“I need more power, Scotty!”

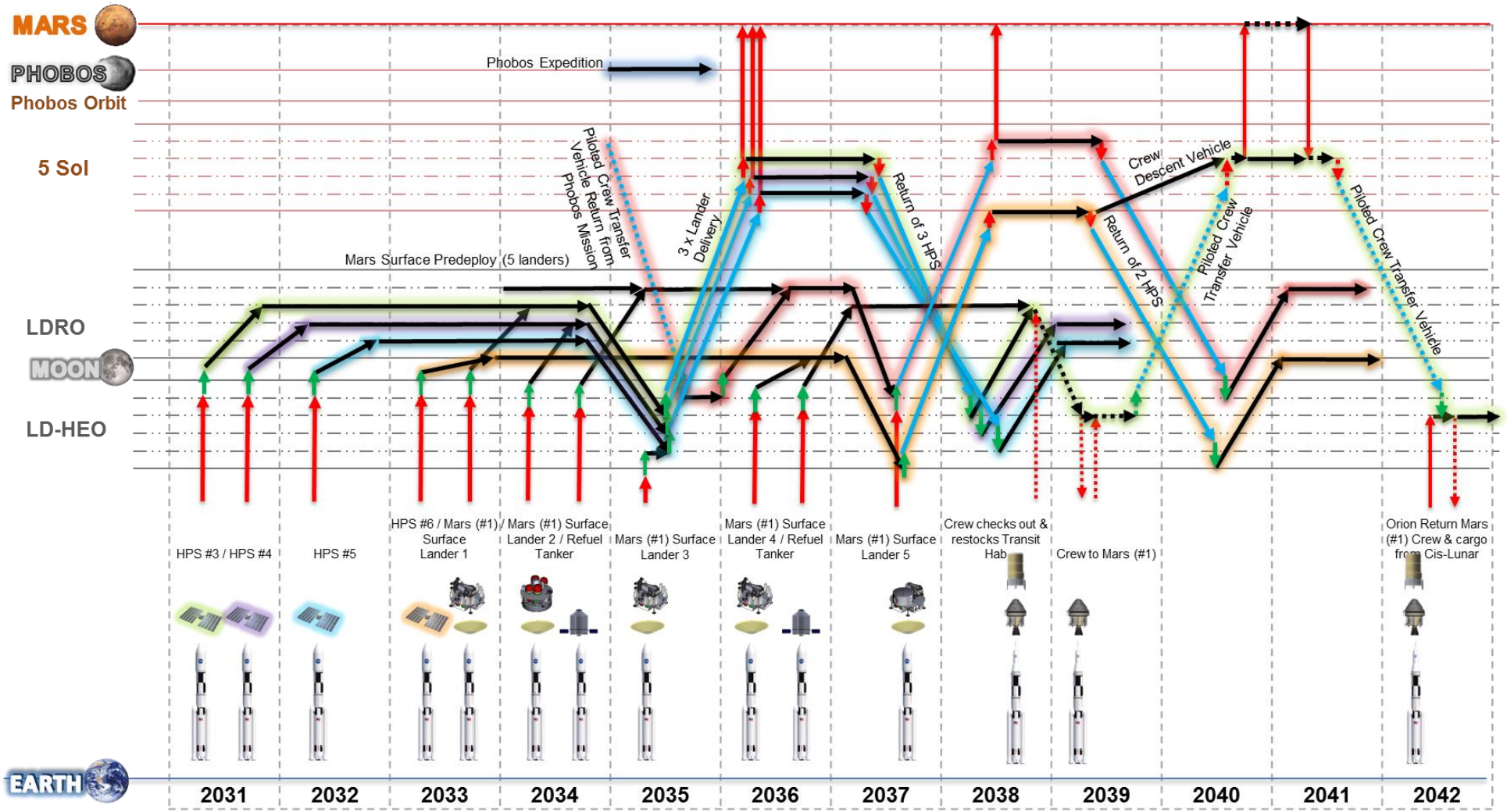
The Potential Impact of High Power Propulsion on the Human Exploration of Space

John H. Scott
EP/Propulsion and Power Division
NASA Lyndon B. Johnson Space Center

Evolvable Mars Campaign

(ca. 2015)

First Crewed Mission to Mars Surface



Lunar Gravity Assist (LGA), Solar Electric Propulsion (SEP), Chemical Propulsion (CP)

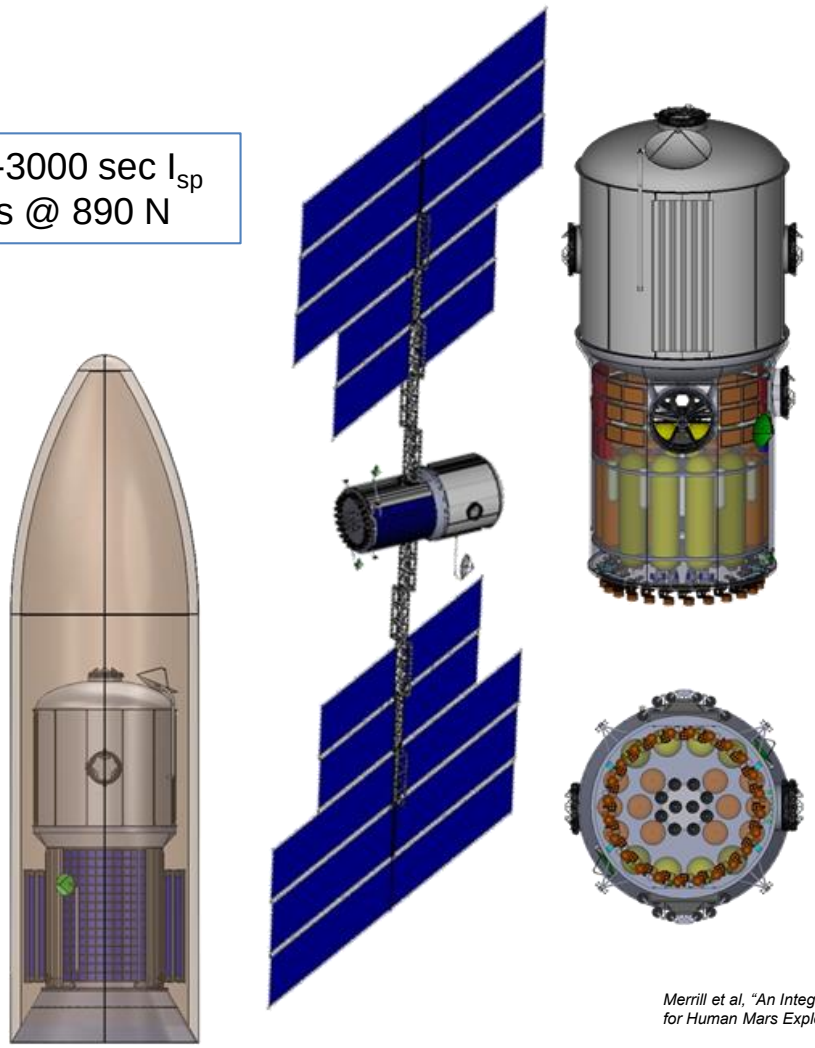
Crew on board (▪▪▪), HPS 1(▬),HPS 2 (▬), HPS 3 (▬), HPS 4 (▬), HPS 5 (▬), HPS 6(▬)

Merrill et al, "An Integrated Hybrid Transportation Architecture for Human Mars Exploration," AIAA 2015-4442

Evolvable Mars Campaign

SEP/Chemical “Hybrid” Stage

- 318 kW_e to EP thrusters @ 2-3000 sec I_{sp}
- MMH/N_2O_4 chemical thrusters @ 890 N

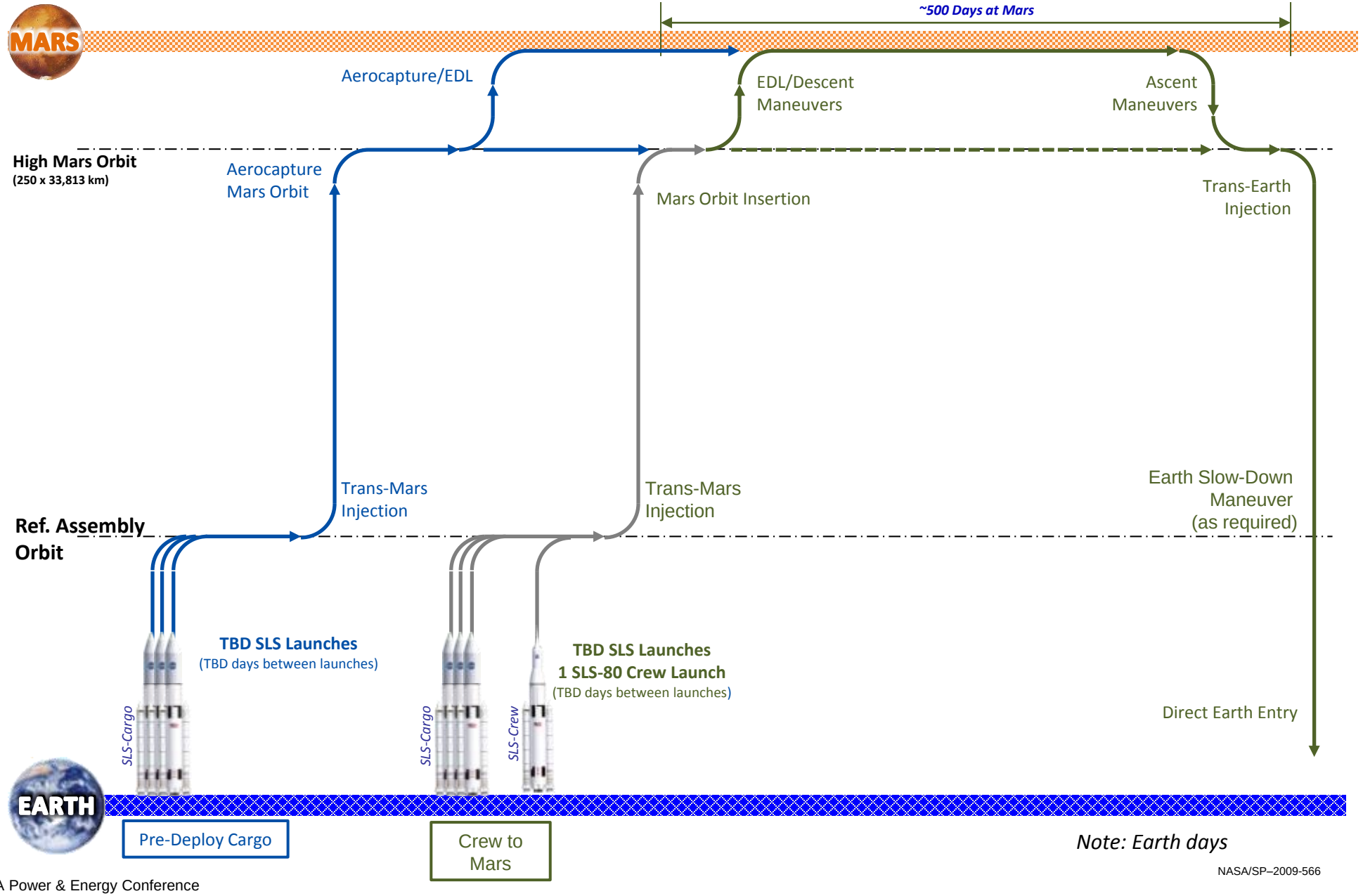


Merrill et al, “An Integrated Hybrid Transportation Architecture for Human Mars Exploration,” AIAA 2015-4442

Design Reference Architecture 5.0

(ca. 2009)

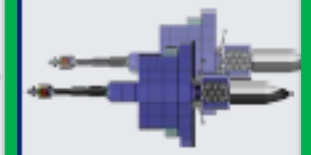
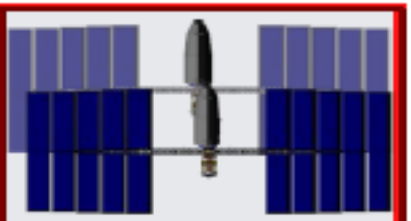
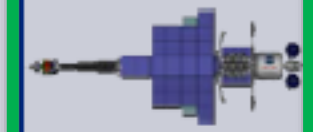
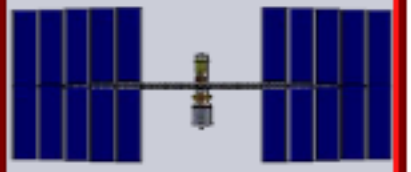
Crewed Mission to Mars Surface



NASA/SP–2009-566

Design Reference Architecture 5.0

In-Space Power/Propulsion Options

Cargo Missions				
Crew Mission				
2037 Conjunction Class "long stay" mission	**Chemical Propulsion**	**Nuclear Thermal**	**Nuclear Electric**	**Solar /Chem**
Electric Propulsion Power level	N/A	N/A	2.5 MW crew/ 1 MW cargo	800 kW Solar
Total Mass	~1250 t	~890 t	~770 t	~780 t
# Heavy Lift (SLS) Launches	~12	9 (7)	~7	~7
SLS Delivery to LEO (t)	105 and 130	105 (130)	105 and 130	105 and 130
SLS Shroud Dia./ Barrel Length	10 / 22	10 / 25	10 / 25	10 / 15
Trip Duration (days to Mars, on Mars, back home)	180 / 500 / 200 880 days total trip	174 / 539 / 201 914 days total trip	309 / 400 / 224 980 days total trip	439 / 300 / 326 1065 days total trip
Comments	Requires propellant depot	Number of launches reduced to 7 with 130 mt SLS		1–2 ATV launches required to provide consumables to E-M L2

NASA/SP–2009-566-ADD2

Integrated Manned Interplanetary Spacecraft Concept Definition

(ca. 1968)

Crewed Mission to Mars Surface

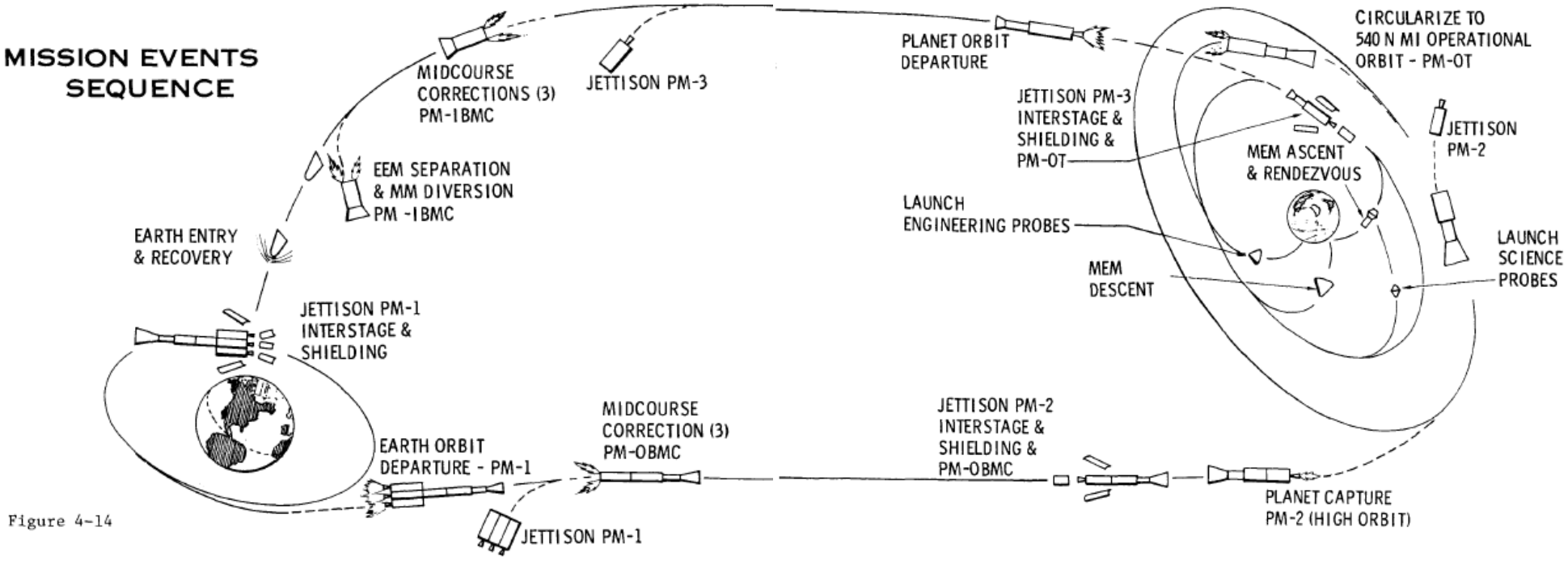


Figure 4-14

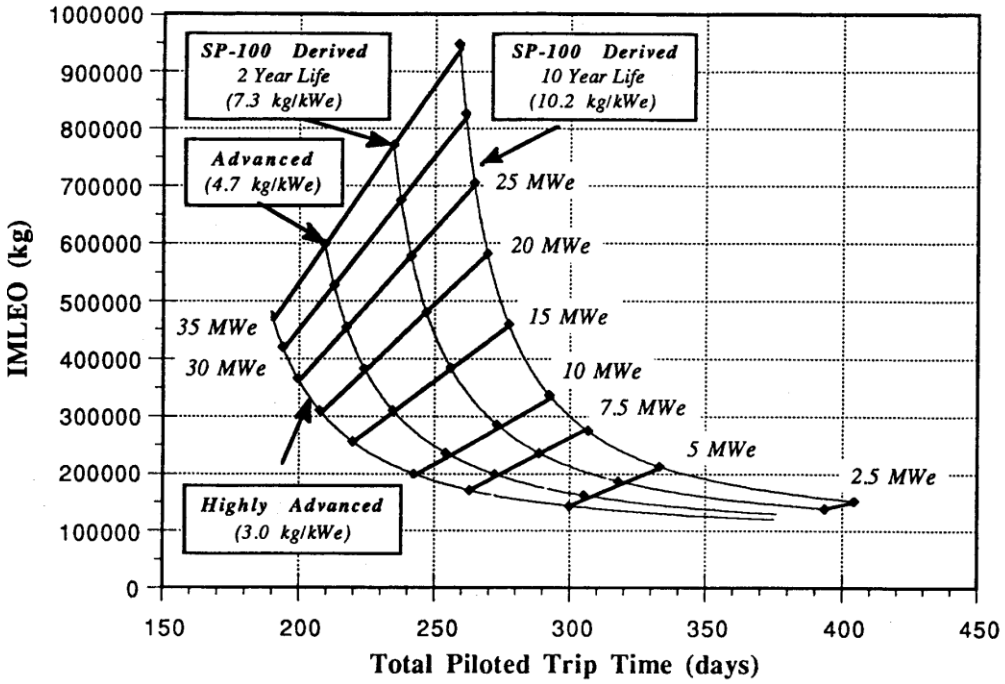
Parametric Mars Architecture Studies

(ca. 1989)

Crewed Missions to Mars Surface

Conjunction "Long Stay" Class

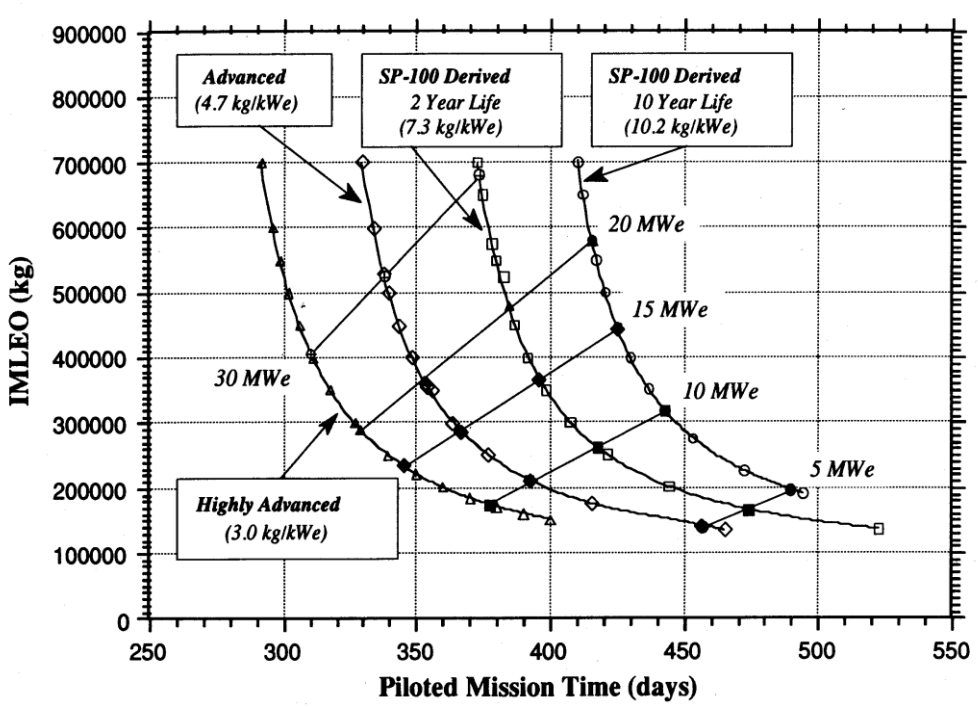
Synthesis Group "America at the Threshold" 1991



Not including surface stay time
Total crewed duration: ~900 days

Opposition "Short Stay" Class

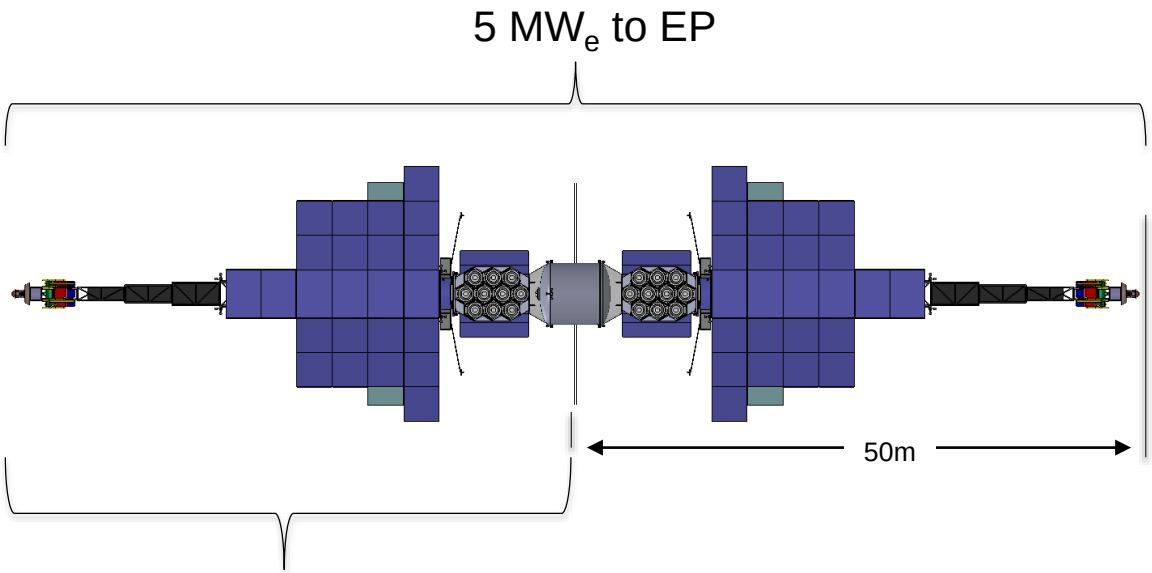
"90-Day Study on the Human Exploration of the Moon and Mars" 1989

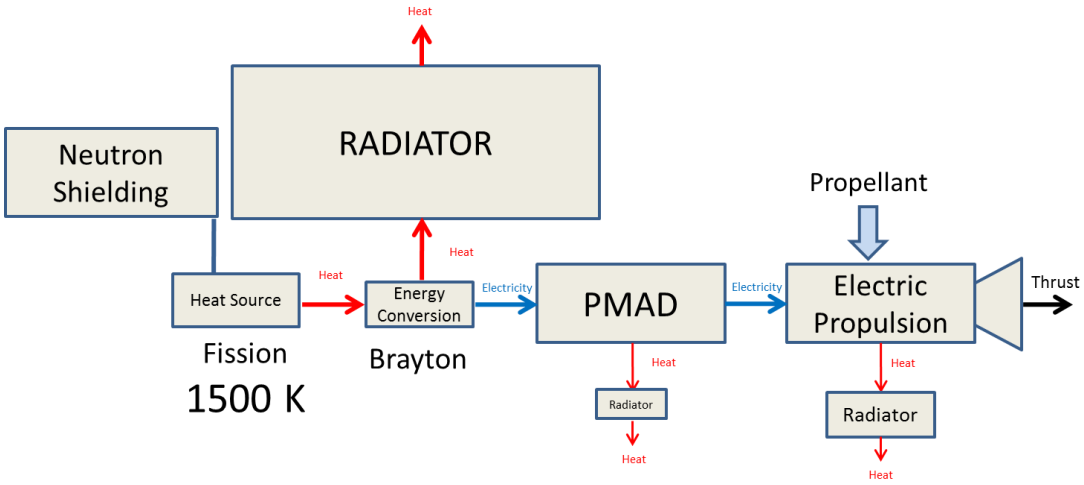


Including 25 day surface stay time

George, Dudzinski, et al, "Piloted Mars Mission Planning: NEP Technology and Power Levels," Space Technology Applications International Forum (STAIF), Albuquerque, NM, 1993.

“SOA” Nuclear Electric Propulsion (NEP)





Solid Core Fission Reactor
Brayton conversion
I_{sp} = ~ 5000 sec
T_{top} = 1500 K
T_{rad} = 500 K avg.
α_{pwr} = ~11 kg/kW$_e$
α_{prop} = ~ 2 kg/kW$_e$

Mason, L., Oleson, S., Mercer, C., and Palac, D., “Nuclear Power System Concepts For Electric Propulsion Missions to Near Earth Objects and Mars,” in Proceedings of Nuclear and Emerging Technologies for Space (NETS 2012), The Woodlands, TX, 2012

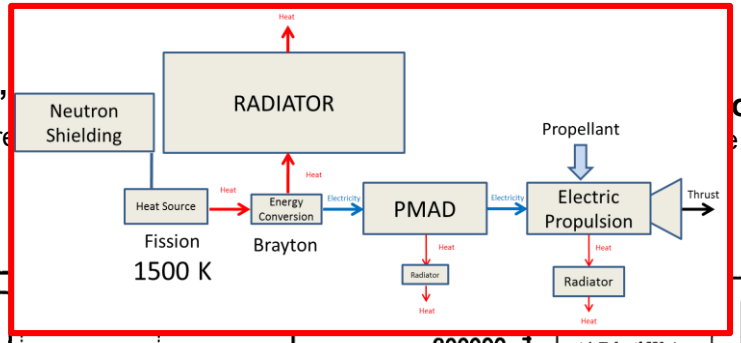
Parametric Mars Architecture Studies

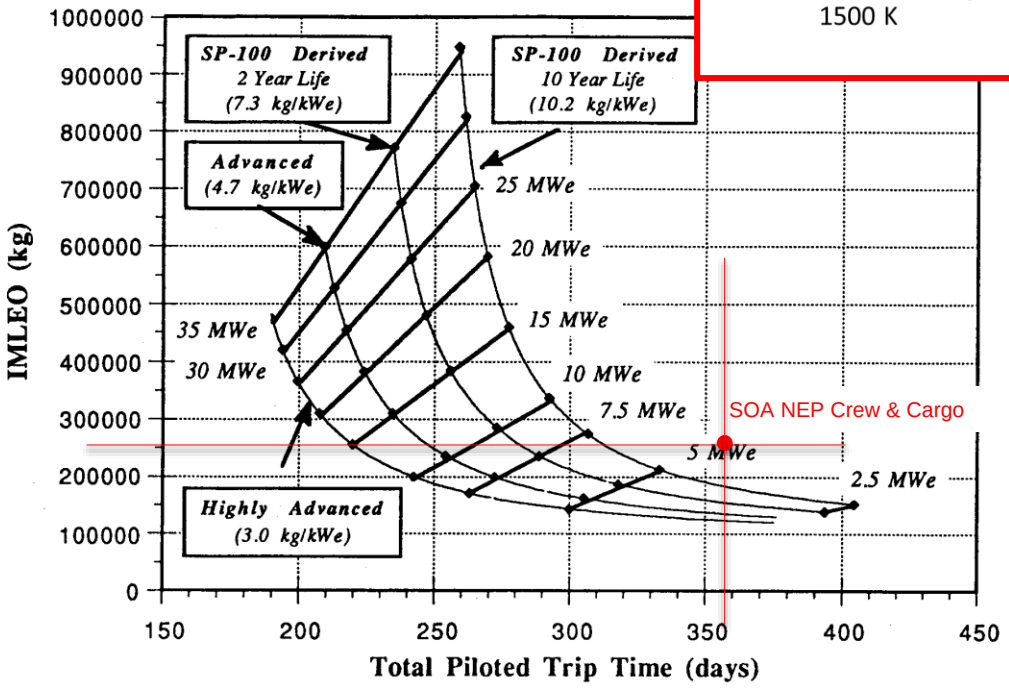
(ca. 1989)

Crewed Missions to Mars Surface with "SOA" NEP (α = ~13 kg/kW$_e$)

Conjunction "Long Stay"

Synthesis Group "America at the Thre



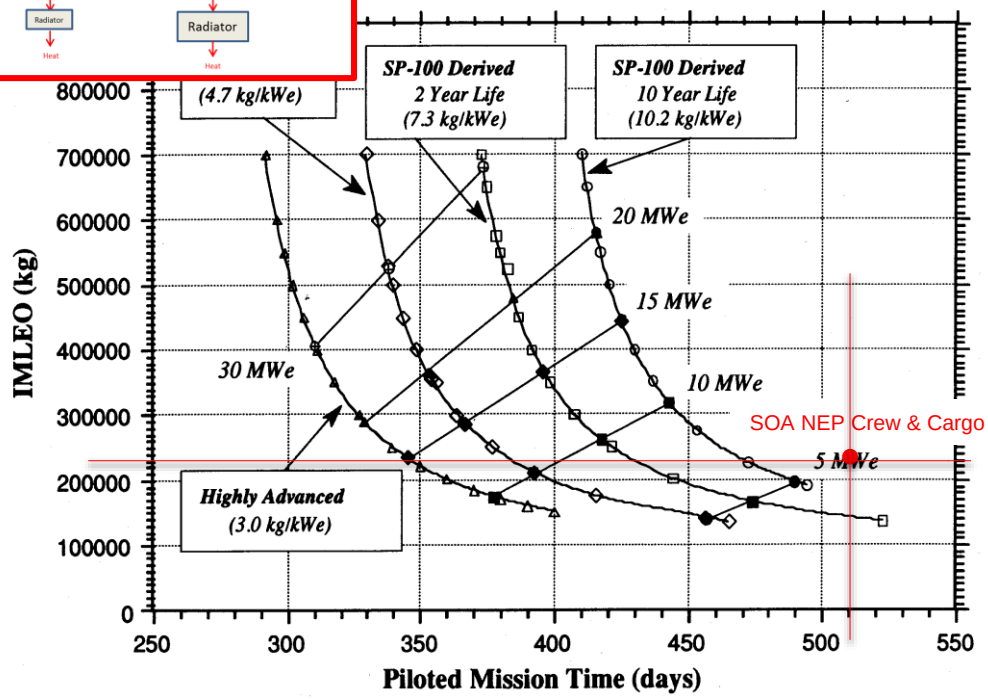


Not including surface stay time
Total crewed duration: ~900 days

- Total IMLEO = ~500 mT
- Piloted In-space time = 360 days

osition "Short Stay" Class

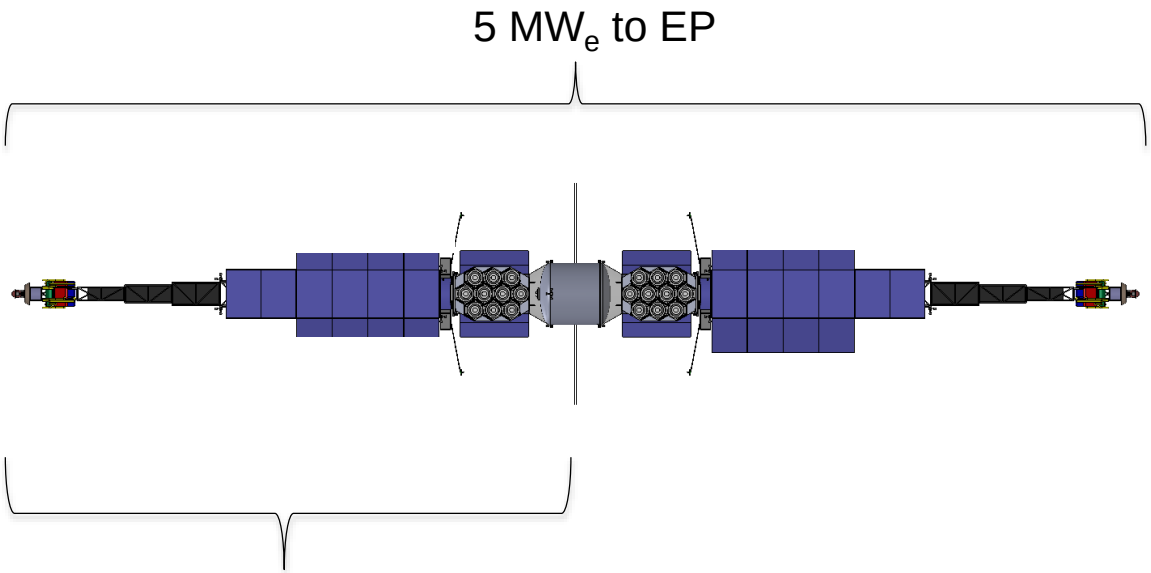
e Human Exploration of the Moon and Mars" 1989

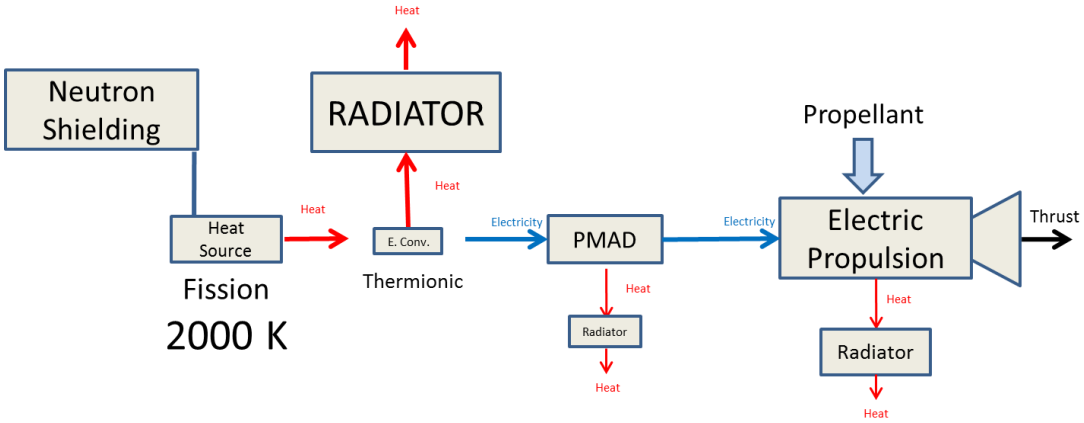


Including 25 day surface stay time

- Total IMLEO = ~480 mT
- Piloted time = 510 days

“Advanced” Nuclear Electric Propulsion (NEP)





Solid Core Fission Reactor
Thermionic conversion
Advanced PMAD
I_{sp} = ~ 5000 sec
T_{top} = 2000 K
T_{rad} = 1500 K
α_{pwr} = ~3 kg/kW$_e$
α_{prop} = ~ 2 kg/kW$_e$

Scott, J., George, J., and Tarditi, A., “Direct Energy Conversion for Low Specific Mass In-Space Power and Propulsion” in Proceedings of Nuclear and Emerging Technologies for Space (NETS 2013), Albuquerque, NM, February 2013

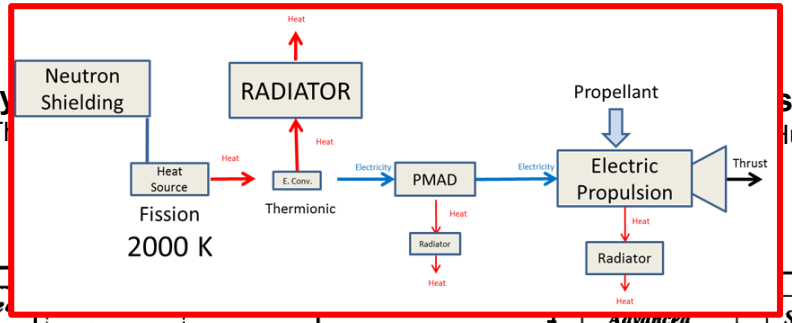
Parametric Mars Architecture Studies

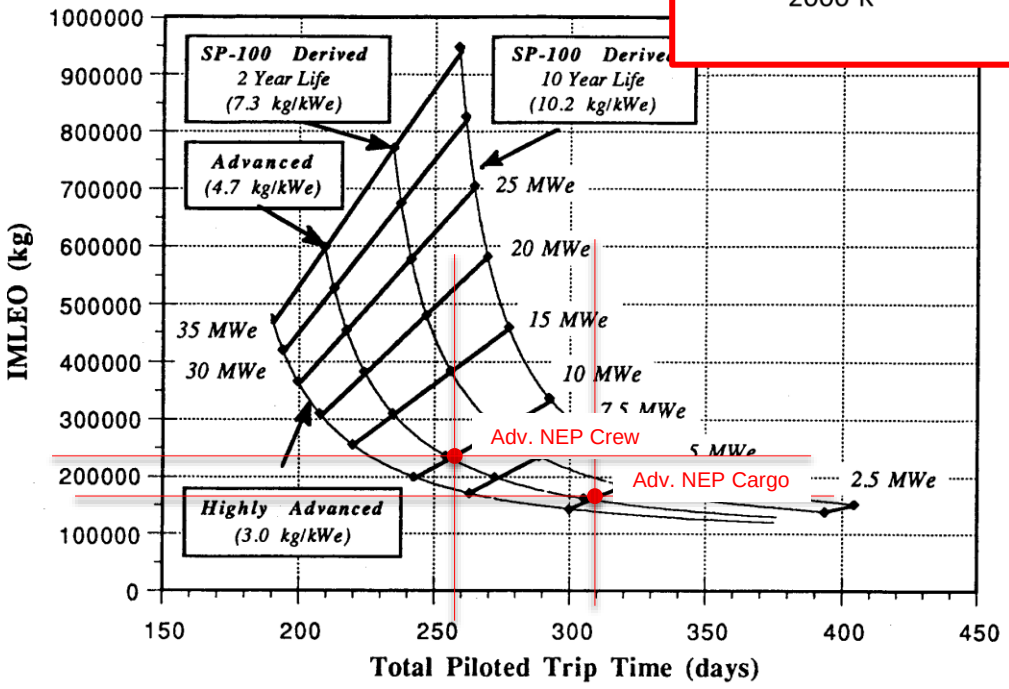
(ca. 1989)

Crewed Missions to Mars Surface with "Advanced" NEP (α = ~5 kg/kW$_e$)

Conjunction "Long Stay"

Synthesis Group "America at the T



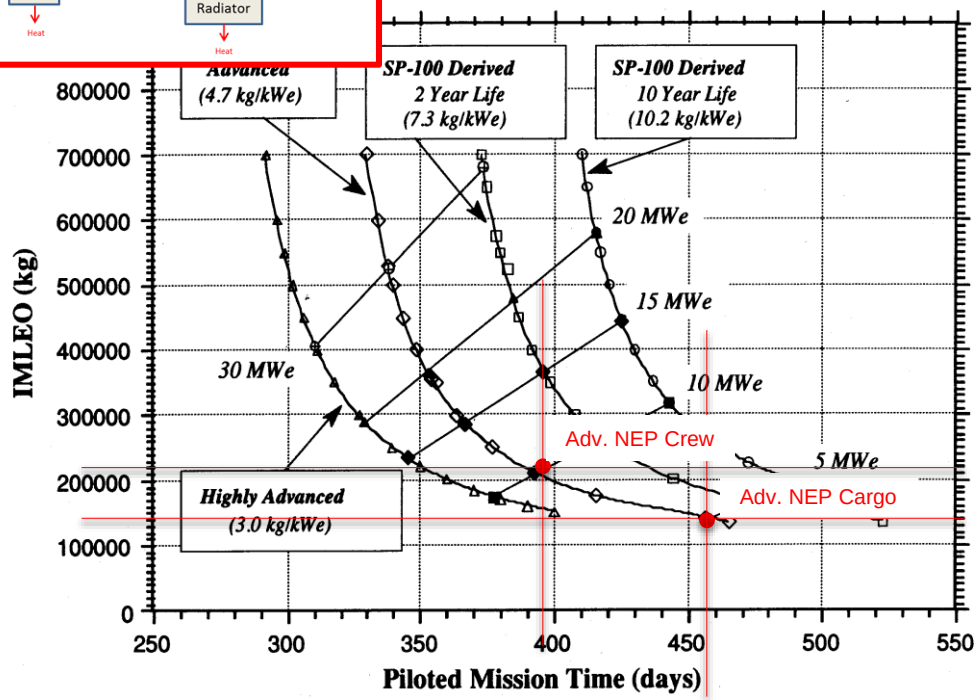


Not including surface stay time
Total crewed duration: ~900 days

- Total IMLEO = ~400 mT
- Piloted In-space time = 260 days

sition "Short Stay" Class

Human Exploration of the Moon and Mars" 1989



Including 25 day surface stay time

- Total IMLEO = ~360 mT
- Piloted time = 400 days

Aneutronic Fusion Power NEP

Fusion Fuel Pairs (Product Energy)

D + T = n^0 (14.07 MeV) + ^{4}He (3.52 MeV)

D + D = n^0 (2.45 MeV) + ^{3}He (0.82 MeV) (50%)
D + D = p (3.02 MeV) + T (1.01 MeV) (50%)

D + ^{3}He = p (14.68 MeV) + ^{4}He (3.67 MeV)

p + ^{11}B = 3 ^{4}He (8.7 MeV)

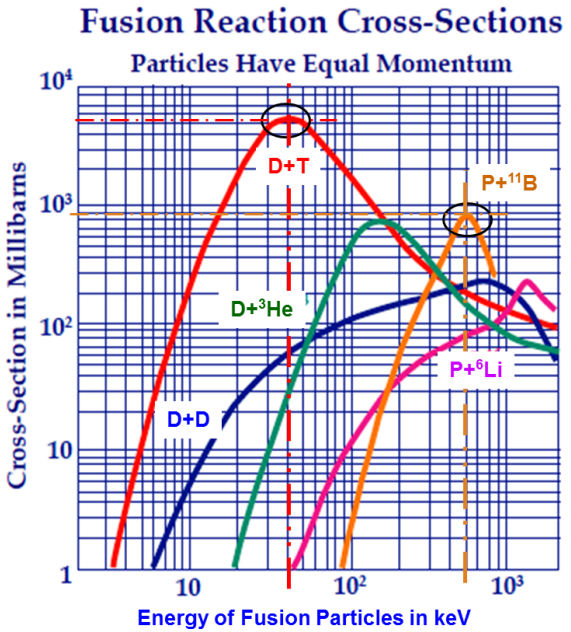
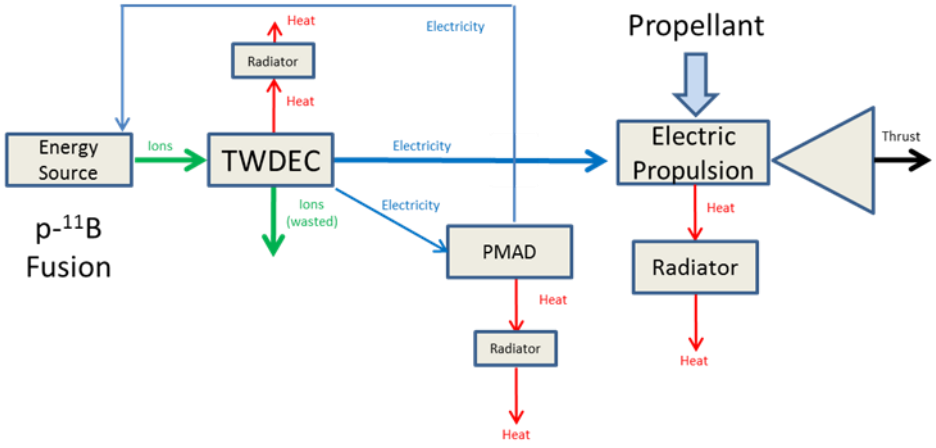


Figure 5 — Typical Fusion Reaction Cross Sections

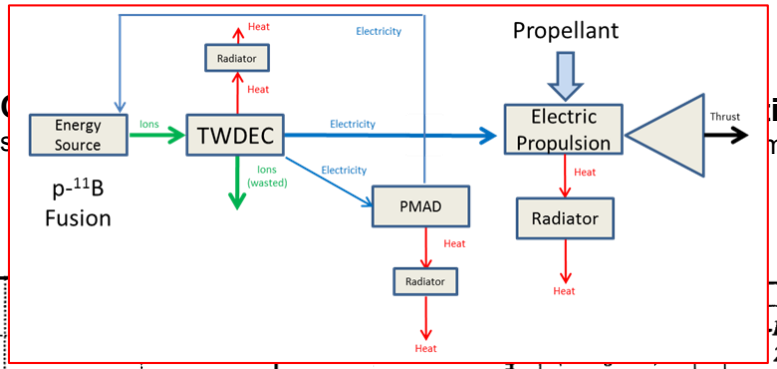


P-^{11}B Fusion Reactor
Direct conversion to power
Advanced PMAD
Advanced Plasma Thruster
I_{sp} = ~ 10000 sec
α_{pwr} = ~2 kg/kW$_e$
α_{prop} = ~ 1 kg/kW$_e$

Parametric Mars Architecture Studies

(ca. 1989)

Crewed Missions to Mars Surface with Aneutronic Fusion (α = ~3 kg/kW$_e$)

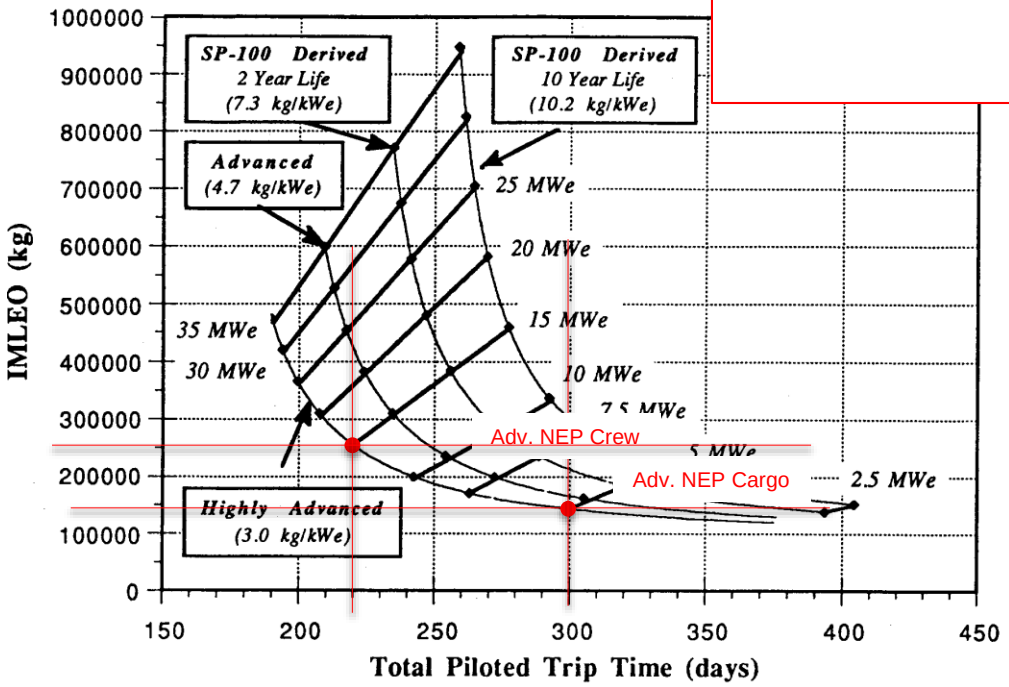


Conjunction "Long Stay" C

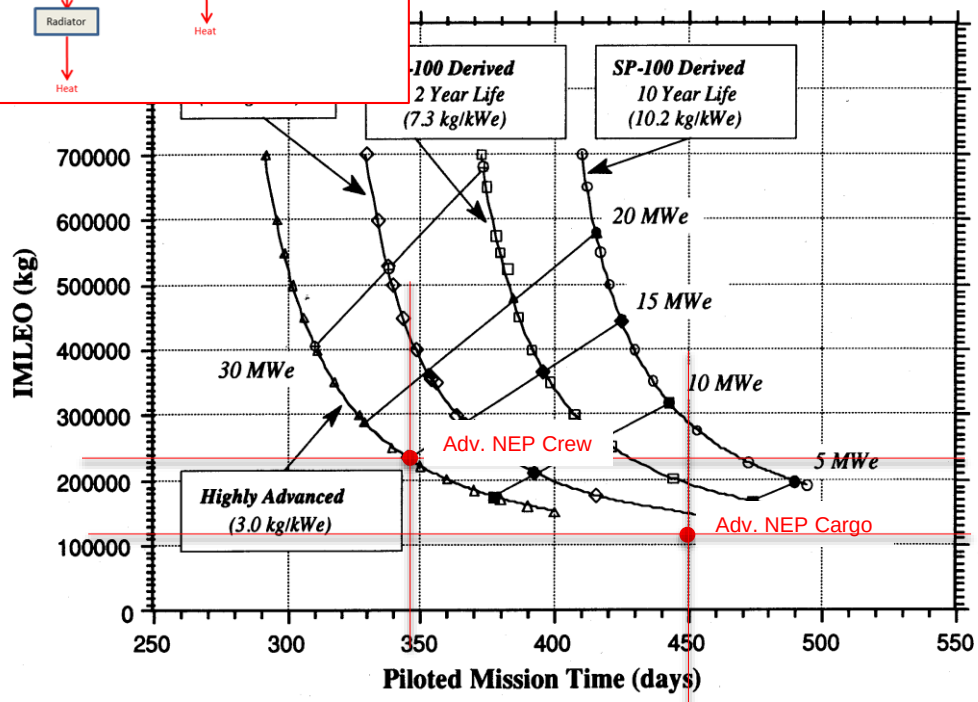
Synthesis Group "America at the Thres

ion "Short Stay" Class

man Exploration of the Moon and Mars" 1989



Not including surface stay time
Total crewed duration: ~900 days

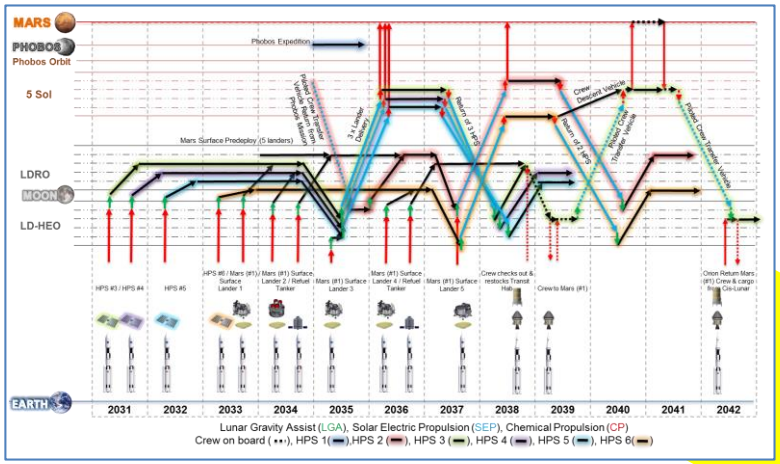


Including 25 day surface stay time

- Total IMLEO = ~400 mT
- Piloted In-space time = 220 days

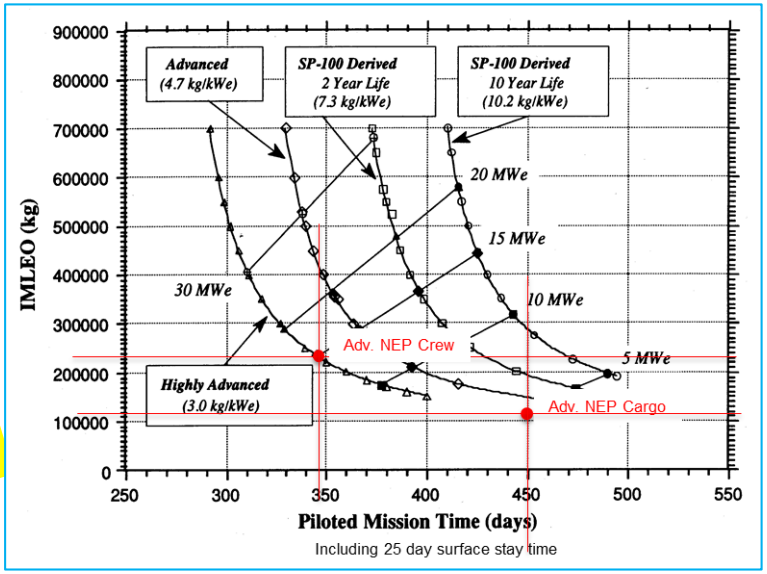
- Total IMLEO = ~350 mT
- Piloted time = 350 days

More Power for Mars?



150 kW_e max power.

- 1600 mT launched to assembly orbit
- 220 mT to Mars surface
- ~300 day surface stay
- ~1000 day mission duration
- *Evolutionary PV technology*



15 MW_e max power.

- 360 mT launched to assembly orbit
- 125 mT to Mars surface
- ~25 day surface stay
- ~350 day mission duration
- *Advanced fusion technology*