LENR at GRC

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BACKGROUND: "Cold Fusion"?

S. Pons and M. Fleischmann holding cold fusion cell

Headlines 1989

Two electrochemists…

Martin Fleischmann

Stanley Pons

claimed to have tapped nuclear power in a simple electrochemical cell.

"It could be the end of the fossil fuel age: the end of oil and coal. And the end, incidentally, of many of our worries about global warming."

-- Sir Arthur C. Clarke

BACKGROUND: The Advantage of Fusion

Burning Coal:

- $C + O_2 \rightarrow CO_2$ (4 eV)

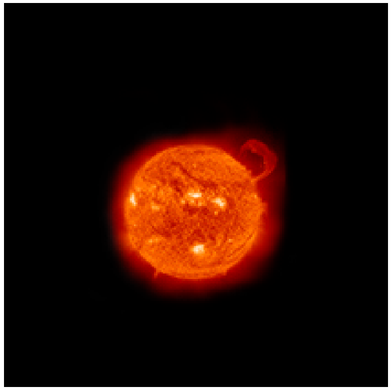
Fission Power Reaction:

- $^{235}U + n \rightarrow {}^{236}U$
  $\rightarrow {}^{141}Ba + {}^{92}Kr + 3 \cdot n$ (170 MeV)

Fusion Processes:

- $D + D \rightarrow T$ (1.01 MeV) + p (3.02 MeV)
- $D + D \rightarrow {}^{3}He$ (0.82 MeV) + n (2.45 MeV)
- $D + D \rightarrow {}^{4}He$ (73.7 keV)+ γ (23.8 MeV)
- $D + T \rightarrow {}^{4}He$ (3.5 MeV) + n (14.1 MeV)
- $D + {}^{3}He \rightarrow {}^{4}He$ (3.6 MeV) + p (14.7 MeV)
  - $D = {}^{2}H$, $T = {}^{3}H$
- Fusion is at least 13% more productive per mass of fuel (without the nasty waste products)

Coal Power Plant

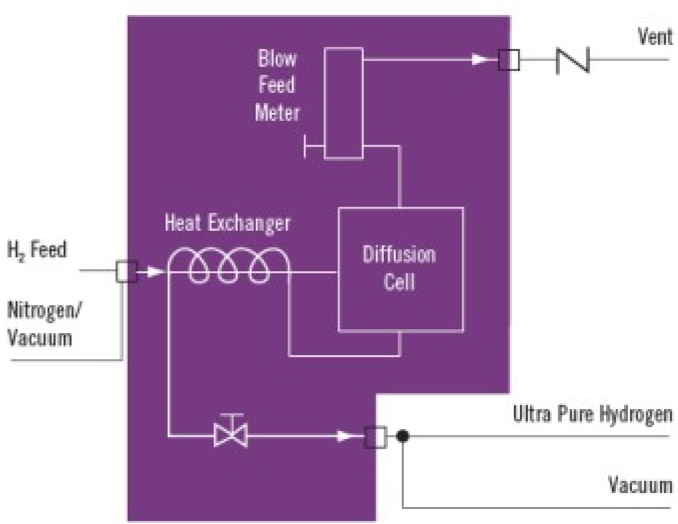


The Sun: a gravitationally confined fusion reactor

BACKGROUND: Purifier Schematic

- Johnson Matthey HP Series palladium membrane hydrogen purifier
- Used in the semiconductor industry and applications where ultra-high purity hydrogen is required (to 99.9999999%)
- An at-hand substitute for a palladium electrolytic cell

Flow Diagram HP Series



BACKGROUND:1989 Cold Fusion Experiment

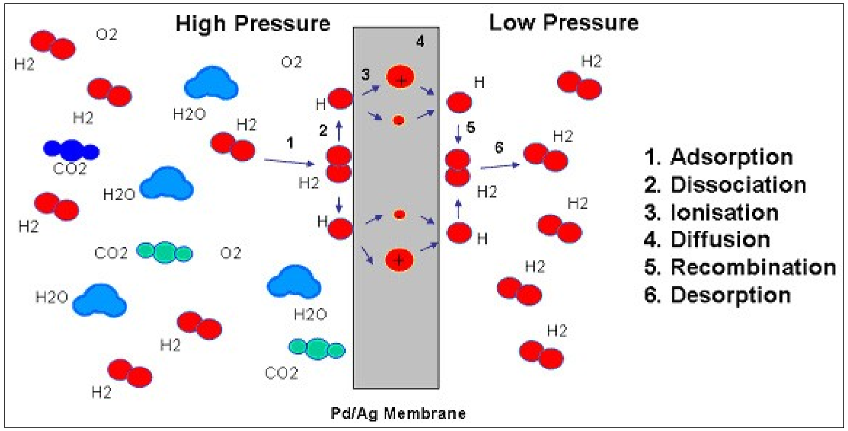
EQUIPMENT

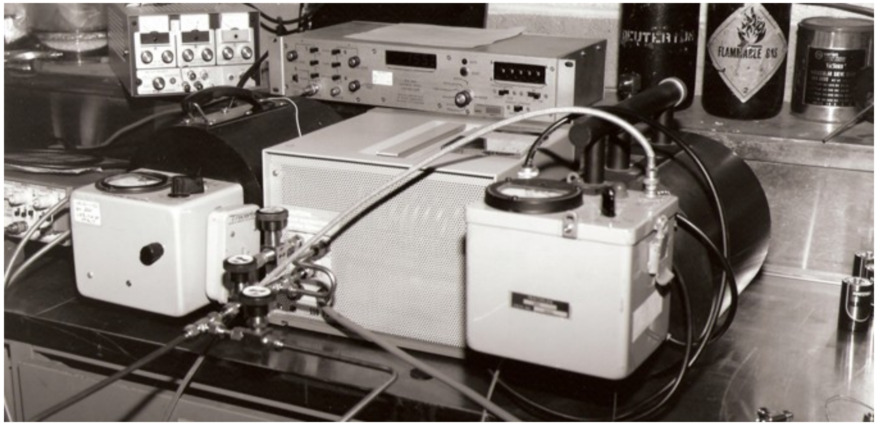
Hydrogen purifiers are made using Palladium membranes

EXPERIMENT

After evacuating purifier, it was loaded with deuterium gas at pressures up to 250 psig.

Purifier temperature and neutron count monitored for several months–non electrochemical variant of Pons-Fleischmann experiment





Hydrogen purifier (center) with neutron detectors on either side

BACKGROUND: 1989 Cold Fusion Experiment

Results:

- Temperature increase noted while gas was loaded into palladium cell, for both D & H
- Neutron detector counts did not differ significantly ($\leq 2\sigma$) from background in any run (Monitored with BF_3 w/ Polyethylene ["Snoopy"] detectors).
- Temperature increase noted when D unloaded at end of experiment
- Compared to hydrogen gas as the experimental control: 15°C increase in purifier temperature consistently seen with D_2 that was not seen with the H_2 control when gasses were unloaded from the purifier.

Purifier plumbing, showing vacuum pump used to evacuate cell, and gas bottle used to load cell

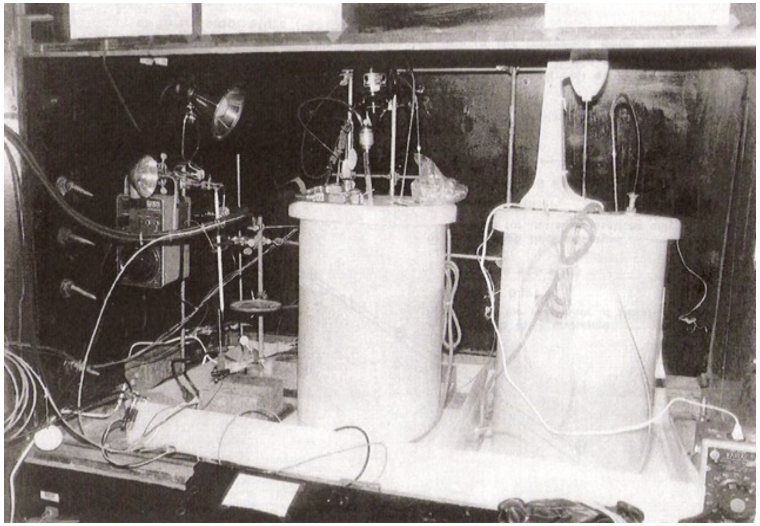
Published:

- *Fralick, Decker, & Blue (1989)* NASA TM-102430

BACKGROUND: H_2O-Ni-K_2CO_3 Electrolytic Cell

Experiment:

- Investigated reports of significant long-term excess heat in light water-Ni-K_2CO_3 electrolytic cells
- Two 28-liter electrolytic cells for tests, one active cell for electrolytic tests, second inactive cell for reference thermal measurements
- Tested at several dc currents and a pulse mode current



Two 28 liter electrolytic cells

Results:

- Apparent current-dependent excess heat exhibited when tested in all modes
- Excess heat consistent as heat from hydrogen-oxygen recombination catalyzed by the Pt and Ni electrodes within the cell
- Did not reproduce the large excess heat reported in literature
  - Gain Factors of <1.7 @ GRC vs. >10 in literature

•NASA TM-107167 (J. Niedra, I. Myers, G. Fralick, R. Baldwin; 1996)

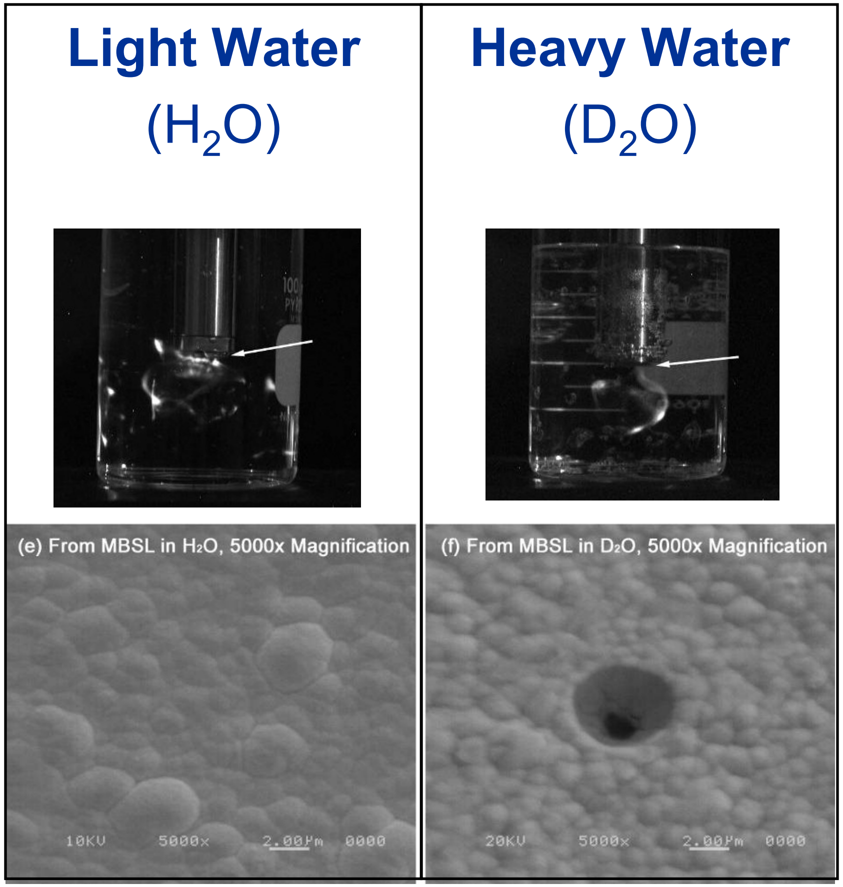
BACKGROUND: Sonoluminescence

Experiment

- Sonoluminescence with Palladium-Chromium (PdCr) Thin Films Over Platinum (Pt) RTD (Resistance Temperature Device)Traces on Alumina

Result

- No Crater seen in H_2O, Crater Formation seen in D_2O
- Large Grain Failures <u>usually</u> seen in thin films due to mismatches in coefficients of thermal expansion at <u>high temperature</u> (~1000°C)



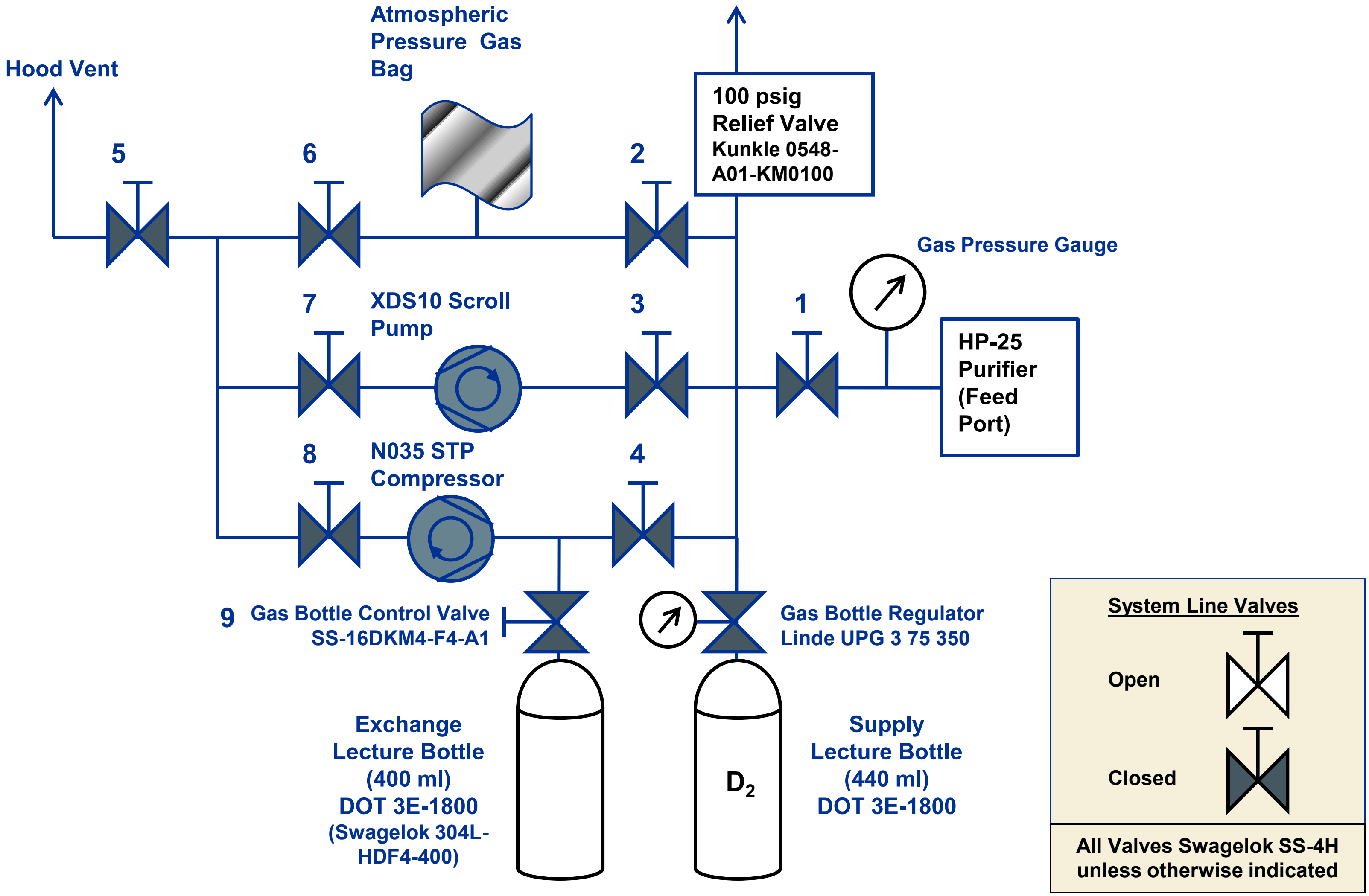
Surface morphology of films exposed to sonoluminescence in light water (left) and heavy water (right)

- John Wrbanek, Gustave Fralick, Susan Wrbanek, & Nancy Hall "Investigating Sonoluminescence as a Means of Energy Harvesting," Chapter 19, *Frontiers of Propulsion Science*, Millis & Davis (eds), AIAA, pp. 605-637, 2009.

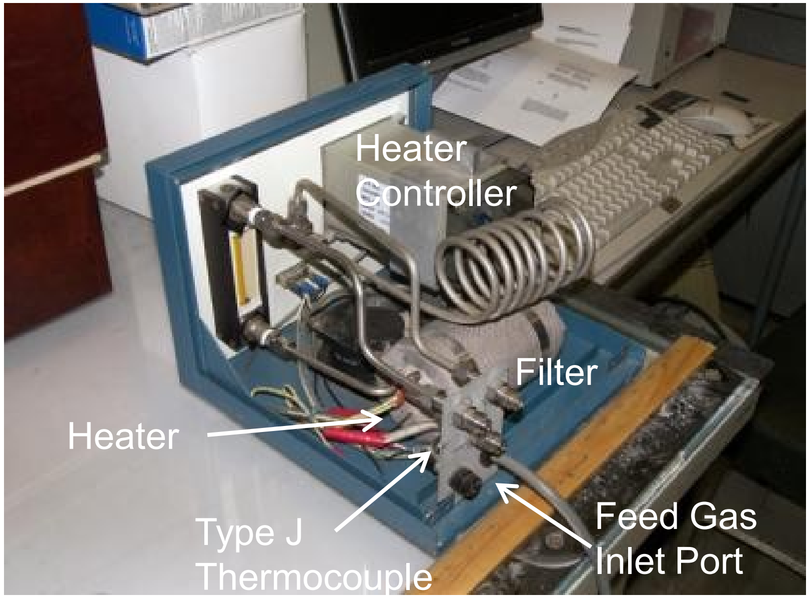
BACKGROUND: Changes from 1989 to 2009

- Previous NASA D-Pd experiment (Fralick, et al.; 1989) looked for neutrons (saw none) – but saw anomalous heating
- NASA H_2O-Ni-K_2CO_3 Electrolytic Cell experiment (Niedra et al,1996) Apparent current-dependent excess heat consistent as heat from hydrogen-oxygen recombination
- NASA Sonoluminescence Experiment (Wrbanek, et al) - Cratering seen with heavy water, not seen with light water
- After 1989, Cold Fusion research evolved into research in “Low Energy Nuclear Reactions” (LENR), primarily at U.S. Navy, DARPA & various Universities
- **2009: NASA IPP-sponsored effort to:**
  - Repeat the initial tests to investigate this anomalous heat
  - Apply GRC’s instrumentation expertise to improve the diagnostics for this experiment
  - Establish credible framework for future work in LENR

APPROACH: Flow System Schematic



APPROACH: 2009 Test Apparatus



Purifier Interior

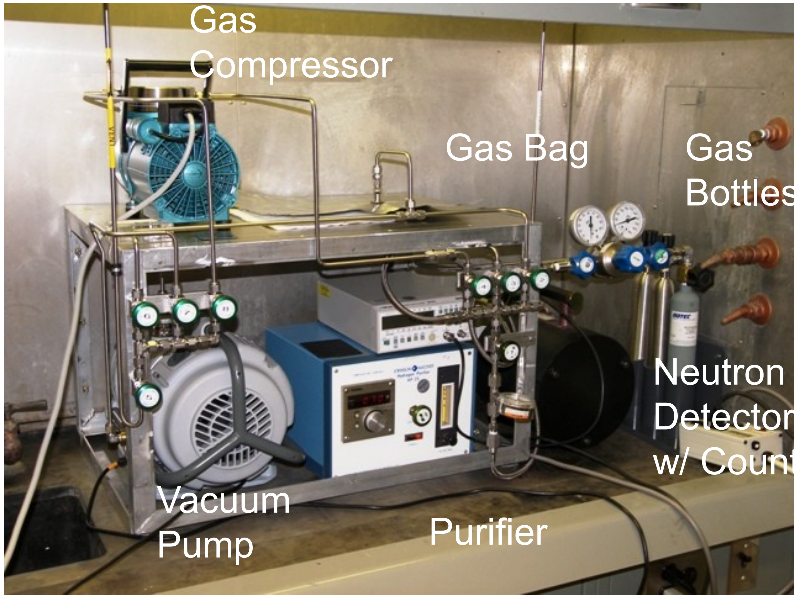


Photo of 2009 GRC test setup

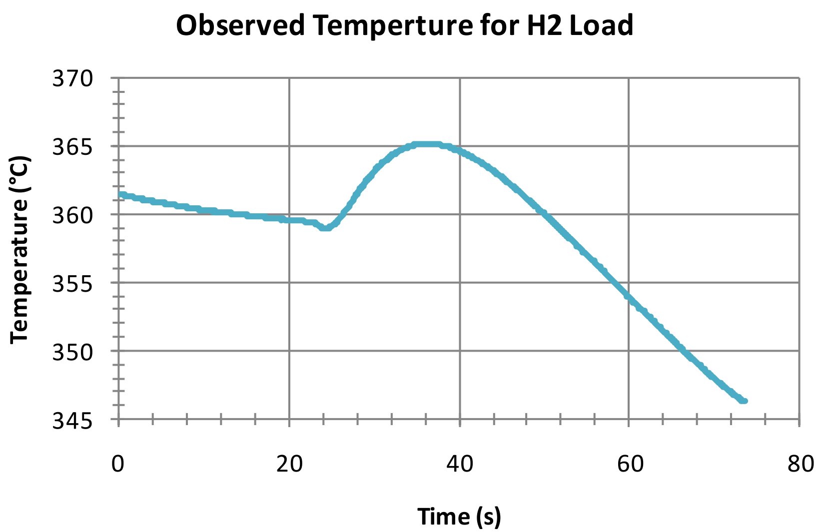
- Johnson Matthey HP-25 hydrogen purifier
  - Purifier Filter contains a ~50g heated Pd-25%Ag membrane
- Load Filter by flowing hydrogen gas into the purifier
- Unload Filter by pumping the gas out of the purifier into a sample bottle
- Turn off filter heater for a time when Loading & Unloading
- Monitor changes in temperature, neutron/gamma background
- Repeat with deuterium gas; Compare results

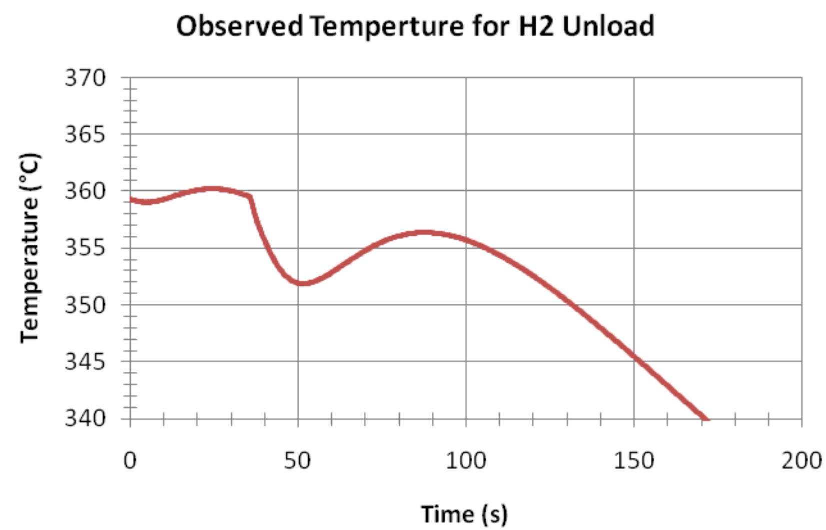
RESULTS : Temperatures vs. Time

Loading

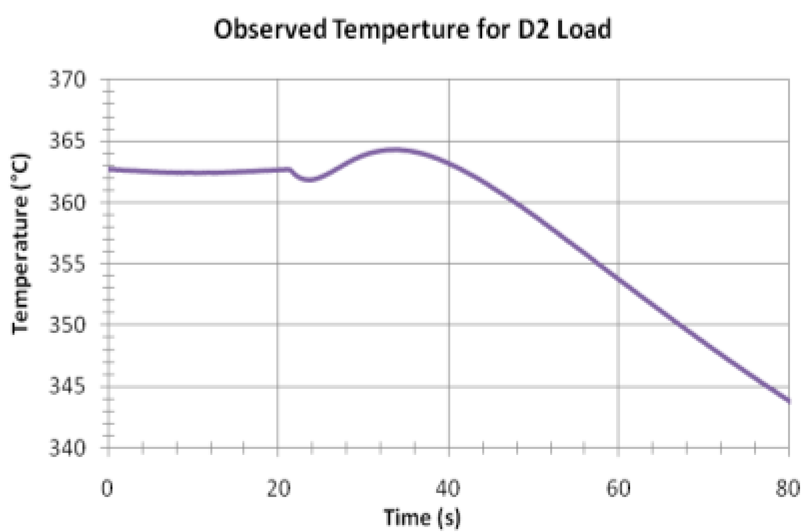
Unloading

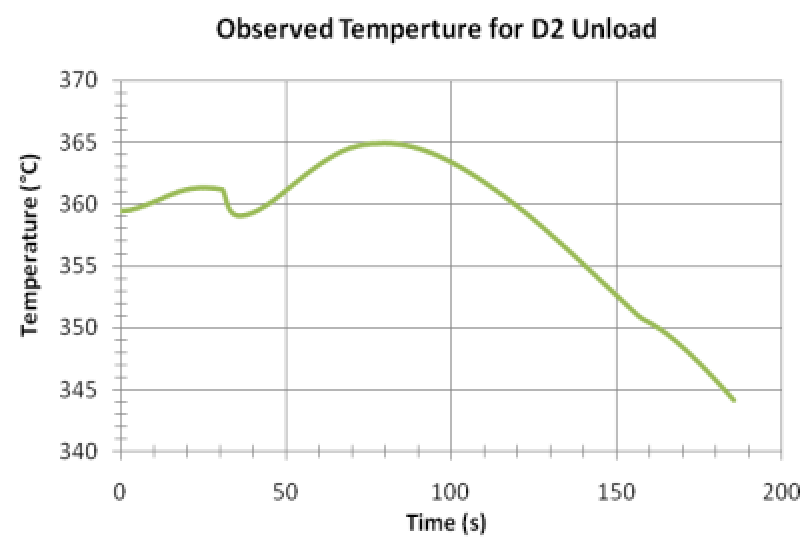
Hydrogen



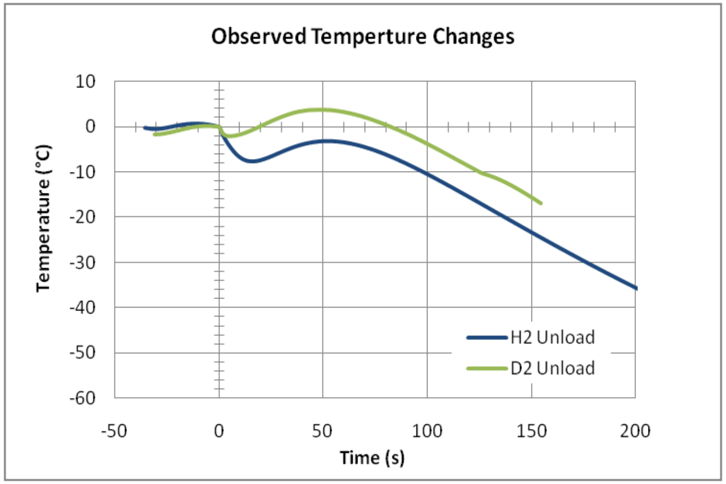


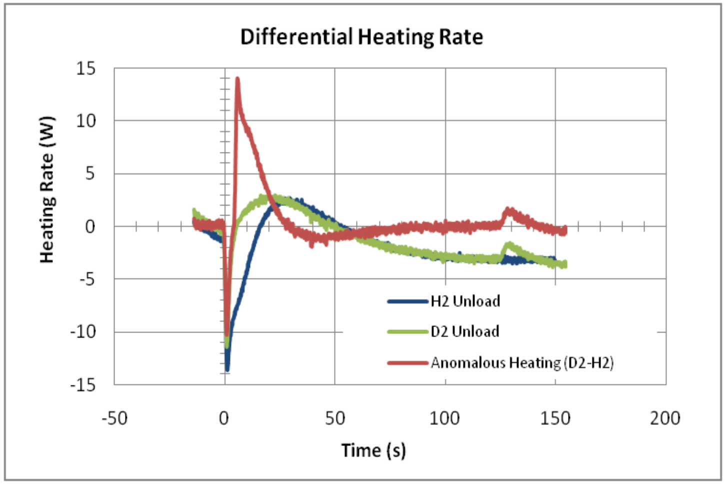
Deuterium





RESULTS (continued): Temperature vs. Time



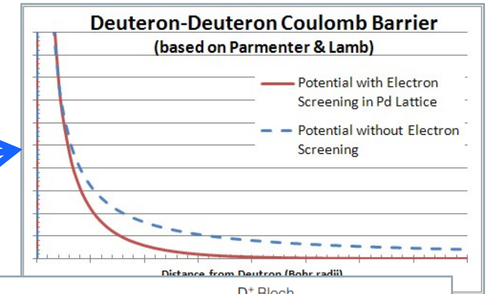


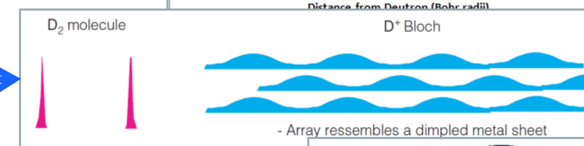
Results of GRC IPP investigation: a) the temperature data is shown for H2 and D2 unloading (left); b) the calculated thermal power in/out is given with the net anomalous heating (right).

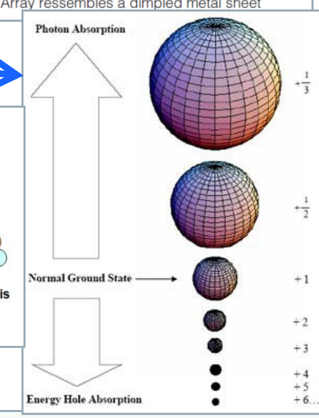
Hypotheses

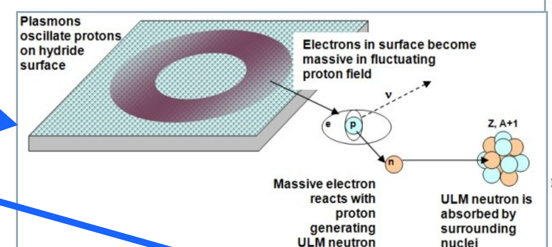
"Pet Theories" (i.e., Hypotheses where proponents already convinced peer-reviewed journals):

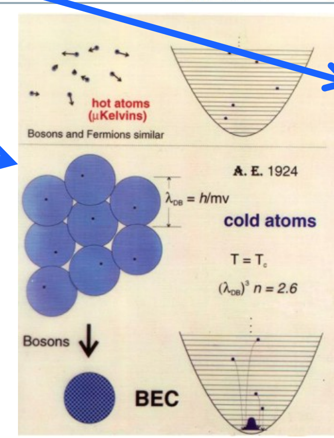
- Electron Screening (Parmenter & Lamb)
- Band States (Chubb & Chubb)
- Shrunken Hydrogen (Maly, Vavra & Mills)
- Ultra Low Momentum Neutrons (Widom & Larsen)
- Dislocation Loops (Hora & Miley)
- Bose-Einstein Condensates (Kim)

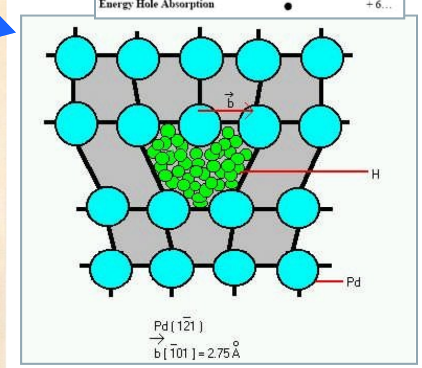








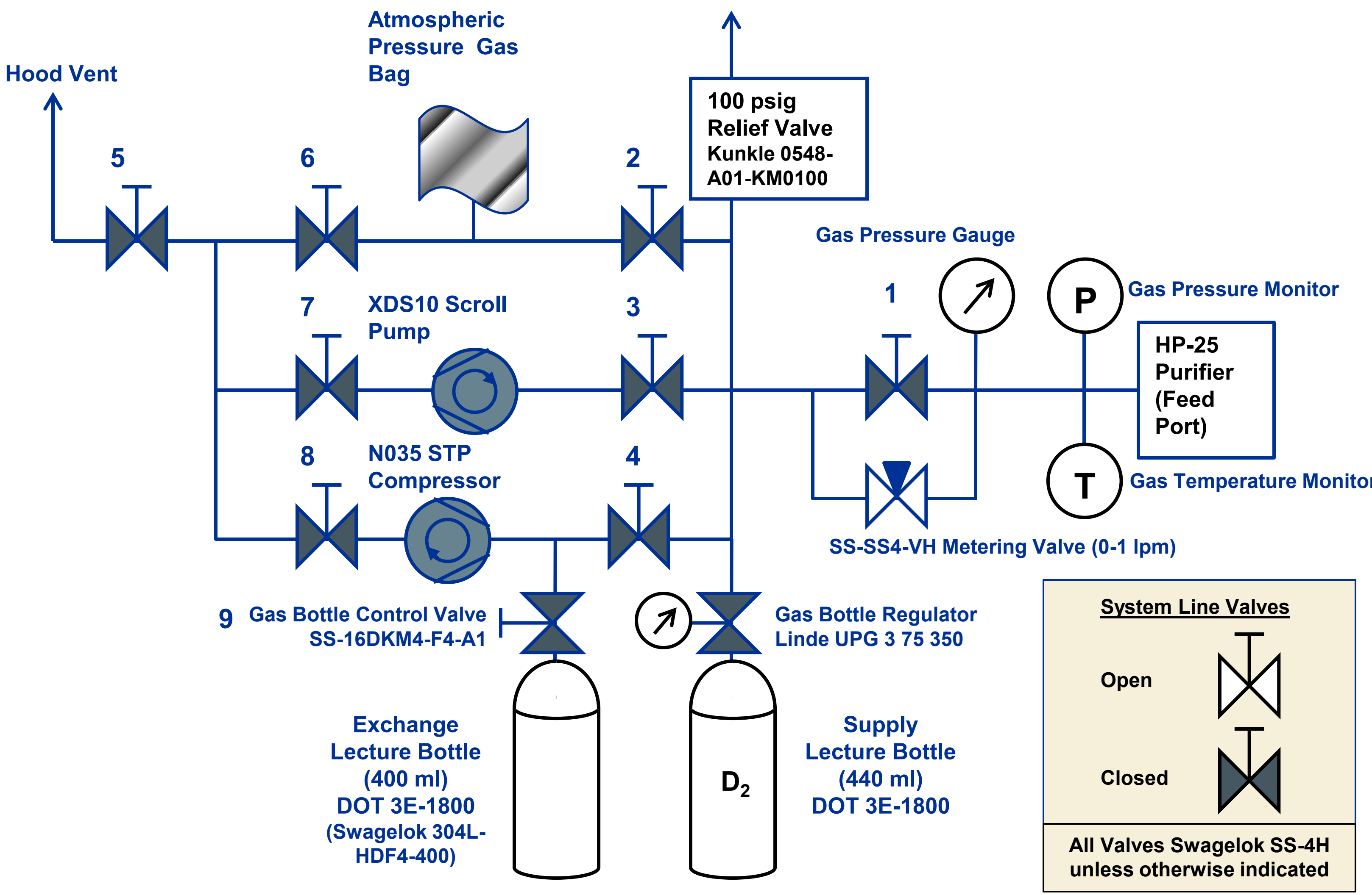




Do any of these encompass <u>all</u> reported observations?

- *More than one effect may be occurring*

2011 Effort: Monitor temperature and pressure simultaneously for different rates of unloading



Future Tests?: Stirling Laboratory Research Engine (SLRE) at Cleveland State University

Stirling Laboratory Research Engine (SLRE)

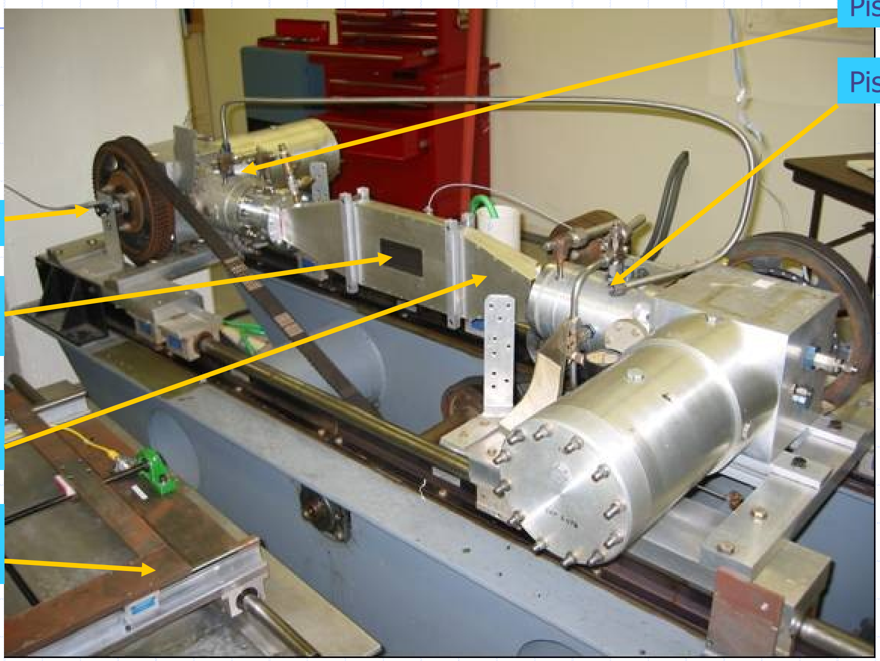


Photo courtesy Professor Mounir Ibrahim. Used by permission

Parameters	SLRE
Design Power, hp (kw)	12 (9)
Design Pressure, psi (N/mm^2)	1000 (7)
Working Gas	H2/He
Cylinder Bore, inch (mm)	2.87 (73)
Piston Stroke, inch (mm)	2.12 (54)
Hot Gas Temperature, F (°C)	1400 (760)
Cold Gas Temperature, F (°C)	150 (65)
Drive System	C' Shaft

PoC: Dr. Mounir Ibrahim
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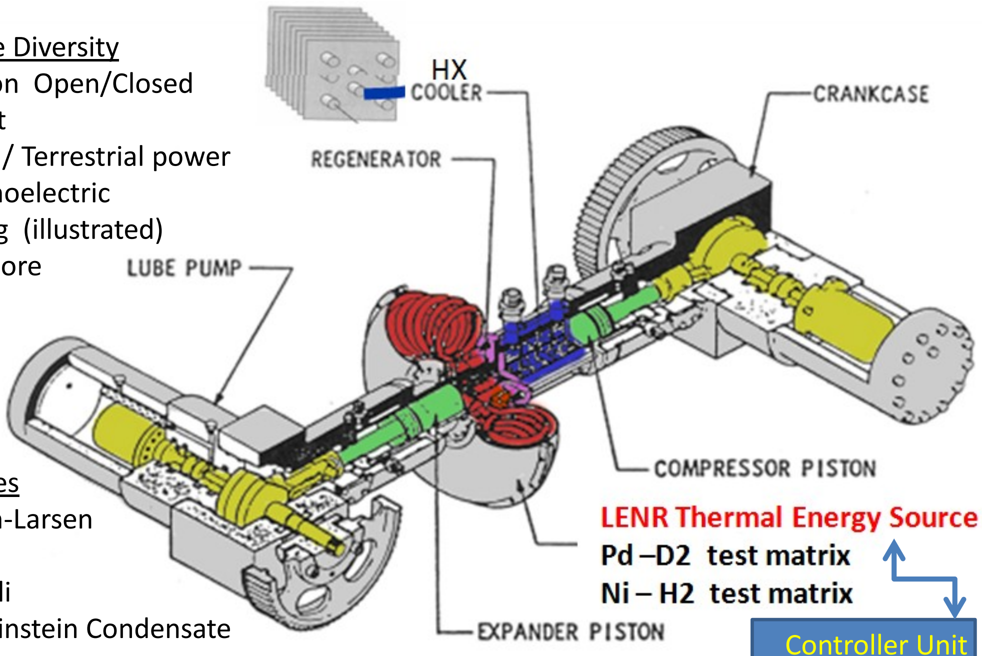
Schematic of the Stirling Laboratory Research Engine at Cleveland State University

LENR Energy to Rotational Power Research Facility

***Research**: Theory, Computational Dynamics, Reactor diversity, matrix elements, size, scale, rates, materials , blends, catalysts operational limits, device interfacing, HX, shielding, controls, instrumentation, communications, safety and more*

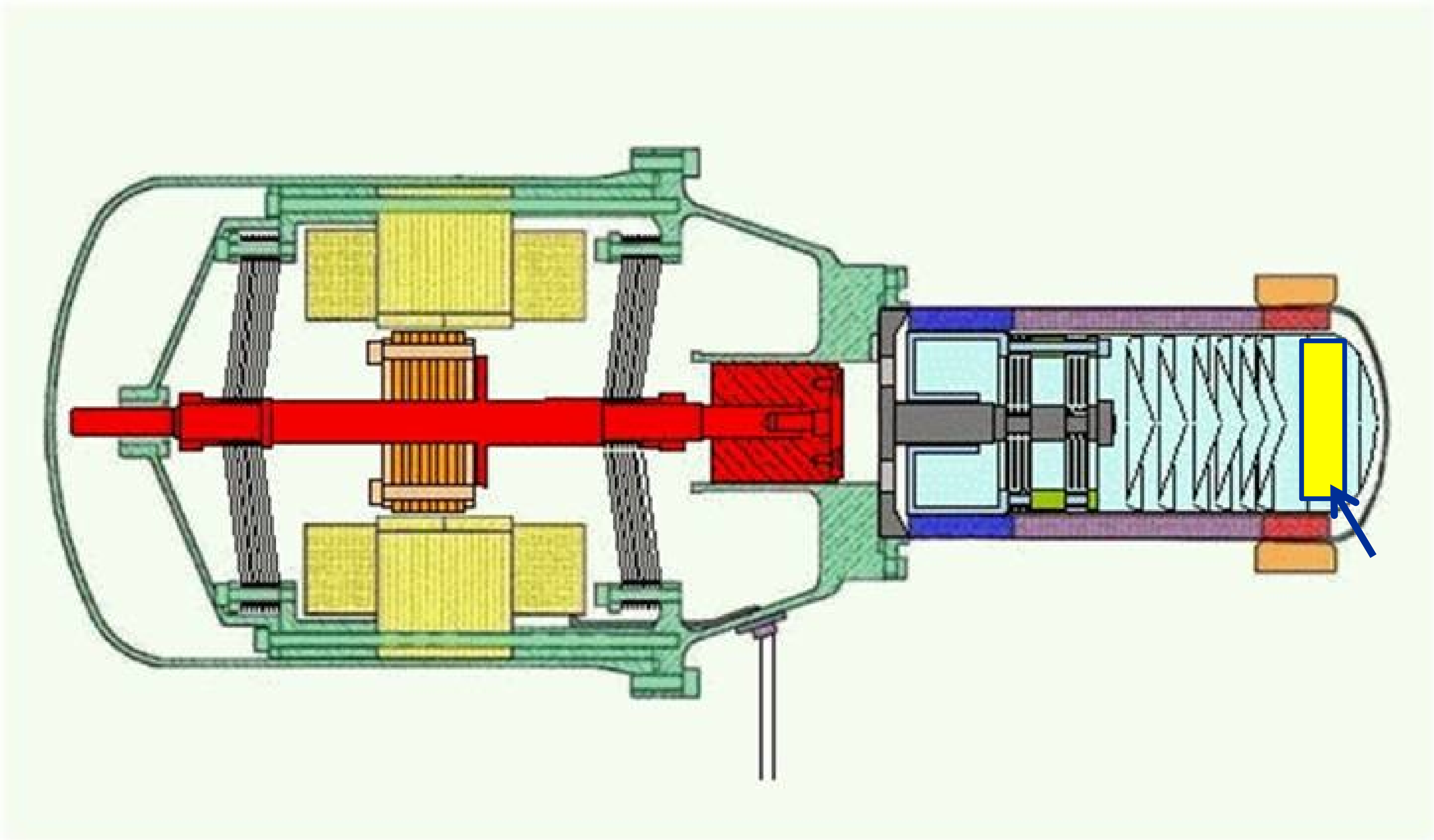
Device Diversity
Brayton Open/Closed
Rocket
Space / Terrestrial power
Thermoelectric
Stirling (illustrated)
and more



Theories
Widom-Larsen
Rossi
Piantelli
Bose-Einstein Condensate
And more

Drawing courtesy Professor Mounir Ibrahim. Used by permission

Future Power Source? Free-Piston Stirling Engine Schematic with D/Pd Energy Source



Benefits for NASA

- Replace ^{238}Pu as power source in deep space missions
  - Currently in short supply
  - Now depend upon foreign sources
  - Perhaps 5 years to supply our own
  - No money in new budget to restart domestic production
- Replace fission reactors as power source for human habitation missions
  - No radioactive waste
  - No radioactive material accident hazard on launch

References

- Fralick, G., Decker, A., Blue, J., "Results of an Attempt to Measure Increased Rates of the Reaction $^2D + ^2D \rightarrow ^3He + n$ in a Non-electrochemical Cold Fusion Experiment," NASA TM-102430 (1989).
- Niedra, J., Myers, I., Fralick, G., Baldwin, R. "Replication of the Apparent Excess Heat Effect in a Light Water-Potassium Carbonate-Nickel Electrolytic Cell", NASA TM-107167 (1996)
- Li, Xing Z.; Liu, Bin; Tian, Jian; Wei, Qing M.; Zhou, Rui and Yu, Zhi W.: "Correlation between abnormal deuterium flux and heat flow in a D/PD system," *J. Phys. D: Appl. Phys.* **36** 3095-3097 (2003).
- Miley, G.H., N. Luo, and A. Lipson, "Proton Transport Through Atomic Layer Coated Thin-films", March Meeting 2003 of the APS, vol. 2, pp.1124, March 3-7, (2003).
- Liu, Bin; Li, Xing Z.; Wei, Qing M.; Mueller, N.; Schoch, P. and Orhre, H. "'Excess Heat' Induced by Deuterium Flux in Palladium Film." *The 12th International Conference on Condensed Matter Nuclear Science*, Yokohama, Japan, Nov. 27 – Dec. 2, 2005
- Widom, A., Larsen, L., "Ultra Low Momentum Neutron Catalyzed Nuclear Reactions on Metallic Hydride Surfaces," *Eur. Phys. J. C* (2006)

References (cont.)

- Wrbanek, J., Fralick, G., Wrbanek, S., "Development of Techniques to Investigate Sonoluminescence as a Source of Energy Harvesting", NASA TM-2007-214982 (2007)
- Biberian, J.P. and Armanet, N.: "Excess Heat Production During Diffusion of Deuterium Through Palladium Tubes" *8th International Workshop on Anomalies in Hydrogen/Deuterium Loaded Metals*, Sicily, Italy, 2007.
- Kim, Y. E., "Theory of Bose-Einstein Condensation for Deuteron-Induced Nuclear reactions in Micro/Nano-Scale Metal Grains and Particles", *Naturwissenschaften 96, 803(2009).*
- Wrbanek, J., Fralick, G., Wrbanek, S., Hall, N. "Investigating Sonoluminescence as a Means of Energy Harvesting," Chapter 19, *Frontiers of Propulsion Science*, Millis & Davis (eds.), AIAA, pp. 605-637, 2009.
- Fralick, G., Wrbanek, J., Wrbanek, S., Niedra, J., Millis, M., "Investigation of Anomalous Heat Observed in Bulk Palladium", IPP Final Report (2009)