Introduction

Fresh out of college, some 37 years ago, Ron Creel was thrust into a challenging and high speed engineering task – design, test verification, and mission support for the thermal control system of a new kind of “spacecraft with wheels”, the Apollo Lunar Roving Vehicle (LRV). Success on this project was acknowledged by several NASA performance citations, which culminated in receipt of the Astronaut’s “Silver Snoopy” award for his LRV thermal system modeling and mission support efforts.

Ron is a Senior Space And Thermal Systems Engineer at Ryan Associates, Inc. (RAI), and has been involved in thermal control and computer simulation of several launch vehicles and spacecraft including the International Space Station and Air Force satellites.

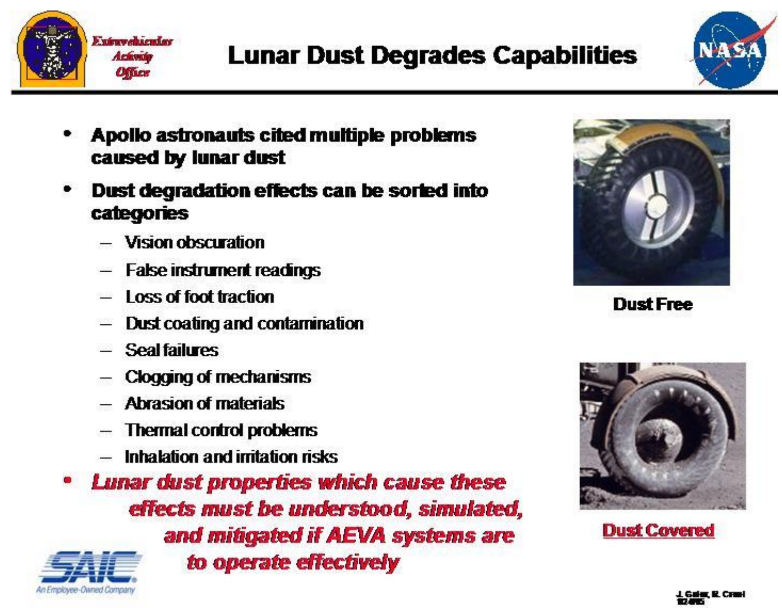
Today, Ron will update his LRV thermal experiences, presented at U.S. universities, International Space Development, Return to the Moon, and Spacecraft Thermal Control Conferences, and at the International Planetary Rovers and Robotics Workshop in Russia, with an eye toward applications to future manned and robotic Moon Rovers for the President’s “Moon, Mars, and Beyond” Vision for Future Space Exploration.

roving.ron@gmail.com

Summary of LRV Thermal Control Experiences

- Adequate Thermal Control Of LRV's Was Accomplished On Apollo 15, 16, And 17
- We Provided Accurate, Responsive Temperature Predictions To Mission Control
  - Test Correlated Thermal Models Were Vital For Mission Support
- We Had Very Limited Success Coping With Adverse Lunar Dust Effects
  - Losing Fender Extensions Increased Dust Exposure For Forward Chassis
  - Earth Testing Results For Dust Removal By Brushing Were Misleading
  - Regret Spending Valuable Astronaut Time Trying To Clean Radiators

LRV Mission Control At Huntsville Operations Support Center (HOSC)



Advanced Extravehicular Activity Dust Effects Summary Prepared For 2005 Lunar Regolith Simulant Material Workshop At MSFC

roving.ron@gmail.com

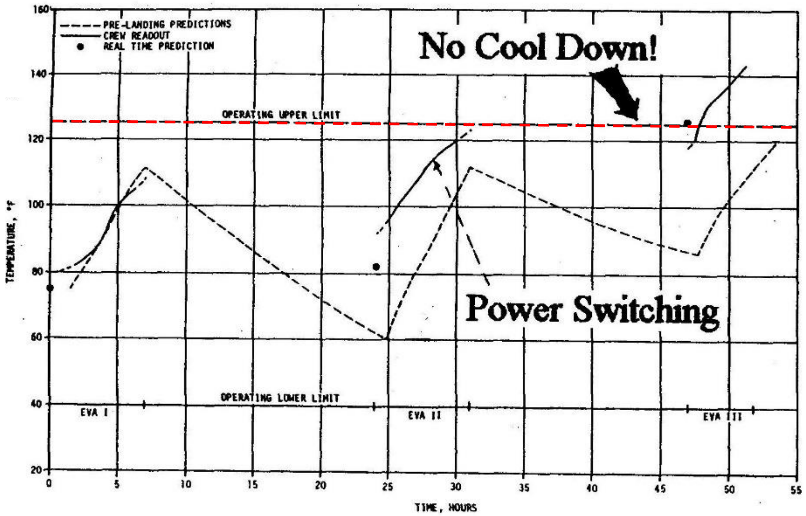
LRV Missions Thermal Control Performance

- FWDCHA Thermal Model Used For Pre-Sortie And EVA Analyses
- Right Rear Fender Extensions Knocked Off on Apollo 16 and 17
  - Increased Dust Exposure for Radiators and Ineffective Cleaning Resulted in Insufficient Cooldowns Between EVA's

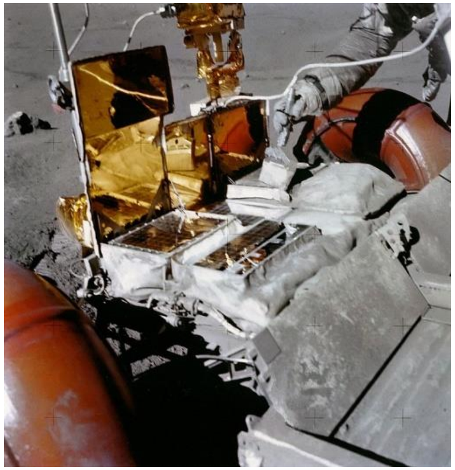
Apollo Dust Brush

- Model Predicted Required Battery Power Switching / Cover Openings
- Batteries and Electronics Ran "Hot", but, Astronauts Were Alerted When to Expect Appearance of "Caution and Warning" Flags

Missing Fender Extension



Apollo 16 Battery No. 2 Temperature



Astronaut Brushing Dust From Radiators

roving.ron@gmail.com

Lunar Mobility Thermal Experience Lesson Learned
Lunar Dust Contamination

Apollo 16 photos:

Lunar Rover checkout drive

Dust on rear fender

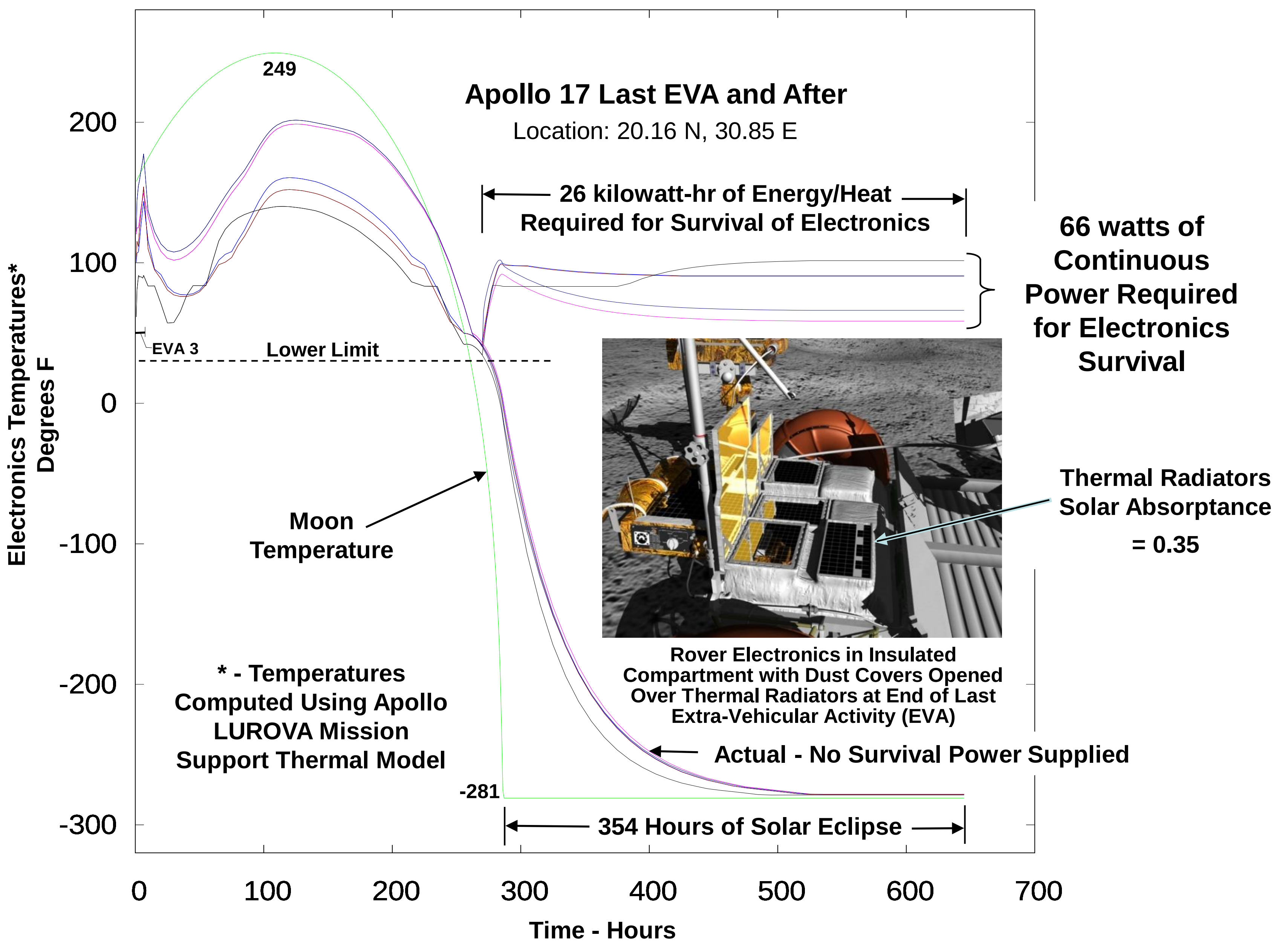
- Lunar dust solar absorptance, $\alpha = 0.93$
  - Dust coverage increases radiator heat absorption which increases the rejection temperature
- Stationary or unmanned installations may remain dust free
  - Corner mirrors left by Apollo missions are still reflective
- Mobile or manned installations have potential to generate more dust movement and require provisions for dust mitigation

Dust Mitigation Essential for Renewed Lunar Missions

Source – Lockheed Martin – STAIF 2006 and IECEC 2006

roving.ron@gmail.com

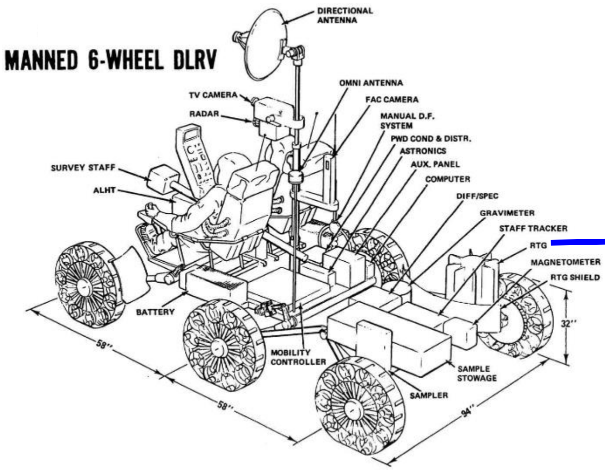
Modeling Power Needed for Extended Thermal Survival on Moon

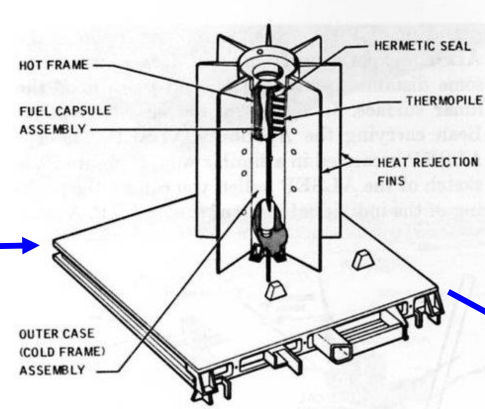


roving.ron@gmail.com

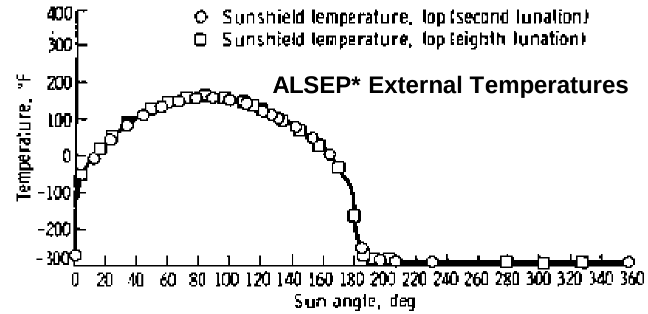
Nuclear Energy Provides Dependable/Efficient Moon Survival Power/Heat

- Nuclear Sources Studied For U.S. Dual Mode Rovers (DLRV's) and Used on Apollo

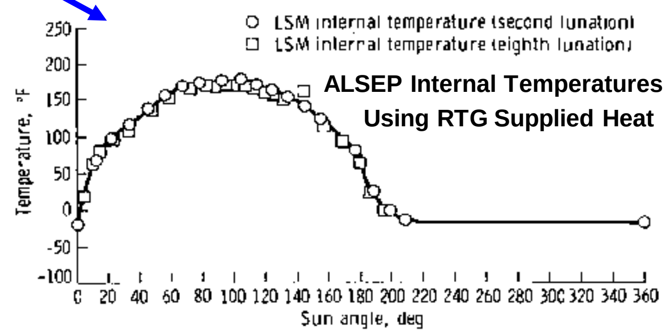




SNAP-27 Radioisotope Thermal Generator. This equipment provides all of the power used by the ALSEP. It furnishes continuously about 70 watts.
S-71-20730.

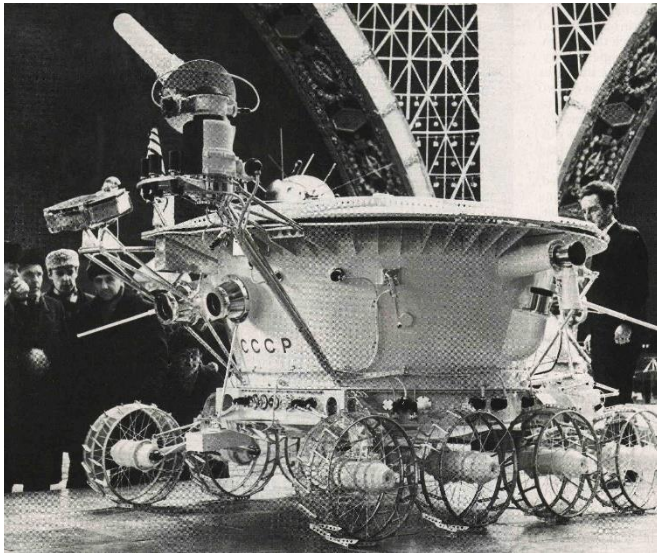


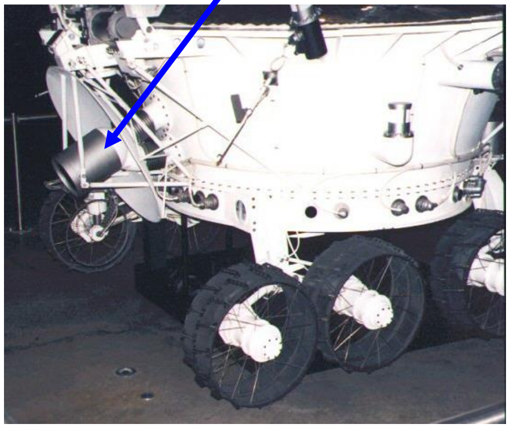
*ALSEP = Apollo Lunar Surface Experiments Package



- Russians Successfully Used Nuclear Isotope Heat Sources For Several Lunar Cycles On Their Lunokhod (Moonwalker) Robotic Rovers

Isotope Heater





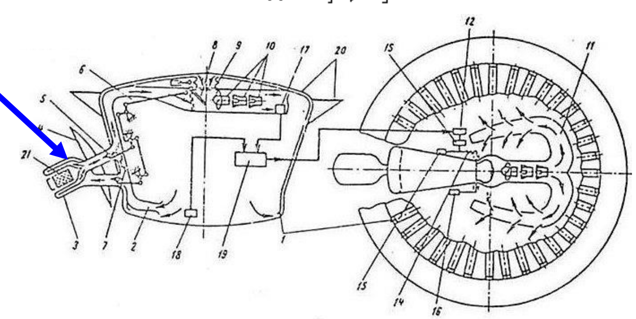


Diagram of lunokhod heat regulating system. 1) air passages of cold channel; 2) air passage of hot channel; 3) heating unit (HU); 4) HU shield; 5) HU "blinds"; 6) control of HU blinds; 7) baffle plate; 8) baffle; 9) connecting sheath; 10) three-step fan; 11) collector; 12) baffle drive; 13) step mechanism; 14) spring traction; 15) cam mechanism; 16) angular movements sensor; 17) SE1 sensing element; 18) SE2 sensing element; 19) radiator-cooler; 20) collector of HU blow-off system; 21) fuel cell.

For monitoring the thermal regime aboard the lunokhod there are telemetric temperature sensors which make it possible to obtain routine information on the temperatures of all lunokhod systems during any communication session.

roving.ron@gmail.com

Stationary Radioisotope Power Systems (RPS) Heat Rejection Thermal Analysis

- ***Lunar night is too long for solar cells / batteries***
  - ***Application is well suited for RPS***
- ***Lunar surface reduces view to space and exhibits extreme temperature variations***

Key Thermal and Optical Properties for Lunar Heat Rejection Evaluations

- Solar flux on moon, S = 1400 W/m^2
- Lunar dust solar absorptance, α = 0.93; emittance, ε = 0.9
- Lunar surface temperature (max) = 127°C (261 °F)

Parameters Investigated for Heat Rejection Study Using TSS and SINDA

- Lunar latitude
- Orientation of radiator surface relative to solar flux
- Lunar surface temperature (day and night dependence)
- Radiator heat dissipation rate (W/m^2) and effect on radiator temperature

Source – Lockheed Martin – STAIF 2006 and IECEC 2006

Moon RPS Thermal Analysis Summary

Stationary Applications

- Orientation makes significant difference in radiator temperatures
- System studied (538 W/m^2) has acceptable rejection temperature at all latitudes

Mobile Applications

- Relationship between geometry and dust mitigation is complex
  - Radiator with 75° geometry ran 10-20°C hotter than radiator with 60° geometry
  - Steeper radiator (75° geometry) should mitigate dust more readily than shallower radiator
  - Dust covered radiators ran 25 to 30°C hotter than radiators with partial coverage
- Radiator with 538 W/m^2 heat rejection approaches the maximum temperature for many Radioisotope Power Systems

> • ***Lunar radiator design is a complex trade balancing temperature constraints, weight, orientation, and dust mitigation***

Source – Lockheed Martin – STAIF 2006 and IECEC 2006

roving.ron@gmail.com