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# Risk Reduction for the System Design of an Enhanced MMRTG

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May 30, 2016

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# Agenda



- Introduction
- Risk Reduction for the System Design
- Conclusion

# Introduction – RTG Primer

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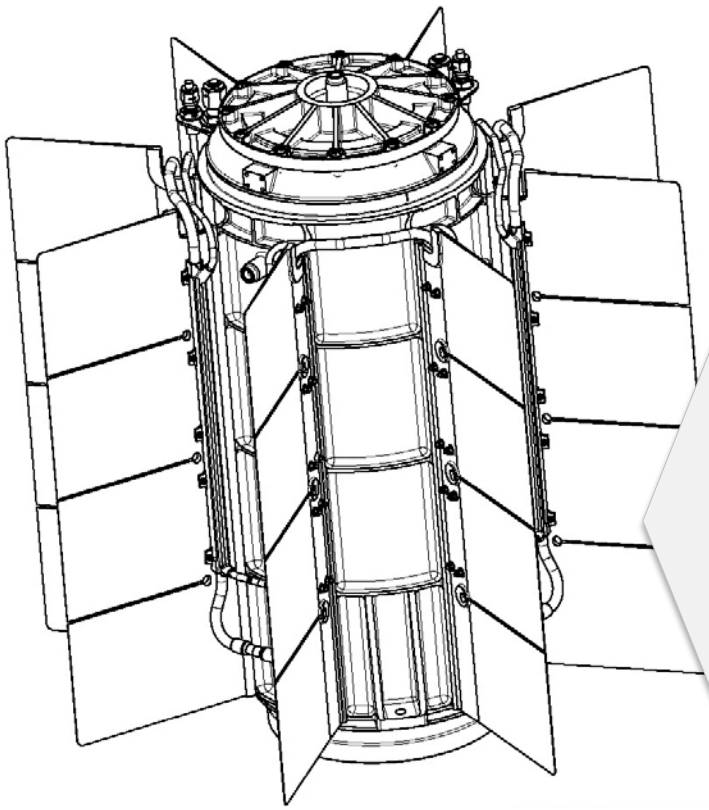
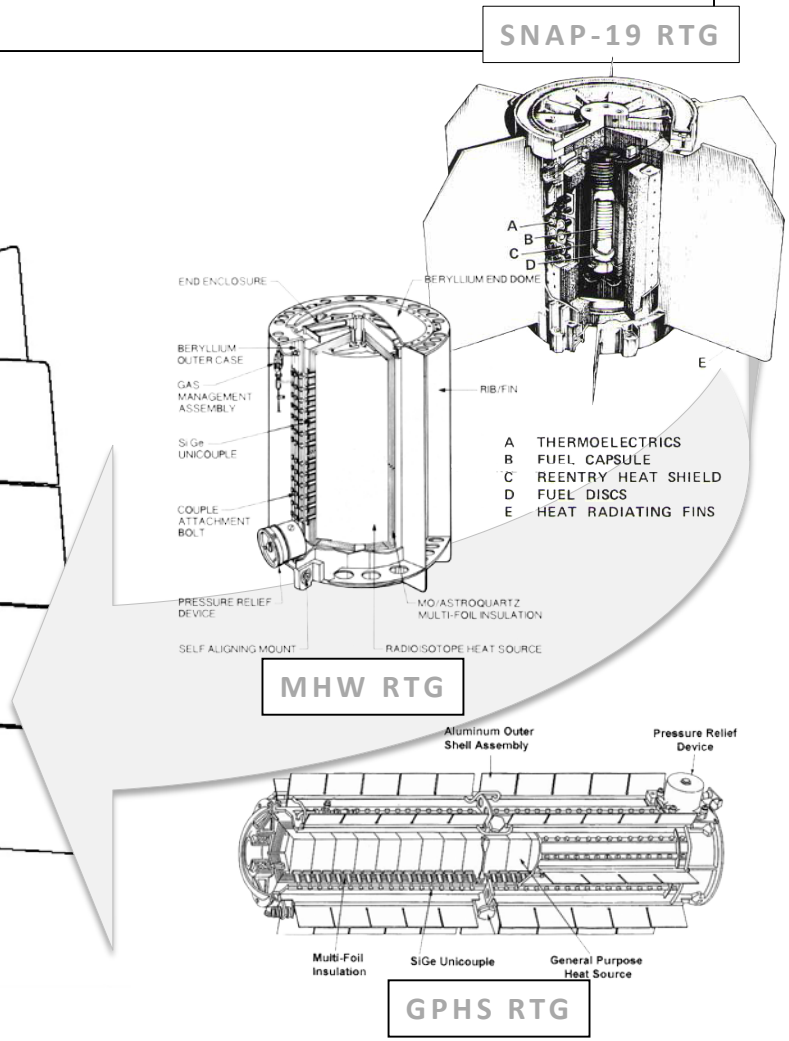
- *Converts heat produced from the decay of plutonium into quiet DC power.*
- *The DOE has produced a variety of RTGs that have been designed and flown over the last 5 decades by NASA.*

<u>The MMRTG</u>

- No moving parts
- An MMRTG weighs approximately 45 kg and produces 110W at launch.
- Only the MMRTG, or Multi-Mission Radioisotope Thermoelectric Generator, can be procured today.
- The MMRTG is powering the Curiosity rover and is likely to fly on the Mars 2020 rover.



MMRTG




RTG – Radioisotope Thermoelectric Generator

# Introduction – the eMMRTG Concept

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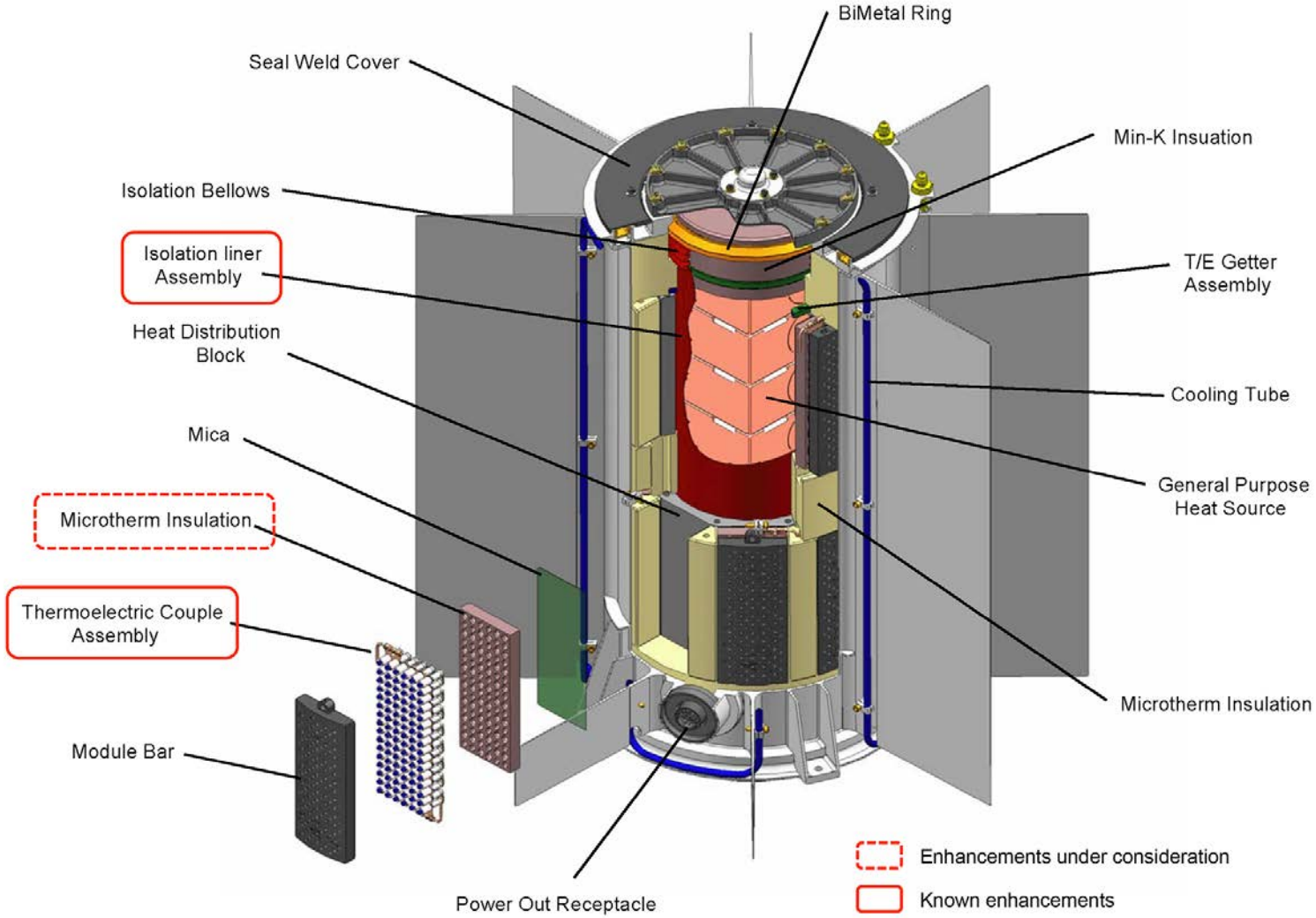

# Introduction – Enhancing Thermoelectric Power Conversion

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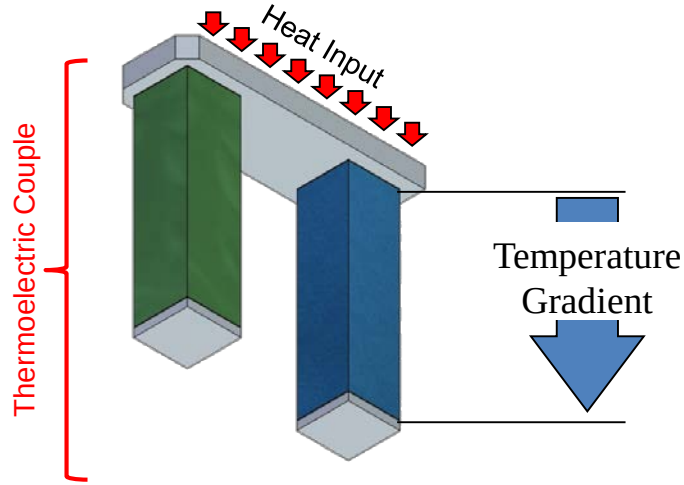


Conversion Efficiency

$$\eta_{max} = \frac{T_{hot} - T_{cold}}{T_{hot}} \cdot \frac{\sqrt{1+ZT} - 1}{\sqrt{1+ZT} + \frac{T_{cold}}{T_{hot}}}$$

*Carnot* — *Material Conversion Performance* — *delta-T*

*Dimensionless Thermoelectric Figure of Merit, ZT*

$$ZT = \frac{\sigma S^2 T}{\lambda} = \frac{S^2 T}{\rho \lambda}$$

Seebeck coefficient, S

Electrical conductivity, s

Electrical resistivity, r

Thermal conductivity, l

Absolute temperature, T

Conversion efficiency is a direct function of ZT and delta-T; the eMMRTG concept enhances both ZT and delta-T

# Risks

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Design changes to the MMRTG to create an eMMRTG introduce risks

- Temperatures are increased
- New materials are introduced
- and so on

# Risk Reduction for the System Design

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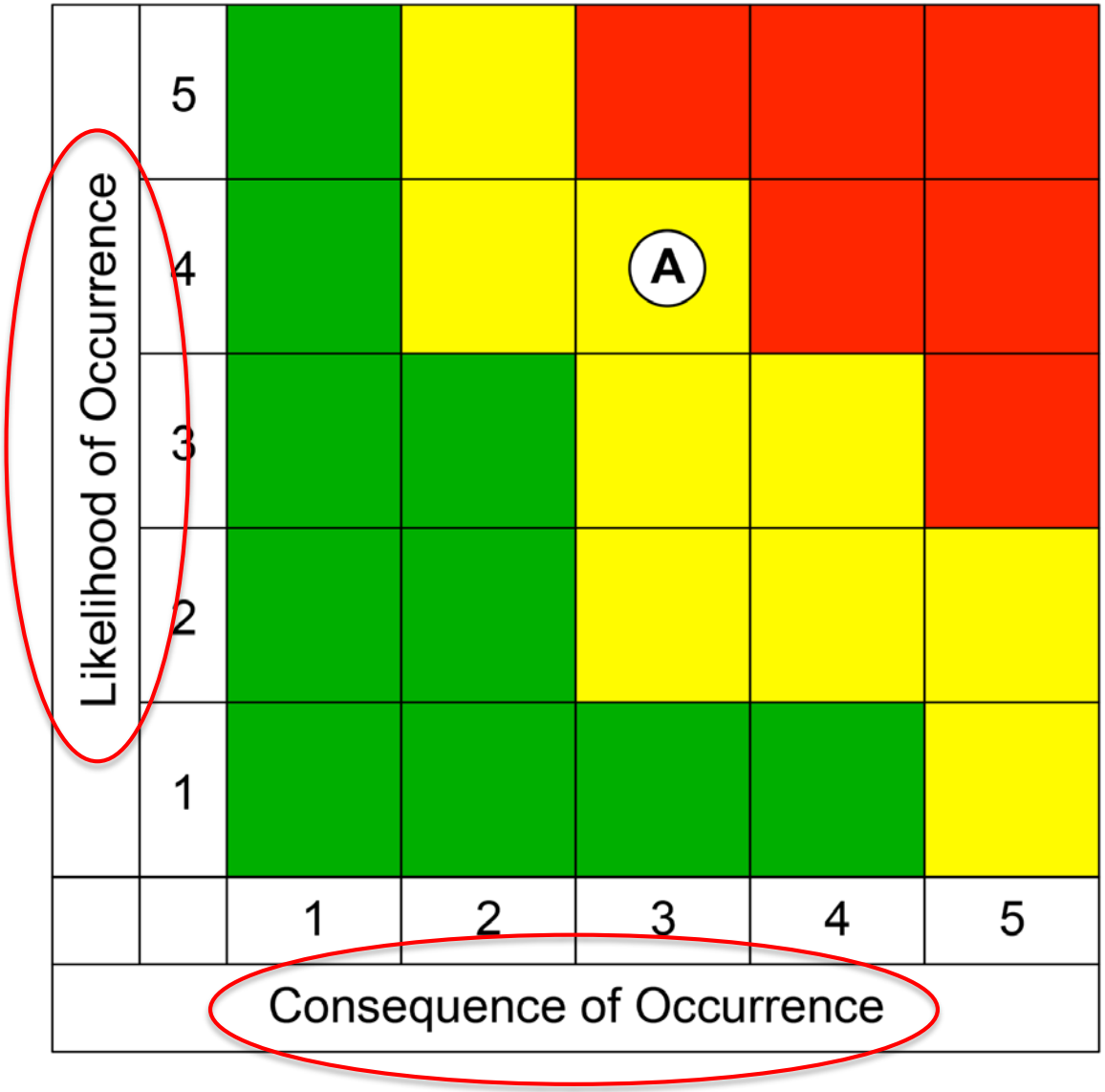
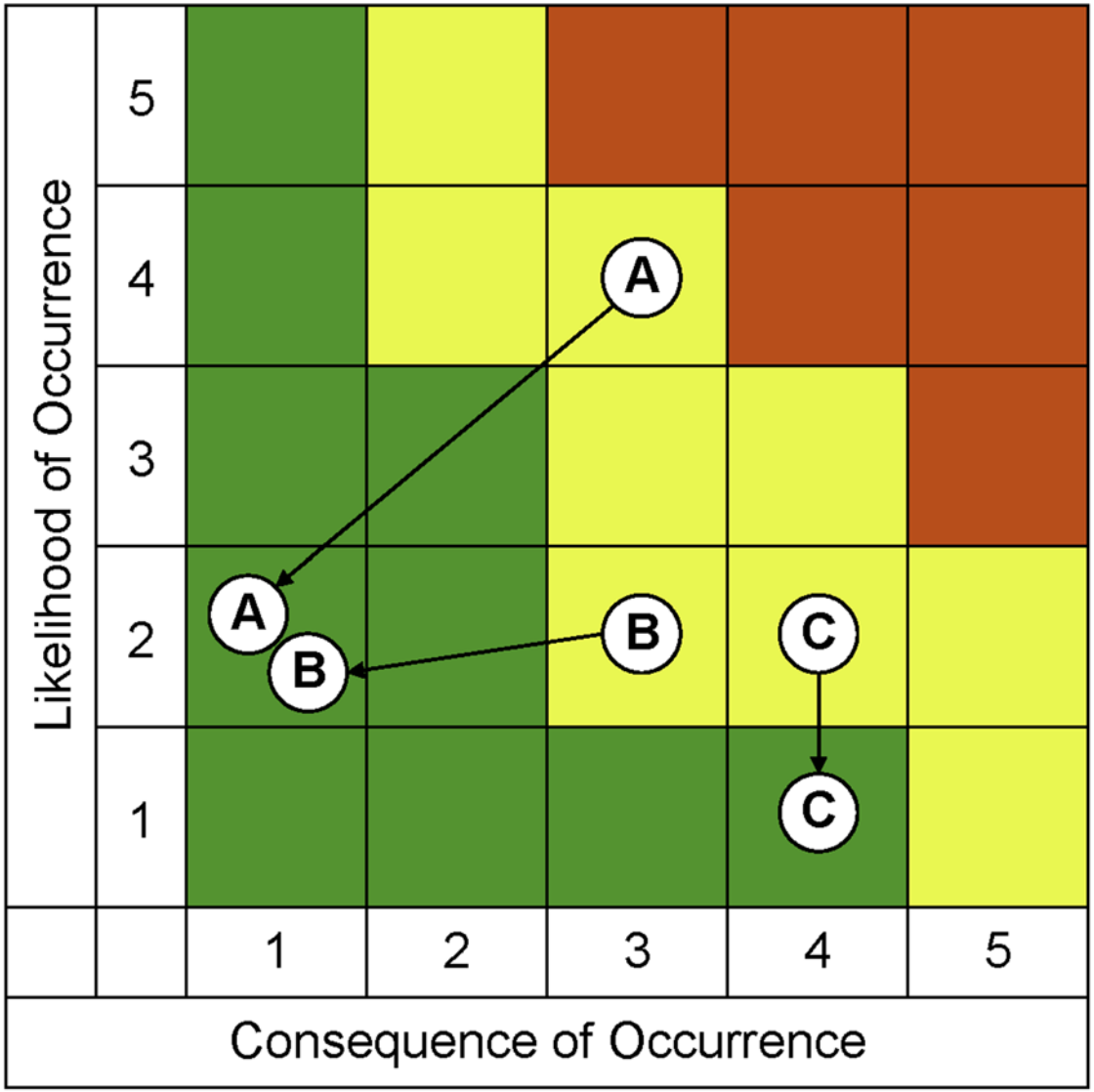
- Each risk is assigned a likelihood of occurrence and consequence of occurrence; 1 being low, 5 high
- For example, risk A would be a 4x3 as depicted in the graphic; it has a high likelihood of occurrence and medium consequence of occurrence
- Red, Yellow, Green add a sense of severity, red being most severe



# Risk Reduction for the System Design

- Additionally, risks with relatively high products (e.g., 4x3=12) may be assigned a mitigation plan
  - Therefore, risks near 1x1 may not be mitigated,
  - while risks with higher products are likely to receive a mitigation plan.

- For example, risk A, when mitigated should achieve a new risk rating of just 2x1. B a 2x1 and C a 1x4.



# Risk Reduction for the System Design

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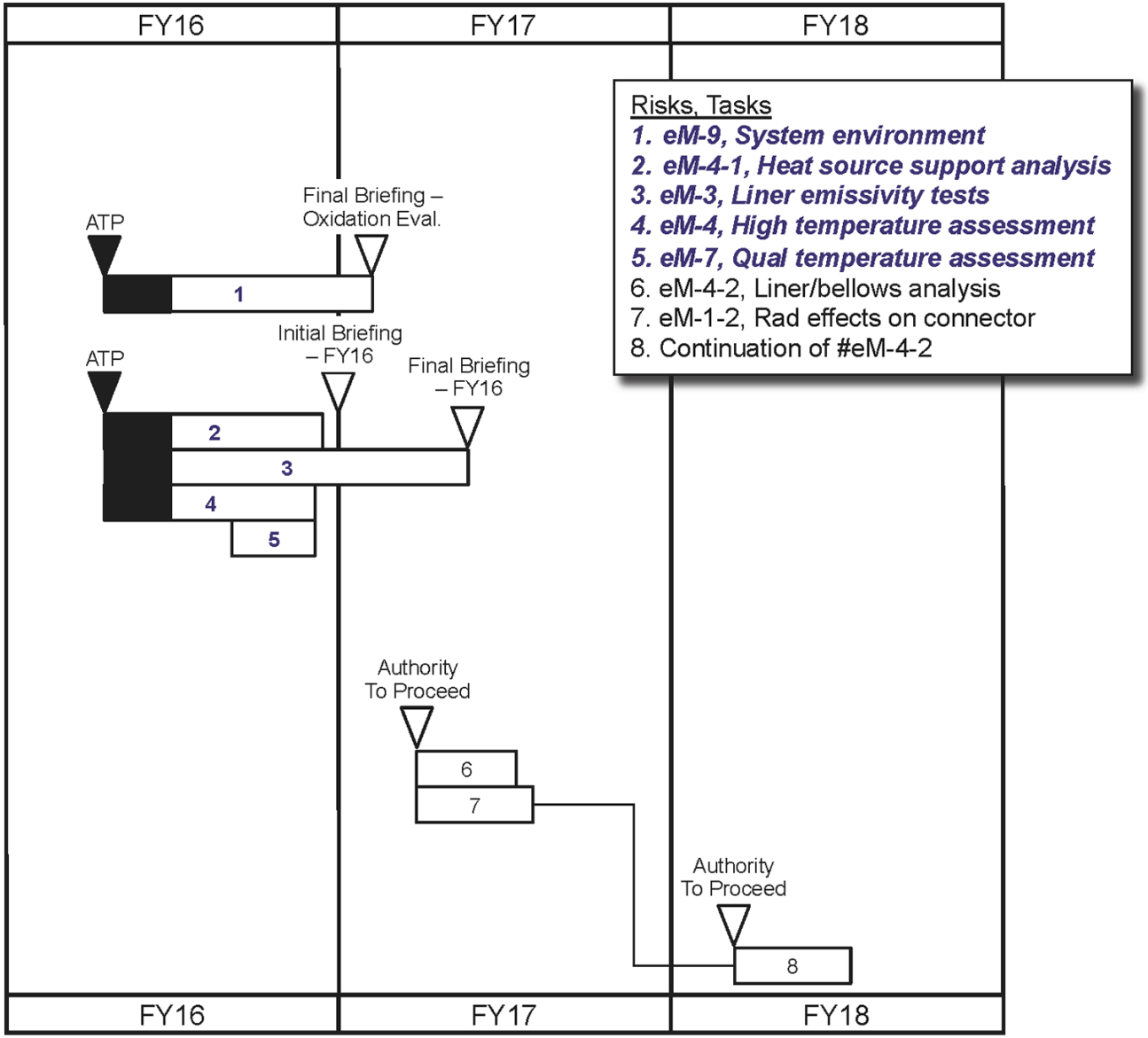
| | Source of issue | Risk |
|---|---|---|
| 1 | System environment | Deleterious reactions could occur between new TECs and gases in eMMRTG increases thermoelectric couple degradation rate beyond allowable limit. |
| 2 | Liner emissivity | The new emissivity may be unstable with time and temperature and/or the change may introduce significant manufacturing issues. |
| 3 | Heat source support | New, higher operating temperature could weaken the heat source support |
| 4 | High temperature | New, higher temperature combined with current uncertainties in predicting MMRTG internal temperatures could force design changes |
| 5 | Qualification temperature | New upper temperature limit for qualification of the generator could impose design changes |

# Risk Reduction for the System Design

- A series of tests and analyses are being applied to the risks identified in creating an eMMRTG
- Because of the nature of the risks, some require development of hardware prototypes that undergo tests while others require Monte Carlo and sensitivity simulations



# Conclusion



- The eMMRTG concept is on track to be completed at the end of FY18, when NASA may choose to fund the US Department of Energy to build flight systems.

- Thank you!