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Research Article

# TSC-Induced Nuclear Reactions and Cold Transmutations*

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**Abstract**

Tetrahedral Symmetric Condensate (TSC) of orthogonal coupling of four deuterons and four electrons behaves as charge-neutral pseudo-particle and induces nuclear interaction with host metal nuclei. Theoretical predictions are shown for processes, reaction-types and nuclear products. Some details are written for 4p/TSC + Ni and 4d/TSC + Cs reactions making transmutations and fission products.


*Keywords:* Tetrahedral symmetric condensate, 4p/TSC+Ni, 4d/TSC+Cs, Transmutation, Fission

## 1. Introduction

We reported possibility of direct nuclear interaction between proton (or deuteron) and host-metal-nucleus in condensed matter systems of metal–hydrogen/deuterium complexes [1,2]. Clean fusion reaction (4D fusion) with $^4$He products as main ash was predicted [1,2] by Electronic Quasi-Particle Expansion Theory [3] (EQPET)/Tetrahedral Symmetric Condensate [1,2] (TSC) models. TSC is composed of four deuterons (or protons) and four electrons with anti-parallel spin arrangement in orthogonal coupling state. TSC is proposed to form in near surface area of metal–deuterium/hydrogen system. Size of TSC will become much smaller than the sizes of inner most K-shell orbits of host-metal atoms, will penetrate like neutron, due to its charge neutrality, through electron clouds of host-metal atoms, and at around its minimum-size (about 5 fm radius) state; we can expect strong nuclear interaction between TSC and host-metal nucleus. Phenomenon taken place with about 60 fs life time of TSC is modelled and numerically estimated as time-averaged treatments.

## 2. TSC and Self-Fusion

Dynamic squeezing motion of TSC can be treated by semi-classical model, due to its three dimensionally constrained and central squeezing motion, as the feature is illustrated in Fig. 1. It is suggested [1–3] that TSC forms dynamically

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at focal points (sites) of PdDx lattice near surface or on fractal sites at surface, although substantiation of modeling in real condensed matter conditions is yet to be studied.

Once TSC is formed in 100 pm size (1 Å) domain of condensed matter system, TSC starts central squeezing motion under three-dimensionally *frozen* condition except for directions toward the central focal point. This squeezing motion can be treated by the classical Newtonian motion due to the three-dimensional constraint of particle freedom, until when deuterons get into the range (about 5 fm) of nuclear strong interaction or electrons reach at the limit of Pauli's exclusion—classical electron diameter (5.6 fm).

For the case of 4d/TSC, formation of 4d to $^8$Be* takes place at the minimum-size TSC state, since the charged-pion range (2.2 fm) of strong interaction is comparable to the classical electron radius (2.8 fm). Fractional fusions of 2d and 3d may happen with very small probability to be negligible [4], because of this specific condition for 4d/TSC. The nature of $^8$Be* is thought to be collectively excited state of cluster with two alpha particles, which goes out with almost 100% weight to the break-up channel of

$$\mathrm{D} + \mathrm{D} + \mathrm{D} + \mathrm{D} \rightarrow {}^8\mathrm{Be}^* \rightarrow {}^4\mathrm{He} + {}^4\mathrm{He} + 47.6\ \mathrm{MeV}. \quad (1)$$

In very short time (of the order of fs). It is proposed [1–4] that claimed excess heat with $^4$He production in CMNS experiments with Pd–D systems is consistently explained by clean 4D fusion of Eq. (1).

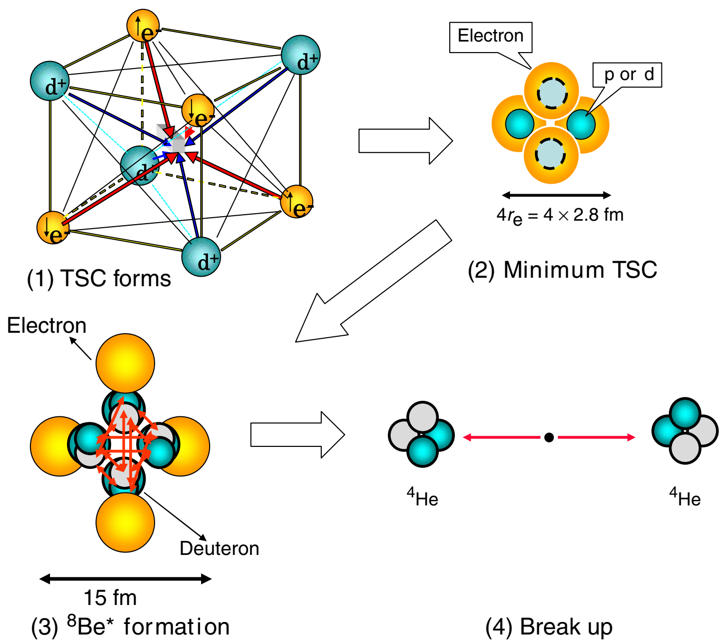


**Figure 1.** Squeezing and fusion process of 4d/TSC (time scale: 0–60 fs), $\langle e \rangle = (e\uparrow + e\downarrow)/2$ in QM view for four electron centers.

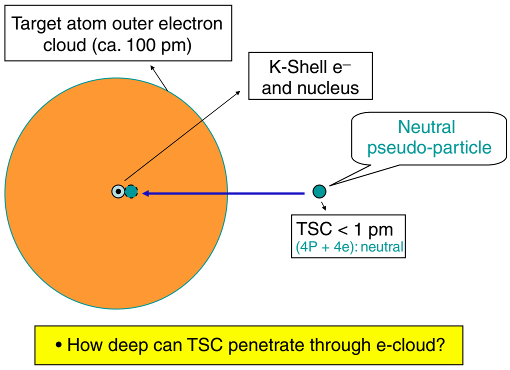


**Figure 2.** Illustration for TSC and host-metal atom interaction.

## 3. TSC–Metal Interaction

### 3.1. Barrier Penetration

As shown in Fig.1, TSC squeezes from about 100 pm size to its minimum-size with about 10 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. During its life, TSC as charge-neutral pseudo-particle may approach to host-metal nuclei with some probability, as illustrated in Fig. 2.

Time-averaged density of TSC in metal deuteride (MDx) or hydride (MHx) is given in our previous papers [1,2] Macroscopic reaction rate $Y$ (f/s/cm$^3$) for M + TSC reaction is given by

$$Y = N_{\mathrm{M+TSC}}\lambda. \tag{2}$$

Here we have to estimate the density $N_{\mathrm{M+TSC}}$ of "united molecule" M + TSC in atomic level.

$$N_{\mathrm{M+TSC}} = \sigma_{\mathrm{A}} N_{\mathrm{M}} N_{\mathrm{TSC}} v \tau_{\mathrm{TSC}}. \tag{3}$$

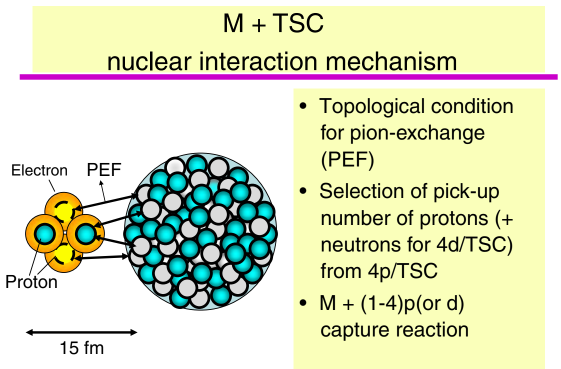


**Figure 3.** Feature of strong nuclear interaction, for closely approached TSC + M-nucleus united molecule.

$N_{\mathrm{M}}$ is the host-metal atom density, $N_{\mathrm{TSC}}$ the time-averaged TSC density, $\sigma_{\mathrm{A}}$ the atomic level cross section (about $10^{-16}$ cm$^2$) for M + TSC combination, and $\tau_{\mathrm{TSC}}$ the mean life of TSC (about 60 fs), respectively. If we can assume $N_{\mathrm{M}} = 10^{23}$ per cm$^3$ and $N_{\mathrm{TSC}} = 10^{20}$ per cm$^3$, we obtain roughly $N_{\mathrm{M+TSC}} = 10^{19}$ per cm$^3$.

### 3.2. Sudden Tall Thin Barrier Approximation

As shown in Fig. 1, TSC around with its minimum-size may approach closely to the interaction range of strong force between protons (deuterons) of TSC and host-metal nucleus. The situation is shown in Fig. 3.

When protons (or deuterons) start to make strong interaction by exchanging charged pions with nucleons of host-metal nucleus, charge neutrality of TSC starts to break and electrons should go outside, since electron does not make strong interaction but weak interaction. Field coupling constant for weak interaction is very small as on the order of $10^{-14}$ of coupling constant (1.0) of strong interaction. According to Fermi's golden rule, reaction cross section is proportional to square of transition matrix element which is proportional to field coupling constant. Therefore, weak interaction between electrons and host-metal nucleons is neglected. Pion Exchange Force (PEF) unit is relative measure of effective surface for very short range (about 2–5 fm) force of strong interaction.

Since electrons should go out of the interaction domain of strong force, protons (or deuterons) in TSC should *suddenly feel* Coulomb repulsion with host-metal nucleus, and also among protons (and deuterons) in TSC itself. The feature of stage is illustrated in Fig. 4.

We derived the Sudden Tall Thin Barrier Approximation (STTBA) [1,2] for calculating reaction rate in this stage.

## 4. Ni + 4p/TSC Reactions

Miley–Patterson [5] reported production of anomalously large foreign elements in their electrolysis experiments with Ni–H systems. Campari et al. [6] also reported large excess heat, anomalous foreign elements and about 660 keV gamma-ray peak. There are many other reports which claimed anomalous heat events and foreign elements production. Most authors claimed *cold transmutations* in condensed matter.

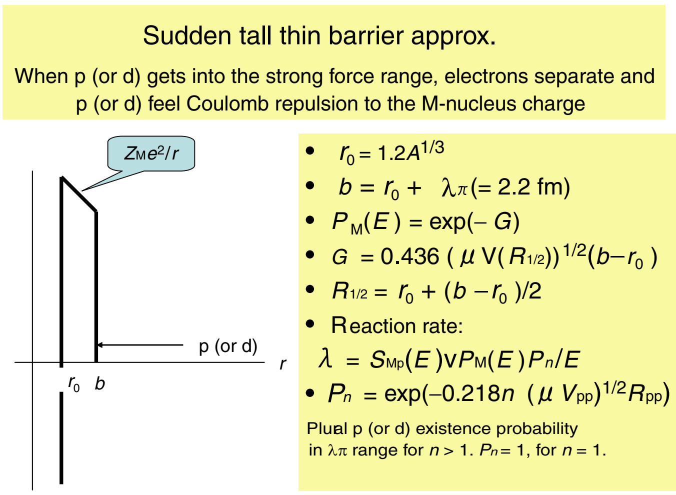


**Figure 4.** Sudden Tall Thin Barrier Approximation (STTBA) for TSC + M system.

**Table 1.** Calculated reaction rates for Ni + 4p/TSC and Ni + 4d/TSC nuclear reactions (results by STTBA calculation; M = Ni)

| | |
|---|---|
| $P_{Mp}(E) = 9.2 \times 10^{-2}$ | $V_{pp} = 1.44/6 = 0.24$ MeV |
| $P_{Md}(E) = 3.5 \times 10^{-2}$ | $P_{2p} = 0.527$ |
| Reaction rates | $P_{2d} = 0.404$ |
| $\lambda_{Mp} = 3.7 \times 10^{-8}$ (f/s/pair) | |
| $\lambda_{Md} = 2.1 \times 10^{-7}$ (f/s/pair) | $S_{Mp}(0) = 10^8$ keV barn |
| $\lambda_{M4p} = 1.0 \times 10^{-8}$ (f/s/pair) | $S_{Md}(0) = 10^9$ keV barn |
| $\lambda_{M4d} = 3.4 \times 10^{-9}$ (f/s/pair) | |
| $\langle$Macroscopic reaction rate$\rangle = \lambda \times N_{M+TSC}$ | $\lambda_{4d} = 4.9 \times 10^{-5}$ |
| With $N_{M+TSC} = 10^{16}$ in 10 nm area, | |
| rate= $10^8$ f/s/cm$^2$ and $Y = 10^{14}$ in $10^6$ s | |

The author applied STTBA for estimating reaction rates of Ni + 4p/TSC nuclear reactions, which are competing process of Ni + p, Ni + 2p, Ni + 3p and Ni + 4p reactions.

Calculated reaction rates are shown in Table 1.

We obtained considerably large values for microscopic reaction rates, and macroscopic yield $10^8$ f/s/cm$^2$ with assuming $N_{TSC+M}$ density = $10^{+16}$ (1/cm$^2$) in 10 nm area of Ni sample surface. Especially, Ni + 4p capture reaction rate $10^{-8}$ (f/s/pair) is large enough to explain claimed foreign elements as fission products of Ni + 4p to Ge* process. Before showing fission products, we show Ni + p reactions in Table 2. The excited compound state Ge* has enough excited energy (19–29 MeV for $^{60}$Ni + 4p to $^{64}$ Ni + 4p) to induce fission. Fission products are calculated by the Selective

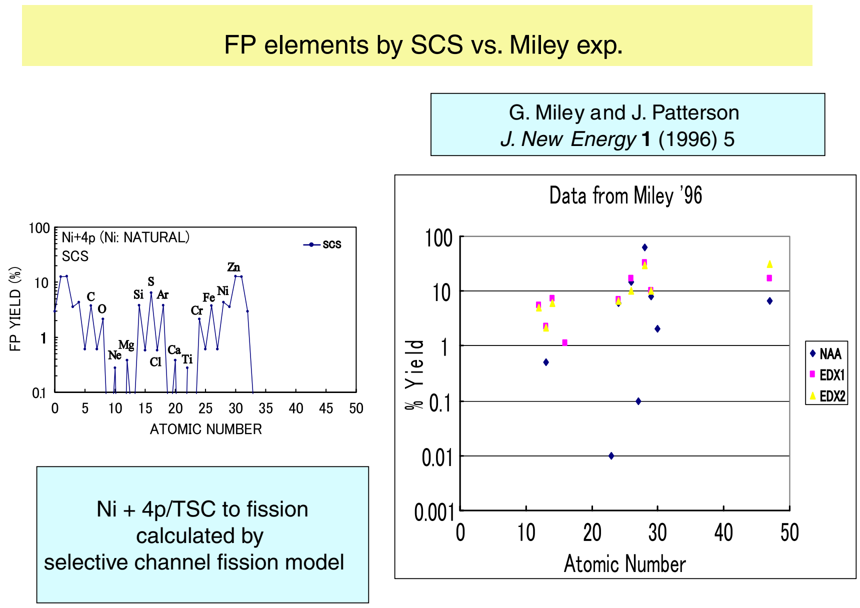


**Figure 5.** Comparison of calculated FP distribution (left figure) and Miley–Patterson experiment (right figure), for Ni + 4p to fission process.

**Table 2.** Products of Ni + p reactions

| | |
|---|---|
| $^{58}$Ni + $p$ $\rightarrow$ $^{59}$Cu* (1.36 months, EC) $^{59}$ Ni* ($7 \times 10^4$ years) | Ni–H gas system exp. By Piantelli (ASTI5);660 keV peak by NaI detector |
| $^{60}$Ni + p $\rightarrow$ $^{61}$Cu* (3.3 h, EC) $^{61}$Ni | |
| $^{61}$Ni + p $\rightarrow$ $^{62}$Cu* (9.7 months, EC) $^{62}$Ni | |
| $^{62}$Ni + p $\rightarrow$ $^{63}$Cu (6.12 MeV); $E_g = 669$ keV | 660 MJ excess energy |
| $^{64}$Ni + p $\rightarrow$ $^{65}$Cu (7.45 MeV) | |
| Prompt gamma-rays emit | |

Channel Scission (SCS) model [7]. Calculations were done for all nickel isotopes. FP distribution for averaged natural abundance is shown in Fig. 5.

We see good agreement, although low-$Z$ elements (C, N, and O) were not given in the experiment, probably due to contaminants in low mass region.

Typical fission products (FP) are shown in Tables 3 and 4. Major contribution of FP is from Ni + 4p fission for higher mass isotopes of nickel. Most interesting point is that most FPs are stable isotopes and radioactive products are very weak. Therefore, this fission process is much cleaner than known fission of uranium. However, the opening of neutron emission channel is possible, although weight is small. Some FPs are decaying by electron capture (EC) process, in few cases of which there are small portion of gamma-ray emission.

## 5. M + 4d/TSC Reactions

In the minimum-size stage of 4d/TSC, four deuterons fuse, by exchanging charged pions, to $^8$Be* compound state with about 2 fm radius. And electrons are kicked outside of the range of strong interaction (see Fig. 1). Therefore, M + 4D interaction becomes M + $^8$Be* capture reaction, as illustrated in Fig. 6.

Iwamura et al. reported [8,9] selective transmutations

$$M(A, Z) + 4\text{D}(\text{or } ^8\text{Be}) \rightarrow M(A + 8, Z + 4). \quad (4)$$

They added $^{133}$Cs or Sr atoms on surface of Pd-complex and permeated $D_2$ gas through the sample complex. They observed repeatedly transmutations; $^{133}$Cs to $^{141}$Pr or $^{88}$Sr to $^{96}$Mo with total transmuted amount of the order of $10^{14}$ to $10^{15}$ atoms per week.

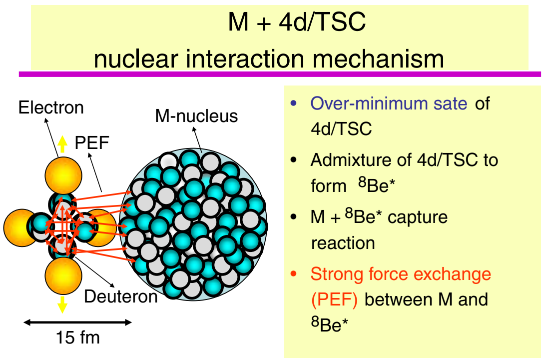


**Figure 6.** Strong interaction for M + 4d/TSC.

**Table 3.** Fission products from Ni + 4p reactions

| |
|---|
| (1) $^{58}$Ni(68%) + 4p → $^{62}$Ge($E_x$ = 11.2 MeV) |
| → 8.8 MeV + $^{4}$**He** + $^{58}$Zn(EC)$^{58}$Cu(EC)$^{58}$**Ni** |
| → 8.8 MeV + $^{28}$**Si** + $^{34}$Ar(EC)$^{34}$Cl(EC)$^{34}$**S** |
| |
| (2) $^{60}$Ni(26.2%) + 4p → $^{64}$Ge($E_x$ = 19.1 MeV) |
| → 16.4 MeV + $^{4}$**He** + $^{60}$Zn(EC)$^{60}$Cu(EC)$^{60}$**Ni** |
| → 13.6 MeV + $^{8}$Be + $^{56}$Ni(EC)$^{56}$Co(EC)$^{56}$Fe |
| → 13.0 MeV + $^{12}$**C** + $^{52}$Fe (EC)$^{52}$Mn(EC)$^{52}$**Cr** |
| → 12.2 MeV + $^{16}$O + $^{48}$ Cr(EC)$^{48}$V(EC)$^{48}$Ti |
| → 13.5 MeV + $^{24}$Mg + $^{40}$Ca |
| → 16.4 MeV + $^{28}$**Si** + $^{36}$**Ar** |
| → 16.7 MeV + $^{32}$S + $^{32}$S |
| → 6.5 MeV + $^{38}$**Ar** + $^{26}$Si(EC)Al($10^5$ years) |
| |
| (3) $^{61}$Ni(1.1%) + 4p → $^{65}$Ge($E_x$ = 21.3 MeV) |
| → 18.9 MeV + $^{4}$**He** + $^{61}$Zn(EC)$^{61}$Cu(EC)$^{61}$**Ni** |
| → 15.9 MeV + $^{12}$C + $^{53}$Fe(EC)$^{53}$Mn(3.7 $\times 10^6$ years) |
| → 11.0 MeV + $^{20}$Ne + $^{45}$Ti(EC)$^{45}$Sc |
| → 17.4 MeV + $^{28}$Si + $^{37}$Ar(EC)$^{37}$Cl |
| → 12.0 MeV + $^{27}$Si(EC)$^{27}$Al + $^{38}$**Ar** |
| → 17.5 MeV + $^{32}$S + $^{33}$S |

Bold font shows stable isotope.
Average kinetic energy of fission product is 9.7 MeV for Ni-natural.

The author applied STTBA analysis for modeled Pd(Cs)/D system to estimate transmutation rate. Results are shown in Table 5.

Calculated rate 4.6 $\times 10^{14}$ atoms per week for Cs-to-Pr transmutation showed considerable agreement with those by Iwamura's experiments.

## 6. 6d/OSC + M Interaction

Iwamura et al. [10] reported transmutation from $^{137}$Ba to $^{149}$Sm, namely mass-12 and charge-6 increased transmutation. This may be M + 6D capture process.

We considered 8D fusion process emits $^{12}$C nuclei with high kinetic energy and M + $^{12}$C capture process can be considered as secondary reaction. The second and more plausible process is direct 6D capture by octahedral symmetric condensate (OSC) for 6D cluster occupying six peaks (vertexes) of regular octahedron orthogonally coupled with six electrons which also occupy vertexes of regular octahedron as shown in Figs. 7 and 8. The squeezing motion of 6d/OSC can be modeled in analogous way to Fig. 1, although we need to treat three-dimensionally more complex system (cuboctahedron, dodecahedron, or regular hexagonal prism).

Self-fusion of 6d/OSC may be 6D fusion as shown in Fig. 9.

$$6\mathrm{D} \to {}^{12}\mathrm{C}^{*} \to {}^{4}\mathrm{He} + {}^{8}\mathrm{Be} + 71.3\ \mathrm{MeV} \to {}^{4}\mathrm{He} + {}^{4}\mathrm{He} + {}^{4}\mathrm{He} + 71.4\ \mathrm{MeV}. \quad (5)$$

And transmutation by M + 6d/OSC is

$$M(A, Z) + 6\mathrm{d/OSC} \to M(A + 12, Z + 6). \quad (6)$$

For example,

$$^{137}\mathrm{Ba} + 6\mathrm{D}(\text{or } ^{12}\mathrm{C}^*) \rightarrow {}^{149}\mathrm{Sm} + \gamma(68.23\ \mathrm{MeV}) \text{ or fission.} \tag{7}$$

Detail analysis for this process is expected. Approximate estimation of reaction rates are as follows. Microscopic 6D fusion rate for minimum state 6d/OSC is given by STTBA as

$$\lambda_{6\mathrm{d}} = (S_{6\mathrm{d}}(E)v/E)\exp(-6\Gamma_{\mathrm{STTBA}}) = 4.8 \times 10^{-2}(\mathrm{f/s/cl}). \tag{8}$$

Using PEF = 30 for 6d fusion,

$$S_{6\mathrm{d}}(E) = 10^{14}\mathrm{keV\ barn}, \tag{9}$$

$$\Gamma_{\mathrm{STTBA}} = 0.523(b^{1/2} - r_0{}^{1/2}) = 0.31. \tag{10}$$

**Table 4.** Fission products from Ni + 4p reactions, continued

| |
|---|
| $^{62}$Ni(3.6%) + 4p → $^{66}$Ge($E_x$ = 24.0 MeV) |
| → 11.0 MeV + $n$ + $^{65}$Ge(EC)$^{65}$Ga(EC)$^{65}$Zn |
| → 21.4 MeV + $^{4}$**He** + $^{62}$Zn(EC)$^{62}$Cu(EC)$^{62}$**Ni** |
| → 11.5 MeV + $^{8}$Be + $^{58}$Ni |
| → 18.9 MeV + $^{12}$**C** + $^{54}$**Fe** |
| → 10.5 MeV + $^{14}$N + $^{52}$Mn(EC)$^{52}$Cr |
| → 8.2 MeV + $^{16}$O + $^{50}$Cr |
| → 13.9 MeV + $^{20}$**Ne** + $^{46}$**Ti** |
| → 15.2 MeV + $^{24}$Mg + $^{42}$Ca |
| → 13.7 MeV + $^{27}$**Al** + $^{39}$**K** |
| → 18.9 MeV + $^{28}$**Si** + $^{38}$**Ar** |
| → 18.6 MeV + $^{32}$S + $^{34}$S |
| |
| $^{64}$Ni(0.93%) + 4P → $^{68}$Ge($E_x$ = 29 MeV) |
| → 16.7 MeV + n + $^{67}$Ge(EC)$^{67}$Ga(EC)$^{67}$**Zn** |
| → 25.6 MeV + $^{4}$He + $^{64}$Zn |
| → 10.0 MeV + $^{6}$Li + $^{61}$Cu(EC)$^{61}$**Ni** |
| → 13.2 MeV + $^{8}$Be + $^{57}$Ni(EC)$^{57}$Co(EC)$^{57}$**Fe** |
| → 10.9 MeV + $^{9}$**Be** + $^{59}$Ni(EC)$^{59}$**Co** |
| → 9.9 MeV + $^{10}$B + $^{58}$Co(EC)$^{58}$Fe |
| → 22.7 MeV + $^{12}$C + $^{56}$Fe |
| → 14.8 MeV + $^{14}$**N** + $^{54}$Mn(EC)$^{54}$**Cr** |
| → 12.7 MeV + $^{16}$O + $^{52}$Cr |
| → 17.6 MeV + $^{20}$**Ne** + $^{48}$**Ti** |
| → 12.7 MeV + $^{23}$Na + $^{45}$Sc |
| → 17.5 MeV + $^{24}$Mg + $^{44}$Ca |
| → 14.8 MeV + $^{27}$**Al** + $^{41}$**K** |
| → 18.7 MeV + $^{28}$**Si** + $^{40}$**Ar** |
| → 18.7 MeV + $^{32}$S + $^{36}$S |

Neutron emission channel may open!
S-values for higher mass Ni may be larger than Ni-58 and Ni-60, due to more p–n PEF interaction.
Bold font shows stable isotope.

**Table 5.** Cs-to-Pr transmutation rate estimated by STTBA model for M + 4d/TSC reaction

| | |
|---|---|
| STTBA prediction for Cs-to-Pr | |
| $S_{Mp} = 10^8$ keV barn | Suppose $N_{M+TSC} = 10^{17}$ in 10 nm layer of surface |
| $S_{Md} = 10^9$ keV barn | |
| $\lambda_{Mp} = 8.4 \times 10^{-10}$ f/s/tsc | |
| $\lambda_{M4p} = 2.3 \times 10^{-10}$ f/s/tsc | Macroyield $= \lambda \times N_{tsc} = 7.6 \times 10^{-9} \times 10^{17} = 7.6 \times 10^8$(f/s/cm$^2$) |
| $\lambda_{Md} = 2.8 \times 10^{-8}$ f/s/tsc | |
| $\lambda_{M4d} = 7.6 \times 10^{-9}$ f/s/tsc | Cs-to-Pr rate $= 4.6 \times 10^{14}$ (atoms per week per cm$^2$) |
| Where combination probability of anti-parallel spin was used for 4p/TSC | |

Here we used $b = r_{ddmin} = 8$ fm and $r_0 = 5$ fm.

And M + 6d/OSC capture rate is similar order as that of M + 4d/TSC, since S-value will be a little larger and barrier factor is a little smaller.

$$\lambda_{M+6d/OSC} \approx 10^{-8}[\text{f/s/(M + OSC)}].$$

If we have $N_{M+OSC} = 10^{17}\text{cm}^{-2}$ in reaction-range (about 10 nm), we have macroscopic reaction rate of $10^9$ f/s/cm$^2$.

Application of EQPET analysis to 6d/OSC is expected. The electronic quasi-particle e*(6,6) is composed of three Cooper pairs coupling orthogonally in three-dimensional rectangular axes, and its screening energy for d–d pair is 9600 eV, which is just near to that of muon.

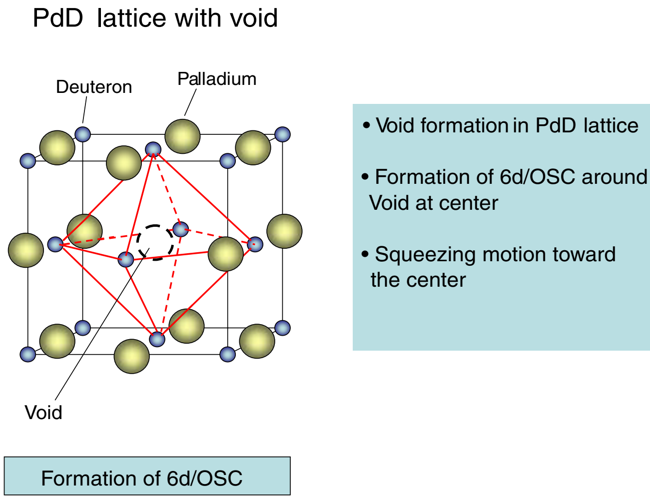


**Figure 7.** Formation of 6d/OSC seed by a central void in PdD lattice.

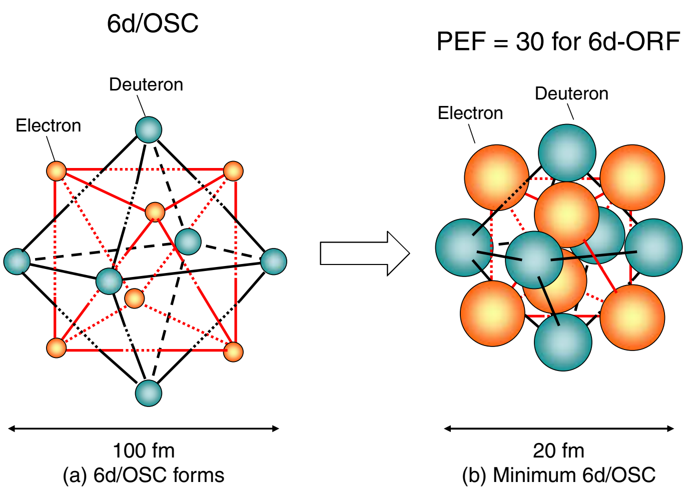


**Figure 8.** Formation of 6d/OSC.

## 7. Conclusions

The TSC of 4D (or 4H) cluster can squeeze very small as 10 fm in diameter at its minimum-size state, and will behave as charge-neutral pseudo-particle for Coulomb barrier penetration through electron clouds of host-metal atom to induced very enhanced nuclear reactions between host-metal M-nucleus and 4p (or 4d)/TSC pseudo-particle. Using STTBA model, reaction rates were estimated for Ni + 4p/TSC and M + 4d/TSC systems. Calculated results have shown good agreements with some of well-known experimental claims of transmutation and fission-products.

However, the present modeling of TSC mechanisms is still primitive and we need further elaboration. Especially, formation mechanisms near surface of host-metal complex is interested for further studies.

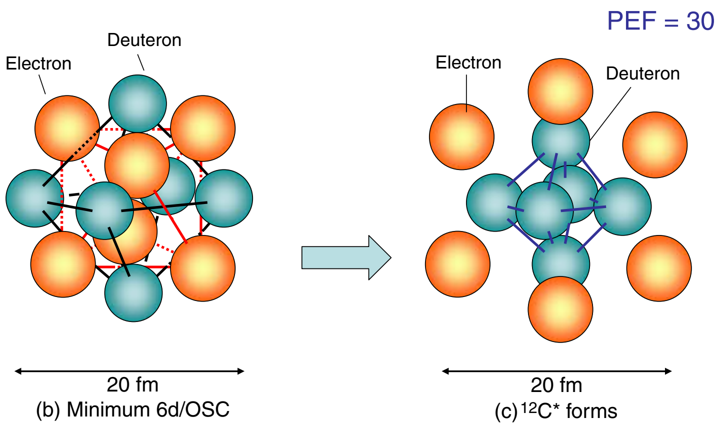


**Figure 9.** Formation of $^{12}C^{*}$ by 6d/OSC fusion.

Formation of 6d/OSC and 6D fusion in defect (void) of PdD lattice was proposed, although we need more detailed modeling of mechanism inducing central squeezing motion of 6 deuterons around central defect.

Cold transmutation scenarios as claimed by many experimentalists, also as studied in this work, are hopeful to apply for transmutation of long-lived radioactive wastes from nuclear plants.

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