Summary of LENR research in Japan

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LENR experiments in Japan in the early days (~2000)

Various types of experiments had been conducted since just after the F-P announcements.

Representative experiments in 90s

- Electrolysis

  F-P type

  Excess heat, Neutron emission, Nuclear products

  Takahashi et al. Proc. of ICCF2 (1992)

  Mizuno, Ohmori et al. DENKI KAGAKU (1996) 1160.

  Ohmori et al. Current Topics in Electrochemistry, 5 (1997) 27.

  Double structure cathode

  Excess heat, He production

  Arata et al. Jpn. J. Appl. Phys. 38 (1999) L774.

  Multi-Layered cathode

  Transmutation products

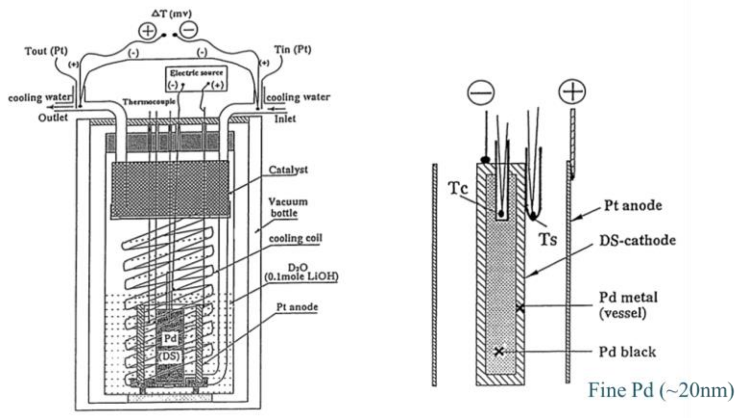
  Iwamura et al. Fusion Technology, 33 (1998) 476.

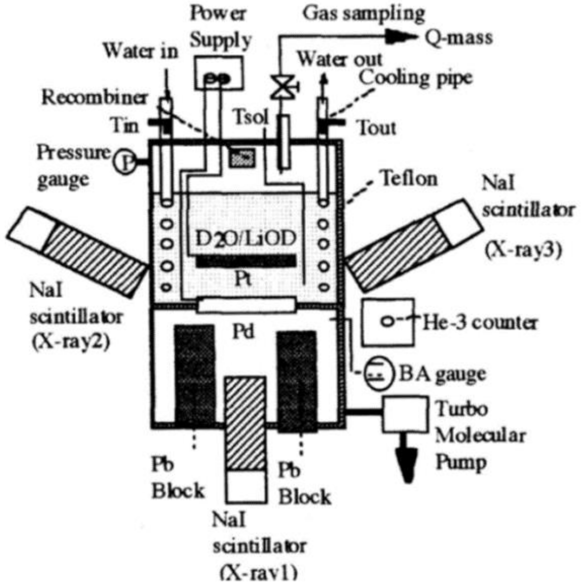
- Deuterium gas loading/unloading

  Multi-Layered metal

  Excess heat, He production

  Yamaguchi et al. Proc. of ICCF3 (1993) 179.





LENR experiments in Japan (2000 ~)

From around ~2000, the following experiments have been mainly conducted;

1) Deuterium/Hydrogen absorption/desorption with nano-sized metal composite particles.
2) Deuterium/Hydrogen absorption/desorption with multi-layered metals complex.
3) Deuterium permeation with multi-layered metal complex.

From some view points, these experiments are characterized

Sample (host material)		Experimental method		Reactant
• nano-sized (fine-structured) metal • Composite materials	×	• Gas loading/unloading • Gas permeation	×	• Deuterium • Hydrogen

Measurement of temperature, heat balance --> *Excess heat*

Elemental analysis --> *Nuclear transmutation*

D/H charging experiment with nanocomposite particles (1)

Collaboration with Technova Inc., Tohoku U, Nissan Motor Co. Ltd, Nagoya U, Kobe U, Kyushu U.
Supported by New Energy and Industrial Technology Development Organization (NEDO-MHE project; 2015-2017)

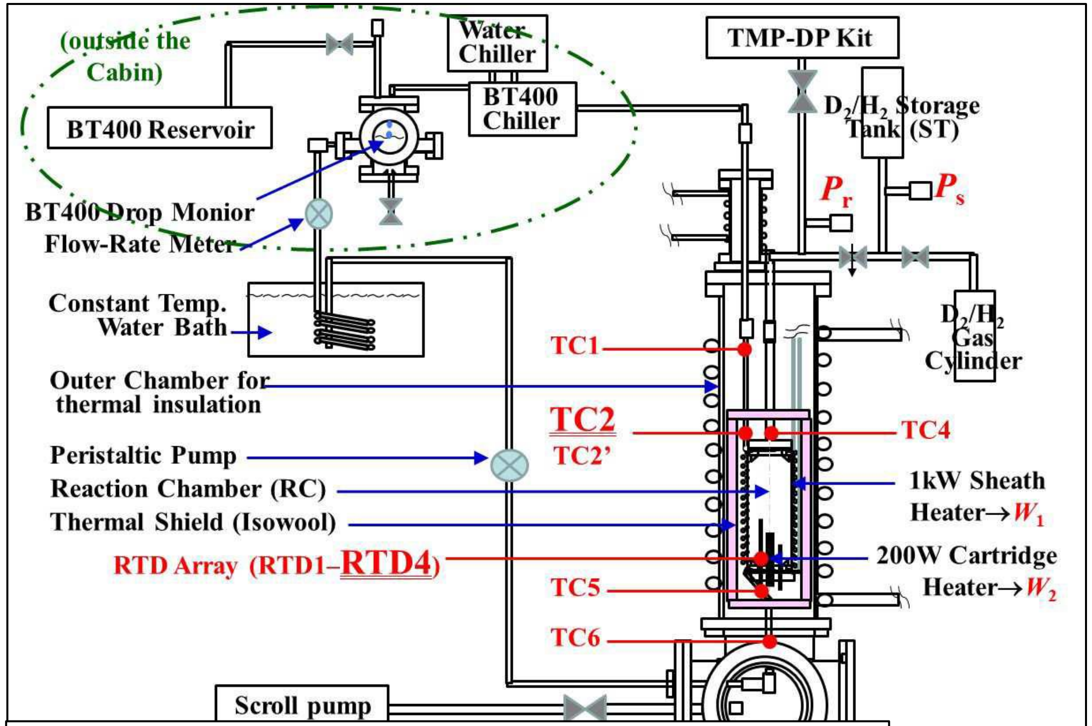
Samples :

- **PdNi/ZrO2 (PNZ) , CuNi/ZrO2 (CNZ)** : melt-spinning of Pd-Ni-Zr/Cu-Ni-Zr alloy → calcination → nanocomposite PdNi/CuNi supported on ZrO2. (*)
- **CuNi/SiO2 (CNS)** : Chemical synthesis by solution → calcination → nanocomposite absorbed on pore surface and/or other surface of mesoporous silica. (*)
- **Pd/SiO2 (PS)** : Embedded Pd nanoparticle to SiO2 microparticles.

** examined the samples with different mixing ratio*

Experiment :

- Charging D/H to the sample filled in the reaction chamber with ZrO2 beads filler at root temp. and elevated temp.
- Four resistive temperature detectors (RTD) measures directly the sample temperature at different position in the rection chamber.
- Six thermocouples measure the coolant temperature.
- D/H loading ratio was measured by the pressure change.
- Calorimetry calibration (mass flow or temperature comparison with heater input power) was done with non-active sample powder (ZrO2 beads) with H-gas or with active sample with He-gas. Both methods gave considerable agreement.

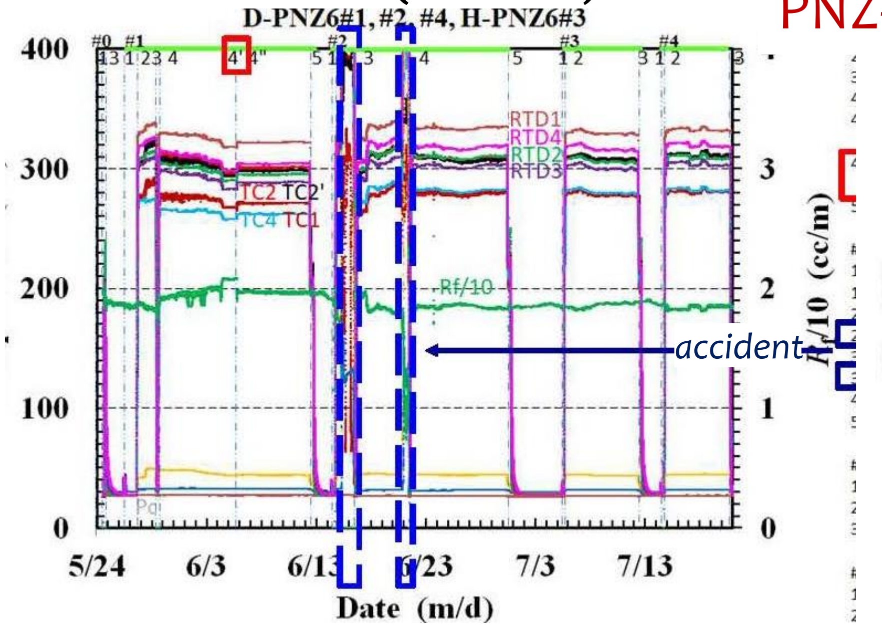


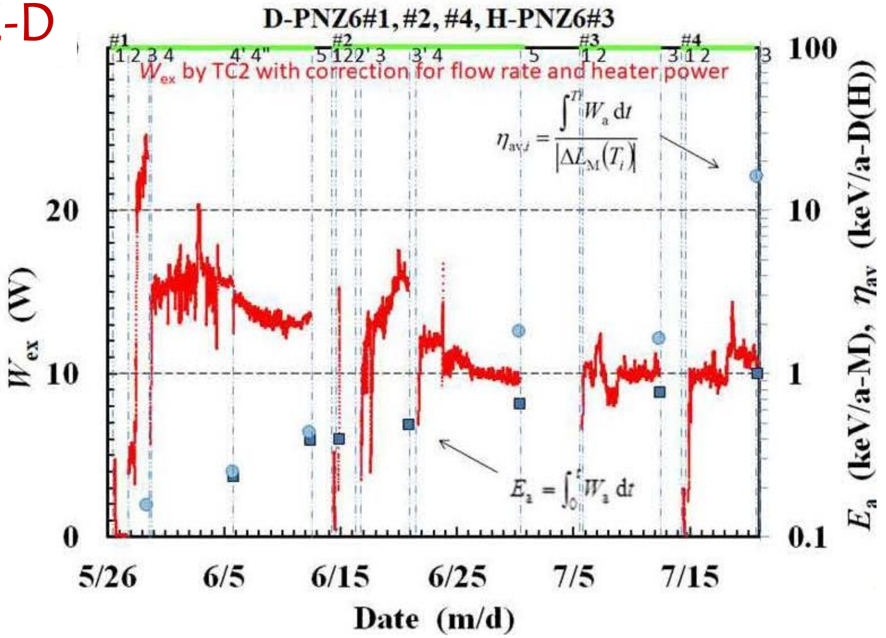
D/H gas-charging-calorimetry system at Kobe U

D/H charging experiment with nanocomposite particles (2)

Introduced the gas into the reaction chamber at room temperature. (Phase 1).
After a few hours, absorption is saturated and associated heat evolution terminated, then the reaction chamber is heated. (Phase 2).

PNZ-D





#x-y
x : Number of series of exp.
y : Number of different heater outputs in each experiment.

- Most samples with binary metal nanocomposite produced excess power of 3-24 W sustainably lasting for up to several weeks.
- The excess power was observed in the Pd/Ni-D, Pd/Ni-H, and Cu/Ni-H system. Difference of D and H was also observed.
- No excess heat was observed for the single element sample (Pd/SiO2).
- The excess power seems to depend on the ratio of Pd/Ni. W(Pd/Ni=1/10) > W(Pd/Ni=1/7)

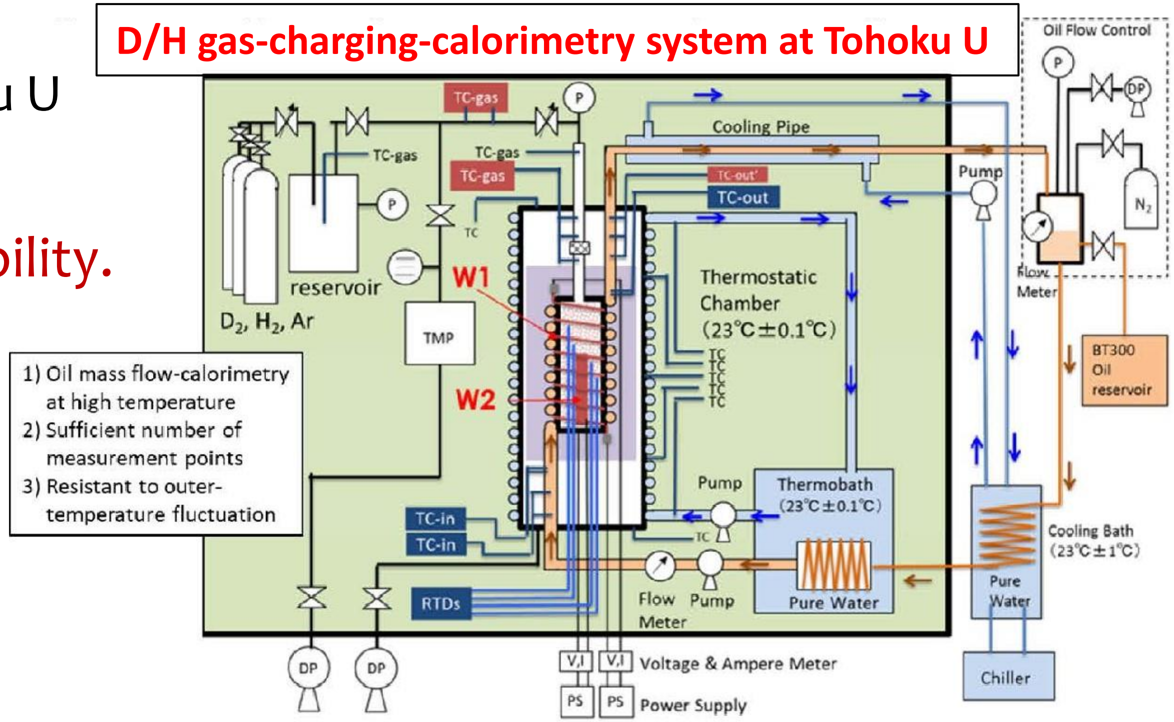
A. Kitamura et al., Int. J. Hydrogen Energy., 43 (2018) 16187. *A. Kitamura et al., Proc. of JCF18 (2018) 14.*

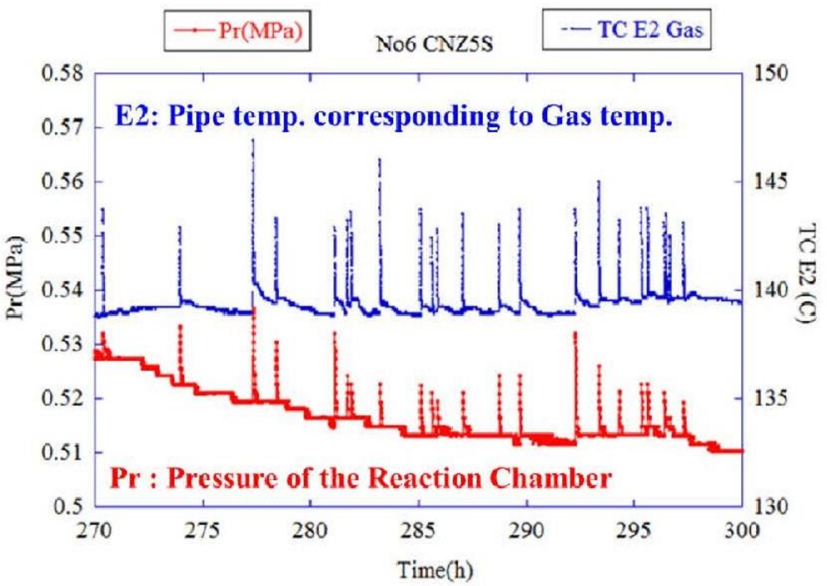
D/H charging experiment with nanocomposite particles (3)

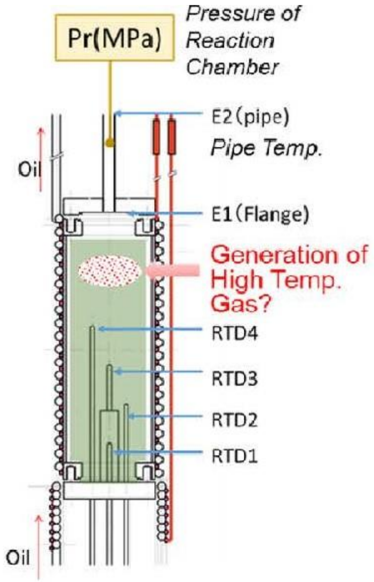
The experiments were performed independently at Tohoku U with the apparatus they originally assembled.

⇒ Similar results were obtained with high reproducibility.

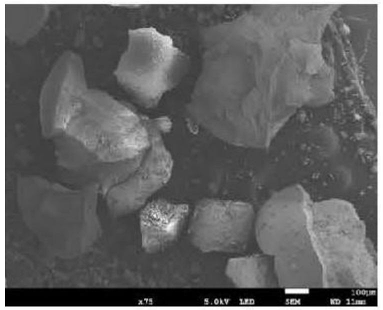
In addition, burst like increase of the temperature at gas inlet was observed simultaneously with pressure increase.







Broken ZrO2 Beads



After the experiment, ZrO2 used for filler was found to be broken.

⇒ strong stress was given locally due to heat burst.

Y. Iwamura et al., Proc. of JCF18 (2018) 32.

D/H charging experiment with nanocomposite particles (4)

Summary of the results for each sample.

No.	Place	Sample name	Composition	Gas	Temp (°C)	Max. power (W)	Released enthalpy	
1	Kobe	PS3	Pd/SiO_2	D	200–300	~ 0	~ 0	
2	Kobe	PNZ3	$PdNi_7Zr_{15}–O_x$	D	200–300	10	7.7 MJ/mol-D	80 eV/D
3	Kobe	PNZ3r	PNZ3-re oxidized	H	200–300	8.0	2.0 MJ/mol-H	21 eV/H
4	Kobe	CNZ5	$CuNi_7Zr_{15}–O_x$	H	200–300	3.3	3.6 MJ/mol-H	37 eV/H
5	Tohoku	PNZ4s	$PdNi_7Zr_{15}–O_x$	D	160–300	3.3	1.4 MJ/mol-D	15 eV/D
6	Tohoku	CNZ5s	$CuNi_7Zr_{15}–O_x$	H	160–250	5.0	6.5 MJ/mol-H	68 eV/D
7	Kobe	PSf1	$Pd/SiO_{2\text{–covered}}$	D	200–300	~ 0	~ 0	
8	Tohoku	PSn1	$Pd/meso–SiO_2$	D	200–300	~ 0	~ 0	
9	Kobe	CNS3	$CuNi_{10}/SiO_2$	H	200–400	4.4	67 MJ/mol-H	700 eV/H
10	Tohoku	CNS3s	$CuNi_{10}/SiO_2$	H	15–300	4.2	11 MJ/mol-H	120 eV/H
11	Kobe	PNZ5	$PdNi_7Zr_{15}–O_x$	D	250–350	4.2	7.6 MJ/mol-D	70 eV/D
12	Tohoku	CNZ6s	$CuNi_7Zr_{15}–O_x$	H	150–300	2.5	5.3 MJ/mol-H	55 eV/H
13	Kyushu	PNZ	$PdNi_7Zr_{15}–O_x$	H	23–450	–	–	
14	Kobe	PNZ6	$PdNi_{10}Zr_{20}–O_x$	D	250–350	25	200 MJ/mol-D	2.1 keV/D
15	Kobe	PNZ7k	$PdNi_7Zr_{15}–O_x$	D	250–350	5.0	3.4 MJ/mol-D	35 eV/D
16	Tohoku	PNZ7s	$PdNi_7Zr_{15}–O_x$	D	250–350	4.0	3.0 MJ/mol-D	31 eV/D

Excess heat was observed with

{Pd/Ni/ZrO2, Cu/Ni/ZrO2, Cu/Ni/SiO2}

×

{H, D}

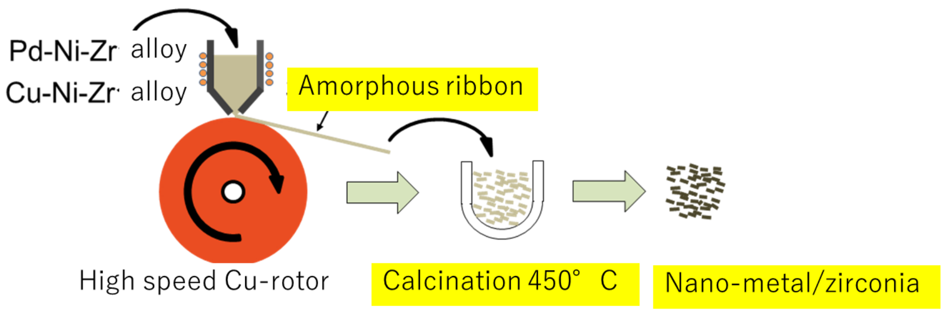
From 2018, further studies have been performed in each group.

- Improve efficiency
- Higher energy generation

D/H charging experiment with nanocomposite particles (5)

Technova Inc. and Kobe U

Melt-Spinning/Oxidation Process for Making Sample



nano-islands of Pd-Ni/Cu-Ni are formed

Optimizing sample conditions and treatment

- 1/7 to 1/10 for Cu/Ni or Pd/Ni in zirconia supporter is good.
- The sample can be reused by repeated calcination.
- The excess power increased the re-calcination process.

2-10 nm diameter particles or nano-islands on the several microns support flake are observed by microscopic analysis

Cu-Ni-Zr (H)

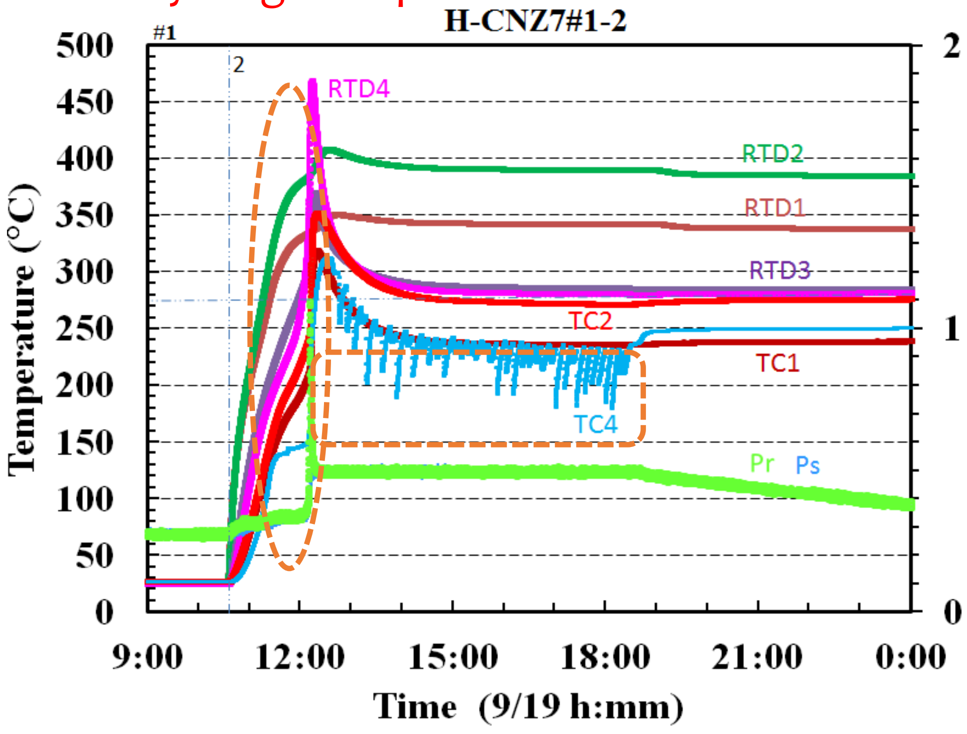
Run ID, nominal	Heater Input (W1, W2) W	Wex (W/kg): CNZ7	Wex (W/kg): CNZ7r
#1-2	120, 80	(152, burst)	96
#1-4	140, 95	12	110
#2-2	120, 80	7	118
#2-4	140, 95	14	126
#3-2	120, 80	9	115
#3-4	140, 95	13	137
Sample (g)		1,150	505

Pd-Ni-Zr (D)

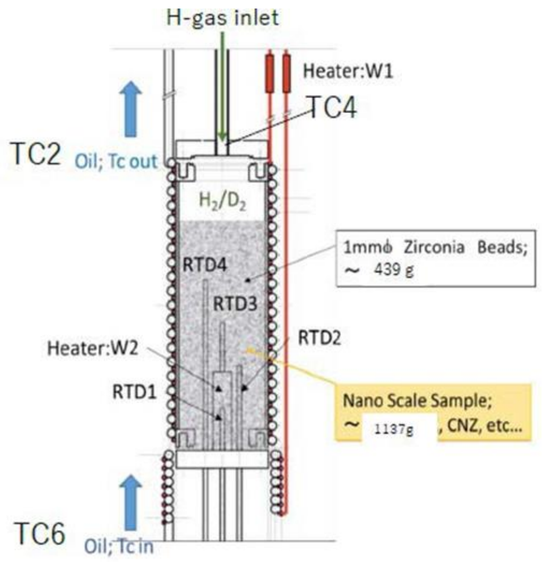
Run ID, nominal	Heater Input (W1, W2) W	Wex (W/kg): PNZ10	Wex (W/kg): PNZ10r
#1-2	120, 80	5	47
#1-4	140, 95	4	95
#2-2	120, 80	10	
#2-4	140, 95	14	77
#3-2	120, 80	8	
#3-4	140, 95	18	124
Sample (g)		965	450

D/H charging experiment with nanocomposite particles (6)

Hydrogen exp.



- Anomalous heat burst with ~ 130 W peak power was observed. This was only observed at the beginning of the temperature elevation phase.
- Oscillatory evolution of temperature was observed at gas-outlet/inlet point of the reaction chamber. This may be same phenomena as reported by Tohoku U group.



PNZ and CNZ type powders, sustainable thermal power of ~ 100 W /kg can be generated for more than several weeks.

A. Takahashi et al., Proc. of JCF19 (2019) 1.
T. Yokose et al., Proc. of JCF19 (2019) 18.
A. Takahashi et al., J. Condensed Matter Nucl. Sci. 33 (2020) 14.

D/H charging experiment with nanocomposite particles (7)

Current summary

- For CNZ-type powders with hydrogen gas, about 200-300 W/kg excess power for a week has been achieved with 100% reproducibility under certain conditions.
- The COP is in the range of 1.2-1.4.
  Note that it is in the experiments for characterizing of the phenomena. (Experimental procedures or sample conditions have not been optimized)
- Typical excess power is 10-100 MJ/mol-H (10-100 keV/H).
  Note that the value "mol-H" here is total amount of absorbed H in the time-interval of excess power observation. But the hydrogen spent for the reaction is considered to be a small fraction of it. Therefore, the excess power per mol-H is underestimated.

  ⇒ Nuclear reaction origin. (the energy is typically ~ 1-10MeV/H)
  Non-nuclear explanations should be still considered.
- Sample and operation conditions for improving the efficiency and the released energy are still under study.
  - Sample condition and impurity control; microscopic analysis of the sample by various methods comparing before and after experiments.
  - Experimental condition; temperature of absorption/desorption.

Excess heat experiments using a nano-sized multilayer composite (1)

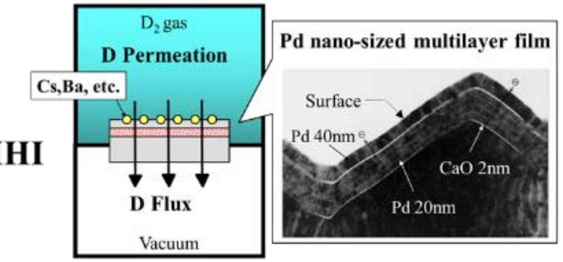
Tohoku U and CLEAN PLANET Inc.

Based on the previous experiments, the following considerable factors were focused ;

Nano-sized particles/multilayer, metal composite, H/D diffusion.

Permeation-Induced Transmutation with nano-sized multilayer thin film

MHI

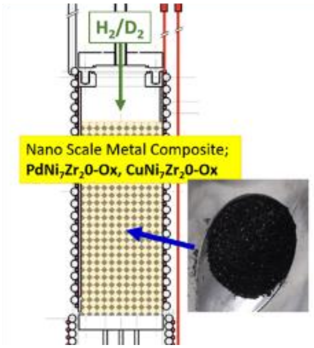


$^{133}_{55}Cs + 4d \rightarrow {}^{141}_{59}Pr + 50.5MeV$

D Diffusion
Nano size
Multilayer
Elemental Analysis

Excess Energy with nano-sized Metal Composite Particles

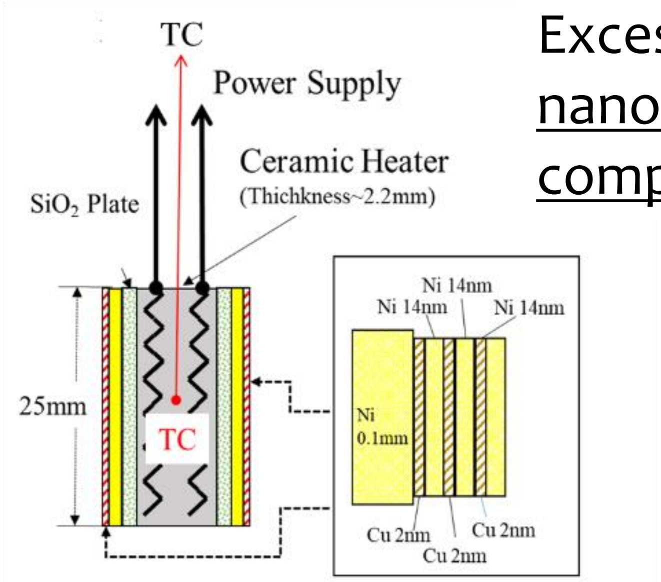
NEDO Project
Mizuno Exp.



Nano size Particles
H/D Diffusion
Heat Estimation

Present Method

Excess Energy with Nano-sized Multilayer Metal Composite and Hydrogen Gas



Nano-sized Multilayer Metal Composite

Excess energy measurement with nano-sized multilayer metal composite and hydrogen gas

Y. Iwamura et al., J. Condensed Matter Nucl. Sci. 33 (2020) 1.
Y. Iwamura et al., Proc. of JCF21 (2021) 1.

Excess heat experiments using a nano-sized multilayer composite (2)

Nano-sized multilayer metal composite

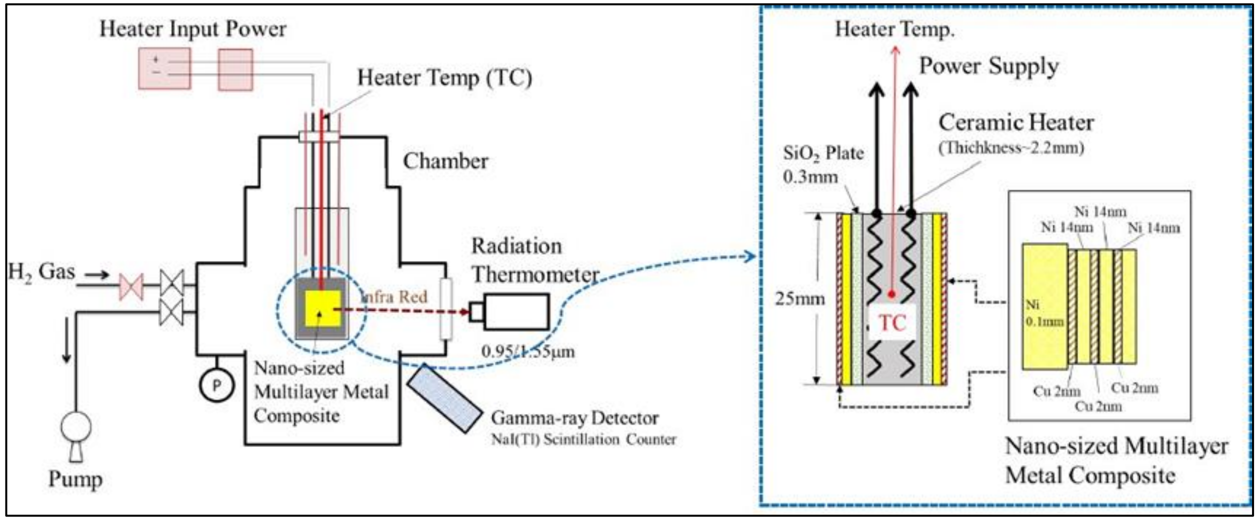
Sample preparation :

- Cu (2 nm) and Ni (14 nm) were deposited onto 0.1 mm Ni foil alternately by sputtering.
- In some cases, CaO or Y2O3 film (2 nm) were inserted into the Ni layer.
- The multilayer composite samples were mounted to both sides of the ceramic heater via SiO2 plates.

Since impurities in the sample could suppress heat generation reaction, close attention is paid to contamination in sample preparation.

Experimental procedure :

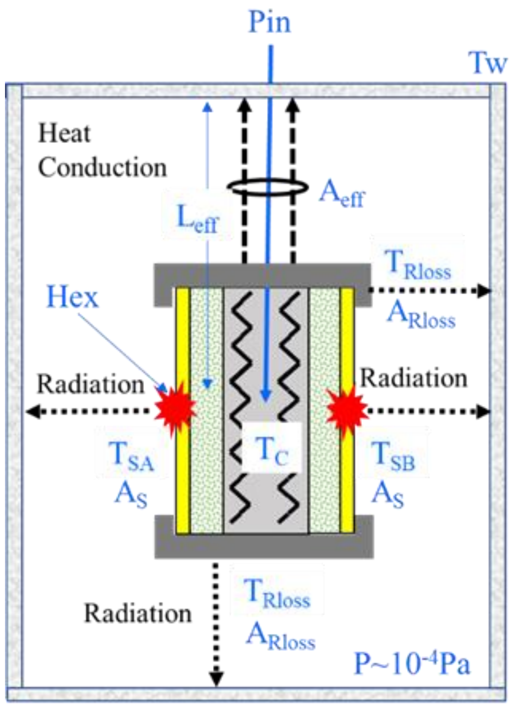
1) Baking the sample (T>200℃)
2) Introducing H2 gas up to about 230 Pa at 250℃ (typically loading for 16h)
3) Evacuating the chamber, then heating up the sample up to 500-900 ℃.
4) Measuring the sample temperature with the thermocouple and the radiation thermometer.
5) Cooling down the sample.
6) Repeating 2) to 5).



"Blank run" with Ni bulk sample was performed to obtain relation between the input power and the thermocouple temperature.

Excess heat experiments using a nano-sized multilayer composite (3)

Details for the excess heat calculation



T : Temperature of each surface
A : Area of each surface

$$k_{eff}\frac{T_C - T_W}{L_{eff}}A_{eff} + A_S\sigma\{\varepsilon_A(T_{SA}^4 - T_W^4) + \varepsilon_B(T_{SB}^4 - T_W^4)\} + A_{Rloss}\varepsilon_{Rloss}\sigma(T_{Rloss0}^4 - T_W^4) = P_{in} + H_{ex}$$

Excess heat

Input power

Heat conduction

Thermal radiation

k_{eff} : Equivalent thermal conductivity

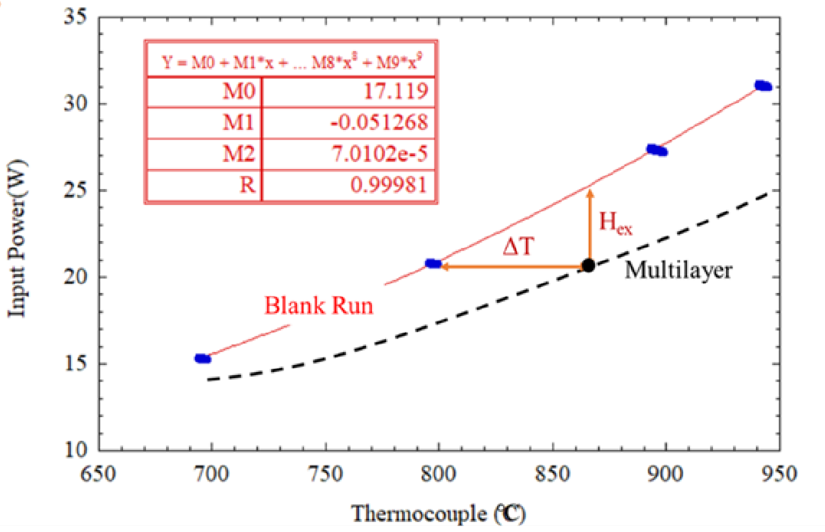
ε : Emissivity

σ : Stefan-Boltzmann constant

Assumptions :

- *Thermal conduction via H2 gas is negligible as H2 pressure is low enough.*
- *Radiation from chamber wall is negligible because Tw is room temperature.*
- *The electrical input power is constant.*

The excess heat (H_{ex}) can be expressed as a function of ΔT

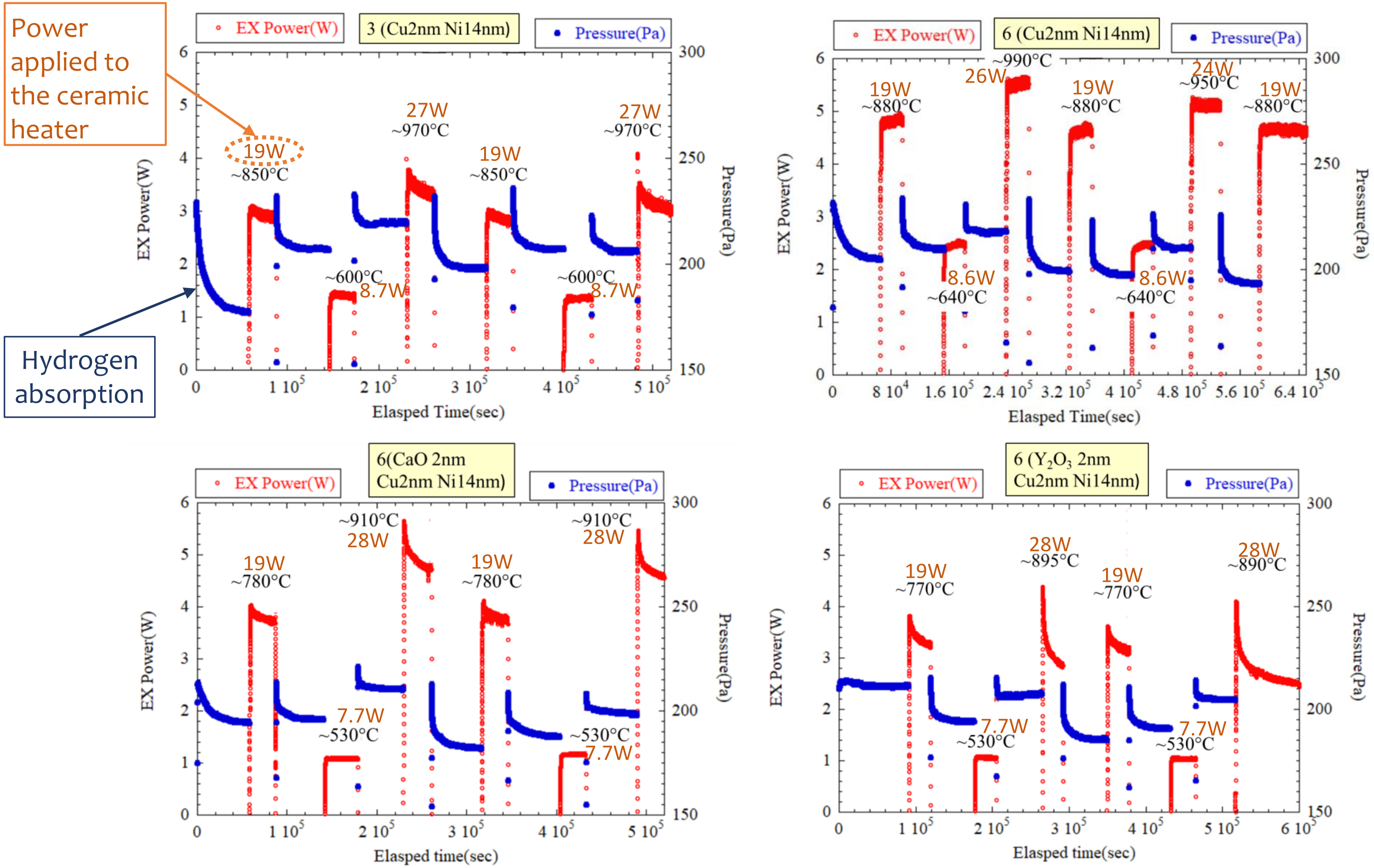


Relation between Input power and Thermocouple temperature for Blank run and Multilayer run.

Y. Iwamura et al., Proc. of JCF21 (2021) 1.

Excess heat experiments using a nano-sized multilayer composite (4)

Results of excess heat measurement for each sample type



- Excess heat tends to increase as temperature increase.
- Excess power varied depending on the sample type even with the same input power was applied.
- Time dependence of the excess power is also different for the sample type; only increase in 6(Cu/Ni).
- Correlation between the amount of heat generated and the amount of hydrogen absorbed has been found.

Excess heat experiments using a nano-sized multilayer composite (5)

Summary table of excess energy for each sample type

	3(Cu/Ni)	6(Cu/Ni)	6(CaO/Cu/Ni)	6(Y_2O_3/Cu/Ni)
Absorbed H (mol)	7.6×10^{-4}	7.3×10^{-4}	5.1×10^{-4}	3.7×10^{-4}
Absorbed Number of H	4.6×10^{20}	4.4×10^{20}	3.0×10^{20}	2.3×10^{20}
Total Excess Energy (J)	4.6×10^{5}	1.1×10^{6}	5.9×10^{5}	2.6×10^{5}
Excess Energy per H (J/H-mol)	6.0×10^{8}	1.5×10^{9}	1.2×10^{9}	6.8×10^{8}
Excess Energy per H (eV/H)	6.0×10^{3}	1.6×10^{4}	1.2×10^{4}	7.1×10^{3}

- The excess energy for 6(Cu/Ni) was the largest.
- The released energy per hydrogen atom was on the order of keV or more.

  ⇒ The phenomenon cannot be explained by a chemical reaction.

Excess heat experiments using a nano-sized multilayer composite (6)

Current summary

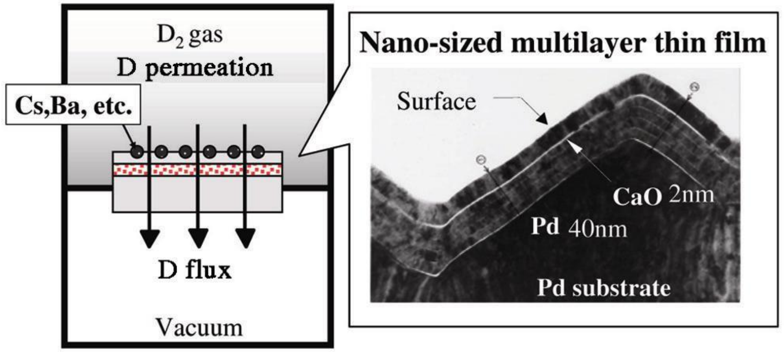
- The excess power of ~1 GJ/mol-H (~ 10 keV/H) has been observed.
- The excess heat is observed with almost 100% reproducibility if the experiment is repeated under the same conditions. However, at the present, there is still variation in the power by experiment.
- The ratio of the output power to the total input power is 1 ~ 2, currently.
- At present, the excess energy per H is calculated assuming the reaction is attributed to total amount of hydrogen absorbed. In fact, only some of those hydrogens are considered to react. Therefore, the excess power shown is underestimated.
- The released energy in order of > 10keV/H is difficult to be explained by a chemical reaction.

Deuterium permeation experiment using Pd multilayer thin film (1)

Mitsubishi Heavy Industries Ltd and Tohoku U

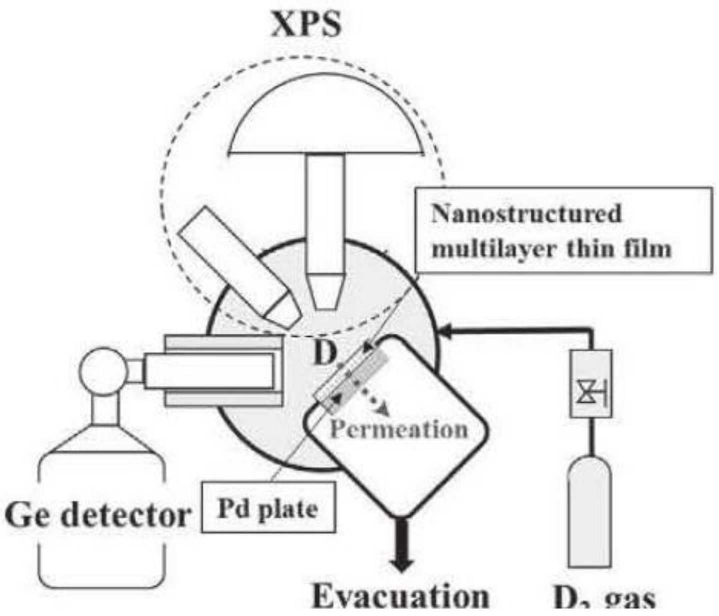
Sample :

- Pd (40 nm) and CaO (2 nm) thin films are alternatively deposited onto Pd film. (typically 5 sets of layer)
- Target substances (Cs, Ba, …) to be transmuted are added onto the surface by electrochemical method or ion implantation.



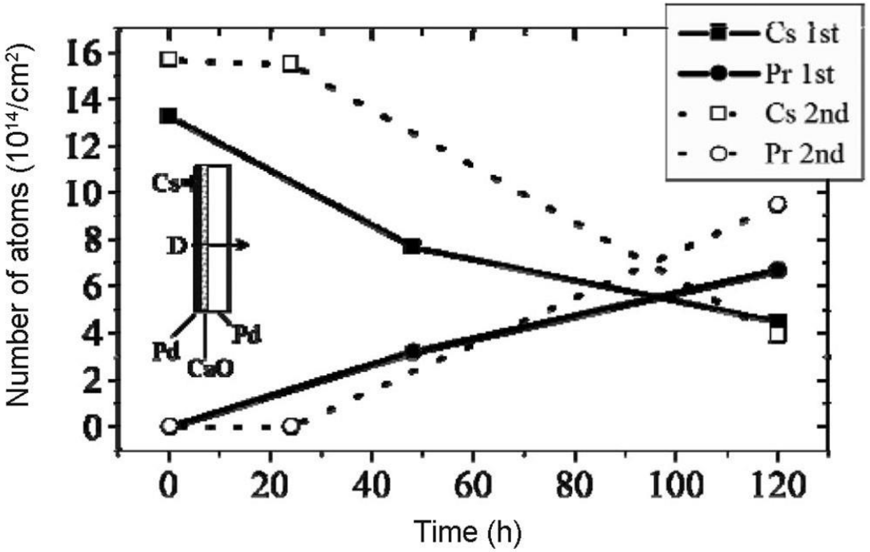
Experiment :

- One of the sample surface deposited a target element is exposed to the 1 atm D2 and the other side faces into the evacuated chamber. The purity of deuterium gas is > 99.6% (most of the impurity is H2)
- Deuterium permeates through the sample. The temperature was typically set at 70 ℃.
- After the experiment, the sample surface was analyzed.



Y. Iwamura et al. Jpn. J. App. Phys., 41 (2002) 4642.
Y. Iwamura et al., Current Science, 108 (2015) 628.

Deuterium permeation experiment using Pd multilayer thin film (2)



- Pr increased and Cs decreased with time.
- This transmutation occurred with good reproducibility.
- The efficiency depends on the flow rate (total amount of D2 permeated).

The following control experiments were performed under the same temperature and pressure as the foreground experiments ;

i) H2 gas permeation experiments using the same Pd multilayer samples (Pd/CaO/Pd).
ii) D2 gas permeation using the same Pd multilayer samples (Pd/CaO/Pd) without Cs.
iii) D2 gas permeation using the Pd sample without CaO.

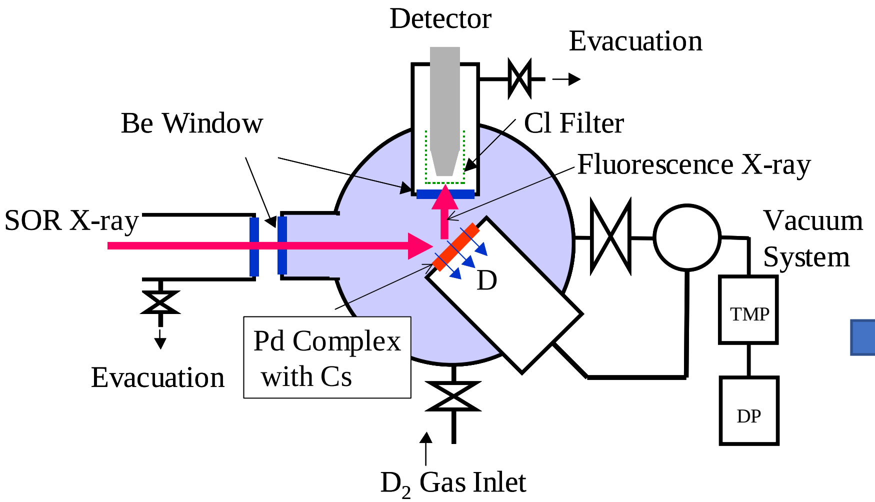
⇒ No Pr was detected in these all the control experiments.

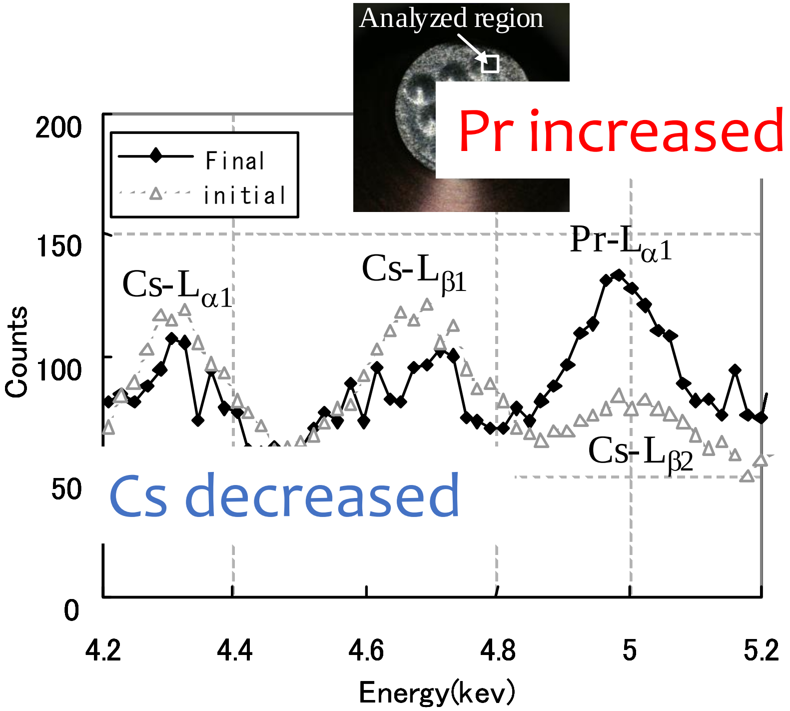
Both deuterium and nanostructured Pd multilayer with CaO are necessary factors to induce the transmutation reactions.

Deuterium permeation experiment using Pd multilayer thin film (3)

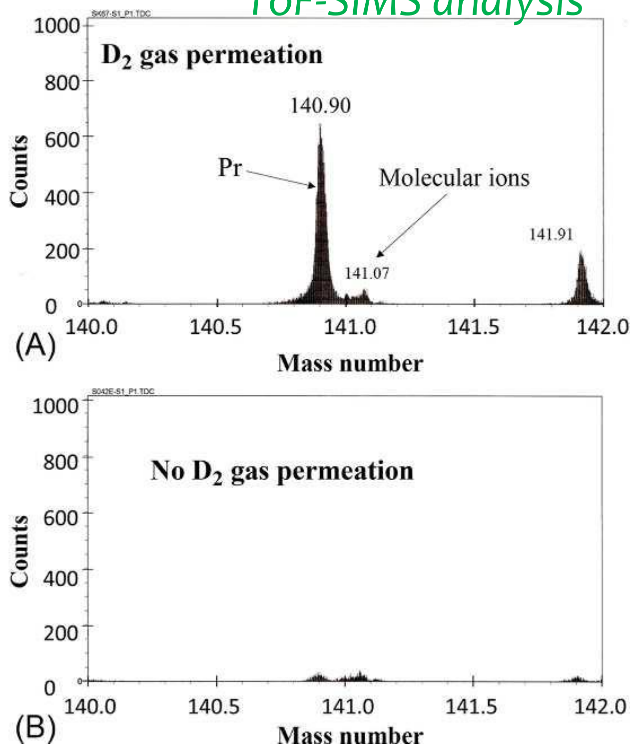
- It was confirmed by some analysis methods.

in situ experiment using SOR X-ray





ToF-SIMS analysis



Y. Iwamura et al., Proc. of ICCF11 (2006) 435.

- The experiments were replicated by other Japanese groups and the phenomena have been confirmed.

T. Hioki et al., Jpn. J. App. Phys., 52 (2013) 107301.

Y. Yamada et al., Proc. of ICCF12 (2006) 196.

T. Higashiyama et al., Proc. of ICCF11 (2006) 447.

Permeation experiment with higher pressure (900 kPa) and temperature (423 K).
→ Cs to Pr transmutation was confirmed quantitatively with ICP-MS analysis.

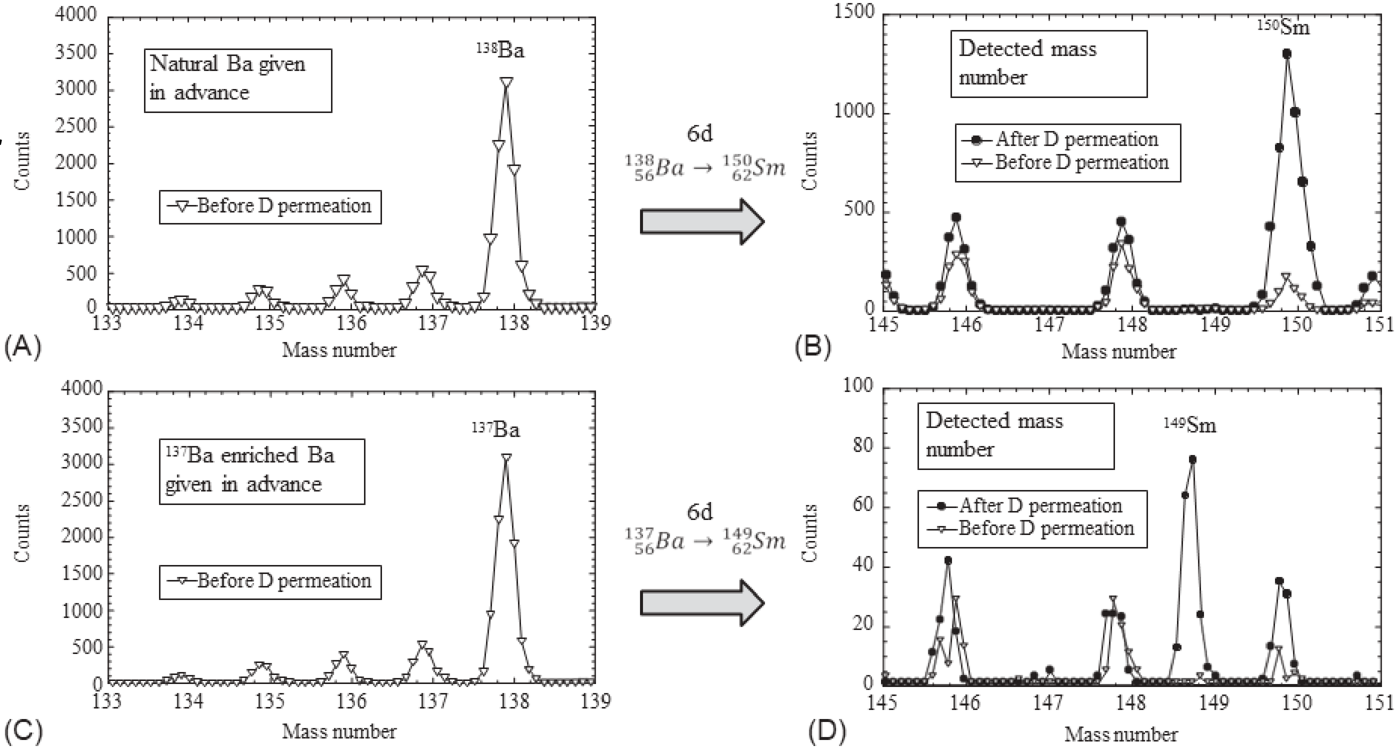
Deuterium permeation experiment using Pd multilayer thin film (4)

Current summary

- A reaction considered nuclear transmutation has been observed in deuterium permeation with nanostructured Pd/CaO multilayer sample. (It is confirmed by various elemental analysis methods)
- The following transmutation reactions have been confirmed so far.

$^{133}_{55}Cs \rightarrow {}^{141}_{59}Pr$ $\quad$ $^{137}_{56}Ba \rightarrow {}^{149}_{62}Sm$ $\quad$ $^{182}_{74}W \rightarrow {}^{190}_{78}Pt$

$^{88}_{38}Sr \rightarrow {}^{96}_{42}Mo$ $\quad$ $^{138}_{56}Ba \rightarrow {}^{150}_{62}Sm$ $\quad$ $^{186}_{74}W \rightarrow {}^{190}_{76}Os$



- Alkali and alkaline earth metals are likely to be transmutable by the present method.
- 2d, 4d, or 6d seem to react with the deposited elements.
- Transmutation approach is much more sensitive to the occurrence of a nuclear reaction rather than excess heat measurement.

1 μg nuclear product → 100 mW released heat

Transmutation for a specific isotope was confirmed.
→could be an evidence of nuclear reaction

Y. Iwamura, "Cold Fusion", ed. by J. Biberian, Elsevier, (2020) 191.

Other activities in Japan

- Other experiments

  PNZ-H experiment (Kyushu U, Waseda U, Nissan Motor Corp.)

  Deuterium absorption/desorption experiment with laser irradiation (Kyoto U)

  Deuterium desorption experiment using multilayer metal sample (Iwate U)

  …

- Japan CF-research society

  Member: ~70, currently

  Objectives :

  Contribute to science and technology development by studying CF phenomena, exchange information between JCF members and organize meeting for CF-research.

  Annual meetings :

  - The meeting has been held 21 times so far. (JCF1-JCF21)
  - The proceedings have been published for all meetings.

    available online from JCF4 from the following link (open access) ;

    http://www.jcfrs.org/proc_jcf.html

JCF

Japan CF-research Society

Summary

- In Japan, LENR/CMNS research has been continuously and actively conducted.
- In recent years, many important results have been obtained.
  - ✓ Deuterium/Hydrogen sorption/desorption with nano-sized metal composite particles and multi-layered metals complex.
    - Excess heat has been observed with good reproducibility
    - It has been observed with not only D but also H.
    - Observed excess power implies that it is possible to be a nuclear reaction origin.
    - Studies for improving the efficiency and increase in generated energy are on going by optimizing the conditions for sample treatment and the experimental procedure.
  - ✓ Deuterium permeation with multi-layered metal complex.
    - Selective transmutation have been observed with good reproducibility.
    - Clusters of deuterons are possibly involved in the reaction.
- What is needed for further progress … *(personal view)*

  Experiments in which conditions were systematically varied → clarify the trigger condition and the reaction mechanism.

  Engineering study for demonstration of practical use of the reaction.

Detailed and the latest results will be added by Japanese colleague.

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