Performance and Mass Modeling Subtleties in Closed-Brayton-Cycle Space Power Systems

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Michael J. Barrett
NASA Glenn Research Center
Cleveland, OH 44135
Michael.J.Barrett@nasa.gov

Paul K. Johnson
Analex Corporation
Cleveland, OH 44135
Paul.K.Johnson@grc.nasa.gov

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Outline

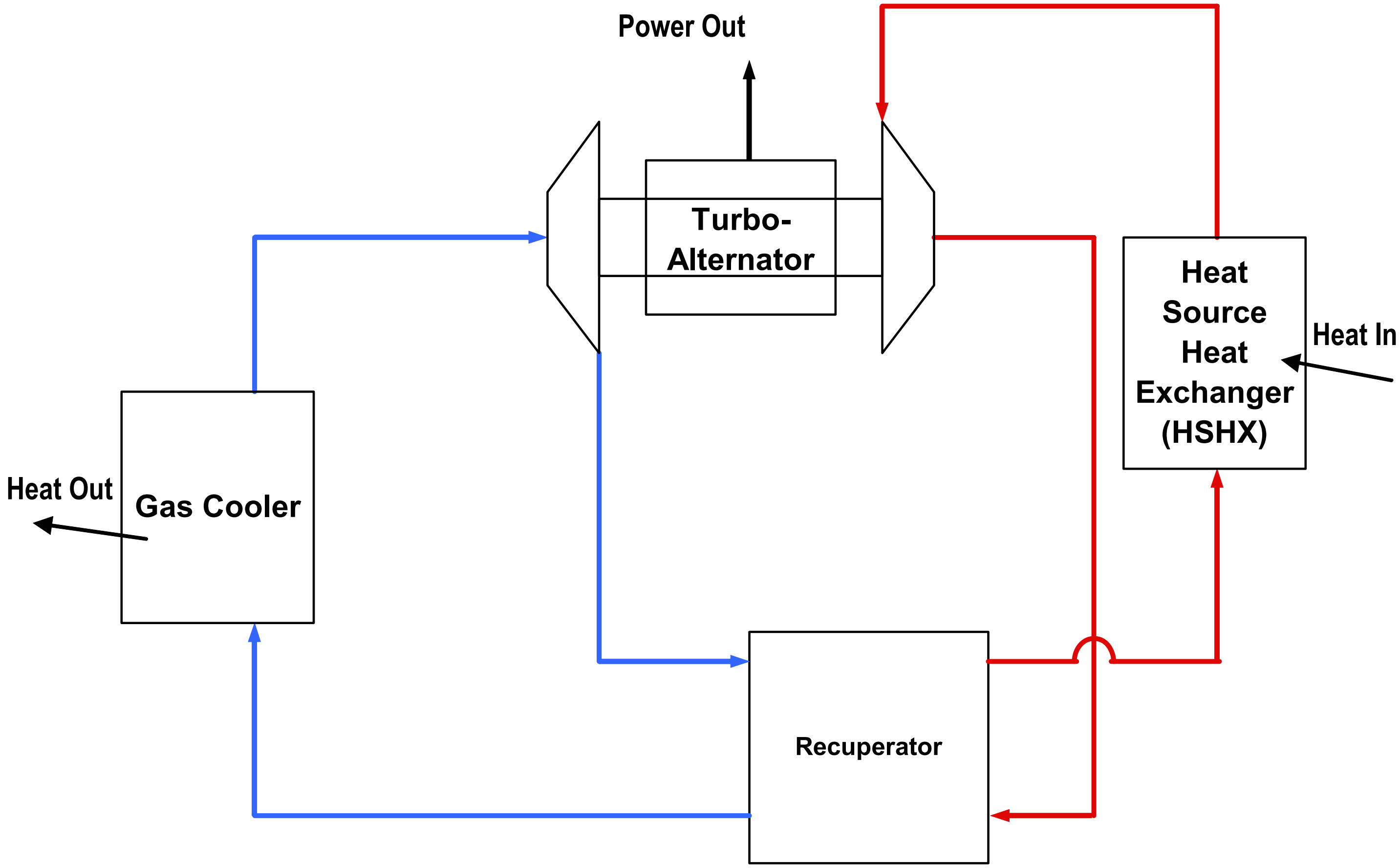
- Introduction
- Modeling Fidelity Effects
- Timescales, Transient Modeling and Validation
- Loss Sensitivities
- Mass Modeling Techniques
- Conclusions

Introduction

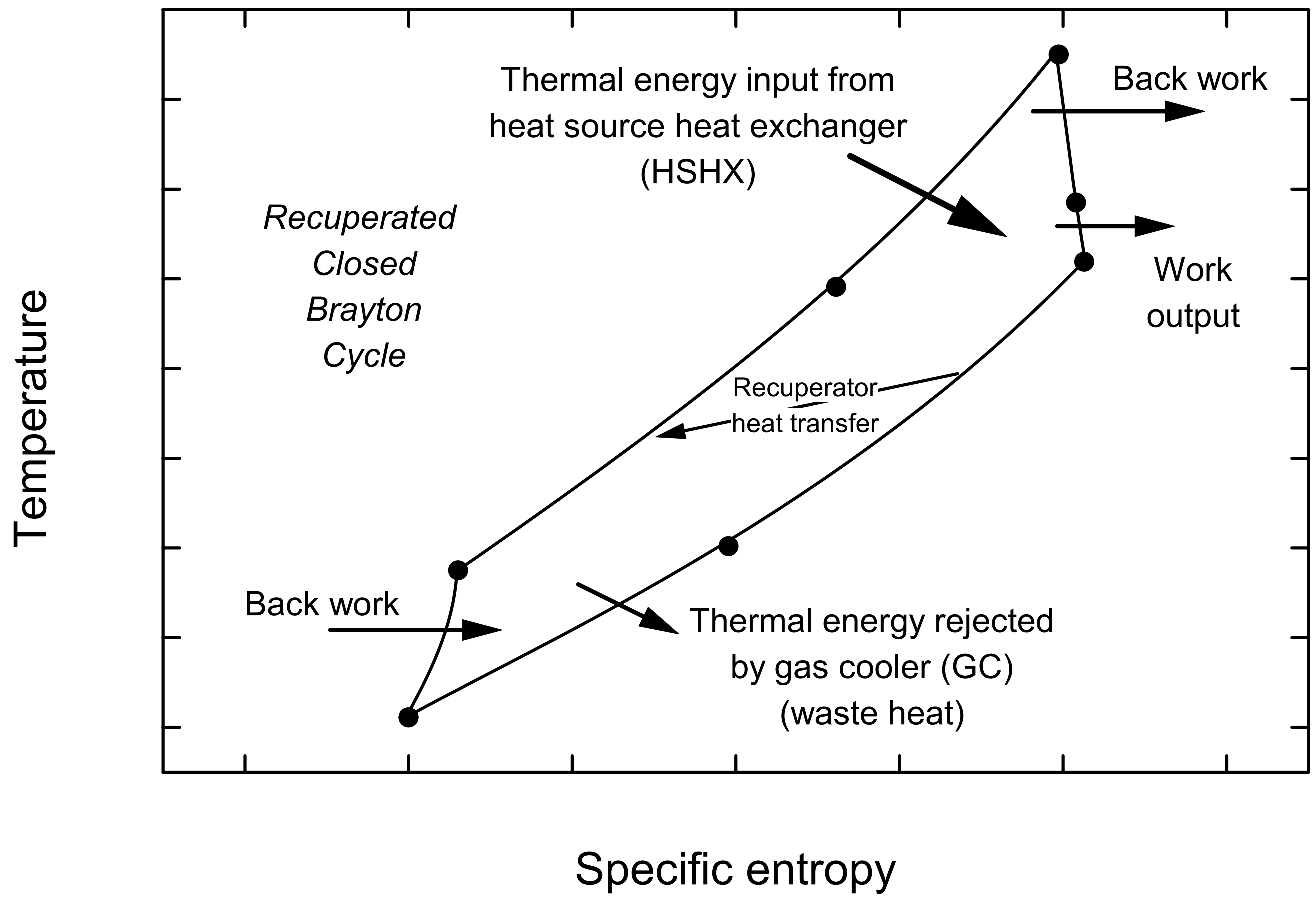
- Closed-Brayton-cycle (CBC) thermal energy conversion is one available option for future spacecraft and surface systems
- Brayton system conceptual designs for milliwatt to megawatt power converters have been developed
- Numerous features affect overall optimized power conversion system performance
  - Turbomachinery efficiency
  - Heat exchanger effectiveness
  - Working-fluid composition
  - Cycle temperatures and pressures

  } Examples

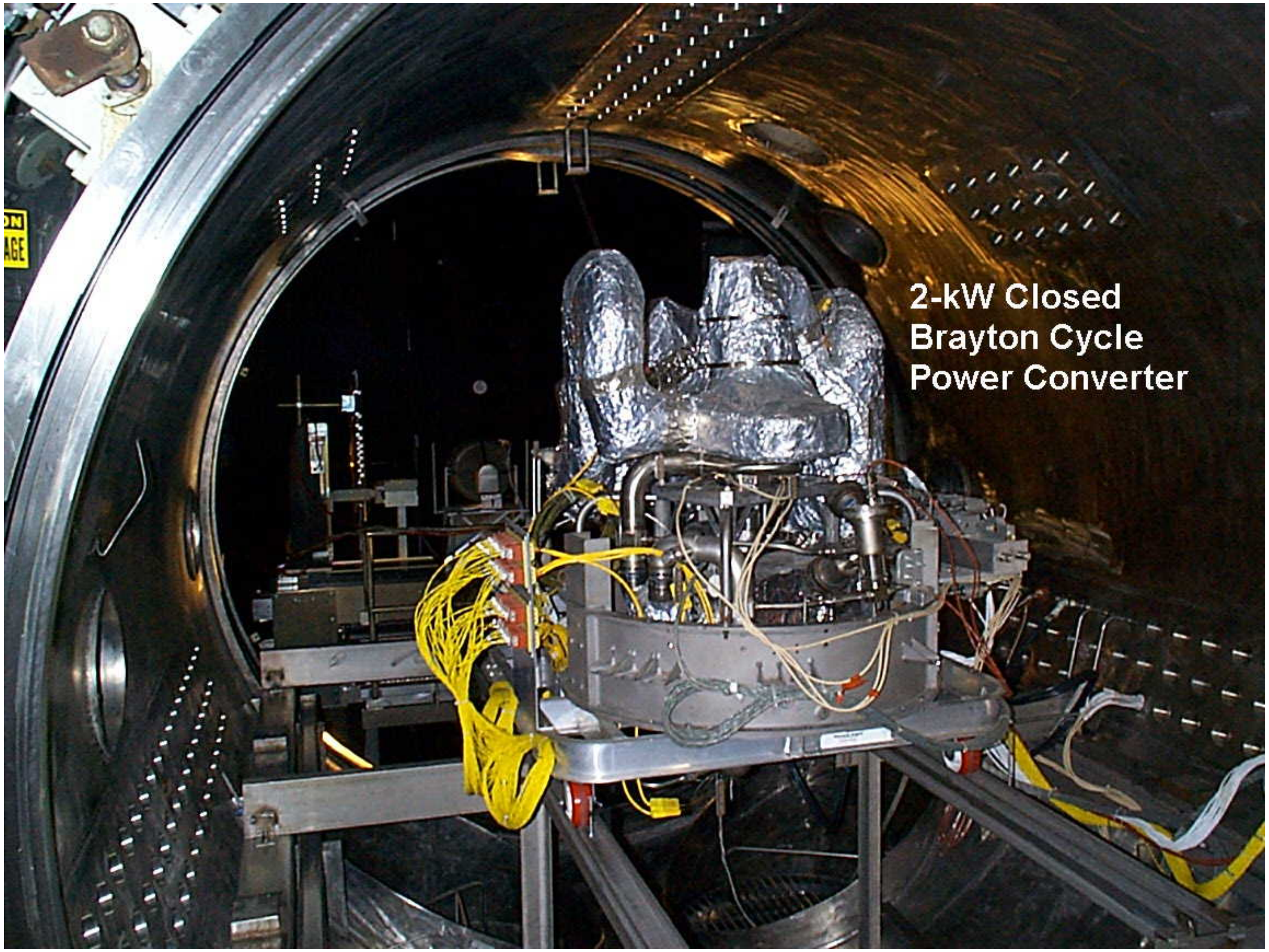
Simple Recuperated Brayton Cycle



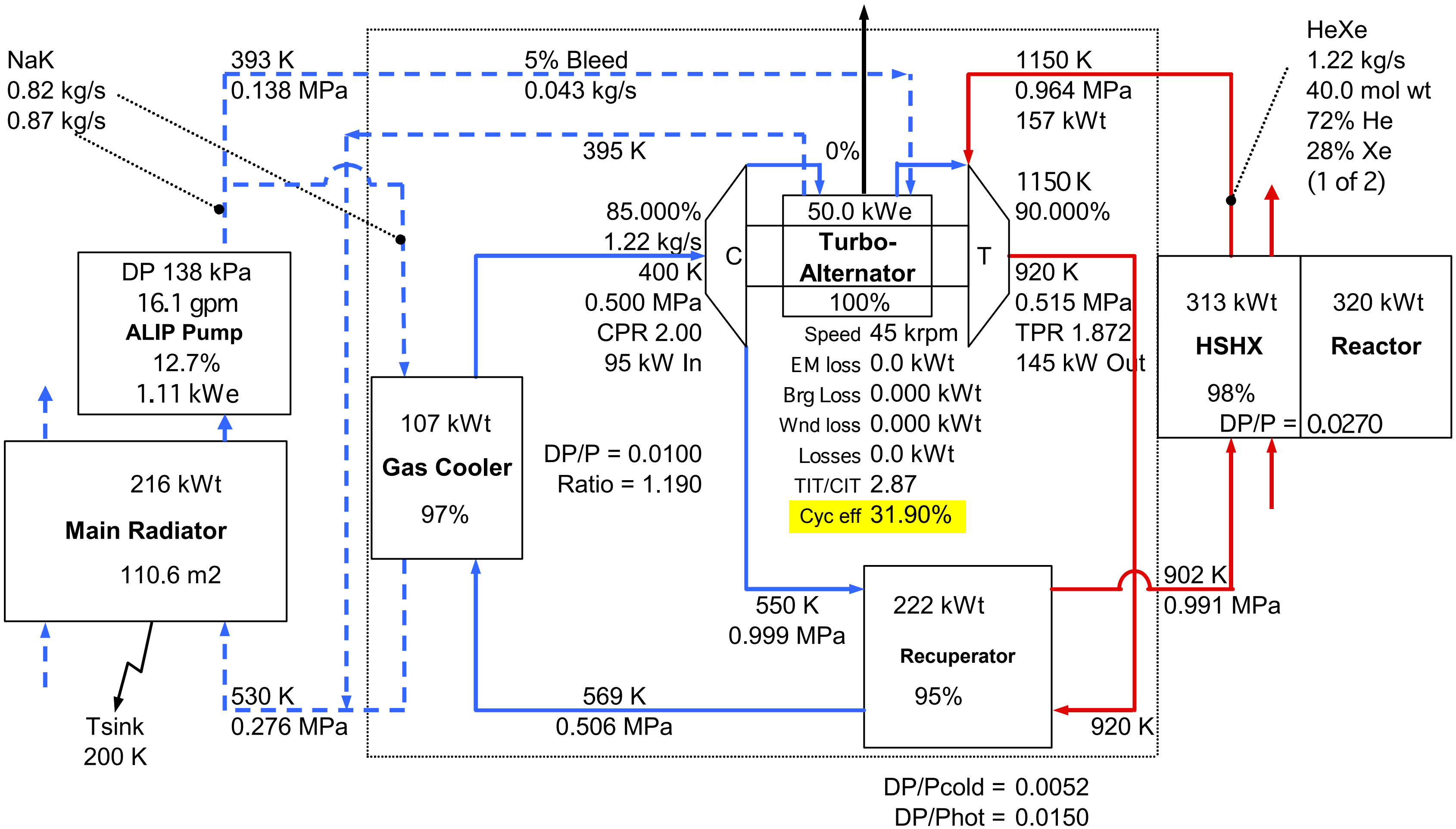
Brayton Cycle T-s Diagram



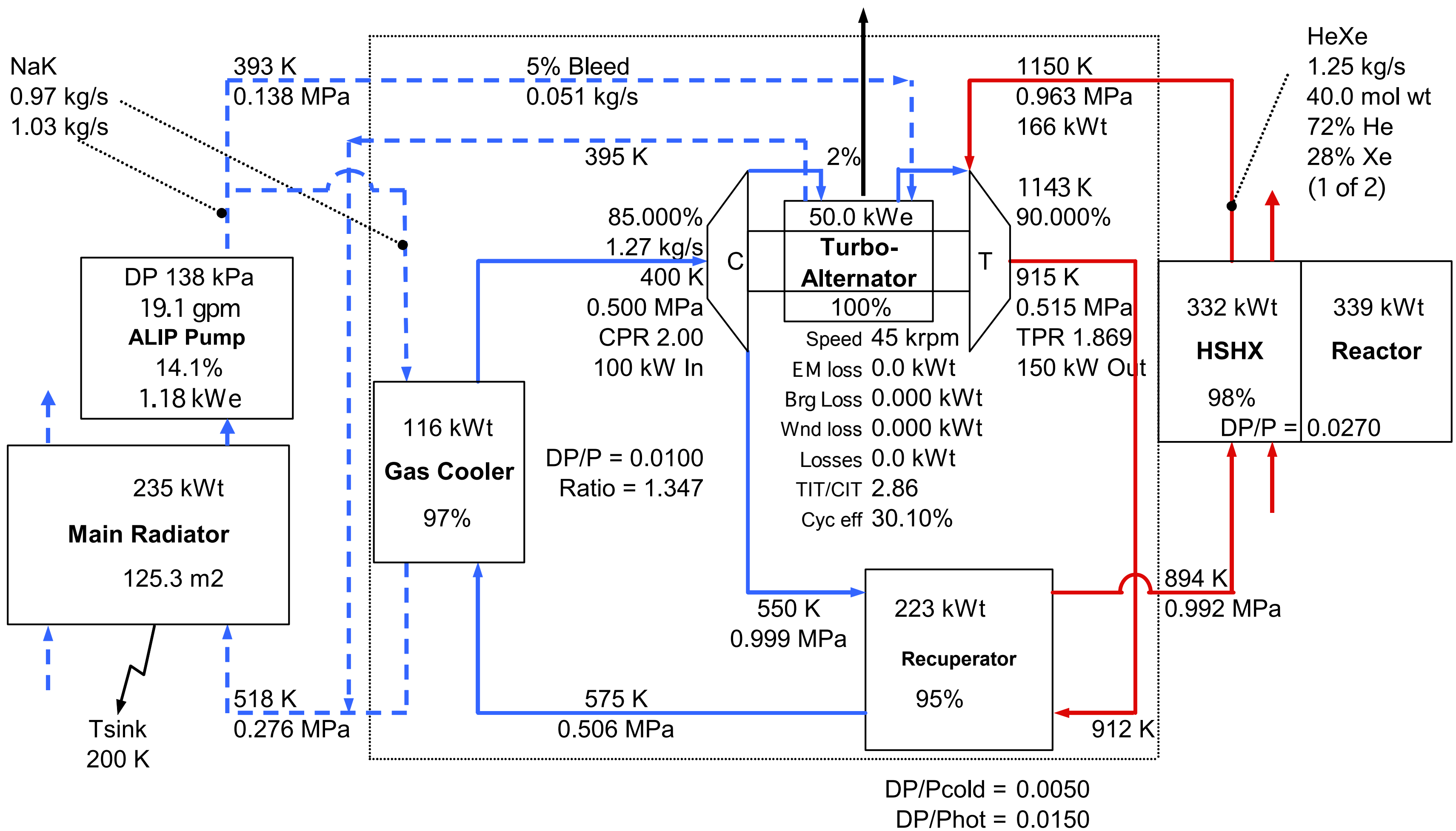
2-kWe Brayton Converter



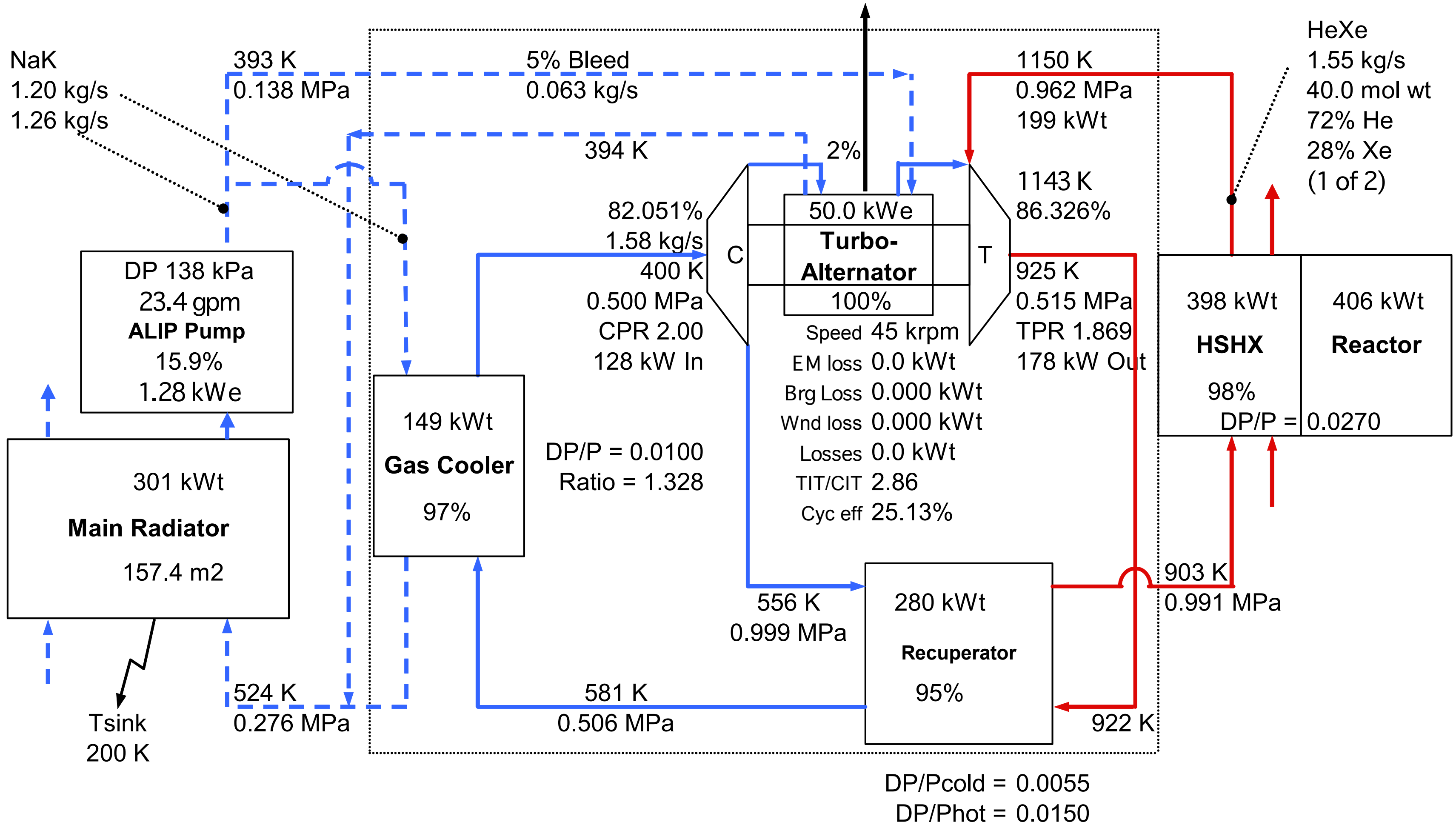
CBC with specified turbomachinery η, 0% compressor bleed, no bearing, windage, or EM losses



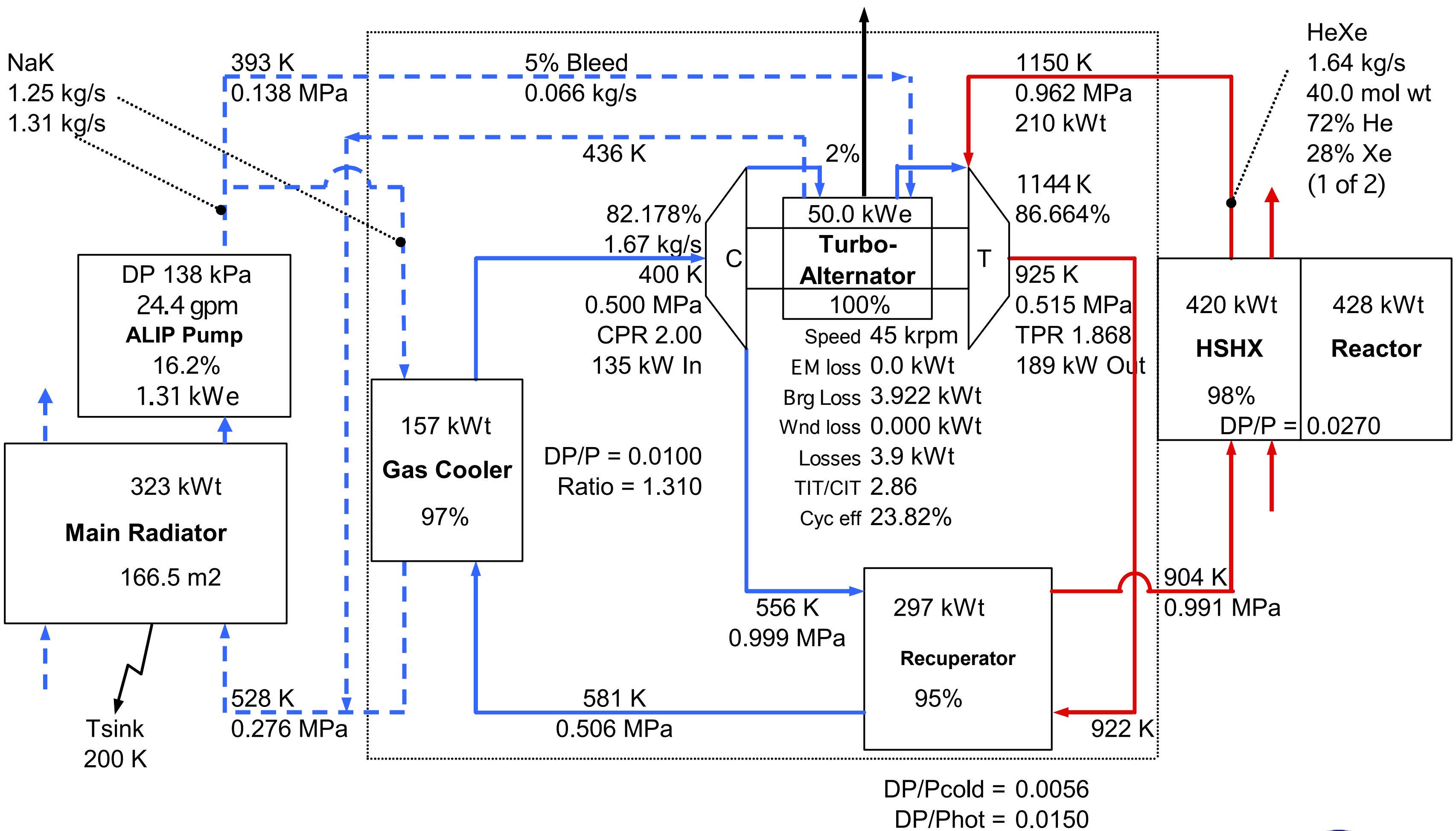
CBC with specified turbomachinery η, 2% compressor bleed, no bearing, windage, or EM losses



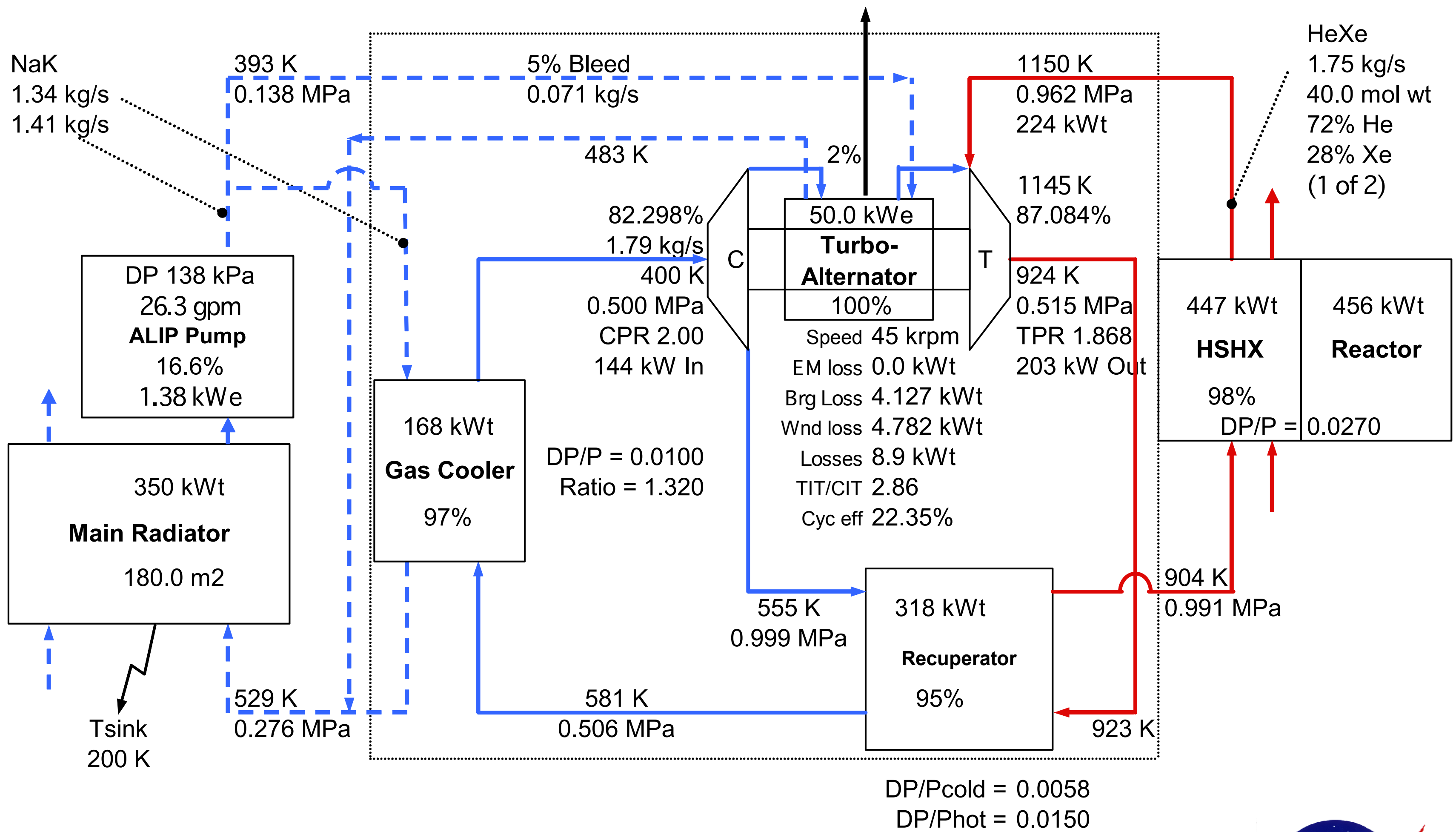
CBC with map-based turbomachinery η, 2% compressor bleed, no bearing, windage, or EM losses



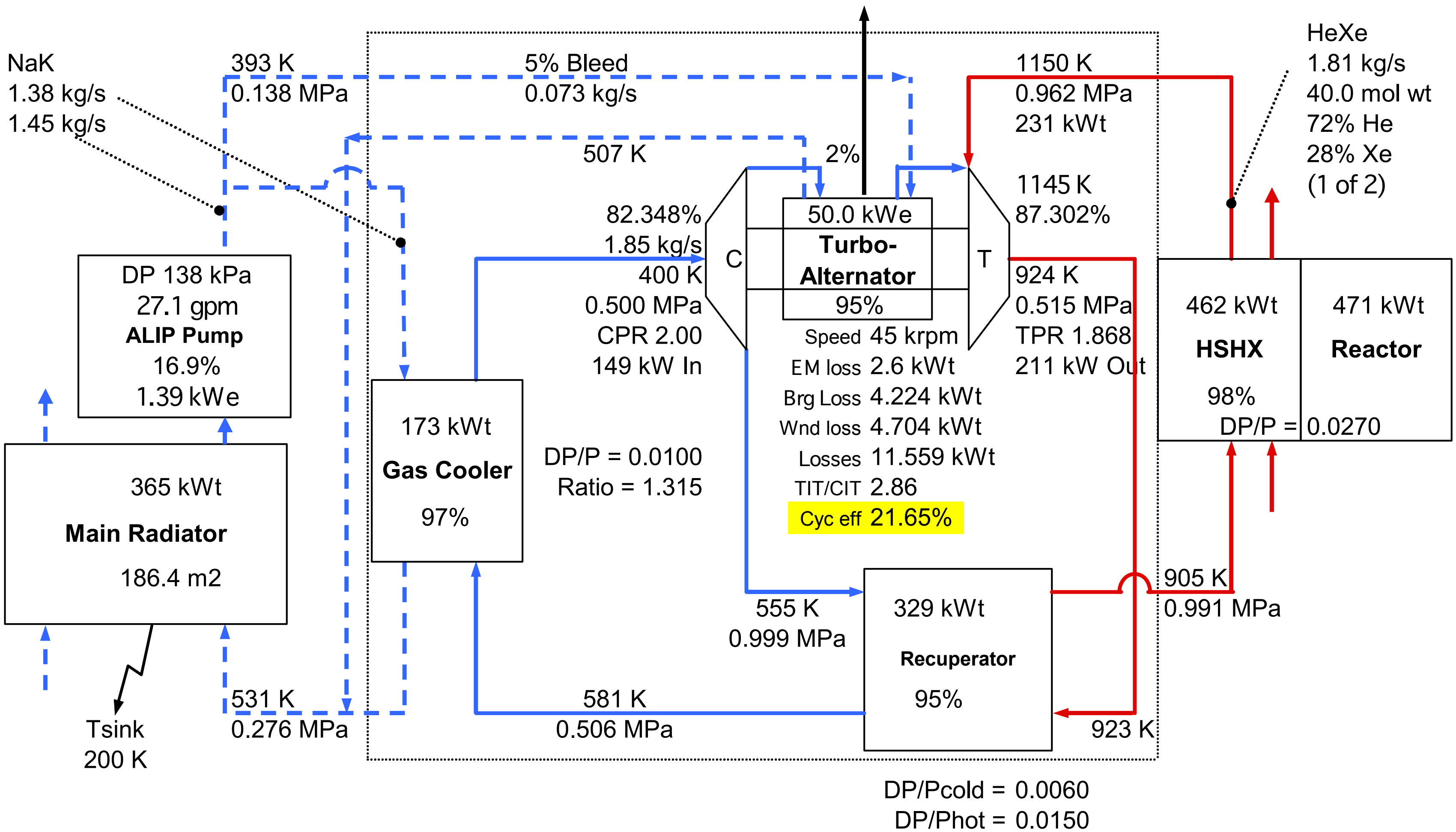
CBC with map-based turbomachinery η, 2% compressor bleed, bearing losses only



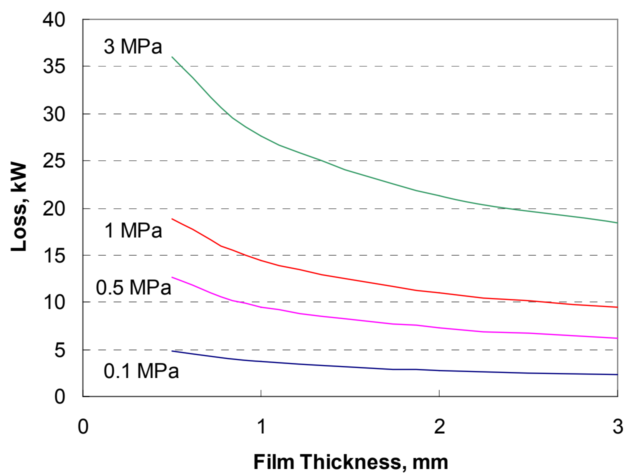
CBC with map-based turbomachinery η, 2% compressor bleed, bearing and windage losses only

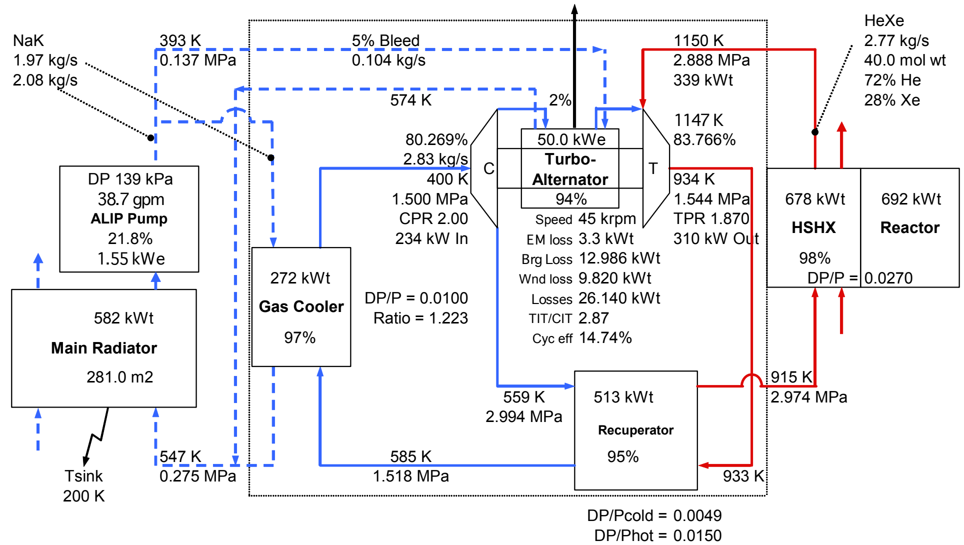


CBC with map-based turbomachinery η, 2% compressor bleed, bearing, windage, and EM losses

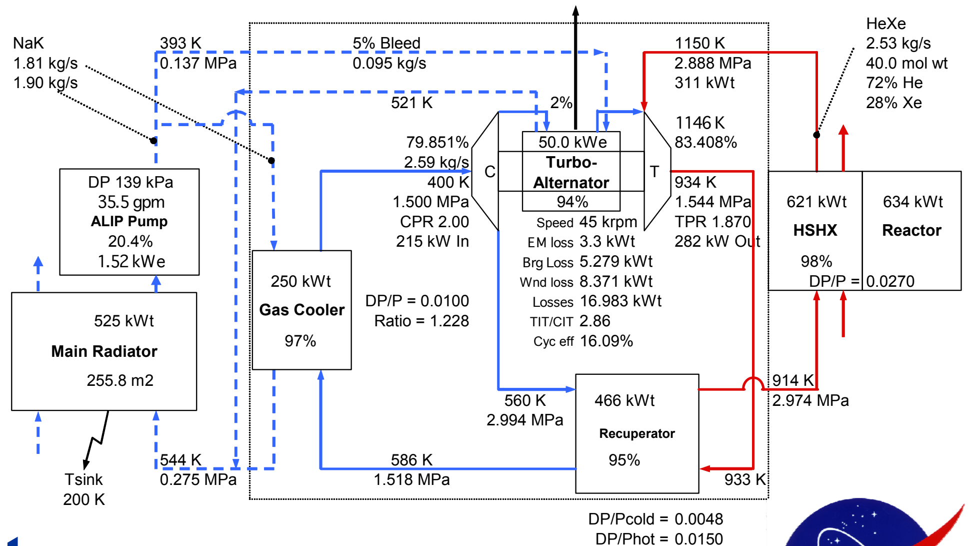


Loss Sensitivities

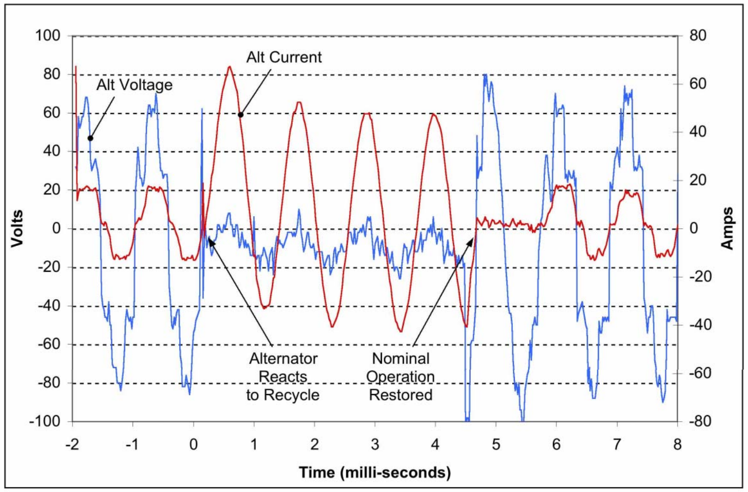


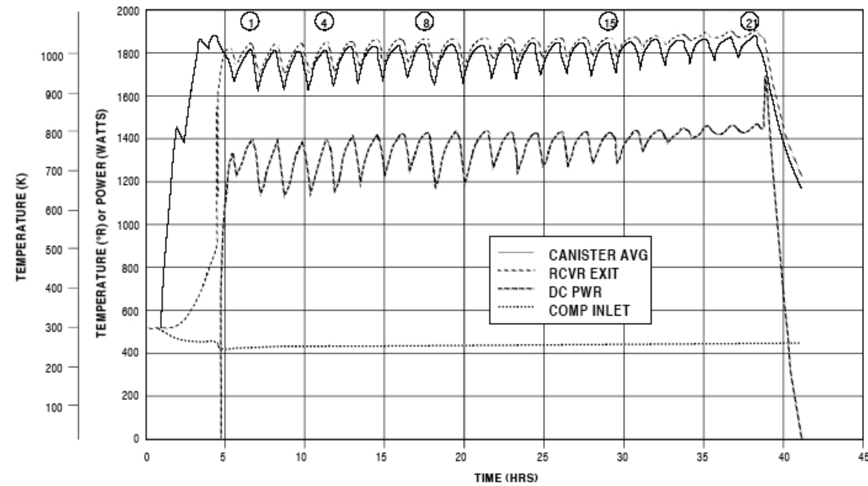


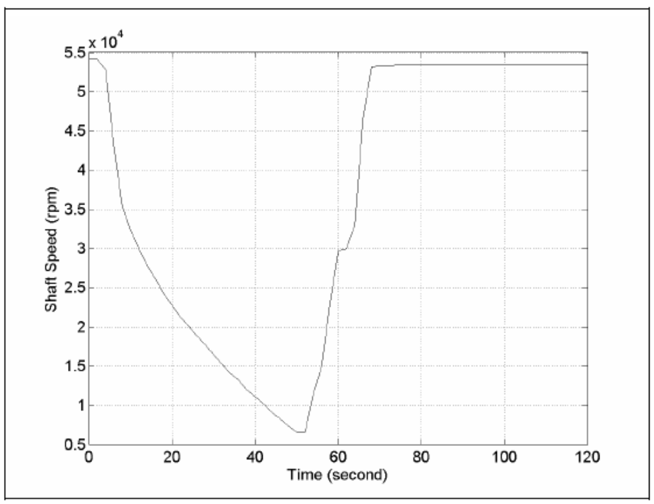
Ongoing research is focused on reducing uncertainty in loss models



Timescales, Transient Modeling and Validation







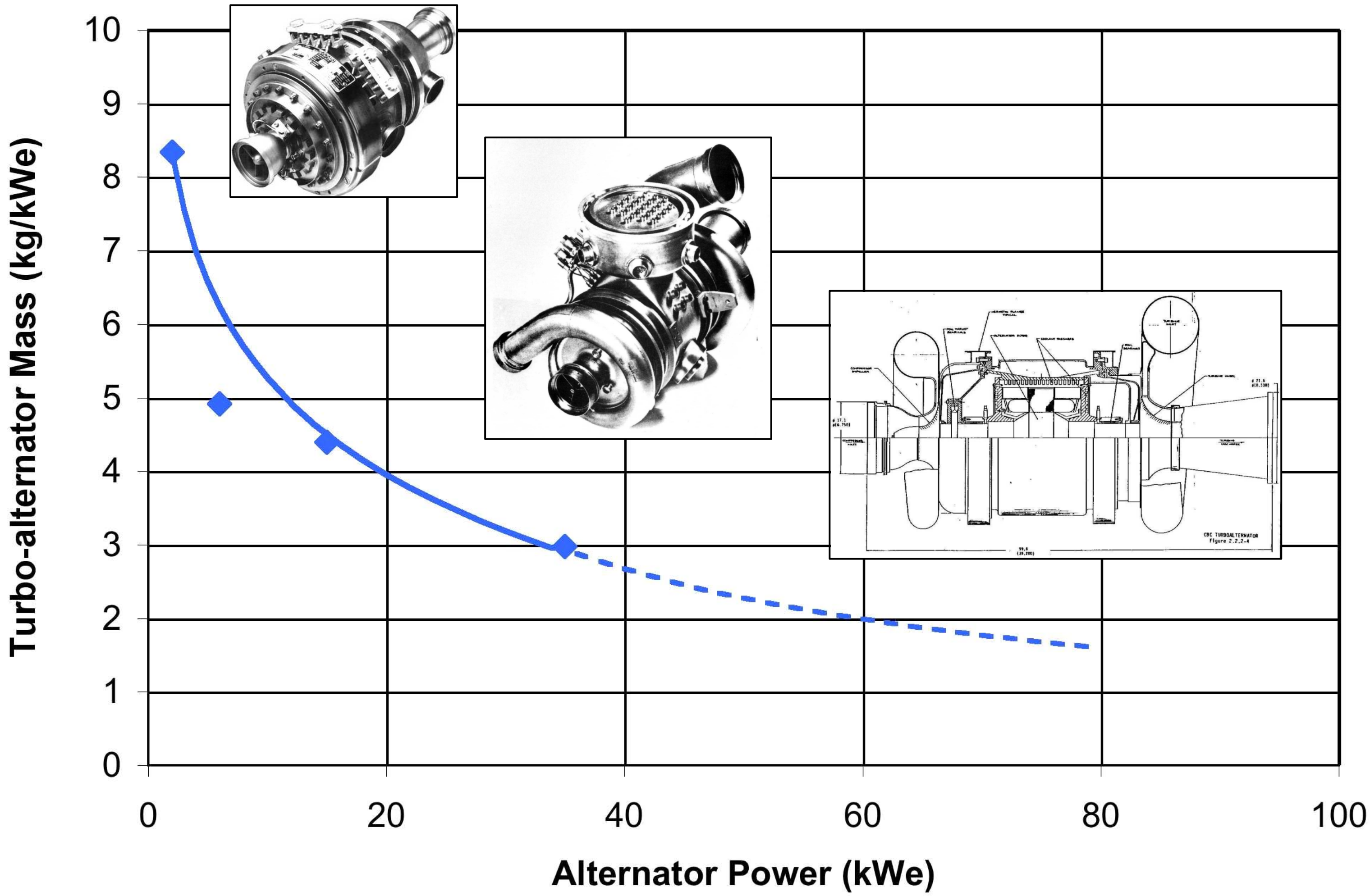
$$\rho V c \frac{dT}{dt} + h_c A (T - T_e) = 0$$

$$\Theta(t) = e^{-t/\tau}$$

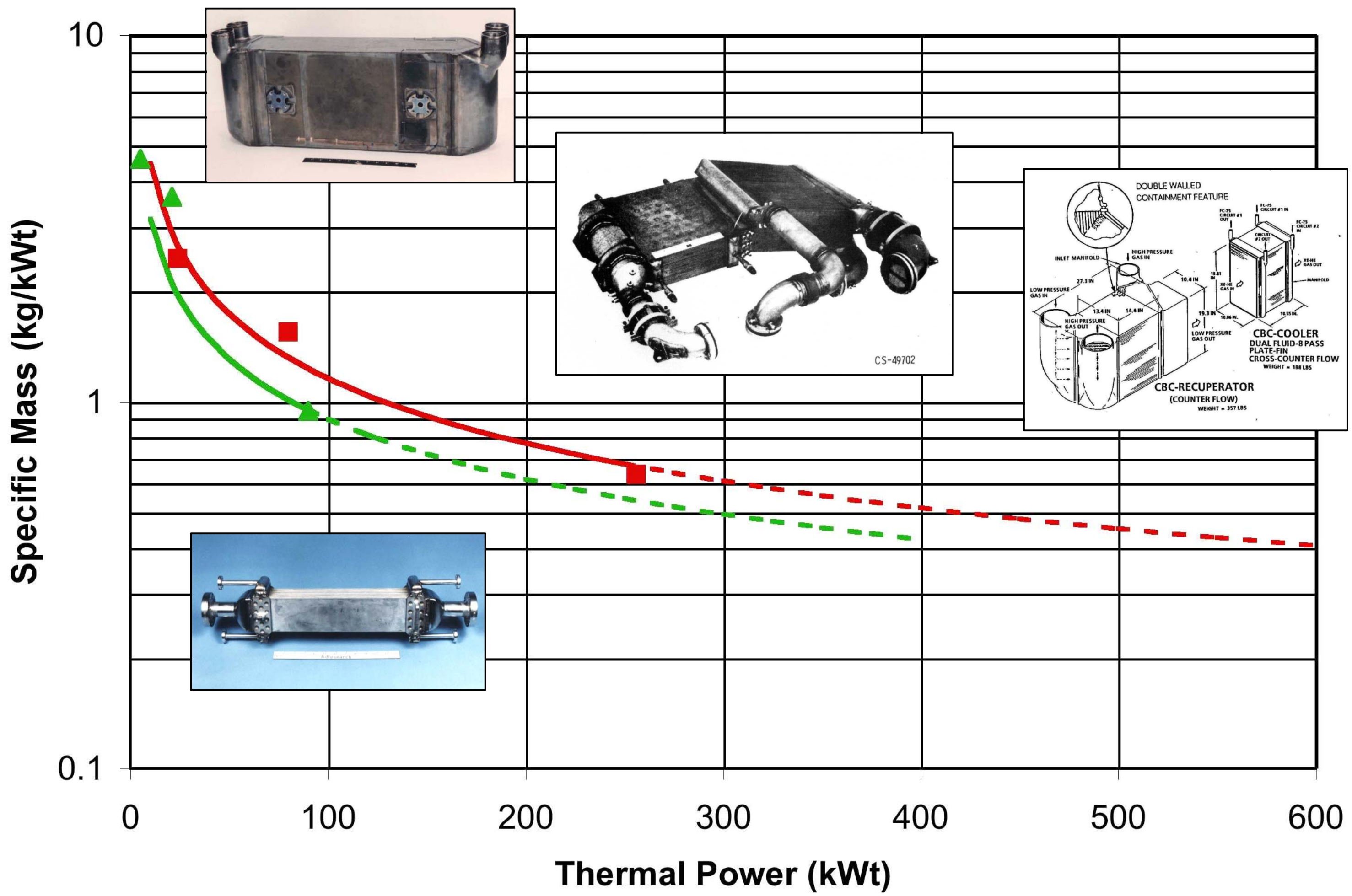
$$\tau = \rho V c / h_c A$$

$$Bi = h_c D / k$$

Specific mass curve for turboalternators



Specific mass curves for heat exchangers



Mass Modeling Techniques

Best when detailed design information is coupled with empirically rooted design algorithm

Recuperator

Item	*Value*	*Units*
Total Length =	0.820	m
Total Width =	0.325	m
Total Height =	0.459	m
Divider Plate Thick =	0.000203	m
Sideplate Thick =	0.00254	m
Outer shell Thick =	0.00356	m

Headers

Item	*Value*	*Units*
Inlet Header Length =	0.193	m
Inlet Header Width =	0.248	m
Outlet Header Length =	0.203	m
Outlet Header Width =	0.257	m
Fin Pitch =	197	fins/m
Fin Length =	N/A	
Fin Thickness =	0.0001524	m

Core General

Item	*Value*	*Units*
Core Length =	0.42418	m
Core Width =	0.313182	m
Fin Pitch =	630	fins/m
Fin Length =	0.00318	m
Fin Thickness =	0.0001524	m

Cold Stream Core (High Pressure)

Item	*Value*	*Units*
Flow Area =	0.0513	m2
Plate Spacing =	0.00318	m
D_{HYD} =	0.001946	m
# Sandwiches =	60	
Heat Xfer Area =	46.5	m2

Hot Stream Core (Low Pressure)

Item	*Value*	*Units*
Flow Area =	0.0645	m2
Plate Spacing =	0.00389	m
D_{HYD} =	0.002073	m
# Sandwiches =	61	
Heat Xfer Area =	54.9	m2

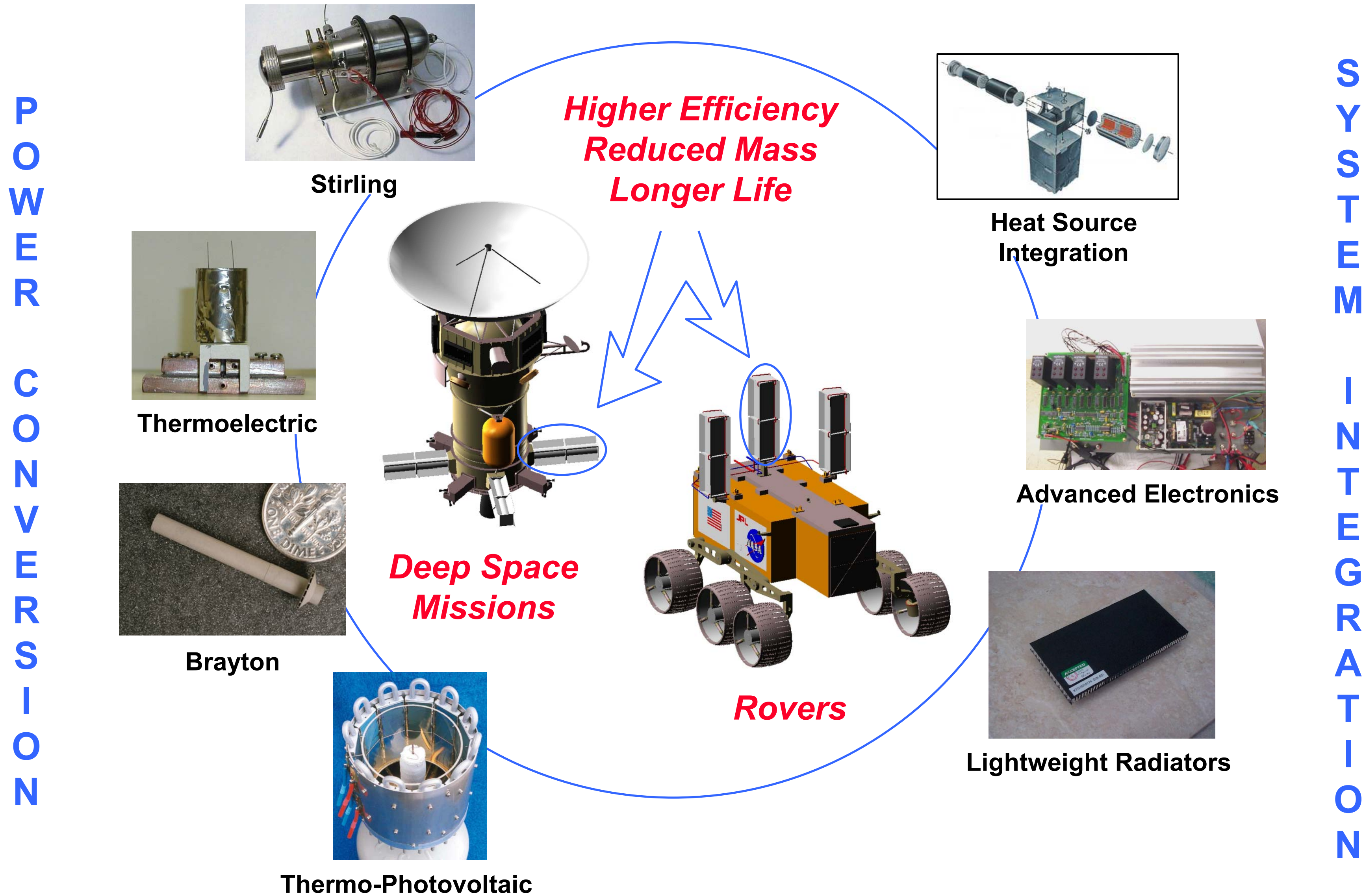
Recuperator mass = 158 kg

Conclusions

- Each performance model's required capabilities are driven by the design question being investigated
  - Conceptual design analyses used to size closed-Brayton-cycle space power conversion subsystems must include realistic representations of turbomachinery efficiencies, mechanical losses and electromechanical losses
  - Efficiency errors of 30% and mass estimate errors of 20% are possible using even moderately unrealistic representations
- Transient CBC performance models can benefit from timescale identification and segregation
  - Characteristic electrical, mechanical and thermal timescales in closed-Brayton-cycle subsystems can vary from fractions of milliseconds to hours
  - Simpler development and use of integrated dynamic models may be possible using timescale separation techniques
- Dimensionless similitude between ground test units and flight systems is essential to meaningful experimental validation of transient models
  - Special attention must be devoted to evaluating ground test hardware with respect to flight-like characteristic dimensionless scales
- Cycle energy balances are sensitive to mechanical losses in bearings and alternators
  - Using two available models, a 40% difference in mechanical loss predictions was demonstrated for a 100-kWe (two-engine) closed-Brayton-cycle subsystem operating at 3 MPa peak pressure
  - More research is needed to reduce the uncertainty in bearing and windage loss predictions
- Closed-Brayton-cycle subsystem mass estimates are typically empirically based or calculated from more detailed component design information
  - Both methods have advantages and disadvantages
  - Grounding a mass estimate in "as-built" data is frequently advantageous

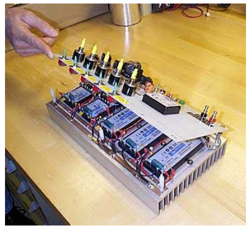
Back-up Charts

Radioisotope Power Systems



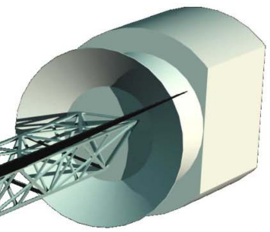
Nuclear Electric Propulsion

Power Management
& Distribution

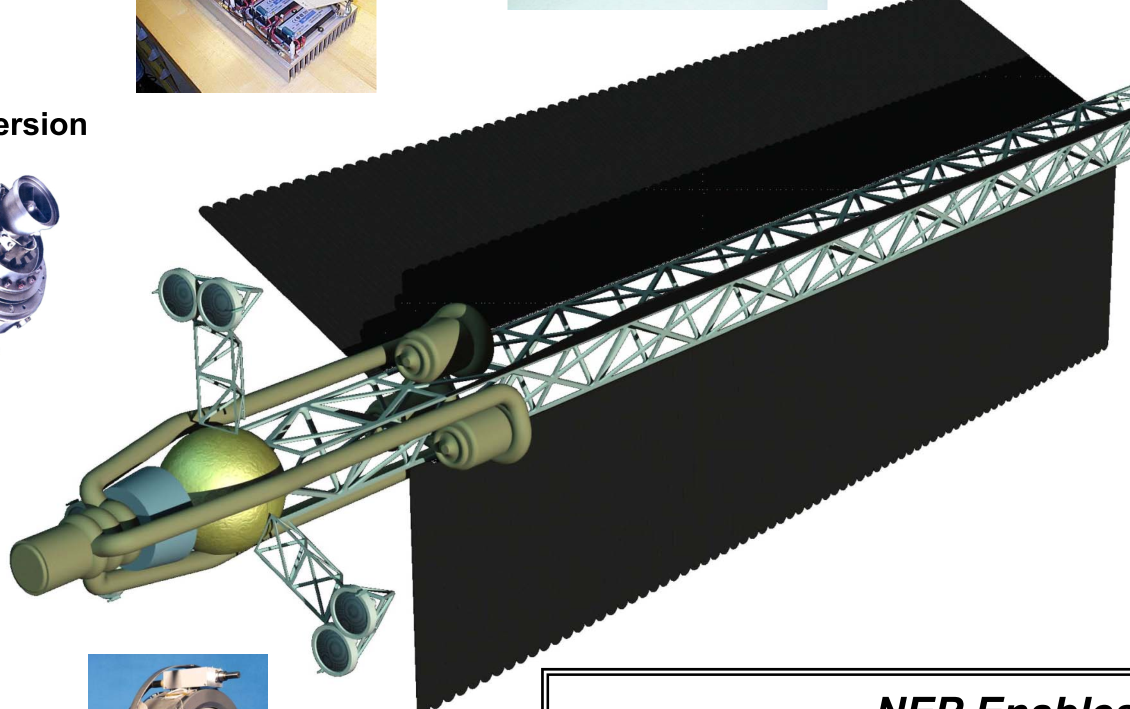


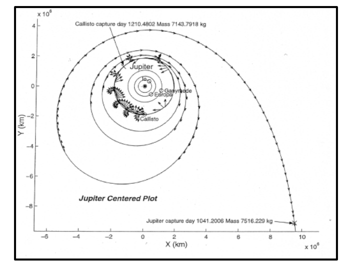
Heat Rejection

Science
Payload

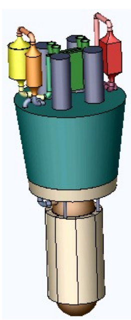


Power Conversion





Trajectory Analysis



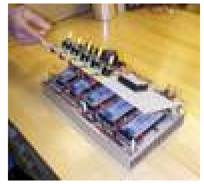
Reactor
Heat Source

Electric Propulsion

NEP Enables:
Outer Planet Orbiters (rather than Flybys)
Multiple Targets on Single Mission
High Power, Long Duration In-Situ Science
High Data Rate Communications

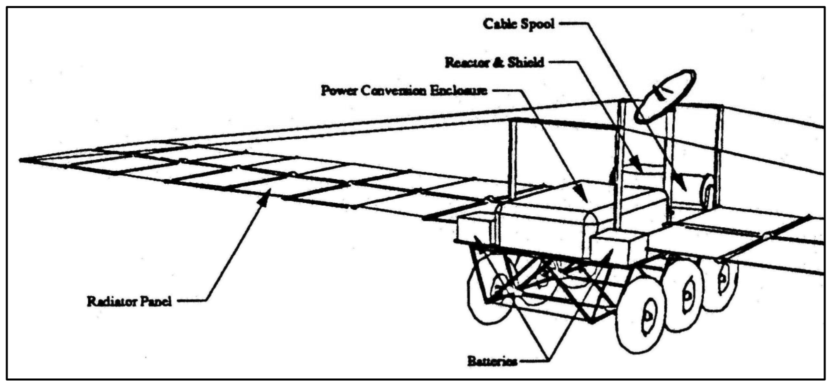
Nuclear Electric Surface Power

Power Management & Distribution



Heat Rejection

Energy Conversion



Reactor Heat Source

Nuclear Surface Power Enables:
Unrestricted Landing Site Locations
Extended Stays through Night Periods
High Power, Long Duration In-Situ Science
High Power Local Resource Mining/Utilization