Transmutation Reactions Induced by Deuterium Permeation through Nano-structured Pd Multilayer Thin Film

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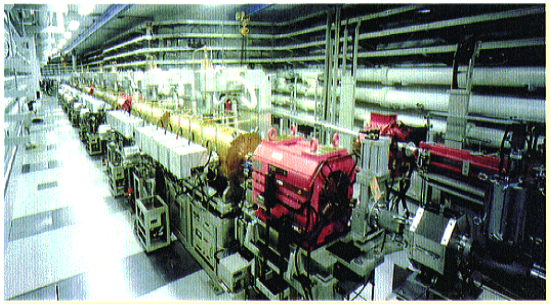
1. Introduction

Merits of Our Transmutation Method

Conventional Transmutation

Requires a large apparatus such as an accelerator and a nuclear reactor

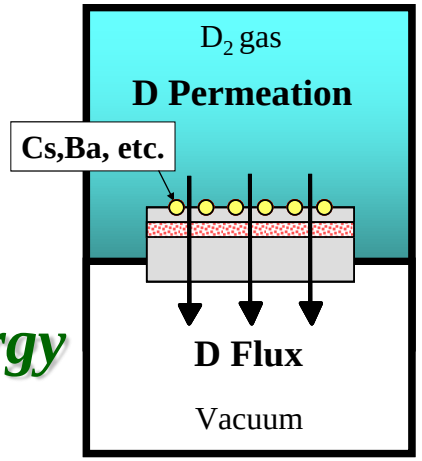


Permeation Induced Transmutation

Nuclear Transmutation can be induced by deuterium permeation through our original nano-structured Pd multilayer film

Compact

Low Energy

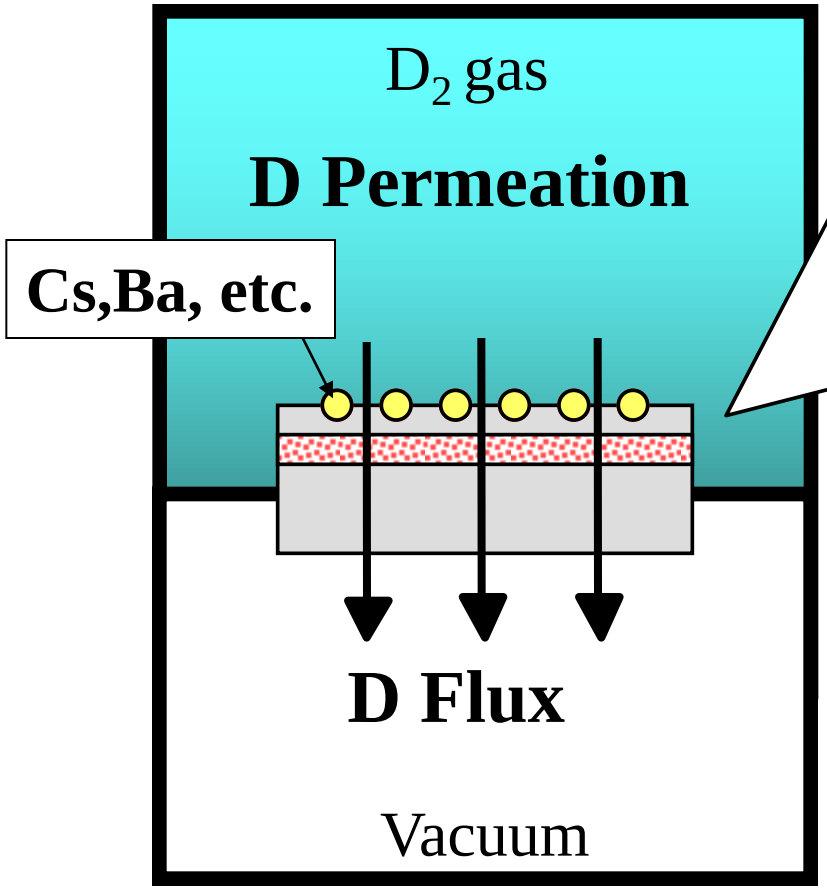


60-80 C
~1atm

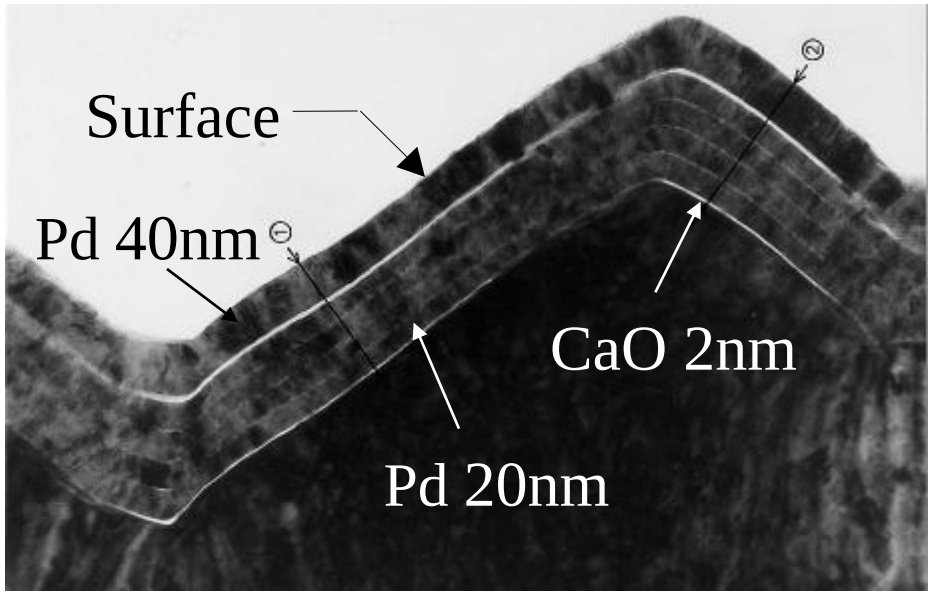
Y. Iwamura et.al, J. Appl. Phys. 41, 4642-4648 (2002)

Features of the Mitsubishi Method

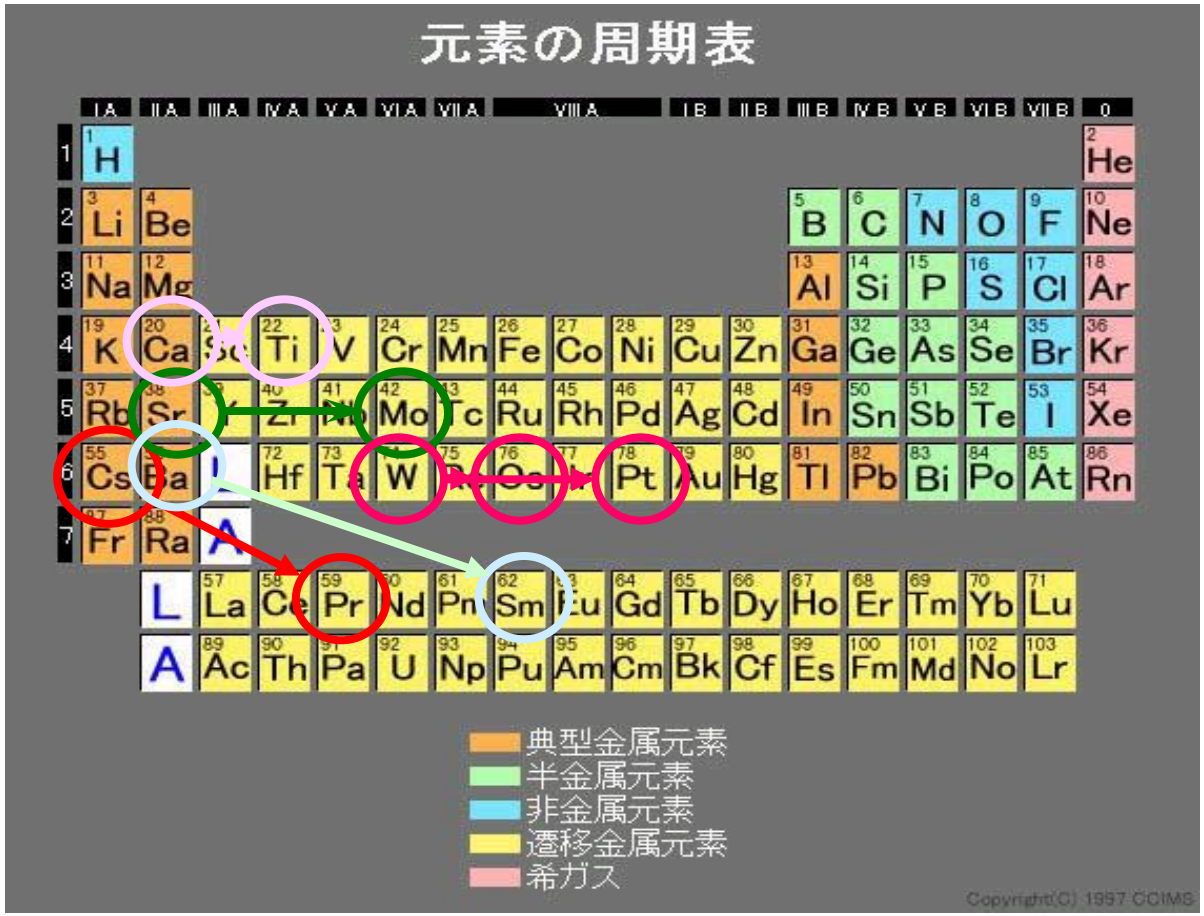
D_2 gas permeation through nano-structured Pd complex



Pd nano-sized multilayer film



Reactions observed so far in MHI



$$^{133}_{55}Cs \xrightarrow{4d(2\alpha)} {}^{141}_{59}Pr$$

$$^{88}_{38}Sr \xrightarrow{4d(2\alpha)} {}^{96}_{42}Mo$$

$$^{138}_{56}Ba \xrightarrow{6d(3\alpha)} {}^{150}_{62}Sm$$

$$^{137}_{56}Ba \xrightarrow{6d(3\alpha)} {}^{149}_{62}Sm$$

$$^{44}_{20}Ca \xrightarrow{2d(\alpha)} {}^{48}_{22}Ti$$

$$^{184}_{74}W \xrightarrow{2d(\alpha)} {}^{188}_{76}Os$$

$$^{182}_{74}W \xrightarrow{4d(2\alpha)} {}^{190}_{78}Pt$$

1)Alkali metals; Electron Emitter
2)2d, 4d, 6d; α capture reactions

Potential Applications

1) Nuclear Transmutation of Radioactive Waste

Radioactive Waste

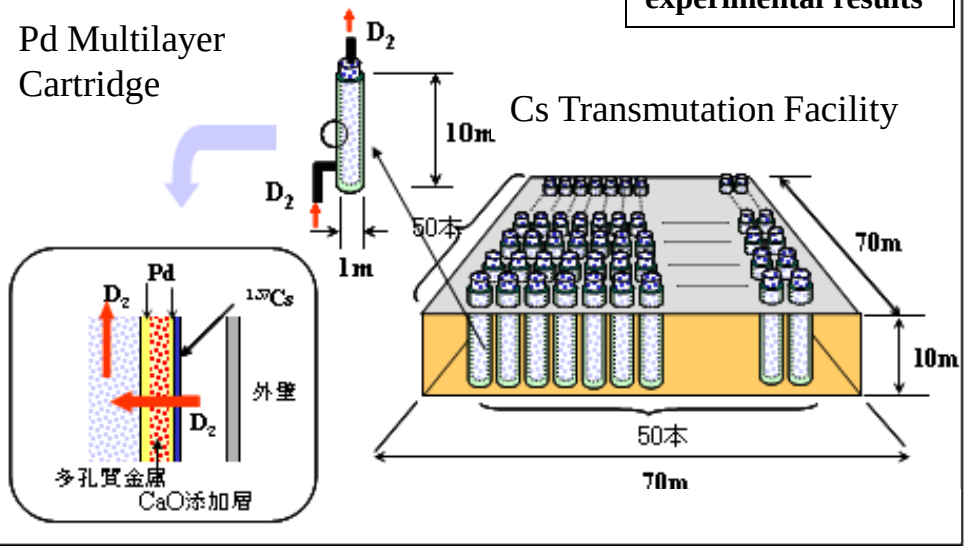
↓

Cs Separation

↓

Cs Transmutation

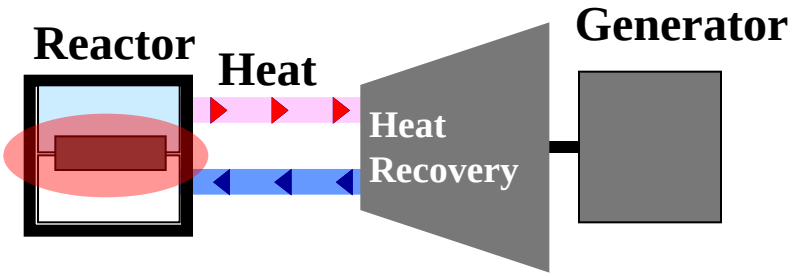
1GW Nuclear Power Plant Based on our experimental results



2) Production of Rare Metals

$$^{182}_{74}W \xrightarrow{4d(2\alpha)} {}^{190}_{78}Pt$$ etc…

3) Portable nuclear energy source



2. Original Experimental Method and Results

Fabrication of Nano-structured Pd Multilayer Film

Washing a Palladium Sample with Acetone

↓

900° C 10H Annealing under Vacuum Condition (< 10^{-6}Torr)

↓

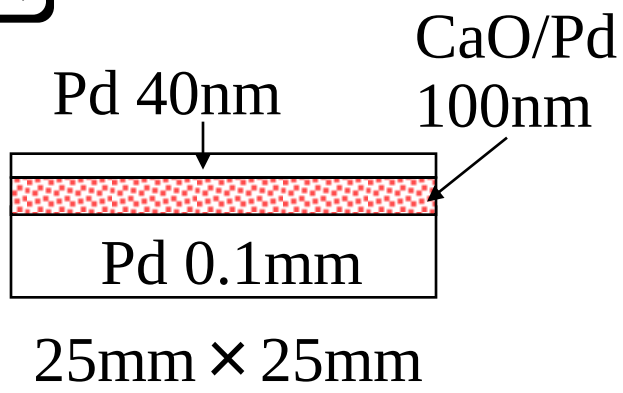
Washing the Sample with Aqua Regia (100sec)

↓

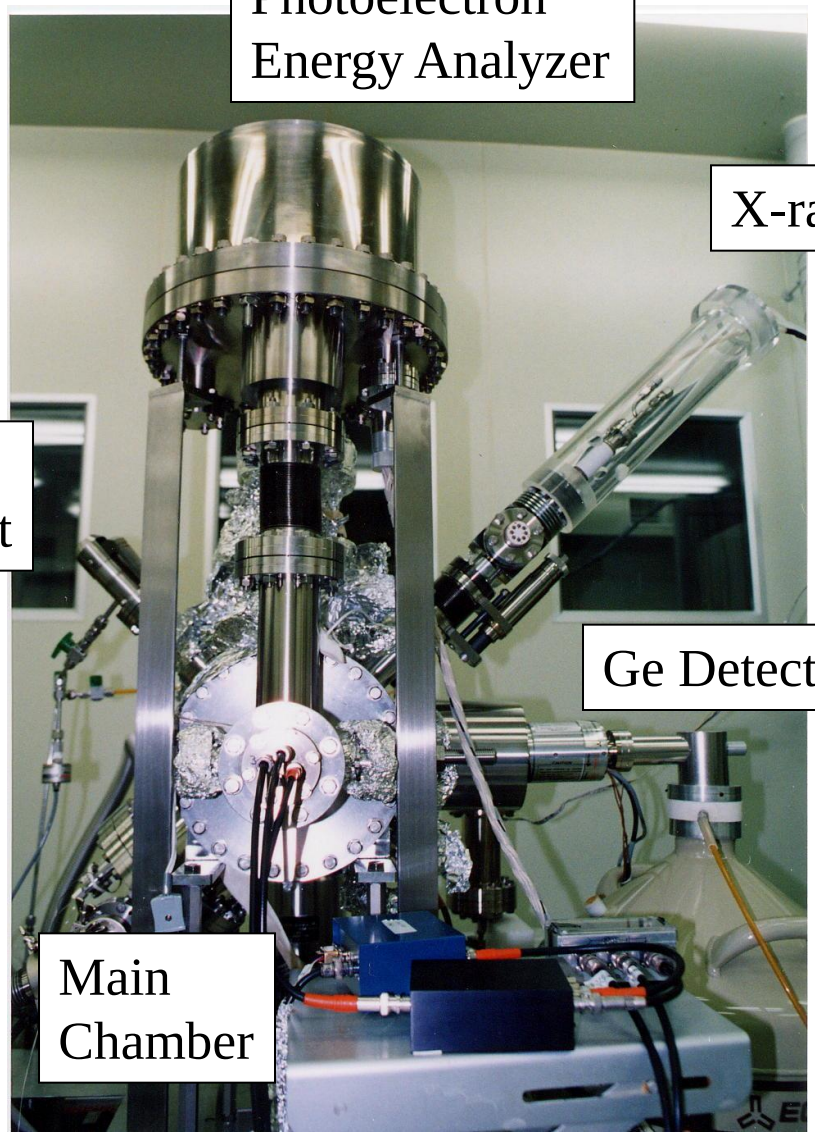
5 times Alternatingly Sputtering of CaO (2nm) and Pd (18nm)

↓

Ion Beam Sputtering of Pd only (40nm)



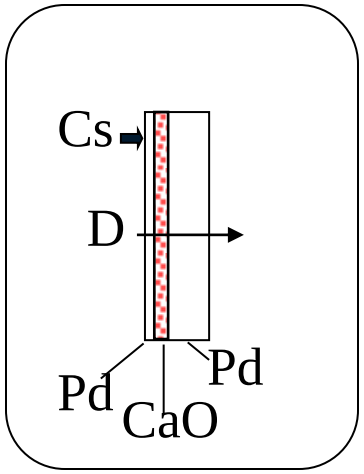
Experimental apparatus with XPS

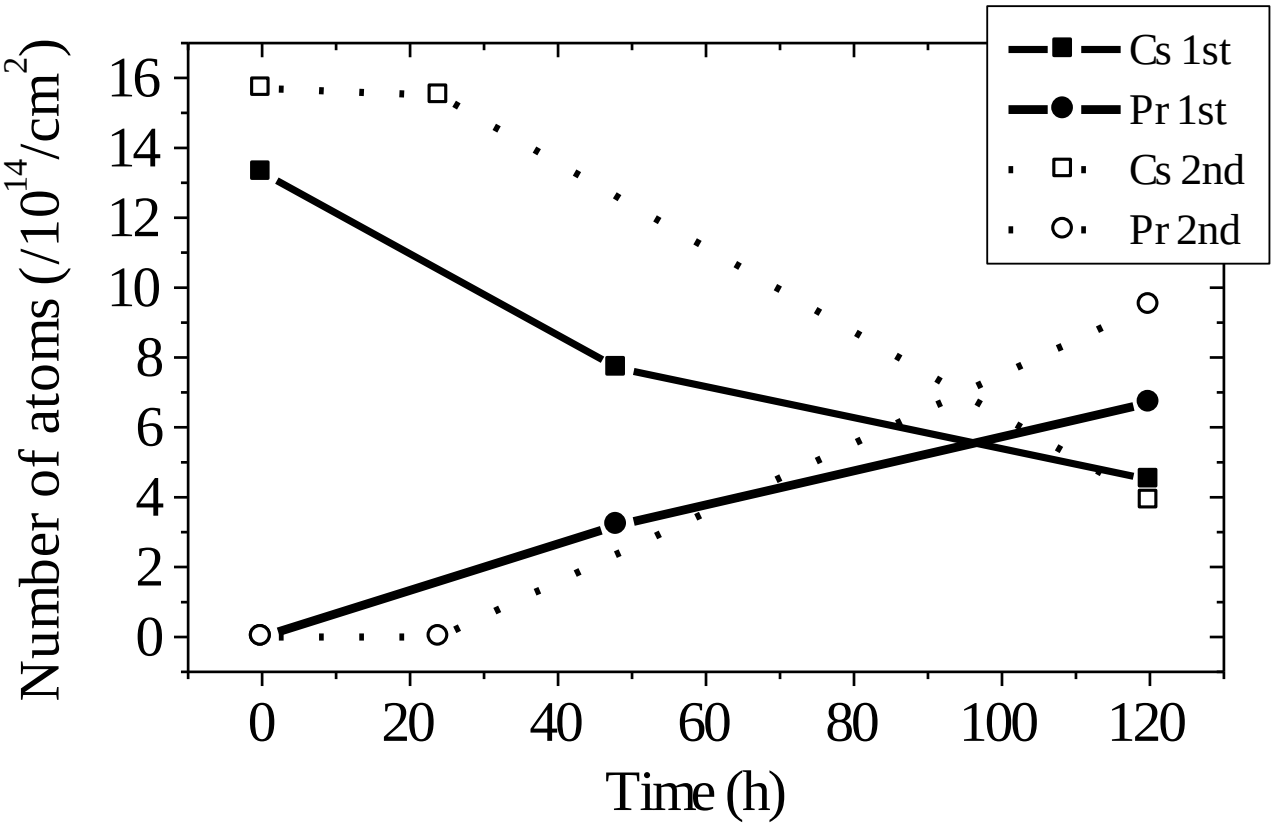


Transmutation of Cs into Pr

$$^{133}_{55}Cs \xrightarrow{4d(2\alpha)} {}^{141}_{59}Pr$$

Atomic Number +4
Mass Number +8

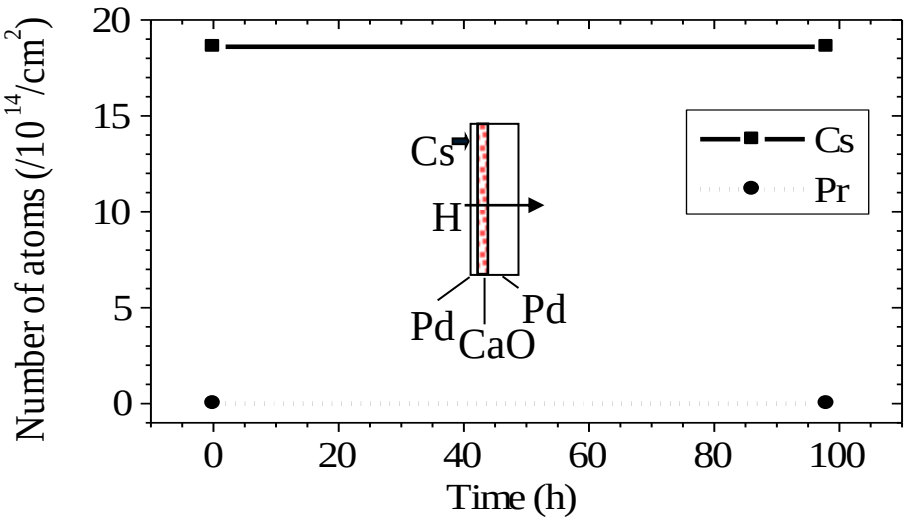


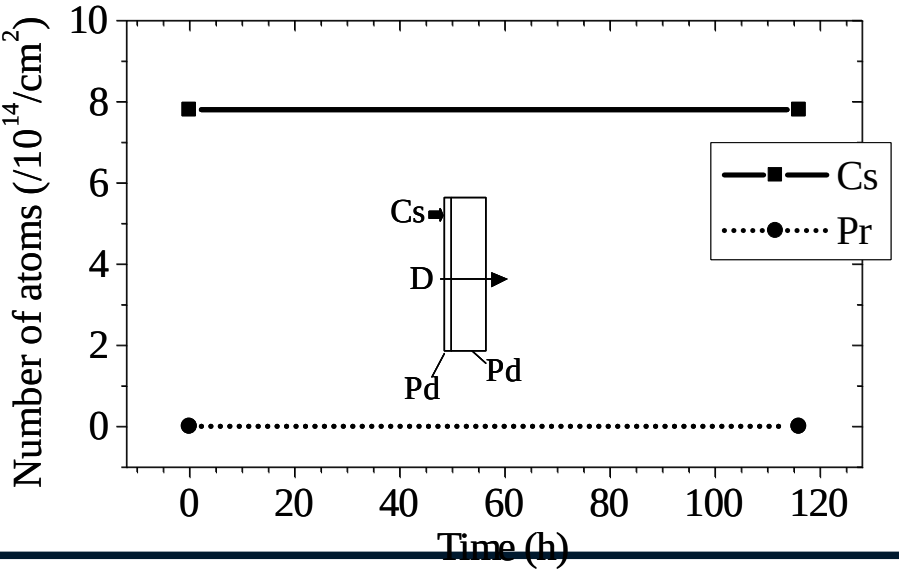


Control Experiments

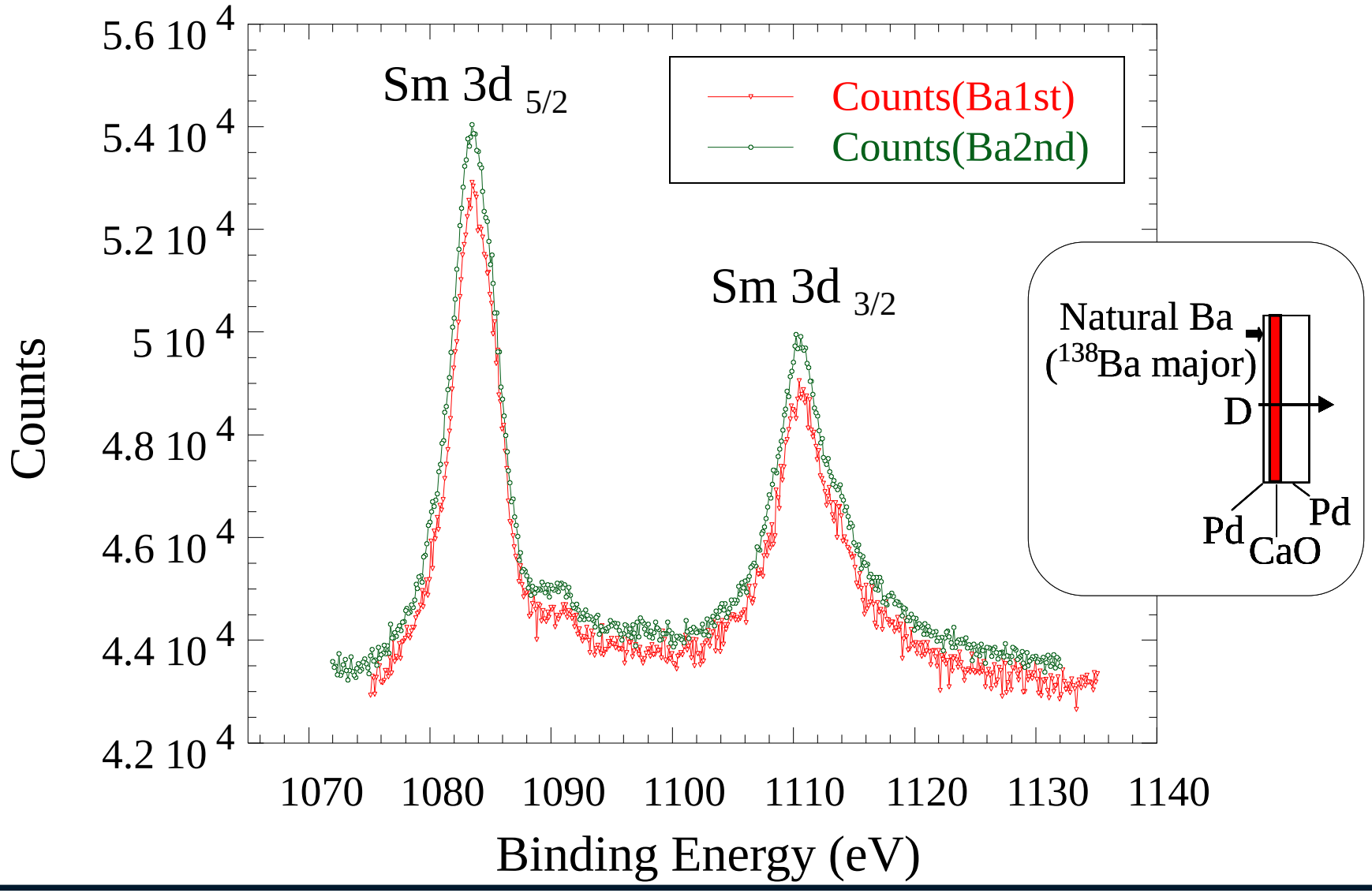
1. H: Cs/Pd/CaO/Pd
2. D: Pd/CaO/Pd
3. D: Cs/Pd//Pd

No Pr detected

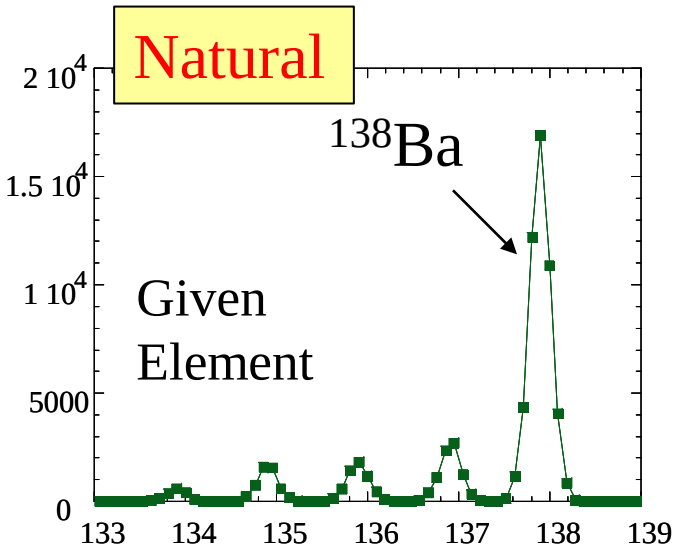




Transmutation of Ba into Sm

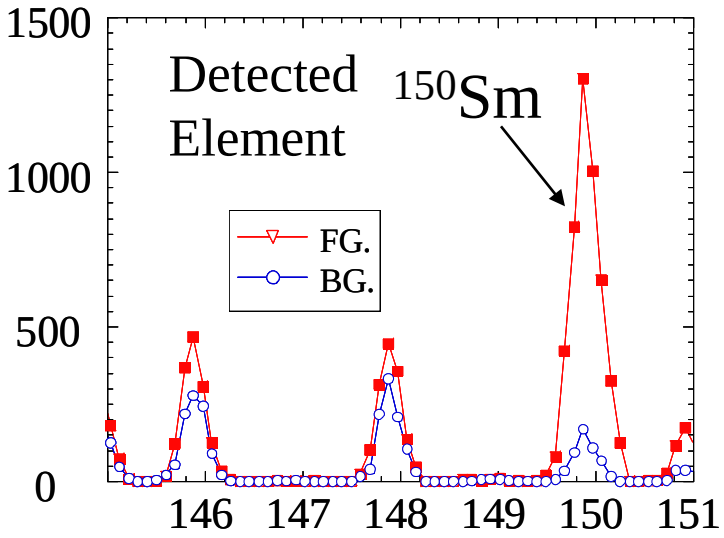


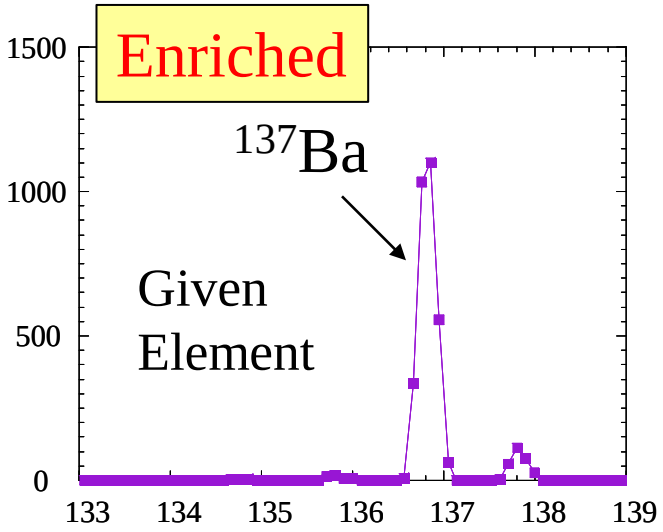
Mass Number Correlation between Ba and Sm



$^{138}_{56}Ba \xrightarrow{6d} ^{150}_{62}Sm$

M +12
Z +6





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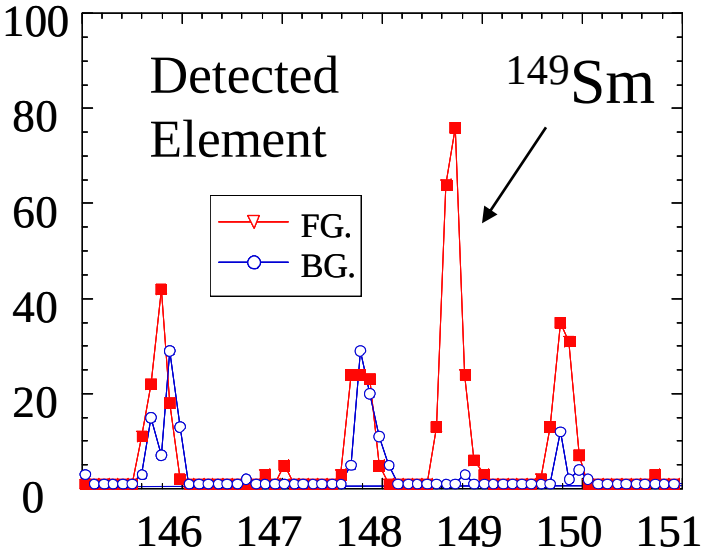
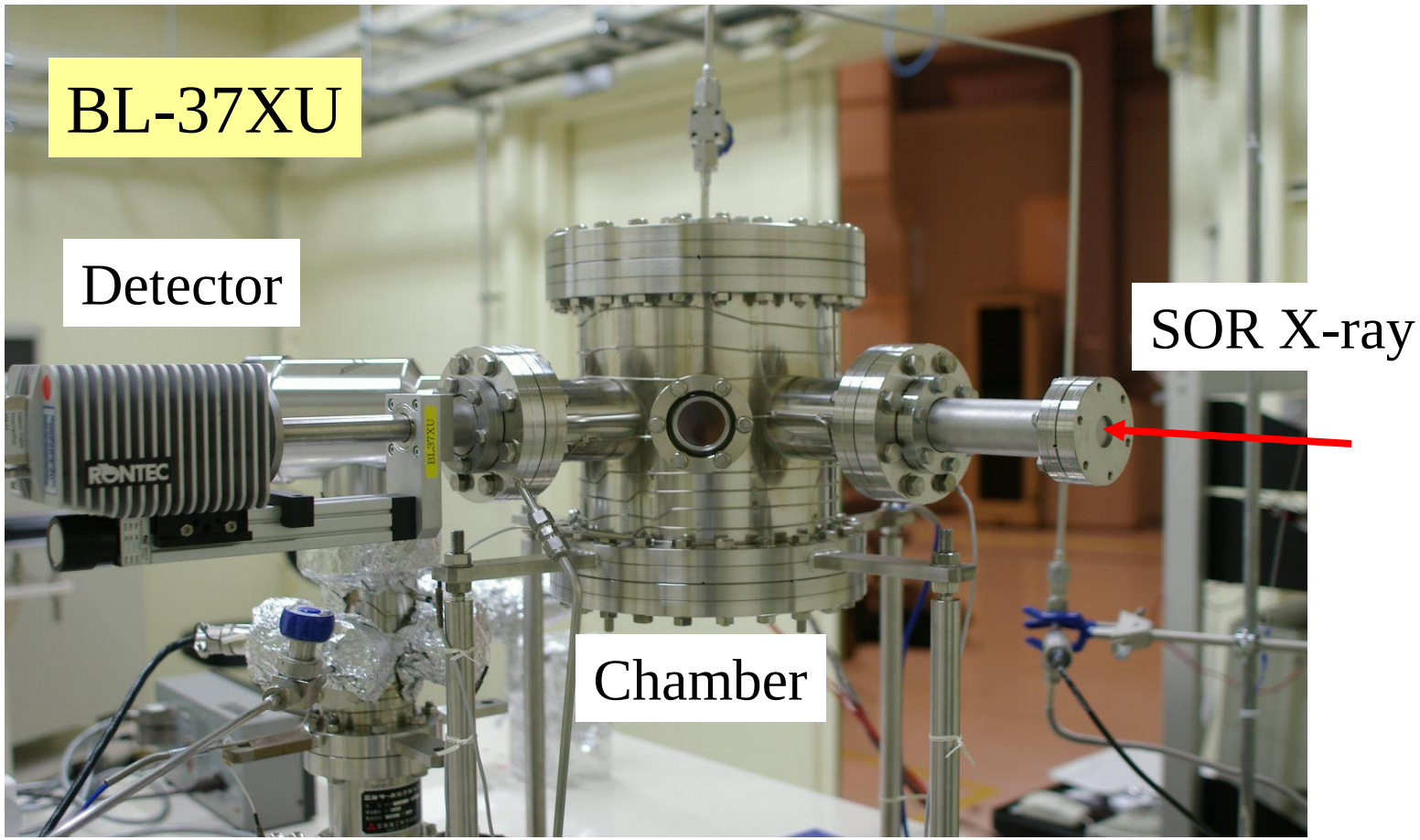


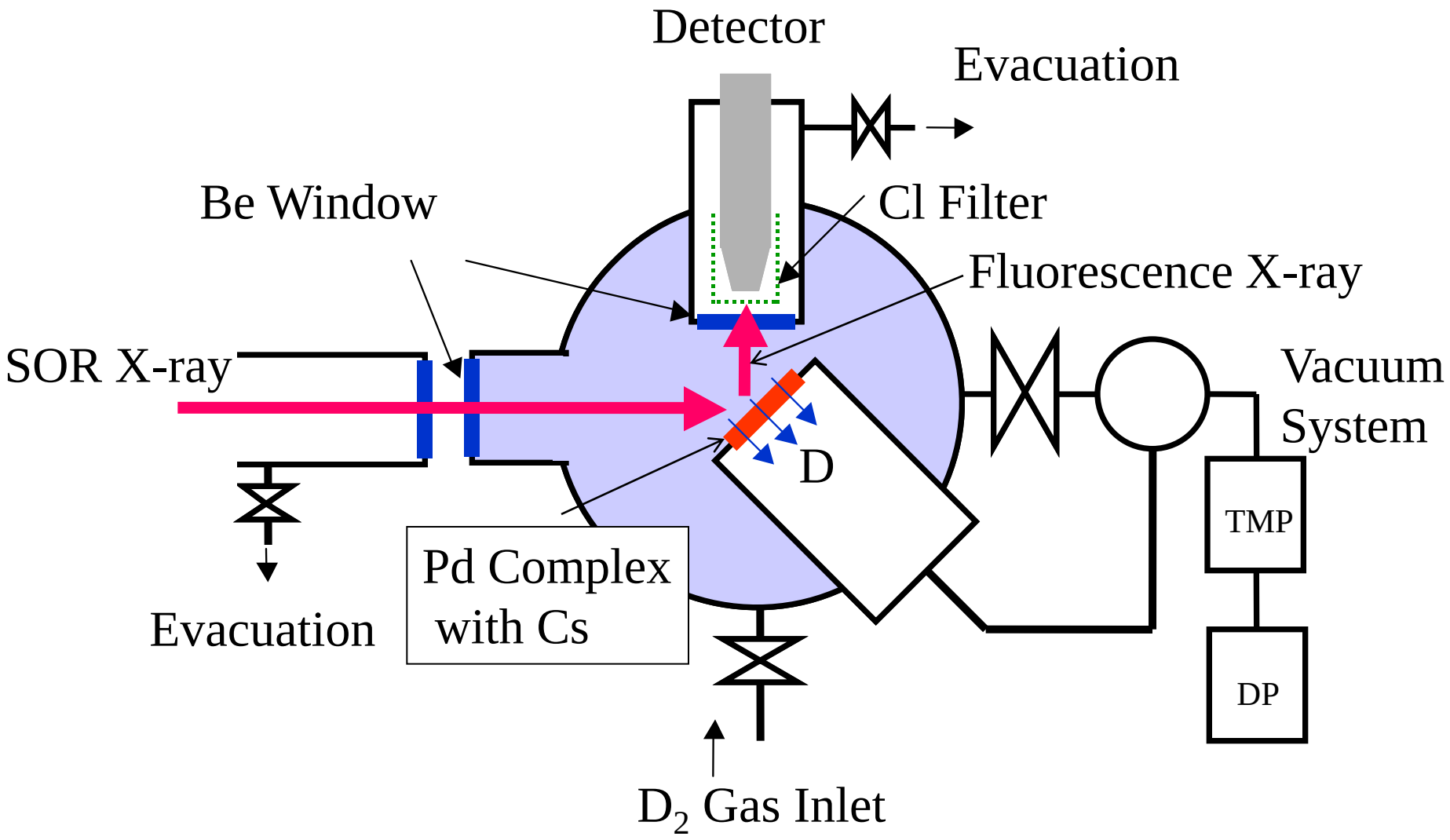
3. *In-situ* Measurement of Transmutation of Cs into Pr

Photo of the *in-situ* Experimental Setup

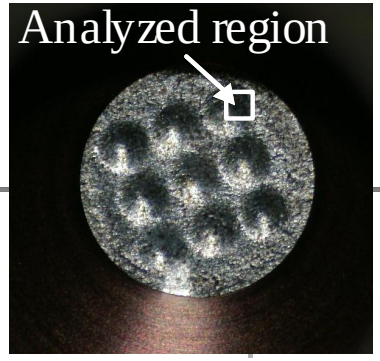


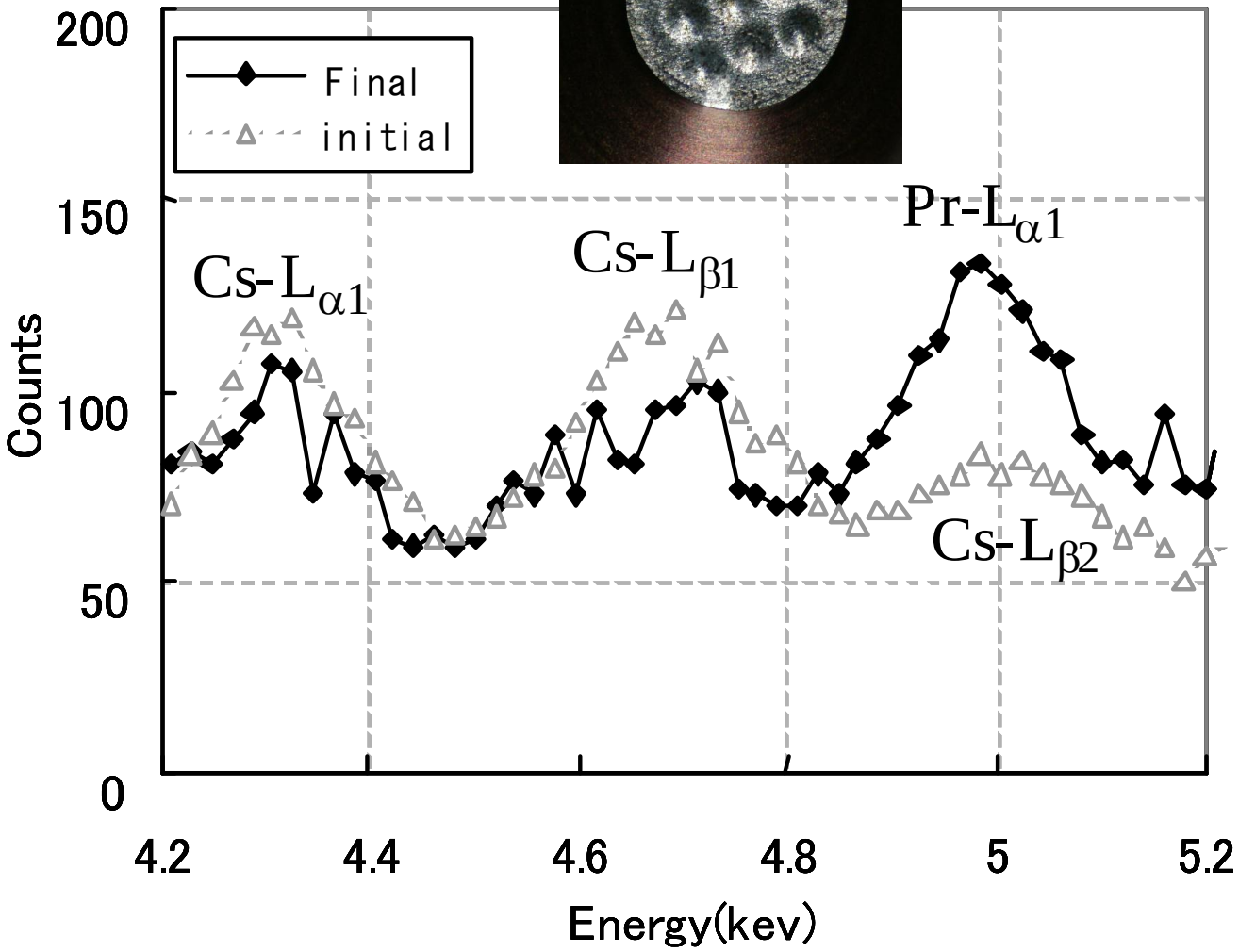
Experimental setup for in-situ measurement at SPring-8,which is one of the largest synchrotron radiation facilities. This setup enables us to observe elemental changes during D2 gas permeation by XRF (X-ray fluorescence spectrometry).

In-situ Measurement Set-up at Spring-8



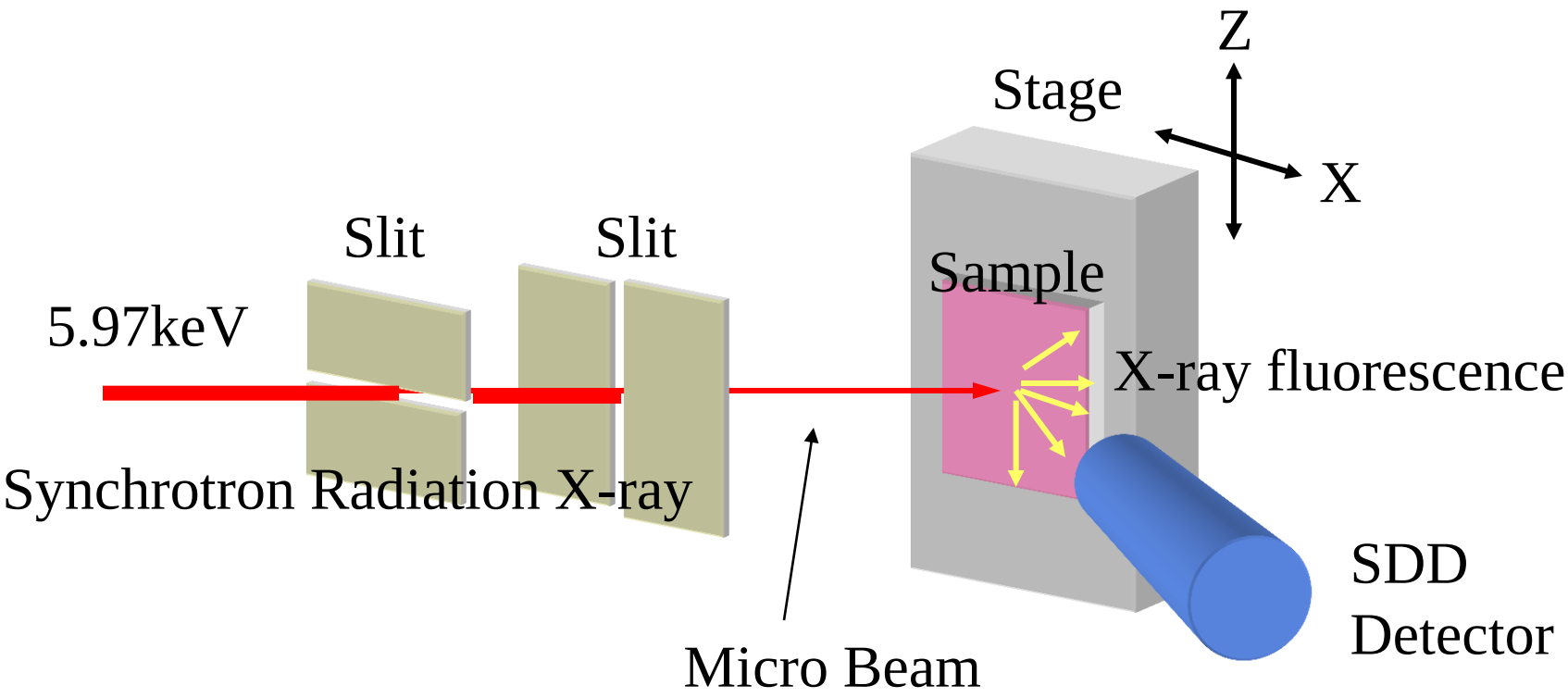
Confirmation of Pr by *in-situ* measurement





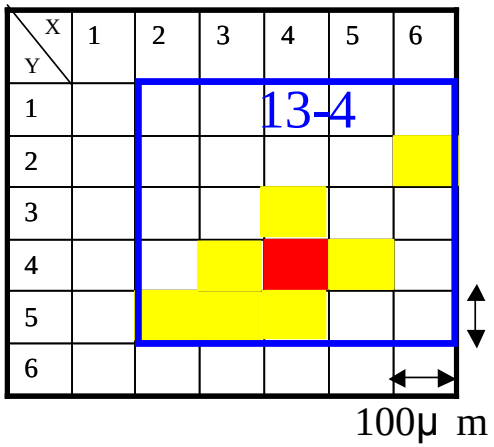
4. Depth and Surface distribution of Transmuted Products

Experimental Setup for Surface Distribution of Pr



Detection of Localized Pr

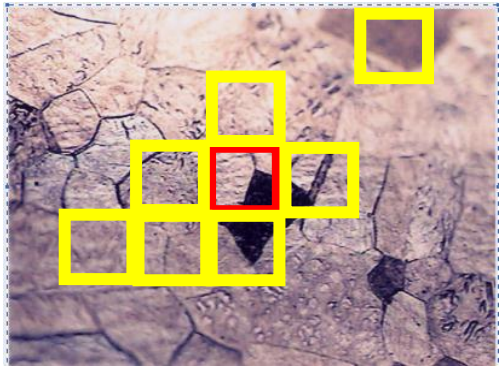
100 micron beam;SP-24, 13-4

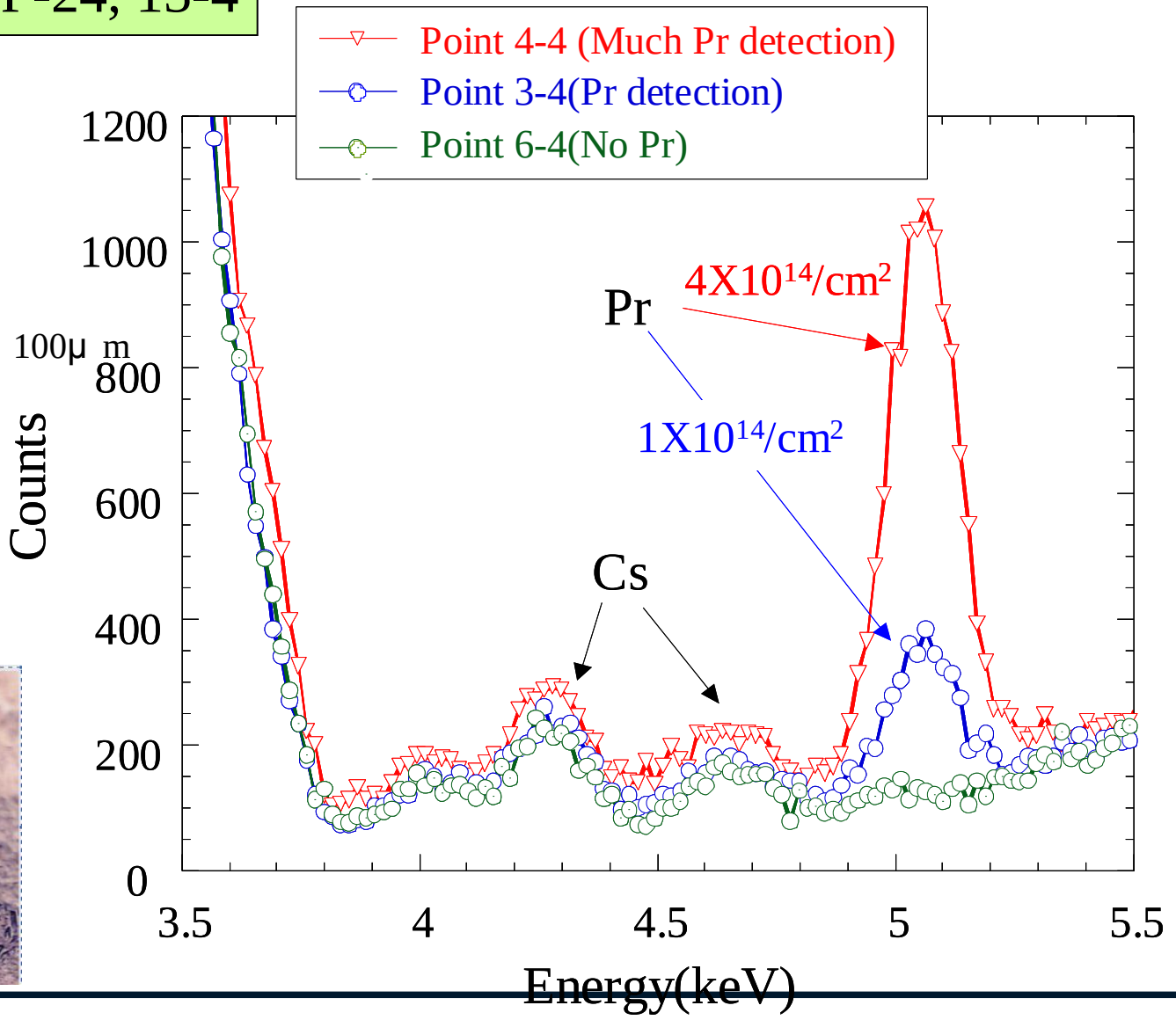


Much Pr detection

Pr detection

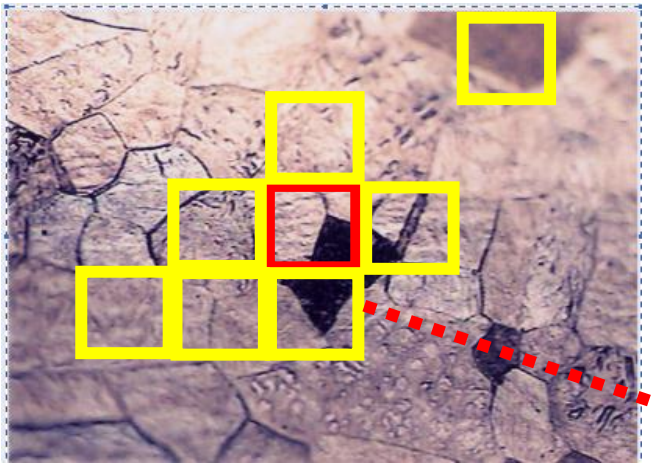
No Pr



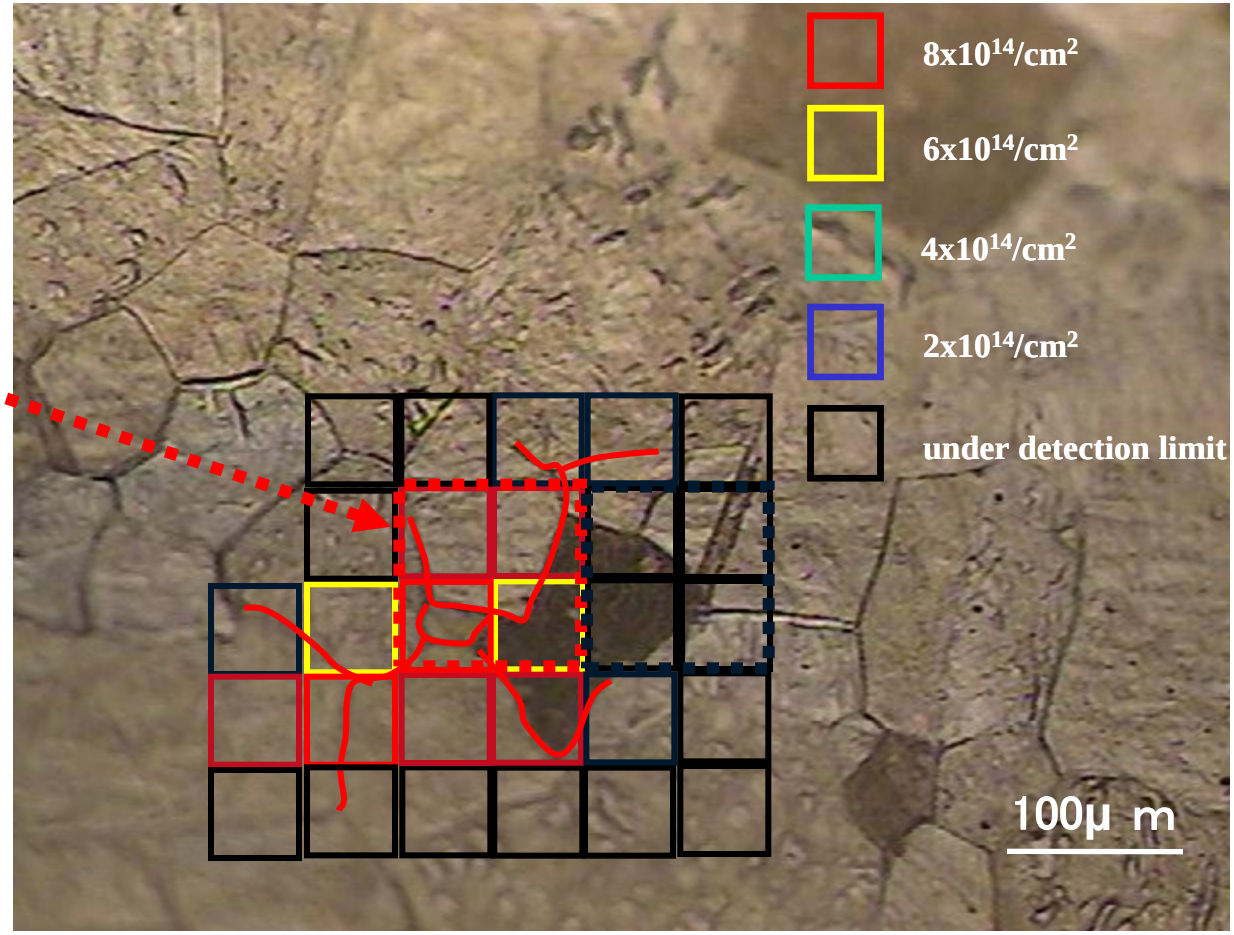


Further smaller beam analysis of Pr

100 μm beam;SP-24



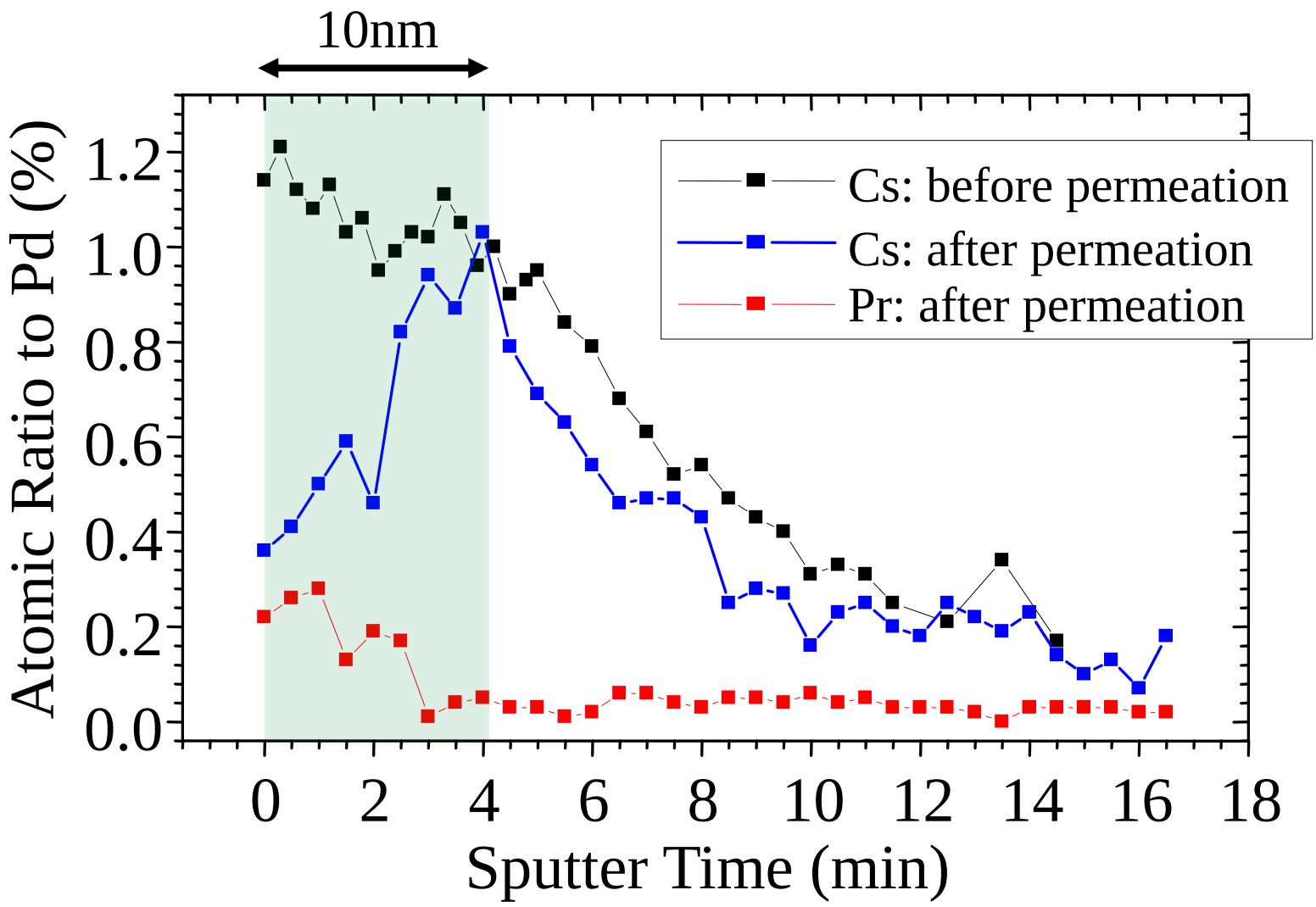
50 μm beam;SP-24



Smaller X-ray beam provides **more localized Pr distribution.**

Existence of hot spots?

Depth Profile of Cs and Pr by XPS



5. Role of CaO

D^+ Ion Bombardment Experiment Performed at Tohoku Univ.

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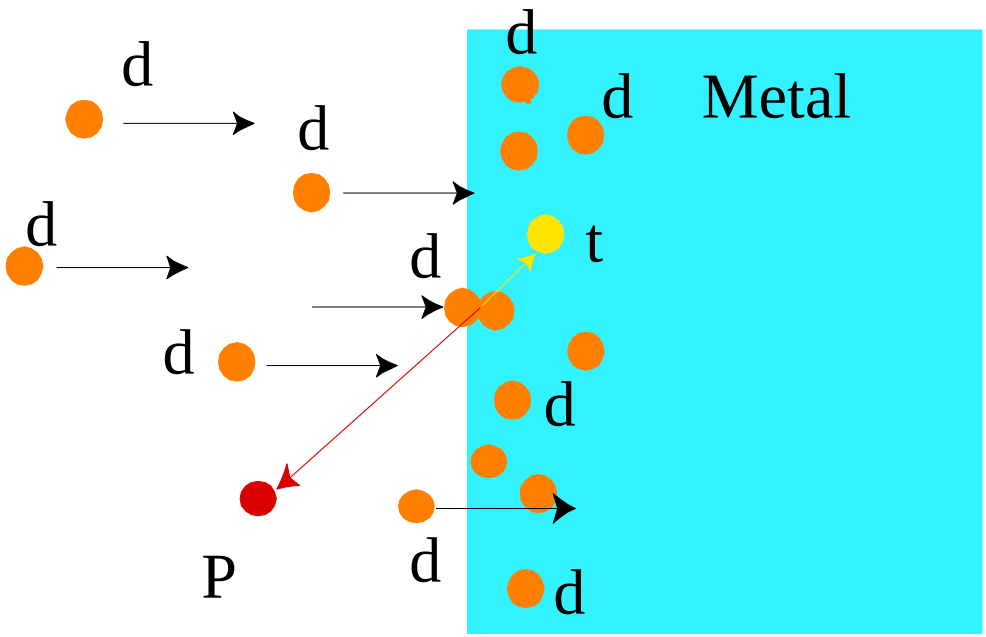
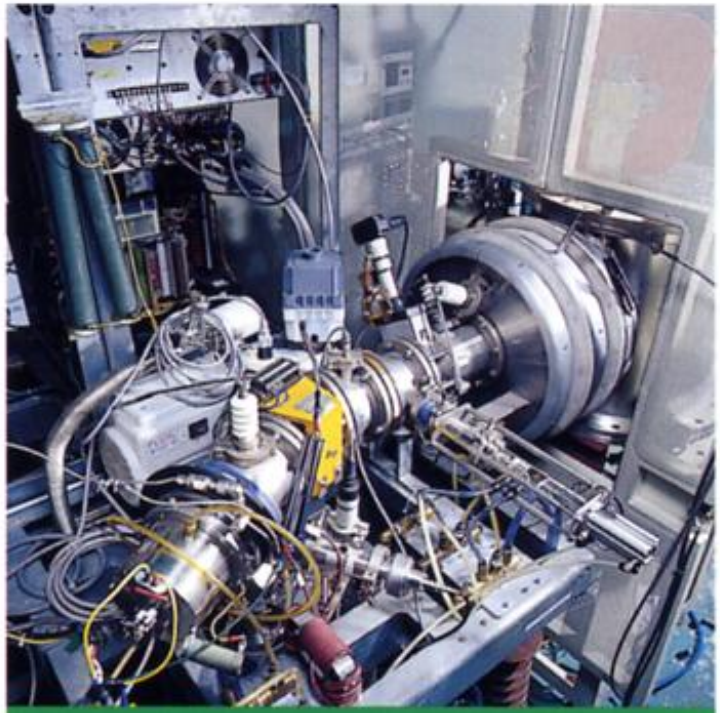
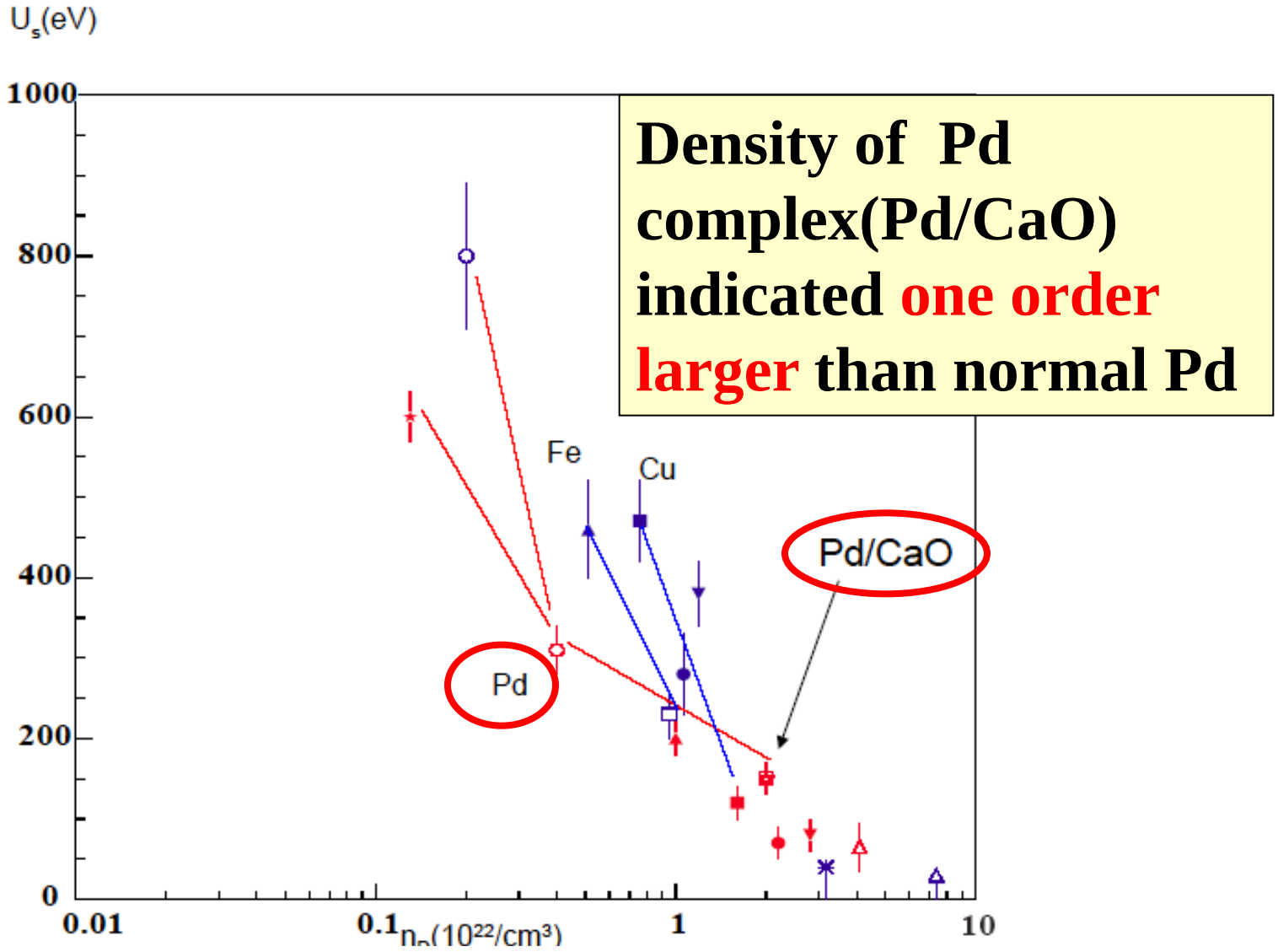
D^+ Ion beam bombardment on metal target



Experimental Apparatus



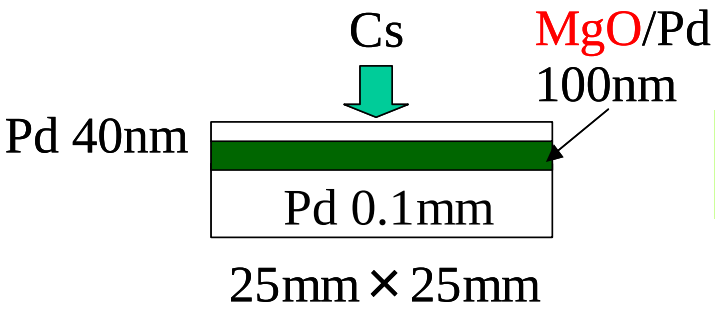
Deuterium Density measured by D^+ Ion Bombardment



Density of Pd complex(Pd/CaO) indicated one order larger than normal Pd

Deuteron Density(10^{22}/cm3)

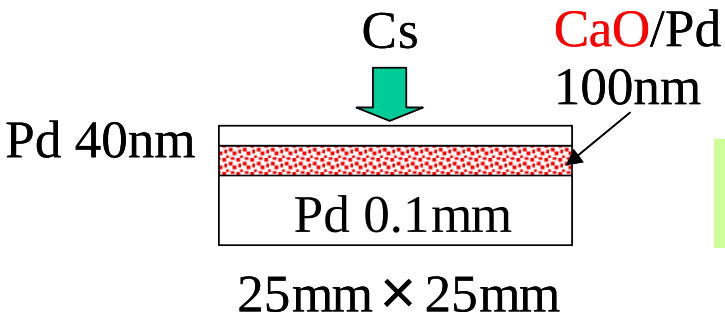
Effect of Intermediate Layer



Work Function

MgO;3.3eV → NO Pr detected

3 cases



CaO;1.2eV → Pr detected !

Many cases

Y_2O_3;2.2eV → Pr detected !

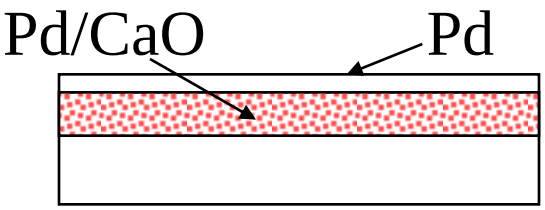
Many cases

Work function of the intermediate layer seems to be important.

→ ***Assumption*** **:Electron rich state is important**

6. Transmutation of W into Pt or Os

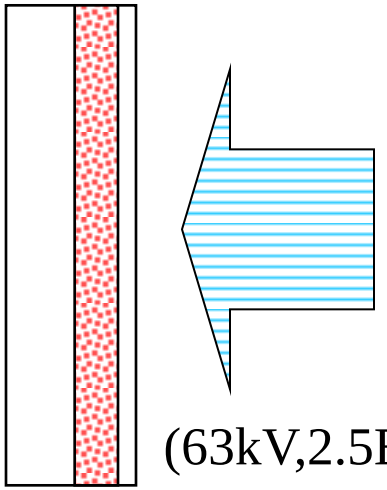
Experimental Procedure



Pd multilayer film

1.Fabrication

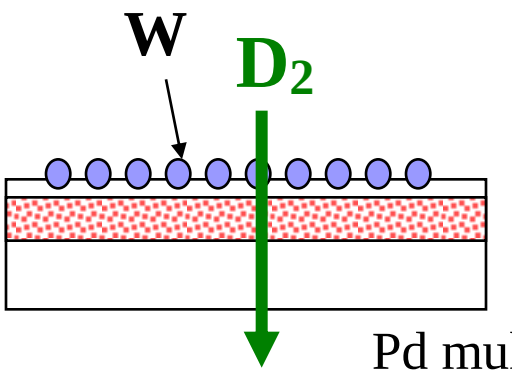
2.W Ion implantation



(63kV,2.5E14 ions/cm2)

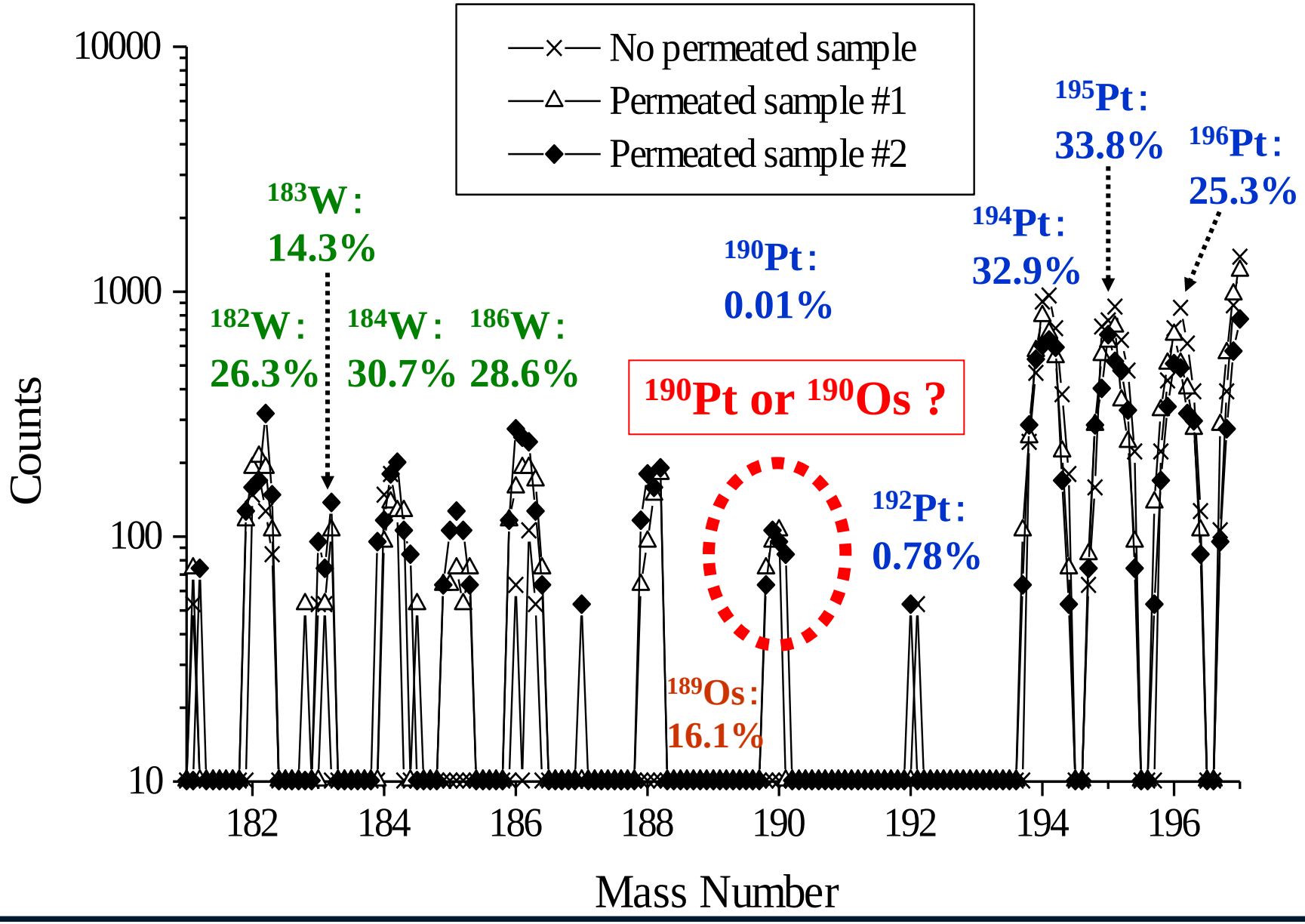
Pd multilayer film

3.D_2 Peameation



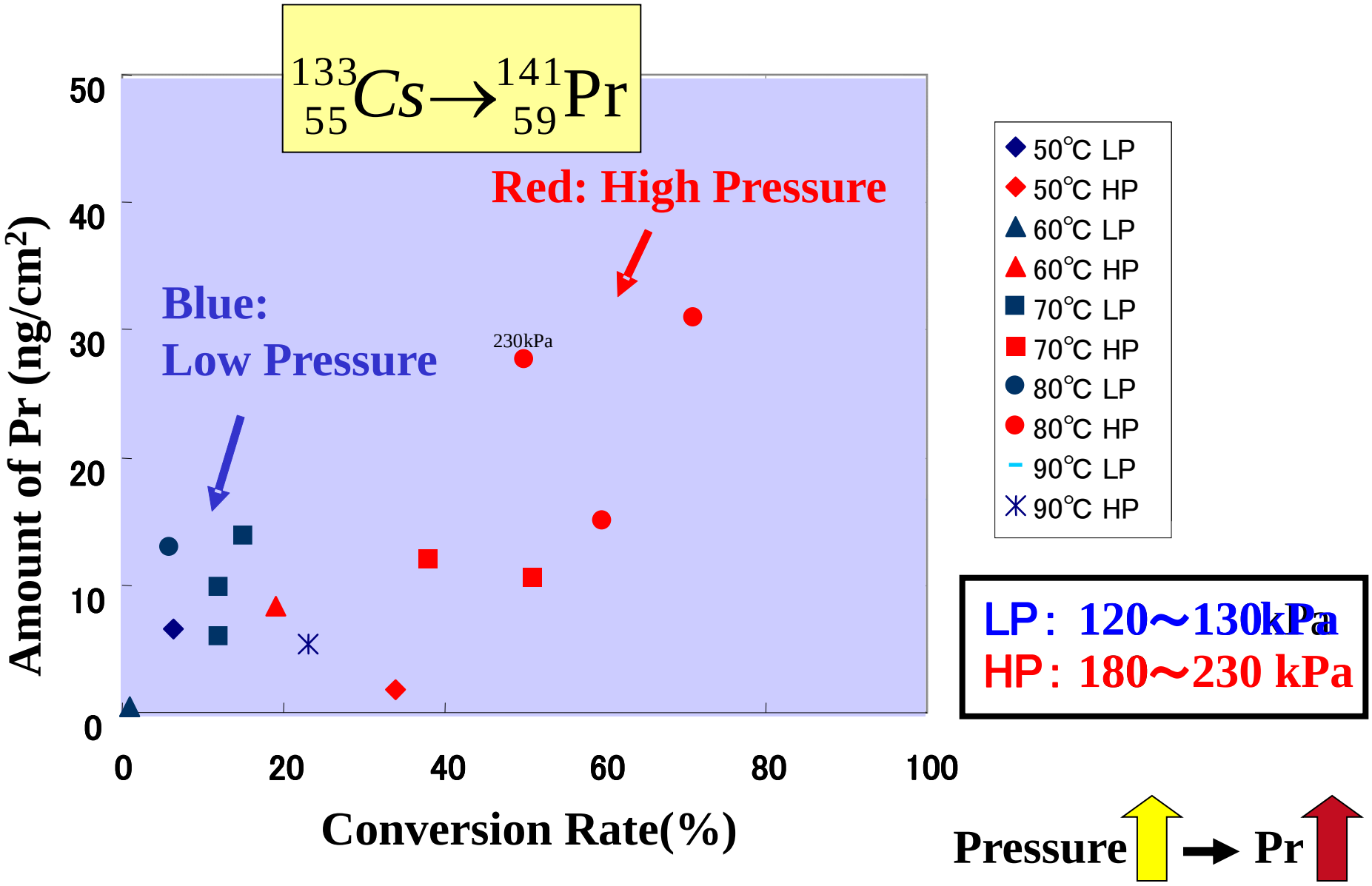
Pd multilayer film

Transmutation of W into Pt or Os

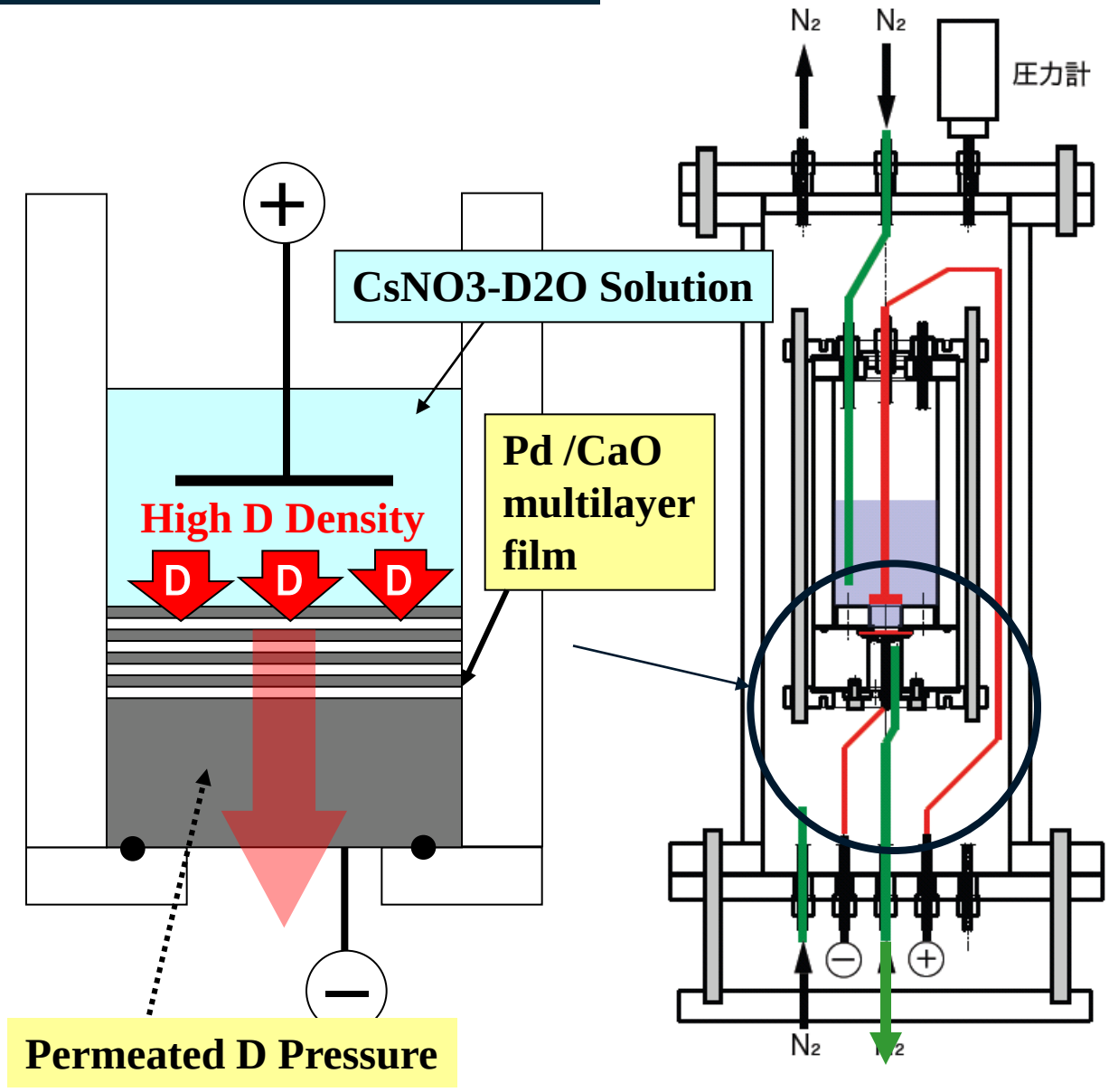


7. Increase of Products using an Electrochemical Method

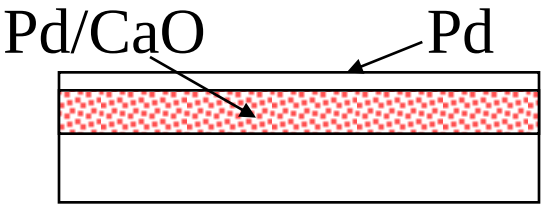
Pr Dependence on D_2 gas pressure



Experimental Apparatus aiming Increase of D Density



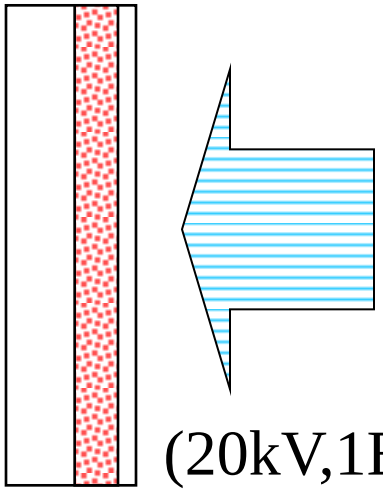
Cs^+ Ion Implantation to Pd/CaO/Pd film



Pd multilayer film

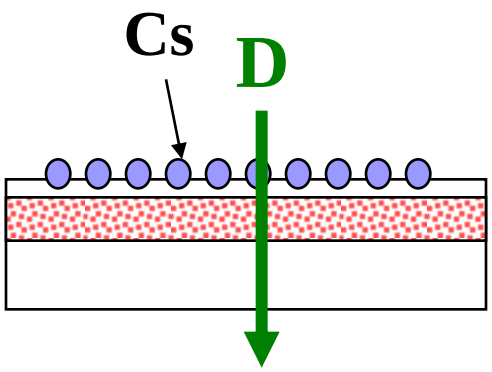
1.Fabrication

2.Cs^+ Ion implantation



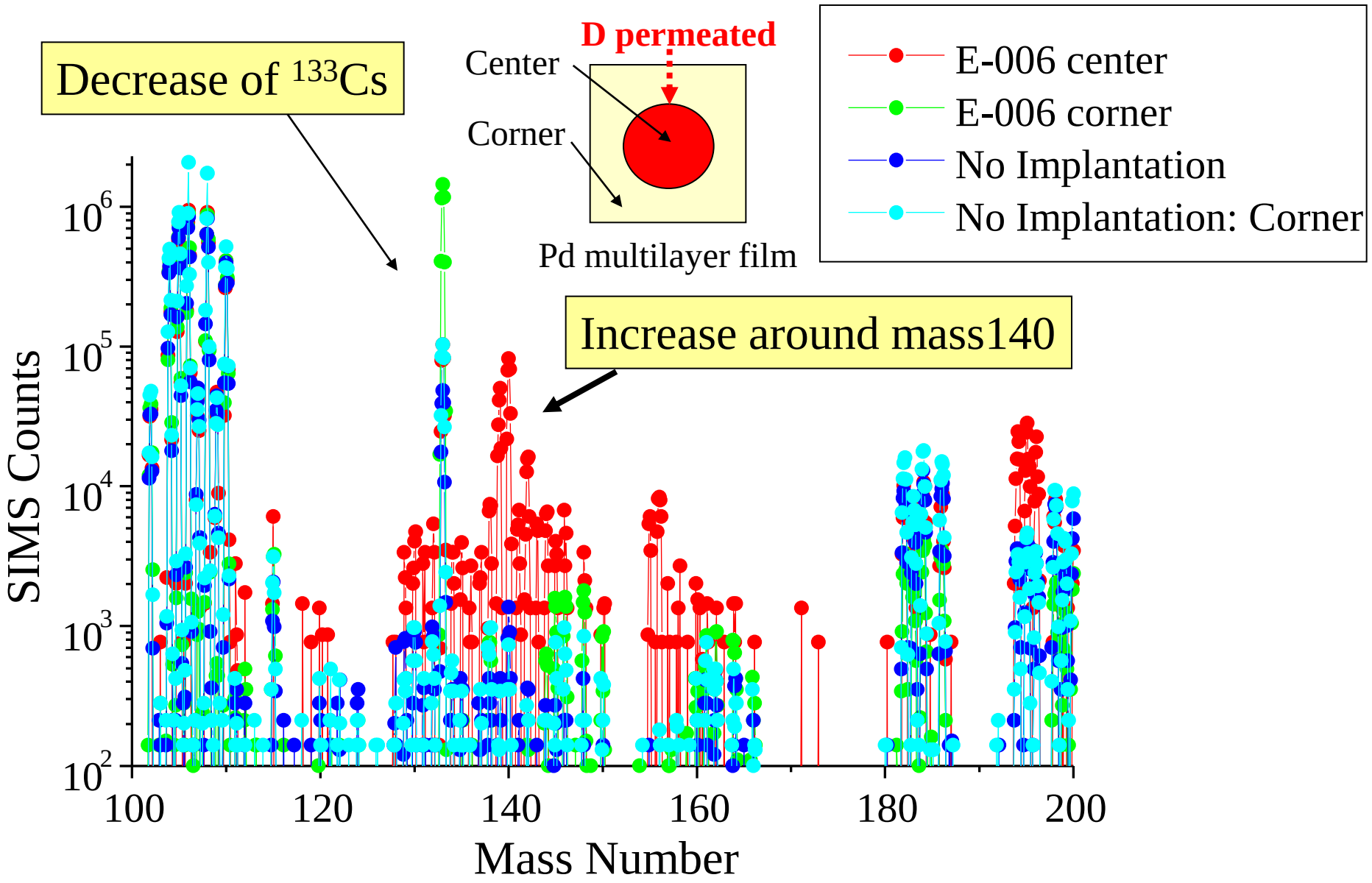
(20kV,1E16 ions/cm^2)

3.D Peameation

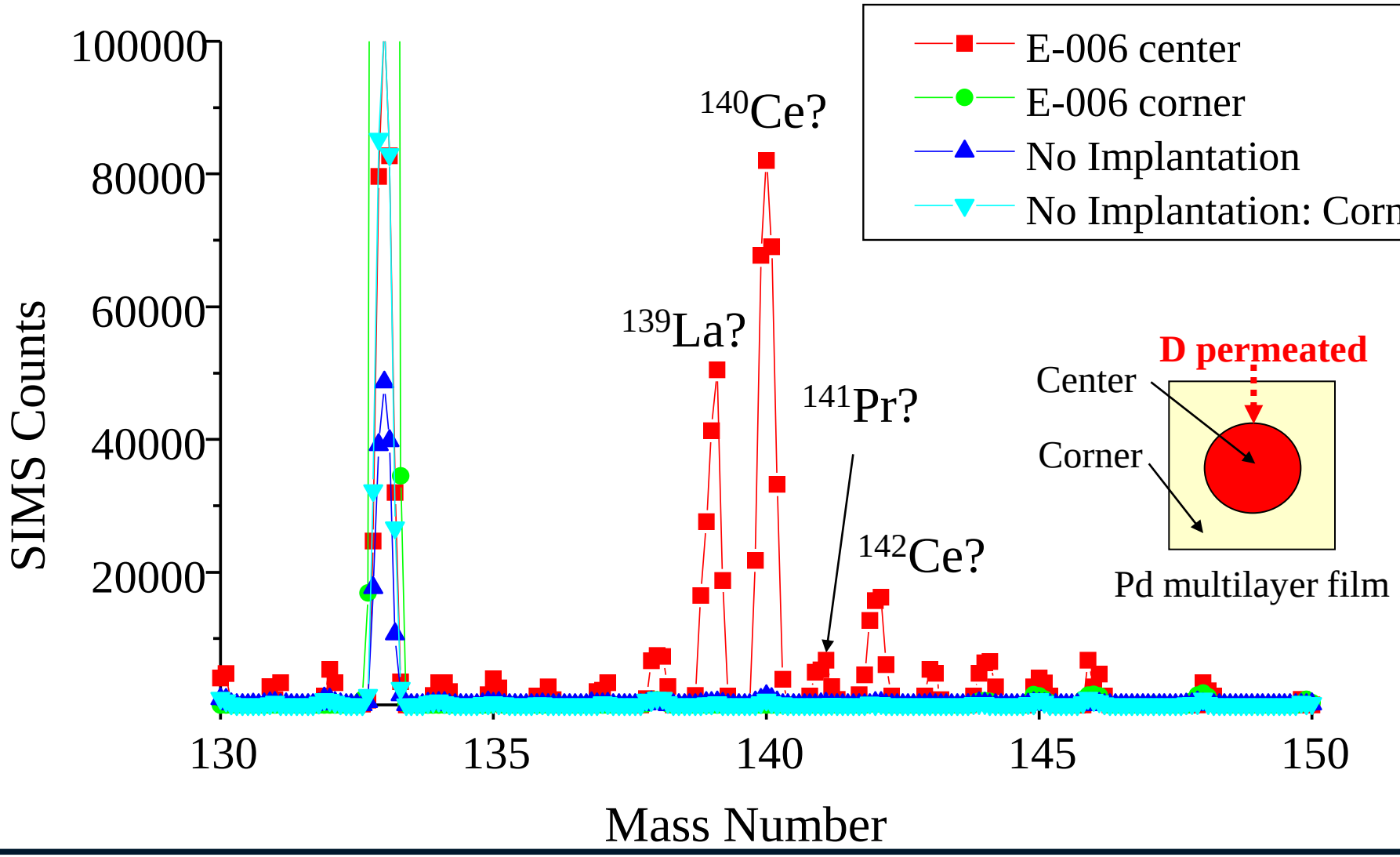


1) Give Cs for transmutation
2) Decrease of work function of surface layer

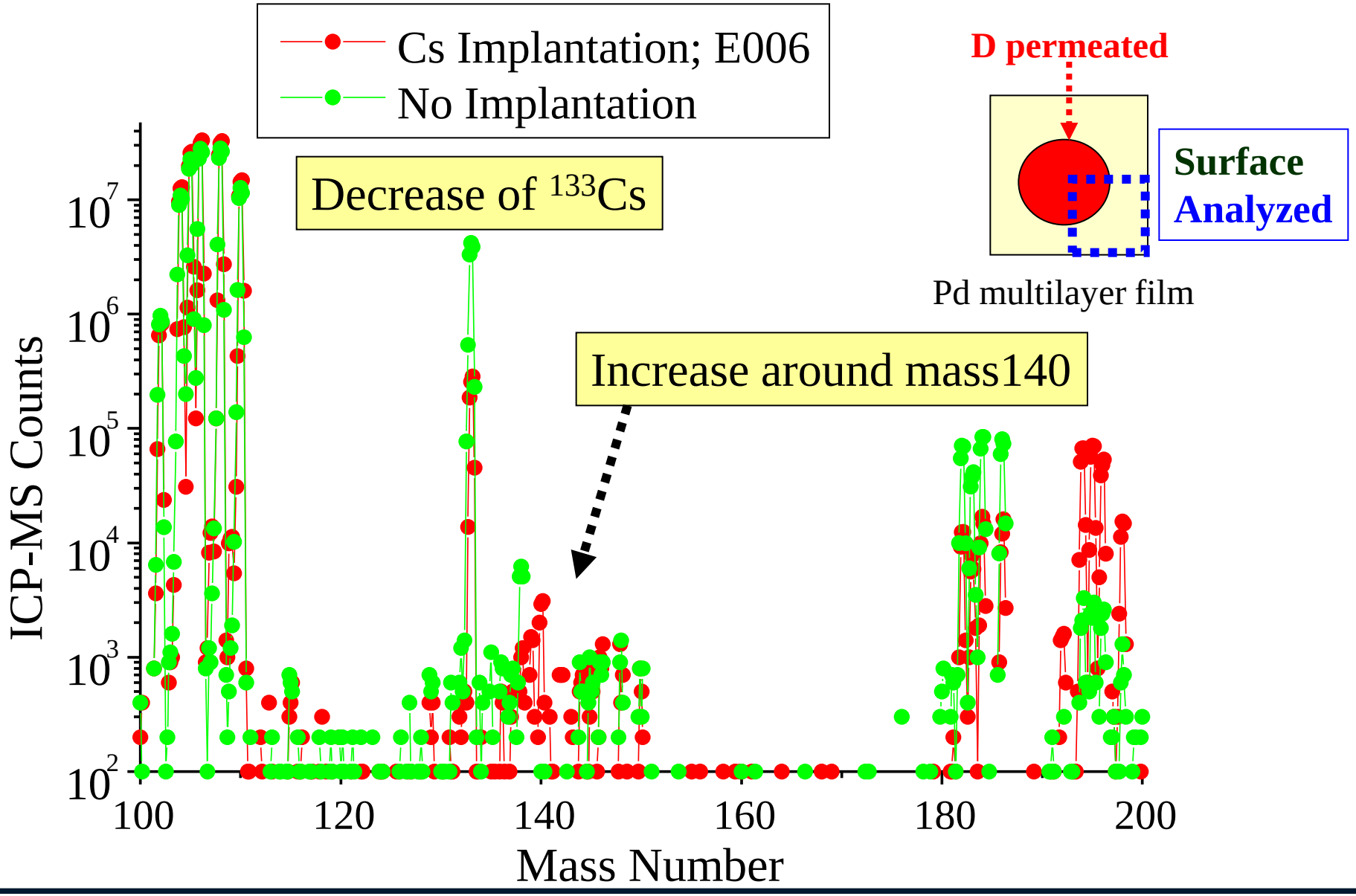
SIMS Analysis; E006 Wide Spectra



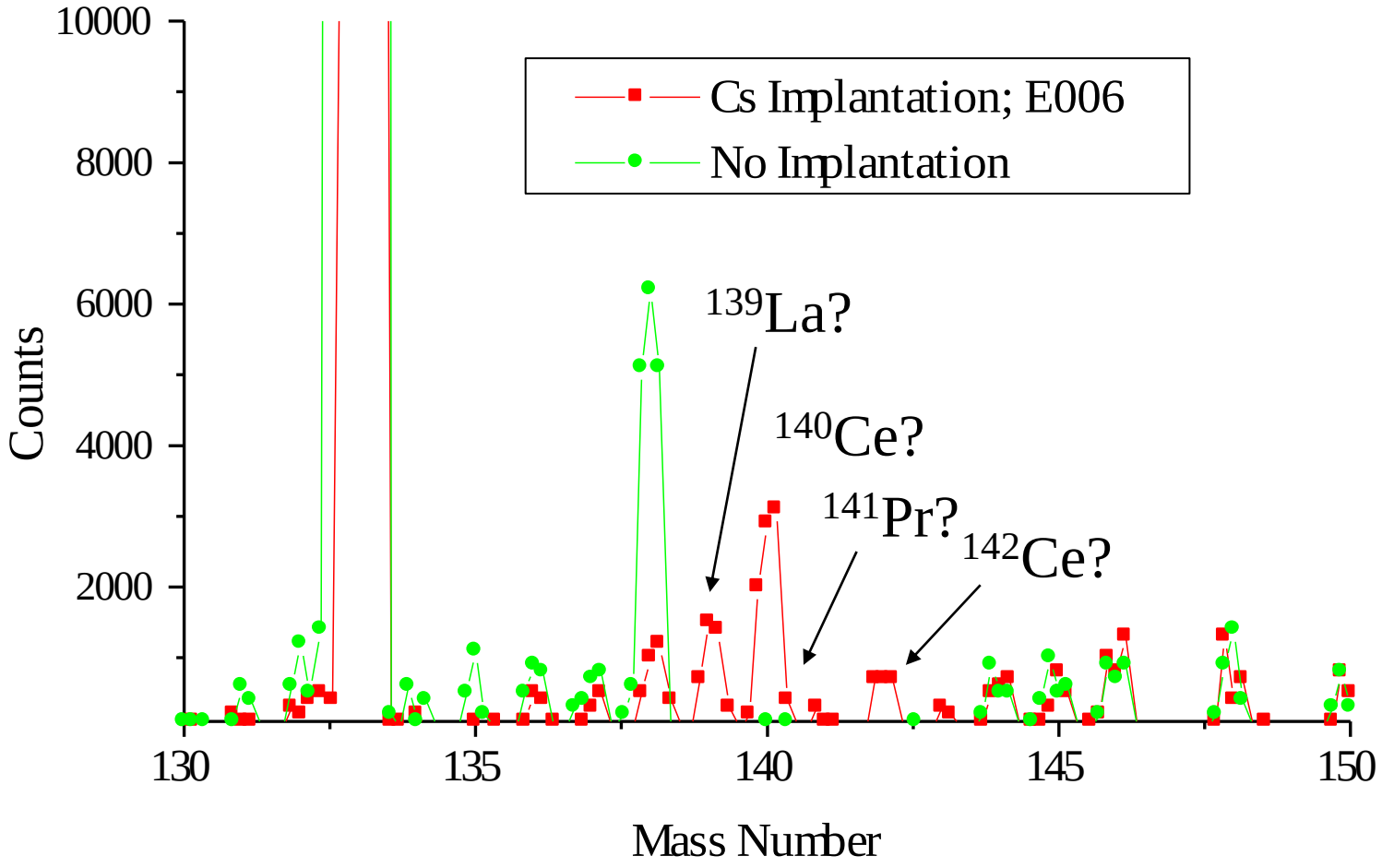
SIMS Analysis; E006



ICP-MS Analysis; E006 Wide Spectra



ICP-MS Analysis; E006



SIMS (point) and ICP-MS (all surface) gave similar results

Different Tendency from D_2 gas permeation

Consideration on Compound Species

Possible compounds for mass 140

^{138}Ba(71.7%)D	^{133} Cs (100%)^{7}Li (92.4%)	^{110}Pd ^{30}Si(3.1%)
^{106}Pd ^{34}Si(4.3%)	^{109}Ag(48.1%) ^{31}P(100%)	^{104}Pd ^{36}Ar(0.33%)
^{102}Pd ^{38}Ar(0.06%)	^{110}Pd ^{28}Si(92.3%)D	^{108}Pd ^{30}Si(3.1%)D
^{105}Pd ^{33}Si(0.8%)D	^{102}Pd ^{36}Si(0.02%)D	^{102}Pd ^{36}Ar(0.3%)D

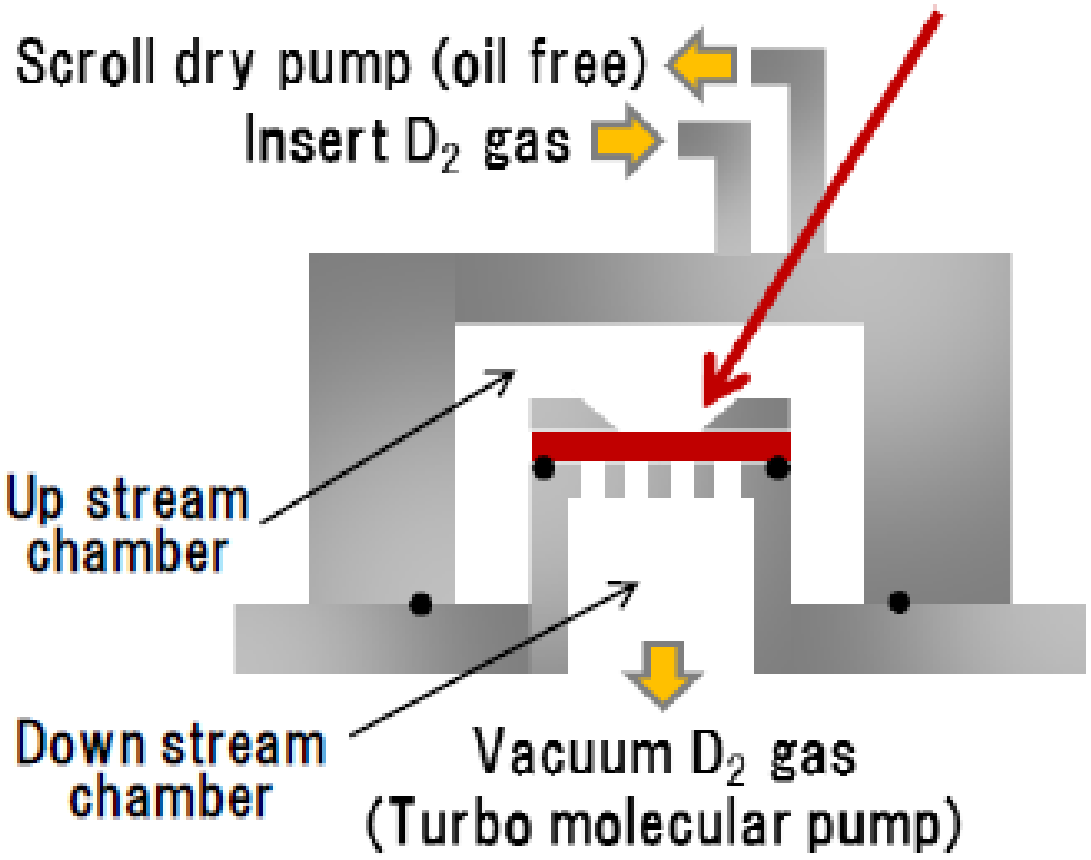
Possible compounds for mass 139

^{137}Ba(11.2%)D	^{133} Cs (100%)^{6}Li (7.6%)	^{110}Pd ^{29}Si(4.7%)
^{106}Pd ^{33}Si(0.8%)	^{104}Pd ^{35}Cl(75.8%)	^{102}Pd ^{37}Cl(24.2%)
^{110}Pd ^{27}Al(100%)D	^{106}Pd ^{31}P(100%)D	^{105}Pd ^{32}S (94.9%)D
^{104}Pd ^{33}Si(0.8%)D	^{105}Pd ^{32}Si(94.9%)D	^{102}Pd ^{35}Cl(75.8%)D

Not explained consistently by these compounds

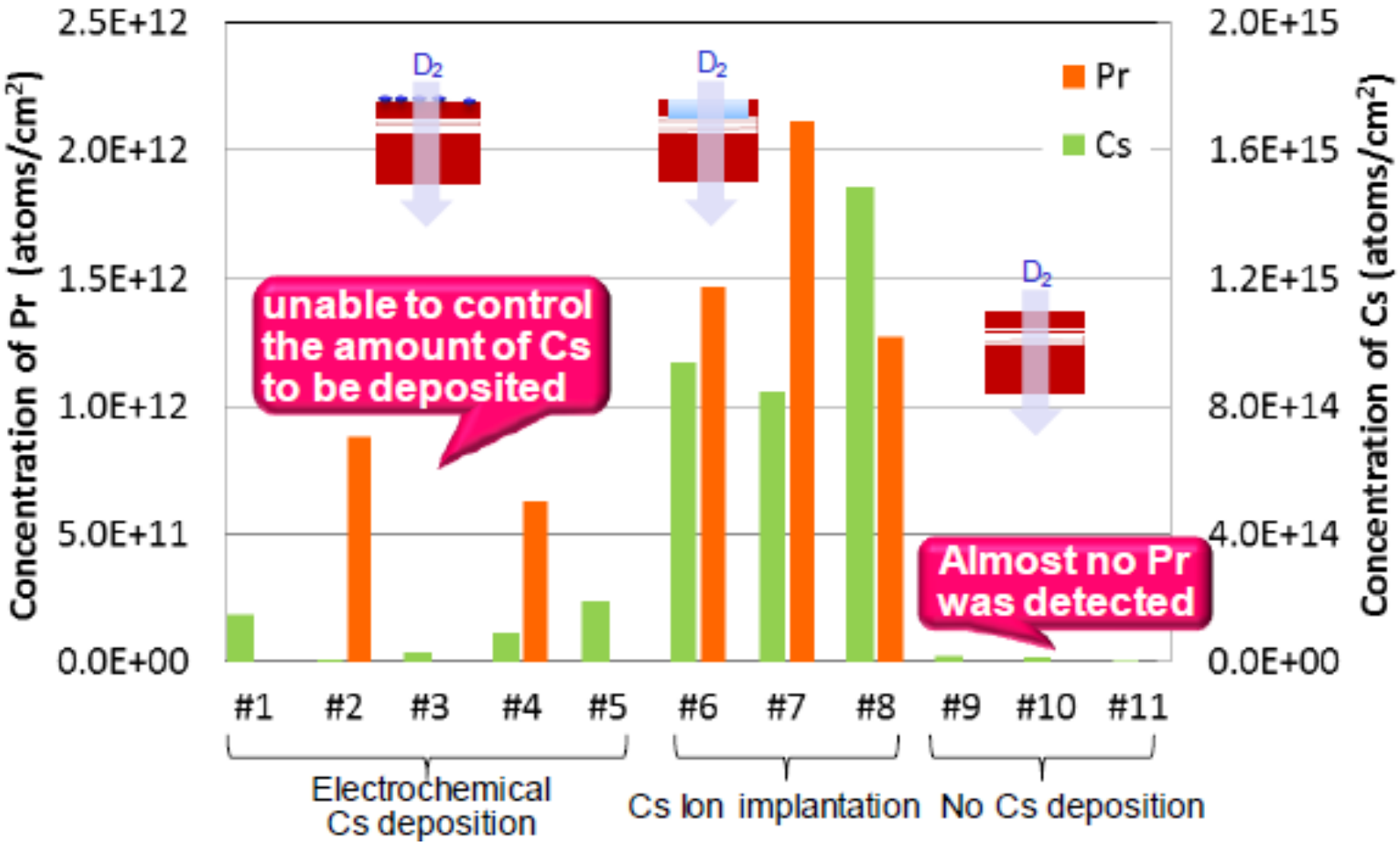
8. Replication Experiments

Replication at Toyota Central R&D Lab. – Setups -



Presented at 17th International Conference on Condensed Matter Nuclear Science, Aug.12-17, 2012, Deajon, Korea

Replication at Toyota Central R&D Lab. – Results -



Presented at 17th International Conference on Condensed Matter Nuclear Science, Aug.12-17, 2012, Deajon, Korea

Concluding Remarks

1. **Low energy nuclear transmutations from Cs into Pr, Ba into Sm and W into Pt or Os have been observed in the Pd complexes, which are composed of Pd and CaO thin film and Pd substrate, induced by D_2 gas permeation.**

2. **Experimental data that indicates the presence of transmutation have been accumulated and experimental conditions for inducing low energy transmutation reactions are gradually becoming clear, although systematic experimental study is still insufficient.**

3. **Replication experiments have been performed by some researchers and similar results have been obtained. Potential applications would be expected for innovative nuclear transmutation method of radioactive waste and a new energy source.**

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