Chemical Engineering at NASA

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Energy Systems Division

Overview

- Background Information
- JSC Engineering Directorate Organization
- My Role as a Chemical Engineer in the Space Industry
  - Battery Testing
    - Why test batteries?
    - Types of Tests
    - Capabilities
  - ISRU
  - Propulsion and Cryogenics
- Questions and answers

Background Information

- First engineer in my family
- Didn't have a lot of money so I started at a junior college
- Alvin Community College
  - Associate in Arts Degree in General Liberal Arts
  - Various Construction and Sales Jobs
  - I wanted something more
- University of Houston
  - Reasons I choose Chemical Engineering
    - I wanted a versatile, challenging, & rewarding career
    - Even if I did not receive my dream job, I would ensure a healthy salary for my family
  - Bachelor of Science in Chemical Engineering with a Minor in Chemistry
- You can find your dream job from any school
  - It's not the school but what you make of it
  - I was labeled a "B" student as an undergraduate
  - But I never stopped working and found a career in my desired field

Background Information

- Highly recommend a Co-op or Internship
  - Experience gained is worth a few points to your GPA
  - No more Roman noodles and water every night
  - Learn what career path best fits your personality
    - Food Industry: Maxwell House (Soluble Processes)
    - Plastics Industry: Bayer Corporation (Polycarbonate Division)
    - Great jobs but something was missing…
- Shortly before graduation I began working my "Law of Averages"
  - Sales term that means if you try everywhere, someone will buy it
  - Went on a lot of interviews and got turned down a lot
  - Received offers from some of the major oil companies and NASA
  - I choose the Aerospace Industry over salary because nothing, in my opinion, is more important than space travel
- NASA is composed primarily of Aerospace, Mechanical, and Electrical Engineers
  - NASA promotes diversity
  - I often find myself offering unique information due to my background
- University of Houston Clear Lake
  - Attended night courses while working for NASA
  - Masters of Science in Physics

JSC Organization

- Before discussing the details of my experiences at NASA…
- Show the JSC organization:
  - AA: Office of the Director
  - BA: Office of Procurement
  - CA: Flight Crew Operations Directorate
  - DA: Mission Operations Directorate
  - **EA: Engineering Directorate**
  - IA: Information Resources Directorate
  - JA: Center Operations Directorate
  - KA: Astromaterials Research and Exploration Science Directorate
  - LA: Chief Financial Officer
  - MA: Space Shuttle Program
  - NA: Safety and Mission Assurance Directorate
  - OA: International Space Station Program Office
  - QA: Commercial Crew/Cargo Project Office
  - RA: White Sands Test Facility
  - SA: Space Life Sciences Directorate
  - W-JS: NASA Office of Inspector General
  - WE: NASA Engineering and Safety Center
  - WR: Department of Defense Payloads Office
  - WS8: NOAA-National Weather Service, Spaceflight Meteorology Group
  - XA: Extravehicular Activity Office
  - ZA: Constellation Program Office
- Many different possibilities for Chemical Engineering at NASA and in the Aerospace Industry

Engineering Directorate Organization

Energy Systems Division Organization

ENERGY SYSTEMS DIVISION

PROPULSION & FLUID SYSTEMS BRANCH

- Fluid Systems and Components
- Attitude Control System
- APU/Hydraulics
- Electromechanical Actuators
- In-Situ Resource Utilization/In-Situ Propellant Production

POWER SYSTEMS BRANCH

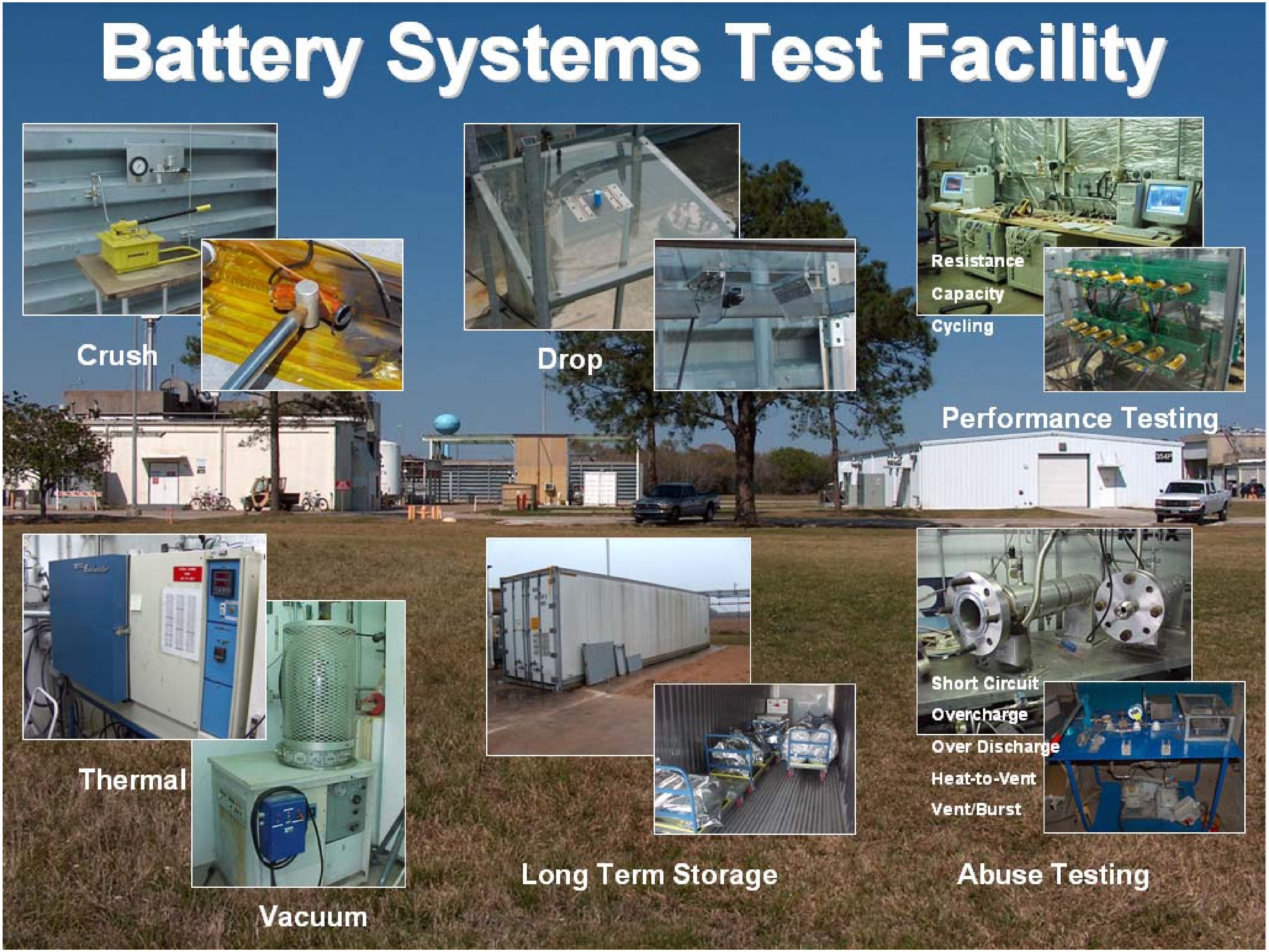
- Power Generation, Storage, and Distribution
- Pyrotechnics
- Batteries
- Fuel Cells
- Electrical Power System Laboratory

ENERGY SYSTEMS TEST BRANCH

- 6 Test Facilities and Support Services
- Environmental Test Services

My Role at NASA

- Cannot speak for all NASA Chemical Engineers
  - Some are in management
  - Some are in other directorates I am not familiar with
  - Some are astronauts
  - Will not go into all of the details but mention specific items related to my experiences
- Became a Test Director
  - Manage many different test programs from the planning, development, operations, and reporting phases
  - Define test requirements, conditions, and procedure
  - Establish technique to meet requirements and schedule and perform any necessary procurements
  - Work closely with the technicians and get hands on experience
- Supported test programs in the areas of:
  - Chemical Storage (primary focus)
  - In-situ Resource Utilization (ISRU)
  - Recently began learning Propulsion and Cryogenic systems



Battery Systems Test Facility
Crush
Drop
Resistance
Capacity
Cycling
Performance Testing
Thermal
Vacuum
Long Term Storage
Short Circuit
Overcharge
Over Discharge
Heat-to-Vent
Vent/Burst
Abuse Testing

Why Test Batteries?

- Batteries are used for many aerospace applications ranging from shuttle to station projects
- Many batteries are high energy and all of them are toxic to some degree
- High energy batteries are often high voltage and can potentially cause a lethal electrical shock
- High temperatures can be generated during charging and discharging causing a touching hazard
- Fire is a constant danger working around batteries since many of the batteries use an electrolyte that is flammable
- A toxic atmosphere can occur during such a fire which would cause a catastrophe in an enclosed life support system such as a spacesuit, in the shuttle, or on station
- A leak in a zero-g atmosphere could cause blindness, death, or even lead to long term problems
- The manufacturers of these batteries do not test for many of the situations NASA will routinely subject them to

Flight Testing

- Acceptance testing on hardware before flight
- Involves independent verification from Quality Control
- Support many Shuttle and Station projects
  - Laptops
  - Handheld PDA’s
  - Bar code readers
  - EAPU for shuttle
  - Life Support Systems for Space Suit
  - Life testing of Station batteries
  - etc

Astronaut Michael Fincke holding the PDA I tested onboard the ISS

Battery Performance

Long and Short Term Cycling

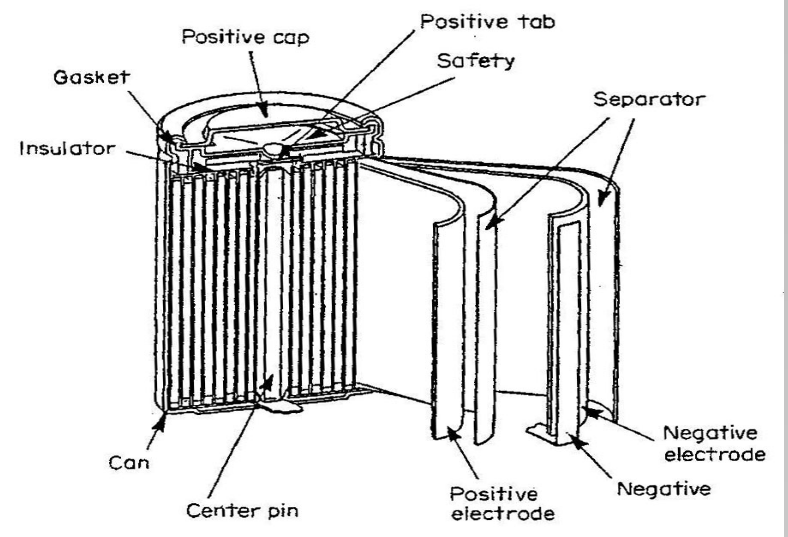
- Determine capacity of batteries
- Determine optimal charge/discharge rates
- Capacities at different thermal environments
- Vacuum tolerance

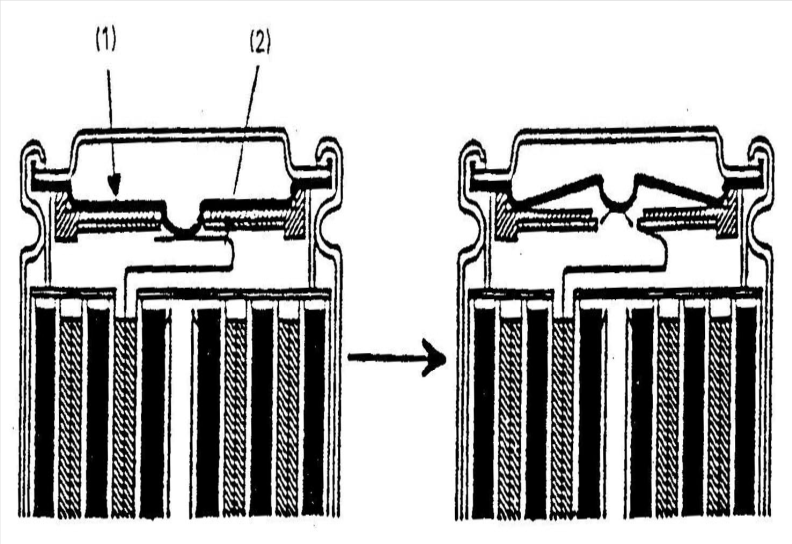
Battery Abuse

- We do everything the label tells you not to
  - Overcharge / Over discharge
  - Short Circuit
  - Thermal/Heat-to-Vent
  - Drop Test
  - Crush Test
  - Vibration
  - Vent/Burst

Battery Abuse

- Positive Temperature Coefficient (PTC)
  - Polymer expands and increases in resistance as the temperature or current increases
  - Decreases current and voltage
  - PTC resets when the load is removed
- Current Interrupting Device (CID)
  - After 5.0V, the electrolyte decomposes into vapor and increases the pressure of the cell
  - CID flips and the cell loses electrical contact
  - Cannot be recovered (fail safe)





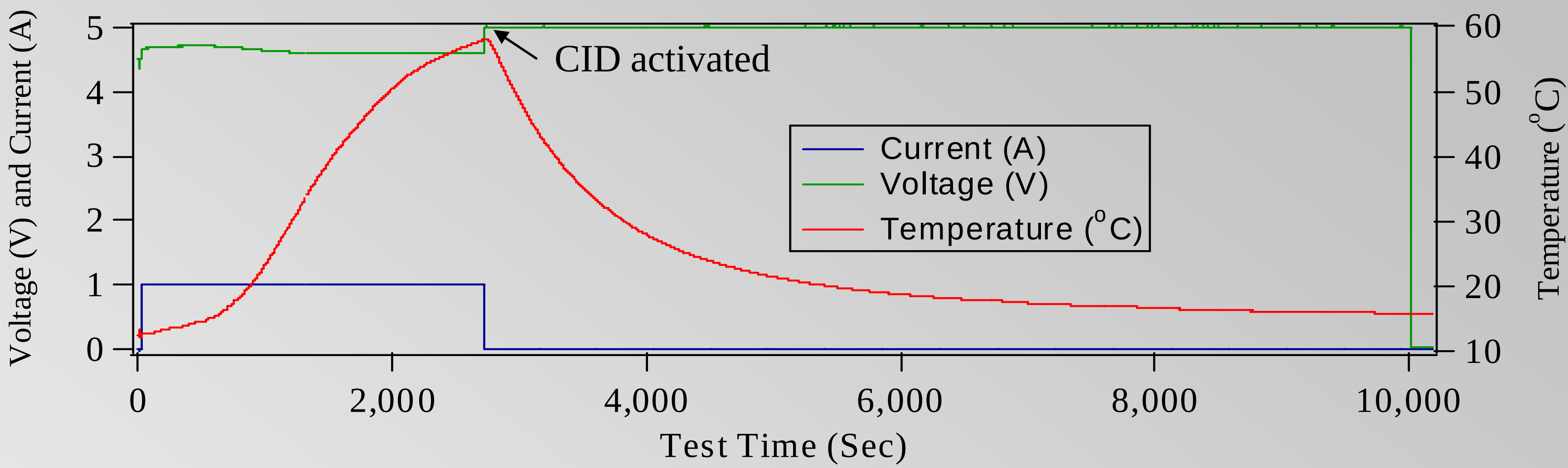
Battery Abuse

- Overcharge and Over-discharge testing:
  - Performed on the cell and battery level
  - Many different methods:
    - High currents for short periods of time
    - Low current for long periods of time
  - Perform standardized charge/discharge cycles before and after testing

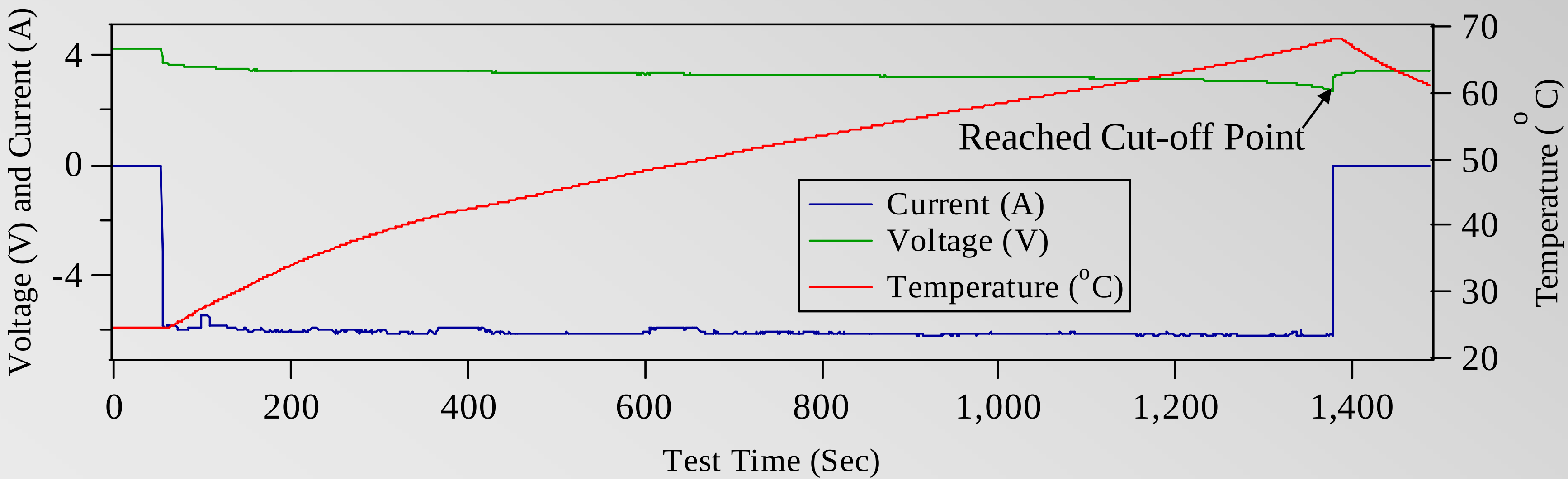
Battery containment box

Battery Abuse

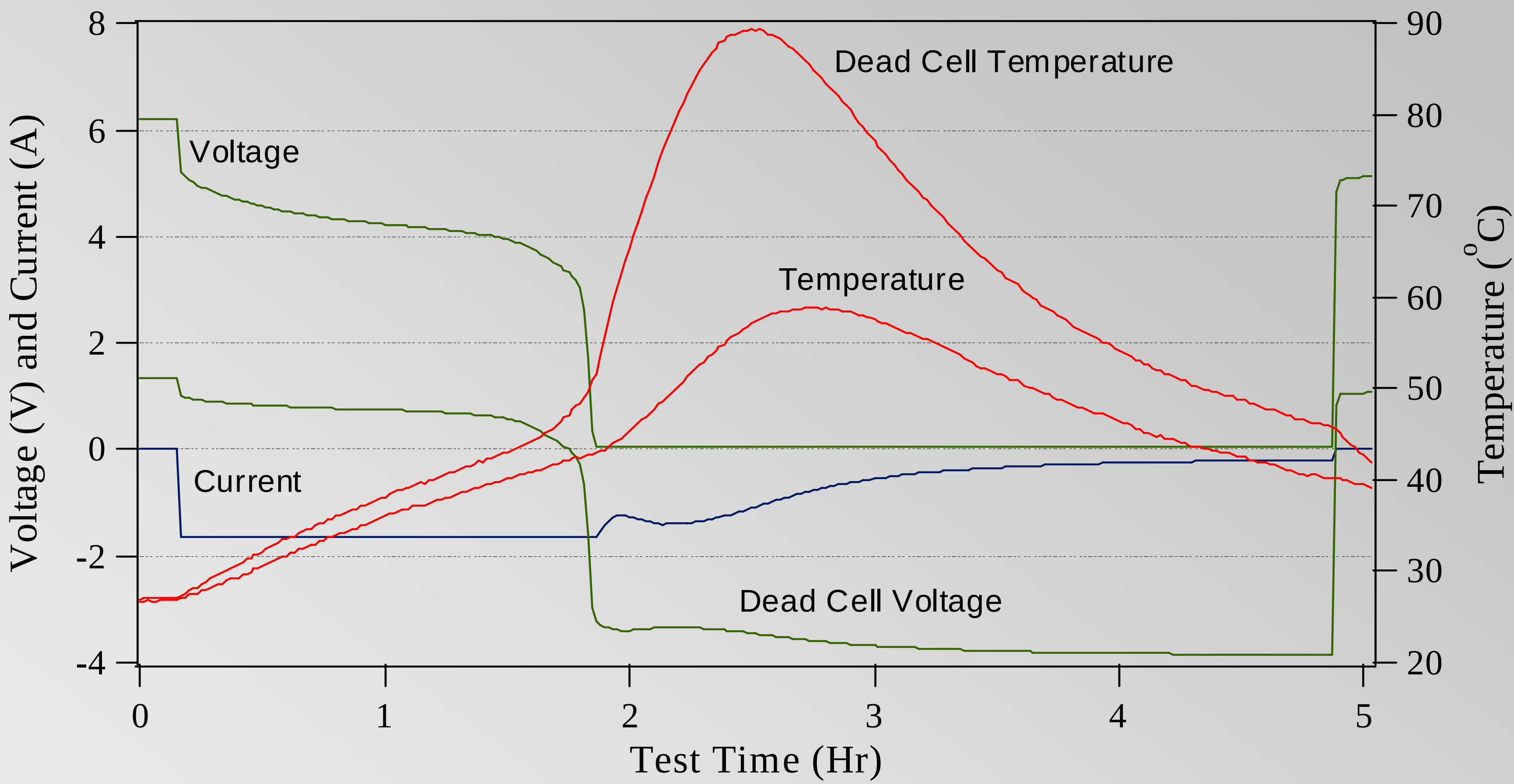
CELL OVERCHARGE



CELL OVER DISCHARGE



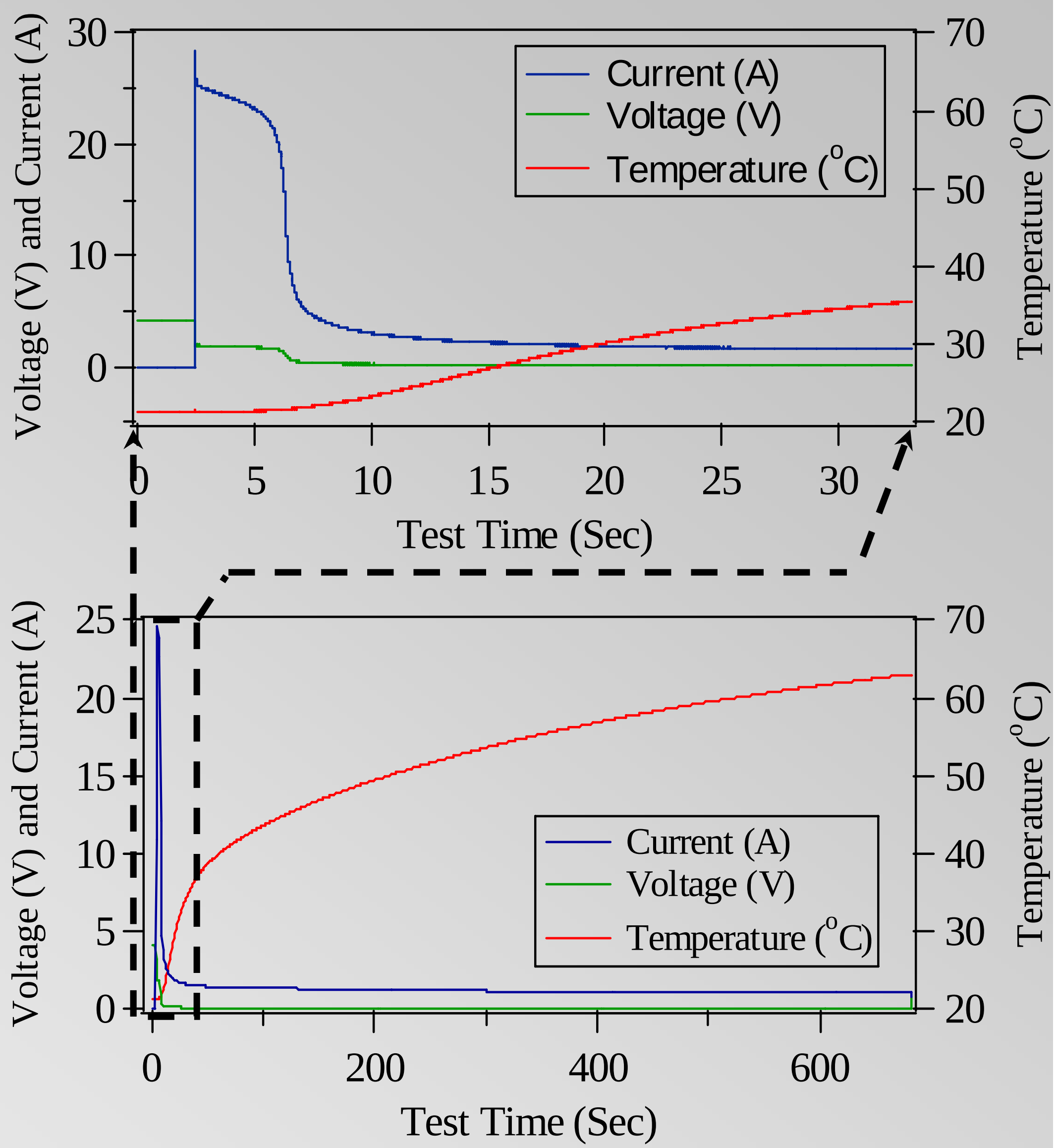
Battery Pack Over Discharge



- Place 3 charged D cells in series with 1 discharged cell in your flashlight and leave it on overnight
- Discharged cells will go into reversal
- Standard alkaline D cells can reach 193^{o}F (89^{o}C)

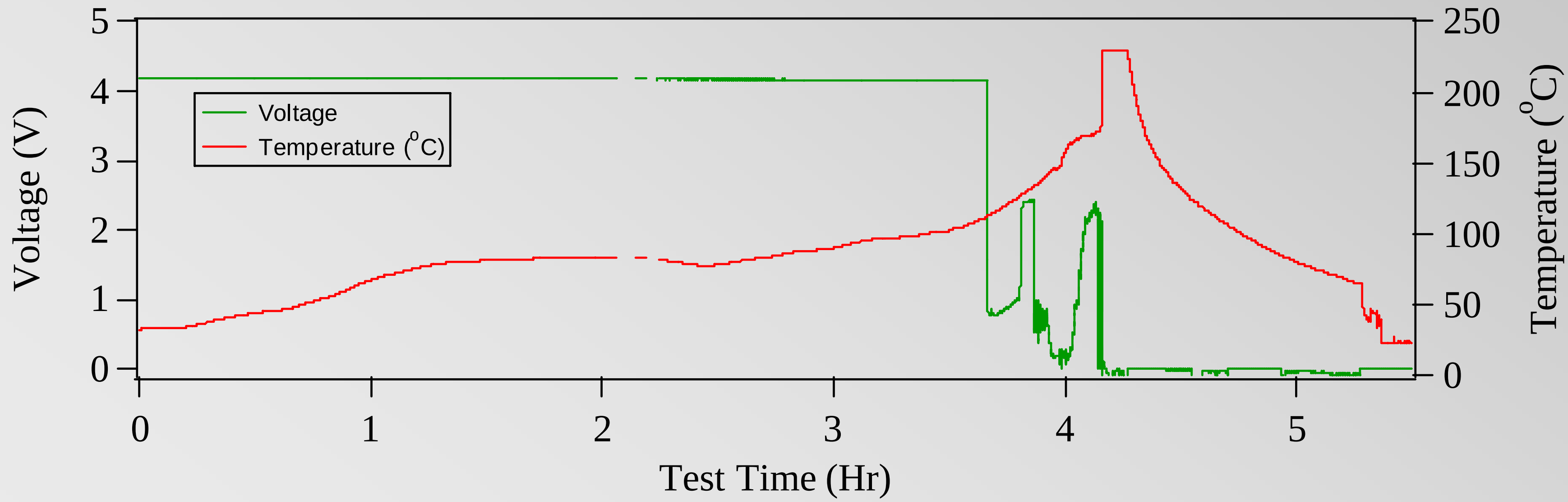
Battery Abuse

- Short Circuit (Hard Short):
  - Apply different resistance across positive and negative terminal
  - Typically 10-50 mOhm
  - Load maintained until temperature increase levels off

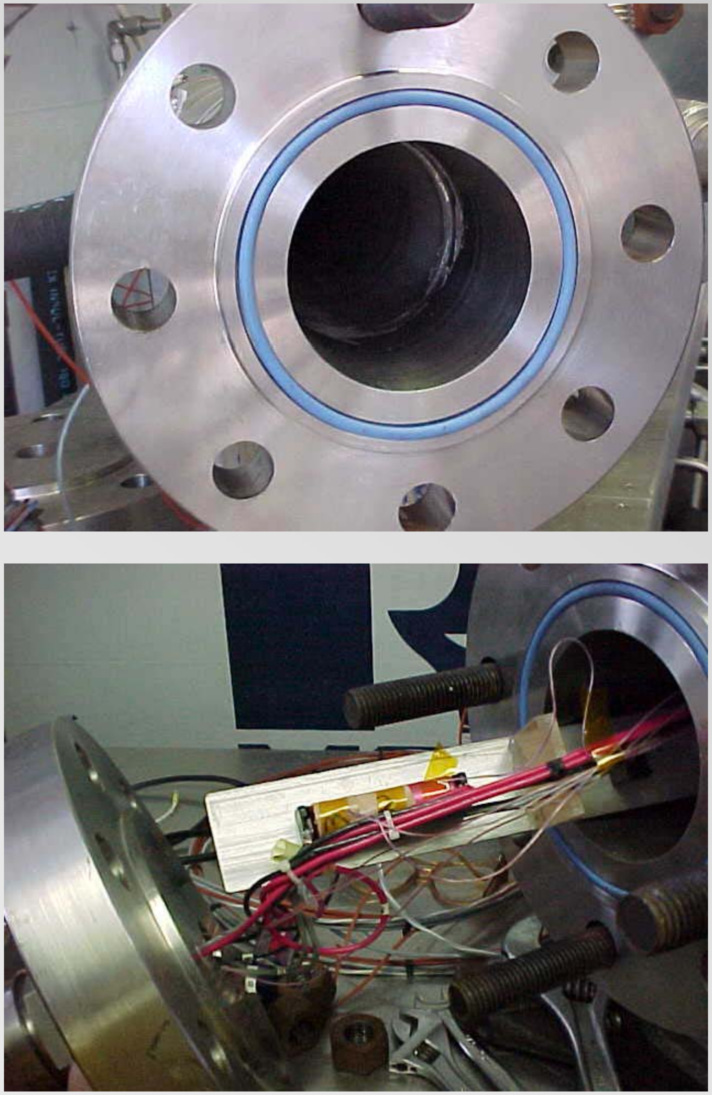


Battery Abuse

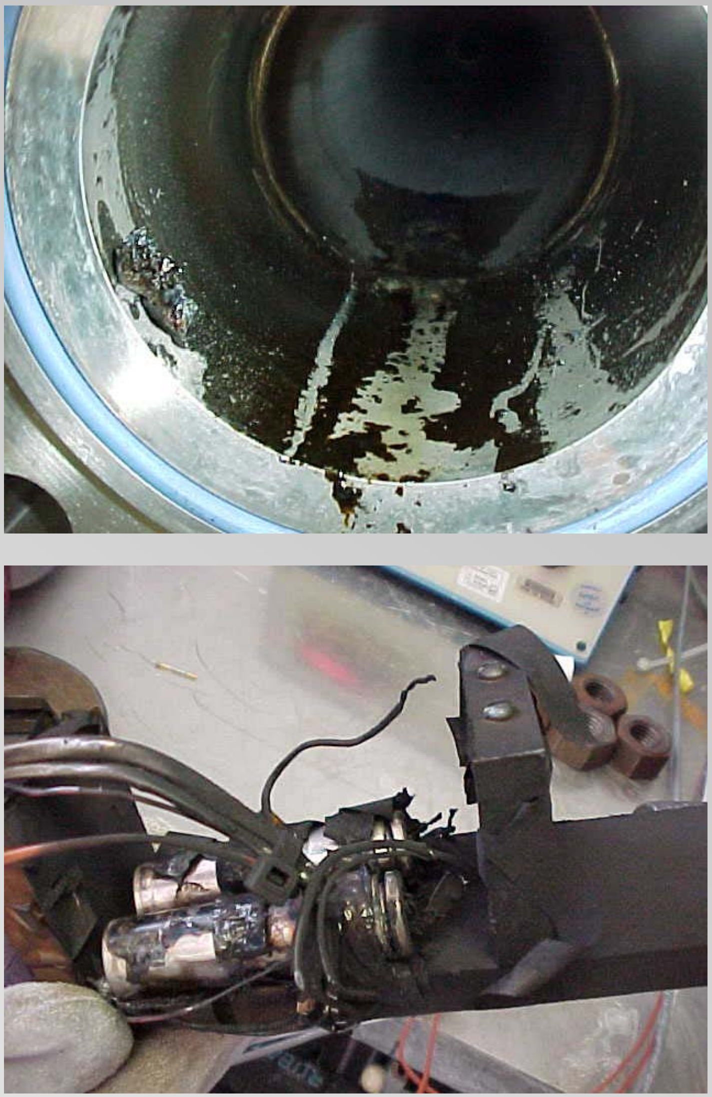
- Thermal and Heat to Vent:
  - Chamber purged with nitrogen and a baseline gas sample obtained
  - Chamber temperature increased to 180°F and maintained for 2 hours
  - Temperature is then increased until venting occurs
  - A contaminated gas sample is obtained
  - The chamber is then purged with GN_2 for 12 hours
  - The weight before and after temperature treatments is recorded
- Example of thermal test:



Battery Abuse



Before Test



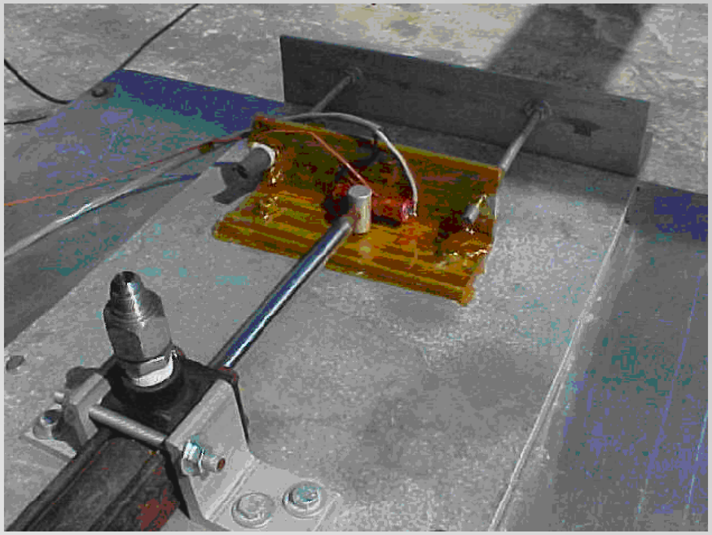
After Test

Battery Abuse

- Drop Test:
  - Drop cells 6ft onto the concrete
  - Test stand is located behind a blast wall
  - Door is remotely opened
  - Temperature is measured before handling
  - Litmus paper utilized to check for leaks
- Performed pre and post charge discharge cycles to verify functionality

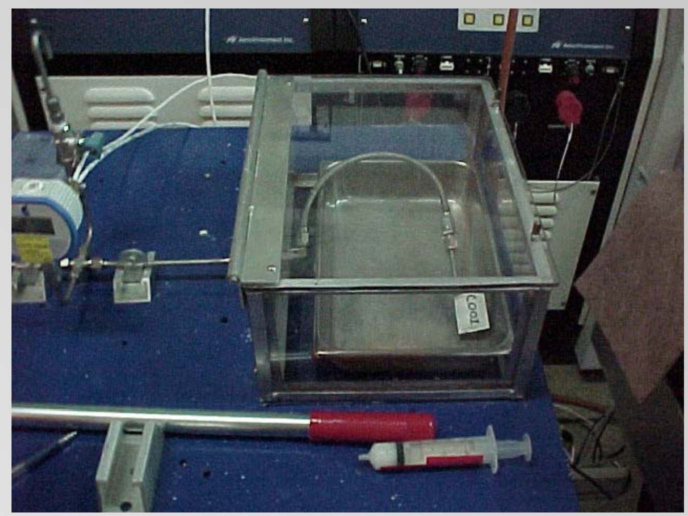
Battery Abuse

- Crush Test:
  - Simulates an internal short
  - Cause deformation without penetration
  - Can measure pressure of hydraulic cylinder and calculate force
  - Monitor OCV and temperature



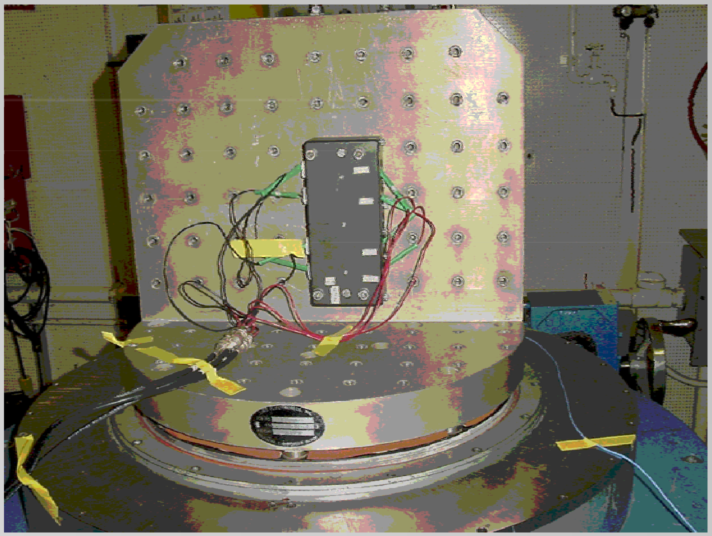
Battery Abuse

- Vent/Burst Test Stand
  - Remove electrolyte in chemical laboratory
  - Epoxy/weld fitting to battery
  - Apply water pressure to battery and measure the pressure the battery vents.
  - Can block vent hole and measure the pressure the battery bursts



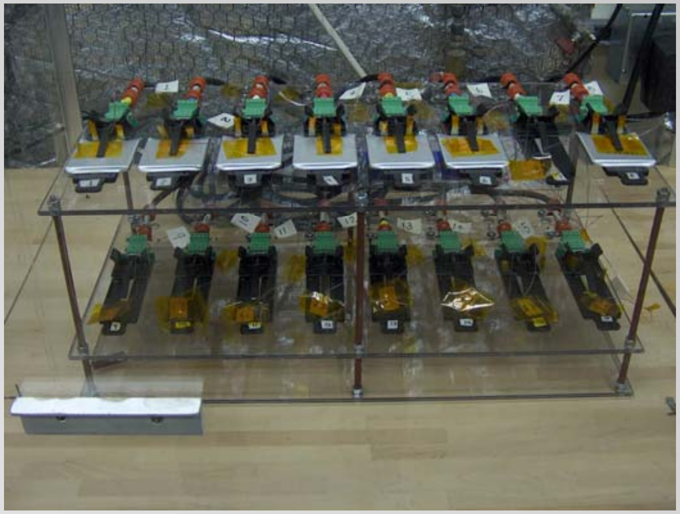
Battery Abuse

- Vibration
  - Lots of vibration at launch
  - Poorly constructed battery prone to internal short
  - Screen all batteries before flight
  - Vibrate in the x, y and z axes to a defined spectrum
  - Cells and batteries undergo charge & discharge cycling before and after testing
- Shock testing is also performed



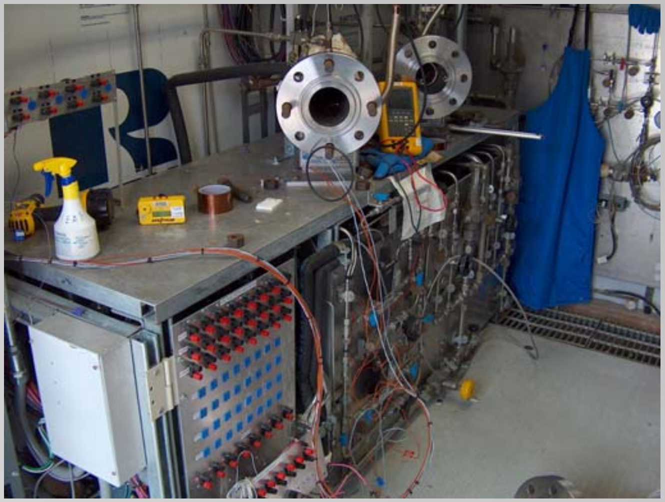
Capabilities

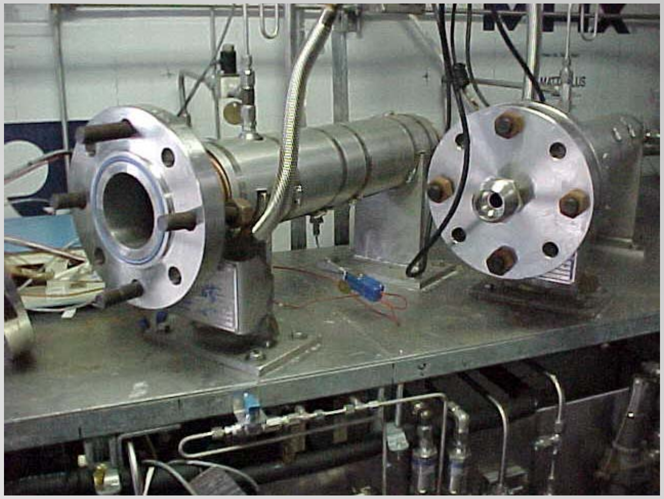
- Automated Battery Test Stands
  - 12 Systems ranging from low current/voltage to high current/voltage
  - Off-the-shelf units (Arbin, Maccor, PEC)
  - NASA constructed units (Labview)
  - Each channel is independent of the other
  - Can record voltage, current, and temperature
  - Constant voltage, current, & Power modes



Capabilities

- Battery Abuse Chambers
  - 2" and 4" Chamber: 0.1 psig to 700 psig
  - 4" Chamber: 10-3 torr to 700 psig
  - All systems are equipped with a relief valve set at 45 psig
  - TNRCC approved for controlled purge of battery vents products
  - An Arbin 8Ch 15V 15A test stand is connected (System 434A)
  - The Labview power system has 6Ch 40V 30A and the data system has 24 voltage, 4 current, and 24 temperature measurements (System 434B)



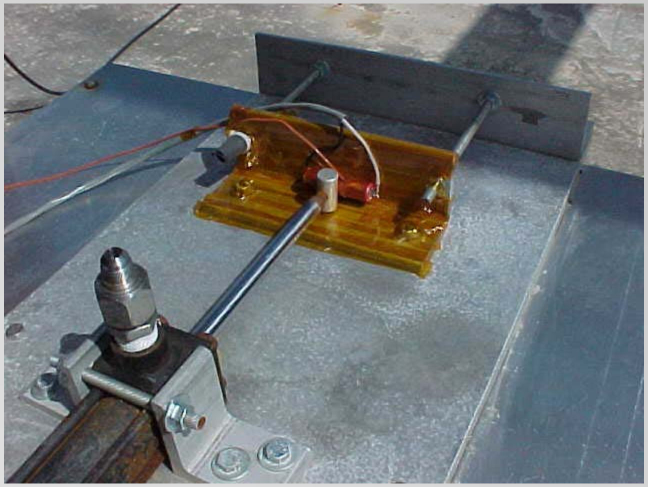


Capabilities

- Bell Jar Vacuum Chamber
  - 10-4 torr
  - 16" diameter x 24" high
  - Pyrex

Capabilities

- Crush Test Stand
  - Operator protected by a blast wall
  - Simulates an internal short
  - Cause deformation without penetration
  - Can measure pressure of hydraulic system and calculate force
  - Monitor OCV and temperature
  - Video camera capability



Capabilities

- Drop Test Stand
  - Trap door operated by solenoid valve connected to a remote switch behind blast wall.
  - 6" long x 7" wide trap door
  - Adjustable drop height of 0' to 8'
  - Video camera capability

Capabilities

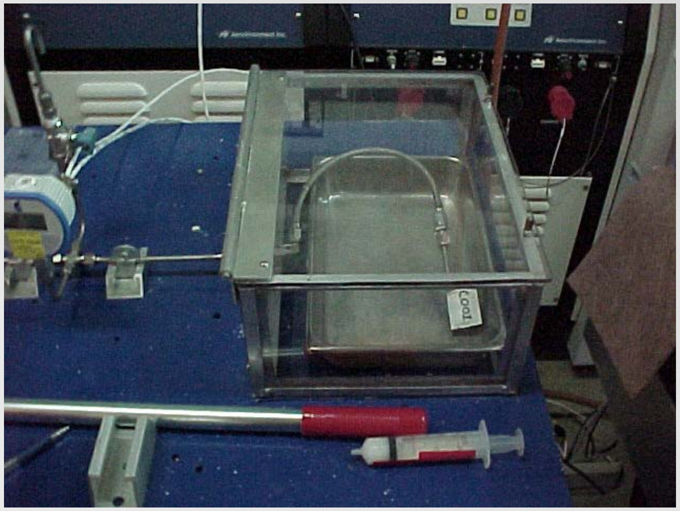
- Machine Shop
  - Disk Sander
  - Drill Press
  - Band Saw
  - Grinder
  - Vice
- Spot Welding
  - Can spot weld tabs onto batteries

Capabilities

- Thermal Chambers
  - Various chamber ranging from 2ft^3 to 8ft in diameter
  - Many have Cryogenic capabilities
  - Can reach up to 500^{o}F (260^{o}C) in some chambers
  - Precise humidity control
  - Unattended operation

Capabilities

- Vent/Burst Test Stand
  - Can apply water pressure to battery and measure the pressure the battery vents.
  - Can block vent hole and measure the pressure the battery bursts
  - MAWP 2500psig



Capabilities

- Walk-in Freezer
  - Temperature range: -4ºF to 80ºF (-20ºC to 27ºC)
  - Usable Envelope:
    - 40' long x 9.5' height x 8' width
    - 8' entrance with 2 swing doors
  - Temperature data recording
  - Alarm
  - Fire Protection System

Sabatier Reactor Testing

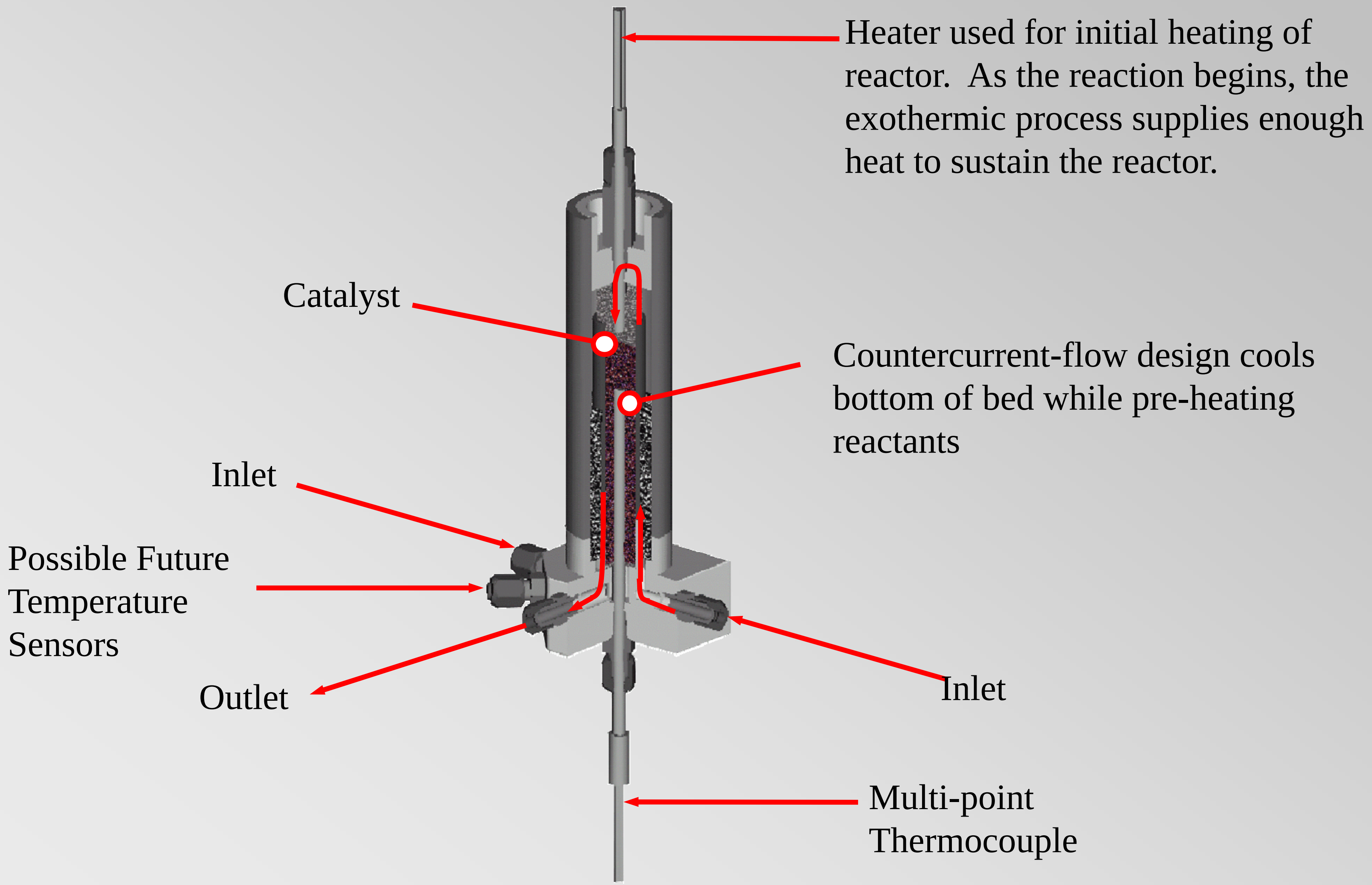
- Objectives:
  - Advance the understanding of Sabatier reactors
  - Develop an innovative reactor design
  - Design, fabricate, and test the reactor in-house
  - Compare results from testing to previous designs
- Potential uses:
  - Life Support on Space Station
    - Convert crew exhaled CO_2 and H_2 (from electrolyzed H_2O) into CH_4 and H_2O
    - Potential reduction of H_2O delivered to ISS by 2,000 lbs/yr for a three person crew
  - Propellant Production
    - Potential Earth launch mass reduction of 20% - 45%
    - Convert Mars atmospheric CO_2 and Earth transported H_2 into CH_4 (fuel) and O_2 (oxidizer)
    - O_2 produced can also be used as back-up to habitat ECLSS (Environmental Control and Life Support System)

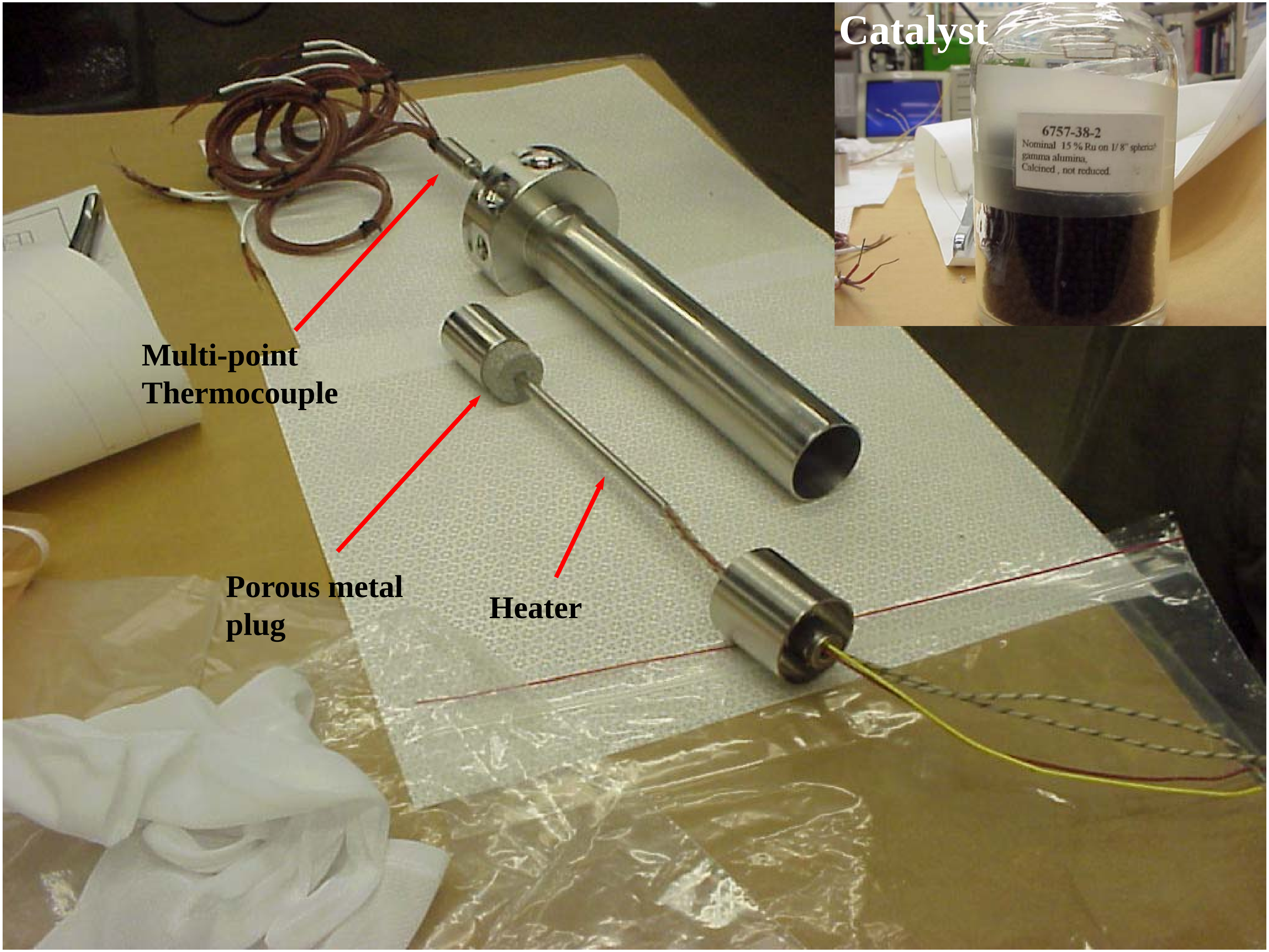
Sabatier Reactor Testing

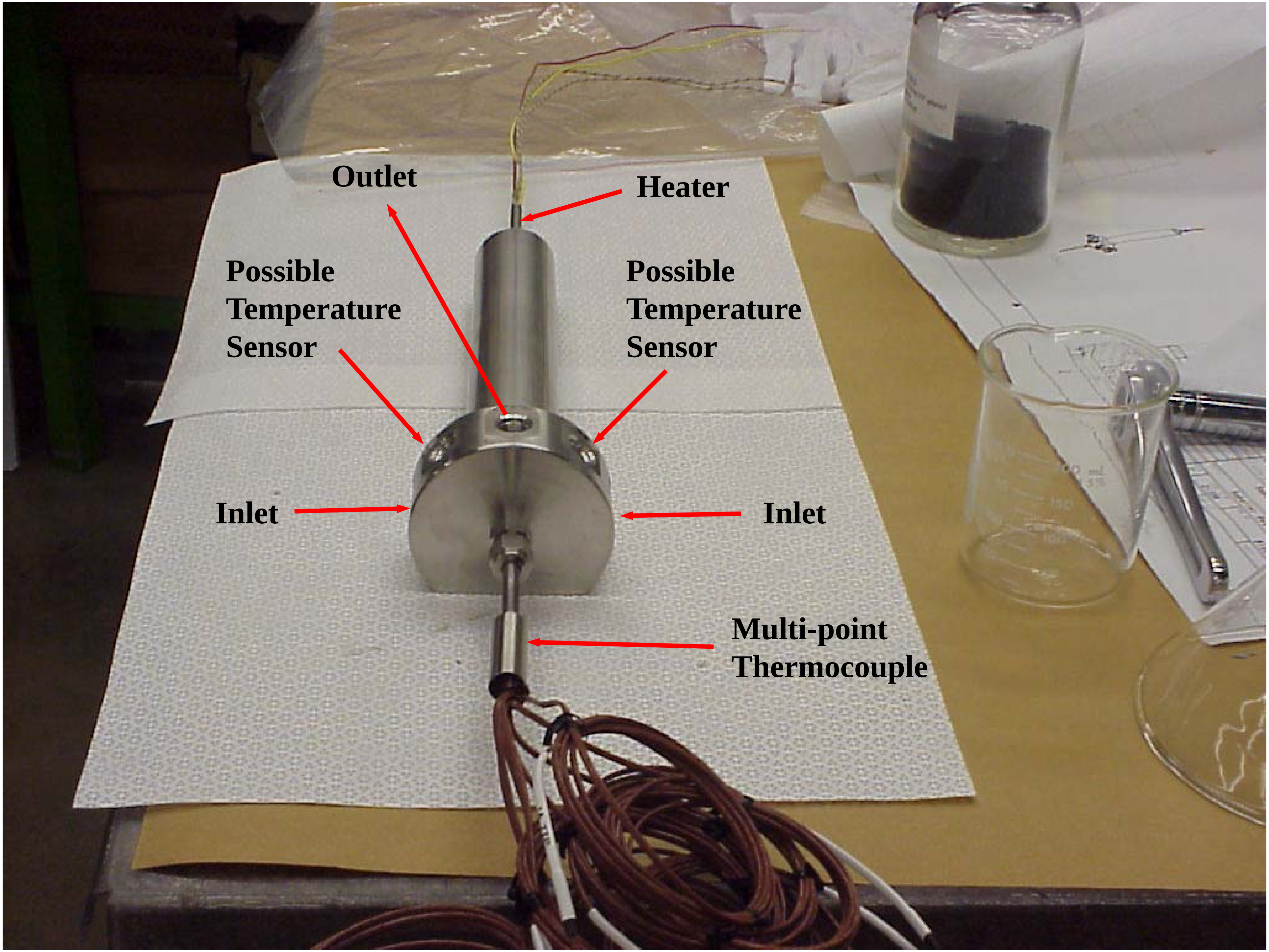
- Sabatier Reactor Specifications
  - Regeneratively cooled, single-pass, packed-bed reactor
  - Exothermic pressure reducing reaction
  - Ruthenium on alumina catalyst pellets
  - Power only required for initial heating of catalyst to kick start reaction
  - Reactor sized for In-Situ Resource Utilization (ISRU) based Mars Sample Return Mission
- Nominal Operating Conditions
  - Nominal Flow Rates:
    - $H_{2\,(g)}$ In: 3,000 sccm @ 50 psia
    - $CO_{2\,(g)}$ In: 750 sccm @ 50 psia
    - $CH_{4(g)}$ Out: 750 sccm @ 45 psia
    - $H_2O_{(g)}$ Out: 1,500 sccm @ 45 psia
  - Core Temperature can reach 593 ^{o}C (1100 ^{o}F)
  - Optimum thermal profile includes high temperatures of inlet catalyst (357-593 ^{o}C) and low temperatures of outlet catalyst (27-127 ^{o}C)

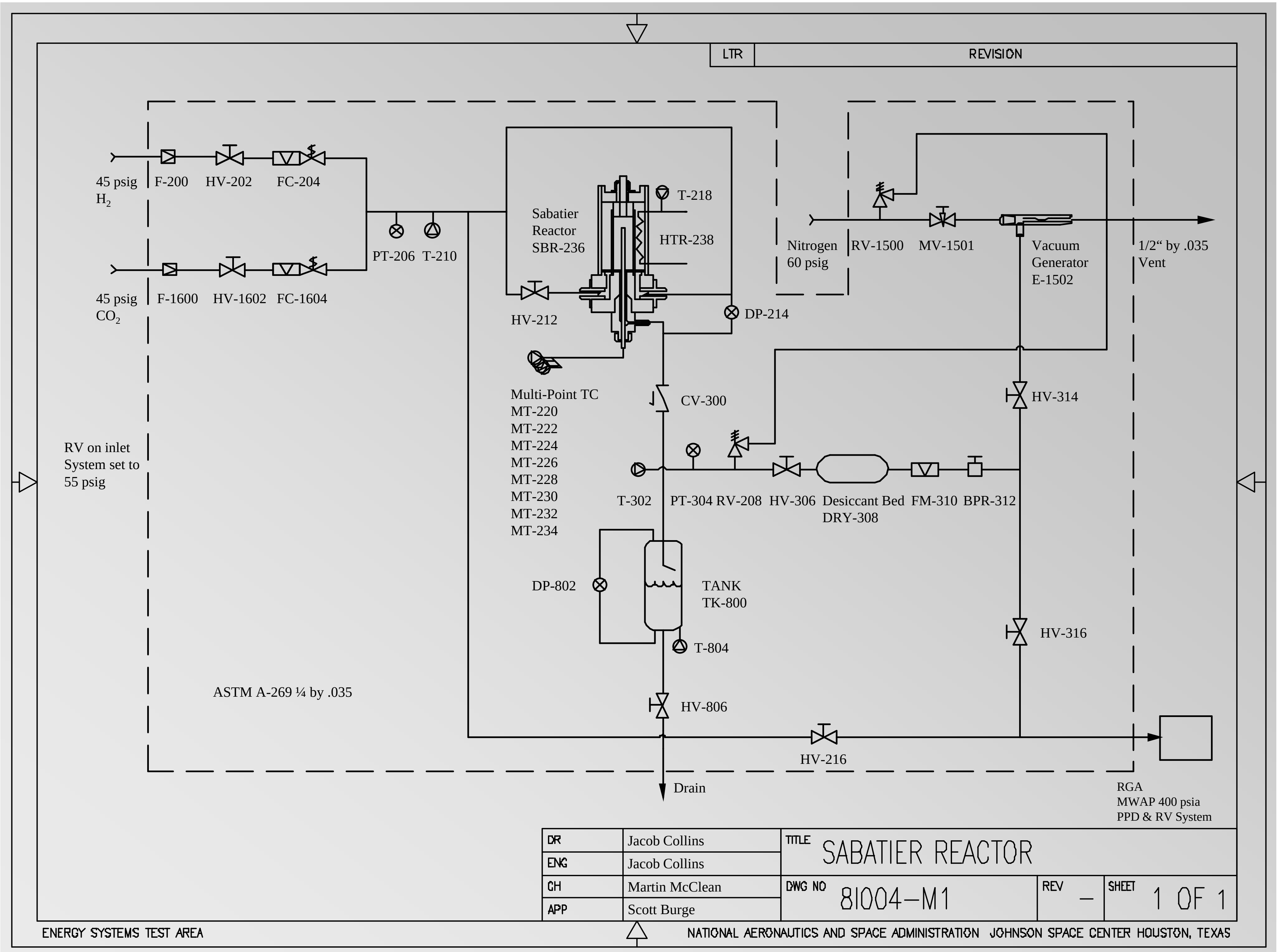
$$CO_{2\,(g)} + 4H_{2\,(g)} \xrightarrow[357\,^{o}C\ (674\,^{o}F)]{cat} CH_{4\,(g)} + 2H_2O_{\,(g)} + 180KJ$$

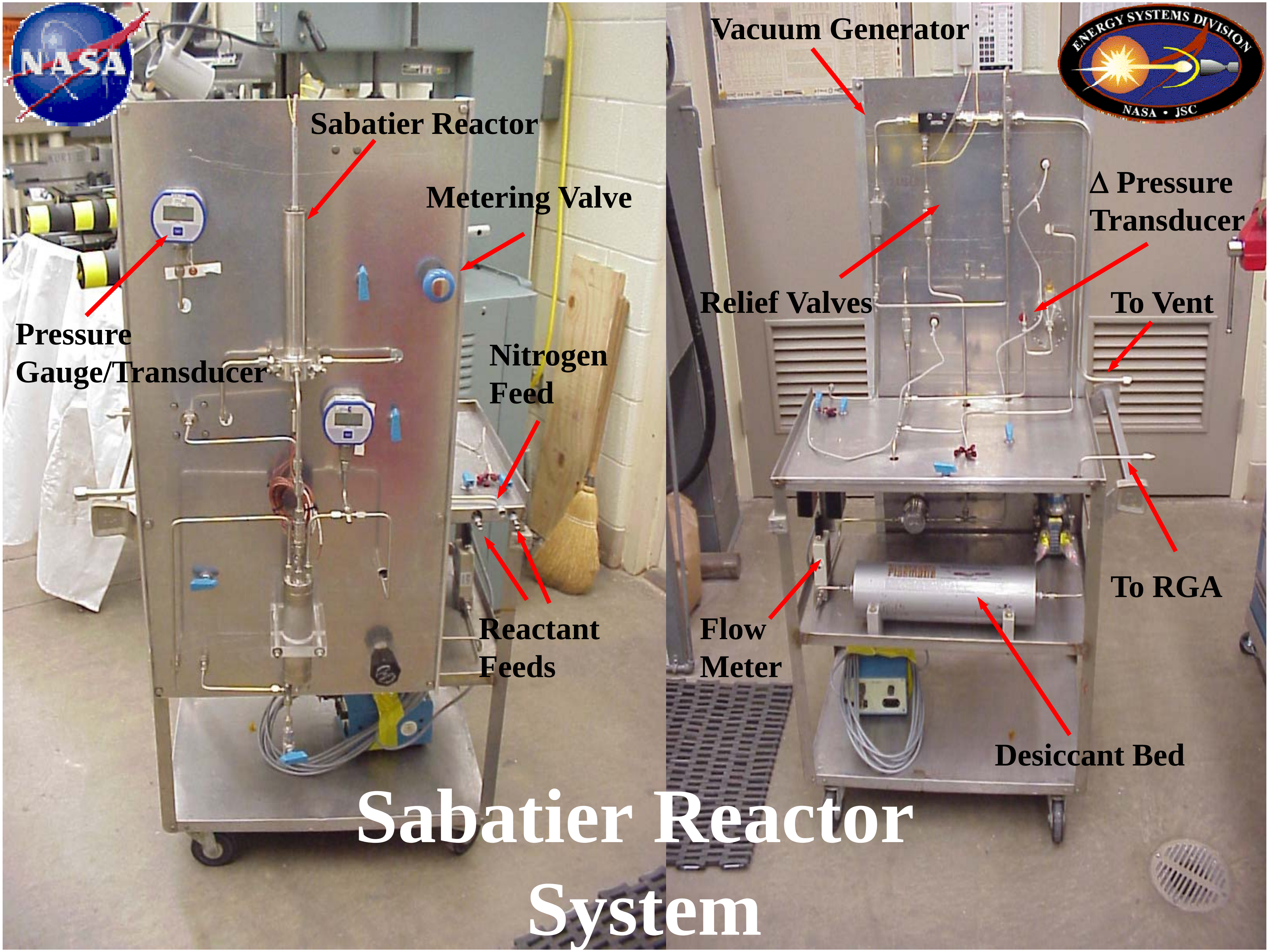
Sabatier Reactor Testing




Catalyst
6757-38-2
Nominal 15 % Ru on 1/ 8" spheric
gamma alumina,
Calcined , not reduced.
Multi-point Thermocouple
Porous metal plug
Heater


Outlet
Heater
Possible Temperature Sensor
Possible Temperature Sensor
Inlet
Inlet
Multi-point Thermocouple


LTR
REVISION
45 psig H_2
F-200
HV-202
FC-204
45 psig CO_2
F-1600
HV-1602
FC-1604
PT-206
T-210
Sabatier Reactor SBR-236
T-218
HTR-238
HV-212
DP-214
Multi-Point TC
MT-220
MT-222
MT-224
MT-226
MT-228
MT-230
MT-232
MT-234
Nitrogen 60 psig
RV-1500
MV-1501
Vacuum Generator E-1502
1/2" by .035 Vent
CV-300
HV-314
RV on inlet System set to 55 psig
T-302
PT-304
RV-208
HV-306
Desiccant Bed DRY-308
FM-310
BPR-312
DP-802
TANK TK-800
T-804
HV-316
ASTM A-269 ¼ by .035
HV-806
HV-216
Drain
RGA
MWAP 400 psia
PPD & RV System
DR
Jacob Collins
ENG
Jacob Collins
CH
Martin McClean
APP
Scott Burge
TITLE
SABATIER REACTOR
DWG NO
81004-M1
REV
–
SHEET
1 OF 1
ENERGY SYSTEMS TEST AREA
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION JOHNSON SPACE CENTER HOUSTON, TEXAS



Sabatier Reactor System

Conclusion

- My background is similar to yours
- JSC Engineering Organization
- Potential for chemical engineering at NASA
- Why we test batteries
- Types of Tests
  - Performed on a variety of Battery chemistries (li-ion, NiMh, Alkaline, Pb-acid, etc)
  - Flight
  - Performance
  - Safety and Abuse
- Capabilities
- Other relevant Chemical Engineering Testing in Aerospace field