



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:

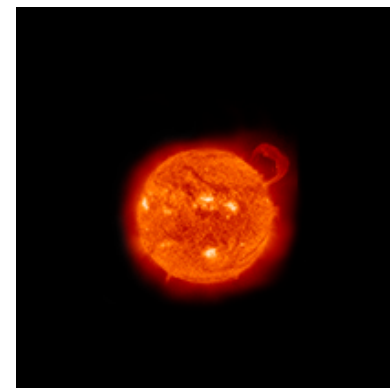
- $^{235}\text{U} + n \rightarrow ^{236}\text{U}$
 $\rightarrow ^{141}\text{Ba} + ^{92}\text{Kr} + 3 \cdot n$ (170 MeV)

Fusion Processes:

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



Coal Power Plant



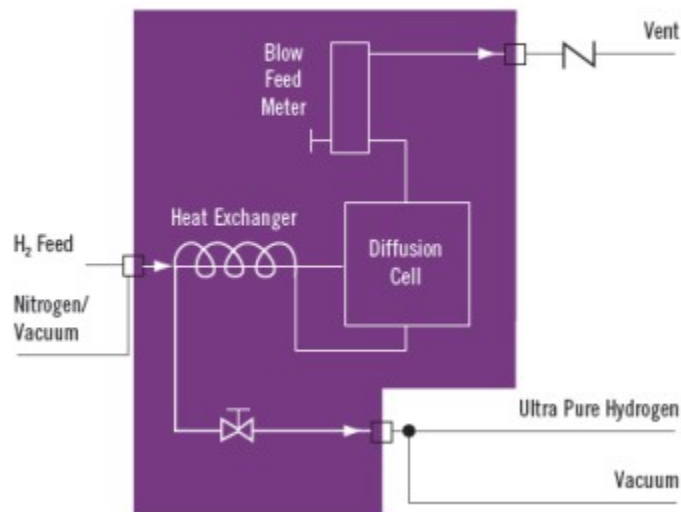
The Sun: a gravitationally confined fusion reactor

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

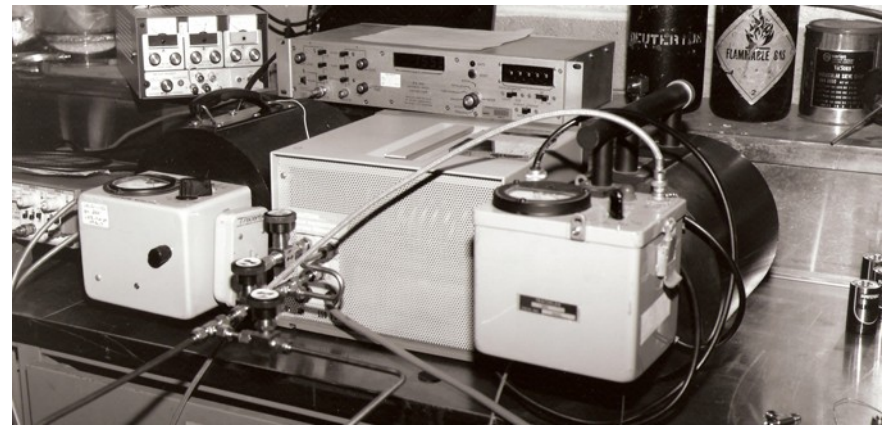
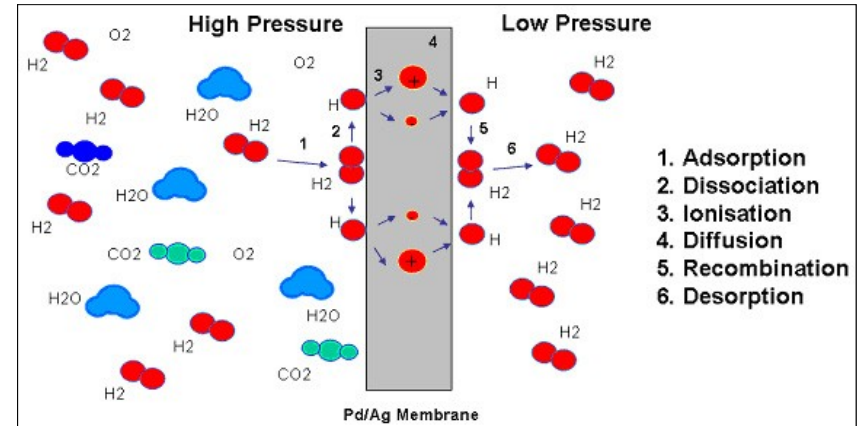
EQUIPMENT

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.

Published:

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

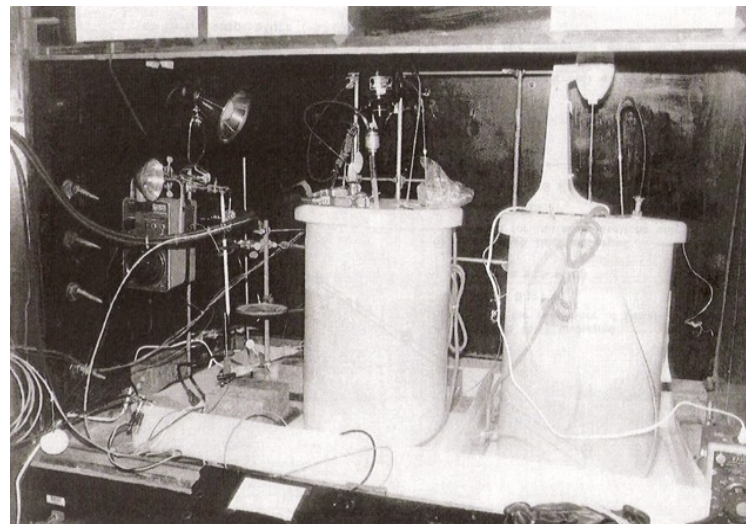


Purifier plumbing, showing vacuum pump used to evacuate cell, and gas bottle used to load cell

BACKGROUND: $\text{H}_2\text{O-Ni-K}_2\text{CO}_3$ 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)

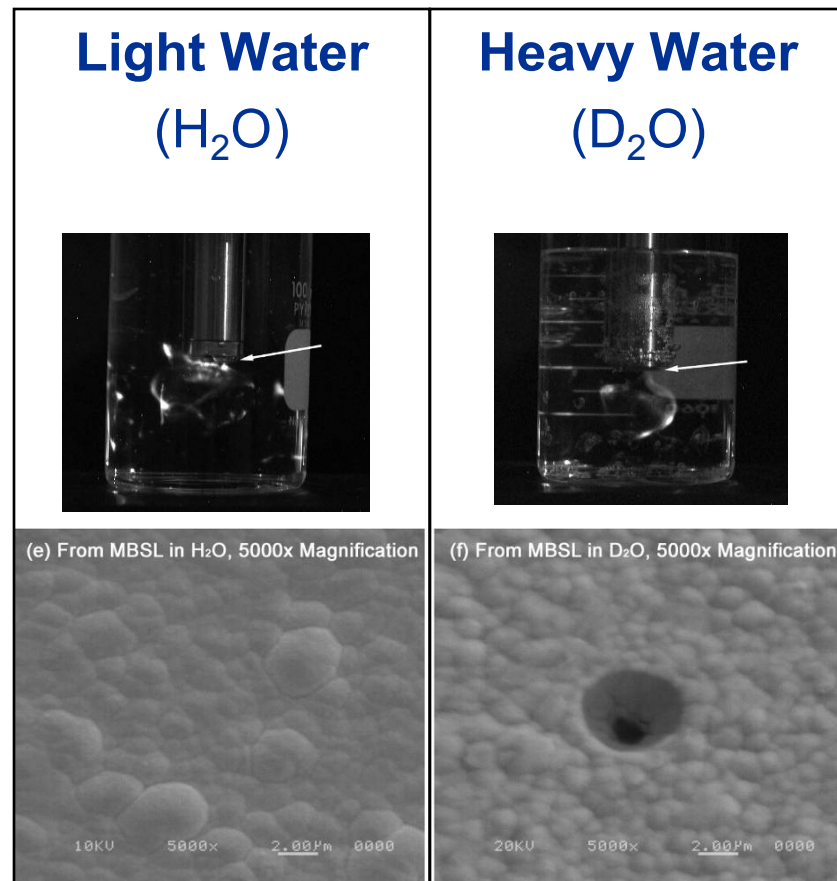
BACKGROUND: Sonoluminescence

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 usually seen in thin films due to mismatches in coefficients of thermal expansion at high temperature ($\sim 1000^\circ\text{C}$)



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.

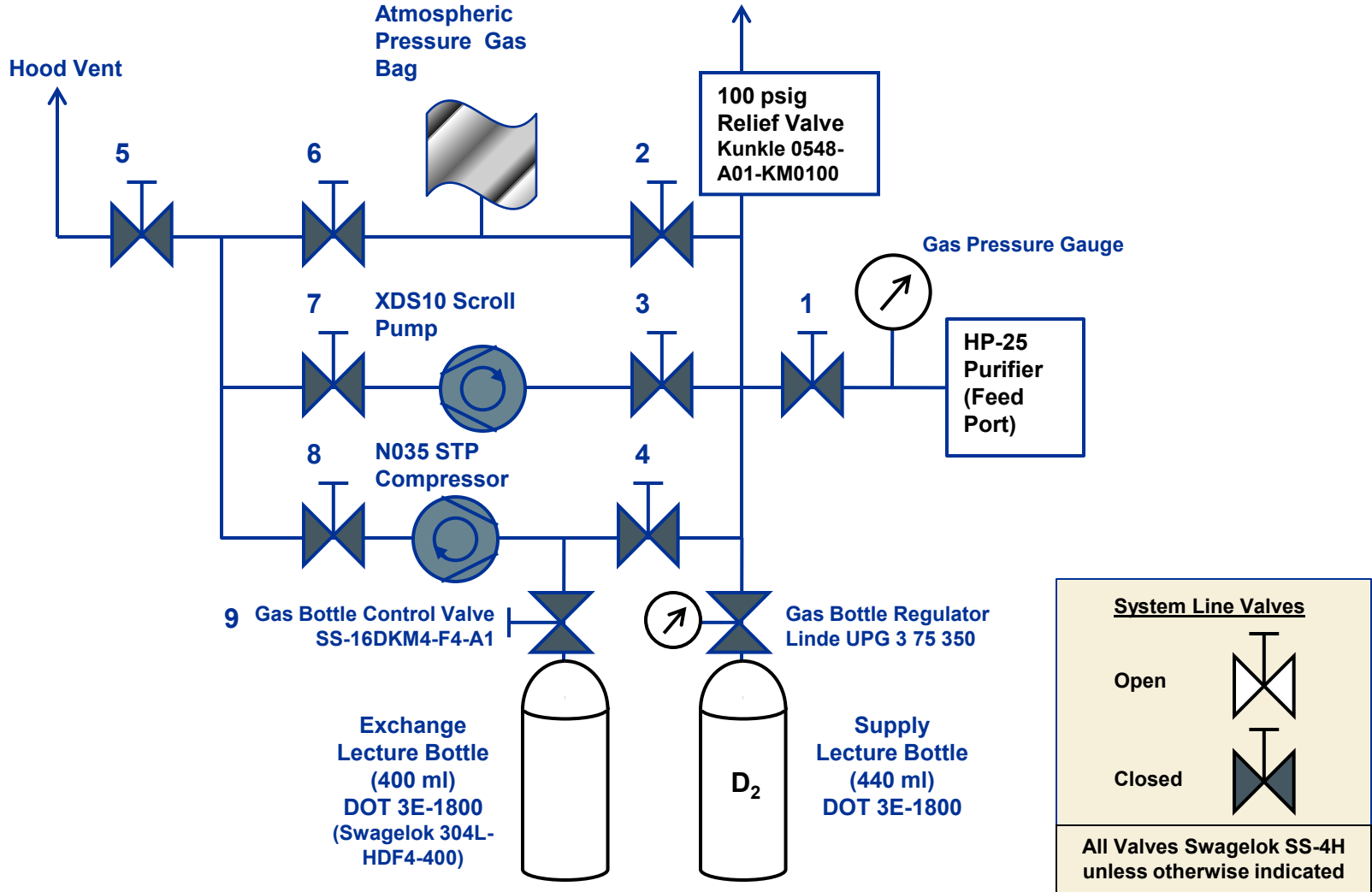


BACKGROUND: Changes from 1989 to 2009

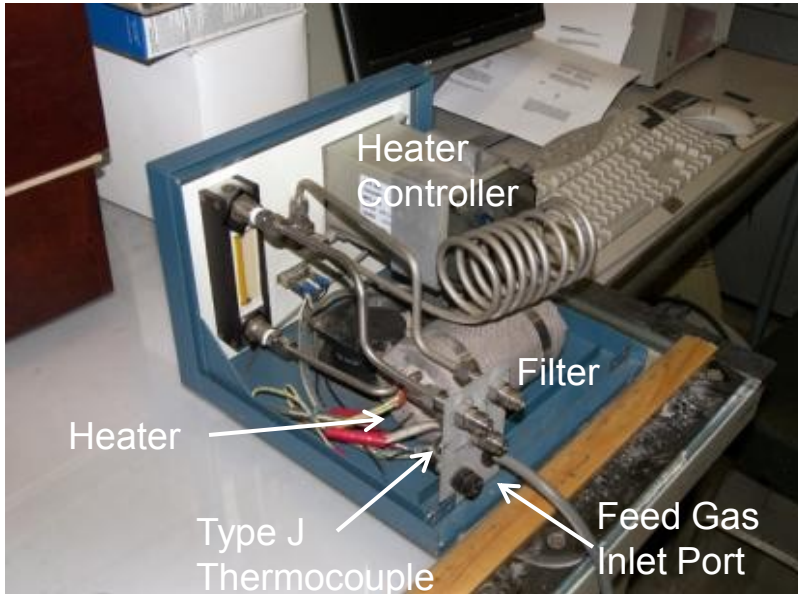
- Previous NASA D-Pd experiment (Fralick, et al.; 1989) looked for neutrons (saw none) – but saw anomalous heating
- NASA H₂O-Ni-K₂CO₃ Electrolytic Cell experiment (Niedra et al, 1996) Apparent current-dependent excess heat consistent as heat from hydrogen-oxygen recombination
- NASA Sonoluminescence 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

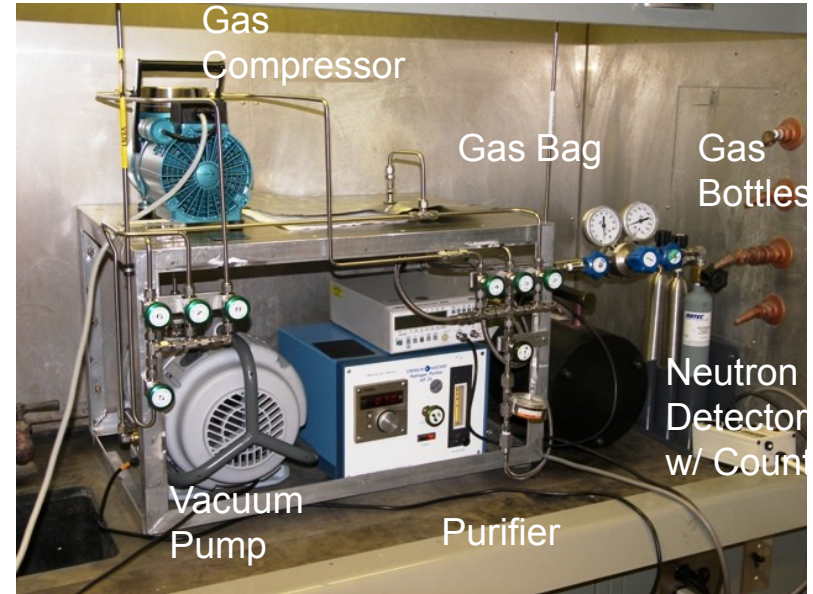


Photo of 2009 GRC test setup

- 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



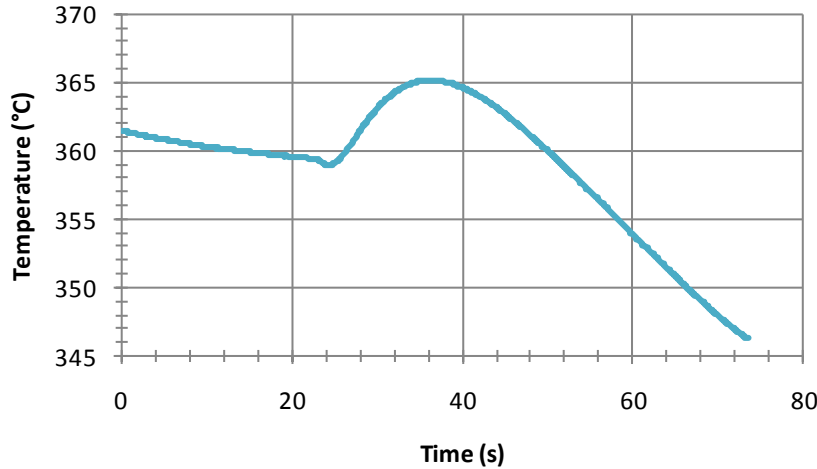
RESULTS : Temperatures vs. Time

Loading

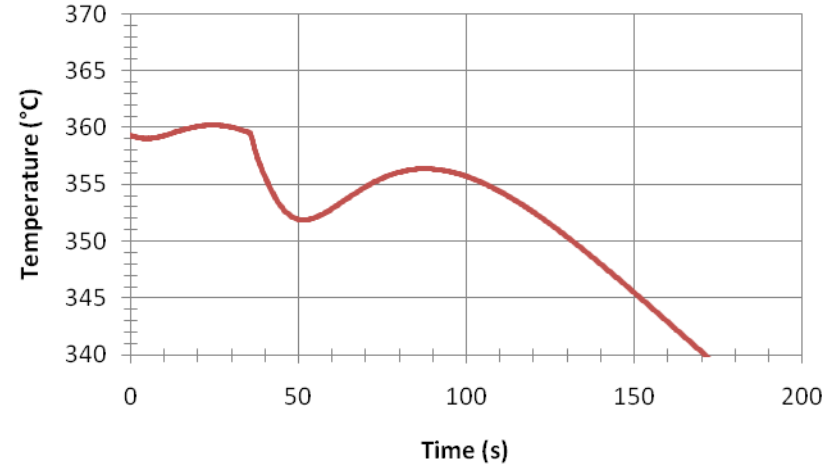
Unloading

Hydrogen

Observed Temperature for H2 Load

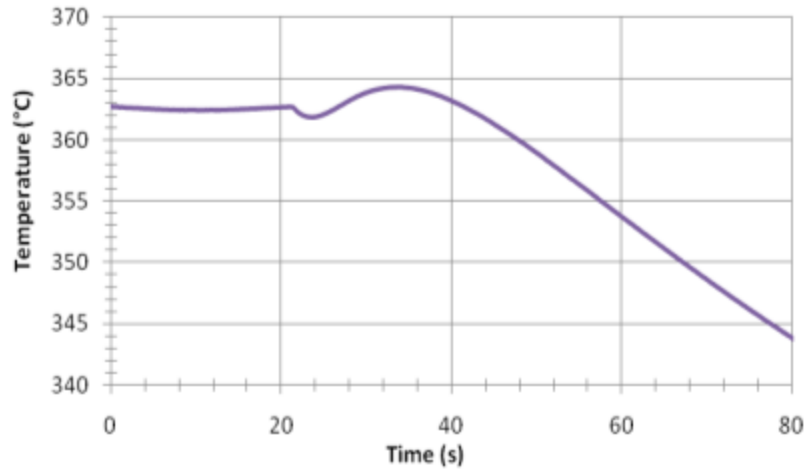


Observed Temperature for H2 Unload

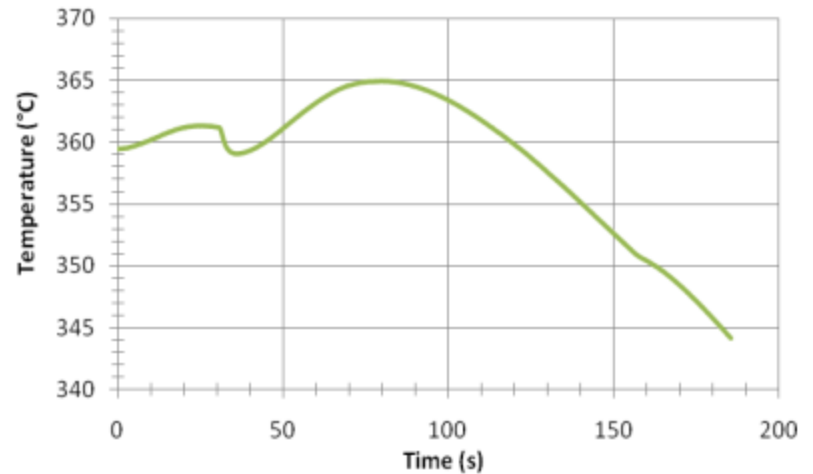


Deuterium

Observed Temperature for D2 Load

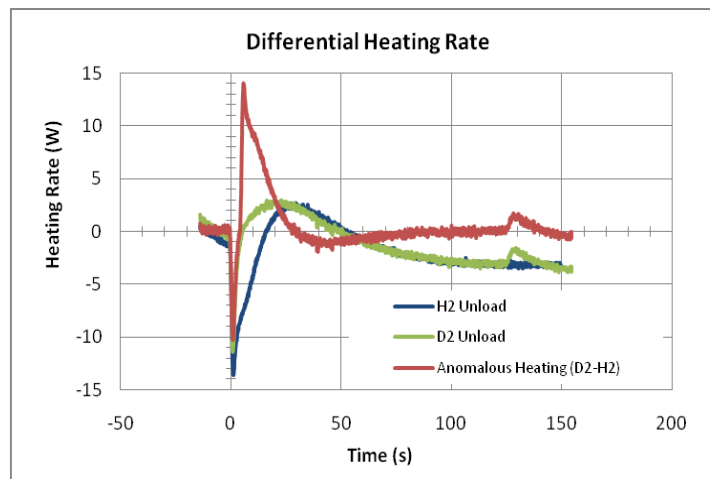
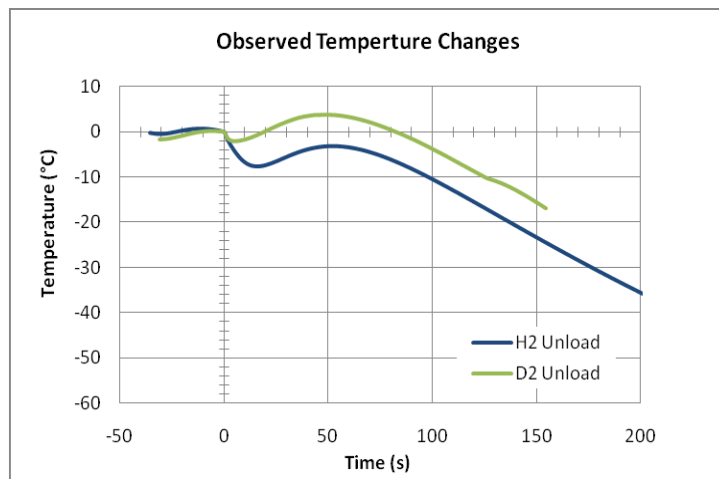


Observed Temperature for D2 Unload





RESULTS (continued): Temperature vs. Time



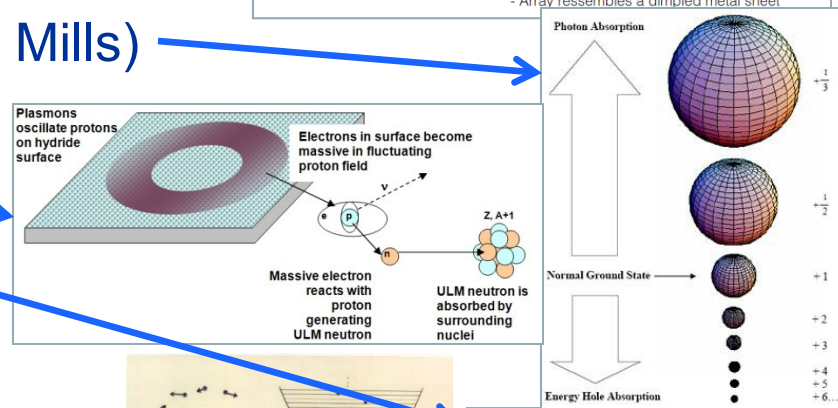
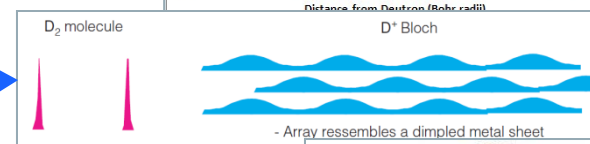
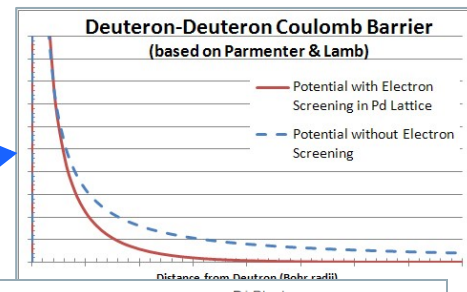
Results of GRC IPP investigation: a) the temperature data is shown for H2 and D2 unloading (left); b) the calculated thermal power in/out is given with the net anomalous heating (right).



Hypotheses

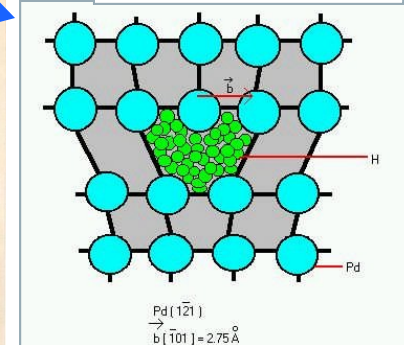
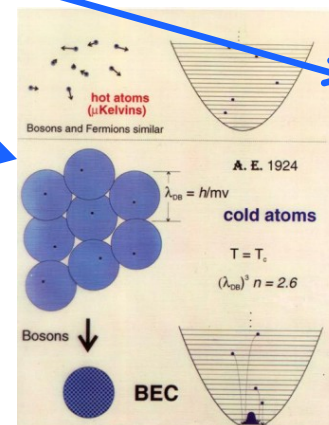
“Pet Theories” (i.e., Hypotheses where proponents already convinced peer-reviewed journals):

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



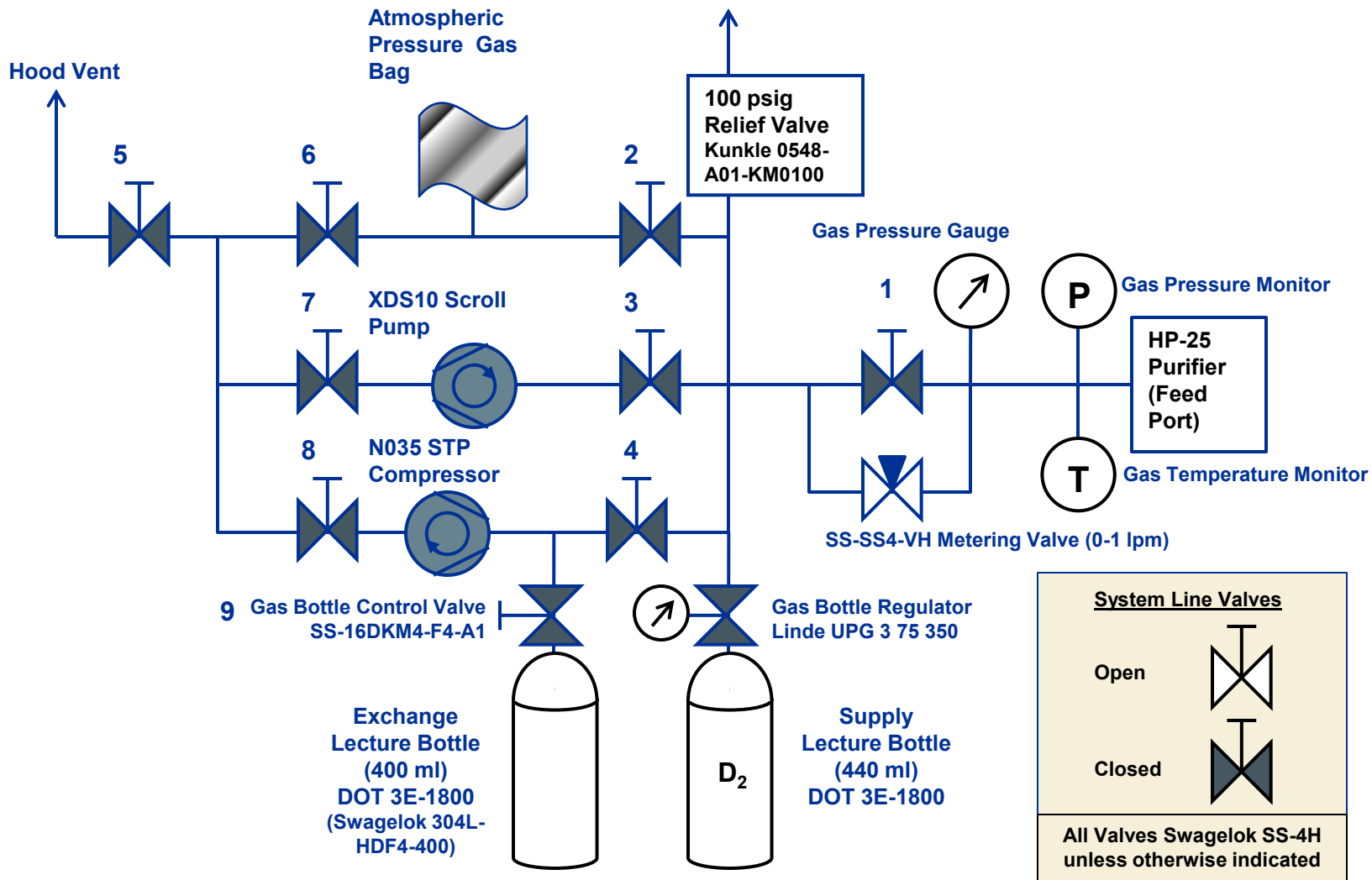
Do any of these encompass all reported observations?

- *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)

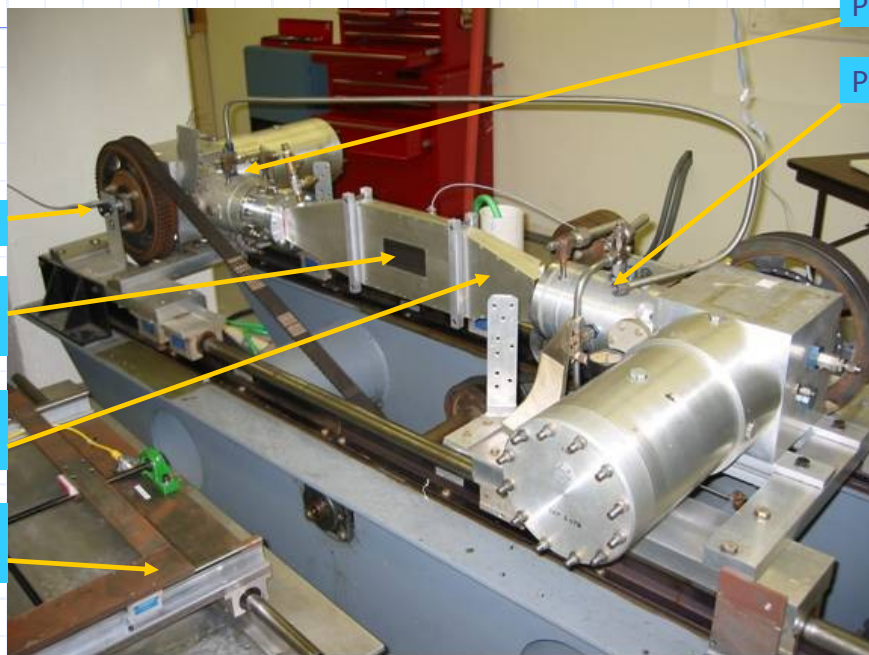


Photo courtesy Professor Mounir Ibrahim. Used by permission

Parameters	SLRE
Design Power, hp (kw)	12 (9)
Design Pressure, psi (N/mm ²)	1000 (7)
Working Gas	H ₂ /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

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Schematic of the Stirling Laboratory Research Engine at Cleveland State University

LENR Energy to Rotational Power Research Facility

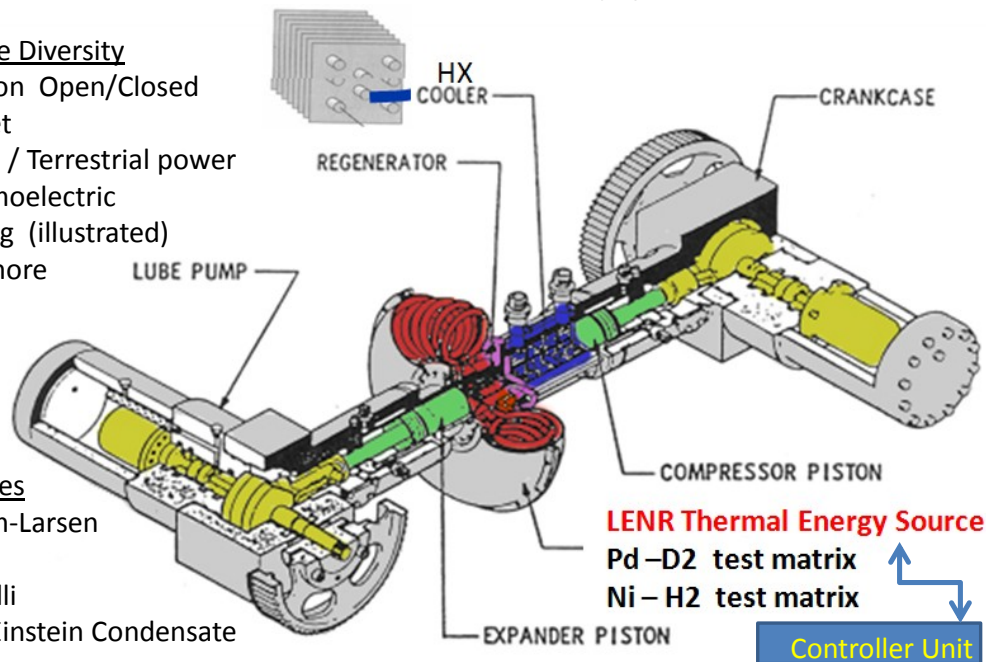
Research: Theory, Computational Dynamics, Reactor diversity, matrix elements, size, scale, rates, materials, blends, catalysts operational limits, device interfacing, HX, shielding, controls, instrumentation, communications, safety and more

Device Diversity

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

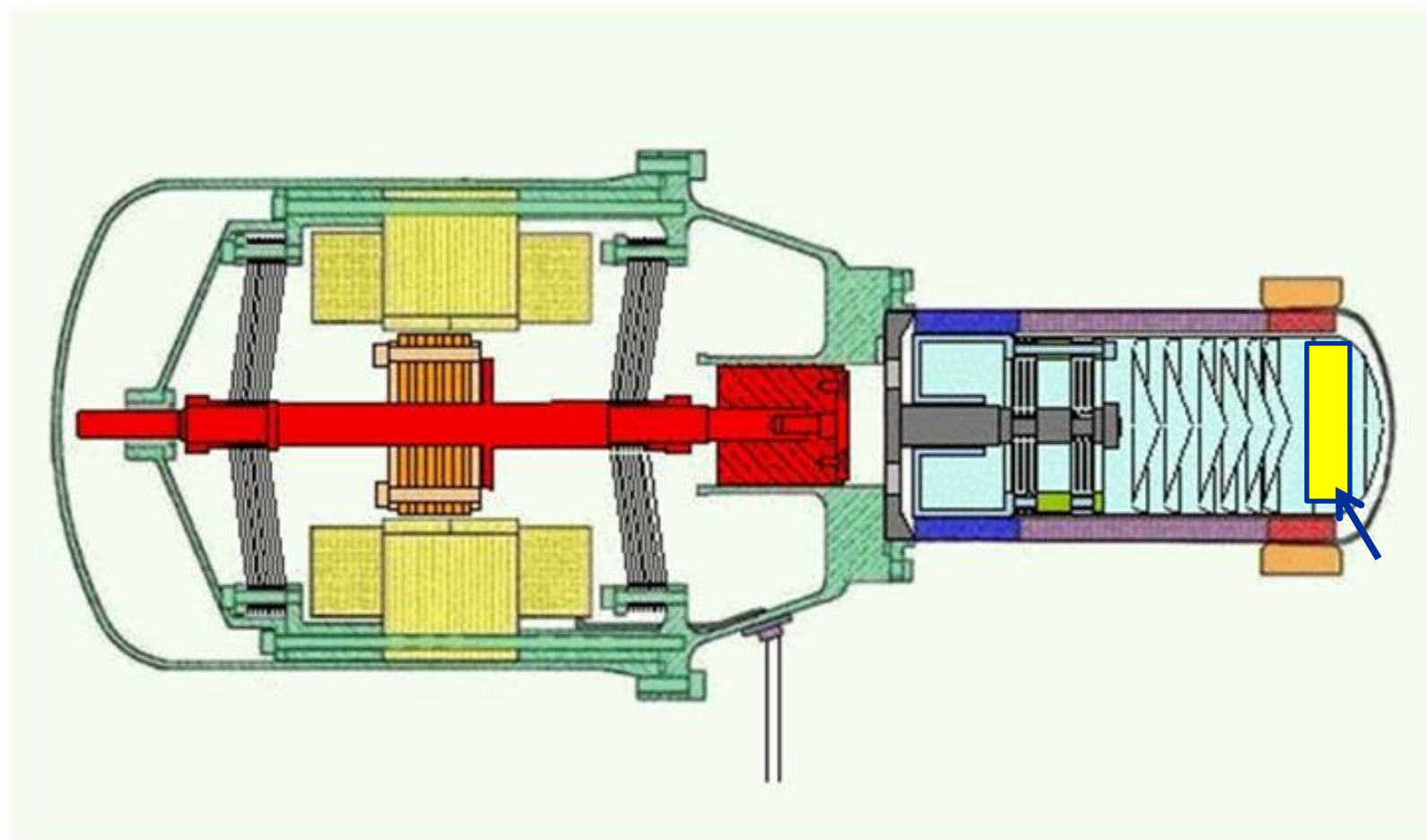
Theories

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

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