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# Twenty Year History in LENR Research Using Pd/D Co-deposition

May, 2009


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SSC Pacific … on Point and at the Center of C4ISR

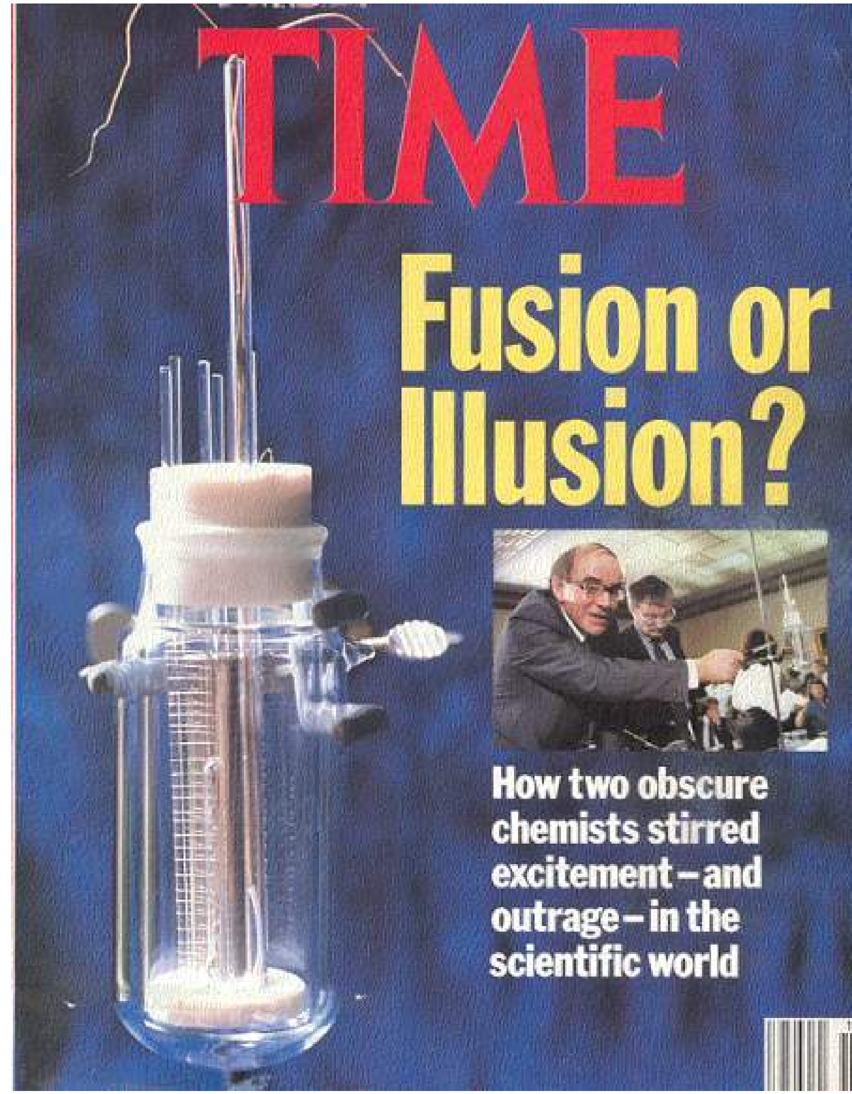
# Attributes of SSC Pacific LENR Research

(Surviving 20 years in this controversial field)

- **Followed the Scientific Process**
  - Carefully design and conduct experiments
  - Repeat/Validate the results
  - Publish the results in peer-reviewed journals
  - Design new experiments based on the results
- **Hiding in plain sight**
  - 23 peer-reviewed technical publications
  - Two articles in "New Scientist" plus NPR feature
  - Numerous web based articles
  - Discovery Science Channel "Brink"
- **Response from the Scientific Community**
  - Bob Park, U of MD "… this is science."
  - Johan Frenje, MIT (Hot Fusion) "… the data and their analysis seem to suggest that energetic neutrons have been produced."
  - Robert Duncan, Vice Chancellor of Research, U of MO, and "60 Minutes" expert, "… this is not pariah science."

# March 23, 1989

- Pons and Fleischmann announce that electrochemical cells are producing more heat than can be accounted for by chemical means and speculated that nuclear reactions must be occurring.
- Physics community notes:
  - the experiments aren't repeatable
  - there aren't any refereed papers
  - the experiments haven't been replicated
  - If it's nuclear, where are the neutrons?"
- Thousands of scientists worldwide attempted experiments—most failed



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# Why the Controversy?

| Reaction | Energy/atom |
|---|---|
| • Nuclear Fission | 200,000,000 eV[1] (200 MeV[2]) |
| • Nuclear Fusion | 20,000,000 eV ( 20 MeV) |
| • Chemical | < 5 eV |

**Nuclear reactions are *millions of times* more energetic than chemical reactions!**

**Triggering nuclear events with electrochemical energies not consistent with theory!**

[1,2] Energies can be expressed in units of eV, electron Volts, or MeV, Millions of electron Volts.

# Why Many Laboratories Failed to Reproduce the Fleischmann-Pons Effect

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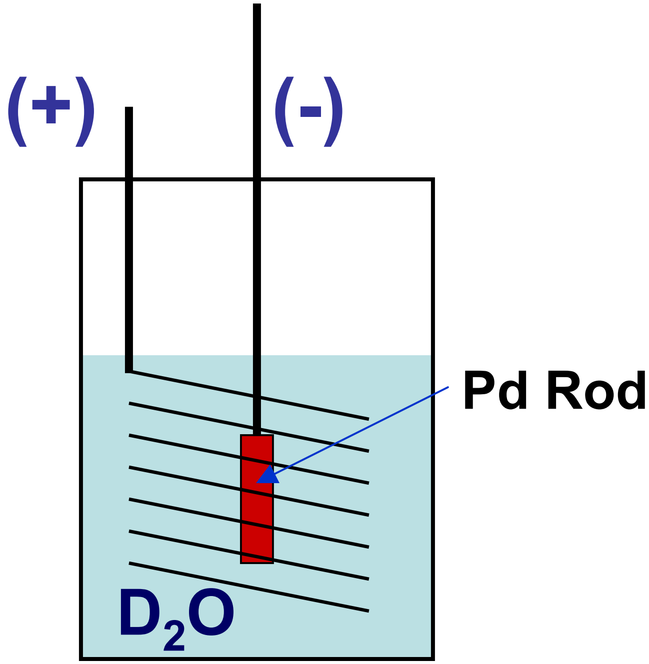
## F/P Approach




$D_2$ is loaded into the Pd electrode over a several day period

- Improper cell configuration
  - Cathode was not fully immersed in the heavy water
  - Asymmetrical arrangement of anode and cathode
- Unknown history of the palladium cathodes used in the experiments
- Lack of recognition that an incubation time of weeks was necessary to produce the effect

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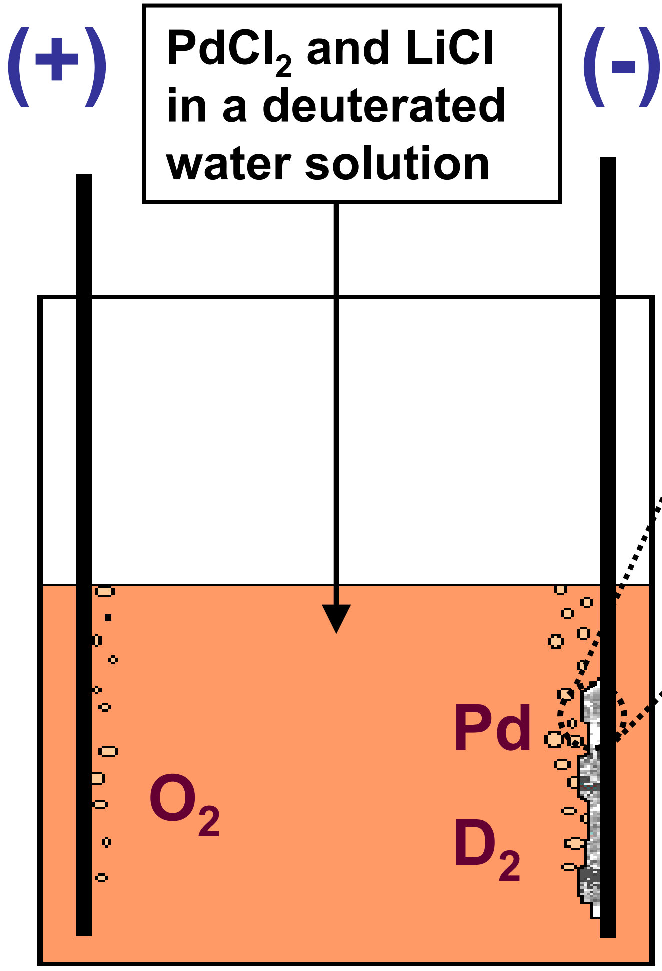
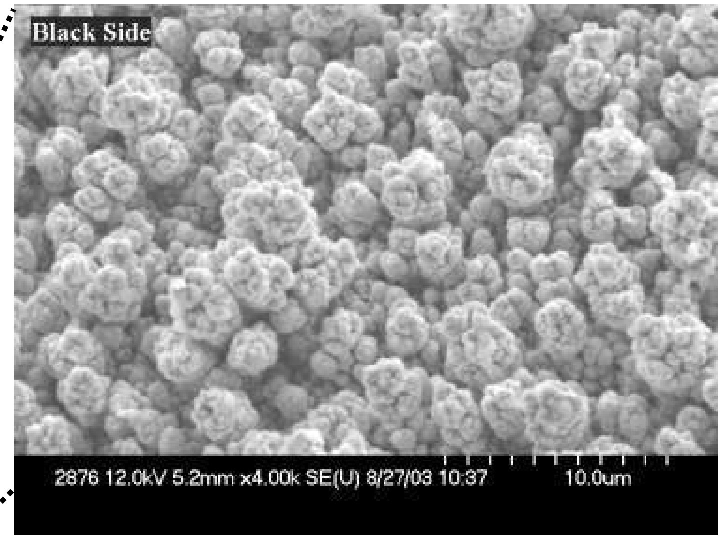
# Another Way to Conduct the Experiment: Pd/D Co-deposition




**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 $D_2$**

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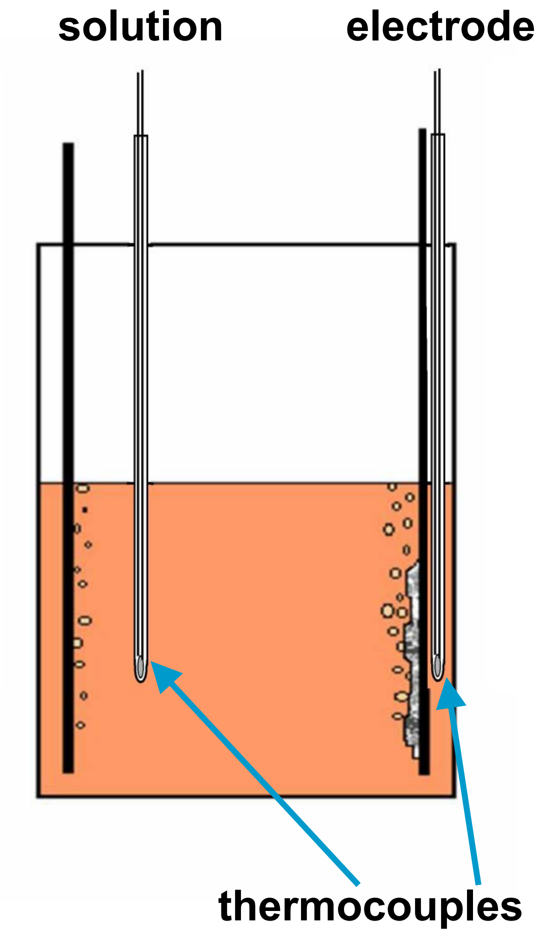
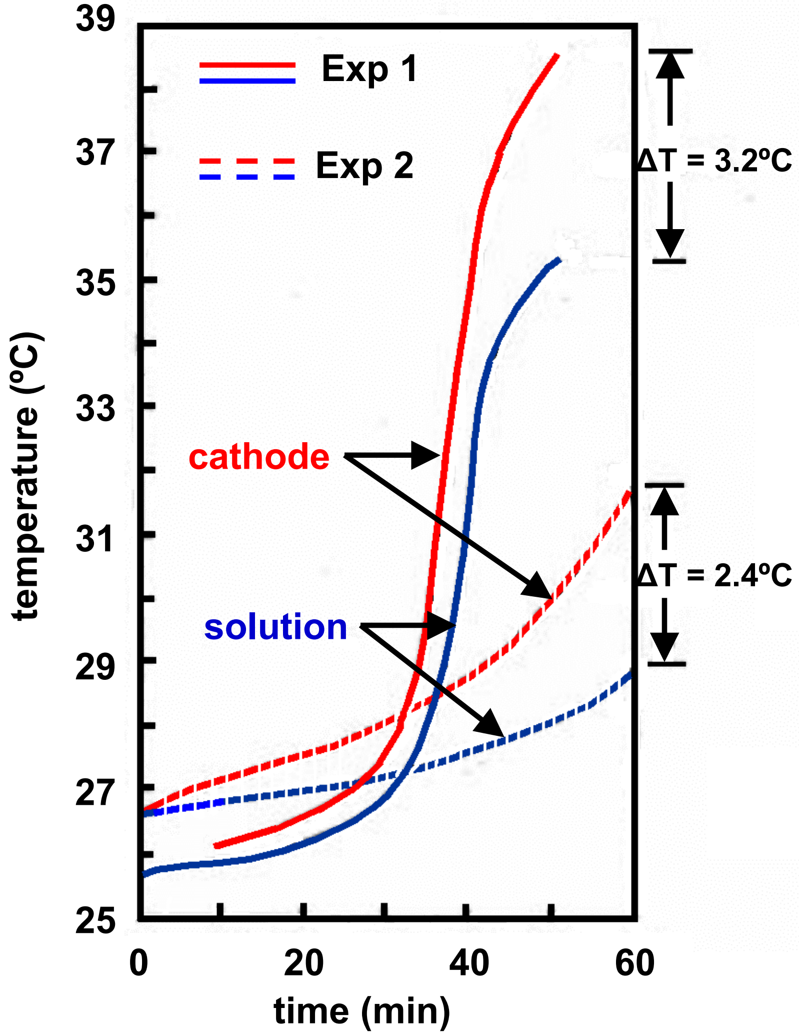
# Advantages of Pd/D Co-Deposition

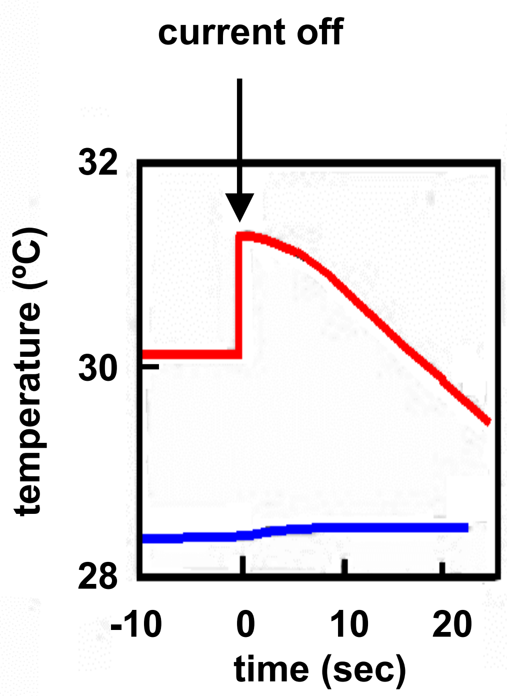
- Short loading times—measurable effects within minutes, no incubation time
  - J. Electroanal. Chem., Vol.337, pp. 147-163 (1992)
  - J. Electroanal. Chem., Vol.379, pp. 121-127 (1994)
  - J. Electroanal. Chem., Vol. 380, pp. 1-6 (1995)
- Extremely high repeatability
- Maximizes experimental controls
- Experimental flexibility
  - Multiple electrode surfaces possible
  - Multiple electrode geometries possible
  - Multiple cell configurations possible
- Extremely high surface area
- Defects are built into the lattice

# Temperature vs Time Profile

J. Electroanal. Chem., Vol.302, pp. 255-260 (1991)




**The Electrode is warmer than the Solution!**

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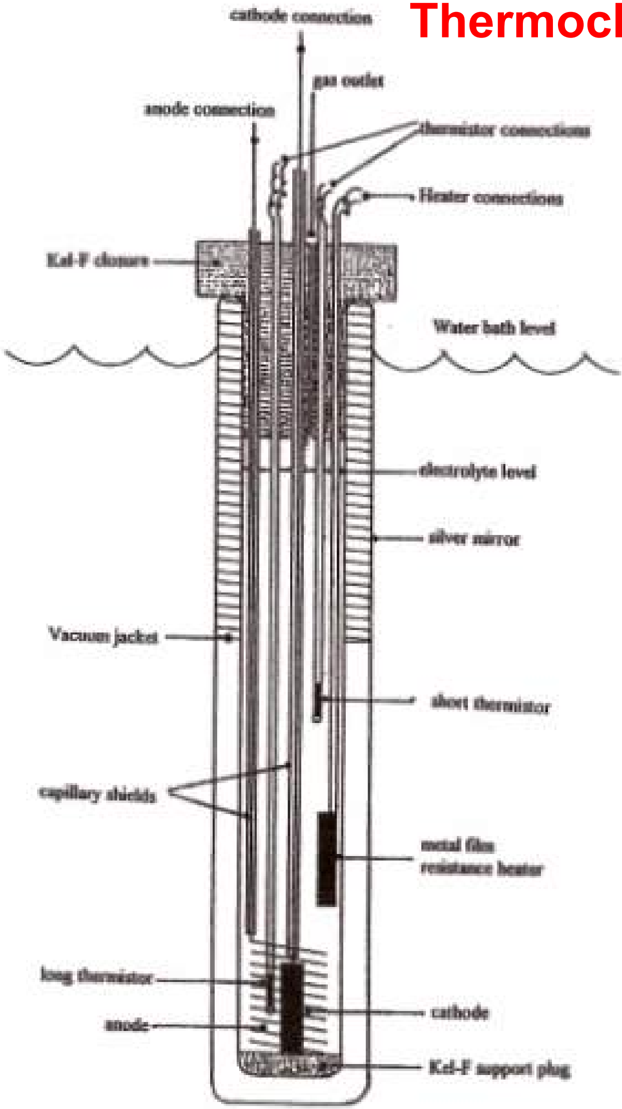
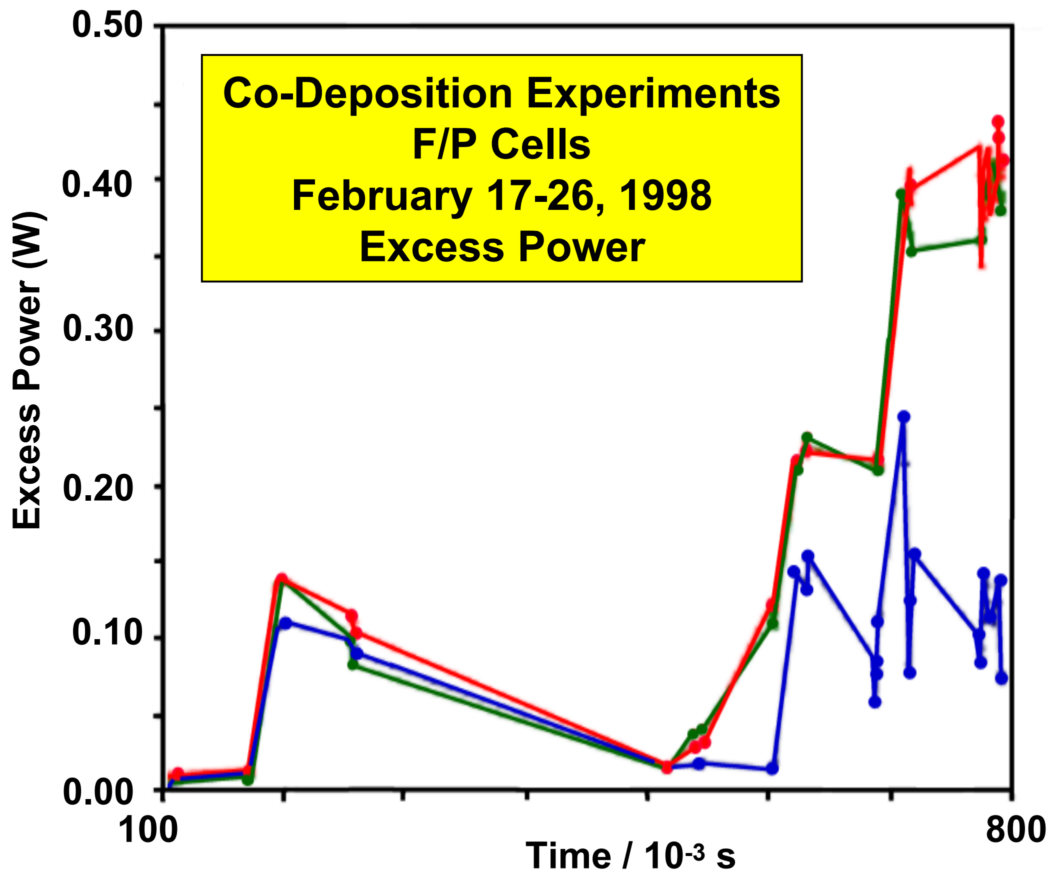
DIXIE STATE COLLEGE OF UTAH

# Excess Enthalpy Generation

Thermochimica Acta, Vol. 410, pp. 101-107 (2004)

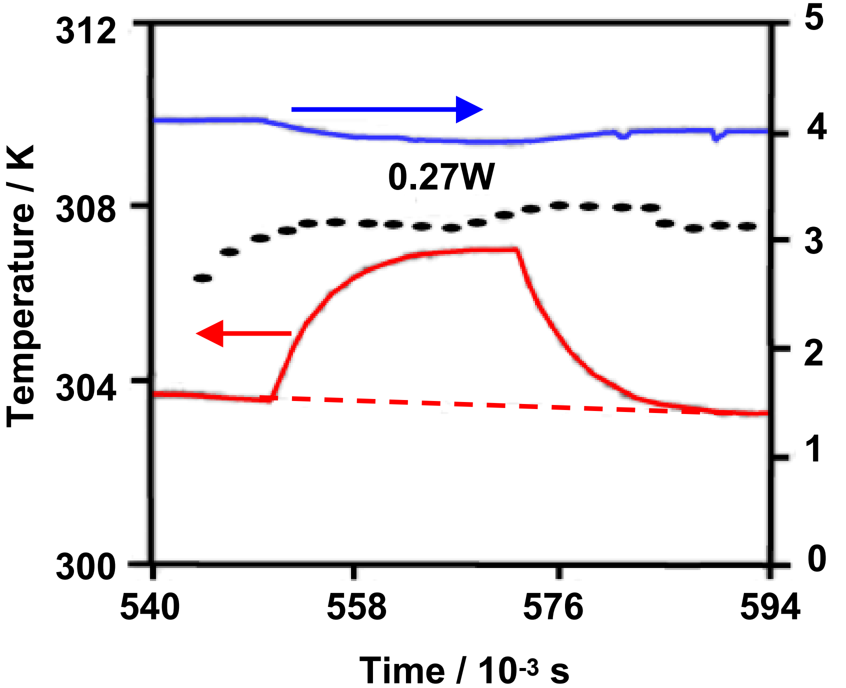



Isoperibolic Dewar Calorimetry Cell

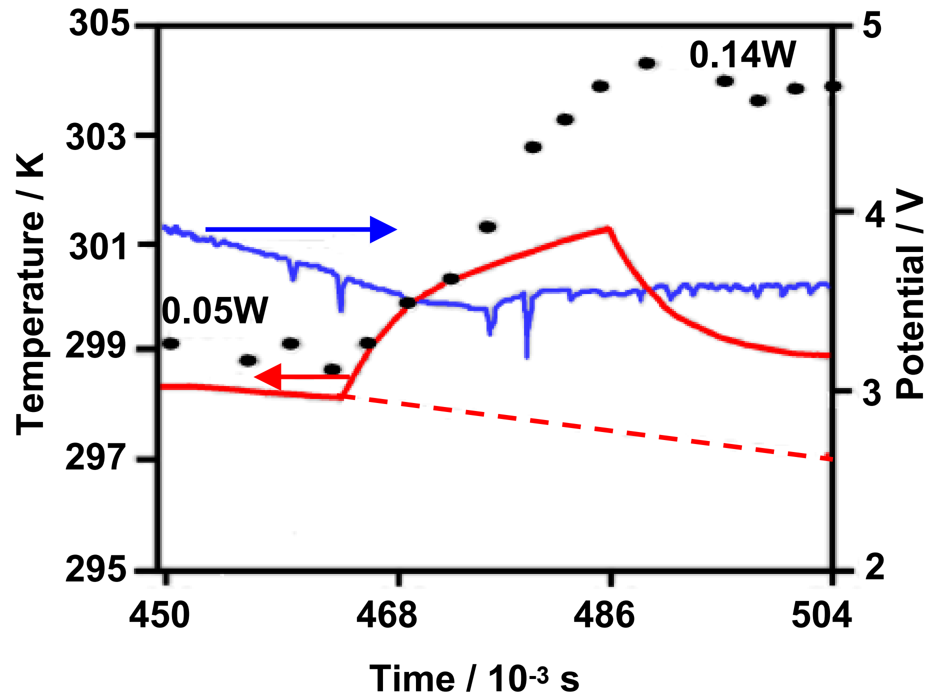



**Pd-D co-deposition reproducibly yields excess power comparable to conventional bulk Pd cathodes**

# Positive Feedback In Co-Deposition Excess Power




Expected behavior when the rate of excess enthalpy generation remains constant




Positive feedback effect

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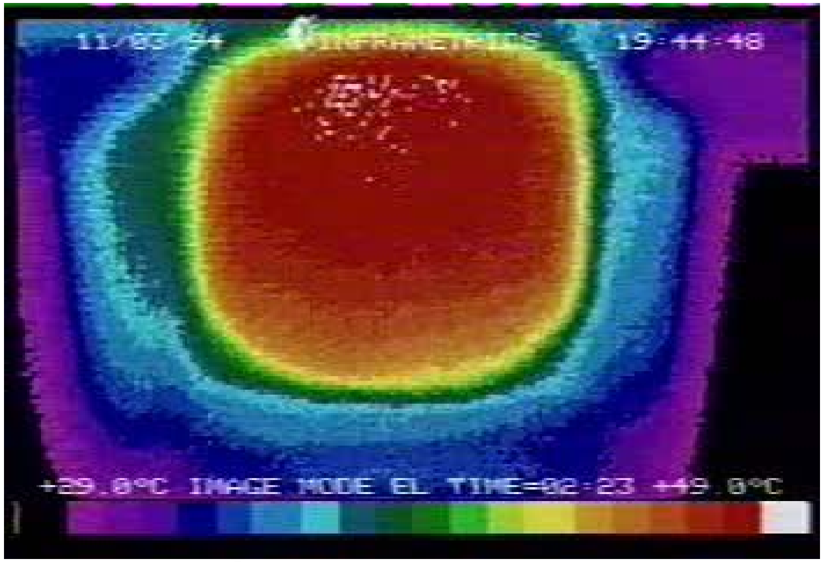
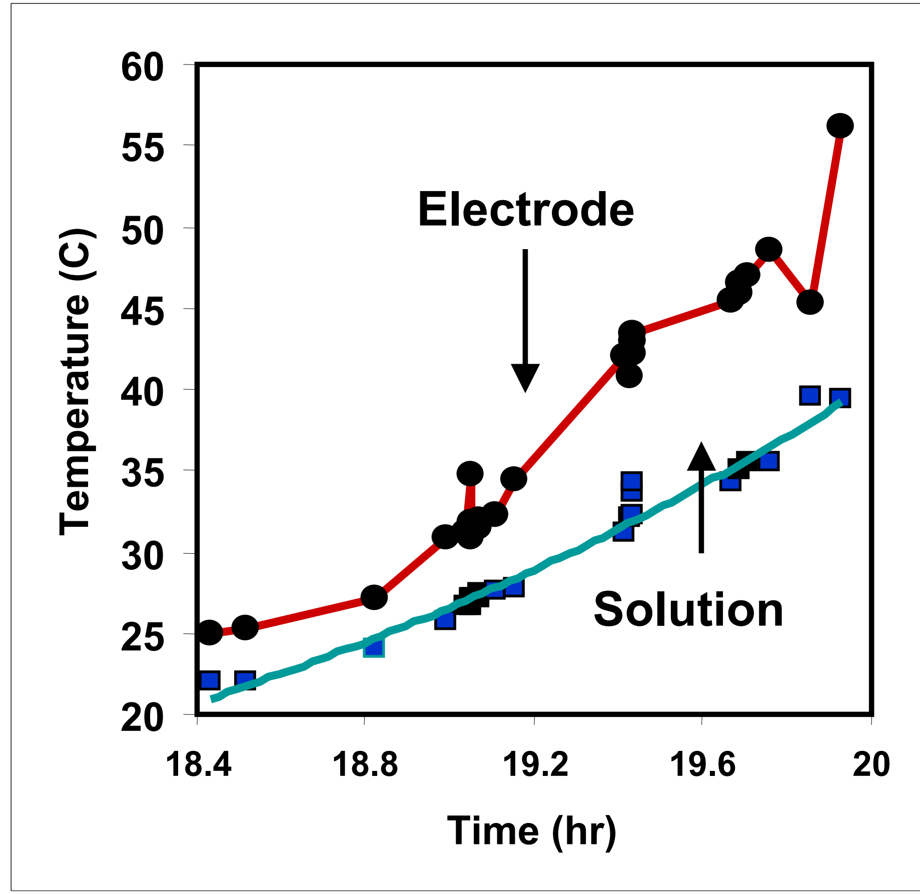
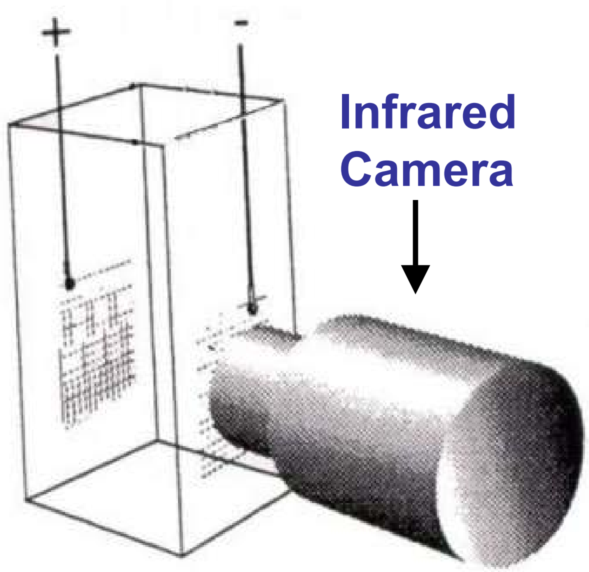
# Formation of ‘Hot Spots’

Il Nuovo Cimento, Vol 112A, pp. 577-585 (1999)




Infrared Camera

**The electrode is the heat source, not Joule heating!**

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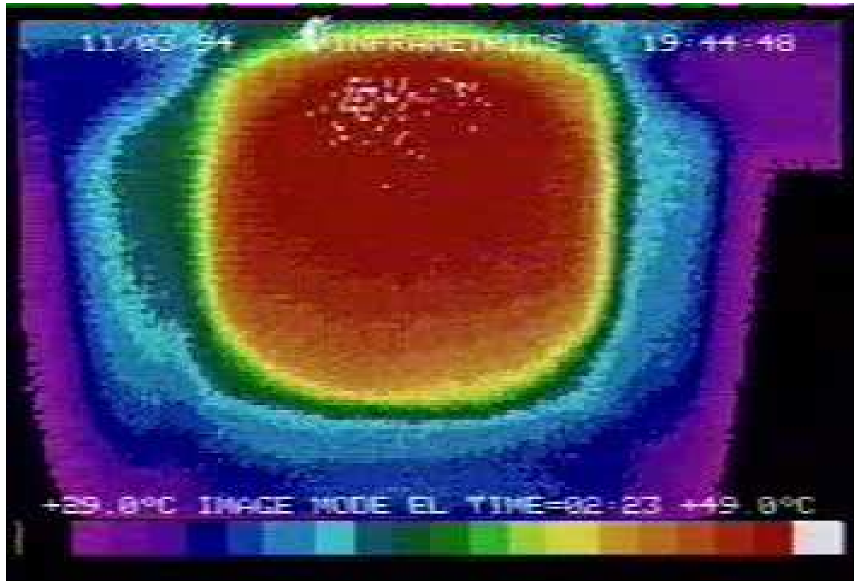
# Measurements of Hot Spots on Cathodes




**Calculations by Dave Nagel, NRL (retired), GWU**

**Release of 1 MeV in a cube of Pd 100 nm on a side gives a temperature (T) rise of $\Delta T$ = 380 K using 3 k $\Delta T/2$ as the increase in vibrational energy, or $\Delta T$ = 55 K using the specific heat for Pd = 26 J/K mole.**

## Conclusion

**Hot spots must be due to nuclear-level energy releases.**

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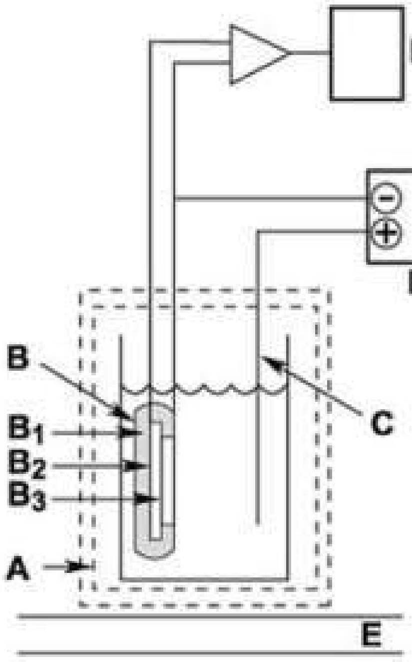
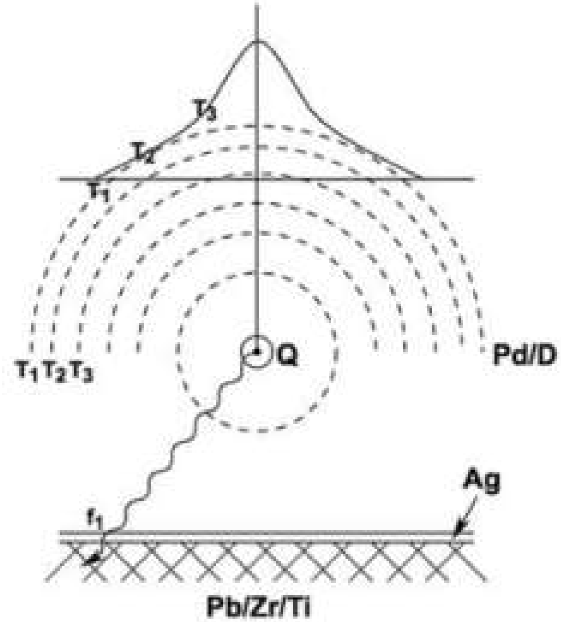
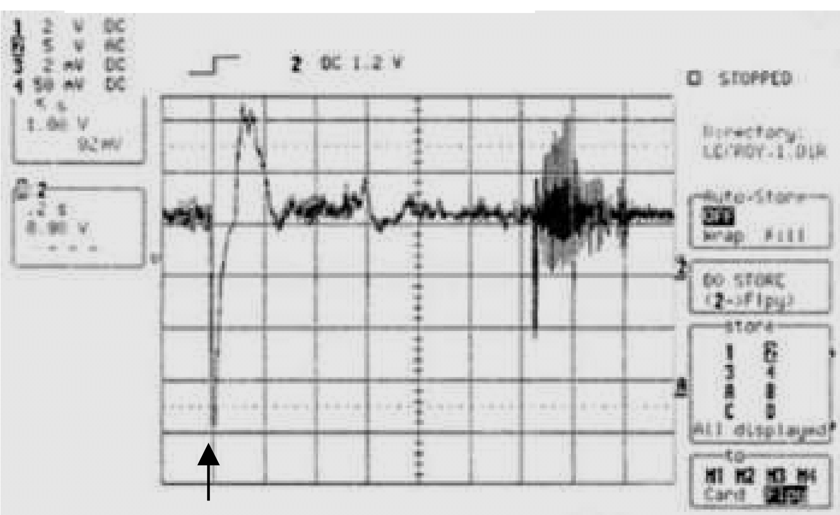
# Piezoelectric Response: Evidence of Mini-Explosions and Heat Generation

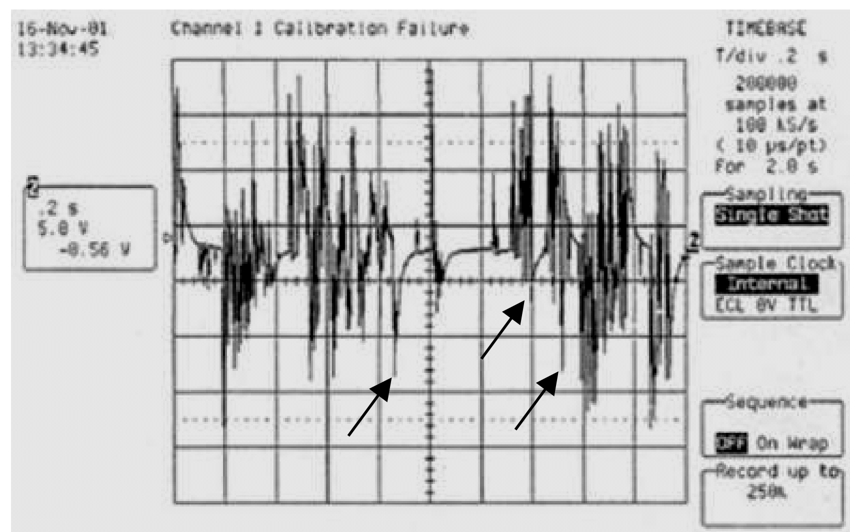



**Piezoelectric crystal responds to both pressure and temperature**




**Isolated event**




**Expanded series of events**

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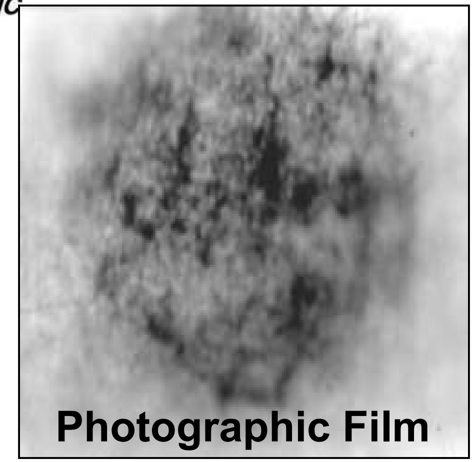
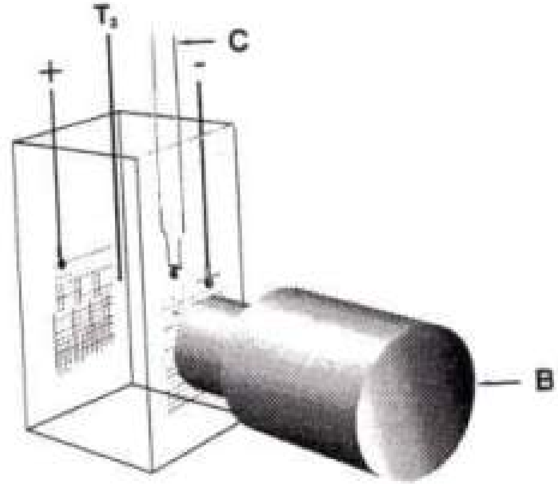
# Emission of Low Intensity Radiation

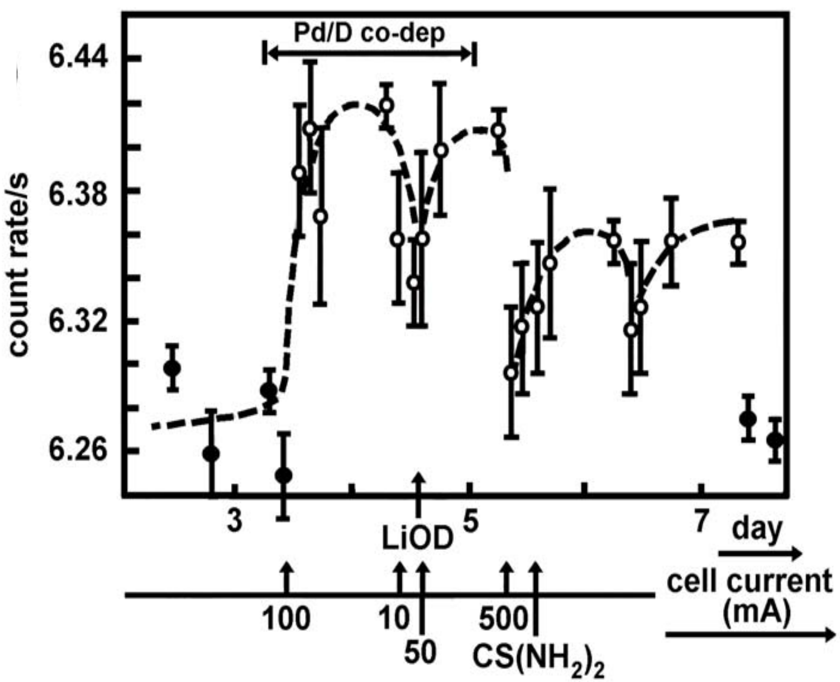
Physics Letters A, Vol. 210, pp. 382-390 (1996)



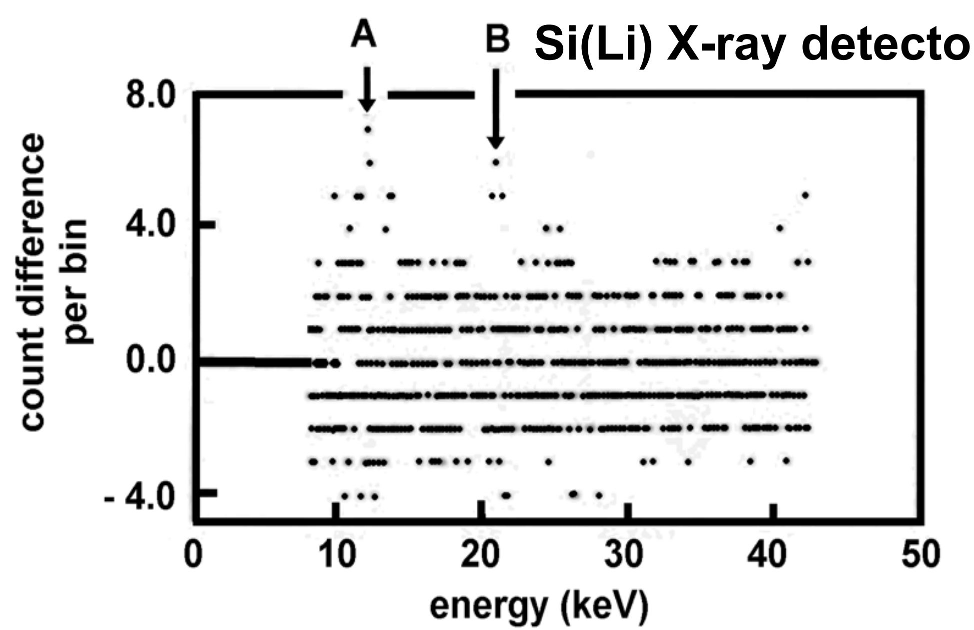




- X-rays with a broad energy distribution are emitted (with the occasional emergence of recognizable peaks (20 keV due to Pd Kα and 8-12 keV due to either Ni or Pt)
- Emission of radiation is sporadic and of limited duration

## HPGe gamma ray detector

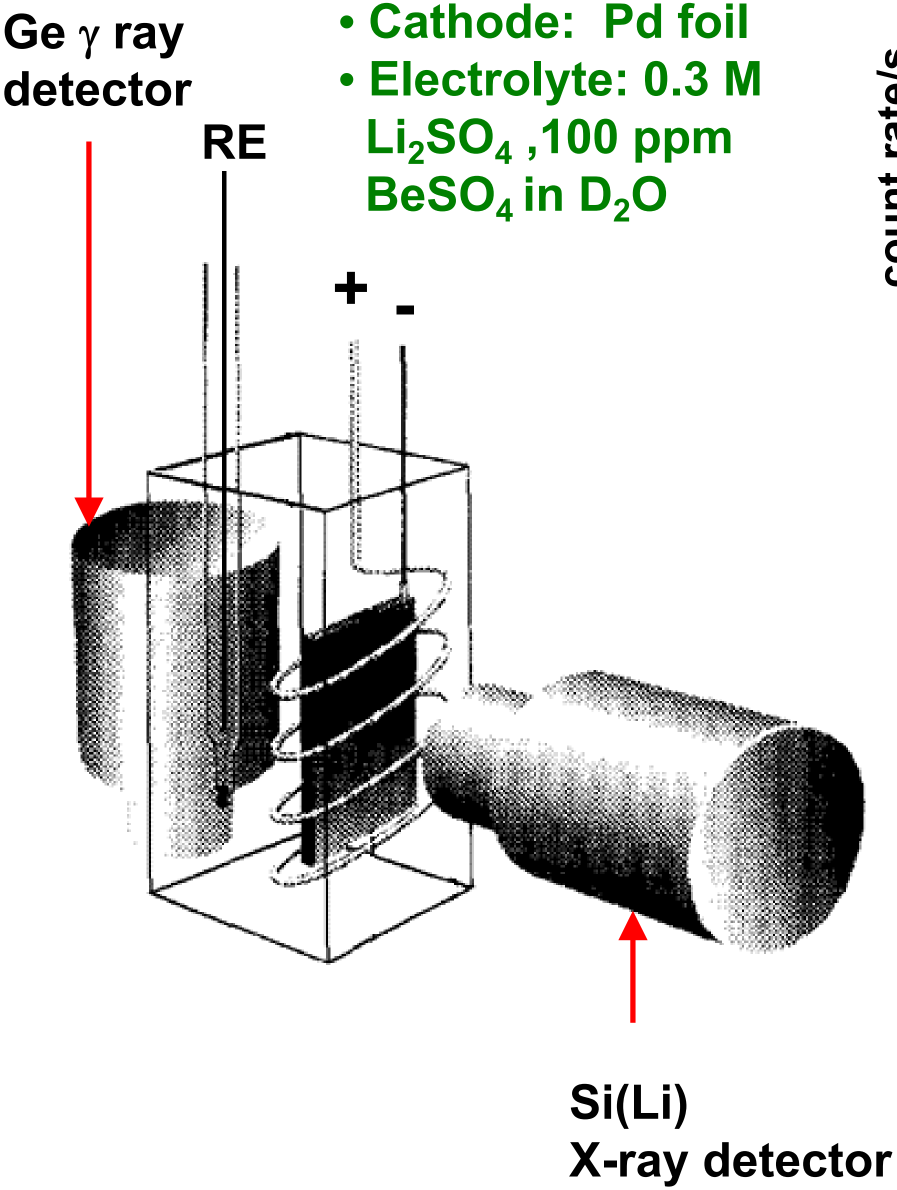


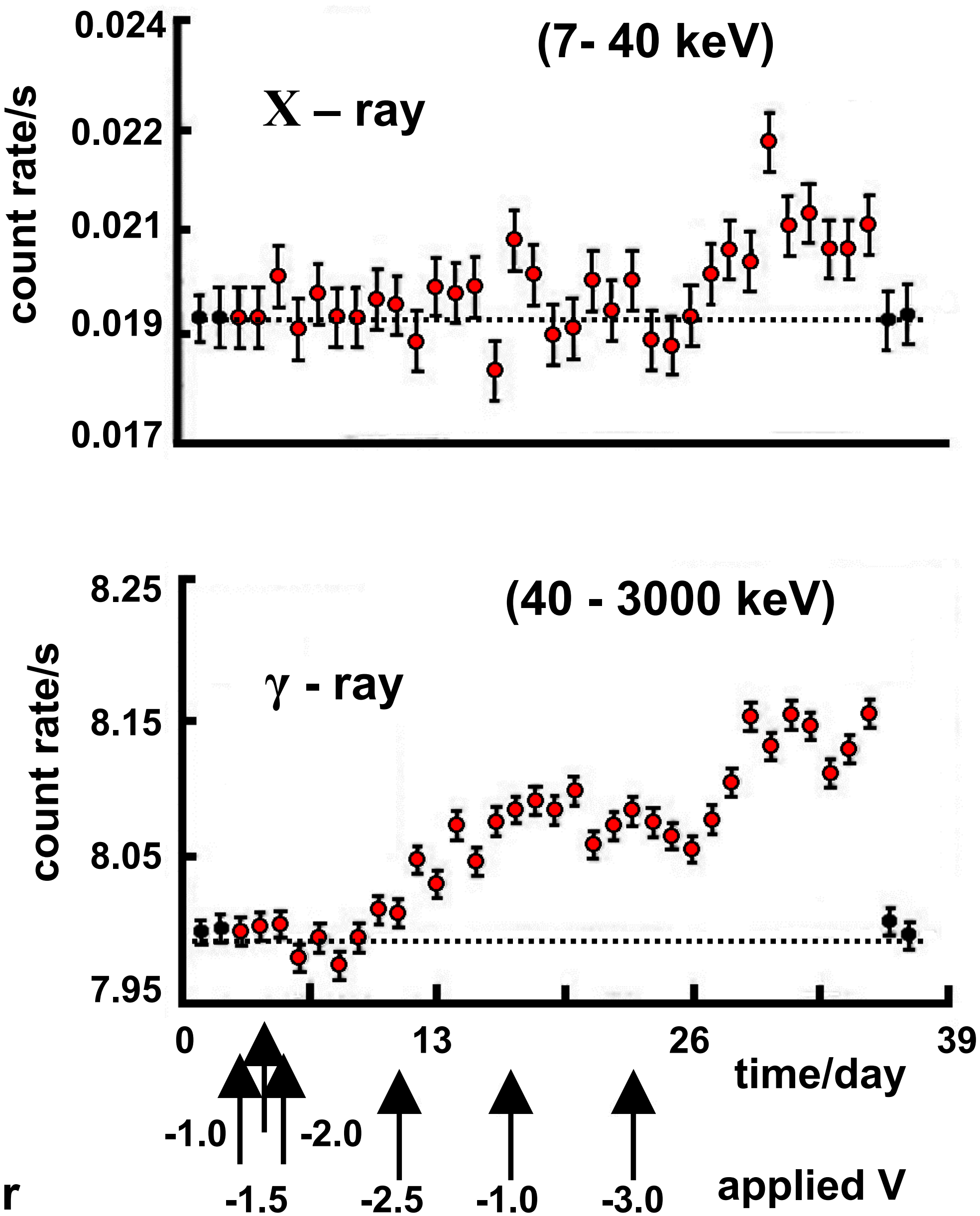

## Si(Li) X-ray detector



# Emission of Low Intensity Radiation

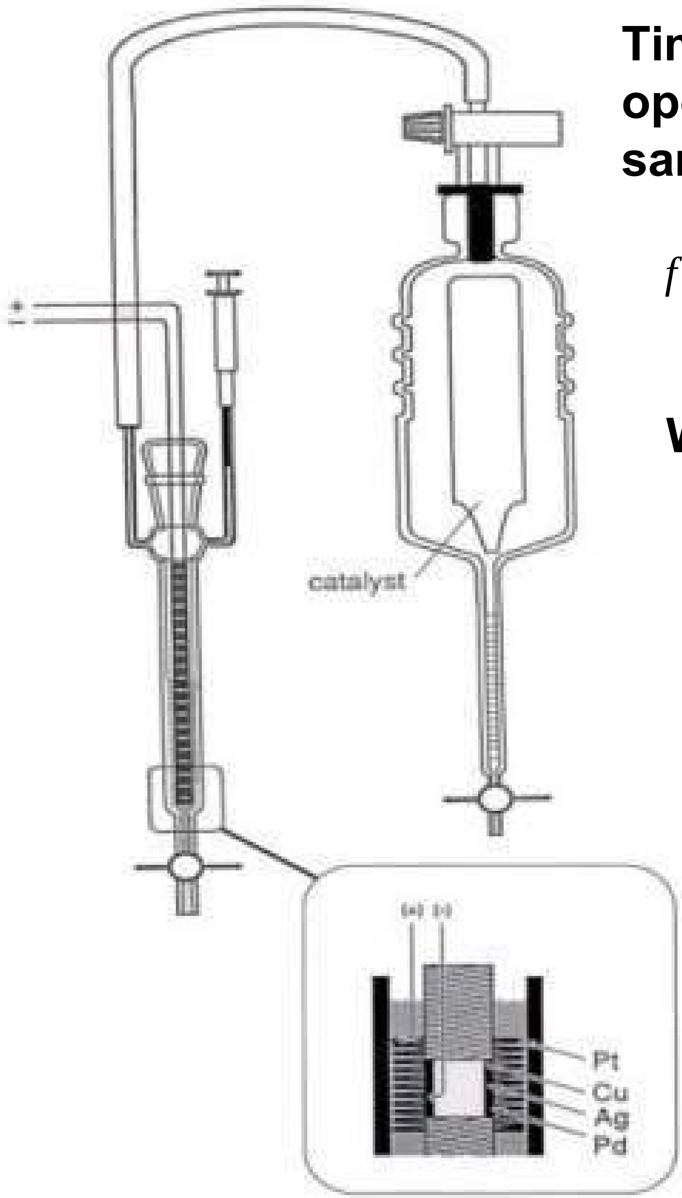
- Cathode: Pd foil
- Electrolyte: 0.3 M $Li_2SO_4$, 100 ppm $BeSO_4$ in $D_2O$



# Tritium Production

## Fusion Technology, Vol. 33, pp.38-51 (1998)




**Time dependence of tritium content of an open cell operating galvanostatically with intermittent sampling:**

$$f(t) = f(0)\left(\frac{m(0)-r(i)t}{m(0)}\right)^{S-1} + \frac{q}{(S-1)r(i)} \bullet \left\{1-\left[\frac{m(0)-r(i)t}{m(0)}\right]^{S-1}\right\}$$

**Where:**

$f$ = tritium mass fraction

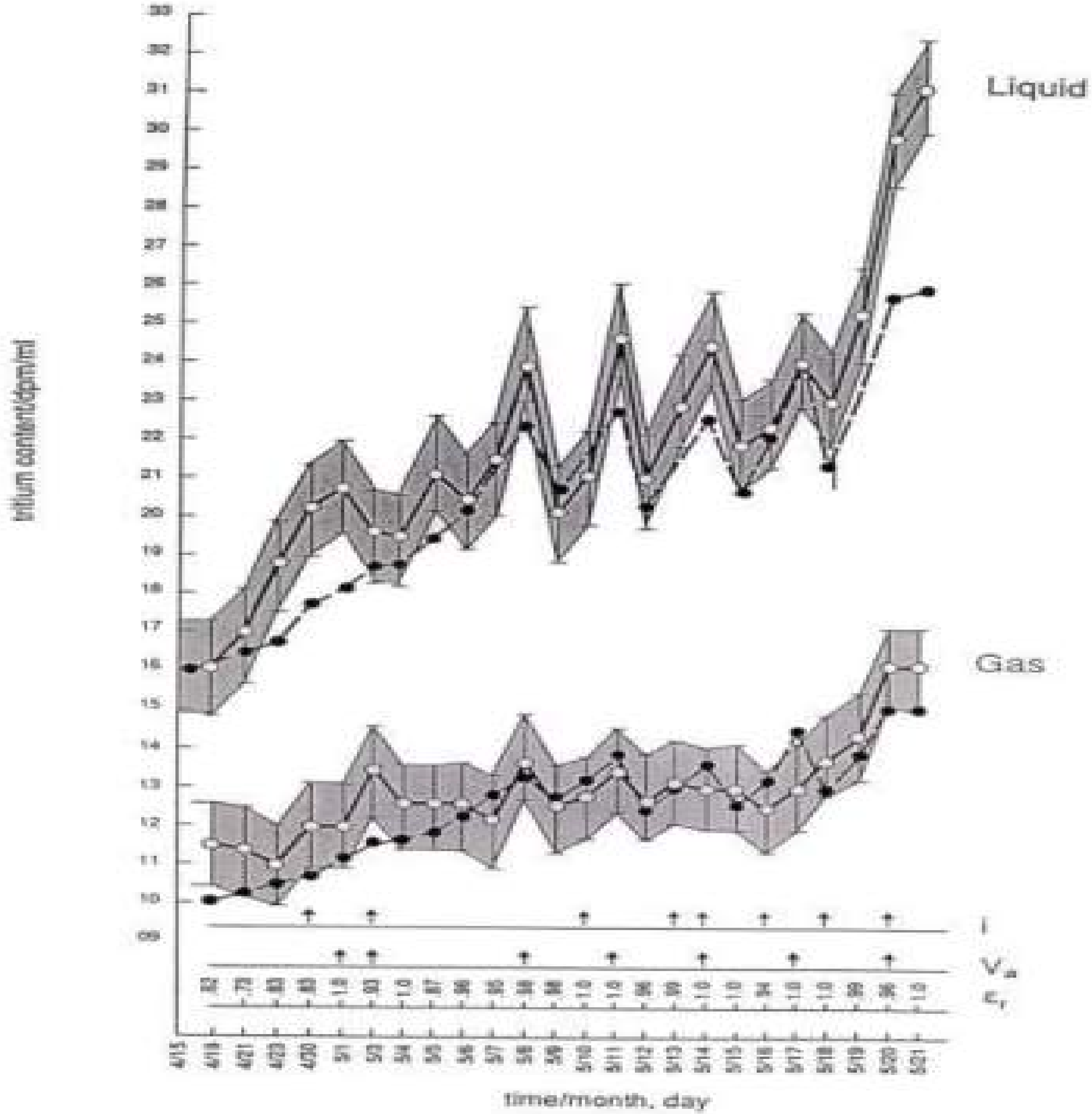
m = mass of the electrolyte phase

r(i) = i$M_w$ / 2F= denotes the rate of change associated with the cell current i

q = rate at which tritium is added/removed from the solution phase

S = isotopic separation factor = $\left(\frac{C_T}{C_D}\right)_G \Big/ \left(\frac{C_T}{C_D}\right)_L$

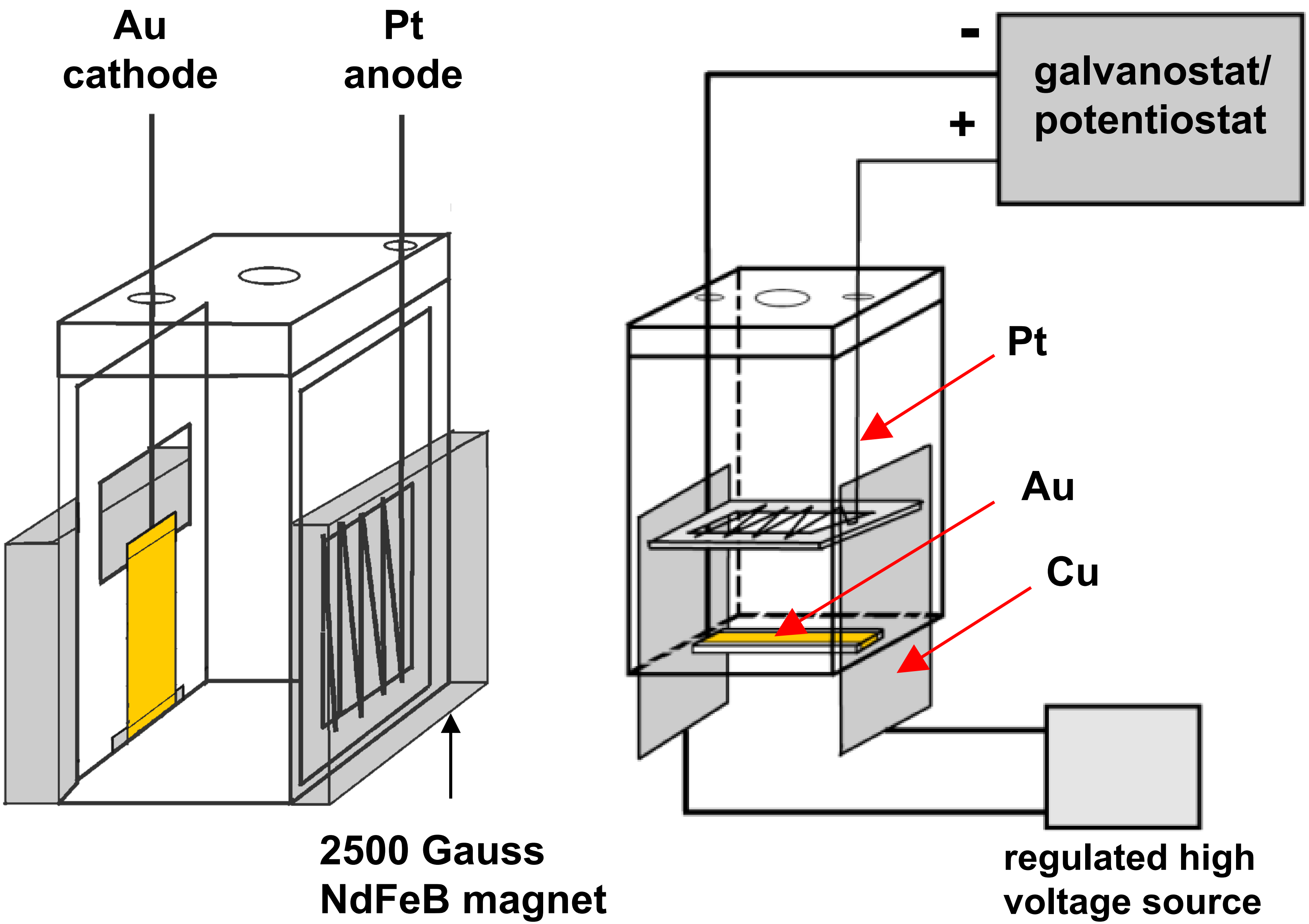
# Summary of Tritium Results




Three gave a rate of tritium production ranging between 3000-7000 atoms $sec^{-1}$ for a 24 hr period

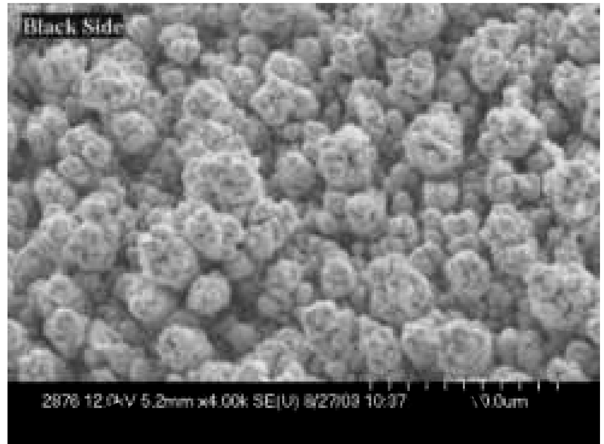
Two experiments showed complete mass balance

# External Electric and/or Magnetic Fields Enhance LENR Effects



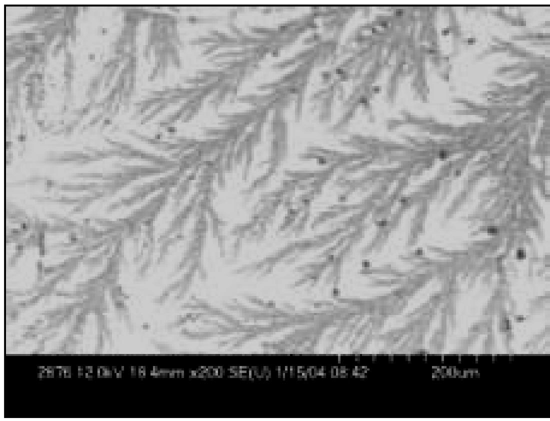
# E-Field Morphology Changes – Reshaping of the Spherical Globules

J. Electroanal. Chem., Vol. 580, pp. 284-290 (2005

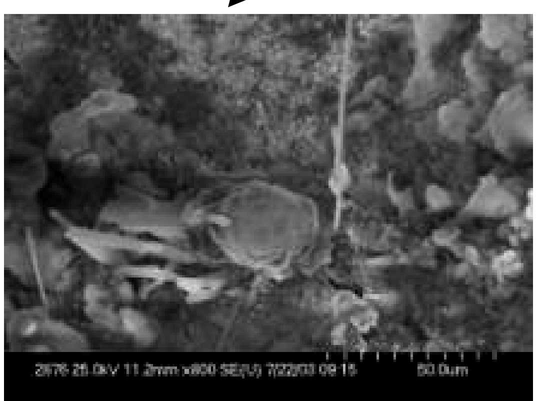



absence of field: cauliflower-like morphology

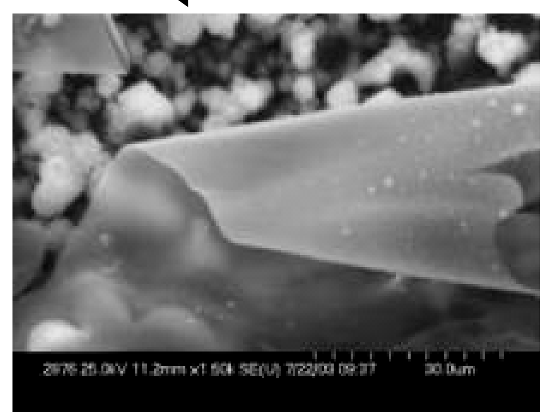
formation of fractals



craters



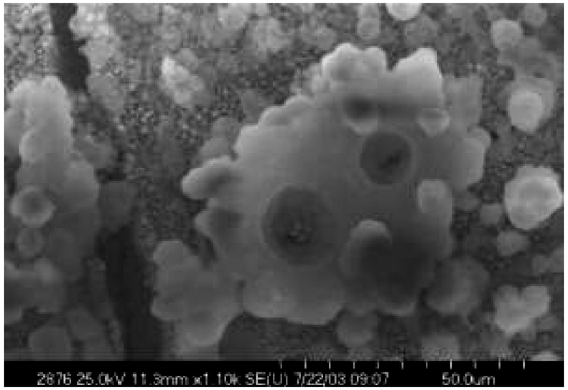
long wires

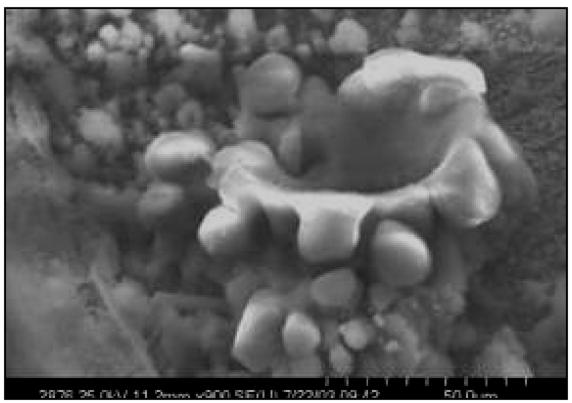


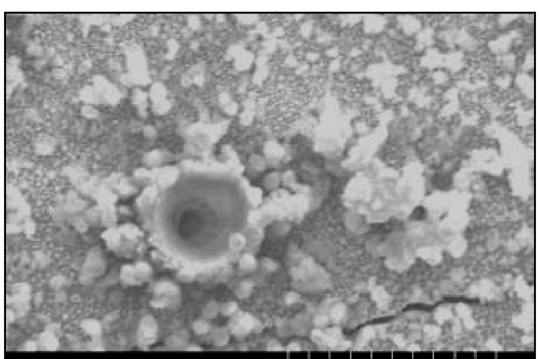
folded thin films

# E-Field: Micro-Volcano-Like Features

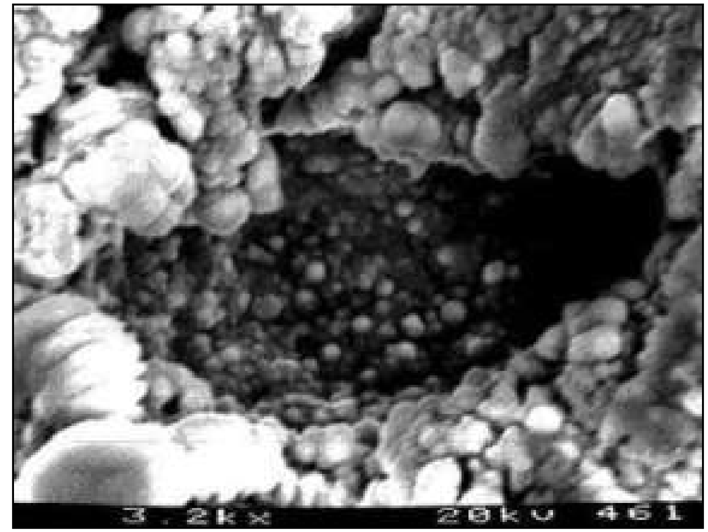
### formed in an applied electric field



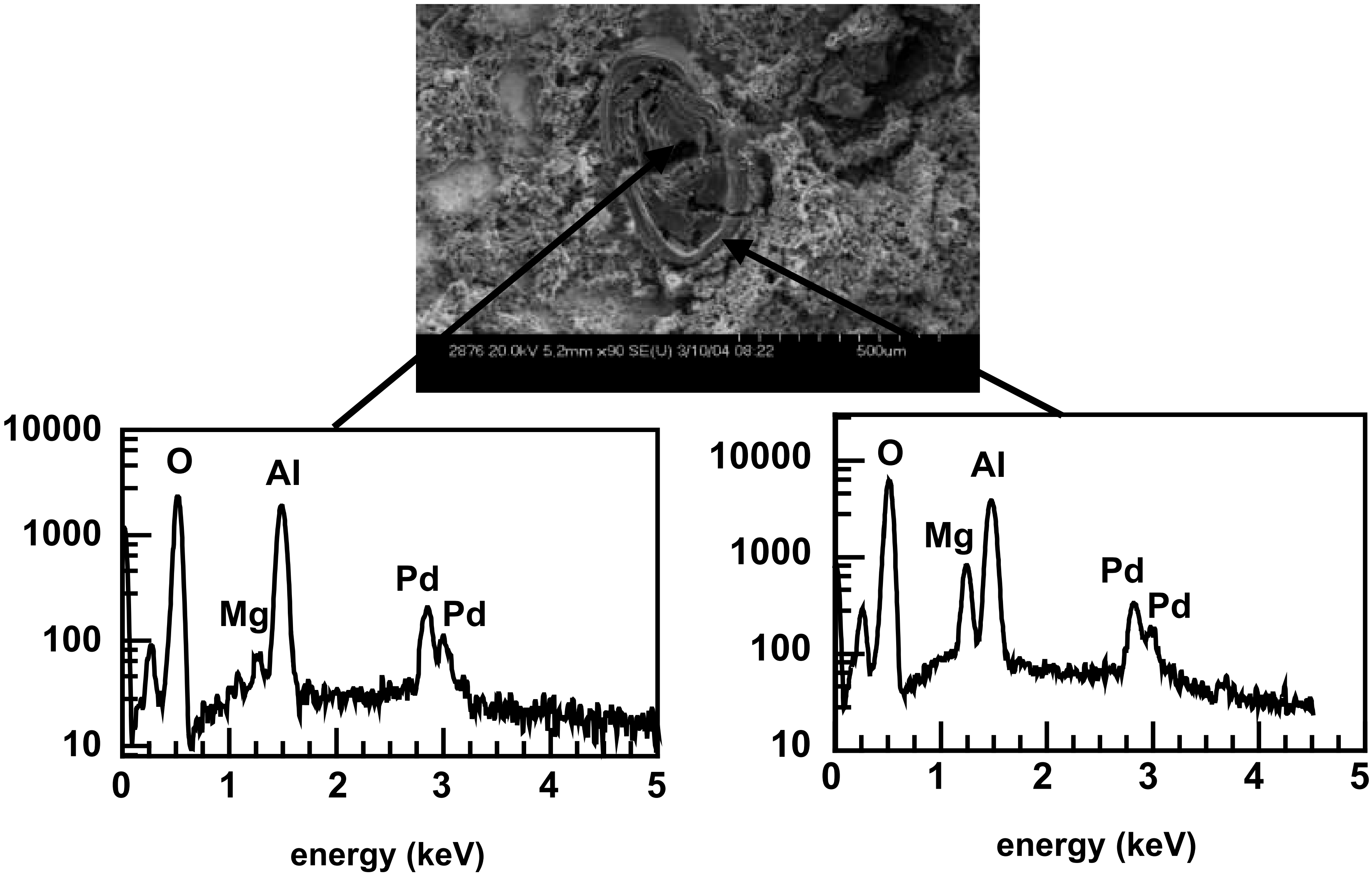


### 'Sonofusion' of Thin Pd Foils
### Roger Stringham



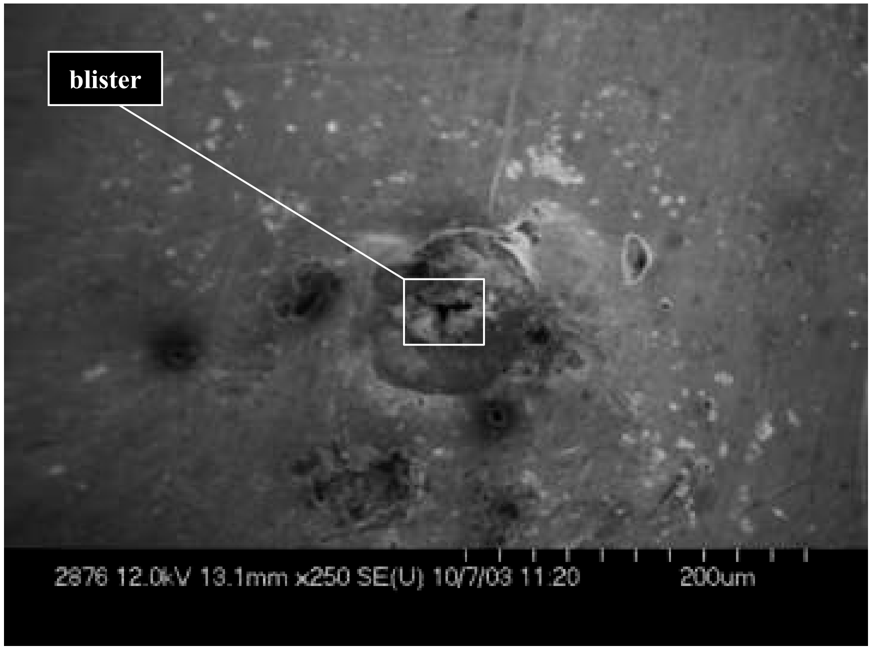

- This kind of damage to metals is consistent with damage seen in materials such as Californium which undergo spontaneous nuclear fission.
- Such volcano like eruptions have been characterized as resulting from large numbers of spontaneous fissions resulting in "spike damage.“
- Features suggestive of solidification of molten metal. Energy needed to melt metal is of a nuclear origin. Should be reflected by chemical analysis of these features

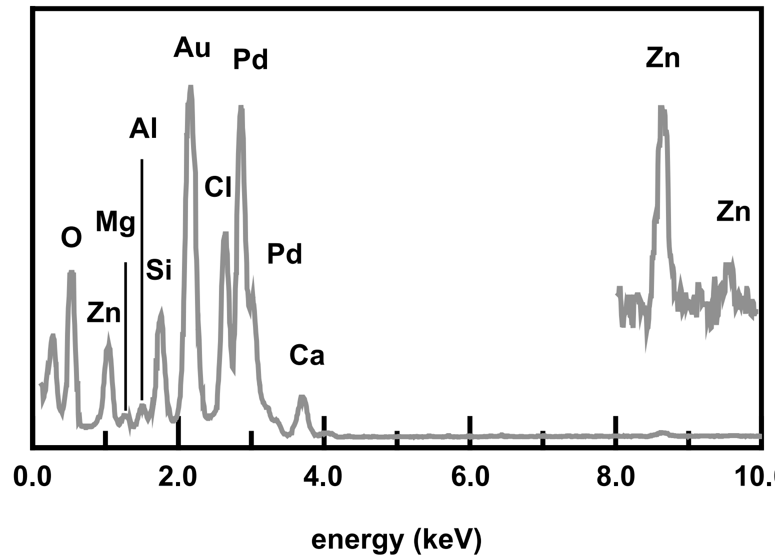
# Chemical Composition of the Inside and Outside Rims of a Crater



# Chemical Composition of a Detached Thin Film ('Blister') Formed in an Applied Electric Field

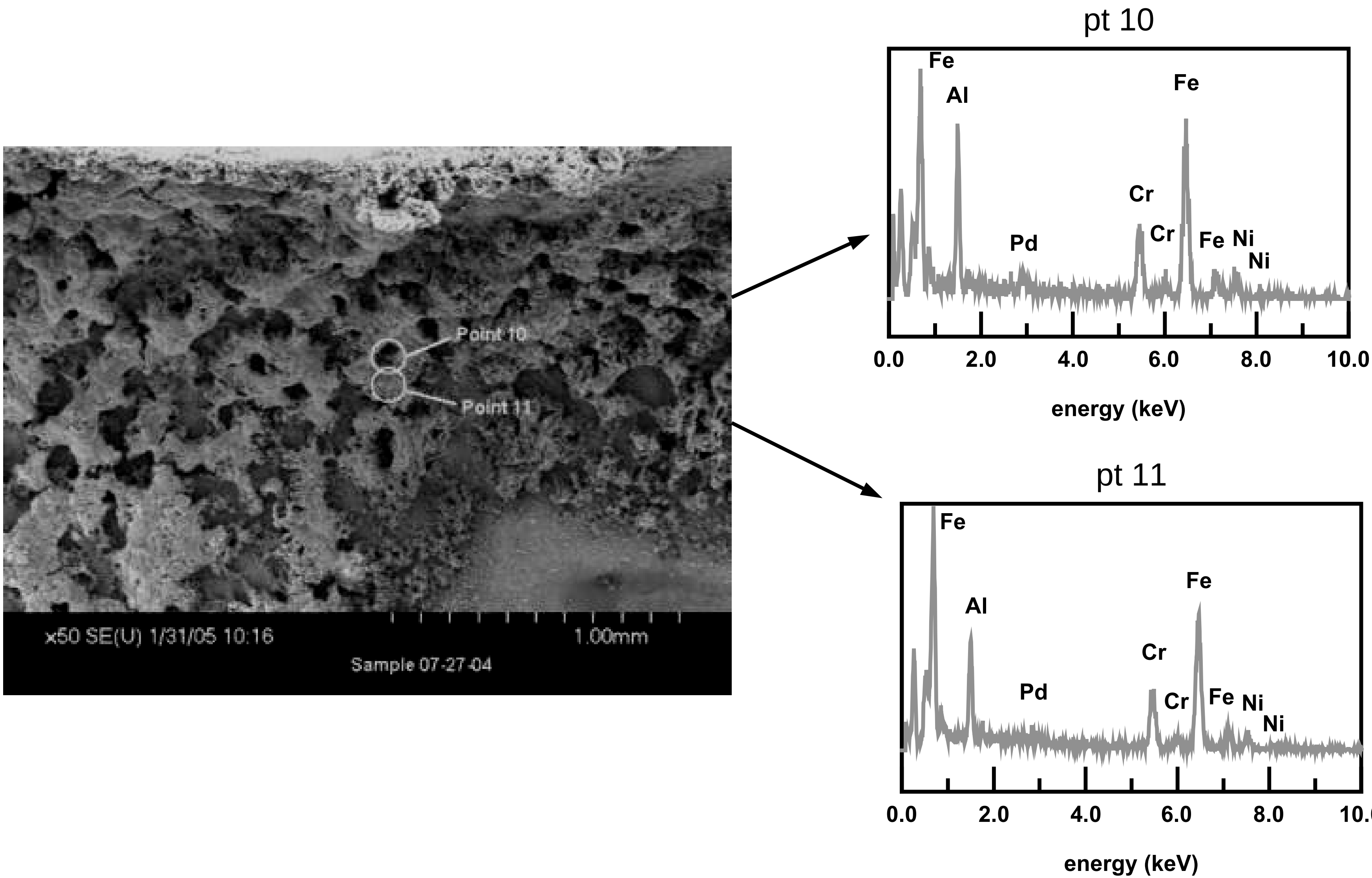
**Naturwissenshaften, Vol. 92, pp. 394-397 (2005)**




- Analysis of the 'blister' shows the presence of Ca, Al, Si, Mg, Zn, Au, O, and Cl.
  - Au, O, and Cl are present in cell components and cannot be attributed to nuclear events.
- Distribution of Ca, Al, Si, Mg, and Zn is not uniform suggesting that their presence is not the result of contamination.
- Ca, Al, Mg, and Si cannot be electrochemically plated from aqueous solutions

# Chemical Composition of Structures Formed in an Applied Magnetic Field



# Observations of Unexpected Elements

## Labs Reporting Transmutation Results (Compilation by Miley, Univ of Illinois)

Hokkaido Univ., Japan - Mizuno et al.; Notoya et al.
Mitsubishi Corporation, Japan - Iwamura et al.
Osaka University, Japan - Takahashi et al; Arata et al.
University of Lecce, Italy - Vincenzo et al.
Frascati Laboratory, Italy – De Ninno et al.
SIA “LUTCH”, Russia - Karabut et al; Savvatimova et al
Tomsk Polytechnical Univ., Russia - Chernov et al.
Lab. des Sciences Nucleaires, France - Dufour et al.
Beijing University, China - Jiang et al.
Tsinghua University, China - Li et al.
University of Illinois, USA - Miley et al.
Portland State University, USA – Dash et al.
Texas A&M University, USA - Bockris et al.
Schizuoka University, Japan – Kozima et al.
Iwate University, Japan – Yamada et al.

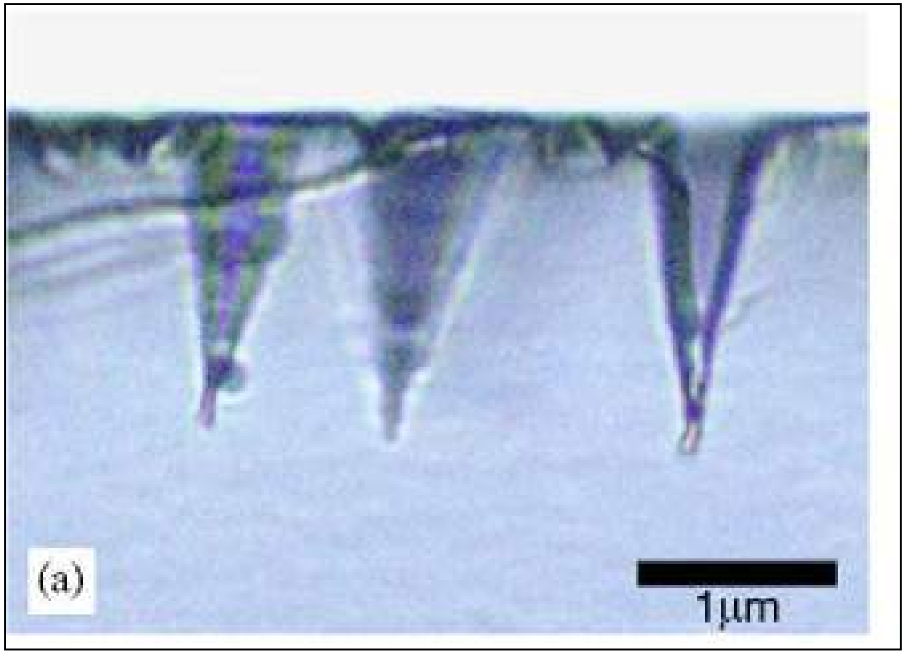
**Number of Labs reporting:**

**11 Fe**
**8 Cu**
**7 Ca, Cr, Zn**
**6 Ni, K**
**5 Ag, Cl, Ti**
**4 Mg, Mn, Co, Pb**
**3 Al, Li, Ba, Os, C, Si**

**SPAWAR Systems Center, Pacific** → **Al, Mg, Ca, Fe, Zn, Si, Cr, Ni**

# Particle Detection Using CR-39

- 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)

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# Weaknesses and Strengths of SSNTDs

S.A. Durrani, Rad. Meas., Vol. 43, p. S26 (2008)

## Strengths

- Small geometry
  - Trails of damage are nm/μm in diameter and length
- Long history and selectivity of track recording
  - (SSNTDs can retain a record of nuclear activity for billions of years)
- Existence of thresholds for registration
  - SSNTDs can register particles only if their charge and LET value are above a threshold
- Ruggedness and simplicity
- Inexpensive
- Integrating capability
- Can respond to both charged particles and neutrons

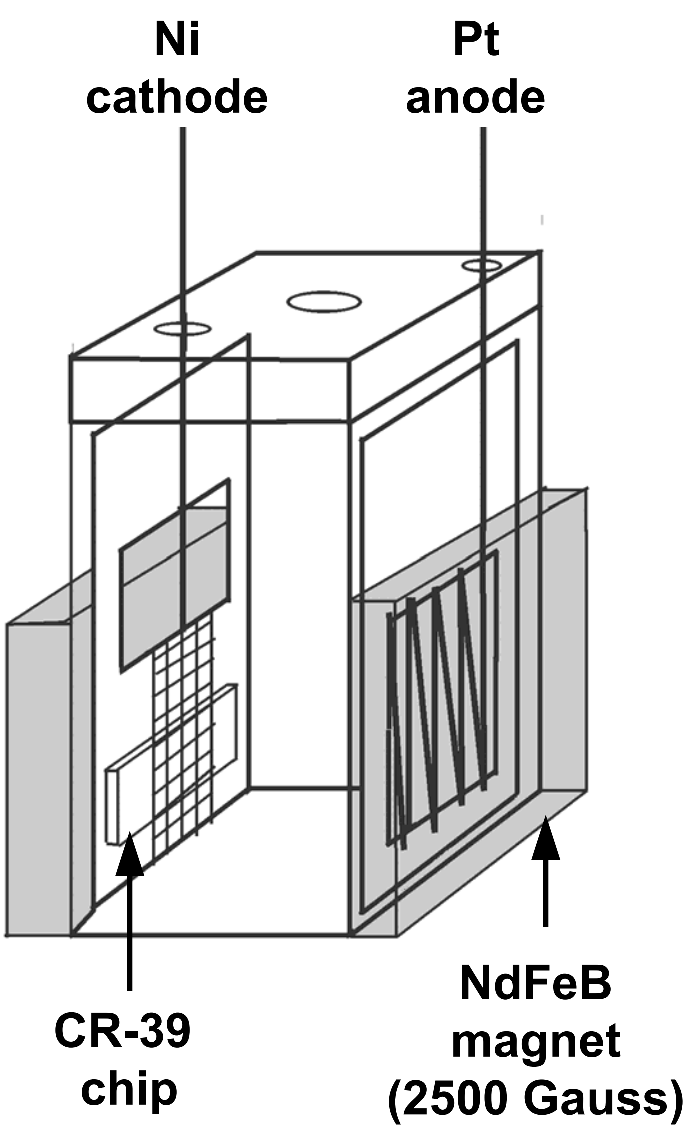
## Weaknesses

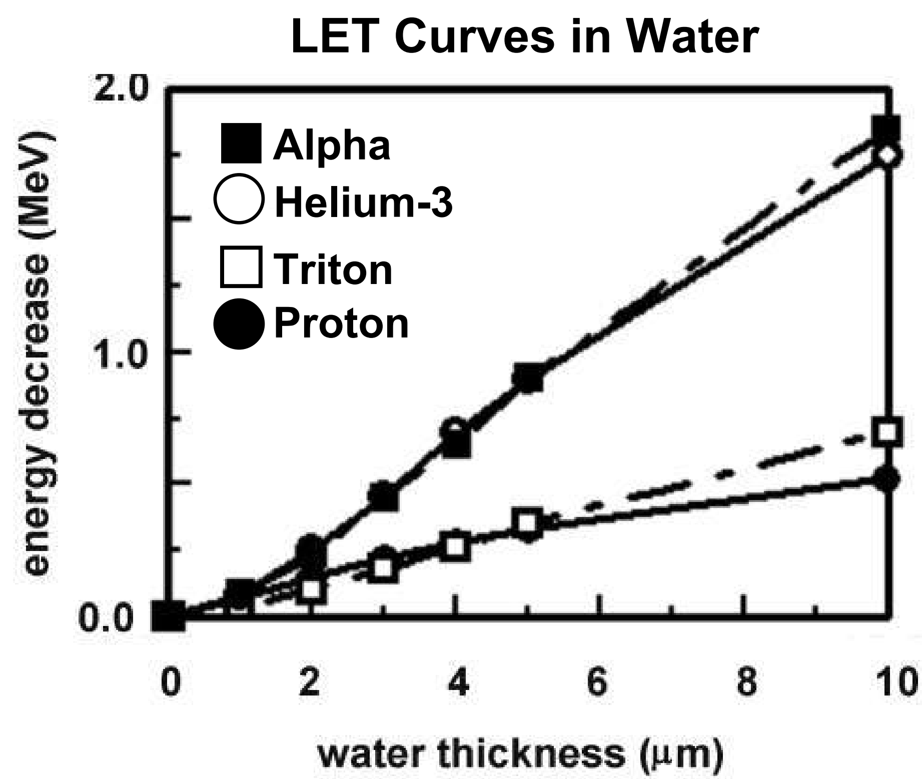
- Lack of real-time capability
- Poor charge and energy discrimination
  - Track size/shape depends upon the charge and mass of the particles as well as the angle of incidence. There is significant overlap in the size distributions of tracks due to p, d, T, $^{3}He$, and $^{4}He$
- Variability in SSNTDs
  - Environmental conditions and manufacturing procedures results in problems of precision and reproducibility
- Lack of theoretical understanding
  - No theoretical work explains how certain properties of materials can predicate or ascertain a viable ability for track formation/retention

# Summary of CR-39 Work Done by Others

- R.A. Oriani and J.C. Fisher, Jpn. J. Appl. Phys., vol. 41, p. 6180 (2002)
  - CR-39 detectors placed above and below Pd sheet cathodes
  - Track density of electrolysis experiments (150-3760 tracks $cm^{-2}$ ) greater than controls (59-541 tracks $cm^{-2}$ )
- A.G. Lipson, et al., Fus. Technol., vol. 38, p. 238 (2000)
  - Electrochemically load Au/Pd/PdO heterostructures with D. Once loaded put cathode in contact with CR-39 and cycle T
  - Tracks consistent with 2.5-3.0 MeV $p^+$ and 0.5-1.5 MeV $t^+$ detected
- A.G. Lipson et al., ICCF10 (2003)
  - In-situ experiments. 50 µm thick Pd foil in contact with CR-39
  - Tracks concentrated in areas where the cathode was in contact with the detector.
- A.G. Lipson et al., ICCF9 (2002)
  - Conduct in situ experiments placing Cu and Al spacers between CR-39 detector and 50 µm thick Pd foil
  - Pd cathodes emit 11-16 MeV α and 1.7 MeV $p^+$ during electrolysis

# Experimental Configuration




- 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

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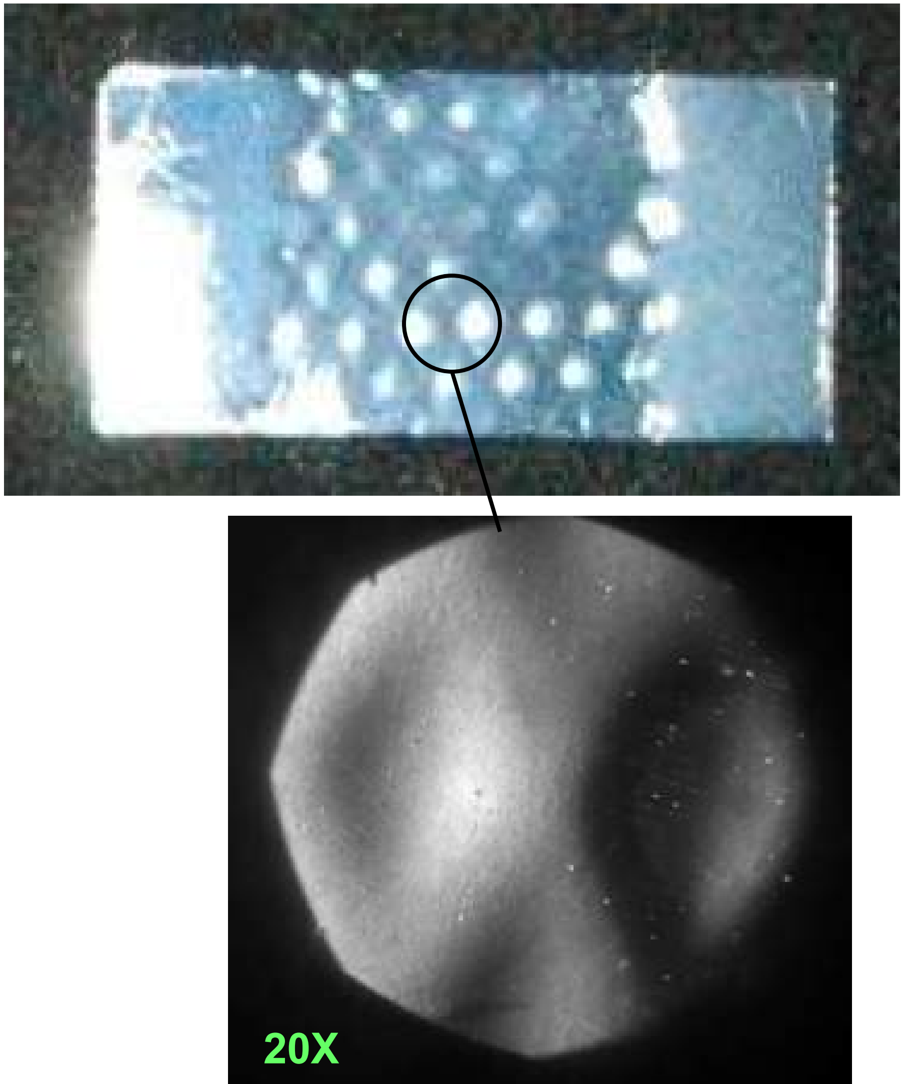
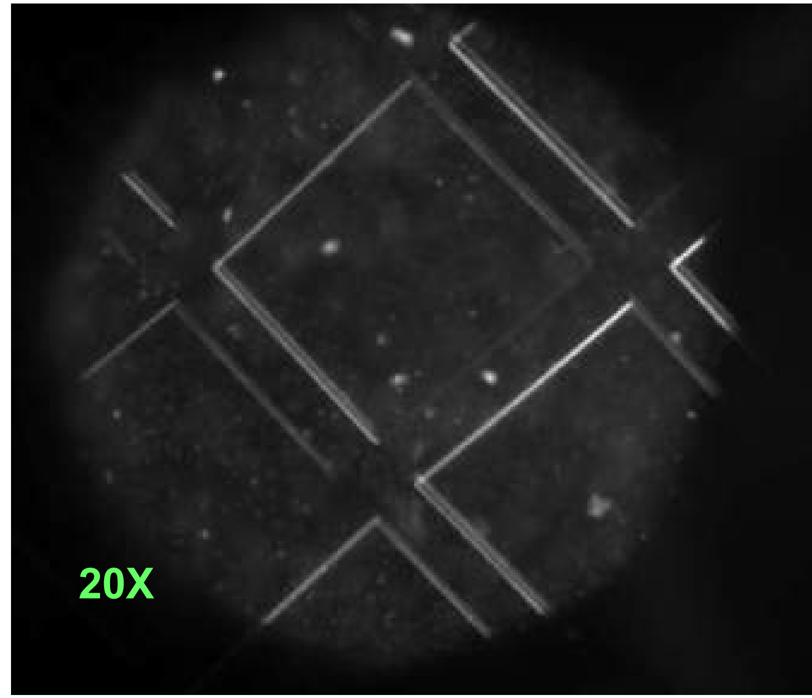
# CR-39: Evidence of X-Ray Emission

**Ni screen in the absence of a field**



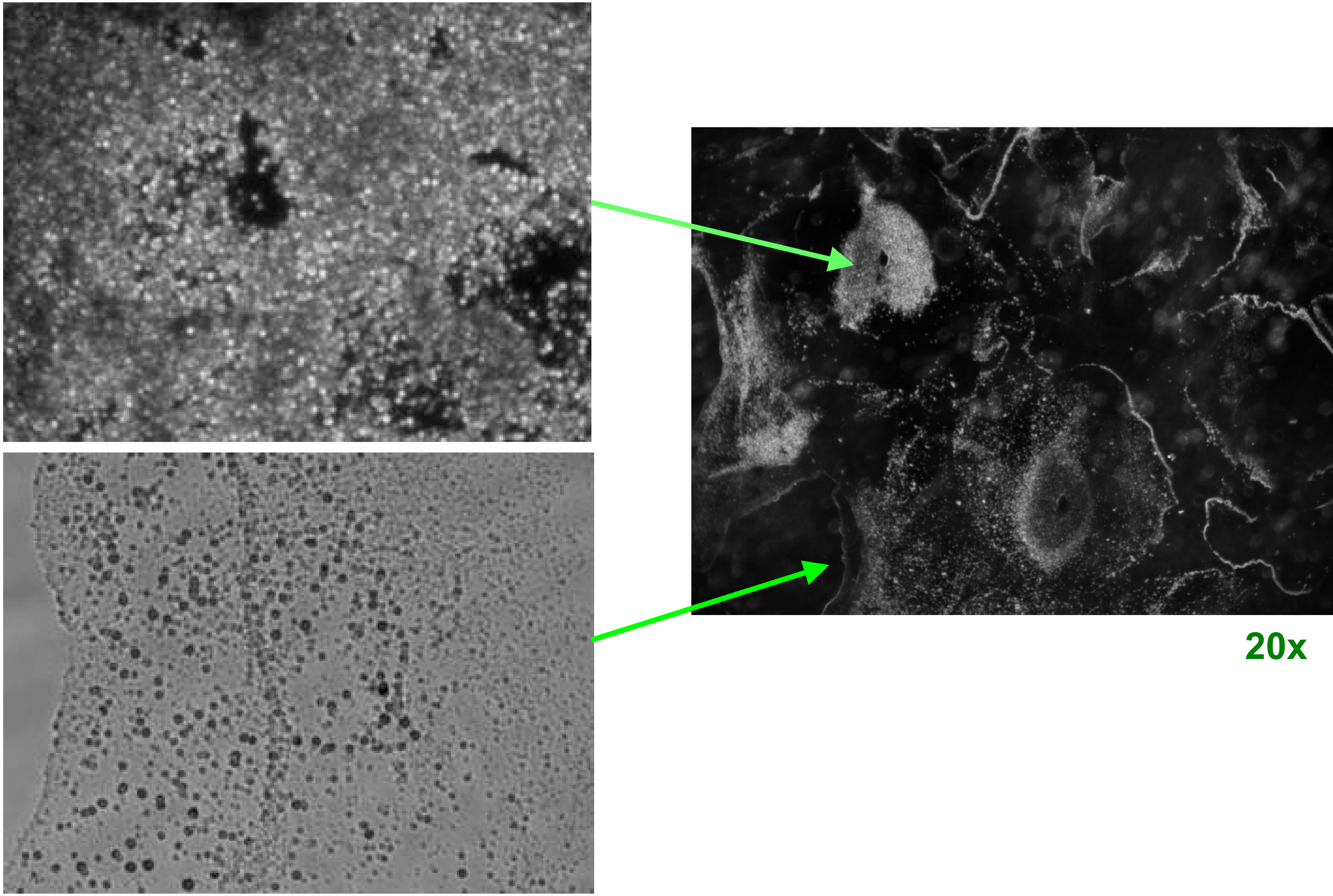

**CR-39 Chip exposed to X-rays from XRD**




**Use of CR-39 for γ-ray dosimetry has been documented in:**

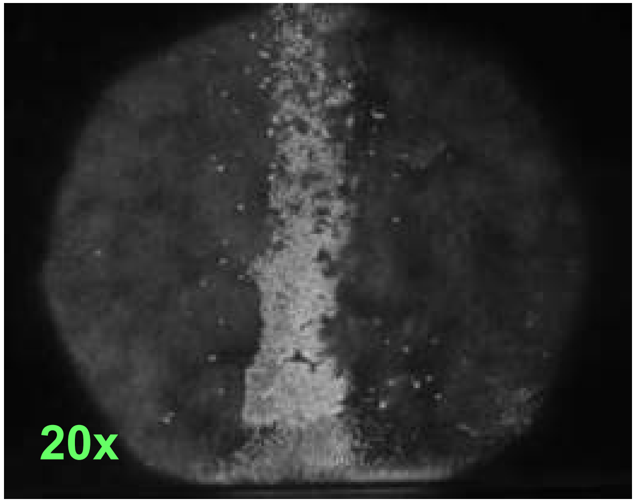
1. A.F. Saad, S.T. Atwa. R. Yokota, M. Fujii, Radiation Measurements, Vol. 40, 780 (2005)
2. S.E. San, J. Radiol. Prot., Vol. 25, 93 (2005)
3. A.H. Ranjibar, S.A. Durrani, K. Randle, Radiation Measurements, Vol. 28, 831 (1997)

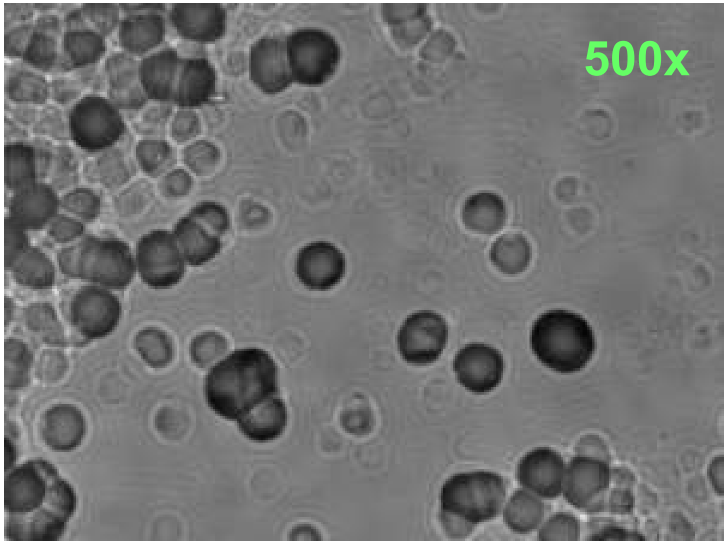
# Ni/Pd/D Evidence of Particle Emission in a Magnetic Field

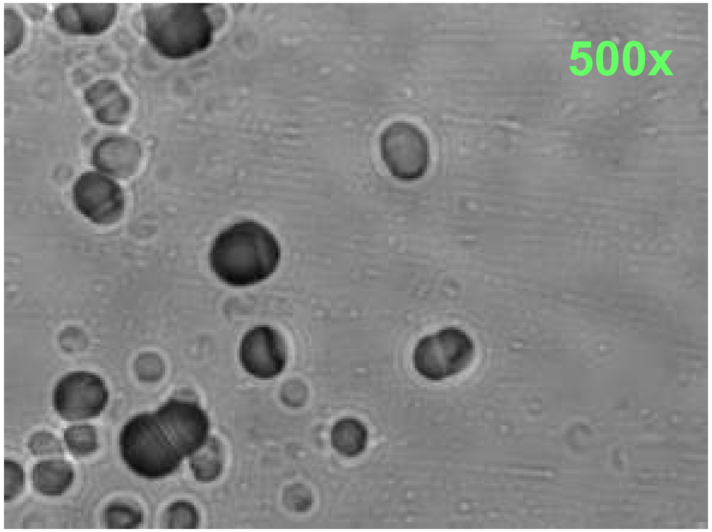


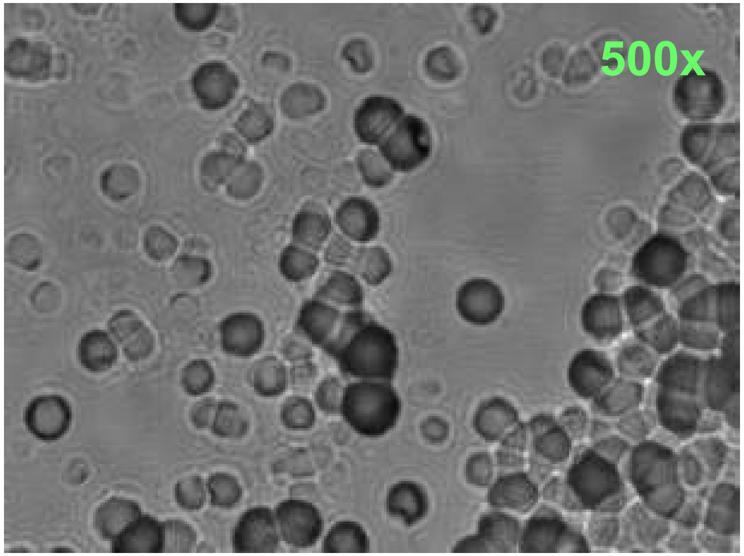
20x

# Ag wire/Pd/D in Magnetic Field



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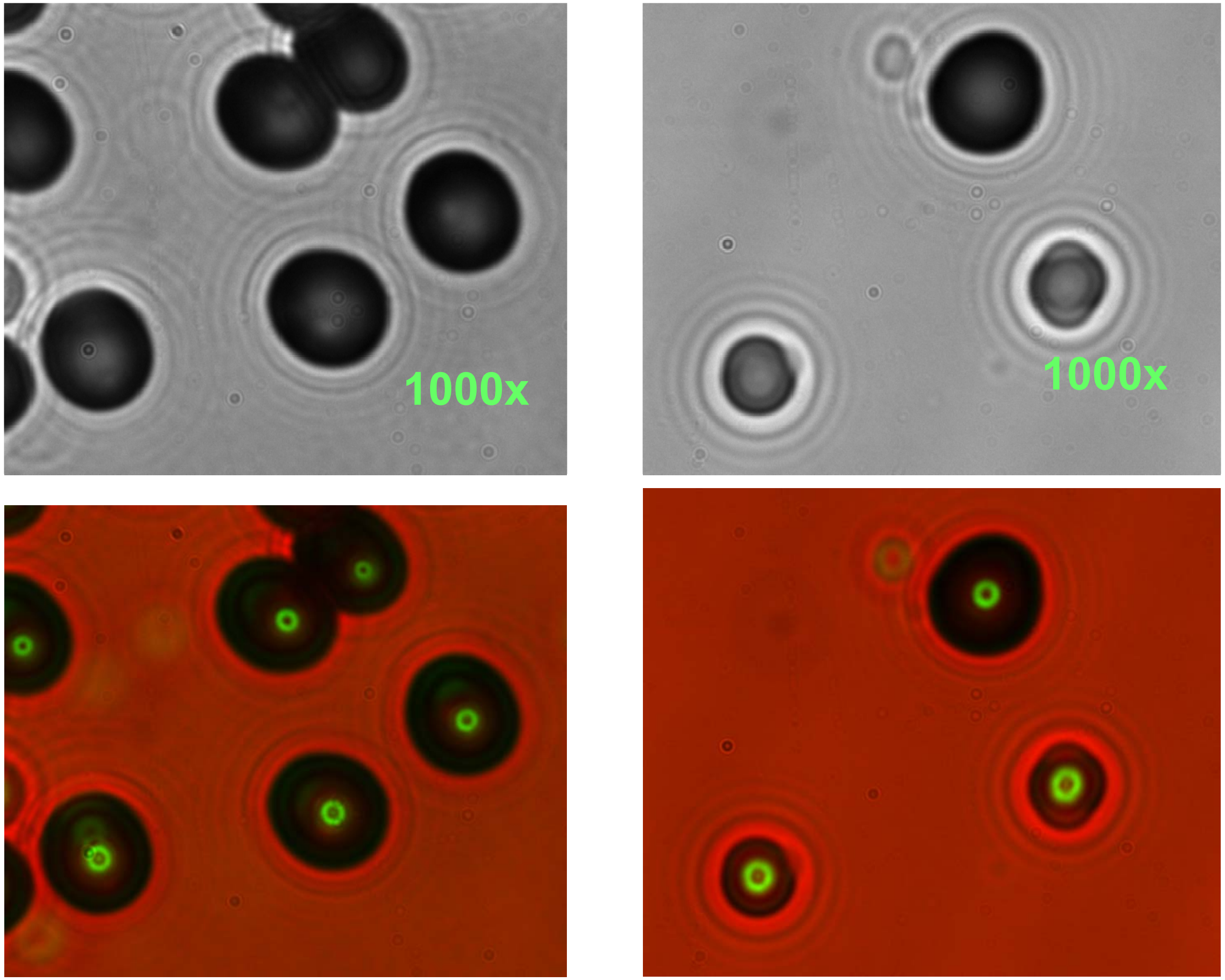
# Is a Feature Due to Background or to a Particle?



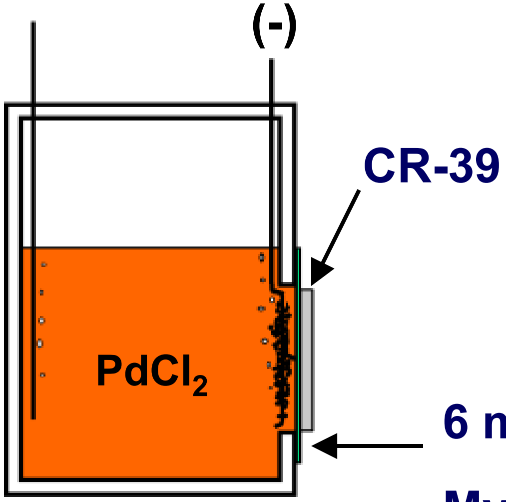

**Features due to background are small, bright, shallow, and irregular in shape. The nuclear tracks are dark when focused on the surface. Focusing deeper inside the pits shows bright points of light.**

# Summary of Control Experiments

EPJAP Vol. 40, p 293 (2007); Vol. 44, p. 291 (2008)

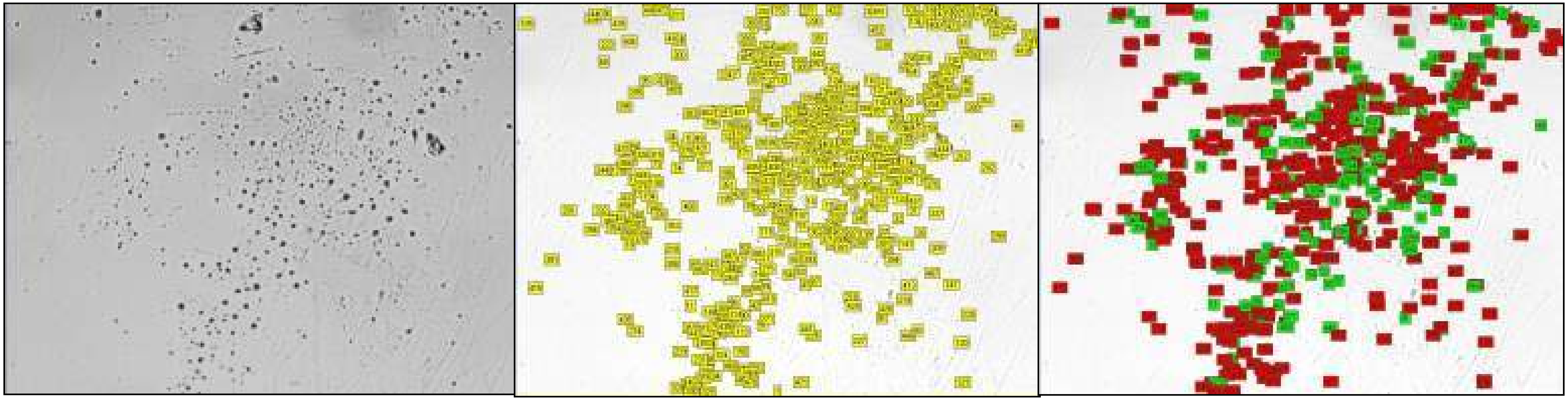
- Pits are not due to radioactive contamination of the cell components
- Pits are not due to impingement of $D_2$ gas on the surface of the CR-39
- Pits are not due to chemical reaction with electrochemically generated $D_2$, $O_2$, or $Cl_2$
- LiCl is not required to generate pits
- $D_2O$ yields higher density of pits than $H_2O$
- Pd/D co-dep gave higher density of pits than Pd wire
- Mylar spacer experiments indicate that the majority of the particles have energies ≤ 1 MeV
  - These conclusions are supported by computer modeling of the tracks using the TRACK_ETCH code developed by Nikezic and Yu

# CR-39 Outside the Cell




- No contact between CR-39 and cell electrolyte.
- Nuclear particle tracks scanned and counted by computer
- 6 μm thick Mylar cuts off < 0.45 MeV p+, < 0.55 MeV t+, < 1.40 MeV 3He, and < 1.45 MeV α

← 600 μm →



Raw image | Computer processed | Computer identified

Nuclear particle tracks scanned and counted by computer

***Tracks not caused by chemical or mechanical damage!***

# Modeling of Tracks Using 'TRACK_TEST'

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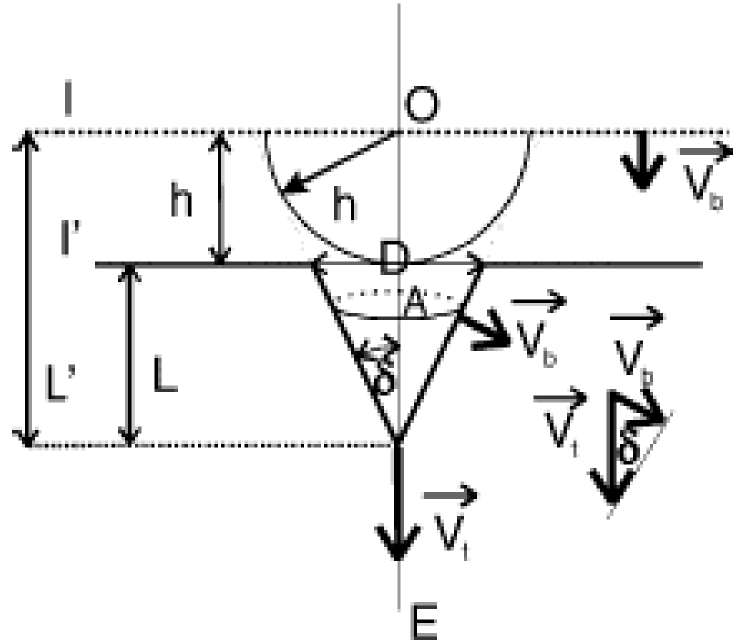
**Geometry of the Track Development:**




## Input Parameters:

(1) Energy of α in MeV

(2) Incident angle between 30 - 90º

(3) Etch rate in μm hr $^{-1}$

(4) Etch time in hr

**$V_T$ , $V_B$ = rates of etching the track and the bulk respectively**

$$V_T = V_B\left(e^{(-a_1x+a_4)} - e^{(-a_2x+a_3)} + e^{a_3} - e^{a_4} + 1\right)$$

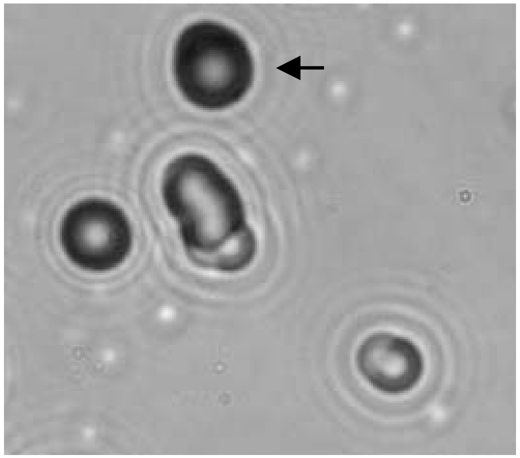
**$a_1$=0.1, $a_2$=1, $a_3$=1.27, and $a_4$=1. *x* is the residual range of the α particle**

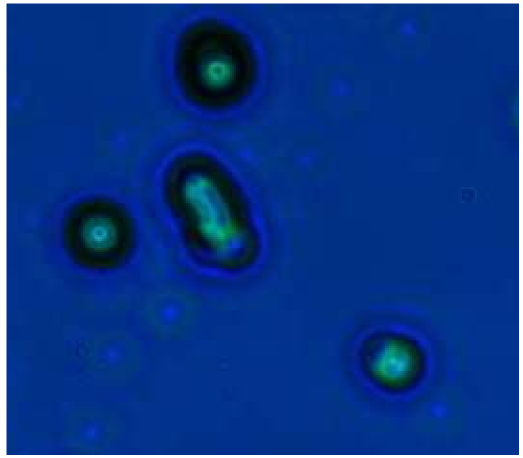
D. Nikezic, K.N. Yu, Radiat. Meas., 37 (2003) 39-45.

D. Nikezic, K.N. Yu, Computer Physics Communications, 174 (2006) 160-165.

# Results of Modeling

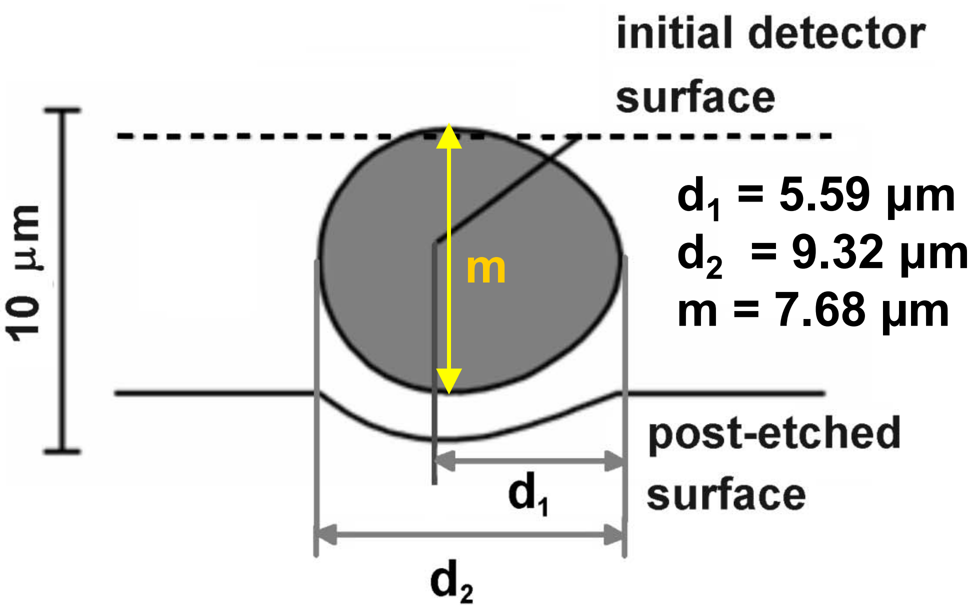
**EPJAP, in press (2009)**



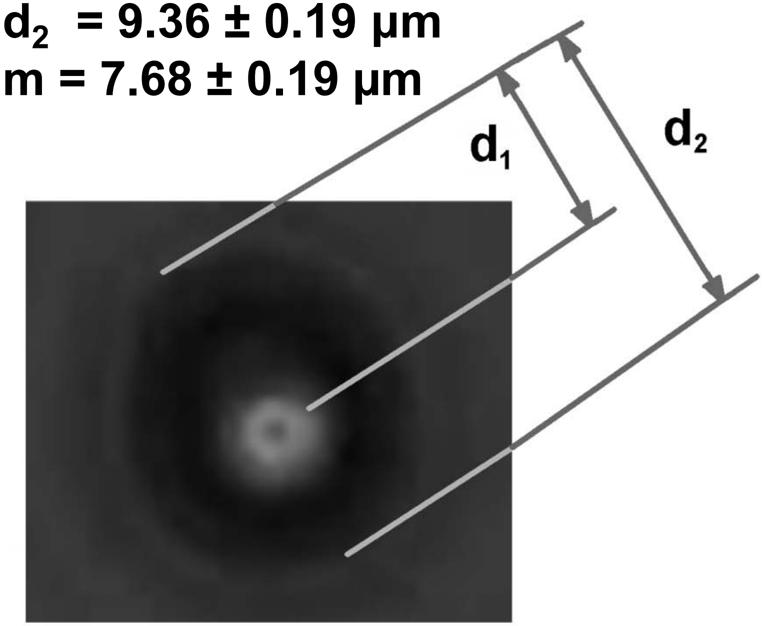


**$E_\alpha$ = 1.3 MeV**
**Incident angle = 35º**
**Etch rate = 1.25 µm $hr^{-1}$**
**Etch time = 6 hr**

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




**$d_1$ = 5.34 ± 0.19 µm**
**$d_2$ = 9.36 ± 0.19 µm**
**m = 7.68 ± 0.19 µm**



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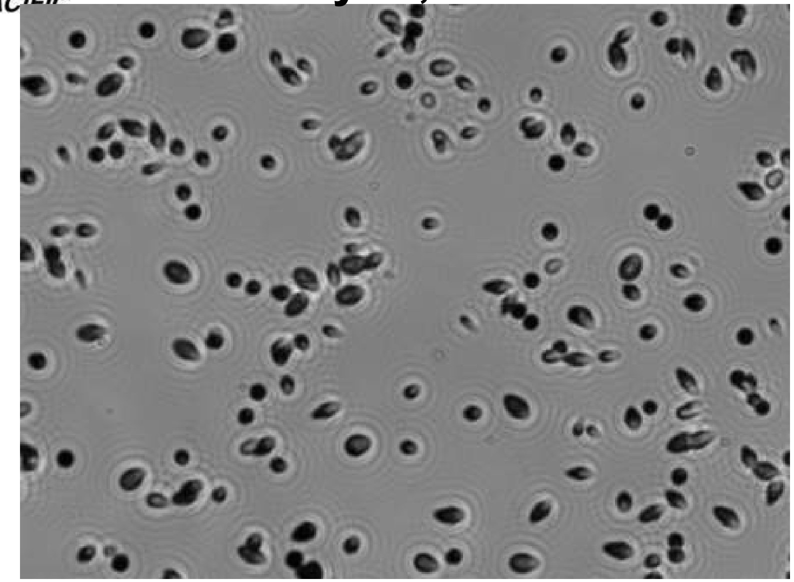
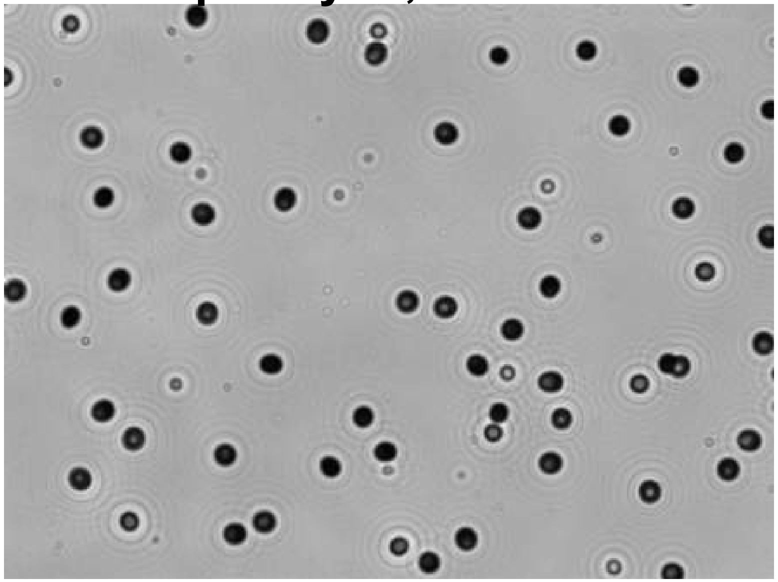
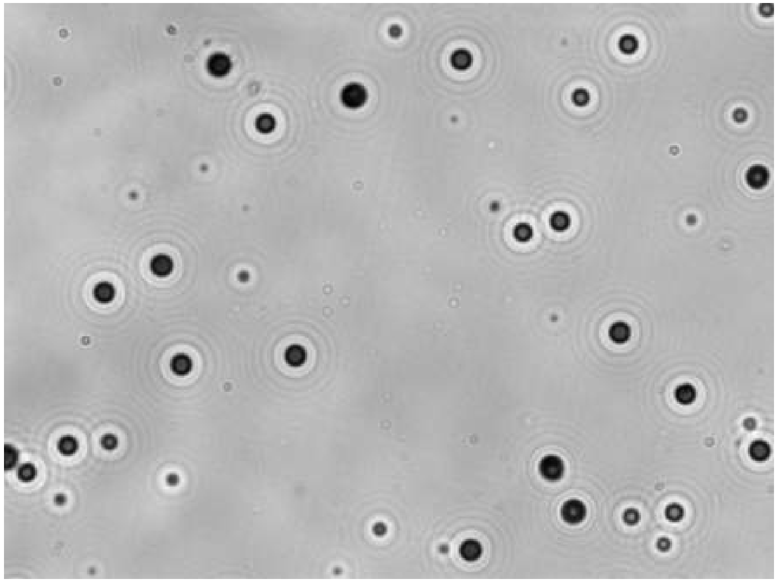
# Simulating the Effect of Water

No Mylar, E = 5.5 MeV



18 µm Mylar, E = 1.92 MeV

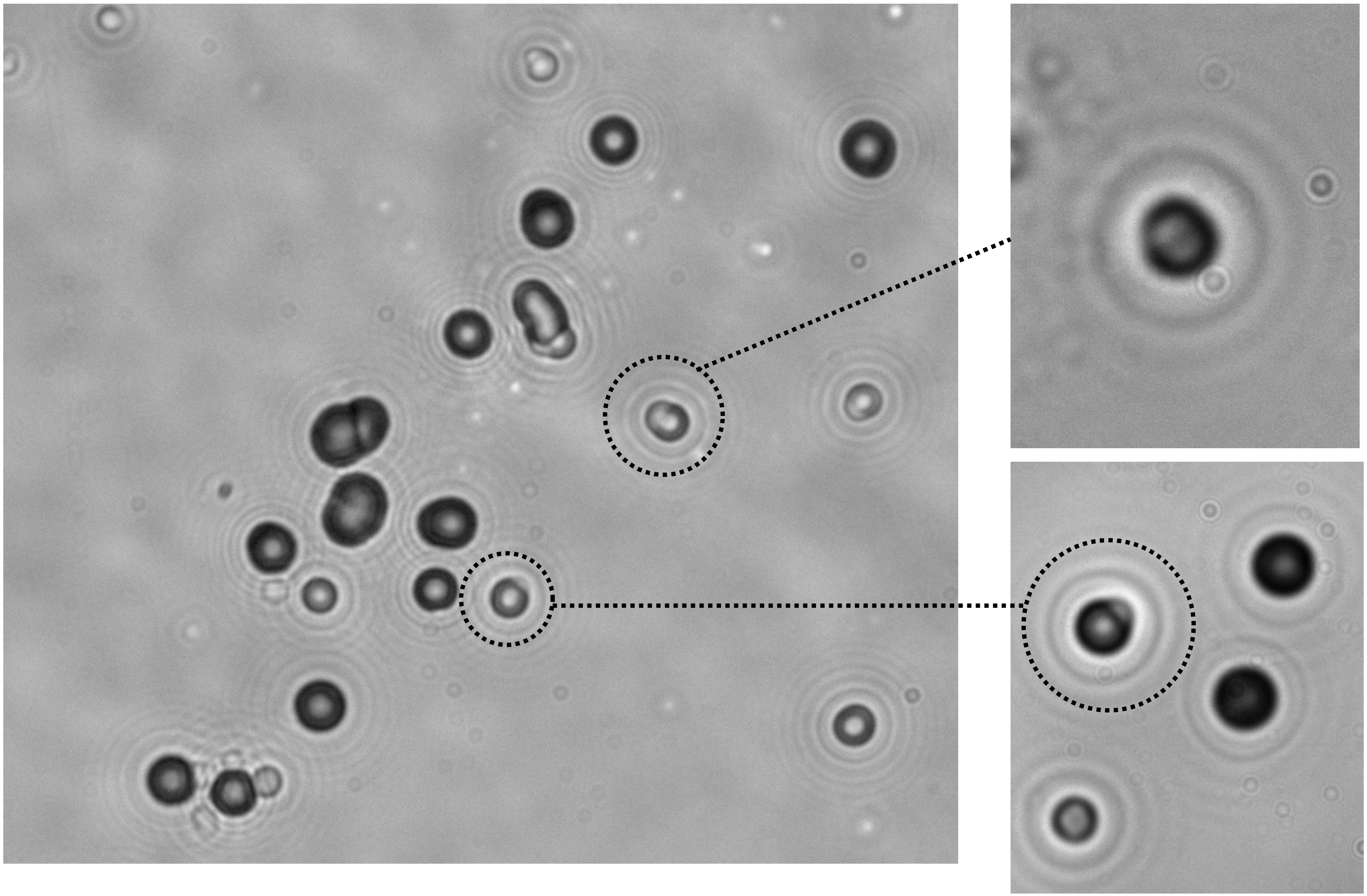




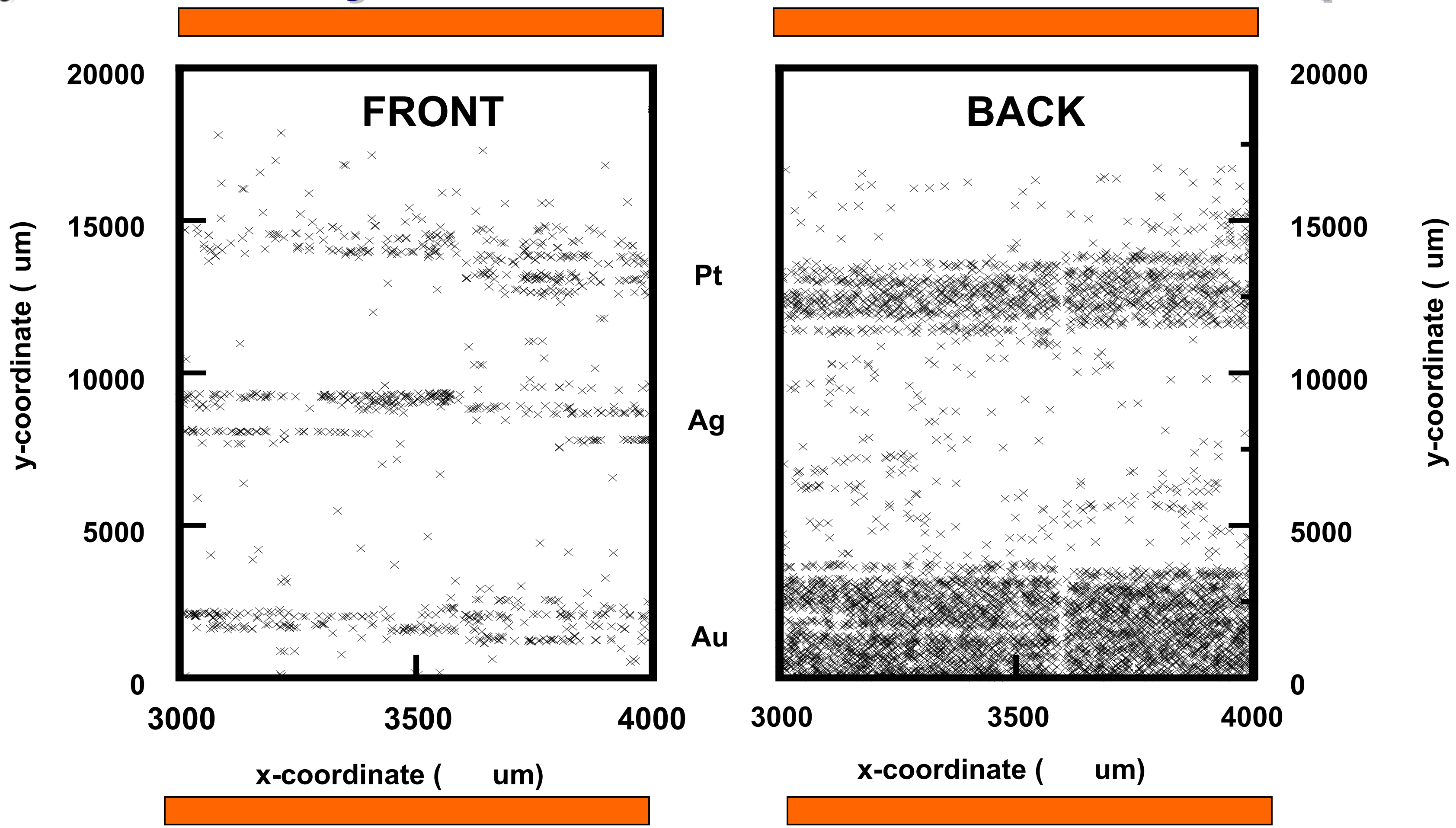
24 µm Mylar, E = 1.09 MeV

# Comparison With ~1 MeV α

EPJAP, in press (2009)



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

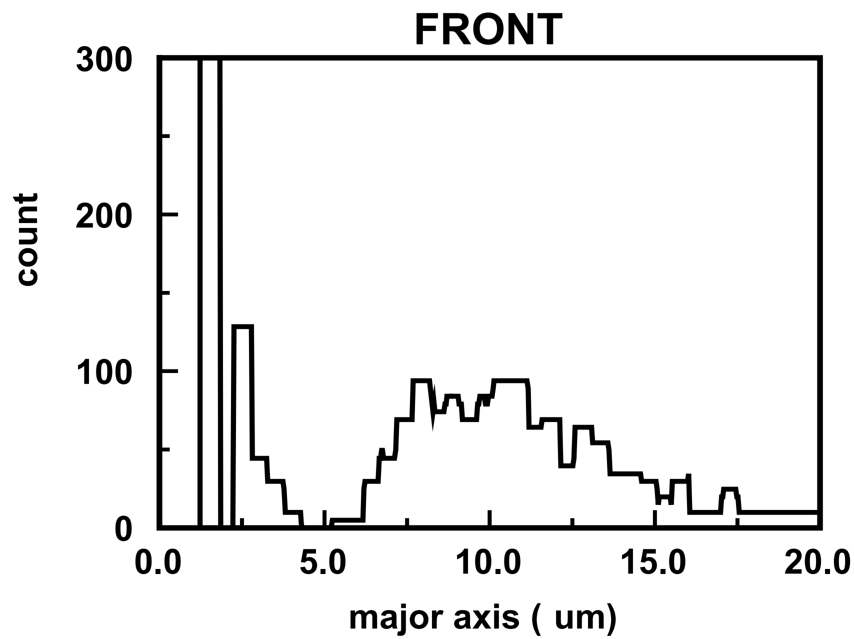


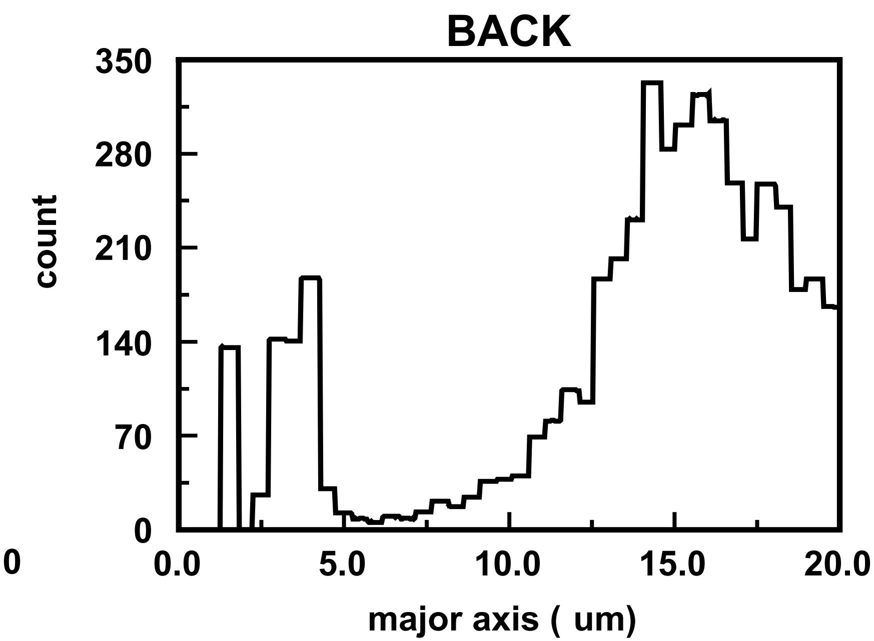

**Same (x,y) locations, front and back.**

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

***No tracks from Ag on back!***

# Counts vs. Major Axis




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

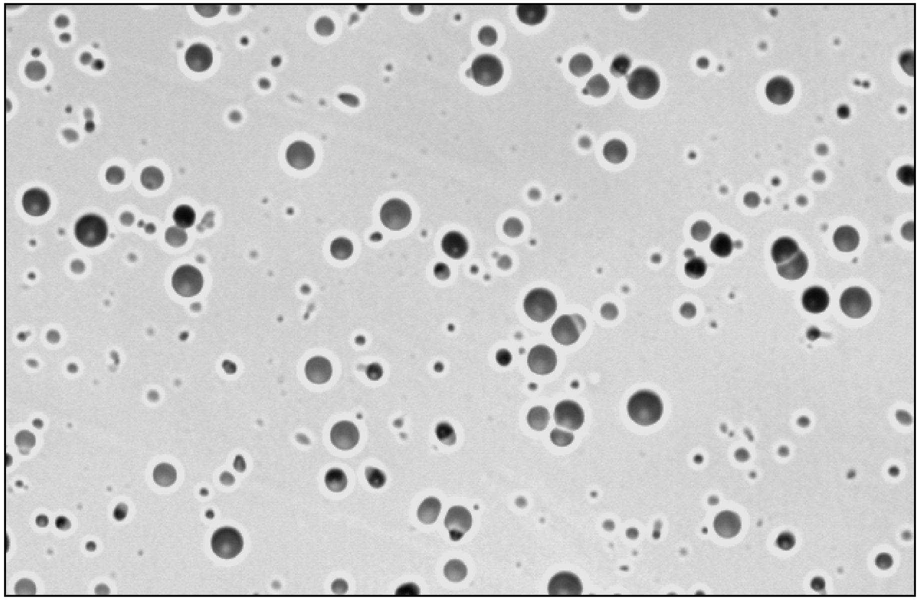
**Mylar experiments: 1-3 MeV α, 0.45-1 MeV $p^+$**

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

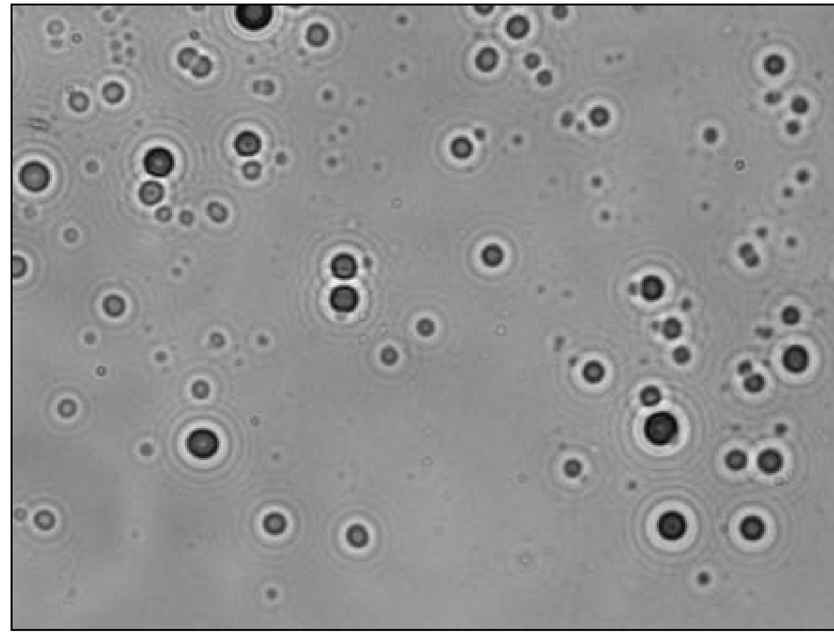
**assignment >40 MeV α? >10 MeV $p^+$? Neutrons?**

# Comparison with Neutrons

$^{238}PuO$ fission neutron source

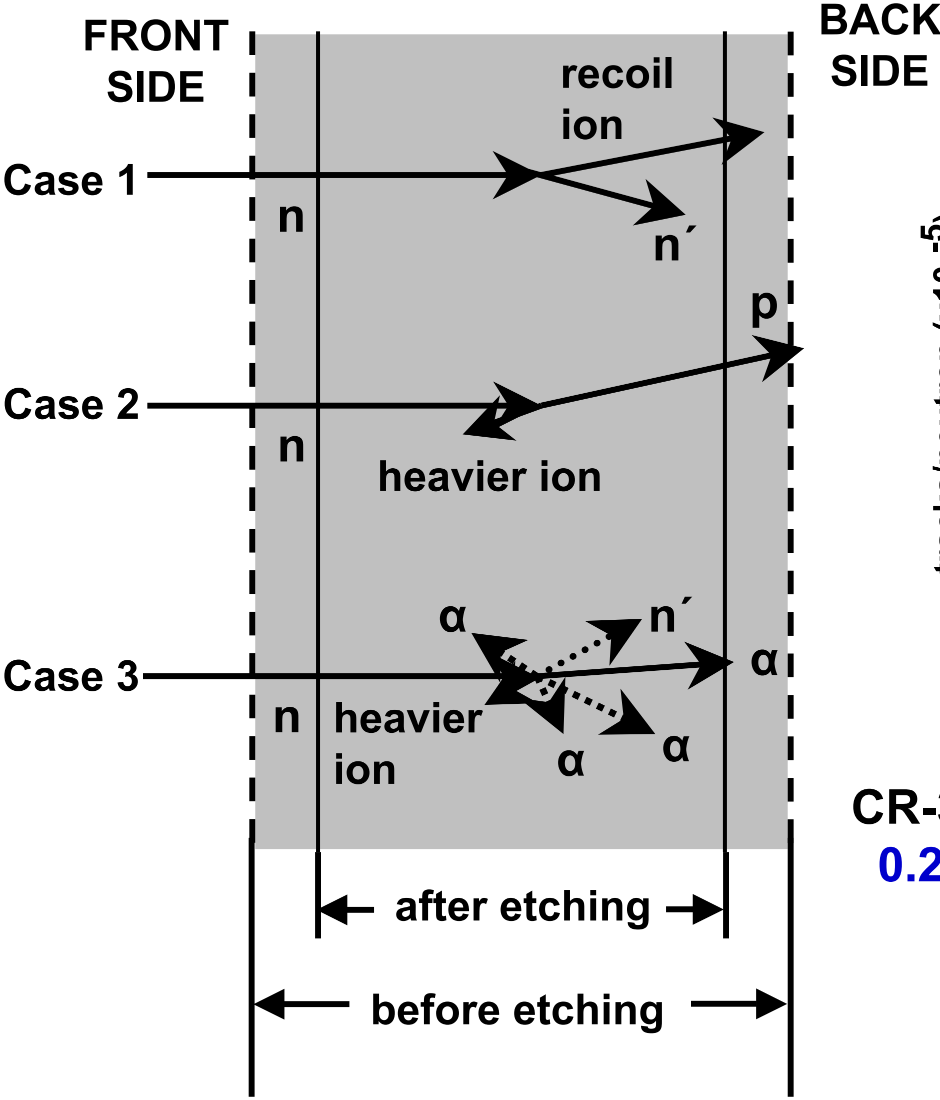


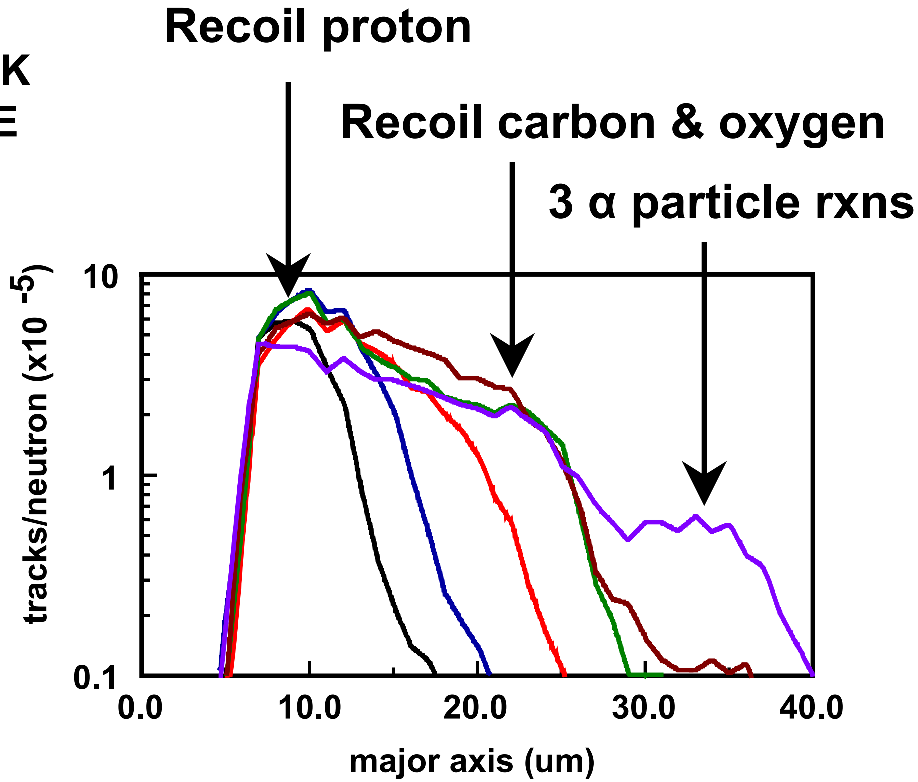
Ag/Pd, backside



- Tracks are primarily circular in shape
- Some tracks are circular with small tails. These are due to recoil protons  that have exited the CR-39 at an oblique angle
- Small latent tracks are observed

# Neutron Interactions with CR-39




CR-39 that has been exposed to 0.114 MeV, 0.25 MeV, 0.565 MeV, 1.2 MeV, 8 MeV, and 14.8 MeV monoenergetic neutrons

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

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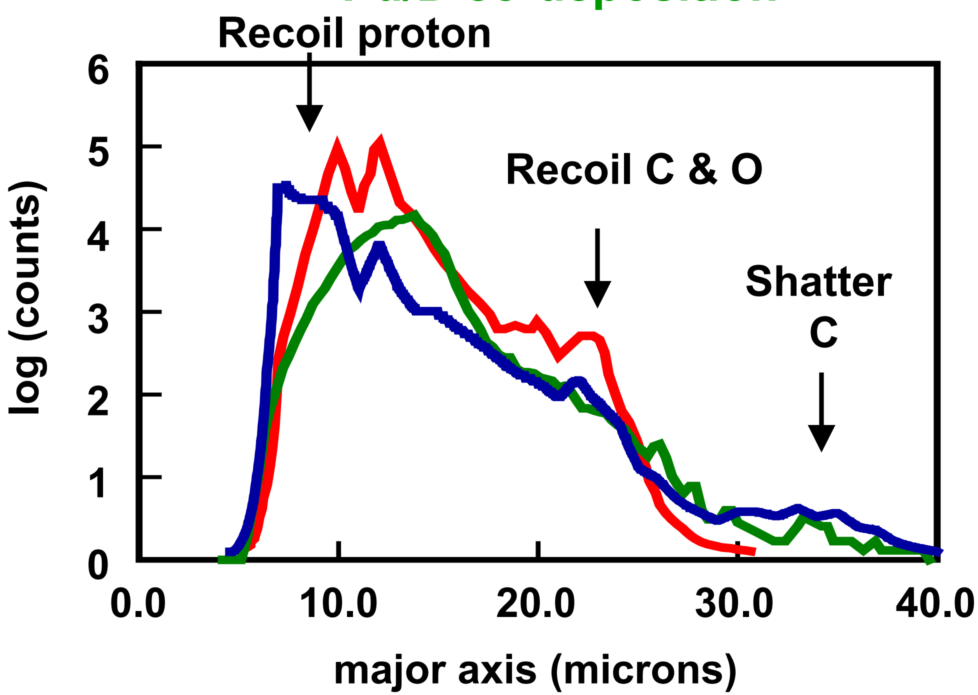
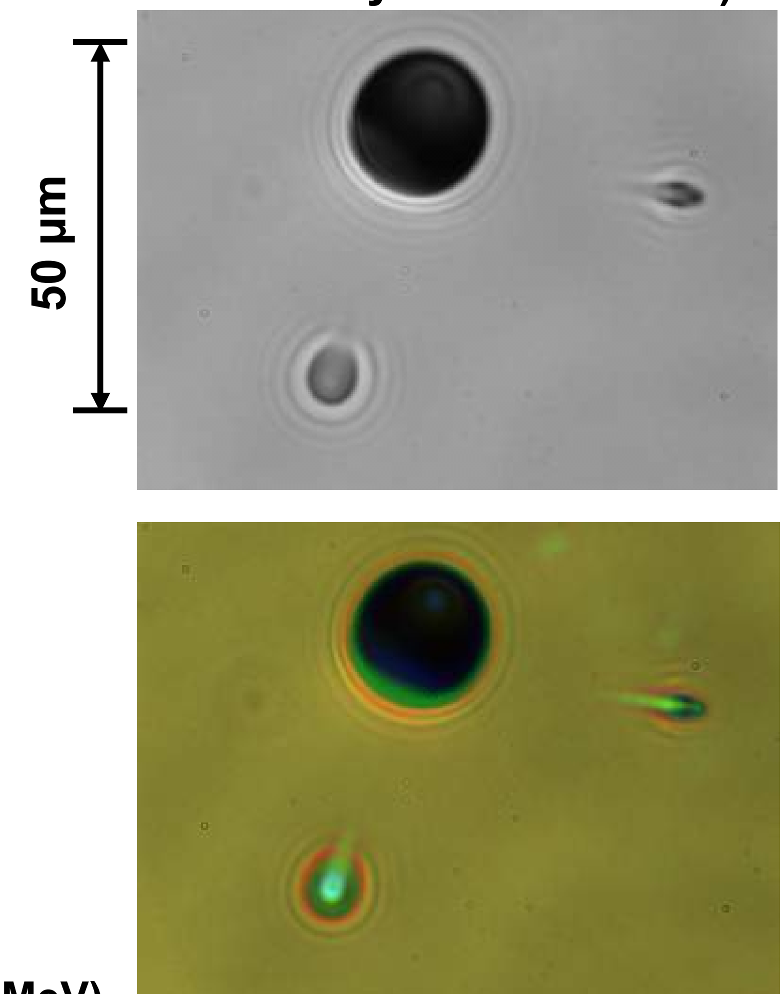
# Comparison With Our Data



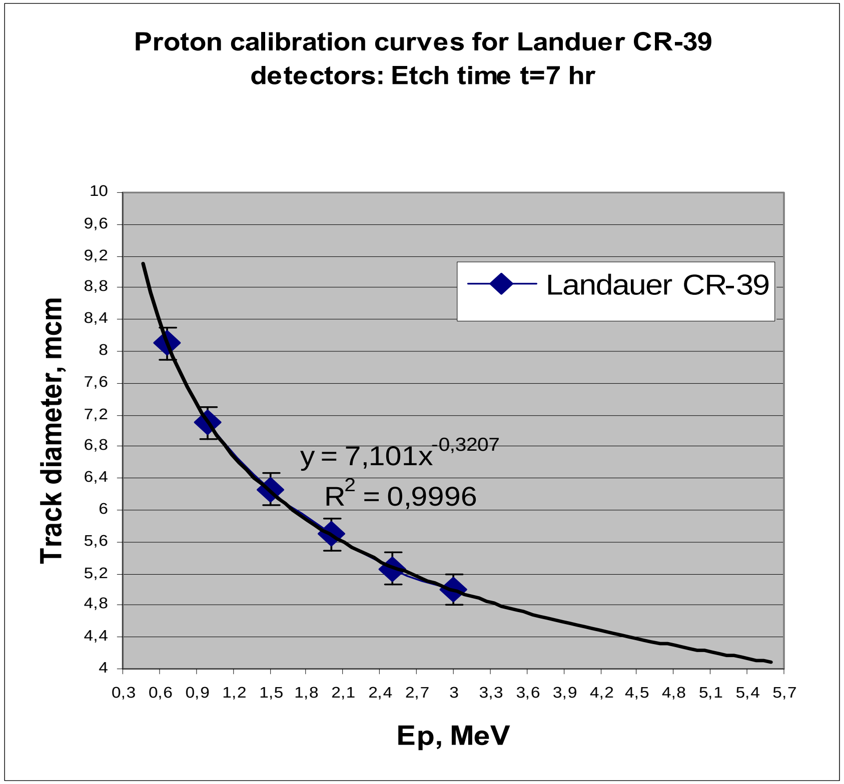

**After etching for 60 hr (53 µm etched away on both sides)**

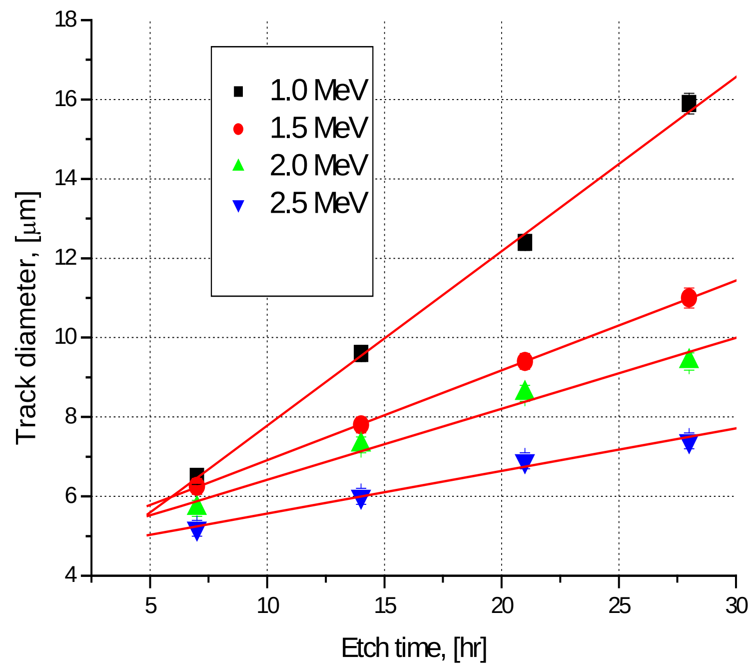



**Data are consistent with DD and DT fusion reactions:**

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)

# SSNTD Proton Calibration




**Proton calibration with Van DeGraaf accelerator (left) -etching conditions 6N-NaOH, t = 70°C, for 7 hr. Track diameter vs. etching time (removed CR-39 depth h = 9.2 – 46 µm) for protons for protons of normal incidence in the energy range of 1.0-2.5 MeV (Right)**

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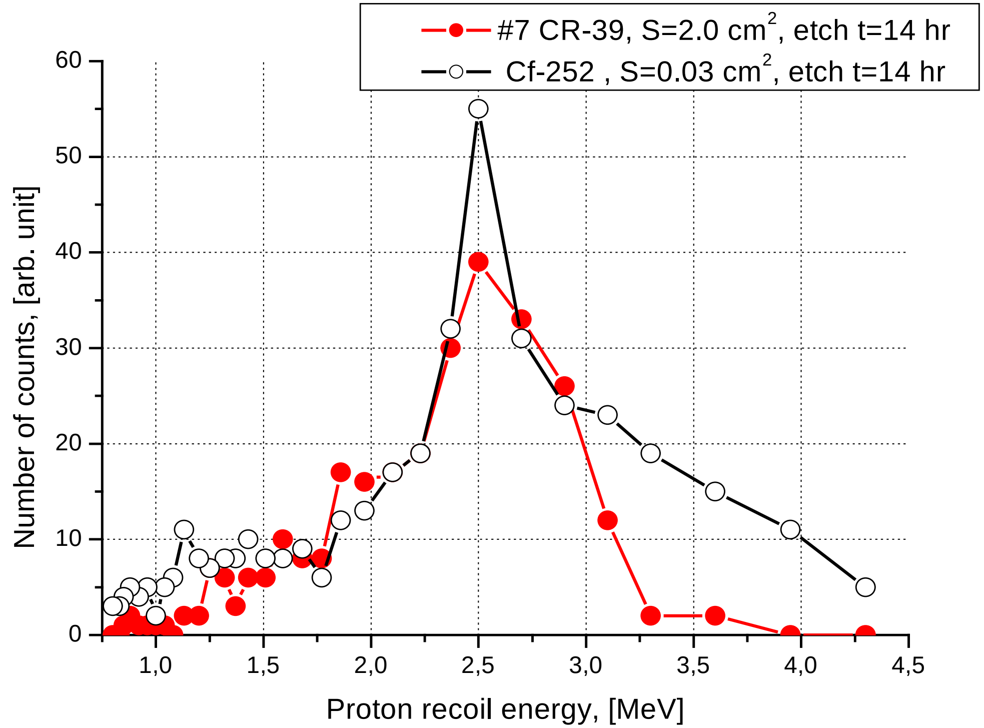
# Neutron Proton recoil spectra[1]




**Protons recoil spectra for CR-39 detectors obtained during electrolysis run (detector #7) and during exposure with Cf-252 neutron source. Etch time is t = 14 hr. The reconstruction of the spectra was deduced from the track density vs. track diameter histograms, taking into account two functions: (a) track diameter vs. proton energies at t = 14 hr and (b) the critical angle $\theta_c$ vs. proton energy**

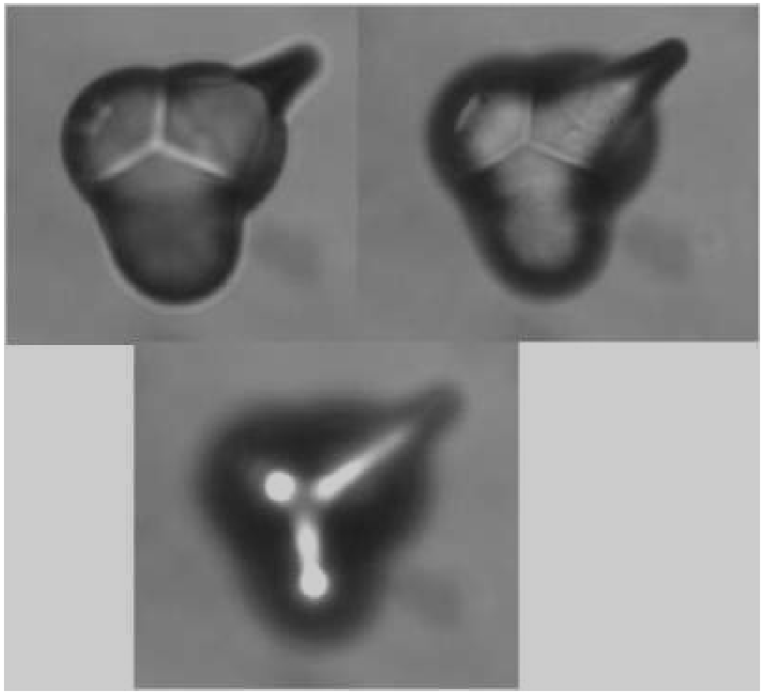
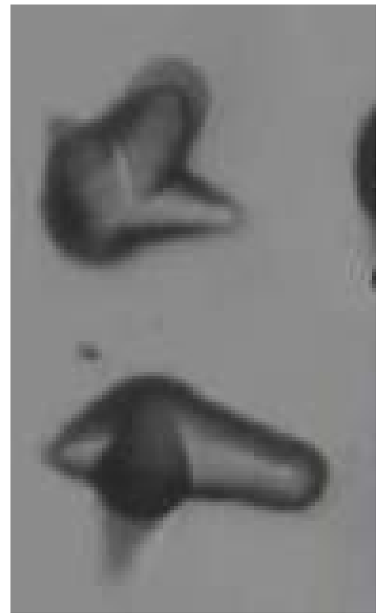
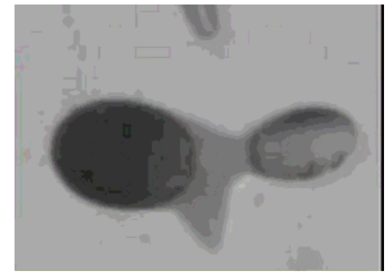
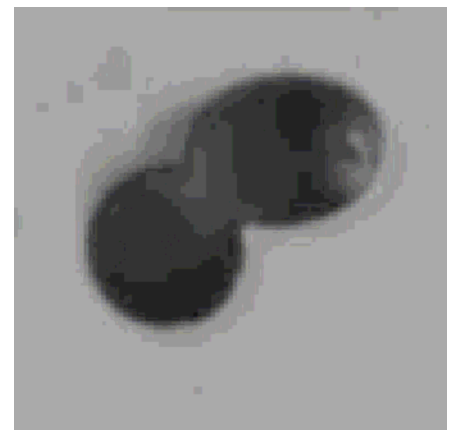
***Spectra indicates nearly monochromatic 2.5 MeV neutrons.***

*[1]Lipson, et al., Anomalous Metals, Catania, Italy (2007)*

**In cooperation with the US Navy SPAWAR-PACIFIC under CRADA**

# Triple Tracks: Evidence of Energetic Neutrons

Joe K. Pálfalvi, Yu. Akatov , J. Szabó, B. Dudás, L. Sajó-Bohus, and I. Eördögh, Ninth WRMISS workshop

- CR-39 contains $^{12}C$ as the main constituent (32% by weight).
- Carbon breaks up into three -particles through the reaction $^{12}C(n; n)3\ ^{4}He$.
- The residuals of the reaction can be viewed in the detector as a three-prong star.
- ≥ 9.6 MeV neutrons are needed to cause the $^{12}C(n,n')3\alpha$ carbon break up reaction.

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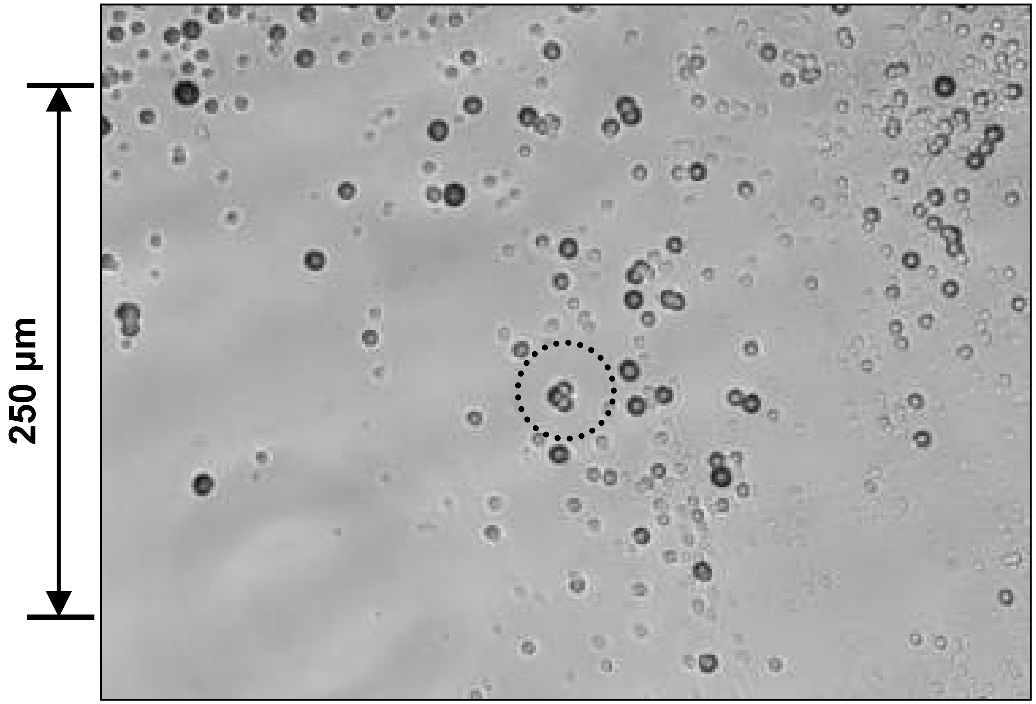
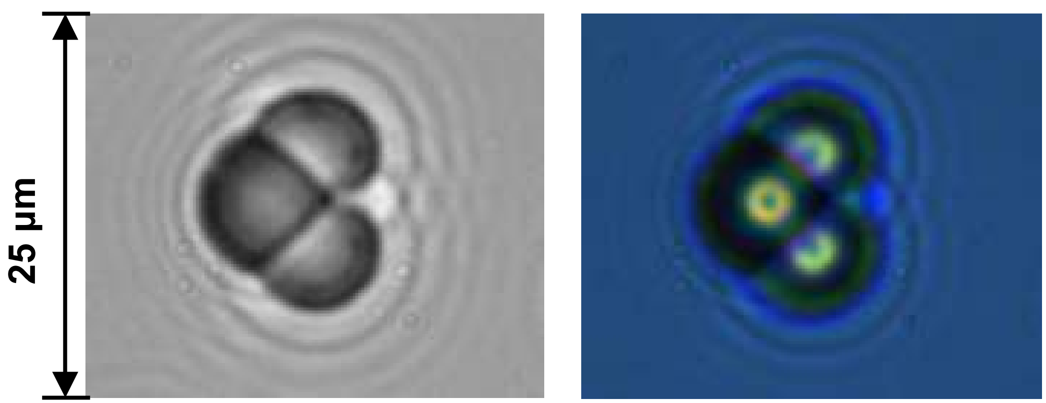
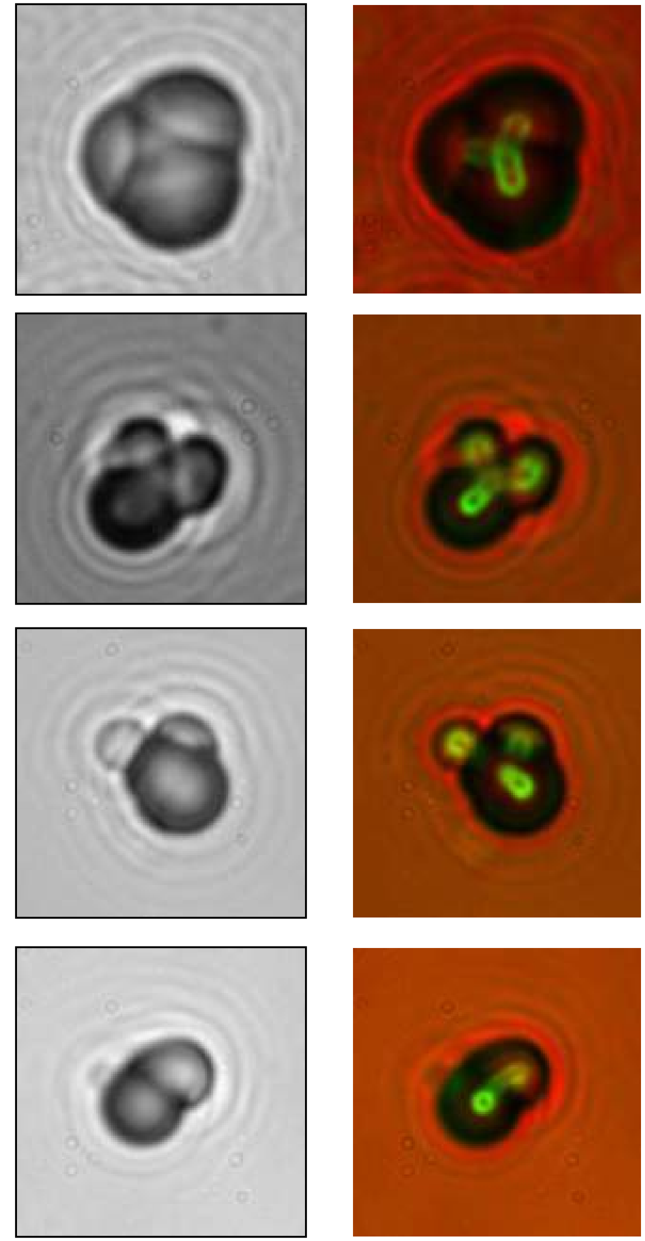
# Triple Tracks Observed in Pd/D Co-deposition

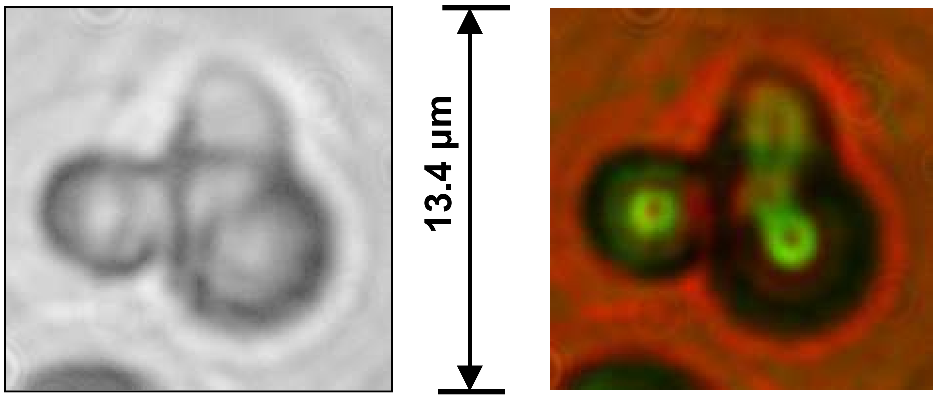
**Naturwissenschaften, Vol. 96, p. 135 (2009)**

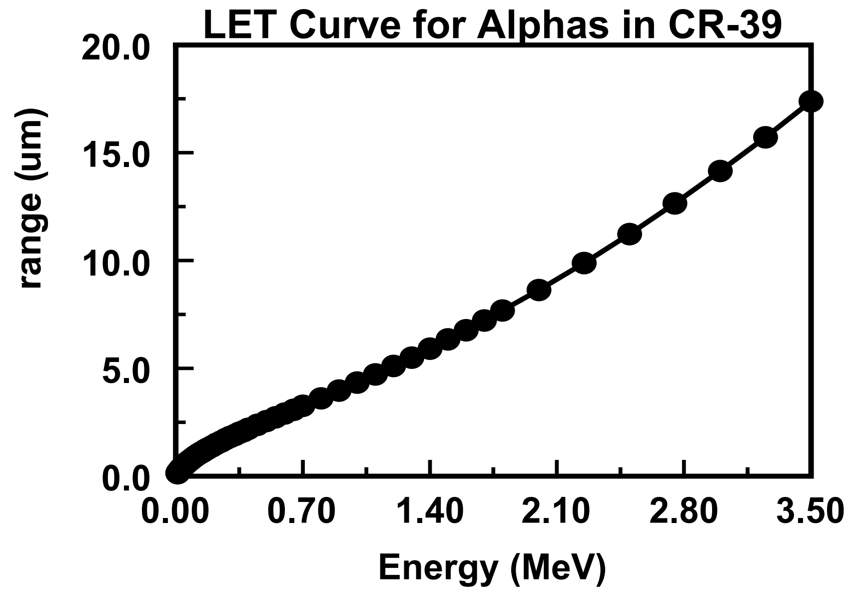


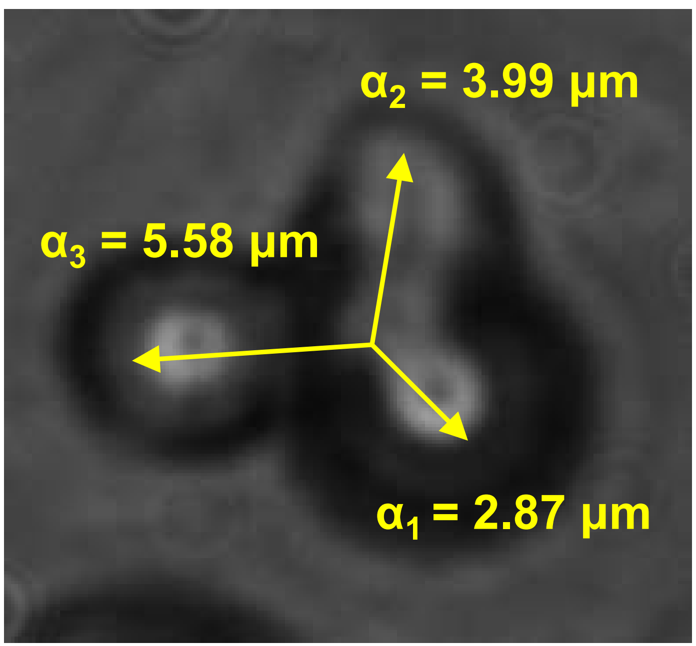



# Calculation of the Energy of the Neutron that Created the Triple Track



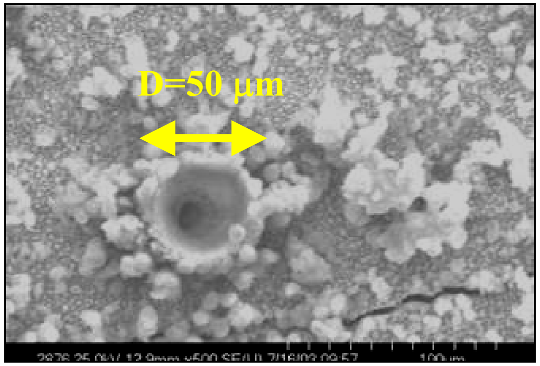



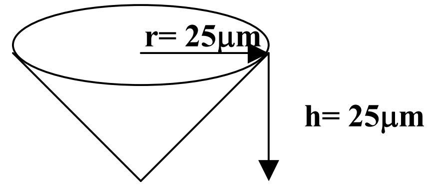

$$E_n = E_{th} + E_{\alpha 1} + E_{\alpha 2} + E_{\alpha 3}$$

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

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

# 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**
**$1.8 \times 10^{-9}$ gm/105.6 gm/mole = $1.6 \times 10^{-7}$ moles of Pd**

***Each ejecta vaporizes a Pd mass of $1.8 \times 10^{-9}$ gm or $1.6 \times 10^{-7}$ mol***

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

***It takes $5.8 \times 10^{-2}$ 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 $3.2 \times 10^{-12}$ J/reaction with 2/3, or $2 \times 10^{-12}$ J, in charged particles/reaction**

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

**Given $5.8 \times 10^{-2}$ J/ejecta /$2 \times 10^{-12}$ J/reaction = $3 \times 10^{10}$ reactions/ejecta**
***Then there are about $3 \times 10^{10}$ nuclear fusion reactions per ejecta site.***

**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**
**= $3.57 \times 10^{5}$ J/mol**

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

**1 MeV = $1.6 \times 10^{-13}$ Joules**

**In cooperation with the US Navy SPAWAR-PACIFIC under CRADA**

# Possible Nuclear Pathways

(1) $^{2}D_{1} + {}^{3}T_{1} \rightarrow {}^{4}He_{2}$ ( 3.5 MeV ) + $n_{0}$ ( 14.1 MeV )

(2i) $^{2}D_{1} + {}^{2}D_{1} \rightarrow {}^{3}T_{1}$ ( 1.01 MeV ) + $p^{+}$ ( 3.02 MeV ) 50%

(2ii) $\rightarrow {}^{3}He_{2}$ ( 0.82 MeV ) + $n_{0}$ ( 2.45 MeV ) 50%

(3) $^{2}D_{1} + {}^{3}He_{2} \rightarrow {}^{4}He_{2}$ ( 3.6 MeV ) + p+ ( 14.7 MeV )

(4) $^{2}D_{1} + {}^{2}D_{1} \rightarrow {}^{4}He_{2}$ + $\gamma$ (24 MeV ) $10^{-6}$

*$\gamma$ difficult to observe*

(5) $^{2}D_{1} + {}^{2}D_{1} \rightarrow {}^{4}He_{2}$ (24 MeV ) 100%

*only heat and He-4*

Reaction 5 is the Thermal Channel of "cold fusion". All energy is absorbed in the lattice in a Mössbauer-like lattice-recoil with a suppressed $\gamma$.

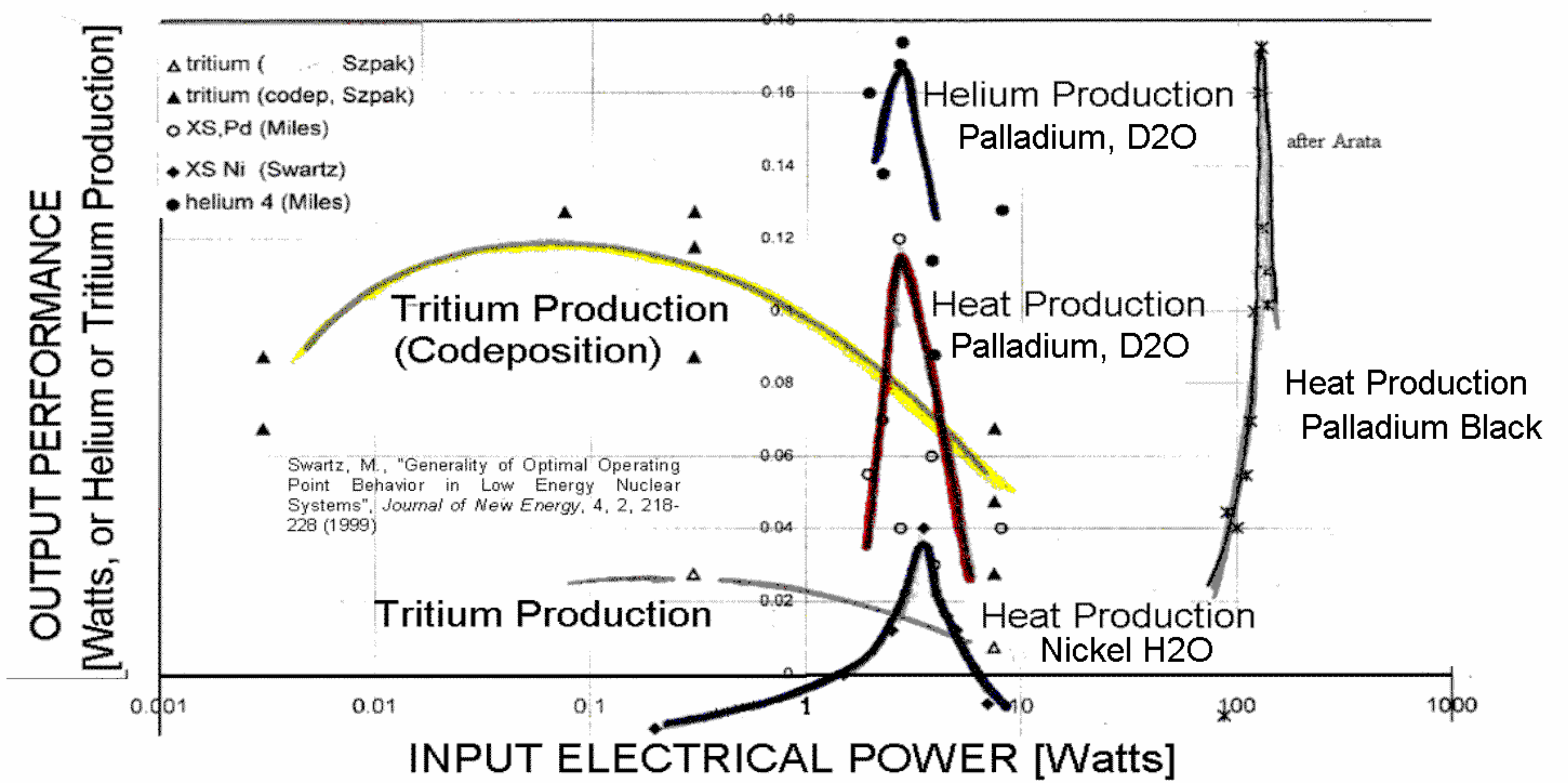
Tertiary nuclear reaction pathways are possible given energetic charged particles and neutrons. These include various capture and fission

reactions. They should leave measurable "nuclear ash".

# OOP Manifolds are Universal

JET Energy Inc.

**Optimal Operating Manifolds from several independent investigators.**
**The vertical axis represents the observed outputs, and is linear.**
**Curves (manifolds) connect the data points of each group.**



# OOP Manifolds are Universal



- OOP manifolds have been discovered to describe a large group of LANR systems.
- OOP Manifolds appear to show the way to relatively reproducible products (Excess heat, helium, tritium).
- OOP Manifolds have similar qualitative shapes along the input power axis, and reflect the apparent biphasic production curves for the products (e.g. heat and helium-4 for Pd loaded with D) as a function of input electrical power.

## Observed to characterize output:

for heavy water helium production, excess heat production from Pd/$D_2O$
for high impedance [Pd/$D_2O$/Pt, Pd/$D_2O$/Au] Phusor LANR devices
for Ni/$H_2O_xD_2O_{1-x}$/Pt and Ni/$H_2O_xD_2O_{1-x}$/Au] Phusor LANR devices
for codeposition systems and codeposition Phusor LANR devices
for classical "FPE" systems
for tritium generated from codeposition and "FPE" heavy water systems
for excess heat and helium production in palladium-black systems
for excess heat in light water nickel systems.

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# Pd/D Co-deposition Replications

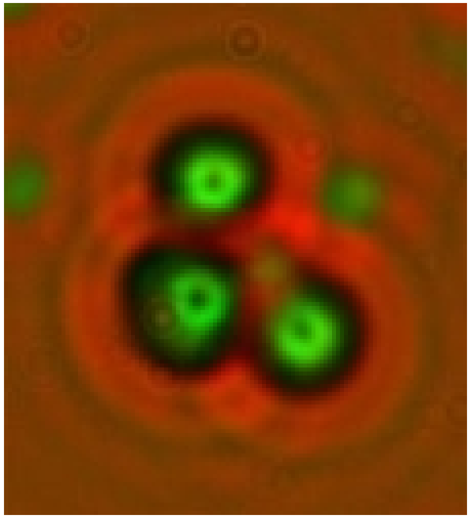
- Heat and Radiation
  - Dr. Melvin Miles, Navy Laboratory in China Lake
- Tritium
  - Dr. John Bockris, Texas A&M
- Energetic Particles
  - Dr. Fran Tanzella, SRI
  - Dr. Winthrop Williams, UC Berkeley
  - Dr. Ludwik Kowalski, Montclair State University
  - 2006, 2007, and 2008 Undergraduate Chemical Engineering Senior Project Groups at UCSD

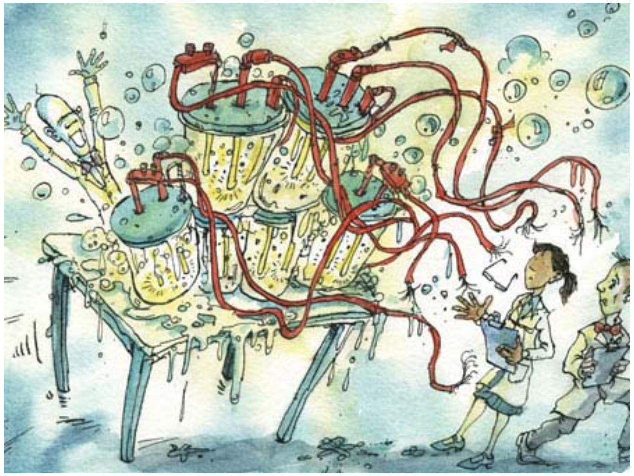
# Peer Reviewed Publications

- **21 peer reviewed Journal articles and 2 book chapters have been published or are going to print:**
  - **American Chemical Society Low Energy Nuclear Reactions Source Books Vol. 1 and Vol. 2**
  - **Journal of Electroanalytic Chemistry**
  - **Naturwissenschaften (Germany)**
    - ***Einstein published here.***
  - **European Physical Journal of Applied Physics**
    - ***Nobel Prize winners, 2007, for Chemistry and Physics published here.***
  - **Thermochimica Acta**
  - **Journal of Fusion Technology**
  - **Il Nuovo Cimento (Italy)**
  - **Physics Letters A**

# Recent Media Coverage following ACS Presentation

**Mar 22-24, 2009 in Salt Lake City**





**The Economist**

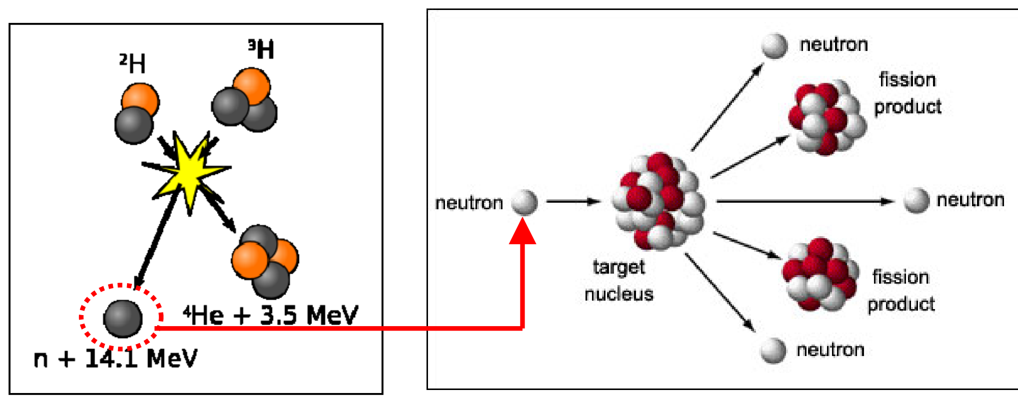
- KSL-TV, CH-5 (NBC, Salt Lake City)
- Top Yahoo News story for several days
- Listed on Drudge Report
- Houston Chronicle
- San Diego Union Tribune
- The Economist
- New Scientist online
- Fox News online
- *Over 100 worldwide news web sites*
- **Discovery Science Channel "BRINK"**

# Discovery Science Channel; "Brink"

**March 27, 2009**

# Remediation of Nuclear Waste

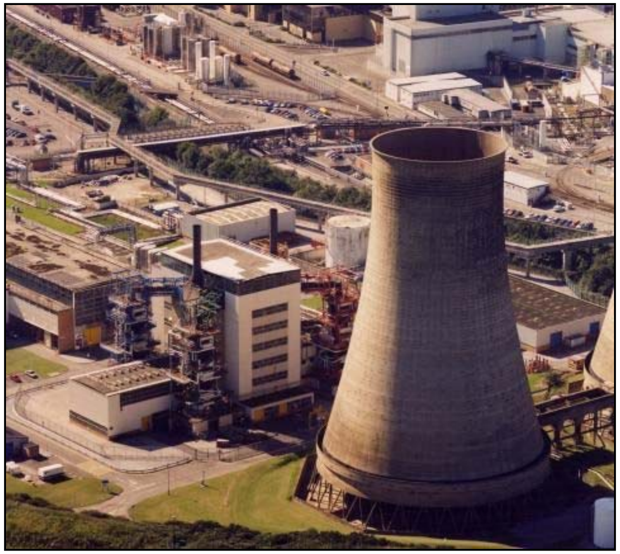
- As of 2007, the United States had accumulated more than 50,000 metric tons of spent nuclear fuel from nuclear reactors
  - It will take 10,000 years of radioactive decay before this spent nuclear fuel will no longer pose a threat to public health and safety
- Solution: a LENR-based hybrid fusion/fission reactor
  - LENR generated neutrons are used to fission $^{238}U$ and the actinides present in the nuclear waste
  - This eliminates the nuclear waste while providing much needed energy
  - No greenhouse gases produced




Fusion Fission

# A Green Power Source

- Eliminates the requirement to purchase foreign oil
- Eliminates energy as a source of conflict
- Provides power for desalinization plants to create fresh water
- Would result in a massive increase of jobs as the country retools to take advantage of the new energy source
- Designs of small power plants would reduce the vulnerability of the electrical grid

# Summary of Experimental Results

- **Evidence of Heat Generation:**
  - Calorimetry of electrodes prepared using Pd/D co-deposition indicates that enthalpy production is higher than that obtained using massive electrodes
  - IR imaging indicates that the heat source is the cathode and not joule heating. Heat generation is not continuous but occurs in discrete spots on the electrode.
  - Evidence of the occurrence of mini-explosions

- **Low Energy Radiation Emission:**
  - Cathodically polarized Pd/D system emits X-rays with a broad energy distribution (Bremsstrauhlung) with the occassional emergence of recognizable peaks (20 keV due to Pd $K_{\alpha}$ and 8-12 keV due to either Ni or Pt)
  - Emission of radiation is sporadic and of limited duration
  - Increase in radiation observed with the addition of $Be^{2+}$ and thiourea, additives known to increase the rate and degree of deuterium uptake

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# Summary of Experimental Results

- **Tritium Production:**
  - The evidence of tritium production is based on the difference between the computed and observed concentration of tritium.
  - Tritium generation is sporadic and burst-like.
  - During bursts, the rate of tritium production ranged between 3000-7000 atoms $sec^{-1}$.
- **Results of External E/B Fields:**
  - Changes in morphology of the Pd deposit are observed that are suggestive of solidification of molten metal
  - New elements are observed that are associated with these features

# Summary of Experimental Results

- **Results Using CR-39 Detector**
  - Particles are emitted in a Pd/D co-deposition reaction
  - Particles are not due to radioactive contamination or to chemical reactions
  - The backside of the CR-39 detector shows that neutrons are emitted during Pd/D co-deposition
    - Additional etching shows the presence of latent tracks due to knock-ons
    - Double and triple tracks are observed that suggest shattering of carbon atoms
  - The CR-39 detector results are consistent with the following fusion reactions:

## Primary DD fusion reactions:

$$D + D \rightarrow T\ (1.01\ MeV) + p\ (3.02\ MeV)$$

$$D + D \rightarrow n\ (2.45\ MeV) + {}^{3}He\ (0.82\ MeV)$$

## Secondary DT fusion reactions:

$$D + T\ (\leq 1.01\ MeV) \rightarrow \alpha\ (6.7\text{-}1.4\ MeV) + n\ (11.9\text{-}17.2\ MeV)$$

$$D + {}^{3}He\ (\leq 0.82\ MeV) \rightarrow \alpha\ (6.6\text{-}1.7\ MeV) + p\ (12.6\text{-}17.5\ MeV)$$

## March, 1989

## Today

- Pons and Fleischmann announce that electrochemical cells are producing more heat than can be accounted for by chemical means and speculated that nuclear reactions must be occurring.
- Physics community notes:
  - the experiments aren't repeatable
  - there aren't any refereed papers
  - the experiments haven't been replicated
  - If it's nuclear, where are the neutrons?"
  - It doesn't match theory
- Thousands of scientists worldwide attempted experiments—most failed


- Current Status:
  - the experiments are repeatable
  - there are many refereed papers
  - multiple experimental replications have been performed
  - multiple nuclear products, including neutrons have been detected
  - Work to update theory underway
- Groups of scientists worldwide have successfully performed experiments

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# Conclusions

- Nuclear events including production of high energy neutrons can be triggered by electrochemical means
  - Potential applications include:
    - Power source
    - Nuclear waste remediation
    - New safe hybrid nuclear reactor designs that don't produce nuclear waste or greenhouse gasses
    - Production of radioactive isotopes for medical and industrial applications
- More research is needed to understand the phenomena
- New theories are evolving based on experimental results

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# Next Steps

- Conduct experiments to optimize and increase the neutron flux over long periods of time
  - Increasing the neutron flux over long periods of time will make this practical for hazardous waste remediation and energy production
- Continue basic research into the underlying physics
  - Explore mechanisms that control reaction paths

# A Debt Owed

- Many thanks to Martin Fleischmann and Stanley Pons, who, twenty years ago, had the audacity to openly challenge all that is “known” about nuclear physics.
- As Martin noted in October, 2007, he and Stan Pons used one of many methods (electrolytic bulk palladium loading) and observed but one of many products (heat). They thought co-deposition would be too hard to do…
- Stan Szpak invented co-deposition because he didn’t have the patience to wait for palladium to load…nor did anyone else!
- To all who have continued to investigate this field of research.
- To the SPAWAR management who allowed us to work and publish in this controversial field.
- Robert Duncan for reviewing the data for himself and reporting what he found.

# Martin Fleischmann, May 12, 2009

In cooperation with the US Navy SPAWAR-PACIFIC under CRADA

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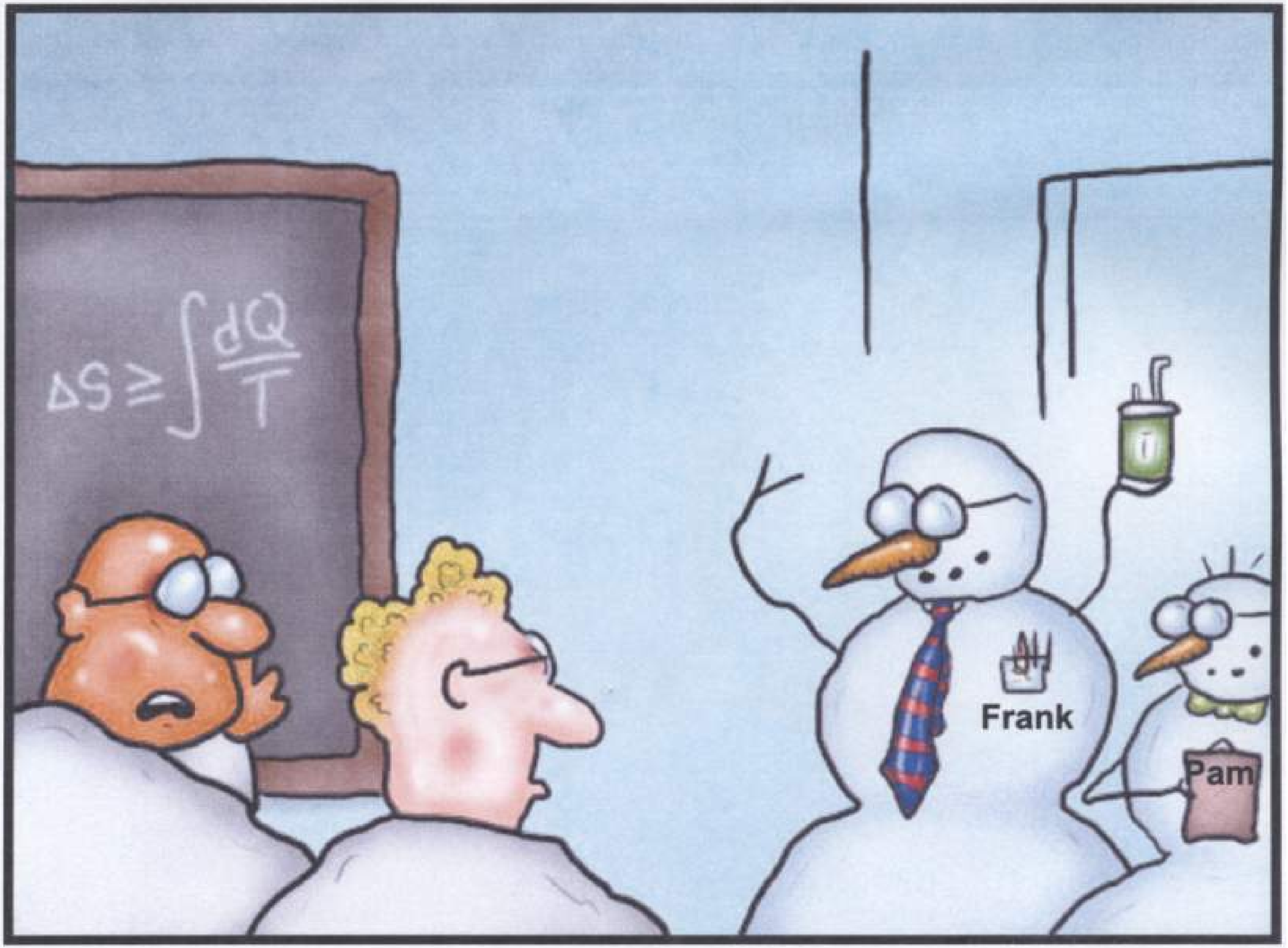


"It's those cold fusion guys again."