# Segmented Thermoelectric Module Technology Enables Right-Sizing Next Generation High Performance RTG System Concepts


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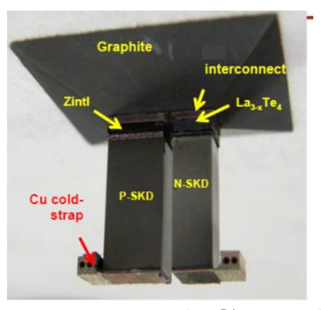
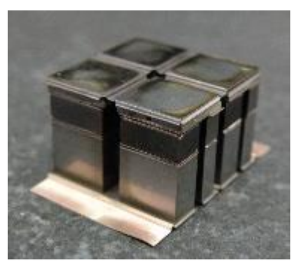
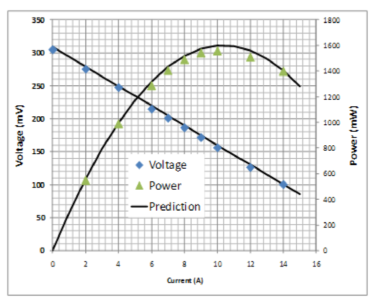
## Advanced Thermoelectric Converter Technology

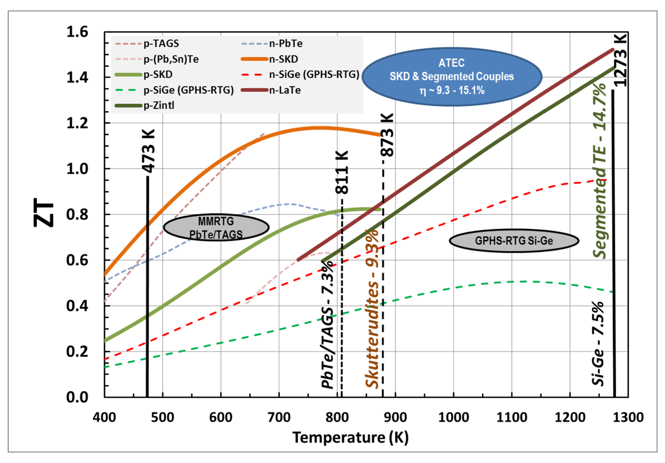


Segmented Couple


Segmented Module

15% Conversion Efficiency at Beginning of Life (BOL)


x2 Efficiency of Heritage RTG Couples



Higher Performance Materials

2x increase in $ZT_{ave}$ over SOA Si-Ge alloys *(1273 to 473K ΔT)* when combined through segmentation

## What Technology and System Heritage?

### Converter Technology Under Development

- Skutterudite couple technology being matured for eMMRTG
- High performance Zintl materials developed by NASA's Thermoelectric Technology Development Project
- Proof-of-principle segmented thermoelectric couples and modules fabricated and tested since 2011
- Multi-foil Insulation and aerogel encapsulation

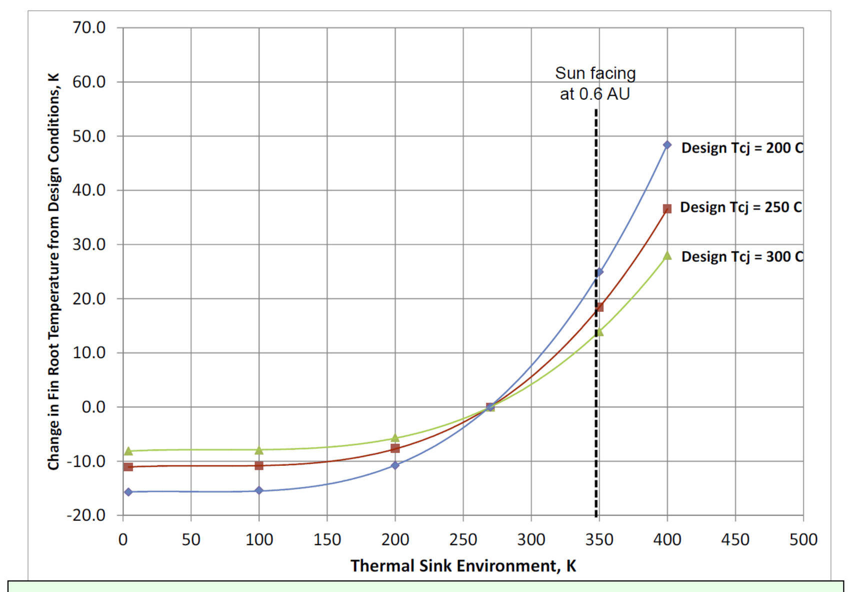
### Generator Heritage

- 18-GPHS GPHS-RTG
  - Cantilevered Si-Ge couples bolted to the radiator and radiatively coupled to the GPHS heat source
  - Mid-span support, end-cap preloads
  - Series-parallel electrical circuitry

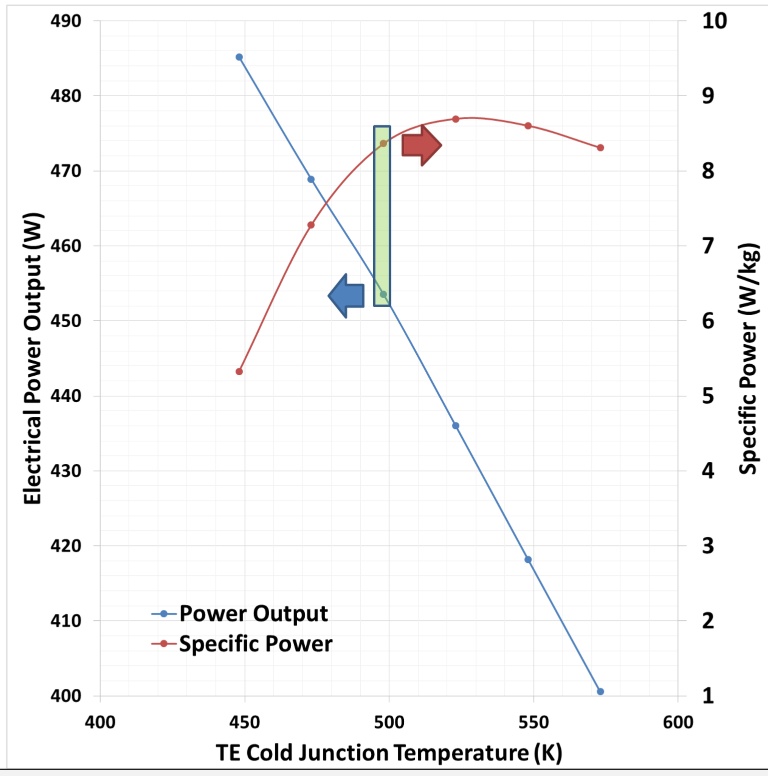
### Modular Concept Heritage and New Development

- MOD-RTG Ground Demonstration System (1980's)
  - 1-GPHS Sections up to 18 GPHS
  - SiGe multicouples
- Segmented TE RTG system studies (2006, 2014) conducted by Industry for NASA's RPS Program Office*
  - TE Couple Cold-end attachment
  - Aerogel and multilayer insulation with zirconia particle spacers
  - Generator end caps preload flexures
  - Thermal and structural models

## How would SMRTGs perform? 3 illustrations

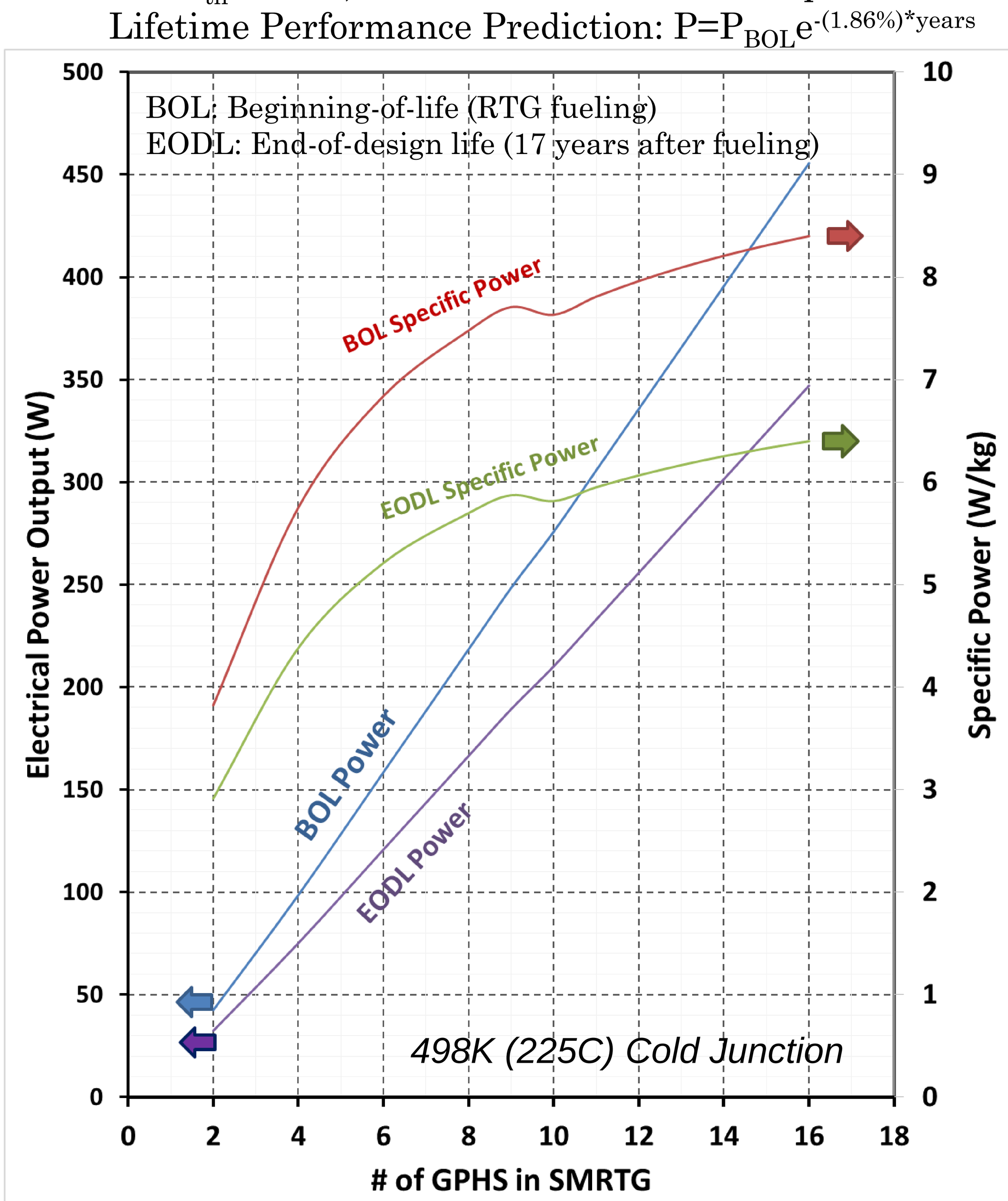


Compatible with a Wide Range of Thermal Sink Environments



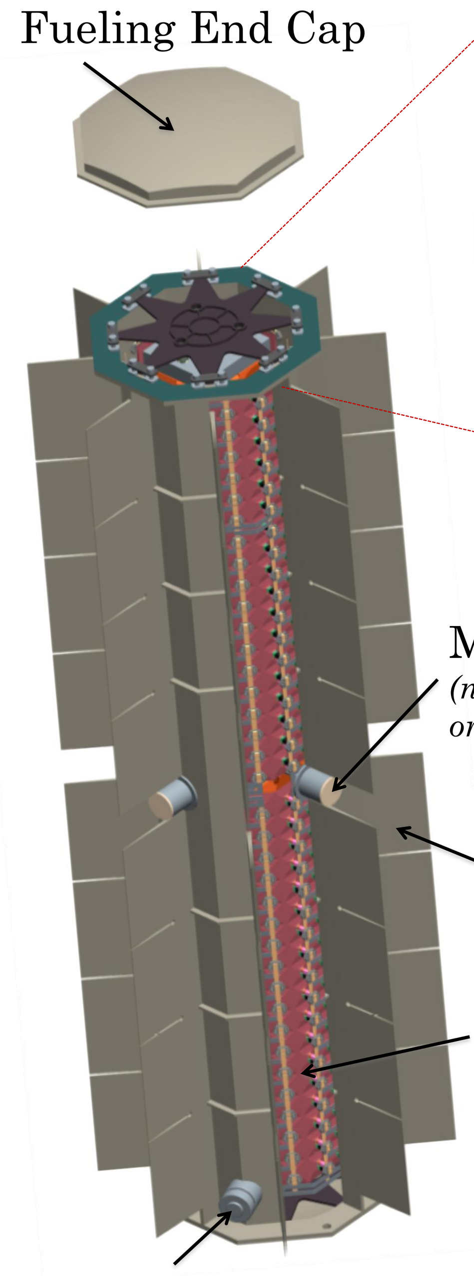
Selection of Cold Side Generator Temperature for Best Combination of High Conversion Efficiency and Specific Power

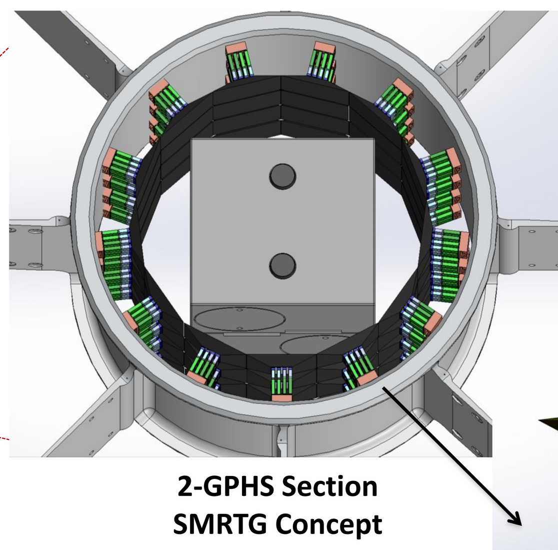
250W$_{th}$ GPHS, 473K radiator fin root temperature
Lifetime Performance Prediction: $P=P_{BOL}e^{-(1.86\%)*years}$



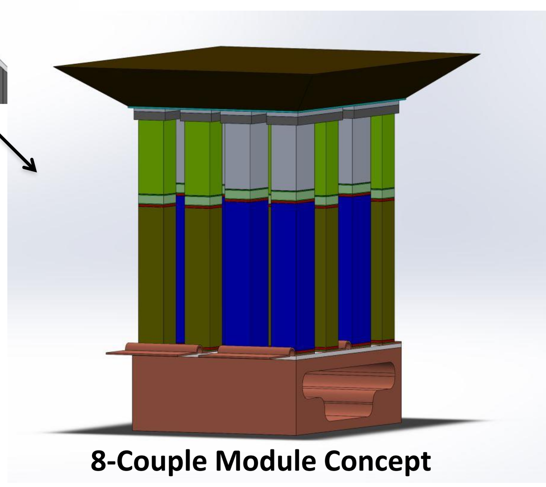

- Modular System Concept Scales Over a Wide Range of Power Output and can Achieve high Specific Power
- New segmented technology is targeting similar low power degradation rate goal than measured for the GPHS-RTG

## Segmented Modular Radioisotope Thermoelectric Generator (SMRTG) Concept



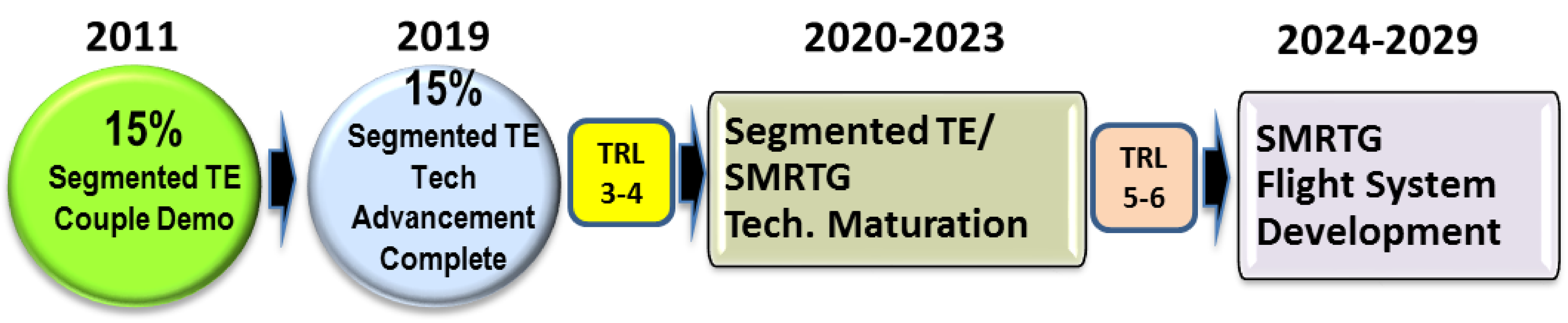


2-GPHS Section SMRTG Concept

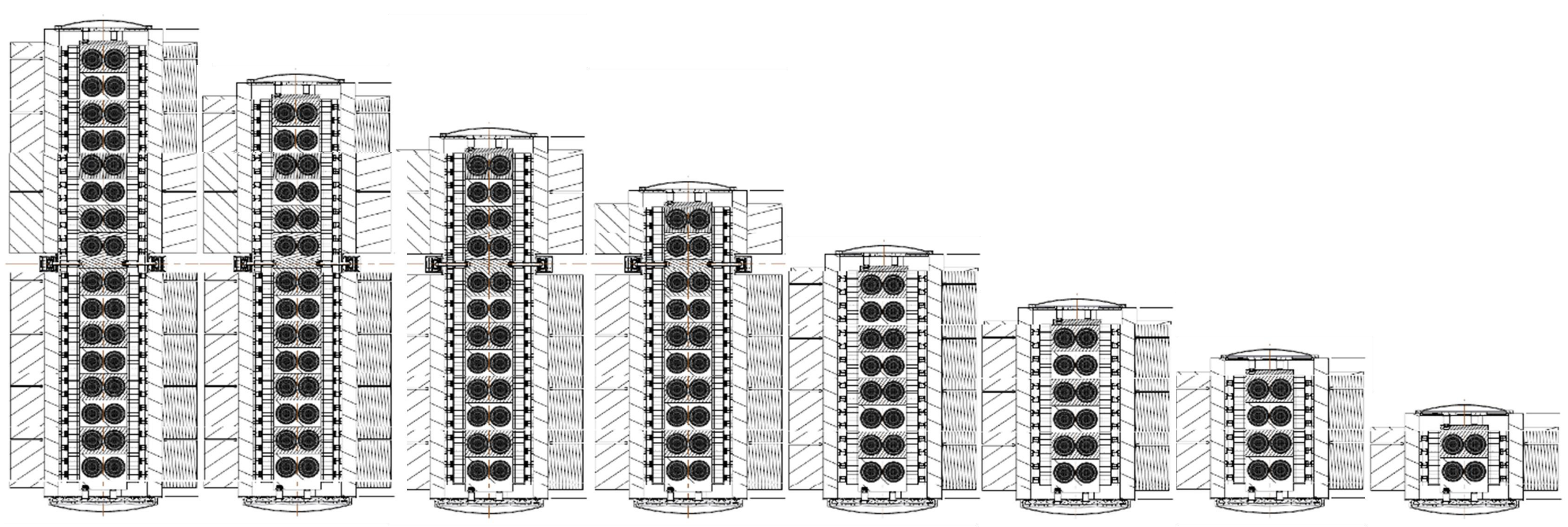
- 15% efficient 8-Couple Segmented Thermoelectric Module
- Enables "right-sizing" RTG
  - Sizing ranging from 16 GPHS down to 2 GPHS
  - 52 modules per 2-GPHS section


8-Couple Module Concept

- 15% efficient 8-Couple Segmented Thermoelectric Module
  - Using high performance TE material segments
  - Low temperature: skutterudites (same as in eMMRTG) or new 9-4-9 and 1-2-2 Zintl compounds
  - High temperature: 14-1-11 Zintl and $La_{3-x}Te_4$

### Notional Timeline for SMRTG Availability





Family Portrait –*Modular sizing from 16 GPHS down to 2 GPHS*, Vacuum Only RTGs

16-GPHS SMRTG Performance Predictions

- *Assumes 250W$_{th}$ GPHS, 473K radiator fin root temperature*
- *BOL Power of 456W*
- *EODL Power of 347W (17 years after fueling)*
- *System mass of 54.2kg, BOL Specific power of 8.4W/kg*

Performance Predictions

- *Assumes 250Wth GPHS, 473K radiator fin root temperature*
- *BOL Power: from 456W (16-GPHS) to 42W (2-GPHS)*
- *Designed to operate in 22-36Vdc range, with a design load voltage equal to 32.8 Vdc*
- *1-GPHS only unit possible (but half the voltage range)*

## Five Take Away Points

1. SMRTG: Next generation high performance GPHS-RTG
2. Use of segmented thermoelectric modules with x2 efficiency
3. Enables "rightsizing" RTGs from ~ 450 W to as low as ~40W
4. A full size SMRTG would have saved Cassini a generator
5. kW-class power missions within reach

*NETS 2015 Presentation, Otting et al. (2015), NASA Nuclear Power Assessment Study Final Report (2015)

Pre-Decisional Information -- For Planning and Discussion Purposes Only