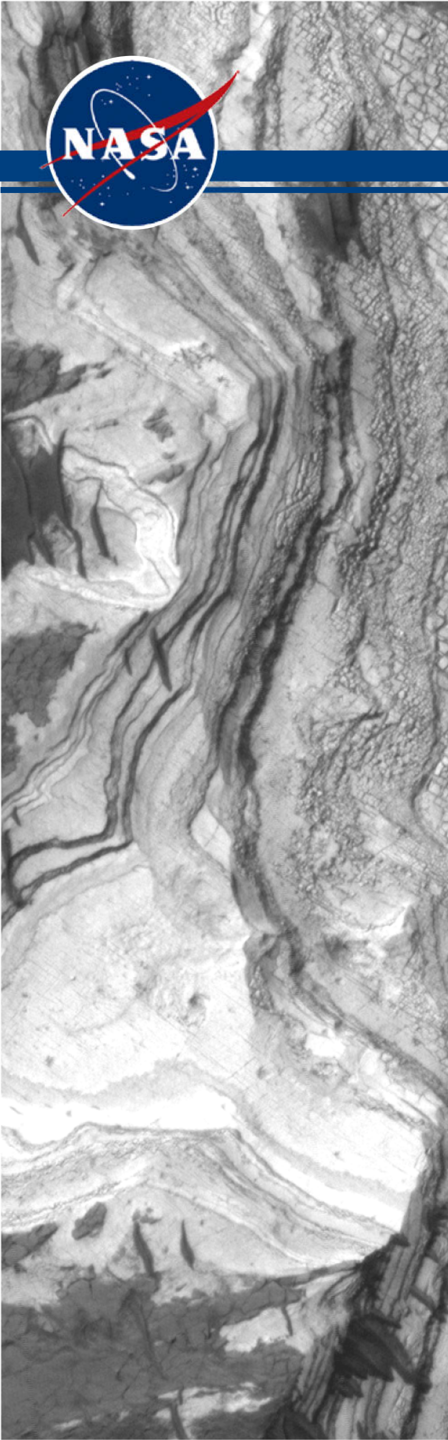


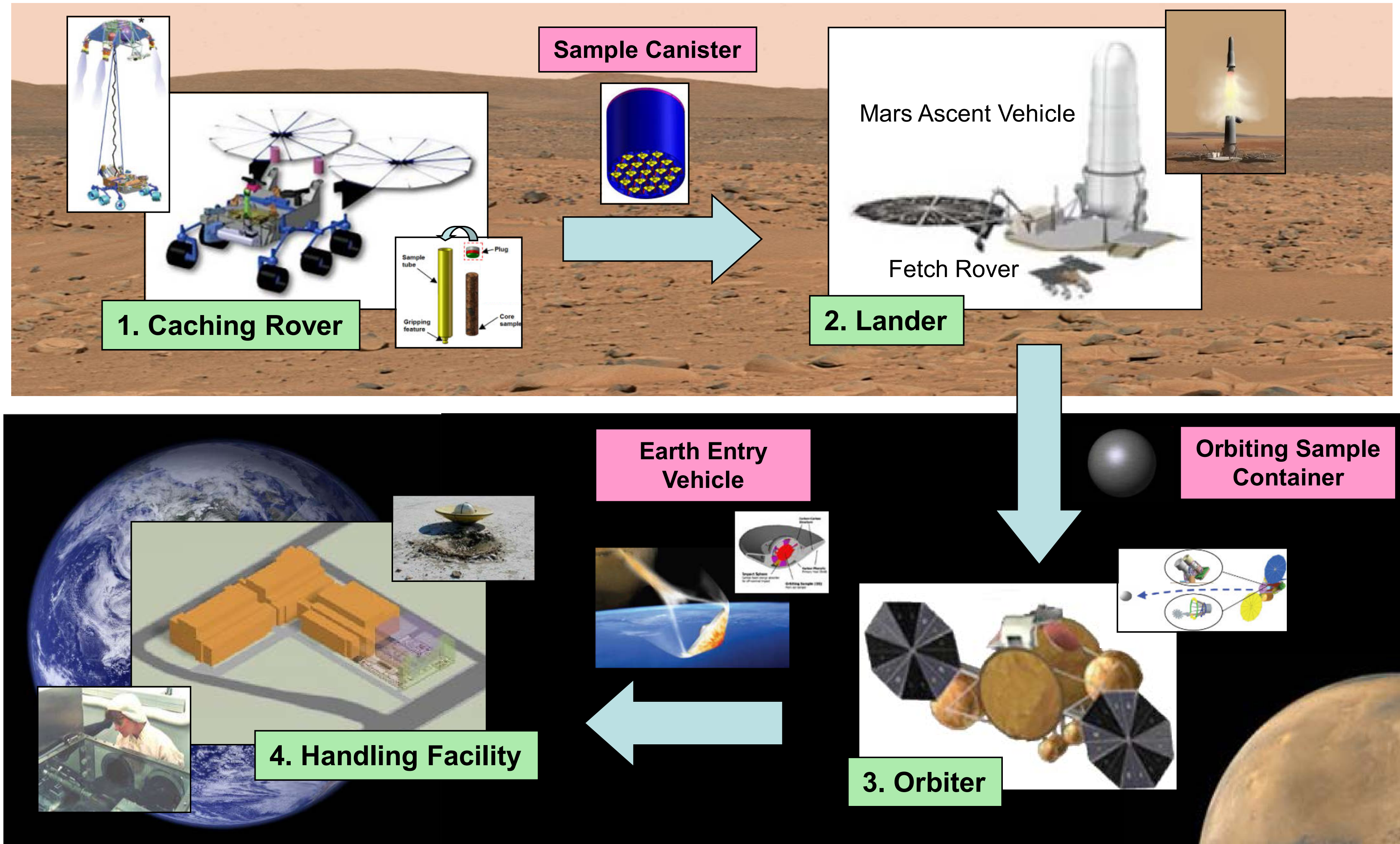
Sample Sealing Approaches for Mars Sample Return Caching

Paulo Younse, Thimal de Alwis, Paul Backes, Ashitey Trebi-Ollennu
Jet Propulsion Laboratory
California Institute of Technology

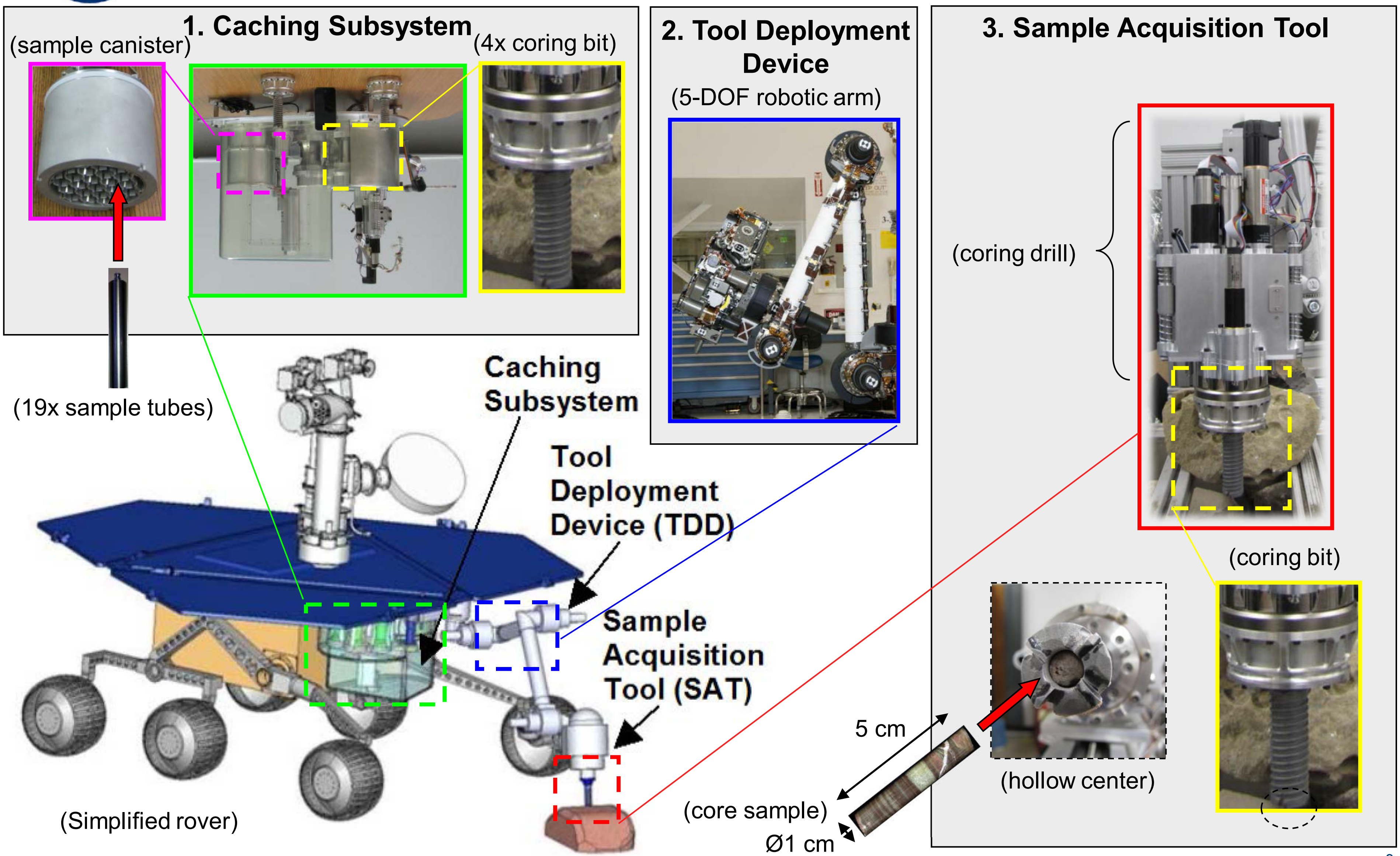
Overview

- **Objective: Investigate sealing methods for encapsulating samples in 1 cm diameter thin-walled sample tubes applicable to future proposed Mars Sample Return**
- **Techniques implemented include a spring energized Teflon sleeve plug, a crimped tube seal, a heat-activated shape memory alloy plug, a shape memory alloy activated cap, a solder-based plug, and a solder-based cap**

Proposed Mars Sample Return Campaign

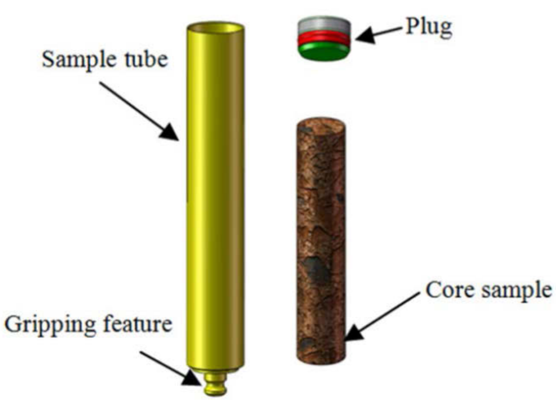


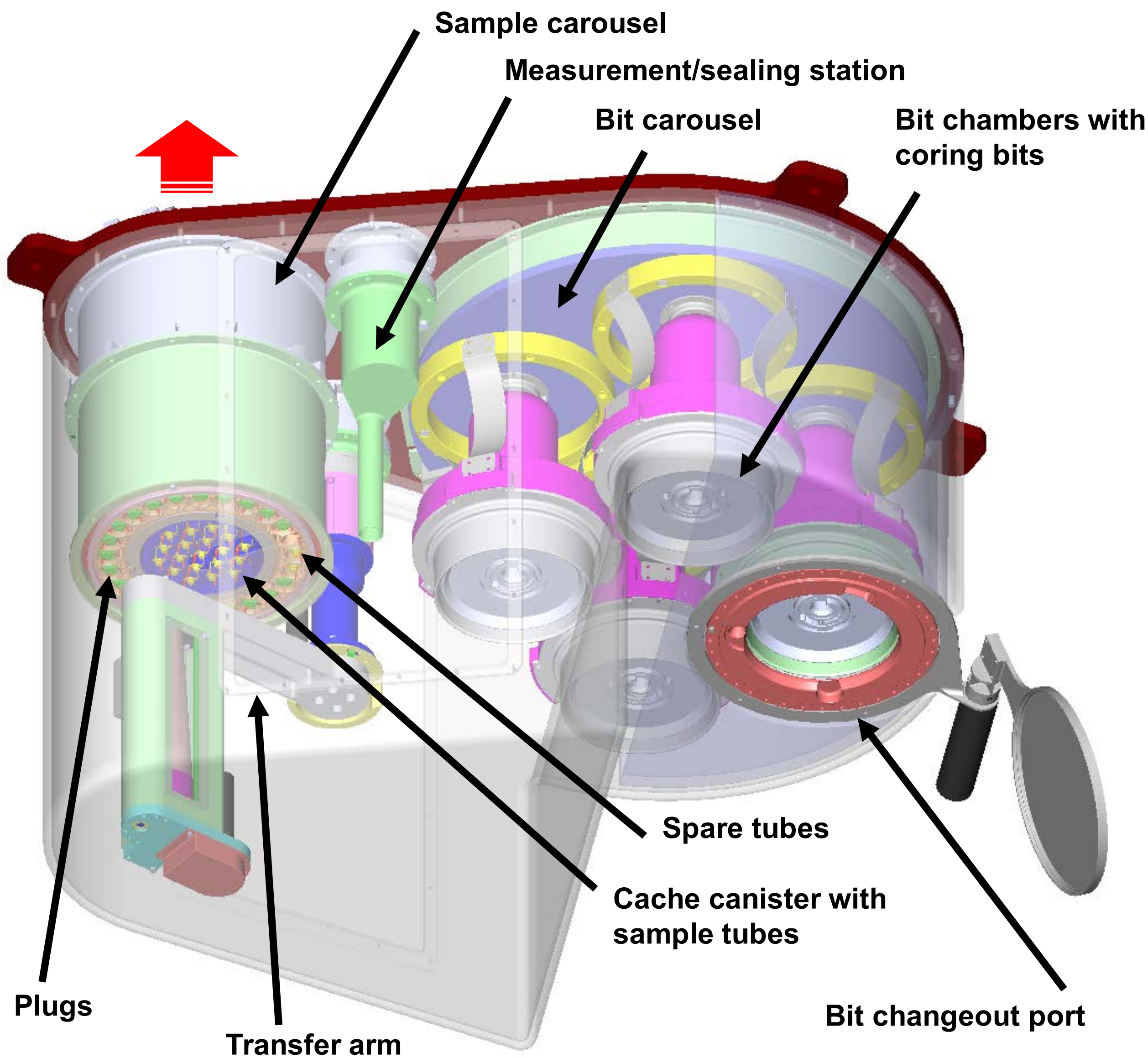
Integrated Mars Sample Acquisition and Handling (IMSAH)



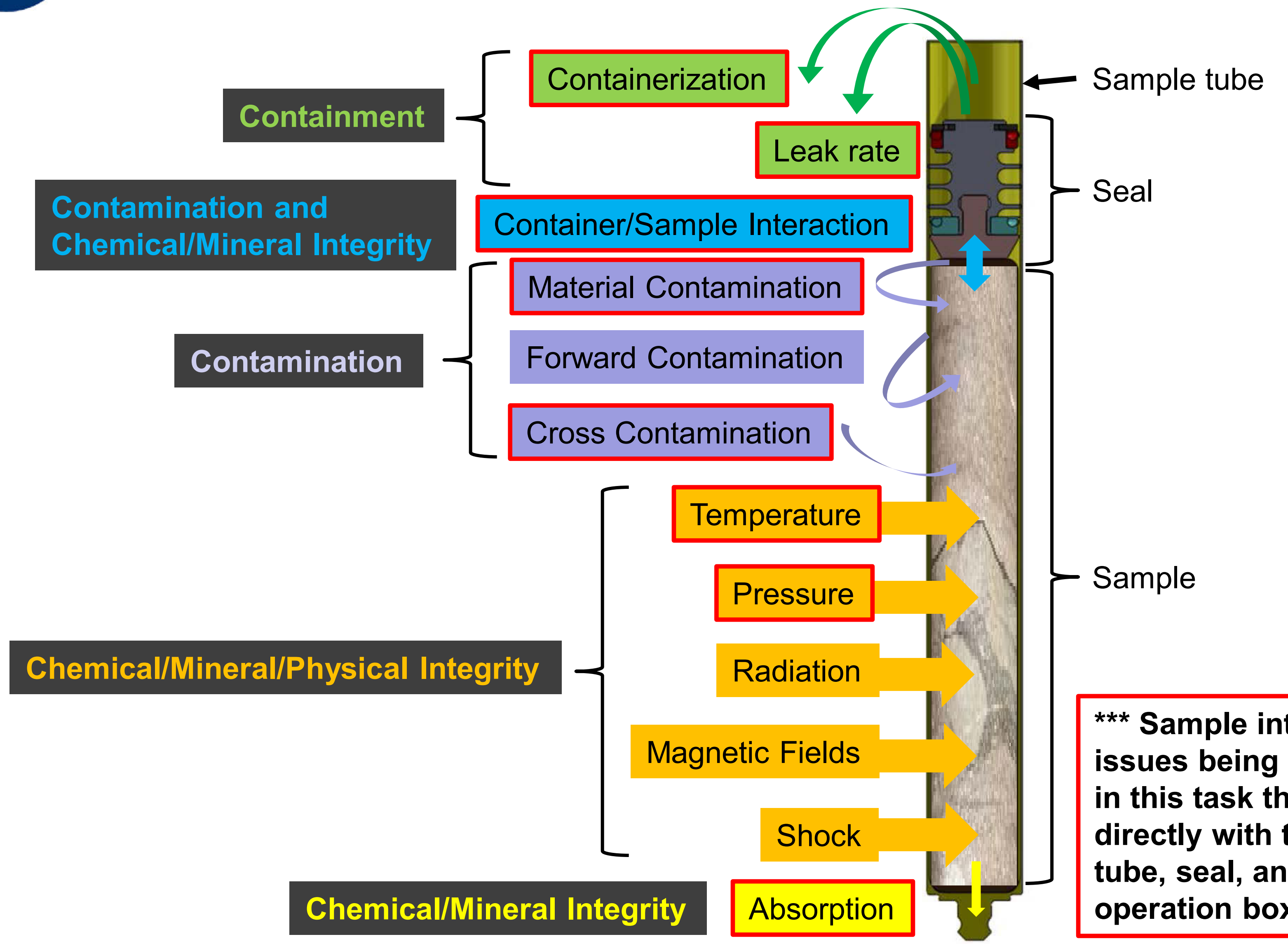
SHEC (Sample Handling, Encapsulation and Containerization) Concept

Removed cache canister





Sample Integrity

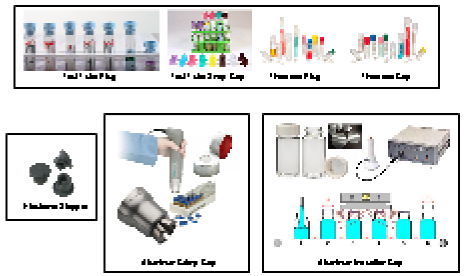


***** Sample integrity issues being addressed in this task that deal directly with the sample tube, seal, and sealing operation boxed in red.**

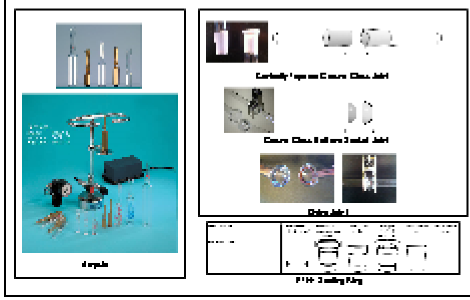
Commercial Sealing Techniques

Mechanical

Pharmaceutical

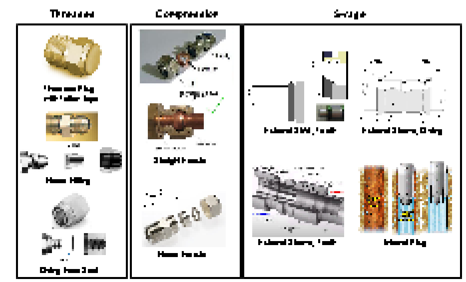


Glass



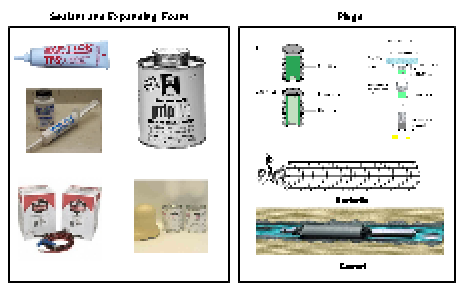
(Includes Vacuum Environments and Petroleum)

Plumbing

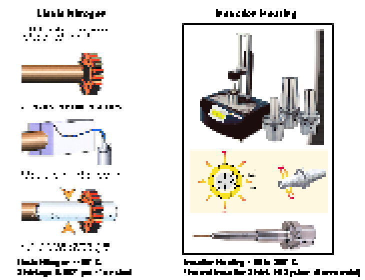


Fluid, Thermal, Adhesive

Injectable Media



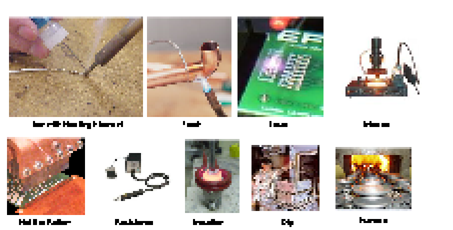
Differential Thermal Expansion



Adhesion

Metallurgical

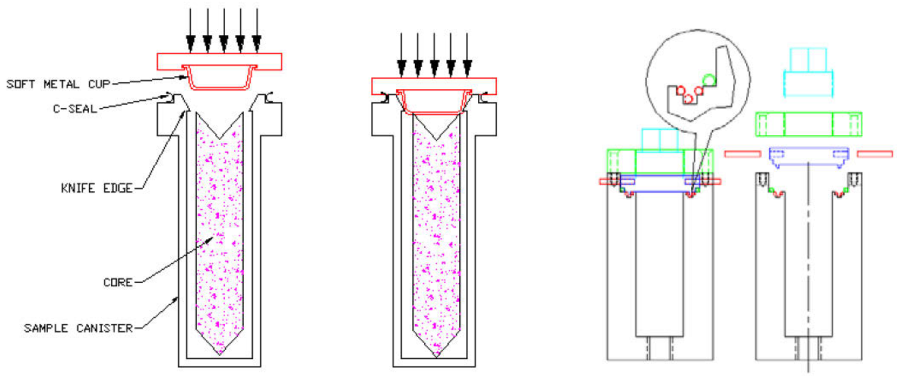
Soldering/Brazing



Soldering: <450 C Brazing: >450 C (American Welding Society)

Welding

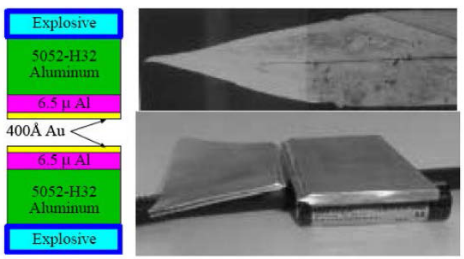
Sealing Techniques in Research



Soft Metal Cup

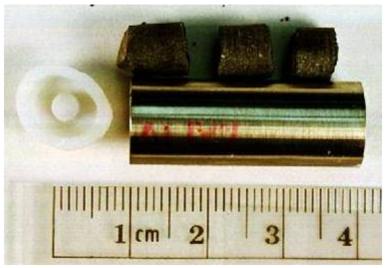
Serial Radial Seal

(Kong et al., 2000)



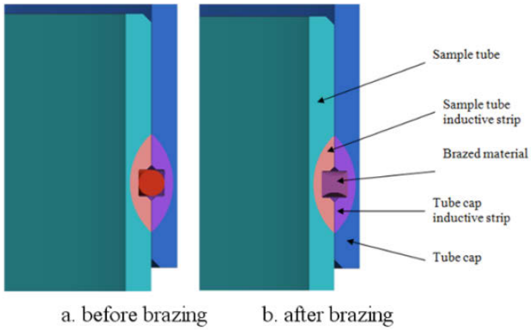
Explosive Welding

(Dolgin et al., 2000)

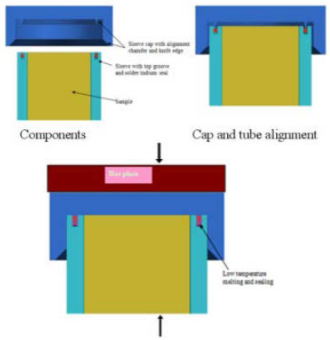


Teflon Cap

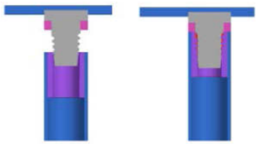
(JPL Athena Study, ~2000)



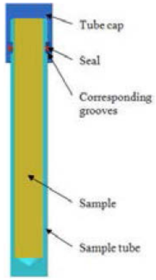
Cap with Brazed Seal Using Induction Heating



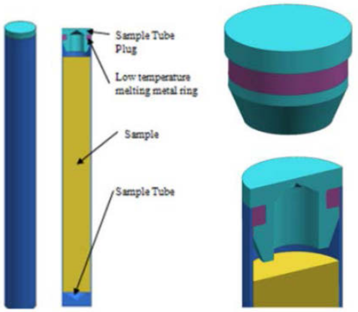
Cap with Knife Edge Sealing and Top Heating for Soldering



Cap with Threads Rotated into Soft Coating on Wall



Cap with Solder Seal



Plug with Radial Solder Seal

(Backes et al., 2009)

Sealing Techniques in Previous Missions

Apollo

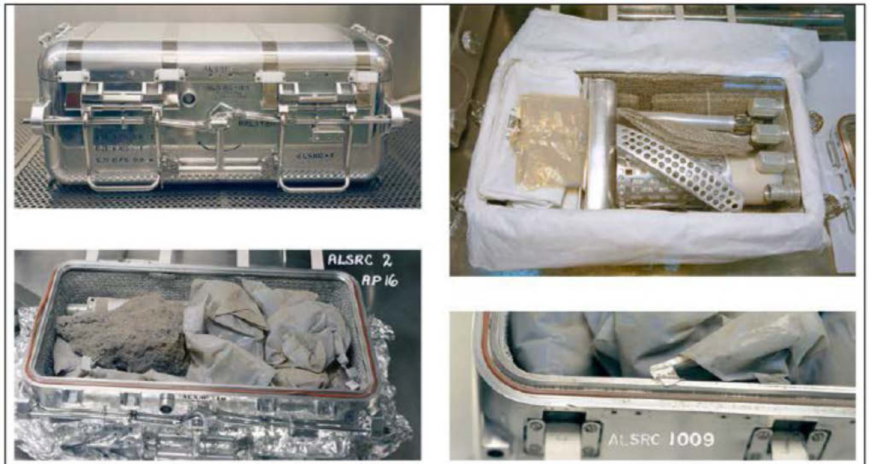


Figure 1. Close up view of Apollo Sample Return Containers in Various Configurations. Upper left, a closed ALSRC (NASA Photograph S72- 37196). Upper right, an ALSRC loaded with clean sample containers and other hardware (NASA Photograph S70-52550). Lower left, ALSRC after being opened on return to the Lunar Receiving Laboratory after being loaded on the lunar surface by the Apollo 16 crew; (NASA Photograph S72-36984).

Genesis

Figure 2a. Close up view Genesis' flight hardware Sample Return Capsule with integrated Science Canister

Figure 2b. Close up view Genesis' flight hardware Science Canister

Stardust

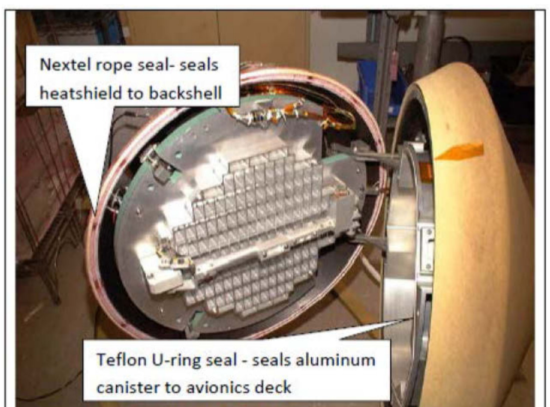


Figure 3. Close up view of Stardust's flight hardware Sample Return Capsule with integrated sample tray assembly (STA) and aluminum canister housing

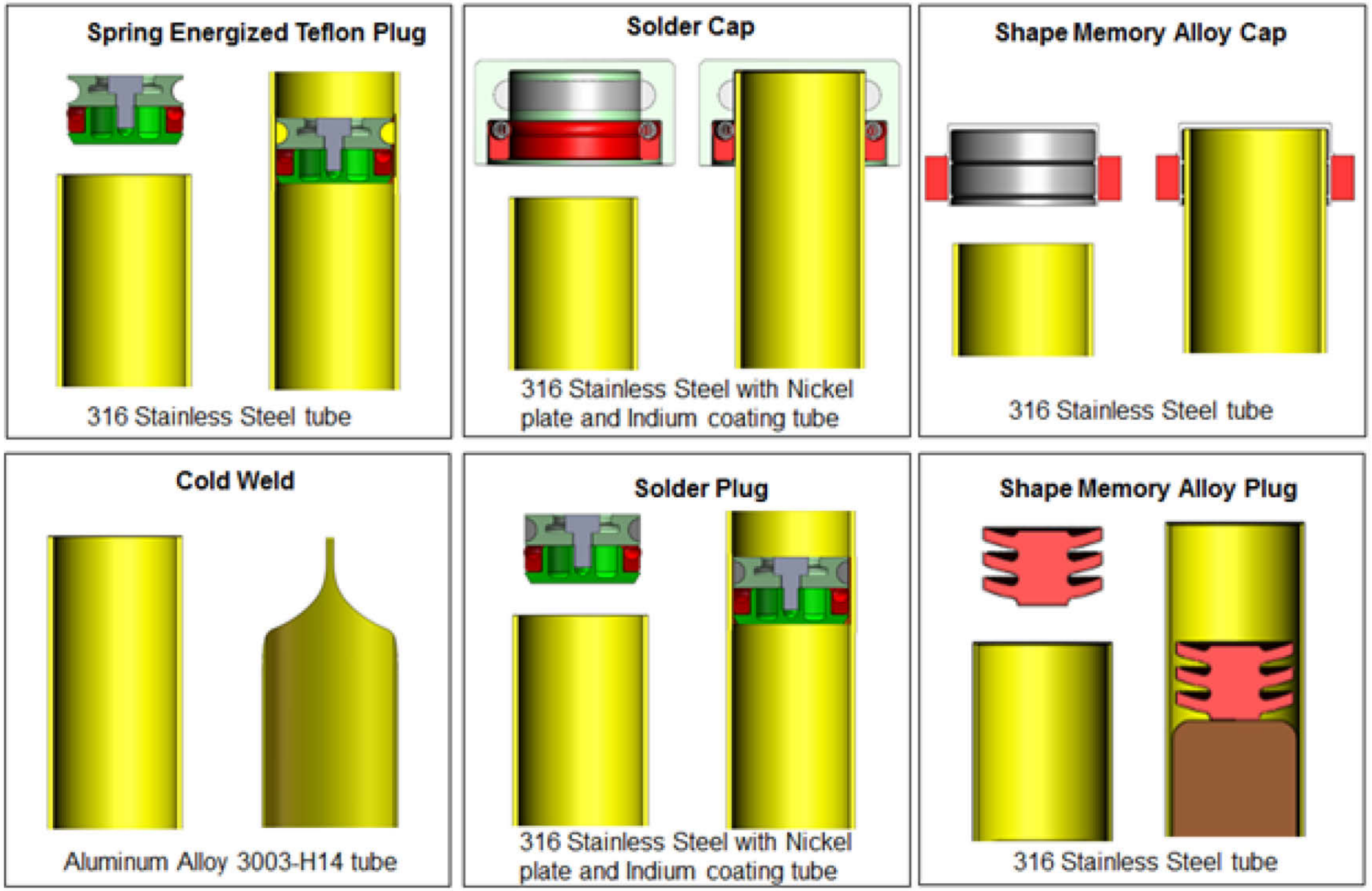
Hayabusa

Figure 4. Close up view of Hayabusa sample container

Design Considerations

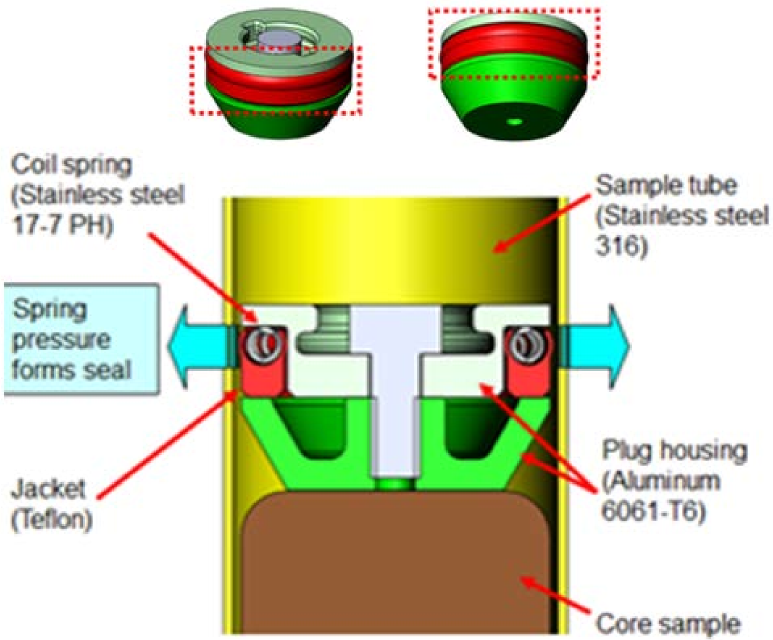
- **Power**
  - The sealing device must operate within the power budget of the rover.
- **Environment**
  - The Martian temperatures assumed for this research activity are -130°C during a Martian winter night up to 40°C during a Martian summer day. The pressure on Mars is assumed to be between 0.2666 to 1.599 kPa.
- **Dust Tolerance**
  - The seals must be dust resistant since the sample tube surfaces would be susceptible to dust upon sample acquisition.
- **Shock and Vibration**
  - The seals must be robust enough to remain intact during vibration seen from rover driving and rover operation.
- **Sample Integrity**
  - Sample integrity must be considered, which would include limiting the potential of damaging the sample due to significant application of heat, pressure, acceleration, impact, magnetic fields, radiation, chemical interactions, and contamination.
- **Hermeticity**
  - To maximize science return on sample return missions, in-situ technologies must be developed to maintain the physical integrity of the sample from acquisition, encapsulation and containment such that volatiles in solid samples, and evolved gases resulting from the sublimation would be retained.
- **Packaging**
  - Considerations must be made to limit the amount of mass and volume required for the seals and sealing device.
- **Risk**
  - Low failure rate for a seal and sealing device is desirable for maximum science return.
- **Autonomy**
  - The sealing process must be executable in-situ autonomously with limited ground-in-the-loop control.

Candidate Sealing Methods

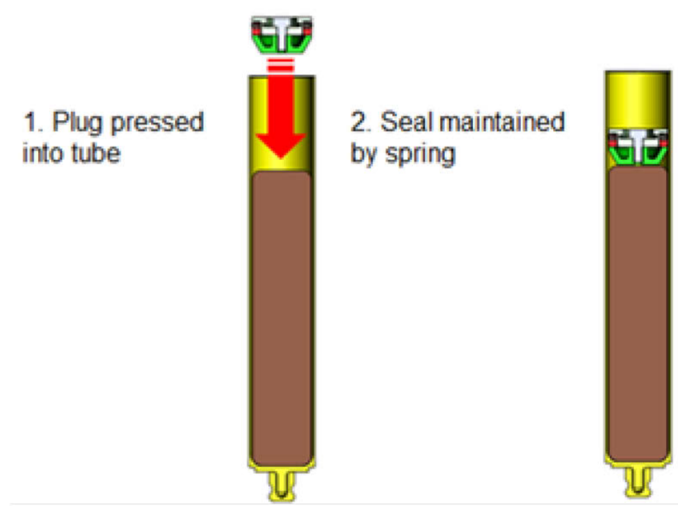


Spring Energized Teflon Plug

Overview



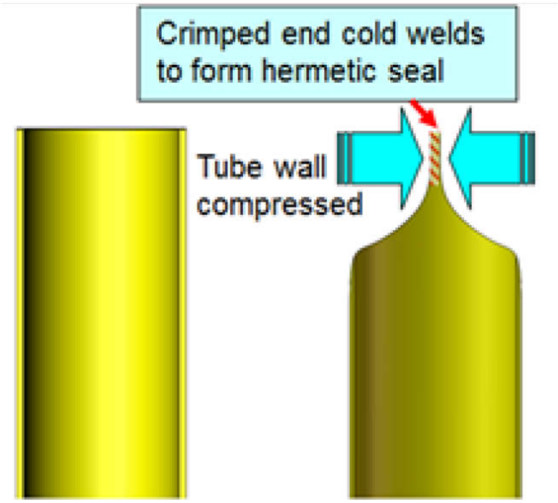
Application



Prototype

Crimped Tube

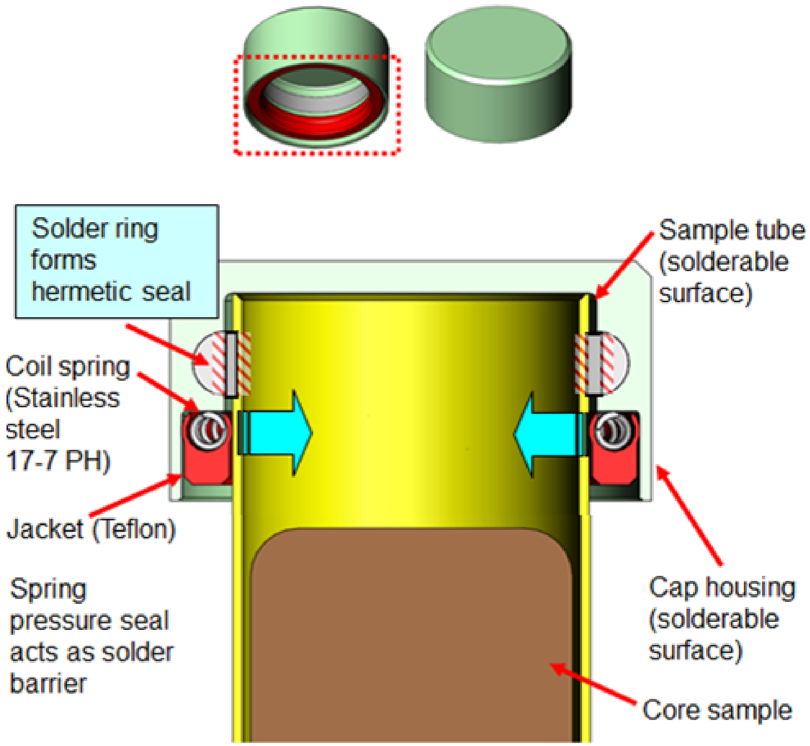
Overview/Application



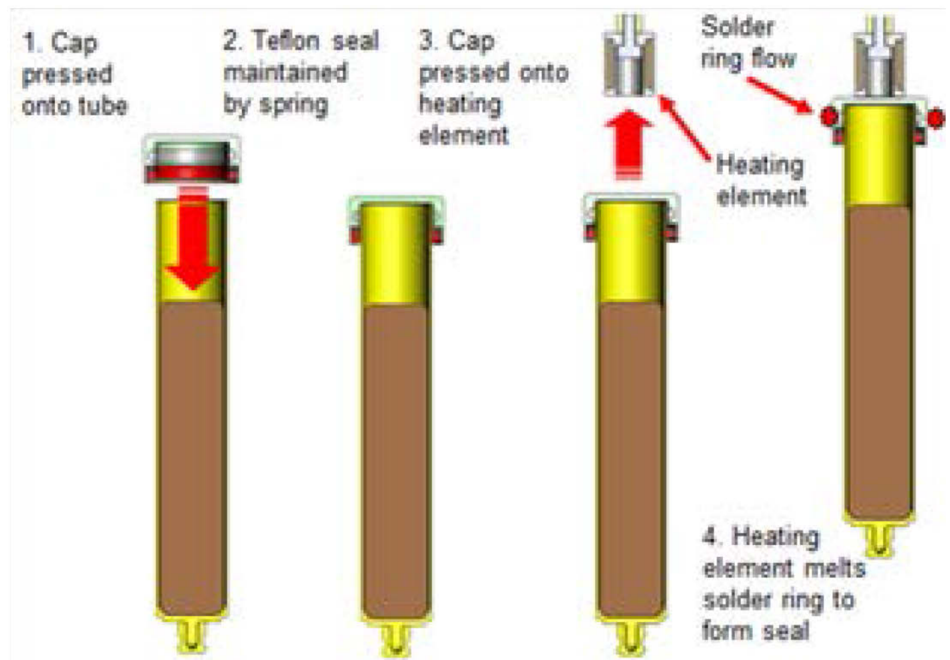
Prototype

Solder Cap

Overview



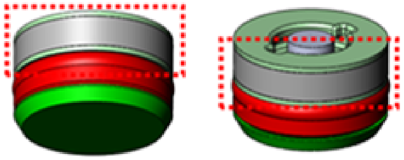
Application

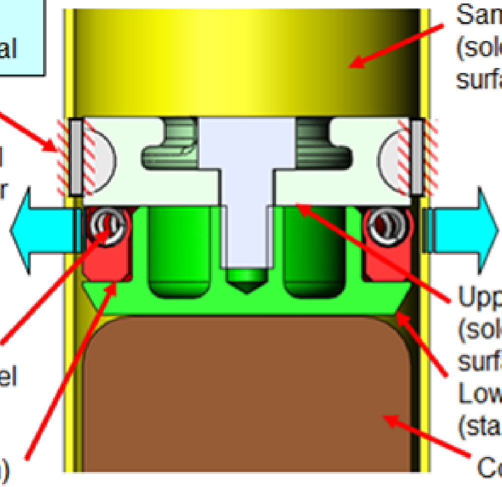


Prototype

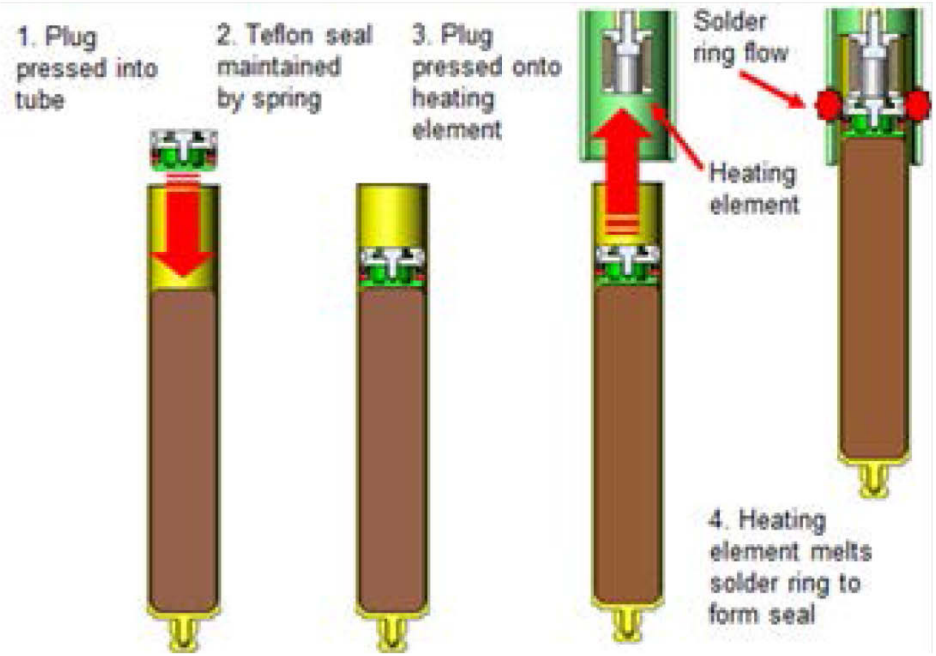
Solder Plug

Overview

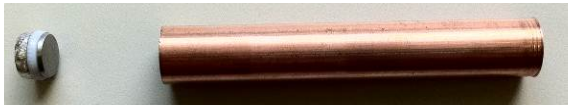




Application

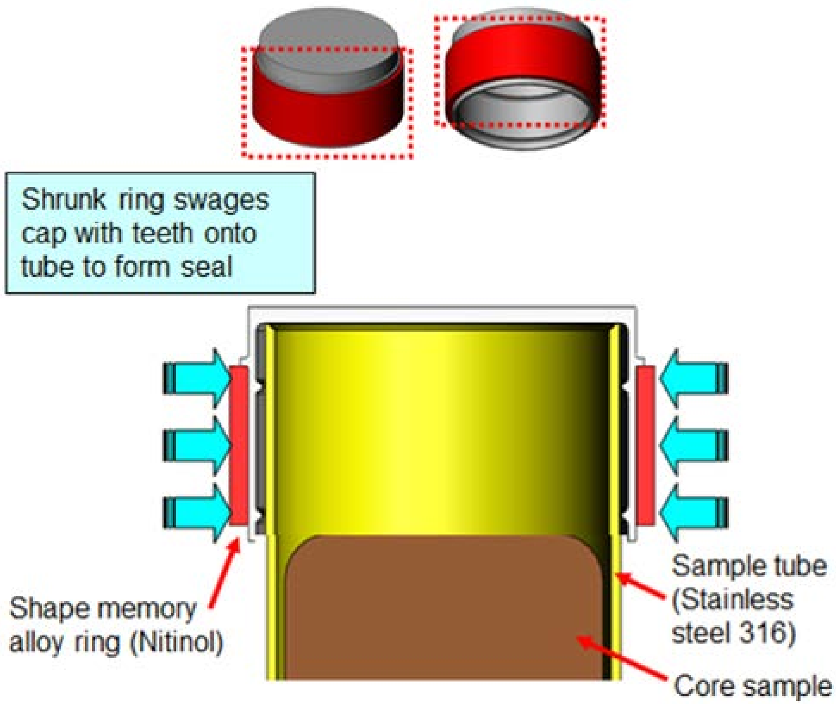


Prototype

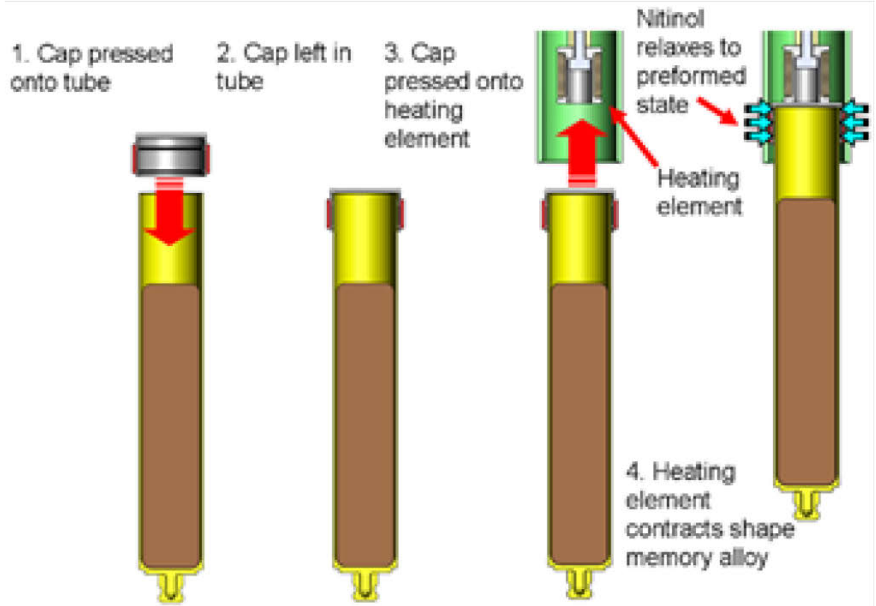


Shape Memory Alloy Cap

Overview



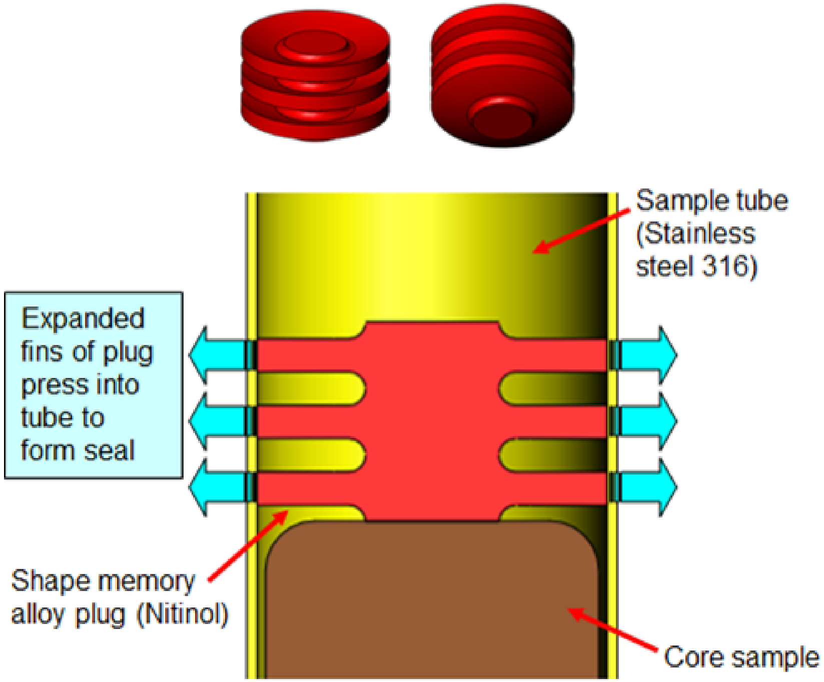
Application



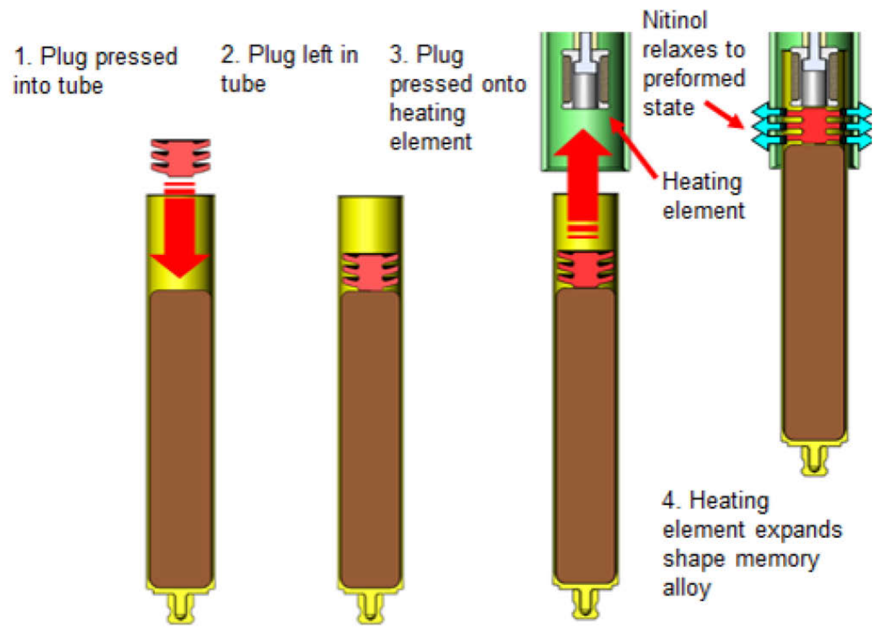
Prototype

Shape Memory Alloy Plug

Overview



Application



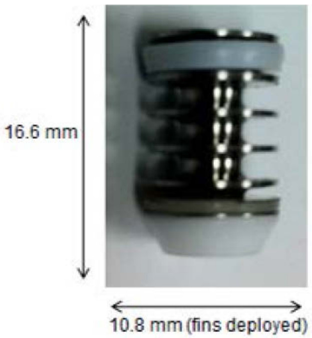
Prototype

Seal Testing

- For each sealing method, three of the test pieces will be sealed in a clean tube, and three will be sealed in a tube covered with a layer of Martian simulant dust.
  (1) Helium leak test
  (2) 1 cycle down to -130 C for 15 min, up to 40 C for 15 min
  (3) Repeat He leak test
  (4) 4 more cycles down to -130 C for 15 min, up to 40 C for 15 min
  (5) Repeat He leak test
  (6) Destructive testing with Instron to measure plug retention force

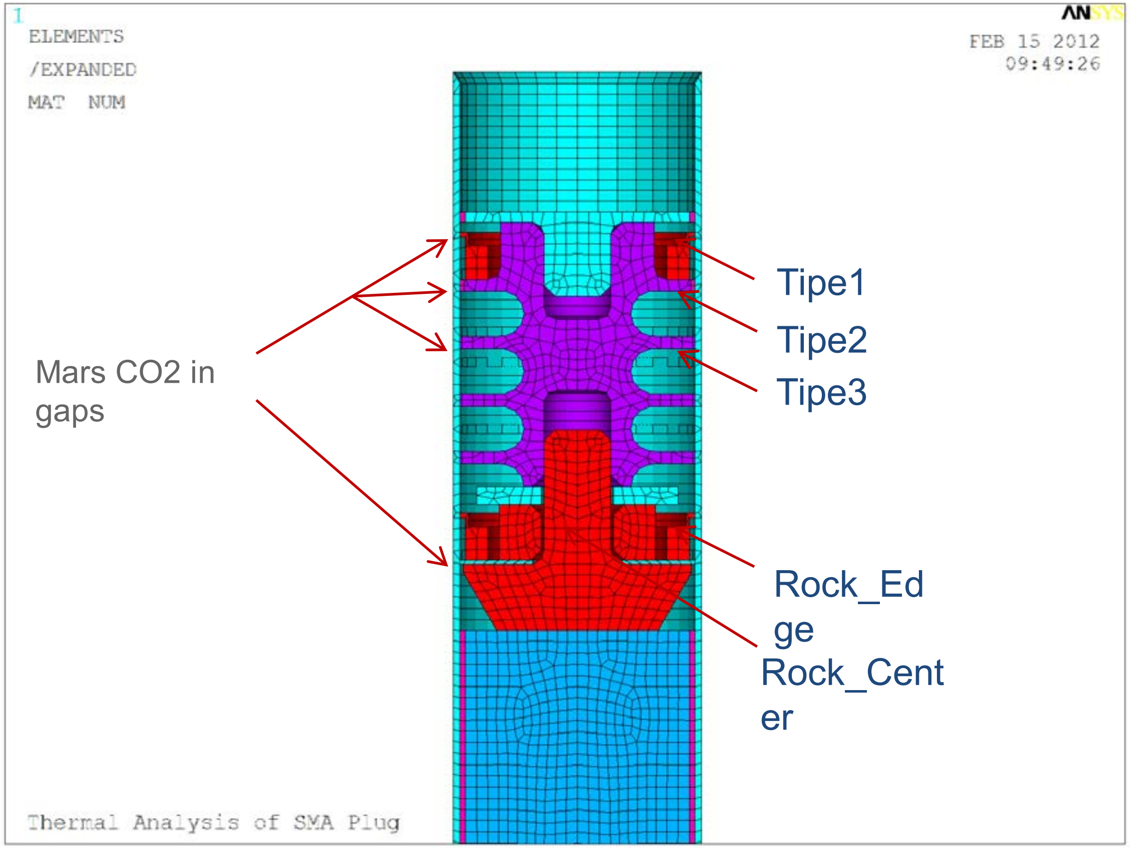
Thermal Analysis of Sealing Process

- **Multiphysics modeling of SMA plug, sample, and sample tube to study heating during sealing process**



SMA Plug Model

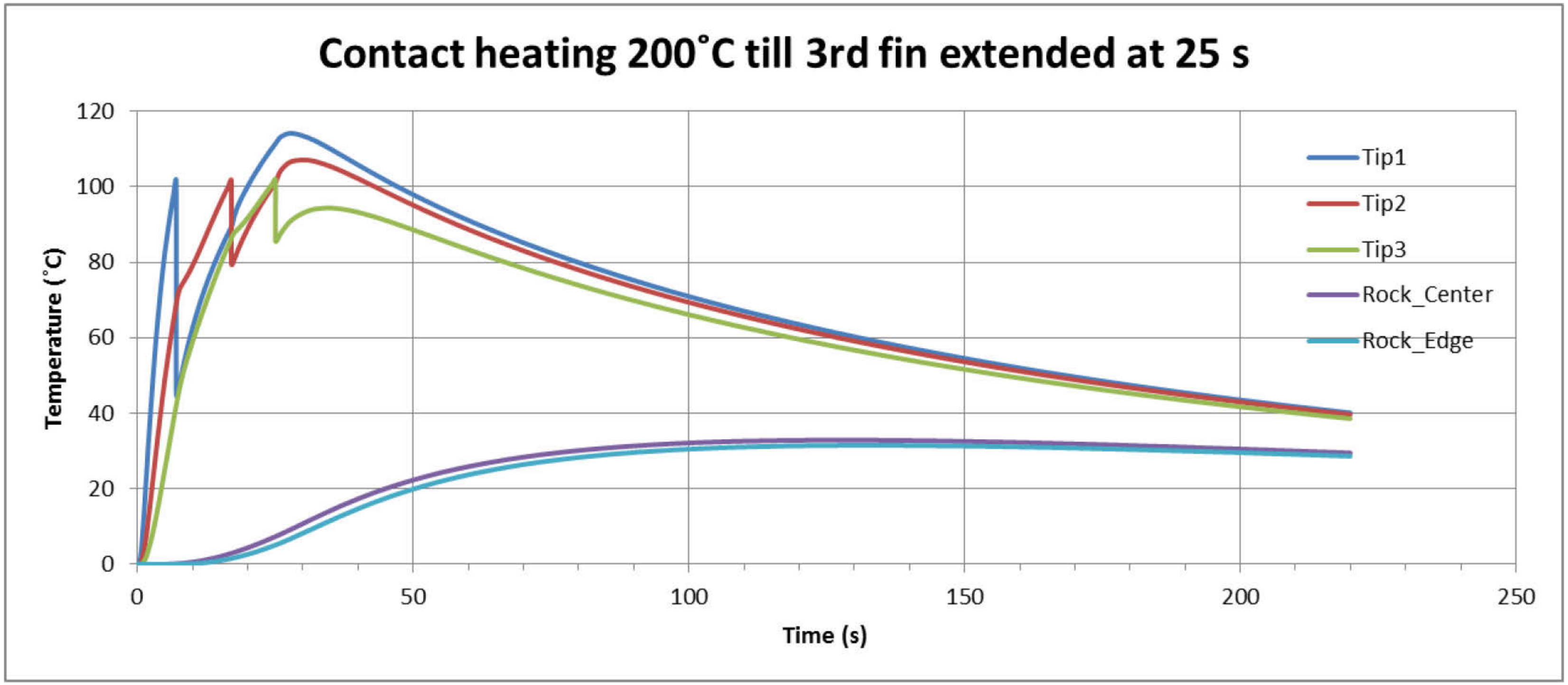
Contact heating 200˚C till 3rd fin over 100˚C
including Martian CO2 in the gaps



Gap between the fin and the tube 0.1 mm
Gap between the rock and the tube 0.25 mm

SMA Plug Simulation Results

Contact heating 200˚C till 3rd fin over 100˚C including Martian CO_2 in the gaps (Conductivity of 0.016 W/m K)



Rock_centr: Temperature at center of the rock up surface. The maximum is 32.9 ˚C .
Rock_Edge: Temperature at edge of the rock up surface. The maximum is 31.5 ˚C .

Total heating energy: 270 J

Initial Testing of SMA Plug with Mars Simulant Dust

Application of Simulant Dust

Sealing with Heat Gun

Initial Helium Leak Testing of SMA Plug

After initial sealing:

CLEAN TUBE

Leak Rate:
0.2×10^{-9} cc/sec

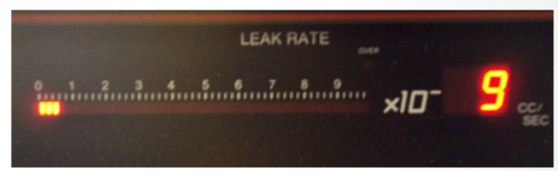
DIRTY TUBE

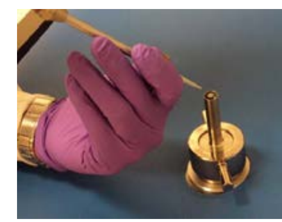
Leak Rate:
2.2×10^{-5} cc/sec

After cycling once down to 132.7° C for 15 min and back up to room temperature:

CLEAN TUBE

Leak Rate:
0.6×10^{-9} cc/sec

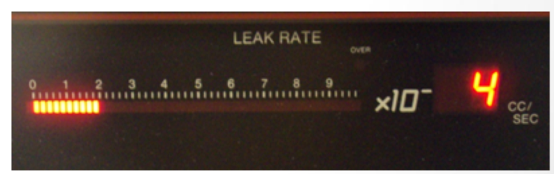




DIRTY TUBE

Leak Rate:
$\approx 2 \times 10^{-4}$ cc/sec

NOTE: Dirty tube expressed severe leakage after cooldown, and actual reading fluctuated between 0.2×10^{-4} and 8×10^{-4}…reading was unstable.



Summary

- Sealing methods for encapsulating samples in 1 cm diameter thin-walled sample tubes applicable to future proposed Mars Sample Return missions were investigated
- Techniques implemented include a spring energized Teflon sleeve plug, a crimped tube seal, a heat-activated shape memory alloy plug, a shape memory alloy activated cap, a solder-based plug, and a solder-based cap
- Thermal models were developed to study heating of the sample inside the sample tube during the sealing process
- Initial helium leak testing and thermal analysis for heating of shape memory alloy plugs showed potential for being a viable hermetic sealing option for Mars Sample Return
- Further testing and analysis will be performed on the other sealing techniques for comparison