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Research Article

Nuclear Products of Cold Fusion by TSC Theory

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Abstract

Prediction of nuclear products both for metal–deuterium systems and metal protium systems is made on the basic physics of cold fusion by the Tetrahedral Symmetric Condensate (TSC) theory. This paper focuses on final state nuclear reactions of intermediate compound states as ^{8}Be* of 4D/TSC fusion and ^{4}Li* of 4H/TSC WS fusion. Prediction of final products is made by the nucleon-halo model of the highly excited intermediate compound states.

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Keywords: BOLEP, 4D fusion, Final products, ^{4}He, ^{3}He, 4H WS fusion, n-Halo model, TSC theory

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1. Introduction

Since 1989, there has been accumulated evidence of anomalous excess heat effects in correlation of 24MeV/^{4}He-generation (Miles [1], McKubre [2], and others) without correspondingly intense emission of particles (n, p, t, ^{3}He, γ) from experiments with Pd–D systems. Recently, another anomalous and long lasting excess heat effect at higher temperatures in Ni–H systems without easily detected nuclear products (the so-called ash) have been reported by Piantelli [3], Rossi [4], Celani [5], Kitamura–Takahashi [6] and some other groups. The level of observed anomalous excess heat looks too large to be explained by known chemical reactions. If the anomalous heat effect is of nuclear-reaction origin, why 'lethal' radiation (i.e., neutrons and gamma-rays) is not associated with the reaction is the big challenge to nuclear theory. The author has made serious efforts to establish theories to give consistent answers to the big question why so radiation-less heat results may happen in Pd–D and Ni–H systems. The summary conclusion of this paper is given in Table 1.

The Tetrahedral Symmetric Condensate (TSC)-related theory has been elaborated for 23 years since April 1989 [7] and the latest review paper [8] is given at ICCF17. The study of D(H)-cluster dynamics by using the quantum mechanical (QM) Langevin equation [9] has concluded that any transient entity (condensate state) as small as a few tens fm size will not be possible for the d–e–d and d–e–e–d systems, as well as 3D-cluster. 4D/TSC-neutral-cluster may make ultimate condensation to very small charge-neutral entity, as small as a few tens fm size or smaller to induce

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Table 1. Major experimental claims of cold fusion and predictions by the TSC theories.

	Claims by experiments	Predictions by TSC models
Metal Deuterium Energy (MDE)	Heat: 24 ± 1 MeV/^{4}He (Miles [1], McKubre et al. [2])	4D fusion ash with low-E alphas (46 keV)
	Weak alpha peaks (Lipson [14], Roussetski [15], etc.)	Minor alpha-peaks by nucleon halo BOLEP minor decay channels
	Weak neutrons (Takahashi, Boss [16], etc.)	High-E neutron by minor triton emission BOLEP in ca. 1.5 keV
	X-rays burst (Karabut et al. [13])	
Metal Hydrogen Energy (MHE)	Heat w/o n and gamma Unknown ash (Piantelli [3], Takahashi–Kitamura [20], Celani [5], etc.)	4H/TSC WS fusion 2–7 MeV ^{3}He and d Very weak secondary gamma and n: ca. 10^{-11} of ^{3}He and d yield

significant level reaction rates of nuclear strong interaction between deuterons. The condensation time for 4D/TSC is as short as 1.4 fs and the yield of 4D/TSC fusion per TSC is 1.0 (100%). Models of TSC formation sites on surface of metal nano-particle and fusion rate formulas with numerical estimations are given until now [8]. The model has been extended to the possible weak-strong simultaneous fusion for the 4H/TSC dynamic condensation [10]. However, to make some more definite predictions for final nuclear products and their secondary radiation-emitting interactions, the yet-to-study problem of final state interactions for the intermediate compound nuclei as ^{8}Be* (Ex = 47.6 MeV) and ^{4}Li* (Ex = 4.62 MeV) should be challenged. A trial study based on the nucleon-halo model by Takahashi–Rocha [11] is a starting point.

2. Three Steps of Nuclear Reaction

In any theoretical model treating nuclear (strong/weak) interactions, we should make explicit approach to the three steps, namely the initial state interactions, the intermediate nuclear excited state and the final state interactions, as shown by the chart in Fig. 1.

To make any nuclear reaction rate meaningfully observable (far more than 1 event per second, on/in condensed matter), pairing (d–d, p–p, for instance) and cluster (4d, 4p, 6d, etc. for instance) quantum mechanical (QM) wave-functions of interacting particles should have enough quantitative weight at the interaction surfaces of strong (about 1.4 fm, 1.4E-15 m, inter-nuclear distance) or weak (about 2 am, 2.0×10^{-18} m, inter-nuclear distance) interaction effective-domain [8]. Some special conditions of dynamic chemical (Coulombic or electro-magnetic EM) trapping potentials of D(H)-cluster may be realized in some mesoscopic catalytic conditions [12]. This is the initial state interactions under the EM force field. The nuclear interaction by strong (charged-pion/isospin exchange) or weak (weak boson/weak-isospin exchange) force field with the EM field pairing/cluster QM wave-function weight (as given by the Fermi's first golden rule [8]) is also the component of the initial state interactions.

Usually, the EM field motion and the strong/weak field reaction can be treated adiabatically by the Born–Oppenheimer wave-function separation. Almost all theoretical models ever proposed treat the initial state interaction only under crude assumptions. The intermediate compound states after the initial strong/weak nuclear interactions and the final state interactions to release excited energy by the mass-defect energy (ΔMc^2) as free energies of emitted 'ground-state' particles have not been properly/explicitly treated in the past proposed theories by many people, except for a few examples as the n-halo model analysis by Takahashi–Rocha [11].

In almost all cases of possible intermediate compound states (to be thought from any nuclear reaction process as proposed by anybody, although only a few models have treated the state properly and most models are blind or ignoring those nuclear physics states), the nuclear excitation energy is known easily by the mass-defect energy (ΔMc^2) but spin-

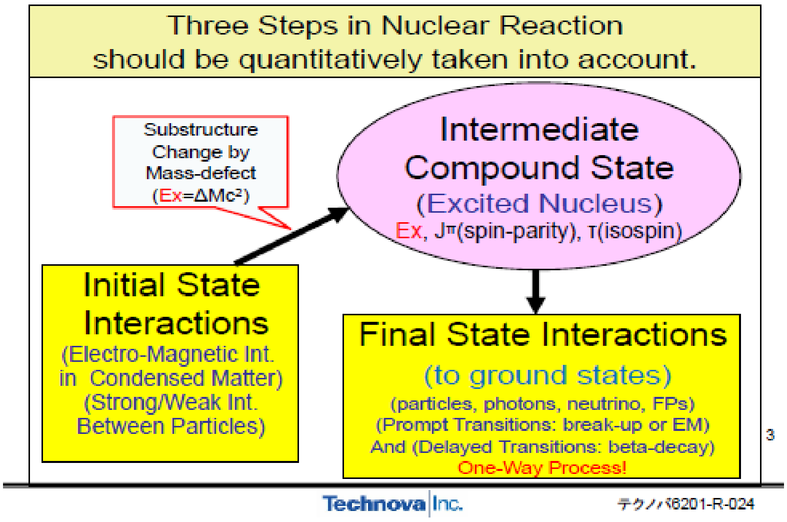


Figure 1. Three steps of nuclear reactions to be treated by any cold fusion theories.

parity and iso-spin are hard to know. So, we need some consistent modeling for the intermediate and the final state interactions to make predictions of the final nuclear products.

The flow from the initial state to the intermediate state is irreversible (a one-way process) due to the drastic change of substructure of composite particle (compound state) by the mass–energy defect: there happens a large entropy (randomness of sub-particles order) increase and the reverse projection to the initial state becomes no-solution (chaotic) mathematics. Therefore, we have to treat the intermediate compound state properly to know the final state interaction products: the process from the intermediate state to the final state products which are stable isotope or particle states with carrying kinetic energies is also irreversible.

Most theories have been proposed by people who are ignorant of the three-step irreversible process. They sometimes make wrong short-cuts 'wishfully' from the initial interaction directly to the final 'selected-by-will' products; an example is the wish of ^{64}Ni + p to ^{65}Cu (g.s.) + Q without prompt (lethal) gamma-rays from the intermediate excited state ^{65}Cu(Ex)*. Such a primitive mistake should be avoided in any nuclear reaction theory.

An illustration of the three steps of condensed matter-nuclear-reactions (CMNR) is shown in Fig. 2 for the 4D/TSC theory.

3. Final Products by MDE

Experimental claims [1,2] show that the final nuclear products of the excess heat phenomenon are ^{4}He atoms with 24±1 MeV/^{4}He-generation and thermal energy without 'hard radiation'. Karabut et al. [13] has made an astonishing claim that they observed very intensive burst of photons in the soft X-ray energy region (1.5 keV in average), the integrated burst energy of which may be corresponding to the total released energy ca. 24 MeV per reaction. There have been no reports of observation of intense high energy alpha-particles corresponding to the anomalous excess heat evolution. However, very weak line-like spectra of alpha particles have been observed in the energy region less than about 17 MeV by Lipson et al. [14] and Roussetski et al. [15]. Boss et al. observed over 14 MeV neutron tracks in CR39 as scarce events [16] probably by the some secondary d–t reaction neutron emission. This work discusses in the

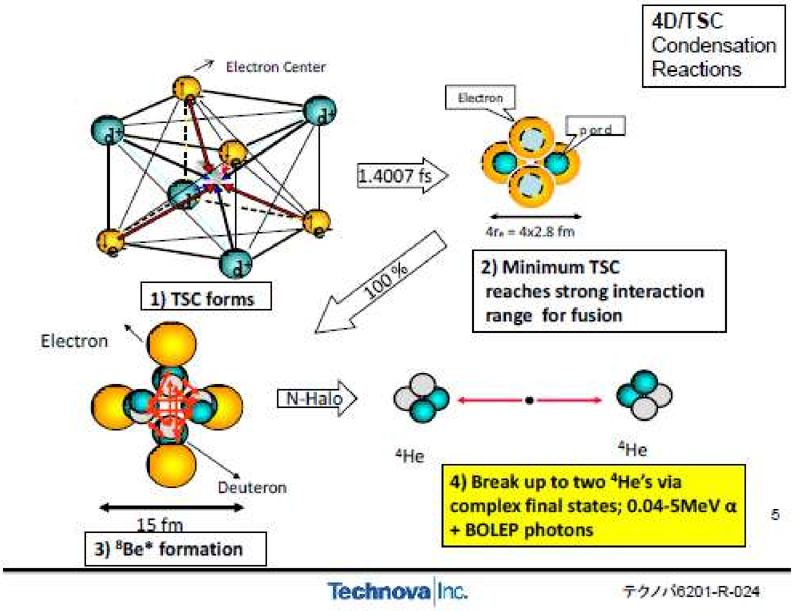


Figure 2. Three steps of 4D/TSC fusion; (1) and (2) are two adiabatic sub-states of EM and strong interactions in the initial state interaction, (3) is the intermediate compound state and (4) is the final state interaction.

following that these typical claims may match with the prediction of n-halo model of the final state interaction for the ^{8}Be* state of 4D/TSC fusion.

The details of modeling the final state interaction for the ^{8}Be* state after the 4D/TSC initial state interaction are given in the Takahashi–Rocha paper [11]. Here we present an overview. In Fig. 3, the image of n-halo model of ^{8}Be* is given in comparison with the n-halo model image of ^{8}Li(g.s). The n-halo-state of ^{8}Li has known to have a 'very long life time' of 838 ms. It is modeled as a core of t–h coupling with two neutron halos. Here h denotes helion (^{3}He nucleus as three-body binding nucleons in nucleus) and t denotes triton (also three-body binding of nucleons). In our image, there exists a vibration between h and t core clusters and additional vibrations between core clusters and neutron halos. In addition, there is rotational freedom between n-halos and core clusters. Such a combination of rotation and vibration would make the life time of ^{8}Li very long; as long as 838 ms. As ^{8}Li is at ground state, there is no freedom to make EM transitions (photon emitted transitions), but the very slow nuclear transition by the weak interaction is possible: the ^{8}Li(g.s.) makes beta-decay to ^{8}Be* (Ex = 3.06 MeV; 2+) state which makes prompt decay to break up to two 1.58 MeV alpha particles [11]. We know that the ^{8}Be(g.s) is of two-alpha cluster state [17] and image is given by the left-hand side figure of Fig. 4.

However, the highly excited state ^{8}Be* as Ex = 47.6 MeV after 4D-multibody-simultaneous fusion may come to the n-halo state as given in Fig. 3 (left-hand side figure), and may have 'very' long life time as that of ^{8}Li(g.s.), because of ca. 15,000 modes/nodes of very finely deformed spherical harmonics states in vibration/rotation boson-state-coupling between core h–h clusters and two-n-halo states [11]. The average nuclear-phonon energy of such complex bosonic coupling states under vibration/rotation nodes was estimated ca. 1.5 keV. The very highly excited energy (Ex = 47.6 MeV) of ^{8}Be* just after a 4D/TSC fusion may make 'avalanche' multiple photon emission via bosonic nuclear phonon coupling to damp its nuclear excited energy by the BOLEP (burst of low energy photons) process, like black-body radiation, to go out to the ground state of ^{8}Be(g.s.) which is known to make prompt two alpha break up with 46

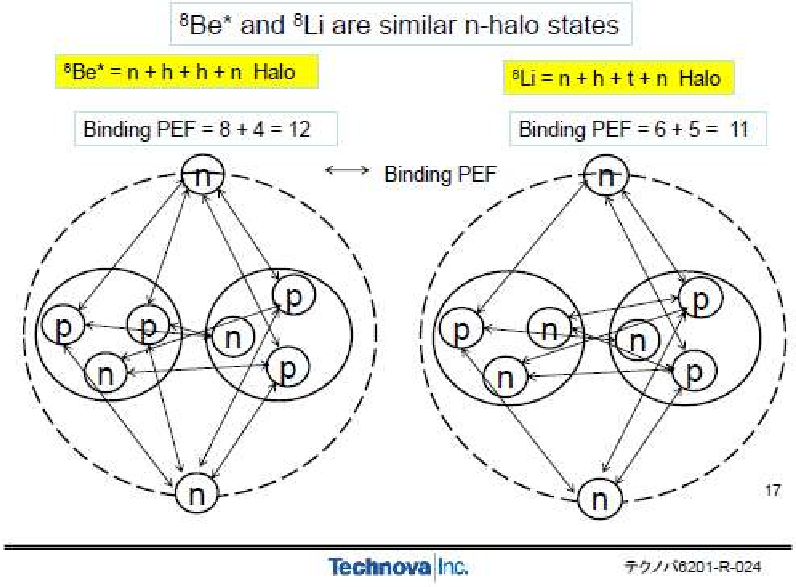


Figure 3. The image of n-halo model of ^{8}Be*, compared with the image of ^{8}Li which has very similar n-halo state with ca. 0.8 s life time.

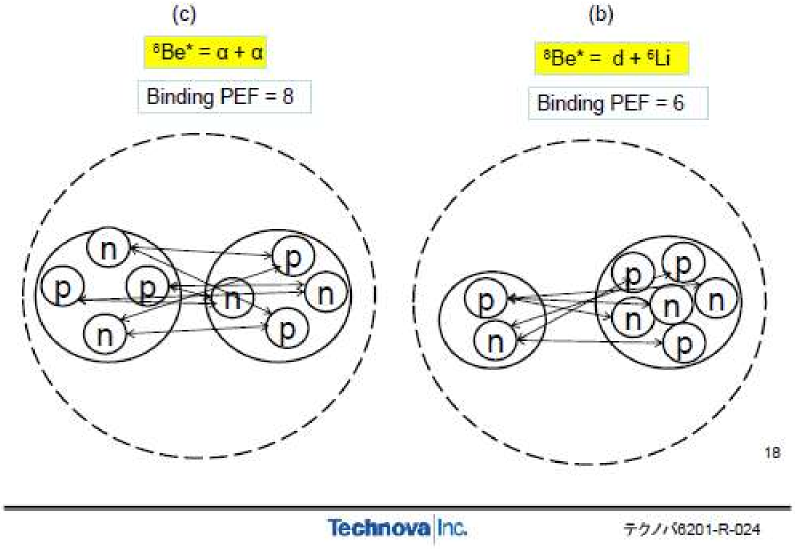


Figure 4. Typical cluster model of lower excited ^{8}Be*; two-alpha cluster and d–^{6}Li cluster.

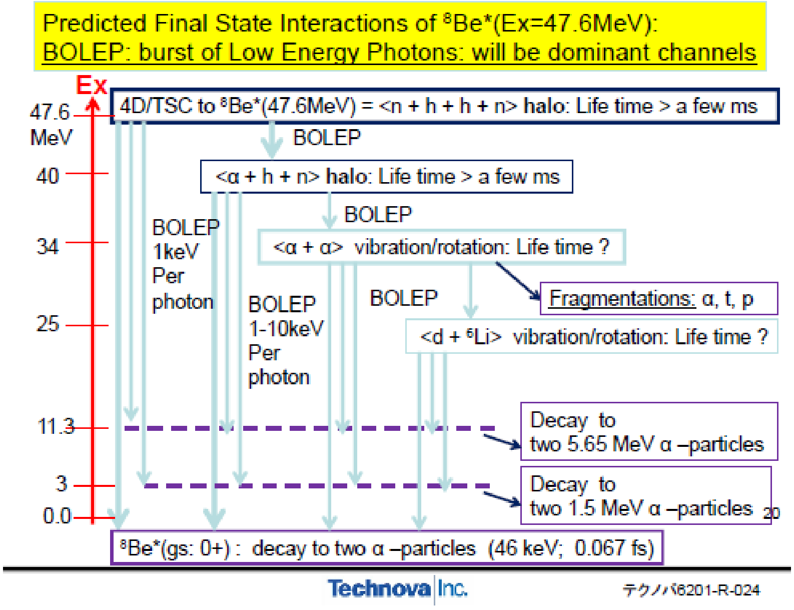


Figure 5. Predicted decay scheme of ^{8}Be*(Ex = 47.6 MeV) after 4D/TSC fusion .

keV/^{4}He in 6.7×10^{-17} s. This BOLEP process was regarded as the major channel of final state interactions.

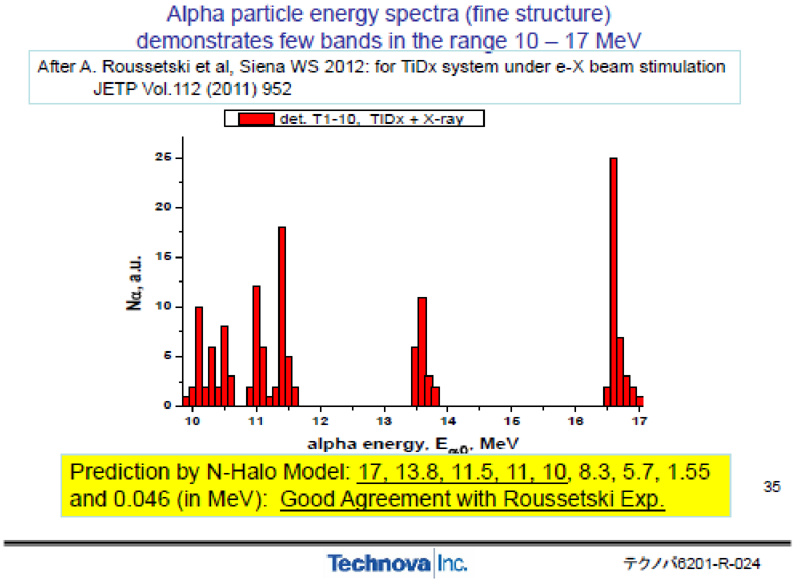
As possible minor decay channels from the ^{8}Be* (Ex = 47.6 MeV) state, Takahashi–Rocha [11] considered intermediate state traps by two-alpha cluster vibration states. The scaling law of excitation energy as a function of effective nuclear binding force (as scaled by PEF, charged pion exchange force number) is used for various possible inner nucleus cluster-halo states. They estimated possible intermediate two-alpha cluster states as given in Table 2. $Ex = 34$ MeV is the upper limit of α–α cluster state excitation [11].

A simplified decay scheme of ^{8}Be*(Ex = 47.6 MeV) of 4D/TSC fusion is shown in Fig. 5. which omits the intermediate two-alpha states at 34, 27.5, 22.98, 22.0, 20.1 and 16.6 MeV levels for making the figure visible for major BOLEP channels.

Table 2. Possible two-alpha decay channels from ^{8}Be*

4D?→^{8}Be* (47.6 MeV) → BOLEP +^{8}Be*(34 MeV) and possible intermediate states which decay to 2α (*Note*: only 11.4 and 3.04 MeV states are drawn in Fig. 5)

Ex (MeV)	Spin-parity	Isospin (T)	KE of α-particle (MeV)
34	(O+)	(0)	17
27.5	0+	2	13.8
22.98	(0+)	(0)	11.5
22.0	2+	0	11
20.1	2+	0	10.05
16.6	2+	0	8.3
11.4	(2+)	0	5.7
3.04	2+	0	1.55
–0.092 (gs)	0+	0	0.046


Alpha particle energy spectra (fine structure) demonstrates few bands in the range 10 – 17 MeV

After A. Roussetski et al, Siena WS 2012: for TiDx system under e-X beam stimulation JETP Vol.112 (2011) 952

Prediction by N-Halo Model: 17, 13.8, 11.5, 11, 10, 8.3, 5.7, 1.55 and 0.046 (in MeV): Good Agreement with Roussetski Exp.

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Figure 6. Alpha line spectra observed by Roussetski agree almost completely with the n-halo model decay channels of ^{8}Be* (*Ex* = 47.6 MeV).

A fragmentation channel from the *Ex* = 34 MeV may emit 5.2 MeV triton via ^{4}He* (*Ex* = 20.2 MeV) of asymmetric fragmentation [11] and may induce the secondary d-t reaction which produces 9–19 MeV high energy neutron. Boss et al. [16] may have detected this neutron by CR39 triple tracks.

The predicted alpha-particle kinetic energies as minor channels gave beautifully coincident agreement with the Roussetski experiment (but for TiD system) as shown in Fig. 6.

Such a completely consistent agreement with many alpha-lines seems very difficult to explain by most other theoretical models proposed for cold fusion, except as a consequence of the TSC theory. This also seems to be strong evidence that the TSC mechanism may work as cold fusion physics. The broad alpha-particle peak at around 15 MeV observed by Lipson et al. [14] in PdD electrolysis system is another example as shown in Fig. 7.

It could be that the most important circumstantial evidence of BOLEP energy damping can be seen by comparing with Karabut et al. [13] result of ca. 1.5 keV ‘X-ray’ bursts, as shown in Fig. 8. The BOLEP by the n-halo model of ^{8}Be* decay may well correspond to the observed behavior of many burst-like soft-X-ray bursts with very intense counts.

The author expects that similar BOLEP-like photon-burst observation will be done for PdD electrolysis and gas-loading systems.

4. Nuclear Products by MHE

Recently many groups have claimed anomalous excess heat by Ni–H gas loading at higher temperature systems. The excess heat by Ni–H is reported to last much longer and with higher power than the PdD system [3–6]. If the observed anomalous heat is originated by nuclear reactions, missing hard radiation is far more mysterious and challenging to theoretical modeling. The author has made a trial explanation [18] based on the TSC theory. Additional discussions on the final state interaction of the 4H/TSC WS fusion which goes to the intermediate compound state of ^{4}Li* (Ex = 4.62 MeV) are given below.

According to the formula of QM-Langevin equation, the velocity of condensation (time-dependent) is inversely proportional to the square-root of mass of confined particle. Therefore, 4H/TSC will condense in 1.0 fs to the small size region of a few tens fm. However, there is no strong-fusion interaction (PEF = 0) between four protons of TSC to finally destroy the TSC state. We conceive that 4H/TSC can condense further to be as ultimately small 4H/TSC-minimum state as a few fm size (2.4 fm p–p distance is the limit, due to hard core of proton with 1.2 fm radius). The problem there is how long the 4H/TSC-minimum state can survive [8,10].

Once a proton-to-neutron transition is generated by the electron capture, we expect instantaneous strong interaction between just born neutron and closely available three protons within the Compton wave length of charged pions 1.4 fm (PEF = 3) as illustrated in step (3) of Fig. 10. As the pion range 1.4 fm is within the Heisenberg Uncertainty in distance, the n + 3p reaction takes place by 100 % with $\langle W \rangle$ value of PEF = 3 (comparable to d–t fusion) [9].

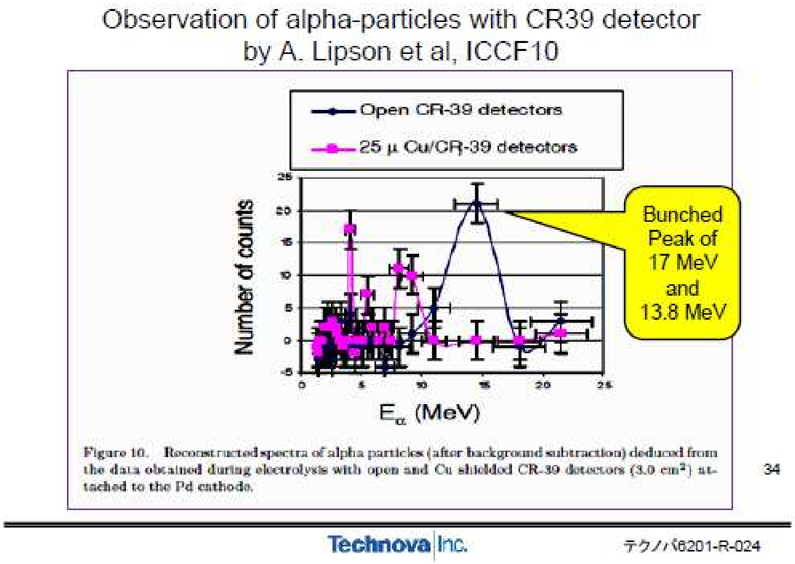
$$\mathrm{3p} + \mathrm{n} \to {}^{4}\mathrm{Li}^{*}(Ex = 4.62\ \mathrm{MeV}). \tag{1}$$

The intermediate compound $^{4}\mathrm{Li}^{*}$ has two break-up channels.

$$^{4}\mathrm{Li}^{*}(Ex = 4.62\ \mathrm{MeV}) \to {}^{3}\mathrm{He} + \mathrm{p} + 7.72\ \mathrm{MeV}, \tag{2}$$

$$^{4}\mathrm{Li}^{*}(Ex = 4.62\ \mathrm{MeV}) \to \mathrm{2p} + \mathrm{d} + 2.22\ \mathrm{MeV}. \tag{3}$$

The branch (2) is thought to be a major out-going channel and we will expect ^{3}He as main nuclear product.



Observation of alpha-particles with CR39 detector
by A. Lipson et al, ICCF10

Figure 10. Reconstructed spectra of alpha particles (after background subtraction) deduced from the data obtained during electrolysis with open and Cu shielded CR-39 detectors (3.0 cm^{2}) attached to the Pd cathode.

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Figure 7. Lipson’s 15 MeV alpha-peak may be a bunched peak of 17 and 13.8 MeV of the n-halo decay of ^{8}Be*.

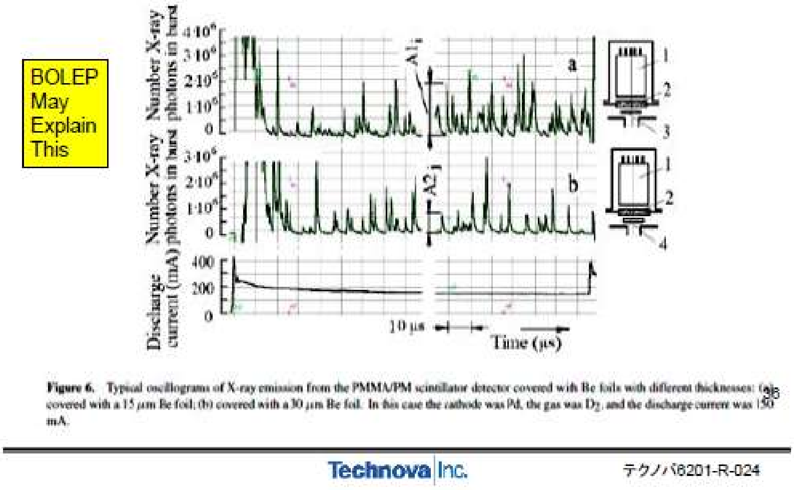


Figure 6. Typical oscillograms of X-ray emission from the PMMA/PM scintillator detector covered with Be foils with different thicknesses: (a) covered with a 15 μm Be foil; (b) covered with a 30 μm Be foil. In this case the cathode was Pd, the gas was D_2, and the discharge current was 150 mA.

Figure 8. Observed X-ray bursts by Karabut et al. .

And 5.79 MeV proton will produce secondary neutron by Ni(p, n) reactions with higher mass Ni isotopes, on the order of 10^{-13} of ^{3}He production rate and Ni(p, γ) secondary gamma-rays on the order of 10^{-11} per 5.79 MeV proton.

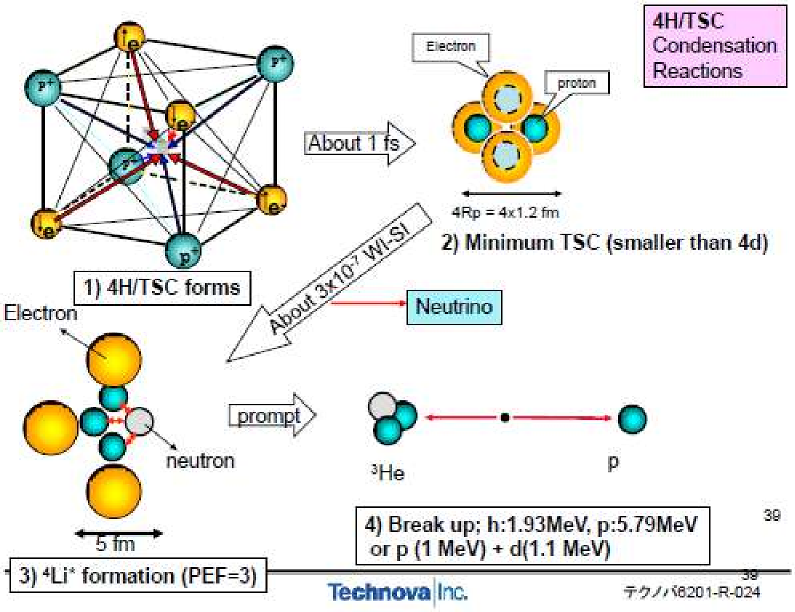
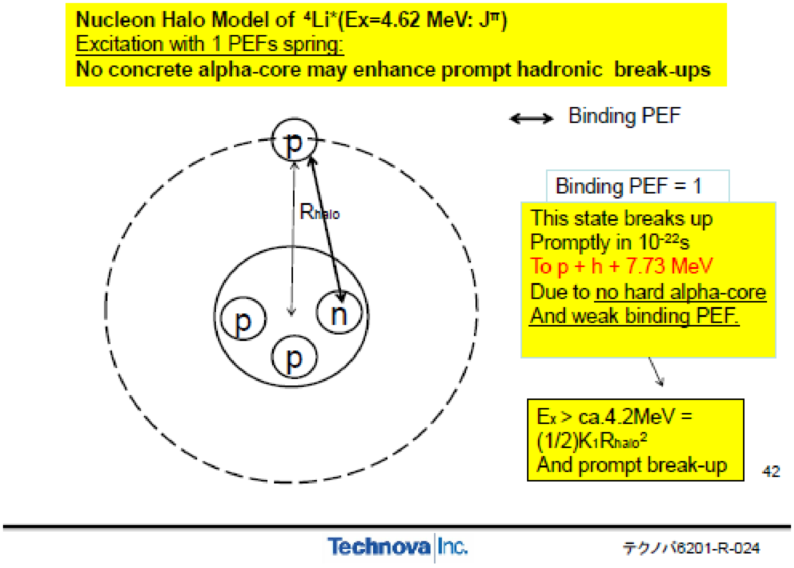


Figure 9. Brief view of 4H/TSC condensation and 4H weak-strong fusion interaction.


Nucleon Halo Model of ^{4}Li*(Ex=4.62 MeV: J^π)
Excitation with 1 PEFs spring:
No concrete alpha-core may enhance prompt hadronic break-ups

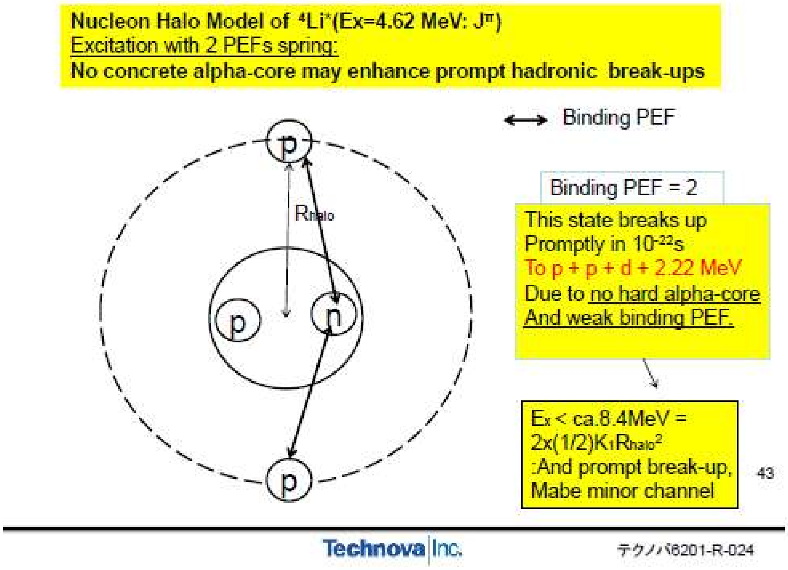
↔ Binding PEF

Binding PEF = 1

This state breaks up
Promptly in 10^{-22}s
To p + h + 7.73 MeV
Due to no hard alpha-core
And weak binding PEF.

E_x > ca.4.2MeV =
$(1/2)K_1R_{halo}^2$
And prompt break-up

Figure 10. p-halo model of ^{4}Li* by 4H/TSC WS fusion.


Nucleon Halo Model of ^{4}Li*(Ex=4.62 MeV: J^π)
Excitation with 2 PEFs spring:
No concrete alpha-core may enhance prompt hadronic break-ups

↔ Binding PEF

Binding PEF = 2

This state breaks up
Promptly in 10^{-22}s
To p + p + d + 2.22 MeV
Due to no hard alpha-core
And weak binding PEF.

E_x < ca.8.4MeV =
$2x(1/2)K_1R_{halo}^2$
:And prompt break-up,
Mabe minor channel

Figure 11. p-halo-d-core sate of ^{4}Li* by the 4H/TSC WS fusion .

Characteristic X-rays (PIXE) from Ni ionization by the proton are also expected.

However, we do not know the branching ratio to the branch (3) which will not produce secondary neutrons and gamma-rays at all. So far detection of ash has been difficult.

The three steps of a nuclear reaction of 4H/TSC WS fusion are shown in Fig. 9. The adiabatic sub-steps (1) and (2) are of initial state interactions.

The excited energy of the intermediate compound state ^{4}Li*(*Ex* = 4.62 MeV) is rather low. However, we may apply the nucleon halo model here too.

Figure 10 shows the p-halo image with h-cluster core for ^{4}Li*. This halo state is similar to the n-halo state with h-cluster core for ^{4}He* (*Ex* = 23.8 MeV) [11] which is well evaluated (see TUNL Nuclear Data library: http://www.tunl.duke.edu/nucldata/index.shtml) as the prompt break-up channel of n + ^{3}He + 3.25 MeV. The p + t + 4.02 MeV break-up channel is thought to be the final state interaction from the p-halo state with t-cluster core for ^{4}He*(*Ex* = 23.8 MeV) and to be a nuclear equivalent state to the p-halo with h-cluster core for ^{4}Li*. From these comparable halo-states between ^{4}Li* and ^{4}He*, the life time of ^{4}Li* is estimated to be on the same order of that (namely $1.0\times\ 10^{-22}$ s) for ^{4}He*. Therefore, the BOLEP type EM transition is not possible to have competing branch for ^{4}Li*.

Obviously the very weak PEF binding (effective PEF = 1) makes the prompt scission of 'p-bond' to break up to p + ^{3}He + 7.72 MeV final state break-up. There seem to be no mechanisms plausible to make its life time longer. The life time of ^{4}Li* is considered to be on the order of $1.0\ \times 10^{-22}$ s, very short as nuclear reaction time. Another halo-state would be the two-p halo with d-core as shown in Fig.11.

The binding PEF = 2 is larger than that of Fig.10, but the binding to the d-core is not strong enough to prevent the prompt three body break-up to d + p + p + 2.22 MeV channel. The life time of this state might be a little bit longer than the case of p-h halo state (Fig.11), so that the ^{3}He + p + 7.72 MeV channel looks major channel. However, we do not know the exact branching ratio.

We have reported that fission products from Ni + 4p fission are predicted to be clean stable isotopes mostly, by the selected channel scission theory [12]. As discussed in the previous section, the life time of 4H/TSC-minimum state may be much longer than we conceived previously, and the size of its neutral entity is much smaller than the past image, the strong interaction with Ni nucleus would be selective to the Ni + 4p capture and 1p to 3p capture processes will be neglected.

Fission products are considered to be mostly from the near symmetric fragmentations of Ge* intermediate compound state. In the past, there were reports on production of foreign elements ('transmutation was thought') by several authors. Miley–Patterson data was analyzed by TSC-induced fission in [19]. Mass spectral analysis for samples before and after use is recommended for Ni-H system experiments as being done by Piantelli-group, Kobe-Technova-group (Sakoh et al.) and Celani-group (INFN).

5. Conclusions

The Final State Interactions of ^{8}Be* by 4D/TSC are qualitatively/semi-quantitatively discussed. Nucleon-Halo State of ^{8}Be* may have rather long life time as rotation of halo-nucleon coupled with vibration motion of alpha- and h-(t-) cluster, and would have narrow spaced energy-band structure, from where EM transition photons (1—10 keV: BOLEP: agreed with X-ray burst by Karabut exp.) damp ^{8}Be*(47.6 MeV) to ^{8}Be(g.s.:0+), as major final state channels.

Direct many hadronic break-up channels may compete with the nucleon-halo state transition, but as minor_channels with discrete α-peaks which agreed very well with Roussetski's experiment and rather well with Lipson's experiment. Quantitative QM studies are to be expected for BOLEP. Simultaneous (very rapid cascade) weak and strong interaction may be predicted in the final stage of 4H/TSC condensation. About 20 W (or more)/mol-Ni heat with ^{3}He and d products is predicted (Clean Heat). Heat level depends on 4H/TSC generation rate probably on surface mesoscopic catalyst sites of binary nano-particles as Cu–Ni [20] and on-going experimental study will provide important hints to elaboration of theoretical models for the Ni–H gas loading systems.

PIXE X-rays (ca. 8 keV) by proton will be detected if the p + ^{3}He + 7.72 MeV is the major final state channel. About 0.2 n per one joule heat will be detected. This is corresponding to the order of 10^5 neutrons/s per one mega-watts of heat level. About four gammas by Ni(p,γ) per joule will be. So, neutron and gamma levels will be very weak and practically very clean (serious radiation protection is not necessary for presumed Ni–H reactor devices).

The 4D simultaneous fusion (^{4}He: ash) and the 4H simultaneous weak-strong fusion (^{3}He, d: ash) are the consequence of the TSC theory that the author has developed until now. The concluding remarks are summarized at the beginning of this paper in Table 1.

Acknowledgment

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