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The Nuclear Transmutations (NTs) in Carbon-Hydrogen Systems (Hydrogen Graphite, XLPE and Microbial Cultures)*

Hideo Kozima
Cold Fusion Research Laboratory
597-16 Yatsu, Aoi, Shizuoka, 421-1202, Japan

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The nuclear transmutation (NT) in the cold fusion phenomenon (CFP) is an astonishing event not expected from the perspectives the pioneering researchers had in their motivation to perform experiments in this field. The researchers, however, seemed to realize the complex nature of the CFP at the first stage of their research not reconciling into the framework they had in their mind as expressed by Fleischmann et al. in their paper published in 1989;

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

1. Introduction

In the events of the cold fusion phenomenon (CFP), the nuclear transmutation (NT) is an astonishing one from the viewpoint of nuclear physicists suggesting a new state of matter in the CF materials (materials responsible to the CFP) entirely different from the states of matter we know in physics and chemistry developed in the 20th century.

We have given reviews of typical experimental data sets and their explanations based on our model [Kozima 1998 (Chapter 9), 2006 (Section 2.5), 2014a] and an extensive bibliography of the data were given by Storms in his book [Storms 2007 (Section 4.5)]. Furthermore, we deduced a stability law for the frequency of detection of a transmuted nucleus in the CFP comparing the experimental data with the abundance of elements in universe [Kozima 2005, 2006 (Section 2.11)] [Suess 1954]. The stability law shows, naturally, that the amount of iron occupies statistically the most abundant element in the transmuted nuclei [Kozima 2005 (Fig. 1), 2006 (Fig. 2.11)] [Storms 2007

(Table 8)].

The stability law for the transmuted nuclei in the CFP suggests that the mechanism working in the CF materials (materials where observed the CFP) is similar to the mechanism of elements production in the universe. To approach the real mechanism resulting in the CFP, we have investigated the CFP with a phenomenological model (TNCF model) where we assumed existence of neutrons (trapped neutrons) in the CF materials. The TNCF model explanation of the CFP has been fairly successful as explained in our books [Kozima 1998, 2006] and papers [Kozima 2014a, 2014b].

The characteristics of the trapped neutrons participating in the CFP are revealed by its wave nature with their de Broglie wave length λ_D comparable to the lattice constants of the CF materials [Kozima 1994]. The neutron with an energy E as an elementary particle exhibits wave property with a characteristic wave length λ_D (called de Broglie wave length)

$$\lambda_D = h/p = h/(\sqrt{2}m_{\rm n}E), \qquad (1.1)$$

where $m_{\rm n}$ is the neutron mass and h is the Planck's constant. The de Broglie wave length takes a value

$\lambda_D = 1 \times 10^{-8}$ cm = 0.1 nm = 100 pm (E = 98 meV = 0.098 eV)

for a kinetic energy of E = 0.098 eV,

and

$\lambda_D = 1.80 \times 10^{-8}$ cm = 1.80 Å = 0.18 nm = 180 pm ($E = E_{\rm th} \equiv$ 25 meV)

for $E = E_{\rm th} \equiv$25 meV = 0.025 eV (the thermal energy at 300 K).

([Kozima 1998 (Section 12.2c)])

The relation (1.1) is plotted in Fig. 1. As we see in the diagram, the de Broglie wave length of a neutron decreases with the inverse-square-root of energy; the wave length of 180 pm at E = 25 meV increases to 360 pm at E = (25/4) meV = 6.25 meV. As we see in the following sections, almost all the lattice constants of CF materials are in the range between this two values, 180 pm and 360 pm.

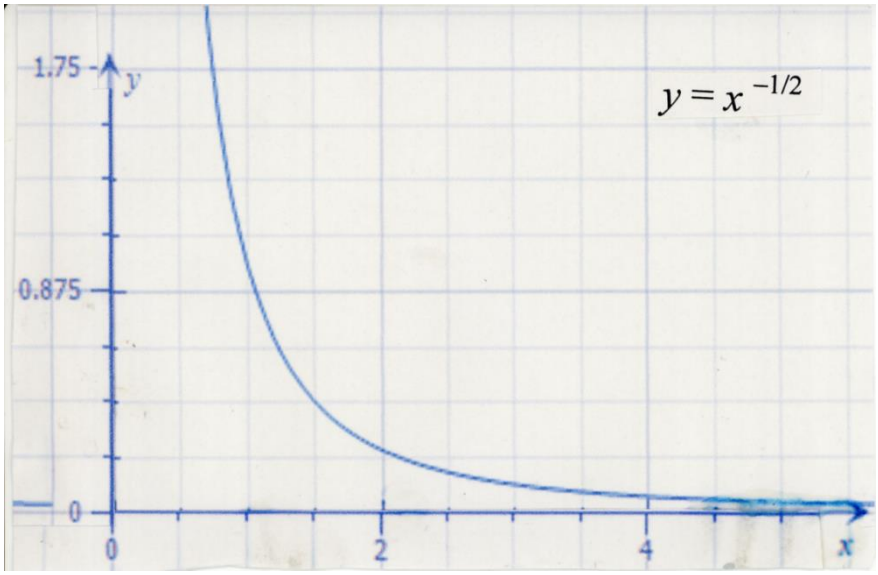


Fig. 1 Diagram of x $(= 2m_nE/h^2)$ vs. y $(= \lambda_D)$. Neutron energy E = 25 meV corresponds to the wave length λ_D = 180 pm. The more the neutron energy decreases, the more the de Broglie wave length lengthens.

It is helpful to recollect nuclear transmutations in transition-metal hydrides which were recently reviewed in our paper [Kozima 2014b]. We show the crystal structure of NiH, one of typical CF materials in transition-metal hydrides, in Fig. 2. The lattice constant a of NiH is 3.731 Å = 373.1 pm.

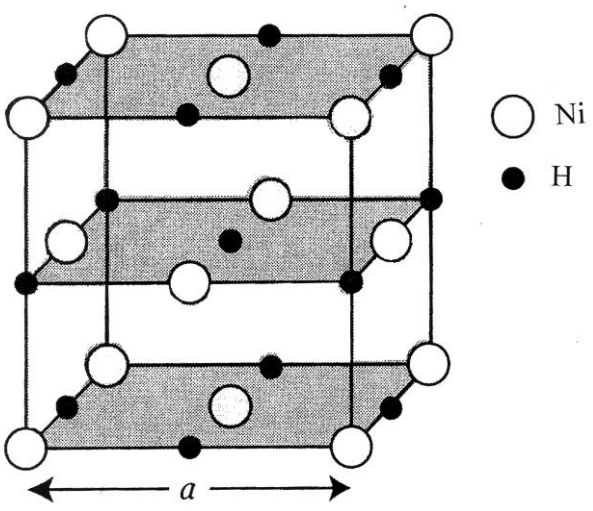


Fig. 2 Atomic arrangement in nickel hydride crystal. Ni(○) atoms locate at corners and centers of faces of a cube with an edge of length a. Hydrogens (●) locate at octahedral interstices (interstitial sites) surrounded by six Ni atoms in this case. (Another interstices surrounded by four Ni atoms are called tetrahedral sites.) The lattice constant

a is 3.731 Å = 373.1 pm.

We take up specific data sets of nuclear transmutation in CF materials composed of carbon and hydrogen in this paper and investigate its mechanism resulting in the nuclear transmutation. The CF materials we take up here are graphite used in the carbon arc, the cross-linked polyethylene (XLPE), and biological materials (microbiological or microbial cultures) where observed the biotransmutation.

Before discussion of the complicated data of biotransmutation obtained in microbial cultures, we would like to give a glimpse on the nuclear transmutations observed in graphite [Kozima 2012] and in XLPE [Kozima 2010] where carbon atoms play a principal role. The carbon atoms in graphite of electrodes in the carbon arc and also in polyethylene of the XLPE form arrays with appropriate spacings, from the viewpoint of the TNCF model, to form neutron bands, which is the key element to induce the nuclear transmutation in the CFP. In the following sections, we show a possible formation of the neutron bands in hydrogen graphite and XLPE.

2. Nuclear Transmutation in Hydrogen Graphite of Electrodes for Carbon Arc [Kozima 2012]

The most peculiar experiments detecting iron (Fe) are the carbon arc where no other transmuted nuclei are observed. Two papers were published in 1994 in the *Fusion Technology* [Sundaresan 1994] [Singh 1994] with a comment by the editor, G.H. Miley. The comment is useful for us to know the situation when these papers were published and cited below even if it is a little long:

Comments by G.H. Miley (Editor of the Fusion Technology)

"*The following two technical notes, "Anomalous Reactions during Arcing between Carbon Rods in Water" and "Verification of the George Oshawa Experiment for Anomalous Production of Iron from Carbon Arc in Water," are unique among the various papers that have been published in Fusion Technology in the area of cold fusion and nuclear reactions in solids. The first discusses experiments intended to prove or disprove earlier reports of anomalous production of iron in a carbon arc, while the second discusses a variety of possible related nuclear transmutations. Both studies are directly, or indirectly, related to the subject of nuclear reactions under non-hot-plasma conditions, i.e., closely related to the field of possible nuclear reactions in electrodes during electrolysis in materials like palladium with deuterium implanted by high gas pressure, plasmas, or electrical discharges. Both studies imply that reactions might*

*occur under electron volt background conditions that are even further removed from hot -plasma react ion conditions than those encountered in electrolytic cells. (However, even in electrolytic cell, there have been sporadic reports of the measurement of various product elements that imply nuclear transmutations can occur under these conditions. [See V.A. Tsarev and D.H. Worledge, "Cold Fusion Studies in the USSR," Fusion Technol., **22**, 138 (1992) and R.T. Bush, "A Light Water Excess Heat Reaction Suggests That 'Cold Fusion' May Be 'Alkali-Hydrogen Fusion,'" Fusion Technol., **22**, 301 (1992).])*

By anyone's standards, these results seem bizarre - indeed, the authors themselves stress the need for much more work. Because of this, four referees, with widely varying backgrounds, were used to review each of these technical notes. The decision to publish came down to the fact that the referees were mostly "neutral" in their assessments, saying that they could find no egregious errors but that the studies were not definitive and, hence, may be premature. Still, based on the responsibility for a journal to disseminate information to the community in a timely way so that further work is fostered or that pertinent issues are raised, the majority recommendation was to publish these technical notes now. Readers should keep in mind the purpose of these technical notes, namely, to provide provocative observations about a possible new field involving fusion-like nuclear reactions." (*Fusion Technol*. **26**. p. iii (1994))

We have analyzed successfully the data sets obtained on the carbon arc experiments [Kozima 2012] and give, however, a short investigation on them in this paper due to the importance of the phenomenon. There are three reliable papers among others on the nuclear transmutation induced by carbon arc in water [Sundaresan 1994, Singh 1994, Hanawa 2000]. In their experiments, following facts are determined. The transmuted nuclei in carbon arc obey the general tendency to fit the stability law discussed above [Kozima 2005, 2006 (Section 2.11)].

2.1 Detection of iron in detritus (carbon residue) after arcing in H_2O (i.e. in existence of oxygen and hydrogen) [Sundaresan 1994].

The original carbon contained 2 parts per million (ppm) iron, and the detritus contained up to 286 ppm of iron. There is a weak correlation between the iron formed and the time of passage of current.

The authors suggest following reactions to explain the production of iron from carbon and oxygen to meet the nucleon number *A* and the proton number *Z*;

$$2\,^{12}_{6}C + 2\,^{18}_{8}O \rightarrow {}^{56}_{26}Fe + {}^{4}_{2}He \qquad (1.2)$$

2.2 In addition to Fe with the same isotopic abundance to the natural one, there appear new elements, Si, Ni, Al and Cr [Singh 1994].

A direct current arc was run between ultrapure graphite electrodes dipped in ultrapure water for 1 to 20 h. It was found, in the first few experiments, that the iron content in the graphite residue was fairly high, depending on the duration of the arcing. Here also there were large variations in the iron concentration in the residue, although the experiments were performed under identical conditions.

The iron in the carbon residue was also analyzed mass spectrometrically for the abundance of its various isotopes, and the results were more or less the same as that of natural iron, Besides iron, the presence of other elements like silicon, nickel, aluminum, and chromium was also determined in the carbon residue.

2.3 There are many kind of elements in addition to the most abundant iron (Fe); Si, S, Cl, K, Ca, Ti, Cr, Mn, Co, Ni, Cu, Zn, and possibly heavier elements [Hanawa 2000].

Energy dispersive X-ray spectrometry, method of X-ray fluorescence (XRF) and particle induced X-ray emission were applied to analyze the product of carbon arc in light water. The result revealed increase or appearance of many kinds of elements; Si, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Ni, Co, Cu, Zn, and possibly heavier elements, however, the relative abundance including null varied case by case. Among them the dominant product Fe was found only in the larger debris.

Among XRF inspections applied to arc traces of used electrodes, an anode showed metallic elements, which suggest that transmutation reactions take place on the anode surface.

2.4 Theoretical Investigation on the Graphite-Hydrogen System

In the experiments performed after 1994, data have revealed characteristics of NT in carbon arc common to the NT observed in CF materials of transition-metal hydrides and deuterides. Therefore, we are encouraged to investigate the NT in carbon arc with the use of the TNCF model successfully applied to other CF materials and also XLPE.

It should be mentioned several words on the data introduced in Section 1.2.

The reaction formula (1.2) was taken up by the authors just to explain the production of Fe from elements existing in the CF materials adjusting the nucleon number *A* and the proton number *Z*. We do not need to pay attention to the formula because such nuclear transmutation does not occur without acceleration mechanism as in CF materials of

carbon arc.

The sentence "*there were large variations in the iron concentration in the residue, although the experiments were performed under identical conditions*." [Singh 1994] is the expression of the qualitative reproducibility popular in the cold fusion phenomenon (CFP) and should not be considered too seriously.

The new elements observed besides Fe in experiments by Singh et al. and by Hanawa show that the NTs in the carbon arc with graphite electrodes are similar events of the CFP observed in other CF materials such as transition-metal deuterides and hydrides.

The determination of the place where "transmutation reactions take place on the anode surface" by Hanawa is very important to investigate the mechanism of the NT in graphite at carbon arc as shown below.

We investigate the NT in carbon arc first and then discuss the biotransmutation and NT in XLPE briefly. A preliminary investigation of the nuclear transmutation in graphite was published in *Proc. JCF12* already [Kozima 2012].

Structure of Graphite and Hydrogen Graphite

Graphite has a layered, planar structure as shown in Fig. 3. In each layer, the carbon atoms are arranged in a honeycomb lattice with separation of 0.142 nm = 142 pm, and the distance between planes is 0.335 nm = 335 pm.

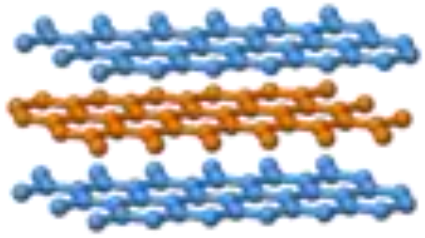


Fig. 3 Side view of layer stacking (after Wikipedia).

Formation of Neutron Bands in Graphite at High Temperature with Surface Layer of Oxides

However, in oxygen containing atmospheres graphite readily oxidizes to form CO_2 at temperatures of 700 °C and above. Therefore, we may suppose that the electrodes of arc are covered with CO_2 layers on the surface. Furthermore, H atoms will be absorbed into the volume to form an intercalation compound, hydrogen graphite HC_x, (x = 6 – 8 ?) which is similar to potassium graphite KC_8 or calcium graphite CaC_6. To understand the lattice structure of the hydrogen graphite, we cite here that of CaC_6 in

Fig. 4.

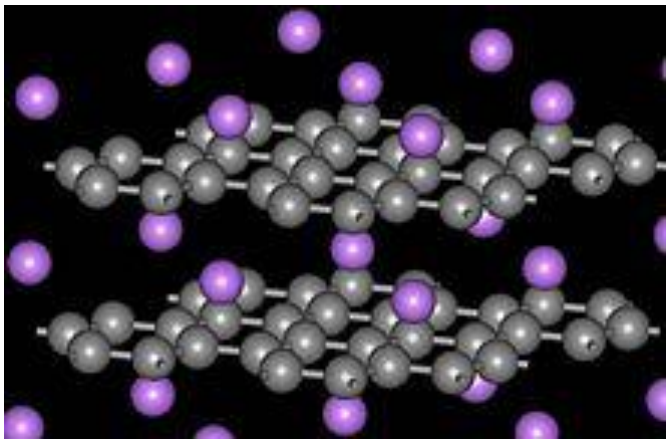


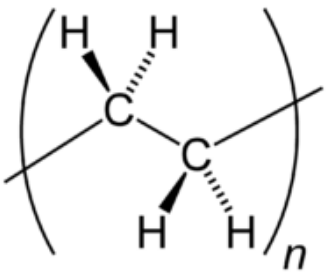
Fig. 4 Structure of CaC_6 (after Wikipedia): violet spheres represent Ca nuclei between layers of carbon nuclei (grey spheres).

Assuming the hydrogen graphite HC_x, (x = 6 – 8) has similar structure to that of CaC_6, then we can expect the super-nuclear interaction [Kozima 2006 (Sec. 3.7.2)] between neutrons in carbon nuclei ($^{12}_{4}C$) on the lattice points of graphite layers mediated by protons at interstitials. The super-nuclear interaction between neutrons in lattice points results in formation of the neutron bands and the neutrons in a band form the cf-matter responsible to the nuclear reactions in the CFP.

3. Nuclear Transmutation in XLPE [Kozima 2010]

The excellent experimental data on the nuclear transmutation in cross-linked polyethylene had been obtained by Kumazawa et al. for more than 10 years from 2004.

To show the essential feature of the atomic alignment in XLPE, we show its molecular structure in Fig. 5:



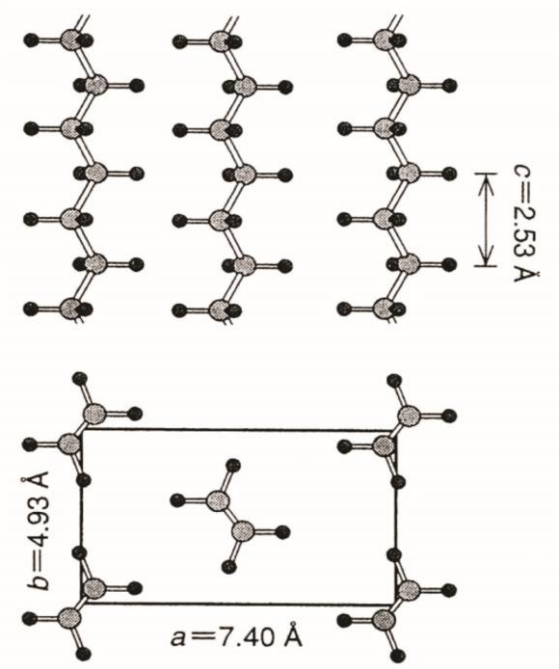


Fig. 5 Lattice structure of XLPE orthorhombic lattice with lattice constants, a = 7.40 Å (740 pm), b = 4.93 Å (493 pm), c = 2.53 Å (253 pm) [Kozima 2010 (Fig. 5)].

We have analyzed the NT data in XLPE obtained by Kumazawa et al. [Kumazawa 2005] using the TNCF model successfully [Kozima 2010]. The analysis has substantiated our approach to the NTs in hydrocarbons and we are encouraged to apply it to the biotransmutation (nuclear transmutation in biological systems) given in the next section.

4. Biotransmutation

Biotransmutation had been noticed very long ago in 1799 by Vauquelin as described by M. Kushi [Kushi 1994].

"*"A belief in the possibility of transmutation dates back to the origin of modern science. In 1799, a French chemist by the name of Vauquelin observed a large quantity of lime (CaO) in the daily excretion of chickens. He fed a captive hen a diet of nothing but oats in order to find out where the lime was coming from. He measured the amount of lime in the oats, and then fed the oats to the hen. He then measured the amount of lime in the excretion and the eggs of the hen, and discovered that it had increased by a factor of twelve. He hypothesized that lime had been created but was unable to explain how or why.*" [Kushi 1994, Kozima 1998 (Section 10.1)]

A possible explanation of the biotransmutation known by the year of 1998 was given in our old book [Kozima 1998 (Section 10.1)]. From the developed point of view of the TNCF model, we have to revise the explanation given there as follows.
The expression given there;

"It might be not absurd if we consider that a living being create a structure feasible to trap thermal neutrons when necessity be felt to transmute potassium into sodium, or else." (underlined at citation),

should be rewritten as follows,

"It might be not absurd if we consider that a living being create a structure feasible to trap thermal neutrons or to form the neutron bands through the super-nuclear interaction between lattice nuclei mediated by protons at interstitials when necessity be felt to transmute potassium into sodium, or else."

The experimental investigation of the biotransmutation has made vast progress in these more than ten years and we can give a more quantitative treatment using developed knowledge of the mechanism of the cold fusion phenomenon.

4.1 Recent Experimental data sets by Vysotskii et al.

The experimental data sets have been obtained in these about 20 years mainly by V.I. Vysotskii and his collaborators [Vysotskii 1996, 2000, 2009a, 2009b, 2013, 2015]. There are data sets showing (1) production of $^{57}_{26}$Fe from $^{55}_{25}$Mn [Vysotskii 1996, 2015] and also (2) acceleration of the decay of radioactive nucleus $^{157}_{55}$Cs in several microbial cultures [Vysotskii 2009b, 2015]. For the benefit of readers, the paper [Vysotskii 2015] is posted at the CFRL website next to the CFRL News No. 94:
http://www.geocities.jp/hjrfq930/News/news.htlm

Experiments were conducted using several bacterial cultures (*Bacillus subtilis GSY 228, Escherichia coli K-1, Deinococcus radiodurans M-1*) as well as the yeast culture *Saccharomyces cerevisiae T-8*. Selection of these cultures was motivated either by their experimentally proven ability to grow in the heavy water based media or by the prospect of using the radiation-stable culture *Deinococcus radiodurans M-1* in transmutation processes given the presence of powerful radioactive fields, as was noted earlier [Vysotskii 2009a].

The bacterial and yeast cultures used in their experiments have following characteristics:

***S. cerevisiae* (*Saccharomyces cerevisiae*)** cells are round to ovoid (egg shaped), 5–10 micrometers (μm) in diameter.

***B. subtilis* (*Bacillus subtilis*)** cells are typically rod-shaped, and are about 4-10 μm long

and 0.25–1.0 μm in diameter, with a cell volume of about 4.6 fL at stationary phase.
***D. radiodurans* (*Deinococcus radiodurans*)** is a rather large, spherical bacterium, with a diameter of 1.5 to 3.5 μm. Four cells normally stick together, forming a tetrad.
***E. coli* (*Escherichia coli*)** is- - - - . Cells are typically rod-shaped, and are about 2.0 μm long and 0.25–1.0 μm in diameter, with a cell volume of 0.6–0.7 μm^3.

The observed acceleration of the decay process of $^{137}_{55}Cs$ isotope is shown in Fig. 6. This behavior of the decay time shortening in transition-metal hydrides had been noticed before and discussed in our paper already [Kozima 2014c].

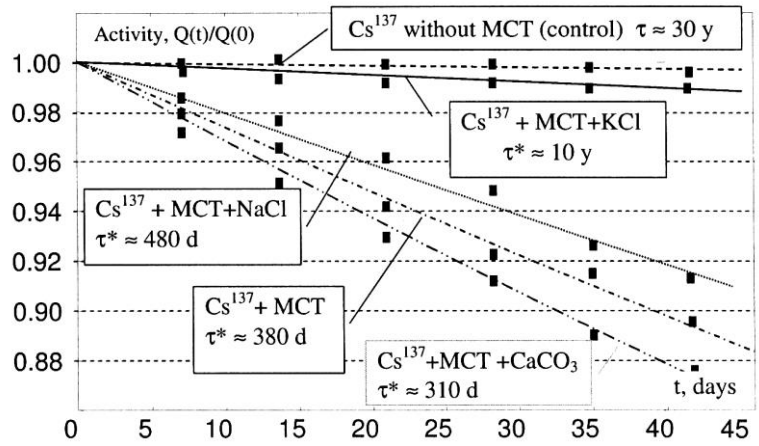


Fig. 6 Accelerated deactivation (accelerated decay) of $^{137}_{55}Cs$ isotope in "biological cells" with presents of different chemical elements [Vysotskii 2009b, 2015].

4.2 Structure of Bacteria relevant to the Biotransmutation (Nuclear Transmutation in Biological Systems)

Perhaps the most obvious structural characteristic of bacteria is (with some exceptions) their small size. It is interesting to notice that this smallness of the bacterial size is not small from quantum mechanical point of view, as we notice below.
For example, *Escherichia coli* cells, an "average" sized bacterium, are about 2 μm long and 0.5 μm in diameter, with a cell volume of 0.6 - 0.7 μm^3. Small size is extremely important because it allows for a large surface area-to-volume ratio which allows for rapid uptake and intracellular distribution of nutrients and excretion of wastes. However, this size of about a few μm is familiar for us in the investigation of the CFP; the size of localized occurrence of nuclear reactions in the CFP has been determined as about a few micrometers [Kozima 2006 (Section 2.5), 2011].

In addition to this fact about the size of the microbial cultures, the molecular structure of bacteria is very interesting from our point of view in terms of the regular

arrangement facilitating interaction with thermal neutrons similar to the XLPE discussed in Section 1.3 and also to the transition-metal hydrides introduced in the beginning of this paper [Kozima 1998 (Section 12.3), 2006 (Section 3.5.2), 2009].

The molecular structure of bacteria, however, is extremely diverse; there are varieties of component structure even if the essential components are common throughout the all bacteria.

To show the general idea of the molecular structure of bacteria, we show first the cell structure of a gram positive bacterium in Fig. 7 and the structure of peptidoglycan, a polymer consisting of sugars and amino acids that forms a mesh-like layer outside the plasma membrane of most bacteria, forming the cell wall, is shown in Fig. 8.

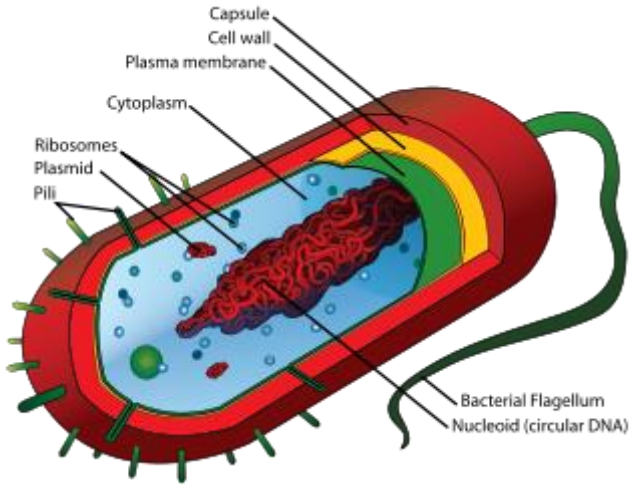


Fig. 7 Cell structure of a gram positive bacterium (after Wikipedia).

Peptidoglycan is made up of a polysaccharide backbone consisting of alternating N-Acetylmuramic acid (NAM) and N-acetylglucosamine (NAG) residues in equal amounts.

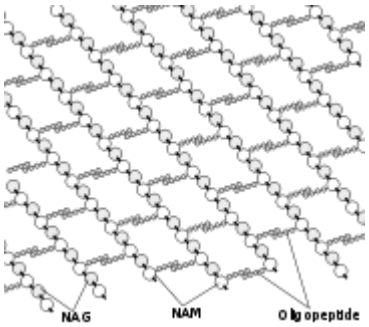


Fig. 8 The structure of peptidoglycan (after Wikipedia).

To understand the periods of molecular structures of bacteria appropriate for the interaction with thermal neutrons, we show the dimension of components of hydrocarbons, ethane, ethylene and benzene, composing the bacteria in Figs. 9 – 11.

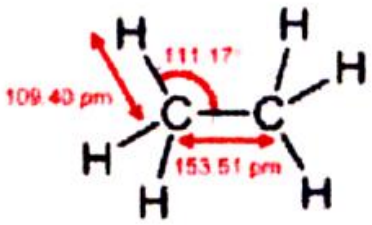


Fig. 9 Ethane molecule

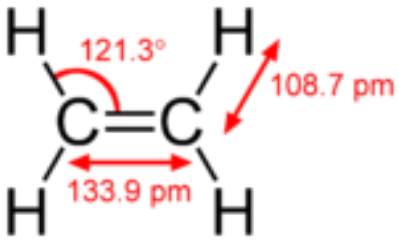


Fig. 10 Ethylene molecule

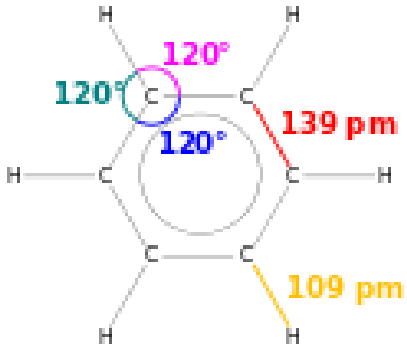


Fig. 11 Benzene molecule

The distances from 108.7 to 139 pm between nuclei in the hydrocarbon molecules given above are compared with the wave length 180 pm of a thermal neutron shown in Section 1.1. This fact shows possibility of interaction of thermal and epithermal neutrons with bacteria resulting in the CFP in biological systems.

The molecular structures of bacteria are, of course, very complicated from one bacterium to another. So, we have to satisfy ourselves only by giving some data of molecular structure of bacteria for a general idea to apply our TNCF model to the biotransmutation (nuclear transmutations in biological system, especially in bacteria).

There are two main types of bacterial cell walls, those of gram-positive bacteria (shown in Fig. 7) and those of gram-negative bacteria as shown in Fig. 12. Gram-positive cell walls are thick and the peptidoglycan (also known as murein) layer constitutes almost 95% of the cell wall in some gram-positive bacteria and as little as 5

– 10% of the cell wall in gram-negative bacteria.

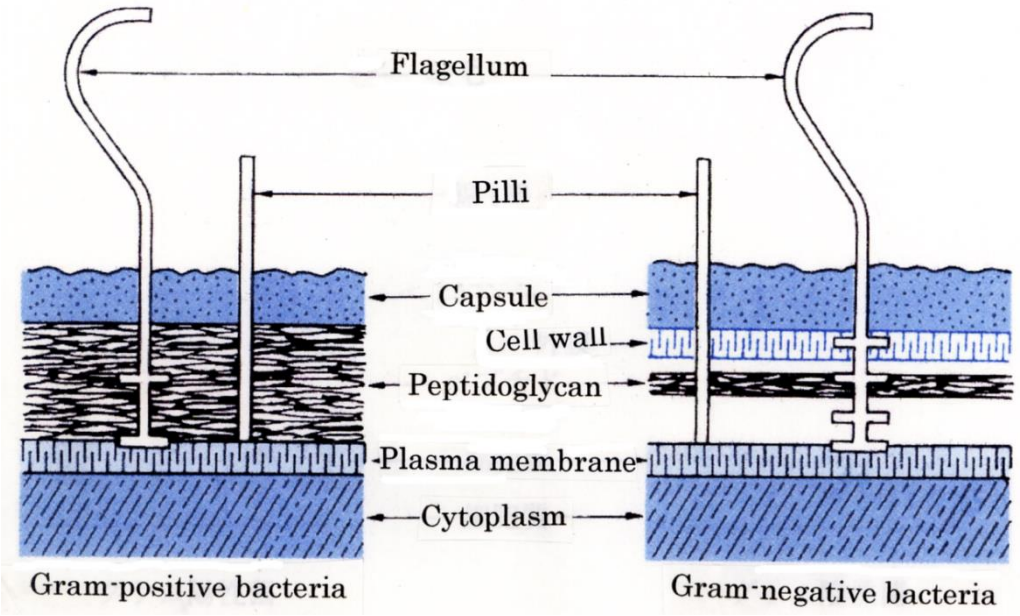


Fig. 12 Structures of cell walls in gram-positive and gram-negative bacteria (after [Ohno 2008]).

The matrix substances in the walls of gram-positive bacteria may be polysaccharides or teichoic acids. These acids are polymers of ribitol phosphate or glycerol phosphate and only located on the surface of many gram-positive bacteria.

Gram-negative cell walls are thin and unlike the gram-positive cell walls, they contain a thin peptidoglycan layer adjacent to the cytoplasmic membrane.

An S-layer (surface layer) is a cell surface protein layer found in many different bacteria and in some archaea, where it serves as the cell wall. All S-layers are made up of a two-dimensional array of proteins and have a crystalline appearance, the symmetry of which differs between species. The exact function of S-layers is unknown, but it has been suggested that they act as a partial permeability barrier for large substrates.

The cell wall has regular array of molecules as shown in Fig. 13 for the case of Staphylococcus and the molecular structure of Glycan strand is shown in Fig. 14.

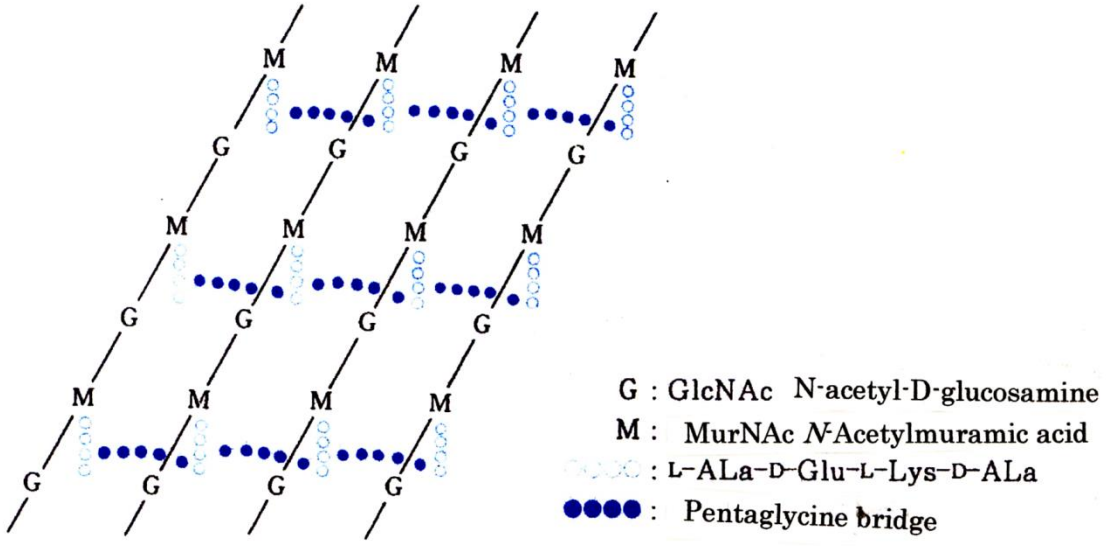


Fig. 13 Structure of the cell wall in Staphylococcus (after [Ohno 2008])

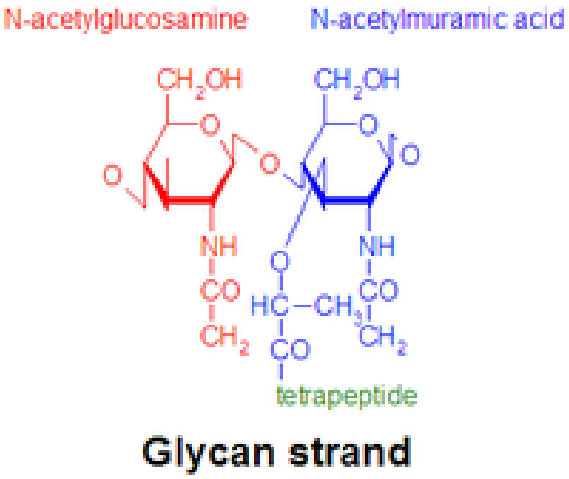


Fig. 14 Molecular structure of glycan strand (after Wikipedia)

Another example of molecular array in bacteria is shown in Fig. 15 for the teichoic acid found within the cell wall of Gram-positive bacteria and appears to extend to the surface of the peptidoglycan layer.

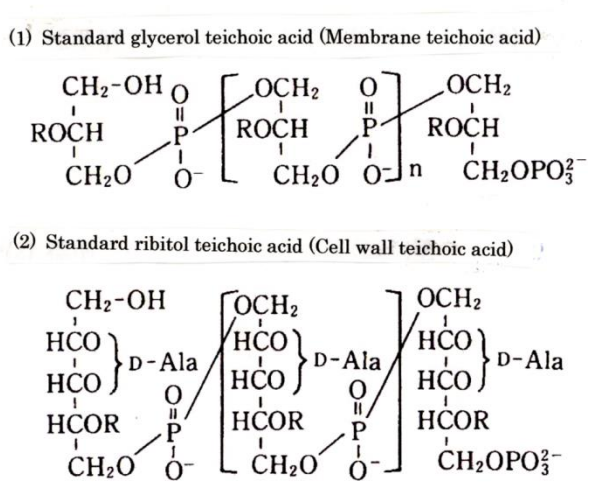


Fig. 15 Molecular structures of teichoic acids; (1) Membrane teichoic acid and (2) Cell wall teichoic acid (after [Ohno 2008]).

Further, the molecular structures of lipopolysaccharide and plasma membrane are shown in Fig. 16 and Fig. 17, respectively.

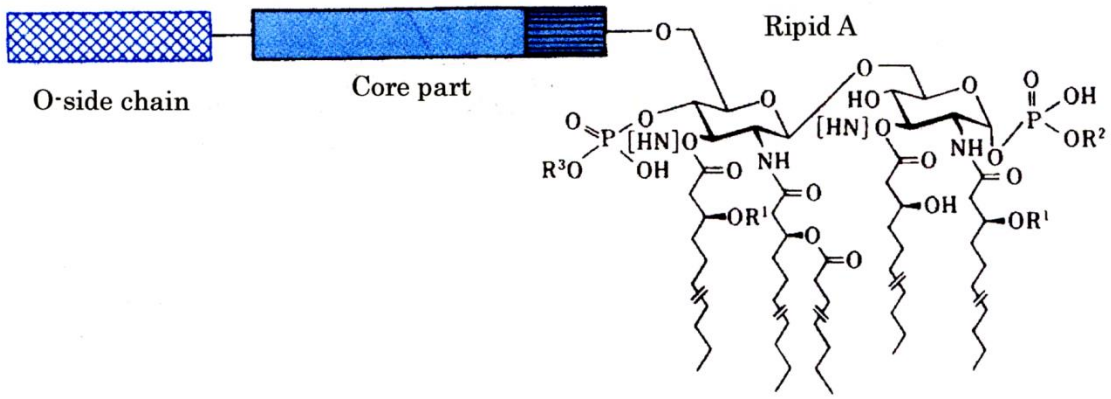


Fig. 16 Molecular structure of lipopolysaccharide (after [Ohno 2008])

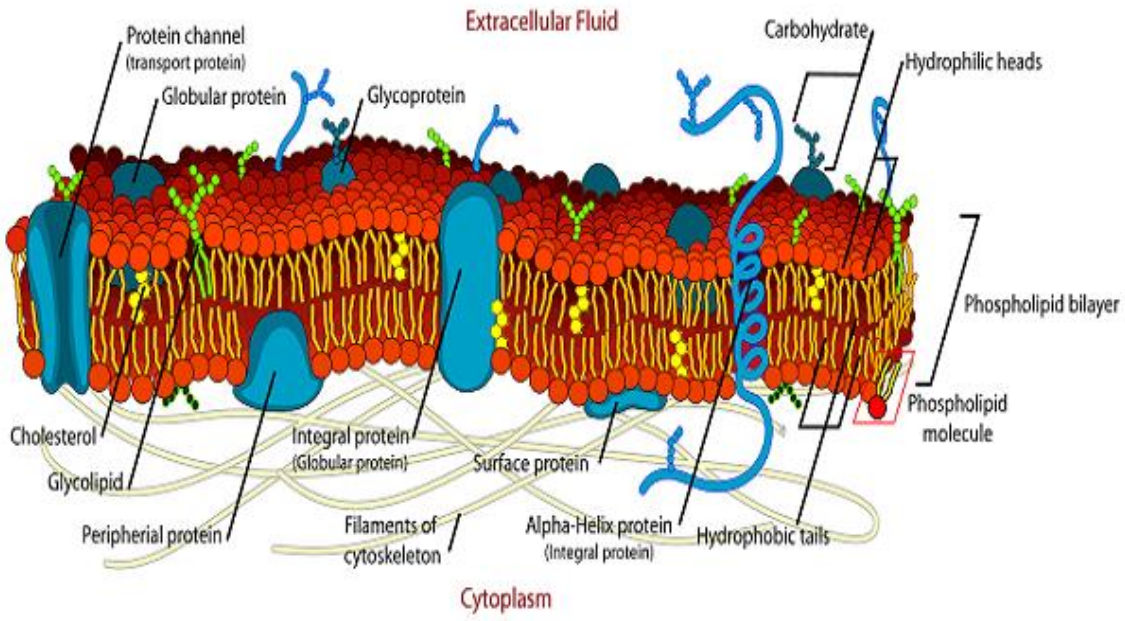


Fig. 17 Structure of plasma membrane
(http://study.com/academy/lesson/plasma-membrane-of-a-cell-definition-function-structure.html)

The structure of plasma membrane (cf. Fig. 17) in the bacteria reminds us the structure of XLPE shown in Fig. 5 where observed various NTs [Kumazawa 2005], which are explained by the TNCF model [Kozima 2010].

These differences in the structure of molecules in bacteria shown above with several examples (especially in Fig. 12) may have close relation to the characteristics of the biotransmutation induced by a bacterium and useful for their applications.

4.3 Theoretical Investigation on the Biotransmutation in Bacterial Cultures

The structures of bacterial cultures used in the experiments by Vysotskii et al. [Vysotskii 1996, 2000, 2009a, 2009b, 2013] are too complicated to treat them in a parallel way to the cases of transition-metal hydrides [Kozima 2014a] and XLPE [Kozima 2012]. We can, however, give explanations of the nuclear transmutations of $^{55}_{25}$Mn into $^{57}_{26}$Fe and the decay time shortening of $^{137}_{55}$Cs on a qualitative justification to apply the TNCF model to these cases.

First of all, we have to recognize the characteristics of bacteria in relation to the interaction with thermal neutrons. The distances between nuclei appropriate to effective interaction with thermal neutrons and regular arrangements of molecules in hydrocarbons in components of bacteria are two important characteristics common to

the cultures used by Vysotskii et al. for the nuclear transmutation. These characteristics remind us the words cited by M. Kushi in his book [Kushi 1994 (p. 25)] from a report, *Energy Development from Elemental Transmutations in Biological Systems*, published by U.S. Army Material Technology Laboratory in 1978;

"*The MgATP when place in layers one atop the other has all the attributes of a cyclotron in accordance with the requirements set forth by E.O. Lawrence, inventor of the cyclotron.*" [Kozima 1998 (Section 10.1)]. A possibility of nuclear reactions in biological cells had been recognized to explain the NTs observed by the year of 1978.

Allowing application of the TNCF model to the problems of biotransmutation, we can use following reactions between a trapped neutron *n* and a nucleus ${}^{A}_{Z}X$ at or in the surface of a bacterium;

$$ {}^{A}_{Z}X + n \rightarrow {}^{A+1}_{Z}X^{*}. \qquad (1.3) $$

In this reaction formula, ${}^{A+1}_{Z}X^{*}$ is an excited state of the nucleus ${}^{A+1}_{Z}X$ which will decay through following several channels in free space;

$$ {}^{A+1}_{Z}X^{*} \rightarrow {}^{A+1}_{Z}X + \gamma, \qquad (1.4) $$

$$ \rightarrow {}^{A+1}_{Z+1}Y + e^{-} + \underline{\nu}_{e}, \qquad (1.5) $$

$$ \rightarrow {}^{A+1}_{Z-1}Y' - e^{-}, \qquad (1.6) $$

$$ \rightarrow {}^{A-4}_{Z-2}Y'' + {}^{4}_{2}He, \qquad (1.7) $$

where $\underline{\nu}_{e}$ is an electron neutrino, γ is a photon (in free space) and Y, Y' and Y'' are daughter nuclides of the reactions. In the CF materials, the photon γ in the free space is absorbed by the cf-matter formed of neutrons in the neutron band and dissipate in phonons to heat the system as a whole [Kozima 2006 (Section 3.7.5)].

Now, let us investigate the biotransmutation observed by Vysotskii et al.

The first example is the production of ${}^{57}_{26}Fe$ in a CF material with ${}^{55}_{25}Mn$. The nuclear reaction responsible to this case is suggested by Eqs. (1.5) and (1.4). We can explain the production of ${}^{57}_{26}Fe$ from ${}^{55}_{25}Mn$ by the following reactions based on the TNCF model;

$$ {}^{55}_{25}Mn + n \rightarrow {}^{56}_{25}Mn^{*}, \quad (\sigma = 13.41\ b) \qquad (1.8) $$

$$ {}^{56}_{25}Mn^{*} \rightarrow {}^{56}_{26}Fe + e^{-} + \underline{\nu}_{e}, \quad (\tau = 2.5785\ h) \qquad (1.9) $$

$$ {}^{56}_{26}Fe + n \rightarrow {}^{57}_{26}Fe, \quad (\sigma = 2.5914\ b) \qquad (1.10) $$

The second example is the decay time shortening of radioactive isotope ${}^{137}_{55}Cs$ which decays according to the following reaction;

$$ {}^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + e^{-} + \underline{\nu}_{e}, \quad (\tau = 30.07\ y) \qquad (1.11) $$

Assuming the existence of the trapped neutron in the TNCF model, we can apply the equation (1.5) to this case;

$$ {}^{137}_{55}Cs + n \rightarrow {}^{138}_{55}Cs^{*}, \quad (\sigma = 0.113\ b) $$

$^{138}_{55}Cs^{*} \rightarrow {}^{138}_{56}Ba + e^{-} + \underline{\nu}_e \quad (\tau = 33.41\ m)$

5. Conclusion

This series "*From the History of CF Research*" reached the Nuclear Transmutation in the Biological Systems (Biotransmutation), a fantastic and astonishing theme beyond common sense of nuclear scientists.

In this paper, we have given our explanation on the nuclear transmutations observed in carbon arc, in cross-linked polyethylene (XLPE) and in biological bodies (biotransmutation). The first two CF materials had been taken up before and the treatment given in this paper is supplemental one.

The biotransmutation taken up in this paper is the most difficult problem to understand from physical point of view due to the complex nature of the material where occurs the phenomenon. When I took up the biotransmutation in 1998 [Kozima 1998 (Section 10.1)], the experimental data were just qualitative combining the initial condition characterized by plants (e.g. watercress) or animals (e.g. chicken) and the final results characterized by increases of some elements (e.g. CaO or $CaCO_3$).

The situation drastically changed mainly by the efforts performed by Vysotskii and his collaborators to identify the elemental changes in rather quantitatively specified materials such biological cultures as *Bacillus subtilis GSY 228, Escherichia coli K-1, Deinococcus radiodurans M-1* as well as the yeast culture *Saccharomyces cerevisiae T-8*. Then, we could explain the experimental data of $^{57}_{26}Fe$ production and the decay time shortening of $^{137}_{55}Cs$ as presented in the Section 1.4.3.

We can recite the sentence proclaiming a possibility of biotransmutation in 1998 to emphasize the weight of the scientific fact even if no framework is absent at the time;

"*From our point of view, on which the excess heat generation and the nuclear transmutation in electrolytic and gas-loading systems are explained by nuclear reactions in them catalyzed by thermal neutrons, the biotransmutation described in the book and cited above should also be explained as follows.*

A body of plants or animals is made of cells with regularity and fundamental elements of the cell are hydrogen (H), oxygen (O) and carbon (C). The ambient thermal neutron, which is plenty on the earth everywhere[69], can be trapped in the body of a living being by a structure with regularity, i.e. the layer structure of MgATP explained in the Kushi's sentence cited above. The trapped neutron can reacts with an element in the body. Such nuclear transmutation as Na → Mg, P → S, K → Ca and Mn → Fe are easily explained by nuclear reactions where occur a neutron capture and a successive beta decay as

follows:

$^{23}_{11}Na + n \rightarrow {}^{24}_{11}Na^* \rightarrow {}^{24}_{12}Mg + e^- + \underline{\nu}_e$,

$^{31}_{15}P + n \rightarrow {}^{32}_{15}P^* \rightarrow {}^{32}_{16}S + e^- + \underline{\nu}_e$,

$^{39}_{19}K + n \rightarrow {}^{40}_{19}K^* \rightarrow {}^{40}_{20}Ca + e^- + \underline{\nu}_e$,

$^{55}_{25}Mn + n \rightarrow {}^{56}_{25}Mn^* \rightarrow {}^{56}_{26}Fe + e^- + \underline{\nu}_e$,

where $\underline{\nu}_e$ *is the electron neutrino.*" [Kozima 1998 (Section 10.1)]

The variety in the structures and properties of bacteria is very diverse and our explanation on the biotransmutation has been only qualitative. It is, however, possible to say that the investigation given above in this paper is a first step to understand the mechanism of biotransmutation and may suffice as a corner stone for the science of biotransmutation, an important part of the CFP, with vast possibility of application, especially in the remediation of hazardous nuclear waste with long-lasting radioactivity.

For instance, we can use bacteria which absorb or adsorb alkaline elements to remediate the radioactivity of the radioactive isotope $^{137}_{55}$Cs. We can use, also, bacteria which absorb or adsorb halogen elements to remediate the radioactivity of the radioactive isotope $^{131}_{53}$I. Biological CF materials have characteristics which are not exist in inanimate CF materials. We can use the characteristics in the application of the CFP effectively.

We hope that the qualitative treatment of the biotransmutation given in this paper using the TNCF model will be a first step to understand the possible nuclear reactions in microbial cultures revealed by the experimental data sets obtained by researchers, especially by V.I. Vysotskii and his collaborators.

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