Nuclear Products Observed in the PdD Co-Dep System

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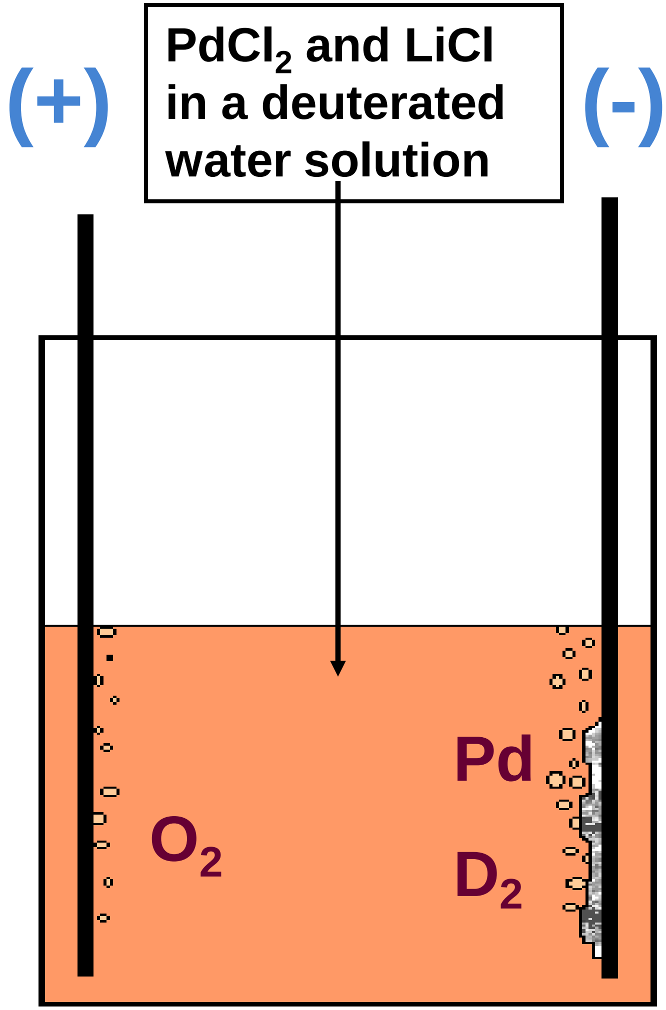
…To Fukushima[1] and beyond: an alternative

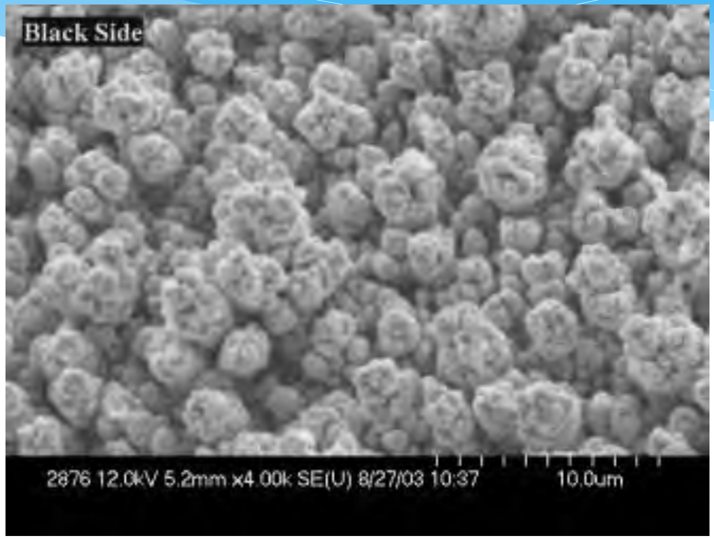
"Are you still using fossil fuels, or have you discovered crystallic fusion?"

--Buzz Lightyear

1. "Radio-microanalytical Particle Measurements, Techniques and Application to Fukushima Aerosols Collected in Japan", Zeissler, Forsley, Lindstrom, Newsome, Kirk and Mossier-Boss, *Methods & Applications of Radioanalytical Chemistry* **(MARC IX)**, Kona, HI March 28 2012

Pd/D Co-deposition





As current is applied, Pd is deposited on the cathode. Electrochemical reactions occurring at the cathode:

$$Pd^{2+} + 2\,e^{-} \rightarrow Pd^{0}$$

$$D_2O + e^{-} \rightarrow D^{0} + OD^{-}$$

The result is metallic Pd is deposited in the presence of evolving D_2

Travels with Nuclear Co-Dep

Vittorio Violante, Italy

Francesco Celani, Italy

Border Guard
Germany

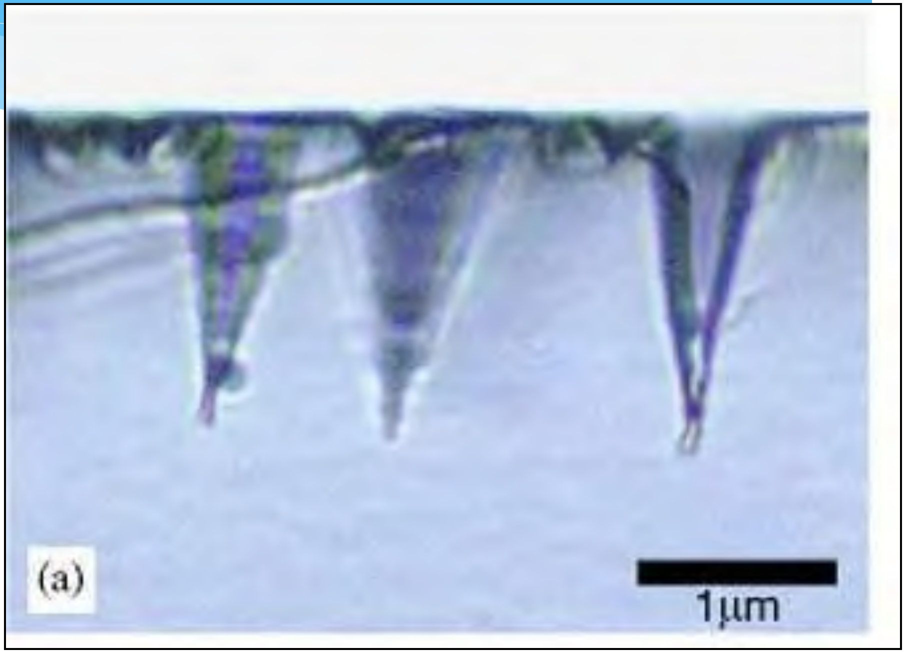
Martin Fleischmann, UK

TASL, UK

Charged particles

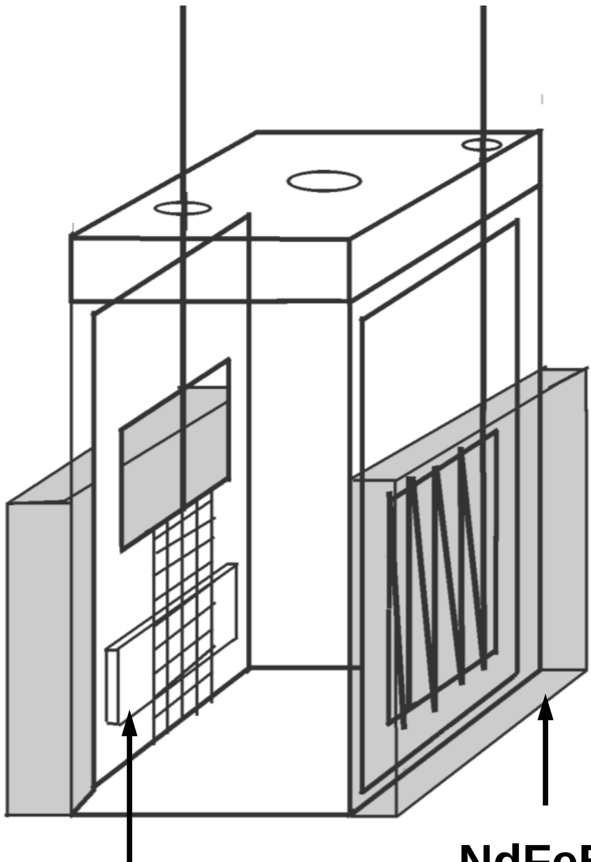
Nuclear Particle Detection

- CR-39, polyallyldiglycol carbonate polymer, is widely used as a solid state nuclear track detector
- When traversing a plastic material, charged particles create along their ionization track a region that is more sensitive to chemical etching than the rest of the bulk
- After treatment with an etching agent, tracks remain as holes or pits and their size and shape can be measured.

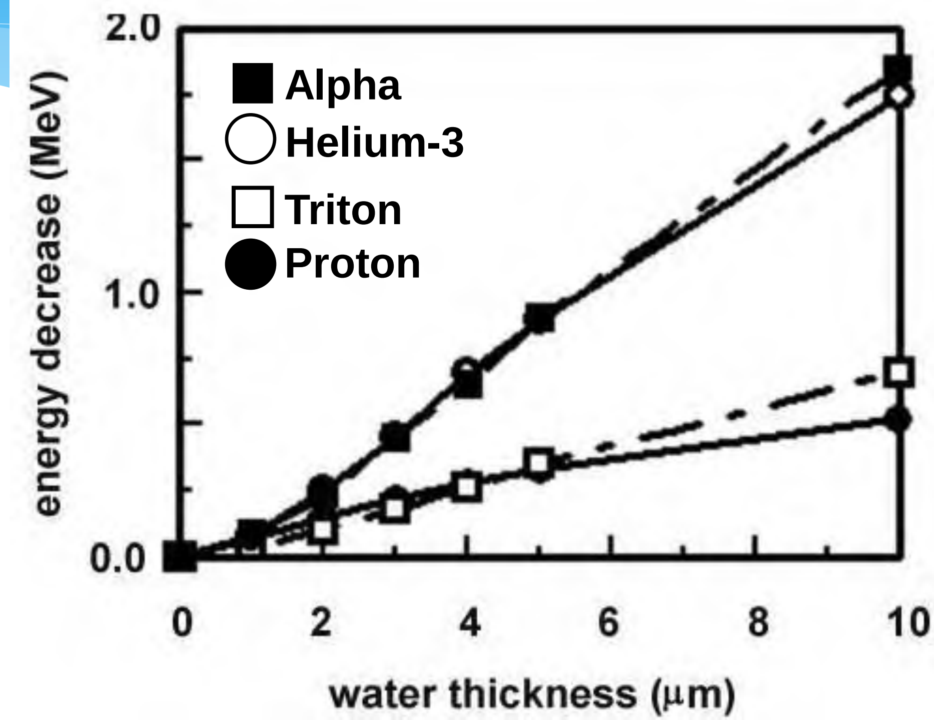


Alpha track cross-sections after etching on a CR-39 detector.
T. Yoshioka, T. Tsuruta, H. Iwano, T. Danhara, Nucl. Instru. and Meth. Phys. Res. A, Vol. 555, p. 386 (2005)

Pd:D Co-Dep Experiment



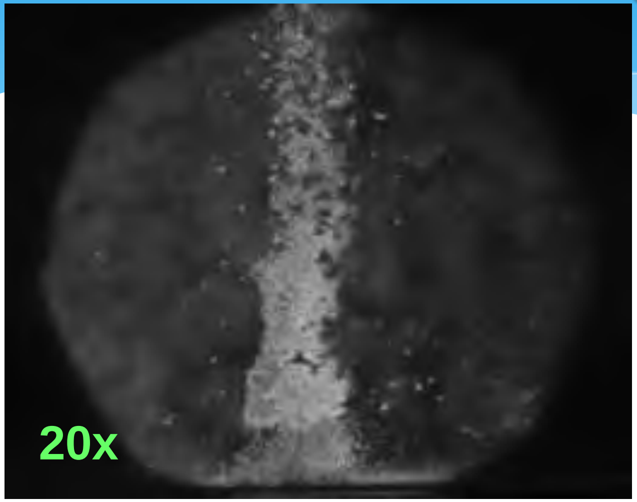
LET Curves in Water

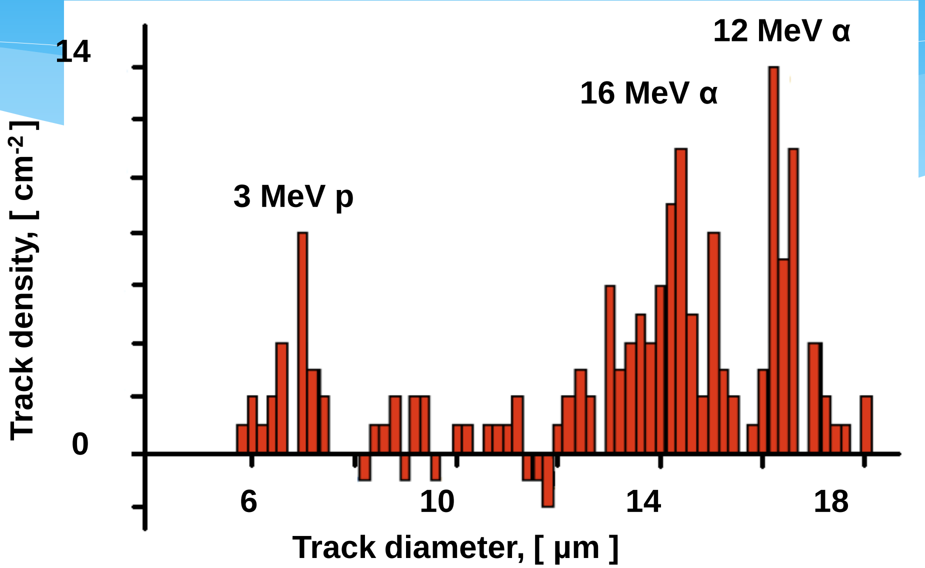


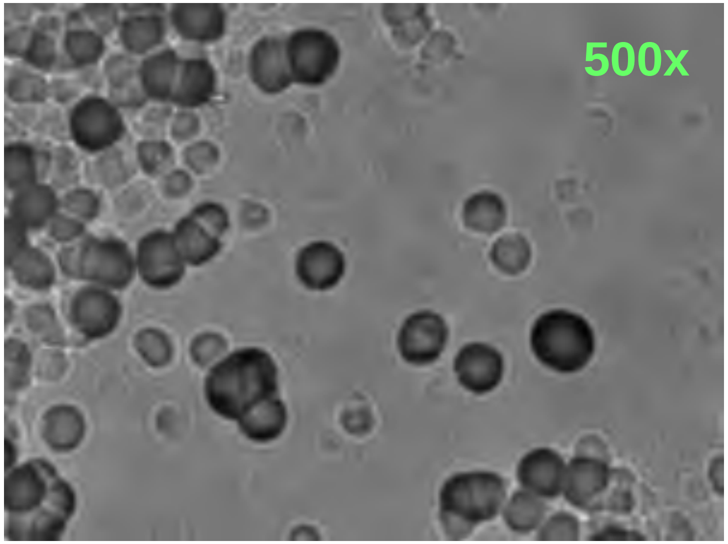
▼ CR-39 in close proximity to the cathode because high energy particles do not travel far

▼ Cathode substrates used: Ni screen; Ag, Au, Pt wires

Nuclear Particle Track Analysis: Charged Particles

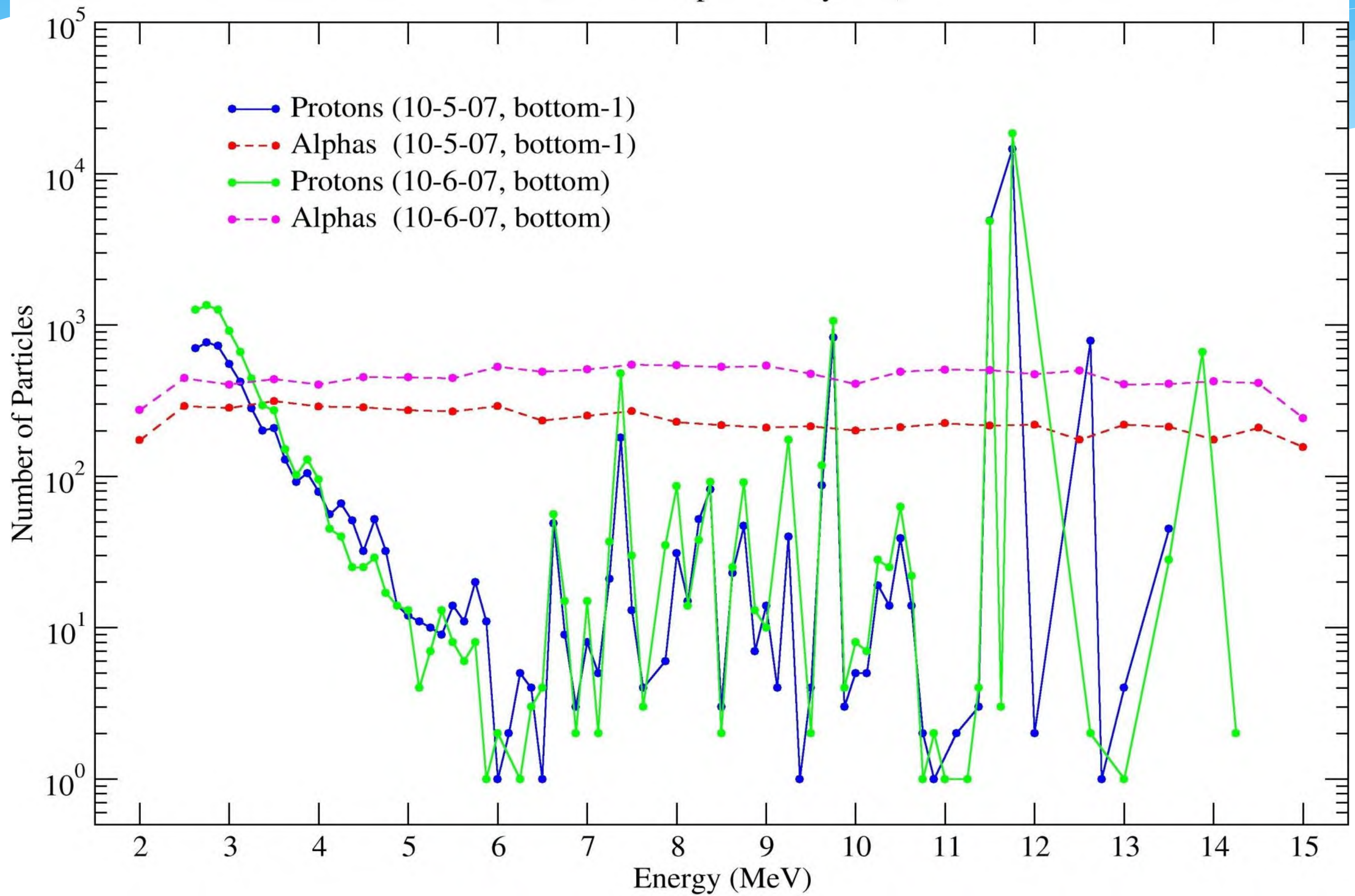






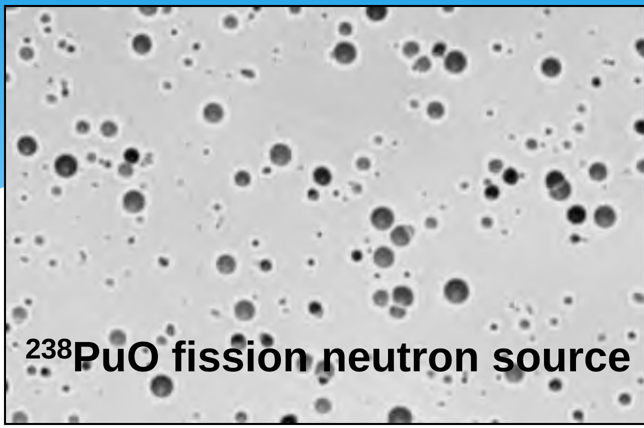
- Control experiments show that the tracks are not due to radioactive contamination, impingement of the D_2 gases on the detector, chemical reaction of O_2 and Cl_2 gases, or the Pd dendrites piercing into the plastic
- Sequential etching shows tracks due to 3 MeV protons and 12-16 MeV alphas

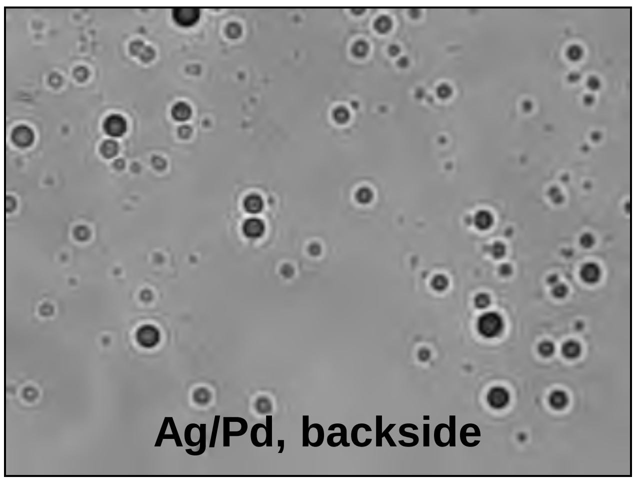
NASA-JSC Analysis of Nuclear Charged Particles (SRI's SPAWAR Pd:D Co-dep Protocol Replication)

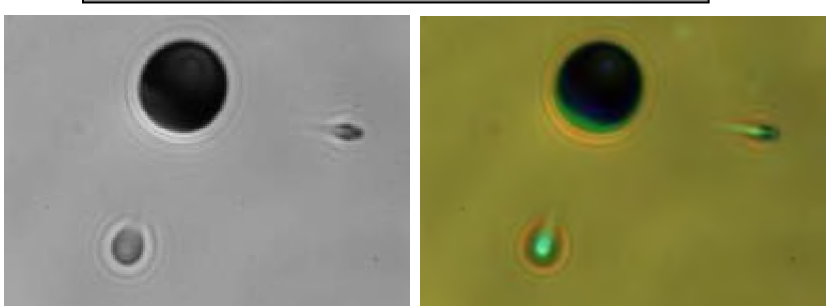


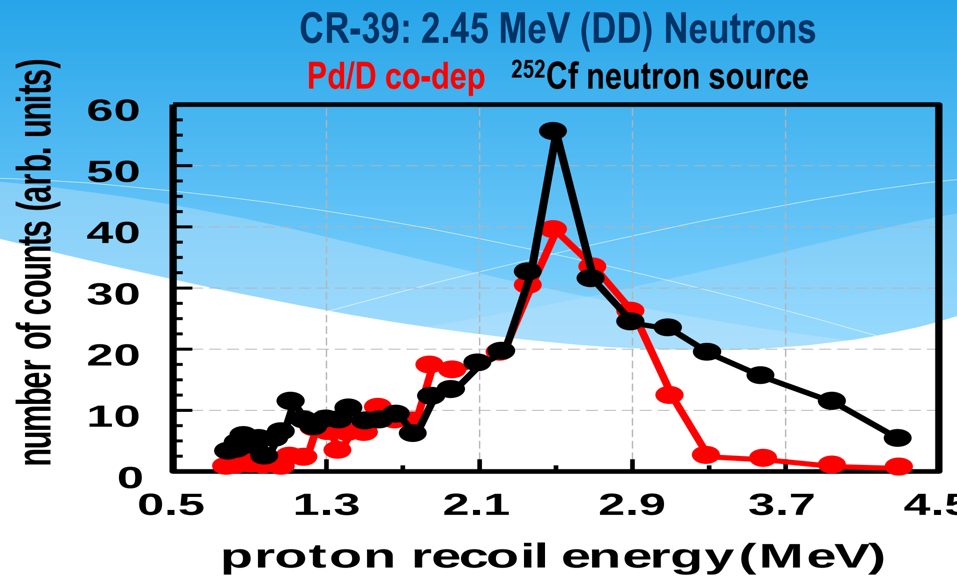
Neutrons

Fast Neutrons: 2.5 MeV





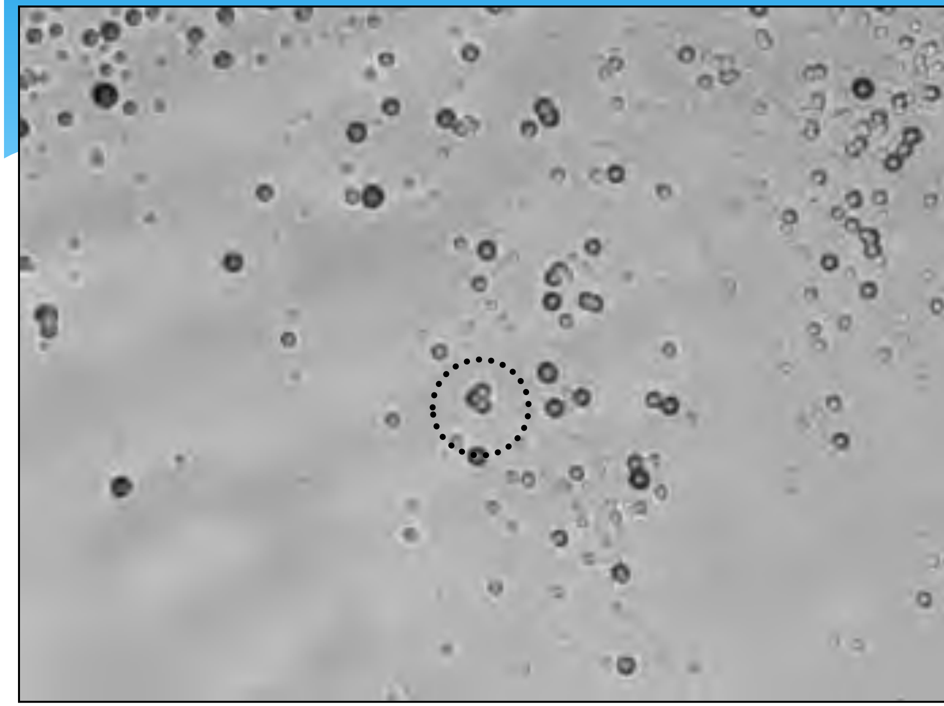




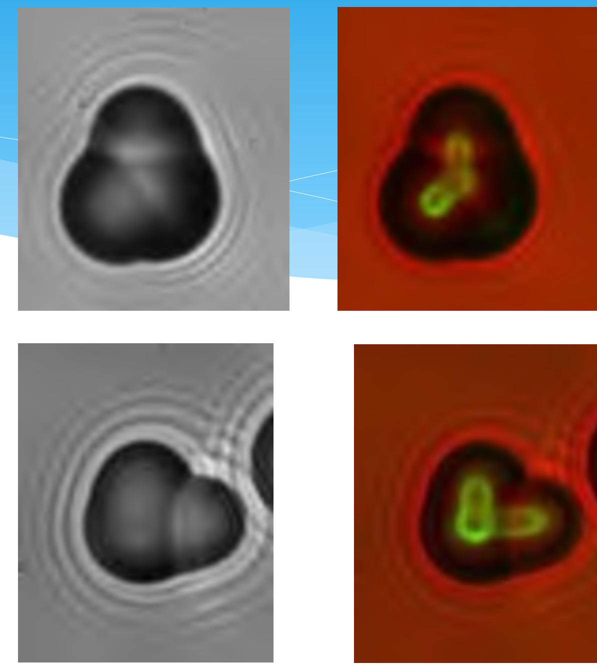
- To go through 1 mm thick CR-39, particles can be either >40 MeV alphas, >10 MeV protons, or neutrons
- Tracks are primarily circular in shape. Some tracks are circular with small tails. These are due to recoil protons that have exited the CTR-39 at an oblique angle
- Small latent tracks are observed.
- Sequential etching shows the presence of proton recoils deeper inside the CR-39
- Estimated neutron energy range is ~2.2-2.5 MeV

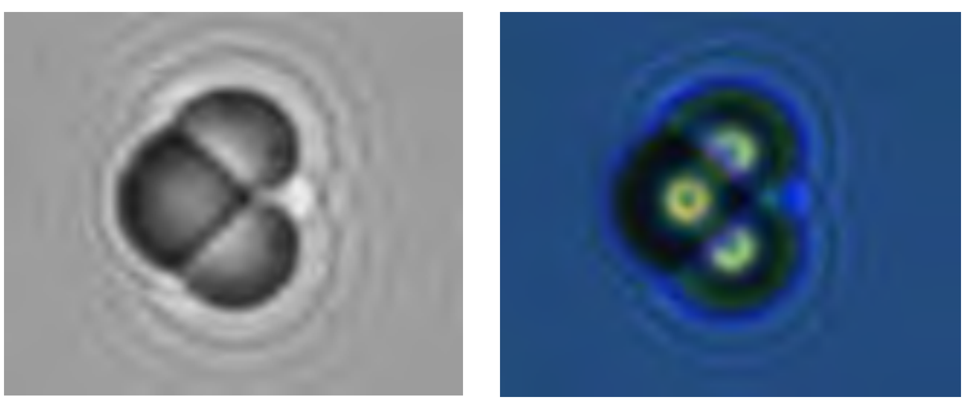
Very Fast Neutrons: > 9.6 MeV Neutrons

Pd/D Co-dep



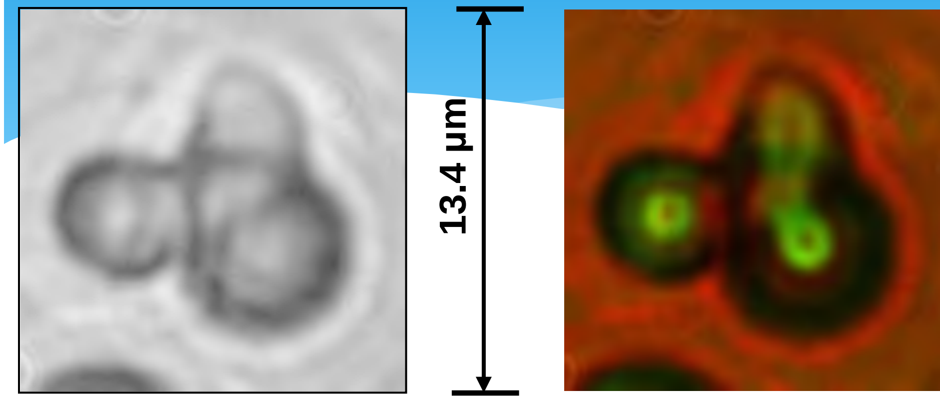
DT neutrons

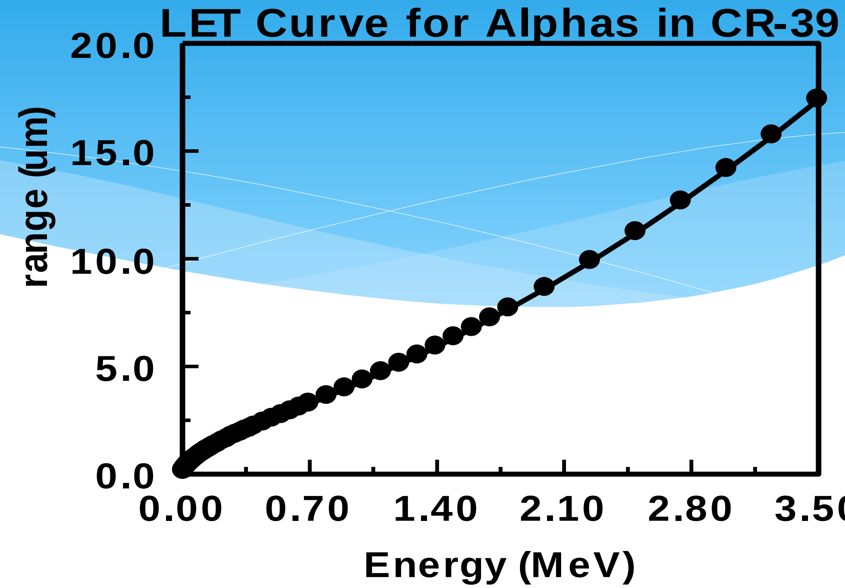


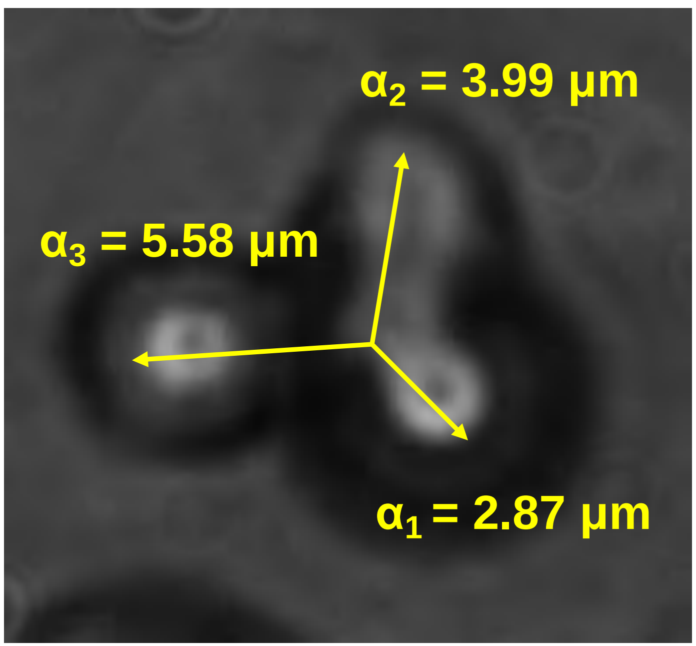


- Triple tracks are formed when a carbon atom shatters into three alpha particles.
- The three alpha particles break away from a center point
- Triple tracks are diagnostic of neutrons with energies greater than 9.6 MeV
- This is the most easily identified neutron interaction inside CR-39 detectors

Calculation of the Energy of the Neutron that Created the Triple Track







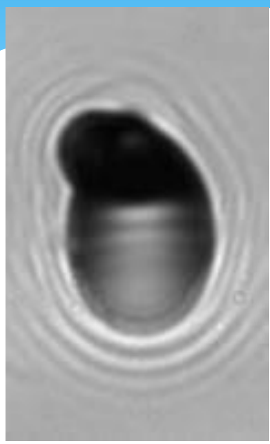
$$E_n = E_{th} + E_{\alpha 1} + E_{\alpha 2} + E_{\alpha 3}$$

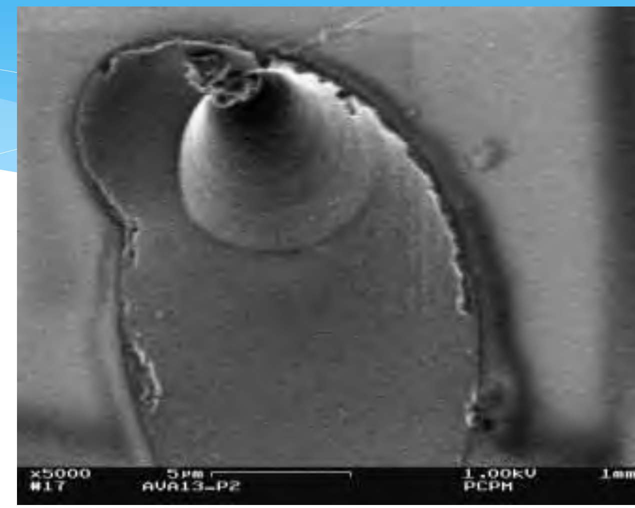
$$E_n = (9.6 + 0.59 + 0.91 + 1.23)\ \text{MeV}$$

$$E_n = 12.33\ \text{MeV}$$

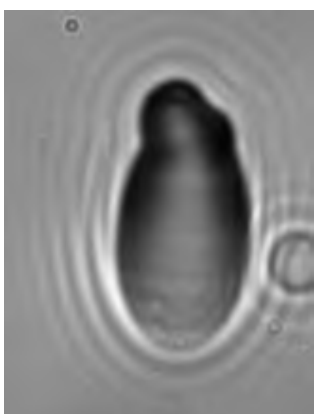
Optical and SEM Analysis of Pd/D Co-Deposition Triple Track

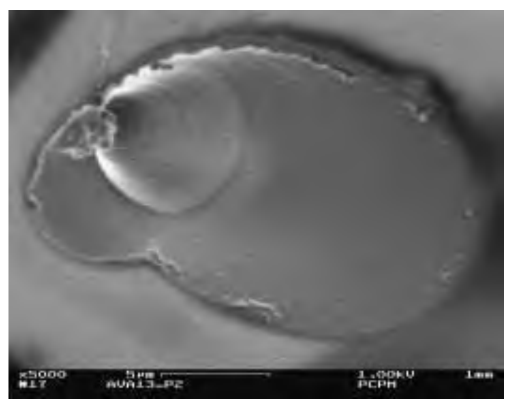
Co-Dep

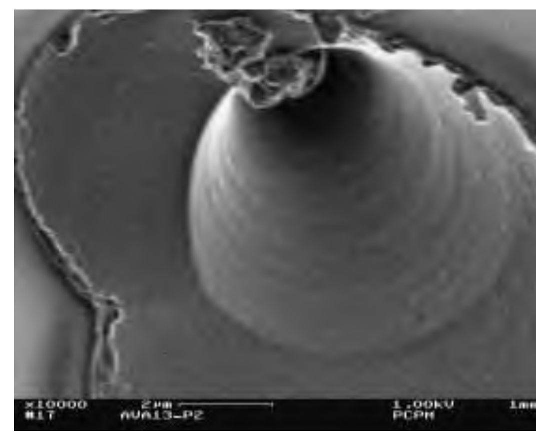




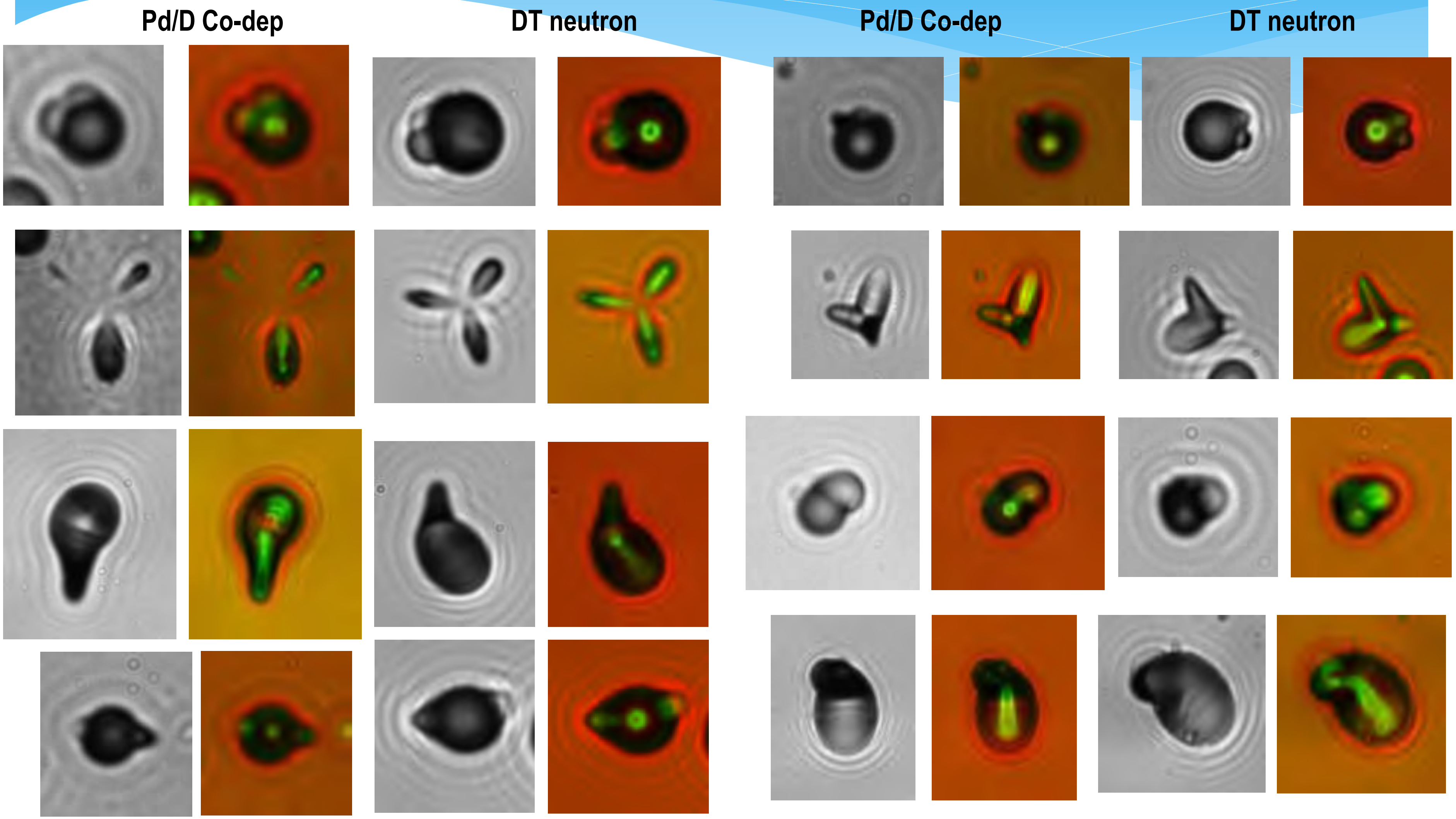
DT Neutron



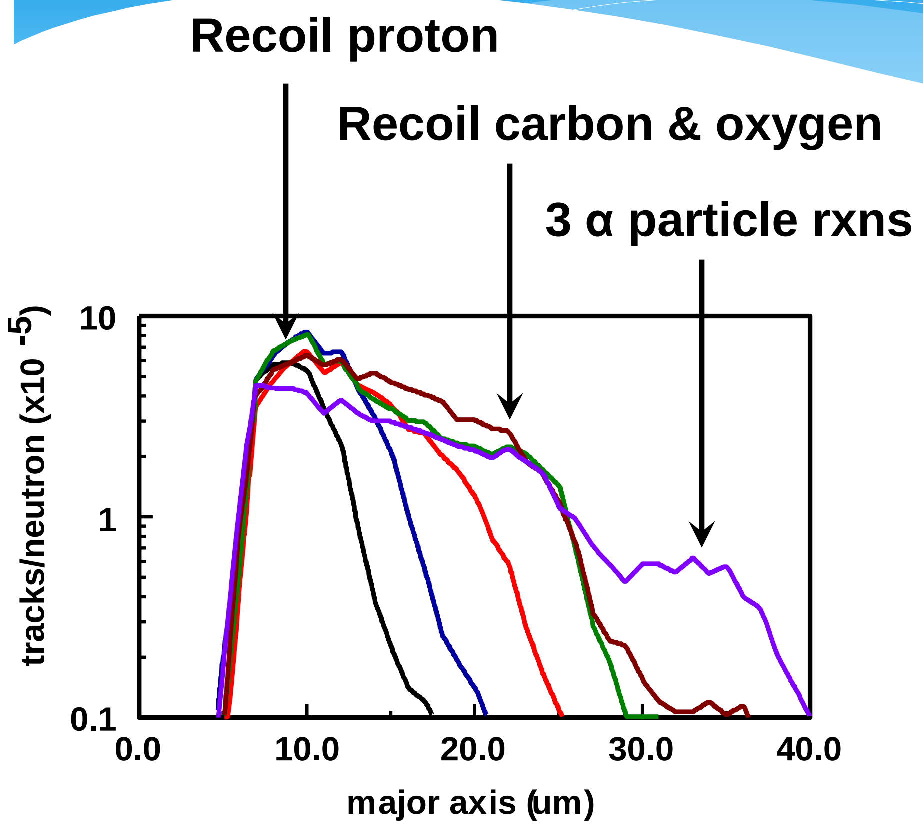




Comparison between PdD Co-dep and DoE DT Neutron Generator Triple Tracks EPJAP, Vol. 51, p. 20901 (2010)



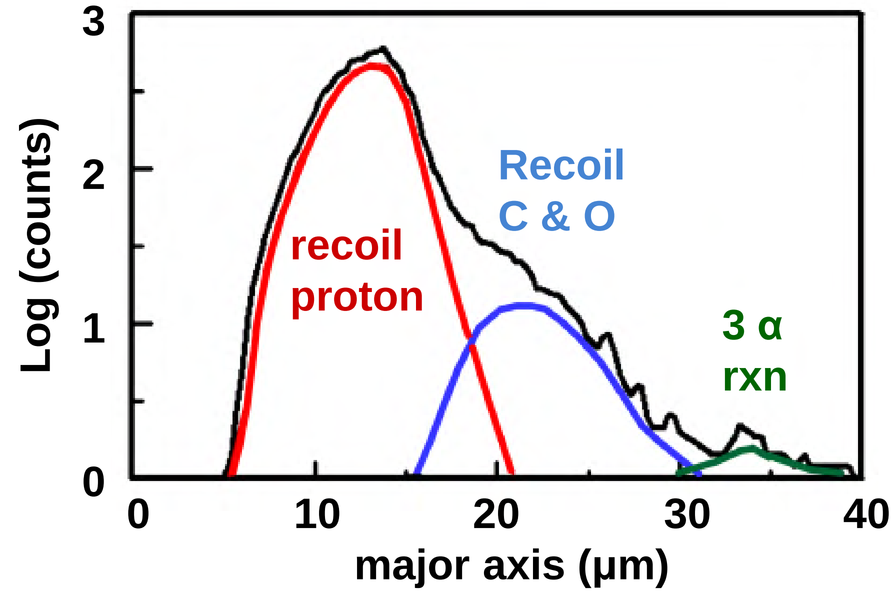
Pd:D Co-dep Neutron Emission



CR-39 that has been exposed to 0.114 MeV (black). 0.25 MeV (blue), 0.565 MeV (red), 1.2 MeV (green), 8 MeV (brown) and 14.8 MeV (purple) monoenergetic neutrons

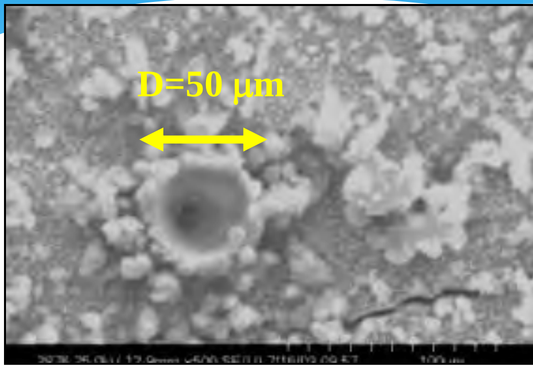
Phillips et al, Radiat. Prot. Dosim Vol. 120, pp. 457-460 (2006).

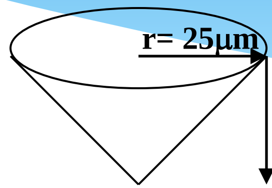
Backside of CR-39 used in Pd/D Co-Deposition



- >40 MeV α, >10 MeV protons, and neutrons can traverse 1 mm thick CR-39
- Three populations of neutrons are observed consistent with recoil protons, recoil carbon and oxygen, and 3 α particle reactions

BUT, Neutron Yield does not Correlate with Heat





Ejecta Volume

$V = 1/3 \pi r^2 h$
$= 1.47 \times 10^5\ \mu m^3$

$V = 1.47 \times 10^{-10}\ cm^3$

Each ejecta vaporizes a Pd volume of $1.47 \times 10^{-10}\ cm^3$

$1.47 \times 10^{-10}\ cm^3 \times 12.02\ g/cm^3 = 1.8 \times 10^{-9}$ gm of Pd
1.8×10^{-9} gm/105.6 gm/mole = 1.6×10^{-7} moles of Pd

Each ejecta vaporizes a Pd mass of 1.8×10^{-9} gm or 1.6×10^{-7} mol

Given 3.57×10^5 J/mol x 1.6×10^{-7} moles = 5.8×10^{-2} Joules/ejecta to vaporize the palladium

It takes 5.8×10^{-2} joules to vaporize this amount of palladium
If the heat is generated primarily by conventional DD/DT fusion reactions, with a 50% branching ratio, then:

The combined average energy of both the primary and secondary DD/DT reactions is about 20 MeV or 3.2×10^{-12} J/reaction with 2/3, or 2×10^{-12} J, in charged particles/reaction

Nearly one third of the energy leaves with 2.45 MeV or 14.1 MeV neutrons.

Given 5.8×10^{-2} J/ejecta /2×10^{-12} J/reaction = 3×10^{10} reactions/ejecta

Useful Constants:

Pd solid density 12.02 g/cc
Pd melting point 1554.9 C
Pd Boiling point 3140 C
Pd heat of vaporization = 357 kJ/mol
= 3.57×10^5 J/mol

$10^{15}\ \mu m^3/cm^3$

1 MeV = 1.6×10^{-13} Joules

Then there are about 3×10^{10} nuclear fusion reactions per ejecta site.

Hybrid Fusion-Fission Nuclear Channels

- Primary DD fusion reactions:

  D + D → T (1.01 MeV) + p (3.02 MeV)

  D + D → n (2.45 MeV) + ^{3}He (0.82 MeV)

- Secondary DT fusion reactions

  D + T (≤1.01 MeV) → α (6.7-1.4 MeV) + n (11.9-17.2 MeV)

  D + ^{3}He (≤0.82 MeV) → α (6.6-1.7 MeV) + p (12.6-17.5 MeV)

- Thermal, aneutronic channel, "cold fusion"

  D + D → ^{4}He (24 MeV)

- Stripping reactions,

  $D(^{a}X_{z},{}^{a+1}X_{z})p$

  $D(^{a}X_{z},{}^{a+1}Y_{z+1})n$

- Fission Reactions

Gamma Ray Observations

High Purity, Cryogenically cooled, Germanium Detector
Percentage as compared to a 3x3 NaI crystal for efficiency

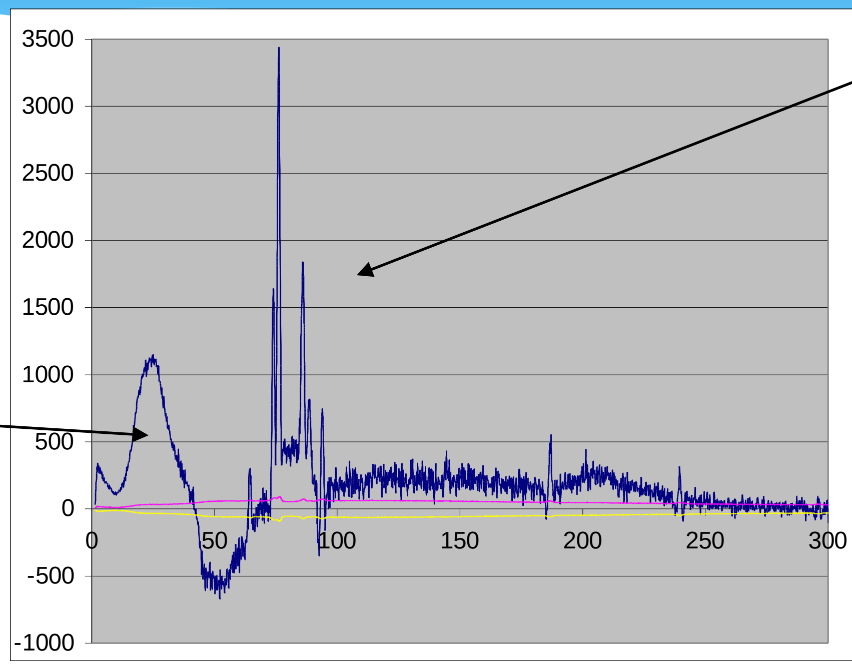
105% 40 keV – 3 MeV (double Al "window")
65% 25 keV – 3 MeV (Al window)
25% 25 keV - 3 MeV (Al window)
15% 5 keV – 3 MeV (Be window)

Gamma Ray
neutron Ge recoil energy spectra

Probable fission or neutron activation.

counts

n,Ge recoil



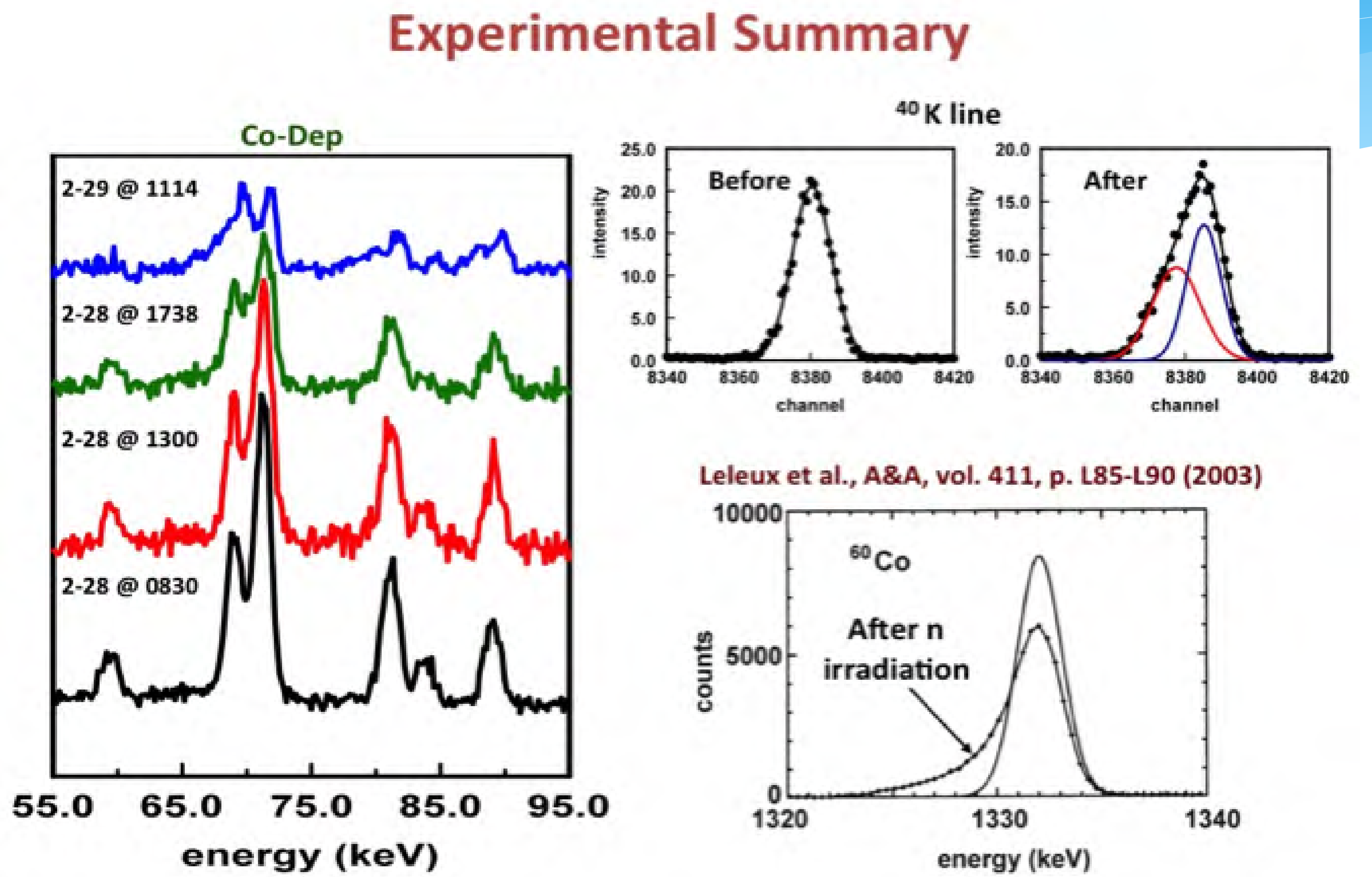
10% cryo-cooled Sandia Ge detector

Energy in keV

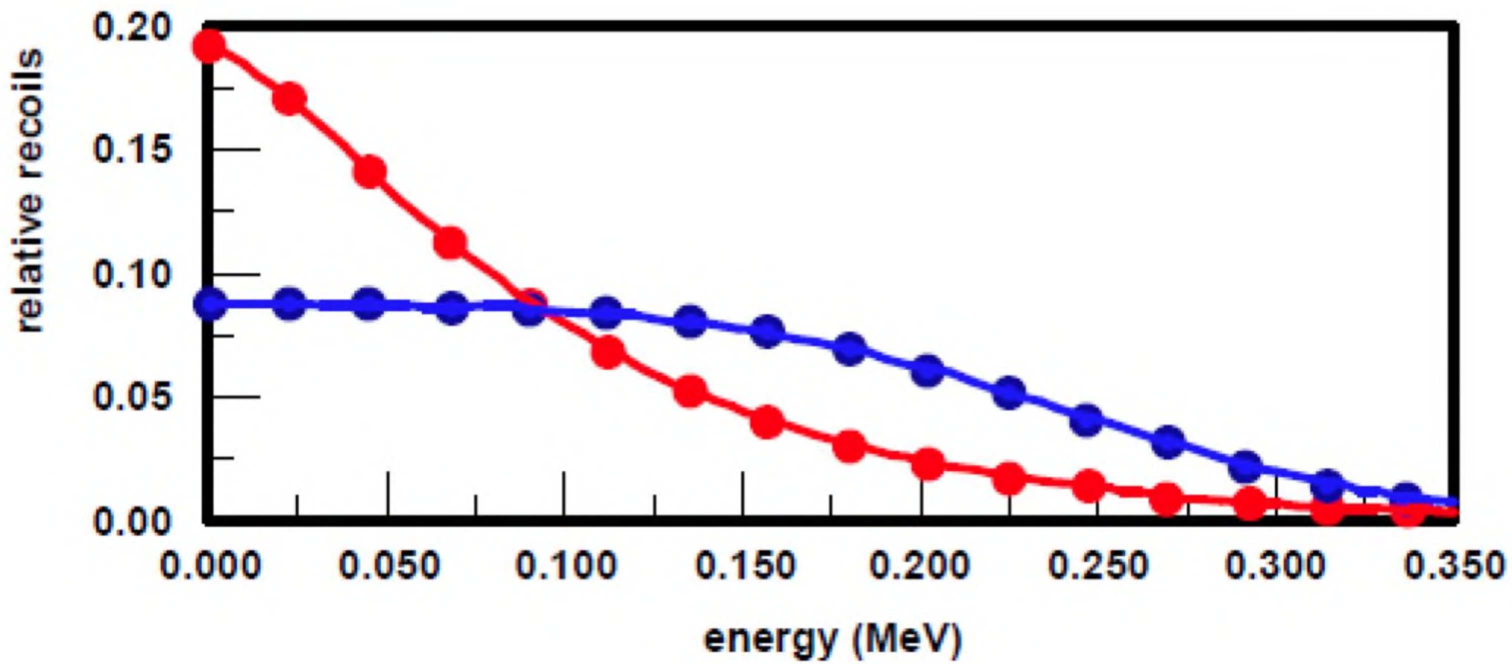
Consistent with primary and secondary neutron energy spectra from scattering of 6+ MeV neutrons, Dr. P. McDaniels, DoE Sandia National Laboratory.

Note: It is common to look for thermal neutron capture on Ge isotopes, however, these are fast neutrons.

Neutron Damaged HPGe Detector



ast neutron energy spectrum exceeds U^{238} fission threshold[1]



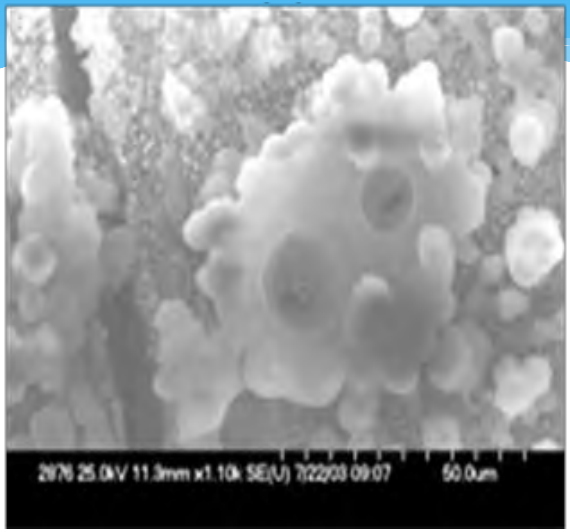
Red: fission neutron elastic Ge recoils

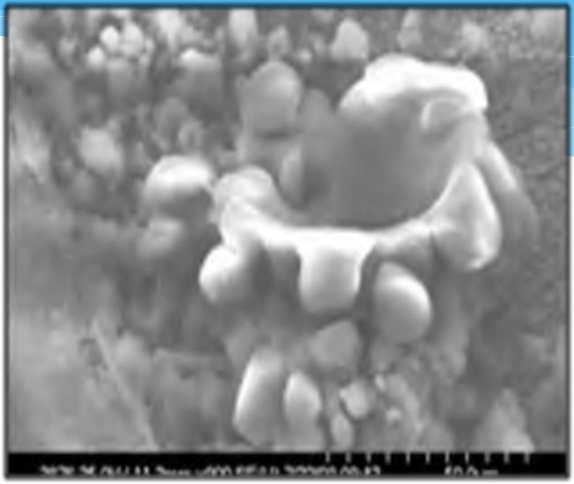
Blue: Co-dep neutron elastic Ge recoils

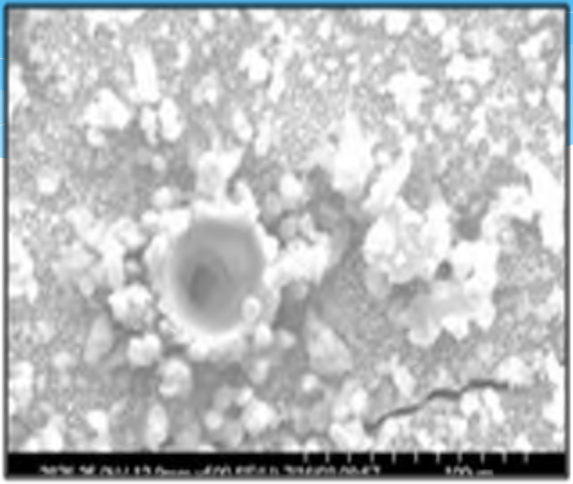
Average neutron energy > 6 MeV

[1]P. McDaniel, Sandia DoE National Laboratory, April, 2008

Microphotographs of nuclear reactions showing intense heat by melting



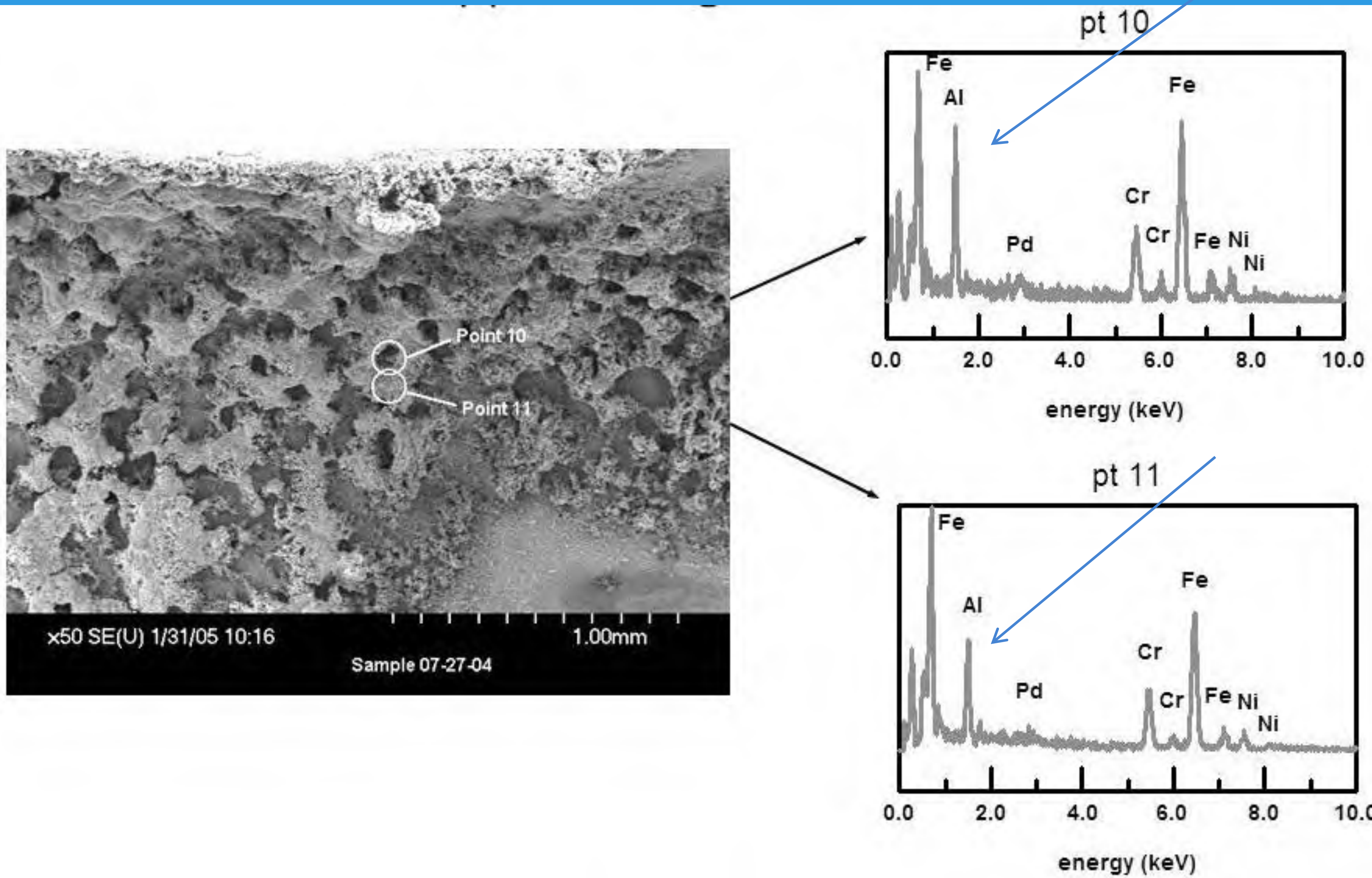




- Palladium melting and vaporizing as a result of nanonuclear reactions
- *Temperatures exceed 5,300 degrees F.*

Transmutation

Nuclear Ash Fissioned to Aluminum (presence of external 2500 gauss B field)



Our Refereed Papers

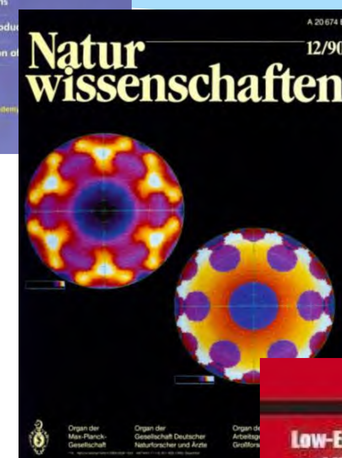
Journals

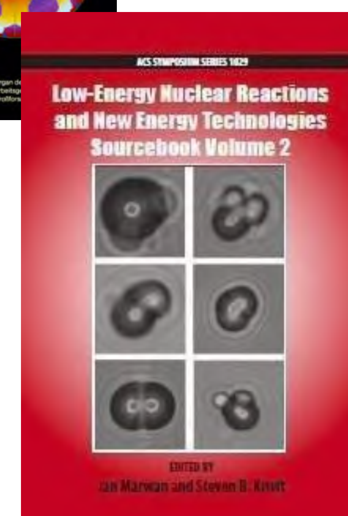
#	Journal	Volume	Year	Subject
1.	*J. Electroanal. Chem.*,	**302**	(1991)	co-dep introduced, heat, tritium, x-rays observ
2.	*J. Electroanal. Chem.*,	**309**	(1991)	modeling of deuterium transport in bulk catho
3.	*J. Electroanal. Chem.*,	**337**	(1992)	modeling and experimental deuterium transpo
4.	*J. Electroanal. Chem.*,	**365**	(1992)	modeling and exp D transport within Pd using
5.	*J. Electroanal. Chem.*,	**373**	(1994)	Tritium modeling and production in co-dep
6.	*J. Electroanal. Chem.*,	**379**	(1994)	deuterium transport in co-dep
7.	*J. Electroanal. Chem.*,	**380**	(1995)	co-dep processes examined and discussed
8.	*Phys. Lett. A.*	**210**	(1996)	co-dep x-rays observed and identified
9.	*Phys. Lett. A.*	**221**	(1996)	thermal imaging and oscillating hot spots
10.	*Fusion Technology*,	**33**	(1998)	tritium production
11.	*Fusion Technology*,	**34**	(1998)	tritium production and co-dep morphology
12.	*Nuovo Cim. Soc. Ital. Fis. A*,	**112**	(1999)	thermal imaging, positive temp feedback
13.	*Fusion Technology*,	**36**	(1999)	co-dep calorimetry
14.	*Thermochimica Acta*,	**410**	(2004)	co-dep calorimetry, excess heat exceeds bulk
15.	*J. Electroanal. Chem.*,	**580**	(2005)	E-field manipulation of co-dep morphology
16.	*Naturwissenschaften*,	**92**	(2005)	co-dep transmutation at ejecta sites
17.	*Naturwissenschaften*,	**94**	(2007)	co-dep charged particles using SSNTD
18.	*Eur. Phys. J. Appl. Phys.*,	**40**	(2007)	SSNTD controls and nuclear particle distribut
20.	*Naturwissenschaften*,	**96**	(2009)	co-dep triple-track, DT fusion observed
21.	*Eur. Phys. J. Appl. Phys.*,	**44**	(2008)	Response to Kowalski: co-dep nuclear tracks
22.	*Eur. Phys. J. Appl. Phys.*,	**46**	(2009)	co-dep nuclear particle specie and spectra
24.	*Eur. Phys. J. Appl. Phys.*	**51**	(2010)	comparison of co-dep and DT fusion tracks
25.	*J. Condensed Matter Nucl. Sci.*	**3**	(2010)	Response to Kowalski: co-dep nuclear species
26.	*J. Environ. Monitoring*,	**12**	(2010)	Response to Shanahan: LENR observations
27.	*J. Condensed Matter Nucl. Sci.*	**4**	(2011)	Review of 20 years of Pd:D co-dep research
28.	*Radiation Measurements*	**47**	(2012)	Comparison of optical and SEM DT track ana
29.	*Detector Phys XIII, SPIE*	**8142**	(2011)	Optical and SEM analysis of DT/PdD tracks

Books

19. *Low Energy Nuclear Reactions Source Book*, American Chemical Society, (2008)
Co-dep model system, SSNTD controls, nuclear species and DT fusion neutrons

23. *Low Energy Nuclear Reactions Source Book II*, American Chemical Society, (2010)
Application of co-dep nuclear particles to RTG portable nuclear electric power





DT Fusion Neutrons in a Pd/D Lattice

Naturwissenschaften (2009) 96:135–142
DOI 10.1007/s00114-008-0449-x

SHORT COMMUNICATION

Triple tracks in CR-39 as the result of Pd–D Co-deposition: evidence of energetic neutrons

Pamela A. Mosier-Boss · Stanislaw Szpak · Frank E. Gordon · Lawrence P. G. Forsley

Received: 30 July 2008 / Revised: 3 September 2008 / Accepted: 14 September 2008 / Published online: 1 October 2008

Abstract Since the announcement by Fleischmann and Pons that the excess enthalpy generated in the negatively polarized Pd–D-D_2O system was attributable to nuclear reactions occurring inside the Pd lattice, there have been reports of other manifestations of nuclear activities in this system. In particular, there have been reports of tritium and helium-4 production; emission of energetic particles, gamma or X-rays, and neutrons; as well as the transmutation of elements. In this communication, the results of Pd–D co-deposition experiments conducted with the cathode in close contact with CR-39, a solid-state nuclear etch detector, are reported. Among the solitary tracks due to individual energetic particles, triple tracks are observed. Microscopic examination of the bottom of the triple track pit shows that the three lobes of the track are splitting apart from a center point. The presence of three α-particle tracks outgoing from a single point is diagnostic of the $^{12}C(n,n')3\alpha$ carbon breakup reaction and suggests that DT reactions that produce ≥9.6 MeV neutrons are occurring inside the Pd lattice. To our knowledge, this is the first report of the production of energetic (≥9.6 MeV) neutrons in the Pd–D system.

Electronic supplementary material The online version of this article (doi:10.1007/s00114-008-0449-x) contains supplementary material, which is available to authorized users.

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Keywords CR-39 · Palladium · Neutrons

Introduction

CR-39 is an allyl glycol carbonate plastic that has been widely used as a solid-state nuclear track detector. These detectors have been used extensively to detect and identify such fusion products as p, D, T, ^3He, and α particles resulting from inertial confinement fusion (ICF) experiments (Séguin et al. 2003). They have also been used to detect neutrons (Phillips et al. 2006). When a charged particle passes through the CR-39 detector, it leaves a trail of damage along its track inside the plastic in the form of broken molecular chains and free radicals (Frenje et al. 2002). After treatment with an etching agent, tracks remain as holes or pits. The size and shape of these pits provide information about the mass, charge, energy, and direction of motion of the particles (Nikezic and Yu 2004). Therefore, CR-39 detectors can semiqualitatively be used to distinguish the types and energies of individual particles. Advantages of CR-39 for ICF experiments include its insensitivity to electromagnetic noise; its resistance to mechanical damage; and its relative insensitivity to electrons, X-rays, and γ-rays. Consequently, CR-39 detectors can be placed close to the source without being damaged. Furthermore CR-39, like photographic film, is an example of a constantly integrating detector, which means that events are permanently stamped on the surface of the detector. As a result, CR-39 detectors can be used to detect events that occur either sporadically or at low fluxes.

Earlier, the use of CR-39 to detect the emission of energetic particles resulting from Pd–D electrolysis

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Comparison of Pd/D co-deposition and DT neutron generated triple tracks observed in CR-39 detectors

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Abstract. Solid state nuclear track detectors (SSNTDs), such as CR-39, have been used to detect energetic charged particles and neutrons. Of the neutron and charged particle interactions that can occur in CR-39, the one that is the most easily identifiable is the carbon breakup reaction. The observation of a triple track, which appears as three alpha particle tracks breaking away from a center point, is diagnostic of the $^{12}C(n,n')3\alpha$ carbon breakup reaction. Such triple tracks have been observed in CR-39 detectors that have been used in Pd/D co-deposition experiments. In this communication, triple tracks in CR-39 detectors observed in Pd/D co-deposition experiments are compared with those generated upon exposure to a DT neutron source. It was found that both sets of tracks were indistinguishable. Both symmetric and asymmetric tracks were observed. Using linear energy transfer (LET) curves and track modeling, the energy of the neutron that created the triple track can be estimated.

1 Introduction

In 1978, Cartwright et al. [1] were the first to demonstrate that Columbia Resin 39 (CR-39), an optically clear, amorphous, thermoset plastic, could be used to detect nuclear particles. When an energetic, charged particle traverses through a solid state nuclear track detector (SSNTD) such as CR-39, it creates along its path an ionization trail that is more sensitive to chemical etching than the bulk material [1,2]. After treatment with a chemical etchant, tracks due to the energetic particles remain in the form of holes or pits which can be examined with the aid of an optical microscope. The size, depth of penetration, and shape of the track provides information about the mass, charge, energy, and direction of motion of the particle that created the track [3]. Besides detection of charged particles such as protons and alphas, CR-39 can also be used to detect neutrons [4].

Since its introduction as a detector for nuclear particles, CR-39 has found extensive use as a charged-particle spectrometer to study inertial-confinement-fusion (ICF) plasmas [4]. This is not surprising given the ability of CR-39 to detect both energetic charged particles and neutrons, which are products of the fusion reactions that occur in the plasma created upon laser-compression of the fuel capsule. Other advantages of CR-39 for use in the ICF field are its integrating capability, existence of a threshold for registration, ruggedness, and a degree of charge and energy discrimination [5]. SSNTDs can be used to record events cumulatively over long periods of time. This is particularly important for events that occur either sporadically or in bursts. The detectors are insensitive to electromagnetic noise and are resistant to mechanical damage. CR-39 detectors are relatively insensitive to gamma or X-ray emissions. Dielectric materials, such as CR-39, can register particles only if their charge and linear energy transfer (LET) value are above a minimum threshold that is dependent upon the composition and structure of the detector. A great deal of effort has been spent by a number of researchers to calibrate the SSNTDs using particle generators for speciation and energy determination [6]. While the size and shape of the track depends upon the energy and charge of the particle that created it, the ability of the detectors to discriminate particles is still poor and is dependent upon etching conditions and methodology. This is compounded by variability between the detectors caused by manufacturing procedures, the age of the detectors, as well as the temperature and storage history of the detectors.

The same advantages that make CR-39 useful in the ICF community also make it attractive for use in detecting particles in the Pd/D system. In addition, the

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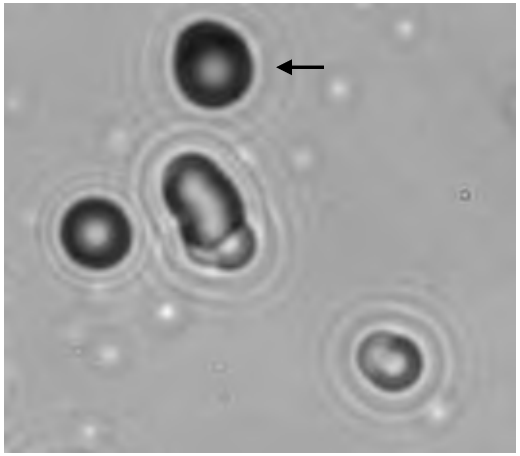
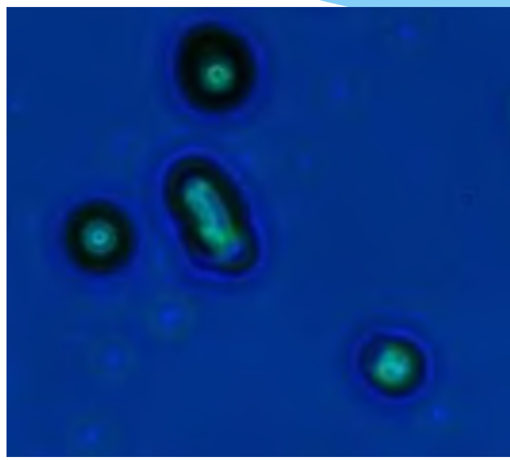
Conclusion

* Multiple Nuclear Channels
  * Fast protons
  * Fast neutrons
* Collateral Damage
  * Tritium previously observed
  * Elemental transmutation
* Aneutronic Thermal Channel

Results of Modeling

EPJAP, (2010)





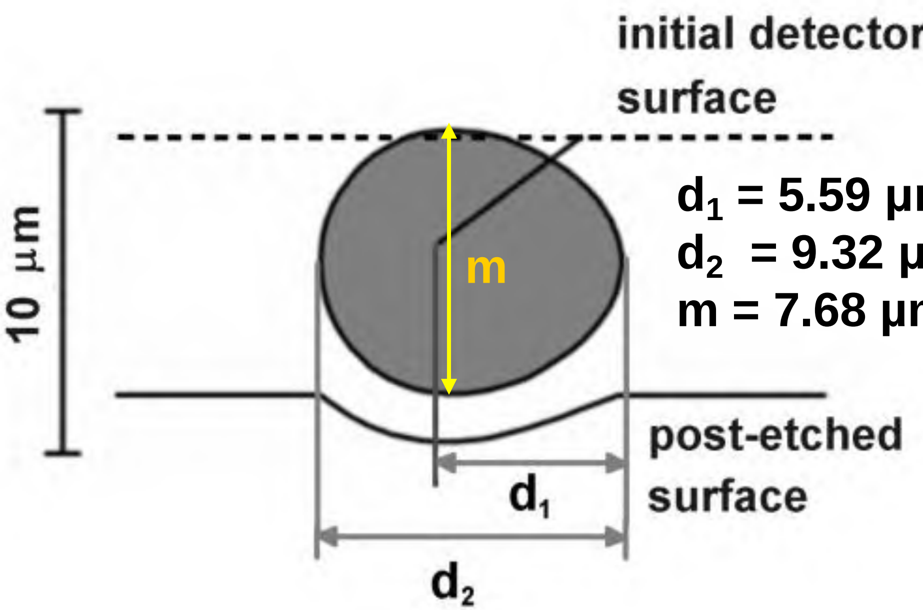
E_α = 1.3 MeV

Incident angle = 35º

Etch rate = 1.25 µm hr $^{-1}$

Etch time = 6 hr

NOTE: This is the energy of the particle when it impacts the CR-39 detector



d_1 = 5.59 µm

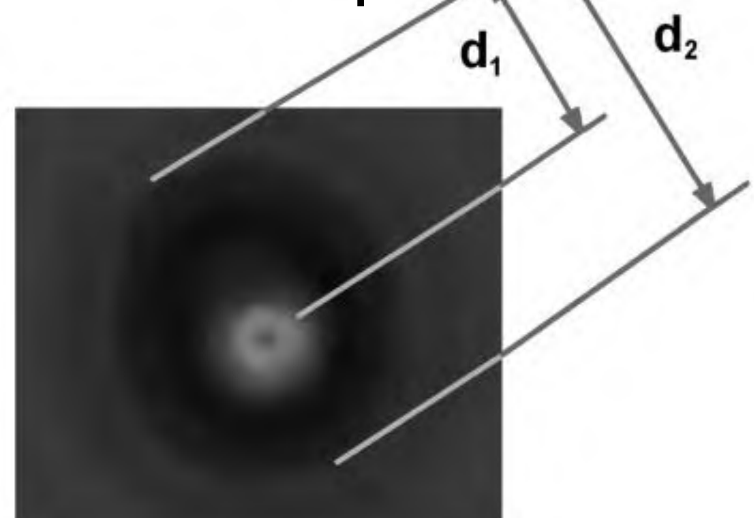
d_2 = 9.32 µm

m = 7.68 µm

d_1 = 5.34 ± 0.19 µm

d_2 = 9.36 ± 0.19 µm

m = 7.68 ± 0.19 µm

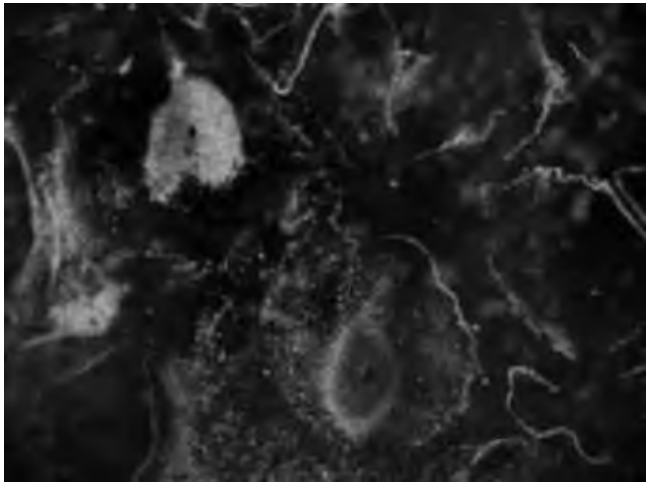


Magnetic & Material Nuclear Control

Mosier-Boss et al., EPJAP, Vol. 40, p. 293 (2007) and Marwan et al., JEM, Vol. 12, p. 1765 (2010)

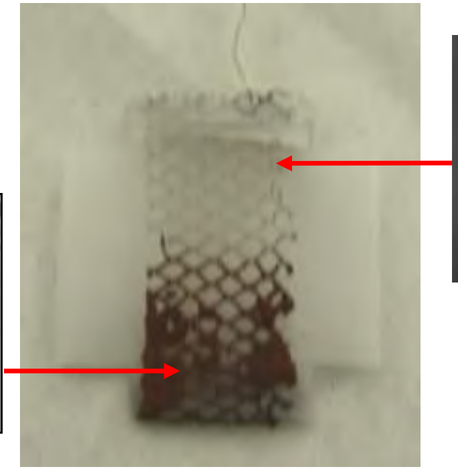
Ni/Pd-D, no external field

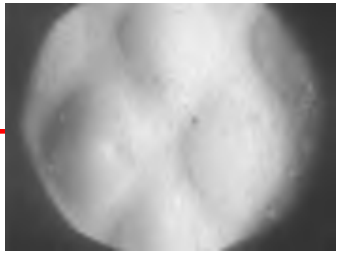
Ni/Pd-D, external B field



- Magnetic field
  - For Ni cathode, external E/B field necessary for nuclear reactions
- Materials
  - Au was plated on half of the Ni cathode
  - No external E/B field
  - Only X-rays on Ni portion
  - Charged particles and neutrons on Au half

Tracks





No tracks

Resulting in Elemental Transmutation