RADIOISOTOPE THERMOPHOTOVOLTAIC (RTPV) POWER SYSTEM FOR SPACE APPLICATIONS

Abstract

Thermophotovoltaic (RTV) energy conversion, coupled to the radioisotope powered General Purpose Heat Source (GPHS) is currently being developed by NASA. The goal of the program is to develop a 100 watt electrical power system with an efficiency of 20%. Spectral control is the key element in obtaining an efficient system. Results presented show that excellent spectral control can be achieved so that reaching the goal of 20% efficiency is possible. Excellent spectral control is achieved by using a combination of selective emitters and optical filters and by eliminating radiation leakage from the optical cavity.

RADIOISOTOPE THERMOPHOTOVOLTAIC(RTPV) POWER SYSTEM for SPACE APPLICATIONS

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OUTLINE

- NASA RTPV Program
- Thermophotovoltaic (TPV) Concept
- Importance & Methods of Spectral Control
- Theoretical Model Results for System Performance
- Conclusion

THERMOPHOTOVOLTAIC (TPV) POWER CONVERSION TECHNOLOGY FOR RADIOISOTOPE POWER SYSTEMS (RPS)

Goals

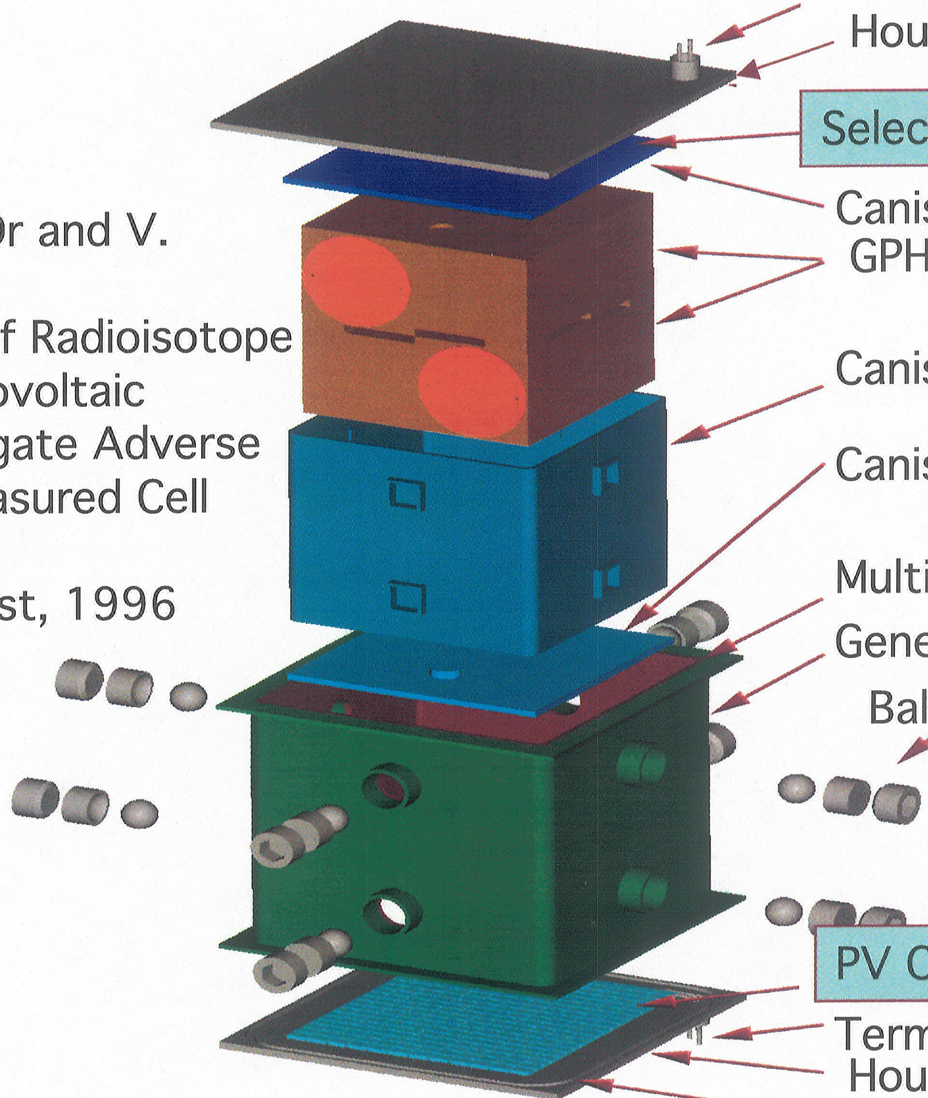
- Develop TPV power converter compatible with an advanced RPS
- Demonstrate system conversion efficiency and specific power that is 2 to 3 times higher than present radioisotope thermoelectric generators(RTG)

PARTICIPANTS

- **Creare, Inc.** – PI, Technical Leader, Integration Manager, Hot-Side and Selective Emitter Fabrication
- **Emcore, Inc.** – Co-I, Advanced InGaAs Cells and Filters
- **NASA Glenn** – Co-I, TPV design for performance and test life issues
- **Polytechnic U.** – Co-I, Radiation Heat Transfer Modeling
- **Oak Ridge NL** – Subcontractor, Materials data and cooling strategies
- **Rugate Technologies, Inc.** – Subcontractor, Filter fabrication

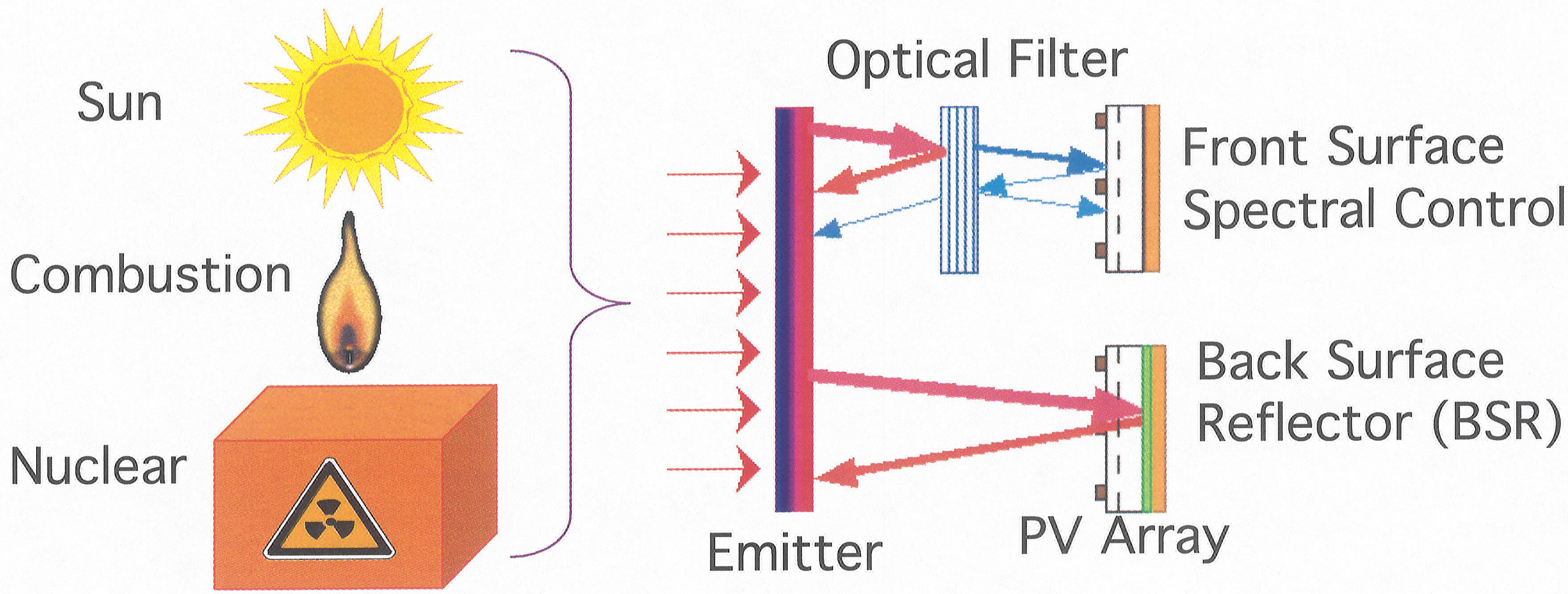
RTPV CONCEPT*

*A. Shock, C. T. Or and V. Kumar;
Modified Design of Radioisotope Thermophotovoltaic Generator to Mitigate Adverse Effect of Measured Cell Voltage;
31st IECEC, August, 1996



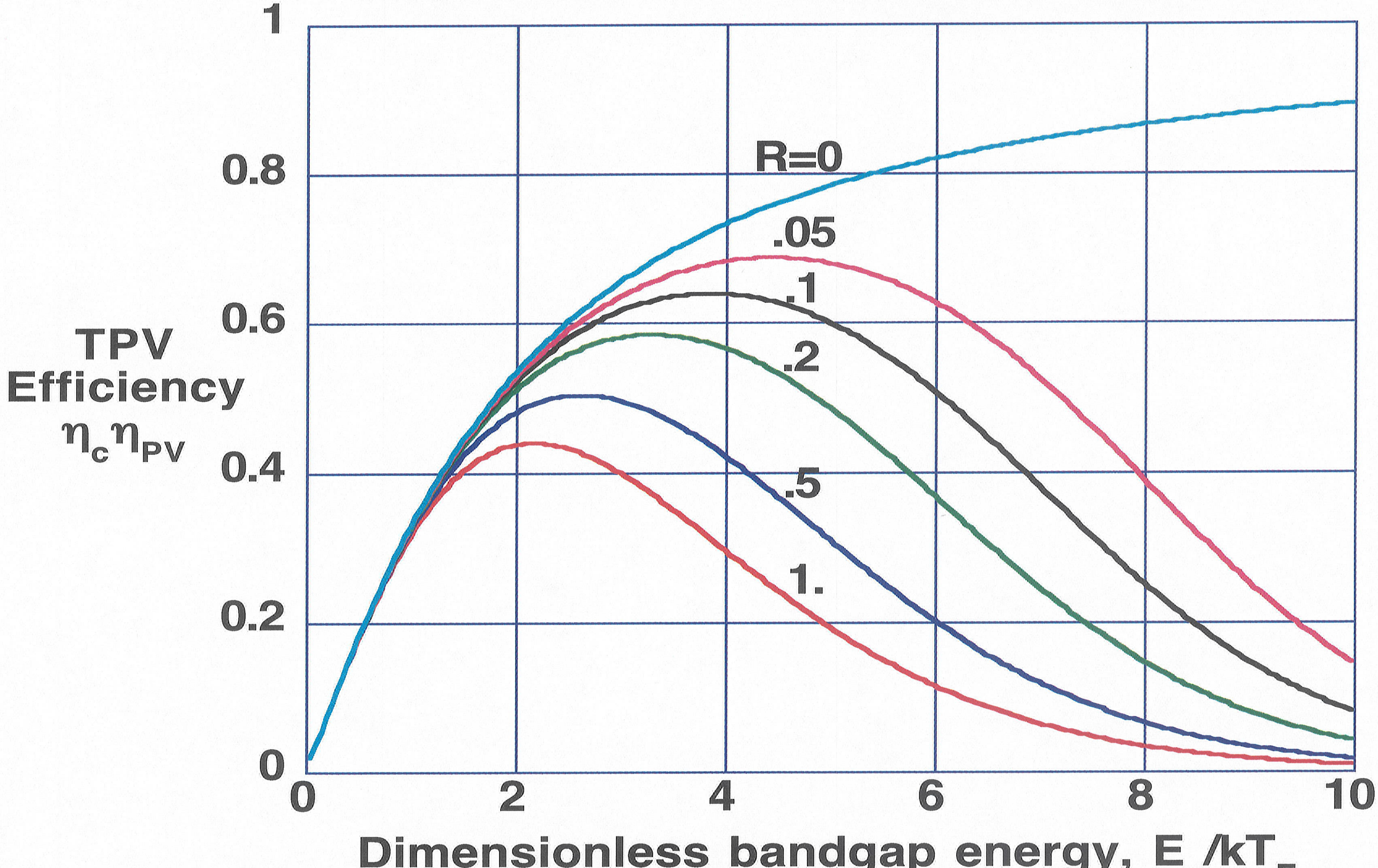
THERMOPHOTOVOLTAIC (TPV) ENERGY CONVERSION CONCEPT

η_{th}(thermal eff.) η_c(cavity eff.) η_{PV}(PV eff.) = η_T (total eff.)



MAXIMUM TPV EFFICIENCY

Spectral control parameter,
R=Nonconvertible Rad./Convertible Rad.



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Design Choices for Maximum Efficiency

Cavity Geometry

- Minimize radiation and conduction losses by:
  - Eliminate gaps allowing radiation to leak out of cavity
  - Use low emittance insulation

Emitter

- Large emittance for $\lambda < \lambda_g$ ($\lambda_g = hc_o/E_g$)

  E_g – bandgap energy of PV cell
- Small emittance for $\lambda > \lambda_g$

Filter

- Large transmittance for $\lambda < \lambda_g$
- Large reflectance for $\lambda > \lambda_g$
- Negligible absorptance for all λ

PV Array

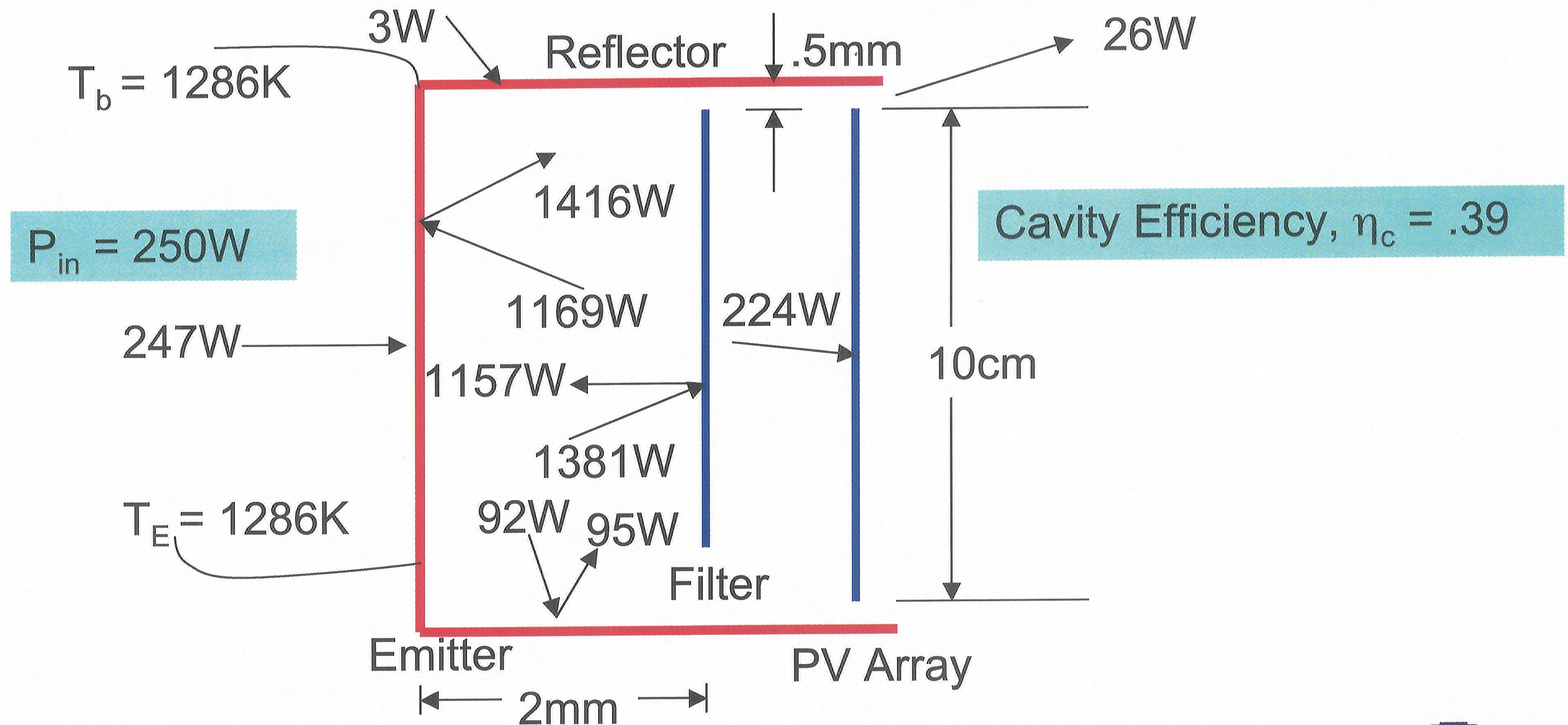
- For given emitter temperature, T_E, there will be an optimum E_g

OPTICAL CAVITY ENERGY BALANCE FOR IDEAL FILTER

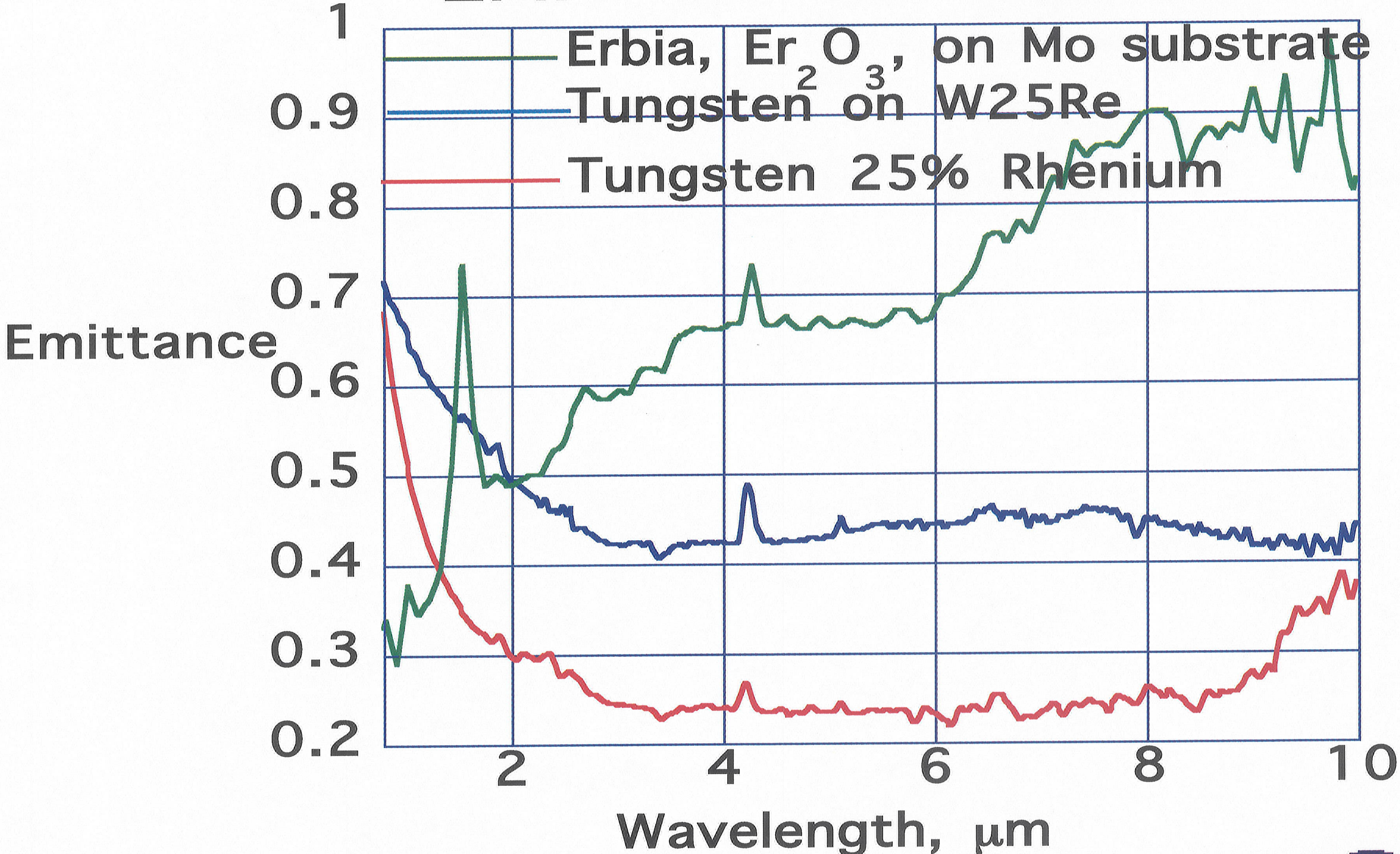
Emitter emittance, $\varepsilon_E = .6$ Reflector reflectance, $\rho_b = .9$

Filter reflectance, $\rho_c = .1$ for $\lambda < 1750$nm; $\rho_c = .9$ for $\lambda > 1750$nm

Filter absorptance, $\alpha_c = 0$



SPECTRAL EMITTANCE OF EMITTER MATERIALS



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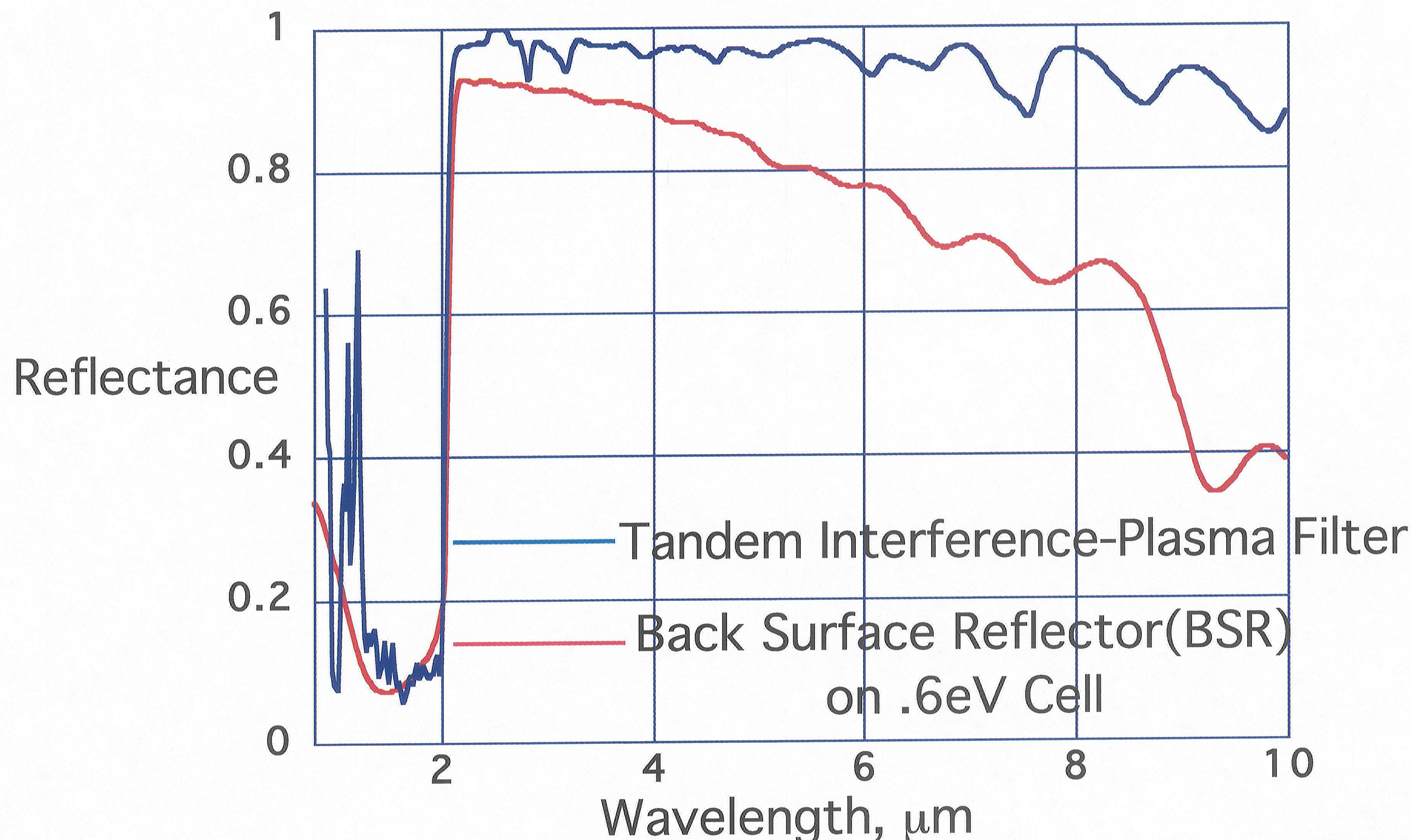
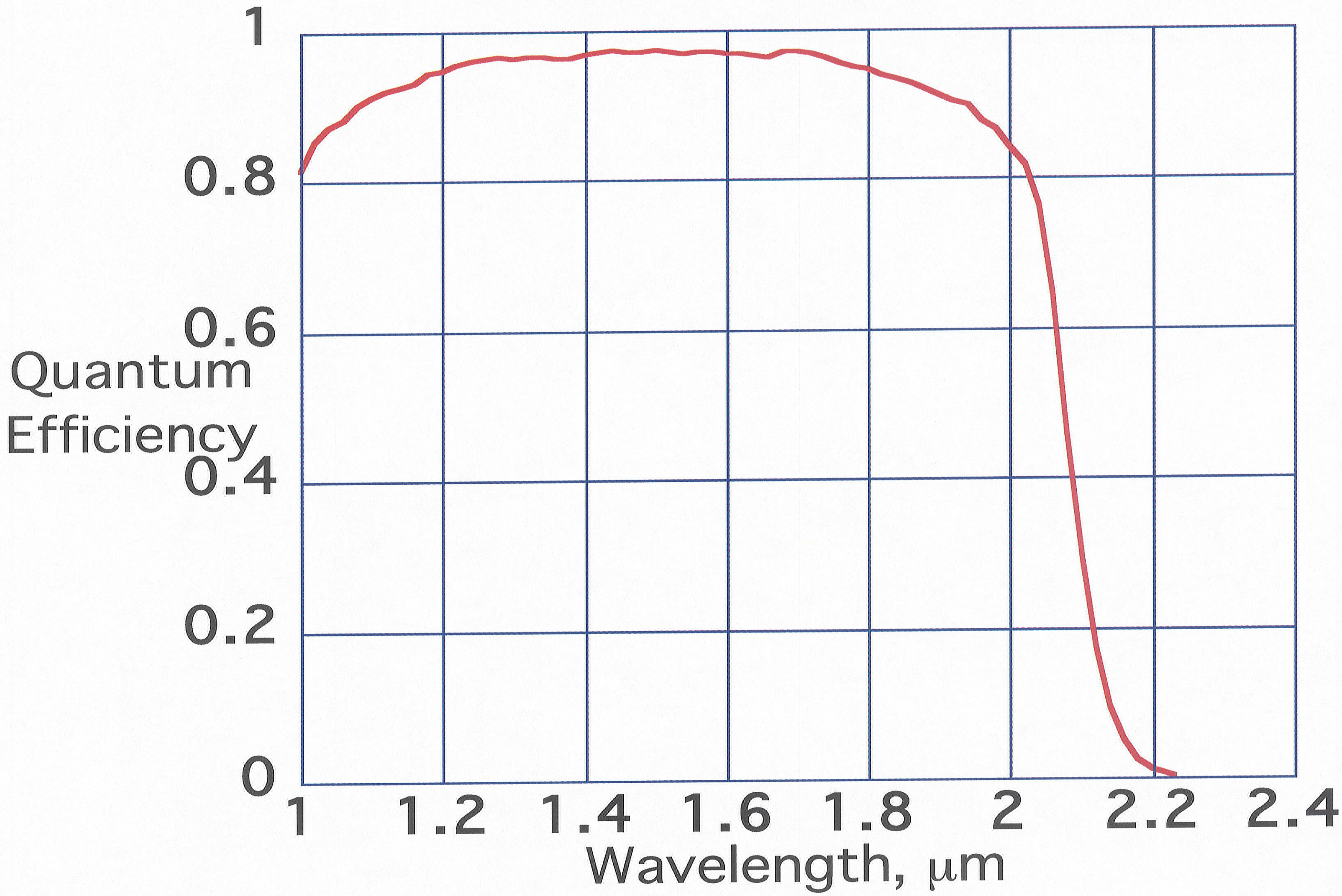
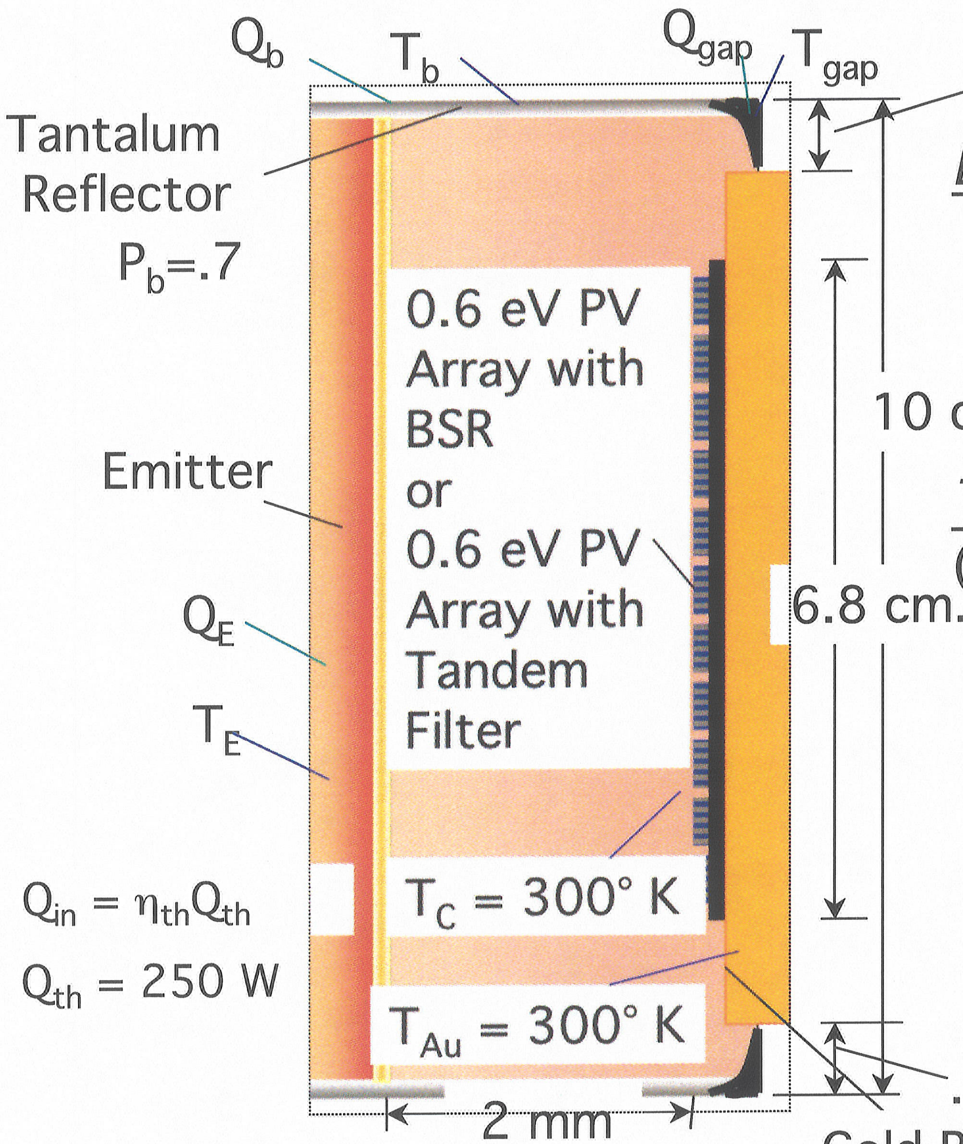
REFLECTANCES FOR SPECTRAL CONTROL



QUANTUM EFFICIENCY of .6eV InGaAs Array



Model of 1/2 RTPV Converter



Design Conditions

- Thermal Input = 250 W
- Vacuum Conditions
- Temperature Limit = 1350 °K

Theoretical Model

(Assume $T_E = T_b = T_{gap}$ & $\eta_{th} = .85$)

- Energy Balance, $Q_{in} = Q_E + Q_b + Q_{gap}$
- Radiation Transfer Equations Solved to Yield: $T_E = T_b = T_{gap}$ and Radiation Fluxes
- Knowing Radiation Fluxes Allows Calculation of η_C & η_{PV}

THEORETICAL MODEL RESULTS FOR DEMONSTRATION EXPERIMENT

Thermal Input = Q_{th} = 250 W, .6eV InGaAs PV array, Tandem filter has no absorptance

Emitter	Filter	Emitter, Reflector, Gap Temp. °K	Cavity Efficiency η_c	PV Efficiency η_{PV}	TPV Efficiency $\eta_C\eta_{PV}$	Total Efficiency for η_{th}=.85 $\eta_T = \eta_{th}\eta_C\eta_{PV}$
W25Re	BSR	1365	.81	.24	.19	.16
W25Re	Tandem Filter	1465	.76	.31	.24	.20
W on W25Re	BSR	1313	.79	.25	.19	.16
W on W25Re	Tandem Filter	1411	.78	.32	.25	.21
Er_2O_3	BSR	1305	.74	.25	.18	.15
Er_2o_3	Tandem Filter	1416	.77	.32	.25	.21

CONCLUSION

- Presently Not Clear Which Method of Spectral Control Will Yield the "BEST" RTPV System
- Factors Other than Efficiency Must Be Considered
  - Lifetime & Reliability Issues
    - Radiation Damage to Filters and PV Arrays
    - Evaporation of Emitter Material on to Filter or PV Arrays
    - Durability of Materials at Elevated Temperatures
  - Mass of System
    - PV Temperature Determines Radiator Size