



# THE NUCLEAR CRYOGENIC PROPULSION STAGE

PRESENTED AT

NUCLEAR AND EMERGING TECHNOLOGIES FOR SPACE (NETS) 2014  
FEBRUARY 24, 2014

*Michael G. Houts*

*Tony Kim*

*William J. Emrich*

*Robert R. Hickman*

*Jeramie W. Broadway*

*Harold P. Gerrish*

*Anthony D. Belvin*

*Stanley K. Borowski*

*John H. Scott*

## *A Vision for NASA's Future ...*

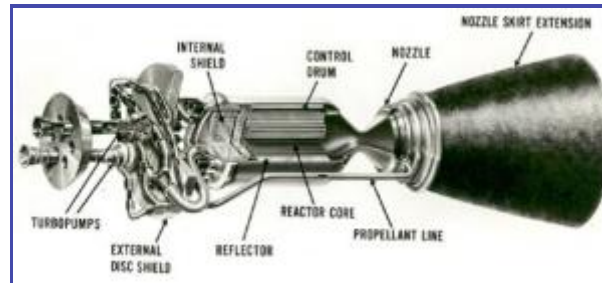
### President John F. Kennedy ...

- ◆ First, I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth....
- ◆ Secondly, an additional 23 million dollars, together with 7 million dollars already available, **will accelerate development of the Rover nuclear rocket**. This gives promise of some day providing a means for even more exciting and ambitious exploration of space, perhaps beyond the Moon, perhaps to the very end of the solar system itself.



Excerpt from the 'Special Message to the Congress on Urgent National Needs'  
President John F. Kennedy  
Delivered in person before a joint session of Congress May 25, 1961

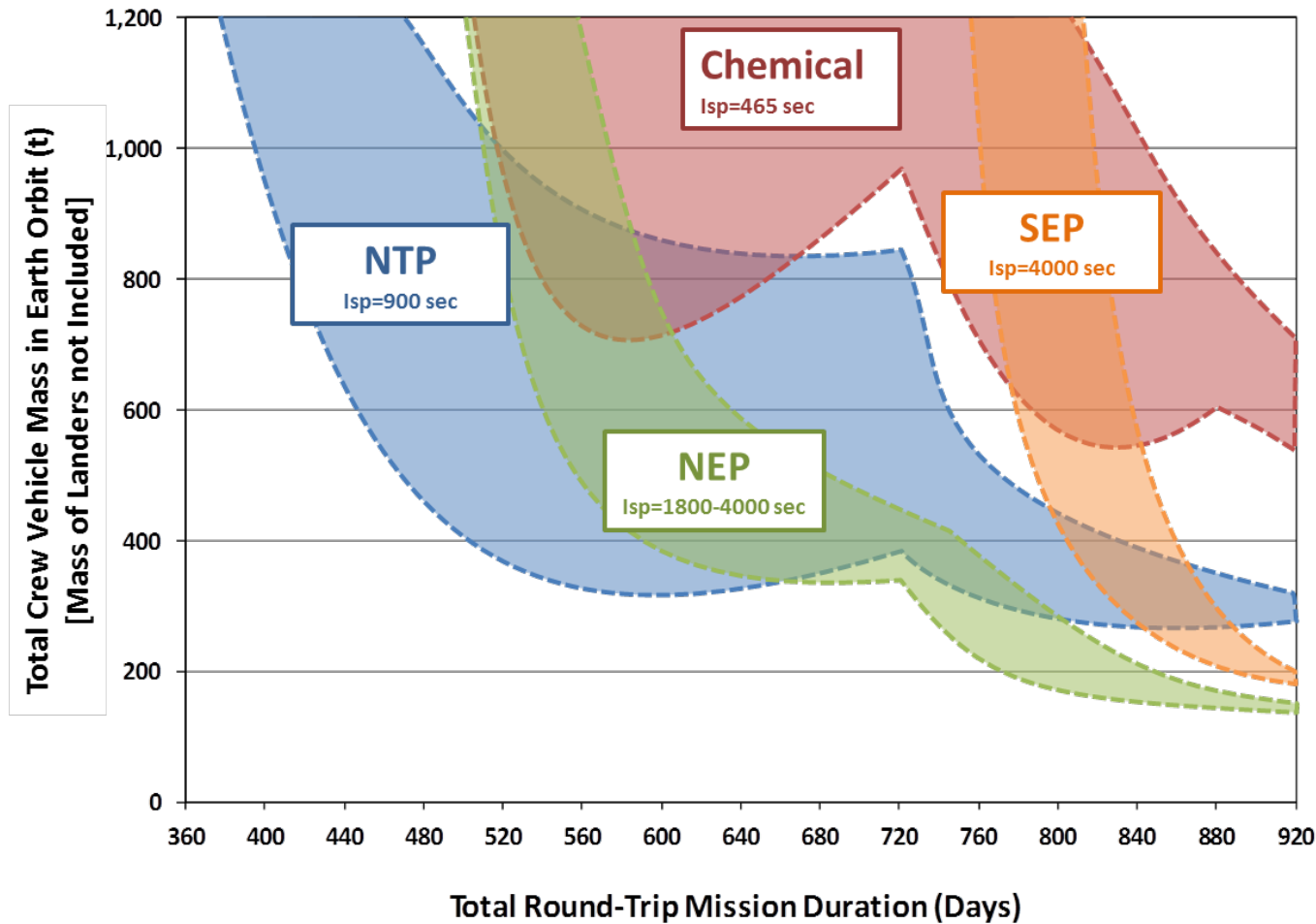
# Nuclear Cryogenic Propulsion Stage (NCPS)



- ◆ **Nuclear thermal propulsion (NTP) is a fundamentally new capability**
  - Energy comes from fission, not chemical reactions
  - Virtually unlimited energy density
- ◆ **Initial systems will have specific impulses roughly twice that of the best chemical systems**
  - Reduced propellant (launch) requirements, reduced trip time
  - Beneficial to near-term/far-term missions currently under consideration
- ◆ **Advanced nuclear propulsion systems could have extremely high performance and unique capabilities**
- ◆ **The goal of the NCPS project is to establish adequate confidence in the affordability and viability of the NCPS such that nuclear thermal propulsion is seriously considered as a baseline technology for future NASA human exploration missions**



# Why is NTP considered for Human Missions to Mars?



Drake, B. G., "Human Mars Mission Definition: Requirements & Issues," presentation, Human 2 Mars Summit, May 2013

**Shortest Trip Times reduce exposure to Galactic Cosmic Radiation**



# Nuclear Cryogenic Propulsion Stage (NCPS) Organizational Structure

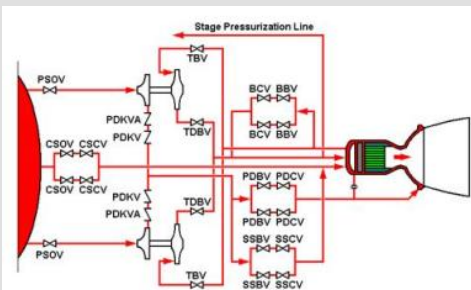


## 1.0 NCPS Project Management

Project Manager: Mike Houts (MSFC)  
GRC Lead: Stan Borowski  
JSC Lead: John Scott  
DOE - NA Lead: Jerry McKamy  
DOE - NE75 Lead: Anthony Belvin

## 2.0 Pre-conceptual Design of the NCPS & Architecture Integration

Co-Leads: Tony Kim (NASA), Stan Borowski (NASA), David Poston (LANL)



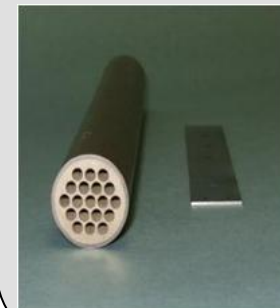
## 3.0 High Power ( $\geq 1$ MW) Nuclear Thermal Rocket Element Environmental Simulator (NTREES)

Lead: Bill Emrich (NASA)



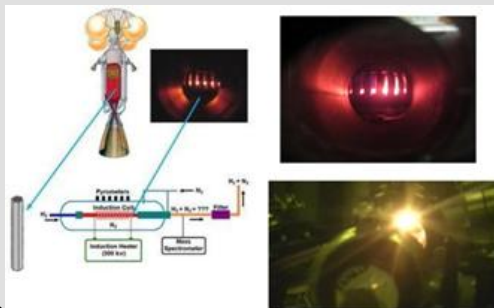
## 4.0 NCPS Fuel Design / Fabrication

Co-Leads: Jeramie Broadway (NASA), Lou Qualls (ORNL), Jim Werner (INL)



## 5.0 NCPS Fuels Testing in NTREES & CFEET

Co-Leads: Bill Emrich (NASA), Robert Hickman (NASA), Lou Qualls (ORNL), Jim Werner (INL)



## 6.0 Affordable NCPS Development and Qualification Strategy

Co-Leads: Harold Gerrish (NASA), Glen Doughty (NASA), Stan Borowski (NASA), David Coote (NASA), Robert Ross (NASA), Jim Werner (INL), Roy Hardin (NRC)





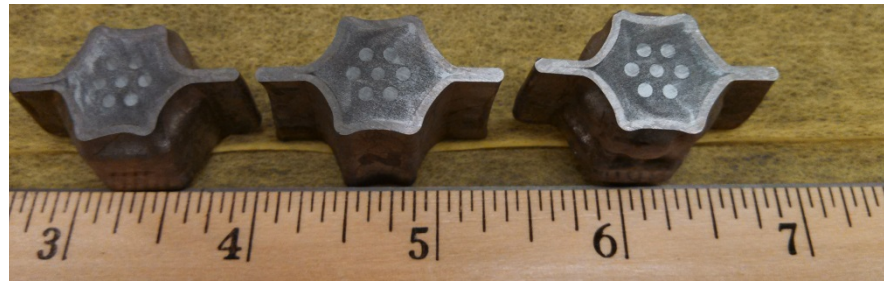
# NCPS Team FY14/15 Milestones

- 1. Fabricate short (~3") cermet fuel element and test in CFEET, 2/14/14**
- 2. Extrude 16" graphite element and coat multiple internal channels of ~16" graphite specimen, 6/30/14**
- 3. Fabricate representative, partial length (~16"), cermet fuel element with prototypic depleted uranium loading and test in NTREES, 8/4/14**
- 4. Fabricate representative, partial length (~16"), coated graphite composite fuel element with prototypic depleted uranium loading, 9/1/14**
- 5. Complete initial NTREES testing of ~16" coated graphite composite fuel element with prototypic depleted uranium loading, 11/1/14**
- 6. Provide an initial NASA/DOE-NE75 recommendation on down selection of leader and follower fuel element types (Cermet vs. graphite composite), 12/15/14**





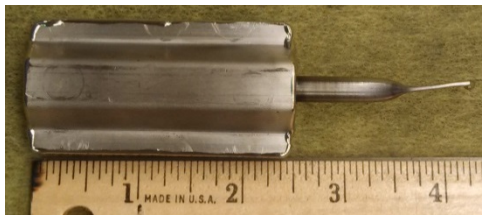
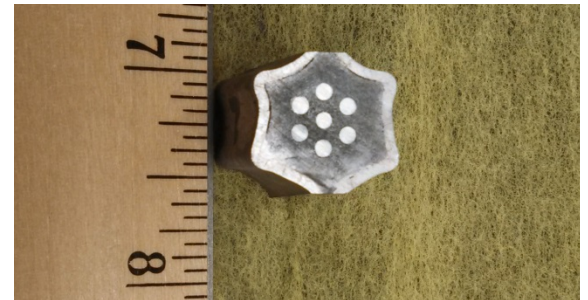
# W/VO<sub>2</sub> CERMET Fuel Element Fabrication: 7 Channel Element with Depleted Uranium



Above left/right: 7 channel W-VO<sub>2</sub> FE during HIP process



Above/Below: 7 channel WVO<sub>2</sub> fuel element post HIP and cross sections



Left & above: LANL sample post fill and closeout prior to shipping

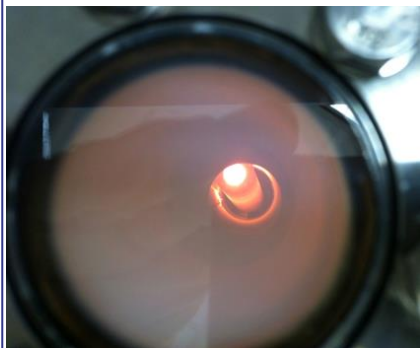


# Short, 7 Channel W/VO<sub>2</sub> Element Fabricated and Tested in Compact Fuel Element Environmental Tester (CFEET)

## CFEET System 50 kW Buildup & Checkout



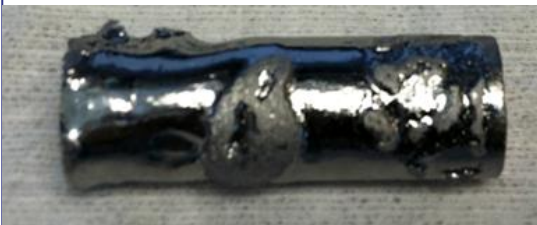
Completed CFEET system. Ready for W-VO<sub>2</sub> and H<sub>2</sub> testing



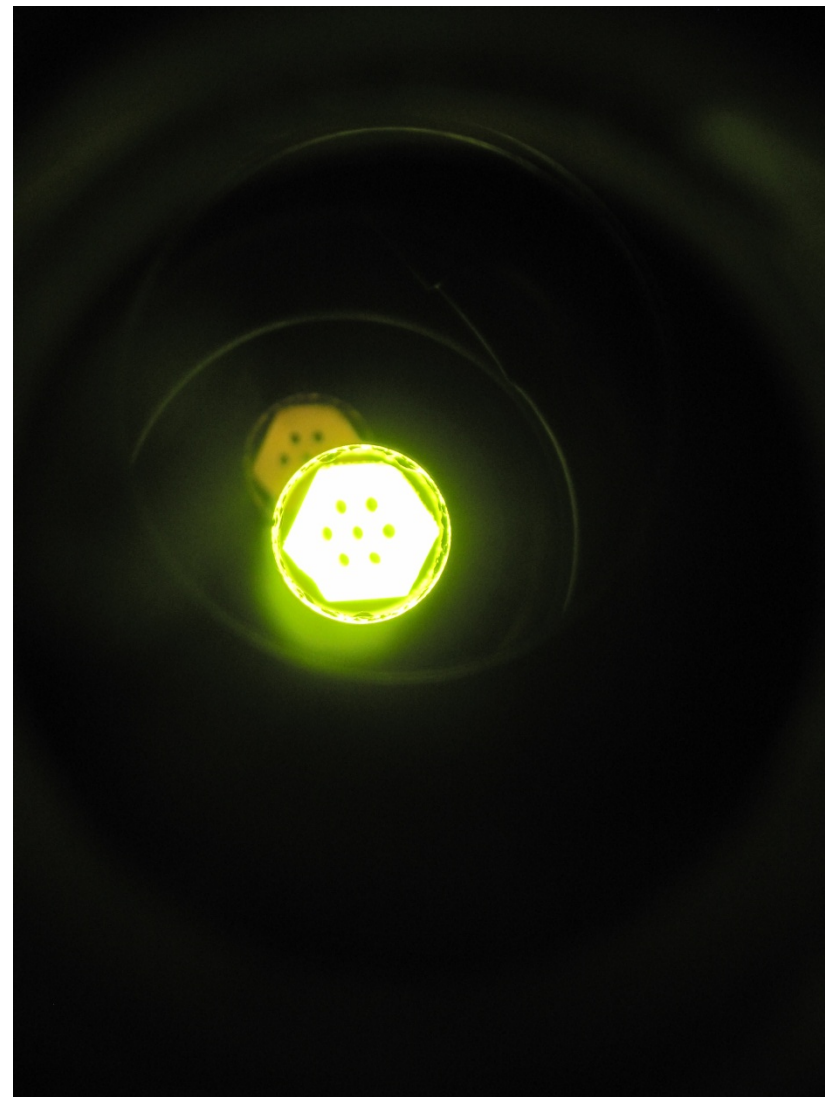
Left: View looking down into the CFEET chamber during shakeout run 1. BN insulator and bright orange sample inside



Above/left: Pure W sample post shakeout run 2. Sample reached melting point (3695K) and was held in place by the BN insulator.



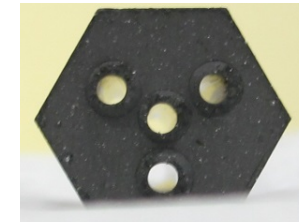
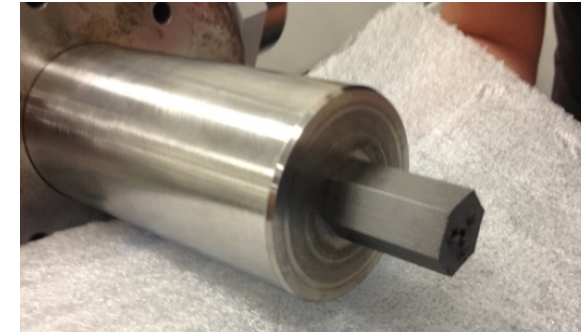
## Initial Testing of Short W/VO<sub>2</sub> Element



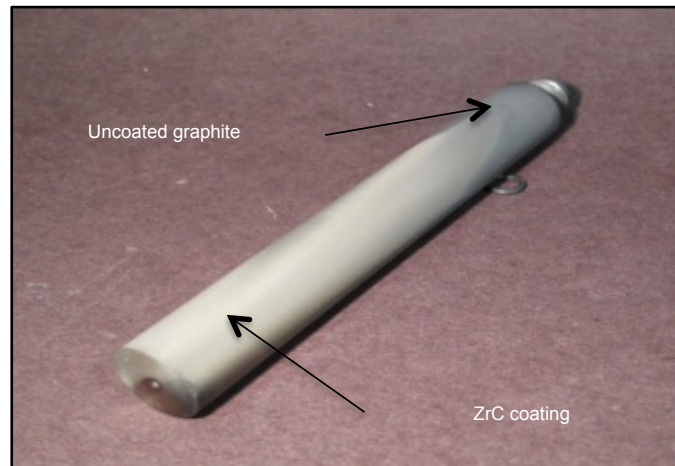
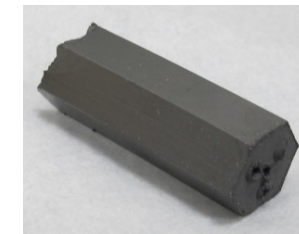




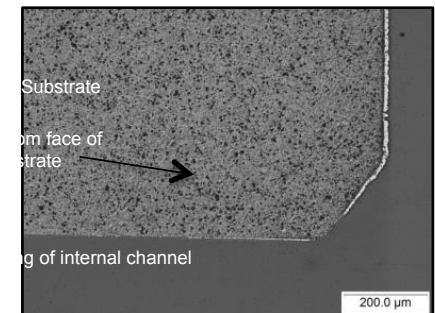
**Above: Members of Oak Ridge National Laboratory fuels team with the graphite extruder; Left: Graphite extruder with vent lines installed for DU capability**



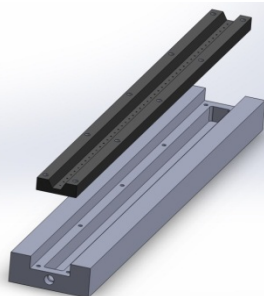
**Above and Left:  
Extrusion samples  
using carbon-  
matrix/Ha blend .  
75" across flats, .  
125" coolant  
channels**



**Above: Test Piece highlighting ZrC Coating**  
**Right: Coating primarily on external surface**

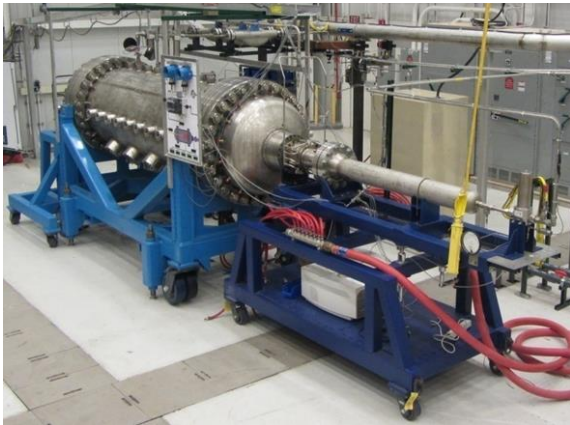


**Right: Layoff  
base /  
Graphite  
insert**





# Nuclear Thermal Rocket Element Environmental Simulator (NTREES)



NTREES Phase 1 50kW (2011)



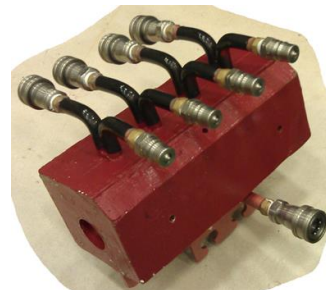
NTREES Phase 2 – 1MW Upgrade (2014)



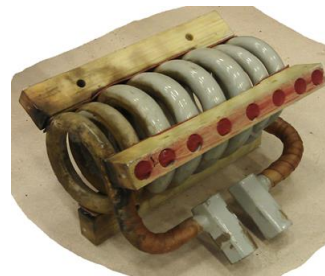
New Cooling Water System now provides 2 separate systems that cool induction coil and power feedthrough, induction heater and H<sub>2</sub>N<sub>2</sub> mixer respectively

## General Description:

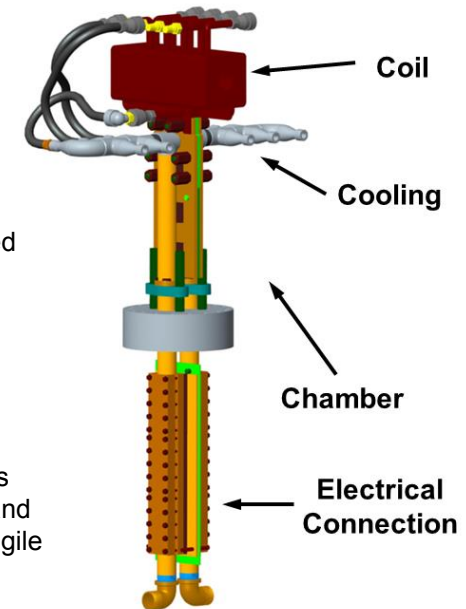
- Water cooled ASME coded test vessel rated for 1100 psi
- GN<sub>2</sub> (facility) and GH<sub>2</sub> (trailer) gas supply systems
- Vent system (combined GN<sub>2</sub>/GH<sub>2</sub> flow)
- 1.2 MW RF power supply with new inductive coil
- Water cooling system (test chamber, exhaust mixer and RF system)
- Control & Data Acquisition implemented via LabVIEW program
- Extensive H<sub>2</sub> leak detection system and O<sub>2</sub> monitoring system
- Data acquisition system consists of a pyrometer suite for axial temperature measurements and a mass spectrometer
- “Fail Safe” design



New Coil is Heavily Insulated and Rugged



Old Coil was Uninsulated and Somewhat Fragile



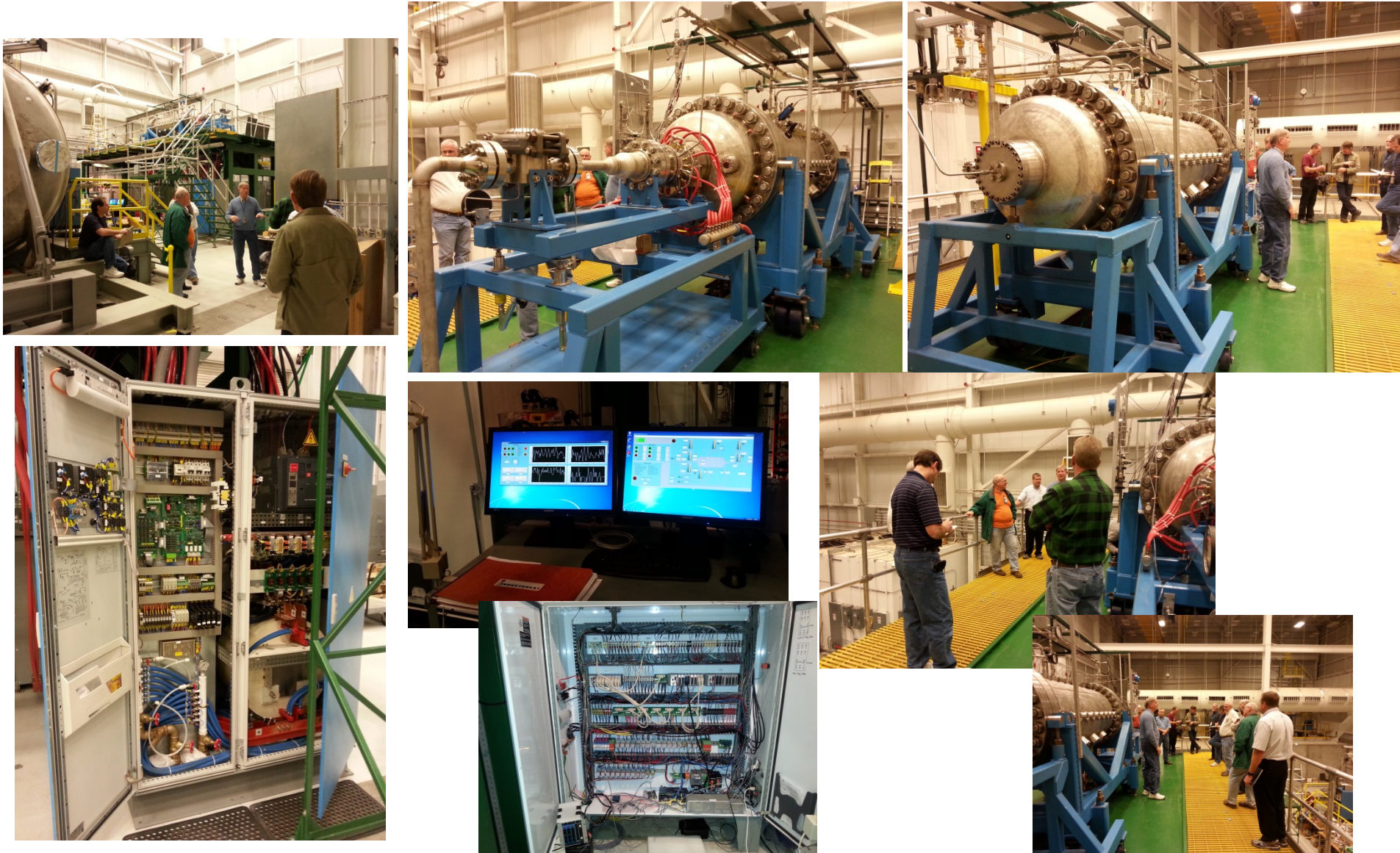
Coil and Feedthrough Assembly





# NTREES 1 MW Operational Readiness Inspection

NTREES Walk-thru for ORI Board: 1/30/14



# What Else Needs Done?

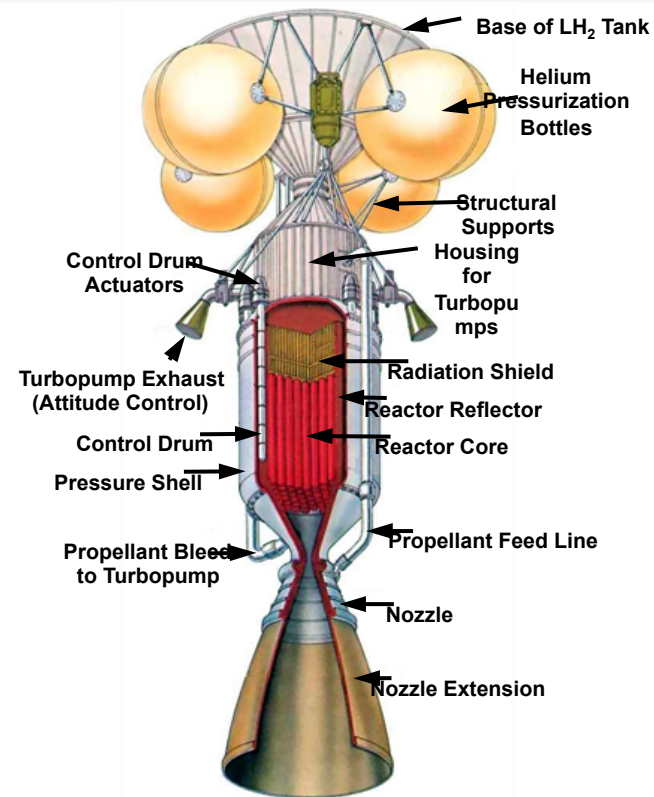
## Observations:

59 years since the start of the Rover / NERVA program

NTP programs typically cancelled because mission is cancelled, not because of insurmountable technical or programmatic issues

Programmatic constraints, technical capabilities, available facilities, mission needs, etc. all continually change

Need to devise an optimal approach to developing a 21<sup>st</sup> century NTP system







# What Else Needs Done?



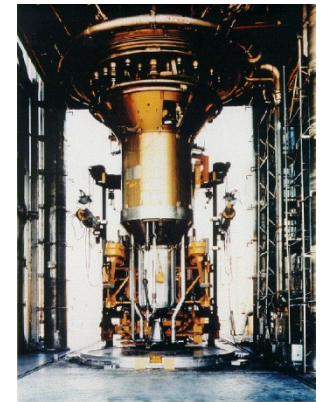
## Options Have Changed Since 1955

**Tremendous advances in computational capabilities (nuclear and non-nuclear).**

**Increased regulation and cost associated with nuclear operations and safeguards.**

**Extensive development of non-nuclear engine components. Extensive experience with various types of nuclear reactors.**

**Recent successes in “space nuclear” public outreach (Mars Science Lab).**





# What Else Needs Done?

**Many Decisions will Affect Long-Term Affordability / Viability of any Potential NTP Development Program**

**Balance between computational and experimental work.**

**Flight qualification strategy / human rating**

**Low-enriched uranium vs highly-enriched uranium**

**Unscrubbed, scrubbed, or fully contained exhaust during ground testing.**

**Choice of facility for any required testing (i.e. NCERC, NASA center, industry, etc.**

**Many others!**



**HEOMD's AES Nuclear Cryogenic Propulsion Stage (NCPS) project is making significant progress. First of six 2014 milestones achieved last week.**

**Safety is the highest priority for NTP (as with other space systems). After safety comes affordability.**

**No centralized capability for developing, qualifying, and utilizing an NTP system. Will require a strong, closely integrated team.**

**Tremendous potential benefits from NTP and other space fission systems. No fundamental reason these systems cannot be developed and utilized in a safe, affordable fashion.**