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Research Article

The Launch of a New Plan on Condensed Matter Nuclear Science at Tohoku University

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Abstract

A new division devoted to Condensed Matter Nuclear Reaction (CMNR) was established at the Research Center for Electron Photon Science of Tohoku University in April 2015. This division consist of researchers from Tohoku University, Mitsubishi Heavy Industries and Clean Planet Inc., who have been actively engaged in the field of CMNR. In this division, fundamental research on condensed matter nuclear reaction, R&D on energy generation and nuclear waste decontamination will be performed.

Keywords: Collaborative research division, Condensed matter nuclear reaction, Electron screening, Nano-structured Pd–CaO complex, Permeation, Transmutation

1. Introduction

The Research Center for Electron Photon Science of Tohoku University and CLEAN PLANET Inc. agreed to the establishment of the collaborative research division: the Condensed Matter Nuclear Reaction Division. This is the first official research division for condensed matter nuclear science and its application in Japan.

In this paper, the research activities of participating members are briefly described. This includes the organization and research plan of the division, research background and objectives.

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2. Activities of Participating Members

2.1. Tohoku university

J. Kasagi and his co-workers of Tohoku University have been investigating the effects of metal environments acting on nuclear reactions. They succeeded in measuring the reaction rates at lower bombarding energies, and were the first to deduce the screening energy of the d + d reaction in metal, which is a quantitative scale of the enhancement at very low energies [1–4].

The excitation functions of the yield of protons emitted in the D(d,p)T reaction in Ti, Fe, Pd, PdO and Au were measured for bombarding energies between 2.5 and 10 keV. It was found that the reaction rate at lower energies varies greatly with the host materials. The most strongly enhanced DD reaction occurs in PdO at E_d = 2.5 keV; it is enhanced by factor of fifty from the bare deuteron rate and the screening energy deduced from the excitation function, which amounts to 600 eV. Figure 1 shows the relative yield of protons emitted in the D(d,p)T reaction in the five hosts as a function of the bombarding energy of deuterons; (a) two independent measurements for PdO, (b) for Pd and Fe and (c) for Au and Ti. In the upper sections, the data normalized to the yield at 10 keV are plotted. In the lower sections, the experimental yields divided by those presented with the dotted curve are shown. The dotted curves correspond to the relative yields calculated for the bare DD reactions without screening. Solid and dashed curves correspond to calculations with the screening energy indicated in each section [4].

An enhancement of this size cannot be explained by electron screening alone but suggests the existence of an additional and important mechanism of the screening in solids. This is the first clear evidence that the fusion reaction rate can be enhanced in the metal environment during keV deuteron bombardment.

They also investigated on Li + d reaction in Pd [5], Li + d and Li + p reactions in Liquid Lithium [6], d + d and Li + d reactions in metal lithium acoustic cavitation [7] under low energy condition.

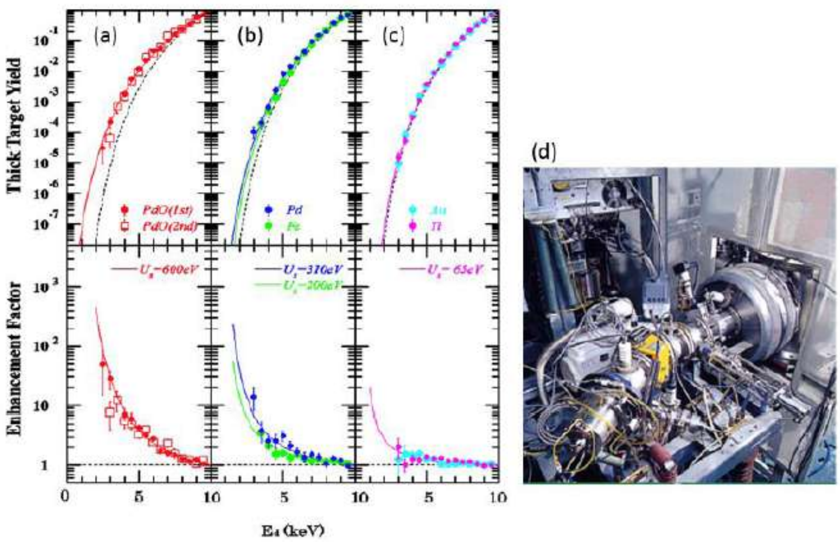

Figure 1. Excitation functions of the yield of protons emitted in the D(d,p)T reaction in Ti, Fe, Pd, PdO and Au [4].

2.2. Mitsubishi heavy industries Ltd.

Y. Iwamura, T. Itoh and their co-workers of the Advanced Technology Research Center of Mitsubishi Heavy Industries have been investigating the condensed matter nuclear transmutation reactions observed in the nano-sized Pd complexes induced by D_2 gas permeation. They first observed transmutation reaction of Cs into Pr using a very simple and compact setup shown in Fig. 2 [8].

They fabricated nano-structured Pd–CaO complexes with an element that is specifically targeted to be transmuted. The sample is a Pd complex composed of bulk Pd on the bottom, alternating CaO and Pd layers, and a Pd thin film on top. The multi-layers of CaO and Pd were obtained by alternately sputtering 2-nm-thick CaO and 20-nm-thick Pd layers five times. The top surface was Pd 40 nm thick. These processes were performed by the Ar ion beam sputtering method or the magnetron sputtering method. After fabricating the Pd–CaO complex, Cs was deposited on the surface of the thin Pd layer.

Elemental changes in the Pd complexes were measured by the X-ray Photoelectron Spectroscopy (XPS) without taking the complexes out of the vacuum chamber. This prevented contamination from outside of the chamber. The first and second results are plotted in Fig. 2(b). There was no Pr at the beginning of the experiments. The number of Cs atoms decreased while Pr atoms increased over time during the experiment. The number of atoms was evaluated by XPS spectra. The amount of deuterium permeation was proportional to the elapsed time. Pr was confirmed by the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and the (Time of Flight Secondary Ion Mass Spectrometry (TOF-SIMS) [9,10, 12] and the in-situ X-ray Fluorescence analysis (XRF) measurement [11,12]. As the control experiments:

(1) H_2 gas permeation experiments using the same Pd multilayer samples (Pd/CaO/Pd),
(2) D_2 gas permeation using the same Pd multilayer samples (Pd/CaO/Pd) without Cs,
(3) D_2 gas permeation using the Pd sample without CaO were performed.

These control experiments were performed under the same temperature and pressure as foreground experiments.

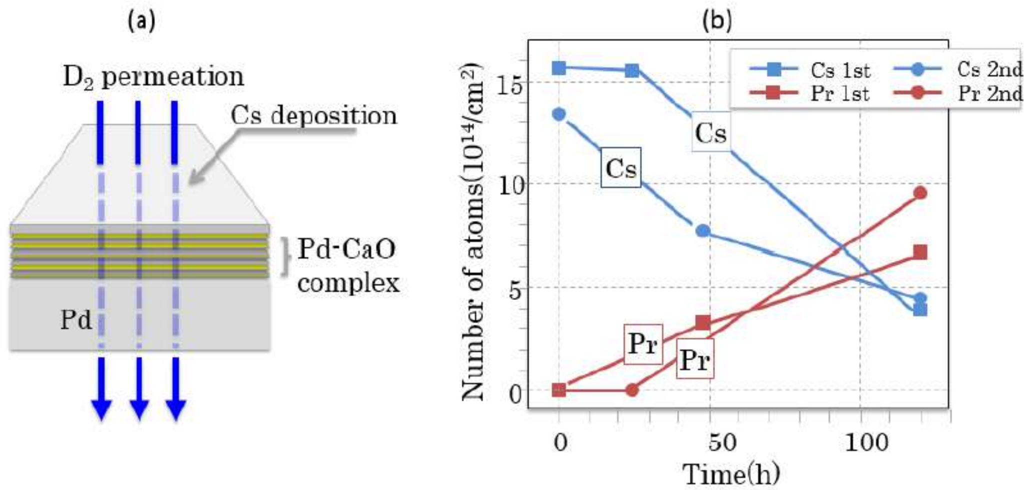

Figure 2. Schematic representation of experimental method; (a) Condensed matter nuclear transmutation method with the nano-sized Pd complexes induced by D_2 gas permeation and (b) experimental results on transmutation of Cs into Pr [8].

No Pr was detected in any of the control experiments. This suggests that both deuterium and nano-structured Pd multilayer with CaO are necessary factor to observe transmutation reactions.

Replication experiments have been performed in some universities and institutes, mainly in Japan. T. Higashiyama et al. of Osaka University observed transmutation of Cs into Pr in 2003 [13]. H. Yamada et al. performed similar experiments [14] using Cs and detected increase of mass number 137 by TOF-SIMS. They used a couple of nano-structured Pd multilayer thin film and observed the increase of mass number 141 (corresponding to Pr) only when ^{133}Cs was present on the Pd sample. T. Hioki and N. Takahashi et al., the researchers of Toyota Central R&D Labs detected Pr using ICP-MS from the permeated Pd sample. They presented these findings at ICCF-17 and published their results in the Japanese Journal of Applied Physics [15]. They performed careful experiments and concluded that the amount of Pr could not be explained by a contamination process.

These replications provide important information concerning about the nature of this phenomenon. Other than Osaka University, the samples were independently fabricated with different Pd dimensions or fabrication techniques. Nevertheless, similar results were observed. These experimental evidences strongly suggest to us that transmutation reactions of Cs into Pr occurred using this simple method.

The D_2 gas permeation transmutation reactions were observed for the other elements. Table 1 summarizes the typical transmutation reactions observed so far [12]. If we deposit ^{138}Ba on the nano-structured Pd film, we obtain ^{150}Sm by D_2 gas permeation. And if we deposit ^{137}Ba on the Pd complex, we obtain ^{149}Sm. The observed transmutation reactions of Ba into Sm belong to a reaction category in which the increase of mass number is 12 and the increase of atomic number is 6. Nuclear transmutation induced by this method is not limited to the category in which the increase of mass number is 8 and the increase of atomic number is 4 (Cs$\rightarrow$Pr).

The obtained experimental results so far suggest that a certain rule seems to exist for this deuterium permeation transmutation. We can notice that 2d, 4d or 6d appear to be reacting with the deposited elements. From another point of view, it might be considered that α-capture reactions occur in deuterium permeation experiments. At present, this is just speculation; however, it is important that a certain rule seems to exist.

To apply this deuterium permeation transmutation phenomenon to practical use it will be necessary to increase the mass of the transmutation products. This phenomenon might be used as an innovative nuclear transmutation method for radioactive waste, or as a new energy source if we can solve many technical problems that would prevent commercialization. Iwamura et al. have been trying to increase the amount of transmutation products for these years. They applied an electrochemical method to increase the local deuteron density near the surface of the nano-structured Pd multilayer film and increased the amount of transmutation products up to $\sim$1 μg/cm^2 [16,17]. Furthermore, they developed a solution circulation type of experimental apparatus aiming consecutive transmutation of Cs in solution [18].

2.3. Clean Planet Inc.

T. Mizuno, H. Yoshino and their colleagues have been developing excess heat generation methods and devices for the past few years. Figure 3 shows the experimental reactor setup and the example of excess heat generation [19]. Their experimental process is as follows. First, Ni metal was heated under vacuum condition and D_2 gas was introduced

Table 1. Typical transmutation reactions observed in Mitsubishi heavy industries Ltd. [12].

Elements		Apparent reactions
Cs	4d	${}^{133}_{55}\mathrm{Cs} \overset{4\mathrm{d}(2\alpha)}{\rightarrow} {}^{141}_{59}\mathrm{Pr}$
Ba	6d	${}^{138}_{56}\mathrm{Ba} \overset{6\mathrm{d}(3\alpha)}{\rightarrow} {}^{150}_{62}\mathrm{Sm}$, ${}^{137}_{56}\mathrm{Ba} \overset{6\mathrm{d}(3\alpha)}{\rightarrow} {}^{149}_{62}\mathrm{Sm}$
W	4d or 2d	${}^{182}_{74}\mathrm{W} \overset{4\mathrm{d}(2\alpha)}{\rightarrow} {}^{190}_{78}\mathrm{Pt}$? ${}^{186}_{74}\mathrm{W} \overset{2\mathrm{d}(\alpha)}{\rightarrow} {}^{190}_{76}\mathrm{Os}$?

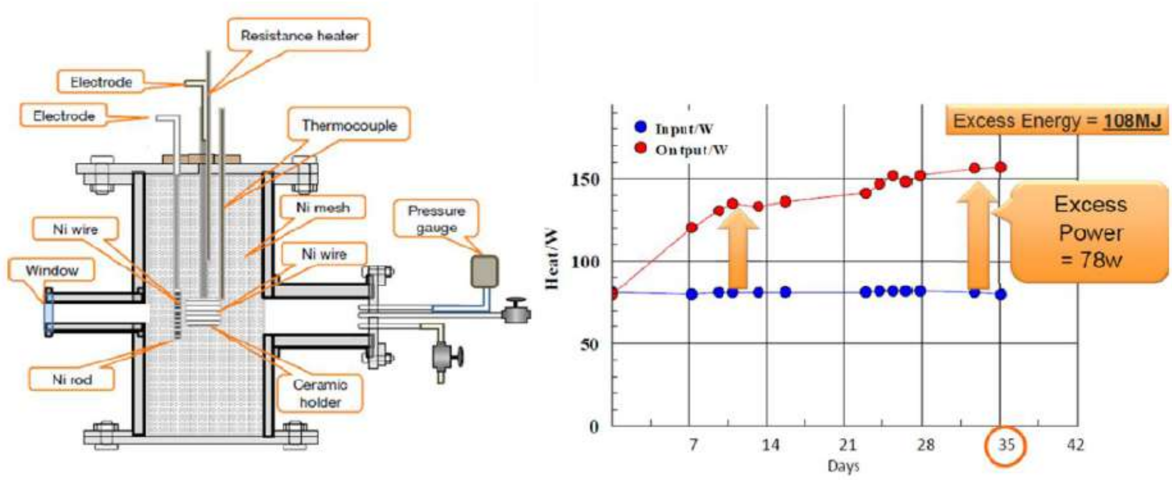

Figure 3. Experimental reactor setup and an example of excess heat generation by Clean Planet Inc. [19].

into the chamber. The Ni mesh was subjected to the plasma discharge and cooled down. This process was repeated 4 or 5 times to create the nano-structured Ni surface. After this activation process, D_2 gas, at about 100–300 Pa, was introduced at 200°C, and then excess heat generation was observed as shown in Fig. 3. In this case, they observed about 78 W excess power that is almost the same as input power.

T. Mizuno is now improving the method of measuring excess heat measurement and analysis, in order to obtain more precise results of excess heat generation [20].

3. Condensed Matter Nuclear Reaction Division (April 2015 –)

The Condensed Matter Nuclear Reaction Division of Research Center for Electron Photon Science at Tohoku University has established in April 2015. It is the first official research division created for condensed matter nuclear reaction (CMNR) and its application in Japan. In United States, the Sidney Kimmel Institute for Nuclear Renaissance (SKINR) at University of Missouri was established in 2012 and the Center for Emerging Energy Sciences (CEES) at Texas Tech. University has recently started. Below, we describe the purpose of the division, organization of the division and the outline of our research plan.

3.1. Purpose of the division

With the aim of creating revolutionary innovation in the energy industry, the Research Center for Electron Photon Science at Tohoku University and Clean Planet Inc. have established a Condensed Matter Nuclear Reaction Division. Through this new joint research collaboration, we will perform the following:

(1) Fundamental Research on Condensed Matter Nuclear Reaction (CMNR),
(2) Development of a New Energy Generation Method,
(3) Development of a New Nuclear Waste Decontamination Method.

Experimental data that indicates the presence of CMNR have been accumulated and experimental conditions for inducing CMNR are gradually becoming clear, although systematic experimental study is still insufficient. So we will

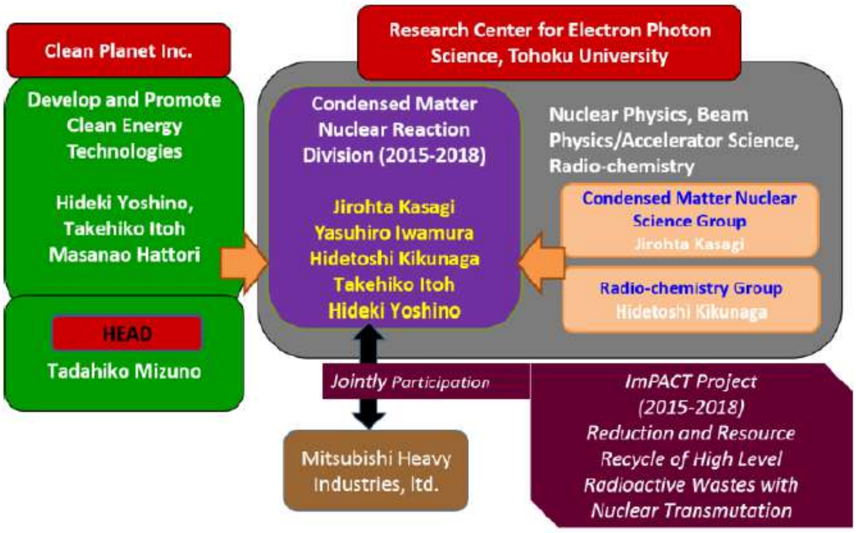

Figure 4. Organization of Condensed Matter Nuclear Reaction Division of Research Center for Electron Photon Science at Tohoku University.

obtain more systematic data and improve the reliability of measurement on CMNR. It leads to better understanding of ultra-low-energy nuclear reactions in condensed matter. We will also work on application development research aimed at commercializing new clean energy devices and new nuclear waste decontamination methods. We hope to bring major changes to Japan's energy industry, through the conceptual change of conventional nuclear reaction.

3.2. Organization of the division

The organization of the new division is illustrated in Fig. 4. Jirohta Kasagi, Yasuhiro Iwamura, Hidetoshi Kikunaga. Takehiko Itoh and Hideki Yoshino participate in the division.

Iwamura and Itoh were investigating nuclear transmutation reactions observed in the nano-sized Pd complexes induced by D_2 gas permeation and left Mitsubishi Heavy Industries, ltd. at the end of March 2015 to join the division. Now Iwamura is a research professor of Tohoku University and Itoh is a visiting associate professor. Itoh is also a director of Clean Planet Inc. J. Kasagi is a professor emeritus and has been investigating the electronic and ionic screening effects on low-energy nuclear reactions in condensed matter as described in the former section. H. Kikunaga is an associate professor and has been engaged in the field of radiochemistry. H. Yoshino is a visiting researcher in this division and also a CEO of Clean Planet Inc.

The nuclear waste decontamination research is supported by the ImPACT Program "Reduction and Resource Recycle of High Level Radioactive Wastes with Nuclear Transformation", which is a Japanese national research project. The Electron Photon Science of Tohoku University and Mitsubishi Heavy Industries jointly participate in this project.

3.3. Outline of Research Plan

The outline of our research plan is shown in Fig. 5. As for the excess heat generation, we will seek the most probable method for energy generation for 2 years. We will try new methods of excess heat generation based on the Mizuno's

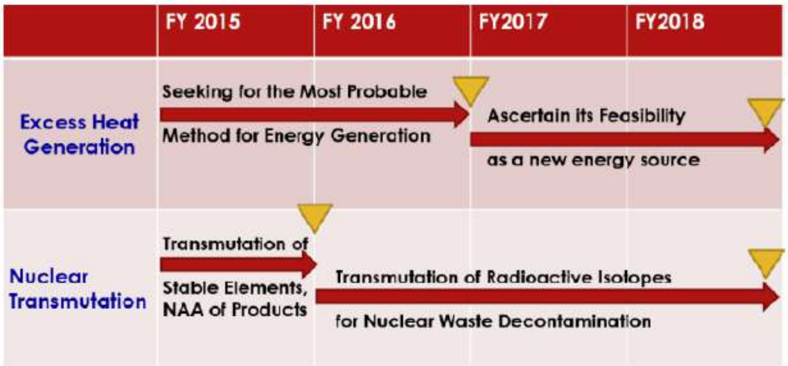

Figure 5. Outline of our research plan.

method and the transmutation method induced by D_2 gas permeation. Measurement of excess heat on the Mitsubishi transmutation method have not been performed. If we measure heat release, this will confirm excess energy. It is very important to measure the released heat precisely as well as to evaluate correct input power. We will develop an elementary method for energy generation until FY2016, and we will ascertain its feasibility as a new energy source. The focus in this stage will be on controllability and reliability of energy production reactions, as well as economical issues.

Nuclear transmutation research will performed with funding from the ImPACT program. Pr, which is transmuted from Cs, will be re-confirmed by other methods such as Nuclear Activation Analysis (NAA) or Rutherford Backscattering (RBS). (However, if we do not get operational resumption of Japan's nuclear power reactors during FY2015, then we may not be able to use NAA.) We will confirm that Pr is transmuted from Cs by RBS. Stable Zr, Se and Pd transmutation will be tried using the transmutation method in the nano-sized Pd complexes induced by D_2 gas permeation. If we obtain the positive results, we will be able to go to the next stage. We will make transmutation experiments using radioactive isotopes for nuclear radioactive waste decontamination after FY2016.

Fundamental Research on Condensed Matter Nuclear Reaction (CMNR) will be performed through these two research activities. We hope to clarify what is happening during CMNR by obtaining systematic experimental data.

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