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2018 Conference on Advanced Power Systems for Deep Space Exploration presentation - eMMRTG Development and Infusion

October 2018

Changing the World's Energy Future

Joe Giglio, Chris Matthes

Idaho National Laboratory

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eMMRTG Development and Infusion

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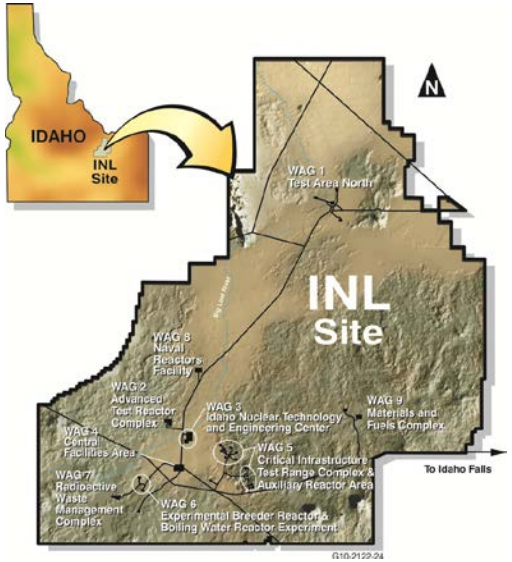

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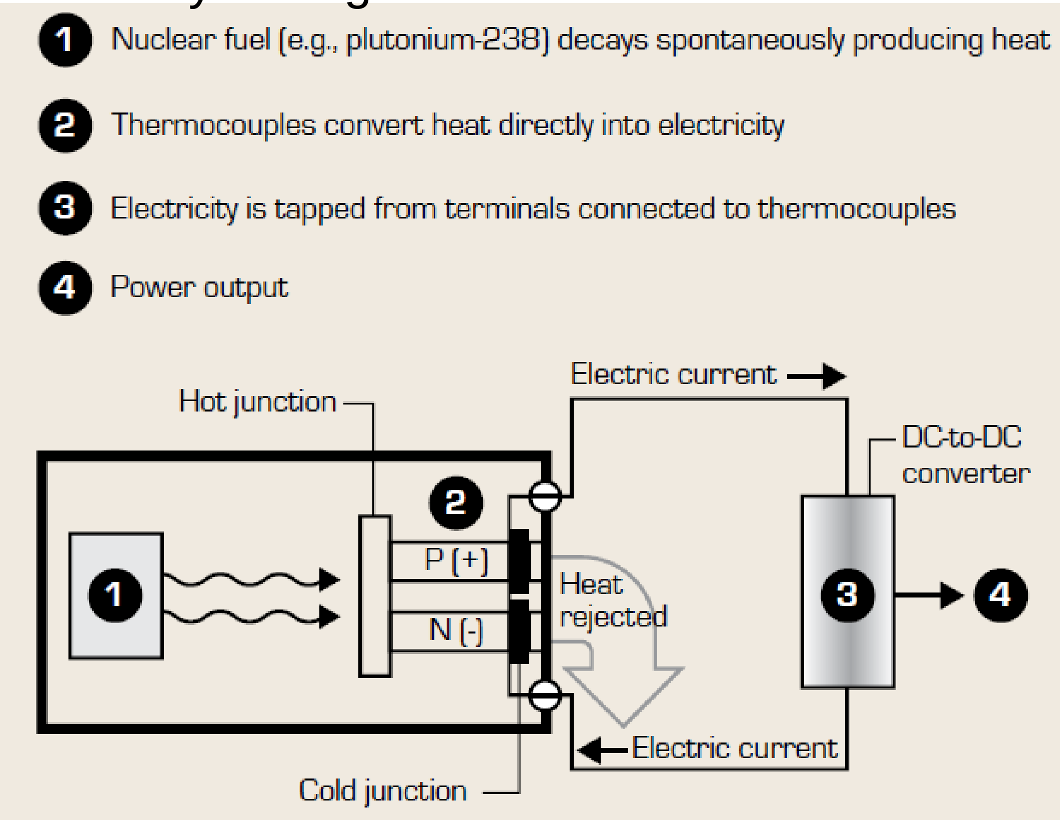
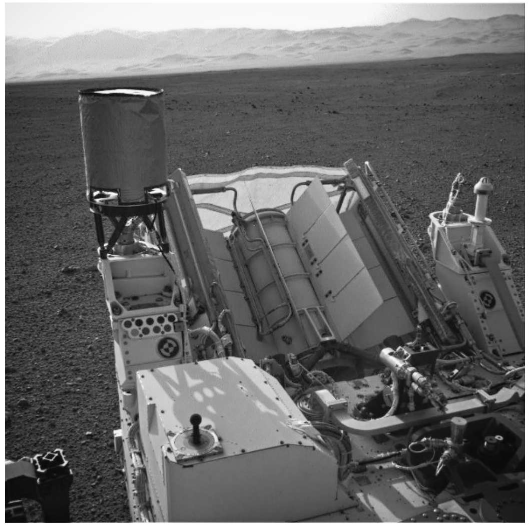
Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)

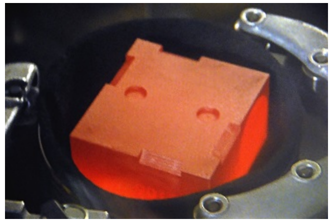
- The MMRTG converts heat generated from the natural decay of Pu-238 (alpha emitter) to electricity through the thermoelectric effect.





Missions
- Mars Science Laboratory
- Mars 2020

Potential Mission
- Dragonfly

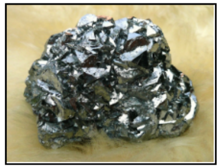


- Sealed thermoelectric cavity which allows planetary (atmosphere capable) and deep space use
- Based on 1970 era thermoelectric materials (PbTe/TAGS)
- Uses the General Purpose Heat Source (GPHS)
- Total power degradation is ~4.8%/year
  - Fuel decay ~1.1%

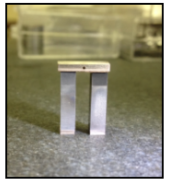
Terminology
BOL- Beginning of Life
BOM- Beginning of Mission
EODL – End of Design Life

Enhancing the MMRTG – Replacing the TE with State of the Art Technology

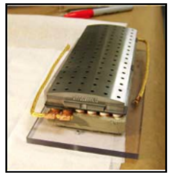
Technology Transfer & Maturation + MMRTG design mods = eMMRTG



Skutterudite (SKD) materials



SKD couples

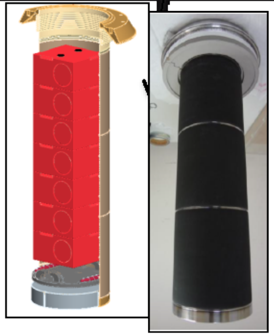


Advanced SKD MMRTG modules

New SKD materials with higher performance and higher maximum operating temperature than MMRTG TE materials

10% increase in conversion efficiency over MMRTG couples

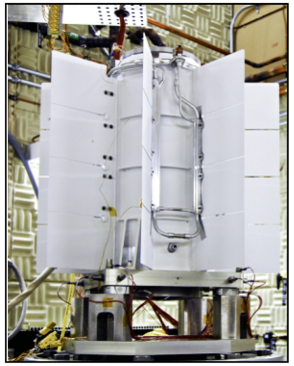
Operating Temperature rises from 800K to 873K



Liner changes boost operating temperature

+

14% increase in conversion efficiency over MMRTG couples



enhanced MMRTG

- ≥ 24% increase in power over MMRTG at BOL
- ≥ 50% increase in power over MMRTG at 17 years

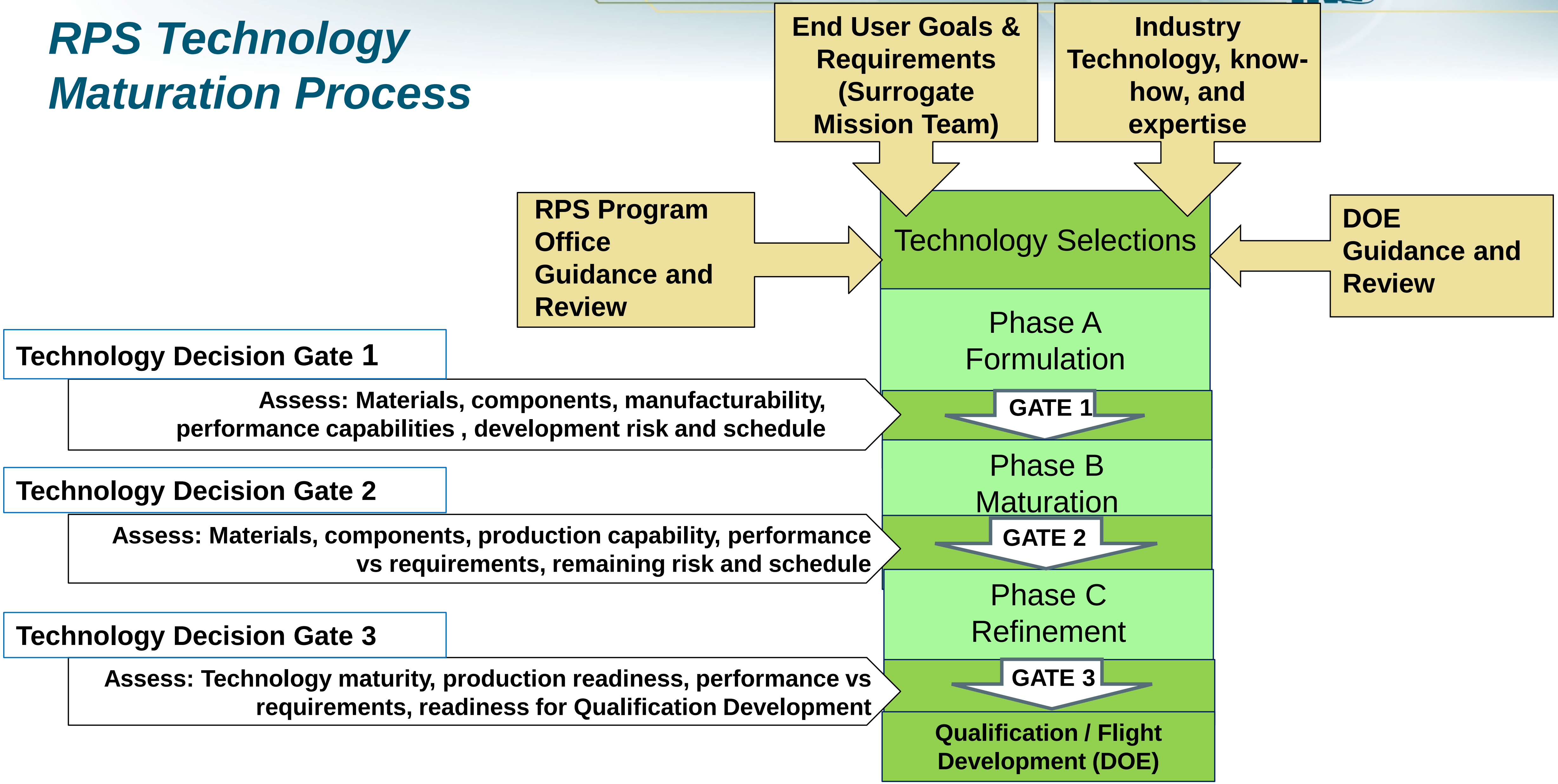
Requirement:
Minimum EODL power of 77 W accounting for all degradation mechanisms when operated at nominal deep space conditions with minimum fuel load (1952 W BOL), fin root temperature of 157°C and load voltage of 34 V.

Minimize changes to a TRL-9 generator

- Replace the PbTe with SKD in the 48 couple module
  - Includes Aerogel insulation for sublimation suppression
- Need to increase the hot junction operating temperature to realize enough benefit for the change
- Increases the operating temperatures from the TE to the fuel
  - Duplicate the emissive coating on the outside of the liner on the inside surface to lower the fuel temperature
  - Requires the fuel support structure to operate hotter than the MMRTG

	MMRTG	eMMRTG
Power, launch, W	110	140 (goal)
Efficiency, BOL	5.5%	7.5%
Power, EODL, W	55	77
Degradation rate, avg	4.8%	2.5%
# GPHSs	8	8
Length, m	0.69	0.69
Mass, kg	45	44

RPS Technology Maturation Process

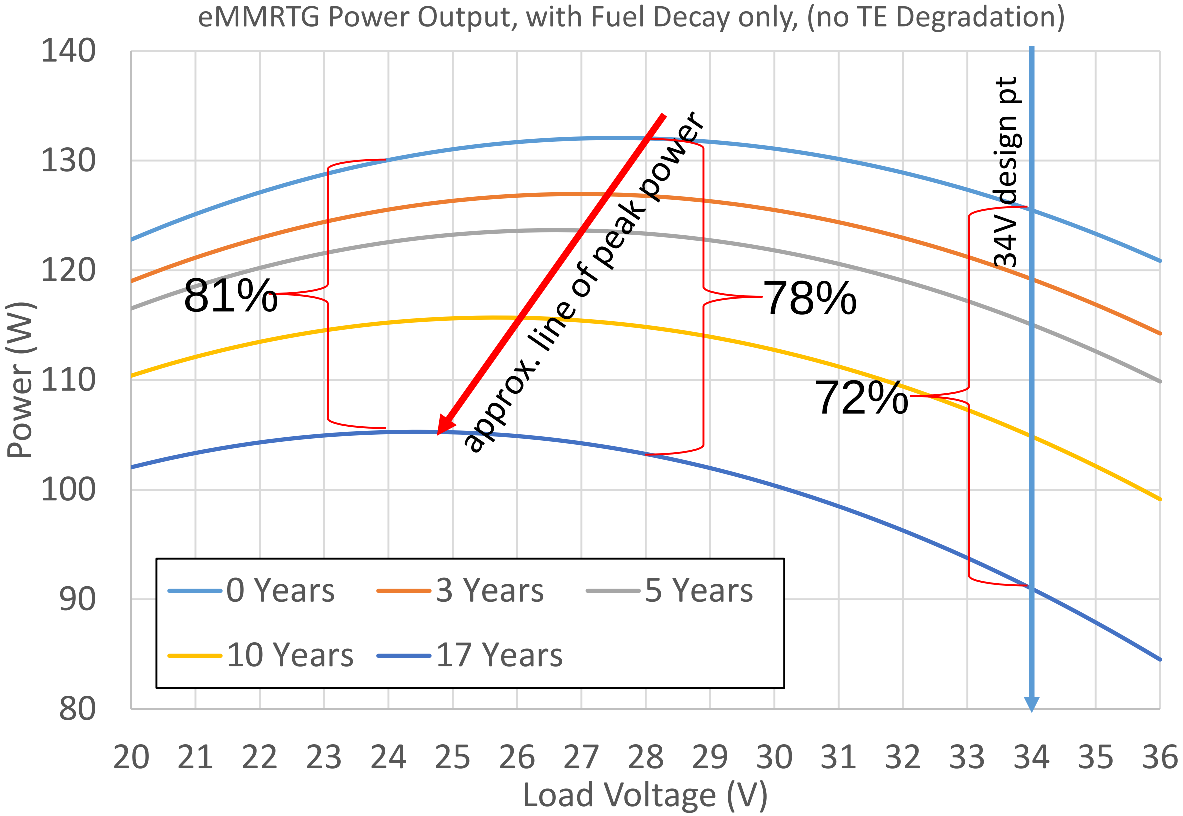


eMMRTG Status

- Approaching Gate 2 (January 2019) – Initial Life and Performance Assessment vs Requirements, Production Capabilities
  - SKD material fabrication transitioned from JPL to Teledyne Energy Systems (TESI).
  - 2 couple configurations (metallization layers) currently on test to characterize temperature dependent degradation rates.
    - Expect 3000+ hour test data in a variety conditions
  - Demonstrating manufacturability, performance and strength
- DOE through a contract administered by INL will assume the development after a successful Gate 2.
  - Tasked to develop and test a 48-couple eMMRTG module (Gate 3)
    - The current technology development team will remain in place.
      - NASA GRC – Project Management
      - JPL –Technology Formulation
      - TESI – Technology Manufacturer
      - Aerojet Rocketdyne (AR) – RTG System Engineering and Prime Contractor
      - INL – Contract Administrator, RTG Fueling and Flight Unit Supplier
  - eMMRTG electrically heated qualification unit build is expected after a successful Gate 3.
  - Maintain the option for an electrically heated eMMRTG or MMRTG flight delivery to INL in 2024 for 2026 launch.

How to Design an RTG Abbreviated Version

- Determine the power input level
- Set thermoelectric operating temperature limits
- Calculate the area/length ratio of the thermoelectrics to achieve the temperature limits
- Determine the peak power voltage output (28 V for MMRTG)
- Determine the number of couples by dividing V_{out} by V_{couple}
- Estimate the weight
- Iterate design until optimized



eMMRTG Design Process

The eMMRTG is not optimized

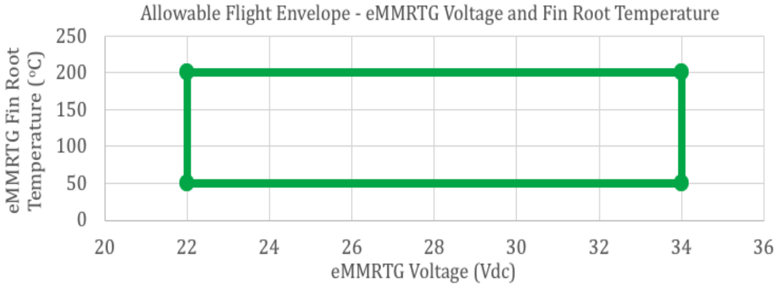
- Input power is the same as the MMRTG
- Structure is the same as an MMRTG
- T_c set by MMRTG design
- Couple length is set by the MMRTG envelope
- Design output voltage set at 34V
- Number of couples equals MMRTG
- Choose a hot junction temperature
- Calculate the cross sectional area of the couple

Choosing an operating voltage beyond the peak power point yields a higher fuel only degradation rate

Characterizing and Selecting the Thermoelectric Performance

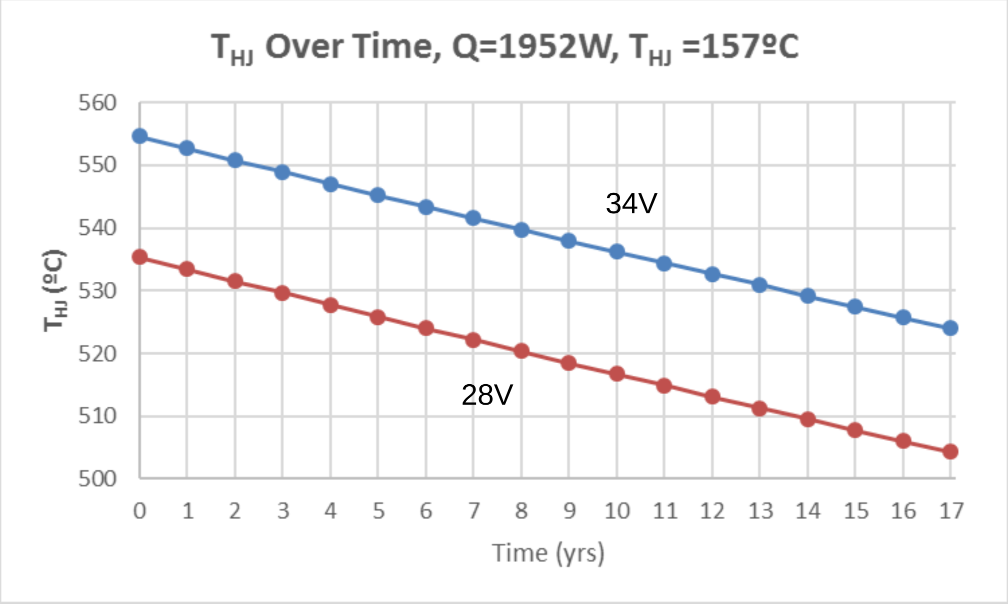
- eMMRTG design case requirement is a deep space environment
- Requirement to operate within the allowable flight envelope
- Final operating temperatures have not been determined
  - Higher T_h equals high power for a given Tc
  - TE degradation is temperature dependent
  - Requires couple leg sizing adjustments
    - Open variable through QU
    - Current predicted changes are within the tolerance band

The allowable flight envelope (AFE) of the eMMRTG from BOM to EODL is defined to be within the box.



Couple BOL Power Derived Requirement Adjusted for Current Couple Sizing		
Th (°C) approx	600	550
Tc (°C) approx	216	175
Environment	Mars Hot	Deep Space
Comments	-	Conditions: • 157°C • Q = 1952 Wth • V = 34 V

- Preliminary testing above the design case T_h and analysis supports the EODL life requirement
- T_h is dependent on operating voltage
  - Lower operating voltage requires more current flow which increases Peltier cooling
  - ~20°C lower Thj from operating at 28V vs 34V



Conclusion

- The eMMRTG design will solidify over the next 15 months
  - Gate 2 in January 2019
    - Select TE couple and insulation configuration design for module testing
    - Publish first iteration of life prediction modeling results
  - Gate 3 in December 2019
    - Thermoelectric module performance predictions
    - Test data from full-scale 48 couple module
- The end user will have a significant impact to the long term performance of the eMMRTG
  - Operating voltage impacts degradation
    - Primarily through natural decay of the fuel
    - Secondary through potential temperature dependent thermoelectric degradation
  - Operating voltage impacts the performance
    - Average of 5 watts, less than the difference between 28V and 34V power, over 14 years is >0.5 MW_e-hrs
    - Recommend choosing an operating voltage based on the timeframe that peak science is performed

Acknowledgements

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- Stan Pinkowski - SKD Technology Development Manager
- Dave Woerner - RPS Principal Engineer
- Chris Matthes - eMMRTG / MMRTG Lead Engineer

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- Joe Vanderveer –System Engineer

Aerojet Rocketdyne

- Bill Otting –Program Manager

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