Evidence for Condensed Matter Enhanced Nuclear Reactions in Metals with a High Hydrogen Solubility

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Typical CMNS effects do not show nuclear signatures

- *Magnitude of specific energy of Excess Heat* (keVs/Pd-atom)?
  not enough by itself to convince in nuclear origin!!!
- *^{4}He and T accumulation*? Detected in atomic form (not as nuclear particles), may be extracted from surrounded media: still indirect evidence!!! If ^{4}He detected is really from giant enhancement of d(d,γ) ^{4}He channel of DD-reaction (the rate is ~ 10^{11} s^{-1}), why no sign of intensive (at least 10^{4} s^{-1} rate) of d(d,p)t and d(d,n) ^{3}He channels (even suggesting their suppression by factor 10^{7} compared to "main" He-4 channel). No intensive X-ray.
- *"Transmutations"*: Only changes in stable isotope are observed. No signature of accompanying nuclear emissions and X-ray radiation.

Nuclear signature of CMNS effects

- DD-reaction enhancement during low energy deuteron bombardment of metallic targets (accelerator and glow discharge experiments)
- Low intensity emissions of DD-reaction nuclear species: 3 MeV protons, 1 MeV tritons, 2.45 MeV neutrons
- Energetic alpha emission ($E_\alpha \geq 10$ MeV). These alphas cannot be emitted by natural radionuclides/cosmic background.
- Soft X-ray ($E_x \leq 1.5$ keV) emission in experiments with pulsed Glow Discharge and during D-desorption from $Pd/PdO:D_x$

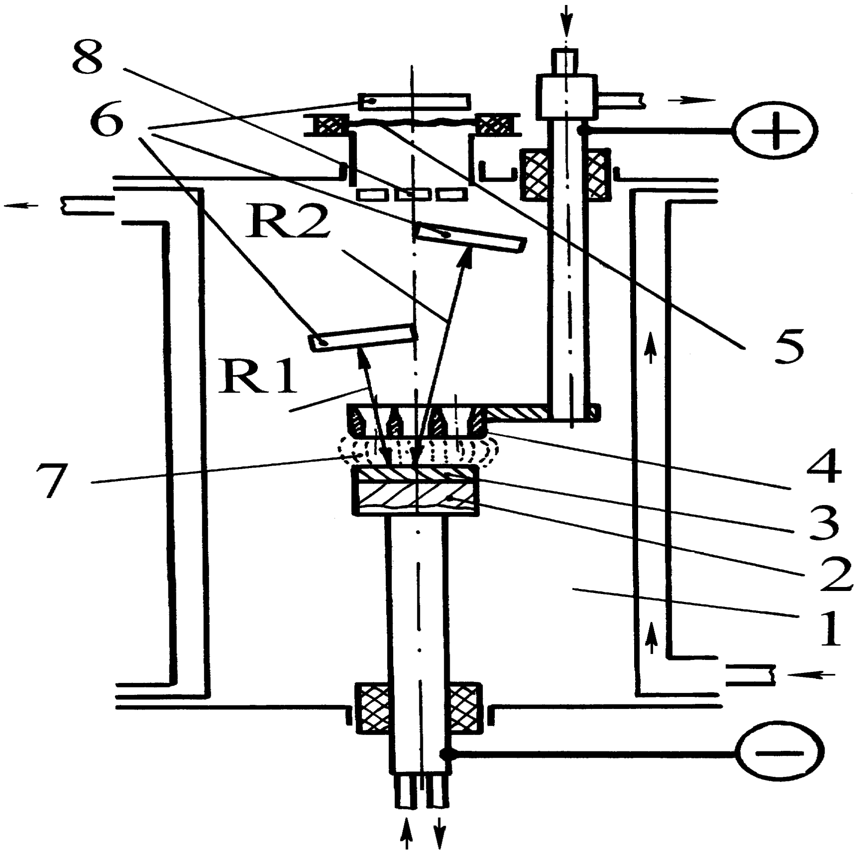
I. Enhancement of DD-reaction in metal targets

- Accelerators (J. Kasagi et al): Low energy, high-current accelerators: 2.5 < (Ed)lab < 20 keV, Beam current I ~ 10-300 μA. Energy spread < 1.0 %. Duo-plasmatron ion source (E ~ 50 keV), decelerating system, magnetic optics to deflect neutrals from target. Target cooling system: (77-300 K). Energy spread < 1 %.
- Pulsed Glow discharge: D_2/H_2 GD, $P(D_2)$ = 2.0 – 10.0 tor. Ti- cathode (S=0.64 cm^2), Mo-anode, (cathode-anode distance: x~ 5.0 mm). Square-shape pulses: duration τ = 200–400 μs; rise time ~1 μs pulse; repetition 2.0 kHz; Voltage: U =0.8-2.5 kV; Current I=150-450 mA. Stability of U and I: ± 10 %. E_d energy spread ~ 15 %.
- Charged particle detectors: Accelerators and GD produce huge noise. Neutron detection is difficult. Si-surface barrier (SSB) dE-E. Full noise suppression. Detection of 3.0 MeV protons from d(d,p)T reaction. Plastic track detectors CR-39 (N_{track} < 20 cm^{-2}) detection of 3.0 MeV protons

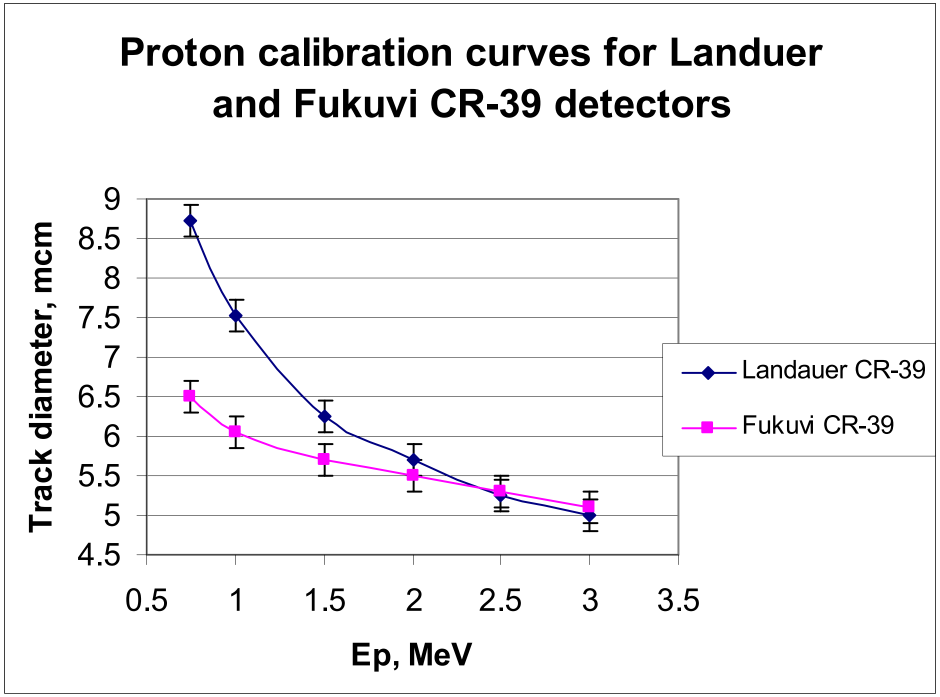
Enhancement of DD-reaction in metal targets at low deuteron energy ($1.0<E_d<10$ keV)

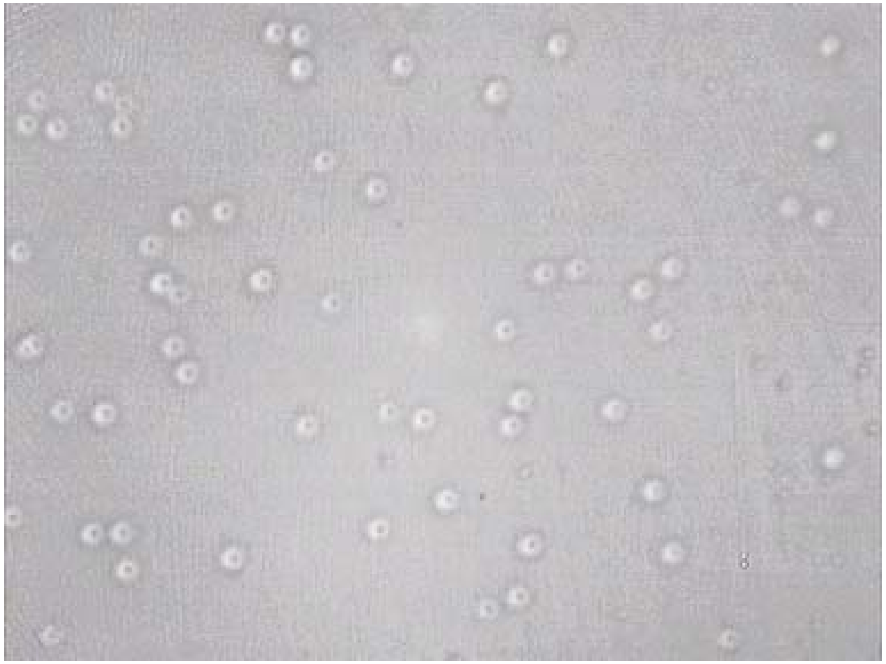
- Most metals show enhancement of DD-reaction yield at E_d << 10 keV compared to the standard yield obtained by extrapolation of the DD-reaction cross-section to these E_d (see accelerator experiments: F. Raiola et al., Nuclear Physics, A719, 61C (2003), J. Kasagi et al., J. Phys. Soc. Jpn., **71**(12), 2881 (2002)).
- Recently, high-current glow discharge measurement showed strong enhancement of DD-yield – about 9 orders of magnitude at E_d =1 keV in Ti target (A. Lipson et al., JETP, **100**, 1175 (2005).

Glow discharge set up



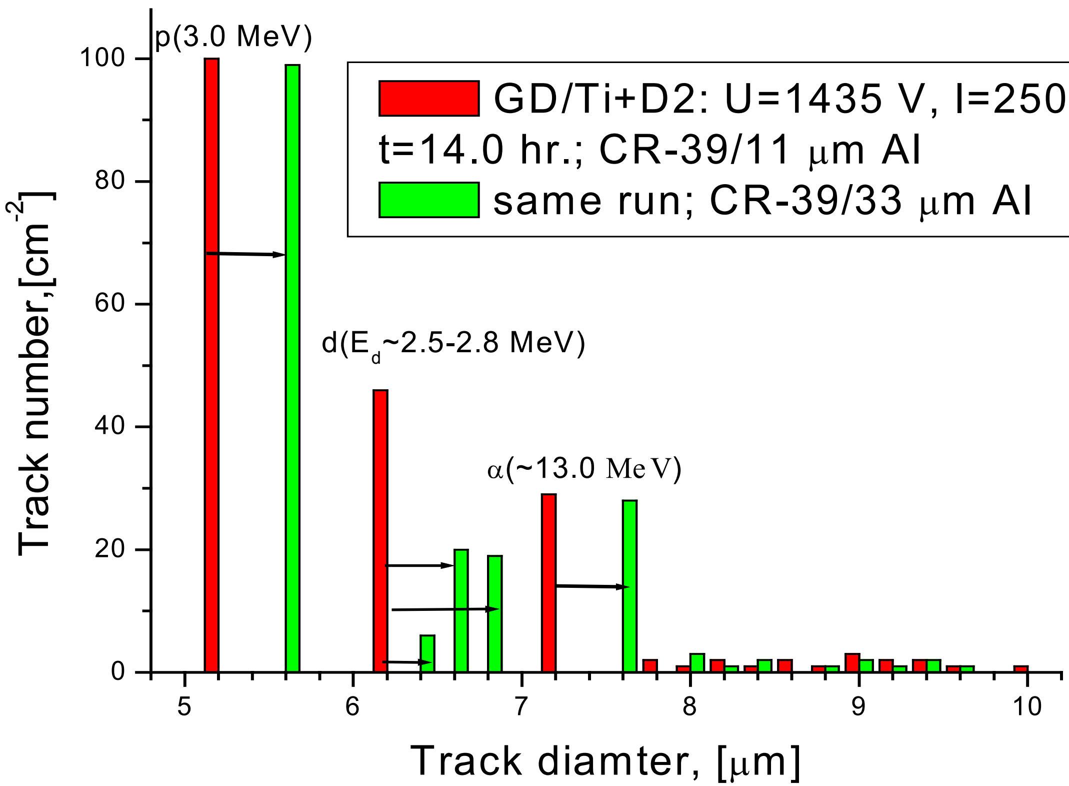
CR-39 track detectors: Proton calibration with Van De Graf accelerator E_p = 2.5 MeV



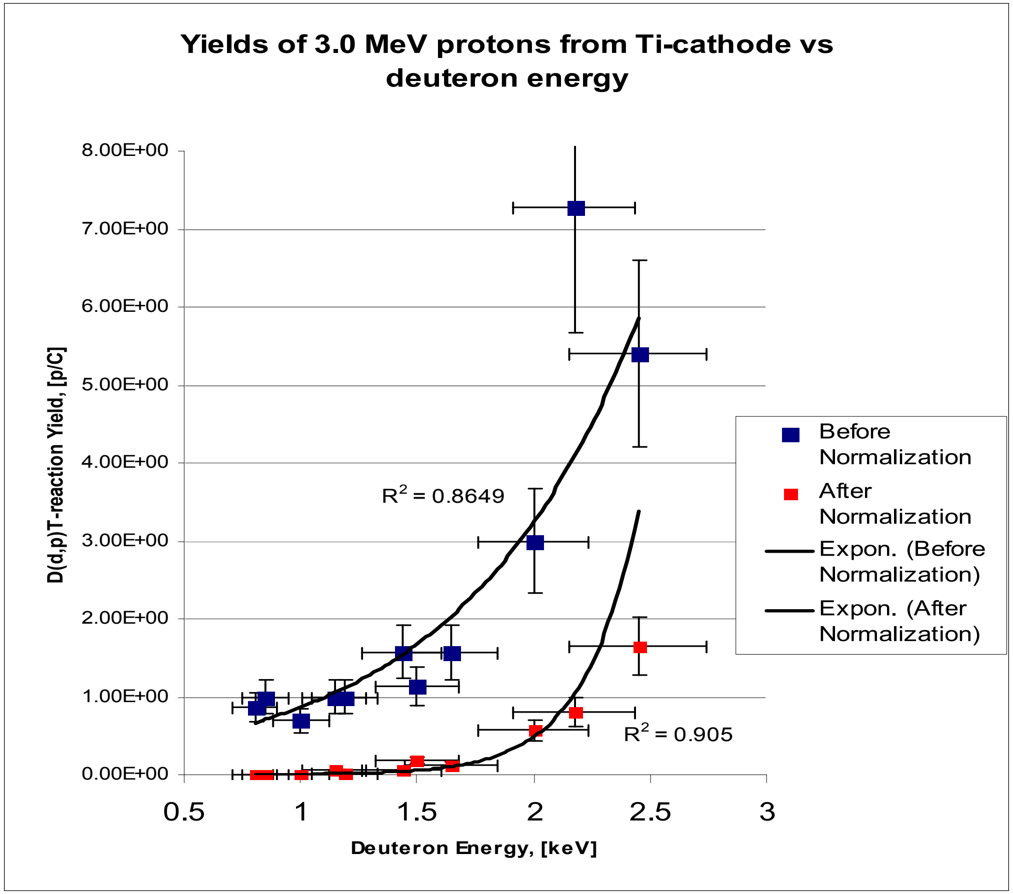


3.0 MeV proton energy estimate by absorption in Al-foil

11μm Al →33μm Al ⇒ d(5.2μm)→d(5.6μm) ⇒ 2.9±0.2 →2.8±0.3 MeV



Yields of 3.0 MeV protons before and after normalization to deuterium concentration



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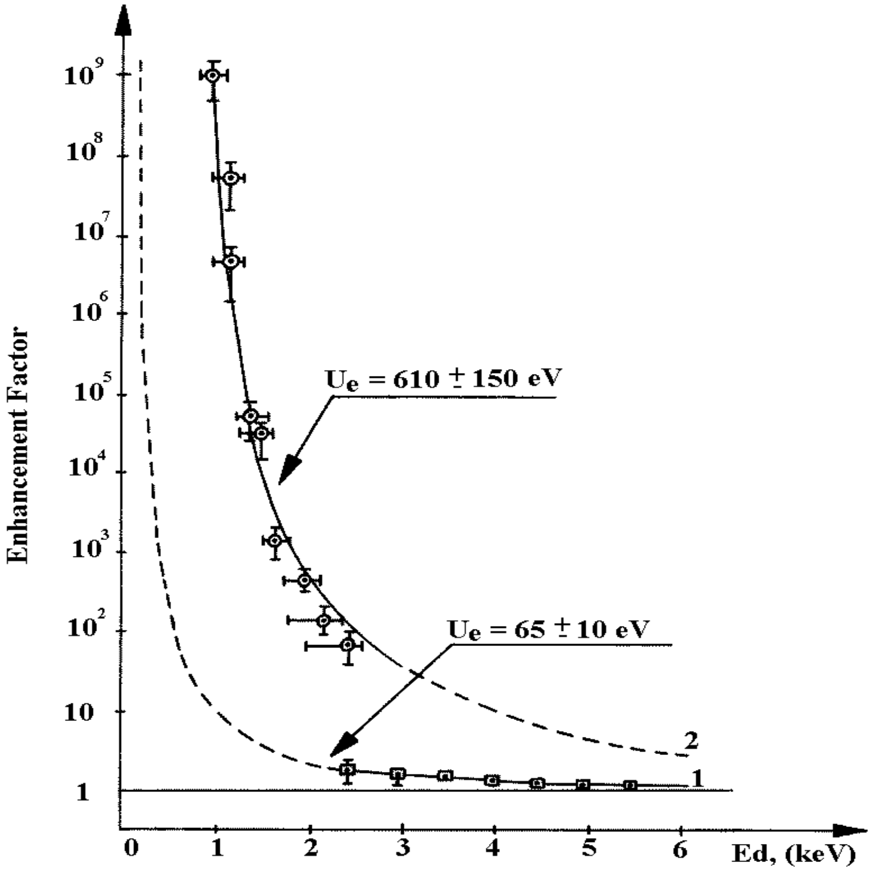
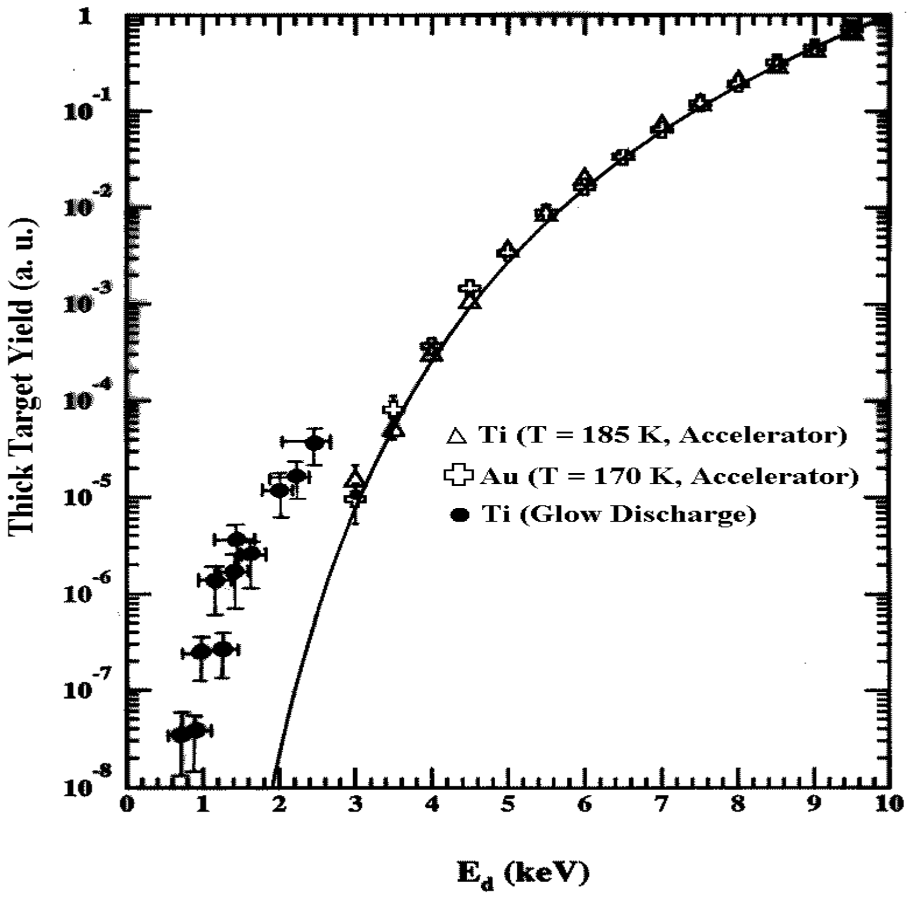
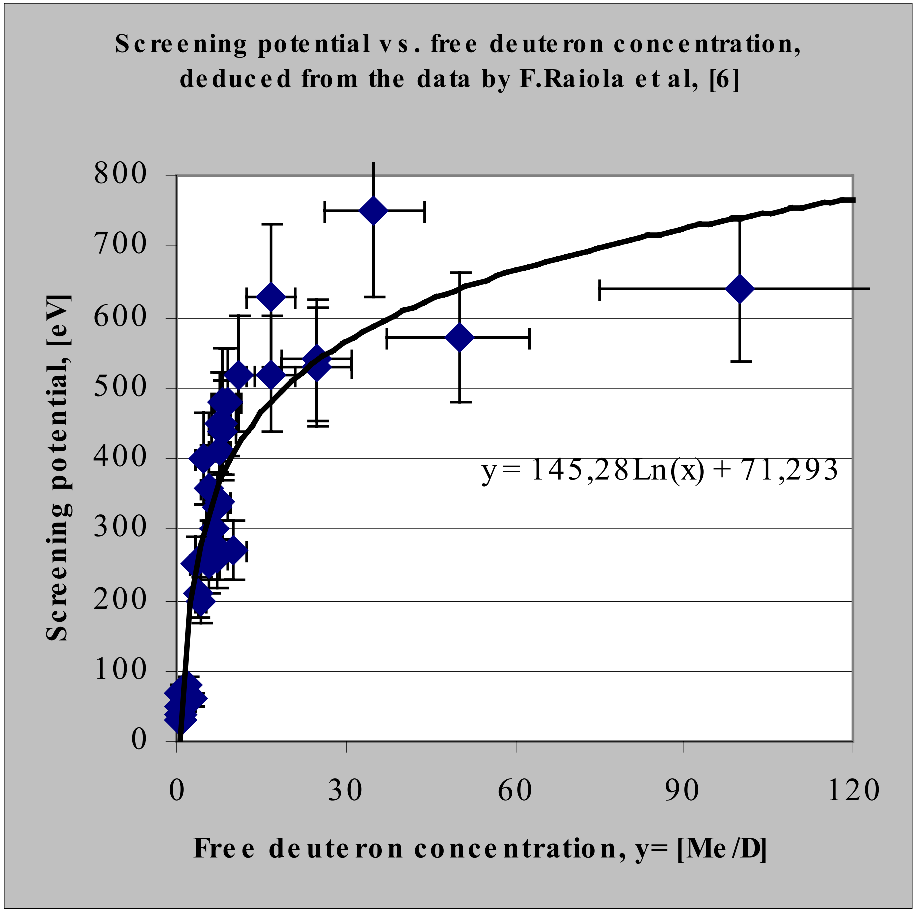
DD-reaction enhancement factor ($f(E) = Y_p(E)/Y_b(E)=\exp[\pi\eta(E)U_s/E]$ for Ti-target: (1)-accelerator; (2)-GD



Thick target yields for accelerator and GD compared to bare yield



Data are taken from F. Raiola et al, Europhys. J.A**19**, 283 (2004) at T_0=290K, J_0=0.03mA/cm^2, $E_d \geq$5keV.
Points are consistent with increase in y = Me/D: Hf, Y, Lu, Sc, Gd, Tm, Ti, Ce, Yb, Sm, Zr, Er, Pr, Eu, Ho, La, Ge, C, W, Sr, Ir, Ba, Ru, Au, Ag, Re, Ni, Nb, Ta, Zn, Bi, Mo, Mn, Mg, Cu, Rh, Fe, Pt, V, Pb, Pd, In, Tl.



Electron Screening in metals

Target/ [Ref.]	ΔE_d(lab), [keV]	ΔJ, [mA]	T, [K]	U_e, [eV]	Closest metal-host level	E(level), [eV]
Ti[7]	5-30	0.054	263	≤30	Ti(M_{II}/M_{III})	32.6
Ti[9]	2.5-10.0	0.06-0.25	186	65±15	Ti(M_I)	58.3
Ti*	0.8-2.45	225-450	≥1800	610±150	Ti(L_{II})	461
Au[7]	5-30	0.054	263	61±20	Au(O_{II})	71
Au[9]	2.5-10.0	0.06-0.25	180	70±10	Au(O_{II})	71
Pd[7]	5-30	0.054	263	800±70	Pd(M_I)	670
Pd[9]	2.5-10.0	0.06-0.30	313	310±30	Pd(M_V)	334
PdO[9]	2.5-10.0	0.06-0.30	193	600±20	Pd(M_{II})	560

II-III. Low Intensity emissions of DD-reaction products (N) and energetic alphas

Neutrons emission (references):

Fracture of deuterated dielectrics, LiD, D_2O (fractoemission): V.A. Kluyev, A.G. Lipson et al, Sov. Tech. Phys. Lett., 1986 (In ~ 10-20 n/impact)

Acoustic cavitation in D_2O with Ti horn: A.G. Lipson et al, Sov. Tech. Phys. Lett., 1990. (In ~ 0.5 n/s).

Ferroelectric phase transition through Curie point (Tc – 220 K) in DKDP single crystal, A.G. Lipson et al, JETP, 1993 (In ~ 20 n/transition).

Superconducting phase transition (Tc = 92 K) in deuterated HTSC ceramic $YBa_2Cu_3O_{7-x}$, A.G. Lipson et al, Tech. Phys., 1995 (I_n ~ 20-30 n/transition).

Exothermic deuterium desorption from Pd/PdO:Dx heterostructure, A.G. Lipson et al, Sov.Tech. Phys. Lett., 1992 (BF_3), Fusion Tech., 2000 (NE-213).

Electrolysis of Pd and Ti in D_2O: S.E. Jones et al, Nature 1989, A. Takahashi et al, 1989, T. Bressani et al, 1991, etc.

Example: Neutron detection from Au/Pd/PdO:Dx sample (in the cell) with pair of NE-213 low Background/20m underground facility, Hokkaido University (A. Lipson et al . Fusion Tech, 38, 2000),

$\Sigma\varepsilon$(2.45 MeV n) = 10 %

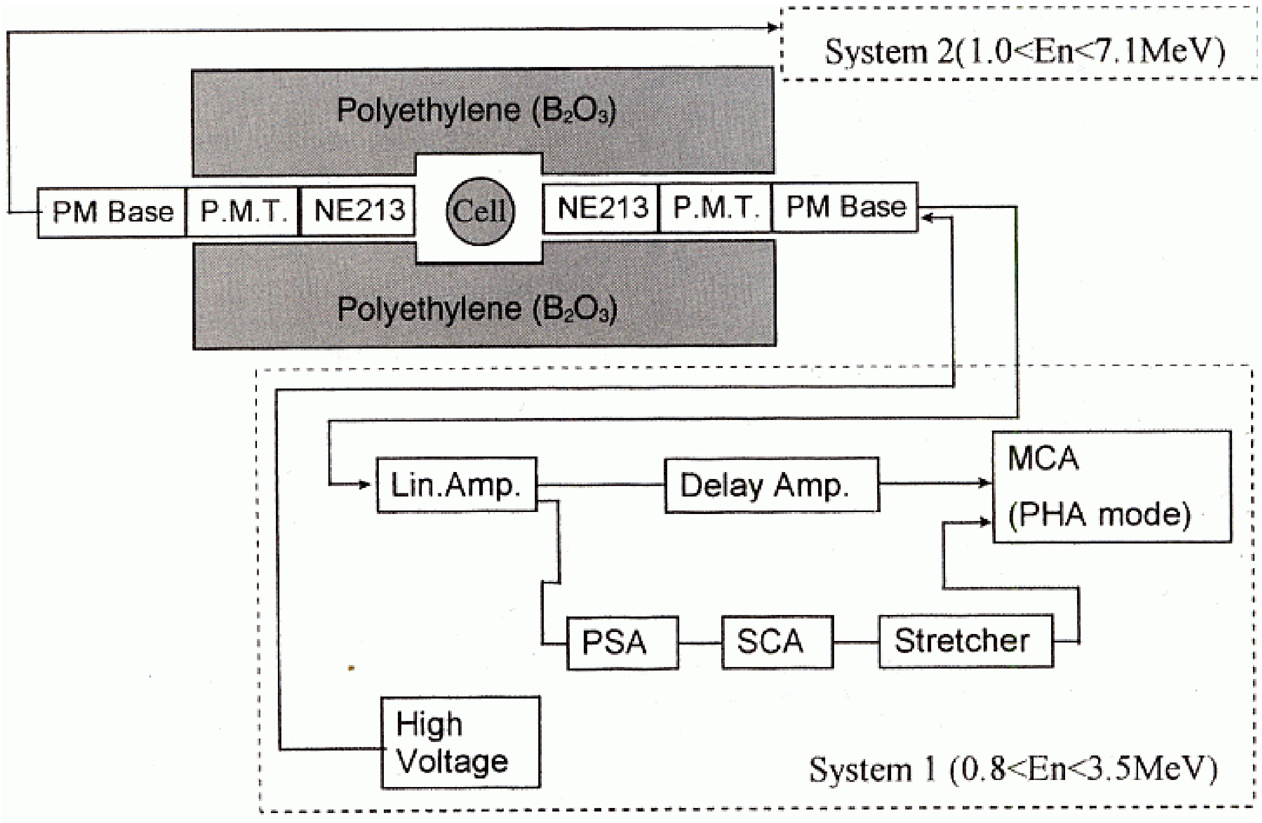
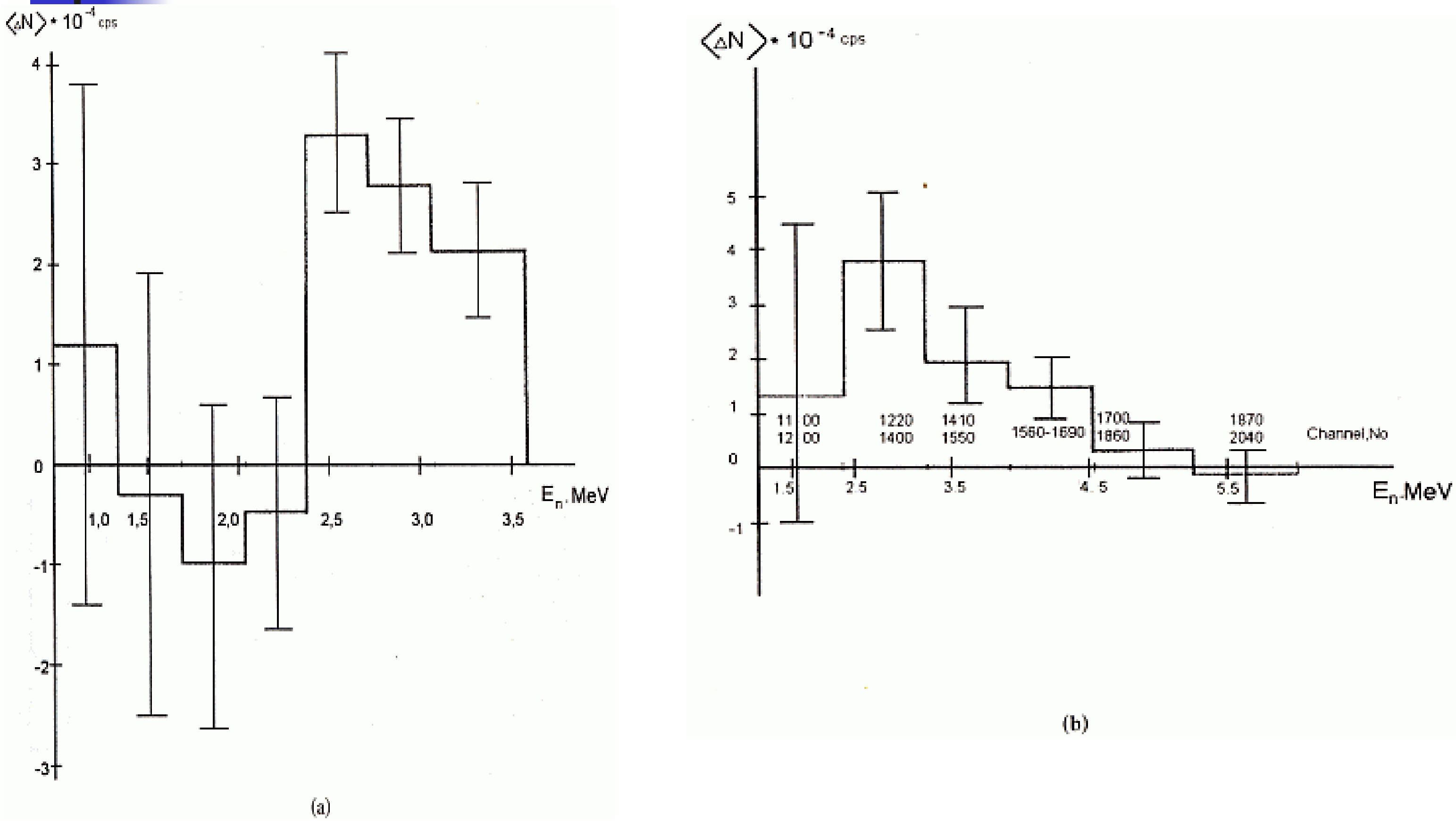


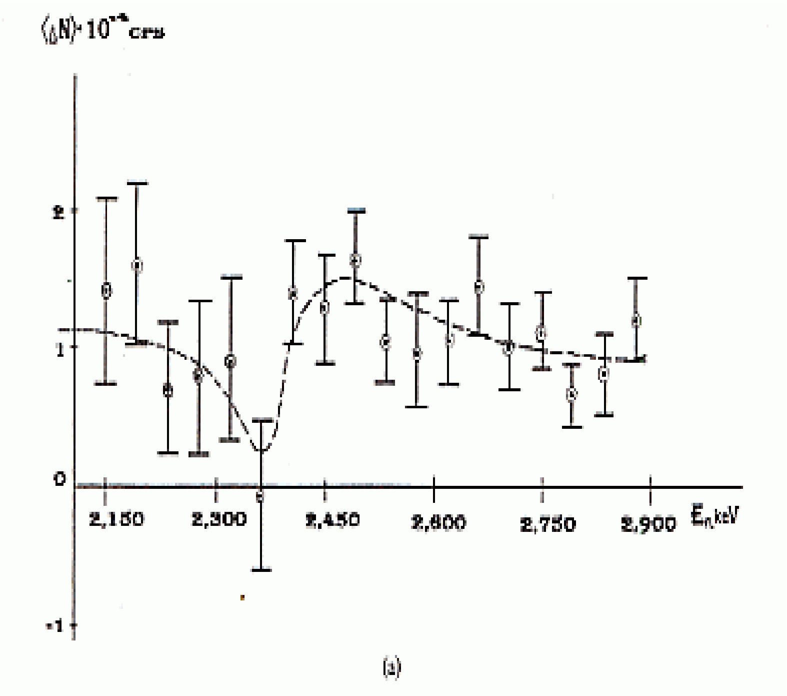
Fig. 1. The NE-213 neutron detection facility.

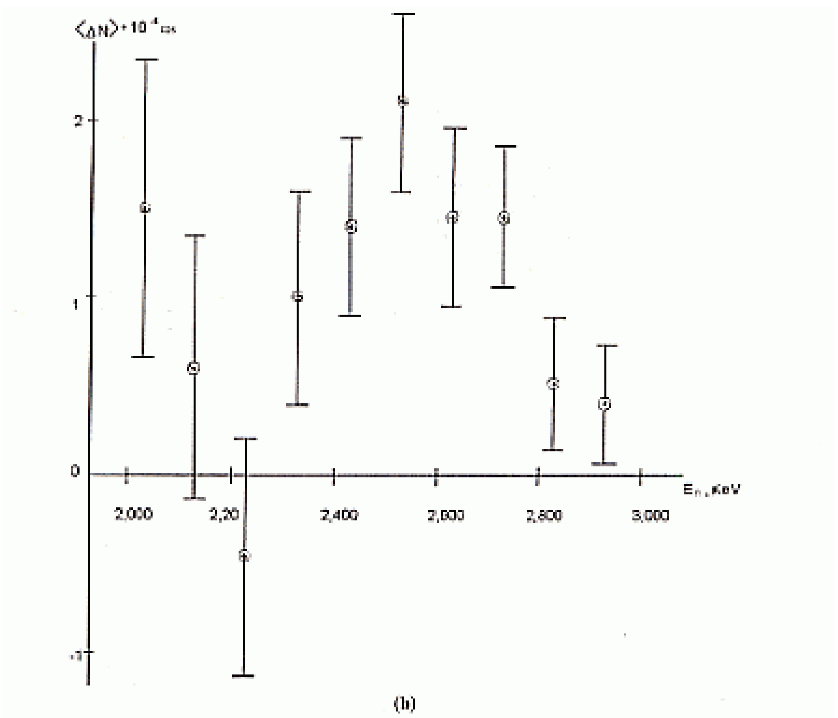
Energy distributions of neutron counts from NE-213 detectors: high gain system 1 (a), low gain system 2 (b)



Neutron spectra of Au/Pd/PdO:Dx sample (with background subtracting) in the 2-3 MeV range derived from high gain (a) and low gain (b) NE-213 detectors:

$I_n = (1.8 \pm 0.19) \times 10^{-2}$ n/s





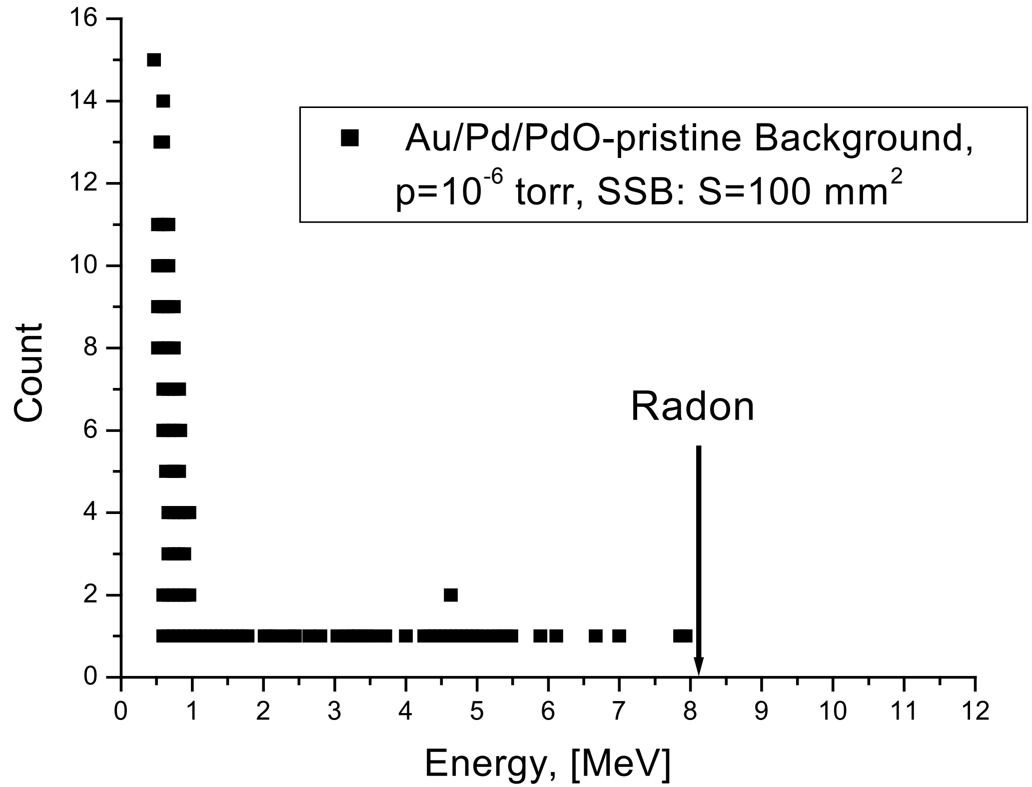
Low Intensity emissions of DD-reaction products (p & T) and energetic alphas

- p-t coincidence measurements at thermal deuterium desorption from TiDx system (S.E. Jones et al, ICCF-10).
- Random 3 MeV proton emission in Pd/PdO:Dx during exothermic deuterium desorption measured with surface Si barrier detectors (A.G. Lipson et al, Fusion Tech., 2000).
- Reproducible 3 MeV proton and energetic alpha (E > 10 MeV emissions in controllable D-desorption from Pd/PdO:Dx with CR-39 (Lipson et al, ICCF10-12)

Typical charged particle background in vacuum (t=8 days in a row)

A.G. Lipson et al., Fusion Tech, **38**, 238 (2000)

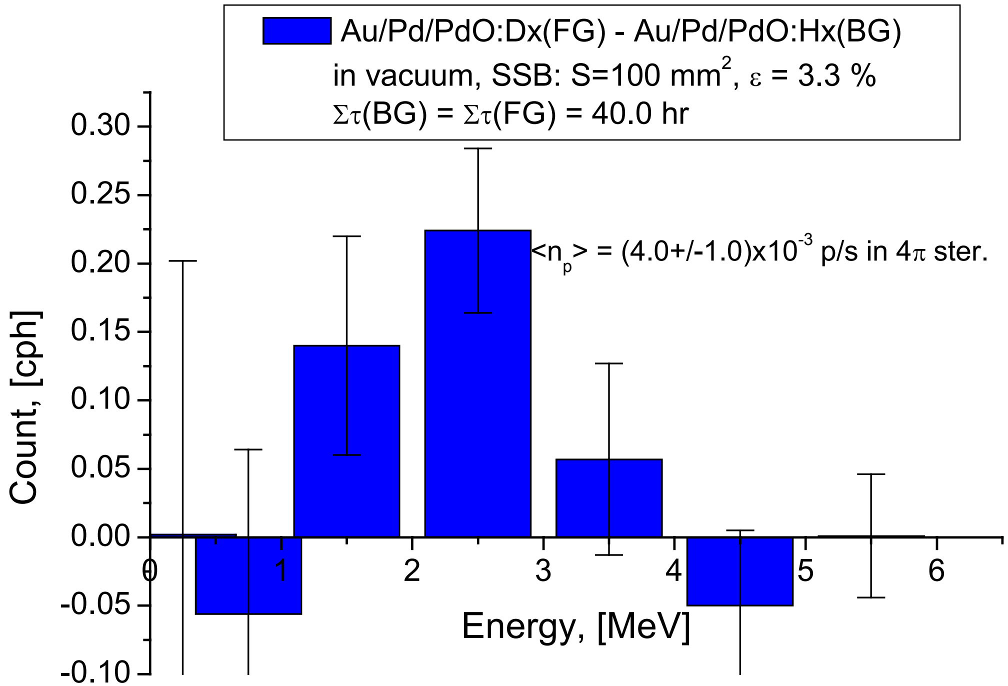
Au/Pd/PdO pristine sample is in front of the SSB-1 (d=15 mm)



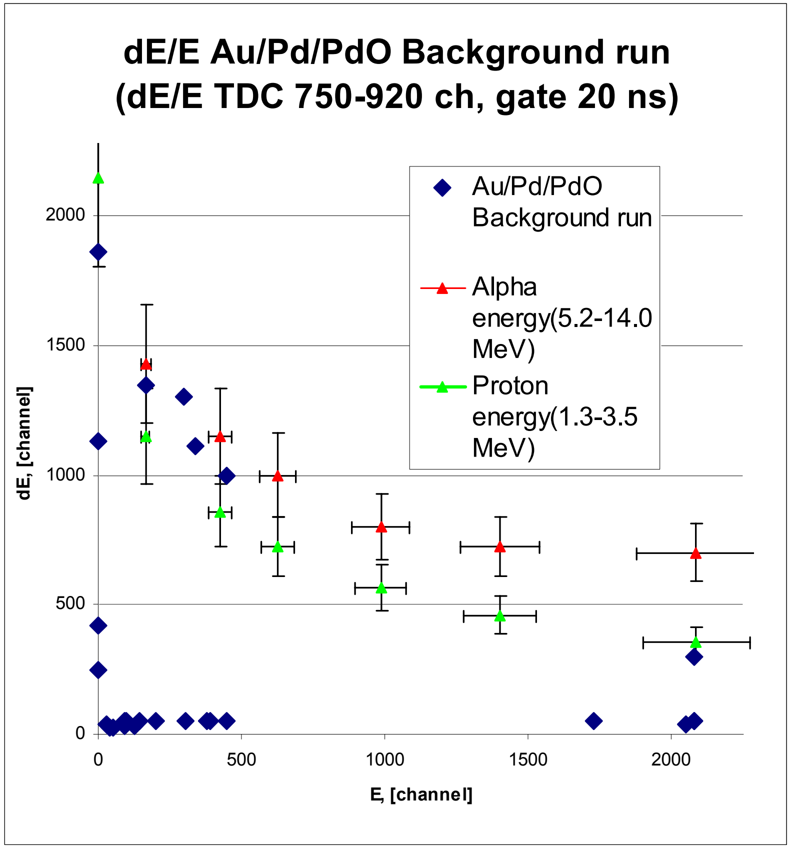
Typical weak spontaneous DD-proton emission from Au/Pd/PdO:D_x (after electrolytic D-loading) in vacuum

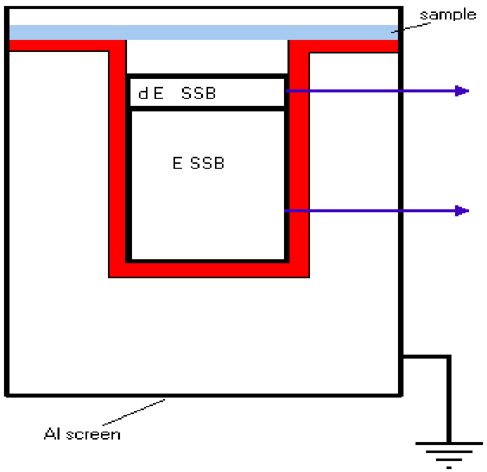
with Au/Pd/PdO:Hx Background subtracting

SSB- measurement



dE/E Background spectra of charged particles from pristine Au/Pd/PdO sample





Total measuring time = 500 hr.

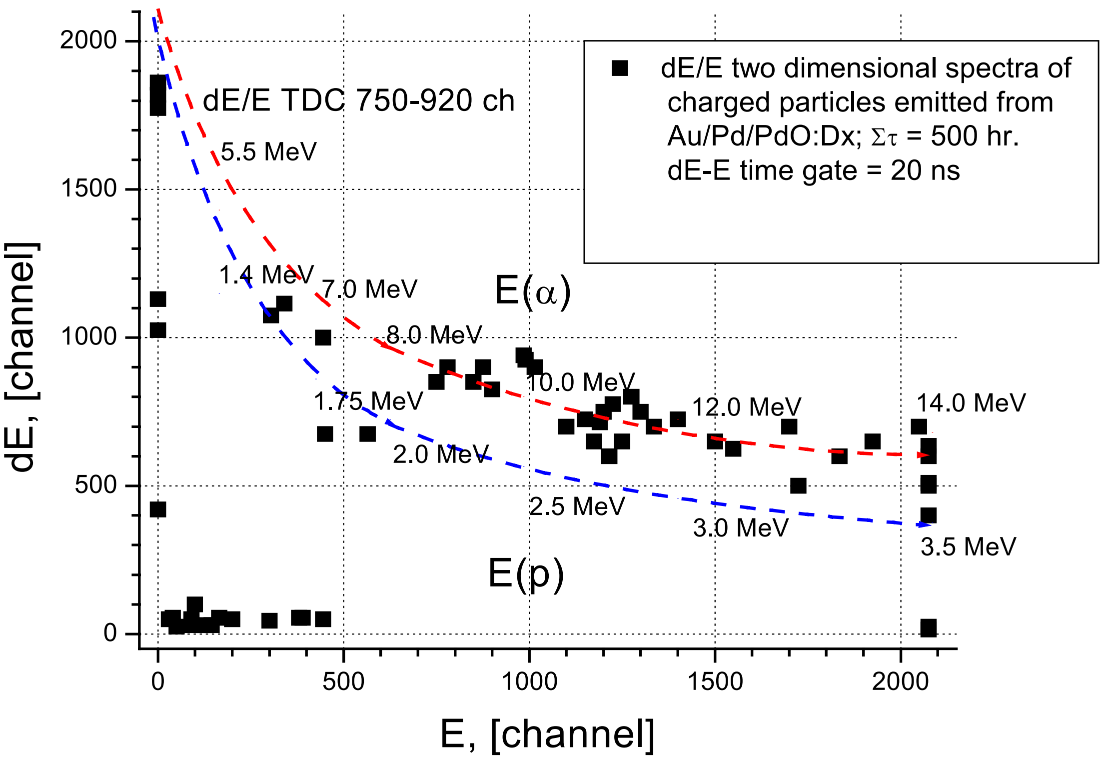
Sample is in front of the dE detector (d=10 mm).

dE/E (SSB: dE=20μm, E=100 μm) 2-dimensional spectra of charged particles from Au/Pd/PdO:D_x (after electrolysis)

Total measure time = 550 hr

$\langle N_\alpha \rangle = (6.4 \pm 1.2) \times 10^{-4}$ [s^{-1}] in 4π

Alphas: $8 < E_\alpha < 14$ MeV



Example of reproducible nuclear emissions in controlled conditions of exothermic D-desorption from PdO/Pd/PdO:Dx hetero-structure. Objectives

- To obtain reproducible nuclear emissions in controlled conditions of exothermic D-desorption from PdO/Pd/PdO:Dx hetero-structure.
- DD-reaction yield (3.0 MeV protons)
- Energetic alphas
- Soft X-rays ?
- Control of sample temperature and D-desorption rate on-line.
- To figure out how these emissions could be linked via D-desorption

Sample preparation

- The samples of Pd/PdO were synthesized by thermal growing of thin oxide layer (PdO_y) of ~ 20 nm thick on top of 110 μm thick annealed cold worked Pd foils (area 5x2 cm2) using an oxygen-propane torch.
- Electrochemical loading of Pd/PdO cathodes by x=D(H)/Pd = 0.7; j ~ 20 mA/cm^2 in 1M-LiOD/D2O using a special cell with divided cathode and anodic spaces.
- In control experiments a similar Pd/PdO sample was electrochemically loaded with hydrogen in 1-M NaOH/H2O
- The Pd/PdO:Dx sample with attached CR-39 or thermal luminescent (TLD) detectors is placed under mechanical loading (m=150 g) for one hour at T =20 °C

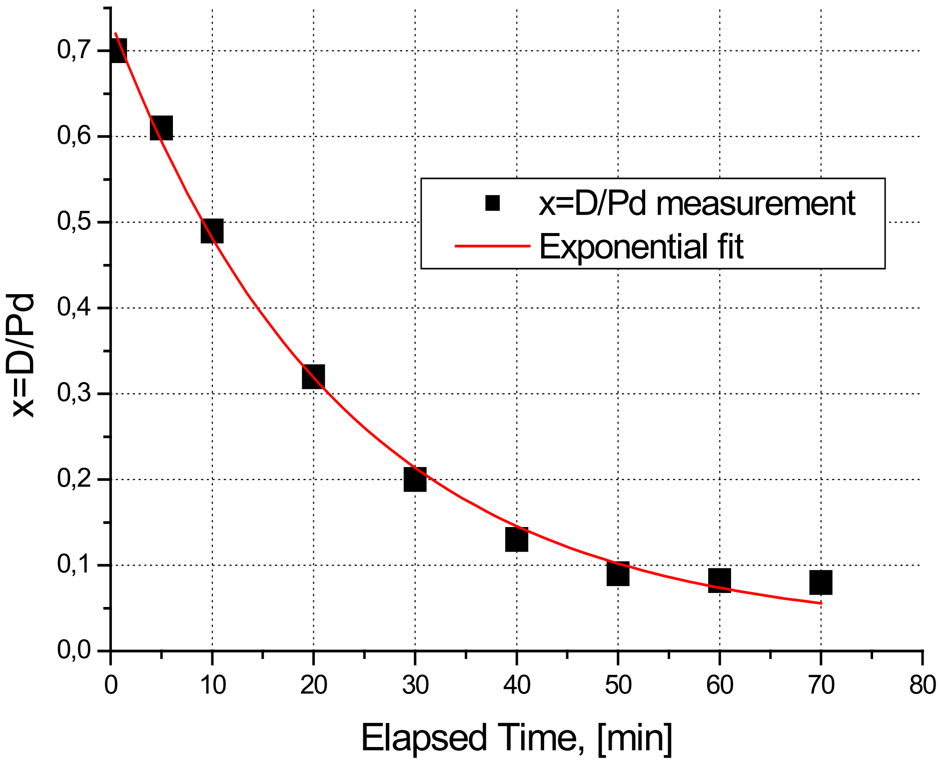
Nuclear Detection

- Charged particle detection: CR-39 (Landauer inc) with set of metal filters (Al 11-44 μm , Cu 25 μm thick) in order to estimate type and energy distributions of emitted particles: Time of exposure t = 12 x 3600 s, accordingly to maximal D-desorption rate.
- Identification of individual tracks by in-depth etching of CR-39 (etching depth in the range of 9.2 - 46 μm (7-35 h etch in6N-NaOH at 70° C) – 3D analysis. Comparison of track diameters with that of similarly etched calibration detectors irradiated with proton or alphas of various energy.

Integral deuterium desorption from 110 μm Pd/PdO heterostructure vs. elapsed time

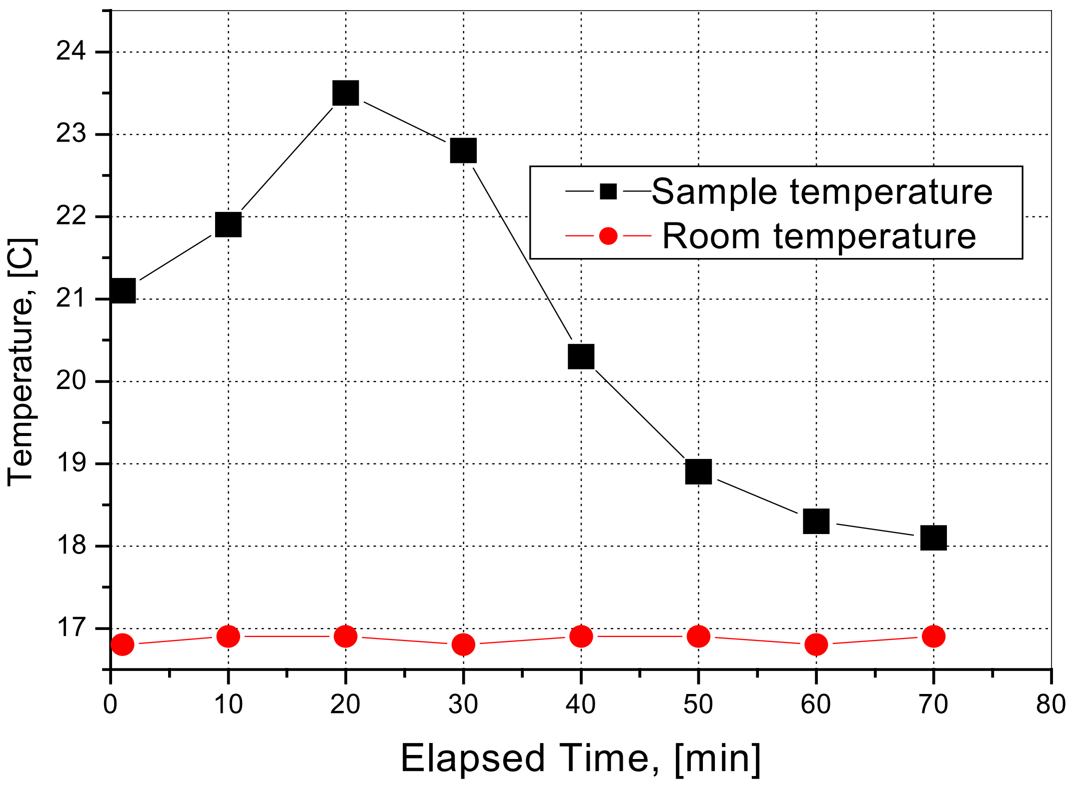
90% of D_2 escape the sample in 1 hr

$\langle dN/dt \rangle = 1 \times 10^{17}$ D/s-cm^2

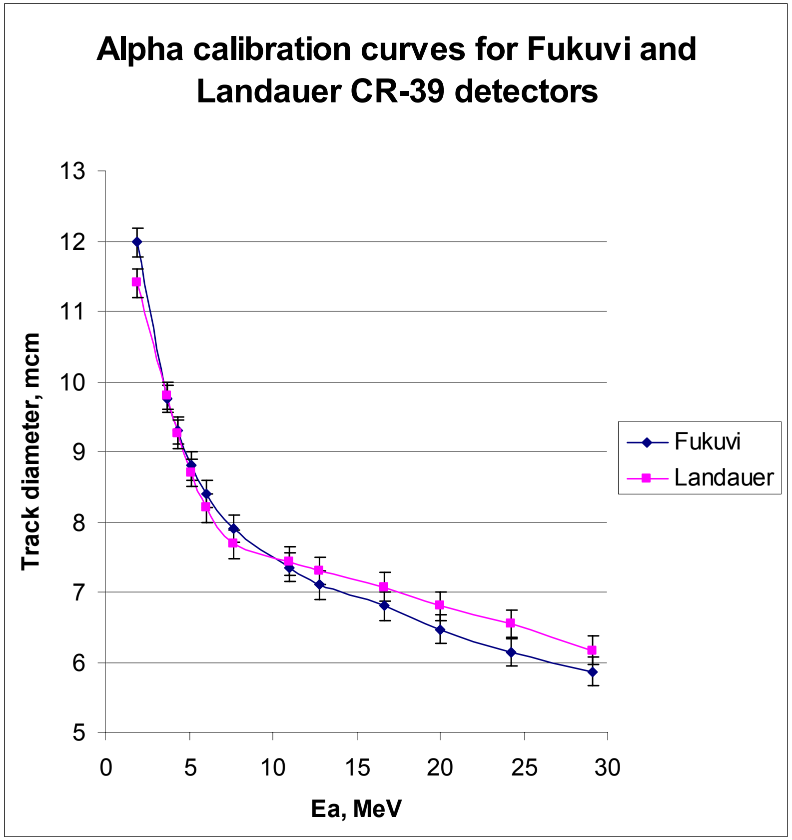


Pd/PdO:Dx temperature vs. elapsed time

The temperature at the surface is ~ 7^{o}K higher than the surrounding T

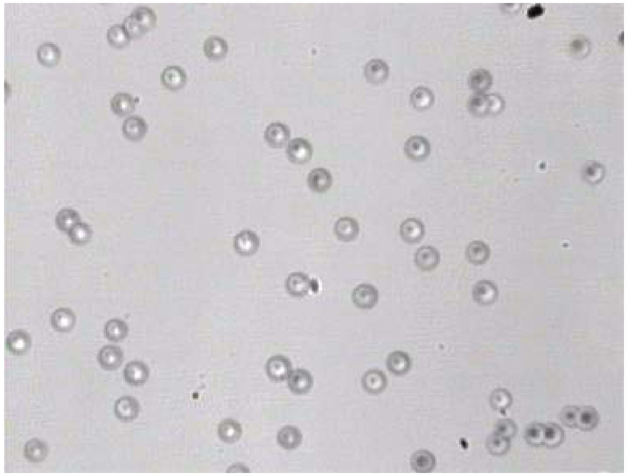


Alpha-sources and Cyclotron alpha beam calibration (2-30 MeV) of CR-39



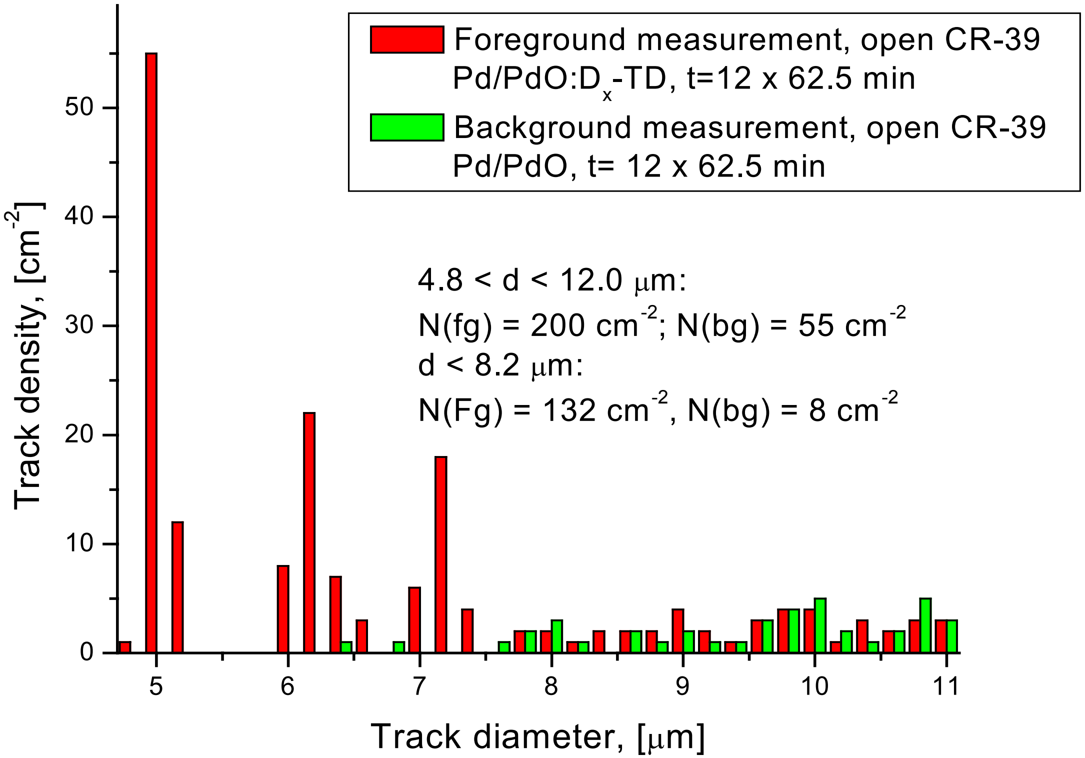
Example: Tracks from 12.0 MeV α-beam @ normal incidence on CR-39 (Landauer) target

image area S= 0.2x0.2 mm, (X 700)- from the right



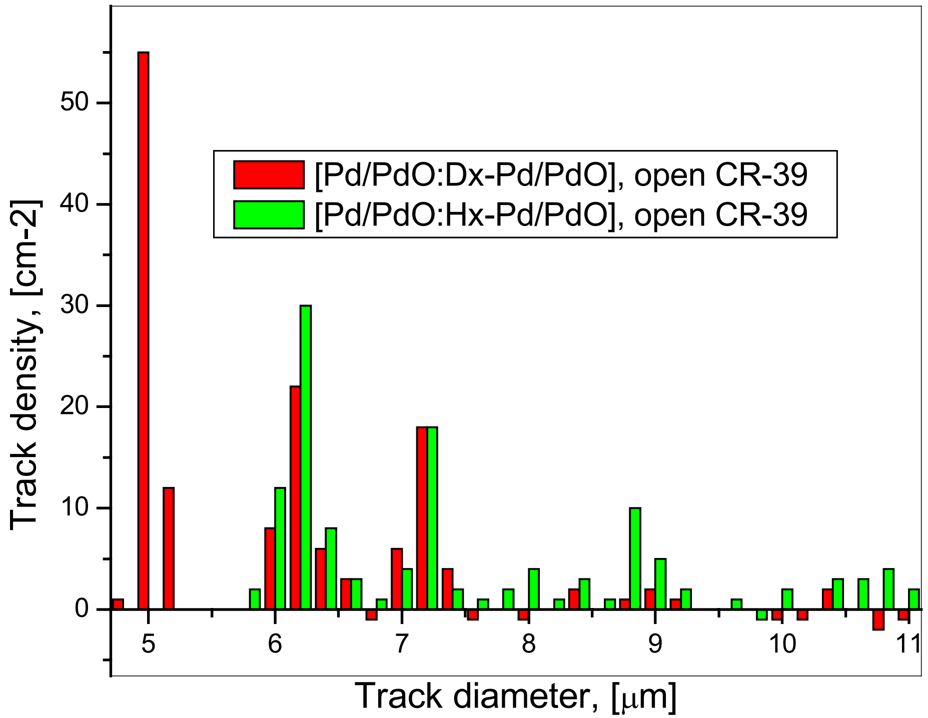
Foreground and Background counts from Pd/PdO:Dx and Pd/PdO; open CR-39 detector

High Fg/Bg ratio, especially below d = 8 μm



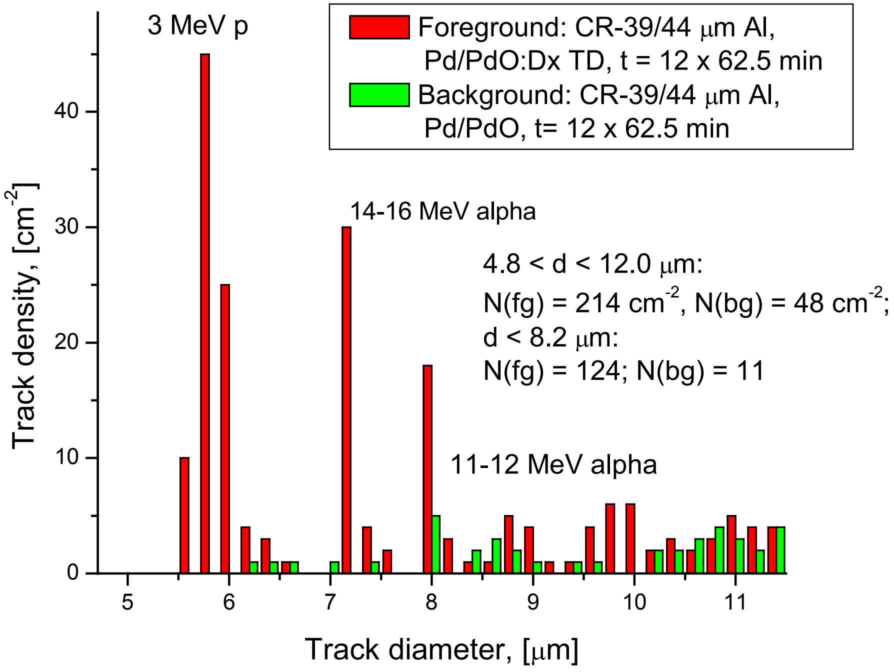
Comparison of Pd/PdO:Dx and Pd/PdO:Hx track distribution (with Background Pd/PdO subtraction)

- Main difference is the ~ 5 μm peak in Pd/PdO:Dx
- No such peak in Pd/PdO:Hx



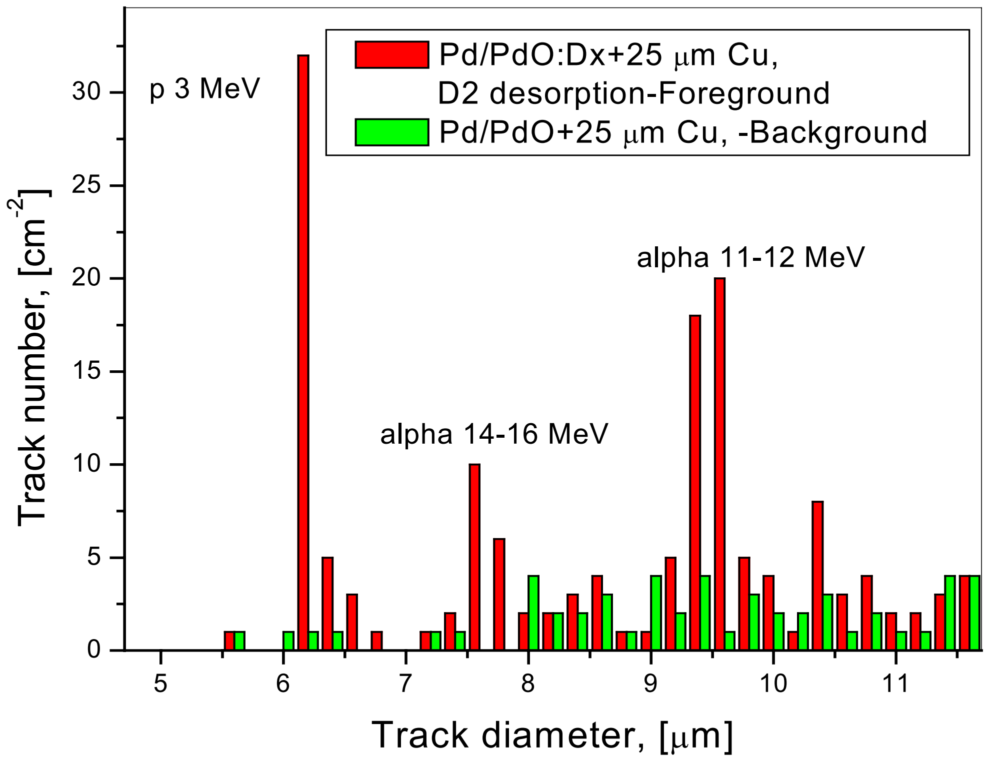
Charged particle spectra of Pd/PdO:Dx with 44 µm Al filter

- shift of DD-proton track band from 5 to 5.6-6.2 µm diameters
- splitting of alpha track band from 7.2 to 7.3–8 µm diameters
- Note large Fg/Bg ratio at d < 8 µm



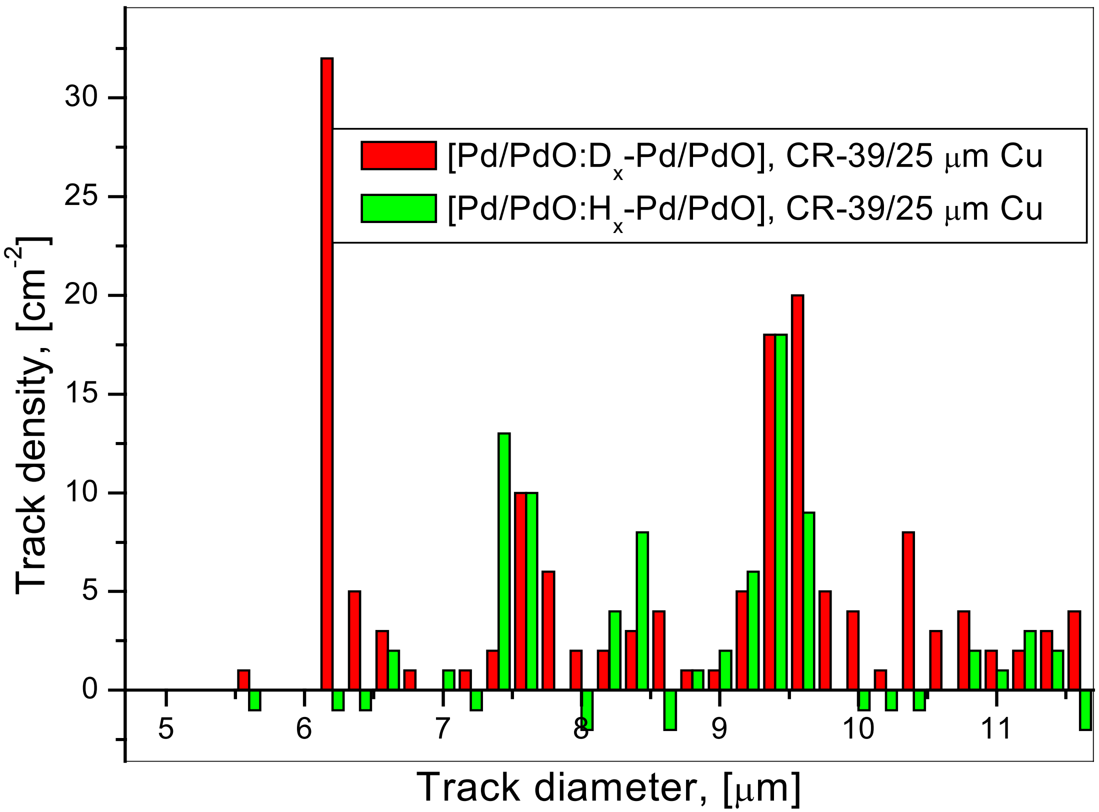
Pd/PdO:Dx spectra with 25 μm Cu filtered CR-39

Shifts of track diameters are consistent with 3 MeV protons and 11-16 MeV alphas



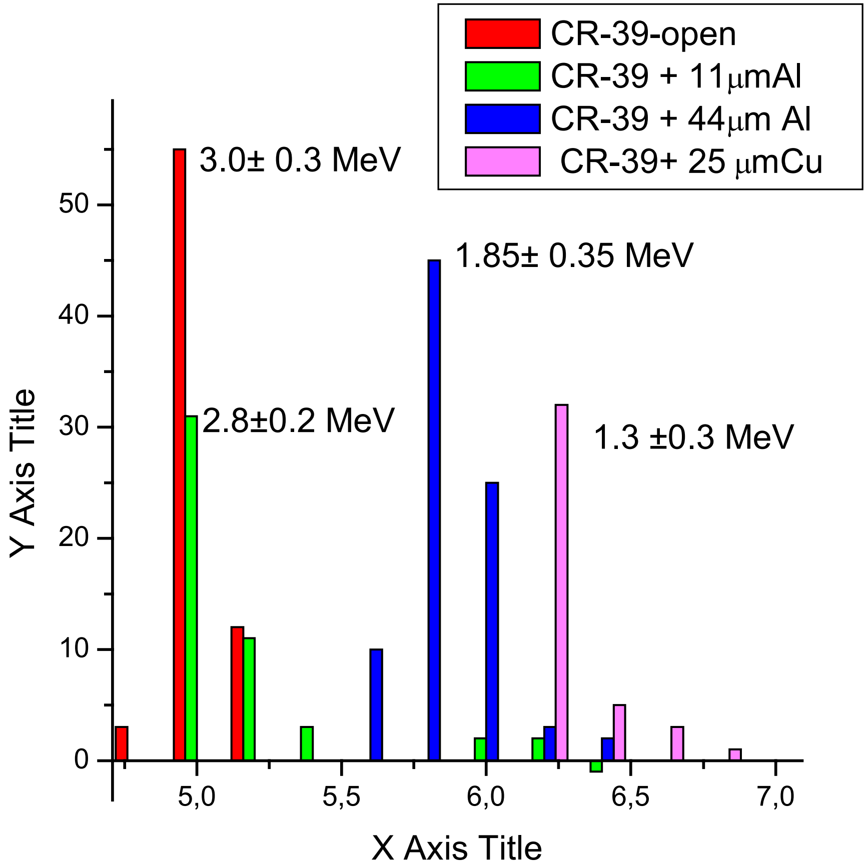
Charged particle spectra for Pd/PdO:Dx and Pd/PdO:Hx filtered with 25 μm Cu (with background subtraction)

Alpha particle spectra of both H and D-loaded samples look similar



Protons of 3±0.3 MeV incident energy from Pd/PdO:D_x are consistent with their stopping power in Al and Cu filters

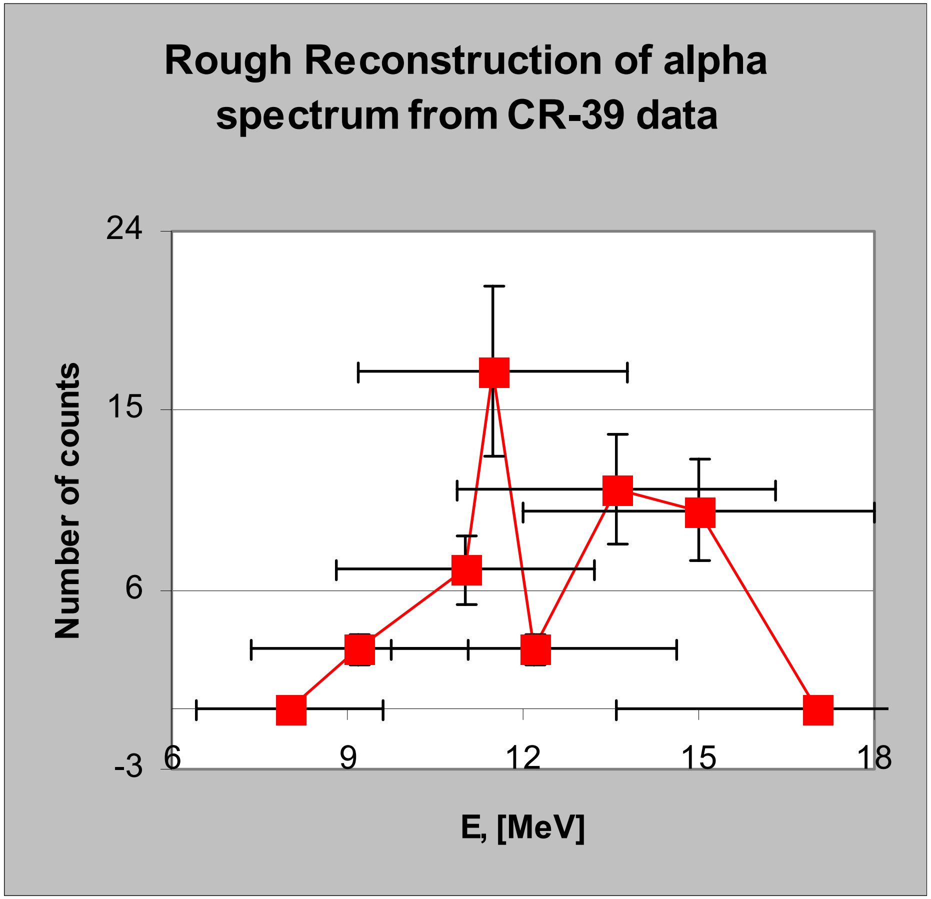
see shift in position of 5 µm peak (open CR-39) to larger diameters



Results on DD-reaction yield and rate

- Exothermic D-desorption from Pd/PdO:Dx generate reproducible DD-reaction yield. Taking into account detection efficiency $\varepsilon = 1/2(1-\cos\Theta_c)$, where Θ_c – is the critical angle for 3 MeV protons (32-37°) we obtain this yield as $Y_p(DD) = (1.15 \pm 0.13) x10^{-2}$ p/s in 4π steradian.
- The yield of 3 MeV proton is in good agreement with 2.45 MeV neutron yield obtained with NE-213 detector pair for similar samples during D-desorption: $Y_n(DD) = (1.8 \pm 0.19) x10^{-2}$ n/s (A. Lipson et al, Fusion Tech., . **38**, 257 (2000)).
- Calculated mean D-desorption rate in Pd/PdO:Dx or deuteron current from the sample found to be dN/dt = 17 mA/cm^2. The DD-reaction yield in that case was Y(DD) = 0.6 p/C(D). This result suggests very high screening potential U_e > 1.0 keV in Pd/PdO:Dx

Reconstructed Energetic alpha spectra for Pd/PdO:Dx samples:



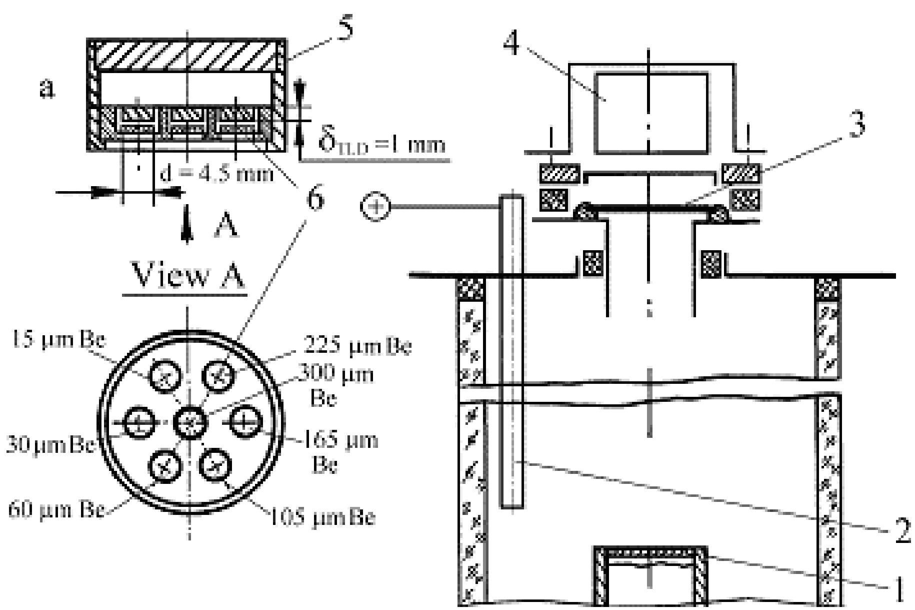
Energetic alpha emission results

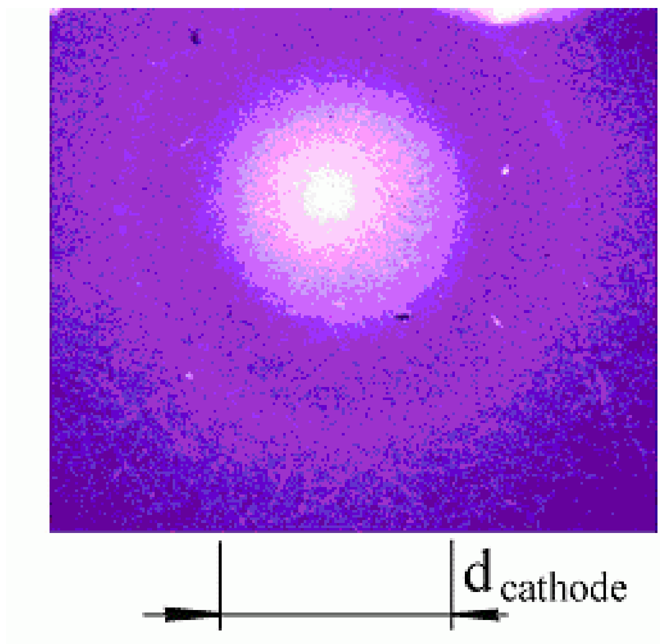
- Using critical angles for 11-16 MeV alphas Θ_c = 42 ° we obtain the yield of energetic alpha particles in Pd/PdO:Dx during exothermic D-desorption Y_α = $(5.5\pm0.9)\times10^{-3}$ α/s in 4 π ster.
- Pd/PdO:Hx samples during H-desorption demonstrate 11-16 MeV spectra that are very similar to that of Pd/PdO:Dx. The yield of alphas at H-desorption is also similar to D-desorption case.
- Reproducibilty of both DD-reaction and energetic alpha emissions during D-desorption is close to 100%.

IV. X-ray emission measurements in pulsed GD

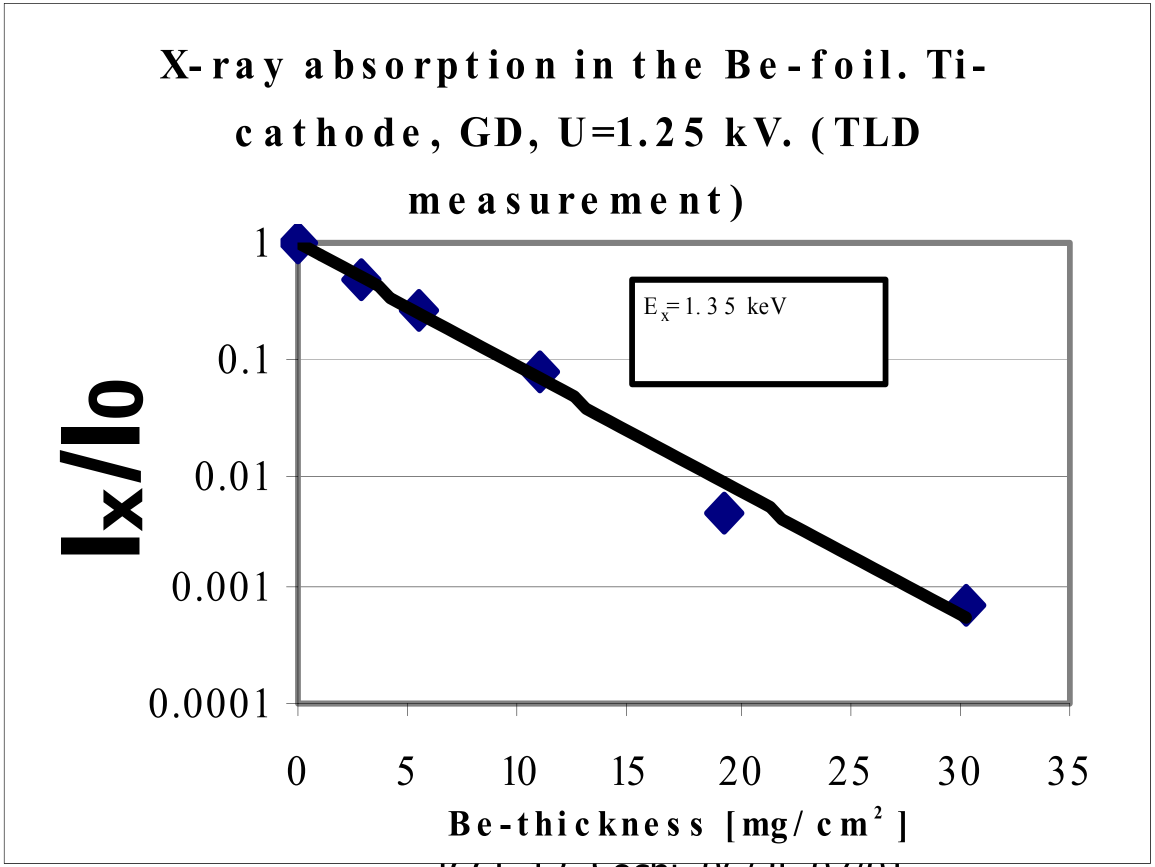
- Sensitive Al_2O_3:C TLD with a set of 15-300 μm (2.8-55.5 mg/cm2) thick Be-foils, pin-hole camera; plastic scintillattor
- Seven TLD, 5 mm diameter each were located 70 mm from the back side of anode, outside of discharge zone.
- In special experiments to obtain the exact position of X-ray source in GD, Mo-anode was shifted 20 mm with respect to cathode.
- TLD calibration with a standard Cs^{137} γ-source

using the pin-hole camera. The objective of 0.3 mm diameter is narrowed by use of a 15μm Be shield in front of the camera. (The image is a positive imprint)

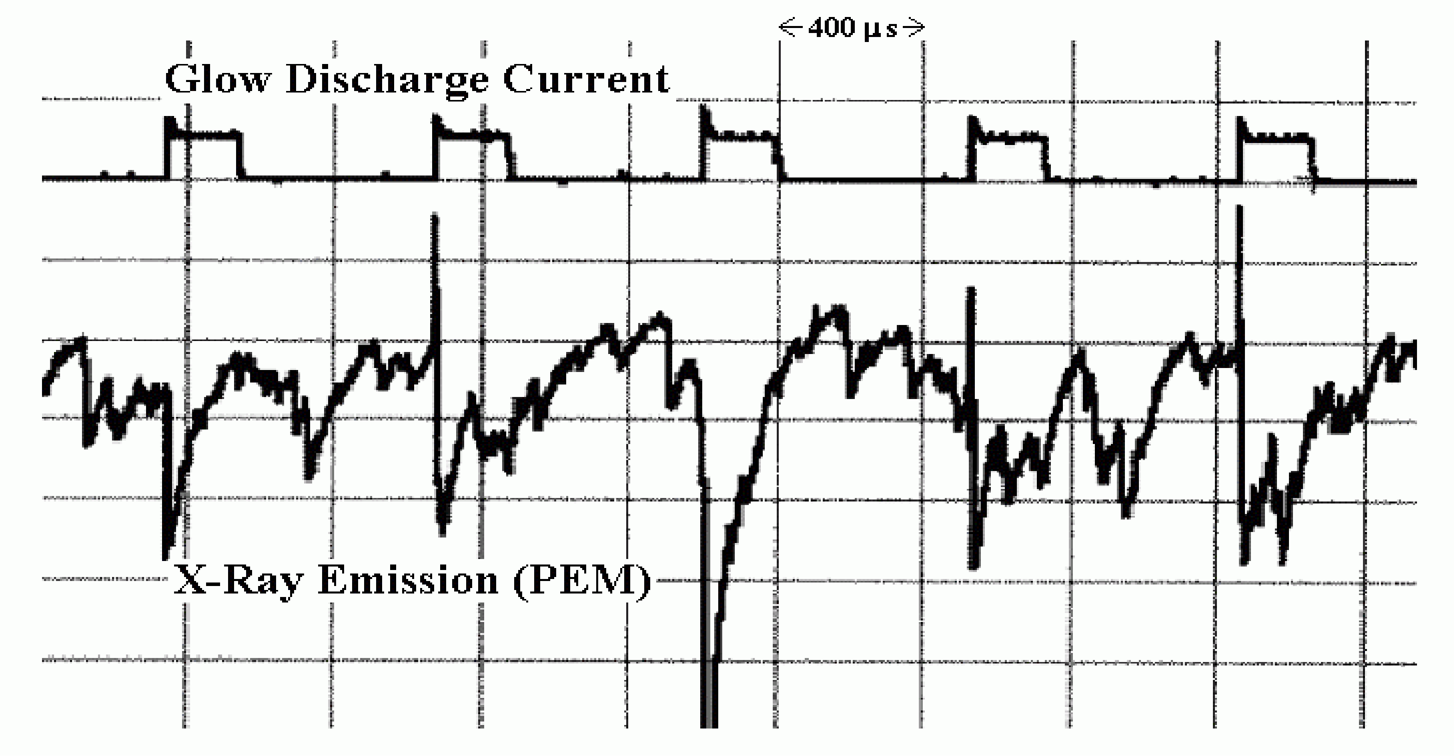




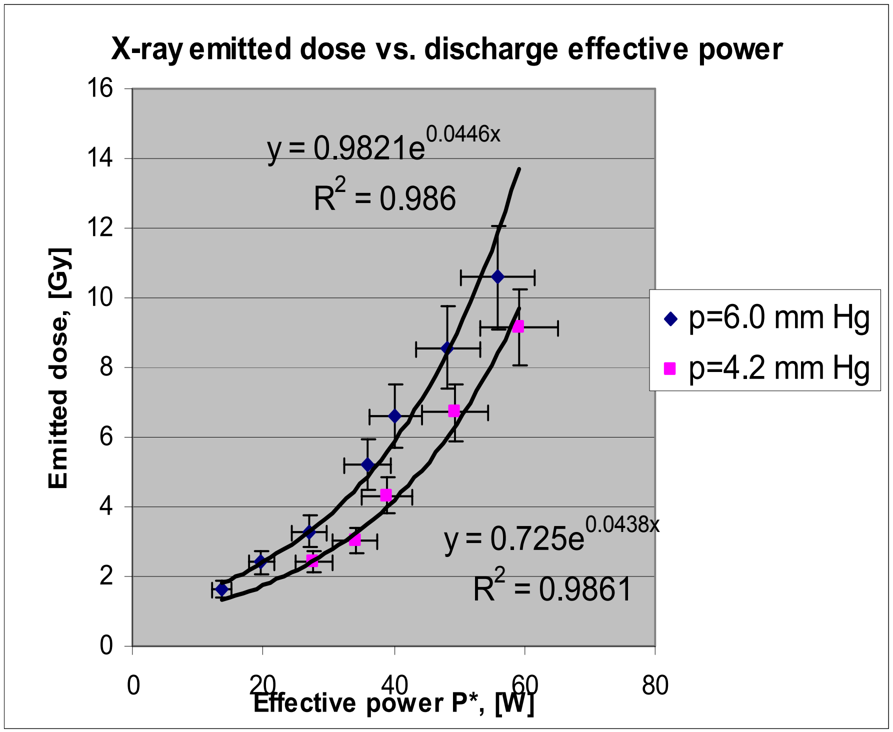
X-ray energy measurement in Ti/D_2 PGD Karabut's type (A. Lipson et al, JETP, 2005)

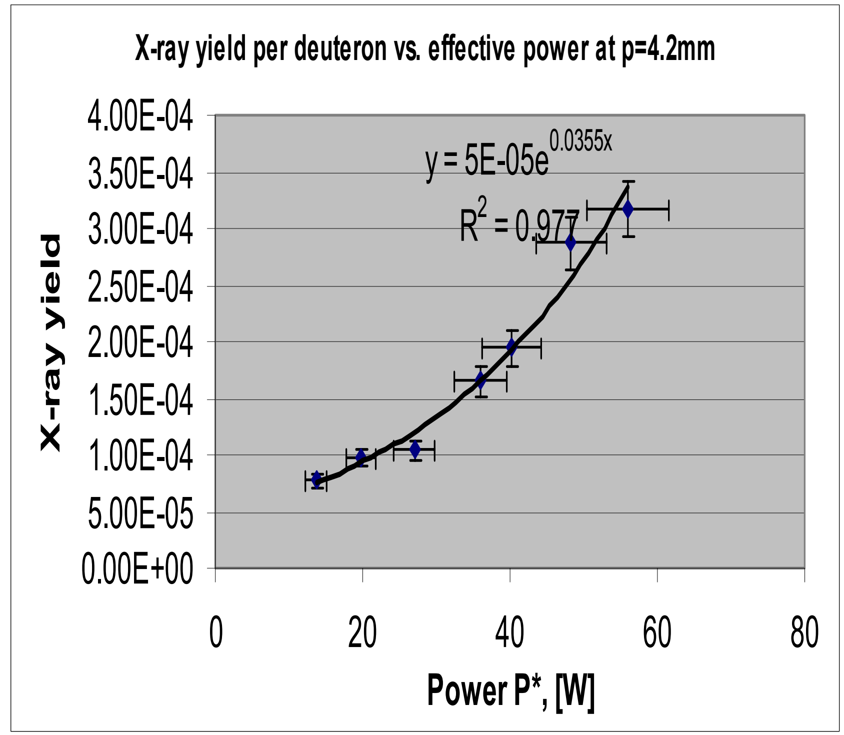


Correlation between X-ray and current pulses in GD



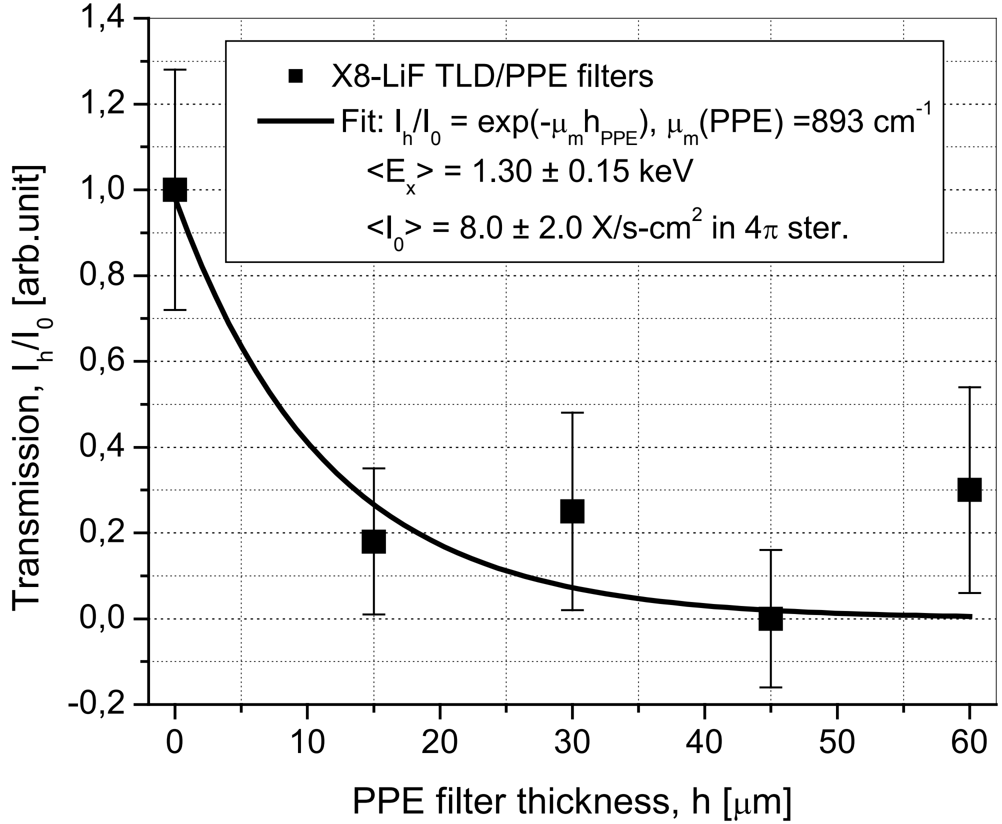
Emitted doses and X-ray yield from Ti-cathode vs. Effective power P*=UIQ; Yield is described by a formula: $I_x = I_0 \exp[(\varepsilon/kT_m)P^*_x/P^*_0]$





X- ray quanta energy in Pd/PdO:D_x foils after electrolysis estimated with 5 pairs of X8 TLD with 0-60 µm PPE filters

- X-ray detection: photo-insensitive X8 LiF TLD (Landauer) units (S= 2x2 mm2, h=1 mm) open and filtered by 1-4 layers of 15 µm polypropylene (PPE)
- 100 runs of 1-48 hr duration
- 50 µm Pd/PdO:D sample
- TLD reading was carried out in Landauer inc.



X-ray dosimetry and flux estimate

- The open TLD showed dose D = 12 ± 2 mrad = 120 μGy. In SI system the equation connecting the dose D_x [Gy] absorbed by LiF TLD with area s= 0.04 cm^2 and mean flux $\langle \Phi_x \rangle$ would be written:

$$\langle \Phi_x \rangle = 2D_x \rho(\mathrm{LiF})/1.6\times 10^{-13}\ [\mathrm{J/MeV}]\times E_x \times \mu_m \times (s/1\mathrm{cm}^2)\times\tau \cong (8 \pm 2)\ \text{X-quanta/cm}^2\text{-s},$$

where ρ(LiF) – is the density of LiF, Ex = 1.3 keV is the X-ray quanta energy and $\tau = 7 \times 10^5$ s – is the total time of TLD exposure with Pd/PdO:Dx sample.

The estimated dose obtained from charged particle absorption by LiF TLD is less than 1 mrad (below detection limit).

Conclusions for controlled D-desorption from Pd/PdO:D_x experiment

- Good reproducibility of charged particle emissions during GD operation and controlled exothermic D-desorption from Pd/PdO:Dx
- Relatively high 3 MeV proton yield indicating large DD-reaction enhancement during D-desorption
- No direct sign of 1 MeV tritons: means that effective depth where DD-reaction originates is ~ 2 μm from the surface. This estimate is in agreement with energy losses for 3 MeV protons
- Identity between energetic alpha spectra during D and H-desorption from Pd/PdOD(H)

Conclusions II

- The energy of X-ray quanta emitted from Pd/PdO:Dx is in good agreement with Karabut's glow discharge results. Suggests similar mechanism caused by D-desorption
- Observed nuclear effects in metals cannot be explained by fracto-fusion because the electric field in the cracks would be too low. Phonon energy of D-desorption focusing or/and concentration in some specific lattice sites near surface (the sites of a high internal strain ?)
- DD-reaction, energetic alphas and X-ray emissions suggest anomalous energy release via "active" lattice sites of non-equilibrium metal deuterides, indicating intra-atomic electric fields of $E \sim 10^{10}$ V/cm

Entire results showed that Exothermic D-desorption is that obvious link between DD-screening, soft X-ray emission and high energy alpha generation from the surface of Pd/PdO:Dx

Possible mechanism - speculations

- Applied energy focusing/concentration in some specific lattice sites near surface (the sites of a high internal strain ?)
- Coherent energy transfer from DD-reaction sites to the light nuclei (P.L. Hagelstein)
- Effective acceleration of these nuclei (p, d and ^{4}He) by intra-atomic electric fields
- ECP emissions suggest anomalous energy release via the “active” lattice sites of non-equilibrium metal deuterides/hydrides

How to convince physicists in nuclear origin of Excess Heat effect ?

- Complete experiment with simultaneous detection of excess heat, atomic ^4He, ^3T, charged particles (DD-products +energetic alphas) and neutron emissions, as well as soft X-rays ($E_x \leq 2.0$ keV), not characteristic K_α of Pd)
- Search for correlations between excess heat events and emissions of atomic, nuclear species and X-rays
- Special electrolytic cells and appropriate state-of-the-art calorimetric and nuclear detection equipment.
- To use novel (nanostructured/nanolayered) samples as the cathodes (Pd-SWCNT-Pd, Pd-Re-Pd and PdO-Pd-PdO) with enhanced charged particle yield.