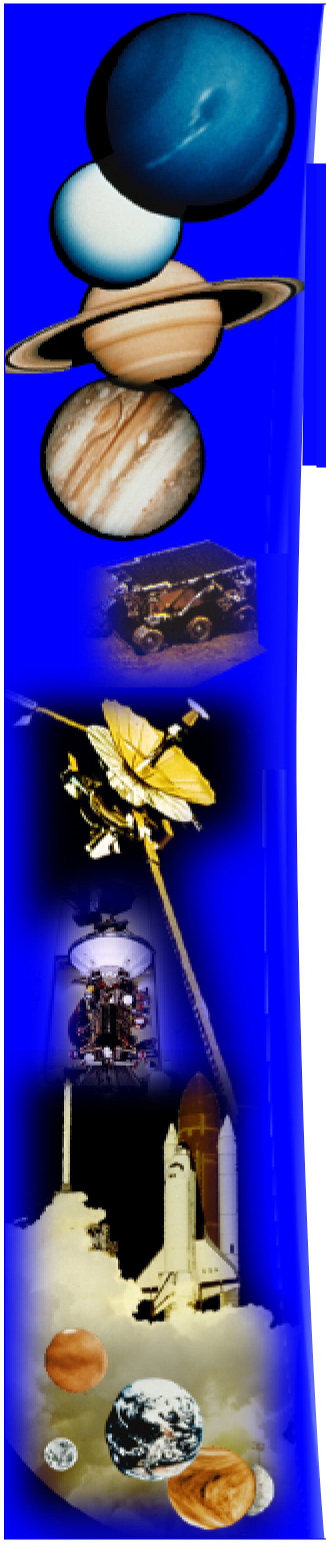


DOE Activities in Space Fission Technology

Jack Wheeler
Space and Defense Power Systems
Office of Nuclear Energy, Science & Technology

November 6, 2001

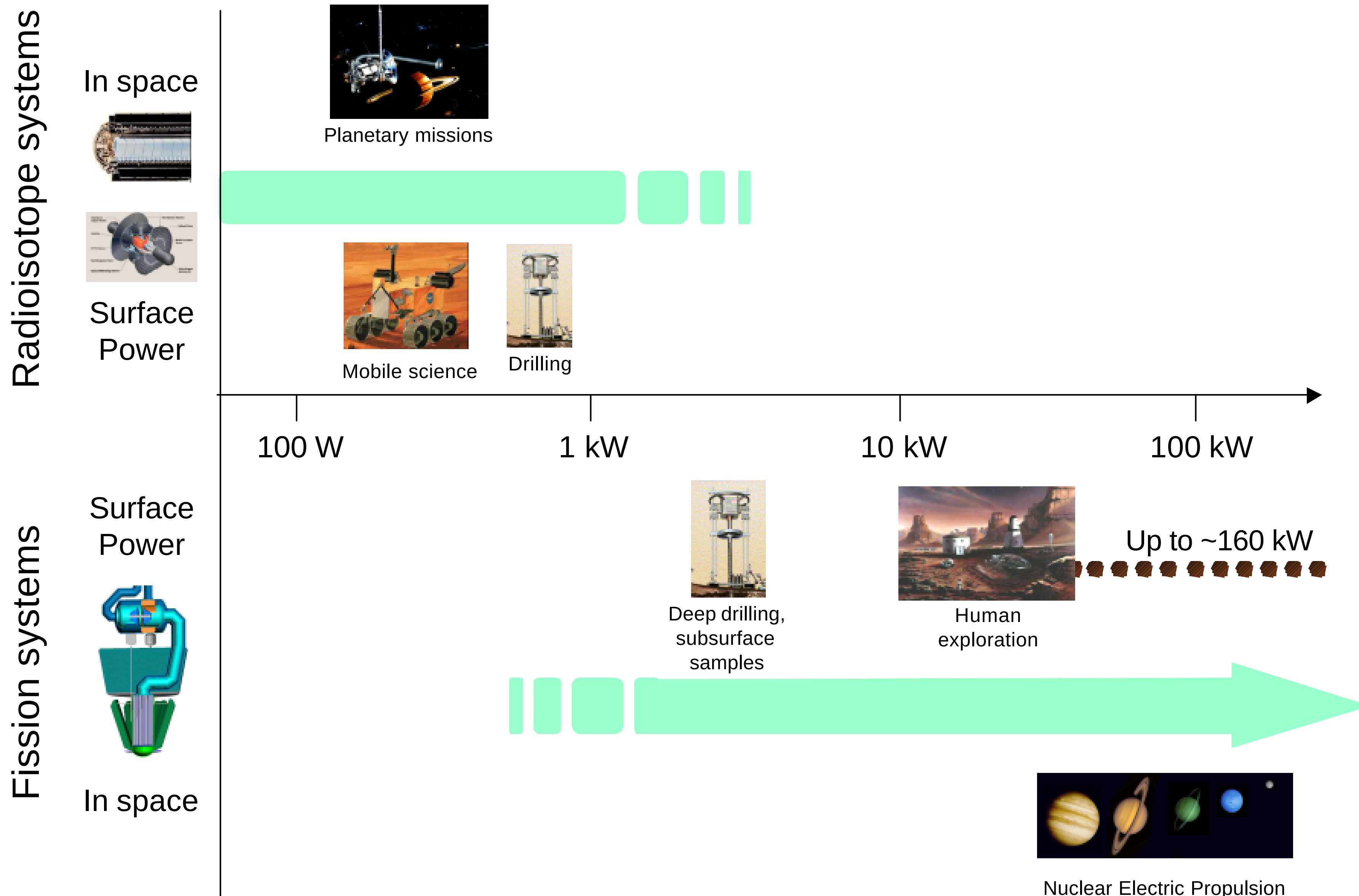
Office of Space and Defense Power Systems

Mission: *Design, develop, demonstrate and deliver compact, safe nuclear power systems and related technologies for use in remote, harsh environments, such as space*

Responsibilities:

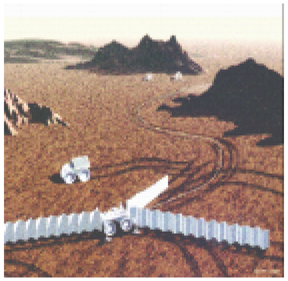
- System development and test
- Safety analysis
- Maintenance of assembly and test infrastructure
- Integration and launch support
- Environmental Impact Statement support
- Public relations support
- State Department support for UN deliberations

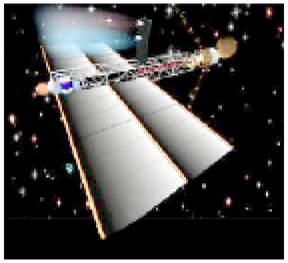
Fission Energy Required for Higher Power Applications



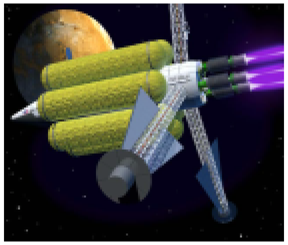
Types of Space Fission Systems Included In Assessment

- **Surface Power Systems**
  – Robotic missions to conduct science, perform exploratory drilling, prove resource utilization
  – Human missions for science, life Support, transportation, propellant production

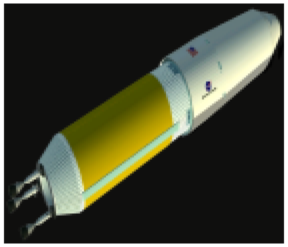




- **Small In-space Power Systems--for nuclear electric propulsion (NEP)**
  – Propulsion for robotic science missions--shorter transit times, longer duration, planetary rendezvous, and increased power for science and observation on arrival



- **Multi-Megawatt Power Systems**
  – For rapid inter-planetary transport and human exploration

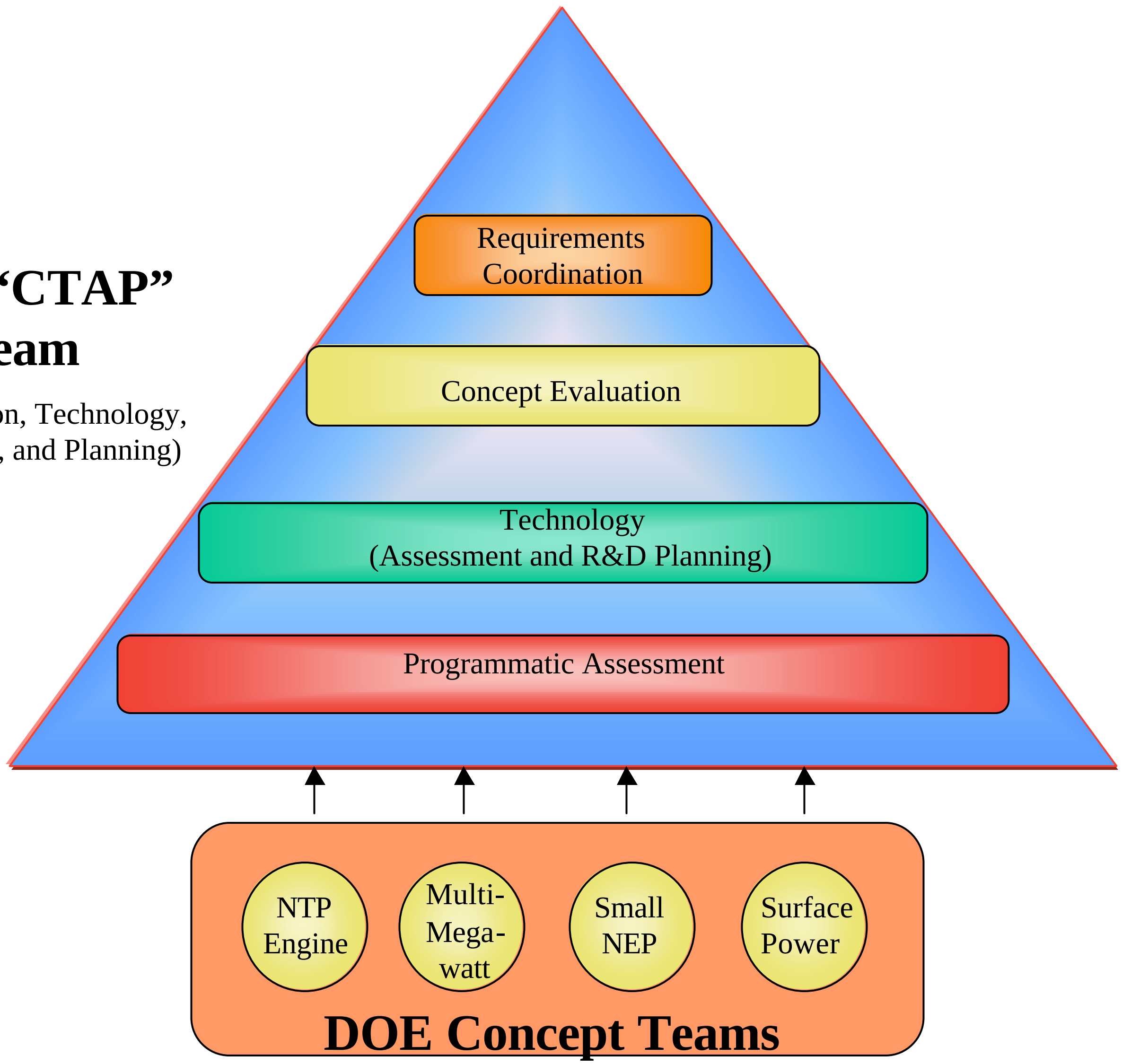


- **Nuclear Thermal Propulsion (NTP)**
  – Propulsion and power (bimodal) for cargo and piloted missions

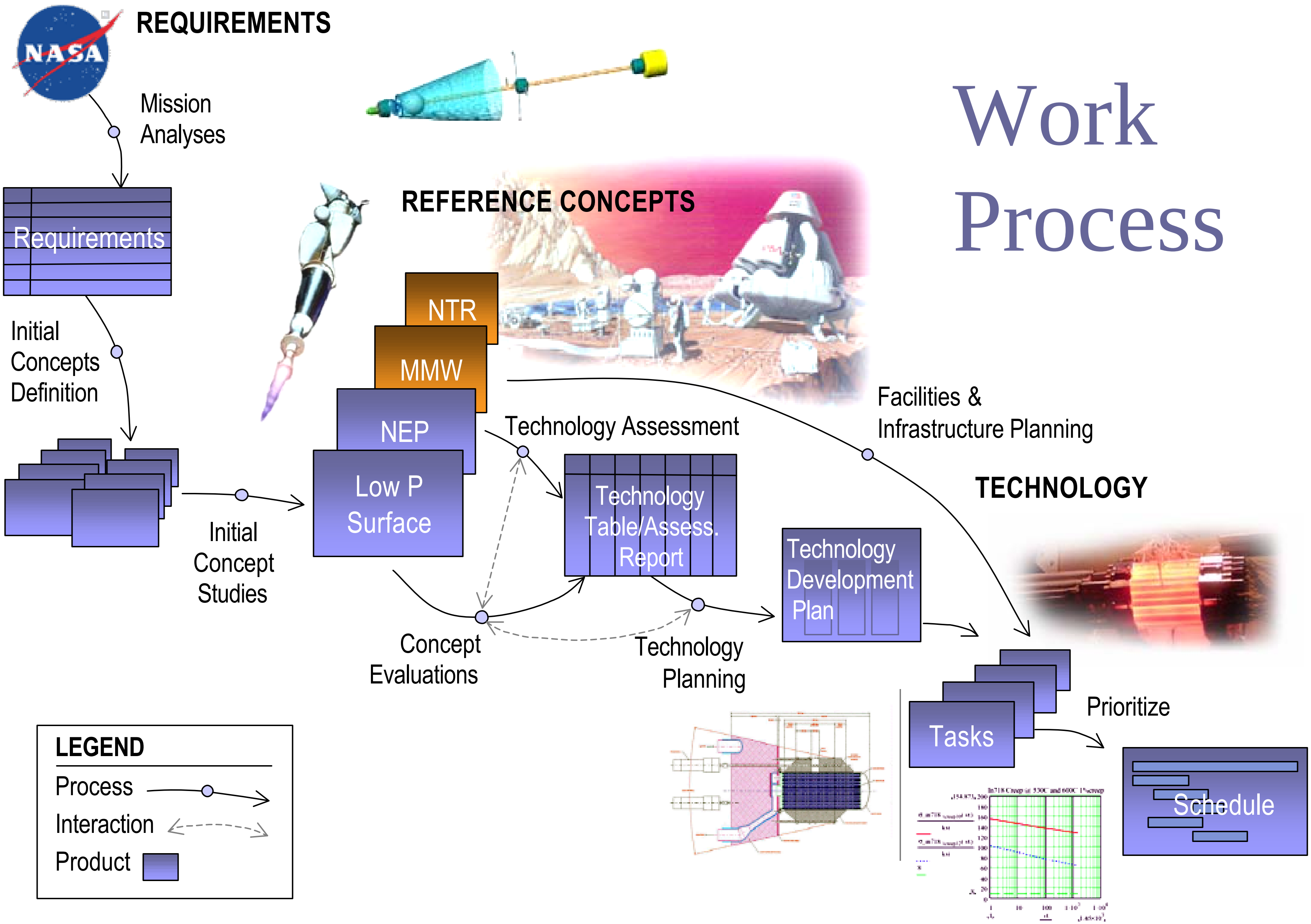
Structure for Assessment

DOE "CTAP" Team

(Coordination, Technology, Assessment, and Planning)



Work Process



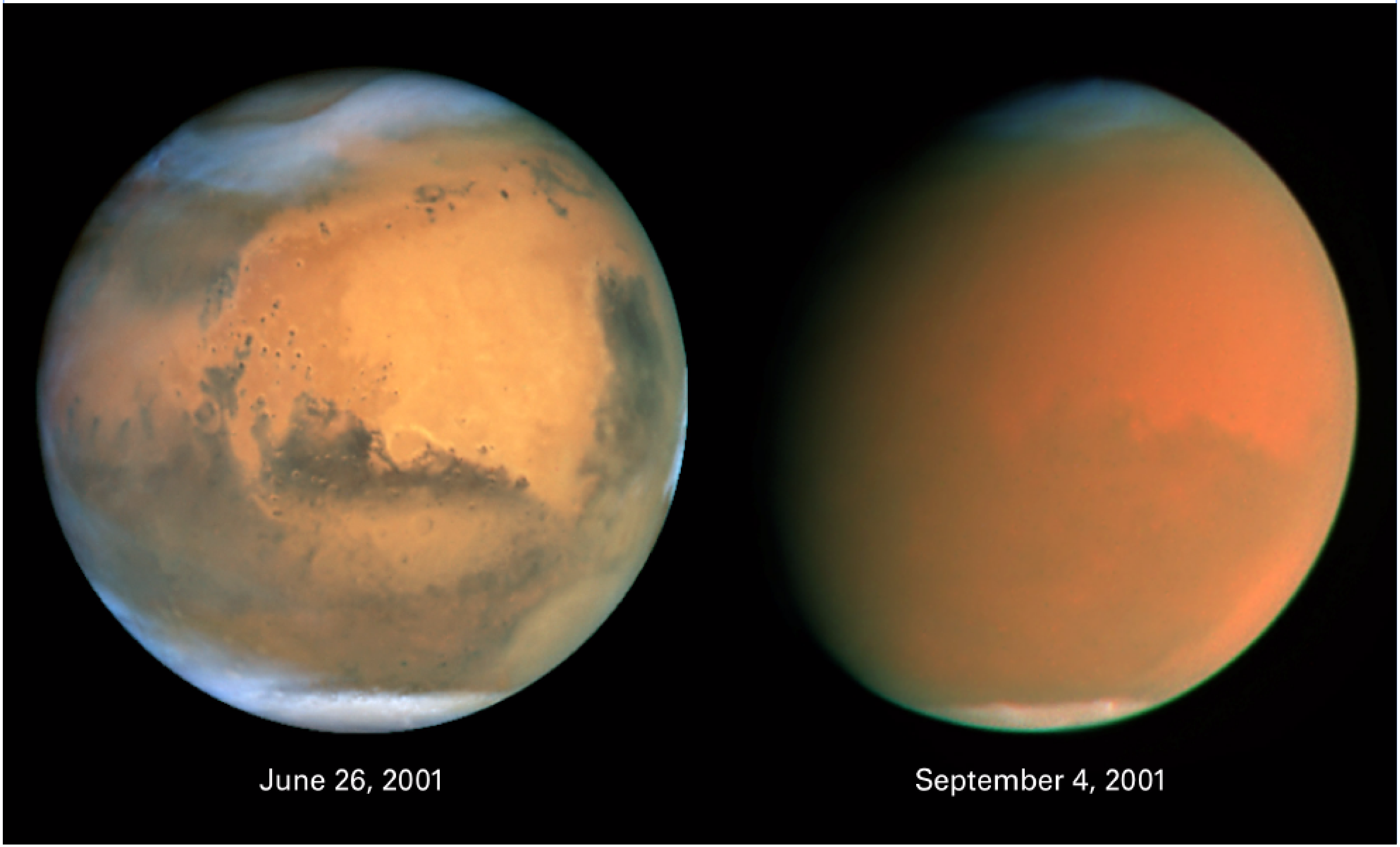
Mission-System Requirements Summary

Mission	Power level	Lifetime	Mass	Payload dose/shield	Operating environment	Other
	Fission System Requirements					
In-space NTP						
Human Mars exploration (Bimodal operation)	335 MWt (25-50 kWe)	1 hr total = 2 yrs standby (5+ yrs)		10^{13} n/cm^2 (1 MeV equiv) 5 x 10^5 Rad (Si) Shadow to 4 m diam spacecraft @ optimum separation	Earth-Mars space	Restarts for 4-6 burns over mission; 2500-3100 K H_2 exit temperature
Outer planet (Bimodal operation)	20.5 MWt (20 kWe)	< 1 hr (10+ yrs)		"	Interplanetary space	
Mars surface						
Initial robotic	2-5 kWe	5-10 yrs		10^{13} n/cm^2 (1 MeV equiv) 5 x 10^5 Rad (Si) 2-pi @ $\leq$ 1 km	Mars atmosphere & dust	Pre-launch sterilization
Outpost/human precursor	15 kWe 20 kWe goal	5 yrs; 10 yrs goal	$\leq$ 1700 kg	"	"	"
First human mission	45-60 kWe	15+ yrs		4-pi, 5 rem/yr @ 90° 50 rem/yr @ 270° @ 2-3 km	"	"
Follow-on human exploration	100-160 kWe	15+ yrs		"	"	"
In-space NEP						
Outer planet	50 kWe	5 yrs full power; 10 yrs standby	< 2500 kg	10^{13} n/cm^2 (1 MeV equiv) 5 x 10^5 Rad (Si) Shadow @ optimum separation	Interplanetary space	
Interstellar	180 kWe	~ 10 yrs		"	Interplanetary & deep space	
High power EP VASIMR for human Mars	5-10 MWe per unit;	<1 yr full power; 30-day standby	4 kg/kWe goal	10^{13} n/cm^2 (1 MeV equiv) 5 x 10^5 Rad (Si) Shadow @ optimum separation	Earth-Mars space	

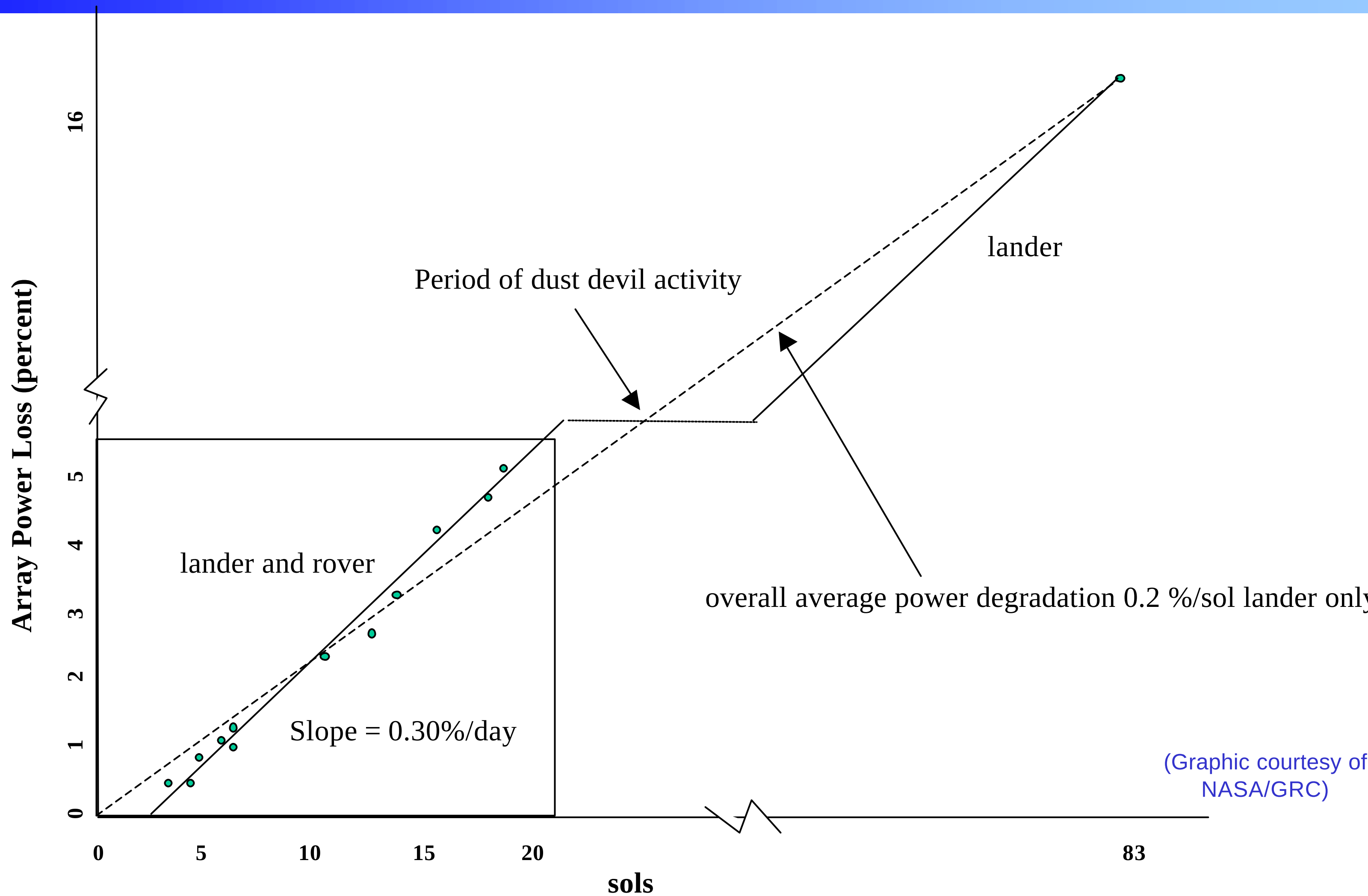
Proposed Near-Term Concept Evaluation Set

Concept	Fuel	Clad	Spect	Reactor Cooling	Max Fluid Temp	Power Conver-sion	Heat Rejection Mechanism	Power Level	Technology Base
In-Space:									
Gas-Cooled & Brayton	UN	Nb1Zr	Fast	Pumped He-Xe	1250 K	He-Xe Brayton	Low-T, Flat or Conical, LHP, H2O	50 kWe	SP-100, GRC, PW, Allied, Allison, Capstone, HTGR, ACRR
Heatpipe & Brayton	UN or UO2	Nb1Zr or Moly	Fast	Li Heatpipe	1350 K	He-Xe Brayton	Low-T, Flat or Conical, LHP, H2O	50 kWe	SP-100, LANL HP, GRC, PW, Allied, Allison, Capstone
Liq Metal & Brayton	UN	Nb1Zr	Fast	Pumped Li	1400 K	He-Xe Brayton	Low-T, Flat or Conical, LHP, H2O	50 kWe	SP-100, GRC, PW, Allied, Allison, Capstone
Mars Surface:									
Heatpipe & Stirling	UN	SS	Fast	Na Heatpipe	1000 K	Stirling	Vertical panels	3 kWe	SP-100, LANL HP, GRC, STC
Liq Metal & Stirling	UZrH	SS	Moder ated	Pumped NaK	800 K	Stirling	Vertical panels	3 kWe	SNAP, SP-100, GRC, STC

The Perfect Storm



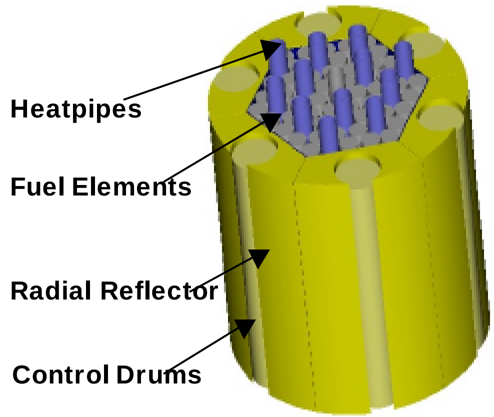
Dust Accumulation Reduced Mars Pathfinder Power by ~16% in 83 Martian Days

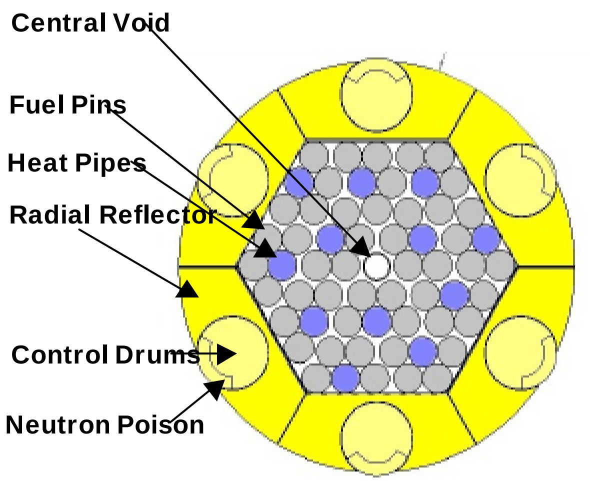


(Graphic courtesy of NASA/GRC)

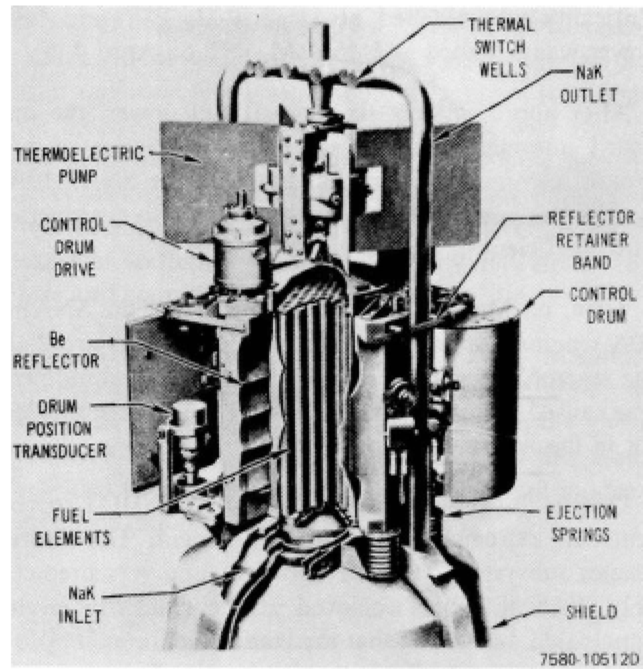
Measured Power Loss (dust coverage) for Sojourner Rover and Pathfinder Lander Photovoltaic Arrays (GaAs 18% efficiency cells)

Mars Surface Power Concepts



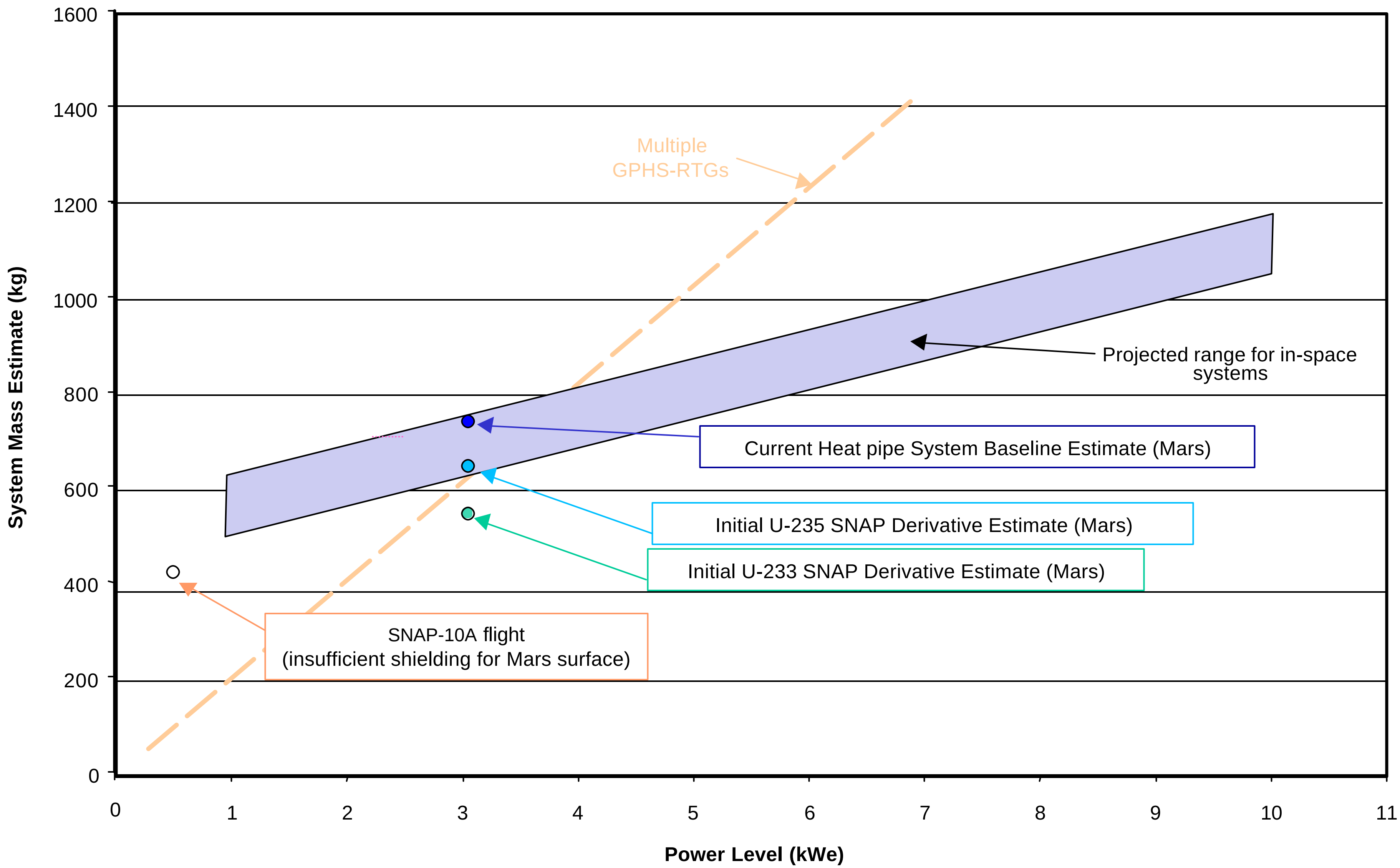


UN Fueled, Heat Pipe Cooled Stirling Engine

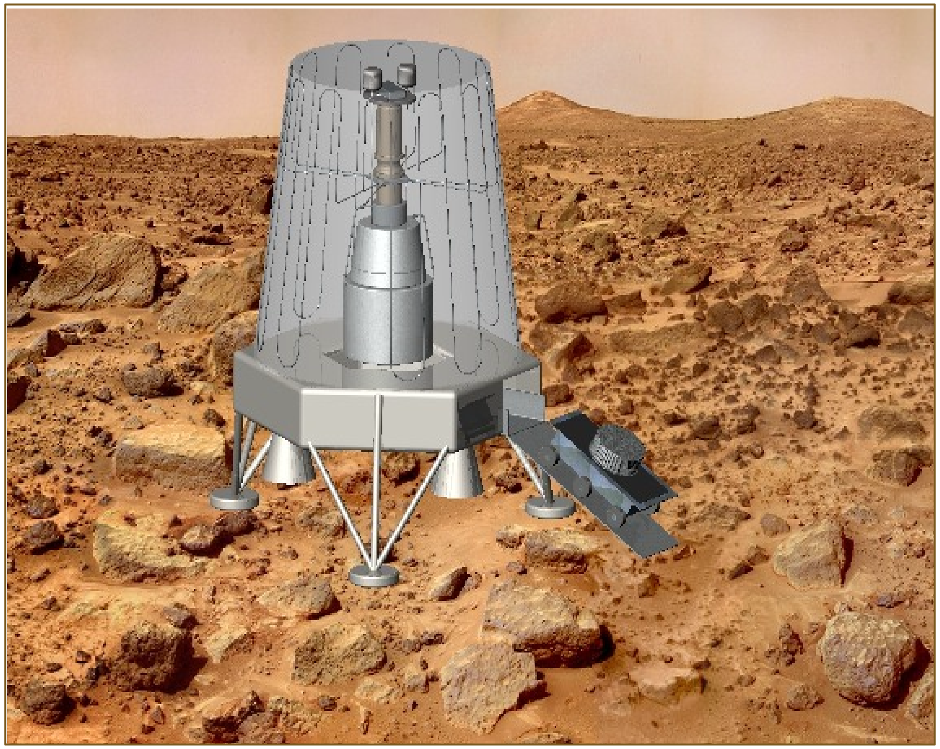


SNAP-10A (U-Zr)H Fueled, NaK Cooled Stirling Engine)

Small Fission Power System Mass Estimates



Very Small Fission Systems: 3-kWe Mars Power System (*Preliminary Concept)*

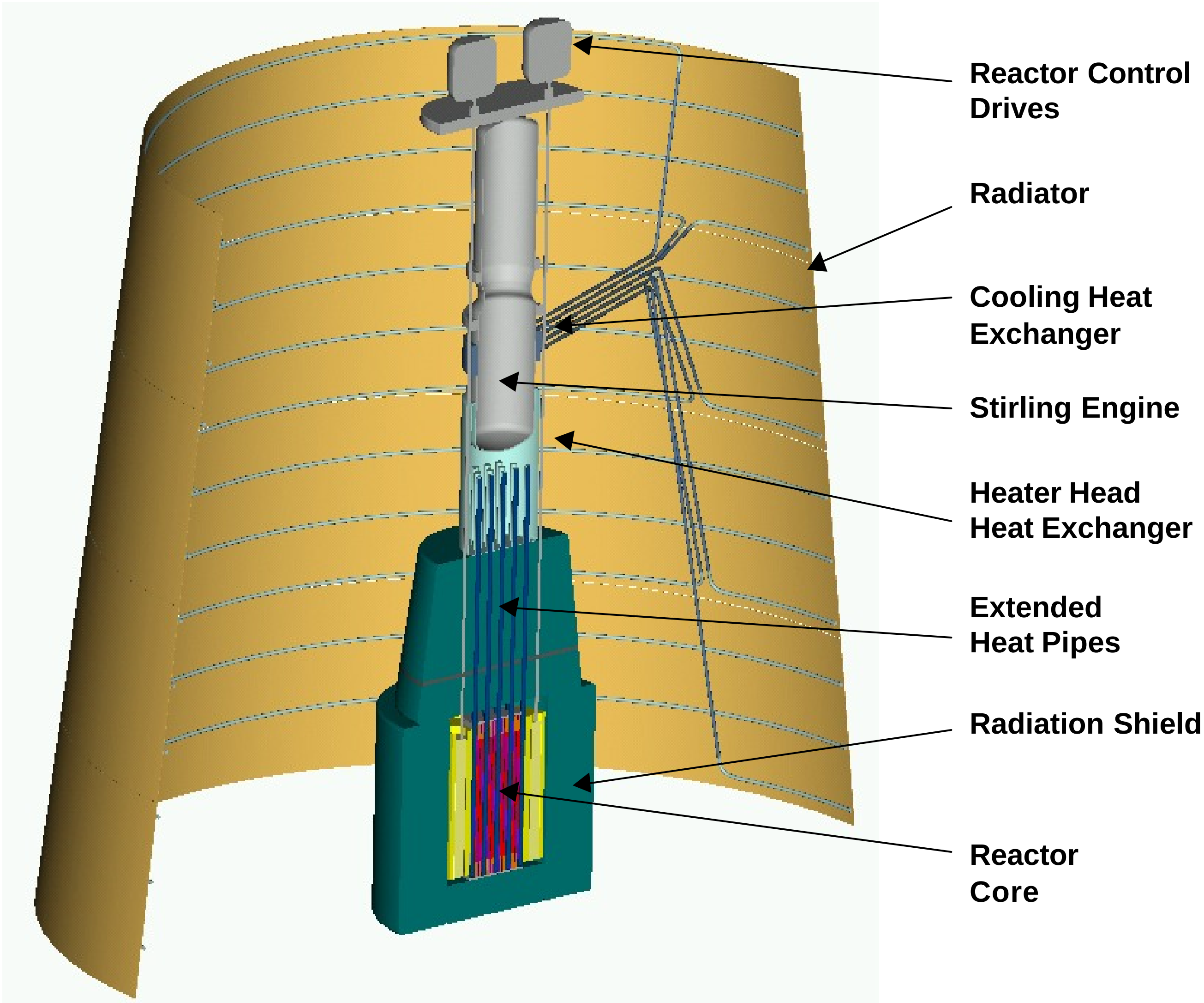


System can be designed to evolve to meet near and intermediate-term future needs

(in-space power, human missions)

- 3 kWe EOM power
- 5 -10 year life
- 2.1 m high x 2.0 m OD
- Scalable to higher power
- Propose science mission/ system integration study for '02

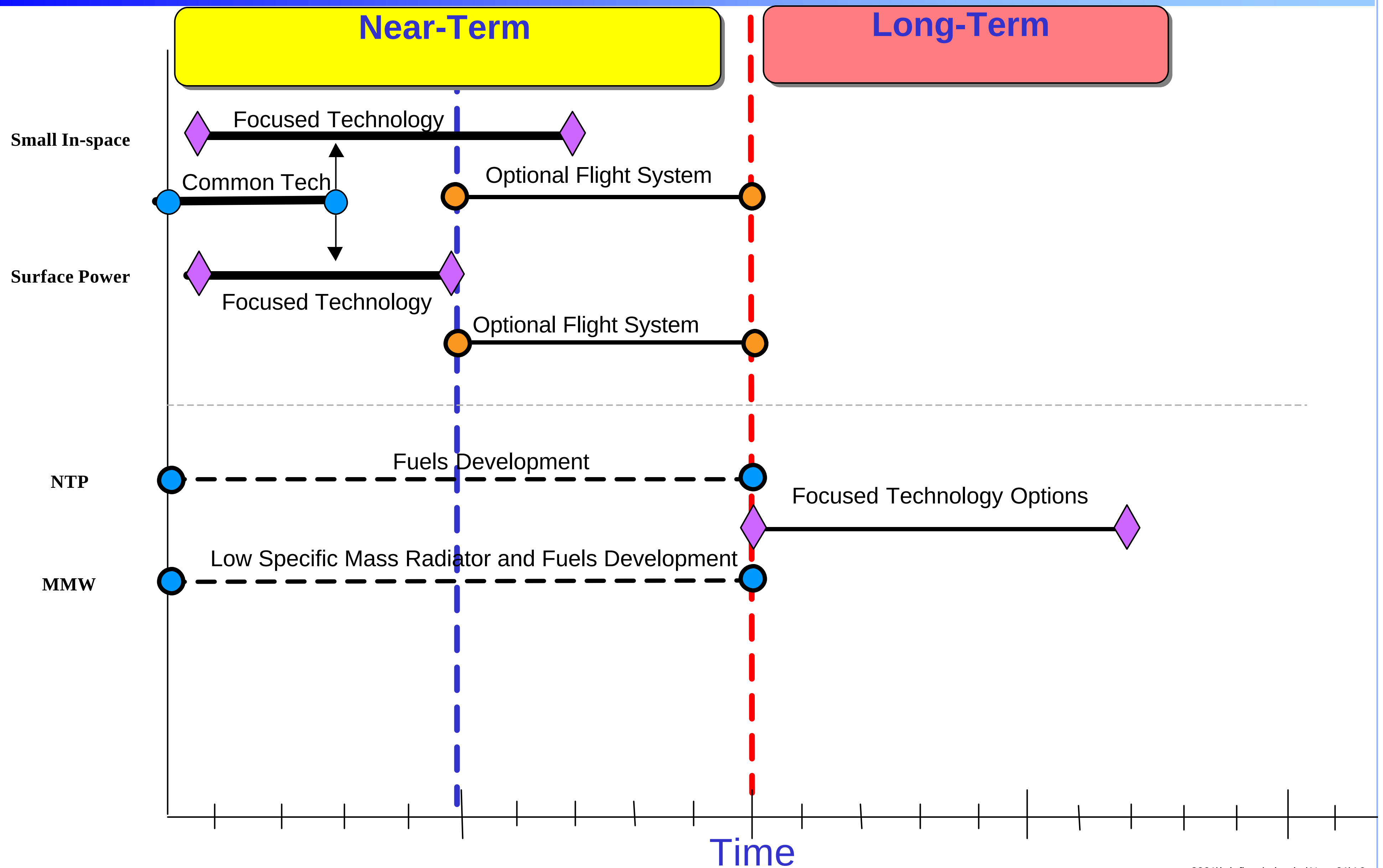
Heatpipe Operated Mars Exploration Reactor
3 kWe Design Description



Technology Development Strategy

- **Utilize past investments in space nuclear systems to reduce development cost**
- **Technology work to be focused and directed**
  - focused on nuclear subsystem
  - directed by work on guiding concept(s) and applications
- **Emphasis on near-term systems**
  - smaller level of effort on more advanced technologies/applications
- **Plan will evolve over time as more specific information and requirements develop and issues addressed**

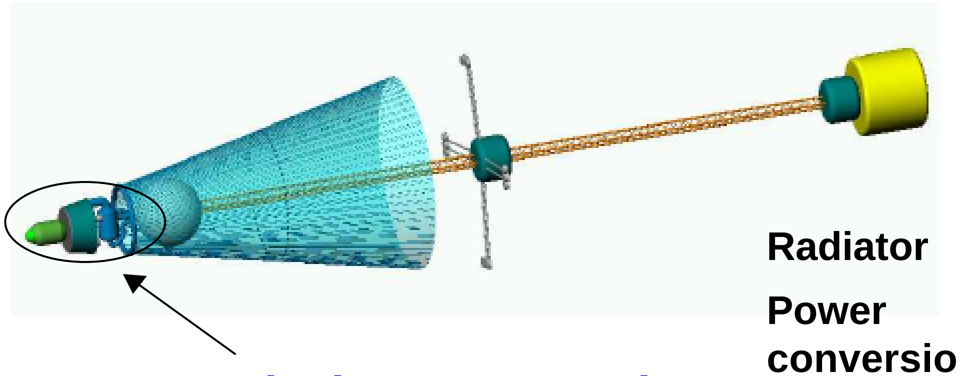
Fission Technology Plan Approach



Space Fission Technology Plan

- Preliminary DOE Technology Development Plan undergoing review
- Focused on nuclear subsystem
- Seeks to set direction for possible future DOE activities that could complement NASA technology activities in related areas

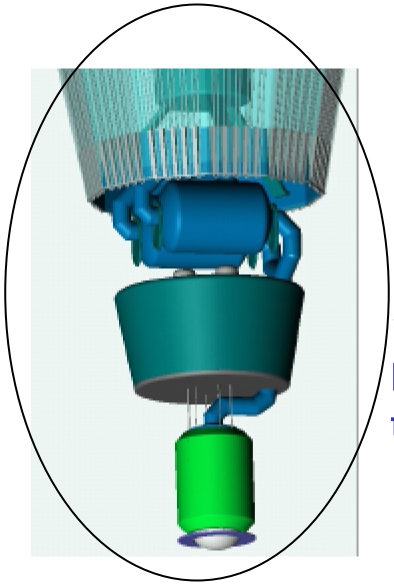
Nuclear Electric Propulsion Vehicle



Fission Power Unit

Radiator

Power conversion



Shield

Heat transport

Reactor

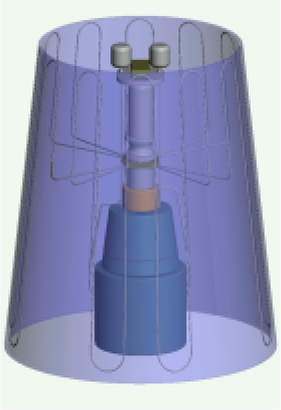
Nuclear Subsystem

Preliminary Concept/Technology Matrix for Near-Term Systems

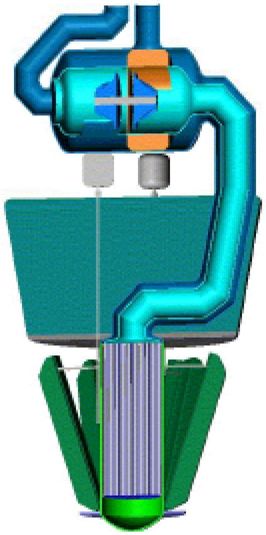
Concept	Core Cooling Components	Fuel: Primary	Fuel: Alternate	Clad: Primary	Clad: Alternate	Reactor Control: Primary	Reactor Control: Alter-nate	Shielding	I&C
In-Space (50kWe):									
Gas-Cooled & Brayton	Pumped He-Xe Loop with Tmax= 1250 K: Compressors, bearings, seals, possible gas-gas HX, fan technology	UN		Nb alloy with Re diff barrier	Ta alloy with Re diff barrier	Solid, movable reflectors (Be, BeO); B4C Control rods	Burnable poisons (Gd2O3, Sm2O3)	Integrated gamma (W) and neutron (Be, B4C, LiH) shield assemblies	Sensors, Processors, Controllers, Switches, Wiring, Insulation, Feedthroughs, Emergency Control Power
Heatpipe & Brayton	Li Heatpipe (Tmax= 1350 K), liquid metal-gas HX		UO2		Ta alloy with Re diff barrier (for UN) or Mo (for UO2)				
Liq Metal & Brayton	Li Coolant Loop (Tmax= 1400 K): liquid metal-gas HX, EM Pump								
Mars Surface (3kWe):									
Heatpipe & Stirling	Na Heatpipe (Tmax= 1000 K); Convective Liquid Metal HX	UN	UO2	SS	Super-alloys	Solid, movable reflectors (Be, BeO); B4C Control rods	Burnable poisons (Gd2O3, Sm2O3)	Integrated gamma (W) and neutron (Be, B4C, LiH) shield assemblies	Sensors, Processors, Controllers, Switches, Wiring, Insulation, Feedthroughs, Emergency Control Power
Liq Metal & Stirling	Pumped NaK Loop (Tmax=1000 K): Liquid Metal HX, EM Pump	UZrH		SS	Super-alloys or Nb Alloy				

Assessment Summary for Concept Areas

- **Mars surface**
  - Concept evaluation set developed
  - Defined concept for entry level system (3 kWe)
  - Focused concept/independent assessment work on heatpipe/stirling



- **Small NEP**
  - Guiding concept set developed
  - Some initial studies performed in FY 01
  - Additional concept definition/independent assessment in FY02
- **Multimegawatt NEP**
  - Conducted analysis of liquid metal and gas cooled/Rankine and Brayton systems
- **Nuclear Thermal Rocket (NTR)**
  - Completed fuel element analysis and examination on performance parameters



Outlook for FY02

- **Focus on small in-space applications**
  - Initiate additional concept definition work, conduct associated independent review, address technical issues
- **As resources permit:**
  - Perform small study to address mission/system integration issues for surface power unit
  - Support programmatic assessments
- **Examine options for future years**