



# 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:

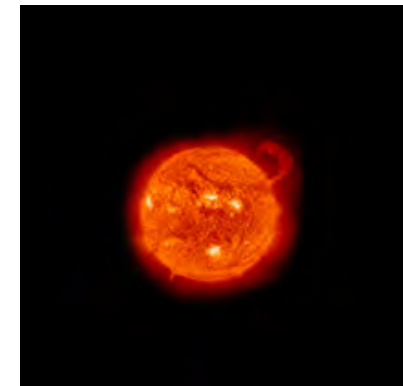
- $^{235}\text{U} + n \rightarrow ^{236}\text{U}$   
 $\rightarrow ^{141}\text{Ba} + ^{92}\text{Kr} + 3 \cdot n$  (170 MeV)

## 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) +  $\gamma$  (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



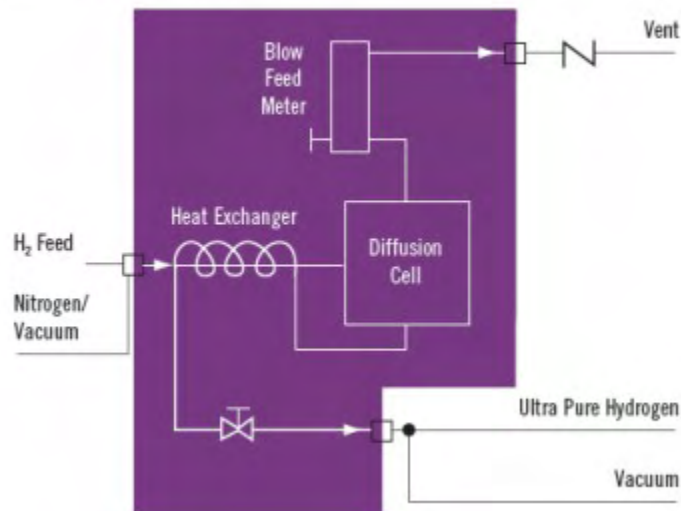
The Sun: a gravitationally confined fusion reactor

# 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

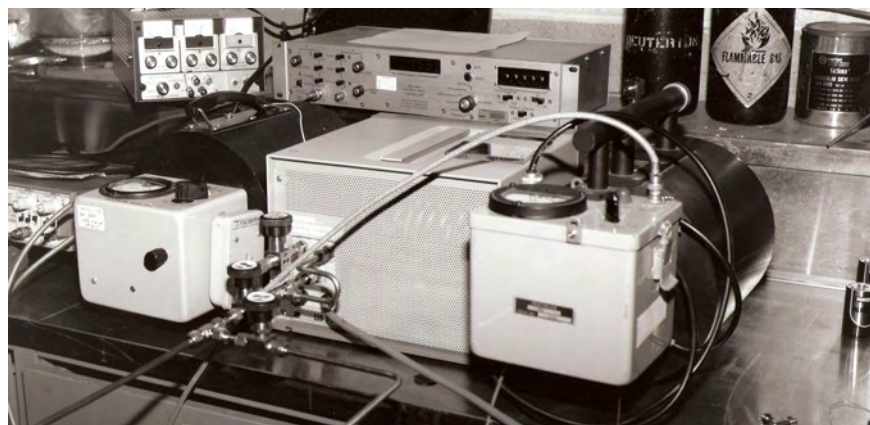
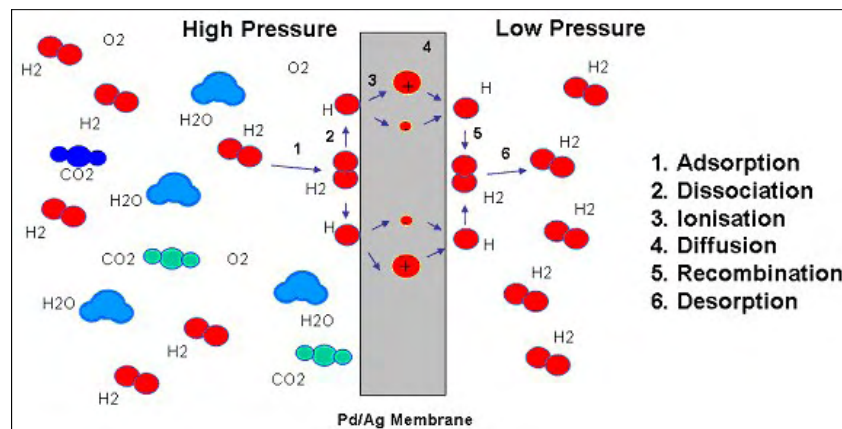
## EQUIPMENT

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  $\text{BF}_3$  w/ Polyethylene ["Snoopy"] detectors).
- Temperature increase noted when D unloaded at end of experiment
- Compared to hydrogen gas as the experimental control:  $15^\circ\text{C}$  increase in purifier temperature consistently seen with  $\text{D}_2$  that was not seen with the  $\text{H}_2$  control when gasses were unloaded from the purifier.

## Published:

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

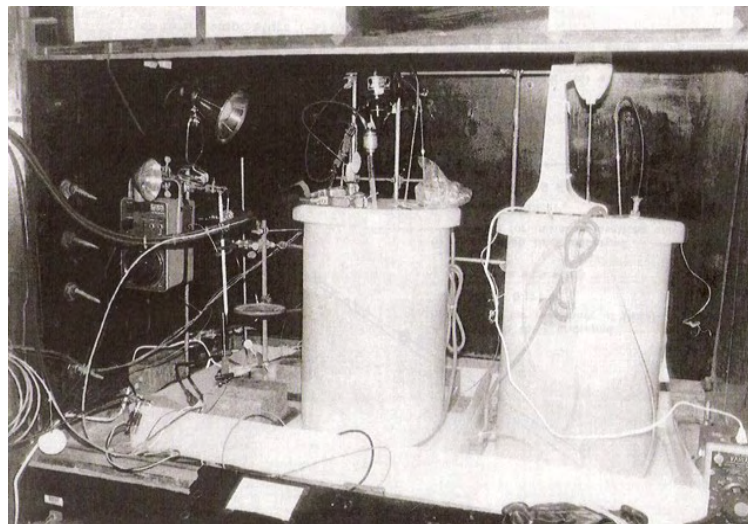


Purifier plumbing, showing vacuum pump used to evacuate cell, and gas bottle used to load cell

# 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- $\text{K}_2\text{CO}_3$  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)

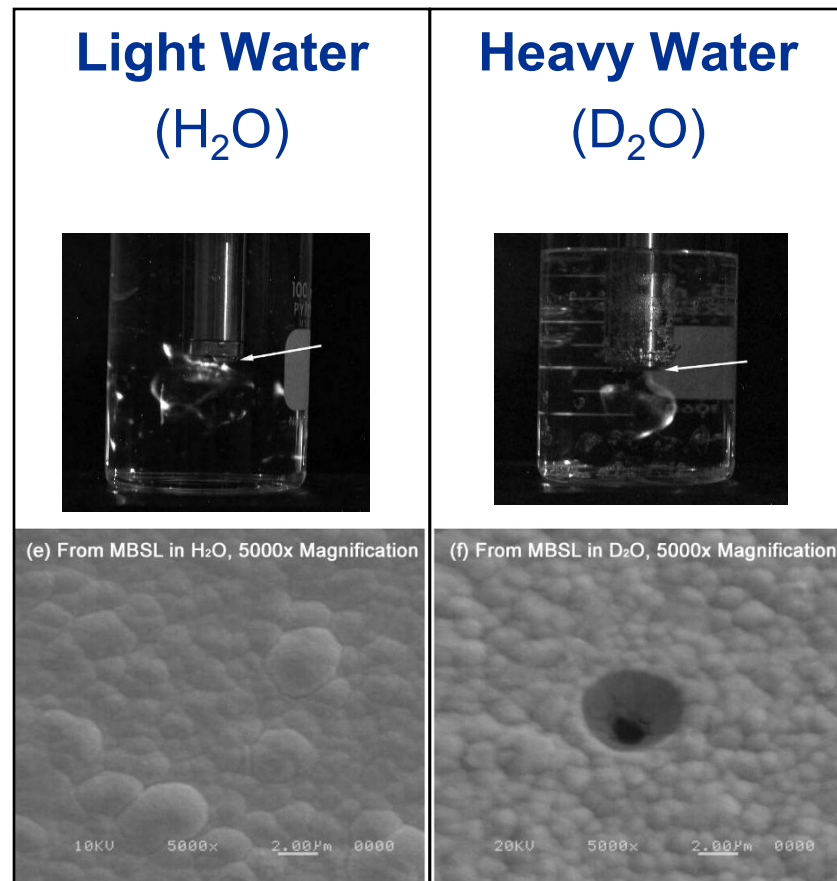
# BACKGROUND: Sonoluminescence

## Experiment

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

## Result

- No Crater seen in  $\text{H}_2\text{O}$ , Crater Formation seen in  $\text{D}_2\text{O}$
- 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.



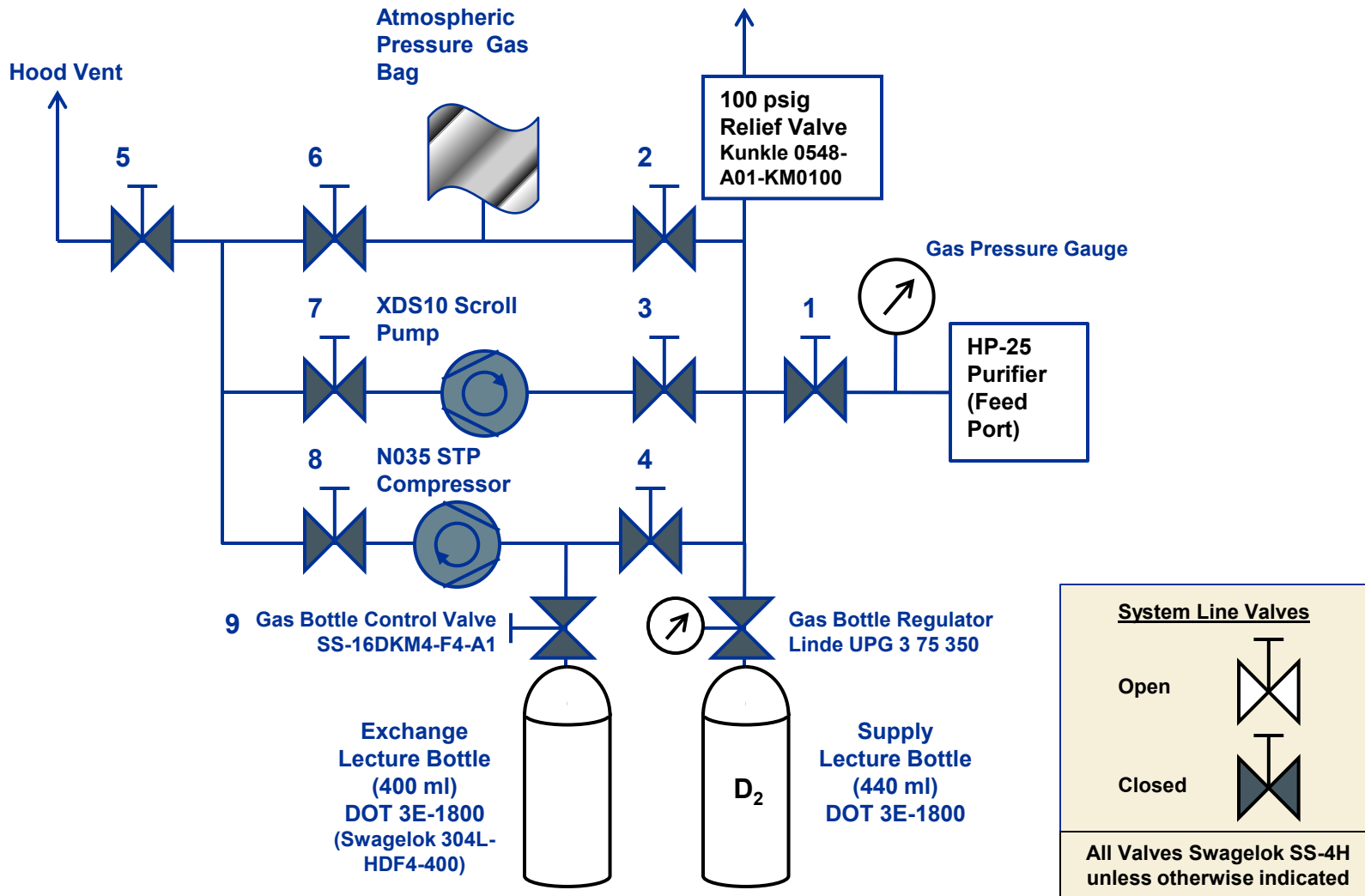


# BACKGROUND: Changes from 1989 to 2009

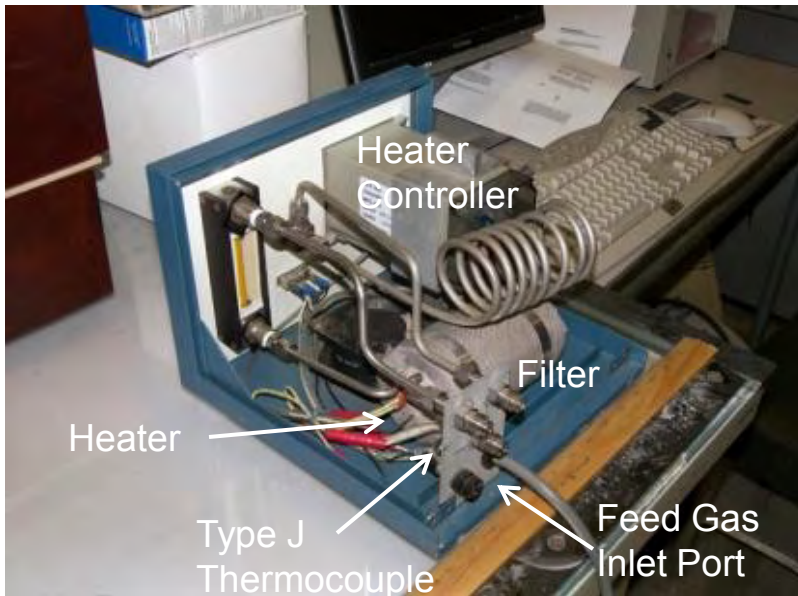
- Previous NASA D-Pd experiment (Fralick, et al.; 1989) looked for neutrons (saw none) – but saw anomalous heating
- NASA H<sub>2</sub>O-Ni-K<sub>2</sub>CO<sub>3</sub> Electrolytic Cell experiment (Niedra et al, 1996) Apparent current-dependent excess heat consistent as heat from hydrogen-oxygen recombination
- 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

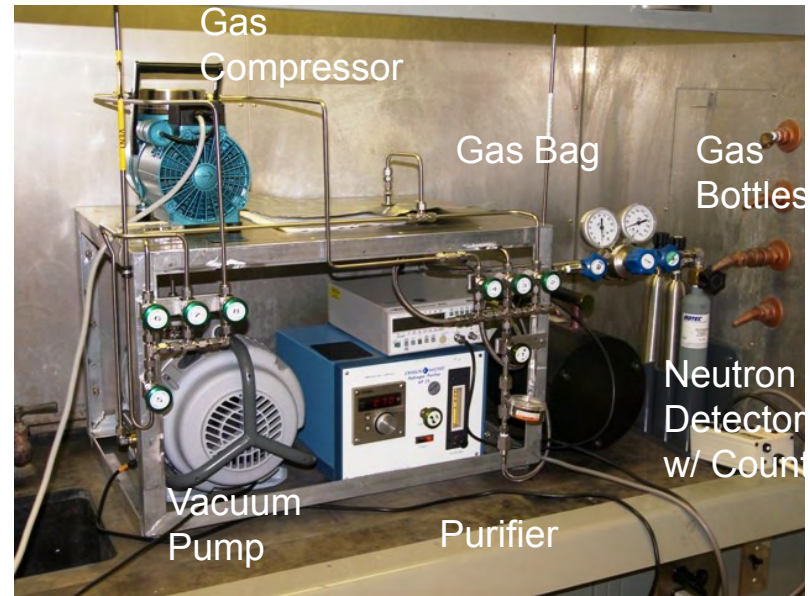


Photo of 2009 GRC test setup

- 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



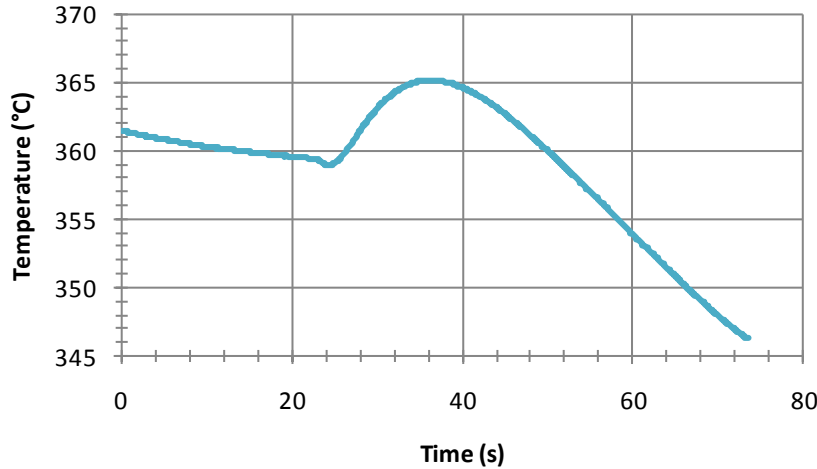
# RESULTS : Temperatures vs. Time

## Loading

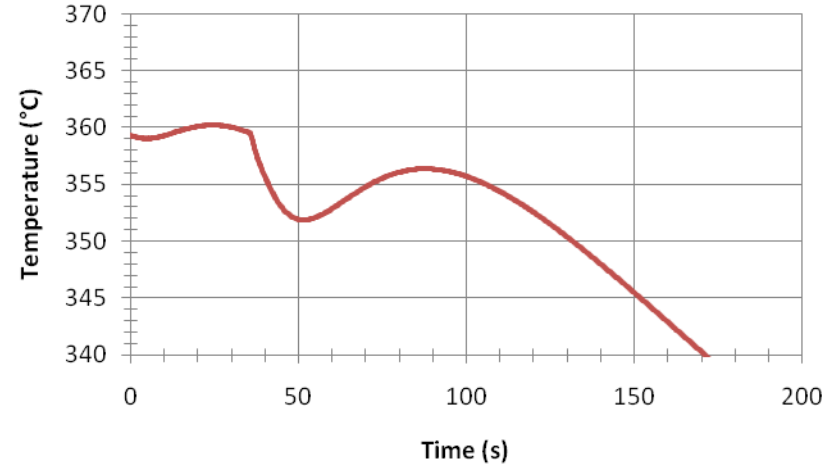
## Unloading

Hydrogen

Observed Temperature for H2 Load

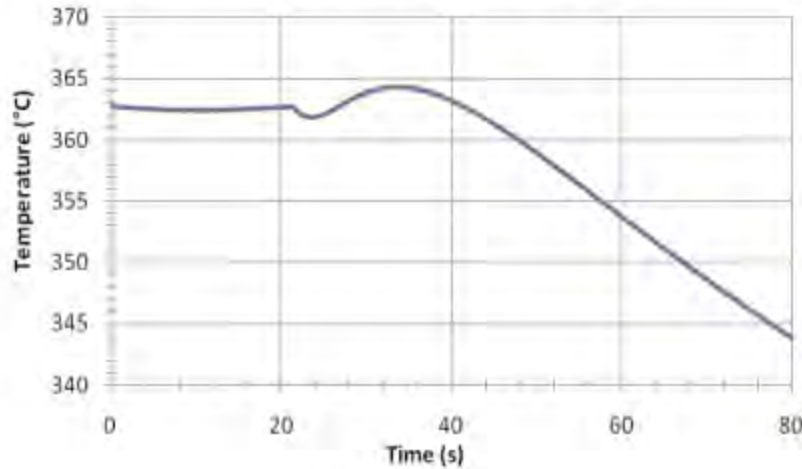


Observed Temperature for H2 Unload

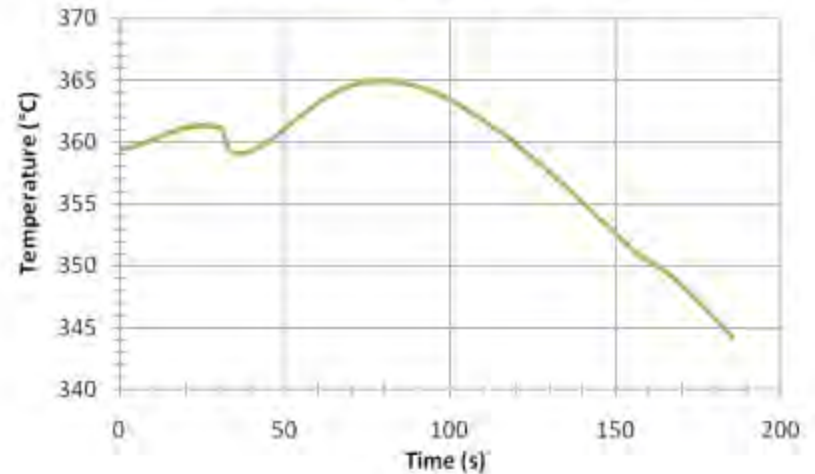


Deuterium

Observed Temperature for D2 Load

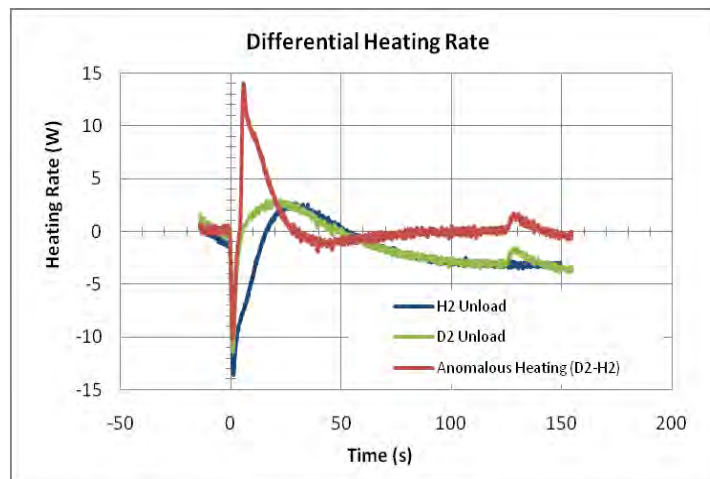
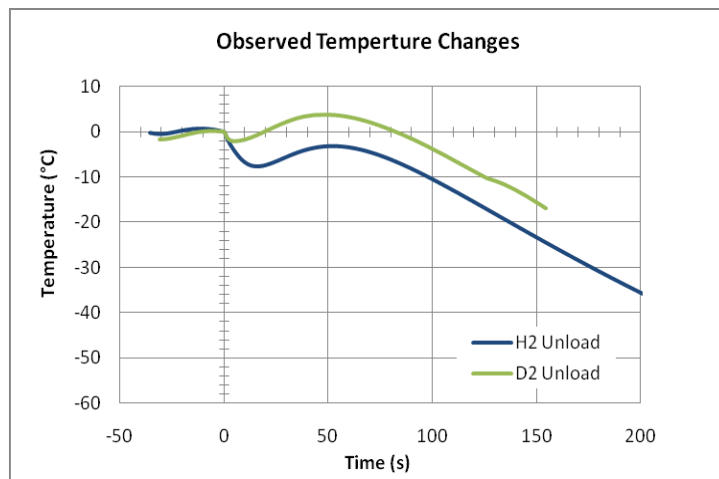


Observed Temperature for D2 Unload





# RESULTS (continued): Temperature vs. Time



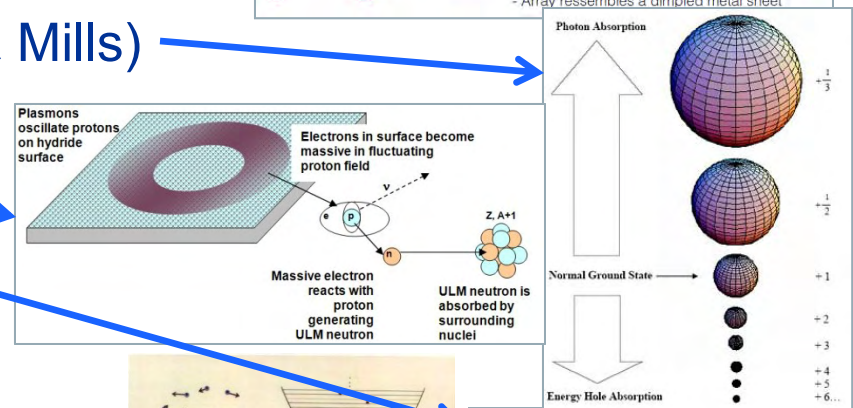
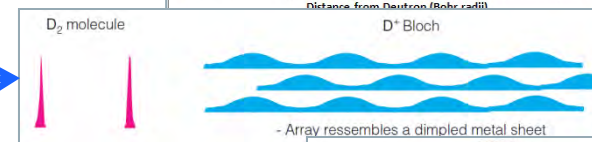
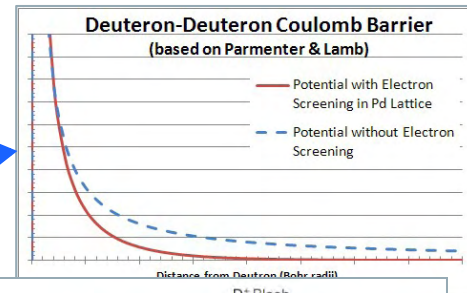
Results of GRC IPP investigation: a) the temperature data is shown for H2 and D2 unloading (left); b) the calculated thermal power in/out is given with the net anomalous heating (right).



# Hypotheses

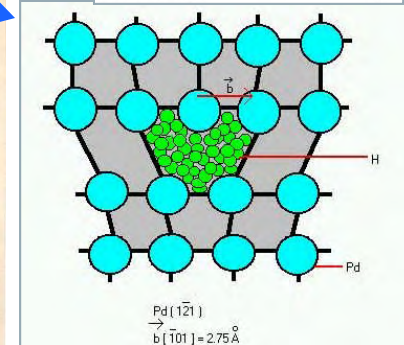
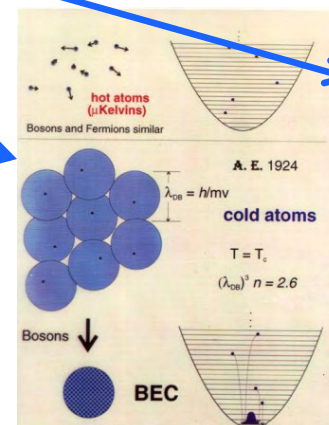
“Pet Theories” (i.e., Hypotheses where proponents already convinced peer-reviewed journals):

- 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)



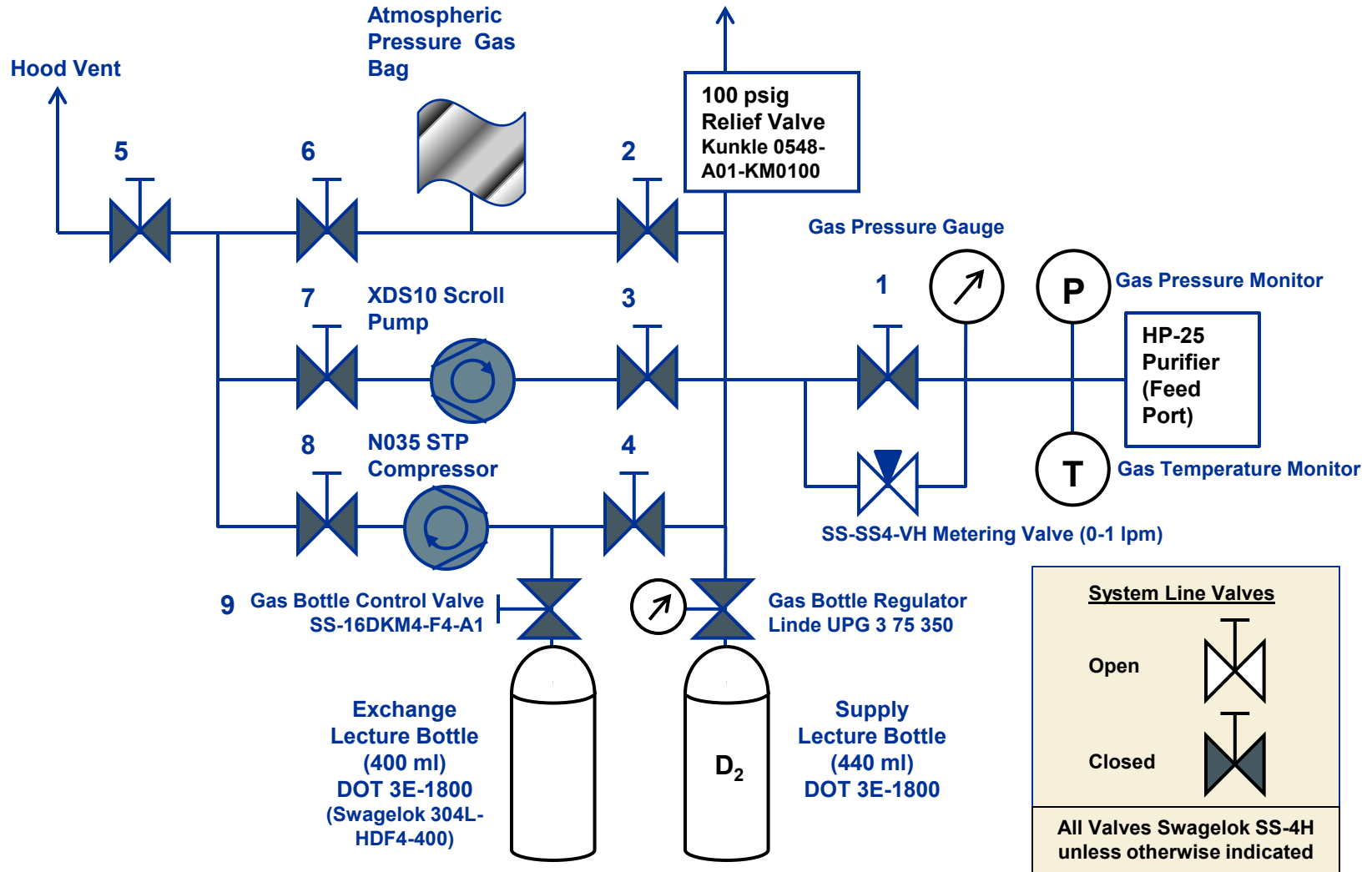
Do any of these encompass all reported observations?

- *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)

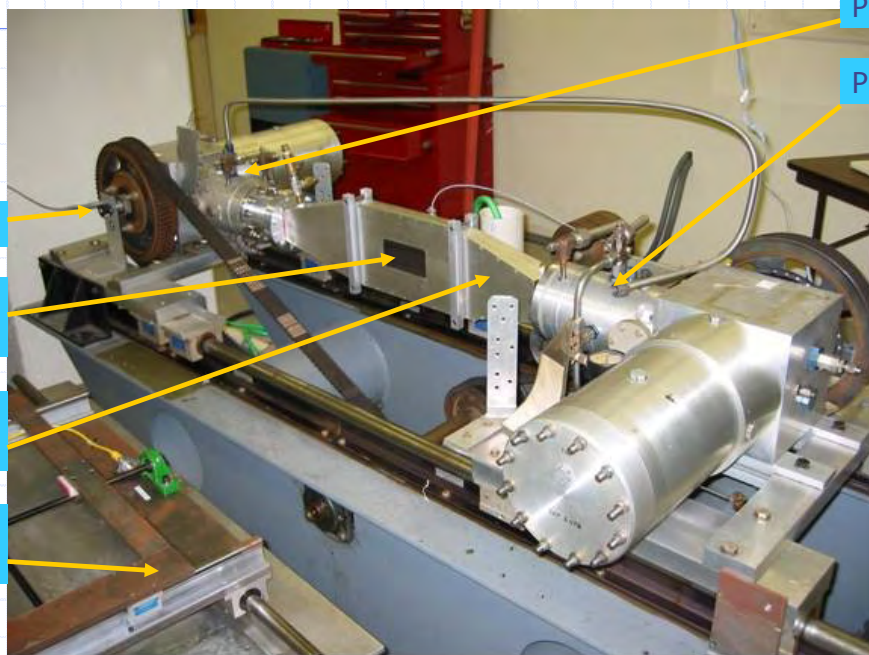


Photo courtesy Professor Mounir Ibrahim. Used by permission

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

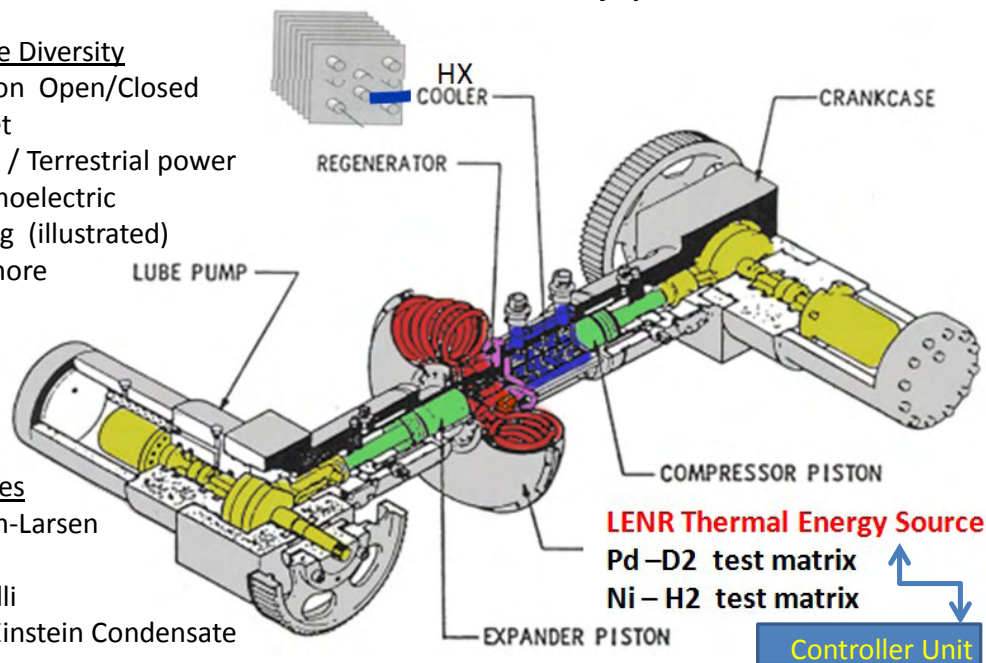
*Research: Theory, Computational Dynamics, Reactor diversity, matrix elements, size, scale, rates, materials, blends, catalysts operational limits, device interfacing, HX, shielding, controls, instrumentation, communications, safety and more*

Device Diversity

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

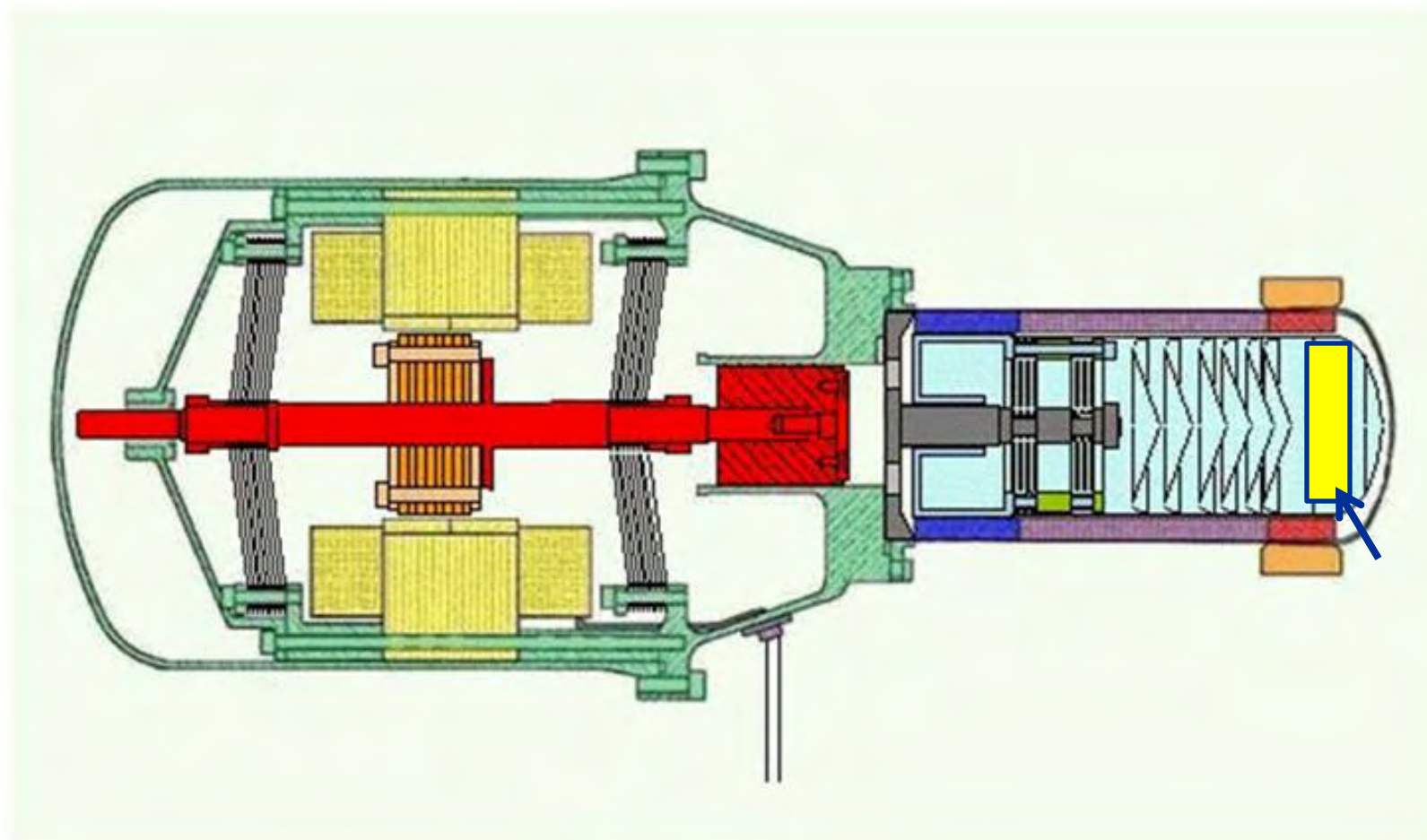
Theories

- 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  $^{238}\text{Pu}$  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



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