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AMTEC for Space Radioisotope Power Applications

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Advanced Deep Space Systems Development Program

- **X2000 Mission System Development**
  - » Development of engineering model spacecraft for outer planets missions
  - » Testbed for flight system component development!
- **Ice and Fire/Outer Planets Exploration Program**
  - » Several Missions being considered:
  - » Europa Orbiter
  - » Pluto Express
  - » Solar Probe

Mission Power Demand

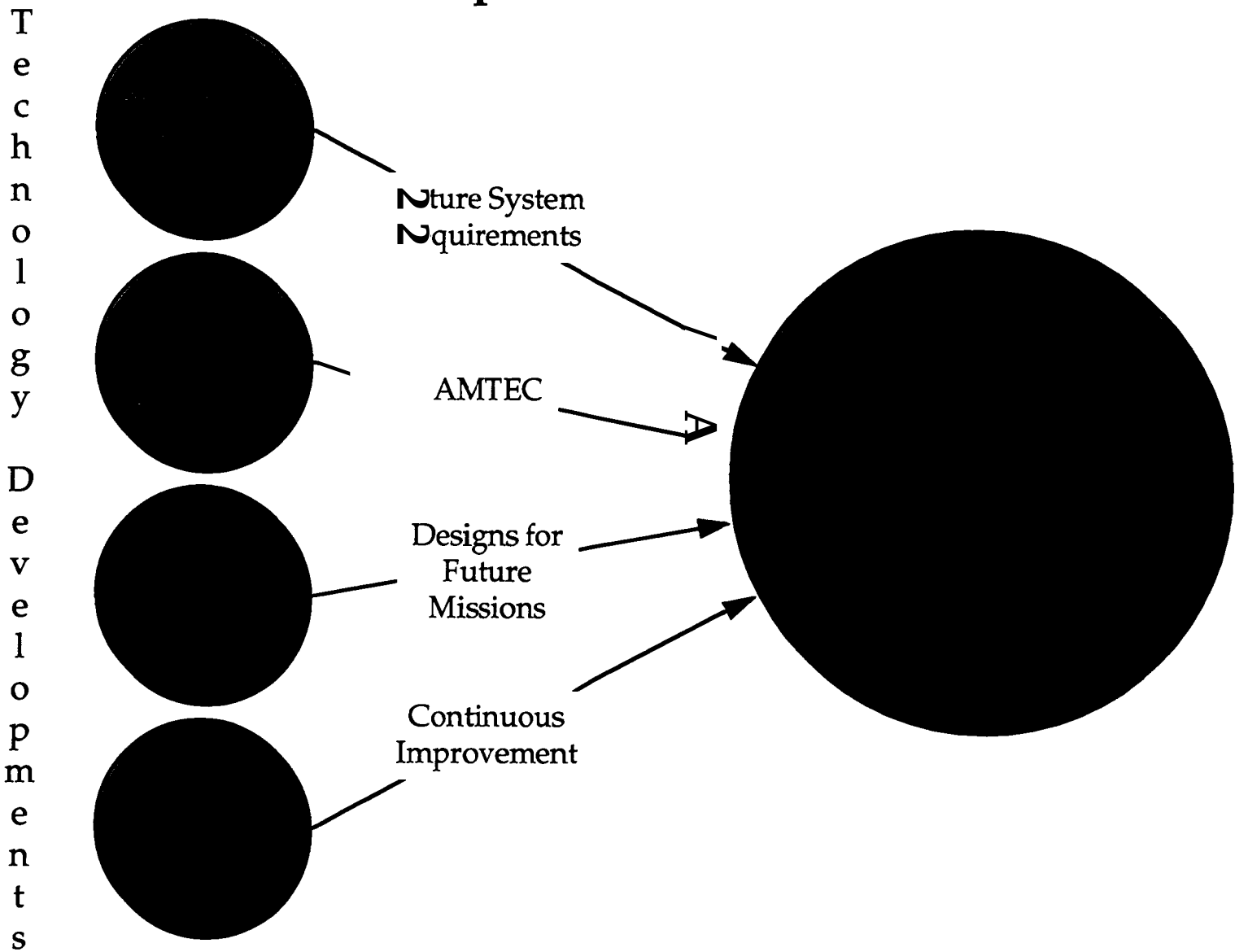
Europa Orbiter	~4 years	1.0 to *5.2* Au	150 W_e	2MRad radiation from Jupiter orbit
Pluto Express	10 to 16 years	*0.7* to 33 Au	104 W_e	Venus Flyby trajectory
Solar Probe	~5 years	5.2 to *0.02 Au*	100 We	Jupiter Gravity Assist trajectory

Power Demand includes **30%** contingency for growth

Advanced Radioisotope Power Source Program

- **Initiated to develop new power sources potentially applicable to new missions**
  - » **Near term needs:**
    - **Europa Orbiter, Pluto Express**
    - **Other Outer Planets Missions**
  - » **Far term:**
    - **smaller, lower power probes**
- **ARPS Plans**
  - » **Develop Advanced RPS for)(2000**
    - **Deliver operational engineering model by end of 1999**
    - **Be prepared to deliver flight ARPS in the event a mission is approved and the ARPS is selected as the power supply**
  - » **Develop third generation power source concepts**
    - **mW, RPS1O through ART (Advanced RPS Technology)**

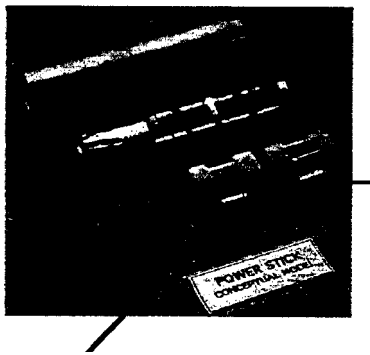
The Radioisotope Power Source of the Future

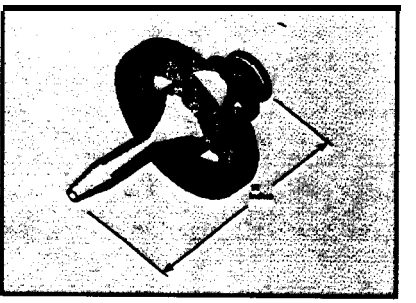


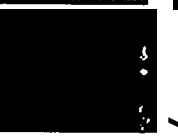
Advanced Radioisotope Power Sources

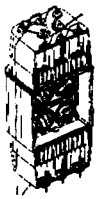
Advanced Technologies:

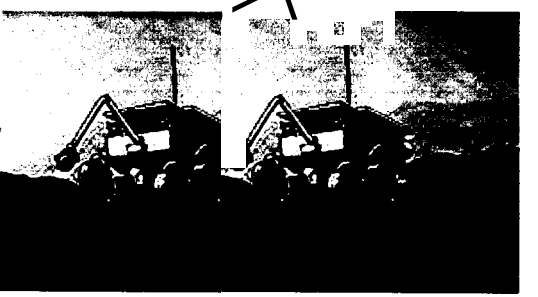
- **New heat source**
  - 2 to 4 W_t class
  - 60 to 120 W_t cl
  - Alternative Rac
- **New con**
  - 0.10 W_e class
  - 10 We class
  - 100 W_e class
- **New therm at.mngt.**
  - Microspacecraft RHU
- **Harsh environments**
  - Hermetically sealed
  - High "g"
  - High temperature
  - High pressure
  - High radiation dose

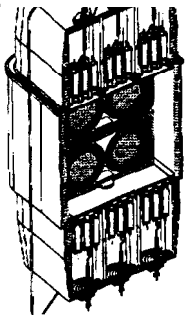


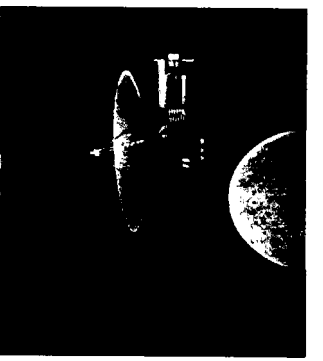




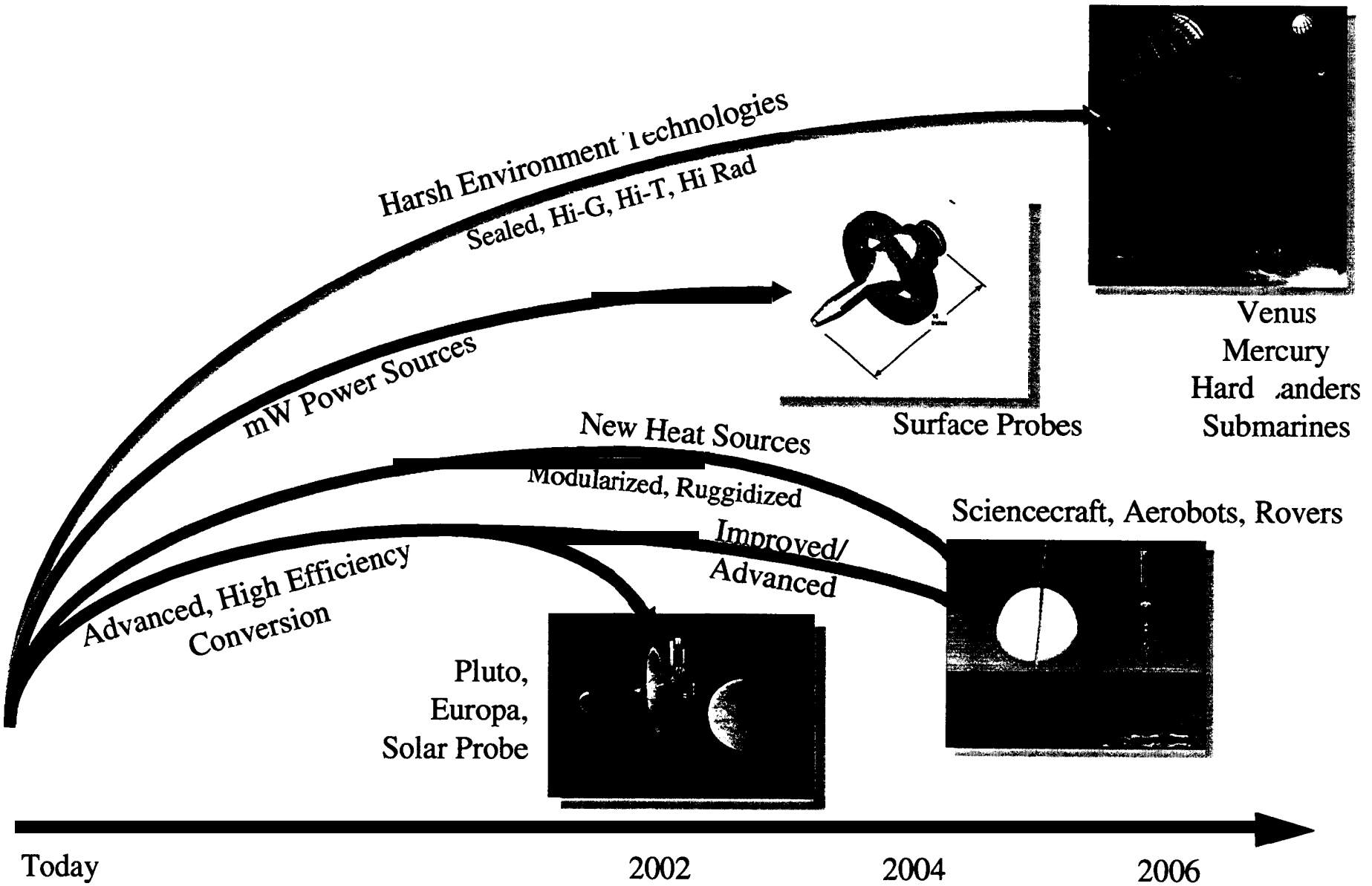




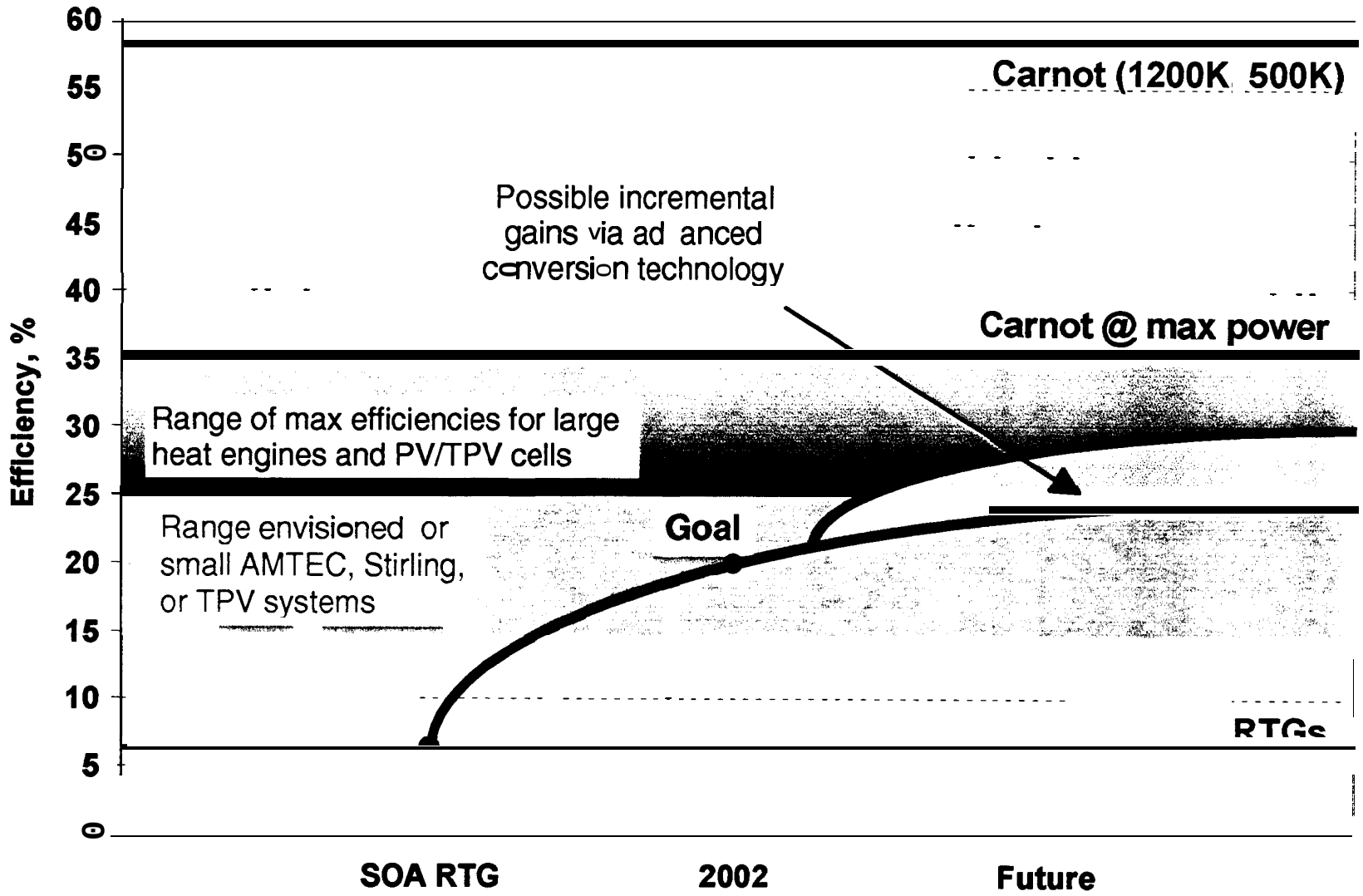




RPS Program Roadmap



RPS Efficiency Compared to Carnot



Advanced Thermal-to-Electric Power Options

- **Advanced Radioisotope Power Source (ARPS) Converter Options Evaluated for)(2000:**
  - AMTEC: Alkali Metal Thermal-to-Electric Converter
    - Thermally regenerated sodium concentration cell
  - Stirling Engine Converter
    - Closed cycle heat engine
  - TPV: Thermophotovoltaic
    - Photovoltaic conversion of thermal radiation
- **All Options use Existing Heat Sources**
  - General Purpose Heat Source modules inherited from Cassini spare RTG
  - Available after 1997 launch of Cassini
  - Note: all systems concepts may be optimized at different points to increase power or decrease mass. Further design and development work is required.

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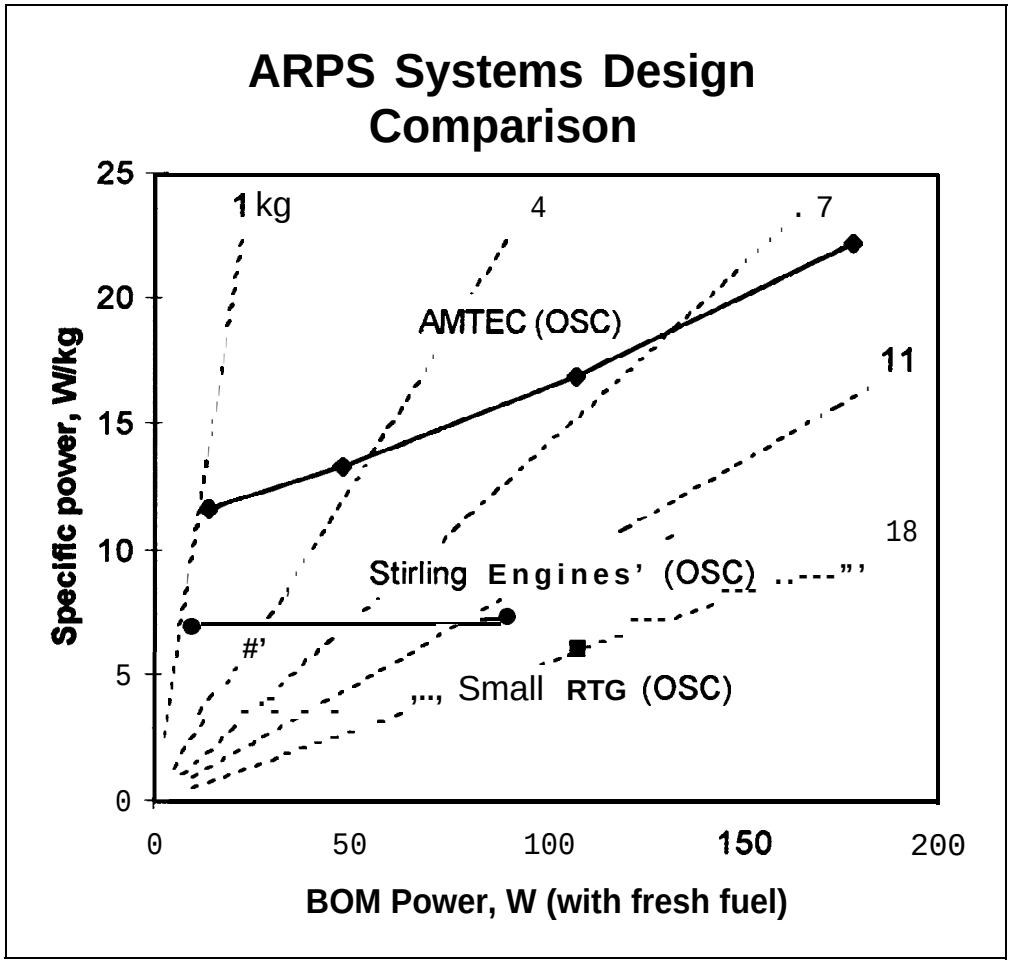
X2000 ARPS Technology Selection

- **Technology Evaluation Team Evaluated Status of Each Option**
  - » DOE led evaluation team with AFPL, JPL, and NASA participation
  - » DOE/NASA/JPL Management Team made selection
- **Status**
  - » Evaluation Complete: AMTEC was selected
  - » DOE RFP issued Feb 17,1997
    - – Seeking Systems Contractor for X2000 ARPS development
  - » Proposals being evaluated
- **Technology Evaluation Criteria**
  - » Performance (demonstrated performance and projected system)
  - » Development and Cost/Production and Cost/Schedule Risk
  - » Spacecraft Interface and Operations
  - » Ability to Scale Conversion (50 W, 10 W)
  - » Safety Impacts
- **ART Workshop being planned for June, 1997**
  - » Sponsored by DOE

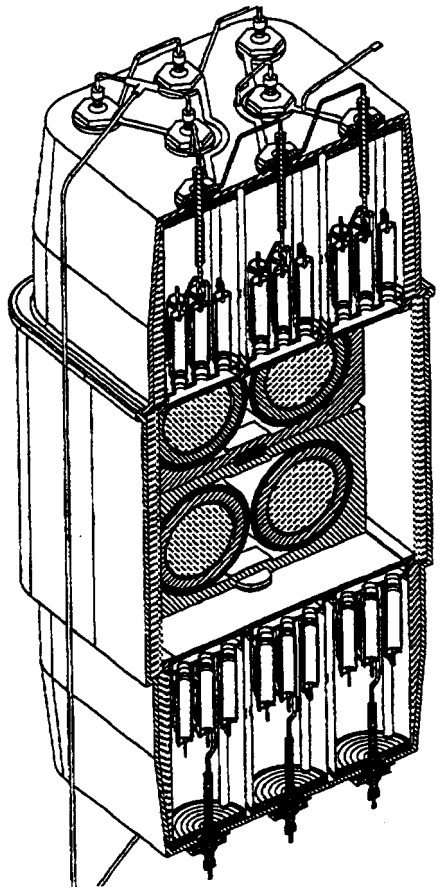
Key Trades: AMTEC or Stirling?



- **S/C Interface & Operations Comparison**
  - » **AMTEC**
    - **No issues that impact the s/c**
  - » **Stirling Engines**
    - **Possible 90 Hz vibration**
      - **Up to 0.2 N force in axis of motion**
      - **Less than 3.15 N-m spec**
        - » **depends on s/c configuration**
    - **EMI of AC power output**
    - **Engine control electronics**
      - **part of s/c avionics**
      - **active control of engine phase**
      - **engine lock-out on failure**
      - **mass of electronics (~1 kg) not included with design mass**
- **Development Status**
  - » **Stirling engines have a lower risk for development compared to AMTEC due to higher level of maturity**

AMTEC Systems Concept

- **Advantages**
  - Low mass
  - Few GPHSS
  - Small radiator
  - Rejected heat (300 “C) useful for s/c thermal control
  - No radiation degradation
  - Static except for Sodium
  - Potential for space solar-thermal and commercial terrestrial applications
- **Issues**
  - Microgravity operation not demonstrated
  - Lifetime not demonstrated
  - System performance not demonstrated



AMTEC Design from:
Schock, A., Noravian C., Or, C., and Kumar, K., (1997) “Design of Radioisotope Space Power Systems Based on **Multitube AMTEC** Converters,” **Orbital** Sciences Corporation, Germantown MD.

2 GPHS version, 6.3 kg
79 We after 12 years

3 GPHS version, 8.0 kg
133 W_e after 12 years

with Cassini spare GPHSS

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AMTEC Critical Issues

● Issues and Concerns

» **Microgravity** Demonstration

- **Multicell** Performance

» Systems Performance Demonstration

- Validate performance prediction code

» System Lifetime Development

BASE Tube

Anode & Cathode

Sodium Wick

Materials compatibility with sodium

- S. Steel, Mo, coatings, brazes, volatile constituents (Cu, Ag)

Electrical Feedthrough at 300 "C

- Metals & braze in sodium, air, vacuum

Multitube cells& system lifetime prediction

Flight design cells life verification

● Accomplishments to Date

» AMTEC Flight Experiment being developed for launch on **STS-88**

» AFPL 8 cell prototypic test

- by summer 1997
- 900 "C hot end, 300 "C cold end

» Lifetime

Single Cell:
2500 hrs at prototypic temp
>10,000 hrs at lower temp (separate cell)

BASE Tube:
No obsewed degradation
Evidence that ceramic gets stronger

Wick
Heat pipe data **supports** long life times

Anode & Cathode:
Long life predictions

Brazes:
No obsewed failures, eliminate Cu and Ag components

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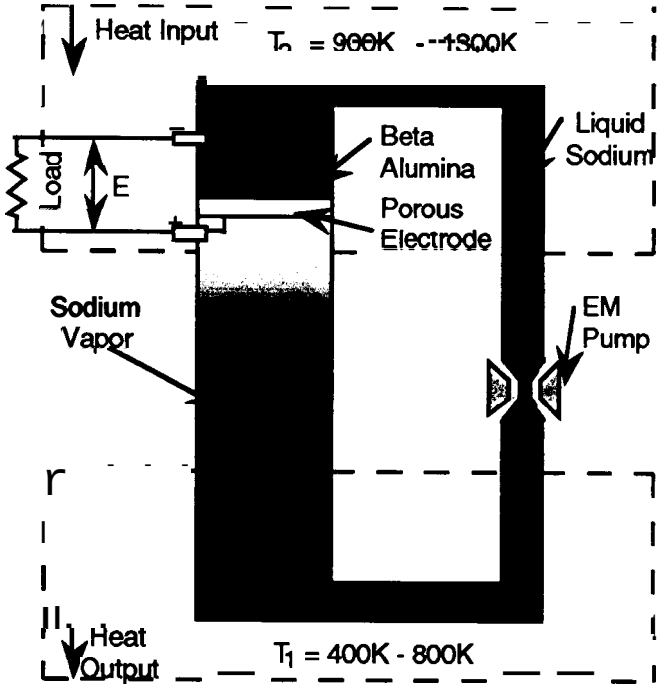
AMTEC Fundamentals

- **AMTEC - Alkali Metal Thermal-to-Electric Converter**
  - » Thermally Regenerated Sodium Concentration Cell
  - » Static System with working fluid circulated in a capillary wick
  - » Thermal to electric efficiency predicted 20 to 30%
  - » Industry Developer: Advanced Modular Power Systems (AMPS) of Ann Arbor, Ml.
- **Recent AMTEC Advances**
  - » Cell operation at 18% efficiency
  - » Demonstration of multi tube cells that promise up to 30% efficiency
  - » Lifetimes > 1 year (not at design temperatures)
  - » Component lifetime models predict very long life possible
  - » Flight Validation Experiment in progress
    - included successful shock and vibration test of cells
  - » Systems design predict 15 to 18 W/kg possible at the ~100 W level with GPHSS



AMTEC Development Status - Systems Demonstration

- **AFPL/NASA Funded Demonstration**
  - » One half of a generator, electrically heated
- **DOE RFP plans**
  - » Includes AMTEC development as the converter technology
  - » Full Scale Engineering Prototype (electrically heated)
    - First by end of 1998
    - – Second by mid 1999, Delivered to DOE for NASA/JPL Testing
  - » Qualification Model delivered by end of 1999 (electrically heated)

AMTEC Development Status - Lifetime Validation

- **AMPS Program**
  - » Demonstrated lifetime of operations cells
  - » Demonstrated and Projected lifetime of components
- **JPL Program re-started**
  - » Will build on existing models
  - » Will evaluate AMPS cells and components
  - » Will incorporate accelerated testing
- **DOE RFP Includes Lifetime Validation**
  - » Will be coordinated with JPL and AMPS

AMTEC Development Status - Microgravity Demonstration

- AMTEC Flight Experiment
- Manifested on STS-88
  - Launch date TBD (along with first 1SS assembly flight)
- Data Analysis and Report Complete 3 months after launch