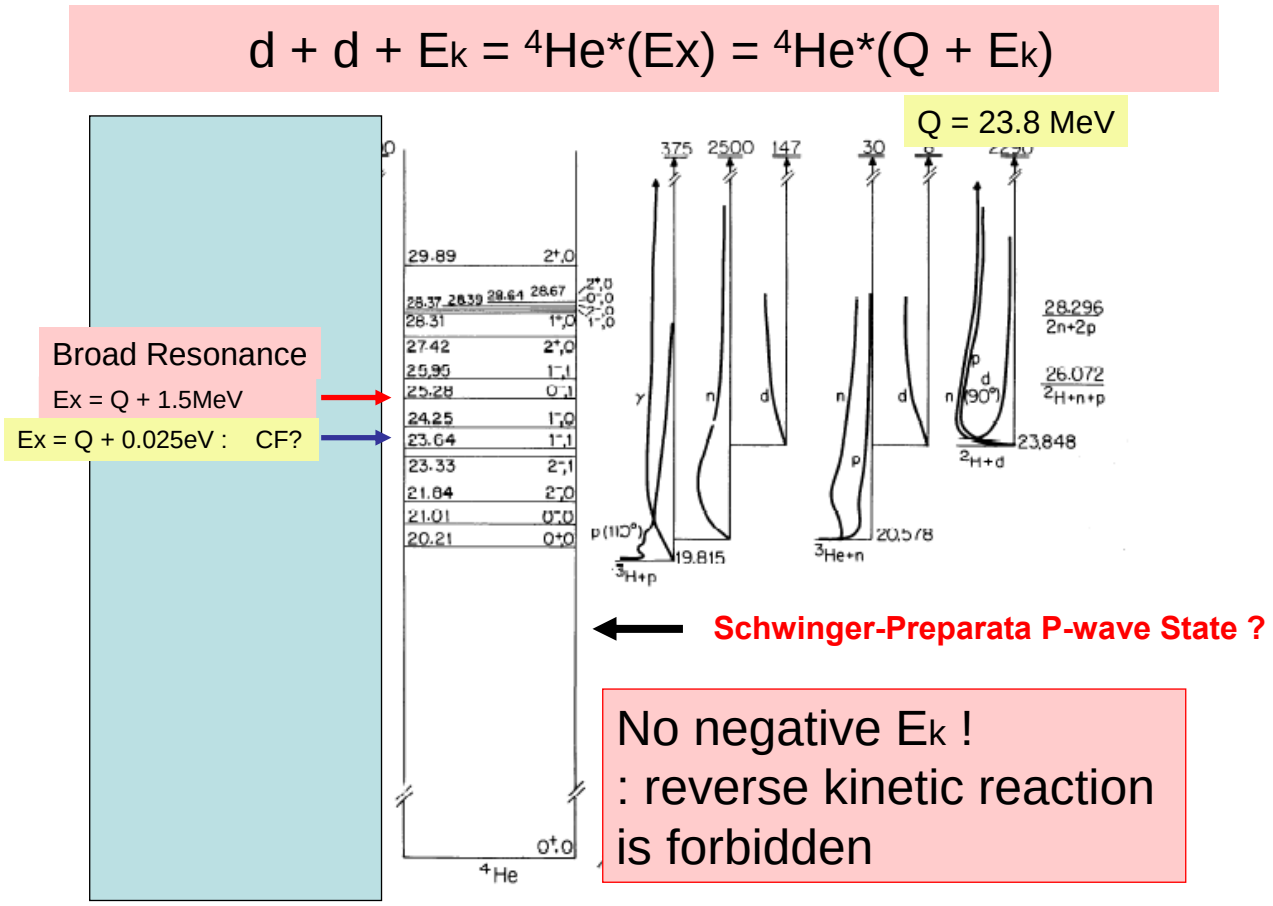
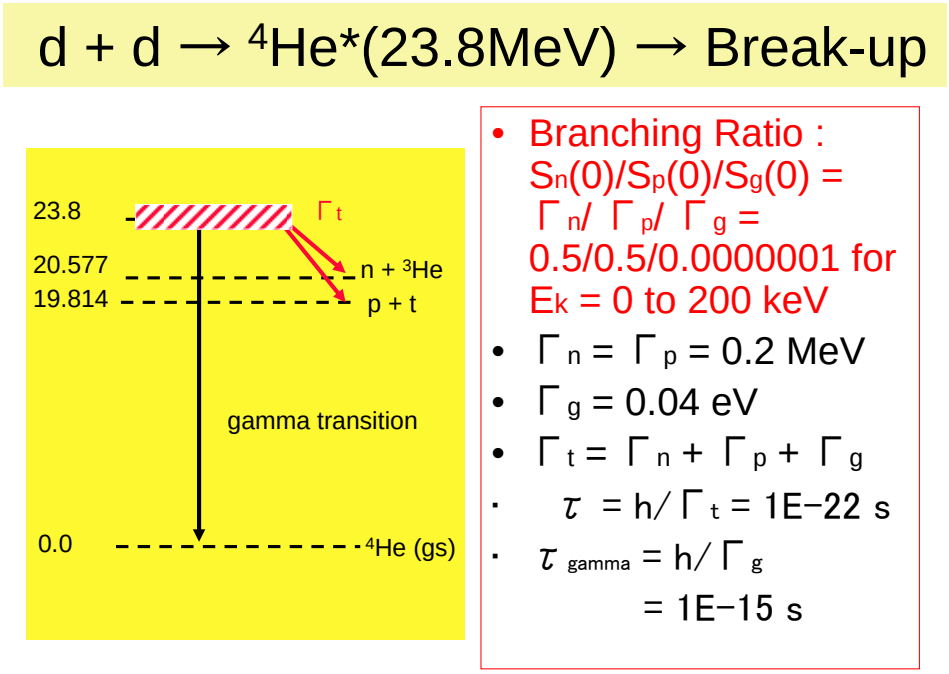


Fig.16: Break-up (out-going, decay) channels of d + d fusion



After long discussions[40] on possible third interactions to change the out-going channels (branching ratios), we can conclude:
"1) The lowest excited energy of ^{4}He*, intermediate compound nucleus, by two-body d + d fusion reaction is 23.8 MeV. Lower excited energy than 23.8 MeV is forbidden by kinematics. As a result, [n]/[t]/[^{4}He] branching ratio becomes almost constant values as $0.5/0.5/10^{-7}$ for Ek = 0eV to 100keV (relative kinetic energy of reaction).
2) If there happens the ^{4}He* (Ex) state with Ex < 19.8 MeV, the final product becomes ^{4}He with ground state, after electromagnetic transition. To realize this process by d + d reaction, there should exist the third coupling field which must take more than the 4 MeV difference energy (23.8 – 19.8) of the d-d system in the initial sate interaction.
3) The many-body interaction process between the d + d pairing and the third field of photon-phonon coupling in the lattice of condensed matter may be considered. Due to the very short range force of d + d strong interaction and its very short life time of virtual intermediate compound state, no processes have ever been proved to remove the 4MeV gap energy. Moreover, the field coupling constant of electro-magnetic interaction looks too weak, on the order of 10^{-2} of that for the strong interaction, to drastically change the state of d + d strong interaction for fusion. Quantitative studies on transition probabilities for proposed models[26-32] will be needed.
4) Deuteron-cluster fusion, i.e. 4D fusion, may produce ^{4}He final product as major ash of reaction. To realize the conditions of 4D fusion, the microscopic ordering/constraint process for the dynamic Platonic symmetry should be satisfied. The EQPET/TSC model is one of theoretical models, although we need further investigations to establish[20-25].

3.2 Brief History of Condensed Cluster Fusion Models

3.2.1 Step-1 Multi-Body Deuteron Fusion Models

In just after two weeks from the announcement of Fleischmann-Pons "cold fusion" claim[35] with large excess heat evolution without correspondingly intense neutron emission from the heavy-water electrolysis with Pd cathode, the author submitted a short note to J. Nucl. Sci. Tech.[41] proposing that the three body deuteron interaction, 3D fusion, by the following D-catalyzed cascade reaction channel to produce main ash of ^{4}He,

$$d + d \rightarrow {}^4He^*(Ex = 23.8\,MeV);\ {}^4He^* + d \rightarrow {}^4He\,(g.s) + d + 23.8\,MeV \quad (1)$$

Ordinary d +d (2D) fusion should have two main outgoing channels with 50 %/50% branching ratio, the n + ^{3}He + 3.27 MeV channel and the p + t + 4.03 MeV channel, and have very small branch (10^{-5} %) of the electromagnetic transition, ^{4}He(g.s.)+ γ + 23.8MeV, in low deuteron kinetic energy. So, the author thought that *the third hadron interaction should participate into the d+d strong interaction to realize a main branch of ^{4}He producing reaction*. The author is still keeping this original view now in 2009 for theorizing the deuteron cluster fusion models in condensed matter environments.

The modeling of Eq.(1) with quantification met however difficulty to predict high level reaction rate, due to very short life time (about 10^{-22} s) of ^{4}He*(Ex=23.8MeV), from proven nuclear physics knowledge. The author elaborated the model to the "simultaneous" 3D and 4D fusion models in the dynamic environment of PdD lattice with excited D-harmonic oscillators (phonons) to be able to predict more than several watts/cc-PdD excess heat with ^{4}He ash (23.8 MeV/^{4}He) and predict also much less (on the order of 10^{-6} to 10^{-12} of helium yield) of tritium and neutron production. It was modeled that fusion reactions by deuteron transient clusters would take place as the following competition process of 2D, 3D and 4D fusions.

$$d + d \rightarrow n + {}^3He + 3.27\,MeV\ (50\,\%);\ p + t + 4.03\,MeV\ (50\,\%) \quad (2)$$

$$d + d + d \rightarrow {}^3He + t + 9.5\,MeV\ (about\ 50\,\%);\ {}^4He + d + 23.8\,MeV\ (about\ 50\,\%) \quad (3)$$

$$d + d + d + d \rightarrow {}^4He + {}^4He + 47.6\,MeV \quad (4)$$

The formation of transient clusters of 2D, 3D and 4D was modeled to approximately quantify based on the concept shown with **Fig.17**. Deuterons sit at O-sites as Einstein oscillator (harmonic oscillator), and have Gaussian wave function for the ground state (energy eigen-value is 32 meV). At higher phonon-excited states, D-wave function changes to draw "U" shape distribution to enhance meeting probability of plural deuterons around the T-site. Fusion rates by 3D and 4D can take over 2D fusion rates in high phonon excited states.

The time-window about 50 fs was conceived for transient 4D cluster formation with about 10 GHz lattice plasma-oscillation under D-phonon excitation as illustrated in **Fig.18**. We also roughly estimated D-cluster formation probabilities as shown in **Fi.g.19**, as a function of D-phonon energy (one phonon = 64 meV was used). Competing fusion rates were then estimated as copied in **Fig.20**.

Later, we elaborated that we needed to consider electron spin combination (in Step-2[20]) and the Platonic symmetry (in Step-3[23, 24] for D-cluster formation). We also found later by the Langevin equation analyses[23, 24, 25] that the initial time window for 4D/TSC formation with much shorter interval as 1.0×10^{-18} s was enough for further 4D/TSC condensation. Also, very small 4D cluster formation probability as 10^{-11} can already realize enough high 4D fusion rates to meet one watt/cc level nuclear

heat-power level. So, we need to re-quantify cluster formation probabilities with more sophisticated solid state physics (or surface physics) modeling.

However, our Step-1 theories could explain why deuteron-related nuclear reaction with observable excess heat level with ^{4}He main ash was possible with apparently radiation less nuclear products. To prove the super-screening scenario of mutual Coulomb barriers among deuterons, we needed further elaboration in Step-2 and Ste-3.

Fig.17: Modeling of transient D-cluster formation under D-harmonic oscillator of PdD lattice[45]

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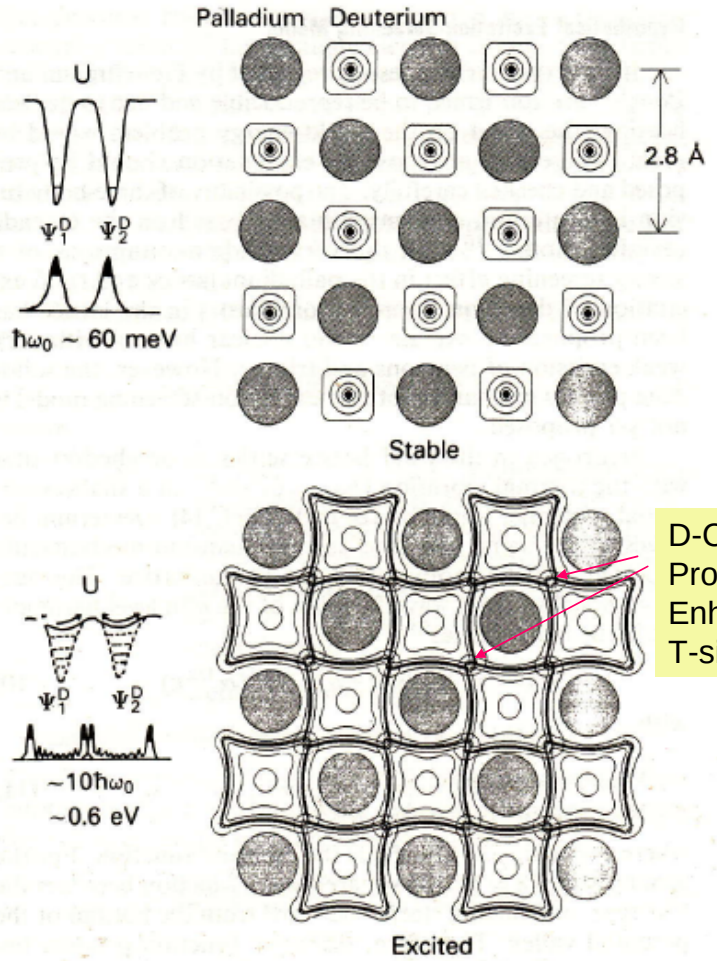


3.2.2 Step-2 EQPET/TSC Models

Elaboration of EQPET/TSC (electronic quasi-particle expansion theory/ tetrahedral symmetric condensate) models was reviewed in our recent papers[20,21].

We have proposed multi-body deuteron fusion process by formation of TSC (Tetrahedral Symmetric Condensate) and OSC (Octahedral Symmetric Condensate). Some numerical results were given by EQPET analyses, which could explain 3-78 W/cc heat-power level with 1.0x10^{11} f/s/cc to 1.0x10^{13} f/s/cc of ^{4}He-atoms production by 4D and 8D fusion reactions, with neutron production rate to be smaller than10 n/s/cc. There are remained open questions about where TSC is formed. We have proposed two mechanisms, as transient motion forming deuteron-clusters with short life time (60 fs).

In the near surface region of PdDx cathode, deuterium full loading (x=1; PdD) may be attained by electrolysis, gas discharge or gas-permeation, at least locally. No experimental techniques have been developed to measure local distribution of x-value, although we know that it should be key information. With very small density (namely 1 ppm was assumed in our paper) PdD_2 states may exist.

Fig.18: Illustration of transient D-cluster formation around T-site (left figure) and D-plasma oscillation with time window for D-cluster formation about 50 fs (right figure)[44]

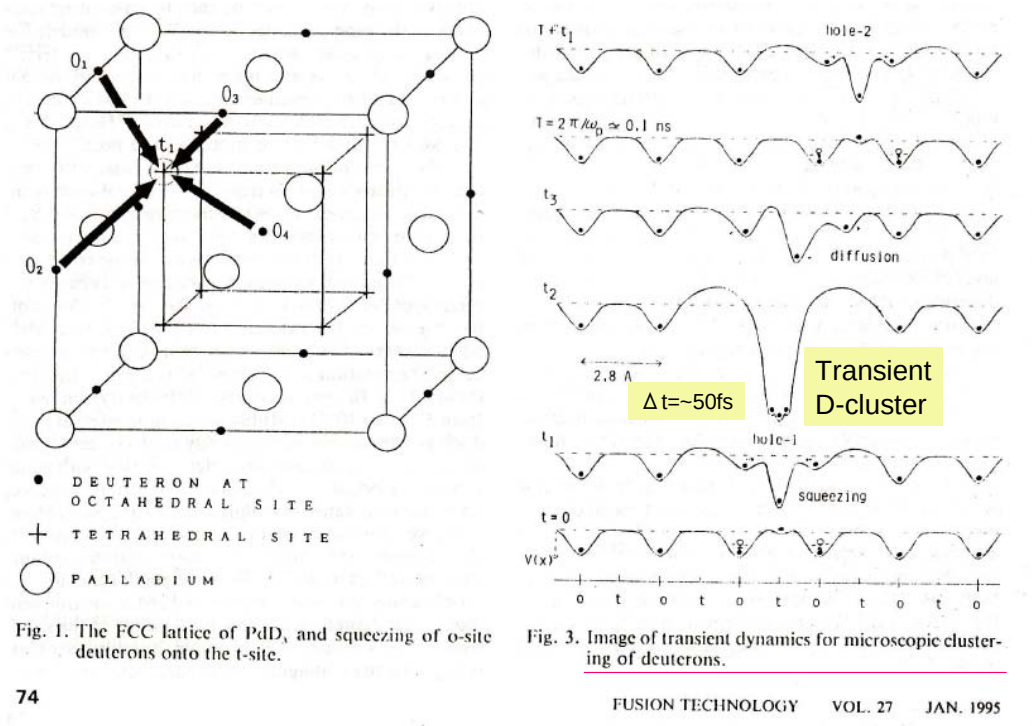


Fig. 1. The FCC lattice of PdD, and squeezing of o-site deuterons onto the t-site.

Fig. 3. Image of transient dynamics for microscopic clustering of deuterons.

Fig.19: Estimation of 2D, 3D and 4D cluster formation probabilities around T-site of PdD lattice as a function of D-phonon excitation energy

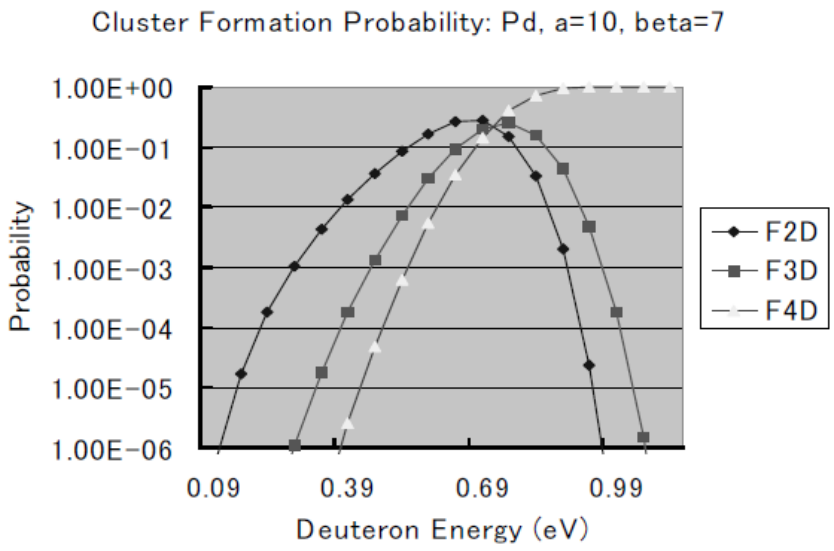


Fig.20: Comparison of logarithmic fusion rates between 2D, 3D and 4D fusions in PdD as a function of D-phonon excitation energy (copied from our paper A. Takahashi et al, Fusion Technology 1995, Fig.4[44])

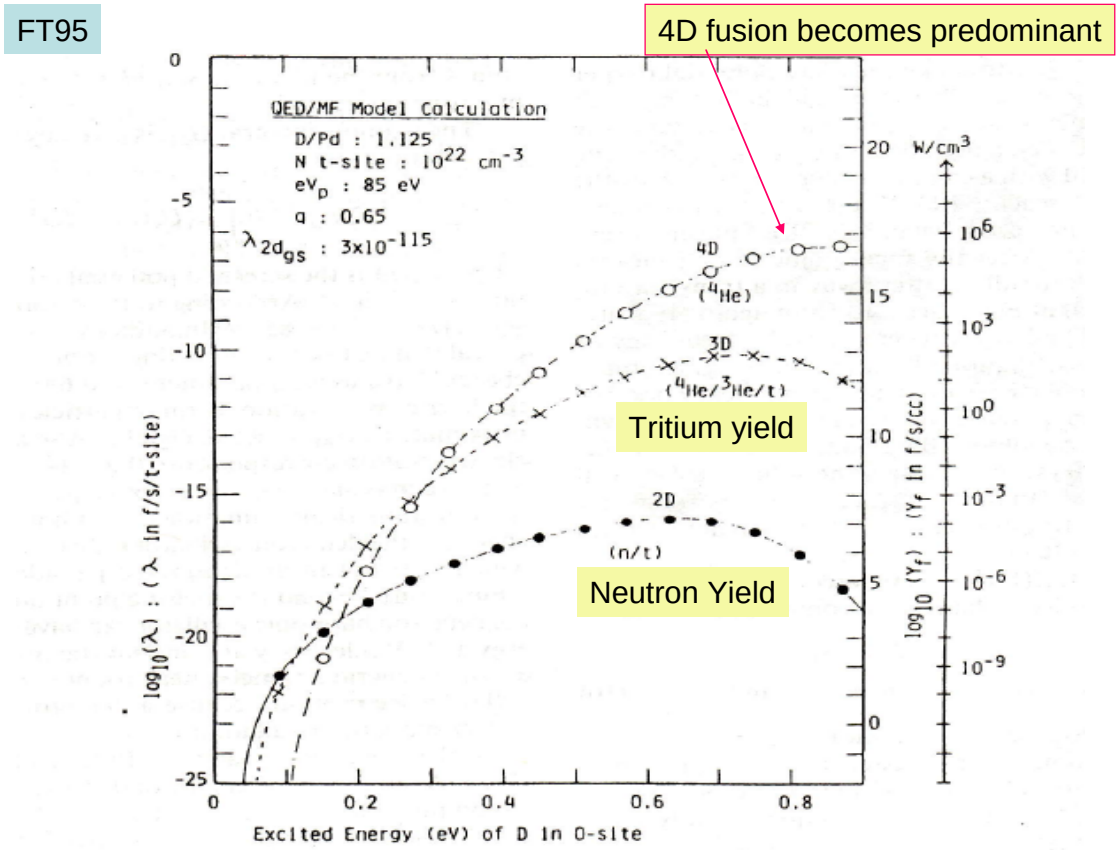


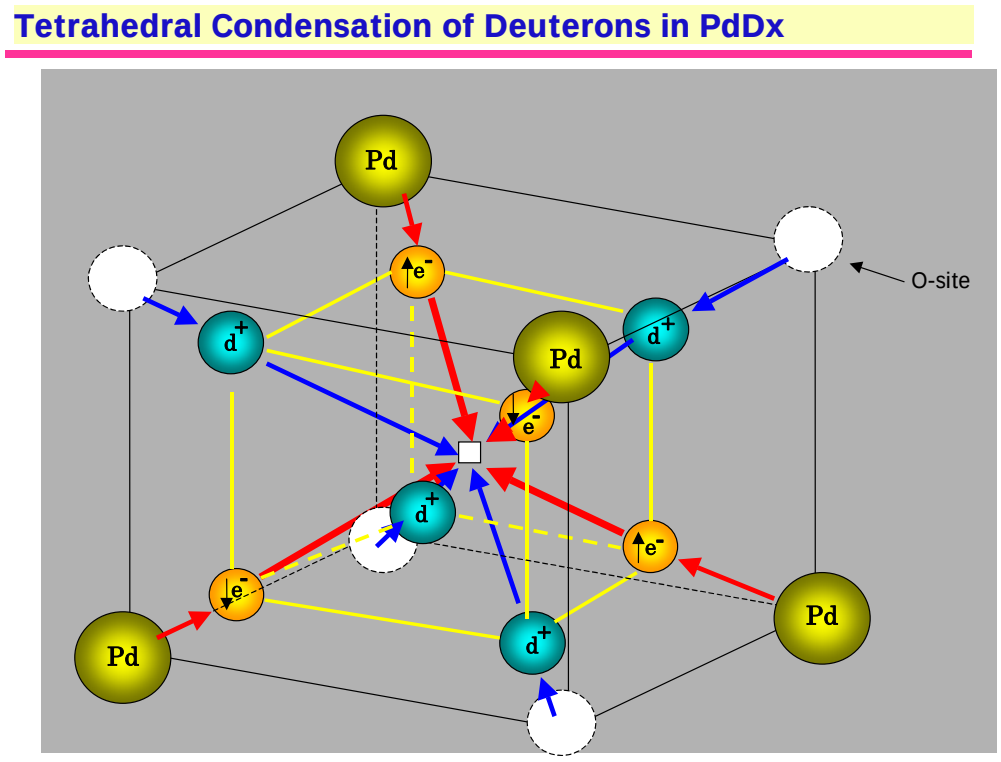
Fig. 4. Roughly estimated fusion rates in PdD_x, by the current model.

Trapped D in Bloch potential has discrete energies with 32meV ground state and 64meV of one phonon energy for excited states. Over 0.22eV, all D-ions in lattice diffuse out of solid if excitation happens at every O-site. By exciting with external UV or EUV laser, due to the classical Drude model, transient cluster of TSC can be formed with certain probabilities, in limited places as near surface region. An illustration of imagined state of moment for 4D/TSC (t=0) formation at a focal point (T-site in this case) is copied in **Fig.21**.

Other speculative models for initiation of 4D(or H)/TSC (t=0) were discussed in references 20 and 21. In EQPET models, we assumed that the total 4D wave function can be expanded by the linear combination of partial wave functions of dde* type molecules with regular electron state e(1,1) and electronic quasi-particle states as e*(2,2) Cooper pair, e*(4,4) quadruplet, and so on.

$$\left|\Psi_N\right\rangle = a_1\left|\Psi_{(1,1)}\right\rangle + a_2\left|\Psi_{(2,2)}\right\rangle + a_4\left|\Psi_{(4,4)}\right\rangle + a_6\left|\Psi_{(6,6)}\right\rangle + a_8\left|\Psi_{(8,8)}\right\rangle \qquad (5)$$

Fig.21: Illustration of initially formed 4D/TSC (t=0) around some T-sites in PdD lattice under D-phonon excitation; 4 centers of electron waves are drawn with "e^-" and will form tetrahedron by exchanging interaction of 1s electron of d^+ and 5s (or 5f) electron state of Pd^- states



In **Fig.22**, condensation motion of 4D/TSC is illustrated reflecting the numerical results we obtained in the Step-3 studies[23-25].

Modal fusion rate is defined[21] as,

$$\lambda_N = a_1^2 \lambda_{(1,1)} + a_2^2 \lambda_{(2,2)} + a_4^2 \lambda_{(4,4)} + a_6^2 \lambda_{(6,6)} + a_8^2 \lambda_{(8,8)} \quad (6)$$

$$\lambda_{nd(i,j)} = \nu(S_{nd} / E_d) \exp(-n\Gamma_{(i,j)}) \quad (7)$$

Estimated fusion rates are shown in **Table-3**.

Modal fusion rate given by Eq.(6) for 4D fusion is attributed almost 100% to the quadruplet EQPET molecule dde*(4,4) state. Therefore, the accuracy of this model is closely related to what the minimum size sate of 4D/TSC is.

Screening energies for d-d reaction are compared in **Table-3**.

Fig.22: Schematic steps of 4D/TSC condensation motion; 1) TSC (T=0) is just formed, 2) TSC gets to the minimum size state after about 1.4 fs condensation time[23-25], 3) strong interaction among 4d forms ^{8}Be* intermediate excited nucleus, 4) ^{8}Be* makes final state interaction to break up (figure copied from Ref-23, Fig.4)

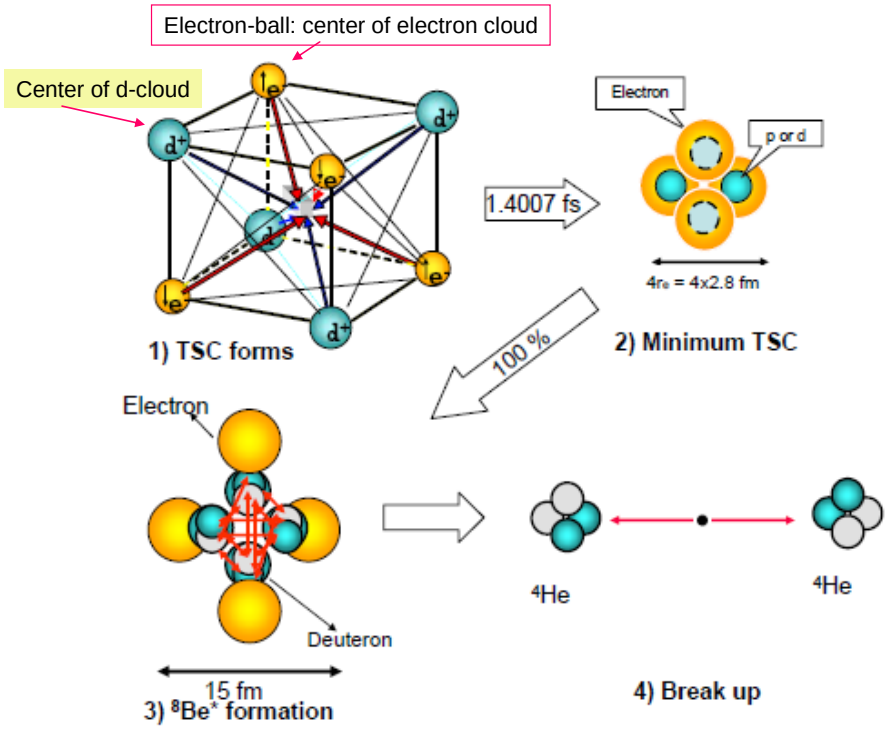


Fig.4: Illustration of 4D/TSC squeezing motion and 4D cluster fusion

Fig.23: Comparison of d-d pair trapping potentials between D_2 molecule, dde*(2,2) and dde*(4,4)

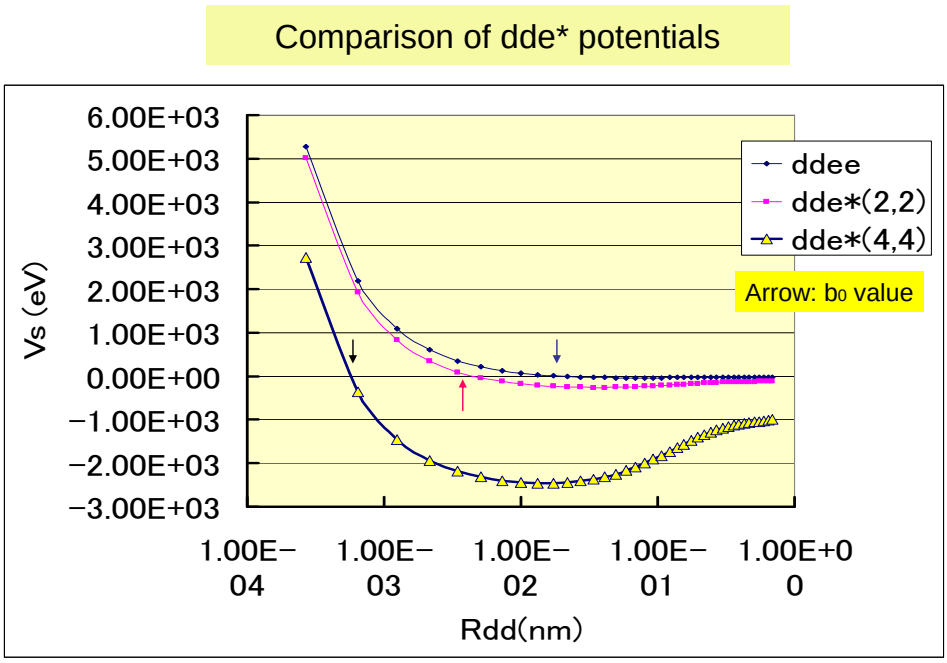


Table-2: Screened energies for various EQPET molecules

e*(m*/me, e*/e)	Screening Energy Us (eV)		b_0 (pm)	
	dde*	dde*e*	dde*	dde*e*
(1, 1) ; Normal electron	36	72	40	20
(2, 2) ; Cooper pair	360	411	4	2
(4, 4) ; Quadruplet	4,000	1,108	0.36	1.3
(8,8) ; Octal coupling	22,154	960	0.065	1.5
(208, 1) ; muon	7,579	7,200	0.19	0.20

Table-3: Typical results by EQPET/TSC for fusion rates, power level and products, for TSC in PdDx, assuming $N_{4D} = 10^{22}$ (1/cc)

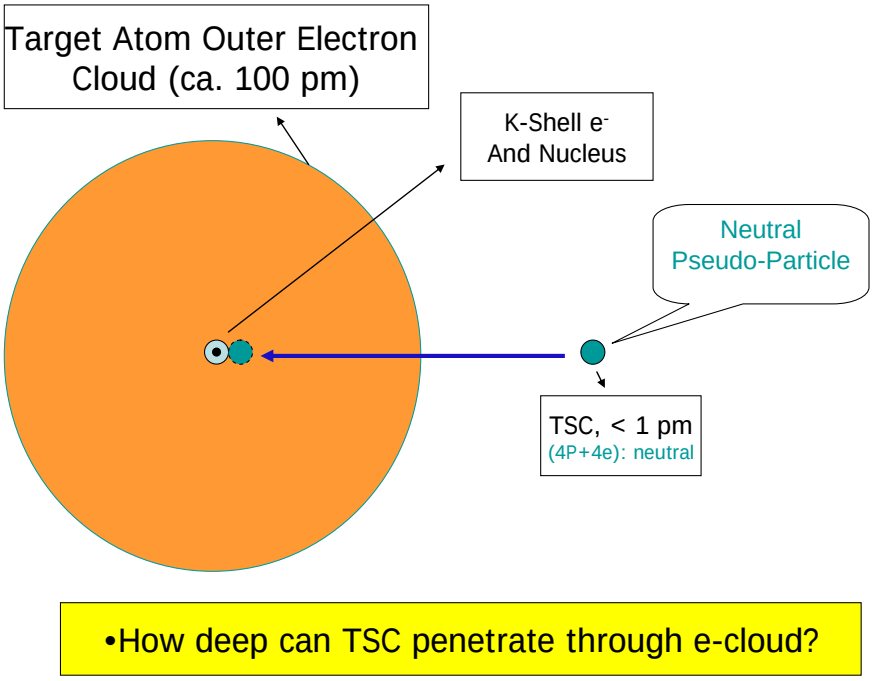
Multi-body	Microscopic fusion rate (f/cl/s)	Macroscopic Yield (f/s/cc) , Power	Ash (fusion products)
2D	$1.9x10^{-21}$	19 (f/s/cc), $1.9x10^{-11}$(W/cc)	Neutron; 10 n/s/cc
3D	$1.6x10^{-13}$	$1.6x10^{9}$ (f/s/cc), $1.6x10^{-3}$ (W/cc)	Tritium; $8x10^{8}$ t/s/cc
4D	$3.1x10^{-11}$	$3.1x10^{11}$(f/s/cc), 3.1 (W/cc)	Helium-4; $3x10^{11}$ h/s/cc

Later, we have considered that the squeezing motion of TSC can be more simply treated by a semi-classical model, because of the three-dimensionally constrained motion of 4d and 4e particles in TSC into the central focal point. Every QM particle-center in TSC can make central squeezing motion with same velocity, to keep charge neutrality of total TSC system – in other words to satisfy minimum system energy state (as calculated by the variational principle of quantum mechanics, QM). Therefore this squeezing motion can be treated approximately by Newtonian mechanics until when 4 deuterons get into the range (about 5 fm) of strong nuclear interaction. When 4 electrons start to separate at minimum TSC state, 4 deuterons suddenly start to *feel* mutual Coulomb repulsion. Nuclear interaction at this stage can be approximately treated by STTBA (Sudden Tall Thin Barrier Approximation)[20]. We obtained: $\lambda_{4d} = 2.3x10^{-4}$ f/s/cl at TSC-minimum state. This microscopic fusion rate is 10^7 times larger order of value than one given in Table-2. We consider therefore that EQPET model gave significant underestimation for 4D fusion rate when rigid constraint of motion in three dimensional TSC motion in condensed matter is attained as shown in Fig.22.

TSC squeezes from about 100 pm size to its minimum-size with about 10-20 fm diameter and behaves as *charge-neutral pseudo-particle*. Life time of TSC is estimated as time difference from 100 pm size state to minimum size with velocity of the order of 10^5 cm/s; we obtain about 60 fs. (This is later found to be much shorter as 1.4 fs as we obtained in Step-3[23-25]). During its life, TSC as charge-neutral

pseudo-particle may approach to host-metal nuclei with some probability when TSC size becomes smaller than the orbit size of inner most K-shell electron orbit of host metal target and TSC has drift momentum of Center-of-Mass system, as illustrated in **Fig.24.**

Fig.24: Illustration of possible approaching process of condensed TSC penetrating through electron shell clouds of host (target) metal nucleus



We proposed therefore the interaction models between TSC-min state of either deuteron-cluster or proton-cluster and host metal large nucleus to induce 4d or 1p to 4p capture process[25)]. This model of TSC-induced 4D fusion and transmutations could well explain ^{4}He production with excess heat results by Arata [15)] and McKubre[39].

3.2.3 Step-3 D-Cluster Dynamics and Fusion Rate by Langevin Equation

To explain apparent hard-radiation-less excess heat with ^{4}He ash in CMNS (condensed matter nuclear science) experiments, especially in dynamic PdDx systems, we have done a long (1989-2009) series of study for modeling D-cluster (or multi-body deuteron) fusion reaction mechanisms to reach at our latest theory in Step-3 studies based on quantum-mechanical Langevin equations[23-25)] (stochastic differential equation).

The basics of methods with Langevin equations for D-cluster dynamics, especially for D-atom, D_2 molecule, D_2^+ ion, D_3^+ ion, 4D/TSC (tetrahedral symmetric condensate) and $6D^{2-}$/OSC (octahedral symmetric condensate) are written in our latest paper[24,25].

First one-dimensional Langevin equations for D-clusters with the R_{dd} (d-d distance) are formulated under the Platonic symmtery[25] of multi-particle D-cluster systems with deuterons and quantum-mechanical electron centers. Under the orthogonally coupled Platonic symmetry for a Platonic

deuteron-system and a Platonic electron system, dynamic equations for so-many-body system of deuterons and electrons with metal atoms (more than 4 deuterons plus 4 1s electrons of deuterium atoms plus 40 4d-shell electrons of 4 Pd atoms in fcc lattice plus surrounding lattice atoms under D-phonon excited states should be considered in our modeling), a simple one-dimensional Langevin equation for the inter-nuclear d-d distance R_{dd} can be formulated, as we showed in the papers[23-25]. By the ensemble averaging of Langevin equation with the weight of quantum mechanical wave-functions for electrons and deuterons, we could further derive a time dependent one-dimensional Langevin equation for expectation value $<R_{dd}>$, which is nonlinear, but could be solved by the Verlet's time step method[23, 24]. We showed in our papers[24,25] that only 4D(or H)/TSC can condense ultimately to be finally very small charge neutral entity with about 10-20 fm radius. At the final stage of 4D/TSC condensation in about $2x10^{-20}$ s, 4D fusion with 2 ^{4}He products takes place with almost 100% probability, according to our HMEQPET calculation[23,24] for barrier factors and fusion rate formula by the Fermi's first golden rule.

Basic Langevin equation for a Platonic symmetric D-cluster having N_e d-d edges and N_f faces of d-d-e (D_2^+)or d-e-d-e(D_2) type is written by Eq.(8). Here, R is the d-d distance and m_d is the deuteron mass, V_s is the d-d pair trapping potential of either d-e-d-e or d-d-e type molecule. The first term of right side in Eq.(8) is the total Coulomb force of D-cluster system, and f(t) is the fluctuation of force for which we introduce quantum mechanical fluctuation of deuteron positions under condensation motion. The quantum mechanical effect of electron clouds is incorporated with the second term of right hand side as "friction" in Langevin equation. For D_2 molecule, $N_e = N_f = 1$. For D_3^+ ion which is known as stable in vacuum, $N_e = 3$ and $N_f = 6$ are given. For 4D/TSC, $N_e = 6$ and $N_f = 6$ are given. For $6D^{2-}$, $N_e = 12$ and $N_f = 24$ are given.

By taking QM ensemble average with d-d pair wave function, assumed as Gaussian distribution, we derived Langevin equation for 4D/TSC as Eq.(9). By taking QM ensemble average of Eq.(10), we obtained Eq.(14). We obtained the time-dependent TSC-cluster trapping potential as Eq.(15).

Similar Langevin equation and trapping potential were derived for $6D^{2-}$ molecule also. We compared central potential curve (at $R'=R_{dd}$) in **Fig.25**. We found that 4D(H)/TSC can condensate ultimately to very small charge neutral entity and has no stable or ground state. This may be the reason that we do not observe D_4 molecule in nature. On the contrary, $3D^+$ molecule and $6D^{2-}$ molecule have stable and ground state.

Equation (14) was numerically solved by the Verlet method[23], as result is shown in **Fig.26**.

Time dependent barrier penetration probabilities (as a function of R_{dd}, since we have one-to-one relation between elapsed time and $R_{dd}(t)$) is shown in **Table-4.**

$$N_e m_d \frac{d^2 R}{dt^2} = -\frac{k}{R^2} - N_f \frac{\partial V_s}{\partial R} + f(t) \tag{8}$$

$$6 m_d \frac{d^2 R_{dd}(t)}{dt^2} = -\frac{11.85}{[R_{dd}(t)]^2} - 6\frac{\partial V_{s2}(R_{dd}(t);1,1)}{\partial R_{dd}(t)} + \langle f(t) \rangle + f'(t) \tag{9}$$

$$6 m_d \frac{d^2 R_{dd}(t)}{dt^2} = -\frac{11.85}{[R_{dd}(t)]^2} - 6\frac{\partial V_{s2}(R_{dd}(t);1,1)}{\partial R_{dd}(t)} + \langle f(t) \rangle + f'(t) \tag{10}$$

$$f'(t) = f(t) - \langle f(t) \rangle \tag{11}$$

$$f(t) = [-\frac{\partial \Delta E_c(R_{dd})}{\partial R_{dd}}] \bmod[\ X^2(R'_{dd}; R_{dd}(t))] \tag{12}$$

$$X^2(R'_{dd}; R_{dd}(t)) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp[-(R'_{dd} - R_{dd}(t))^2/(2\sigma^2)] \tag{13}$$

$$6m_d \frac{d^2\langle R_{dd} \rangle}{dt^2} = -\frac{11.85}{\langle R_{dd} \rangle^2} - 6\frac{\partial V_s(\langle R_{dd} \rangle; m, Z)}{\partial \langle R_{dd} \rangle} + 6.6\left\langle \frac{(R' - R_{dd})^2}{R_{dd}^4} \right\rangle \tag{14}$$

$$V_{tsc}(R': R_{dd}(t)) = -\frac{11.85}{R_{dd}(t)} + 6V_s(R_{dd}(t); m, Z) + 2.2\frac{|R' - R_{dd}(t)|^3}{[R_{dd}(t)]^4} \tag{15}$$

Fig.25: Comparison of cluster trapping potential between 4D/TSC and $6D^{2-}$/OSC. TSC condenses ultimately to very small R_{dd} value (ends at R_{dd}-min=about 20 fm), while OSC converges at R_{dd}=about 40 pm (corresponding to the ground state).

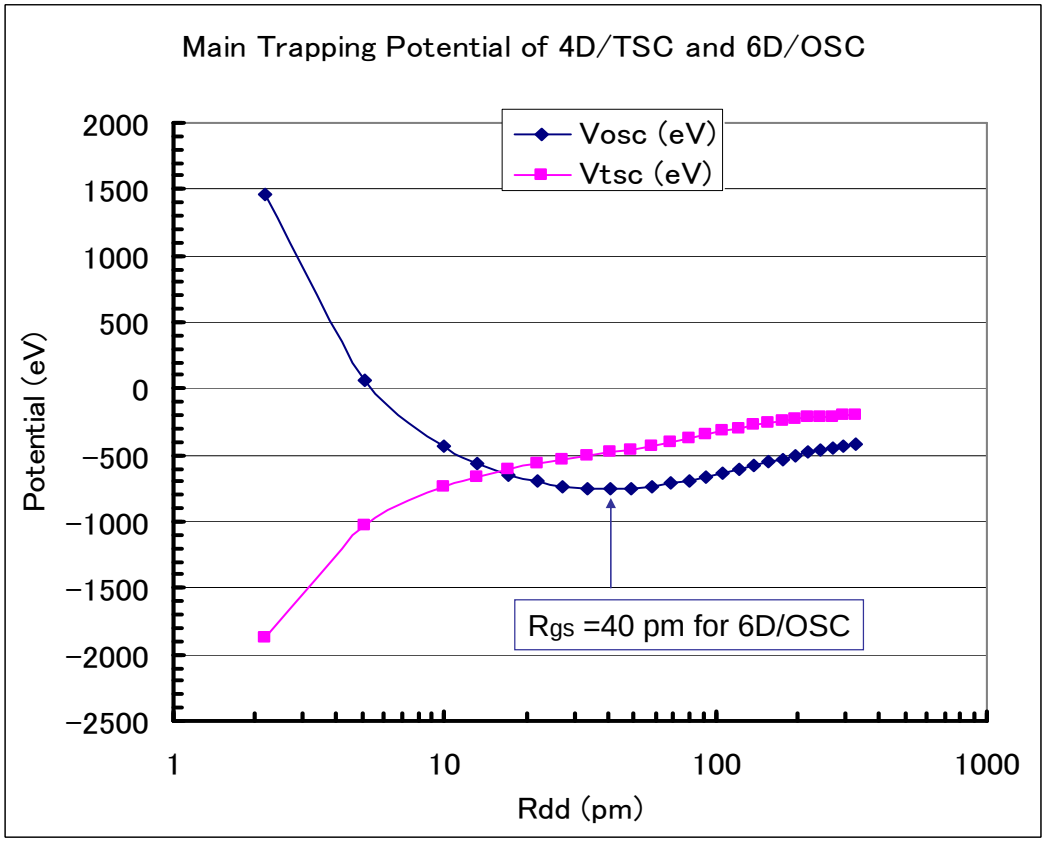


Fig.26: Numerical solution of Eq.(14) by the Verlet method[23]. Time is reversed starting from the condensation time 1.4007 fs.

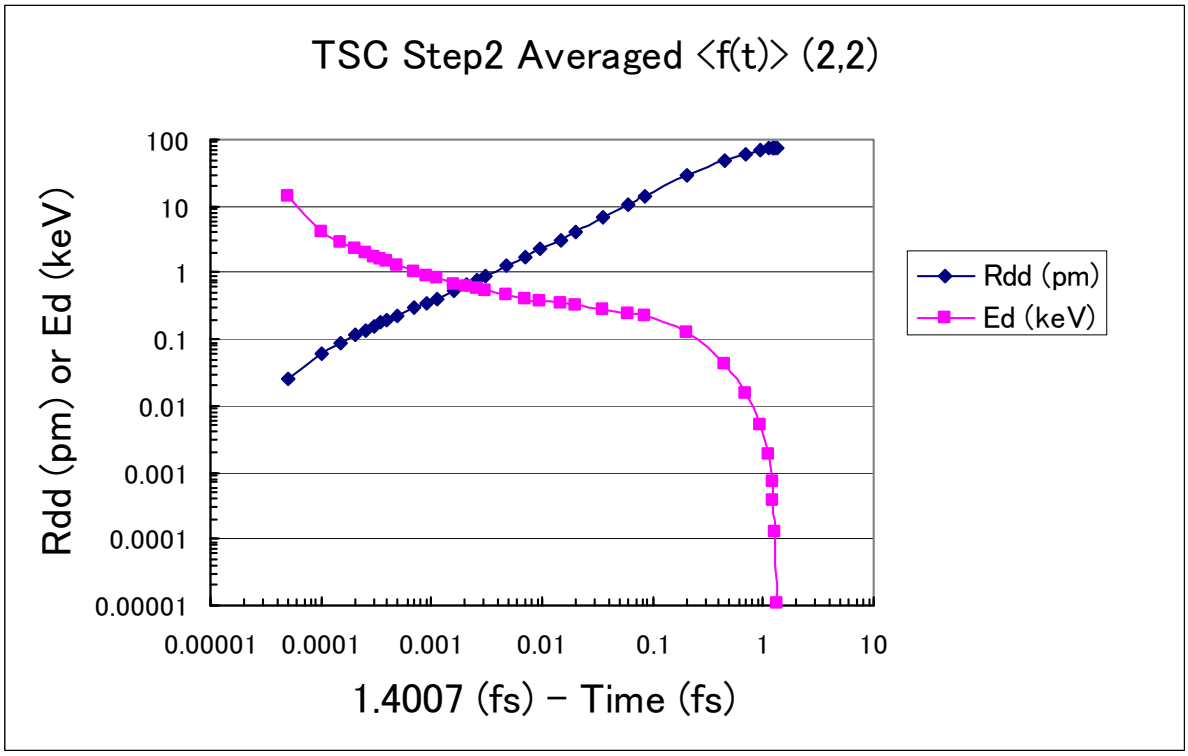


Table-4: Calculated time-dependent (equivalently R_{dd} dependent) barrier factors of 4D/TSC condensation motion

Elapsed Time (fs)	R_{dd} (pm)	P_{2d}: 2D barrier facotor	P_{4d}: 4D barrier factor
0	74.1 (D_2 molecule)	1.00E-85	1.00E-170
1.259	21.8 (dde*(2,2); Cooper pair	1.30E-46	1.69E-92
1.342	10.3	2.16E-32	4.67E-64
1.3805	4.12	9.38E-21	8.79E-41
1.3920	2.06	6.89E-15	4.75E-29
1.3970	1.03	9.69E-11	9.40E-21
1.39805	0.805 (muon-dd molecule)	1.00E-9	1.00E-18
1.39960	0.412	9.40E-7	2.16E-13
1.40027	0.206	3.35E-5	1.12E-9
1.40047	0.103	1.43E-3	2.05E-6
1.40062	0.0412	1.05E-2	1.12E-4
1.40070	0.0206 (TSC-min)	4.44E-2	1.98E-3

Fusion rate is calculated by the following Fermi's golden rule[21],

$$\lambda_{nd} = \frac{2}{\hbar}\langle W \rangle P_{nd}(r_0) = 3.04 \times 10^{21} P_{nd}(r_0)\langle W \rangle \quad (16)$$

Here P_{nd} is barrier factor for nD-cluster and <W> is the averaged value of imaginary part of nuclear optical potential[21]. The extrapolation of <W> value to 4d fusion was made by using the scaling law $\langle W \rangle \propto (PEF)^5$ with PEF-value which is given in unit of derivative of one pion exchange potential (OPEP) (simple case of Hamada-Johnston potential[25] for pion exchange model) . We got the next value of 4D fusion yield per TSC generation,

$$\eta_{4d} = 1 - \exp(-\int_0^{t_c} \lambda_{4d}(t)dt) \quad (17)$$

Using time-dependent barrier factors as given in Table-3, we obtained $\eta_{4d} \cong 1.0$. *This result means that:*

We have obtained that 4D fusion may take place with almost 100 % yield per a TSC generation, so that macroscopic 4d fusion yield is given by simply with TSC generation rate Q_{tsc} in the experimental conditions of CMNS.

However, when we consider that one deuteron has spin-parity 1^+ and combination of 4d has total spin state 4, 3, 2, 1 and 0, the 4d fusion with out-going channel to two ^{4}He (0^+:gs) particles is forbidden, by spin-parity conservation (for S-wave in/out channels), except for the 0^+ spin-parity state (T=0) of 4d combination, to be explained detail analysis including P-wave and D-wave states with isospin elsewhere.

The ultimate condensation is possible only when the double Platonic symmetry of 4D/TSC is kept in its dynamic motion. The sufficient increase (super screening) of barrier factor is also only possible as far as the Platonic symmetric 4D/TSC system is kept. Therefore, there should be always 4 deuterons in barrier penetration and fusion process, so that 4d simultaneous fusion should take place predominantly. The portion of 2D (usual) fusion rate is considered to be negligible[23, 25].

Typical nuclear products of 4D fusion are primitively predicted to be two 23.8 MeV α-particles. but the final state interaction of ^{8}Be* is complex yet to be studied. There may be dominant outgoing channels via excited states of fragmented composite particles as ^{4}He* and ^{6}Li*, which would produce ^{4}He-particles (α-particles) mostly in 2-5 MeV region. These α-particles are difficult to detect in liquid-phase D-loading cells, and also difficult even in gas-loaded cells, due to attenuation of particles in liquid, gas and solid. Fragmentation may go through "symmetric" as ^{4}He*(Ex) + ^{4}He*(Ex) + (47.6MeV-2Ex), or "asymmetric" as ^{4}He(g.s.)+^{4}He*(Ex) + (47.6MeV-Ex). If Ex is the first excited state 20.21 MeV (see Fig.15), ^{4}He*(Ex=20.21) breaks up to t (1.8-3.4MeV) + p(0.6-2.2MeV). This triton may cause the secondary DT (d + t) reactions in its slowing down in PdDx matter and emits energetic neutrons in 10-17 MeV region, which may be the explanation of SPAWAR triplet tracks[12-14].

We consider lastly that the principle of dynamic condensation motion of TSC in the view of Heisenberg uncertainty principle (HUP). At the starting condition of 4D/TSC (t=0), d-d distance R_{dd} was estimated to be the same value (74.1 pm) with that of D_2 molecule. At this starting point, mean electron kinetic energy of one "d-e-d-e" face EQPET molecule of TSC 6 faces was 17.6eV. During

the non-linear condensation of TSC, as parameters are given in Table-3, size of "d-e-d-e" EQPET molecule decreases from R_{dd}=74.1pm at t=0 to R_{dd}= 20.6fm at t=1.4007 fs. In the view of HUP, electron wave length should decrease accordingly to the decrement of R_{dd}. At t=1.4007fs, mean kinetic energy of electron for "d-e-d-e" EQPET molecule was estimated[4)] to be 57.6keV. Considering the relations, $\lambda\!\!\!^{-} = \hbar/(mv)$ of de Broglie wave length and $(kinetic-energy) = \frac{1}{2}mv^2$, we understand that effective quantum mechanical wave length of trapped electron in TSC has decreased dramatically in the 1.4007 fs condensation time. The estimated trapping potential depth of TSC at t=1.4007fs was -130.4keV. This is understood as an adiabatic state in very short time interval (about 10^{-20} s) to trap such high kinetic energy (57.6keV) electrons in very deep (-130.4 keV) trapping potential, for fulfilling the HUP condition. By the way, mean kinetic energy of relative d-d motion was estimated to be 13.68keV at this adiabatic state, which also diminished relative deuteron wave length trapped in the adiabatic TSC potential. In this way, very short R_{dd} (in other word, super screening of mutual Coulomb repulsion) was realized in the dynamic TSC condensation to give very large 4D simultaneous fusion rate.

It is also worthwhile to point out that the simultaneous 4D fusion in the final stage interval, about $2x10^{-20}$ s, of TSC-minimum state should take place with relative kinetic energy about 10 keV, which is accidentally similar to the target plasma temperature of DT plasma-fusion device (ITER, for instance). In this sense, the 4D condensed cluster fusion in not "cold fusion".

3.2.4 Concluding Remarks

How to super-screen Coulomb barrier, how to be ^{4}He of ash and why to have no apparent hard radiations are able to be resolved by the 4D/TSC dynamic condensation motion, basically. The Langevin equation-based analysis can be extended for neutral clusters as 6D/OSC and 8D/OSC with further elaboration of substantial modeling. Main future works should be considered as:

1) How to enhance 4D/TSC (t=0) rate in nano-structure of metal-deuterium systems should be investigated, since this gives key information of stimulation-conditions in experiments. TSC formation process in regular PdD lattice under external stimulation, on surface of nano-particle or nano-structure samples or interfaces with incoming deuteron (or D_2) flux should be modeled or experimentally tried.

2) Detail of ^{8}Be* final state interaction and out-going channels should be studied. This compound excited state may have complex final state interaction to various out-going channels as symmetric and asymmetric fragmentations and α + ^{4}He*(Ex<47.6MeV) + (47.6MeV-Ex), gamma-transition of ^{8}Be*(47.6MeV-E_γ) + Eγ and minor channels of n, p, and t emission, etc. Lower excited states of ^{8}Be* have many out-going channels to ^{4}He(g.s) + ^{4}He(g.s). Combination of spin-parities and isospins are complex. Charged particle spectroscopy and particle-identification by experiments should be cross-checked with such theoretical predictions.

3.3 How Three Miracles Are Overcome by the Condensed Cluster Fusion Models: Q&A

Q1) Skeptic people have criticized that three miracles must happen for "Cold Fusion" to occur: (1) A

giant increase of the probability for fusion reactions to occur at low energy; How?

A1) Tetrahedral Symmetric Condensate (TSC) of 4 deuterons plus 4 electrons in lattice/surface dynamics of PdDx (or other metal maybe OK) condensed matter can realize this requirement as explained below.
TSC is predicted to form in transient dynamics of fully deuterium-contained condensed matter. The dynamic ordering -or self-organization- mechanism of condensed matter can realize it, namely the formation of three dimensionally symmetric (Plato type) cluster in transience. This is the reason why CF/CMNS may happen only in condensed matter, not in random mechanism of plasma fusion or stellar nuclear reactions or accelerator-based nuclear reactions. The dynamic condensation of TSC is realized time-dependently (dynamically) to get to the formation of very small (in 20 fm- $20x10^{-15}$ meter- diameter) charge-neutral entity of 4D cluster effectively within about 0.00002 fs (femto-second) (10^{-15} second) time interval of the final phase of TSC condensation. TSC condenses into the very small charge-neutral entity in the condensation time of 1.4 fs, started from usual molecular size (about 0.5 angstrom) of just formed TSC in time-zero:
This condensation mechanics was confirmed by the author's "quantum-mechanical Langevin equation" analysis that is a new kind of dynamic theory for molecular dynamics. In that very small time-interval of about $2x10^{-20}$ second (0.00002 fs), the condensed "minimum"-cluster of 4D/TSC can easily make strong nuclear interaction of 4D fusion, because 20 fm diameter of the small charge-neutral entity, a kind of transient very small molecule, realizes significant (on the order of 10^{-4}) Coulomb barrier penetration probability for getting into the range of nuclear strong interactions between deuterons of the condensed cluster.
Numerical calculation of quantum-mechanical mean kinetic energy between deuterons in the condensed "minimum"-cluster of 4D/TSC is rather high as about 10keV, not low as room temperature (0.025eV, typically) but similar to "hot plasma fusion condition". This effective high kinetic energy of deuteron can exist only for about 0.00002 fs time-interval, by strongly deep transient trapping potential of TSC (about -130 keV deep). This effectively high transient kinetic energy should be met to satisfy the requirement of Heisenberg Uncertainty Principle (HUP), namely the nature of quantum mechanical behavior of particles, even for transient motion.
The question how to overcome the very high Coulomb barrier of fusion is thus overcome in the very short time interval of dynamics by the 4D/TSC theory.
This very rapid mechanism does not affect the expansion of regular lattice (e.g., PdDx) visibly, since the time-integrated rate of "electron pressure" effect to steady-lattice is negligibly small.

(Q2) For some reasons (2) the expected fusion products (neutrons and tritium) are largely absent; Why?

A2) Tritium is minor branch product of 4D fusion by TSC (the author will present this in ICCF15 and ACS2010 meetings). Neutrons (with higher energy in 3-17MeV region) are secondary reaction products of t + d reactions of primary triton emission of 4D fusion minor channel with very low yield, after 4D fusion, hitting deuterons in PdDx. The TSC theory gave quantitative predictions of tritium and neutron yields, which were given 10^{-5} to 10^{-8} for T/^{4}He yield ratio, and 10^{-10} to 10^{-12} for n/^{4}He yield ratios: these are not in contradiction to the claims of experiments as far as we believe in observations with estimated error bars.

(Q3) If ^{4}He is the reaction channel, where is the gamma ray?

A3) 4D fusion products are complex with many competing channels-yet to be studied-, but theory can predict there are major products of ^{4}He by many lower energy (mostly less than 5 MeV and minor rates in 24 MeV) alpha-particle emissions which can induce mostly secondary soft X-rays and visible-range (or its near outsides) photons, which are mostly absorbed inside cell to be hardly detected

outside, in their slowing down process (by ionization and recombination of electrons and nuclear collisions) in condensed matter.
Gamma ray emission is not predicted in primary channels of 4D fusion.
Usually known 2D (d + d) fusion rate is negligibly small in the TSC theory analysis, thus gamma rays by the d + d to ^{4}He + 23.8MeV-gamma-ray cannel are not visible (very much weak if existing as minor reaction channel).

Q4) What does the TSC theory say about those three "miracles"?
A4) The 4D/TSC theory can clear the “three miracles", as mentioned above.

Q5) Which scientific paradigm does the TSC theory belong to?
A5) This is the extension of known physics as quantum mechanics for atomic, molecular and nuclear reaction dynamics. The developed "quantum-mechanical Lagevin equation method" is a new tool for molecular dynamics analysis for very rapid transient particle-wave motion, which is expected to apply for other phenomena than "cold fusion" or "condensed matter nuclear science".
The TSC model is also the extension of dynamic models for solid state physics and molecular physics. The author does not know if it can be a scientific paradigm shift, but people will find if the TSC theory and the quantum-mechanical Langevin equation method would survive long.

Q6) Does the TSC theory make any predictions which can be or have already been tested empirically?
A6) Yes, for some very important experimental claims:
(1) Major ash of ^{4}He product without gammas-rays,
(2)Tritium production with minor yield than ^{4}He,
(3) Very weak neutron emission with high energy component,
(4) Needs of high loading radio near (D/Pd) =1.0,
(5) Needs of ordering (self-organization) process (dynamic) of condensed matter,
(6) Needs of microscopic dynamic mechanism in nano-meter scale lattice or surface of condensed matter,
and so on (maybe the claimed "transmutation" results are predicted by the TSC plus host large metal nucleus interactions and their capture and fission-like products.)

Q7) Are there any assumptions in the TSC theory? If so which?
A7) Qualitatively, no assumptions are used in the finally established 4D/TSC model (published in recent papers). So, this is a kind of the first principle theory. But quantitatively, the model still assumes that the initial formation rate of TSC in dynamic motions of particles of condensed matter is large enough. This assumption should be further investigated to clear. Maybe clear experimental conditions which would have realized reproducible "cold fusion" or "condensed matter nuclear effects" should give great hints to shape up the TSC theory in the stage of surface and lattice physics of condensed matter- or solid state physics.

Q8) Can the TSC theory explain LENR of heavy elements (transmutations)?
A8) The author does not like the term LENR, which should mean usually known low energy nuclear reactions as thermal neutron induced fission, thermo-nuclear fusion and natural radio-activities, and therefore very misleading and harmful for the scientific understanding of questioned issues.
As explained above, the TSC theory can have potential to predict so called "cold transmutation" mechanism and its products-ash. But the extension of theory for "transmutation" is yet to be studied, although the author published a few papers about it (See online journal of JCMNS Vol.1).

Q9) Which theory of other theoreticians is close to the TSC theory?
A9) The TSC theory is very unique. No other models ever proposed are not close to it.
The author understands that no other proposed theories could have realized to clear the big barrier of

quantification, namely to explain the phenomena with numerically estimated reaction rates and its products; in other words, if theories could have predicted that the phenomena could really happen with observable reaction rates.

4. Summary and Future Problems

This paper has reviewed *an essence* of recent research development in the emerging condensed matter nuclear science (CMNS). The review was focused on the experimental claims of anomalously large excess heat observations associating apparent "nuclear ash" of ^{4}He atoms by the experimental systems of metal-deuterium interactions, because the phenomena and underlying mechanisms are very important pertaining to our further R&D efforts towards the development of portable (or distributable) clean "nuclear" energy devices based on the new kind of potential clean fusion reactions.

Activity of CMNS research is extended in other aspects as "cold transmutation", plasma electrolysis, plasma-discharge of deuterium gas, beam-implantation type basic nuclear physics studies, and so on, even including metal-protium (light hydrogen) interactions. However, the review did not mention about these extended researches.

The excess heat phenomena by palladium-deuterium systems are most seriously taken. From recent reports, three methods look promising for understanding the phenomena and developing "green energy devices".

1) **The D-gas loading with nano-Pd powders method**, which was first reported by Arata-Zhang, is expected to provide the way with simple and rather pure conditions to understand underlying physics. Kitamura et al group has replicated Arata-Zhang results on anomalous heat-power evolution. Data by Kitamura group (paper published in Physics Letters A, 2009) shows integrated heat production rate, in their experimental device using nano-Pd/ZrO_2 composite samples, about 6 kJ/g-Pd, which is about 10 times of integrated power of lithium-ion-battery about 0.4 kJ/g-Li.
2) **The super-wave heavy-water electrolysis method**, which are under study by the joint team of Energetics Technologies (Israel) + SRI (USA) + ENEA (Italy). The conditioning of nano-structure surface of Pd cathode by irradiation of ultrasonic waves is another key issue of the method. The joint team has reported in 2009 that a) about 70% reproducibility of excess heat production has been attained, b) gain=(out-put power)/(input power) was more than 5 for many cases of experimental runs, c) power density is reaching at 40 W/g-Pd and lasting several days (about 10 MJ/g-Pd for integrated heat).
3) **The co-deposition electrolysis method**, which are under study by SPAWAR (San Diego, USA) and JET-Technologies (USA). They have reported that the method has shown almost 100% repeatable effects of anomalous excess heat (0.1-0.3 W level) and associating generation of "very weak" nuclear products (tritium, neutron, X-ray, charged particles). The co-deposition of palladium plus deuterium on cathode realizes fractal nano-surface of

cathode which would have helped to absorb deuterium into Pd lattice very rapidly and conditioned for high reproducibility of excess heat production.

People are now speculating the reasons why nano-structure of Pd is needed, to get to such consensus as; We need the full D-loading condition (x=1.0, for full O-sites occupation by deuterons) for PdDx lattice to induce CMNE (condensed matter nuclear effect). When we have used bulk-metal Pd cathodes, the full loading (x=1.0) condition could be attained only in near-surface zone and the near-surface full loading would have blocked the rapid diffusion of deuterons deeply into inner Pd lattice. Therefore, the realization of "maximum" effective surface area of Pd cathode (or gas-absorbing particle powder) is of key issue. This means that we need very fractal nano-structure of metal samples.

Why does nano-structure of metal sample induce CMNE? This is still a big challenge to theories. However, in philosophical view point, CMNE should have been caused because of the ordering/constraint/self-organization characters of PdDx lattices or more generally of D-contained condensed matters. Known fusion reactions of hydrogen isotopes (p + p; weak interaction taking place in the sun, p + d, d + d, and d + t; strong interactions) are taking place at random conditions of particle motion in gas, plasma, and beam-target interactions. The ordering/constraint/self-organization mechanisms, probably dynamic, are of some thing to do with CMNE. Many theoretical models have been proposed in 1989-2009 for this challenging puzzle. Only few theories have got to the level of quantitative prediction of CMNE. The Condensed Cluster Fusion theory by the author can be one of such few theories. Tetrahedral Symmetric Condensate (TSC) of 4 deuterons plus 4 electrons in lattice/surface dynamics of PdDx (or other metal maybe OK) condensed matter can realize this requirement of theorization. We may expect other theories to have full quantification in their developments.

For scoping further problems towards the engineering phase R&D, some comments are given in the following issues.

When we imagine electric power generating portable devices to develop, we need to realize persistent generation of heat-power with gain > 3.0, considering the conversion efficiency from thermal to electric is 30-40 %. The super-wave heavy-water electrolysis method has cleared this criterion partially. Reproducibility is increasing by the effort of research teams, but it should reach at 100% quantitatively repeatable level. To realize sustainable power generation, controllable conditions should be established for practical power generating devices. Since water comes to a boil at 100 deg C in 0.1 MPa outer pressure, pressurized experimental devices will have been tested to increase power density and gain.

The D-gas loading with nano-Pd powders method looks more promising than the liquid-phase D-loading methods, by the following reasons:

This method is suitable to understand the underlying physical mechanisms of CMNE, because of its rather pure experimental conditions. By knowing the underlying mechanisms (principle), we can plan, design and test proto-type devices for portable clean power generating devices. It will be easier to increase cell temperature for gas-driving systems, and we would realize higher temperature (300-500 deg C) driving devices with increased power density. As palladium is expensive rare metal, we need to

seek other less expensive metals as nickel and their alloys. Already, researches in that direction have started in some countries (USA, Japan, and others).

After the initial very controversial and dismissing saga of "cold fusion" (1898-1992), a faint stream of persistent research efforts by about 300 researchers in the world has gradually accumulated positive data of CMNE and has founded the international society of research community, ISCMNS (International Society of Condensed Matter Nuclear Science). Some of established science societies, as ACS, have opened places for academic information exchange in their meetings and paper publications. We would be standing at a turning point of this emerging field of CMNS. However, the author concerns that researchers in the CMNS community are getting "very" aged and there is only very small number of young new comers. We need to overcome with the poverty in very limited research funds, somewhat closed information exchange, patenting difficulty, and so on.

As a conclusion, the author hopes to say that the emerging CMNE induced clean energy, probably by condensed cluster fusion of deuterons in condensed matter, is expected to provide "green power generating portable devices" for the 21st century human society.

Acknowledgements

The author acknowledges the support of colleagues in Technova Inc., and is grateful to discussions and critical reading of draft manuscript for Prof. Akira Kitamura (Kobe University) and Prof. Norman Cook (Kansai University). He also appreciates opinion exchange with the CMNS internet group.

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