A Review of Transmutation and Clustering in Low Energy Nuclear Reactions

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Outline

- Review of Transmutations
- Revisit Pd loading experiment on the Modified Missouri Magnetic Mirror Experiment (M^4X)
- Discuss MU research on hydrogen loading in diamond

Transmutations - Description

- Alternatives to the D + D reaction have been observed in LENR cells
- Essentially, D nuclei are absorbed by heavier atoms forming new species and releasing energy
- Other species detected using Energy-Dispersive X-ray Analysis (EDX) or Secondary Ion Mass Spectrometry (SIMS)

Types of LENR experiments

LENR Approaches
Electrolysis
Electro-diffusion
Gas discharges
Electron beam impact & exploding wires
Sonic waves
Ion implantation
Gas diffusion through thin films
Laser beams
Biological samples

Apparent Transmutations

Institution	Country	PI
University of Illinois	USA	Miley
Shizuoka University	Japan	Kozima
Iwate University	Japan	Yamada
Hokkaido University	Japan	Mizuno
Mitsubishi Corporation	Japan	Iwamura
Osaka University	Japan	Takahashi
University of Lecce	Italy	Vincenzo
Frascati Laboratory	Italy	De Ninno
Lutch Laboratory	Russia	Savvatimova
Tomsk Polytechnic	Russia	Chernov

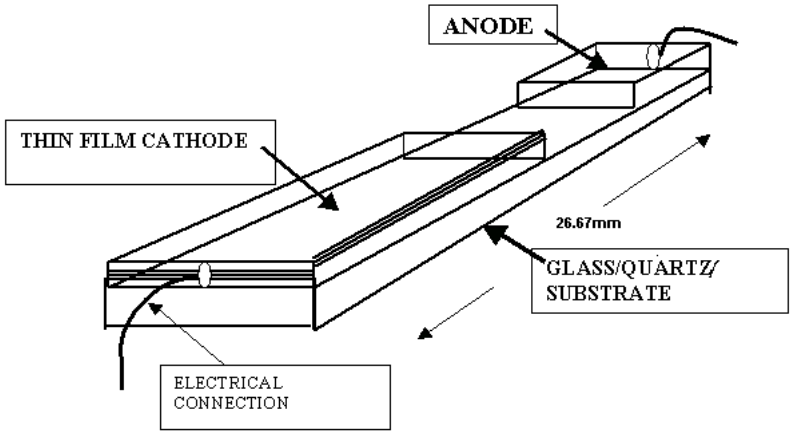
Apparent Transmutations (cont.)

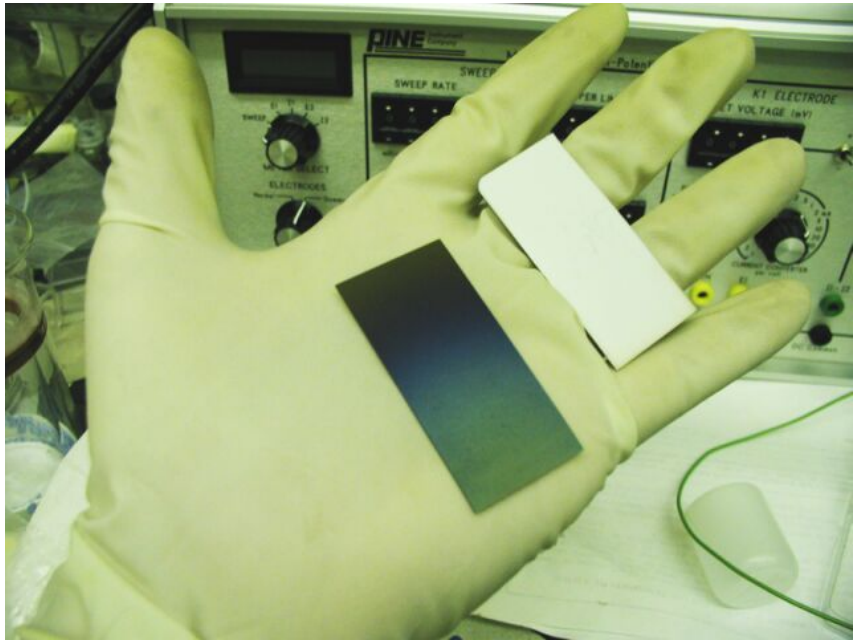
Institution	Country	PI
Lab. des Sci. Nucleaires	France	Dufour
Proton-21	Ukraine	Adamenko
Tsinghua University	China	Li Xingzhong
Portland State University	USA	Dash
Texas A&M University	USA	Bockris

Miley *et al.* (UIUC)

- Open type calorimeter, measurements of excess heat production were carried out during electrolysis in Li_2SO_4/H_2O solution with Pt-anode and Pd-Ni thin film cathodes (2000-8000 Å thick) sputtered on the different dielectric substrates (alumina, macor-ceramics, glass, polymethyle – methacrylate (PMMA)). Excess heat indicating power levels approaching a kW/cc in the thin film were measured.

Miley *et al.* (UIUC)





Miley *et al.* (UIUC)

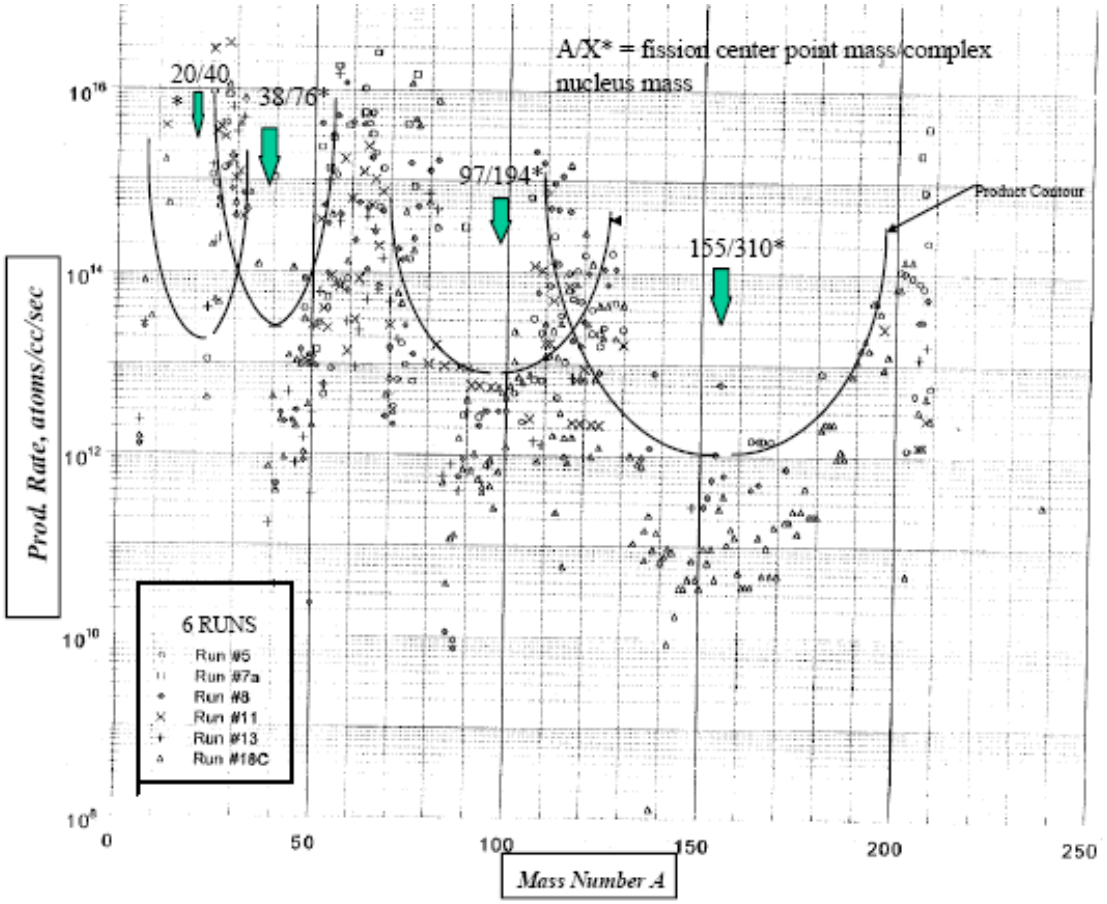
- Peaks at:

A = 20 – 30

50 – 80

110 – 130

190 – 210



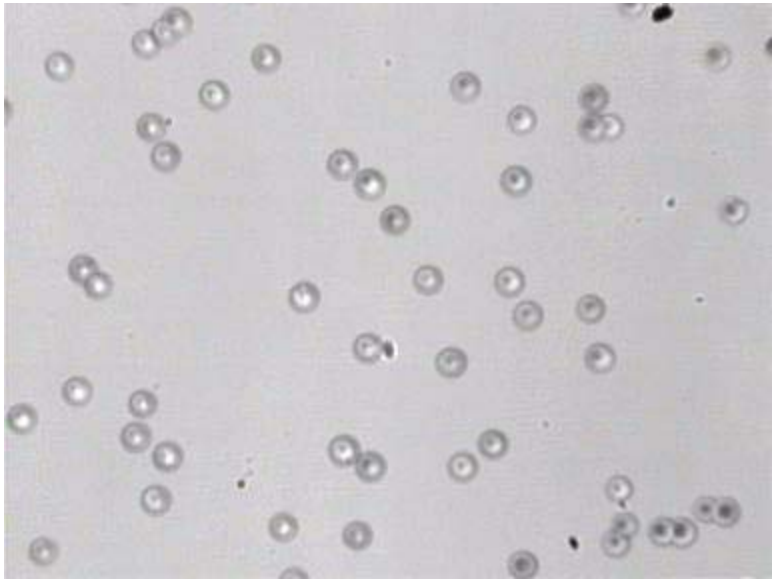
Miley, ICCF8, 2000

Miley *et al.* (UIUC)

- Discovery of 4-peak nuclear reaction products using thin films
- *Production rate (atoms/cc-sec) vs.A* shows zones of high yield (~ 10^{16} atoms/cc-sec) separated by low yield zones (<10^{12}), ~ fission of heavy neutron rich complexes.
  Sims broad surface scan shows numerous localized reaction areas.

Miley *et al.* (UIUC)

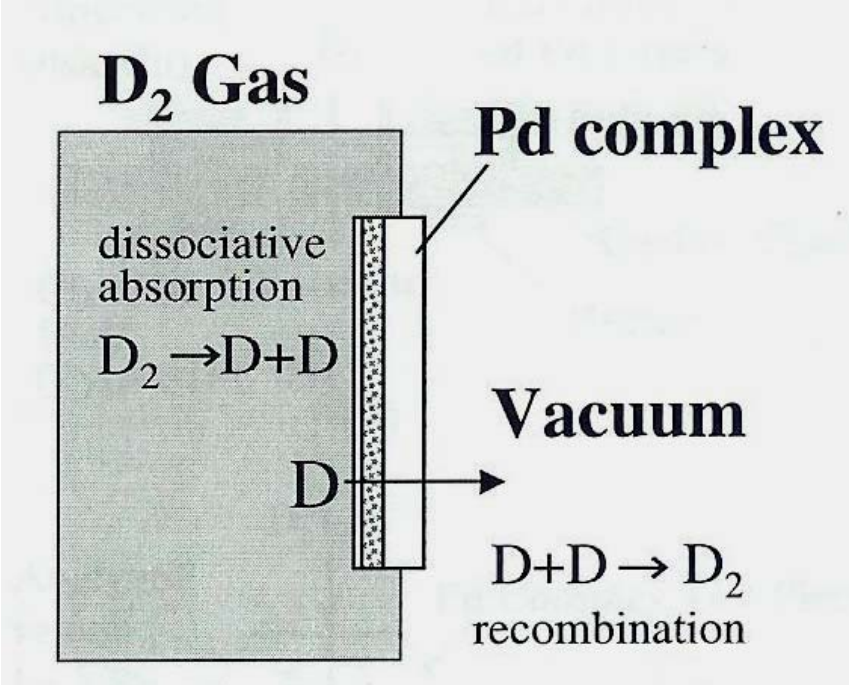
- Other evidence for nuclear reactions
  - MeV charged-particles
  - Soft X-rays



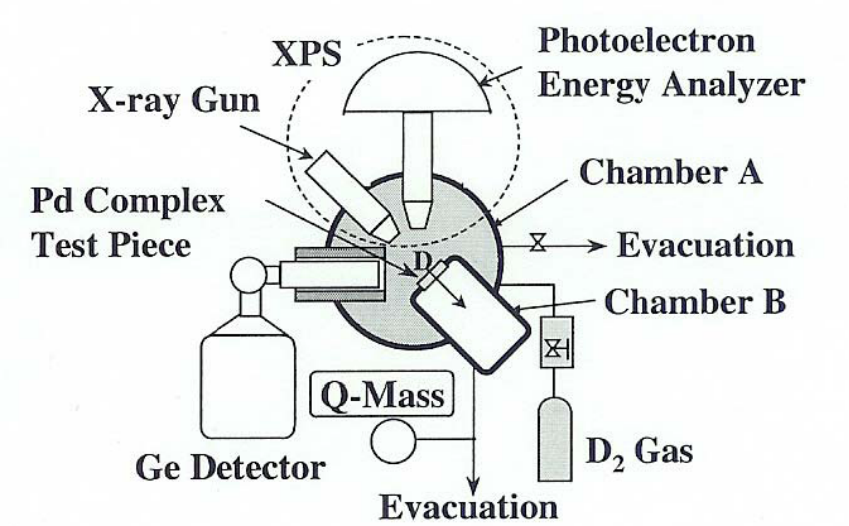
Tracks in CR-39 from 12.0 MeV α-particles; image area S= 0.2x0.2 mm, (X 700)

Iwamura *et al.* (Mitsubishi)

- Transmutation by diffusion of D2 gas through thin films
- Transmutation of Cs and Sr observed



Iwamura *et al.* (Mitsubishi) (cont.)



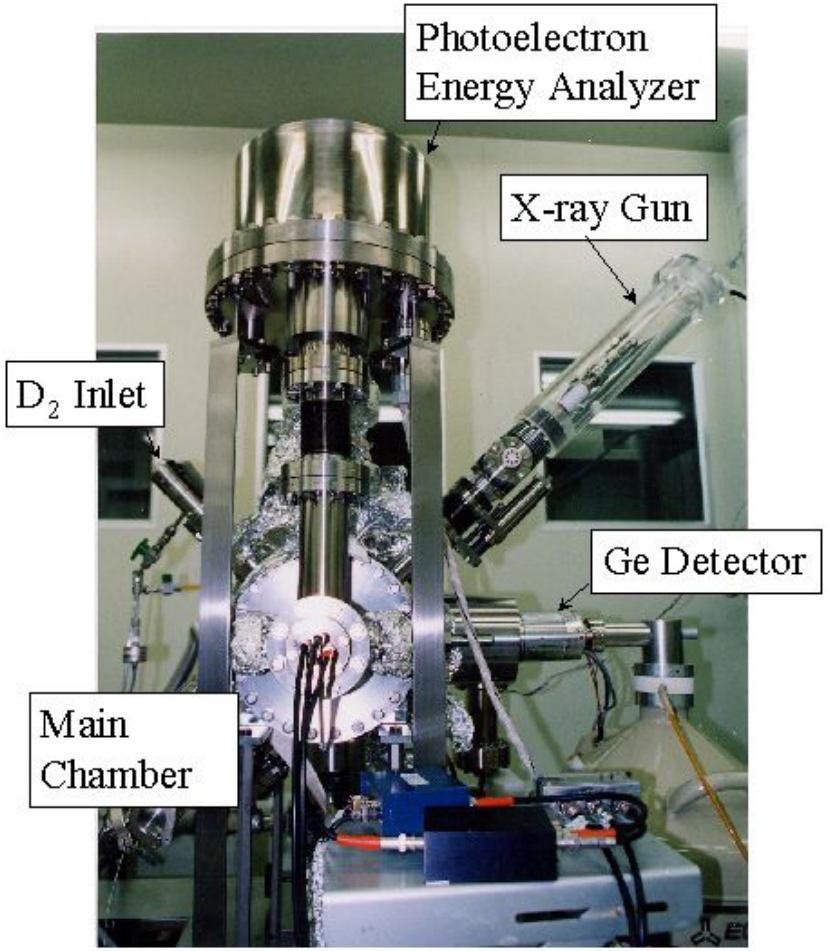
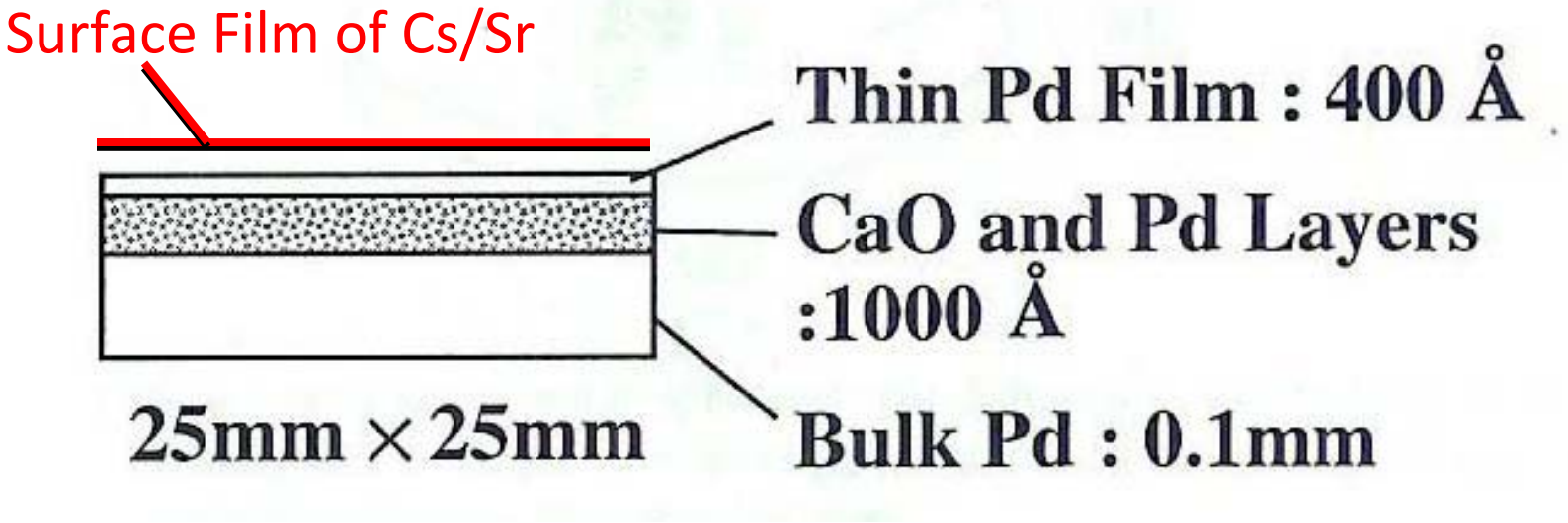
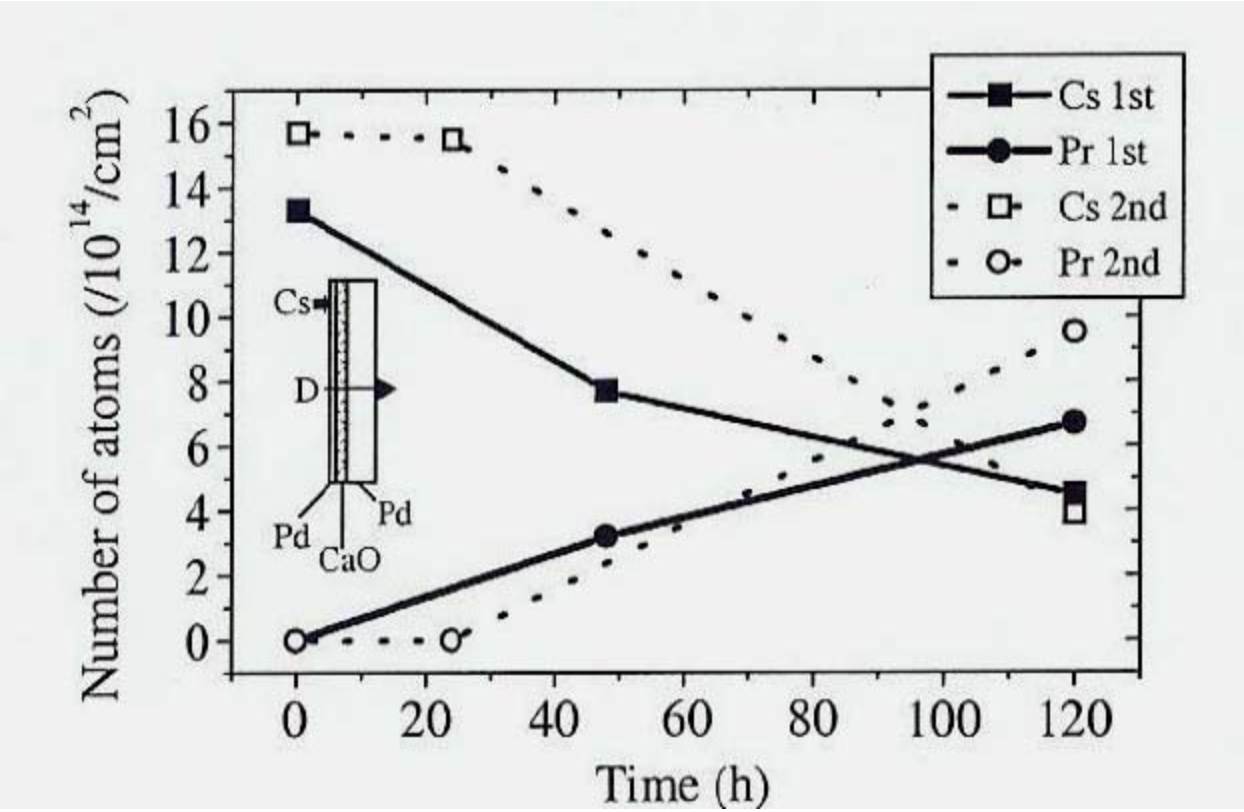


Photo is *courtesy of T. Iwamura*

Iwamura *et al.* (Mitsubishi) (cont.)

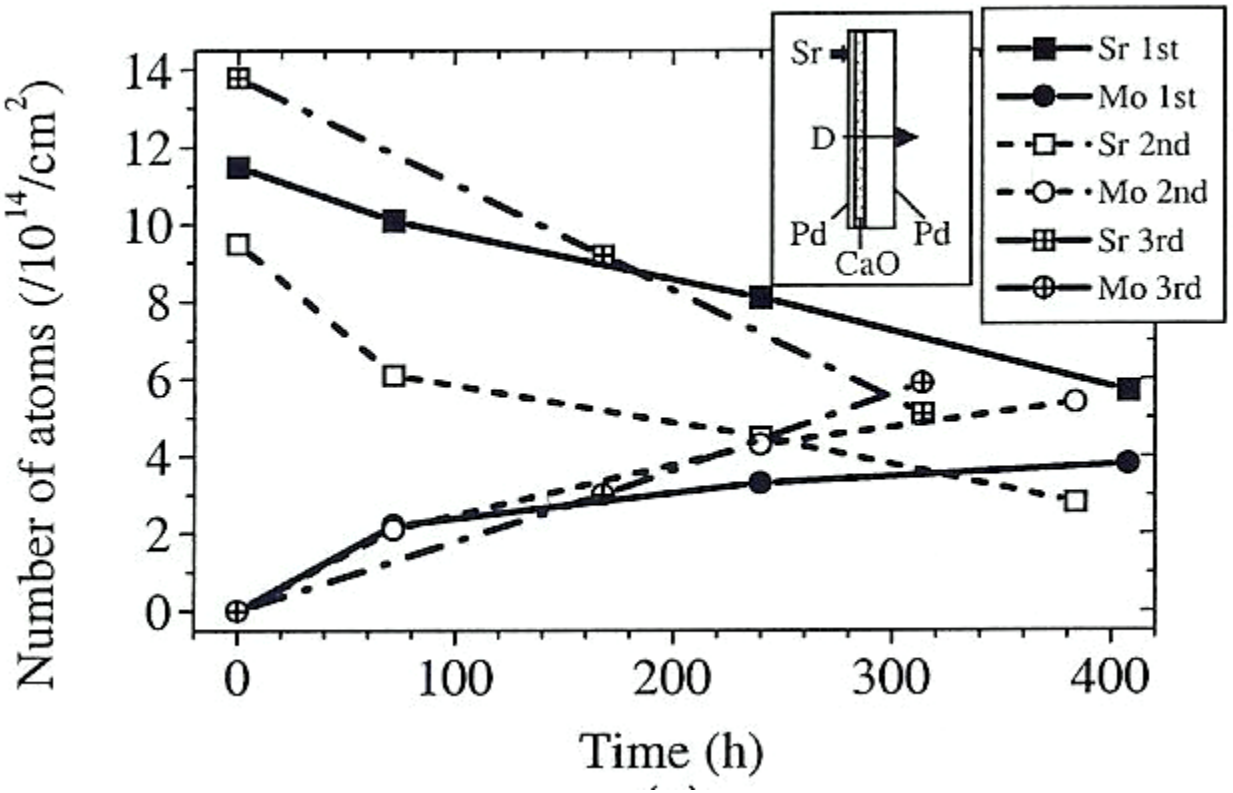


Iwamura *et al.* (Mitsubishi) (cont.)



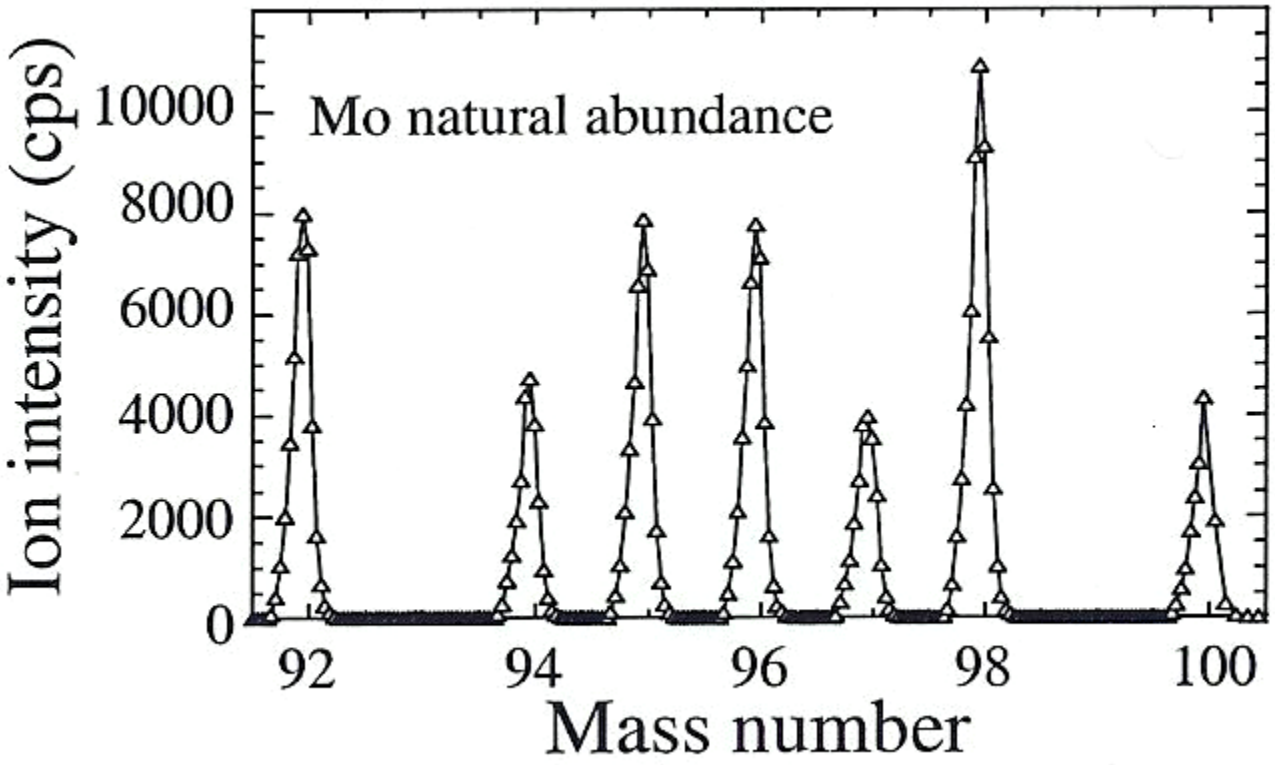
Pr ↑ - Cs ↓

Iwamura *et al.* (Mitsubishi) (cont.)



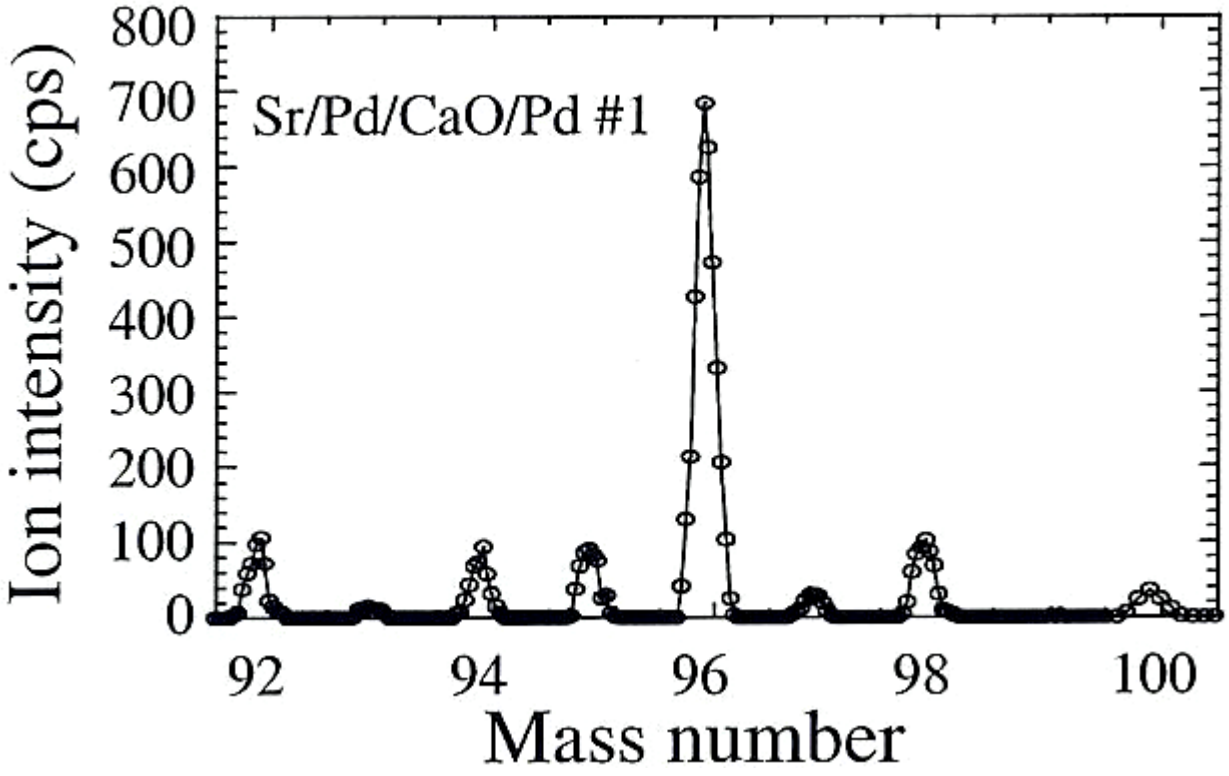
Mo ↑ - Sr ↓

Iwamura *et al.* (Mitsubishi) (cont.)



Sims measurement on natural Mo

Iwamura *et al.* (Mitsubishi) (cont.)



Sims measurement w/ D2 flow

Iwamura *et al.* (Mitsubishi) (cont.)

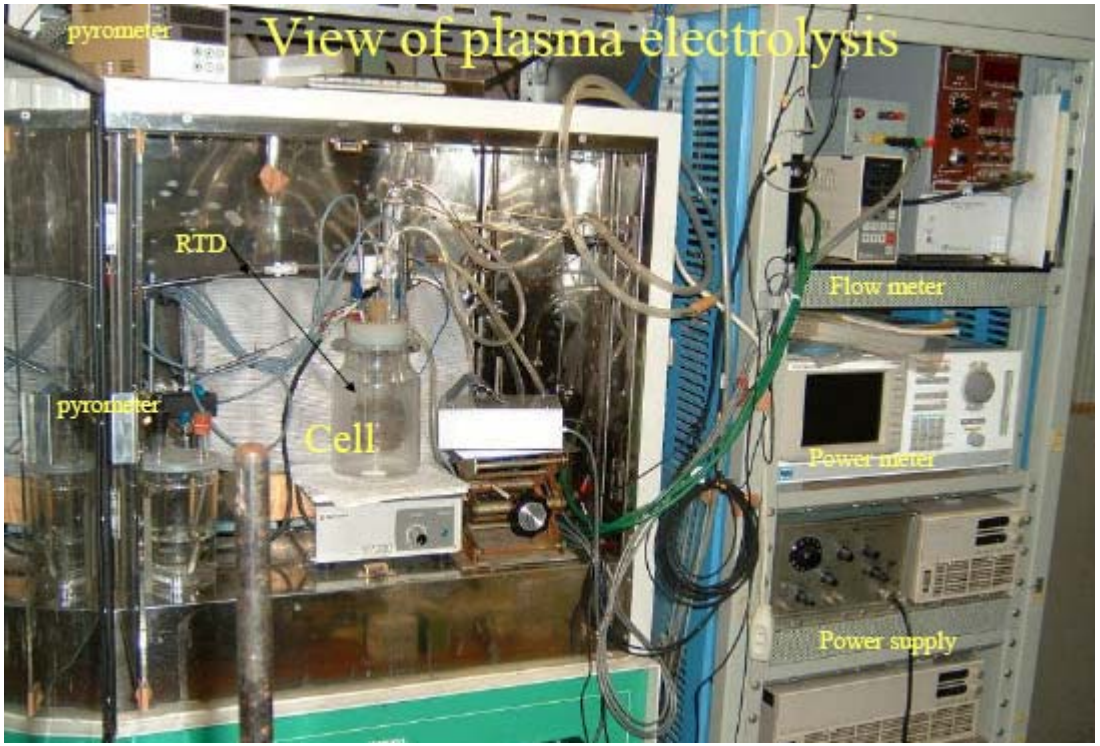
- Without CaO film: no transmutation
- Without D2: no transmutation

Possible Reactions

$$^{133}_{55}\mathrm{Cs} + 4\left(^{2}_{1}\mathrm{H}\right) = ^{141}_{59}\mathrm{Pr} + 50.5\ \mathrm{MeV}$$

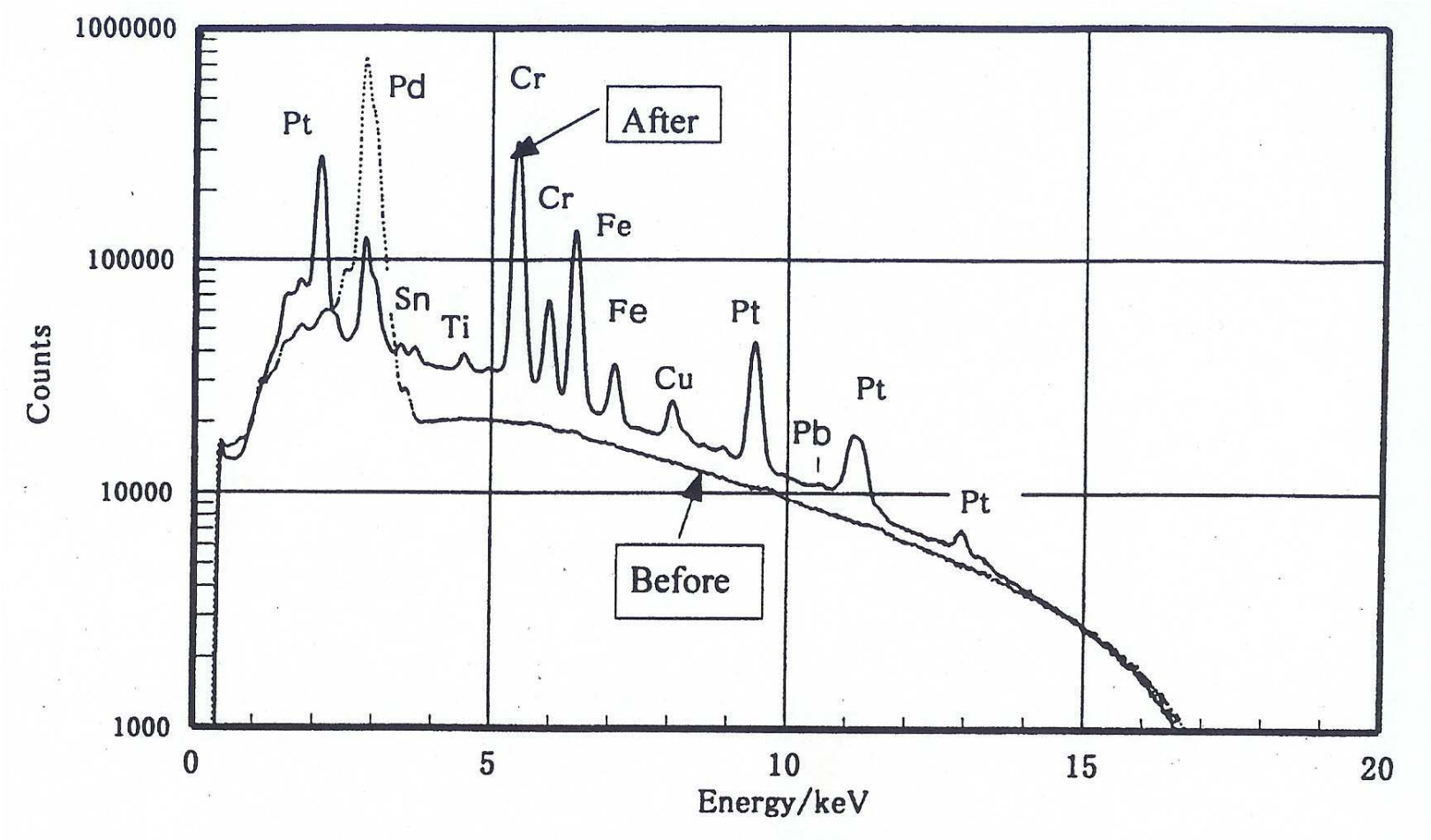
$$^{88}_{38}\mathrm{Sr} + 4\left(^{2}_{1}\mathrm{H}\right) = ^{96}_{42}\mathrm{Mo} + 53.5\ \mathrm{MeV}$$

Mizuno *et al.* (Hokkaido University)



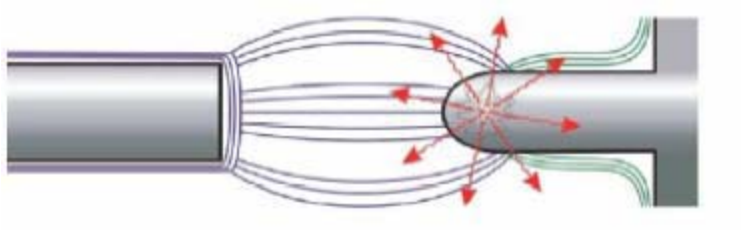
Courtesy of T. Mizuno, Hokkaido Univ.

Mizuno *et al.* (Hokkaido University)



X-ray spectroscopy

Adamenko *et al.* (Proton-21)



cathode e-beam anode

Electron beam
< 500 keV, < 50 kA, 30 ns, < 2.5 kJ

Adamenko *et al.* (Proton-21)

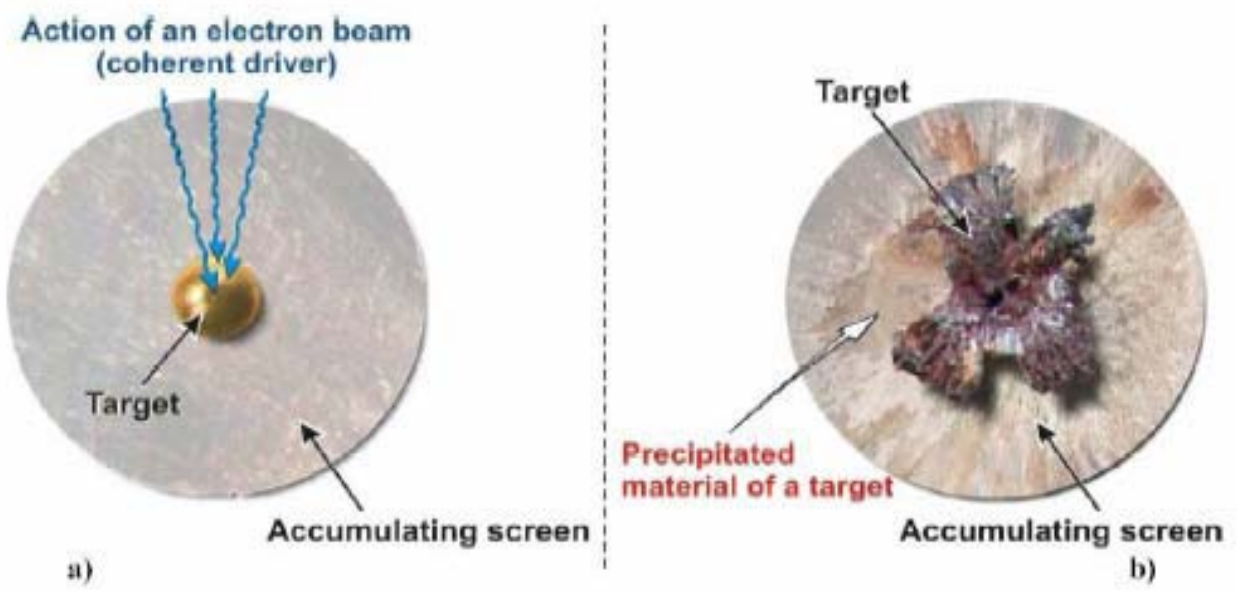


Fig. 1. Scheme of the experiment on target material compression that depicts the initial state of the sample (a) and its state after the experiment (b).

Explosion Energy > Input Energy

Adamenko *et al.* (Proton-21)

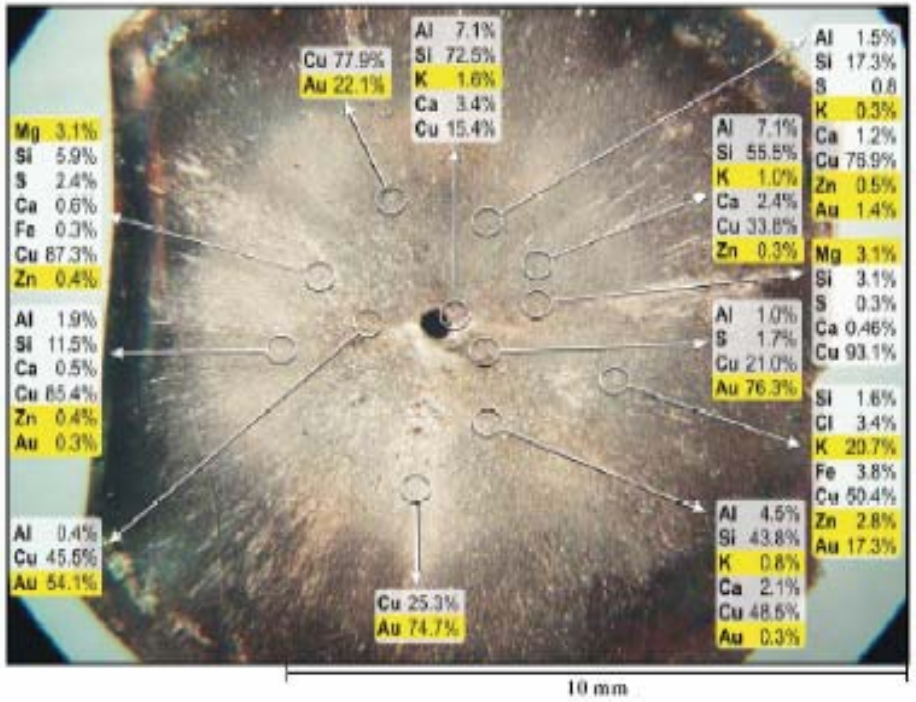
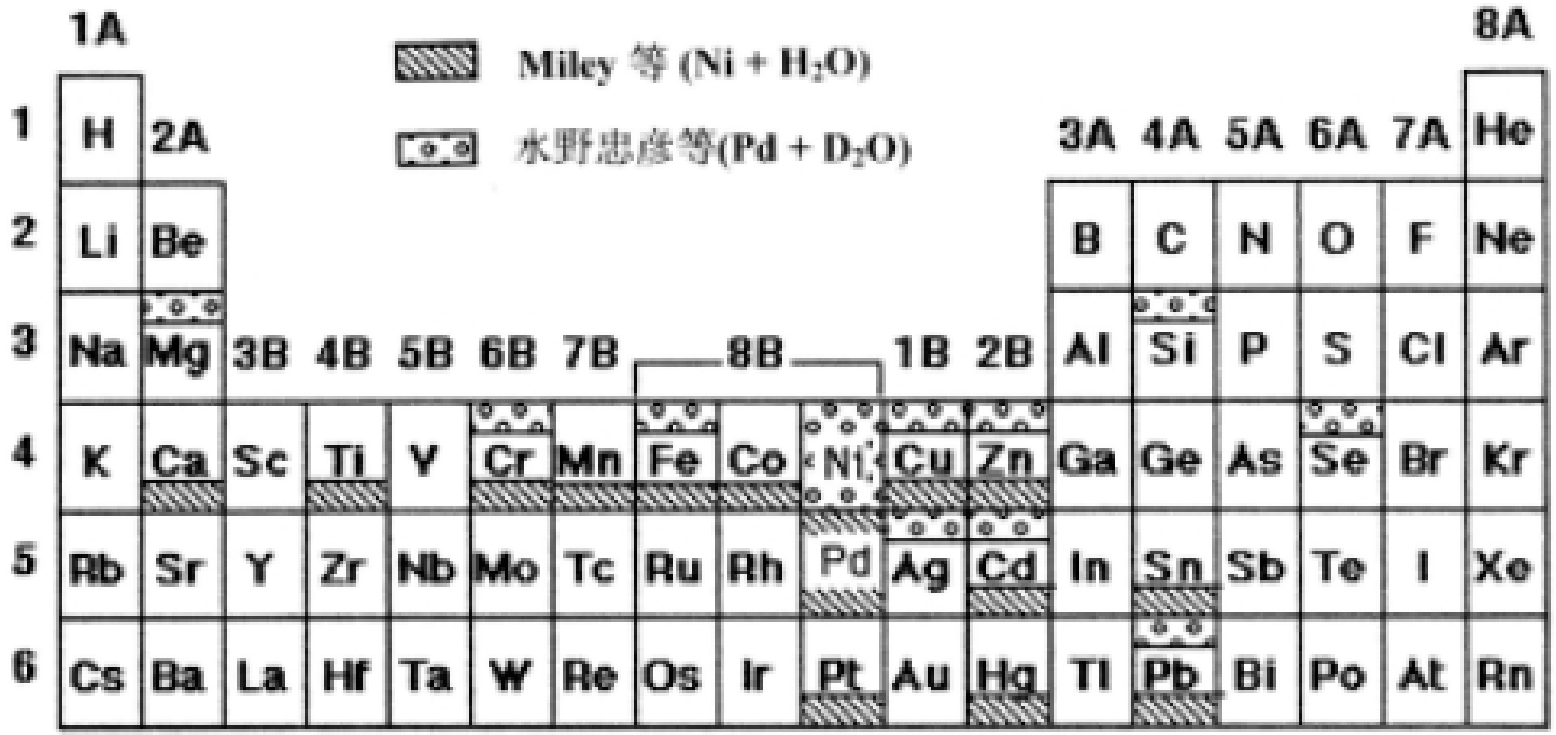


Fig. 20. Accumulating screen after experiment No. 2107.
The material of the accumulating screen is copper (Cu 99.99%).
The method of investigation is X-ray electron probe microanalysis.
(Element detection range – from Na to U).

X-ray electron probe microanalysis

Summary

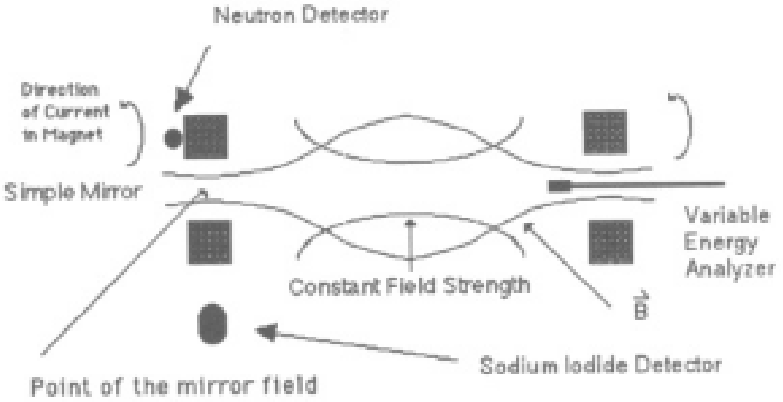

Miley 等 (Ni + H_2O)
水野忠彦等(Pd + D_2O)
1A
8A
1 H 2A 3A 4A 5A 6A 7A He
2 Li Be B C N O F Ne
3 Na Mg 3B 4B 5B 6B 7B 8B 1B 2B Al Si P S Cl Ar
4 K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
5 Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
6 Cs Ba La Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn

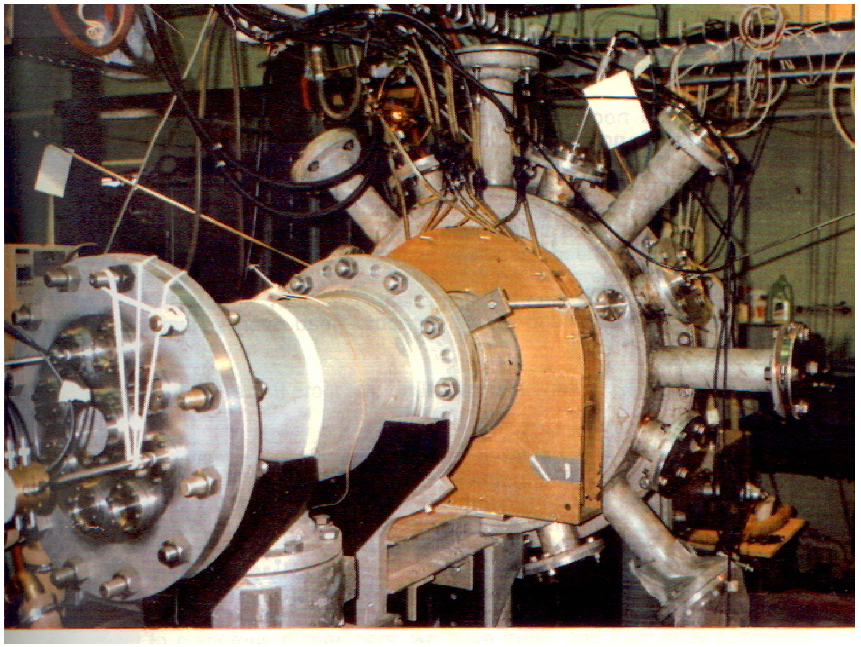
M^4X Description

- (1989) Modified Missouri Magnetic Mirror Experiment (M^4X) used to initiate cold fusion in Maxwellian plasma and sub-atmospheric D2 gas
- 3 experiments performed from March 1989 – May 1989
- Interesting results… but nothing conclusive

M^4X Description

Parameter	M^4X
*r*1 (radius of point cusp)	0.15 meter
*r*2 (radius of line cusp)	0.42 meter
w (width of line cusp)	0.13 meter
Max B_r	0.4 Tesla
Max B_z	0.68 Tesla
ECR Heating (2.5 GHz)	2.5 kW
ECR Heating (10.5 GHz)	10 kW
ICR Heating (0.1 – 2 MHz)	1 kW
ICR Heating (2-5 MHz)	10 kW
Plasma density	10^{18} m^{-3}
Hot electron temp.	500 keV
Bulk electron temp.	1 to 5 eV
Hot ion temp.	15 keV
Bulk ion temp.	0.5 to 10 eV
Plasma volume	9 liters





Diagnostics

- BF_3 neutron detector
- Sodium iodide detector with MCA for gamma spectroscopy
- Thermocouples
- RGA

Samples

Pd mounted in VEA

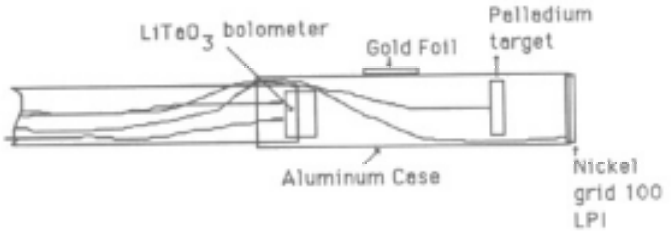


Fig. 2. Design of the target used in plasma loaded cold fusion experiments.

Langmuir probe target

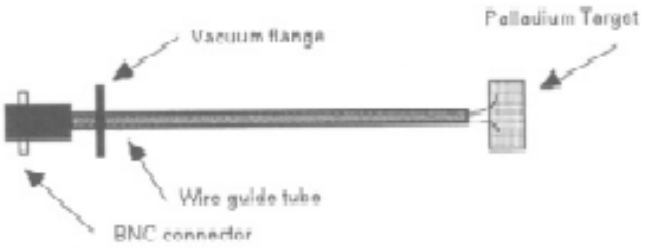


Fig. 3. Target using Langmuir probe design.

Experiment 1, 3/27 to 4/16/89

- Palladium sample

(7mm X 7mm X 0.25 mm)

- Mounted on ion energy analyzer
- Base pressure (9×10^{-7} Torr)
- Background neutron count rate of 1±1 neutrons per 7 min. with Ar gas at low flow rate
- Background neutron count rate of 3±1.73 neutrons per 7 min. with D2 gas at low flow rate

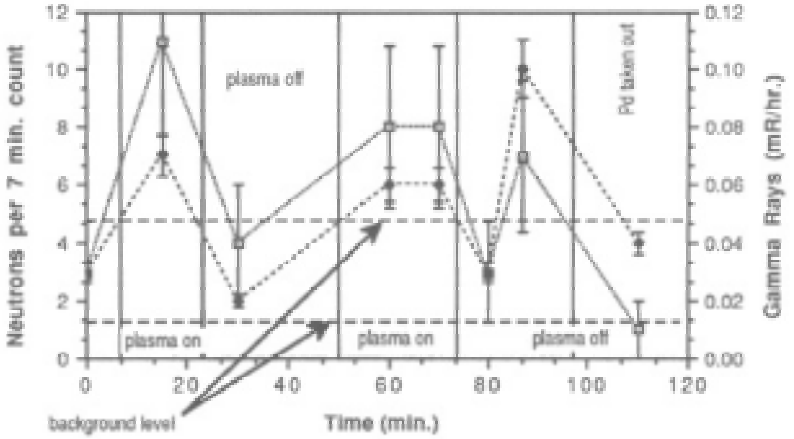


Fig. 5. Neutron counts and gamma-ray readings taken in experiment 1 3/27 to 4/16/89. -------□------- Neutrons; ———♦——— Gamma Rays;

- First plasma cycle, temp. rose from 69°F to 90°F
- Second cycle, temp. increased to 110°F
- Burst of neutrons and gammas at end of second cycle coincident with decrease in temp. from 110°F to 80°F

Experiment 2, 4/17 to 4/27/89

- Palladium sample

(7mm X 7mm X 0.25 mm)

- Mounted on ion energy analyzer
- Base pressure (7×10^{-7} Torr)
- Background neutron count rate of 40±6.3 neutrons per 30 min. with Ar and D plasma
- Pd sample placed in D2 gas

  (1×10^{-5} Torr)
- Peak neutron count rate of 297±17.2 counts per 30 min. over 9 hour period
- After 9 hours, Pd sample heated; neutron rates abruptly drop above 100°F

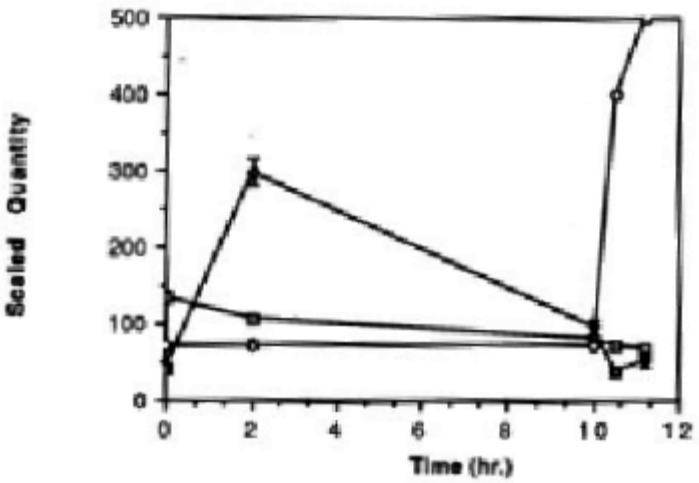


Fig. 6. Neutron counts, pressure and temperature readings taken during experiment 2 4/18 to 4/27/89. —□— Pressure (10 μPa); —◇— Neutron Counts; —○— Pd Temp. (F);

Experiment 3, 5/12 to 5/20/89

- Palladium sample

(25.4mm X 25.4mm X 0.5 mm)

- Mounted on Langmuir probe
- Neutron background obtained over 140 hours
- Peak neutron production rate of 100 sigma
- Unusual 8.1 MeV gamma with 3 MeV width observed at 200 hours

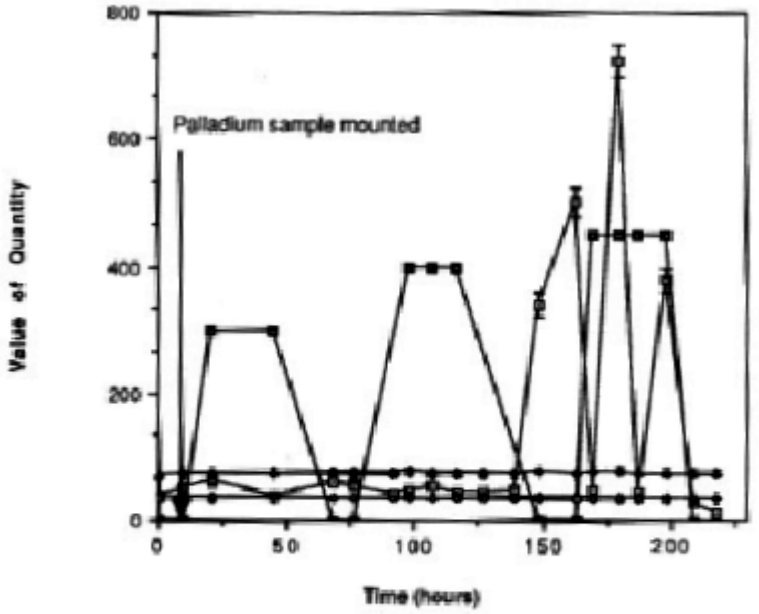
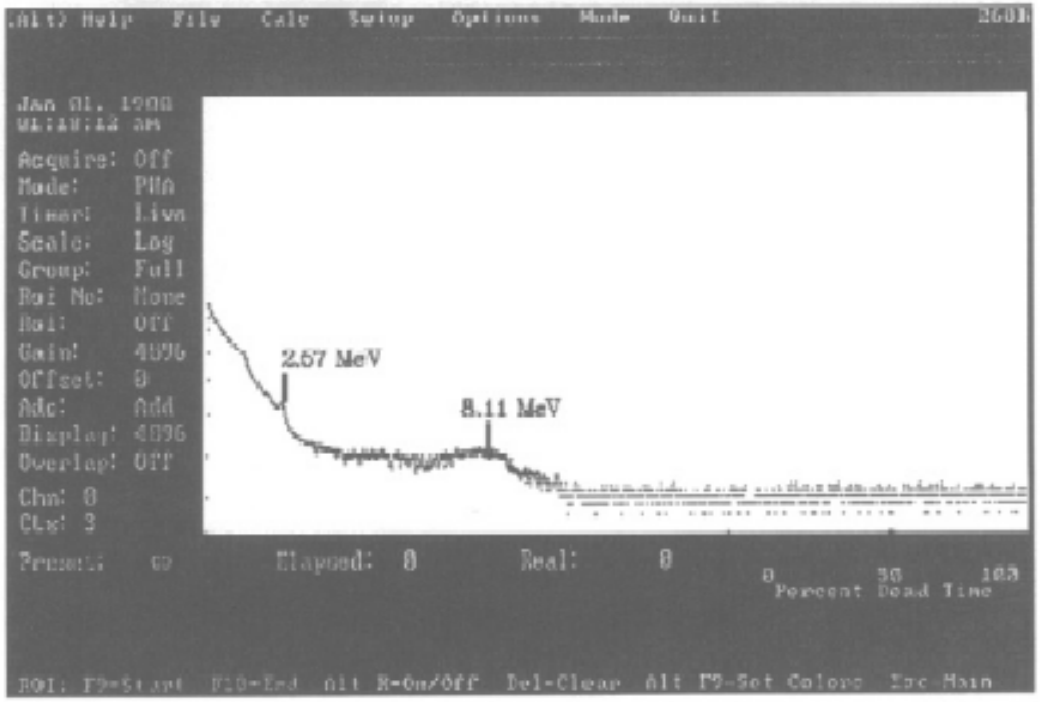


Fig. 7. Neutron counts, pressure, deuterium leak rate, and temperature readings taken during experiment 3 5/12/89 - 5/22/89. Neutrons in a 500 min count, temperature in F, pressure in Torr, and Deuterium leak rate setting in arbitrary units. —□— Neutrons; —♦— Temperature; —□— Pressure; —◇— Leak;

Experiment 3, 5/12 to 5/20/89



Summary

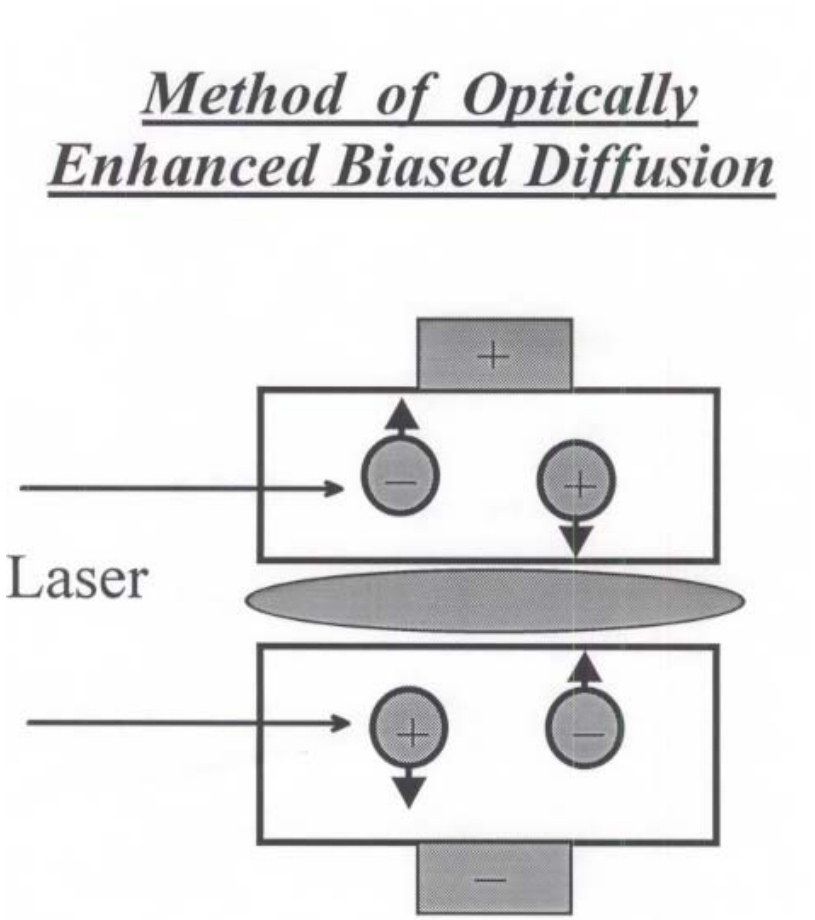
- Maxwellian plasma loading of Pd target resulted in apparent neutron and gamma production
- Sub-atmospheric loading of Pd target resulted in apparent neutron production but no gamma production; neutron production ceased for sample temp. > 100°F
- In third experiment, neutron production observed after 150 hours; no gamma production until release of 8.1 MeV gamma at 200 hours

Hydrogen Loading in Diamond-Description

- Hydrogen is loaded into several diamond samples including Type IIa diamond plates and CVD diamond films
- Hydrogen is loaded into the diamond samples using Field Enhanced Diffusion with Optical Activation (FEDOA); a technique originally developed by M.A. Prelas, G. Popovici, T. Sung, S. Khasiwinah at the University of Missouri for the doping of diamond with impurities

FEDOA

- Dopant “sandwiched” between 2 samples
- Bias, 100-250 VDC
- Heat samples, 500-1000 °C
- Use laser to assist in ionization of dopant
- Laser has at least 1 order of magnitude impact on impurity concentration diffused into diamond



Diagnostics

- Prompt Gamma Analysis via Neutron Activation (PGA)
  - measures bulk concentrations
- Secondary Ion Mass Spectroscopy (SIMS)
  - suitable for concentration measurements in sample surface
- Mass change measurements
  - measures bulk concentrations

Samples

- Type IIa diamond plate material from Harris Diamond Corporation (H); the USA affiliate of Drukker International, Beversestraat 20, 5431 SH Cuijk, Netherlands.
- CVD diamond plates from Kobe Steel (KB), Research Triangle Park, North Carolina.
- Two CVD diamond plates were obtained from Diamler-Benz (ULM).
- A sample was obtained from AsTex Corp. (A) as well. It was produced using a microwave CVD process.
- A sample was obtained from Norton Diamond Films (N) that was produced using an arc jet CVD process.

Samples

Sample Type	ID #	Treatment	Mass Meas.	PGA	SIMS
1. type IIa plate	H13	8 hrs-H	Done	NA	NA
02. type IIa plate	H16	8 hrs-H	Done	NA	NA
03. type IIa plate	H19	8 hrs-H	Done	NA	Done
04. CVD	ULM01	8 hrs-H	NA	Done	NA
05. CVD	KB07	8 hrs-H	Done	NA	NA
06. CVD	KB08	8 hrs-H	Done	NA	NA
07. CVD	KB09	8 hrs-H	Done	NA	Done
08. type IIa plate	H21	51 hrs-H	Done	NA	NA
09. type IIa plate	H23	51 hrs-H	Done	NA	NA
10. type IIa plate	H22	51 hrs-H	Done	NA	Done
11. CVD	ULM02	48 hrs-H	NA	Done	NA
12. CVD	KB02	51 hrs-H	Done	NA	NA
13. CVD	KB05	51 hrs-H	Done	NA	NA
14. CVD	KB06	51 hrs-H	Done	NA	Done
15. type IIa 10 mg	H30	48 hrs-H	Done	NA	NA
16. Norton CVD 20 mg	N01	48 hrs-H	Done	Done	NA
17. AsTex CVD free standing	A01	48 hrs-H	Done	Done	NA

Preliminaries

- A 1:1 ratio of hydrogen atoms to carbon atoms in the diamond samples corresponds to:

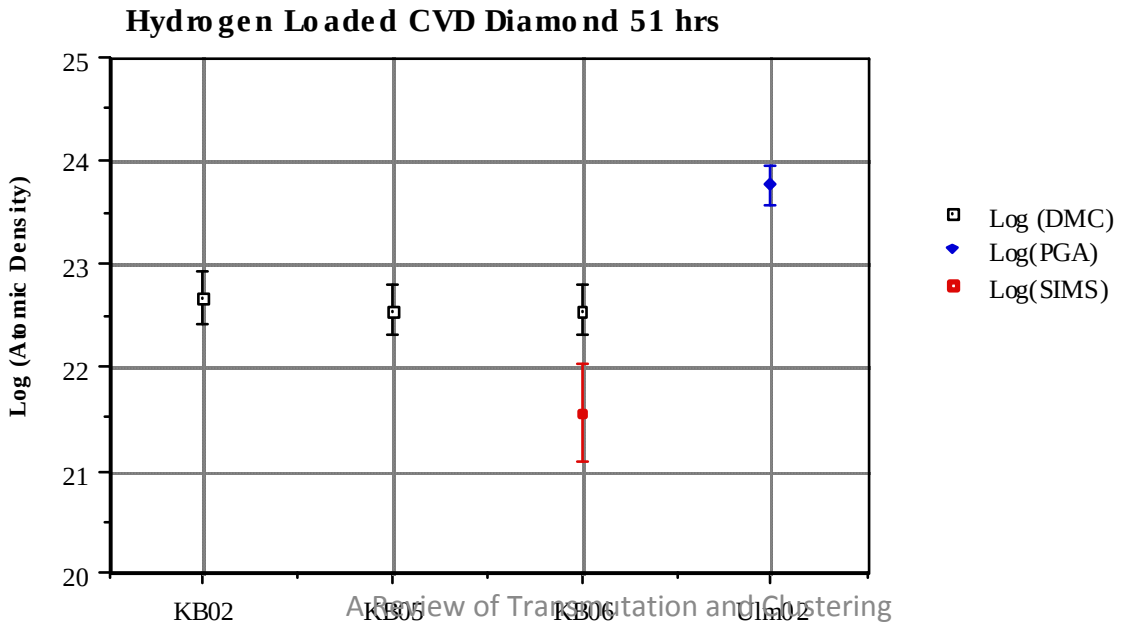
$$\%\Delta m = 8.33\%$$

$$N_i = N_H = 2.112\times10^{22}\times\left(8.33\%\right) = 1.76\times10^{23}\,\text{atoms/cm}^3$$

$$\left(Equivalent\ Atmosphere\ STP\right)_H = \left(829.2\right)\times\left(8.33\%\right) = 6907$$

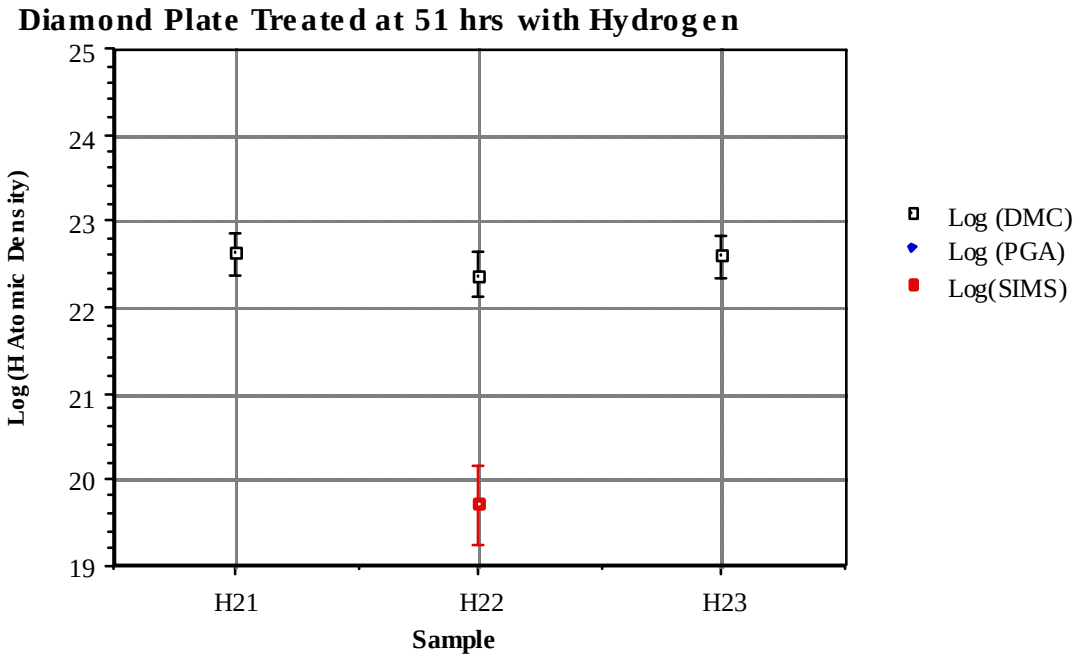
CVD diamond sample hydrogen loading results (48-51 hr)

Sample	Mass Gain (μgm)	Mass Change (%)	Atomic Density (x10–23)	SIMS Atomic Density (x10–23)	Equivalent Atmosphere STP (atm)	% H by mass
KB02	40 +/- 10	2.3 +/- 0.54	0.48+/- 0.12	na	2,613	2.22
KB05	30 +/- 10	1.7 +/- 0.34	0.36 +/-0.12	na	1,931	1.68
KB06	30 +/- 10	1.7 +/- 0.34	0.36+/-0.12	0.02 to 0.05	268 to 1,931	1.68
ULM02	758 +/- 10	27.0*	5.69	na	30,631	21.22



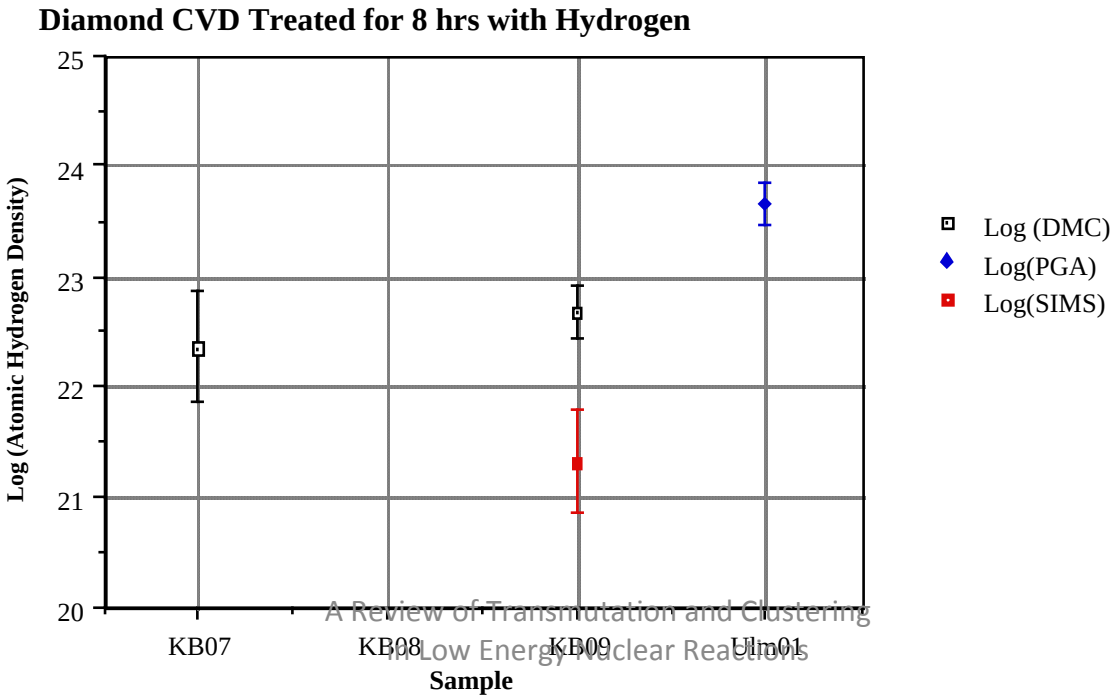
Type IIa diamond sample hydrogen loading results (48-51 hr)

Sample	Mass Gain (μgm)	Mass Change (%)	Atomic Density (x10–23)	Equivalent Atmosphere STP (atm)	% H by mass
H21	50+/-10	2.0+/-0.4	0.41+/-0.12	2,273	1.90
H23	40+/-10	1.8+/-0.4	0.39+/-0.12	2,046	1.81



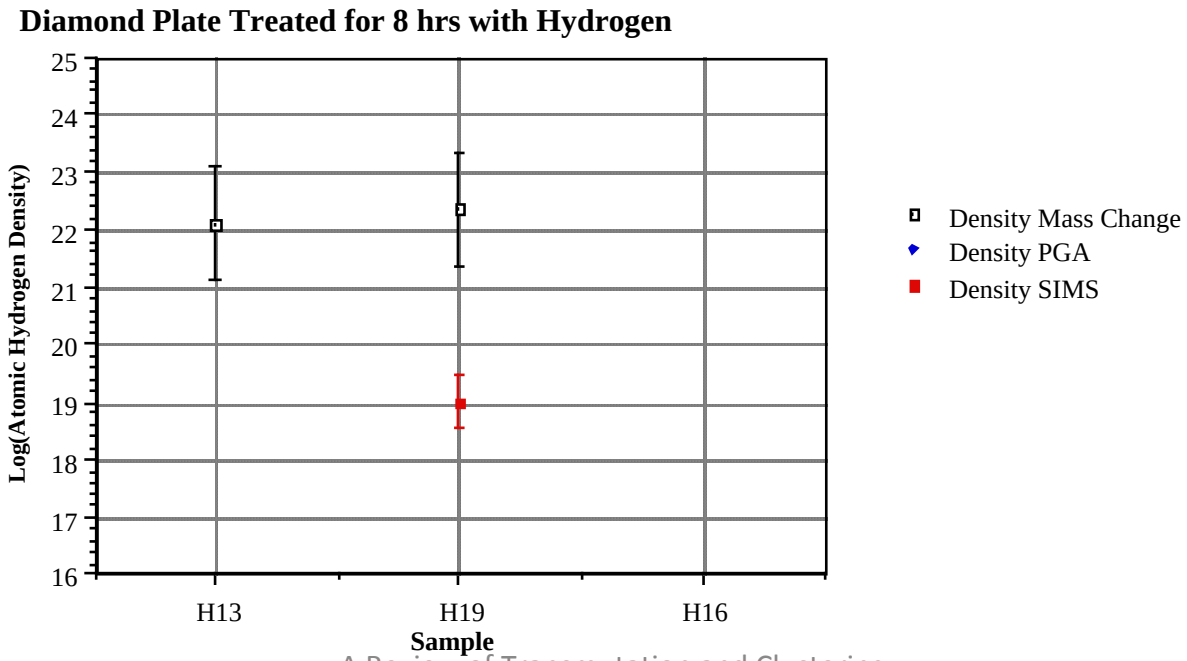
CVD diamond sample hydrogen loading results (8 hr)

Sample	Mass Gain (μgm)	Mass Change (%)	Atomic Density (x10–23)	SIMS Atomic Density (x10–23)	Equivalent Atmosphere STP (atm)	% H by mass
KB07	20+/-10	1.1+/-0.6	0.23+/-0.13	na	1,250	1.08
KB08	–10+/-10	–	–	na	–	na
KB09	40+/-10	2.3+/-0.5	0.48+/-0.11	0.01 to 0.04	2,613	2.22
ULM01*	615+/-10	22.0*	4.63	na	18,159	17.97



Type IIa diamond sample hydrogen loading results (8 hr)

Sample	Mass Gain (gm)	Mass Change (%)	Atomic Density (x10–23)	SIMS Atomic Density (x10–23)	Equivalent Atmosphere STP (atm)	% H by mass
H13	0.00001	0.6+/-0.6	0.13+/-0.13	na	682	0.61
H19	0.00002	1.1+/-0.6	0.23+/-0.13	0.001	1,250	1.08
H16	–0.00001	–	–	na	–	na



Questions?