A Revolutionary Radioisotope Thermoelectric Generator (RTG) Based on Low Energy Nuclear Reactions (LENRs)

George H. Miley[1,3], Xiaoling. Yang[1] , Heinrich Hora[2]

1, Department of Nuclear, Plasma and Radiological Engineering, Univ. of Illinois, Urbana, IL

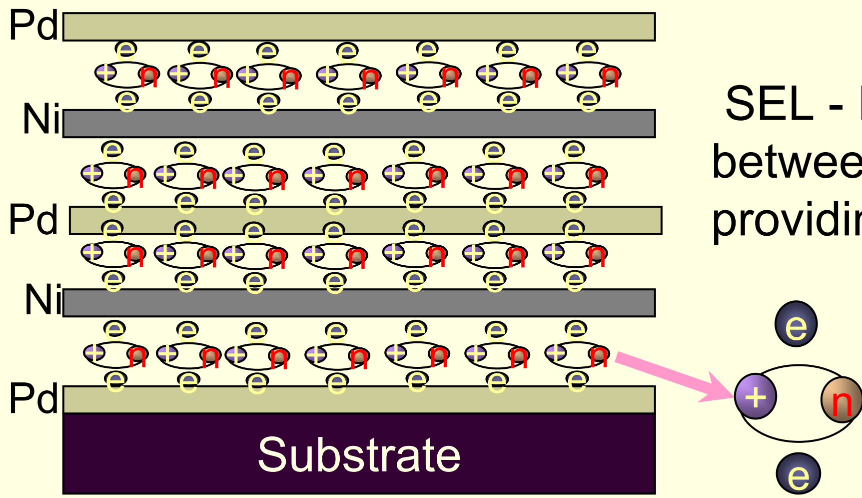
2. Dep. Theoretical Physics University of New South Wales, Sydney, Australia

3. NPL Associates, INC., Champaign, IL 61821

Outline

- Previous experiments using thin-film plate type electrodes conditioned for cluster formation.
- Evidence for D-clusters and recent experiment results
- Possible triggering methods the initiate nuclear reactions in these high density clusters
- Preliminary gas loading nanoparticle experiment
- Road Map and Future goal of the LENR study for Radioisotope thermoelectric generator (RTG) applications

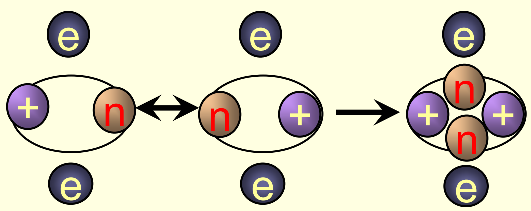
SEL Theory Lead the Design of Our Early Experiments



Swimming Electron Layer (SEL) Theory

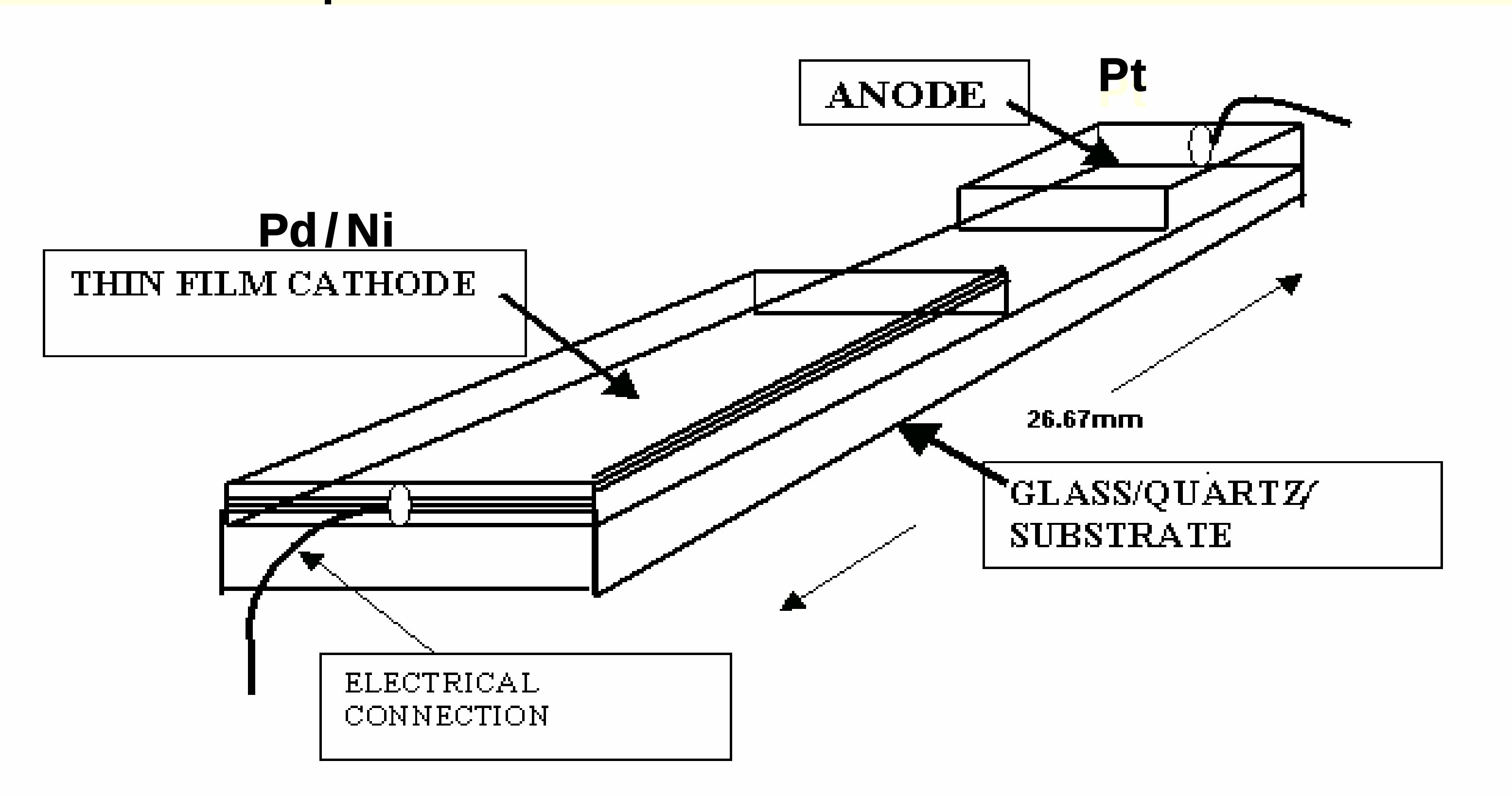
Zoom-in View

SEL - High density electron clouds – exists between metals of different Fermi energy, providing the necessary screening



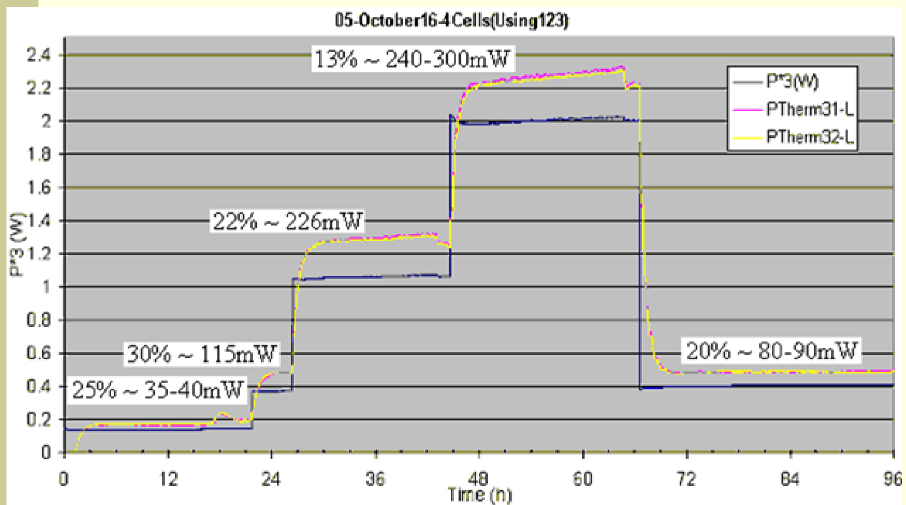
SEL Theory Lead to Multilayer Thin-film electrodes to obtain better control over manufacturing film & defects

- Concept



Multilayer thin-film electrode design with alternating layers of Pd & Ni.
Planar A-K structure used to maximize H2 concentration via electrodiffusion

Calorimetry Shows During Electrolysis Thin-Film Electrodes Produce Significant Excess Heat

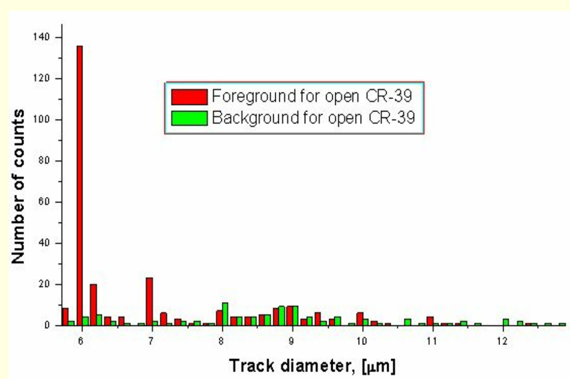


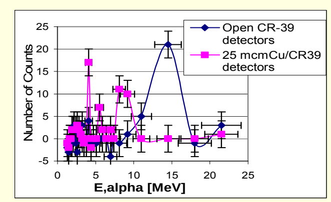
Heat measurement for two layers electrode: 8000Å Pd and 1000Å Ni on Alumina.

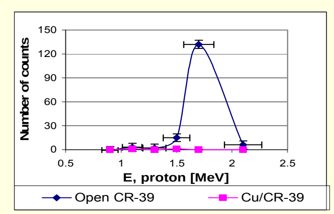
P_{therm}: Measured Heat power;
$P^*=I\,(U-U_0)$: Input electrical Power

Run Number	Excess Power (W)	
	Calculated	Measured
#7	1.9 ±0.6	4.0 ±0.8
#8	0.5 ±0.2	0.5 ±0.4
#18	0.7 ±0.3	0.6 ±0.4

MeV charged-particles are detected: Alpha-Particles and Protons



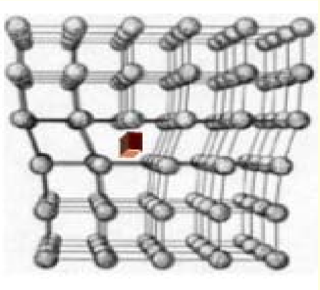


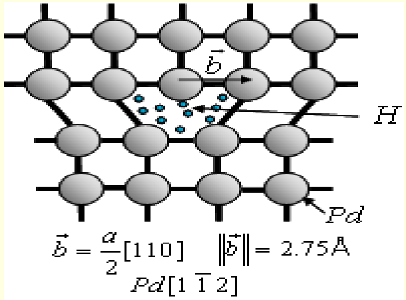


Our Recent Dislocation-Loop-Cluster Studies

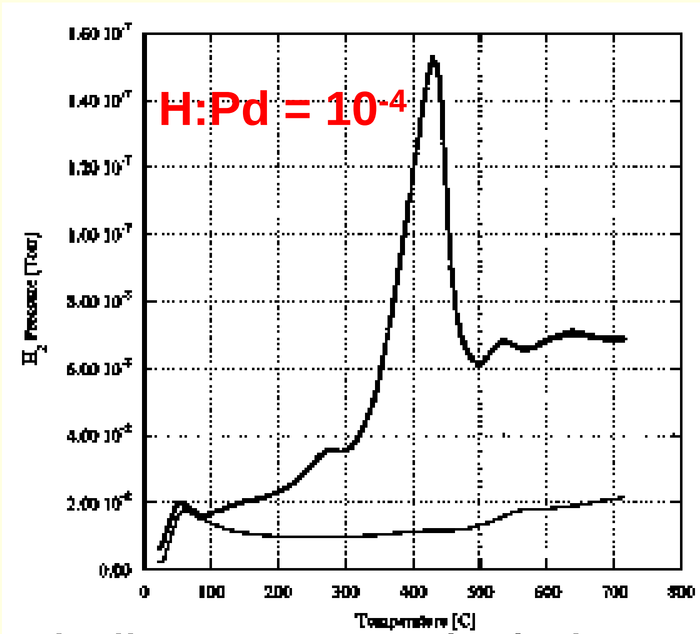
- Pd thin foil – 12 μm
- Loading and unloading deuterium/hydrogen was done by cyclically cathodizing and anodizing Pd foil → dislocation loop and cluster formation

PdO
Pd
PdO





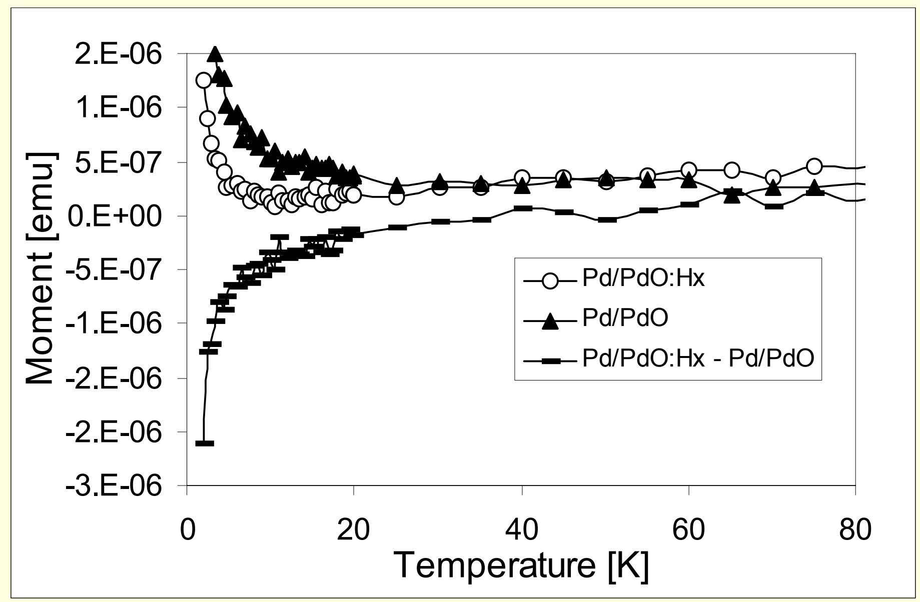
Temperature Programmed Desorption (TPD) Experiment and SQUID Measurement



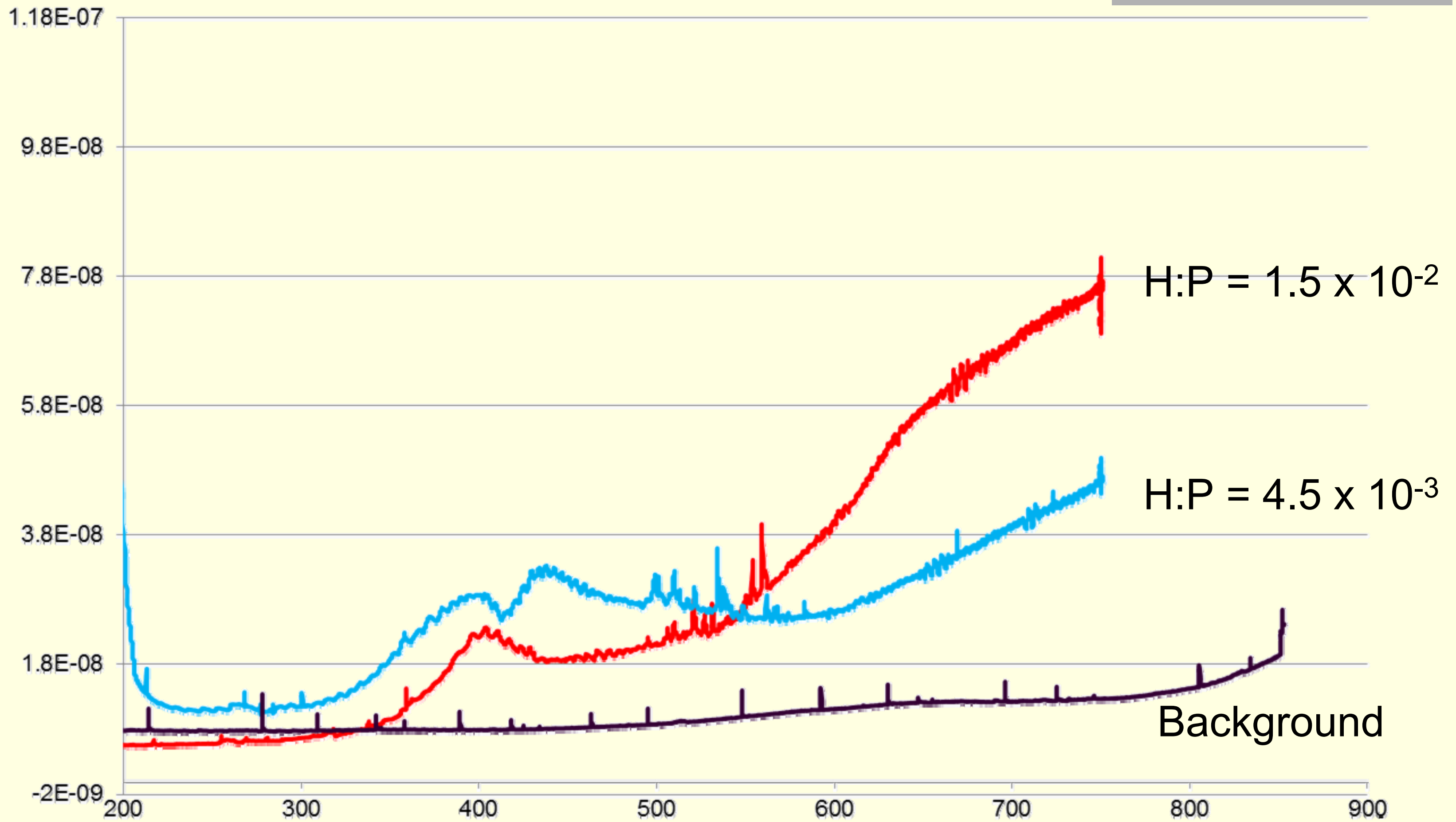
Binding Energy calculation – close to the binding energy between hydrogen and dislocations

$$\varepsilon_H = k_B \frac{T_2 T_1}{(T_2 - T_1)} \ln(P_2 / P_1) = 0.65eV$$

The magnetic moment of H_2- cycled PdHx samples in the temperature range of $2 \leq T < 50$ K is significantly lower than M(T) for the original Pd/PdO.



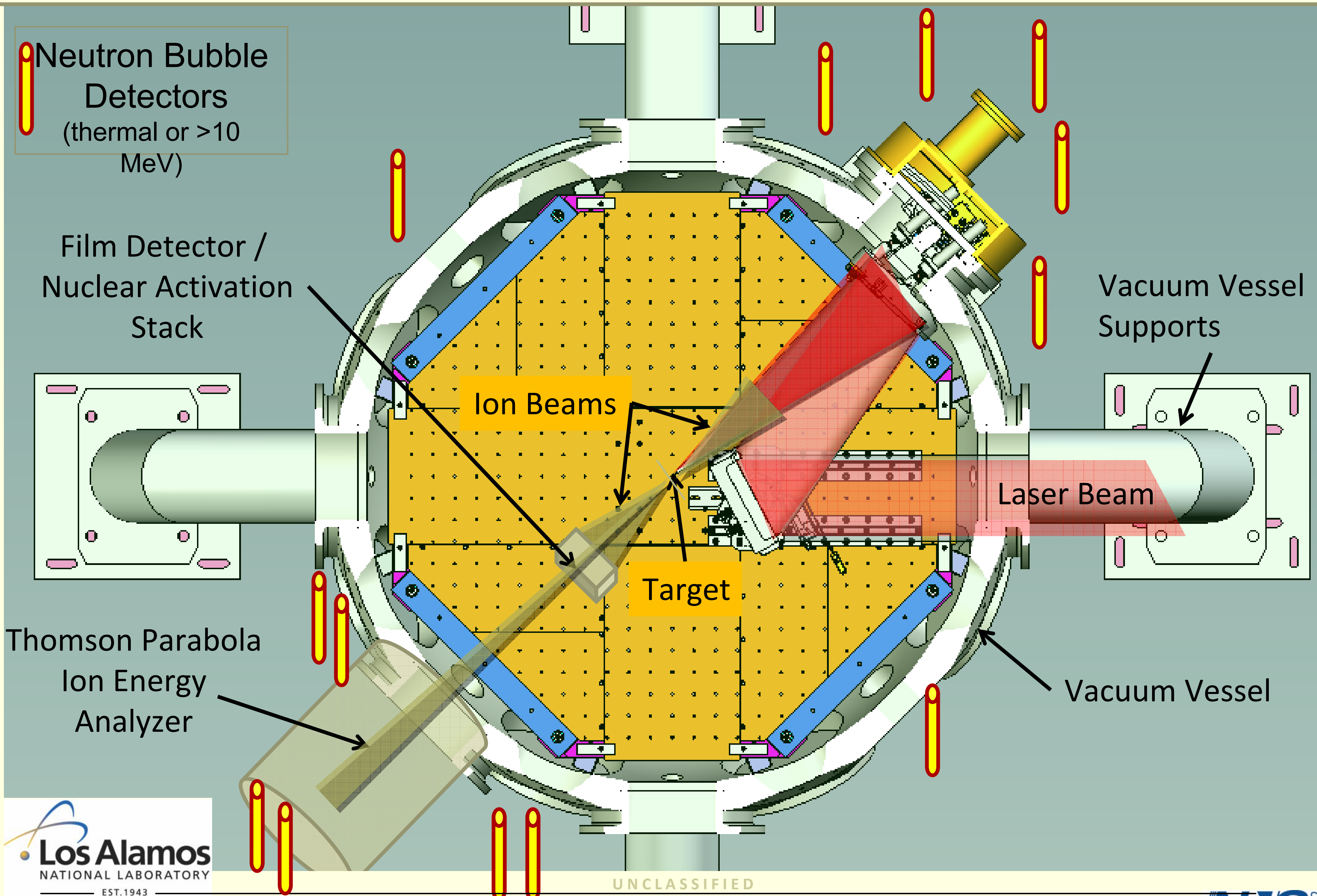
Recent TPD Results from Newly Fabricated Thin films – Much Improved!



We are funded to do experiments at LANL to study the extraction of MeV D+ ions from these clusters using the TRIDENT petawatt laser

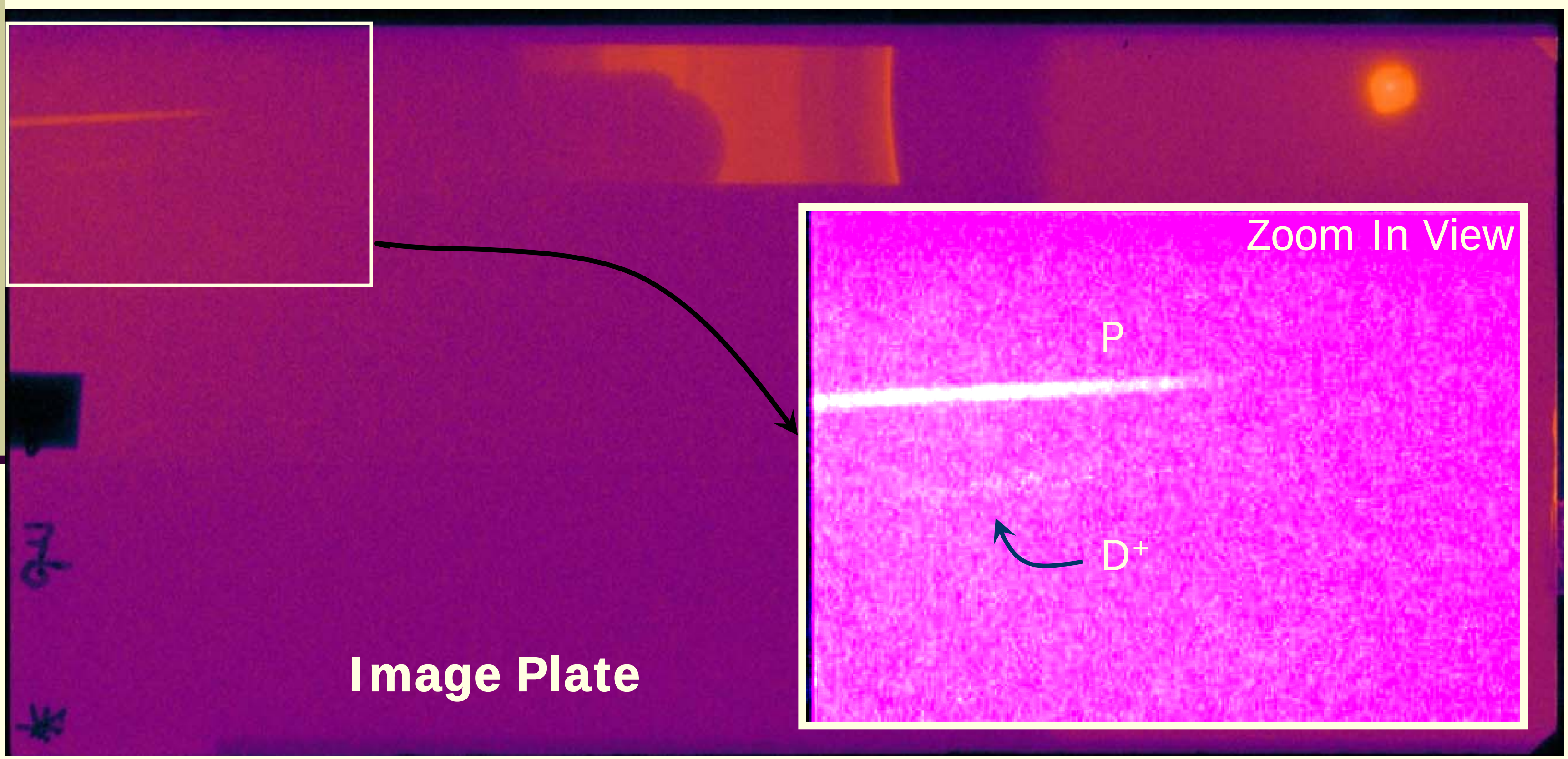
ANOTHER PROOF OF CLUSTERS – PETAWATT LASER BEAM EXTRACTION

DEUTERON ACCELERATION EXPERIMENT IN LANL



Ion Trace of PdD Separated by Thompson Parabola WITH Ti Filter

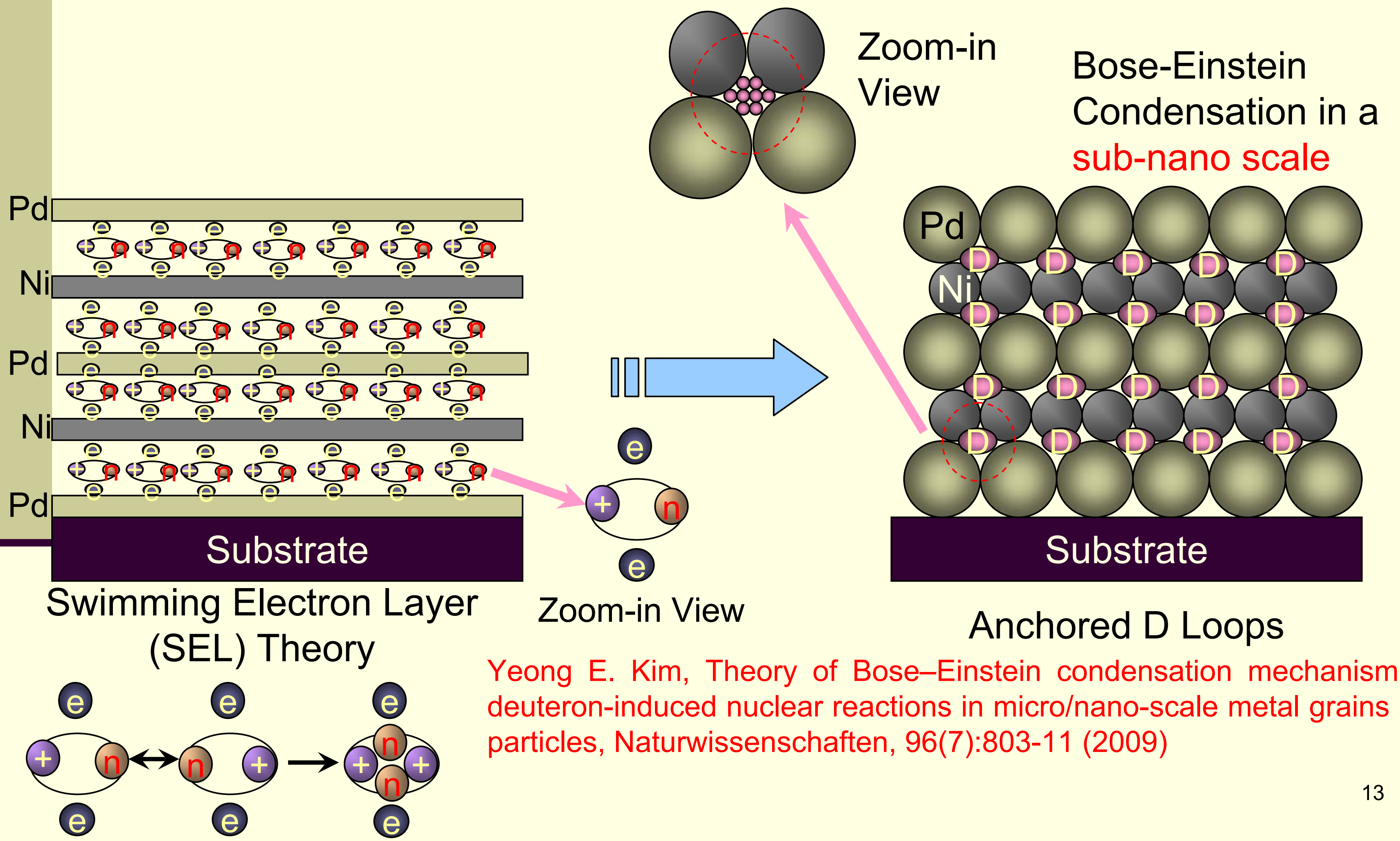
Laser Energy in 81.9 J out 67.1



Comments –TRIDENT results

- Demonstrate acceleration from clusters
- Flux and energy depressed, probably by impurity protons (and C?)
- Next experimental campaign
  - Continue to improved cluster packing fraction
  - Reduce contamination (p and C).
  - Obtain more insight from ongoing supporting simulation studies.

Conclusion: High density deuterium cluster formation (Pseudo Bose-Einstein Condensation) at room temperature occurs and is fundamental as a way to create nuclear reactive sites for LENR



Yeong E. Kim, Theory of Bose–Einstein condensation mechanism for deuteron-induced nuclear reactions in micro/nano-scale metal grains and particles, Naturwissenschaften, 96(7):803-11 (2009)

Triggering The Reaction

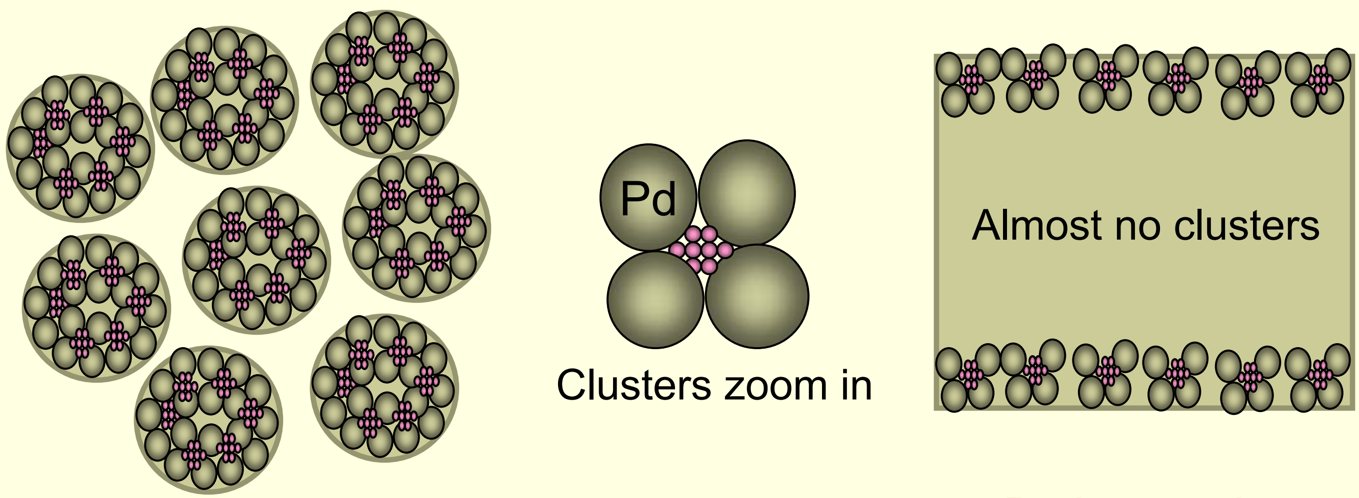
- Electrolysis (pulse or ramp)
- Gas loading (pulse pressure)
  - Smaller heat capacity
  - Higher temperature change as compared with an electrolysis system.
  - Without the constraint of being limited by the boiling temperature of the fluid
- Glow Discharge (bombardment)
- Low energy laser; ultrasound; em radiation,…..

Recent work is designed to extend the thin-film technique to nanoparticles.

For applications this will allow high temperatures with gas loading – i.e. improved performance when energy conversion is integrated into the cell

Cluster Formation in Nanomaterials

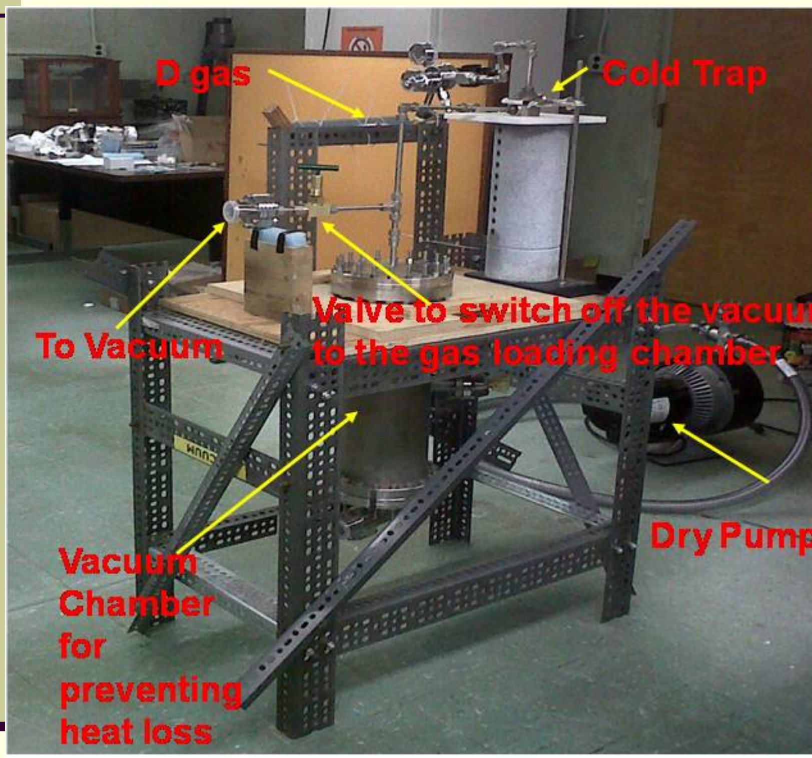
- Clusters mainly forms at the places that is close to the material surface.
- Nanomaterials have more surface area, thus have good ability to form abundant clusters



Nanoparticles

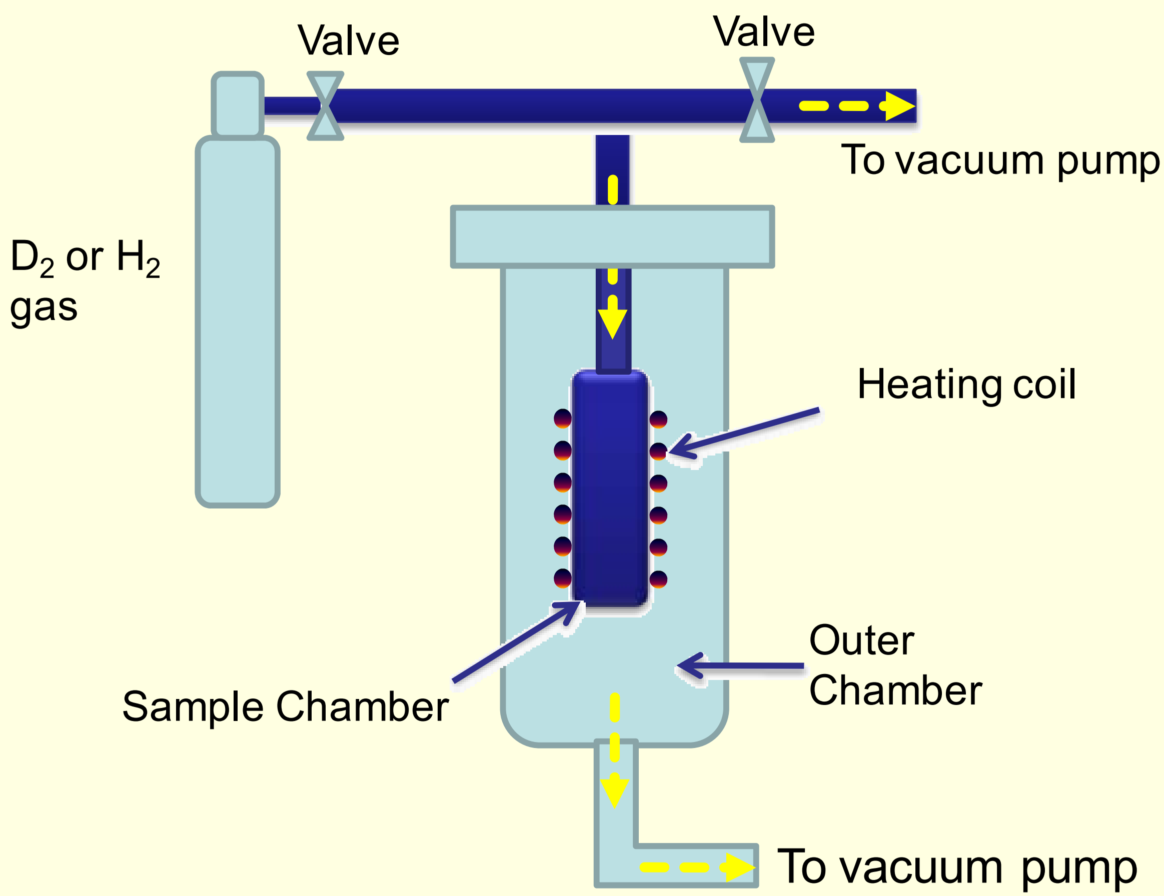
Bulk material

Our Gas Loading System



2.2cm inner diameter
$25cm^3$ total volume

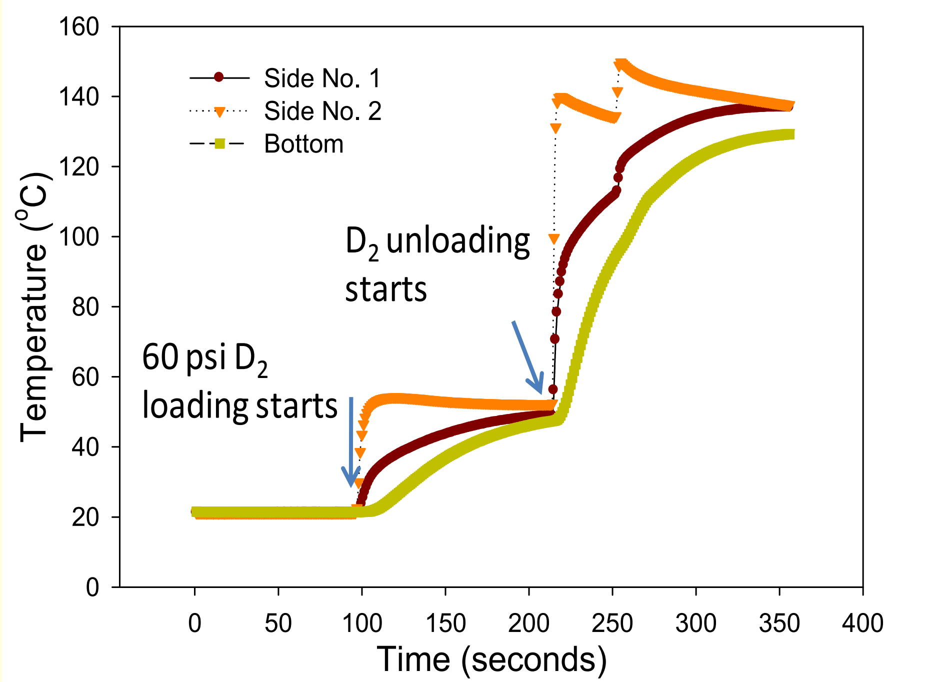
Inside View



Valve
Valve
To vacuum pump
D2 or H2 gas
Heating coil
Outer Chamber
Sample Chamber
To vacuum pump

Preliminary Excess Heat Measurement Using Our Gas Loading Calorimetry System

High purity (99.999%) D_2 gas at 4 atm
20g ZrO_2Pd_{35} nano powder
Room temperature.



Adsorption: Exothermic chemical reaction
Desorption: Endothermic chemical reaction
Chemical reaction Energy = $\Delta H \times M_{D2}$
ΔH = -35,100J per mole of D_2 for the formation of PdD_x for $x < 0.6$;
M_{D2} is the total moles of D2 that combined with Pd

Total Energy (chemical + Nuclear) Calculation:
Total energy $= \Delta T(M_{chamber} S_{chamber} + M_{powder} S_{powder})$

Δ T is temperature change, M is mass, and S is the specific heat

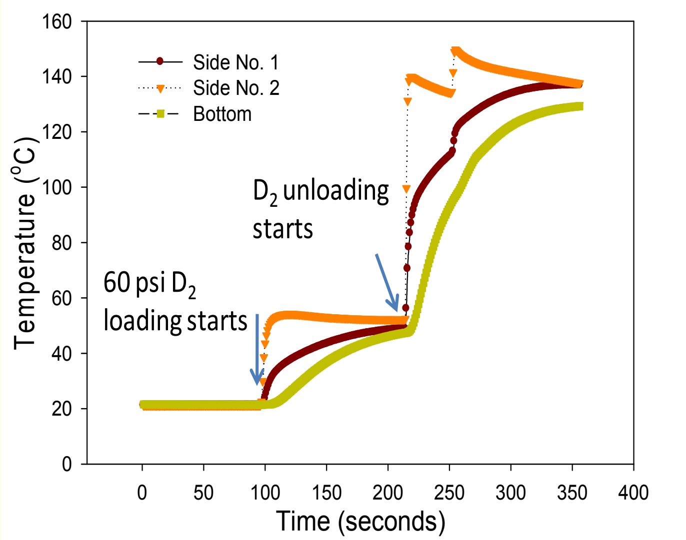
Preliminary Excess Heat Measurement Using Our Gas Loading Calorimetry System (continue)

Adsorption

Exothermic energy from chemical reaction --- **690J**

Actual measured energy -- **1479J**

Nuclear Power Density -- ca. 350W/kg
9kg, 2.25L nanoparticles = 3kW
at 4 atm and room temperature



Desorption

Endothermic chemical Reaction

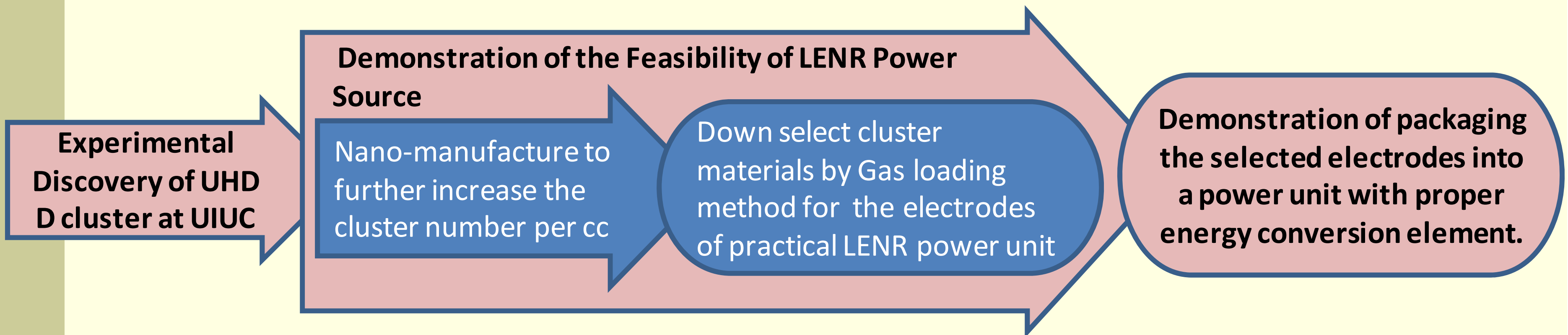
More heat were produced but mechanism is unclear

But power will be more extraordinary

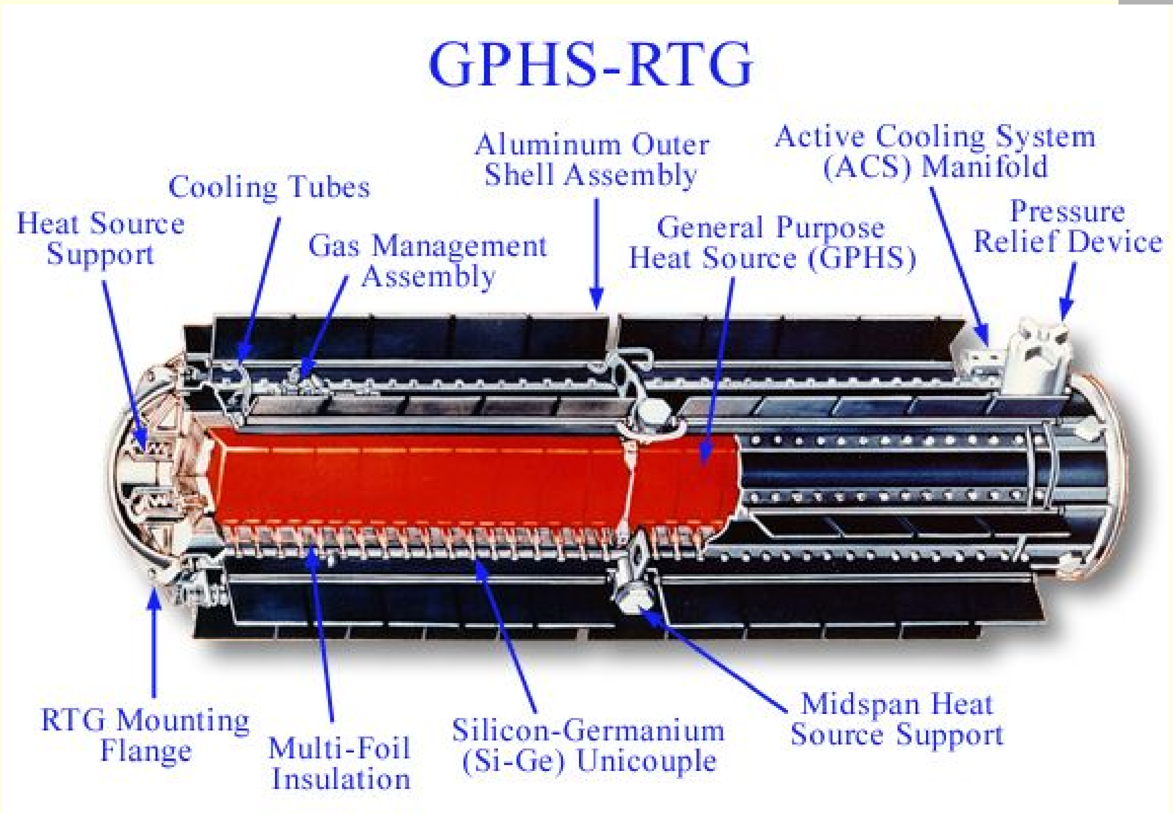
Summary – gas loading

- Experimental evidence confirms cluster formation in dislocation loops.
- Methods to fabricate high loop density under study.
- Further experiments should consider nanomaterials of different size and composition

Road Map to a Prototype LENR Unit Development



The LENR power cell is well suited for use as a “New Type RTG” with the LENR cell replacing the PU^{238}



Drawing of an GPHS-RTG that are used for Galileo, Ulysses, Cassini-Huygens and New Horizons space probes.
source:http://saturn.jpl.nasa.gov/spacecraft/safety.cfm

LENR vs. Pu^{238} for Heat Production

- Pu^{238}: 540 W/kg

  3 kW = 5.6kg, 0.28L

- LENR: 350W/kg at 4 atm and room temperature

  3kW = 9kg, 2.25L nanoparticles

  Can be improved by elevating D_2 pressure and sample temperature!!!

Many issues remain

- What is the energy producing reaction and can it be optimized?
- Alternate metals (reduce costs, improve operation, etc.
- Alternate gaseous fuel? H2,D2, Tritium, D-T, etc?
- Are there any radioactive products?
- Any emissions? Soft x-rays, charged particles, gammas?
- Lifetime issues – radiation damage to the electrode materials? Effect of reaction production structure and also on stopping later reactions?
- Burn up of fuel? Burn up of fuel in local sites?
- Is there any direct energy conversion possibility?
- If heat, what is the optimum temperate-conversion method.
- Control methods?
- ……………..

Acknowledgment

- This work is supported by the New York Community Trust and NPL Associate Inc.
- Recent experimental work was under the assistance of Monish Singh, Erik Ziehm, Chi Gyun Kim, Ittinop Dumnernchanvanit, and Seth Hartman.

FOR FURTHER INFORMATION, CONTACT

GEORGE H. MILEY
GHMILEY@UIUC.EDU
217-3333772

XIAOLING YANG
XLYANG@ILLINOIS.EDU