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System-Level Risk Reduction Activities for the eMMRTG Project

Christopher Matthes, Pd.D., Caltech/Jet Propulsion Laboratory
Christofer Whiting, Ph.D., University of Dayton Research Institute

Pre-decisional information for planning and discussion only

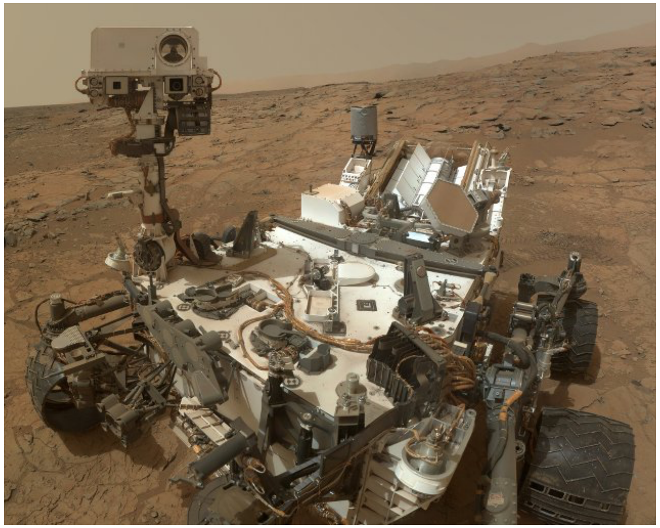
University of Dayton Research Institute

Jet Propulsion Laboratory
California Institute of Technology

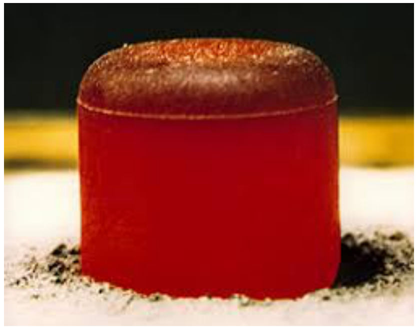
Agenda

- Background
  - eMMRTG Project overview
  - NASA risk process
- System-level risks
- Testing & Results
- Conclusions and current status

What is a Radioisotope Thermoelectric Generator (RTG)?



- Provides electricity to missions in remote and challenging environments where solar power is impractical or insufficient
- Thermoelectric (TE) materials convert heat into electricity
  - RTGs use radioisotopes as the heat source
  - Heat is the natural byproduct of isotope decay
- Used by NASA missions of various types for over 50 years



Multi-Mission RTG (MMRTG)

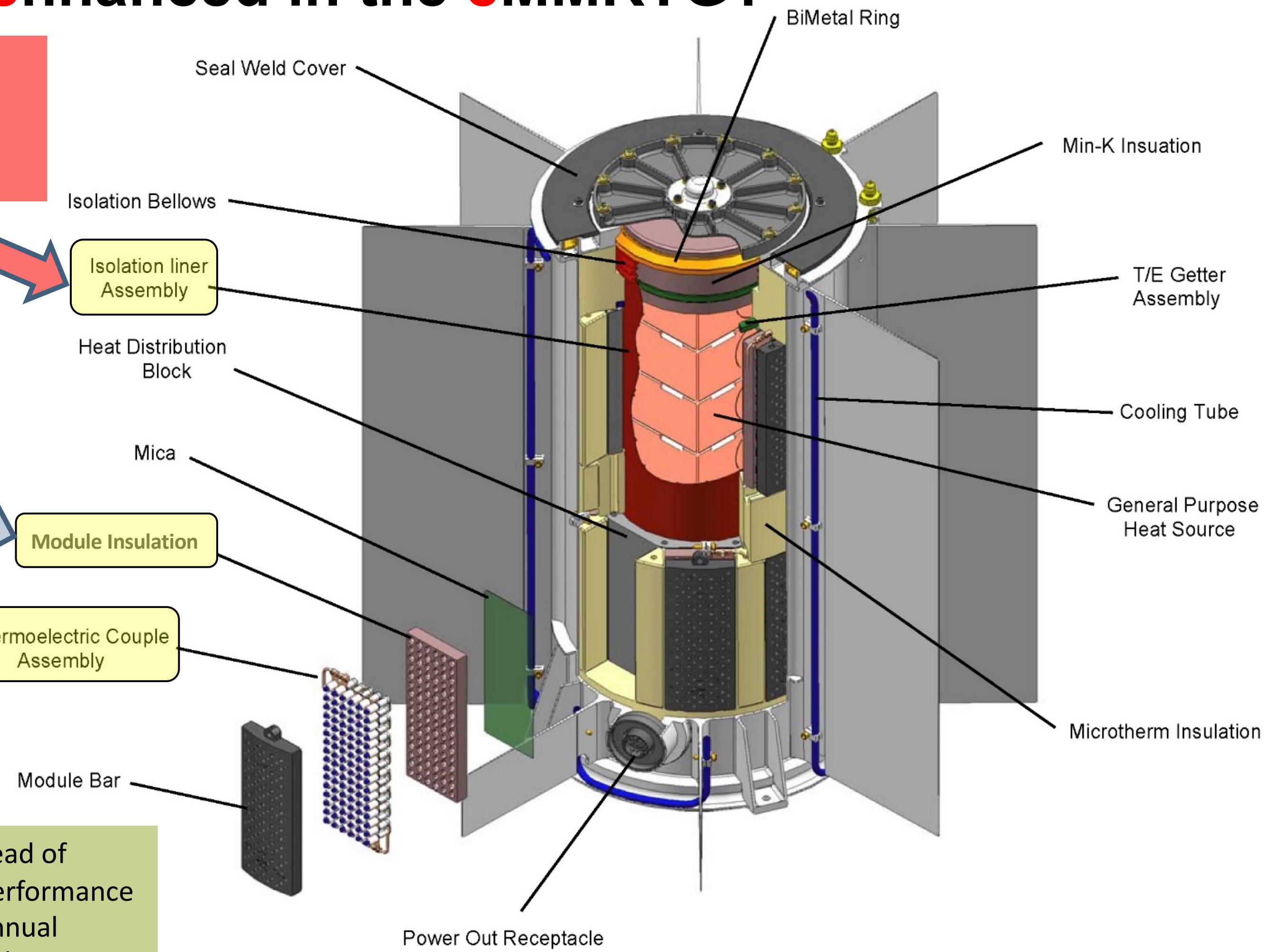
- Sealed thermoelectric cavity allows both planetary (atmosphere capable) and deep space use
- Based on 1970s-era TE materials (PbTe/TAGS)
- Uses the General Purpose Heat Source (GPHS)
- Missions: Mars Curiosity, Mars 2020

The enhanced MMRTG (eMMRTG) Project seeks to improve power output through a block upgrade to the current system

What is being enhanced in the eMMRTG?

Oxide layer added to inner surface of liner to increase surface emissivity and lower temperature of Min-K support system

Insulation changed from Promalight to aerogel-based insulation to provide adequate sublimation suppression for skutterudite (SKD) materials and easier integration with couples

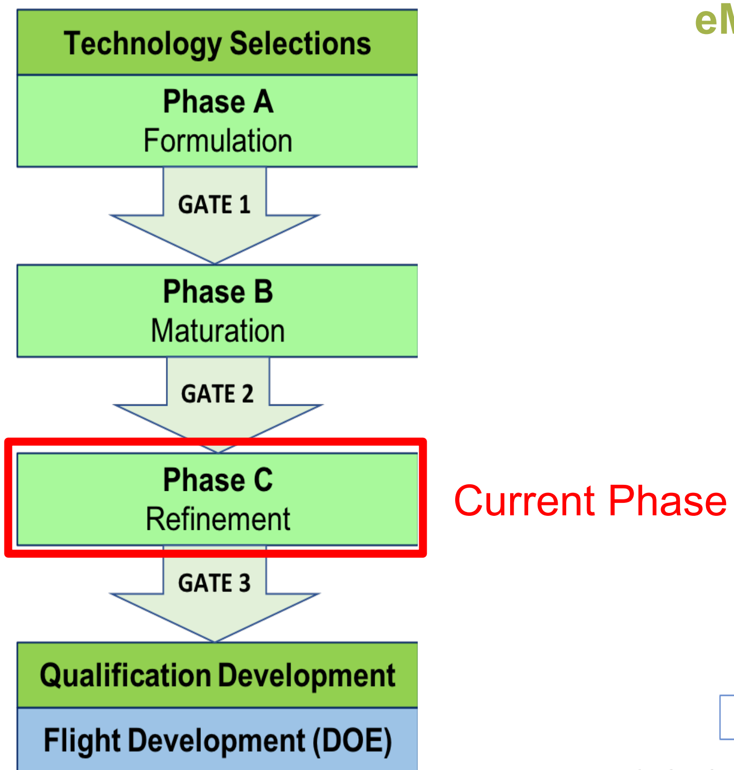


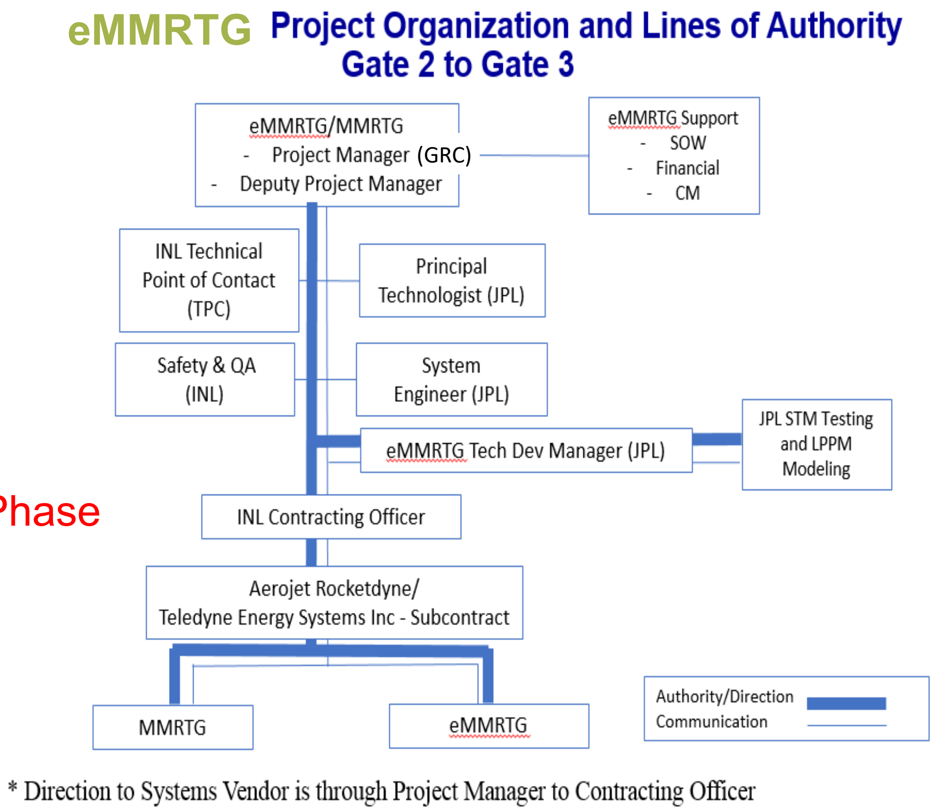
Using skutterudite (SKD) couples instead of PbTe/TAGS couples provides better performance (better ZT and larger ΔT) and lower annual power degradation rates are projected (~ 2.5%/year target)

The MMRTG thermoelectric converter (composed of sixteen 48-couple modules packaged in fibrous insulation) operates under inert gas in an hermetically sealed environment that contains O_2 and H_2 getters

eMMRTG Project Lifecycle and Organization

- The eMMRTG Project is managed out of **NASA Glenn Research Center** with technical support from **NASA JPL**
- System development will by supported by a contract through **DOE Idaho National Laboratory** with **Aerojet Rocketdyne** and **Teledyne Energy Systems, Inc.**





eMMRTG System-Level Risks

Design changes

Addition of aerogel to TE modules

Outgassing products may interact with more reactive system-level materials

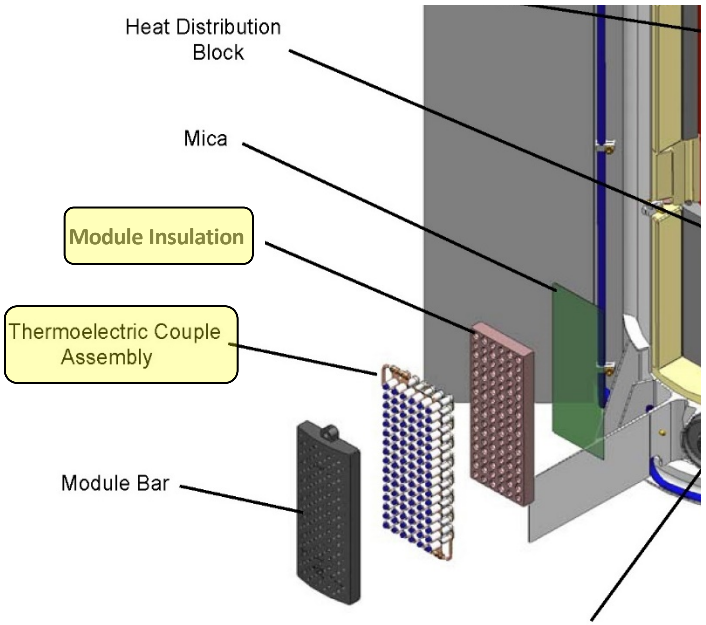
Zr getter effectiveness at removing new gas products is unknown

Addition of skutterudite (SKD) TE materials

Antimony from SKD composition introduced into TE cavity

Zr getter effectiveness may be affected by antimony contamination

Zr getter functionality



NASA Risk Analysis Ratings

Consequence vs. Likelihood

Rating	Consequence	Implementation Risk	Mission Risk
5	Very High	Cannot achieve flight readiness with remaining resources	Mission Failure
4	High	Consume all (100%) of remaining resources	Significant reduction in return
3	Moderate	Consume significant (26-99%) remaining resources	Moderate reduction in return
2	Low	Consume little (10-25%) of remaining resources	Small reduction in return
1	Very Low	Consume minimal (<10%) remaining resources	Minimal reduction in return

Rating	Likelihood	Definition
5	Very High	Almost Certain (> 90%)
4	High	More Likely than Not (75 < P < 90%)
3	Moderate	Significant but Not Assured (30 < P < 75%)
2	Low	Unlikely (10 < P < 30%)
1	Very Low	Very Unlikely (< 10%)

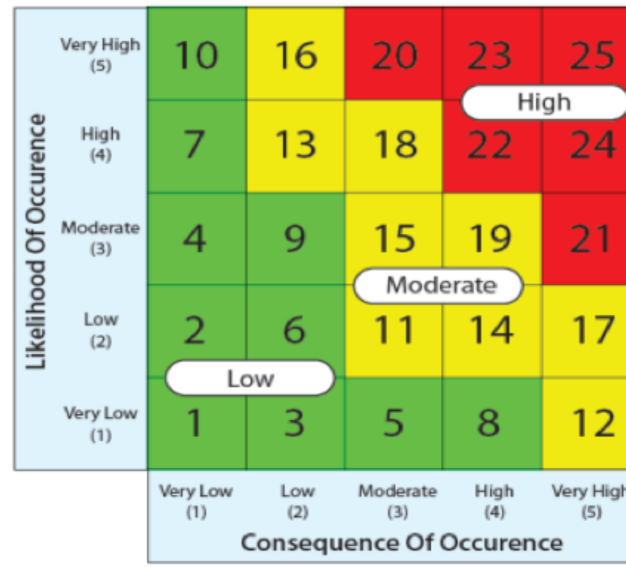


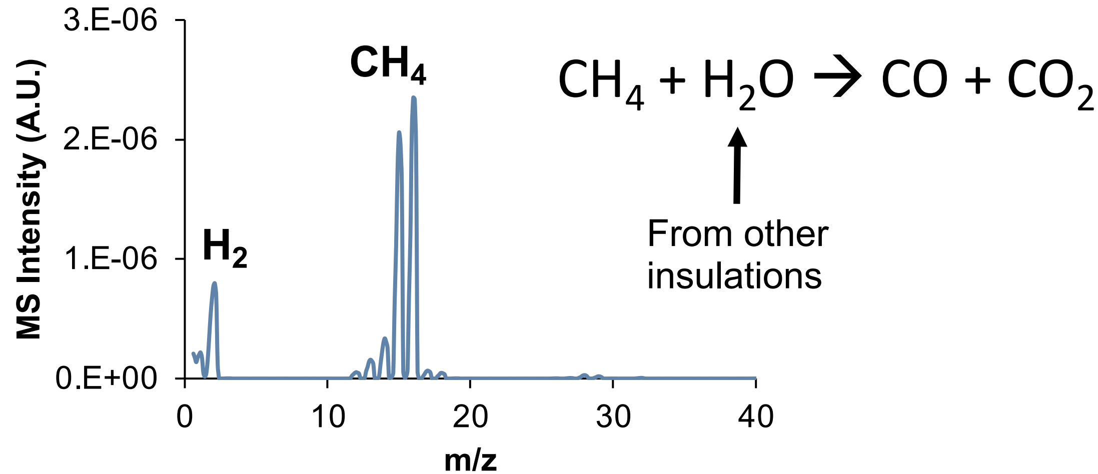
Figure 5. NASA 5x5 Risk Matrix

			CY16				CY17				CY18					CY19			
		FY16				FY17				FY18				FY19				FY20
Technical risk		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
eMMRTG-009	eMMRTG system level risk for oxidation	3 x 4										2 x 4	2 x 3		1 x 2			
eMMRTG-010	eMMRTG system level risk for antimony reactions	2 x 4													1 x 3			
eMMRTG-011	eMMRTG system level risk for HMIC outgassing products	3 x 4											2 x 3		1 x 2			

Aerogel Outgassing Products

Aerogel (HMIC)

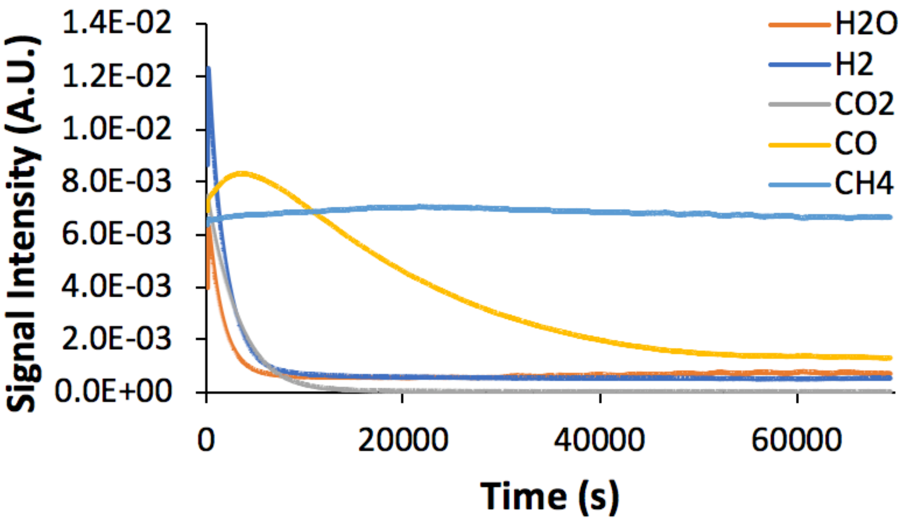
Gases produced during operation



- Throughout generator operation at high temperatures, the aerogel in the TE module produces non-inert outgassing products
- The presence of these non-inert gases may result in undesirable interactions with system-level materials

New TE insulation introduces risk that must be characterized and mitigated

Zr Getter Functionality



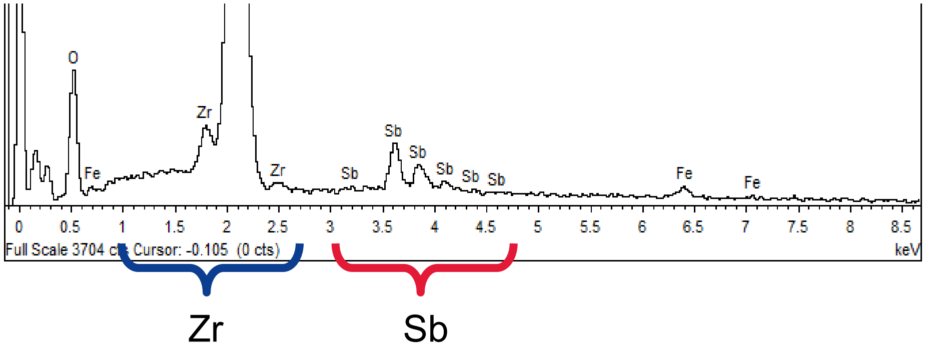
Getter coffin assembly with Pt coffin lid (left) and coffin base containing Zr compact (right)

- Getter found to react with significant quantities of all the tested gases
  - CH_4 was slowest, but full reaction expected in relatively short term
  - Getter functionality eliminates most long-term risk

- H_2 found to exist at a low equilibrium level
  - Some long-term risk could remain if found to be detrimental

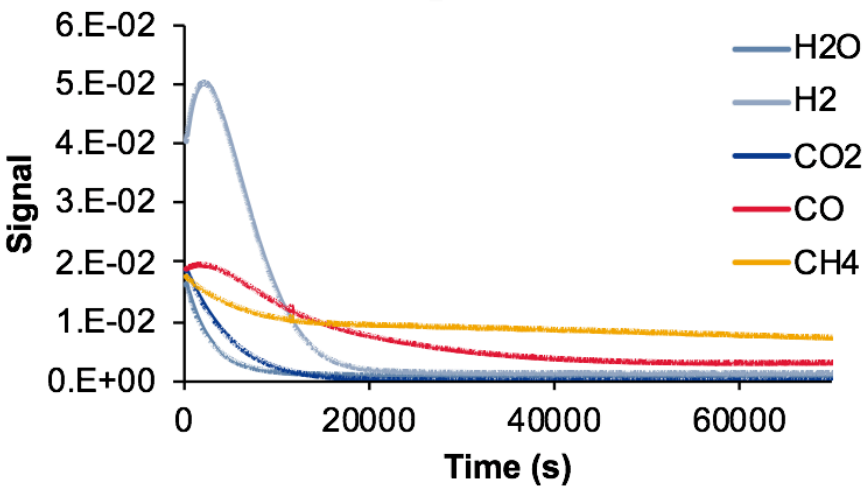
Getter has been shown to be effective at removing most non-inert gases from the system over the long-term. Low H_2 levels present low risk but can be further mitigated

Effect of Sb on Zr Getter Functionality



- Presence of antimony in EDS spectrum showing minor surface contamination
- Source: equipment cross-contamination between getter and SKD couples

- Reaction rates between Zr getters activated with and without Sb were compared

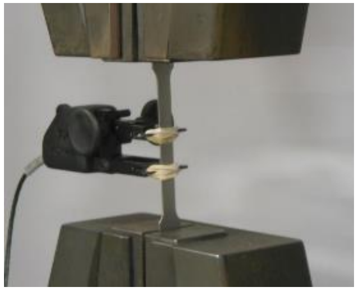


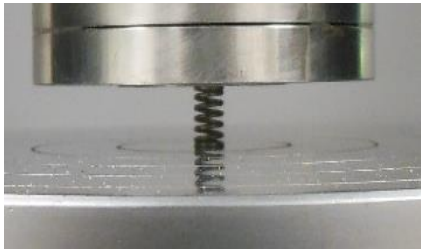
- Minor contamination with Sb does not appear to have a significant impact on reaction rates with any of the gases studied
- Sb found to slow the reaction with CH_4 slightly, but with no long-term functional effect
- Minimizing contamination of getter-coffin assembly will ensure proper functionality

Mitigation plan: Update manufacturing procedures to ensure minimal cross-contamination occurs

Material Compatibility Testing

- Materials identified according to risk priority:
  - Inconel piston springs providing compressive loading on TE couples within the TE module
  - Pt wire, PtRh wire used in PRT and grounding wire
  - Haynes 25 used for heat source isolation liner
- Materials were tested under constant flow of CH_4, H_2, CO_2, CO gas mixture at temperatures close to operating conditions
  - Tests occurred at 1, 3, and 6 month durations
  - Following test, materials underwent destructive physical analysis (DPA) to assess changes in properties
- Results: No observable long-term material effects attributable to the new HMIC gas products
  - Springs: No measurable difference in force at set point between test and control samples
  - Pt and Pt-10Rh wires: No increase in resistance
  - Haynes 25: Embrittlement due to thermal aging observed, a known phenomenon factored into structural analysis





Ensuring that gases produced by HMIC do not result in long-term reactions with system-level materials allows the eMMRTG design to proceed with confidence

Conclusions & Current Status

- Zr getter has been shown to be effective at removing non-inert gases produced by aerogel over the long-term
- Material compatibility testing has shown low risk of short-term reactions between gases and system materials
- Procedures have been identified to ensure sufficiently low risk moving forward
  - Implement measures to ensure no contamination of getter (e.g. furnace bake-out following couple bonding)
  - Possible cold-side getter to remove residual H_2 in generator
- A successful Gate 3 Review following Phase C would initiate qualification unit build with a potential 2024 delivery

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov

University of Dayton Research Institute