

# Lunar Water Resource Demonstration (LWRD)

ex luna, aqua

Anthony C. Muscatello

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# Major Contributors

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- NASA: Jeremy Parr, Mark Nurge, Dale Lueck, Janine Captain, Curtis Ihlefeld, Tom Moss, Jackie Quinn, and Bill Larson



# Outline

- **Background**
- **RESOLVE Project and Field Demonstration**
- **LWRD Key Design Requirements**
- **Design**
  - Fluid systems design
  - Water Bed design
  - Other component design
  - ProE 3-D model
  - Hydrogen bed calculations
  - Actual components
- **Mass Reduction Strategy**
- **Power Estimate**
- **Planned Testing Deviations**
- **Lab and Field Demonstration Results**
- **Hydrogen Quantification Test Results**
- **Major Milestones**
- **Summary**

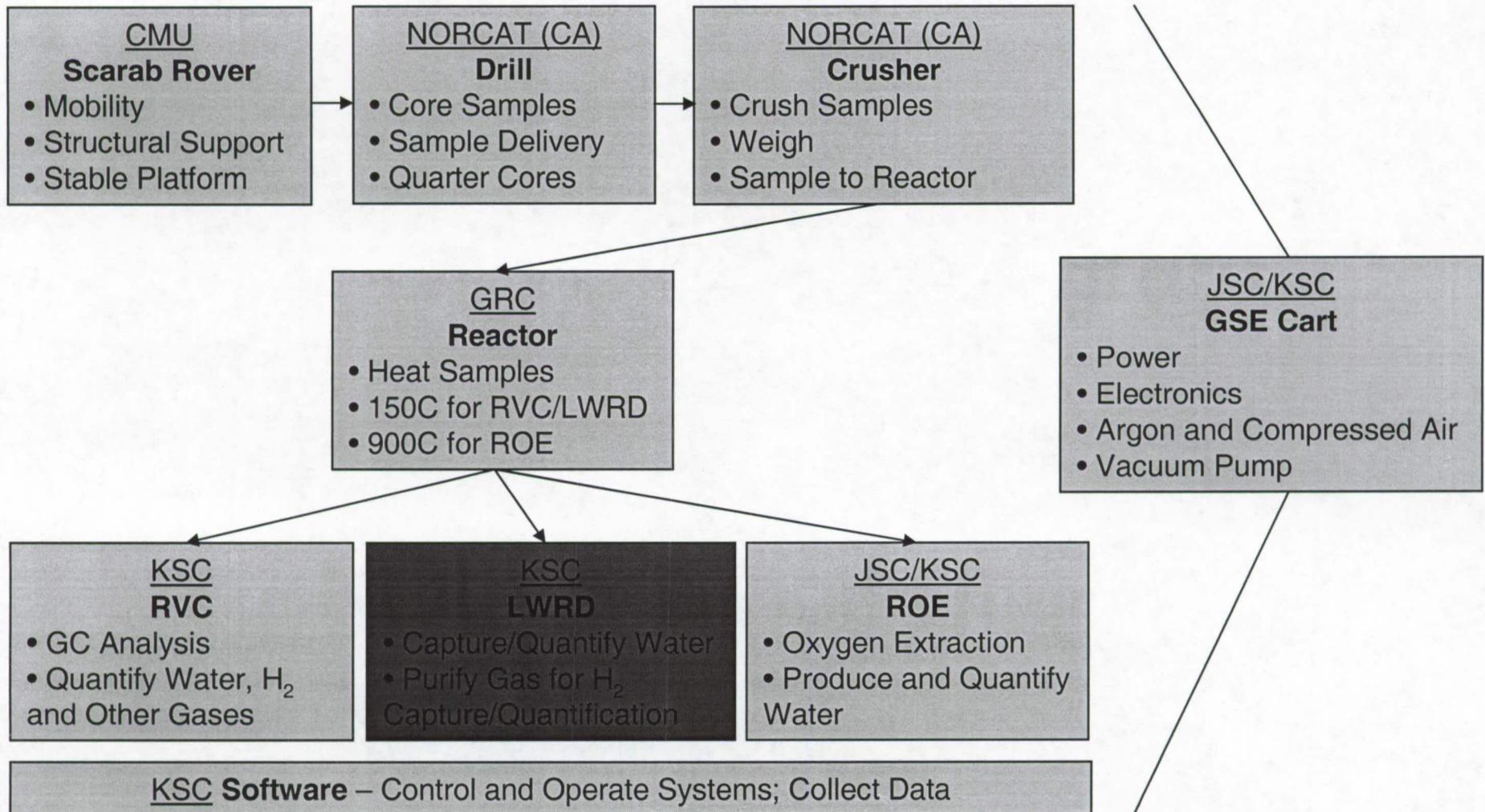


# Background

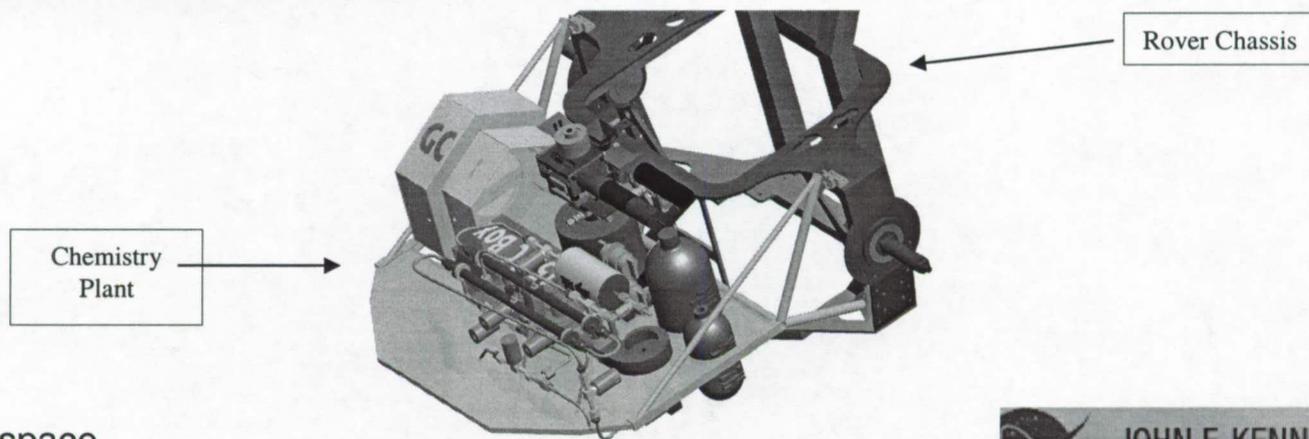
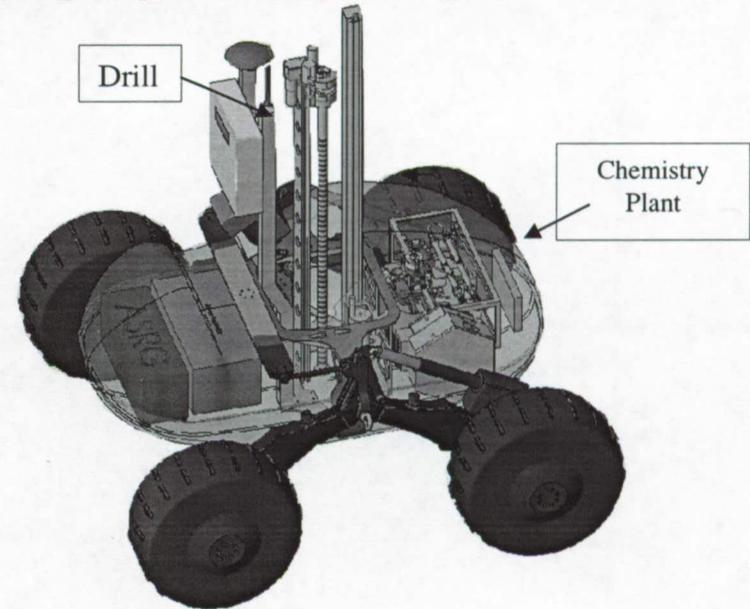
- LWRD is part of RESOLVE (Regolith and Environment Science & Oxygen and Lunar Volatile Extraction)
- RESOLVE is an ISRU ground demonstration:
  - A rover to explore a permanently shadowed crater at the south or north pole of the Moon
  - Drill core samples down to 1 meter
  - Heat the core samples to 150C
  - Analyze gases and capture water and/or hydrogen evolved
  - Use hydrogen reduction to extract oxygen from regolith
- The field demo took place on Mauna Kea as an analog site for the Moon (EBU2)
- JSC, GRC, KSC, NORCAT, CSA and CMU involved
- EBU1 established feasibility



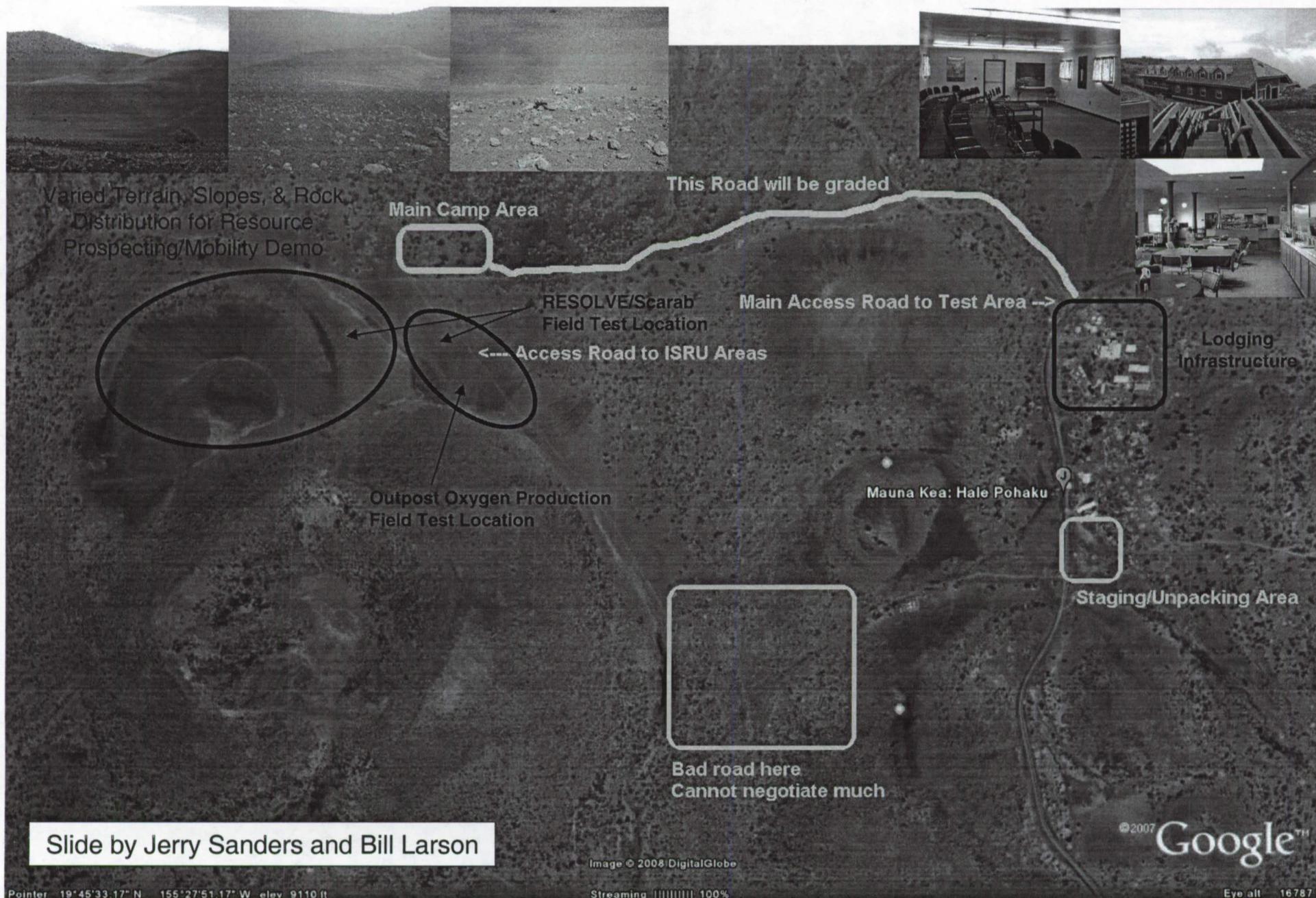
# RESOLVE Block Diagram



# RESOLVE/Scarab Rover



# Nov. ISRU Field Test Infrastructure and Test Layout



# Lunar-Like Terrain on Mauna Kea



# Purpose of LWRD

- Capture up to 6 g of water per regolith/soil core sample and quantify up to 20 g of water (backup to GC measurements)
- Capture and quantify up to 0.15 g of hydrogen from same core sample (backup to GC measurements)
- Quantify within 20% accuracy

# Key Design Requirements

- Prevent water condensation
  - Operate in 150C/130C Hot Boxes
  - Heated head recirculation pump
  - Heat trace Reactor gas lines
- Minimize number of transfers
  - 500 cc Surge Tank
- Absorb water at 130C
  - “Moisture Gone” zeolite absorbent
- Have sufficient water absorption capacity
- Quantify water
  - Desorption of MG is too slow; use RH probe, P, V, and T

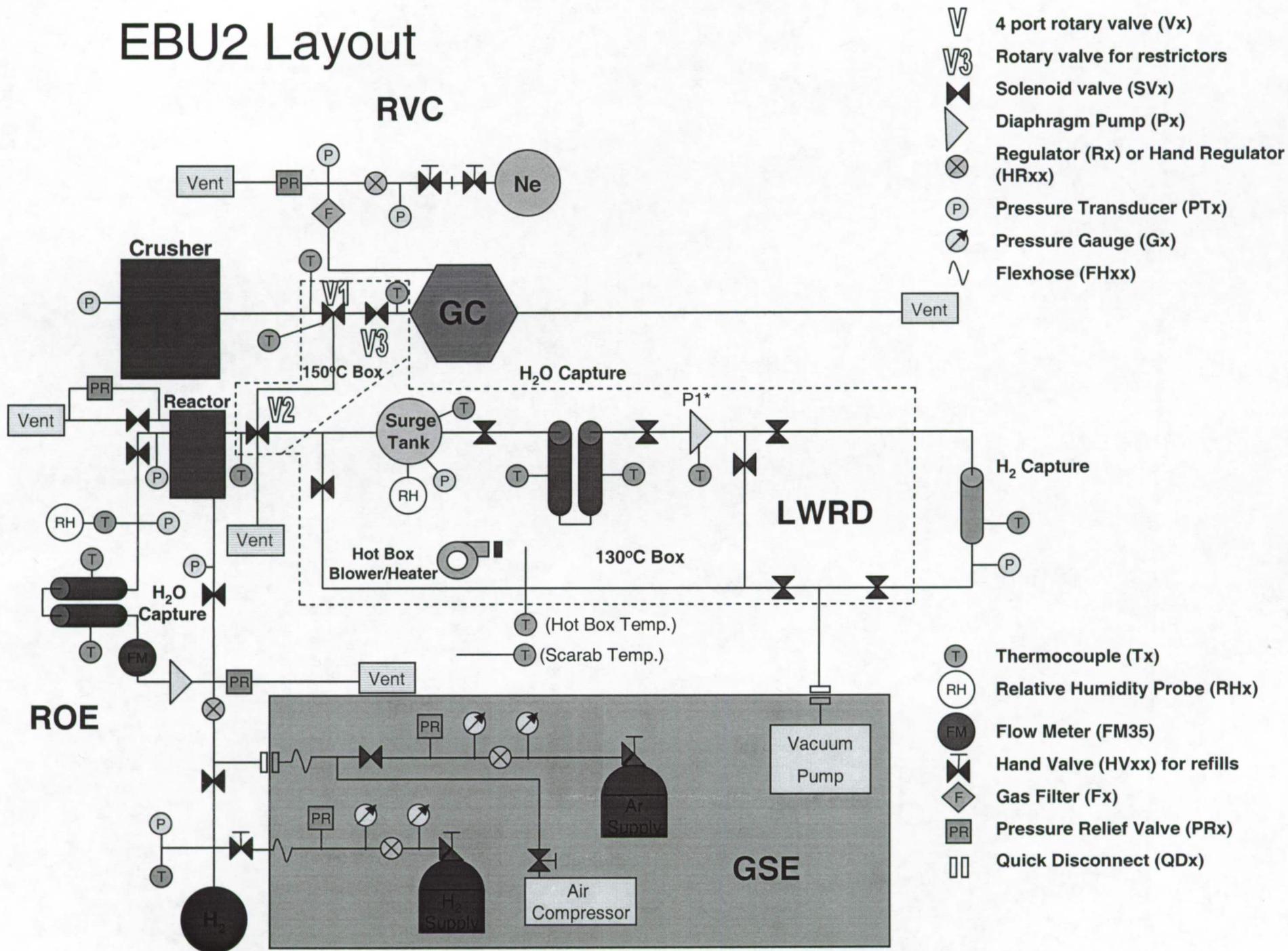
# Key Design Requirements (Cont.)

- Absorb/desorb hydrogen efficiently
  - FSEC developed new hydride former; works at room temp.
- Operate during 8-12 hr workday
  - Desorb water beds overnight (or during ROE)
  - Split full RESOLVE ops over two days
- Stay under 60 kg mass limit
  - Minimized masses of individual components
  - Transferred Ar, vacuum pump and electronics to GSE
- Demonstration on Mauna Kea in November 2008
  - Keep close track of schedule; fix issues quickly
- Limited budget
  - Work efficiently; minimize equipment costs

# LWRD Process Summary

- At 150C in the Reactor, transfer gases to Surge Tank; measure RH, P, & T; and transfer to Water Beds two times (up to ~1.5 g water)
- Transfer residual gases to Hydrogen Bed, vent unabsorbed gases, heat to 300C and measure P & T of desorbed gas in Surge Tank and H<sub>2</sub> Bed (skipped this step in Hawaii demo)
- Subsequent transfers: measure RH, P, & T in Surge Tank since gases will consist of >90% water vapor; and vent
- Repeat sequence for each quarter core

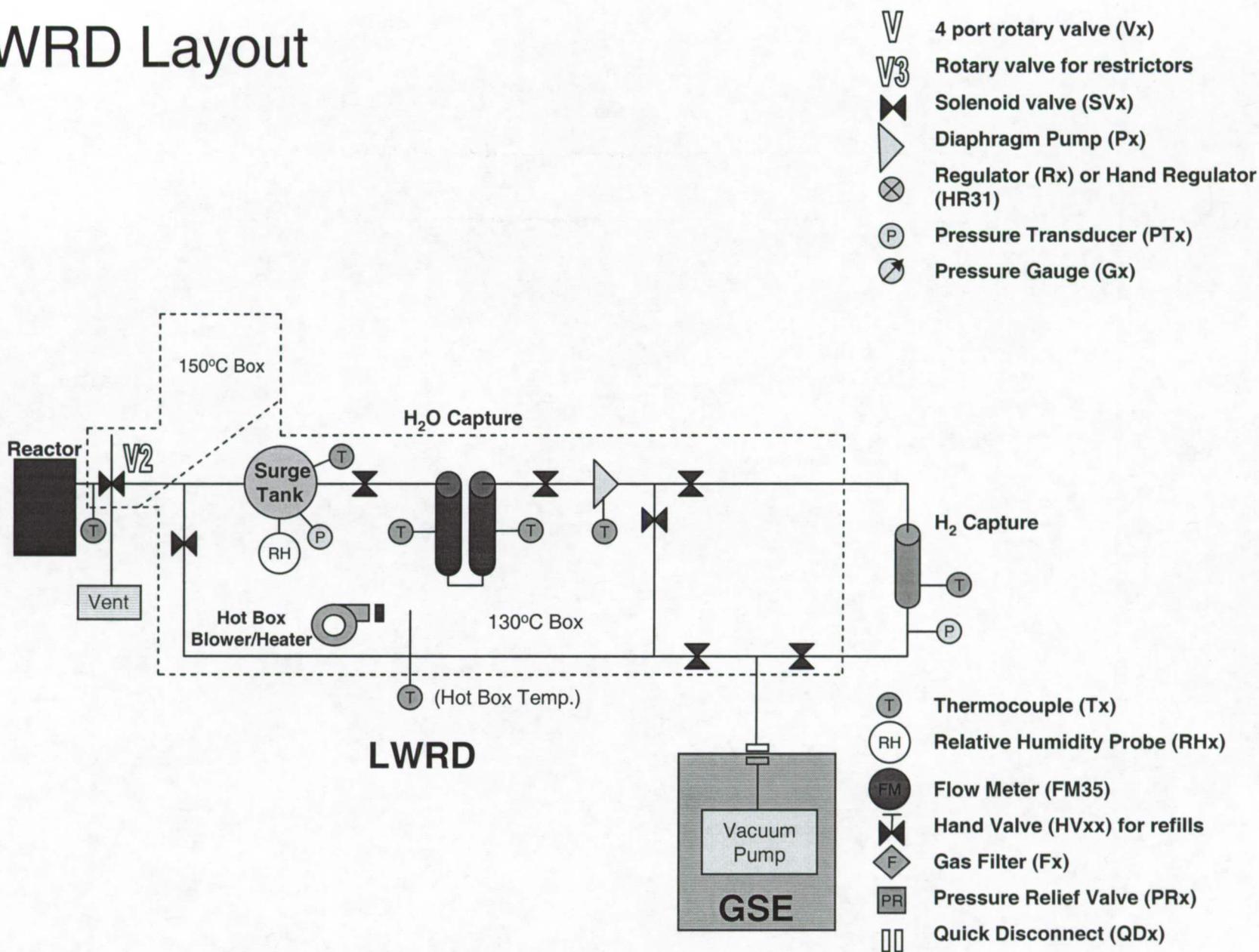
# EBU2 Layout



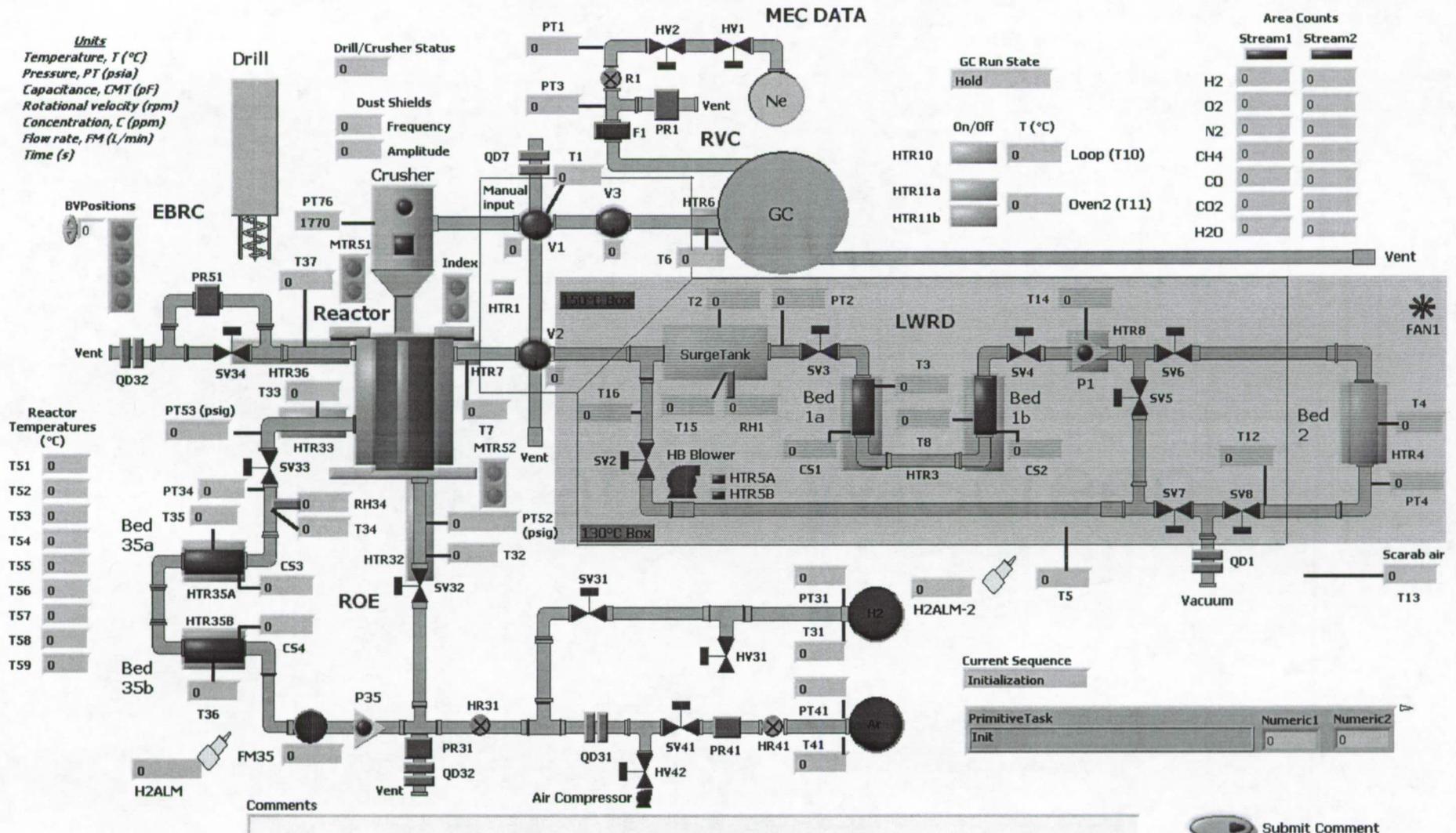
-  4 port rotary valve (Vx)
-  Rotary valve for restrictors
-  Solenoid valve (SVx)
-  Diaphragm Pump (Px)
-  Regulator (Rx) or Hand Regulator (HRxx)
-  Pressure Transducer (PTx)
-  Pressure Gauge (Gx)
-  Flexhose (FHxx)

-  Thermocouple (Tx)
-  Relative Humidity Probe (RHx)
-  Flow Meter (FM35)
-  Hand Valve (HVxx) for refills
-  Gas Filter (Fx)
-  Pressure Relief Valve (PRx)
-  Quick Disconnect (QDx)

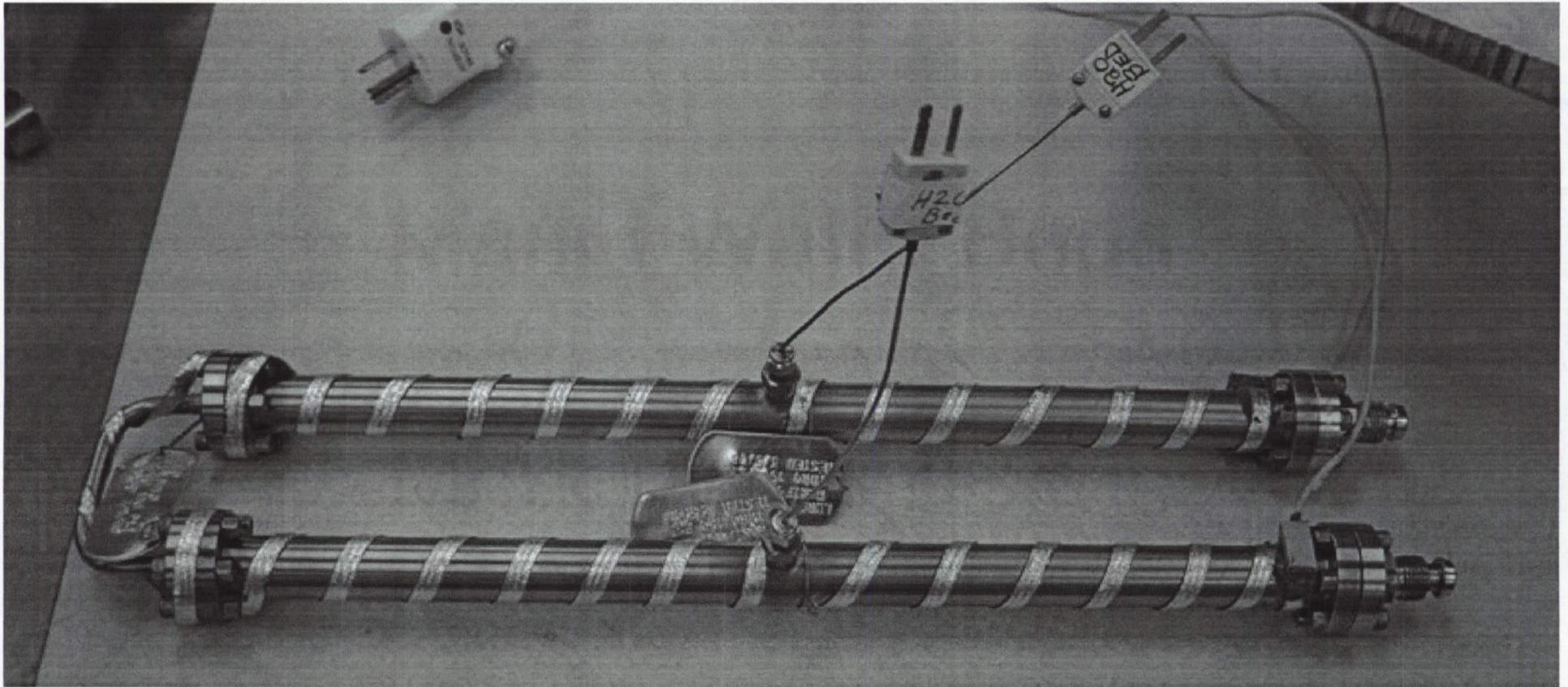
# LWRD Layout



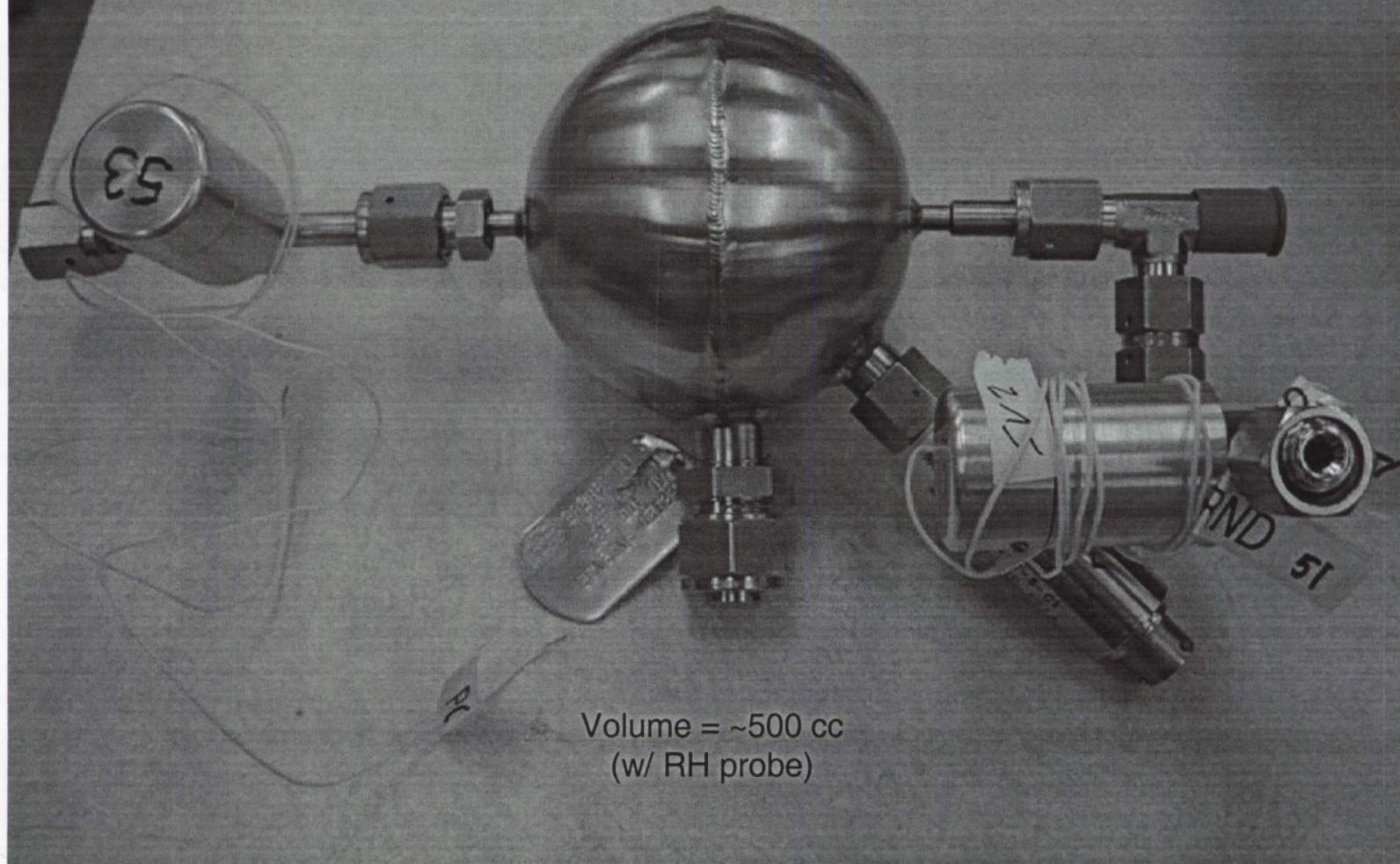
# MEC LabVIEW Screen



# Mark I Water Beds

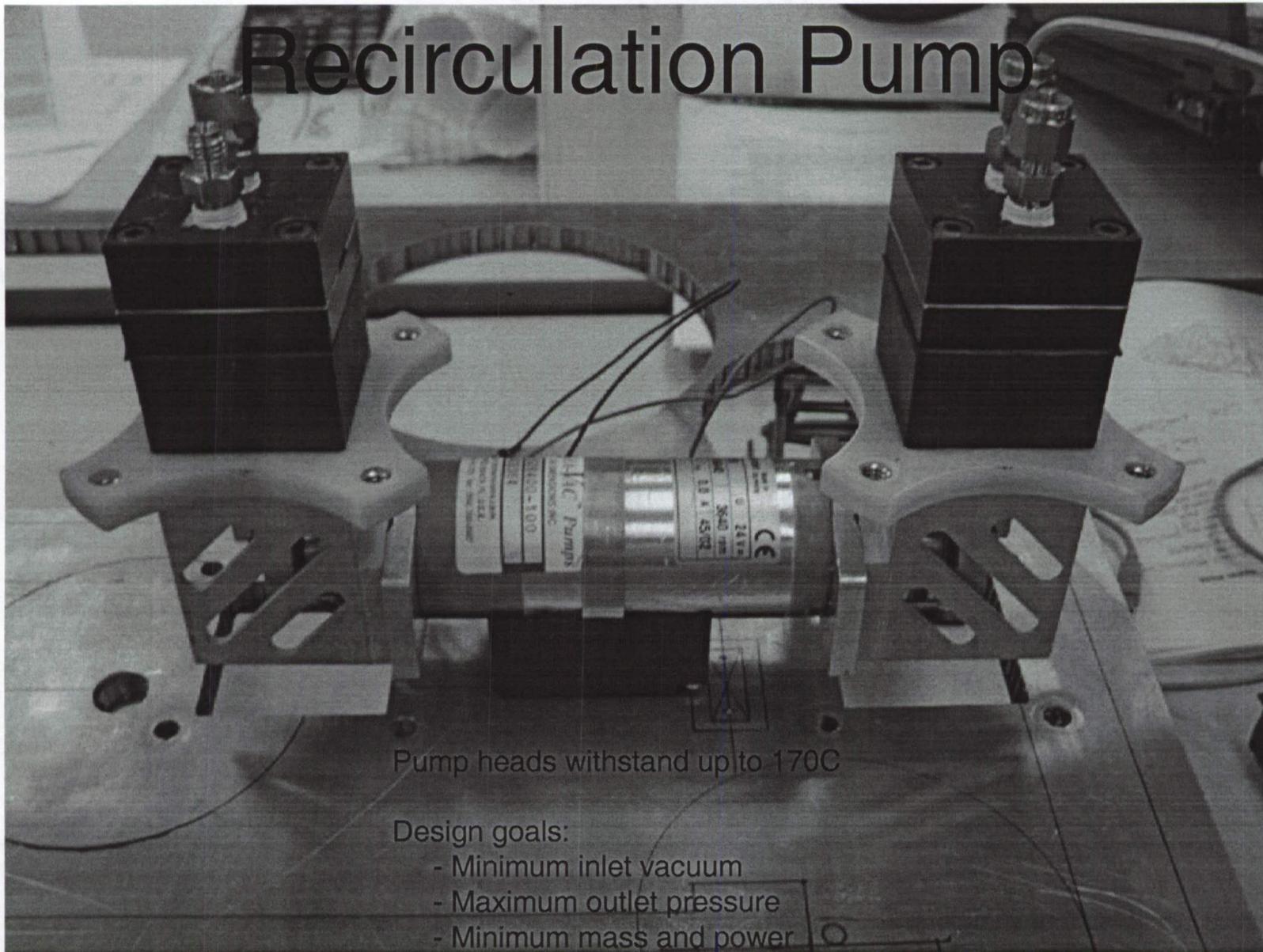


# LWRD Surge Tank



Volume = ~500 cc  
(w/ RH probe)

# Recirculation Pump

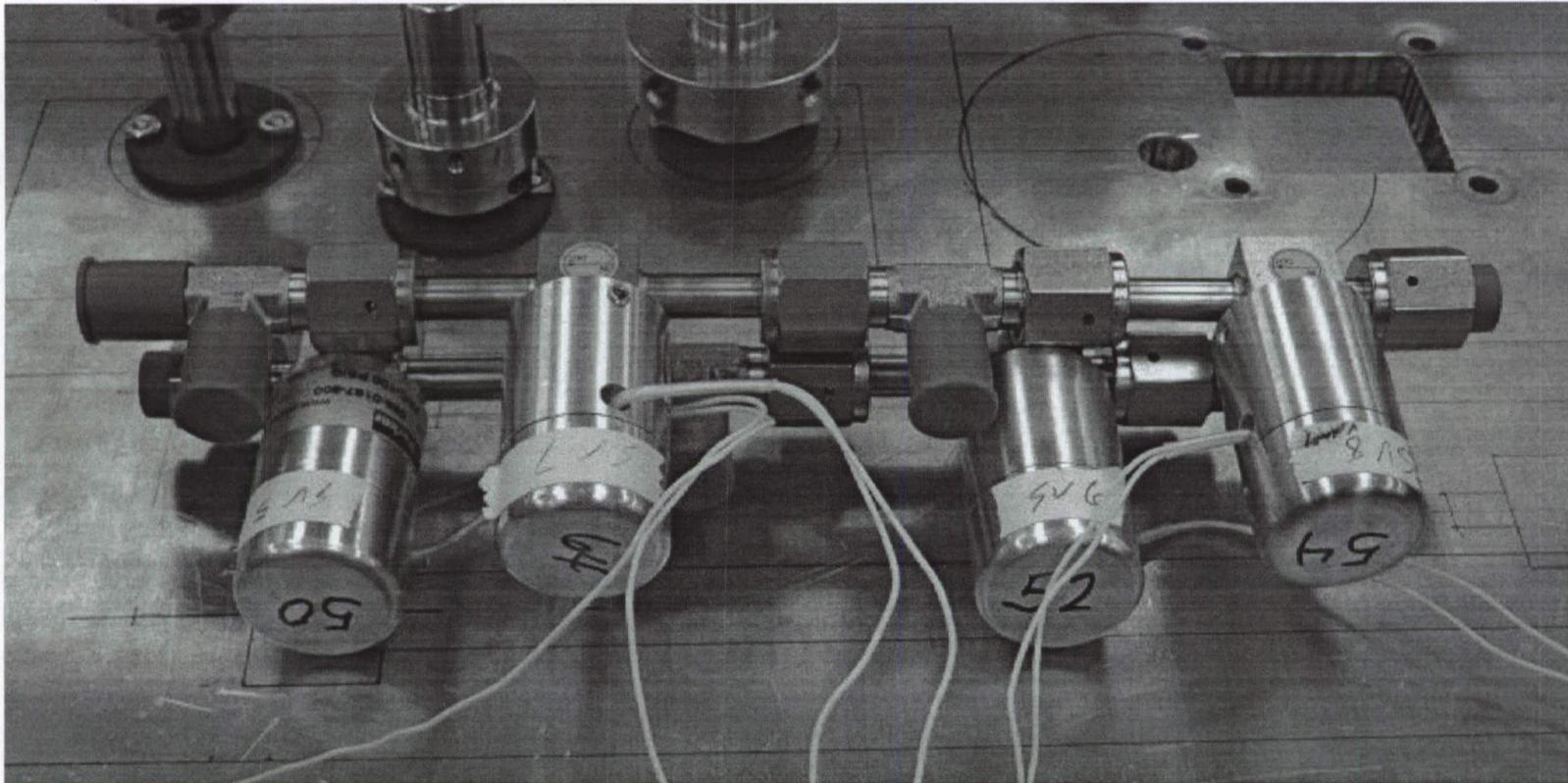


Pump heads withstand up to 170C

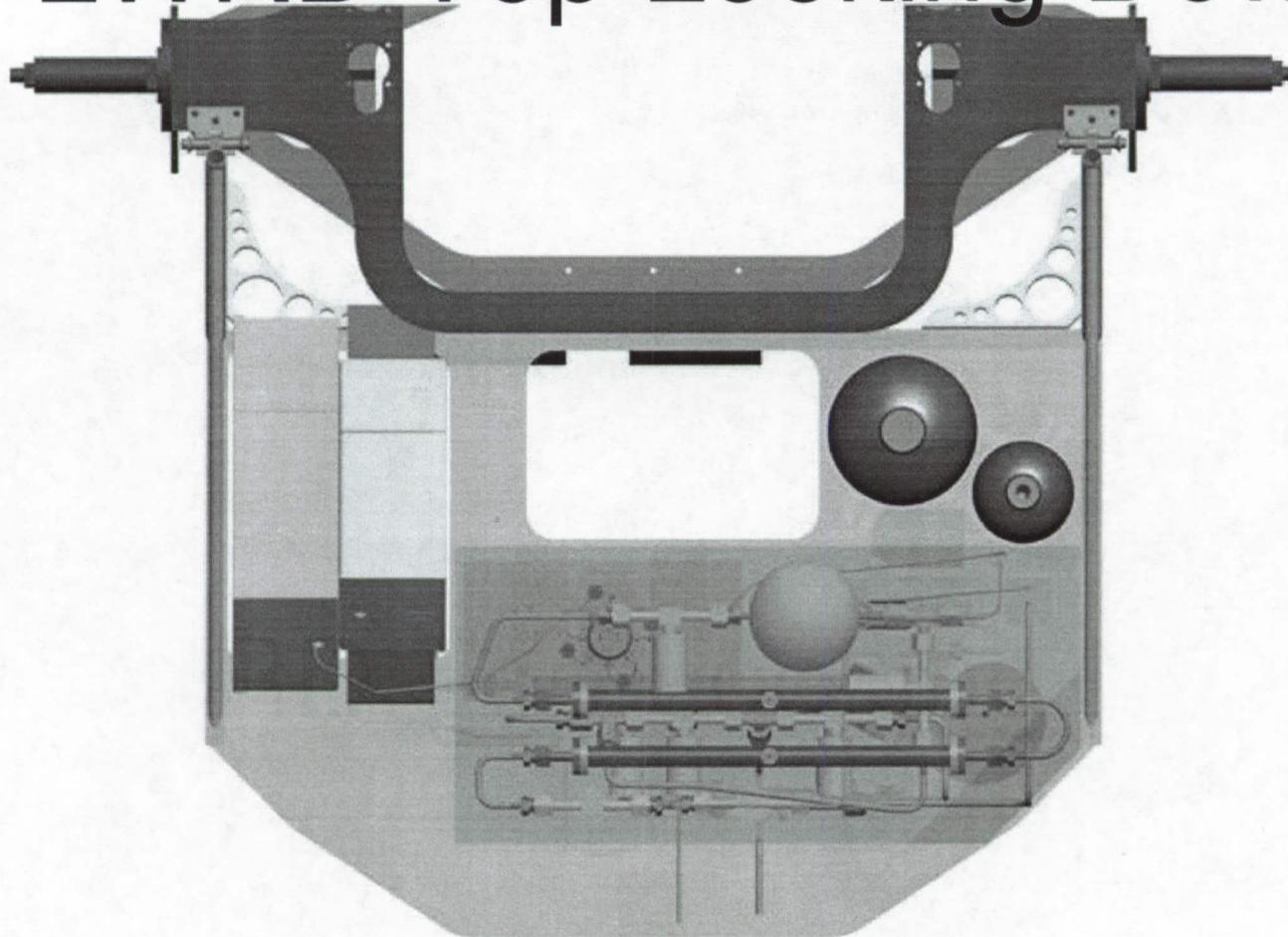
Design goals:

- Minimum inlet vacuum
- Maximum outlet pressure
- Minimum mass and power

# High Temperature Latching Solenoid Valves

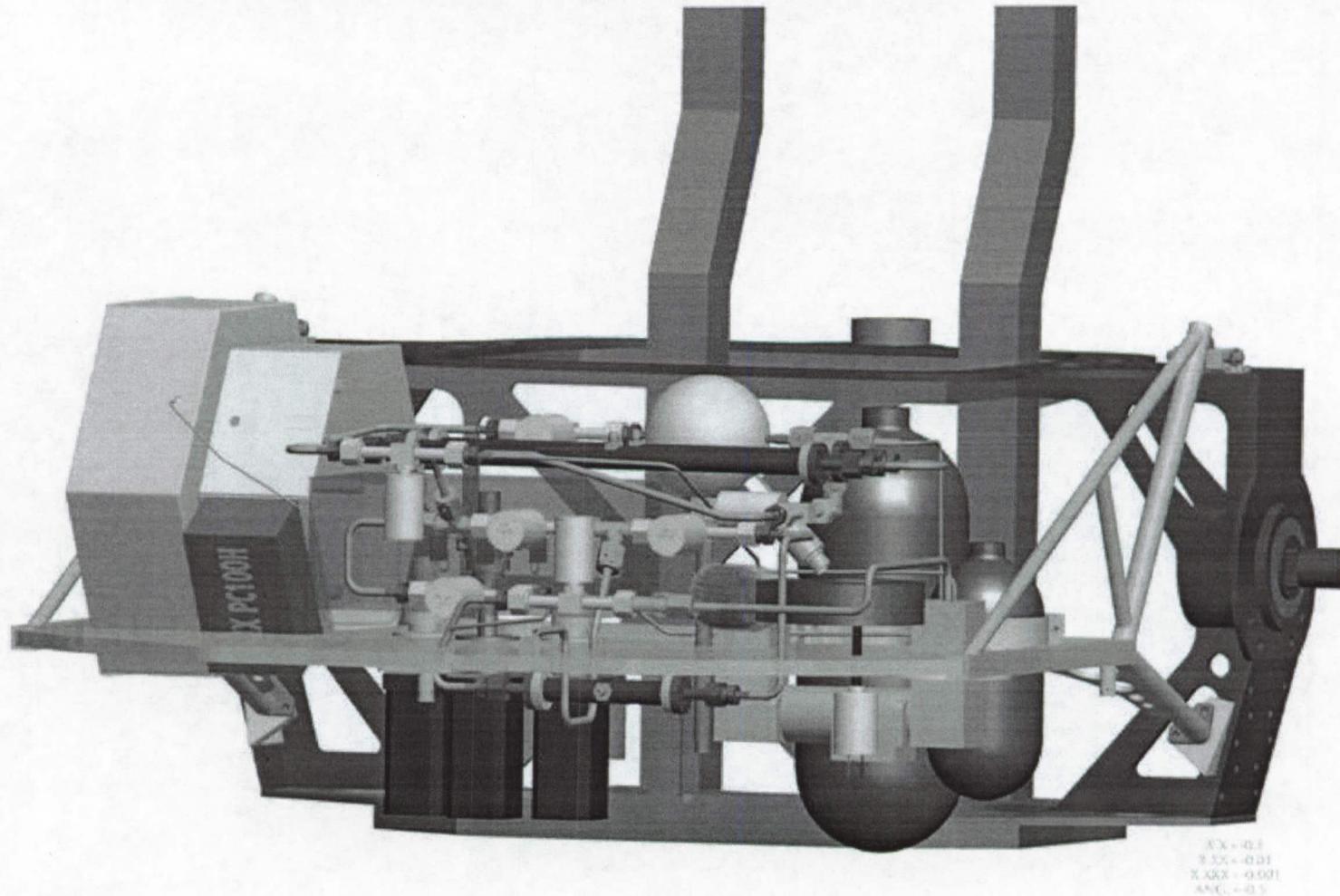


# LWRD Top Looking Down



XX-011  
3,XX-001  
X,AAA-0,001  
ANG, +0.5

# LWRD Side View – 130C Box Removed



# LWRD Design Activities (cont.)

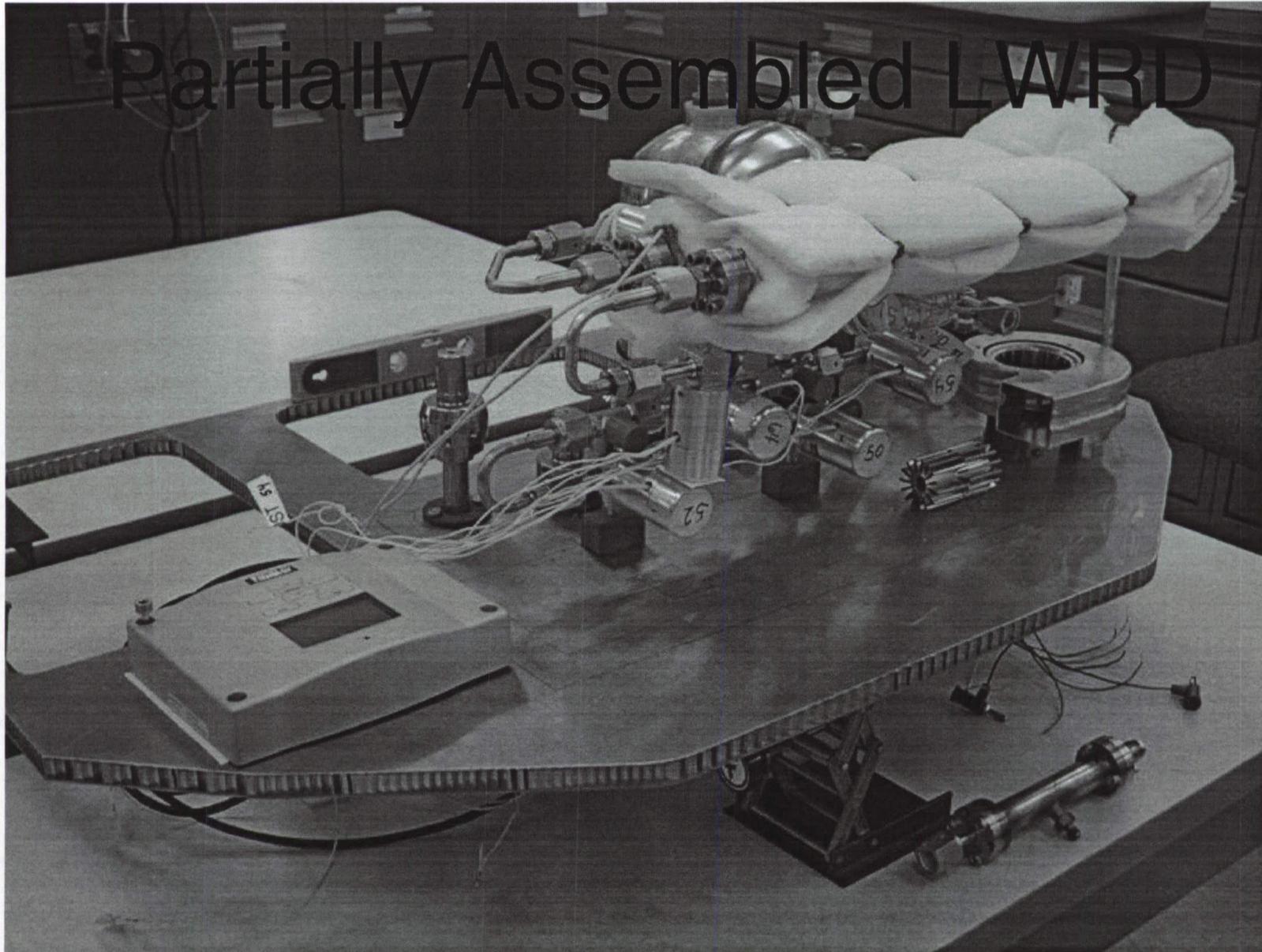
- Worked with GRC and JSC on heat tracing of lines from Reactor to RVC/LWRD and ROE
- Updated thermal analysis of Hot Boxes (with GRC)
  - Recalculated power for different warm up times
  - Estimated heat loss/power makeup
- Developed several operations timelines and stepwise operations
- Updated the Mass Analysis and developed a simple strategy to save weight if necessary
- Recirculation tests of Water Beds show complete water absorption in 3 min at 3 LPM and 1 LPM at 130C
  - Amount absorbed = 6.6 g at 3 LPM



# Hydrogen Desorption

- H<sub>2</sub> Bed size = 50 g of new absorber
- Absorber H<sub>2</sub> capacity = 0.10 g (0.2%)
- Average lunar H<sub>2</sub> expected = 0.088 g (0.11% H<sub>2</sub>)
- Free bed volume = 25.3 cc
- $\Delta P$  at 300C = 1200 psi (rated at 150 psi) + equilibrium like water bed desorption
- Therefore, use Surge Tank;  $\Delta P = 32$  psi
- Encourages dehydrating to completion

# Partially Assembled LWRD



47<sup>th</sup> AIAA Aerospace  
Sciences Meeting

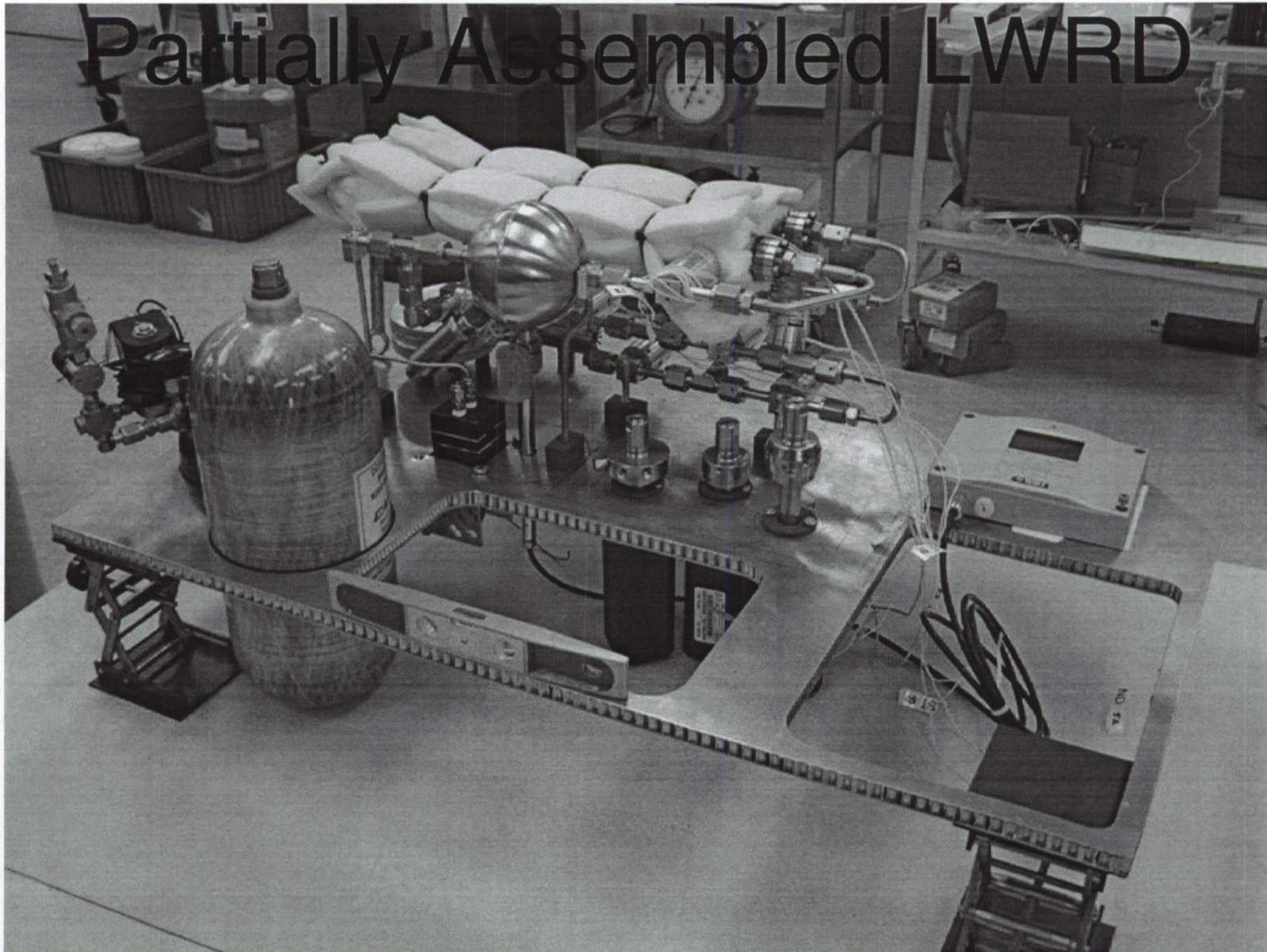
*NASA KSC LWRD Team*

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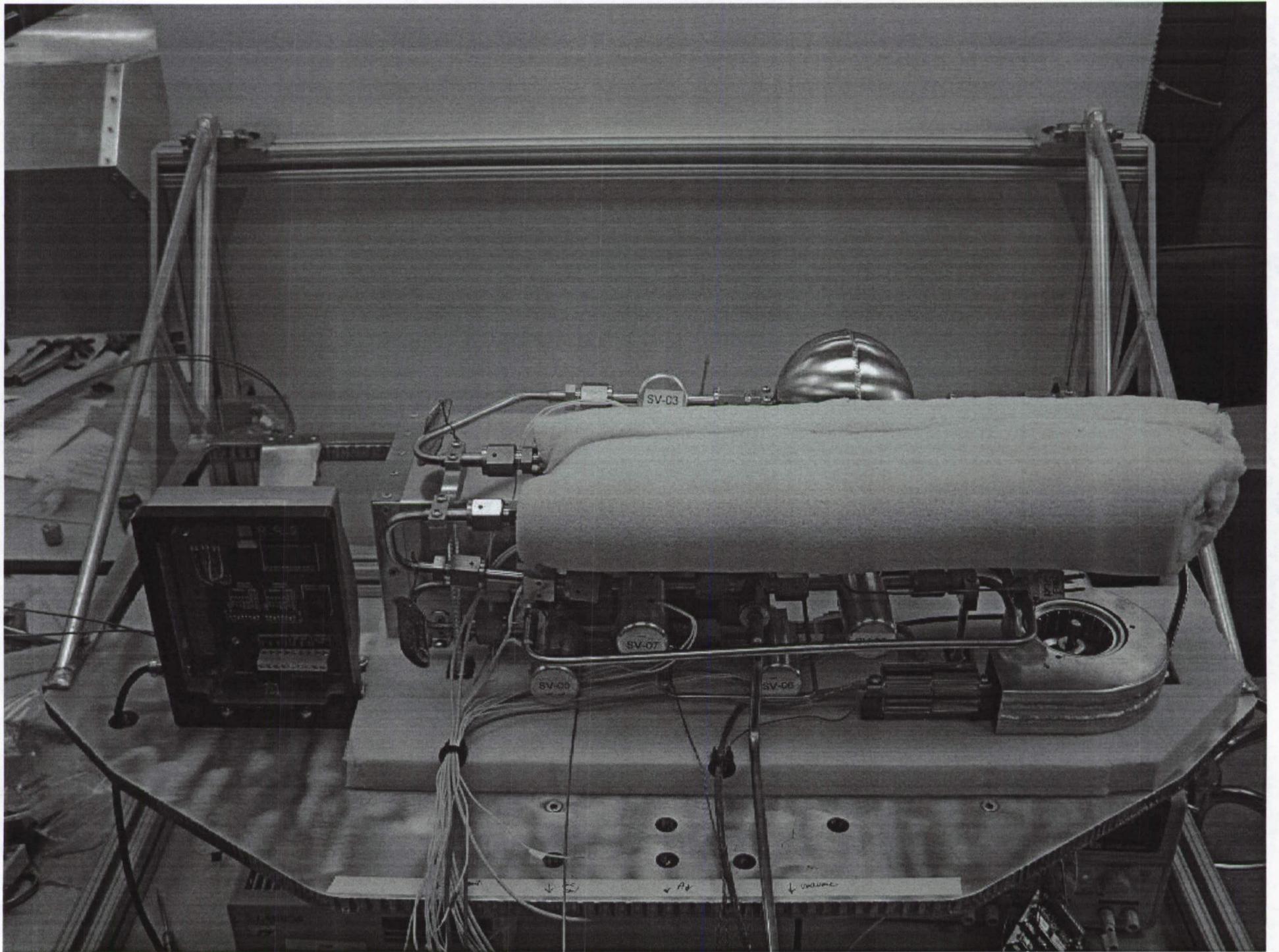


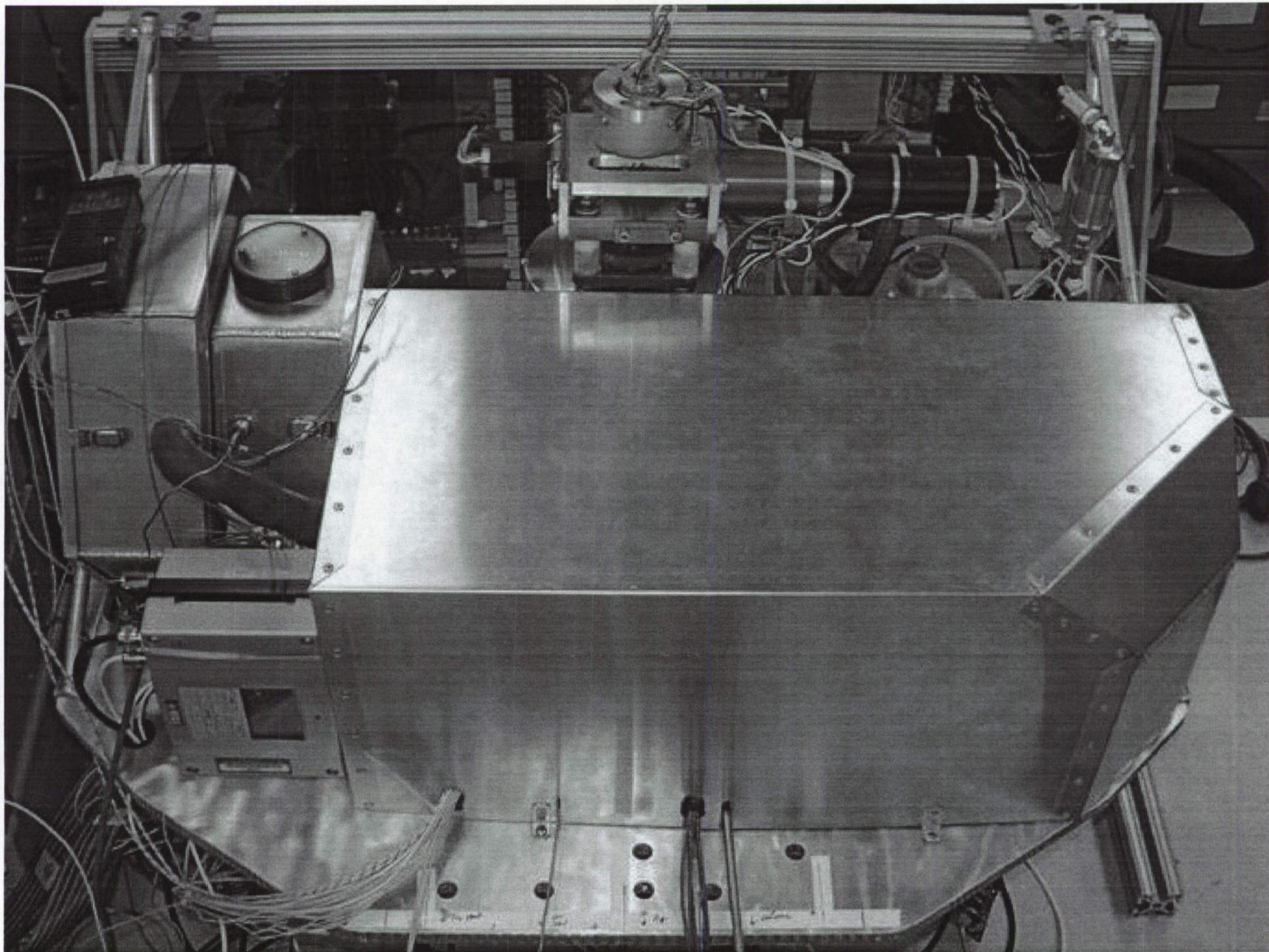
JOHN F. KENNEDY  
SPACE CENTER

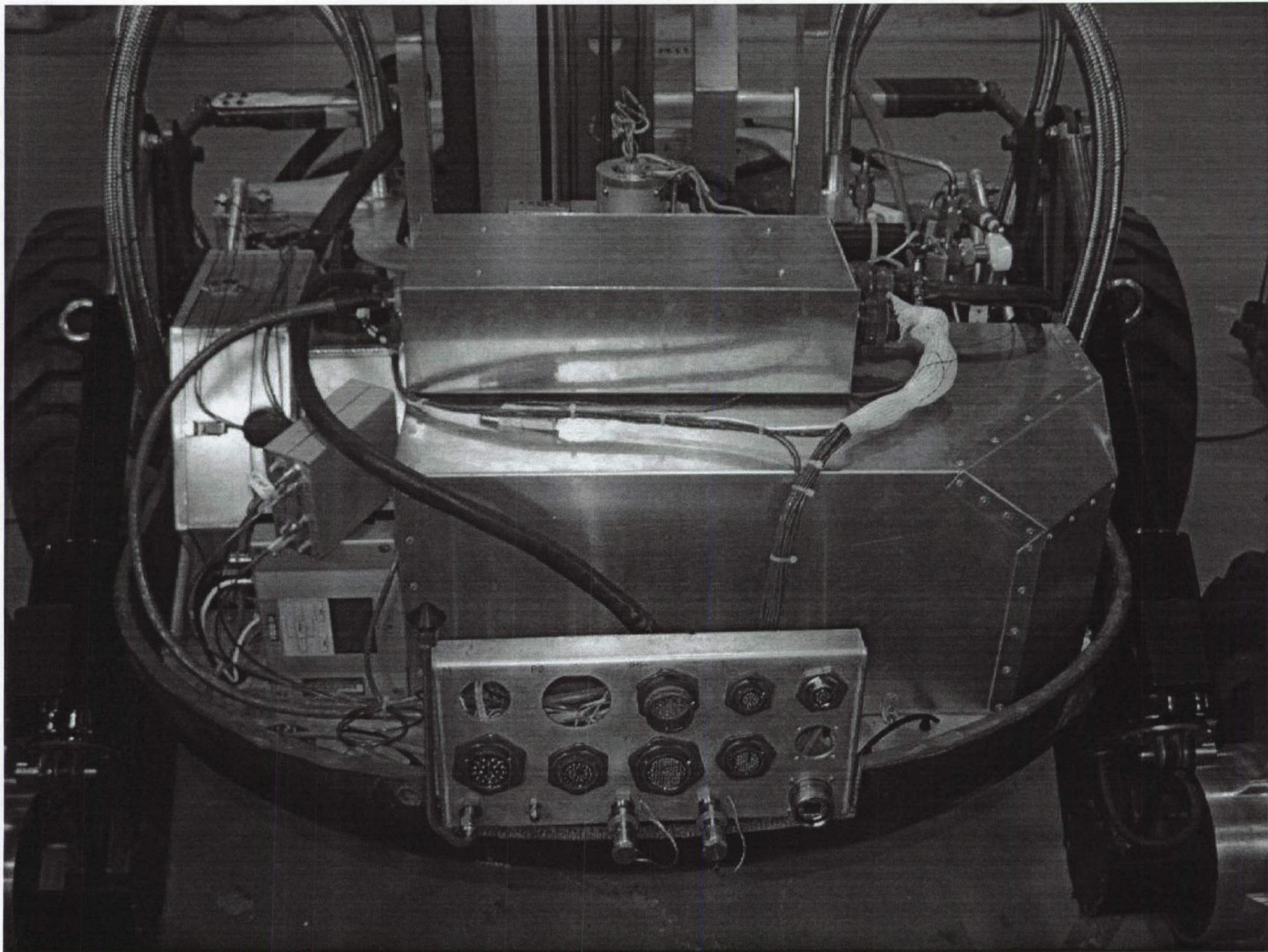
# Partially Assembled LWRD









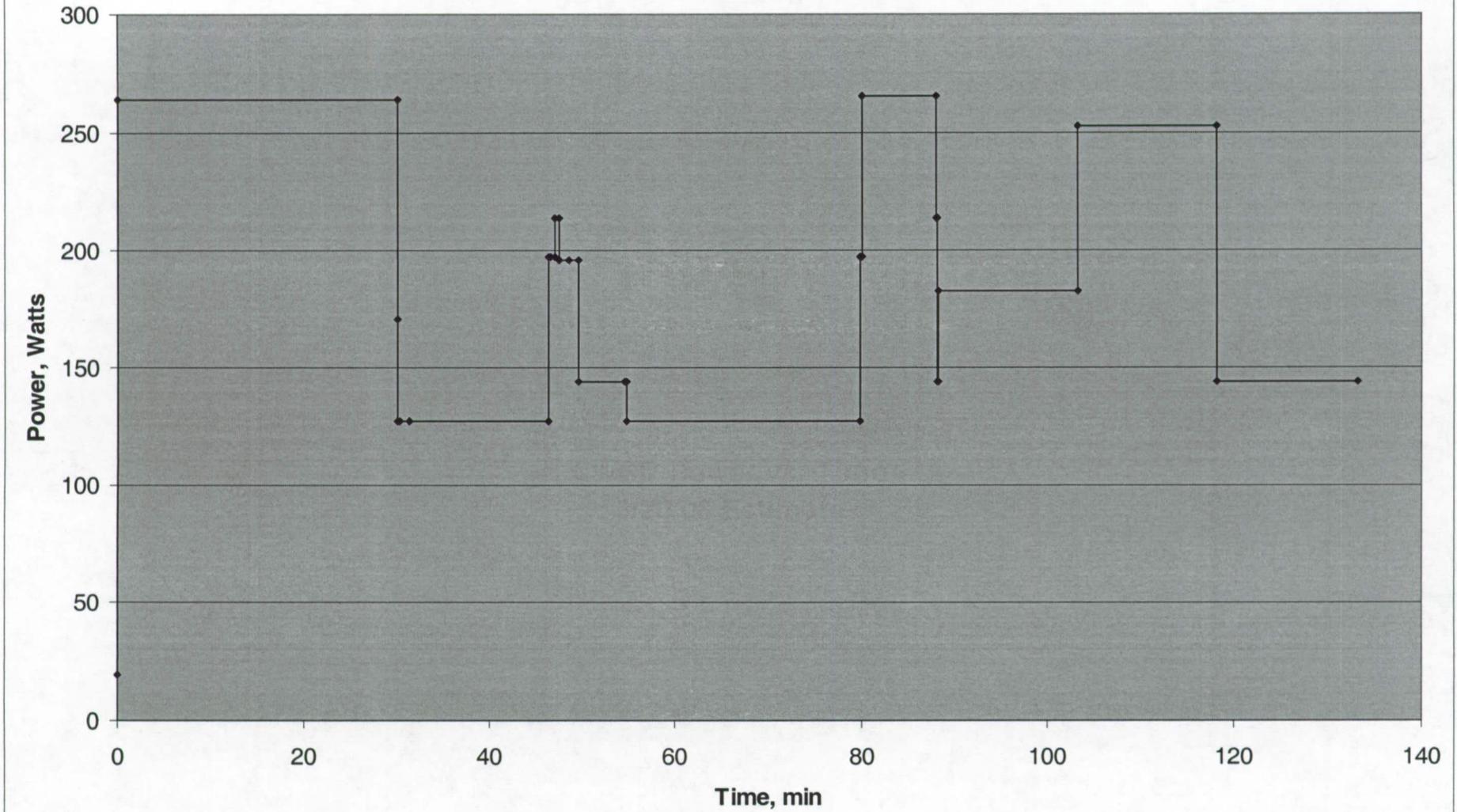




# Mass Reduction Strategy

1. Construct the system as planned with 1.4 kg of mass savings available from removal of one ROE water bed and the hydrogen bed during the demo if needed.
2. Keep the neon and hydrogen tanks on the rover.
3. Once everything is constructed and we have actual masses, remove those tanks if necessary (-3.8 kg).

### LWRD Power vs. Time 3/20/08 Estimate



# Planned Testing Deviations

- Lab – full capabilities demonstration
- Hawaii – no hydrogen absorption/  
desorption/quantification demonstration

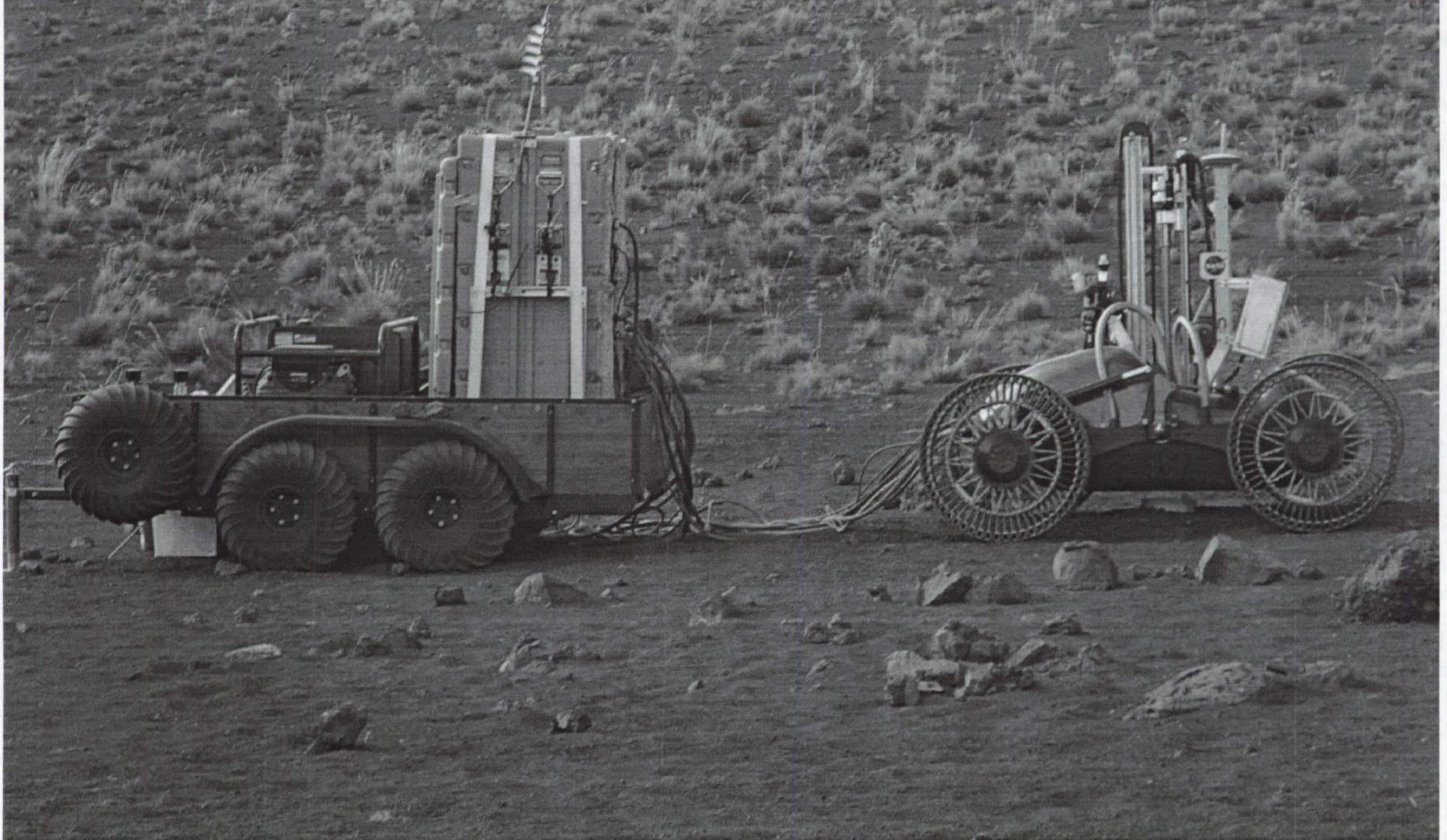




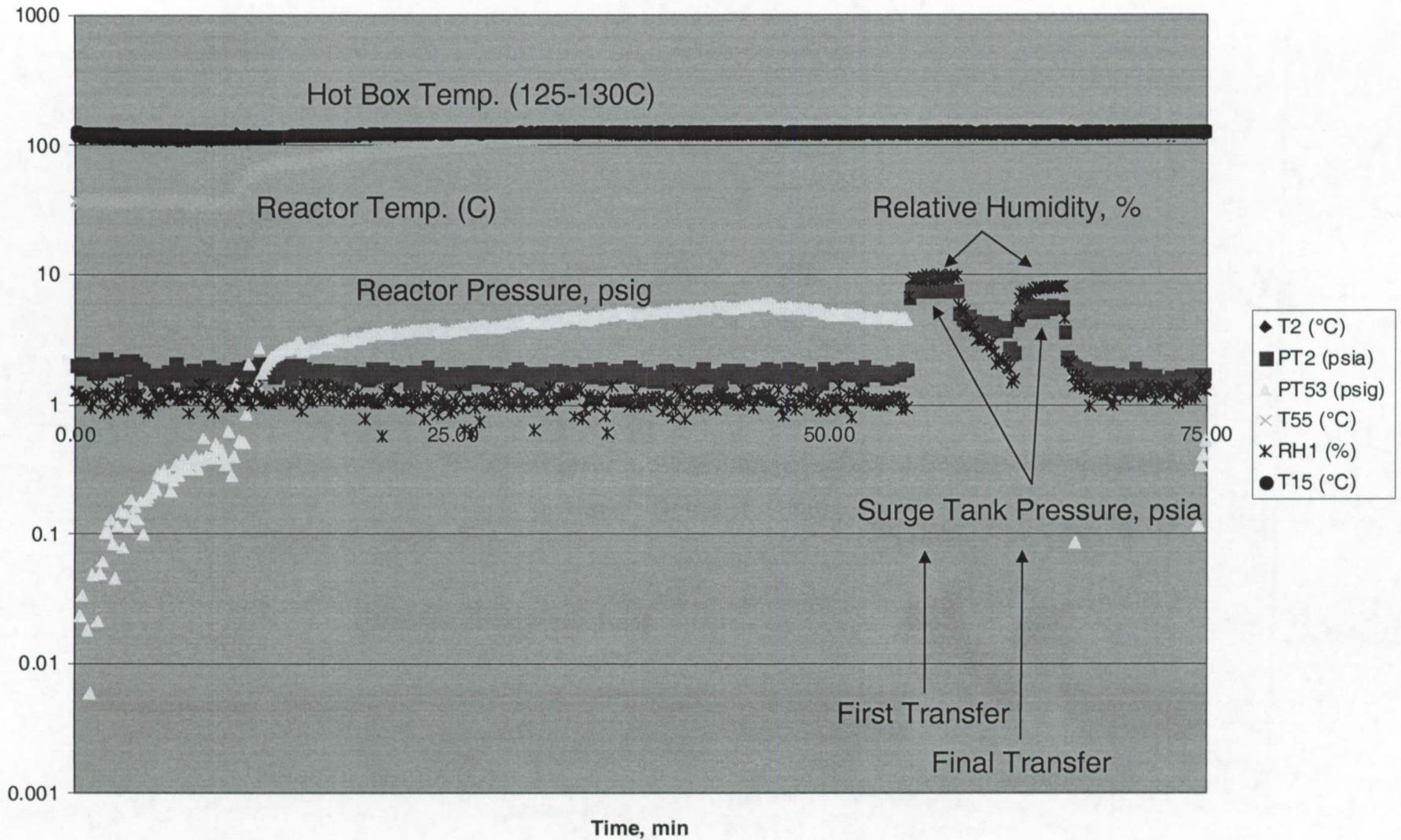




# GSE Cart and Rover Ready to Operate



# Hawaii Demo, 11/4/08



# Lab/Field Demonstration Results

| Date     | Total Water Transferred | Mass of Tephra         | % Water |
|----------|-------------------------|------------------------|---------|
| 9/24/08  | 0.27g                   | 85g                    | 0.31    |
| 9/24/08  | 0.08g                   | 90g                    | 0.09    |
| 9/24/08  | 0.35g                   | 85g                    | 0.41    |
| 9/25/08  | 0.33g                   | 85g                    | 0.39    |
| 9/25/08  | 0.29g                   | 85g                    | 0.34    |
| 11/4/08  | 0.11g                   | 66g                    | 0.17    |
| 11/5/08  | 0.13g                   | 72g                    | 0.18    |
| 11/6/08  | 0.16g                   | 92g                    | 0.17    |
| 11/8/08  | 0.13g                   | 71g                    | 0.19    |
| 11/9/08  | 0.11g                   | 76g                    | 0.15    |
| 11/10/08 | 0.19g                   | 90g (LN <sub>2</sub> ) | 0.22*   |

# Field Demonstration Results

| Date     | GC results (corrected) | LWRD results (corrected) | % difference |
|----------|------------------------|--------------------------|--------------|
| 11/5/08  | 48mg                   | 39mg                     | -18%         |
| 11/6/08  | 47mg                   | 57mg                     | 21%          |
| 11/8/08  | 46mg                   | 47mg                     | 3%           |
| 11/9/08  | 45mg                   | 34mg                     | -24%         |
| 11/10/08 | 52mg                   | 65mg                     | 24%          |
|          |                        | Average difference       | 18%          |



# Hydrogen Quantification Results

(To be entered when they become available)

| <b>Date</b>    | <b>Mass of H<sub>2</sub> in Reactor, g</b> | <b>LWRD results, g</b>    | <b>% difference</b> |
|----------------|--------------------------------------------|---------------------------|---------------------|
| <b>12/x/08</b> | 26.4mg                                     | xx mg                     | yy%                 |
| <b>12/x/08</b> | 26.4mg                                     | xx mg                     | yy%                 |
| <b>12/x/08</b> | 44.0mg                                     | xx mg                     | yy%                 |
| <b>12/x/08</b> | 70.4mg                                     | xx mg                     | yy%                 |
| <b>12/x/08</b> | 70.4mg                                     | xx mg                     | yy%                 |
|                |                                            | <b>Average difference</b> | <b>zz%</b>          |

# Major Milestones

|                                               |          |
|-----------------------------------------------|----------|
| Complete Final Design                         | 2/15/08  |
| Component Assembly and Testing                | 4/15/08  |
| RESOLVE Integration and Testing at KSC        | 9/12/08  |
| Shipping, Integration w/Rover, Testing at CMU | 9/27/08  |
| Field Test on Mauna Kea                       | 11/13/08 |
| Final Report                                  | 1/31/09  |



# Summary

- LWRD Team has accomplished all major goals in design, construction, and testing
- Redesigned compared to EBU1 because of changes in assumptions and requirements
- Successfully completed November field demo on Mauna Kea in Hawaii
- Achieved acceptable agreement with GC results for water and hydrogen as a backup system