POSITRONICS RESEARCH, LLC

NIAC
NASA Institute for Advanced Concepts

Positron Propelled and Powered Space Transport Vehicle for Planetary Missions

Positronics Research, LLC, Santa Fe, NM

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Team Members

- Dr. Gerald Smith – Principal Investigator
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- Mr. Kirby Meyer – Engineer
- Dr. Les Thode – Physicist

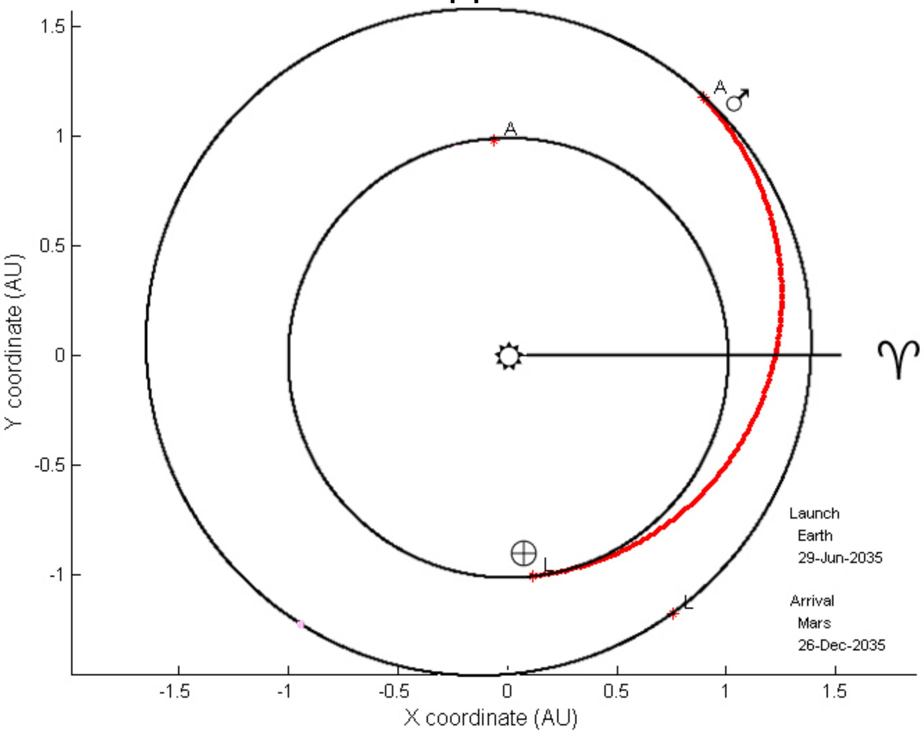
Mars Missions Require Large Payload Masses and Significant ΔVs to Reduce Radiation Exposure

- Studies* suggested payloads of 60,000 kg.
- Orbital mechanics suggest ΔV = 3.7 km/sec for 6-month, one-way transit to Mars.
- Rocket equation:

$$\Delta V = u_{eq} \ln\left(\frac{M_O}{M_b}\right) \cong I_{sp} g \cdot \ln\left(\frac{M_o}{M_b}\right)$$

- Assuming 40,000 kg for tank and engine, a chemical system to Mars could be 250,000 kg!
- Apollo payload ~44,000 kg. Result: Massively complex staged system, expensive.

A 2035, Earth-Mars Opposition Mission Scenario

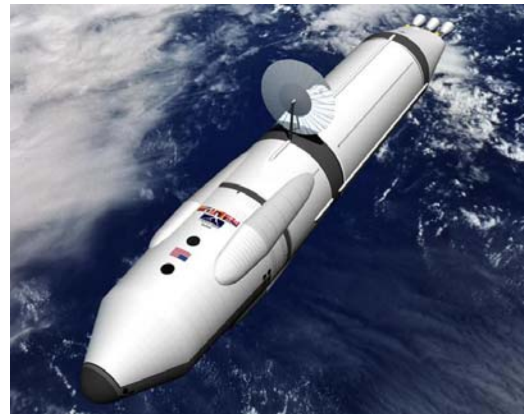


*B.G. Drake, ed. "Reference Mission Version 3.0: Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team," http://ares.jsc.nasa.gov/HumanExplore/Exploration/EXLibrary/docs/MarsRef/addendum/index.htm, June 1998.

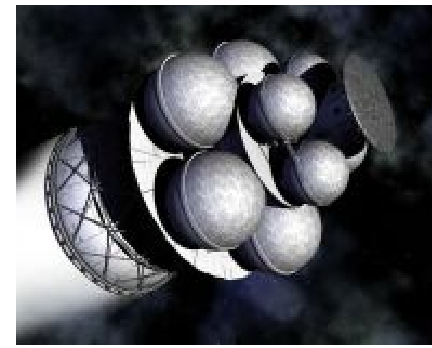
Studies Suggested I_{sp} >1000 sec to Reduce System Weights

- High Isp, high thrust system limits propulsion types to:
  1. Nuclear-thermal (NERVA/Rover).
  2. Fusion (e.g. Daedalus).
  3. Antimatter.
  4. Combinations of above.

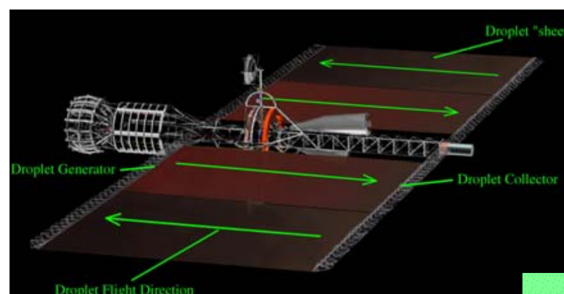
Propulsion	Isp (sec)
Nuclear-thermal	800-3000
Fusion	10^4 - 10^5
Hybrid antimatter fusion	13,000
Direct positrons	10^7



Nuclear-thermal, NASA GRC

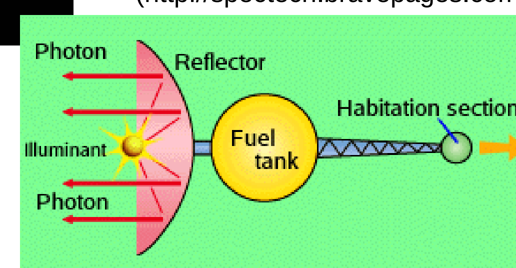


Daedalus (http://www.aemann.pwp.blueyonder.co.uk/)



ICAN Antiproton-Catalyzed Microfission/Fusion (ACMF), PSU.

Direct positrons (Sänger) (http://spectech.bravepages.com)



Why Positrons?

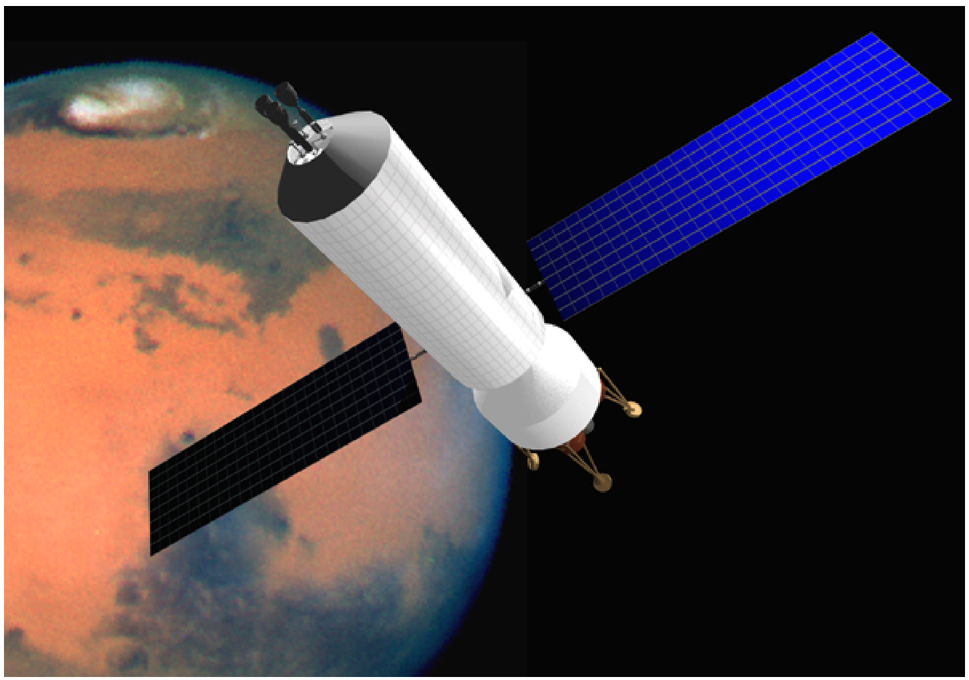
- Antimatter has highest specific energy in existence.
- No residual radiation.
- Large amounts can be made available.
- Promising storage developments.**

- We estimate approximately 4 mg of positrons for a one-way trip to Mars with a system mass of 100,000 kg (e+ not used for powering payload).

Propulsion Type	Specific Energy (MJ/kg)
Chemical	
LO_2/LH_2	10
Atomic H	400
Fission	8×10^6
Fusion	3×10^8
Antimatter	1.8×10^{11}

**discussion restricted under provisions of AFRL contract #F08630-02-C-0018

Goal: Investigate Candidate Systems That Can Use Positrons



PRLLC solid-core spacecraft

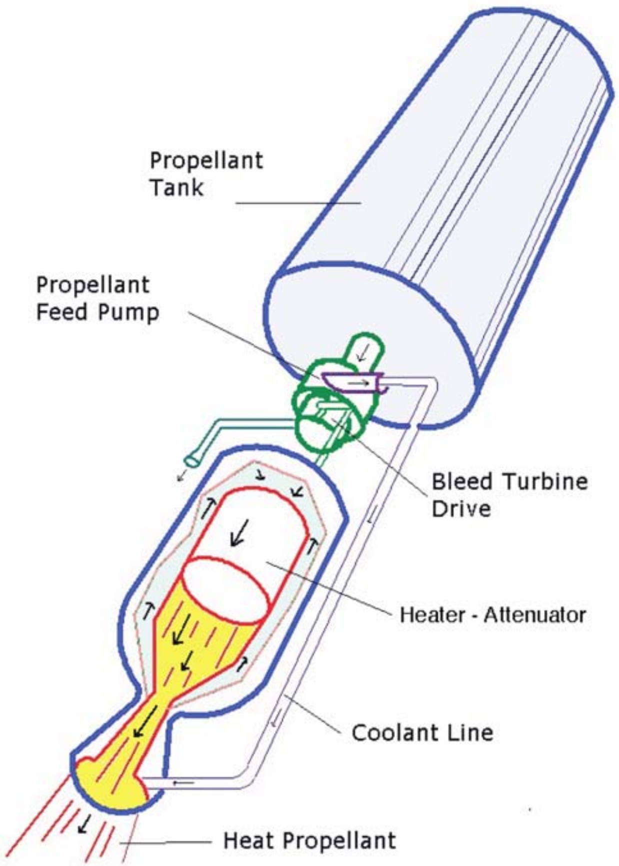
- Positron-electron annihilations create two, 511 keV gamma rays.
- Last positron concept developed by Eugen Sänger, 1935. Reflected gamma rays created thrust.
- There is presently no means to reflect gamma rays. They must be used to heat another propellant.
- Goal: delineate properties of positron-driven engine for fast access to Mars.

1. **Solid Core.**
2. **Gas Core.**
3. **Other concepts.**

Solid-Core Engine and Power Systems

Positron Solid-Core Energy Source

- Flexible for both propulsion & power
- Outstanding performance capability
  - High I_{sp} , ~1000 sec, propulsion.
  - High thrust, comparable to chemical & nuclear-thermal engines.
  - High specific mass systems (P/M or T/W).
- Not an operating or shutdown radiation source
  - No shielding required.
  - Does not need to be separated from Crew/Payload.
  - No shutdown cooling required.
- Simple operation
  - On-Off operation.
  - No complex control mechanisms.
  - No criticality requirements.
- Nearer-term than other hi-tech options.

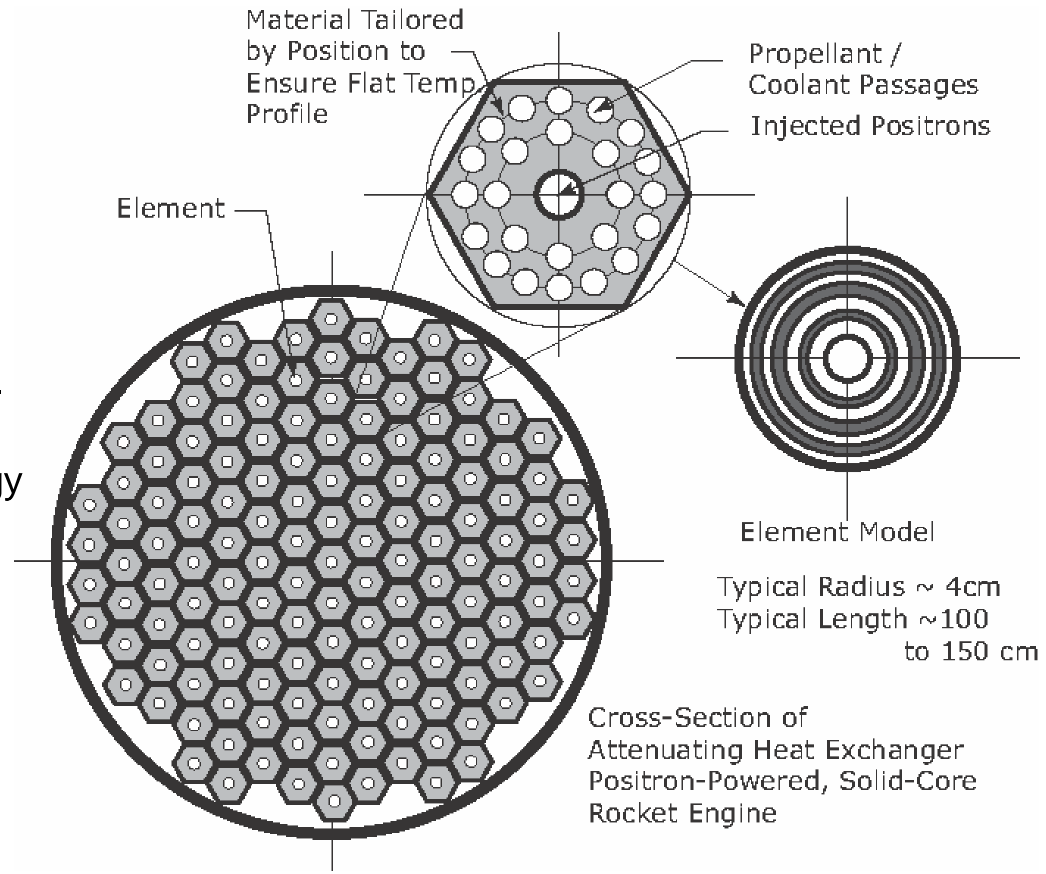


Positron-Powered Rocket Engine
Modified from Experienced Gained from the Space Nuclear Program (Rover); LA-10062-H, D.R. KoenigMay 1986

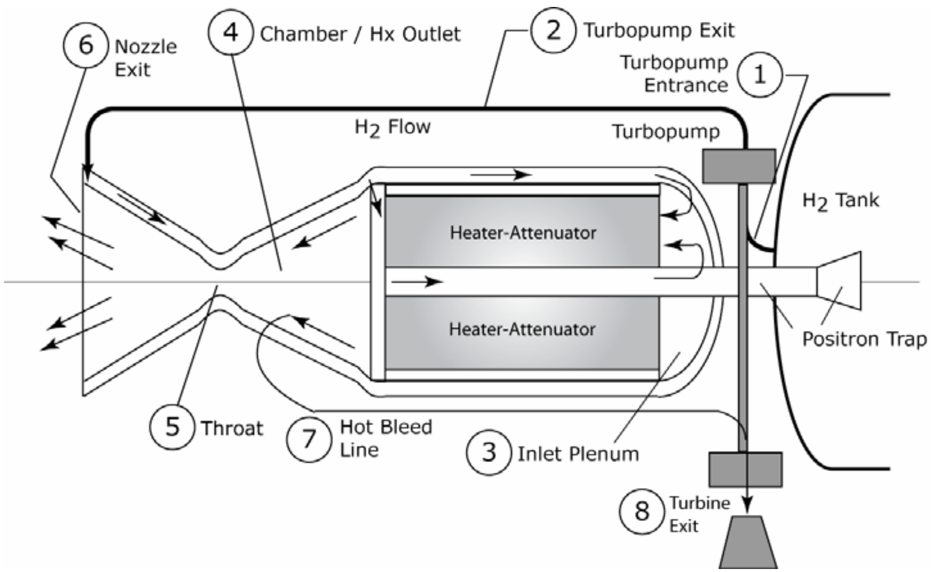
Positron Heater-Attenuator

The Energy Source of a Positron-Powered System

- Similar in arrangement to NERVA/Rover configuration
  - Hexagonal elements appropriately supported for structural & vibration considerations.
  - Flow channels orificed to preclude viscosity instability.
- Element configuration
  - Central channel for positron injection.
  - Propellant/coolant channels.
  - Materials tailored to ensure flat energy profile; i.e., flat exit propellant. temperature profile.
- Element model
  - Concentric annular shells.
- Power & material temperature determine number & geometry of elements.



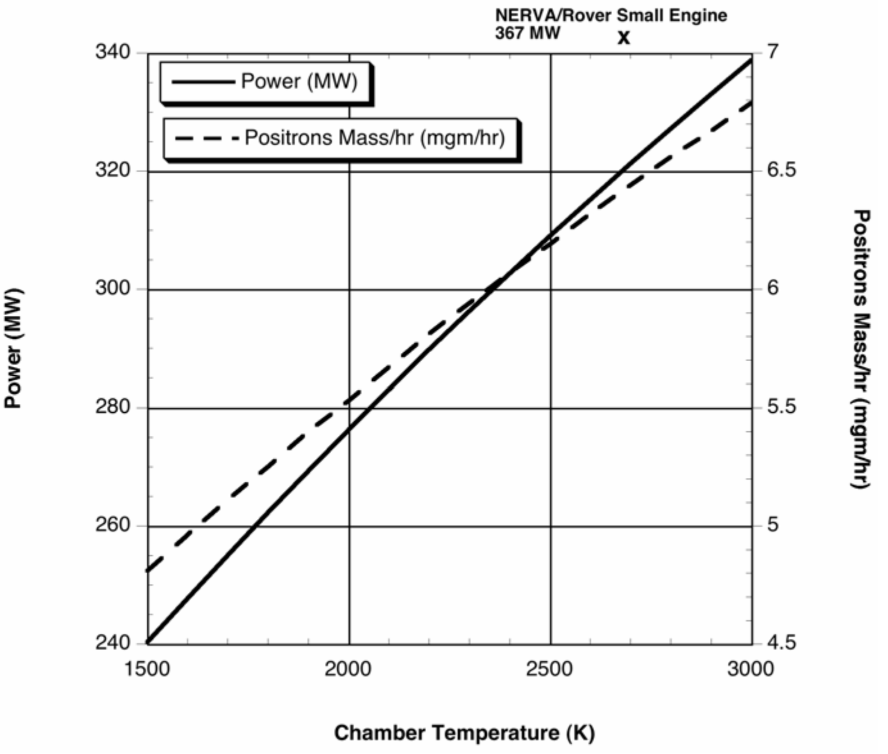
Thermal-Fluids Rocket Engine Model



- A thermal-fluids model for concept analysis
  - Hot-bleed cycle.
  - Determines temp., pressure, & enthalpy at every point indicated.
  - Determines engine performance - thrust, I_{sp}, power, nozzle geometry.
  - Determines e+ utilization (number and mass rates) and propellant utilization.
  - Estimates turbopump requirements.
  - Estimates ΔP thru heater-attenuator.
  - Dependant upon geometry of attenuator-heater.
- Model based on thermodynamic principals, energy balance and momentum balance.

Solid-Core Positron Rocket Results

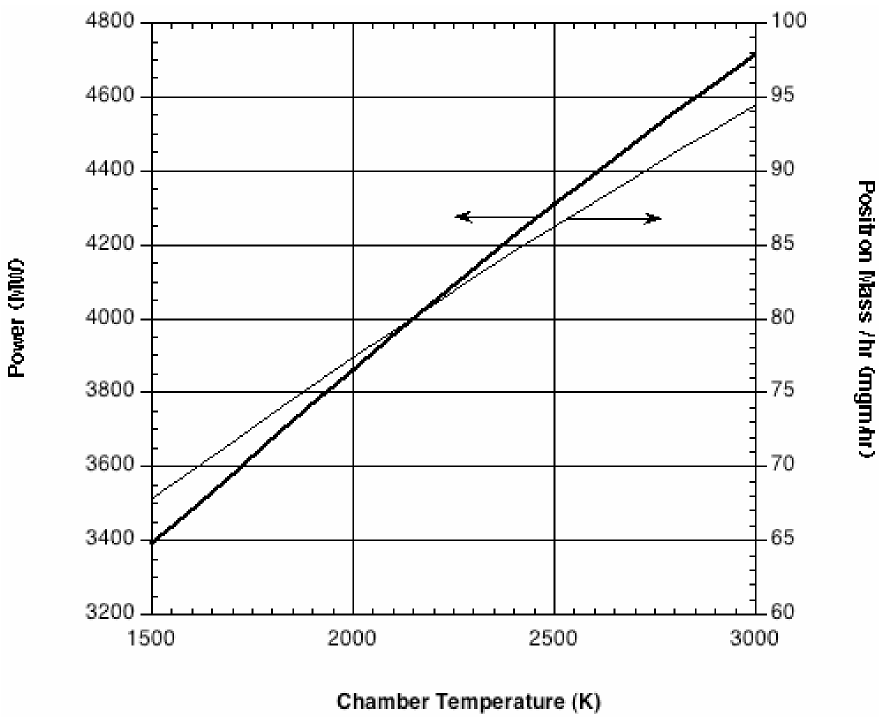
- Analyzed two classes of rocket engines
  - Small engines - 72 kN (16k lb_f) thrust.
  - Large engines - 1000 kN (225k lb_f).
  - Results base-lined to results from NERVA/Rover.
- Results of analysis comparable to NERVA / Rover published results.*
- Geometry optimized for material surface temperatures up to 3000 K.

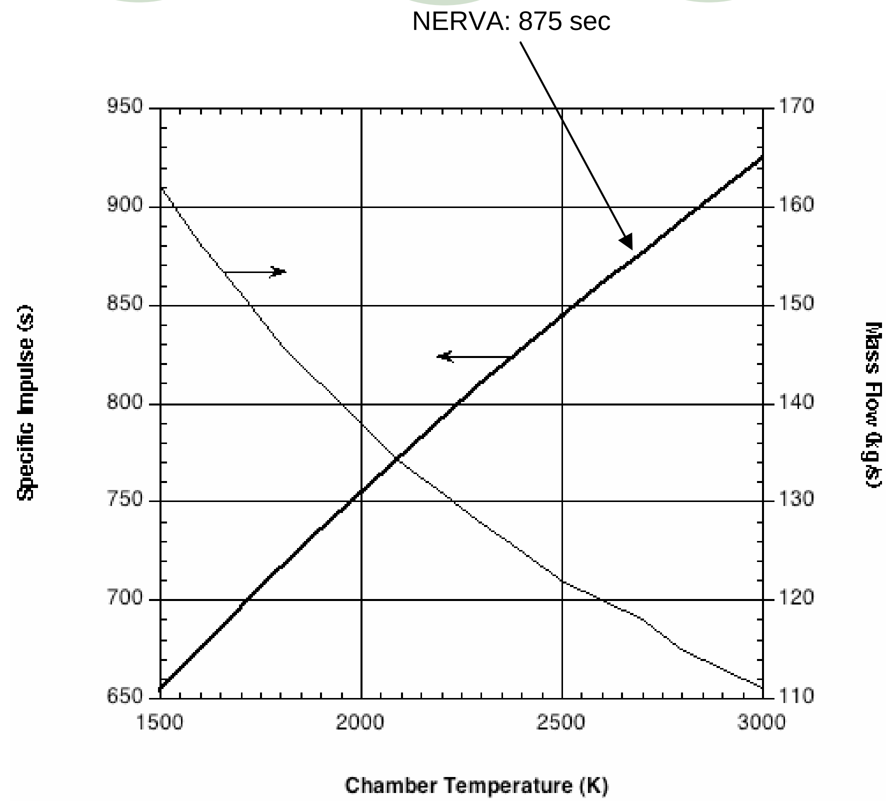


Small Engine (72 kN) Results

*Daniel R. Koenig, "Experience Gained from the Space Nuclear Rocket Program (Rover)," Los Alamos National Laboratory report LA-10062-H, May 1986

Solid-Core Positron Rocket Results (continued)

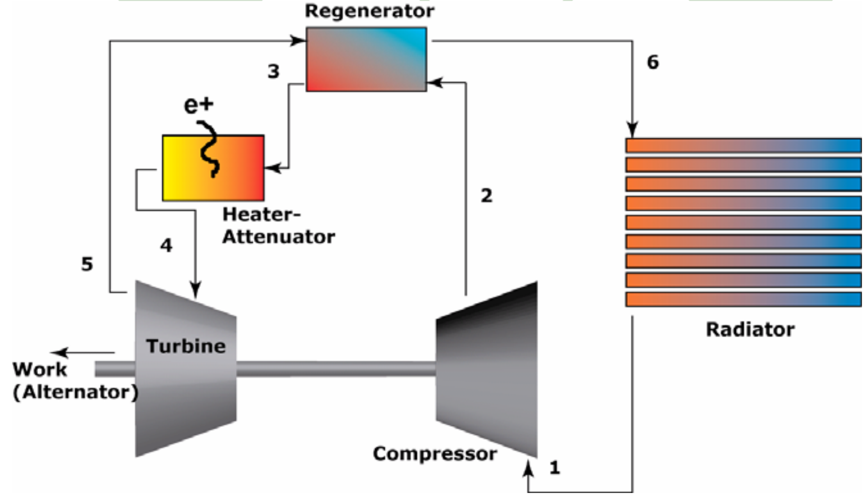


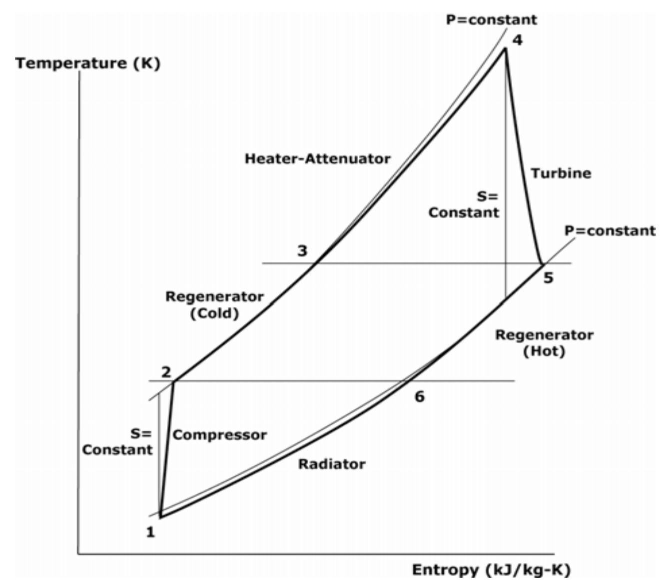


Large engine (100 kN) results. Specific impulse graph matches that for small engine.

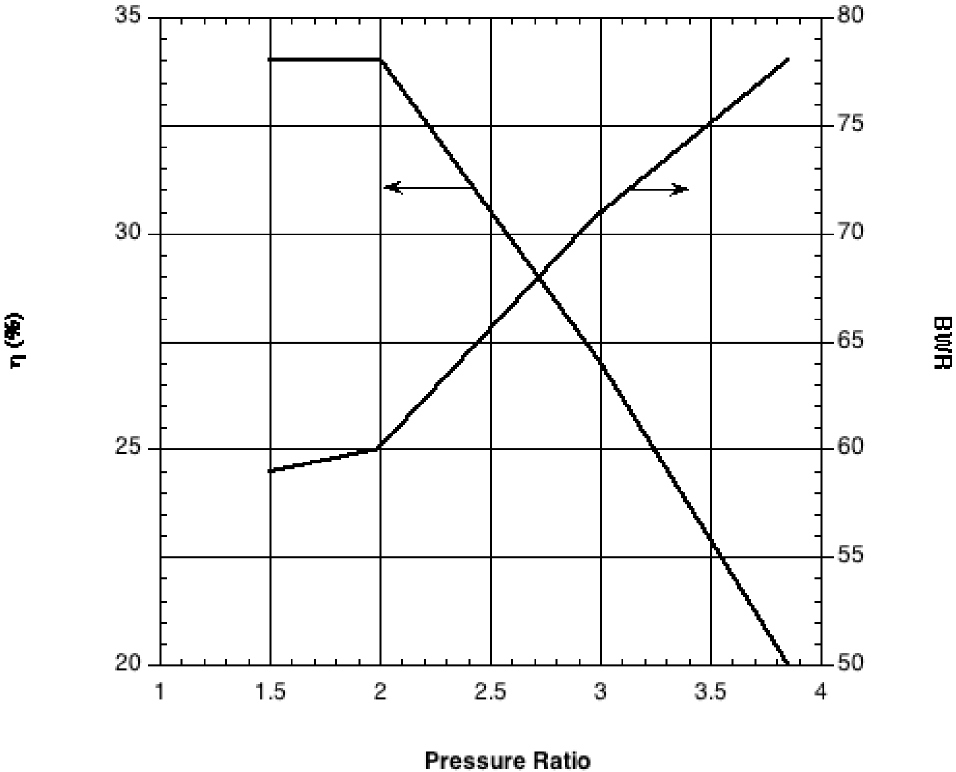
Closed Brayton Cycle (CBC) Model Using Positrons for Power Plant and/or Martian Surface

- A thermal-fluids model for concept analysis
  - Variable He-Xe mixtures and compressor/turbine pressure ratio.
  - Regeneration (allows for 2-stage w/ reheat and inter-cooling).
  - Determines temp., pressure, & enthalpy at every point indicated.
  - Determines cycle performance - efficiency and back-work ratio.
  - Estimates radiator size, regenerator size and heater-attenuator material temperatures.
  - Determines e+ utilization (number and mass rates).
  - Estimates ΔP thru heater-attenuator.
  - Dependant upon geometry of attenuator-heater.
- Model based on thermodynamic principles, energy balance and momentum balance.





Solid-Core Positron CBC Results

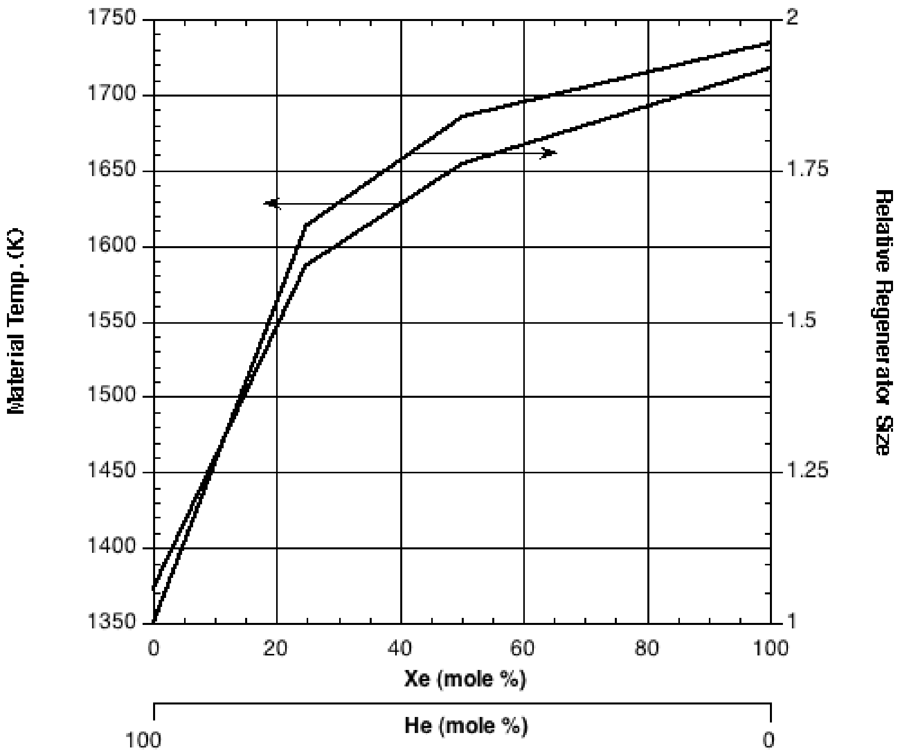


Expect about 30% efficiency, 7 µg/hr

- Results are for 100 kW_e available system power.
  - Example: Efficiency of 25% means 400 kW of e+ power necessary for 100 kW output.
- Selection of pressure ratio is a trade-off of system mass and efficiency.
  - Efficiency decreases with pressure ratio.
  - Back-work ratio (BWR) increases.

Solid-Core Positron CBC Results
(continued)

- Some performance parameters are also dependent on He-Xe ratio (density and molecular weight)
  - Material temperature
  - Component sizes
- Optimal near He = 72%.
- Lower desired temperatures mean lighter materials such as titanium can be used.



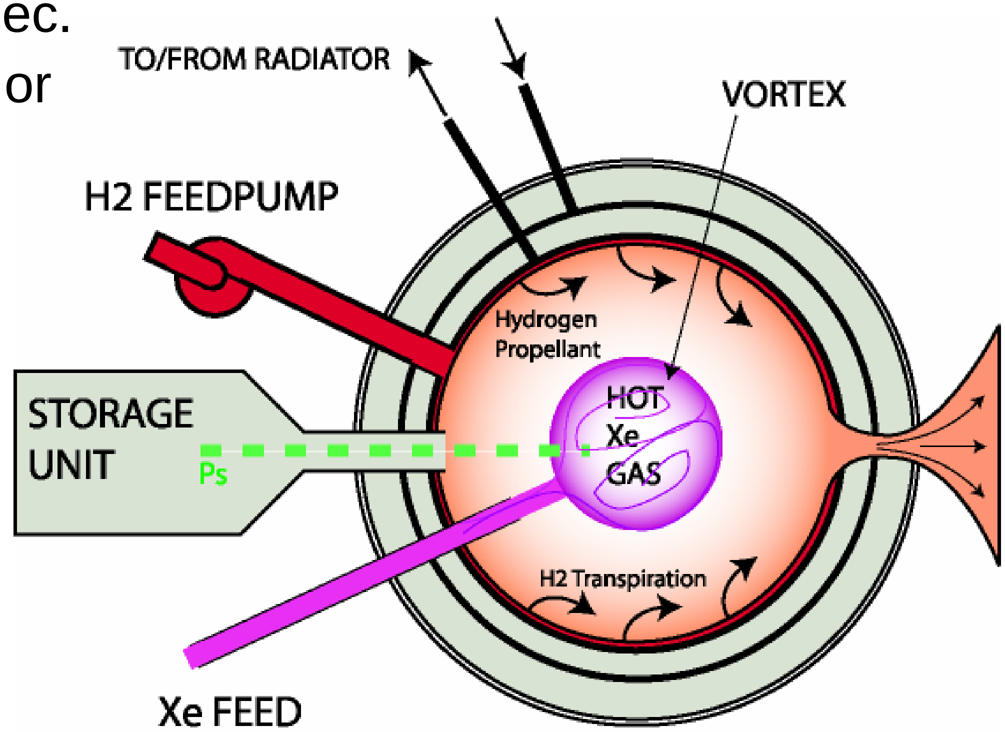
•He has a larger specific heat than Xe (5.193 vs 0.159 kJ/kg-K.)
•Xe density is larger than He (1.23 vs 40.5 kg/m3).

Gas-Core Concept

Gas-Core Rocket Should Exceed the Solid-Core's Performance and Meet Mars Mission Profile

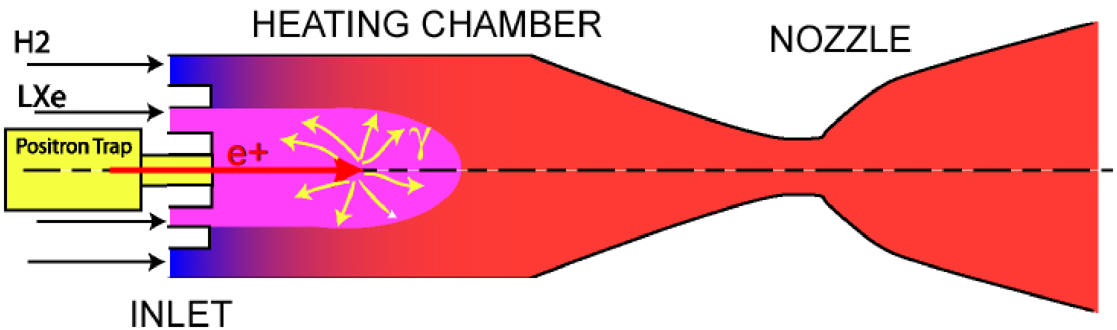
- The theoretical maximum of e+ solid-core system Isp of 1150 sec.
- Mars mission spacecraft mass or TOF can be reduced if Isp is improved.

- Since solid-core system has proven similarities to nuclear-thermal rockets, the gas-core should meet 1150 sec.
- The gas-core should meet ~100 kN thrust requirements and have reasonable efficiency.

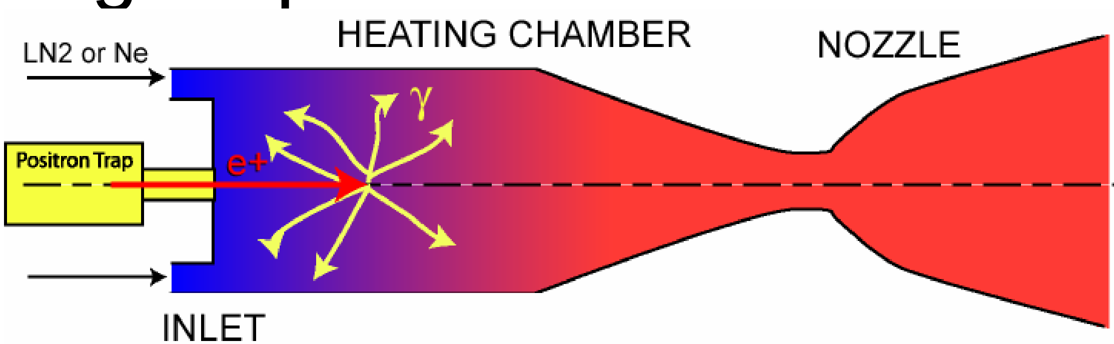


1-D and 2-D Cylindrical Simulations; Open-Cycle Gas-Core Concept may be of One or Two Species

- Two species



- Single-species



$$u_e = \sqrt{\frac{2\gamma\overline{R}}{(\gamma-1)\overline{M}} T_c \left[1 - \left(\frac{p_e}{p_c} \right)^{(\gamma-1)/\gamma} \right]}$$

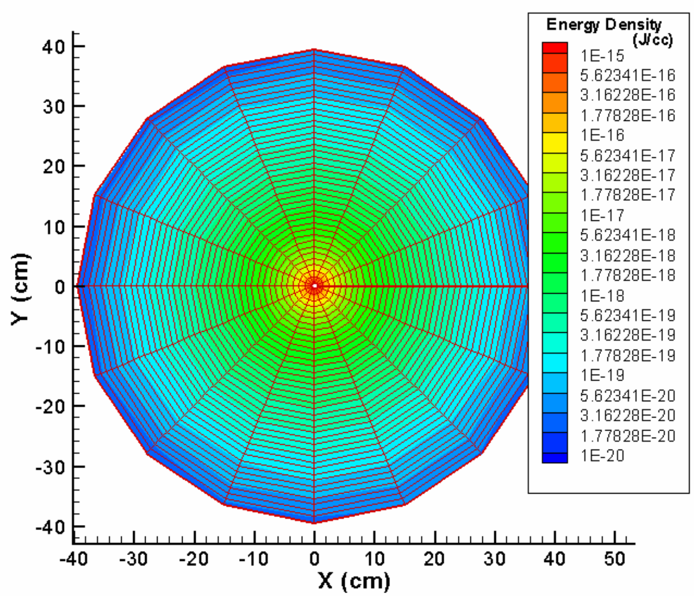
Suggests low molecular weight for high Isp, but high density needed for gamma-ray attenuation

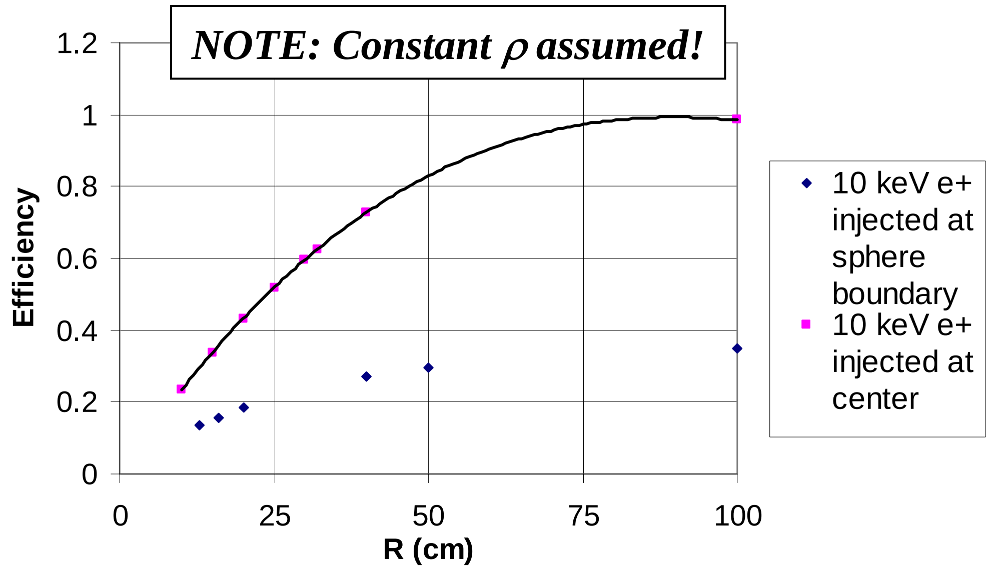
Attenuation Simulations Provided An Approximate Radius of Engine for Single Gas

Analytically:

$$E_{ABSORBED} = E_0 (1 - \exp(-\mu \rho r))$$

- Determined that efficiency would be too low with He or H2 (single gas/liquid) unless pressures exceeded material limits.
- Numerically used GEANT4 to get attenuation data for LN_2.
- Results show minimum of R=25 cm for >50% efficiency. Used R=40 cm. (75%). Here, gamma ray source must be located at center.





Two Codes were Used – a 1-D Euler Equation solver and a 2-D CFD commercial package (ANSWER)

SYSTEM CODE (in-house FORTRAN code)

- Assumes laminar, inviscid flow.
- Solves throat geometry.
- Provides 1-D solution as input to CFD codes.

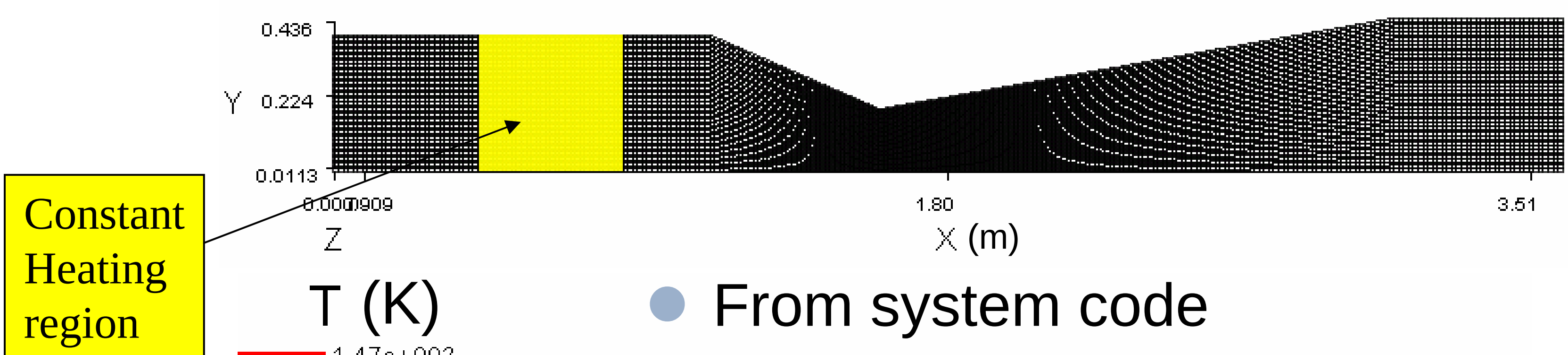
ANSWER (commercial FORTRAN,JAVA code)

- Can handle laminar, turbulent, viscous flow.
- Provides 2-D cylindrical solution.
- Includes wall effects, annular flow vortices.

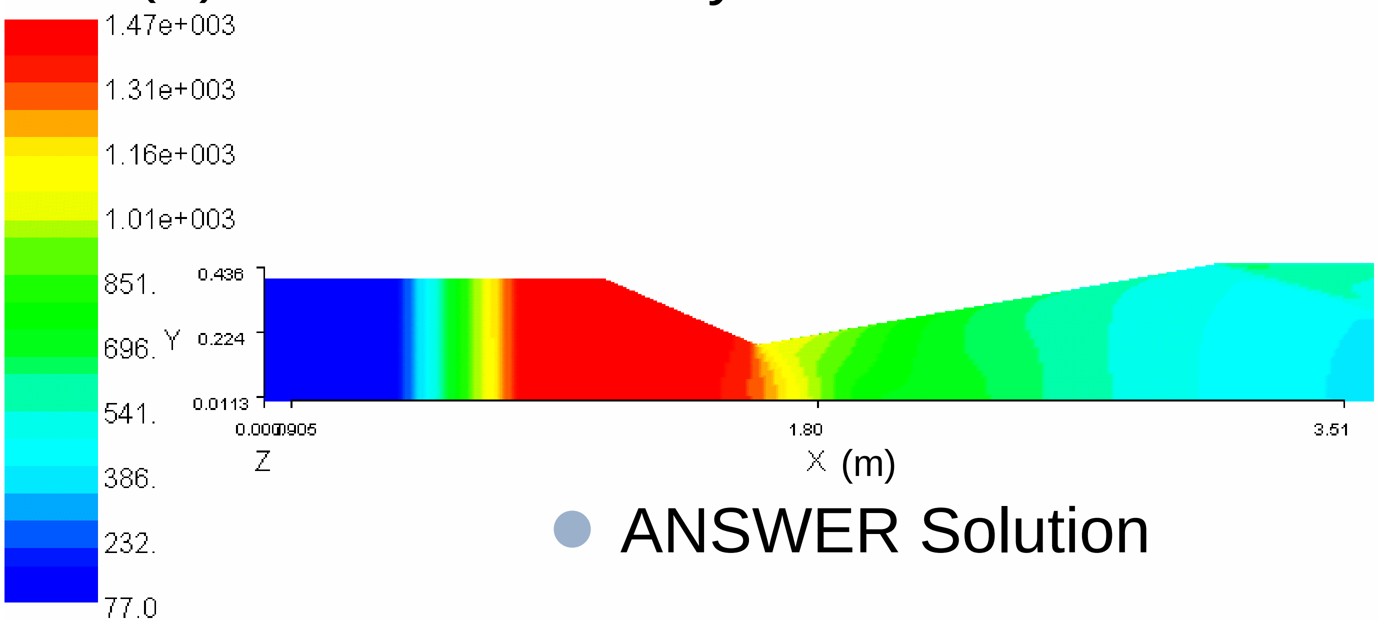
Validation

- Flow is highly turbulent but inviscid since N_2 has low viscosity.
- Tests show turbulent solution behaves laminar-like w/o diffuser at inlet, so ANSWER solution should match favorably to System Code.

Typical Mesh Generated by System Code is Directly Used in ANSWER (Single-species)

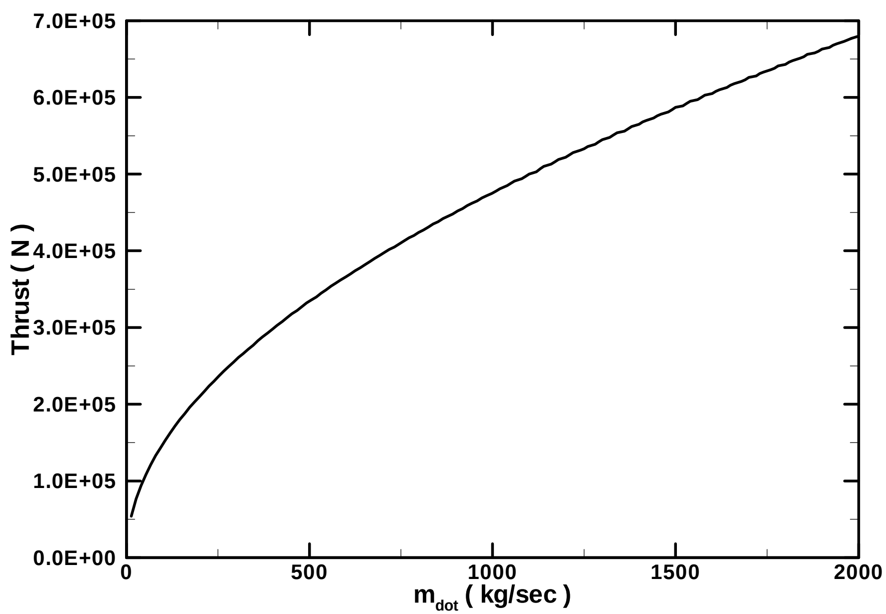


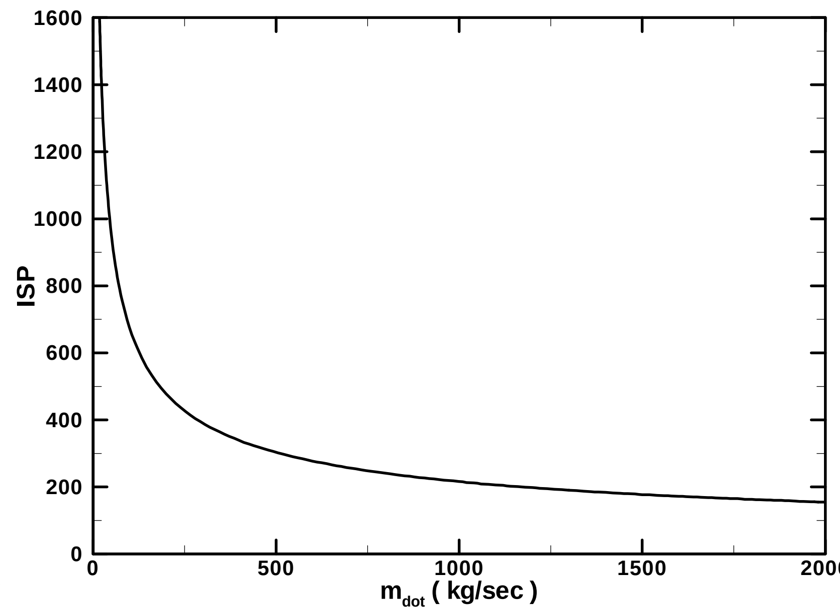
- From system code



- ANSWER Solution

Results Using For Mars Mission (~300 MW) Show High Thrust, Low Specific Impulse with Constant Heat Density

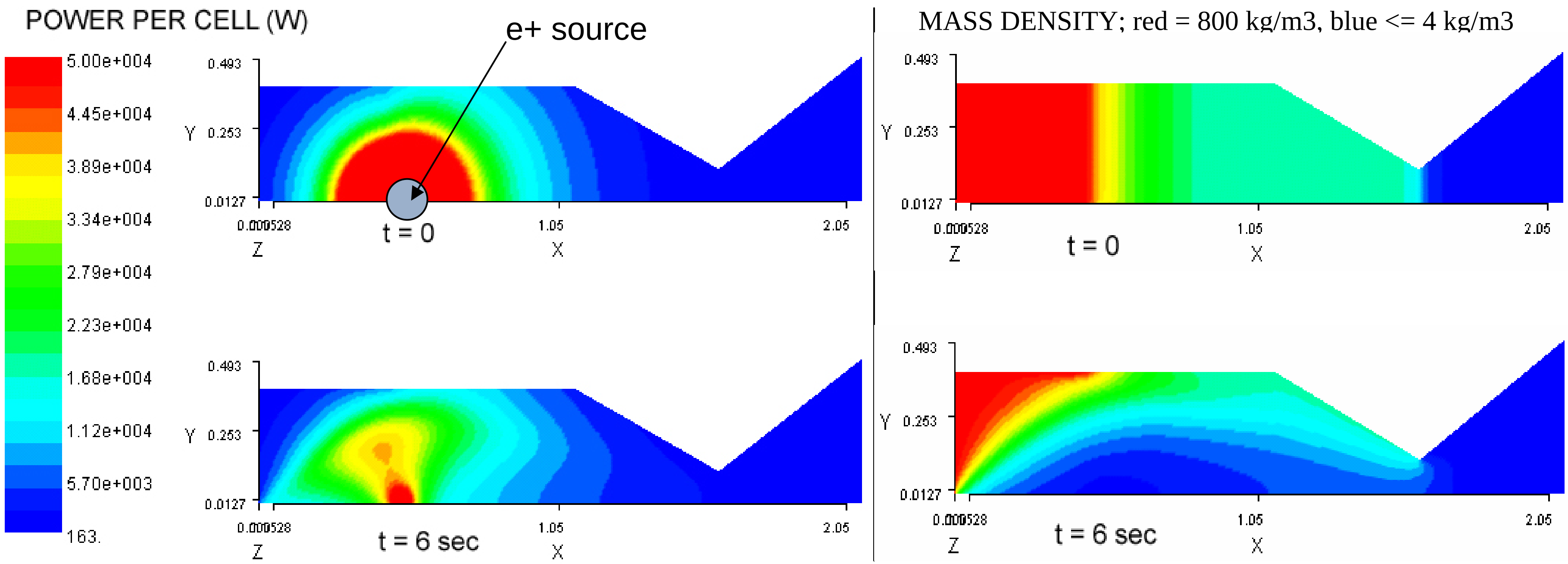




- Values are shown for nozzle expansion ratio = 30.
- Reducing flow rate < 100 kg/sec (T = 100 kN) may provide >1000 sec Isp.
- But up to this point, we assumed a constant heat source. Now we address a point source with dependence of mass density:

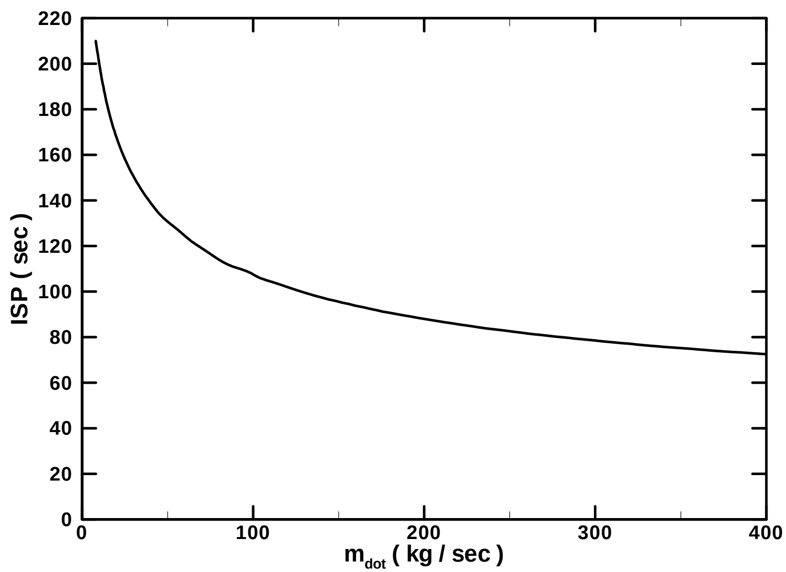
$$E_{ABSORBED} = E_0(1 - \exp(-\mu\rho(r)r))$$

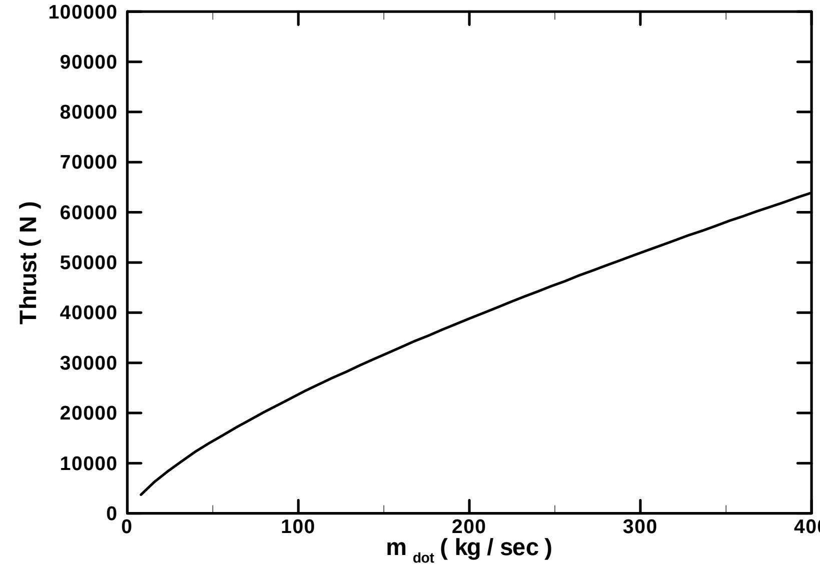
Validation of 1-D Results in 2-D CFD Code. Mass Density Interface Moves Upstream.

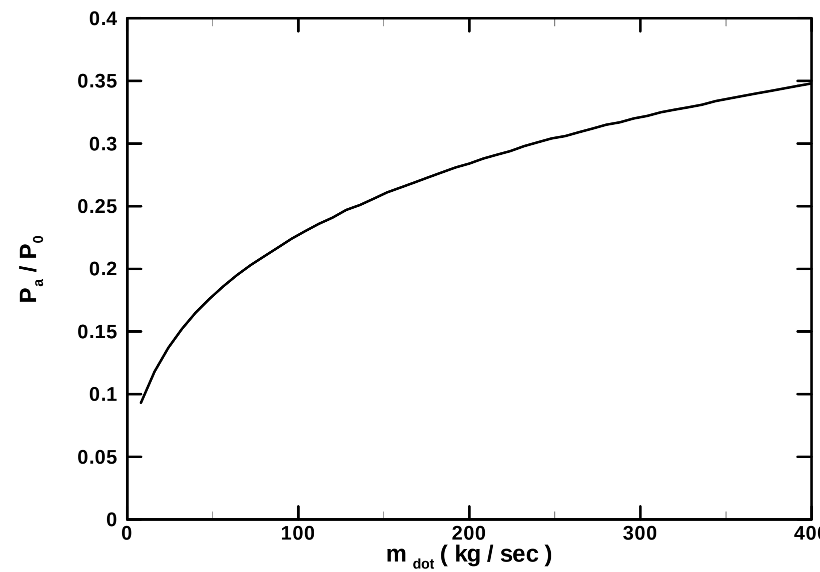


Single species (LN2)

Single-species System Code Results







- "High" Isp (> 200 sec) only occurs with poor efficiency (Pa/P_0 < 10%)
- Single-fluid concept may be infeasible since high density region moves away from energy source.

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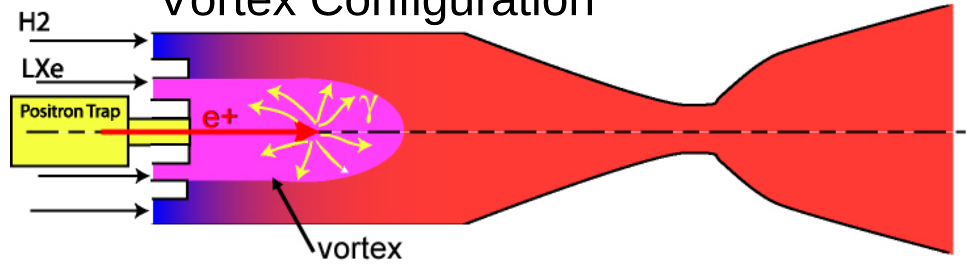
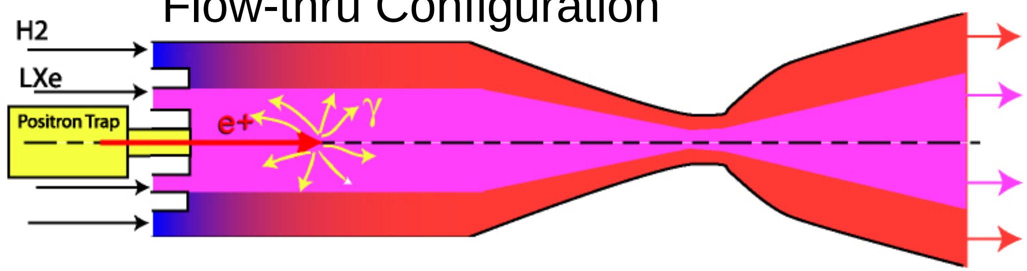
Two-Fluid Concept Variations

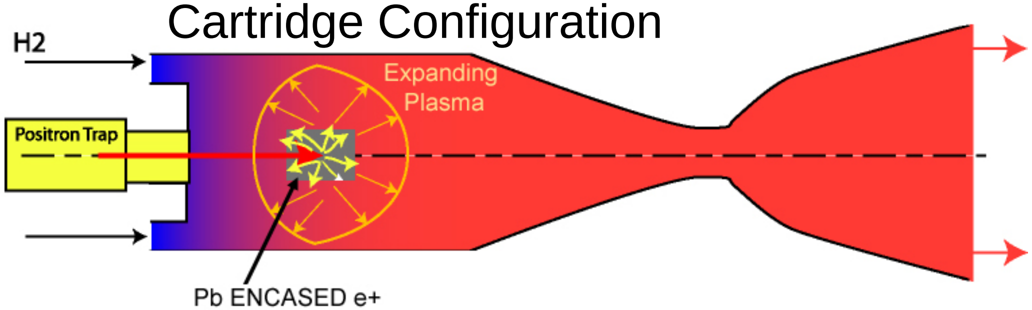
Vortex Configuration



Flow-thru Configuration



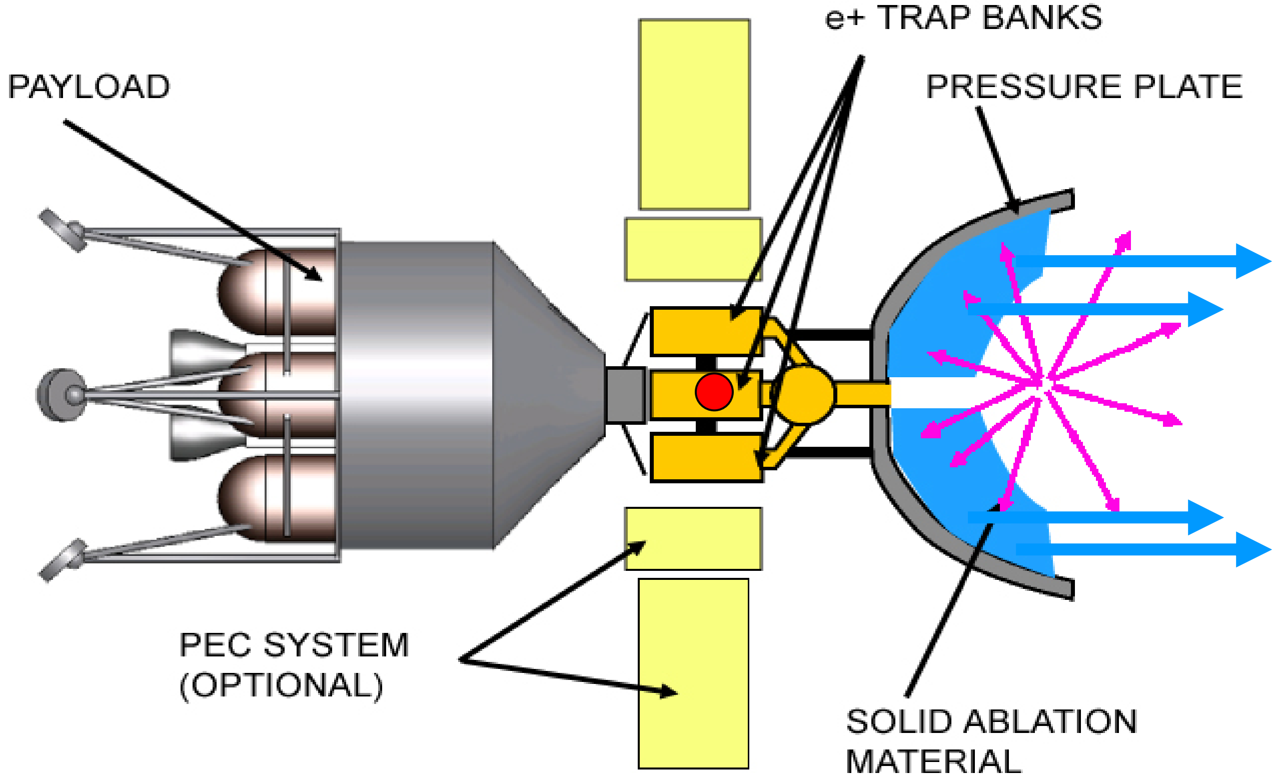
Cartridge Configuration



- Vortex Configuration
  - Will not work because evidence shows heating changes density profiles, causing vortex to destabilize.
- Flow-thru Configuration
  - May behave similar to single-fluid if Xe mass flow rate is significant, reducing I_{sp}.
  - Work in progress.
- Cartridge Configuration
  - e+ encased with Pb annihilate, creating plasma.
  - Lower energy photons heat H2.
  - Early studies show excellent promise with Isp = 2600 sec, with Pb/H2 flow ratio 5:1.
  - Have to examine effects of varying mass density in system, transport to walls, pulsed behavior.

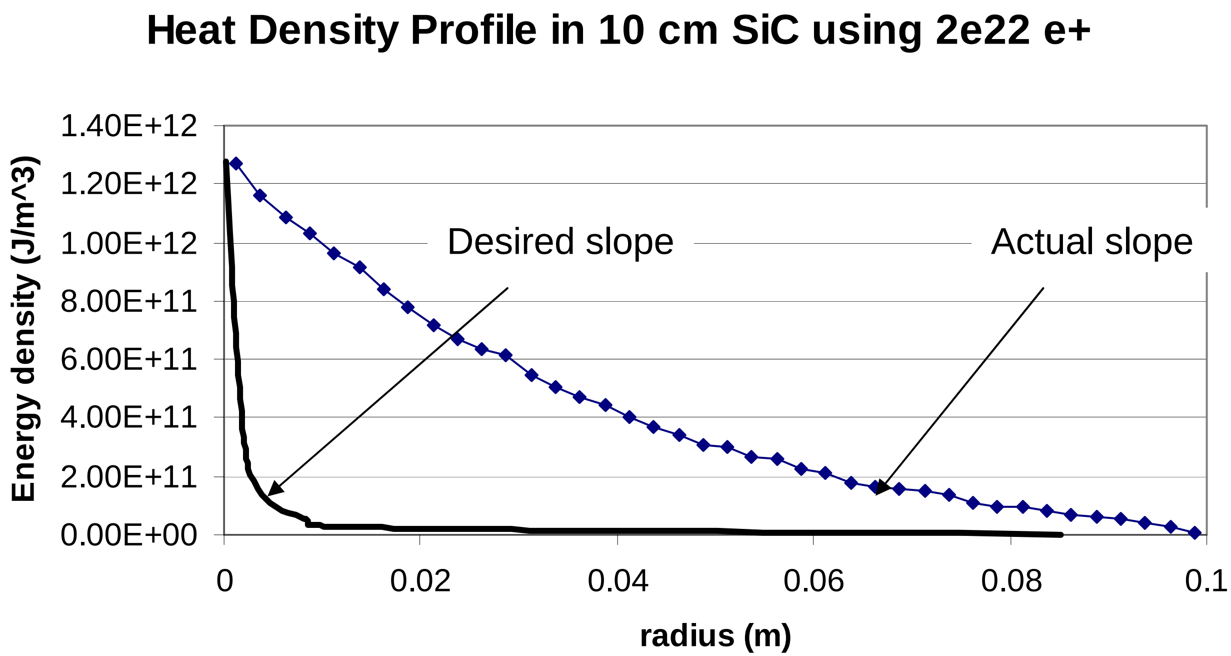
Other Concepts

Solid Ablation Concept as a Realistic Sänger Rocket Keeps High Density Close to Positron Source



- Concept: 21st century Sanger rocket, where solid ablation material replaces unrealistic photon reflector.
- Small prompt radiation in direction of spacecraft still makes system attractive.
- Intrinsic 50% efficiency must be compared against valid gas-core concepts.

Task: Find Optimal Ablation Material and Geometry for 511 keV Gamma Rays



- Minimize penetration depth to increase local energy density at surface for ablation.
- 511 keV gamma rays have long attenuation length.
- Encase e+ cartridges with lead. Lead plasma radiating at lower eV ablates solid propellant such as SiC.* Has similarity to gas-core cartridge concept.

*W. Lance Wertham, "Antiproton-Catalyzed Microfission/fusion Space Propulsion, " M.S. Thesis, Dept. Aerospace Engineering, PSU, 1995.

Phase II Prospectus

- Solid Core Work:
  - A transport design/analysis effort to determine a system that will allow relatively flat radial and axial power profile.
  - Use of codes such as GEANT for attenuation studies. Material identification.
  - CFD analysis for the propulsion engine.
  - Efficiency studies of an integrated power plant with engine.
  - Experimentally design and analyze an electrically-heated heater attenuator w/ gas flow for comparison against code.
- Gas-Core Work:
  - Investigate pulsed behavior of cartridge scheme.
  - Examine wall temperature effects.
- Ablative Sänger Concept:
  - Study penetration depth of gamma rays and derive ablation material(s).
  - Investigate non-impulsive mission scenarios.

Conclusions

- Positron-based engines are “thick”.
  - “Thick” means gamma rays travel further to interact with propellant.
- Solid-Core engine will work.
  - More detailed studies required.
- Gas-core concept
  - High density gas must be kept close to high-energy gamma rays.
  - Means of reducing energies of photons to allow low-Z, high I_{sp} propellant should be investigated.
- Ablative Sänger engine promising based on previous work at Penn State.