Neutron and Charged Particle Spectroscopy

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From Fukushima[1] and beyond…

"The Beast that will not die"[2]
--- The Economist

"Are you still using fossil fuels, or have you discovered crystallic fusion?"[3]
--Buzz Lightyear

1. *Zeissler, Forsley, et al,* "Radio-microanalytical Particle Measurements, Techniques and Application to Fukushima Aerosols Collected in Japan", *Journal of Radioanalytical and Nuclear Chemistry,* accepted. (2012)
2. "Table-Top Fusion: The Beast that will not die", Economist, May 26, 2009.
3. "Toy Story", Pixar.

Overview

- Diagnostics and Tradeoffs
- Real-time Energetic Neutron Detection
    - Liquid Scintillator spectroscopy
    - Damaging HPGe gamma detector
- Witness materials
- Solid State Nuclear Track Detectors
- Acknowledgements
- Thanks

Energetic Particle Diagnostics

- Solid State Nuclear Track Detectors
  - Charged particles and neutrons
- Cryogenically Cooled High Purity Germanium (HPGe)
  - x-rays, gamma rays and *neutrons*
- NaI(Tl)
  - gamma rays
- Bicron 412 Plastic Scintillator
  - neutrons
- Bicron 501A Liquid Scintillator
  - neutrons
- Bubble neutron Detectors
  - neutrons
- ^{3}He
  - neutrons
- Silicon Barrier Detectors
  - Alpha, betas, electrons
- Proton recoil
  - neutrons
- Witness Materials
  - Neutrons
- Liquid Scintillator
  - Alphas, betas, gammas

Diagnostic Tradeoffs

- **Cryogenically Cooled High Purity Germanium** (HPGe)
  - x-rays and gamma ray (5 keV – 3 MeV), high resolution
  - Sensitive to neutrons
- **NaI(Tl)**
  - **Gamma rays (40 keV – 3 MeV)** , 1 second integrations, poor resolution
  - Less-sensitive to neutrons
- **Bicron 412 Plastic Scintillator**, (No moderator)
  - Charged particles and neutrons, sensitive to gammas, Fast, poor energy resolution, modest efficiency
- **Bicron 501A Liquid Scintillator** (No moderator)
  - Charged particles and neutrons, sensitive to gammas, Fast, good efficiency, good energy resolution
- **^{3}He** (moderated with polyethylene)
  - neutrons, with good gamma rejection, No energy resolution,
- **Silicon Barrier Detectors**

  Proton and alpha high efficiency, high resolution, prefers vacuum
- **Bubble Detectors** (Bubble Technologies)
  - Neutrons, only neutrons, Integrating, no time resolution, limited spectroscopic resolution
- **Proton recoil neutron detector** (Los Alamos National Laboratory, Eglin/Ludlum: Precila)
  - Neutrons, flat response from thermal +20MeV, poor efficiency, no energy resolution
- **Liquid Scintillator** (Beckman LS-6500)
  - Alpha, beta, gamma, poor energy resolution, modest species resolution
- **Witness Materials (Cu, Zn, In, Au, U)**
  - Activation, mostly neutrons, poor energy resolution and efficiency

Solid State Nuclear Track Detector Tradeoffs

- **Solid State Nuclear Track Detectors (SSNTD)**
  - charged particles and neutrons,(insensitive to gamma)
  - Modest energy resolution, speciation and spatial information
  - Integrating detectors, no time resolution
  - Immune to electronic issues (noise, EMP)
  - **Low Temperature** (CR-39, Lexan, cellulose nitrate, etc.)
    - High efficiency, charged particles, low efficiency, neutrons (10^{-4} – 10^{-6})
    - Operating Temperature Range < 20C – 50C
    - Etching in 6.5 M NaOH, 70C, 6 hours
  - **High Temperature SSNTD** (BP-1 Glass, BK-7 Glass, Mica, Moscovite Mica)
    - Lower efficiency to charged particles and neutrons than low temp SSNTD
    - Operating Temperature Range < 20C - >500C
    - Etching in HF at 50C or Plasma Etch

LENR/LANR Issues

- Electrolytic systems: container and electrolyte
  - Liquid incompatible with most detectors
  - r^2 solid angle losses: distance from active region
  - X-rays and charged particles absorbed
- Gas systems: container and high temperature
  - r^2 solid angle losses: distance from active region
  - X-rays and charged particles absorbed
  - High temperatures and gas pressures preclude many diagnostics
  - EMP and EMI issues (e.g. glow discharge)

But, neutrons and hard gammas get through!

(and no one wants them ☹)

This talk emphasizes fast neutron detection

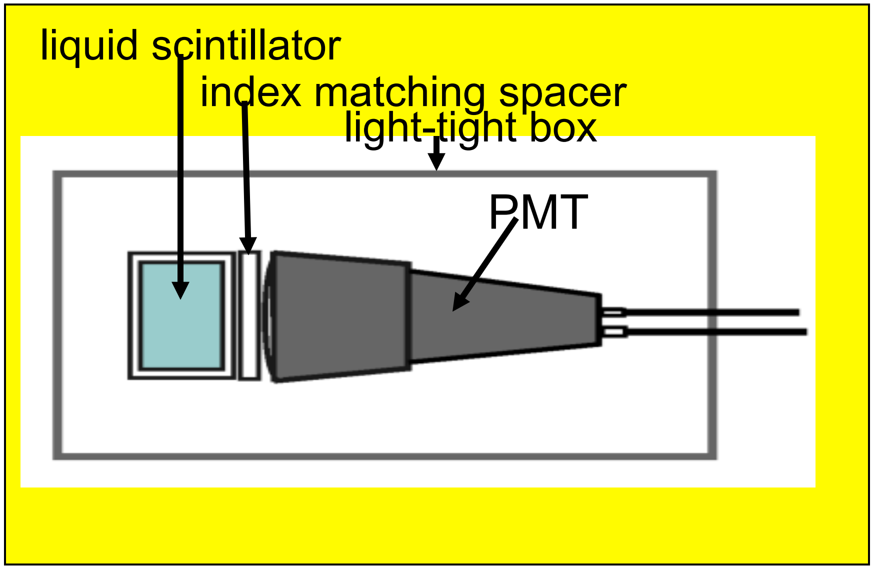
Real Time, Energy Resolved, Neutron Detection

Real-Time Neutron Detection

Liquid scintillator-based neutron detector

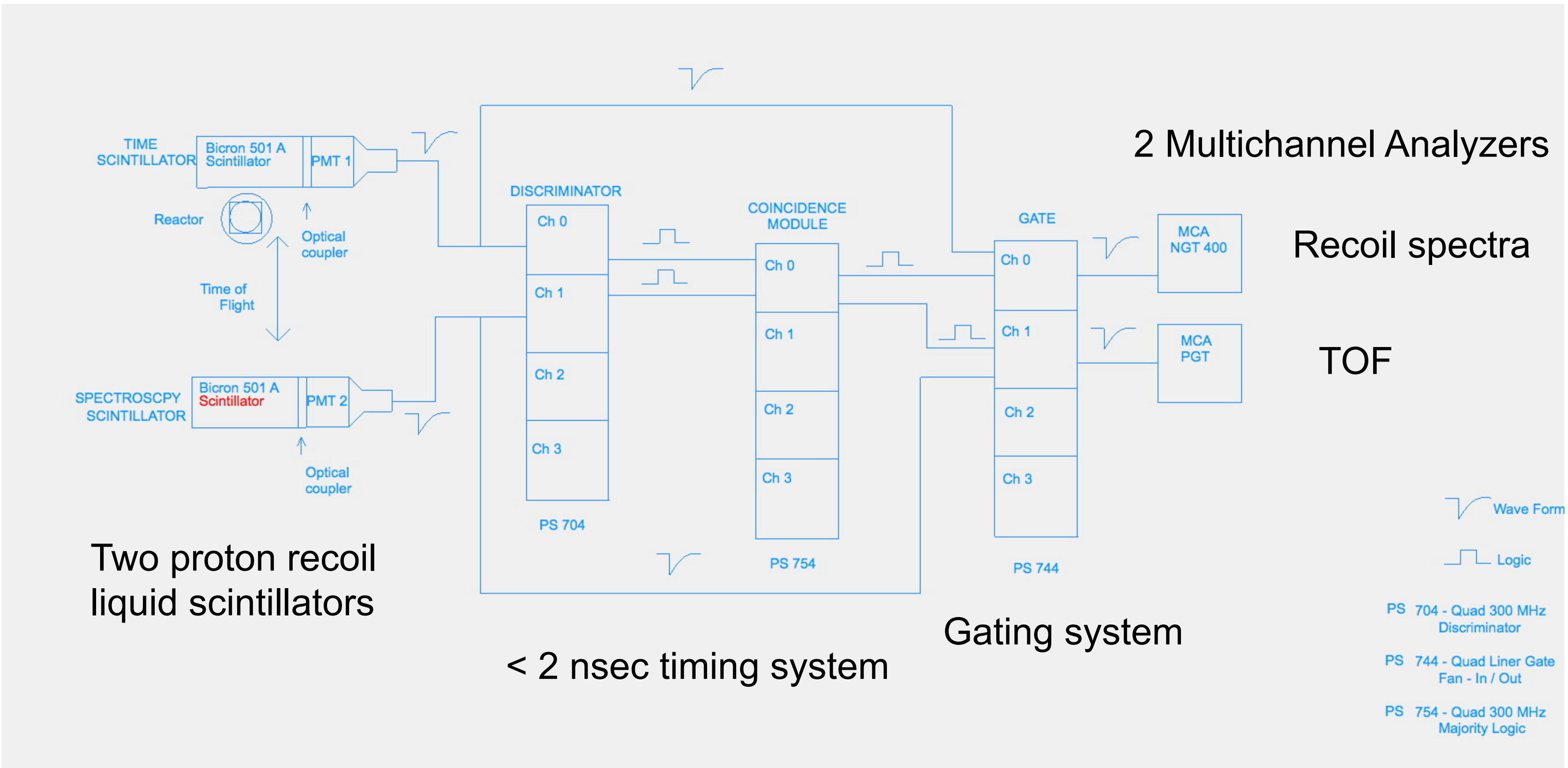
Advantages of this detector over COTS detectors:

1. Neutrons are spectrally and temporally resolved
2. Good neutron detection efficiency (5%)
3. Pair of detectors can be used for time-of-flight (TOF).
4. Pair of MCA's can be used for simultaneous energy measurements.



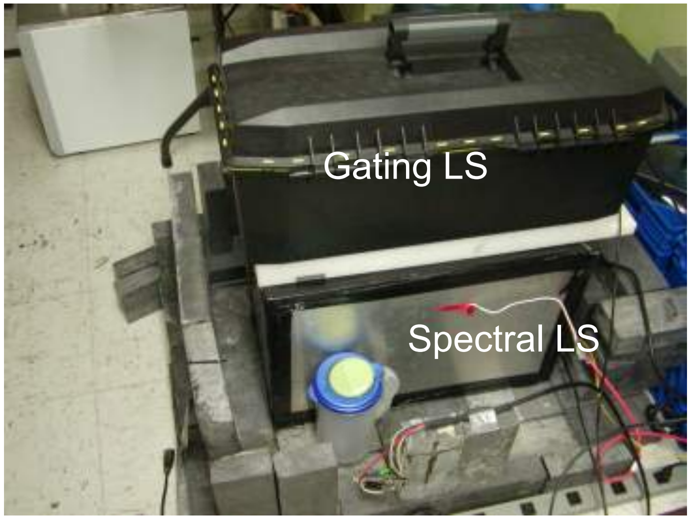
Gated Coincidence Detection

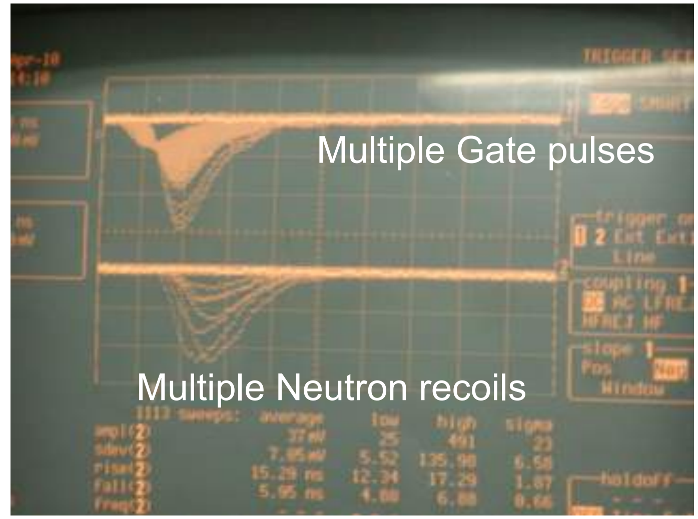
Time-of-Flight and unfolded recoil spectra allow simultaneous neutron energy measurements.

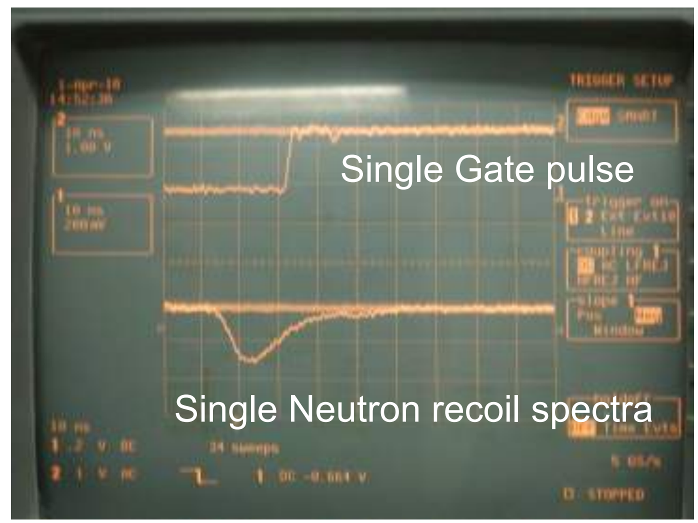


Gating system nearly eliminates background!

Coincidence Detection for Neutrons

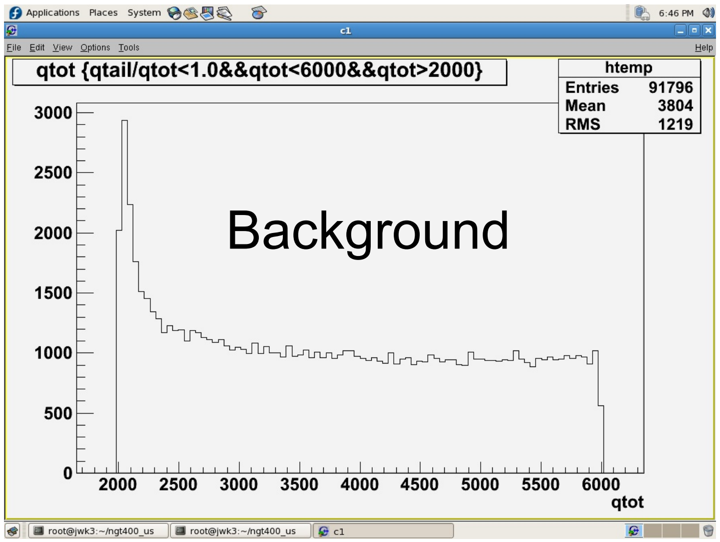


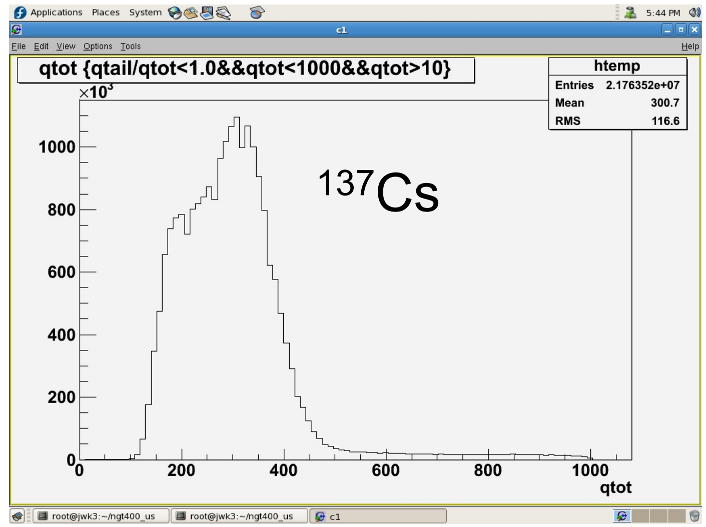


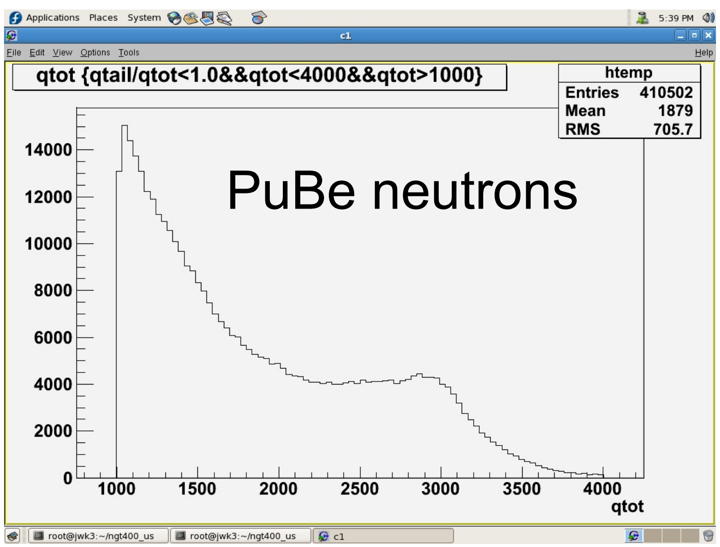


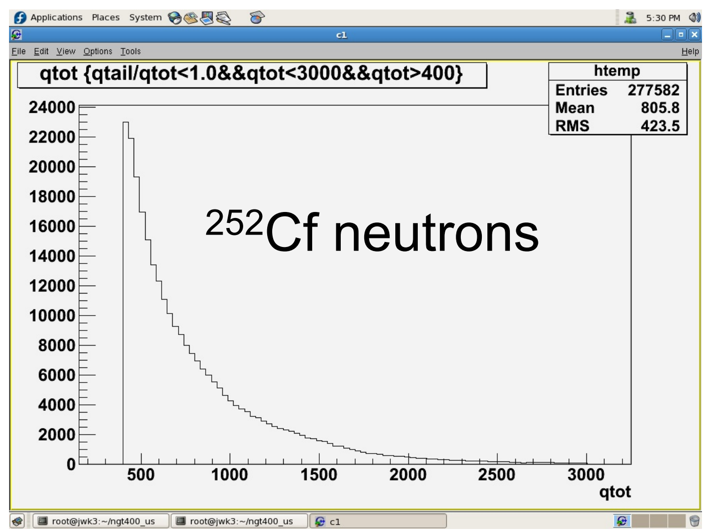
Cosmic ray astronomy with coincidence gating from muon induced spallation neutrons

Proton recoil liquid scintillator calibration









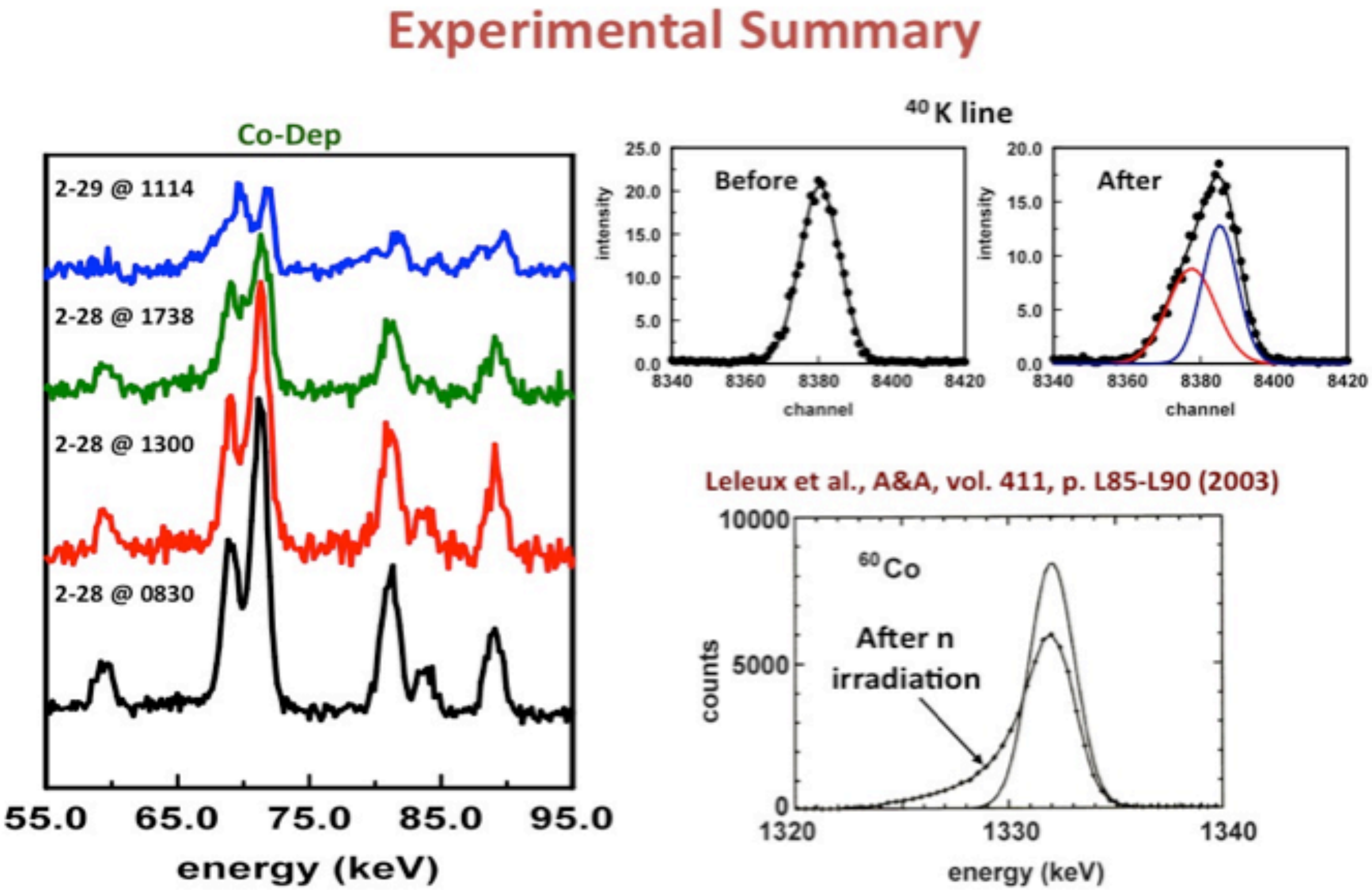
HPGe Neutron Detector[1]

[1]Not a good idea.

HPGe Detection of Neutrons

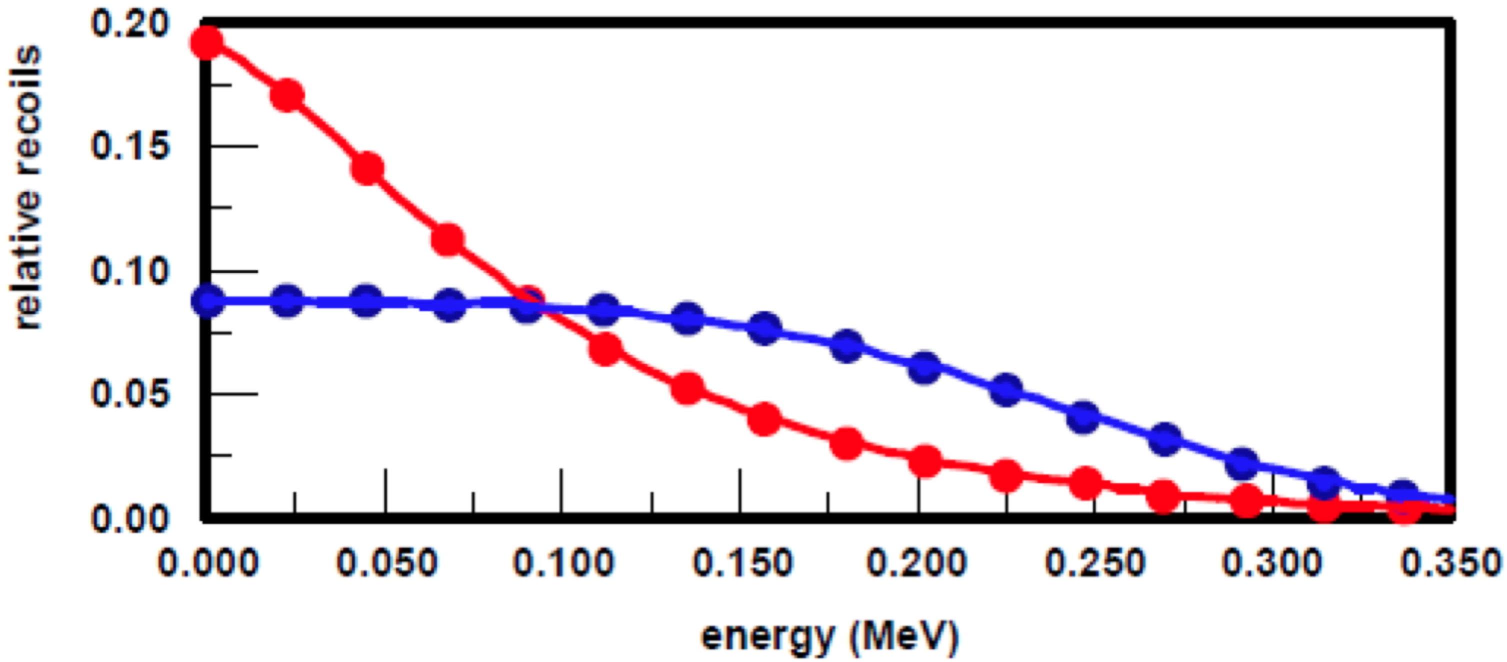
- HPGe
  - Cryogenically cooled germanium gamma ray detectors with Be window (5 keV – 3 MeV) or Al window (40 keV – 3 MeV)
- Neutrons
  - Thermal neutrons cause Ge isotope activation
  - Fast neutrons cause electron trapping defects

Neutron Damaged HPGe Detector



Damage consistent with average neutron flux of 10^6 n/sec for > 24 hours. (but, expensive neutron detector!)

However, this allowed measurement of a LENR fast neutron energy spectrum[1]



Red: calculated fission neutron elastic Ge recoils

Blue: measured Co-dep neutron elastic Ge recoils

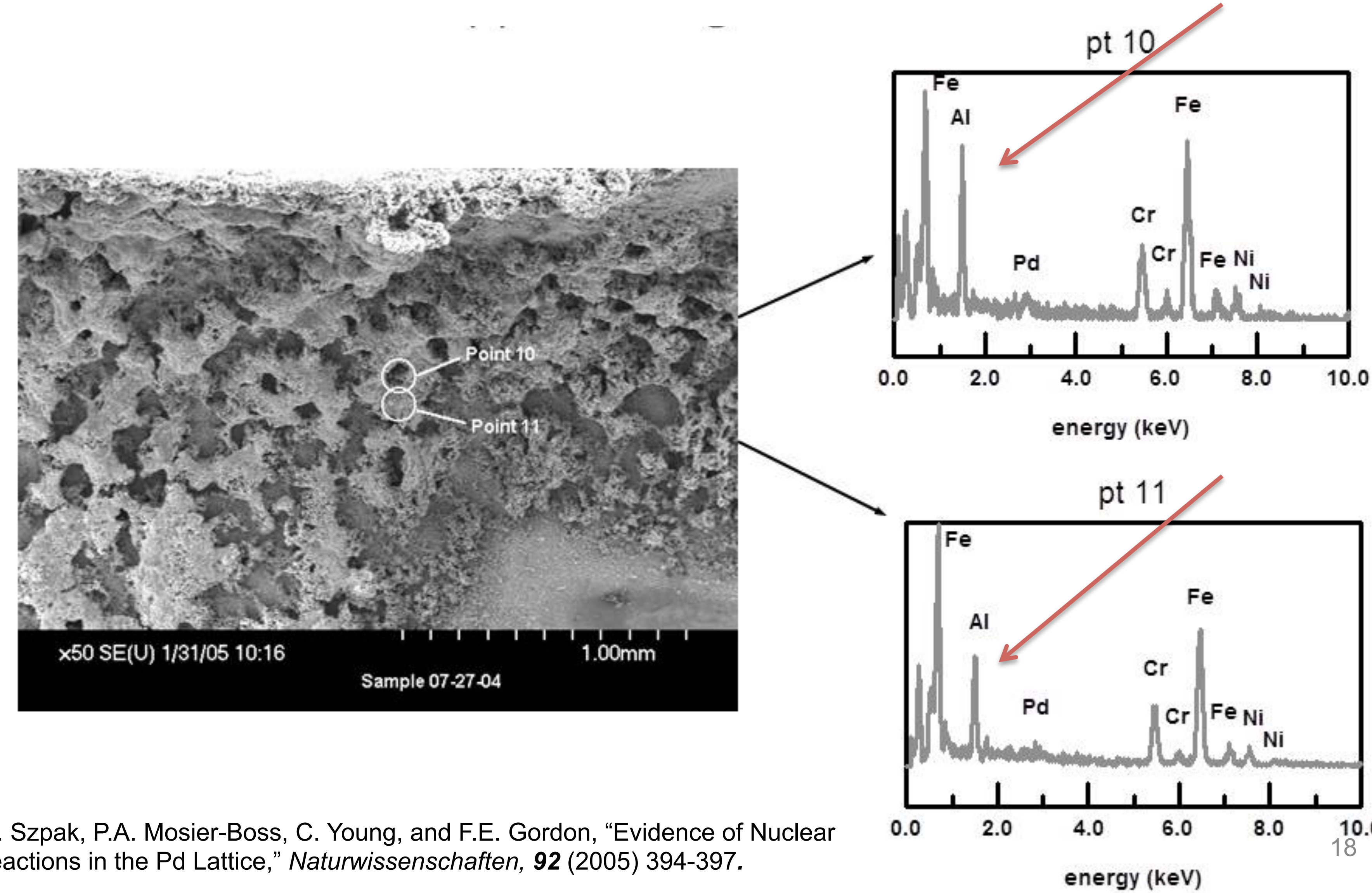
Average neutron energy > 6 MeV

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

Witness Materials

- Via transmutation!

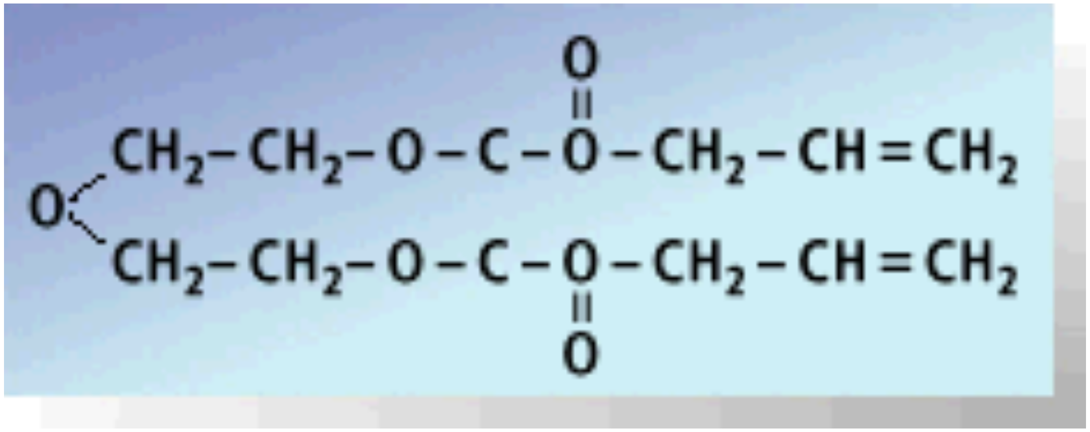
Pd Fissioned to Aluminum (presence of external 2500 gauss B field)[1]



[1]S. Szpak, P.A. Mosier-Boss, C. Young, and F.E. Gordon, "Evidence of Nuclear Reactions in the Pd Lattice," *Naturwissenschaften, **92*** (2005) 394-397.

Solid State Nuclear Track Detectors

CR-39

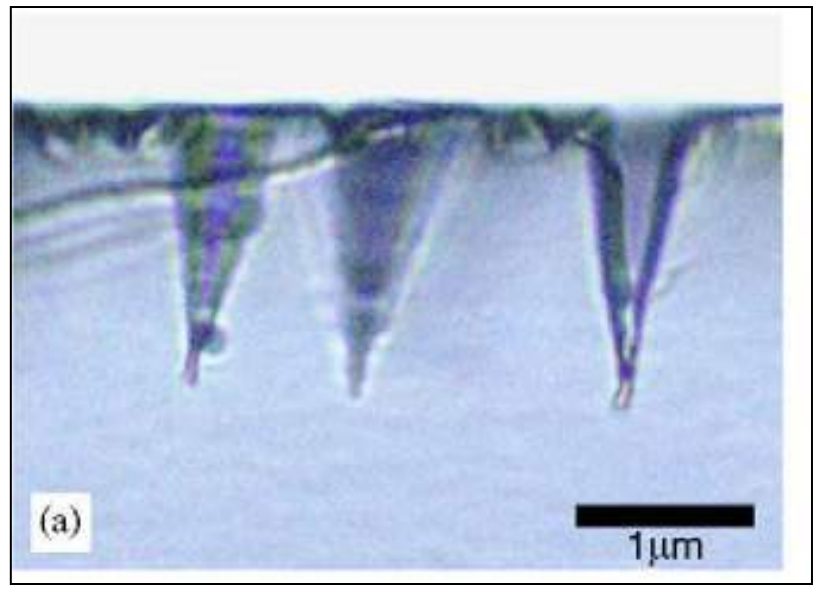


Polyallyl diglycol carbonate (PADC): $C_{12}H_{18}O_7$
Polymer: clear hard plastic, density 1.32 g/cm^2 Commonly used for plastic lenses

Neutrons scatter off CR-39 atoms
Recoil atoms stripped of outer electrons. Resulting charged particles lose energy by ionization:

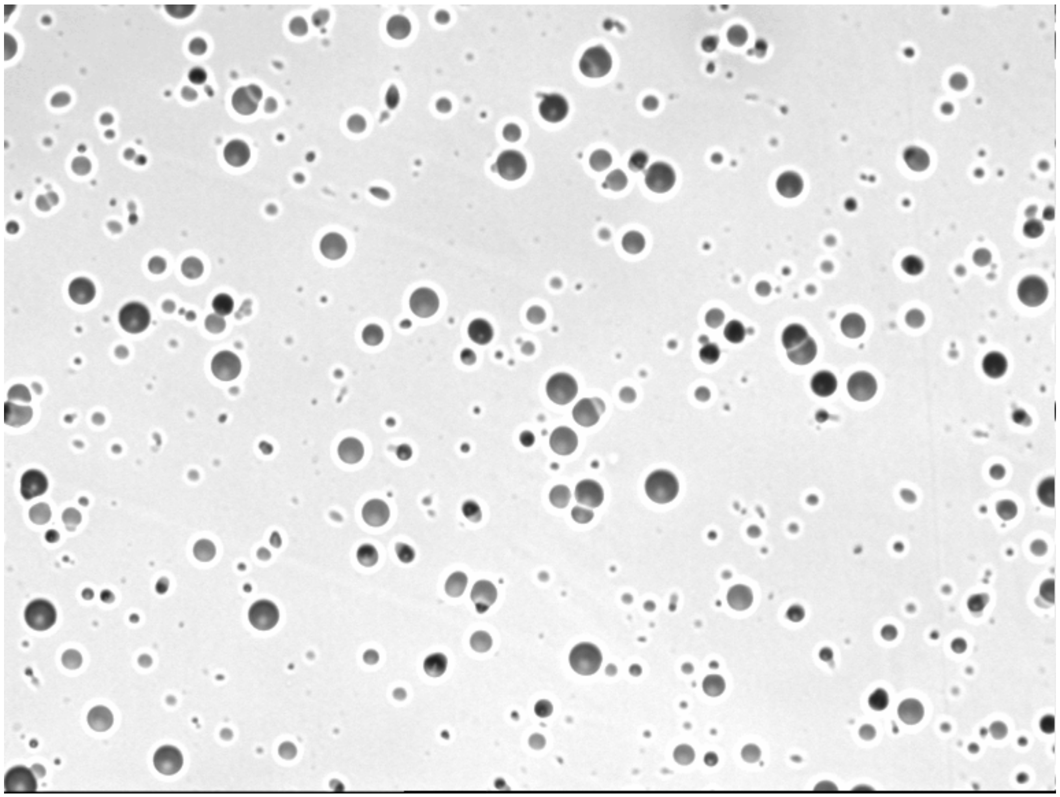
- Causes dislocations in polymer
- Leaves latent tracks tens of nanometers in diameter

NaOH etching preferentially along tracks enlarge to micrometers in size for viewing with optical microscope



Unusual side view of etched tracks

SNM[1] ID using CR-39 Neutron Spectroscopy



Microscope image of etched CR-39 foil exposed to neutrons from ^{238}PuO fission source

Neutron Spectroscopy developed by Dr. Gary Phillips, Georgetown University[2]

funded by:

National Nuclear Security Agency, US DoE

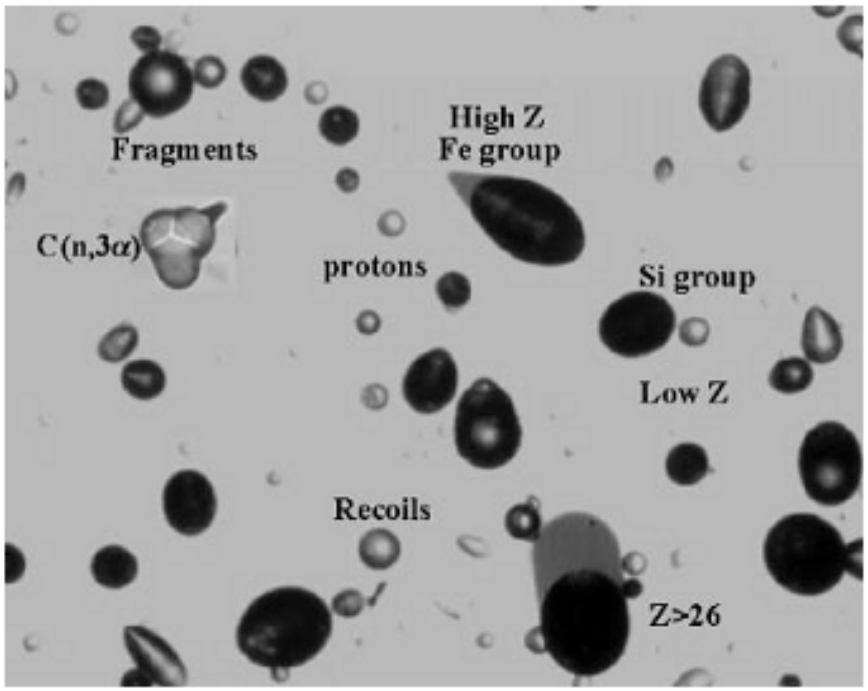
Defense Threat Reduction Agency (DTRA), US DoD

[1]SNM: "Special Nuclear Material"

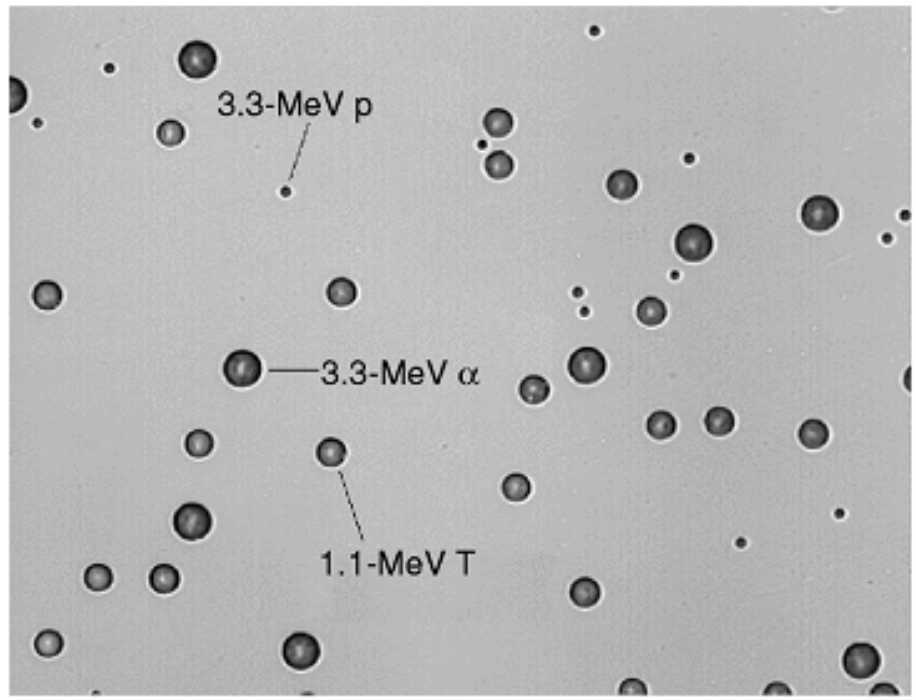
[2]G. Phillips*, et al, 14th Inter. Solid State Dosimetry Conf.* New Haven, CT, 28 June 2004

Particle Identification Using CR-39

International Space Station
Palfalvi et al., Rad. Prot. Dos., Vol. 110, p. 393 (2004)

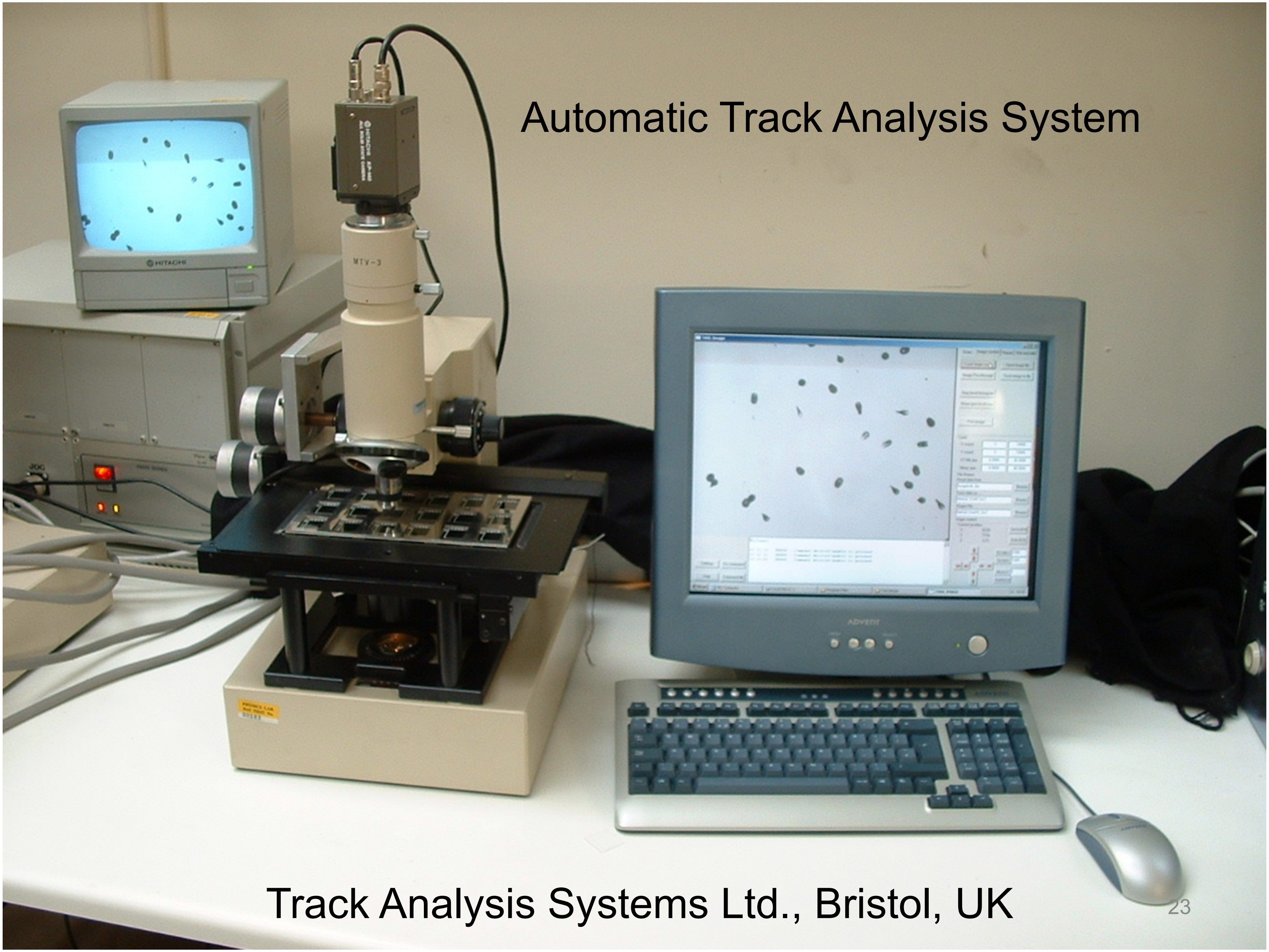


Inertial Fusion Implosions
Séguin et al., Rev. Sci. Instru., Vol. 74, p. 975 (2003)



- ▼**Detect protons, alphas, tritons, neutrons, and higher Z particles**
- ▼**Ideal to probe the nuclear reactions inside Pd lattice**

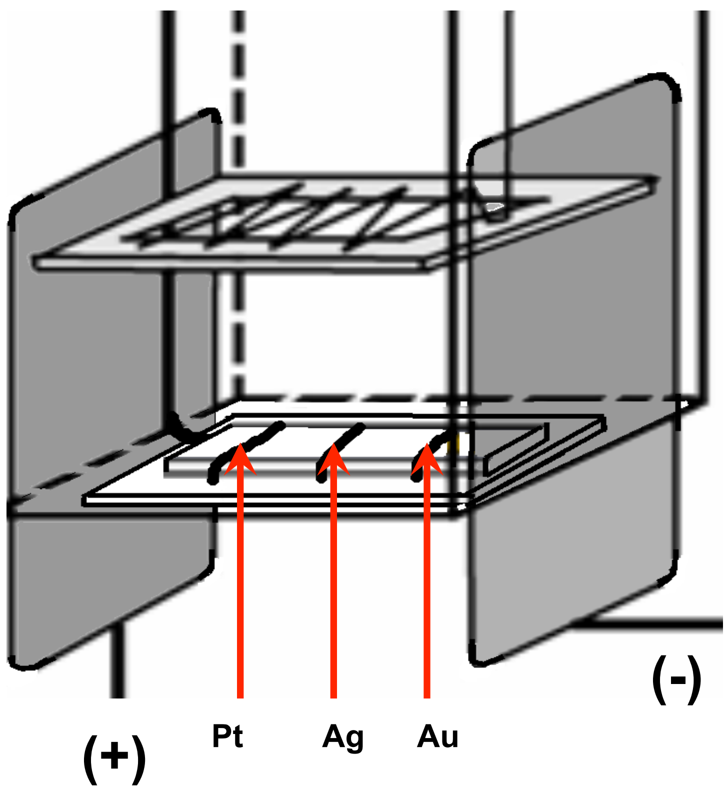
Automatic Track Analysis System

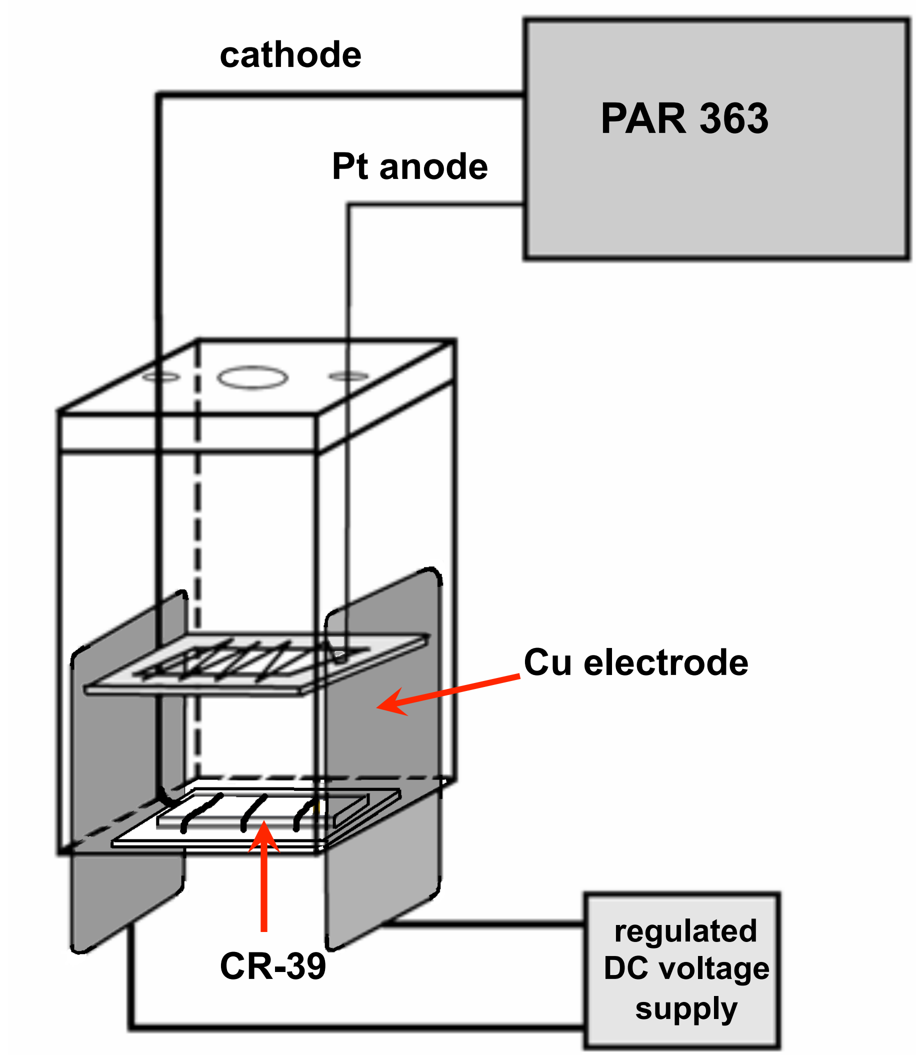


Track Analysis Systems Ltd., Bristol, UK

Pd/D Co-Deposition

Pd/D Co-Deposition, Three-wire Cathode E-field Experimental Configuration





US Patent 8,419,919[1]

US008419919B1

(12) **United States Patent**
Boss et al.

(10) **Patent No.: US 8,419,919 B1**
(45) **Date of Patent: Apr. 16, 2013**

(54) **SYSTEM AND METHOD FOR GENERATING PARTICLES**

(75) Inventors: **Pamela A. Boss**, San Diego, CA (US); **Frank E. Gordon**, San Diego, CA (US); **Stanislaw Szpak**, Poway, CA (US); **Lawrence Parker Galloway Forsley**, San Diego, CA (US)

(73) Assignees: **JWK International Corporation**, Annandale, VA (US); **The United States of America as represented by the Secretary of the Navy**, Washington, DC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1036 days.

(21) Appl. No.: **11/859,499**

(22) Filed: **Sep. 21, 2007**

Related U.S. Application Data

(60) Provisional application No. 60/919,190, filed on Mar. 14, 2007.

(51) **Int. Cl.**
C25D 5/48 (2006.01)
C25C 1/20 (2006.01)

(52) **U.S. Cl.**
USPC **205/220**; 205/102; 205/265; 205/627

(58) **Field of Classification Search** 204/229.4, 204/660, 663; 205/339, 340, 565, 627, 102, 205/220, 265, 441
See application file for complete search history.

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J. O'M. Bockris, R. Sundaresan, Z. Minevski, D. Letts. "Triggering of heat and sub-surface changes in Pd-D Systems." The Fourth International Conference on Cold Fusion. Transacations of Fusion Technology, Dec. 1994. vol. 25, No. 4T. p. 267.*

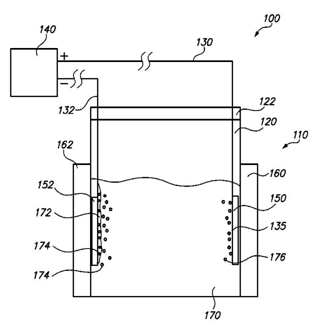
(Continued)

Primary Examiner — Keith Hendricks
Assistant Examiner — Steven A. Friday
(74) *Attorney, Agent, or Firm* — Ryan J. Friedl; Kyle Eppele

(57) **ABSTRACT**

A method may include the steps of supplying current to the electrodes of an electrochemical cell according to a first charging profile, wherein the electrochemical cell has an anode, cathode, and electrolytic solution; maintaining a generally constant current between the electrodes; exposing the cell to an external field either during or after the termination of the deposition of deuterium absorbing metal on the cathode; and supplying current to the electrodes according to a second charging profile during the exposure of the cell to the external field. The electrolytic solution may include a metallic salt including palladium, and a supporting electrolyte, each dissolved in heavy water. The cathode may comprise a second metal that does not substantially absorb deuterium, such as gold. The external field may be a magnetic field.

7 Claims, 10 Drawing Sheets



System and Method for Generating Particles

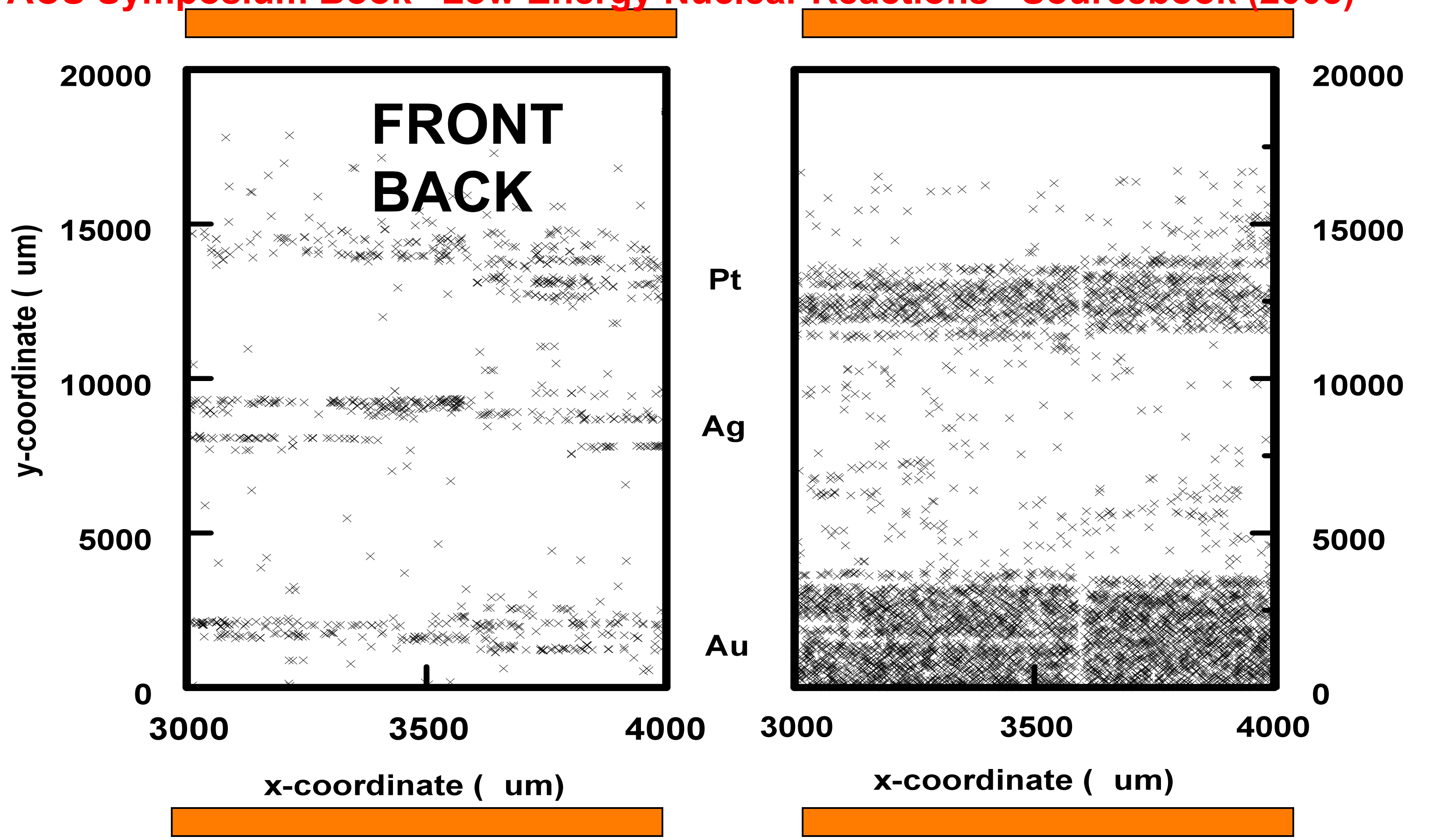
Generated particles may be captured by other nuclei to create new elements, to remediate nuclear waste, to treat cancerous tumors, or to create strategic materials. Previous efforts to create a reproducible method and corresponding system to generate particles during electrolysis of palladium in heavy water have been unsuccessful.

[1]*Issued April 16, 2013*

Charged Particles

Front and Back Surface Comparison: 1 mm by 17 mm scan, 6000V E Field Exp.

ACS Symposium Book “Low Energy Nuclear Reactions Sourcebook (2008)

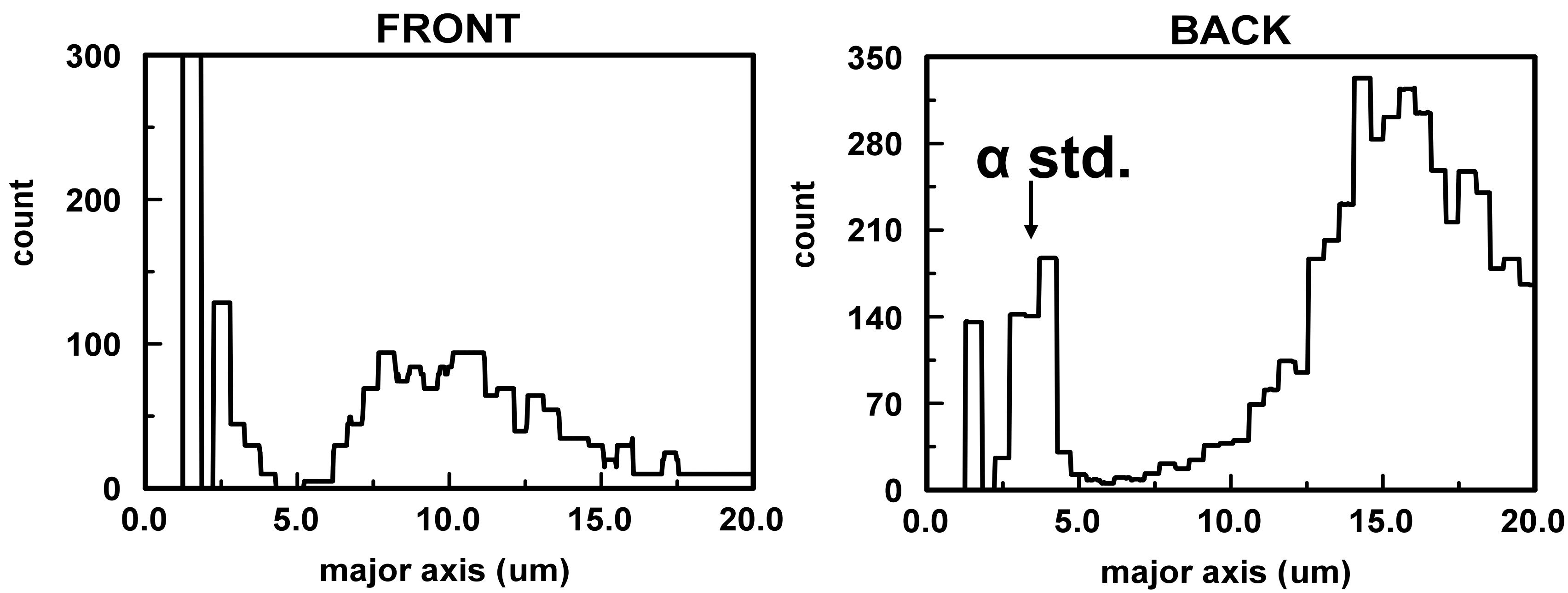


Same (x,y) locations, front and back.

Pt, Ag, Au tracks on front. Pt and Au tracks on back.

No tracks from Ag on back!

Three Wire Experiment: Counts vs Major Axis



Front: d1, 2 μm; d2, 3.5 μm; d3, 8 - 12 μm

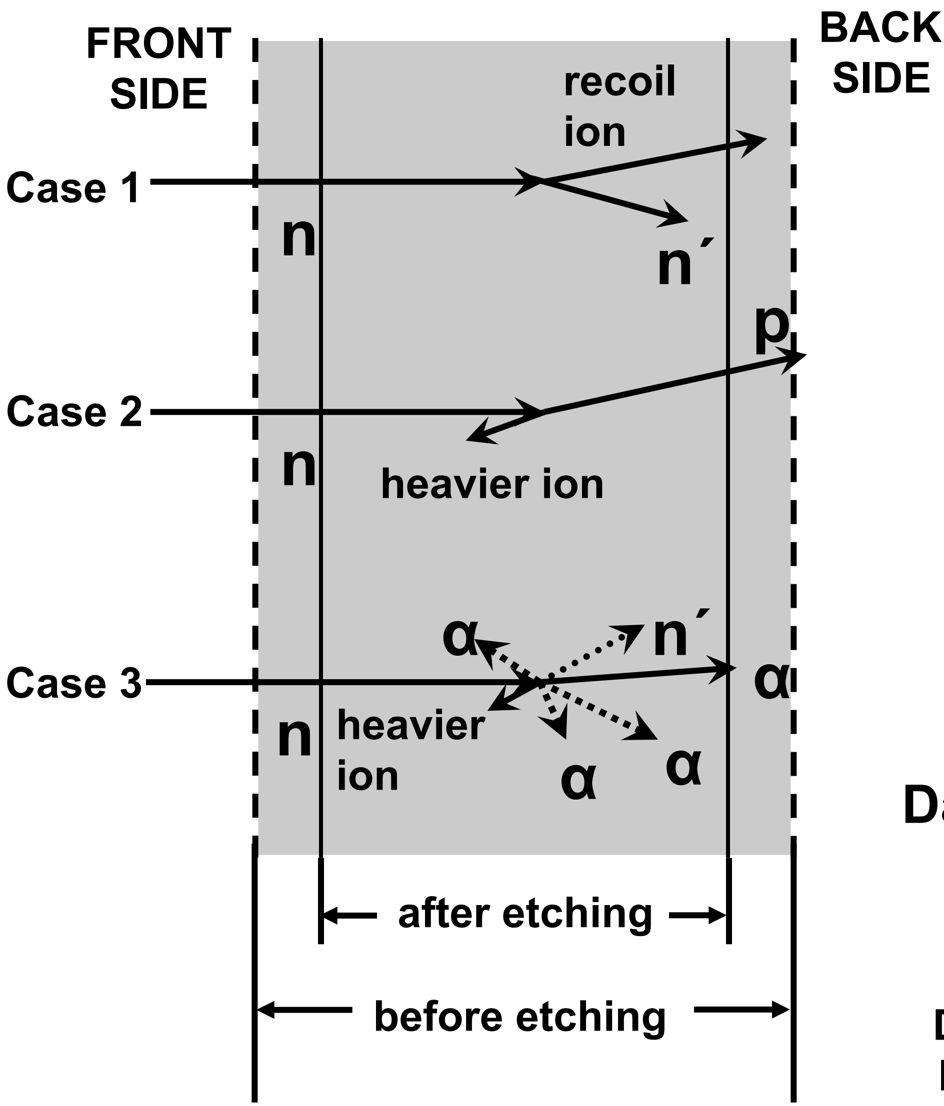
Mylar experiments: 1-3 MeV α, 0.45-1 MeV p^+

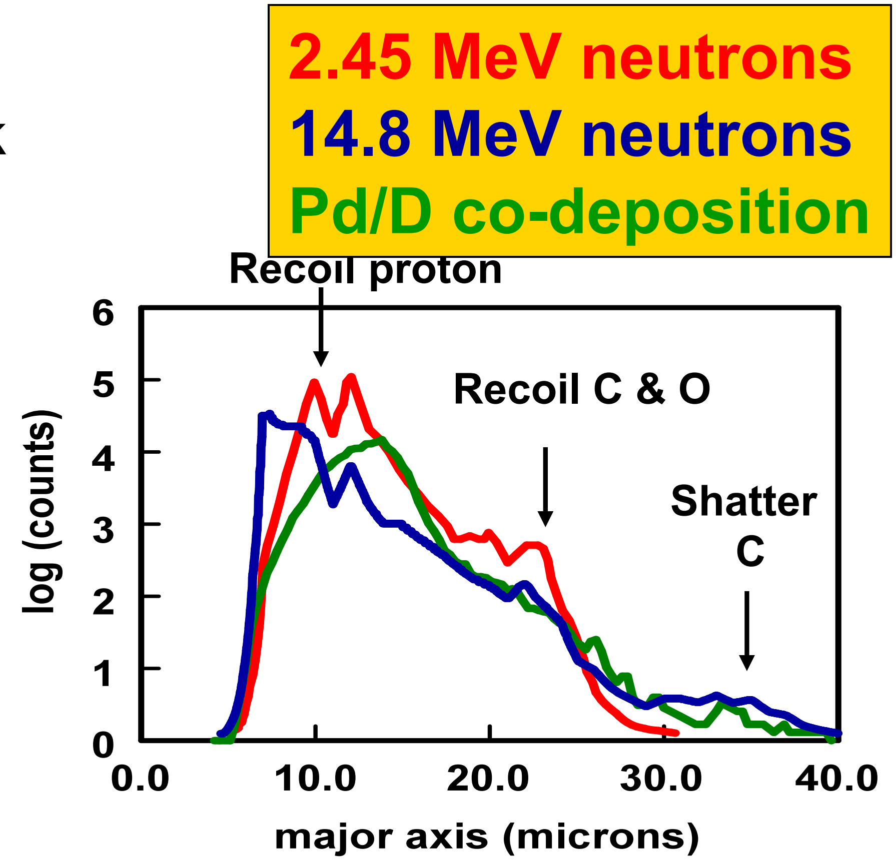
Back: d1, 2 μm; d2 3.8 μm; d3,12 - 20+ μm

assignment >40 MeV α? >10 MeV p^+? Neutrons?

Neutron Spectroscopy

Neutron Interactions with CR-39

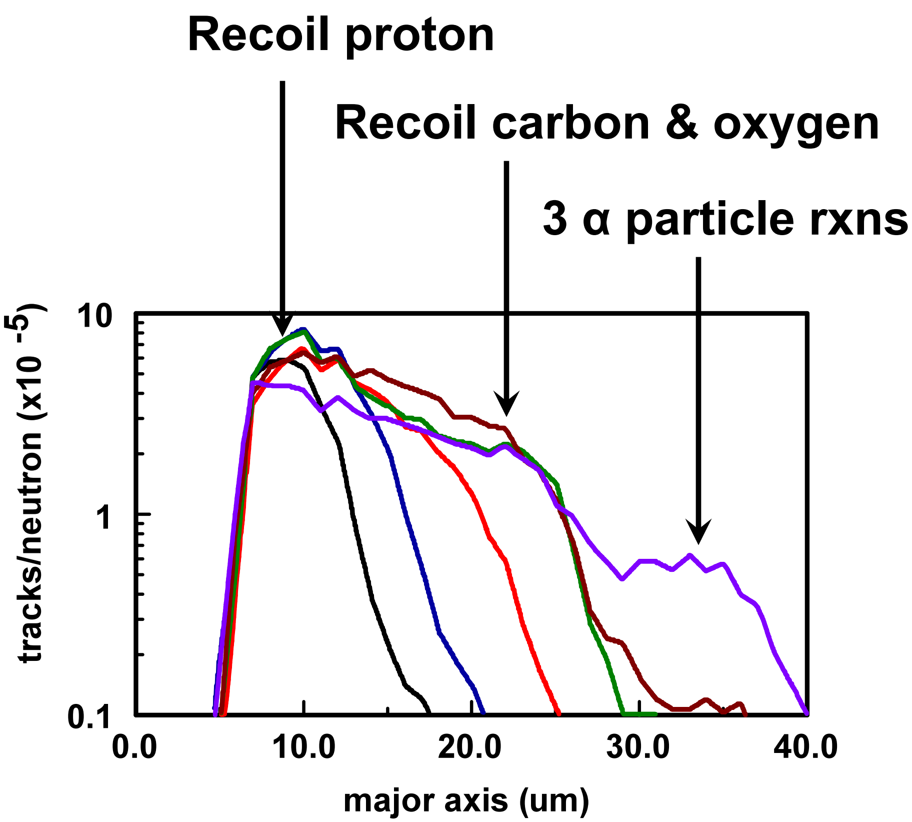




Data are consistent with DD and DT fusion reactions:

D + D → T (1.01 MeV) + p (3.02 MeV)
D + D → n (2.45 MeV) + 3He (0.82 MeV)
D + T (≤1.01 MeV) → α (6.7-1.4 MeV) + n(11.9-17.2 MeV)

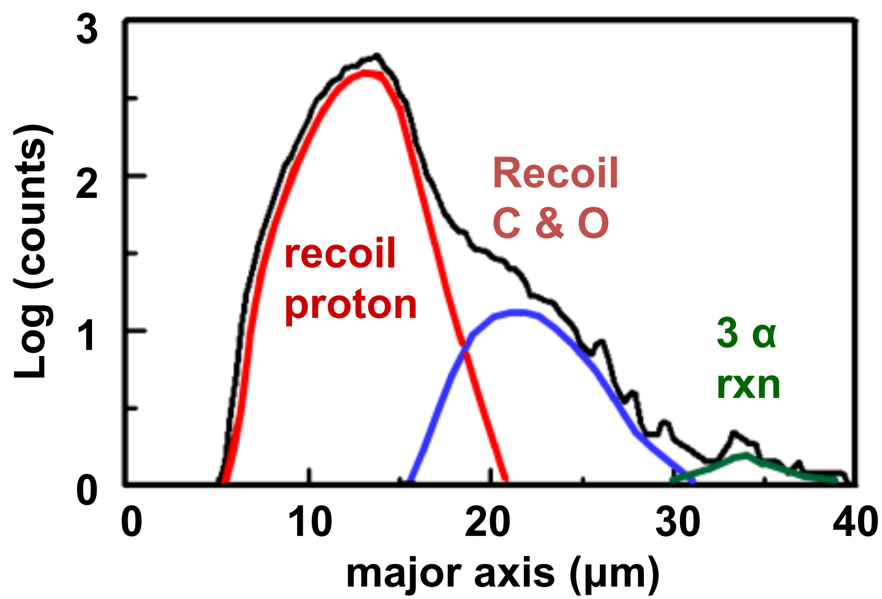
Pd:D Co-dep Neutron Emission



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).

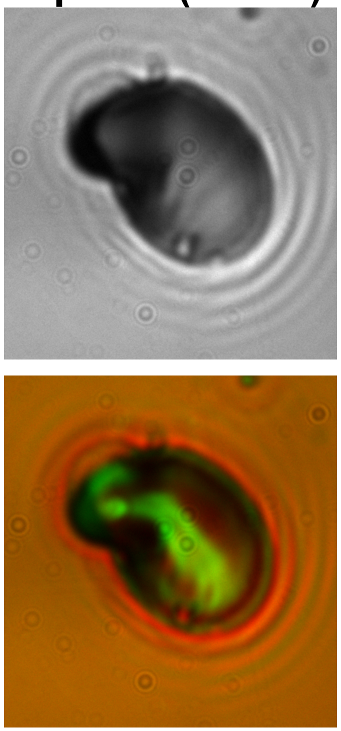
Backside of CR-39 used in Pd/D Co-Deposition



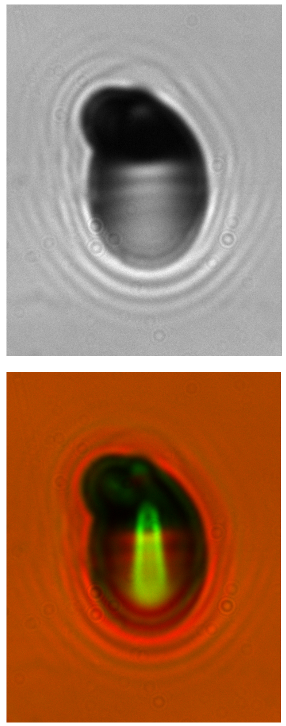
- >40 MeV α, >10 MeV protons, and neutrons can traverse 1 mm thick CR-39
- Three populations of neutrons are observed consistent with recoil protons, recoil carbon and oxygen, and 3 α particle reactions

Optical vs. SEM Imaging of Pd/D Co-Deposition and DT Generator Triple Tracks

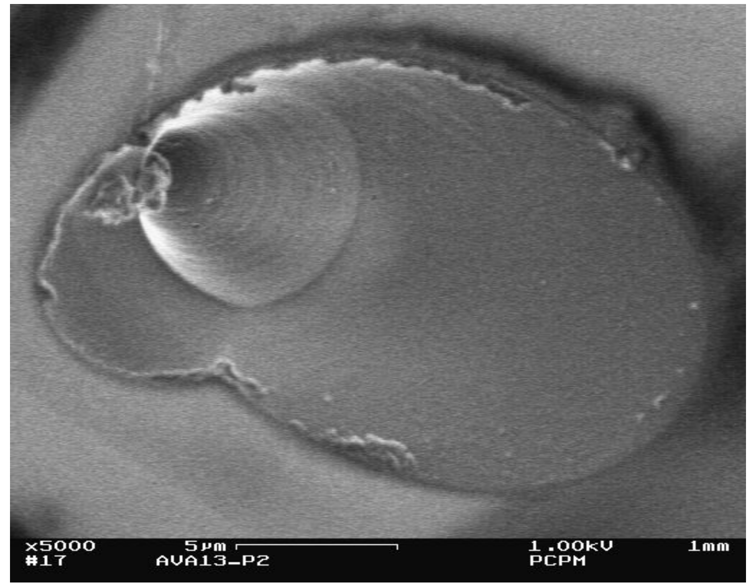
DT Neutron Optical (1000x)



Pd/D Triple Optical (1000x)



Pd/D Triple SEM (5000x)



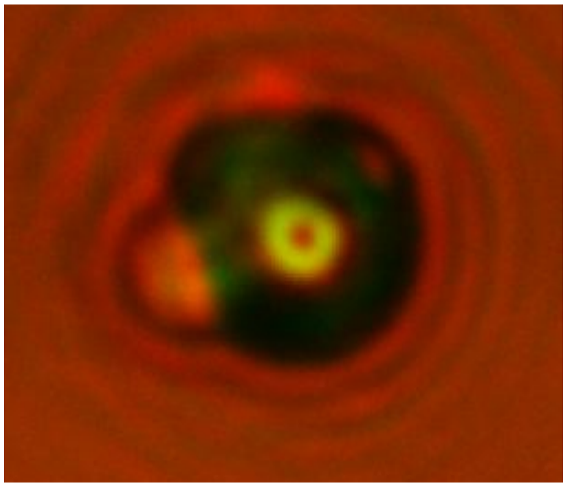
DT neutron triple track resembles Pd/D generated triple track

Optical image of Pd/D triple track:

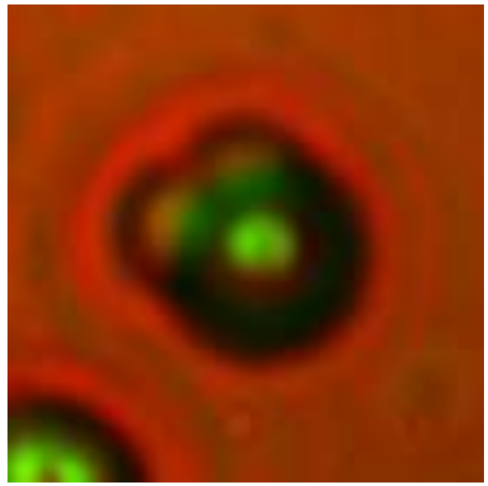
- **Bright streak in big lobe suggests bottom is shallow and rounded**
- **No bright centers in two smaller lobes may mean steep walls**

SEM image of Pd/D triple track supports these conclusions

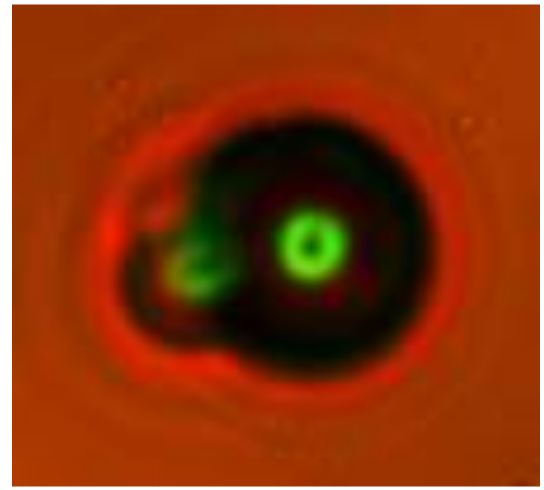
Comparing DT Triple tracks



TiD e-Beam Exp



Pd Co-dep



DoE DT neutron generator

Triple tracks: $^{12}C(n,n')3$ alpha

Threshold reaction > 9.6 MeV neutron

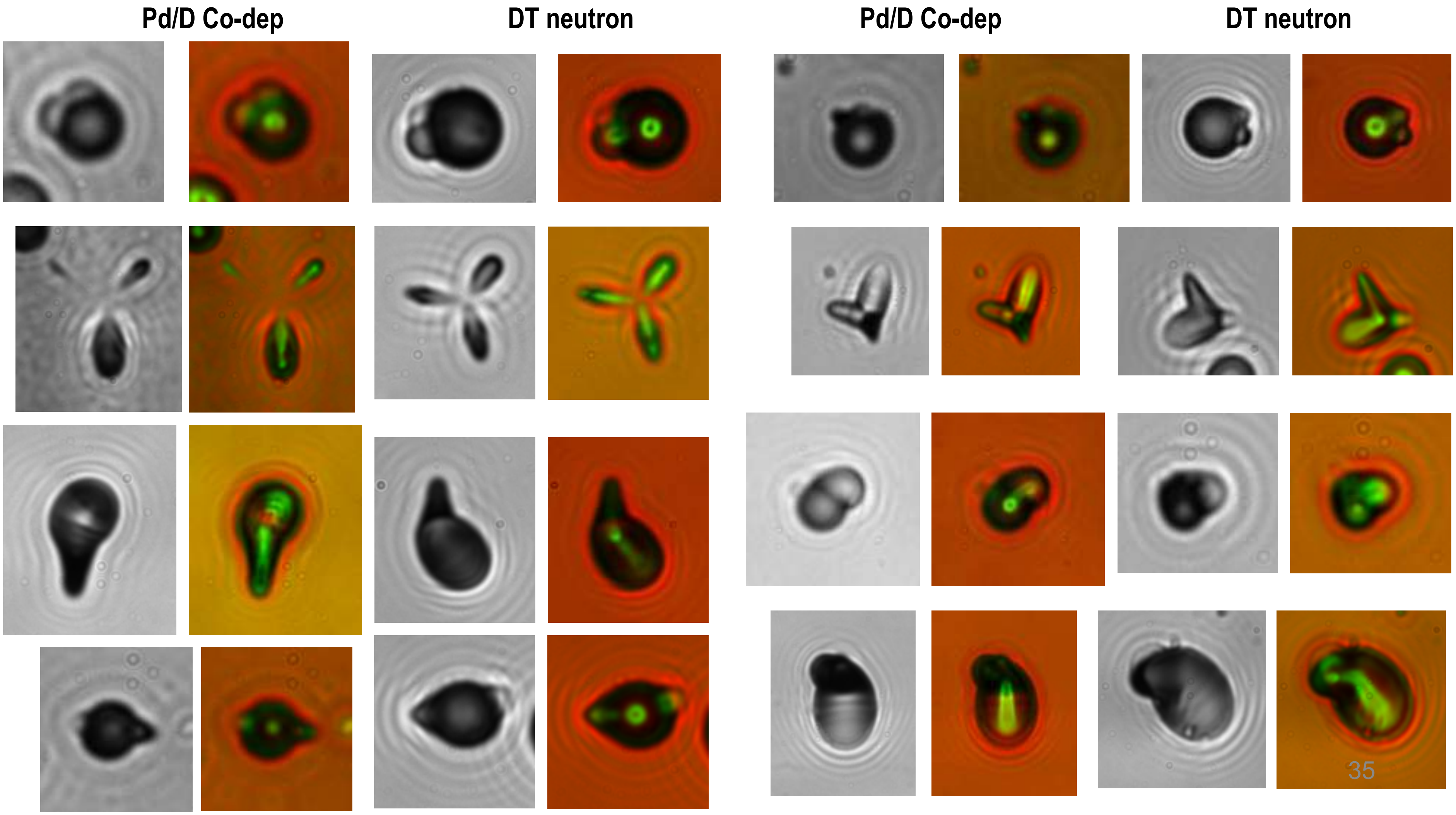
CR-39 efficiency approx 10^{-4}

No Triple tracks have ever been seen in background detectors

> 10,000 DT fusion neutrons for every triple track

Pd/D Co-dep Solid vs
DoE DT Neutron Generator Triple Tracks

Mosier-Boss et al., EPJAP, Vol. 51, p. 20901 (2010)

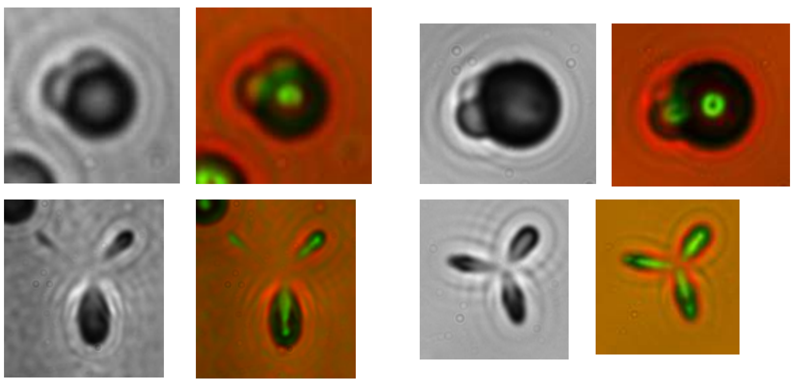


PdD Co-deposition Fast Neutrons and Charged Particles >7 nuclear channels represented

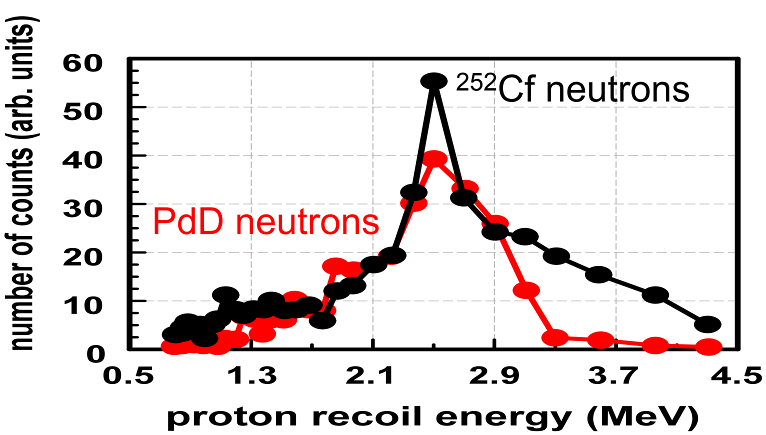
14.1 MeV DT neutrons

With DoE laboratory and NNSA funding

Pd/D Co-dep **DoE DT fusion neutrons**



2.5 MeV DD neutrons



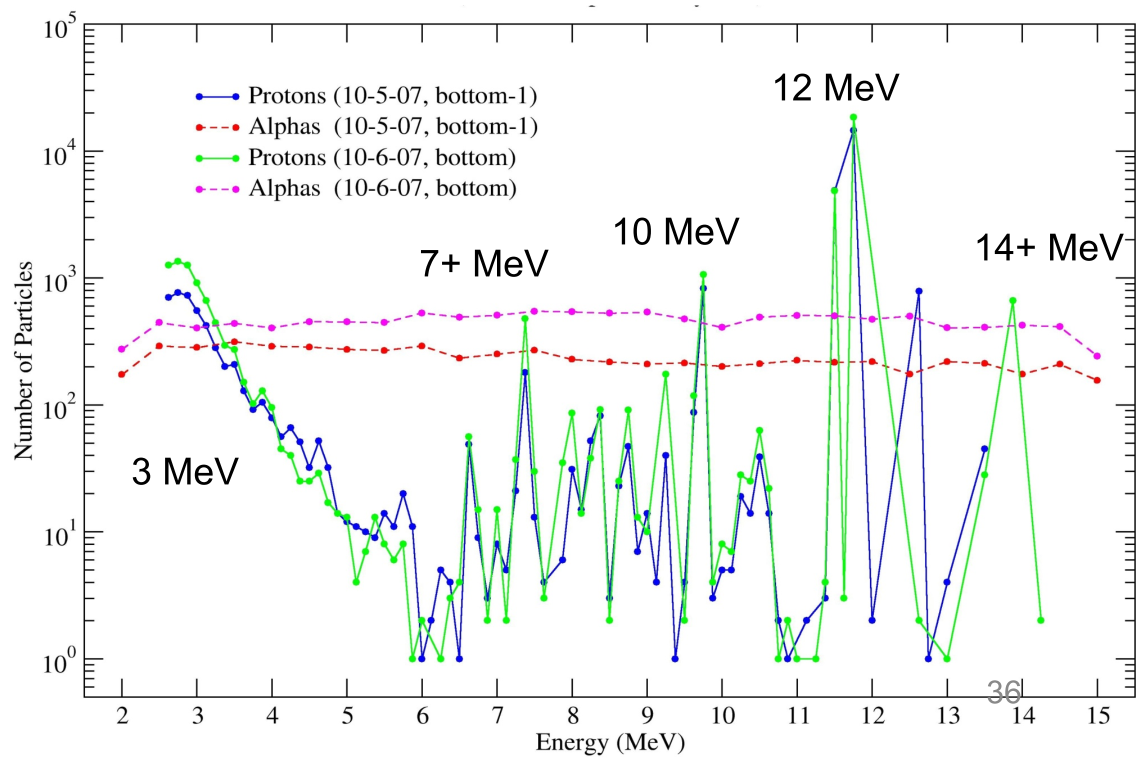
SRI replication analyzed by Dr. Lipson & Dr. Roussetski, Lebedev

Charged Particles: protons and alphas

SRI Replication of PdD co-dep protocol
LET Analysis by Dr. Zhou, NASA JSFC

Two separate reactors & detectors with nearly identical spectra!

> 35,000 tracks, in both reactors.



Solid State Lattice, Fast Neutron Generation

DoE Lab with NNSA funding

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

2009

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

70 years after fission discovered

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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′)3α 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.

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′)3α 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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Multiplicity of observed or conjectured Nuclear Channels*

* Thermal, aneutronic channel, "cold fusion"
  - $D + D \rightarrow {}^4He$ (24 MeV) ?
* Primary DD fusion reactions:
  - $D + D \rightarrow T$ (1.01 MeV) + p (3.02 MeV)
  - $D + D \rightarrow n$ (2.45 MeV) + ${}^3He$ (0.82 MeV)
* Secondary fusion reactions
  - $D + T$ (≤1.01 MeV) → α (6.7-1.4 MeV) + n (11.9-17.2 MeV)
  - $D + {}^3He$ (≤0.82 MeV) → α (6.6-1.7 MeV) + p (12.6-17.5 MeV)
* Stripping reactions,
  - $D({}^aX_z, {}^{a+1}X_z)p$
  - $D({}^aX_z, {}^{a+1}Y_{z+1})n$
* Fission Reactions: *going down the periodic table*
  * Pd -> Fe -> Al?
* Capture Reactions: *going up the periodic table*
  * Pd -> Ag -> Cd?
  * D -> D+2 recursively?
  * Multi-body D capture?

If you transmute a nucleus, by whatever means, it's nuclear!

*Reactions and products we've observed

Summary

- Nuclear effects caused by energetic neutrons and charged particles observed by a variety of diagnostics
- More real-time work required
- Cosmic ray spallation neutron flux *inconsequential*
- Statistically significant co-dep tracks observed (*>10^5/detector*)
- Multiple nuclear reactions and exit channels are present
  - Fast neutrons: 2.5 MeV, 6 MeV, 14.1 MeV
  - Fast protons: 3 MeV, 7+ MeV, 10 MeV, 14 MeV
  - Fast alphas: up to 16 MeV
- Results published in peer-reviewed Journals
- Pd/D energetic particle production *technology patented*

Cooperative, multi-country efforts made this possible!

Refereed Papers: The beast that would not die…

Condensed Matter Nuclear Reaction Peer-Reviewed Publications

#	Journal	Volume	Year	Subject
1.	*J. Electroanal. Chem.*,	**302**	(1991a)	co-dep introduced, heat, tritium, x-rays observed
2.	*J. Electroanal. Chem.*,	**309**	(1991b)	modeling of D transport in bulk cathodes
3.	*J. Electroanal. Chem.*,	**337**	(1992)	modeling and experimental D transport obs.
4.	*J. Electroanal. Chem.*,	**353**	(1993)	co-dep and Tritium
5.	*J. Electroanal. Chem.*,	**365**	(1994a)	D modeling and Pd transport using XRD
6.	*J. Electroanal. Chem.*,	**373**	(1994b)	Tritium modeling and production in co-dep
7.	*J. Electroanal. Chem.*,	**379**	(1994c)	deuterium transport in co-dep
8.	*J. Electroanal. Chem.*,	**380**	(1995)	co-dep processes examined and discussed
9.	*Phys. Lett. A*.	**210**	(1996a)	co-dep x-ray spectroscopy, lines identified
10.	*Phys. Lett. A*.	**221**	(1996b)	Response to Vigier: thermal imaging
11.	*Fusion Technology*,	**33**	(1998a)	tritium production
12.	*Fusion Technology*,	**34**	(1998b)	tritium production and co-dep morphology
13.	*Nuovo Cim. Soc. Ital. Fis. A*,	**112**	(1999a)	thermal imaging, positive temp feedback
14.	*Fusion Technology*,	**36**	(1999b)	Co-dep calorimetry
15.	*Thermochimica Acta*,	**410**	(2004)	Co-dep calorimetry, excess heat exceeds bulk rate
16.	*J. Electroanal. Chem.*,	**580**	(2005a)	E-field manipulation of co-dep morphology
17.	*Naturwissenschaften*,	**92**	(2005b)	co-dep transmutation at ejecta sites
18.	*Naturwissenschaften*,	**94**	(2007a)	charged particle nuclear tracks using SSNTD
19.	*Eur. Phys. J. Appl. Phys.*,	**40**	(2007b)	SSNTD controls and nuclear particle distribution
21	*Eur. Phys. J. Appl. Phys.*,	**44**	(2008b)	Response to Kowalski: co-dep nuclear tracks
22.	*Naturwissenschaften*,	**96**	(2009a)	co-dep triple-track, DT fusion observed
23.	*Eur. Phys. J. Appl. Phys.*,	**46**	(2009b)	co-dep nuclear particle specie and spectra
25.	*Eur. Phys. J. Appl. Phys.*	**51**	(2010b)	comparison of co-dep and DT fusion tracks
26.	*J. Condensed Matter Nucl. Sci.*	**3**	(2010c)	Response to Kowalski: co-dep nuclear species
27.	*J. Environ. Monitoring*,	**12**	(2010d)	Response to Shanahan: LENR observations
28.	*J. Condensed Matter Nucl. Sci.*	**4**	(2011a)	Co-dep calorimetry
29.	*J. Condensed Matter Nucl. Sci.*	**4**	(2011b)	Review of 20 years of Pd:D co-dep research
30.	*Detector Phys XIII, SPIE*	**8142**	(2011c)	Optical and SEM analysis of DT & PdD tracks
31.	*Radiation Measurements*	**47**	(2012a)	Comparison of optical and SEM DT tracks
32.	*J. Condensed Matter Nucl, Sci*	**6**	(2012b)	Neutron detection and characterization
33.	*J. Condensed Matter Nucl, Sci*	**6**	(2012c)	Co-dep calorimetry
34.	*J. Condensed Matter Nucl, Sci*	**6**	(2012d)	Review: LENR Nuclear Products
35.	*Electrochimica Acta*,	**88**	(2013)	Gamma and alpha induced Pd x-ray fluorescence

Book Chapters

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

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

red indicates nuclear effects: 23 papers,
green indicates thermal effects: 8 papers

Condensed Matter Nuclear Reactions

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Cluster Identified?[1]

Black beast of Argh; Track Cluster Anomaly…. Related???

Or radioactive dust bunny?

1. *Monty Python*, Terry Gilliam

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The Future:
Consumer CMNS refueling!*

*Approved by "Buzz Lightbeer."—Woody.
Also courtesy of *Back to the Future*