LENR Products: Lattice Confinement Fusion (LCF), Fission, or Both?

National Aeronautics and Space Administration

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Outline of Talk

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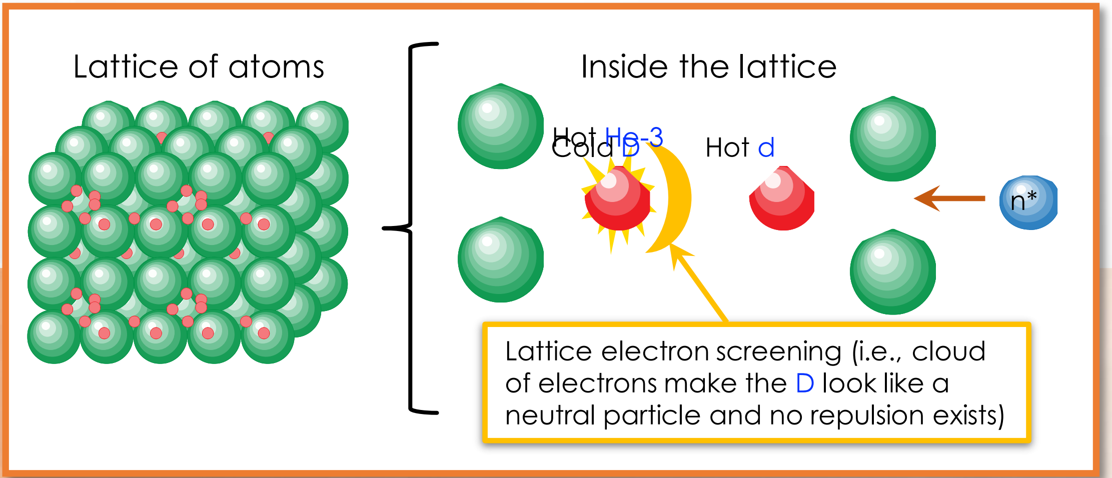
- Overview of LENR Products and Lattice Confinement Fusion (LCF)
- Gas Cycling Experiments
  - Observed anomalous behavior when cycling deuterium with Pd/Ag tube
  - Suspected Pd fission from high energy neutrons from LCF
- Bremsstrahlung Irradiation Experiments
  - Neutron spectroscopy showed evidence of dd fusion and higher energy neutrons
  - Gamma spectroscopy showed evidence of uranium fission products
- Electrolytic Wet Cell Experiments
  - Evidence of dd fusion and higher energy neutrons
  - Observed transmutation products on outer co-deposition layer
- Transmutation Theories
  - Electron Screened Fusion
  - Possible Fission Pairs
  - Hybrid Fusion Fission
- Summary

Overview of LENR Products and Lattice Confinement Fusion

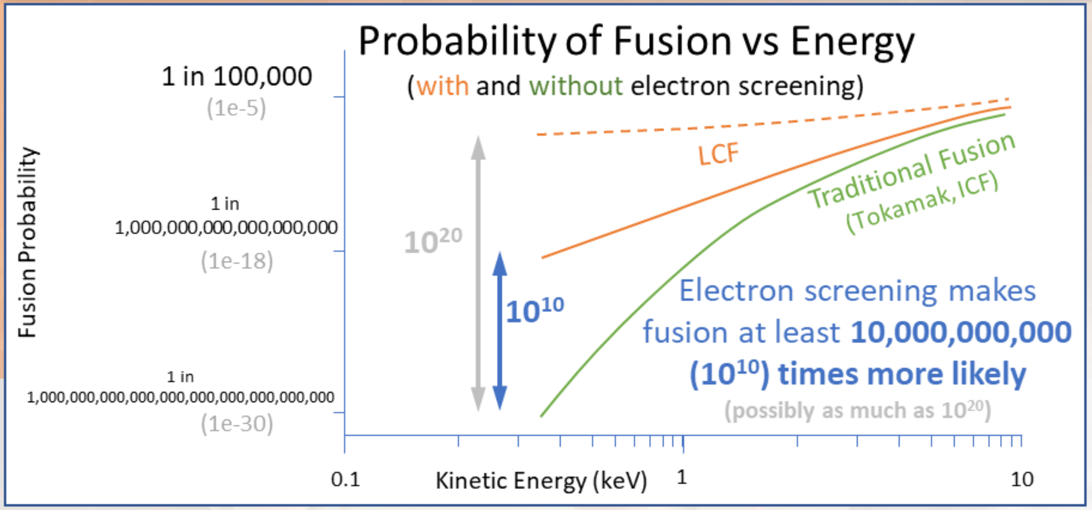
Fusion Reaction	MeV	Occurrence	Useful particle energy (MeV)
$D(d,n)^3He$	4.00	primary ≈ 50%	n=2.45
$D(d,p)T$	3.25	primary ≈ 50%	p=3.00
$D(^3He,p)\alpha$	18.30	secondary	p=15.00
$D(t,n)\alpha$	17.60	secondary	n=14.10
$T(t,\alpha)2n$	11.30	low probability	n=1 to 9
$^3He(^3He,\alpha)2p$	12.86	low probability	p=1 to 10



Part A: **Electron Screening**
(increases fusion probability)

Part B: **High Fuel Density**
(billion times more dense than traditional fusion)

A + B + Trigger = Viable Fusion



https://www1.grc.nasa.gov/space/science/lattice-confinement-fusion/

Gas Cycling Experiments: Description

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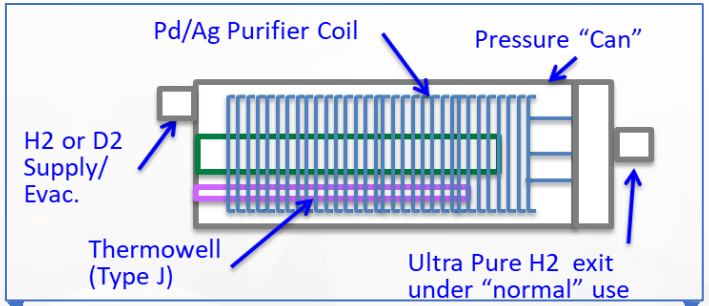
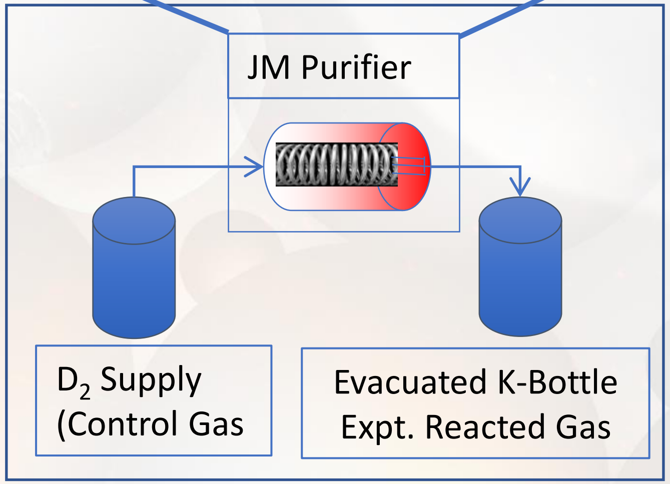
High flux of D through Pd/Ag hydride system:

- Test Article: Johnson-Matthey (JM) hydrogen purifier
- Inspired by electrolytic wet cell experiments and LENR claims, Gustave Fralick (1989) used JM purifier to load Pd with D_2
  - Easier than loading D_2 during a wet cell experiment
  - Very little neutrons above background observed
  - Observed temp rise of 17 °C in 15 sec unloading D_2 but not with H_2
- Experiments in 2014 & 2018: pressurized cycling of D_2 gas produces heat & surface transmutations on PdAg tubing; evidence of LENR[1,2]





Repeat of temperature rise during D_2 gas unloading

- 1989: 17°C temp rise in 15 s
- 2009: 5°C temp rise
- 2012: 25 °C temp rise
- 2014: 25°C temp rise in 4 s
- 2018: 12 °C temp rise in 45 s

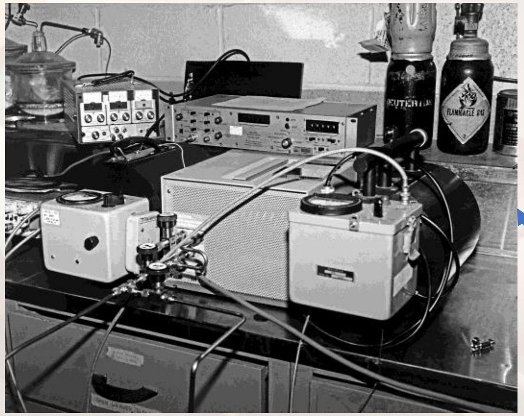


Photo of 1989 experimental setup showing the JM Purifier (center) with 2 SNOOPY neutron detectors (one on either side of the purifier).

[1]G. Fralick, et al, "Transmutations observed from pressure cycling palladium silver metals with deuterium gas", International Journal of Hydrogen Energy, vol. 45, no. 56, pp. 32320-32330, 2020.

[2]B. Liu, et al, "Nuclear transmutation on a thin Pd film in a gas-loading D/Pd system," J. of Condensed Matter Nuclear Science, 13, pp. 311–318, 2014.

Gas Cycling Experiments: Bulk Analysis

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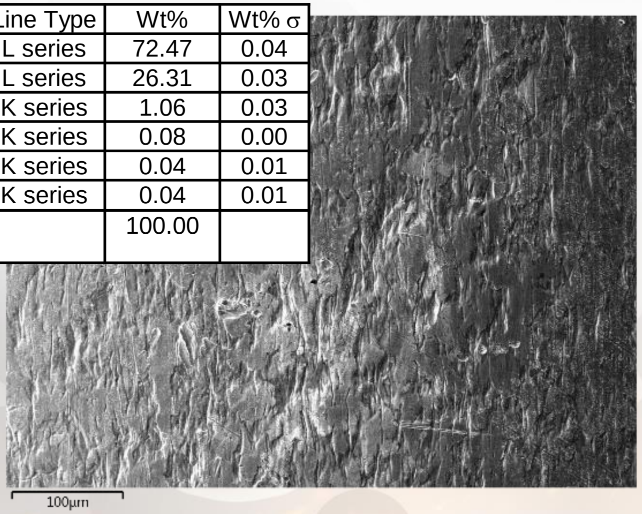
- Inductively Coupled Plasma Atomic Emission Spectroscopy
  - Elemental bulk analysis of PdAg tubing
  - Elevated levels of Cr, Cu, Fe, Mn and Zn detected in exposed PdAg tubing

Element	**Pd25Ag Bulk Results**			**Units**
	Control/Unexposed	Exposed	Δ	
Ag	25.0	24.9	–0.1	wt%
Pd	75.0	75.1	+0.1	wt%
Al	30	30	0	ppm
Cr	**Not detected**	**2**	**+2**	**ppm**
Cu	**20**	**140**	**+120**	**ppm**
Fe	**20**	**40**	**+20**	**ppm**
Mg	1	1	0	ppm
Mn	**Not detected**	**0.5**	**+0.5**	**ppm**
Na	2	2	0	ppm
Pt	105	105	0	ppm
Si	40	30	–10	ppm
Zn	**Not detected**	**285**	**+285**	**ppm**

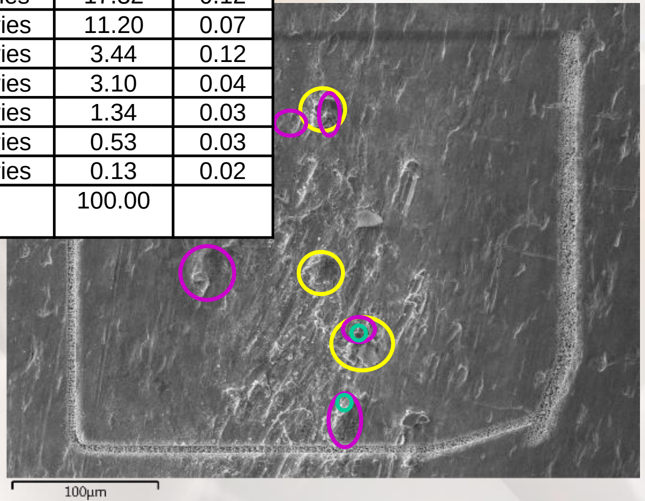
Gas Cycling Experiments: Surface Analysis Comparison

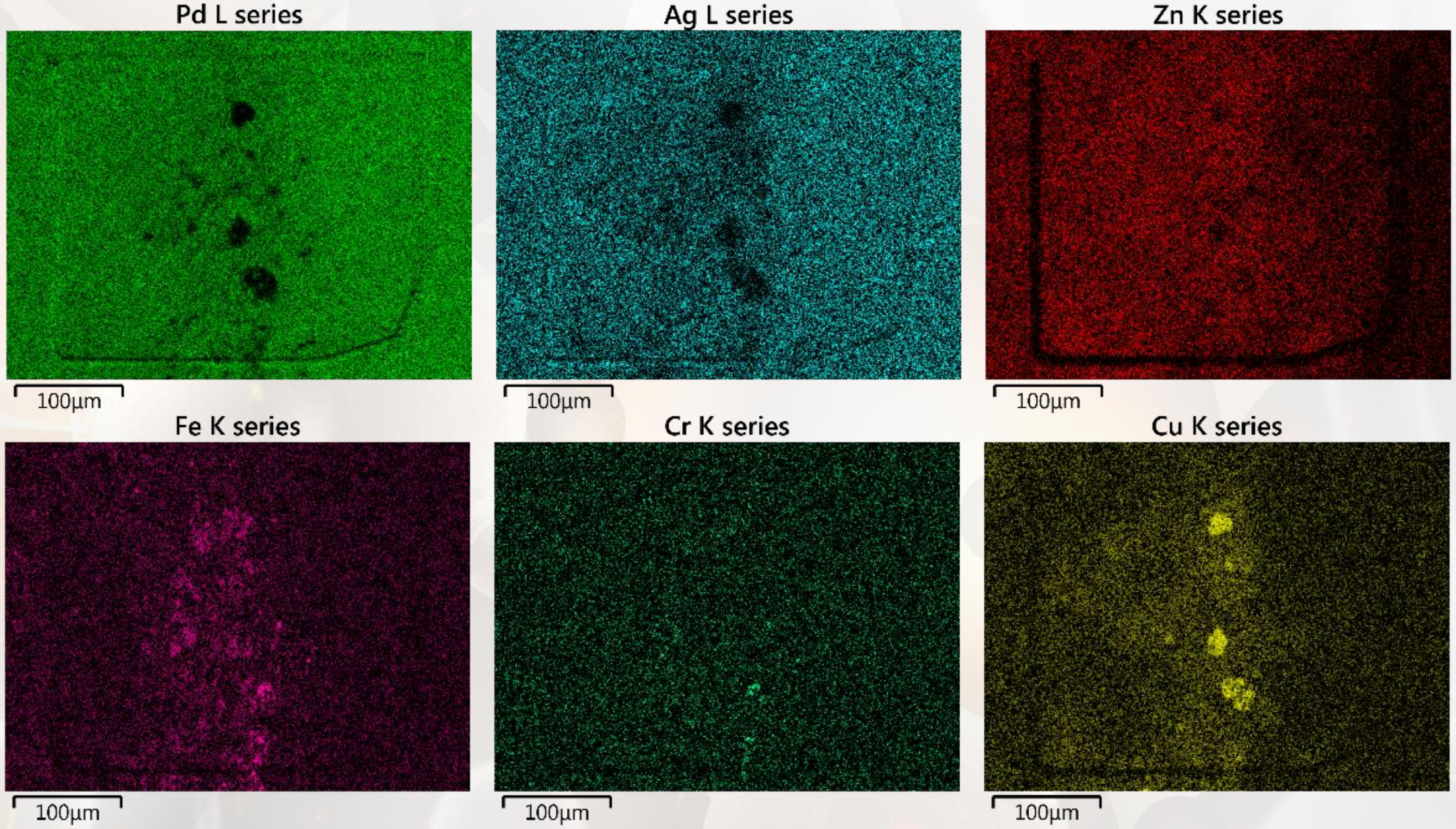
- Unexposed PdAg tube: mostly Pd, Ag with trace of Fe, Si, & Al.
- Exposed PdAg tube: Fe, Cr & Cu spots with overall spread of Zn
- Created a 'trench' with Ga ions to identify area for ToF-SIMS analysis

Element	Line Type	Wt%	Wt% σ
Pd	L series	72.47	0.04
Ag	L series	26.31	0.03
O	K series	1.06	0.03
Si	K series	0.08	0.00
Fe	K series	0.04	0.01
Al	K series	0.04	0.01
Total:		100.00	

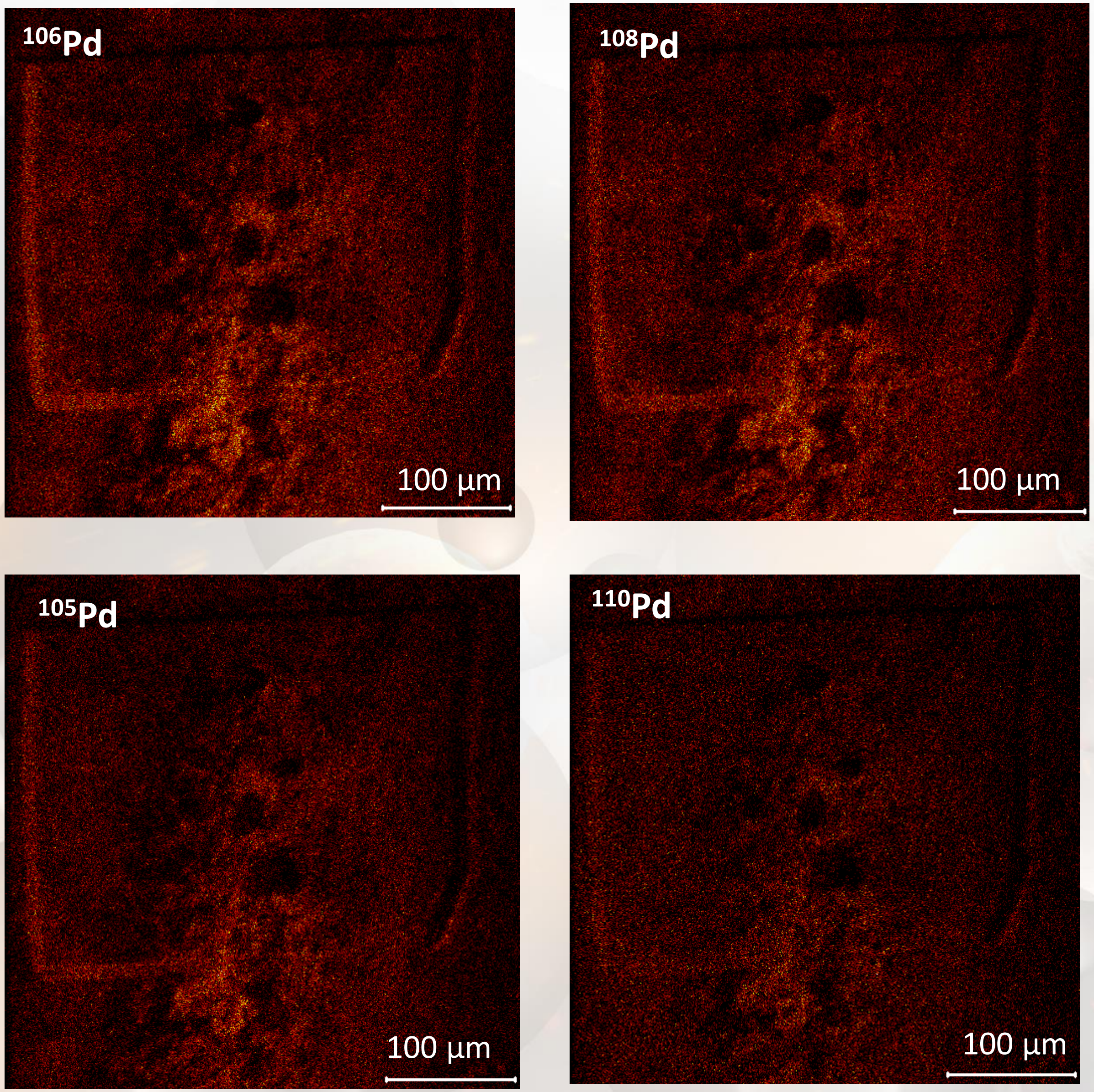


Element	Line Type	Wt%	Wt% σ
Pd	L series	62.95	0.14
Ag	L series	17.32	0.12
Zn	K series	11.20	0.07
O	K series	3.44	0.12
Cu	K series	3.10	0.04
Fe	K series	1.34	0.03
Ni	K series	0.53	0.03
Cr	K series	0.13	0.02
Total:		100.00	

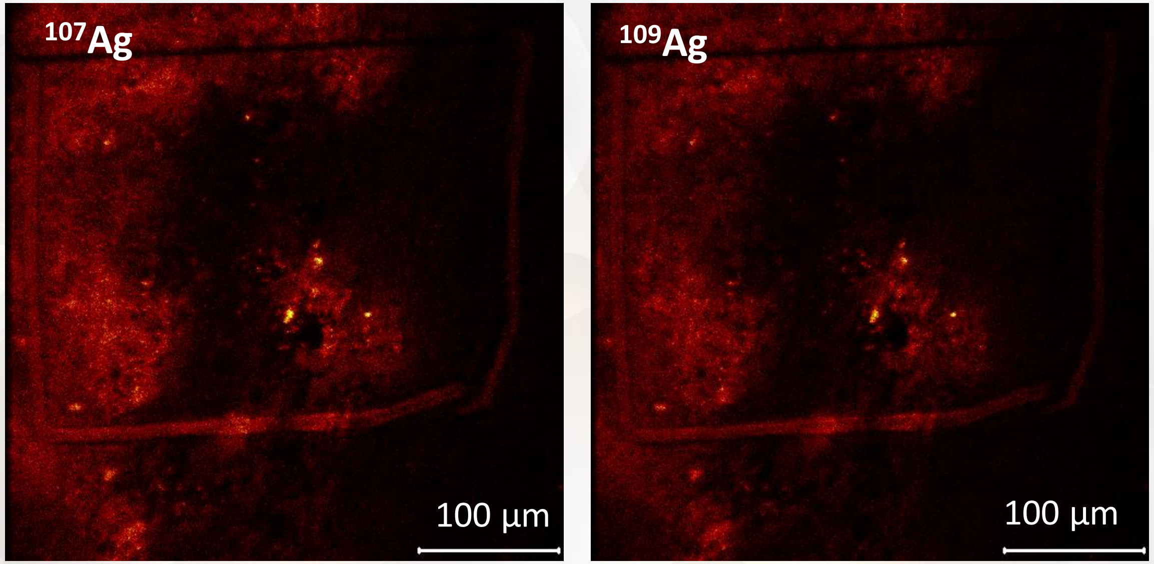




ToF SIM Spectroscopy: Isotopic Surface Analysis



Isotopic distribution of Pd and Ag



Note: TOF-SIMS is qualitative though very sensitive.

ToF SIM Spectroscopy: Isotopic Surface Analysis

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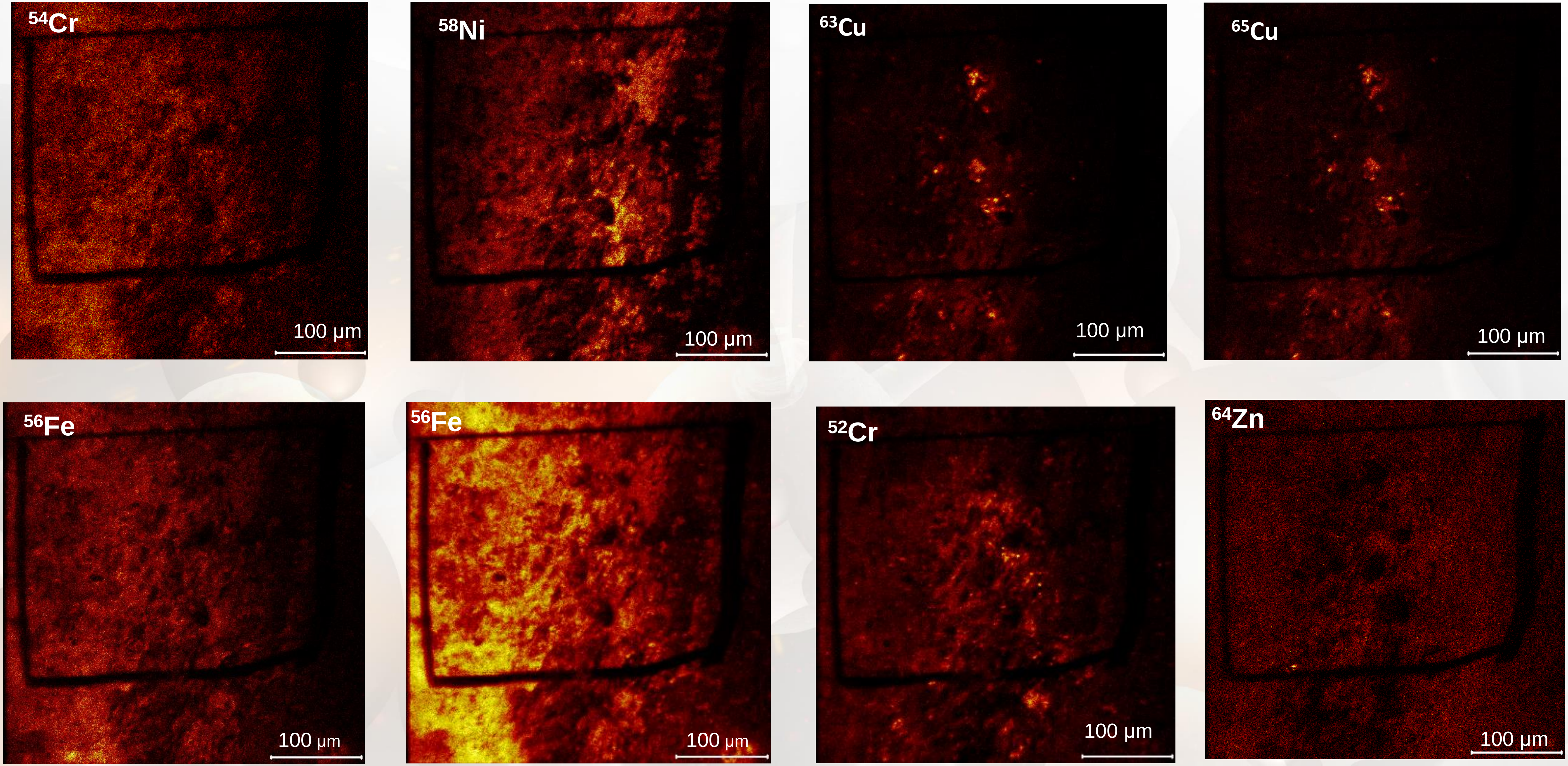

Bremsstrahlung Irradiation Experiments: Description

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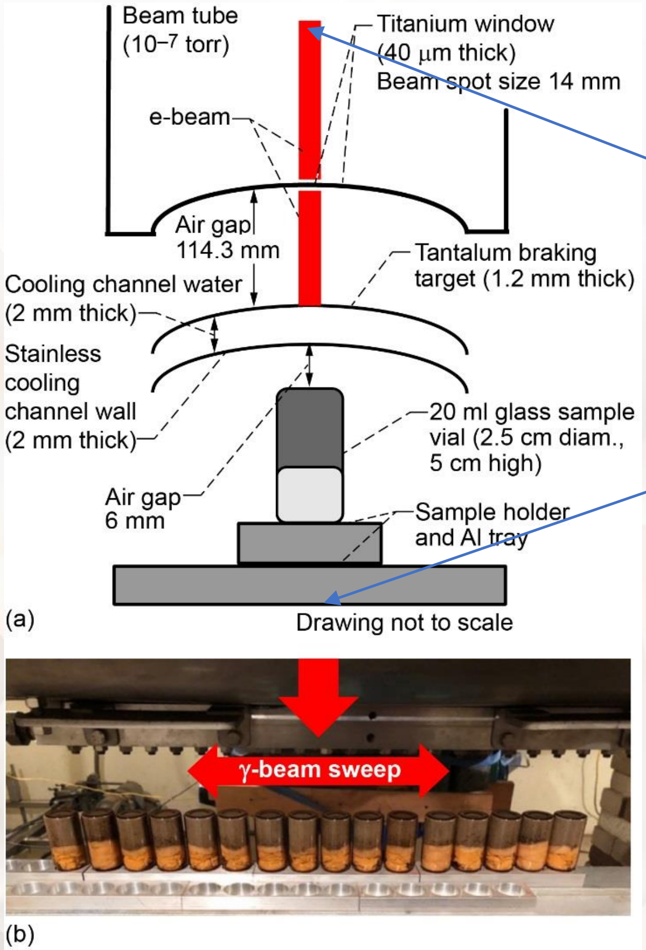
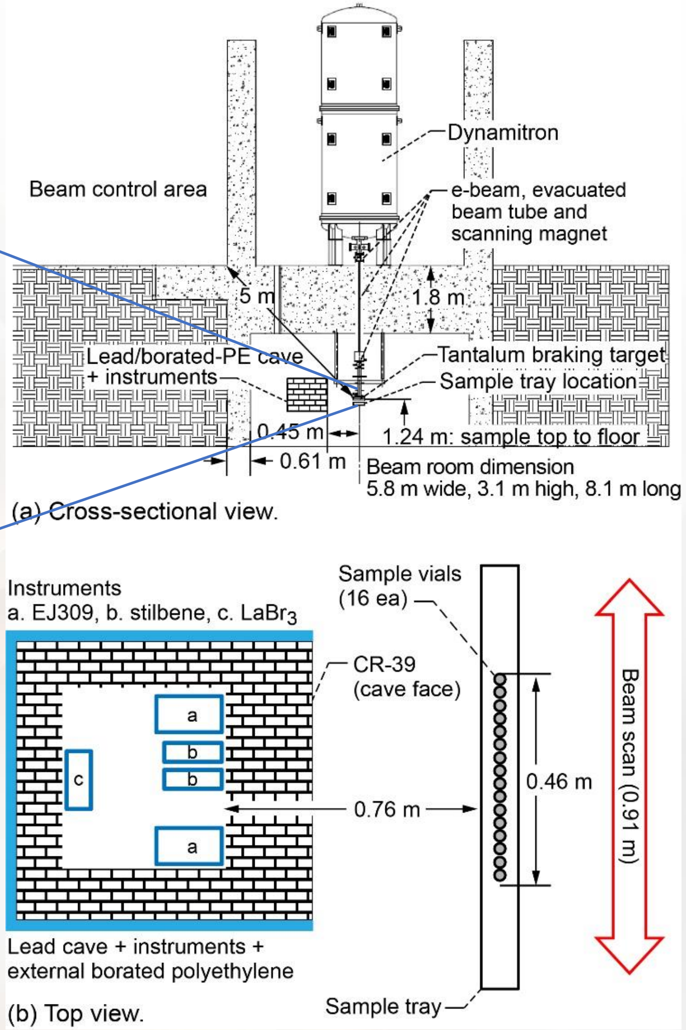
Objective

- Investigate volumetric screening of deuterated targets exposed to gamma-ray photons at sub-threshold (<2.226 MV D-photo-dissociation) and higher energies up to 3 MV.





Steinetz et al, 2020, *Phys Rev C* **101**, 044610

Bremsstrahlung Irradiation Experiments: Neutron Spectroscopy

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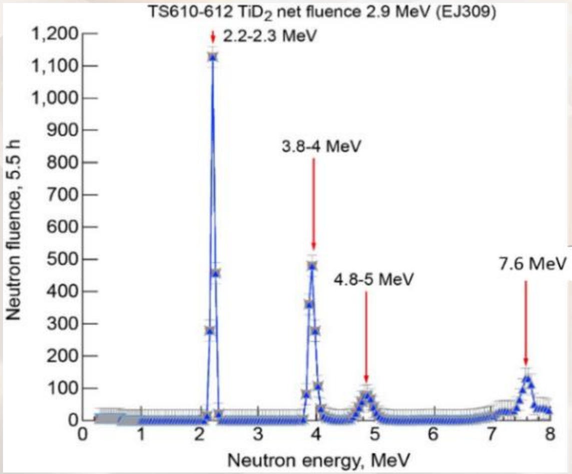
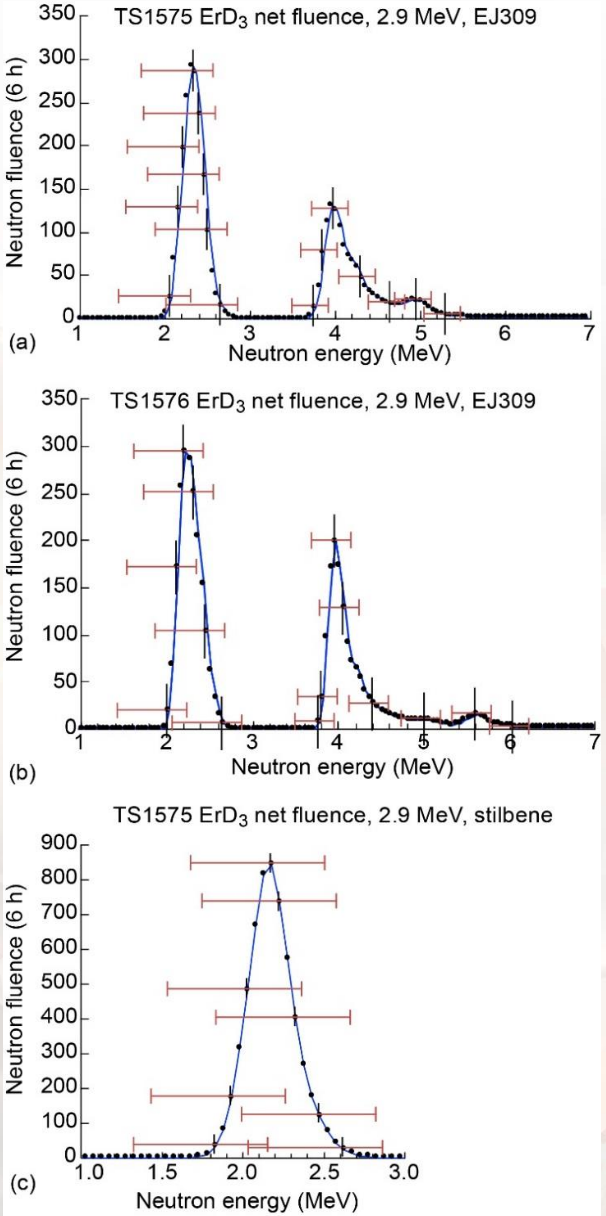
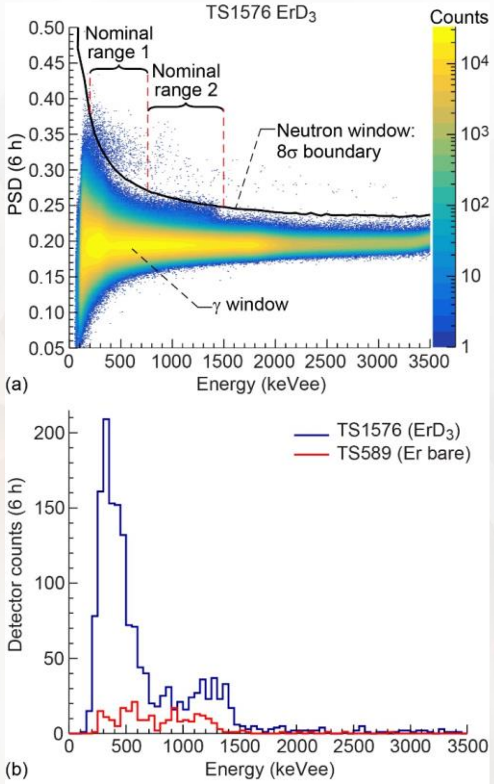
Findings

- Exposure of TiD_2 and ErD_3 to a 2.9MV beam resulted in dd fusion and higher energy neutrons
    - Energetic neutrons transfer KE to stationary deuterons; energize deuterons and with electron screening, fuse with stationary deuterons in metal lattice (dd fusion)
    - Subsequent fusion reactions take place due to boosted or Oppenheimer-Phillips neutrons as evidenced by neutron spectroscopy data







Steinetz et al, 2020, *Phys Rev C* **101**, 044610

Bremsstrahlung Irradiation Experiments: Gamma Spectroscopy

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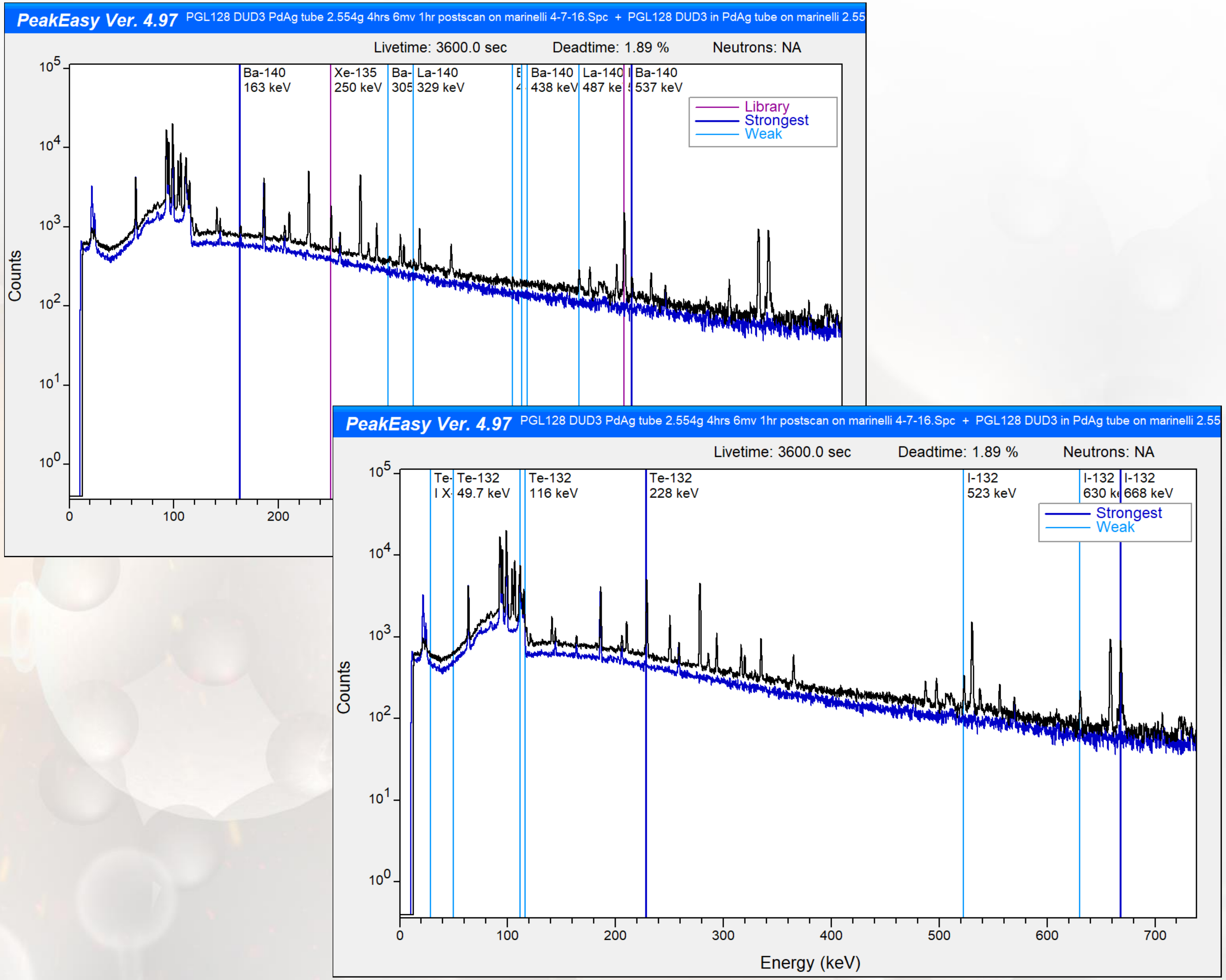
Findings

- Exposure of DUD_3 to 6MV beam resulted in fission products
  - Energetic neutrons from dd fusion reactions and subsequent reactions create boosted or Oppenheimer-Phillips neutrons
  - Those higher energy neutrons then fission the irradiated DU as evidenced by gamma spectroscopy
  - Fission products include:
    - ^{140}Ba , ^{140}La
    - ^{135}I , ^{134}I, ^{133}I , ^{132}I, ^{132}Te
    - ^{135}Xe, ^{135m}Xe
    - ^{92}Sr, ^{91}Sr, ^{92}Y, ^{91m}Y
    - ^{87}Kr



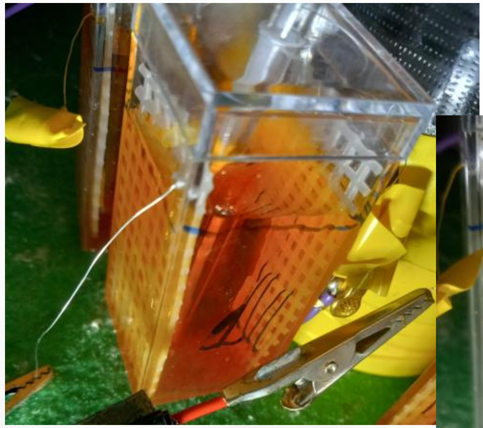
Electrolytic Wet Cell Experiments: Description

Objective

- Evaluate bubble detectors as real-time dosimeters monitoring the co-deposition process[3], install neutron spectroscopy to evaluate the neutron product energies, and determine if there are neutron emissions above background levels

Findings

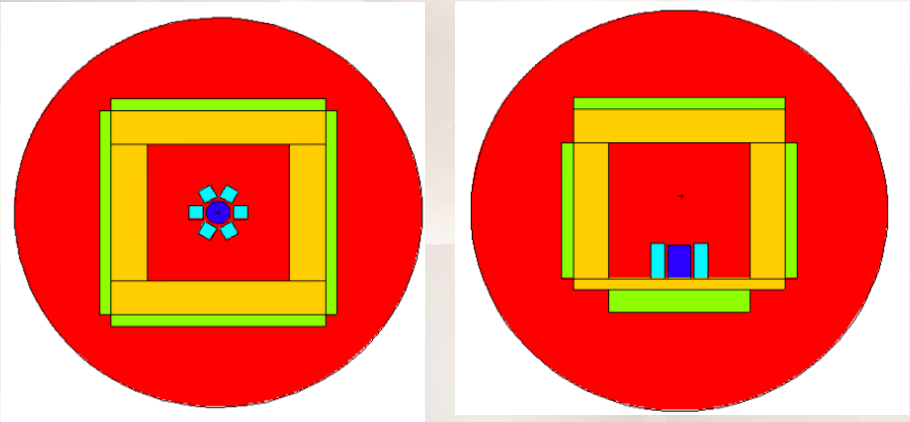
- Exposure to low electric currents (< 500mA) resulted in dd fusion (2.45 MeV) and higher energy neutrons



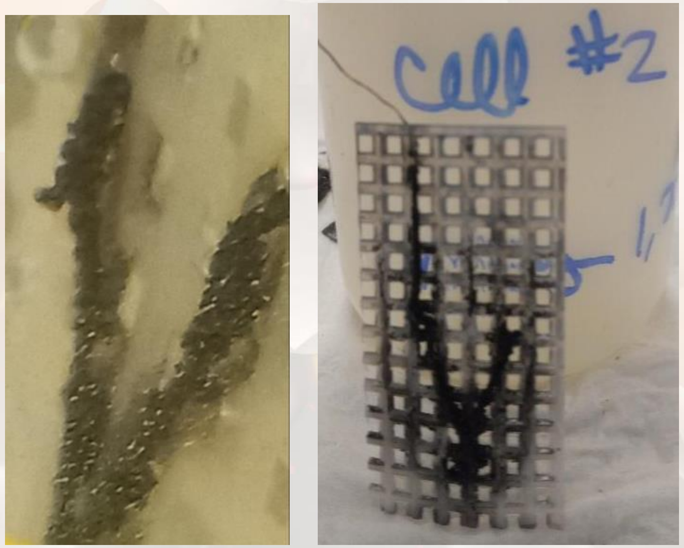
Aug 7 - five days after start

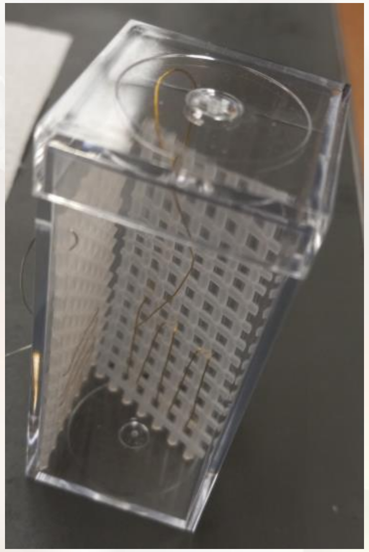
Aug 14

MCNP Model of Experiment

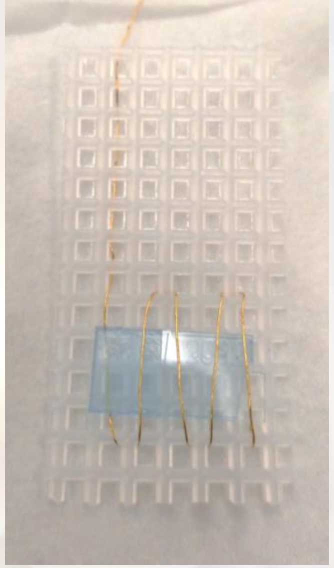


Resulting co-dep layers from previous experiments





Cell Prep



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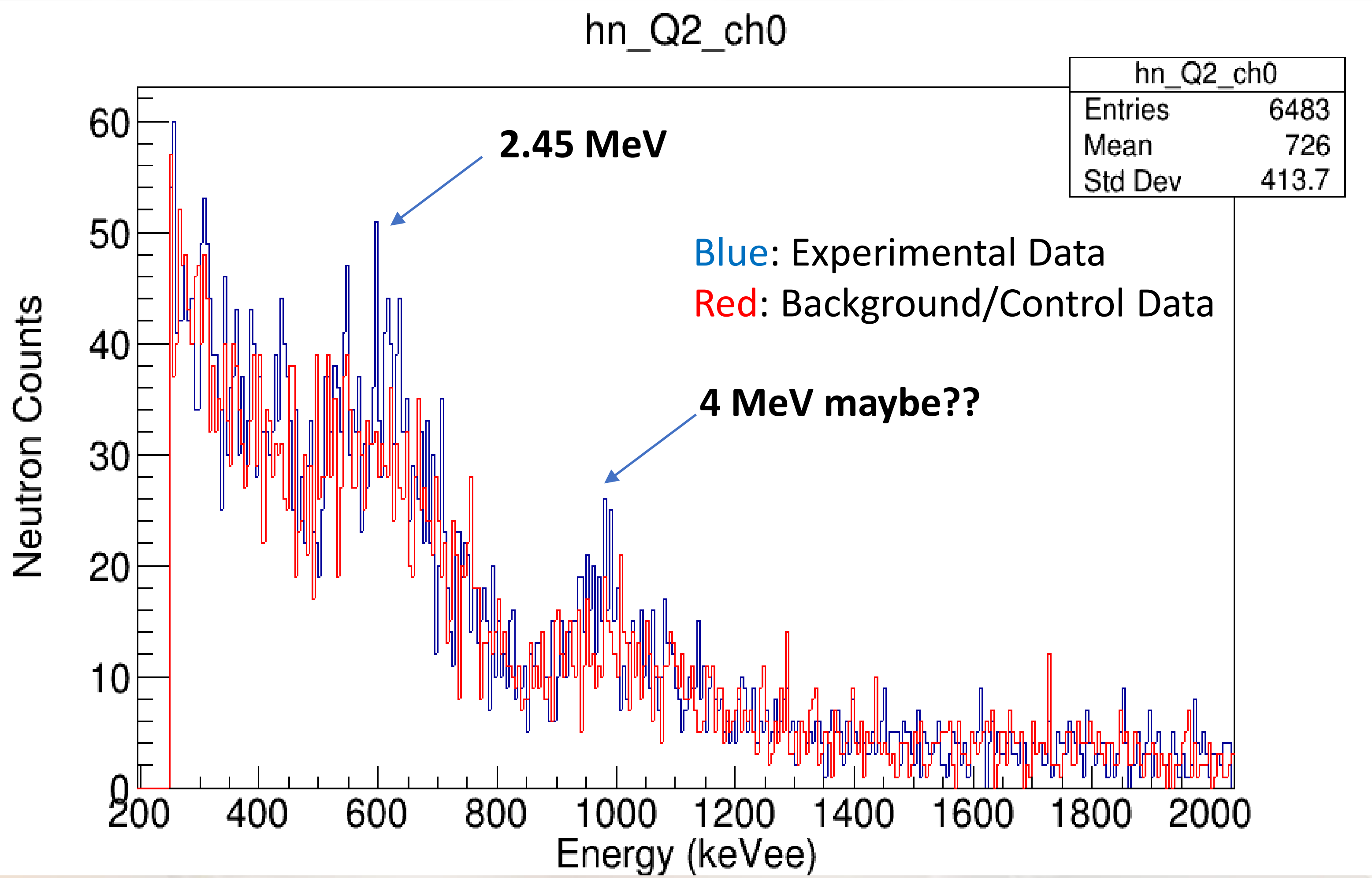
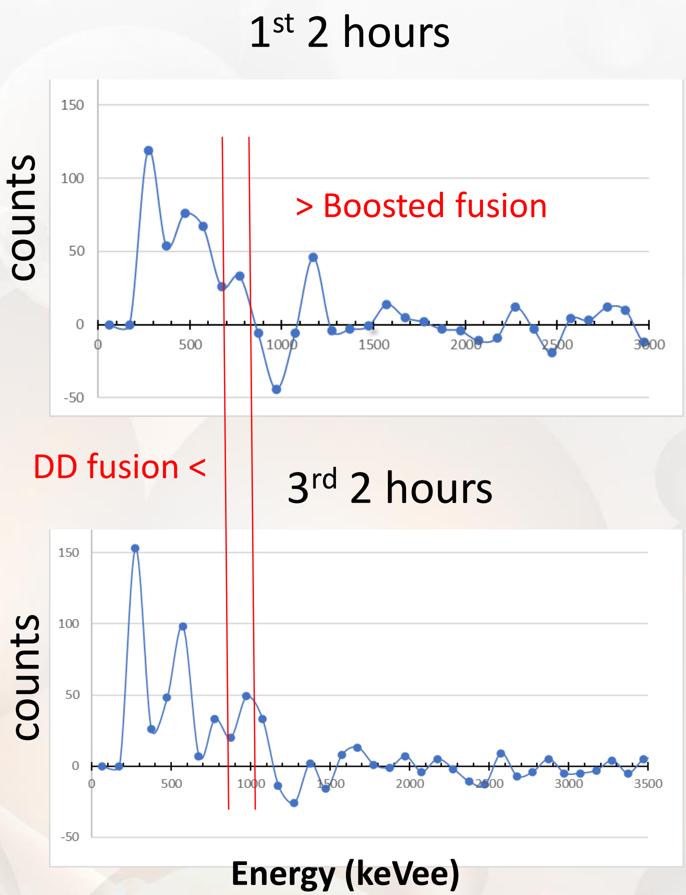
[3] P. J. Smith et al, "Electrolytic co-deposition neutron production measured by bubble detectors", J. Electroanal. Chem. 882 (2021) 115024.

Electrolytic Experiments: Neutron Detection



Fusion Scaling:
Periodically Rebuild
the Nuclear Active Environment



Fusion neutrons emphasized in 1st 2 hours

Electrolytic Experiments: SEM Analysis

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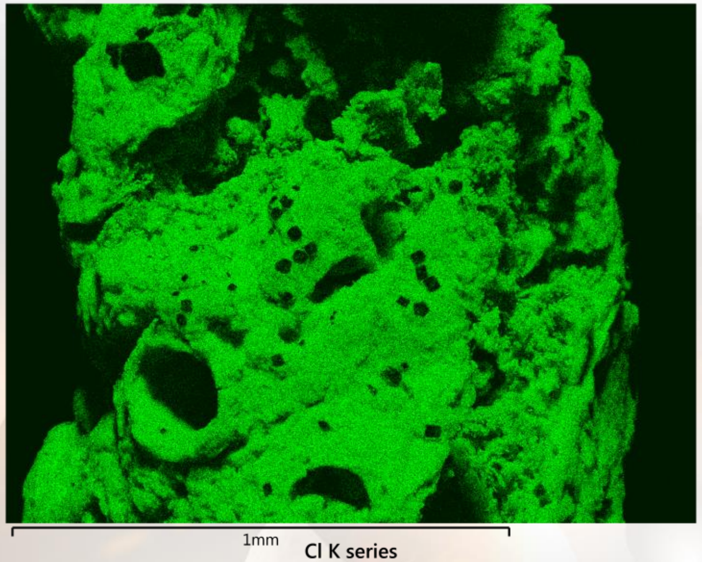
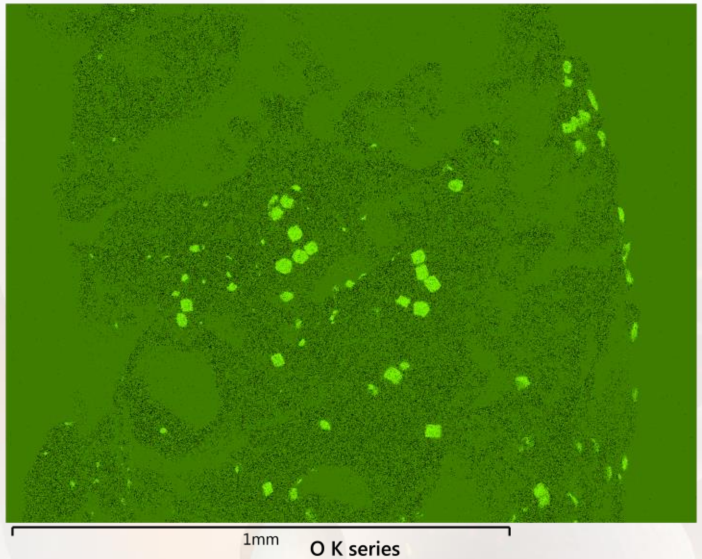
- SEM/EDS of Cathode
  - Interesting Calcium Peroxide spots on surface of co-dep layer

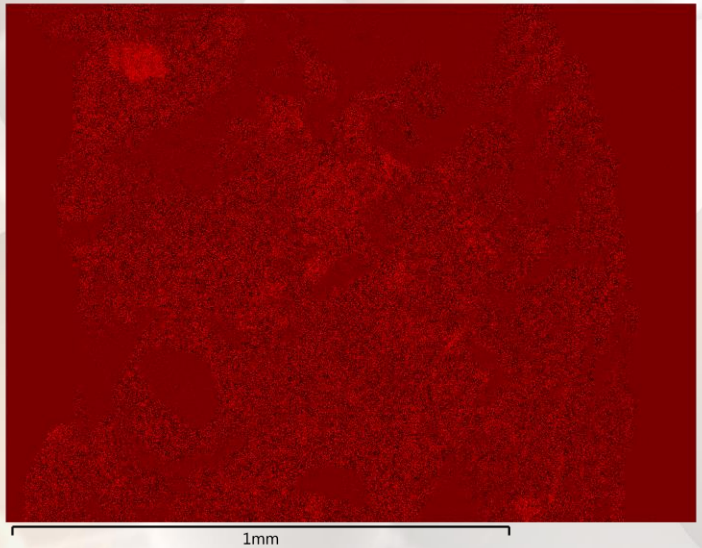
Pd L series



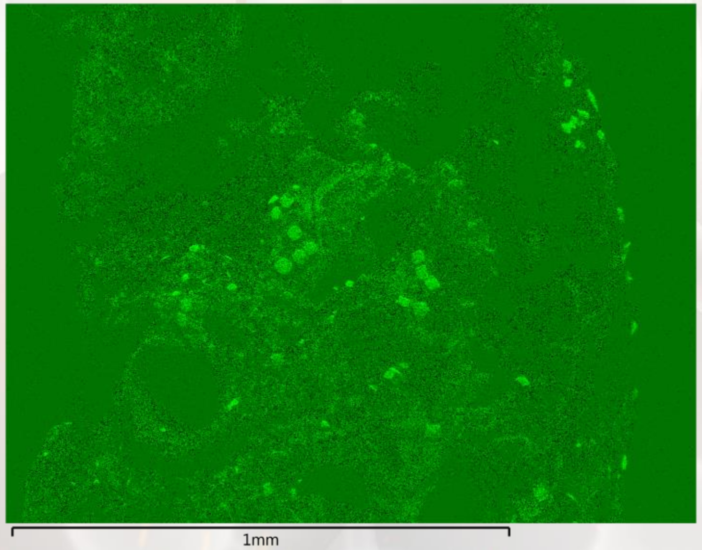
Ca K series

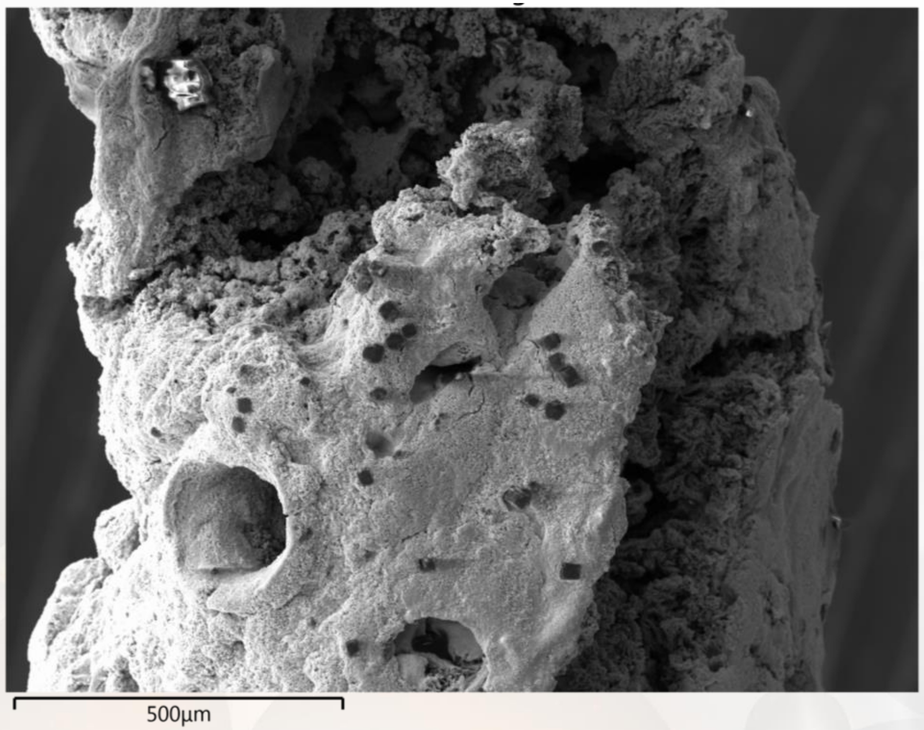


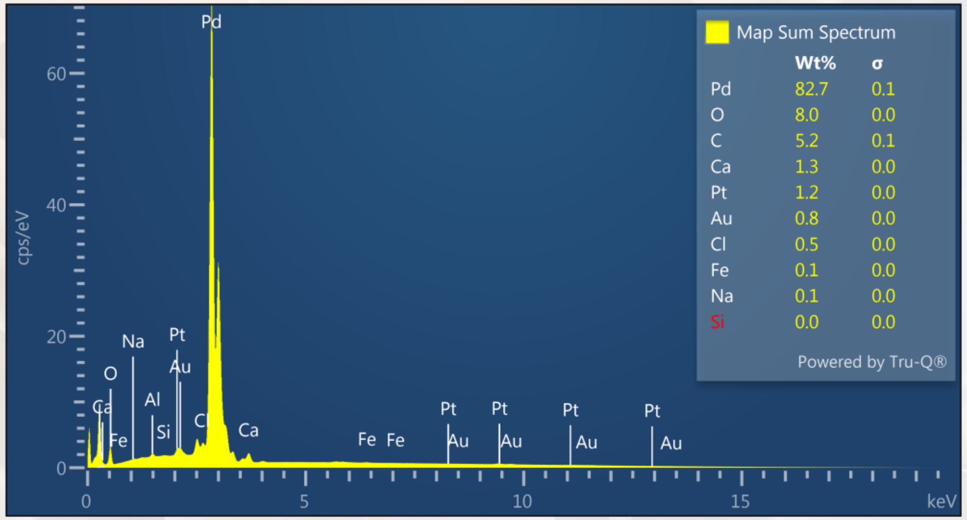
Cl K series



O K series







Electrolytic Experiments: SEM Analysis

- SEM/EDS of Cathode
  - Interesting Calcium Peroxide spots on surface of co-dep layer

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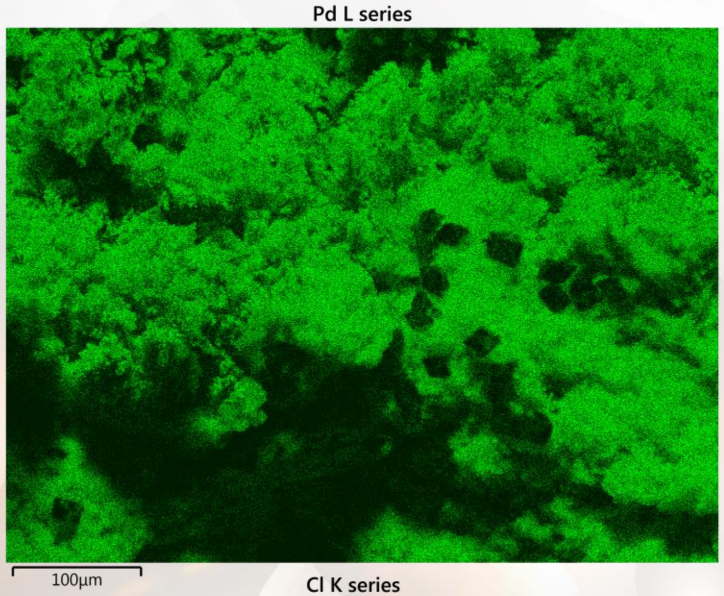
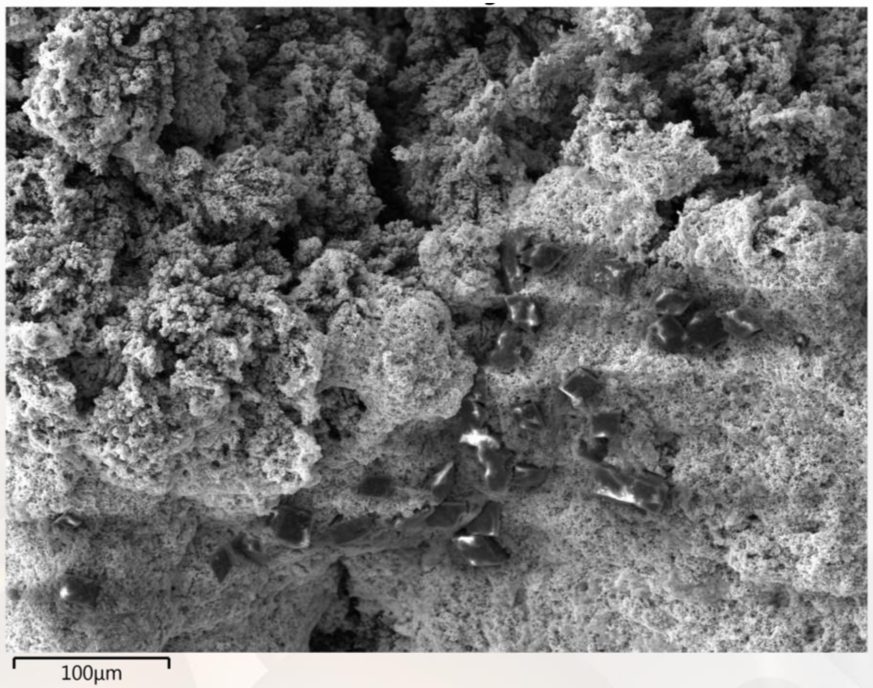
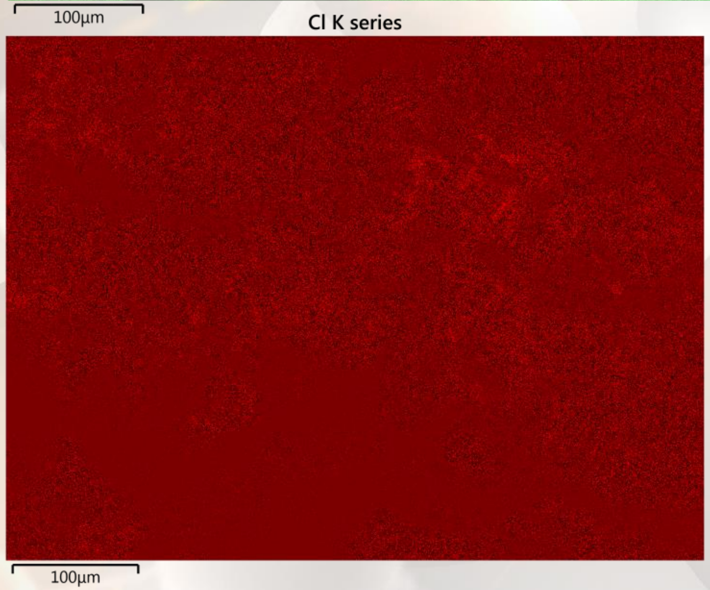
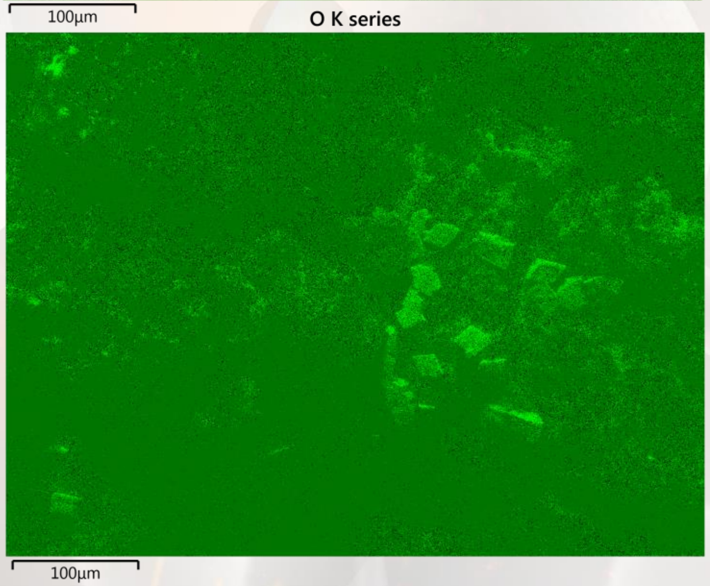
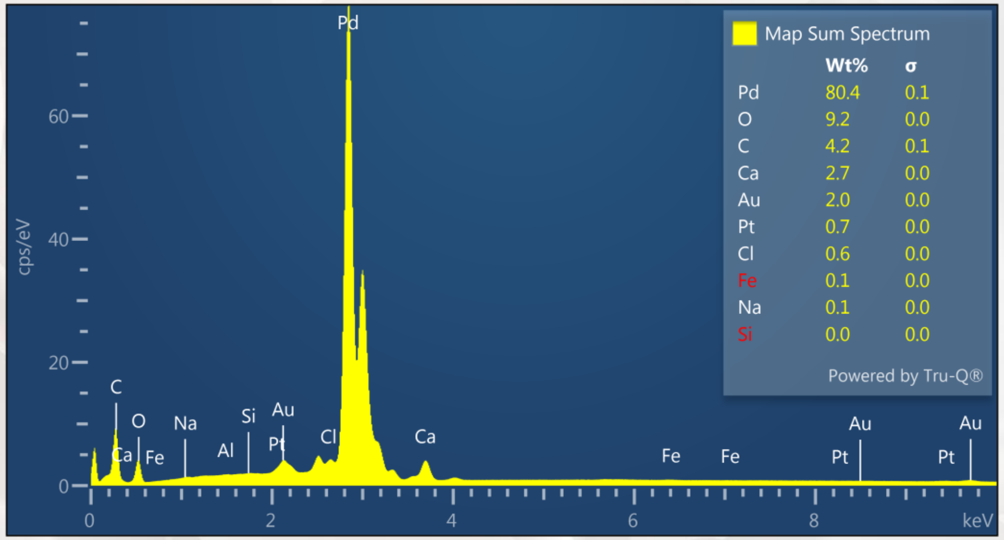










Transmutation Theories: Fissioning of Resulting Unstable Isotopes

- Takahasi[5]: Photofissioning of Pd
  - Pairs such as Fe+Ca and Ti+Cr
  - Nuclear excitation by low-energy, high-flux photons
  - Electrolysis experiments
- Fissioning of fused d-Pd or d-Ag; unstable Ag or Cd
  - Many pairs are possible with one of the pairs undergoing beta decay often many times to a stable isotope
  - These isotope pairs have been observed on post-test PdAg alloy samples as well as others.
    - Fe+Ti; Mn+Cr; Fe+Cr

[5] A. Takahasi, M. Ohta, and T. Mizuno, "Production of stable isotopes by selective channel photofission of Pd," Jpn. J. Appl. Phys. 40, pp. 7031-7046, 2001.

Transmutation Theories: Fission Parameter

- Non-actinide palladium deuteride (Z=46) has a fission threshold[6] < 10 MeV despite expected 50 MeV fission barrier height
- The electrostatic Coulomb to strong force "fissility" relationship[7] (which was initially derived for characterizing spontaneous fission), $Z^2/A>17$, holds as low a Z as strontium ($^{84}Sr_{38}$, Z=38, $Z^2/A=17.2$)
- However, parameter was based upon the "liquid drop" nuclear model developed for actinides.
- Fissility relationship $Z^2/A>17$; for $^{105}Pd_{46}$ = 20.15 and for $^{107}Ag_{47}$ = 20.65, hence are both potentially fissile.

[6] R. Wisniewski, et al., "Deuteron Disintegration, Thermonuclear and Nuclear Fission Reactions Induced by γ Quanta in D-Saturated Palladium and Dense Deuterium Gas with Synthesis of New Structures", Journal of Surface Investigation. X-ray, Synchrotron and Neutron Techniques, 7 (2) (2013) 239–247.

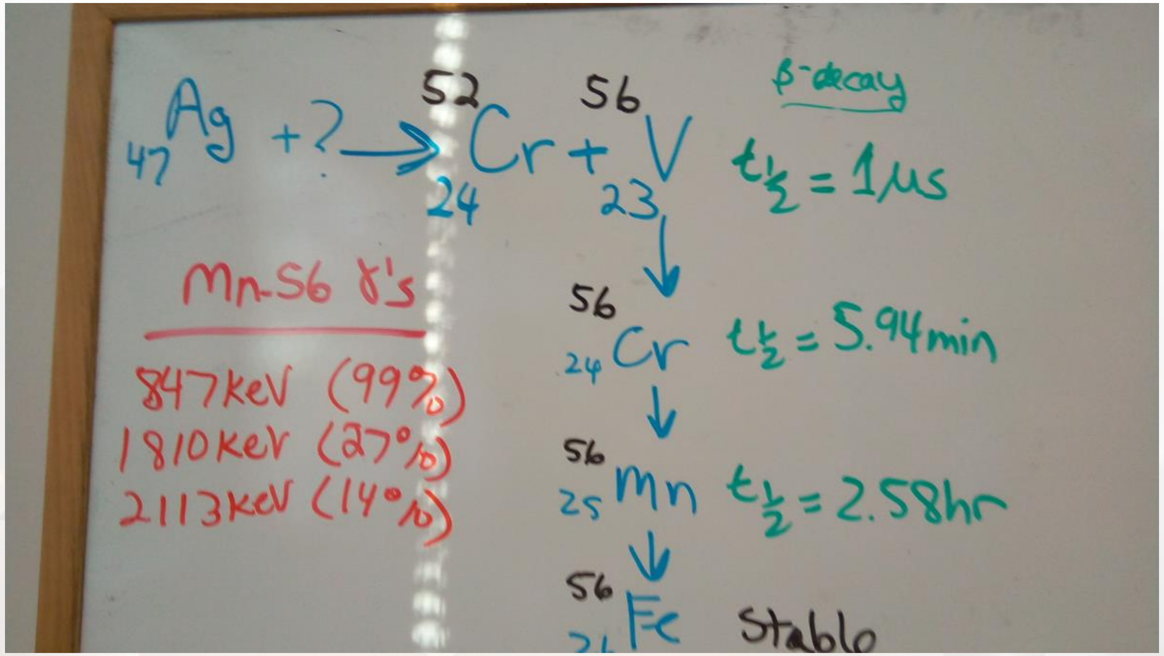
[7] K.N. Mukhin, "Experimental Nuclear Physics: Volume I, Physics of Atomic Nucleus", Mir Publishers, (Moscow) (1987) 467. Translated from the 1983 Russian version.

Transmutation Theories: How Do We Fission Pd?

- Actinides: Traditional Fission
  - Thermal neutron fission for odd A nuclei (^{235}U, ^{239}Pu) and fast neutron fission for even and odd A nuclei (^{235}U, ^{239}Pu, ^{232}Th, ^{238}U)
- PdD system
  - Fission is possible via absorption of a nucleon
    - Neutron absorption result in release of ~8 MeV of binding energy is shared as KE amongst nucleons
    - O-P reaction: $^{a}M_{z}(D,p)n+^{a+1}M_{z}$; KE of p > 6MeV
  - Certain fusion reactions generate 14MeV neutrons and 15MeV protons
  - Pd fission barrier is near the top, requiring ~40-50 MeV to fission
  - However, ^{105}Pd has oblate nucleus with *Jp=5/2+*
  - Gamma excitation enables sub-threshold fission

Transmutation Theories: Fissioning of Unstable Isotope Ag

- ^{64}Zn and ^{44}Ca
  - ^{106}Pd + ^{2}D -> ^{108}Ag* -> ^{64}Zn + ^{44}Cl
  - ^{44}Cl beta decays to stable ^{44}Ca
- ^{65}Cu and ^{43}Ca
  - ^{106}Pd + ^{2}D -> ^{108}Ag* -> ^{65}Cu + ^{43}Ar
  - ^{43}Ar beta decays to stable ^{43}Ca
- ^{52}Cr and ^{58}Ni (observed in ToF-SIMS data)
  - ^{108}Pd + ^{2}D -> ^{110}Ag* -> ^{52}K + ^{56}Ni
  - ^{52}K beta decays to ^{52}Ca -> ^{52}Sc -> ^{52}Ti -> ^{52}V and then to stable ^{52}Cr
- ^{52}Cr and ^{56}Fe (observed in ToF-SIMS data)
  - ^{106}Pd + ^{2}D -> ^{108}Ag* -> ^{52}Cr + ^{56}V
  - ^{56}V beta decays to stable ^{56}Fe

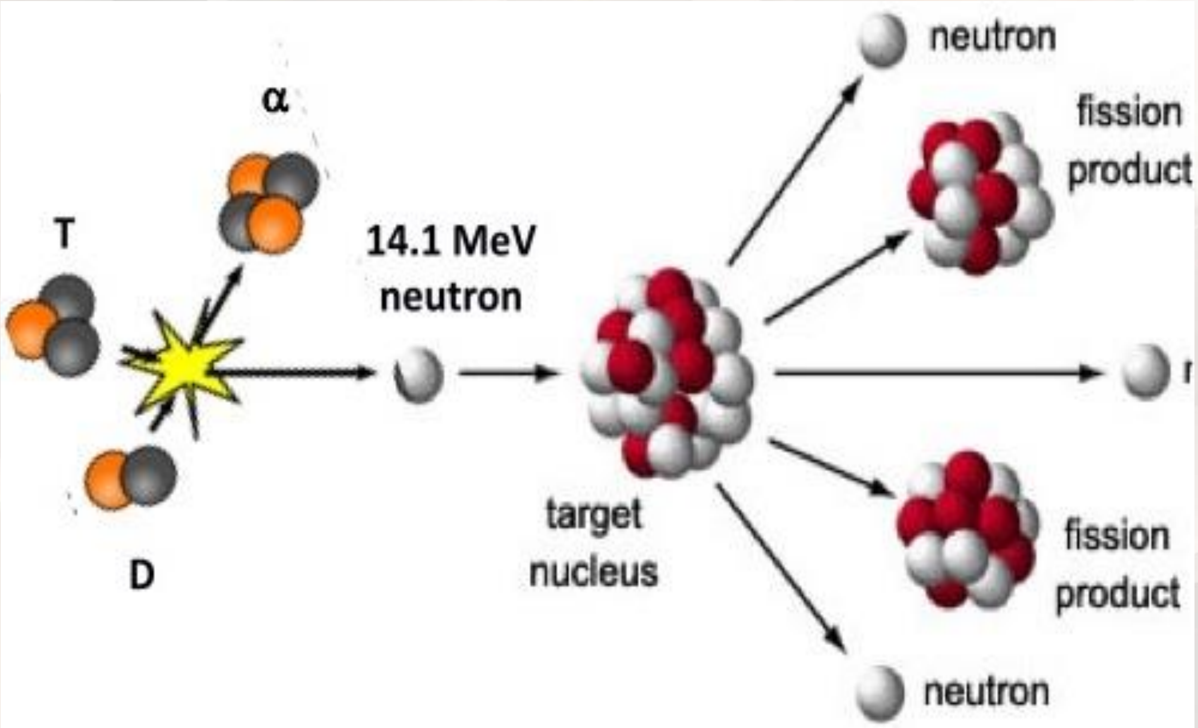


Transmutation Theories: Fissioning of Unstable Isotope Cd

- ^{49}Ti and ^{60}Fe
  - $^{107}Ag + ^{2}D \rightarrow ^{109}Cd^{*} \rightarrow ^{60}Fe + ^{49}Ti$
  - ^{60}Fe has a 2.62E6 year ½ life
- ^{54}Cr and ^{57}Fe (observed in ToF-SIMS data; 2 pathways possible)
  - $^{109}Ag + ^{2}D \rightarrow ^{111}Cd^{*} \rightarrow ^{54}Cr + ^{57}Cr$
  - ^{57}Cr beta decays (½ life of 21.1 s) to ^{57}Mn (½ life of 85 s) and then stable ^{57}Fe
  - $^{109}Ag + ^{2}D \rightarrow ^{111}Cd^{*} \rightarrow ^{54}Ti + ^{57}Fe$
  - ^{54}Ti beta decays (½ life of 2.1 s) to ^{54}V (½ life of 49 s) and then stable ^{54}Cr
- ^{53}Cr and ^{58}Fe (2 pathways possible)
  - $^{109}Ag + ^{2}D \rightarrow ^{111}Cd^{*} \rightarrow ^{53}Cr + ^{58}Cr$
  - ^{58}Cr beta decays (½ life of 7 s) to ^{58}Mn (½ life of 3 s) and then stable ^{58}Fe
  - $^{109}Ag + ^{2}D \rightarrow ^{111}Cd^{*} \rightarrow ^{53}Ti + ^{58}Fe$
  - ^{53}Ti beta decays (½ life of 33 s) to ^{53}V (½ life of 1.5 min) and then stable ^{53}Cr

Transmutation Theories: Hybrid Fusion-Fast Fission

- Takes advantage of both processes
  - Fusion reactions provide the neutrons to fission non-fissile material
  - Require ~2MeV neutrons to fission Th and natural U
  - Fusion reactions can provide up to 14.1 MeV neutrons



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$^3He(^3He,\alpha)2p$	12.86	low probability	p=1 to 10
Fission Reaction	**MeV**	**Occurrence**	**Useful particle energy (MeV)**
$^{232}Th(n,\gamma)f$	200	high probability	n=1 to 9
$^{232}Th(p,\gamma)f$	200	some probability	p=1 to 10
$^{238}U(n,\gamma)f$	200	high probability	n=1 to 9
$^{238}U(p,\gamma)f$	200	some probability	p=1 to 10

Summary

- Transmutations observed with deuterium gas cycling of PdAg alloy with various material analysis techniques
- Fusion and higher energy neutrons and fission products detected with bremsstrahlung irradiation experiments
- Transmutations observed with electrolytic wet cell co-deposition of $PdCl_2$/LiCl on cathode wires
- Electron screening greatly reduces Coulomb barrier facilitating deuteron/proton capture by Pd or Ag isotope
- Capture causes resulting isotope to be unstable
  - Unstable enough to cause fissioning?
  - Possibly another yet unknown vehicle assists with fissioning of the unstable isotope
- Many fission pair possibilities exist
- Additional experiments are needed to confirm the working fusion/fission theory

Acknowledgement

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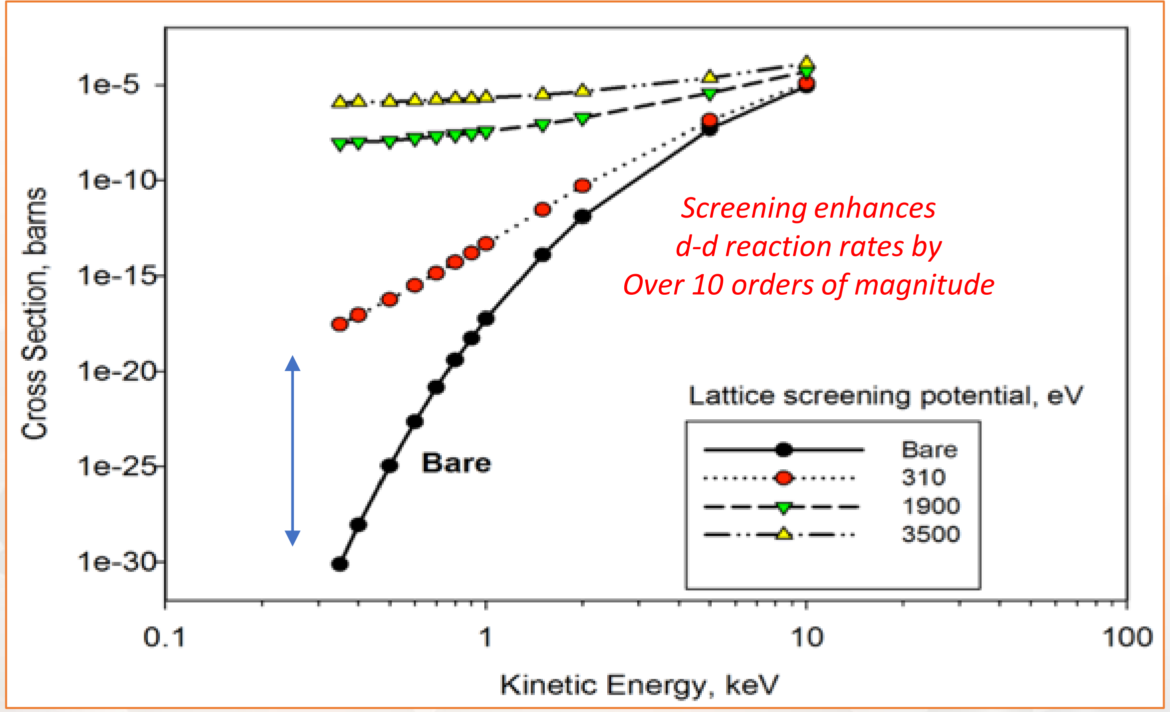
Backup

Transmutation Theories: Electron Screening

- Electron screening results in a *more transparent Coulomb Barrier*, *shifting the Gamow Factor,* as if deuterons were at far higher energies.
- This exponentially increases fusion rates.
- Laboratory astrophysics using accelerated deuteron beams across the Periodic Table show lattice and plasma screening provide up to 3+ keV screening.
- From LCF Theory development[4], a *higher probability of large angle scattering of screened charged particles* results on screened deuterons.



Electron Screened Enhanced Cross Sections

However, screening is only effective below 10 keV.

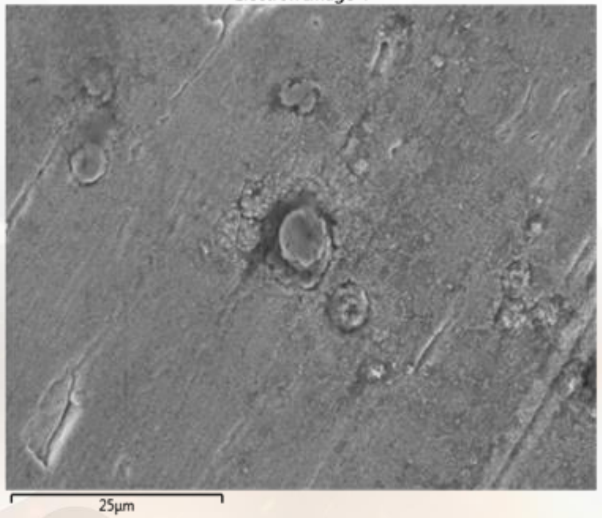
$$\sigma_{\text{bare}}(E) = \frac{S(E)}{E}\exp\left[-G(E)\right]$$

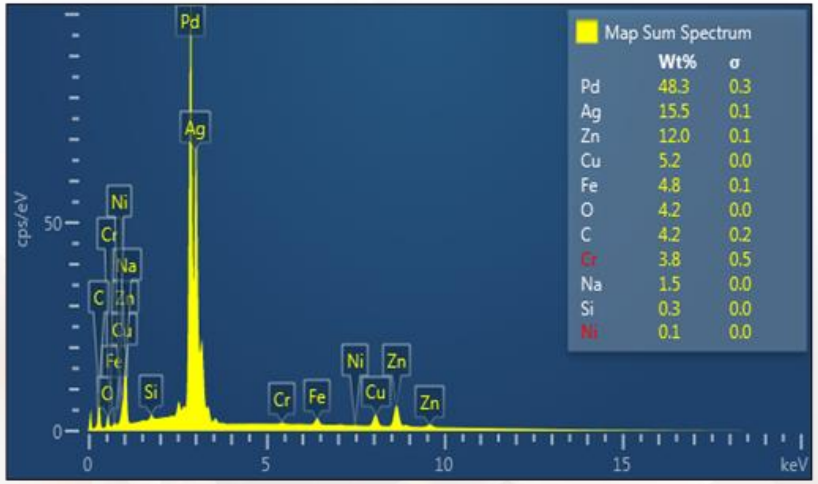
[4]V. Pines, et al, "Nuclear fusion reactions in deuterated materials," Phys Rev C, 101, 044609, 2020.

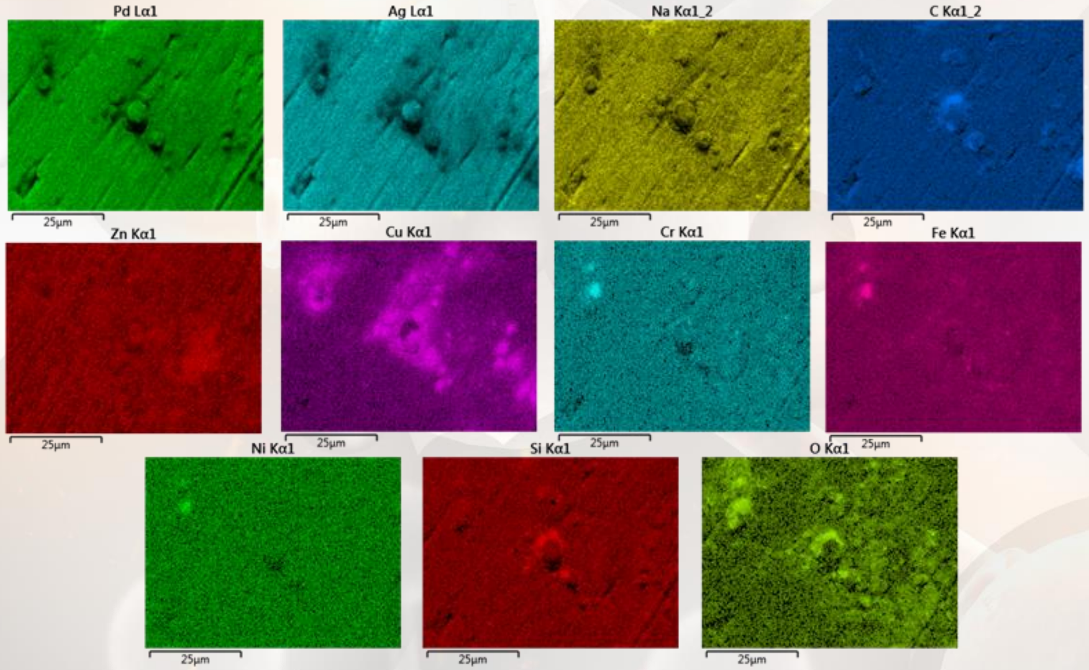
Additional area with transmutations (2018)

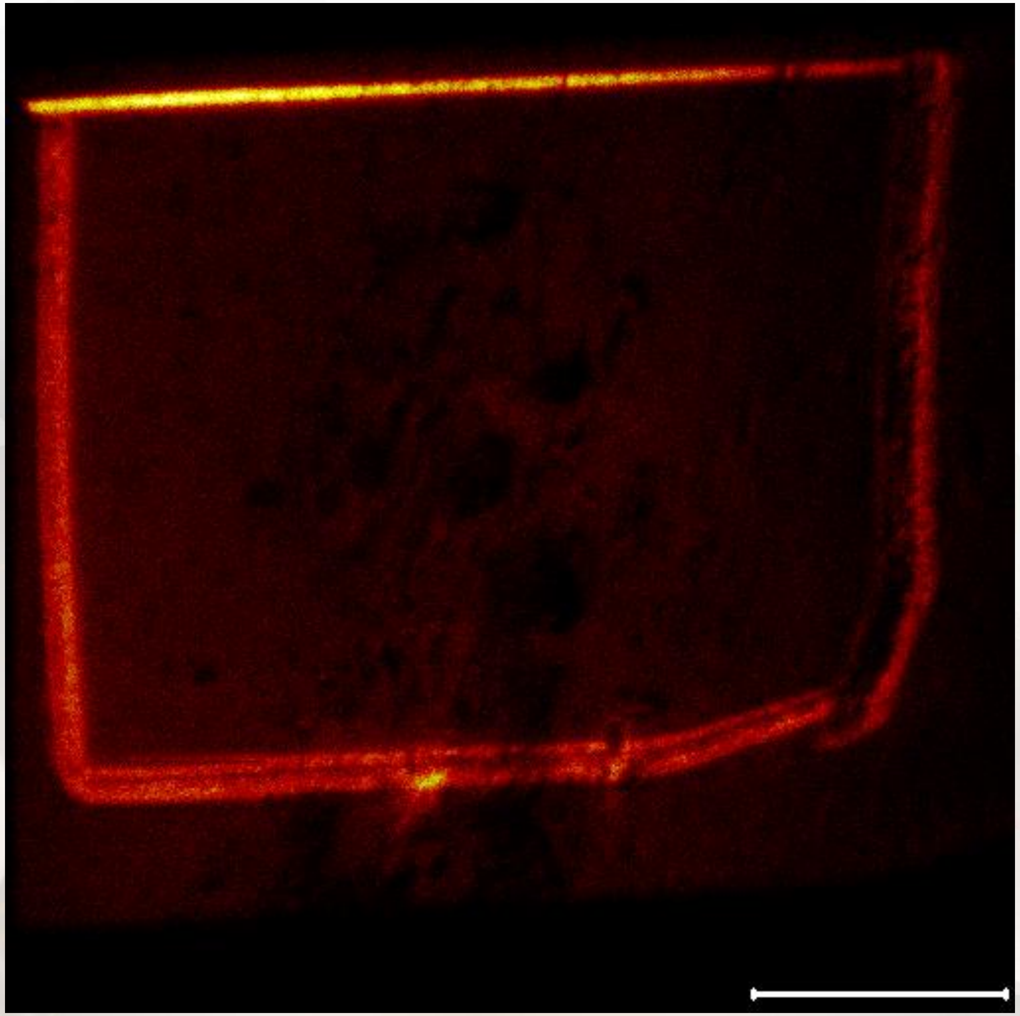
National Aeronautics and Space Administration

Electron Image 4



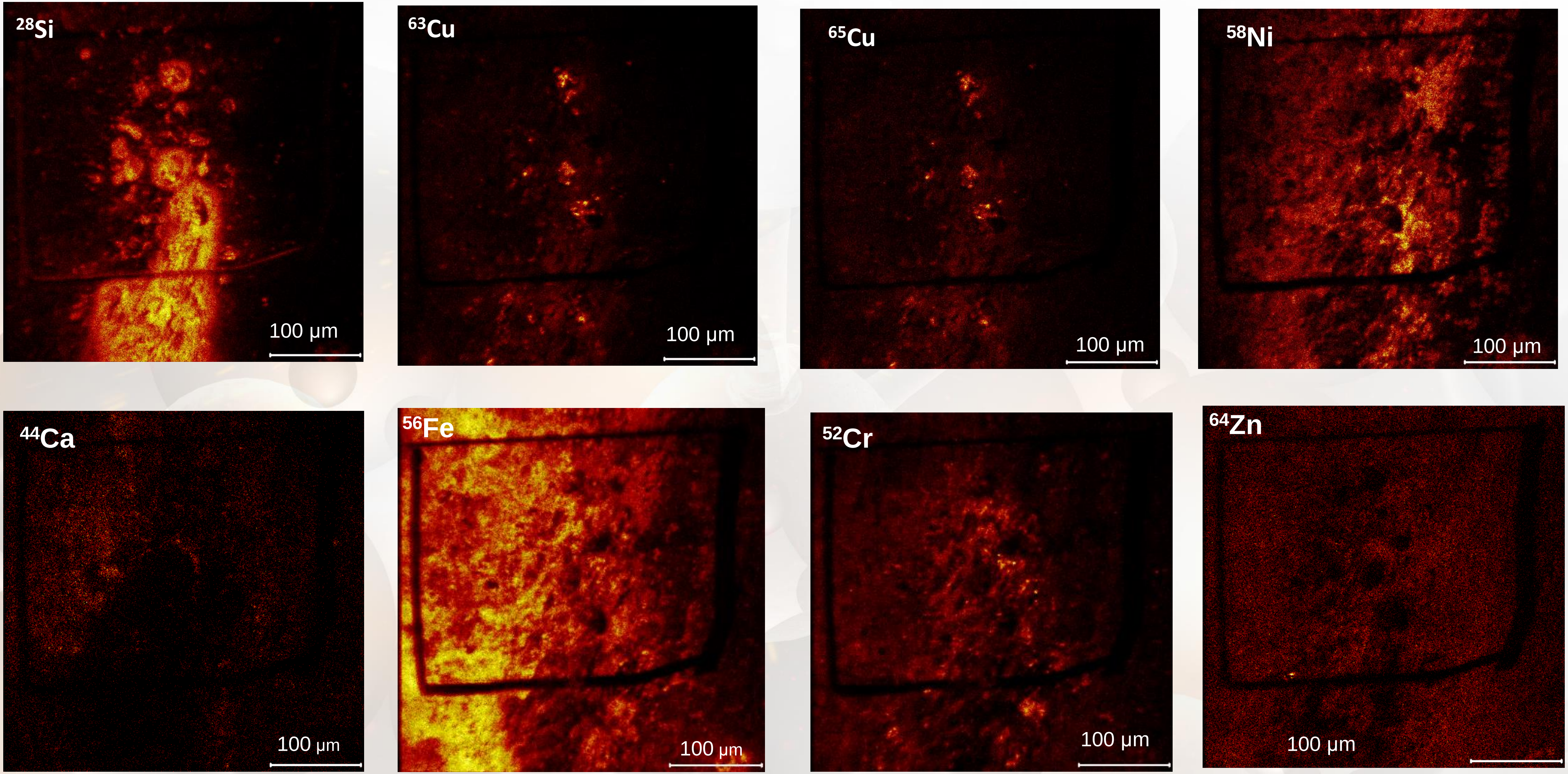






Ga - 68.91 (512x512)
Cts: 2519497; Max: 137; Scale: 100µm

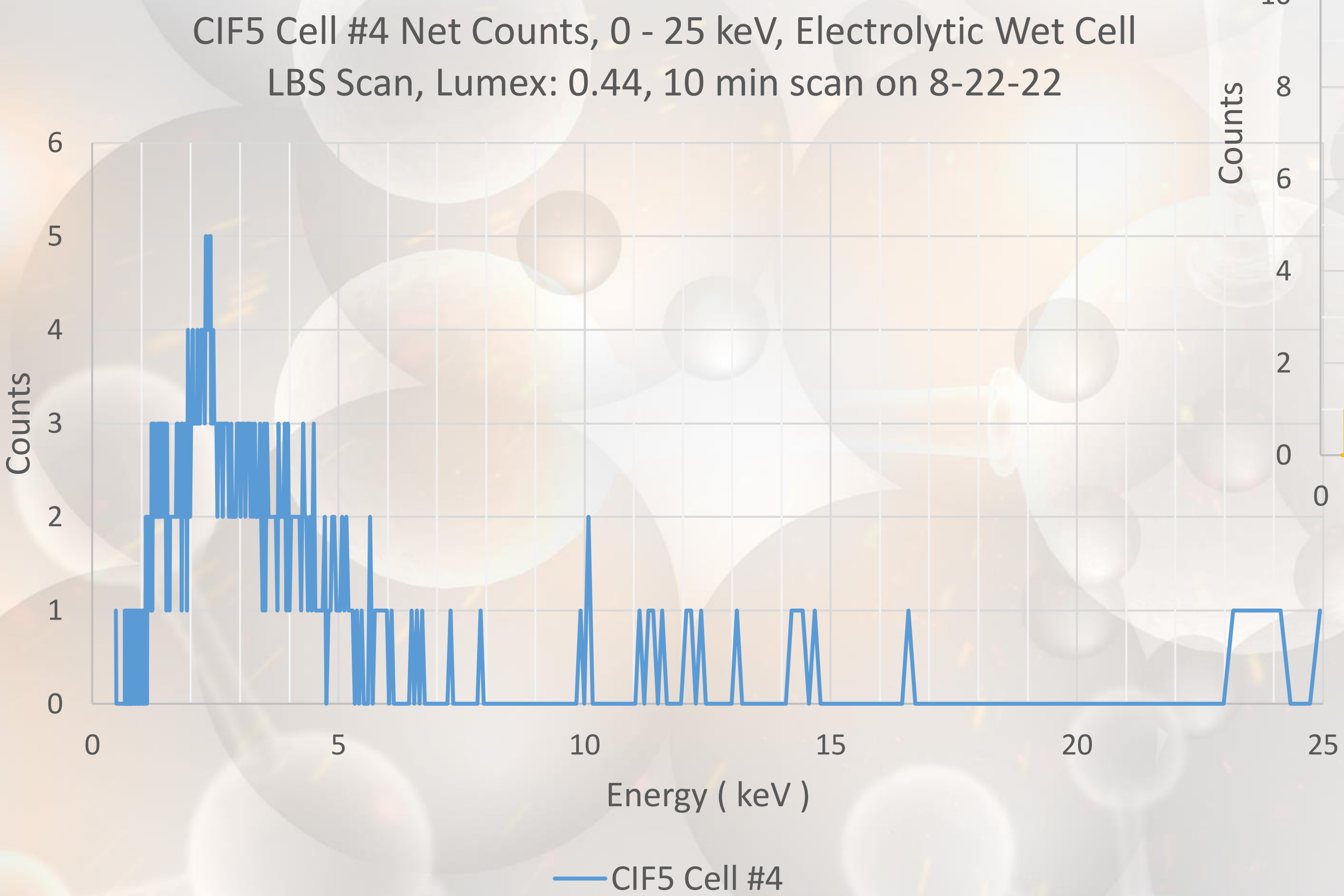
ToF SIM Spectroscopy: Isotopic Surface Analysis

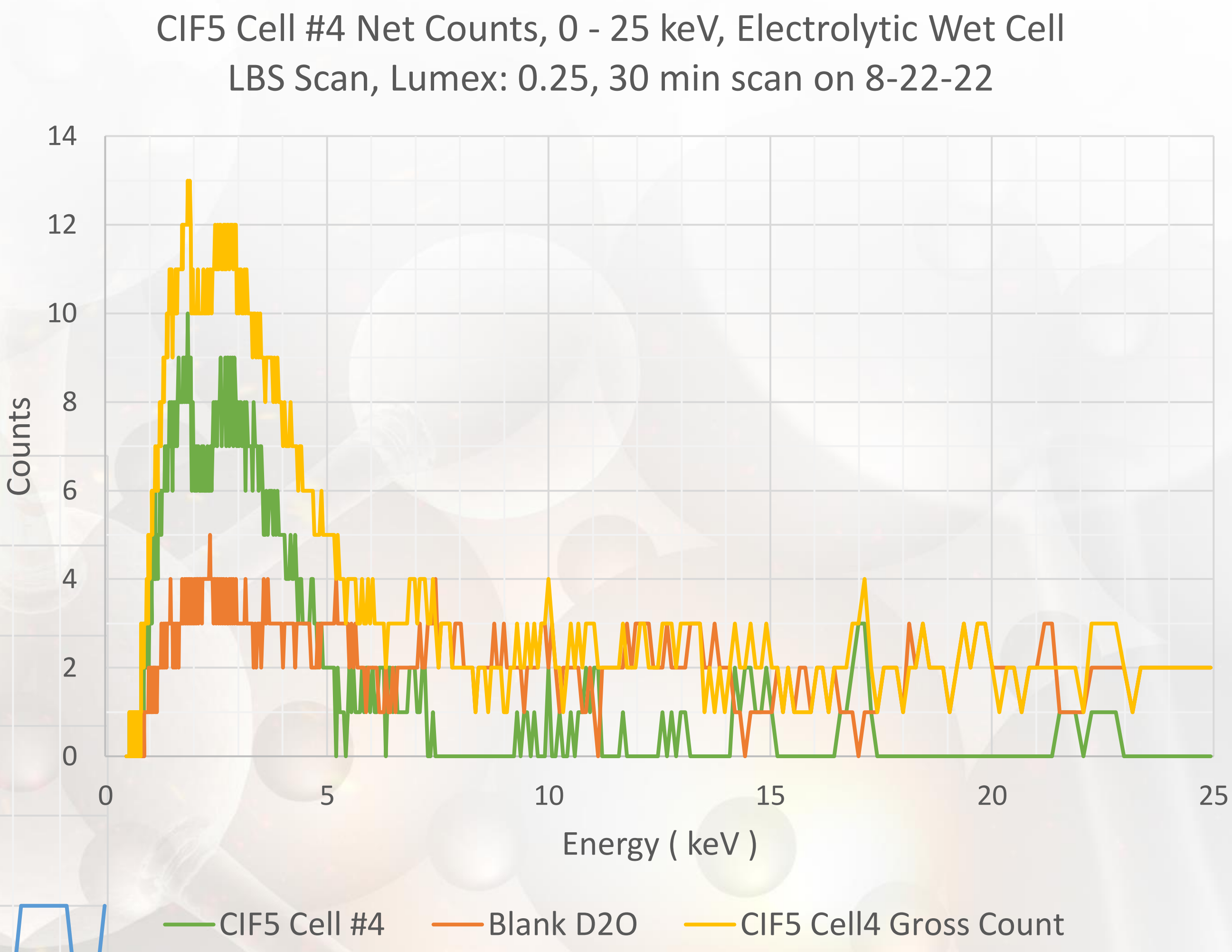


Electrolytic Experiments: Tritium Detection

National Aeronautics and
Space Administration

- Run #5 started on July 8
  - Bubble detectors added
    - EXP: 20 bubbles vs CNTRL: 10 bubbles
  - LBS Data indicates tritium present
    - 10 min scan & 30 min scan

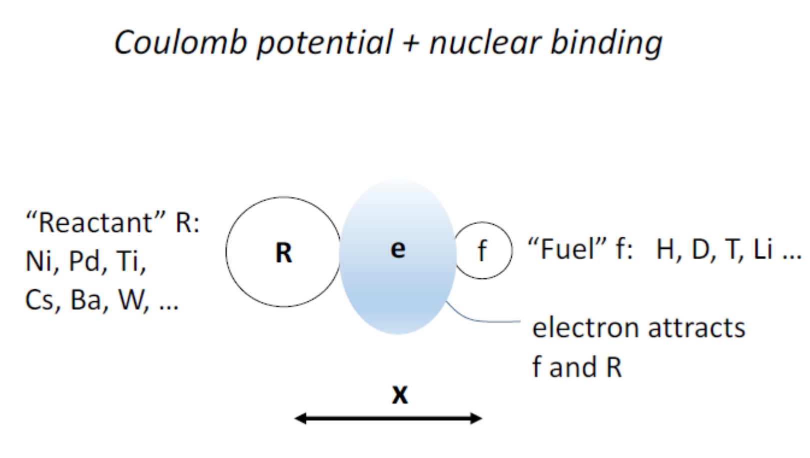


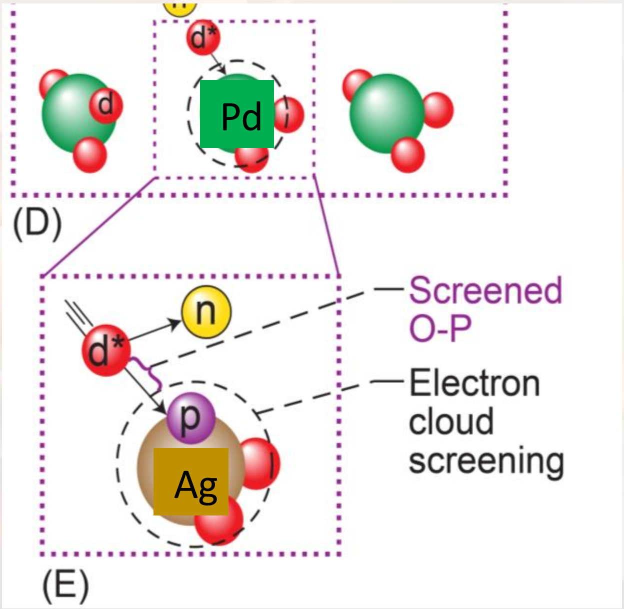


Transmutation Theory: Electron Screened d-Ag or d-Pd Fusion

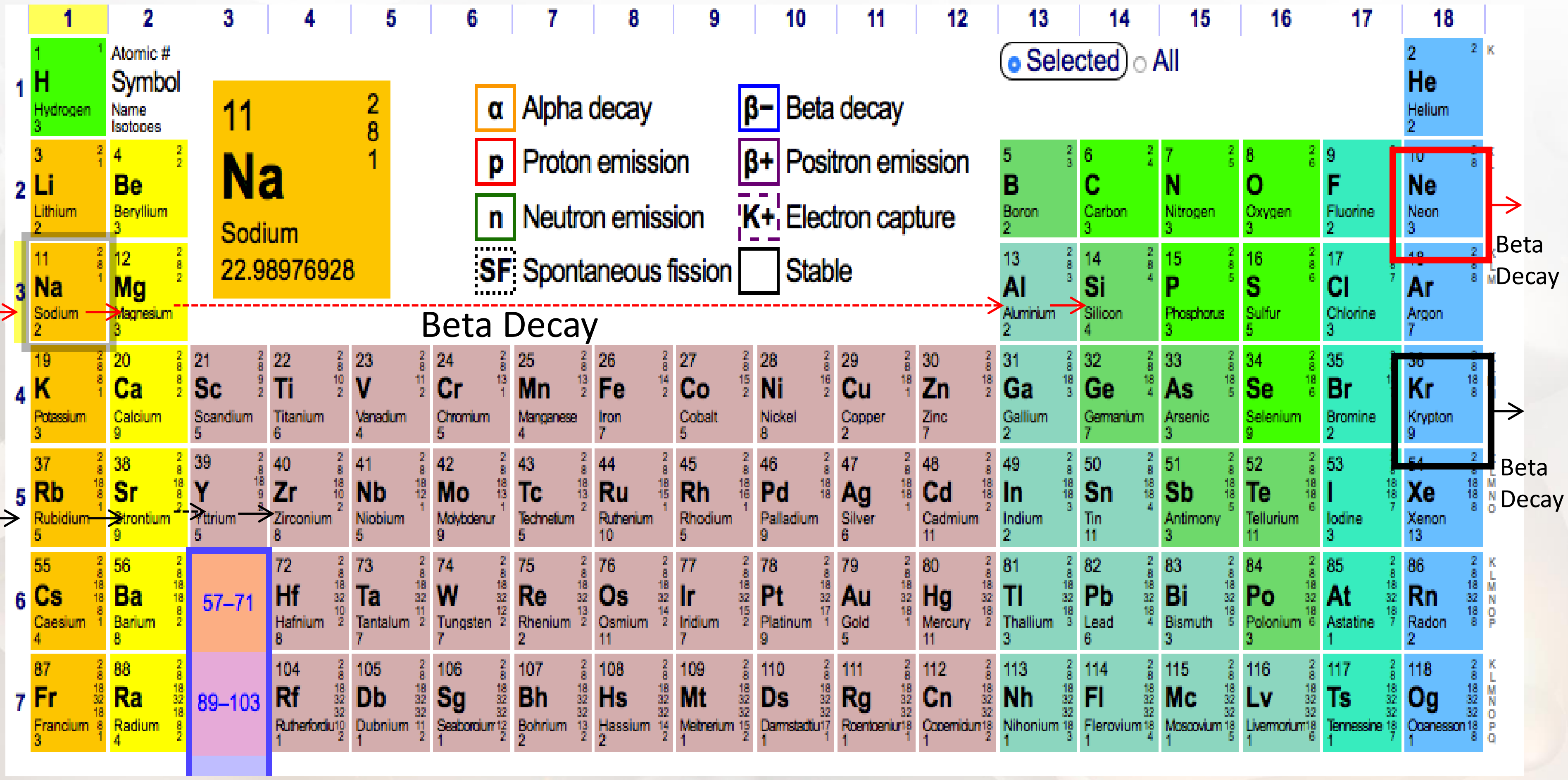
- Zuppero & Dolan
  - Heavy electrons and 3-body interactions
- Pines & Pines (NASA GRC work)
  - Electron screening theory (described in previous slide)
- Possible for deuteron to be completely ‘consumed’ by either Pd or Ag with enough electron screening to overcome the Coulomb barrier
- d-Pd and d-Ag reactions that follow conservation laws:
  - $^{106}Pd + ^{2}D \rightarrow ^{108}Ag^{*}$ (Q=10.83 MeV)
  - $^{108}Pd + ^{2}D \rightarrow ^{110}Ag^{*}$ (Q=11.08 MeV)
  - $^{105}Pd + ^{2}D \rightarrow ^{107m}Ag$ (Q=13.13 MeV)
  - $^{104}Pd + ^{2}D \rightarrow ^{106}Ag^{*}$ (Q=10.86 MeV)
  - $^{107}Ag + ^{2}D \rightarrow ^{109}Cd^{*}$ (Q=13.24 MeV)
  - $^{109}Ag + ^{2}D \rightarrow ^{111}Cd^{*}$ (Q=13.67 MeV)

Nuclear Three-Body Particle Model





Inert Gas as Insight to Pd Fission Paths
Neon or Krypton Unstable with too Many neutrons



- Beta Decays are all milli-sec to at most hours with very few showing gamma radiation (nature hides her tracks)
- Materials: SEM/EDS saw Na, Mg, Al, Si, + Sr others in J-M Tube bundle;