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Mars Surface Power

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Introduction

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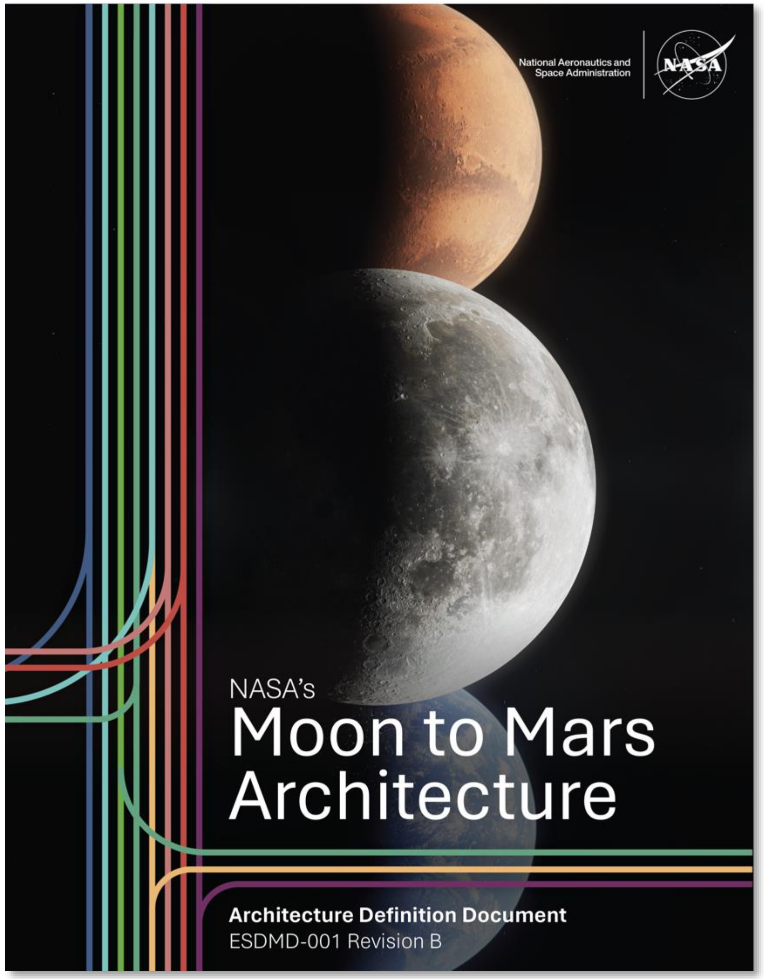

Nuclear fission power selected as primary surface power generation technology for initial crewed missions to Mars

- 2024 Architecture Concept Review outcome
- Exercise in process as much as decision outcome
- Documented in Appendix B of the Architecture Definition Document

Background

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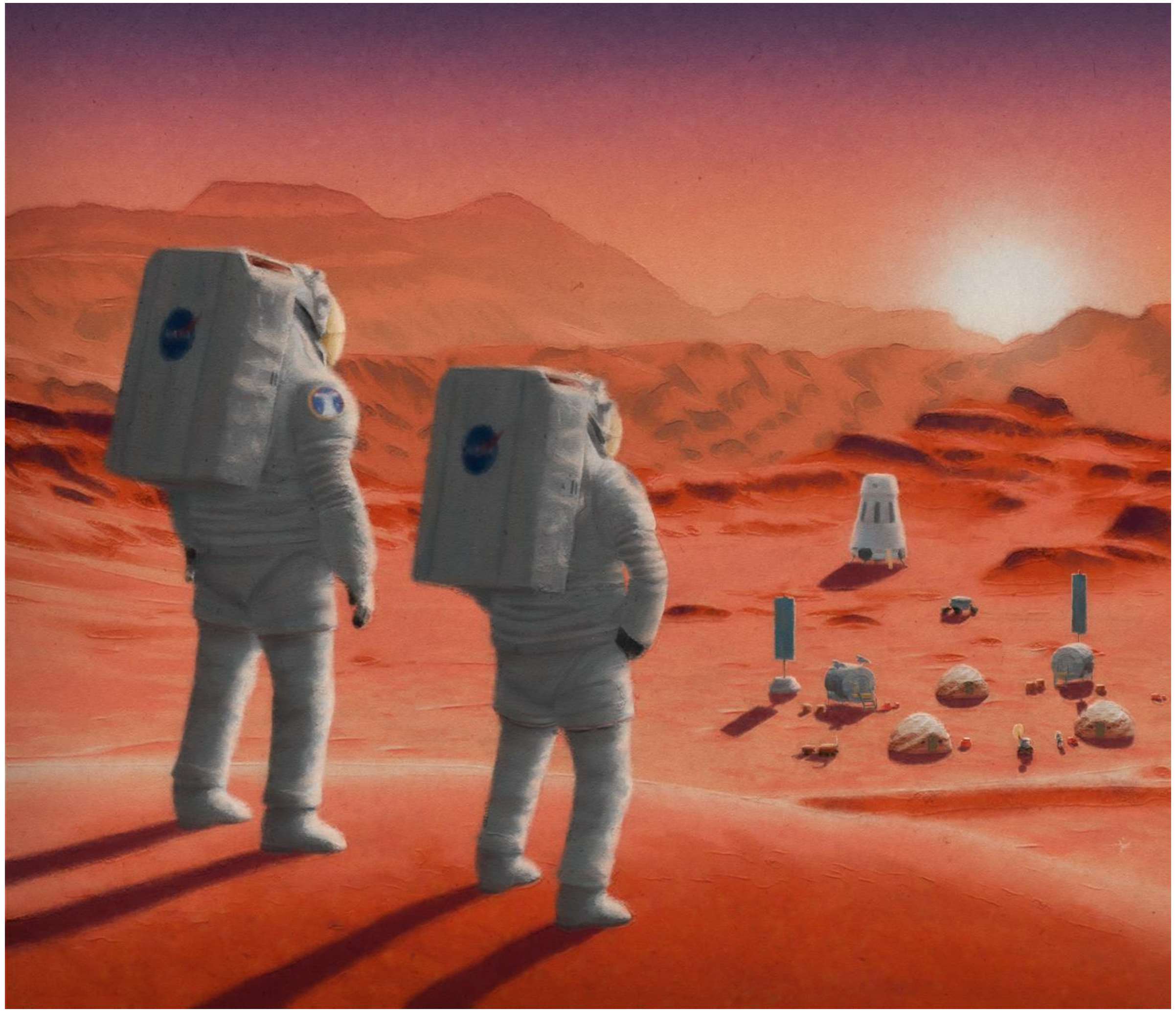
- Decision identified due to impacts on the architecture
- Assessment process involved numerous stakeholders, technical experts, and technical authorities
- Primarily driven to mitigate loss of mission risks

Lays the groundwork for future architecture implementation decisions



Decision Attributes

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- Brainstorming and draft attributes
- Stakeholder review and consensus
- Data mapping to attributes
- Stakeholder Scoring
- Scoring rationale review and discussion

Attributes*

Relevant Decision Attributes	
Reliability / Availability	Robustness to Near Surface Temperature Variations
	Robustness to Surface <u>Solar Flux</u> Variations
	Robustness to <u>Nominal Dust</u>
	Robustness to <u>Dust Storms</u>
	Maintainability/Repairability
Power Needs	Minimum Power Needs for Initial Segment
	<u>Scalability</u>
	Operational Lifespan
Extensibility to Future Segments	
<u>Affordability</u> Drivers	

**Attributes were developed, reviewed, and scored by STMD, SAO, M2MPO, OSMA*

Consensus that 5 highlighted attributes are most impactful

Technology Trade Space and Down Select

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Nuclear Technologies

- Fission surface power systems (FSP)
- ~~Radioisotope thermoelectric generators (RTGs)~~

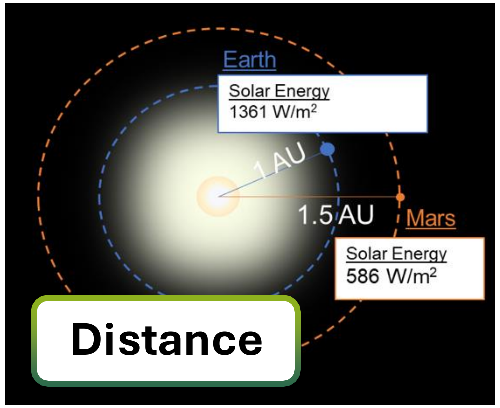
Non-Nuclear Technologies

- Photovoltaic array with energy storage
- ~~Primary batteries~~
- ~~Primary fuel cells~~
- ~~Wind power generation~~
- ~~Geothermal power generation~~
- ~~Biogeneration concepts~~

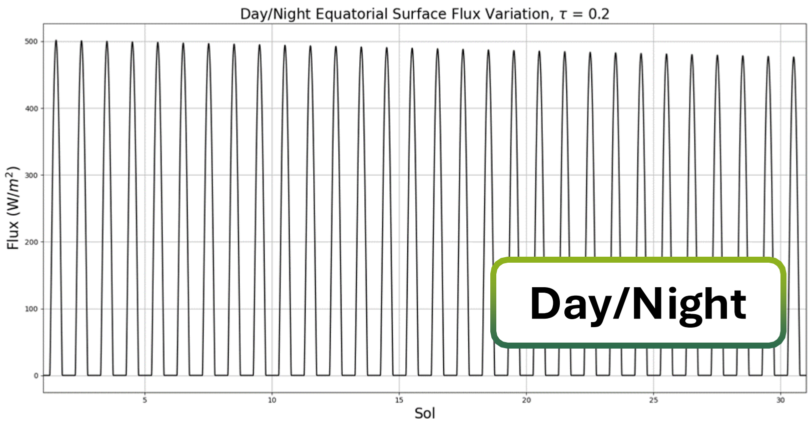
RTG	PRIMARY BATTERIES	PRIMARY FUEL CELLS	WIND	GEOTHERMAL	BIO-GENERATION
Scalability issues Pu-238 production limit & low TRL alt. fuels	Poor scalability Not practical (mass) even for 2 crew/30 sol/no ISRU	Energy to make reactants exceeds energy generated Needs reactant delivery	Insufficient sustained winds for reliable power production	Energy-intensive infrastructure build needed to implement	Complicated by planetary protection constraints

Reliability/Availability:
Robustness to Reduced Solar Flux on Mars

- **Mars is 1.5x farther from the Sun than Earth, so ~57% less solar energy reaches Mars' atmosphere**
  - Larger solar array surface area (more mass) is needed on Mars
- **Mars has a day/night cycle like Earth, so no solar power is generated about half of each Martian day**
  - Energy storage mass is needed for continuous ops and keep-alive



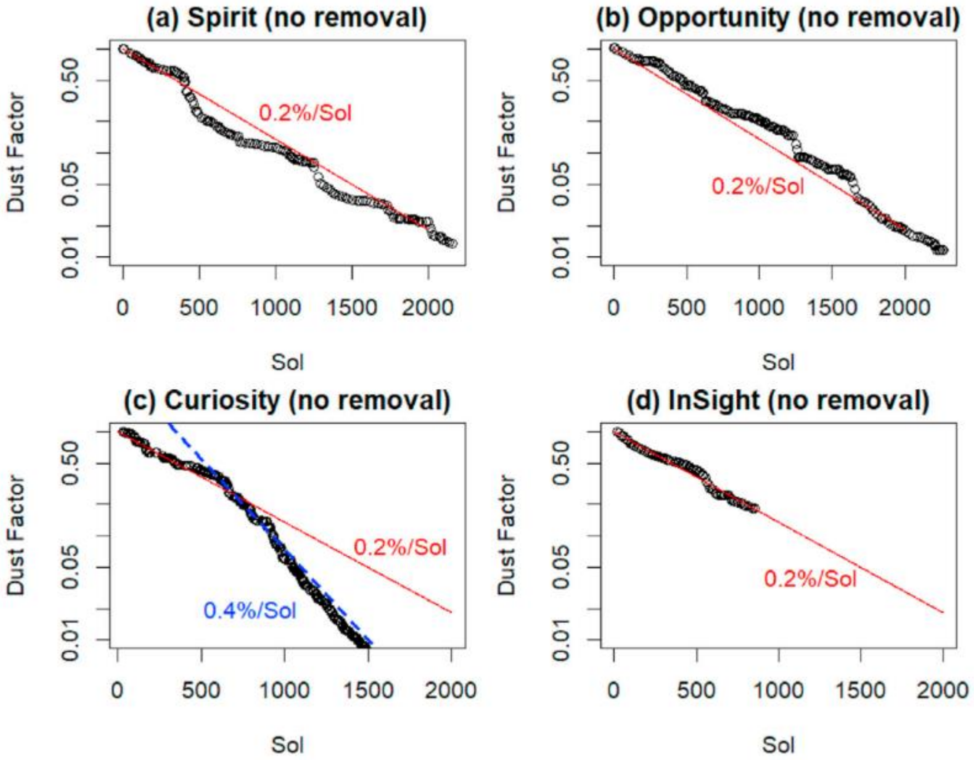
Fission power output is not affected by solar flux



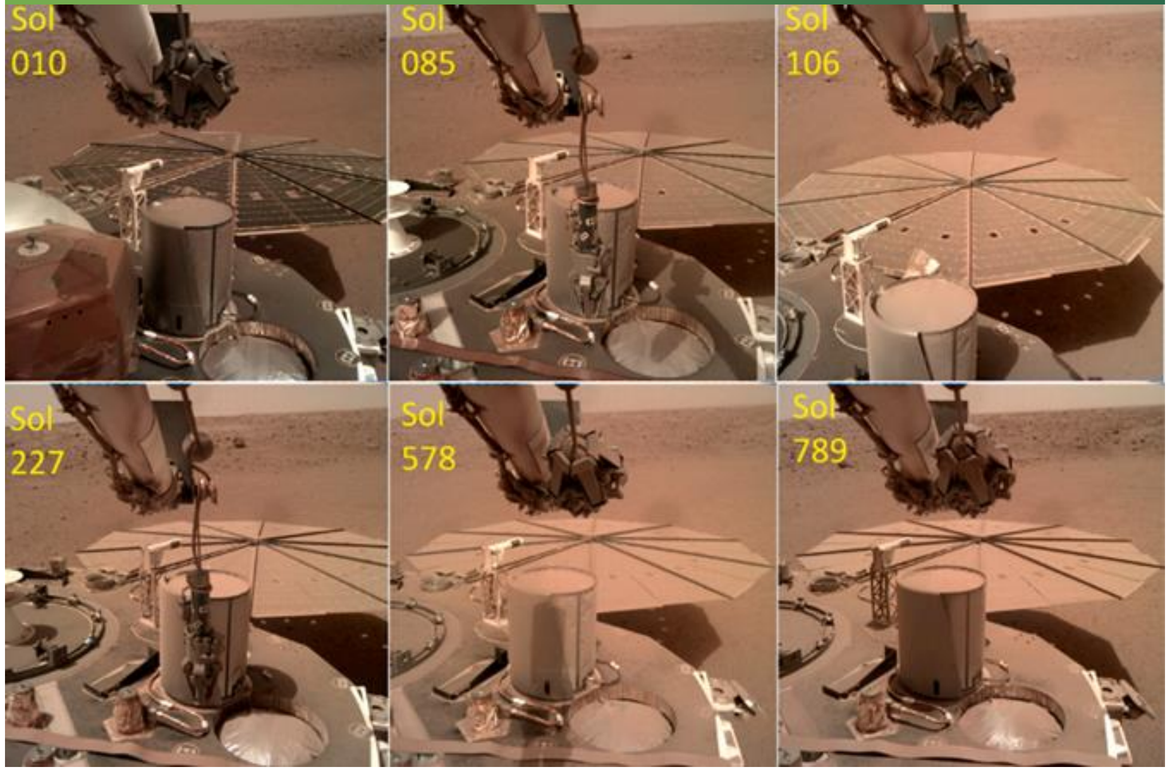
	Reference Mission		
	2009 DRA 5	**2016 EMC**	**2020 POD**
Cargo Need	26 kW ISRU	26 kW ISRU	9 kW No ISRU
Crew Need	~35 kW *(Hab, Lab, rover MAV)*	31 kW *(Hab, Lab, Rover, MAV)*	9 kW *(MAV, rover, prop transfer)*
Mass Comparison Solar vs. Fission			
Solar	**22.5 t Solar**	**11. 7 t Solar (N. hem.)**	**11.22 t Solar**
Fission	**6 to 8 t (40 kW)**	**9 t (5 x 10 kWe)**	**7.93 t (10 kW + spare)**

Reliability/Availability:
Robustness to Nominal Mars Dust

- **Nominal dust reduces solar array performance**
- **Dust suspended in the atmosphere exacerbates seasonal flux variation issues**



Steady accumulation of dust on the InSight solar arrays



Data from multiple Mars assets shows solar **power degradation of ~ 0.2 % per sol** without active dust mitigation

Reliability/Availability: Robustness to Dust Storms

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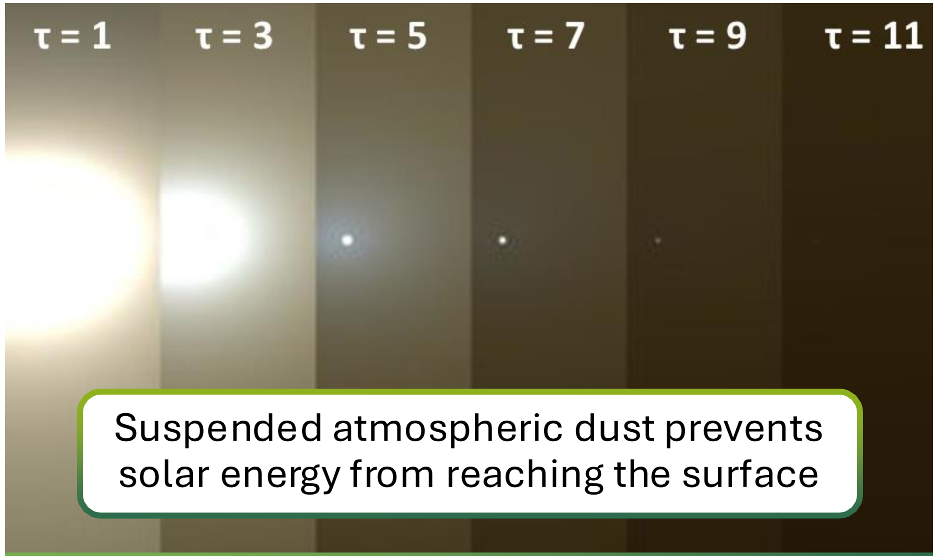


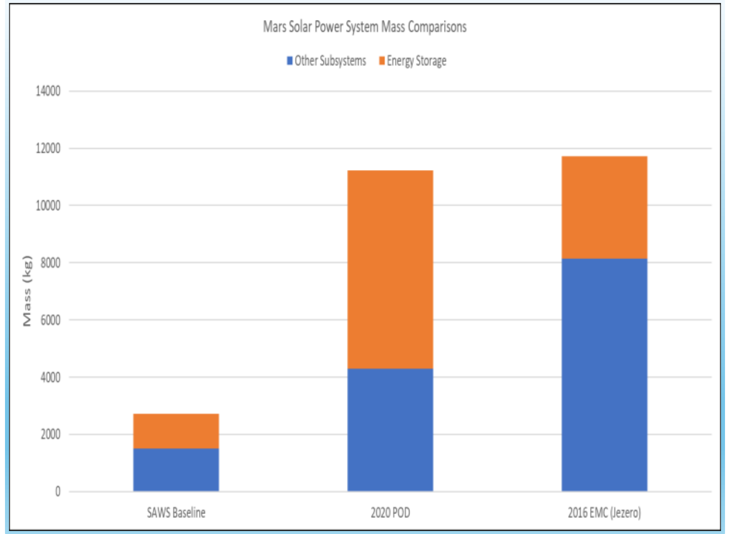
Suspended atmospheric dust prevents solar energy from reaching the surface

View of the Sun as the 2018 storm progressed

Power studies prior to 2018 under-estimated solar power mass based on storms less than half as severe (τ = 5) as 2018 storm (τ = 10.8)

Fission power output is independent of solar availability, so fission power mass is stable regardless of storm severity or duration

Solar power mass increases with storm severity/duration



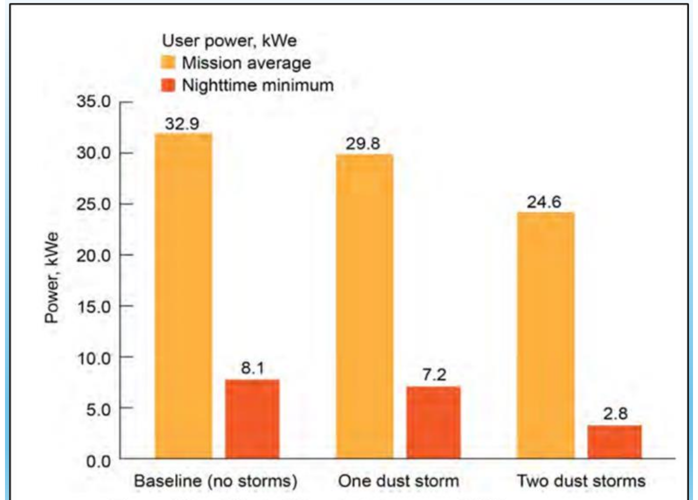


Figure 127.—Effect of Mars dust storms on SAWS user power.

Scalability

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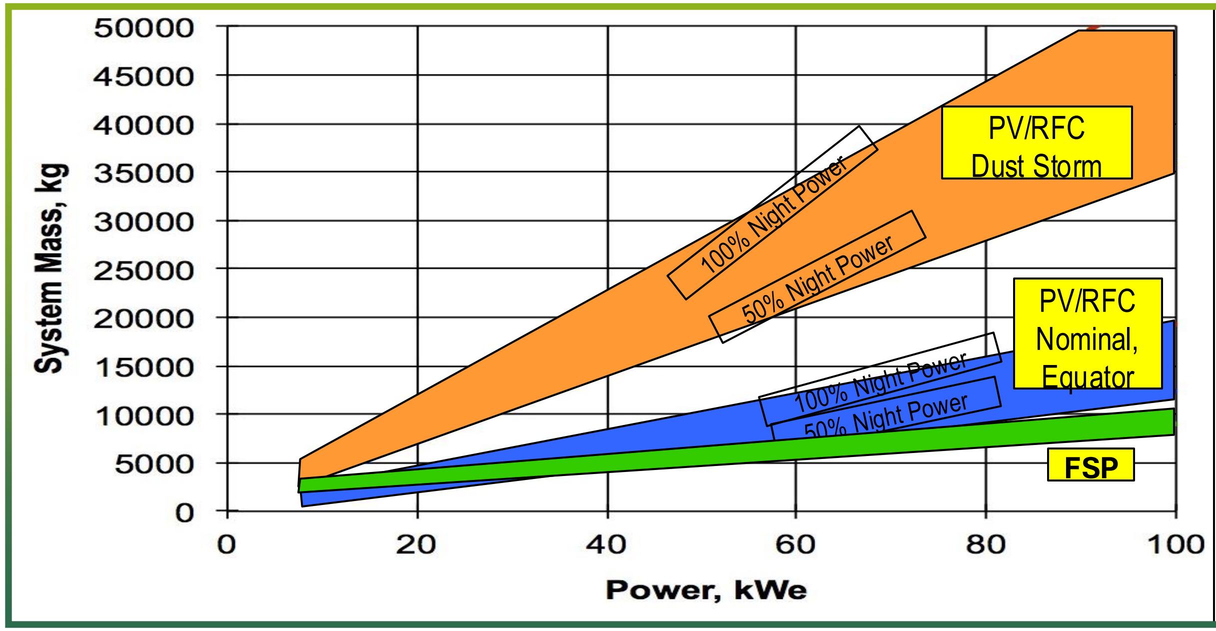
Fission Power

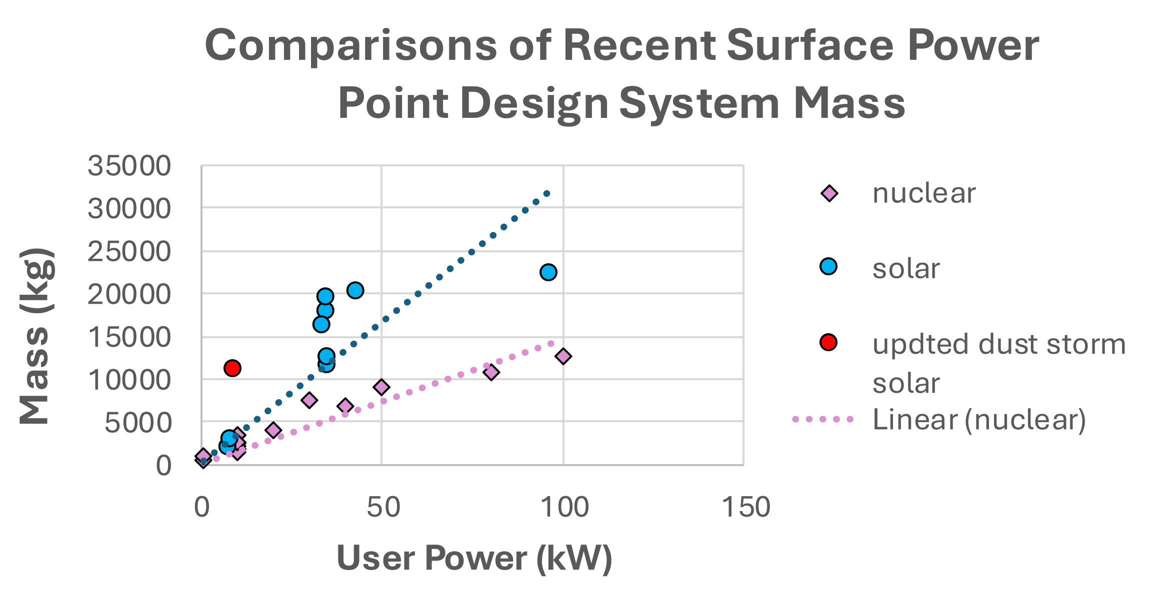
☑ Lower, linear mass with increasing power

Solar Power w/Energy Storage

☒ Trends higher mass above 10 kW, dependent on ops, latitude, and dust storm assumptions

Fission vs. Sun-tracking PV arrays with RFC energy storage --
Assumes 450 W/m2 (Nominal, Equator), 100 W/m2 (Dust Storm), 12 Hour Night





Affordability Drivers

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Development & Construction

- Heritage development
- Facilities Availability

Payload Processing

- Safety/Security
- Heritage Experience

Policy and Certification

- Space Policy Directive 6 encourages High Assay Low Enriched Uranium (HALEU)
    - Lowers safety/security overhead
- NASA is leading a dozen federal agencies to identify/address space nuclear policy gaps

Performance

- Particularly robust to loss of mission

Deployment and Autonomous Ops

Maintainability is a separate attribute, but note that nothing on fission power systems requires EVA maintenance

Architecture Measure of Effectiveness

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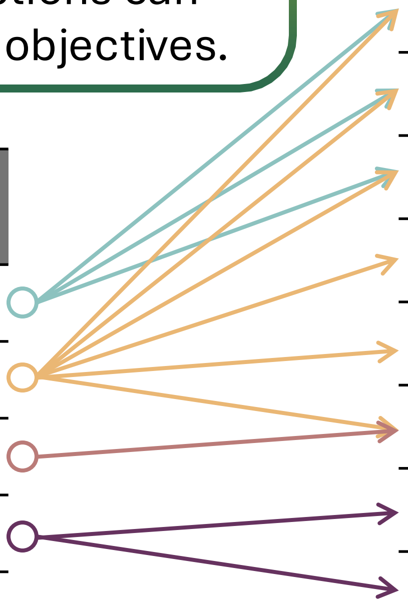
Decision Attributes were defined specifically for the Mars Surface Power decision to represent the trade-offs of how well the decision options can *potentially* satisfy agency objectives.

Decision Attributes
Robustness to Solar Flux
Robustness to Dust Storms
Scalability
Affordability Drivers



	Potential Impact from...	
Measure of Effectiveness (MOE)	Fission Power	Photovoltaic with Storage
Surface Location Access	◆	◇
Environmental Access	◇	●
Power	◆	◇
Crew Utilization	◇	◇
Uncrewed Utilization	◇	◇
Mass	□	■
Cost	■	□
Development Complexity	□	□

DEGREE OF IMPACT

■	Major Impact -2
□	Moderate Impact -1
●	Neutral Impact 0
◇	Moderate Improvement 1
◆	Major Improvement 2

Note: *This is the first decision to be added to the Mars architecture. A baseline Mars MOE assessment does not yet exist.*

Conclusion: Fission Trades More Favorably

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	Attribute	Nuclear (Fission)	Non-Nuclear (Solar)
1	Robustness to Dust Storms	☑ Reliable power generation through severe storms	☒ Limited/no reliable power generation during storms with tau >7 increases system mass energy storage
2	Scalability	☑ Mass advantage Increases with increasing power	☑ Competitive mass at/below 10 kW ☒ Mass disadvantage grows with power need
3	Robustness to Solar Flux	☑ Power not appreciably affected by season, latitude, or day/night	☒ Mass/volume dependent on season/location; need energy storage mass for night-time operations
4	Affordability	☒ Higher development & unit cost ☑ Potential lunar cost/risk buy down	☑ Lower development & unit cost ☑ Potential for lunar activity cost/risk buy down
5	Robustness to Nominal Dust	☒ Dust build-up on radiators may require active/passive mitigation	☒ Dust build-up on arrays will require active mitigation ☒ Dust suspended in the atmosphere will reduce power generation and increase stored energy mass needed

Summary of Decision

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Nuclear fission power selected as primary surface power generation technology for initial crewed missions to Mars

Read the White Paper
https://bit.ly/3VN2Z1r