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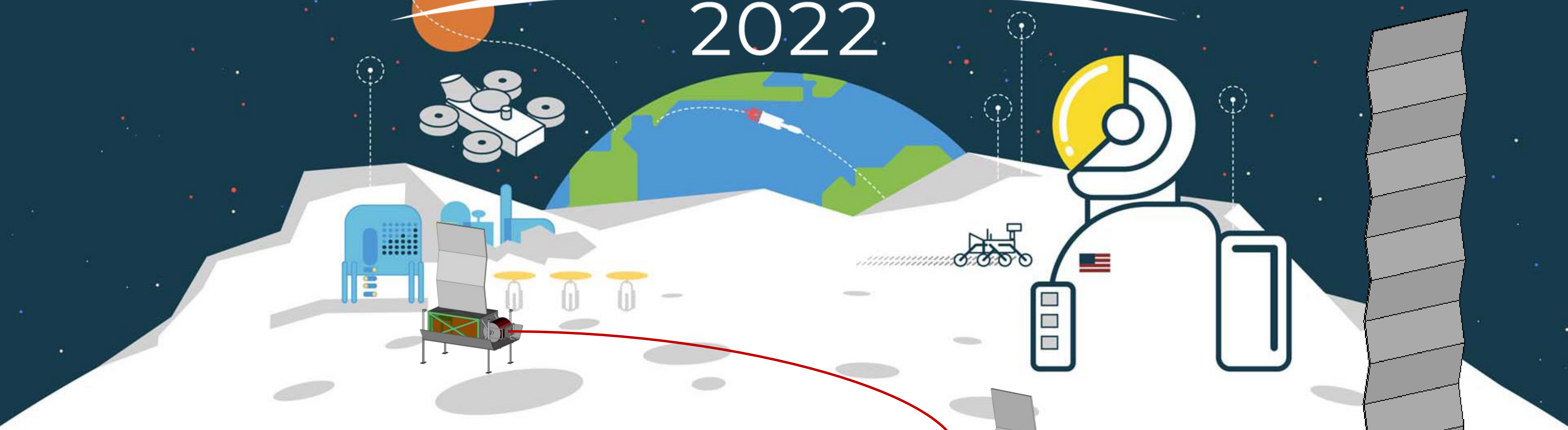
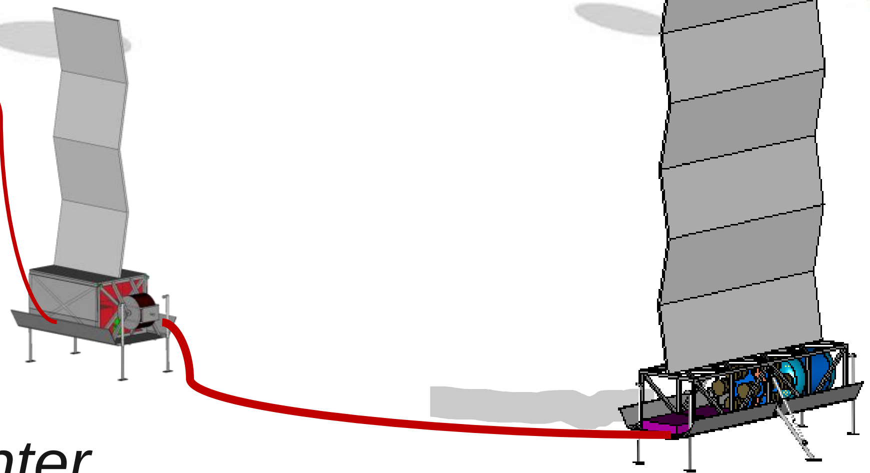
NUCLEAR and EMERGING TECHNOLOGIES for SPACE



A Deployable 40 kWe Lunar Fission Surface Power Concept



Steven Oleson

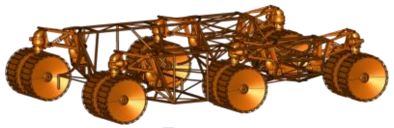
Compass Team Lead, NASA Glenn Research Center

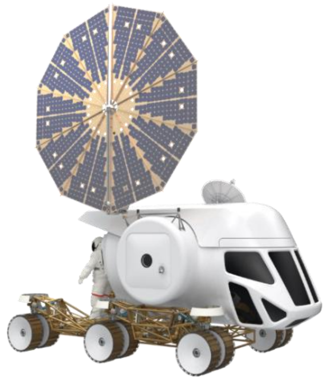
Team

Team Roster	Fission Surface Power Project	Compass Team
Customer	Todd Tofil	
Study Lead (test driver)	Bill Taylor	Steve Oleson
System Integration	Bill Taylor, Michael Pepen	Betsy Turnbull, Christy Schmid
Chassis/mobility		Jim Fittje
Mechanical Systems	Vicente Suarez/Jeff Larko	John Gyekenyesi, Jim Fittje
Thermal Control Module	Tony Colozza	Tony Colozza
Power:		Paul Schmitz, Brandon Klefman, Lucia Tian
Reactor/Shielding Module	DV Rao	Paul Schmitz
Power Conversion Module	Scott Wilson/Marc Gibson/ Chris Barth	Paul Schmitz
PMAD/Power Node	David Pike	Paul Schmitz, Brandon Klefman, Lucia Tian
C&DH/Software		Nick Lantz
Communications		Bushara Dosa
Configuration	Tom Godfroy	Tom Packard
ATLO	Bill Taylor/Tim Schuler	
Cost	Tom Parkey	Natalie Weckesser, Cassandra Chang, Marissa Conway, Jon Drexler
Schedule	Erin Wood	
SMA	Marc Gibson	

40 kWe FSP Deployability Concept

- Purpose: Develop a concept for a 40 kWe Fission Surface Power (FSP) system that is deployable
  - Trade: South pole (baseline) vs Equatorial (quick one-off)
  - Trade: Stirling and (Brayton design- pushed as later work due to dissimilarity)
  - Trade: Where is the power delivered – assumed one user point
- Approach: The reactor will be deployed by a chassis common with the pressurized habitat which also needs delivered and off-loaded from the lander (this approach avoids integrating the reactor into a specific lander as well as avoids how the chassis is off-loaded)
  - Comment on impact of leaving on the system on the lander deck
- Starting Point: 6 wheel Pressurized Rover chassis
  - Mass capability ~ 8-9t – but can be exceeded for this study if necessary
  - Volume: stay in the same volume as the Pressurized Rover
    - Fallback – On-lander habitat

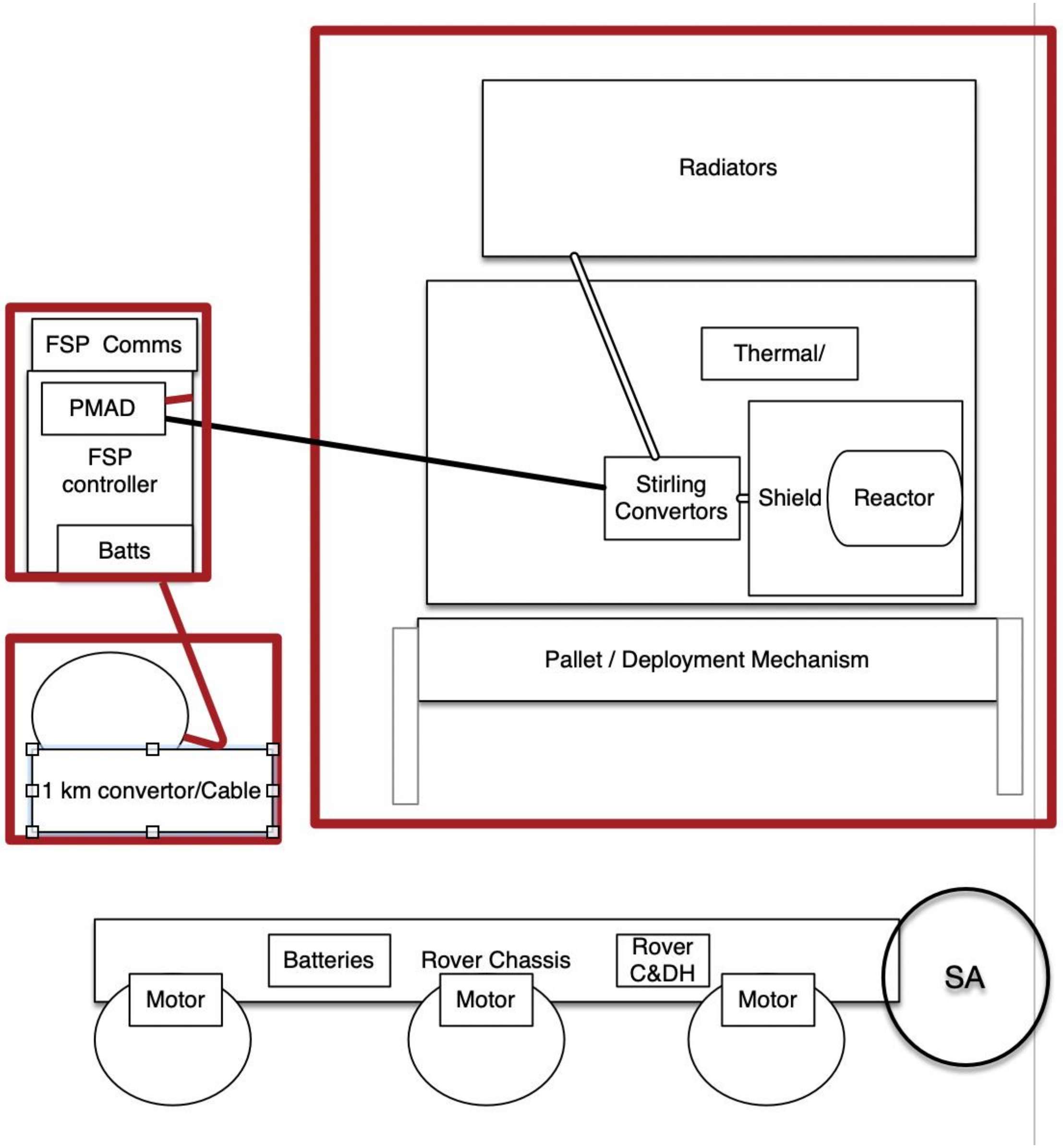




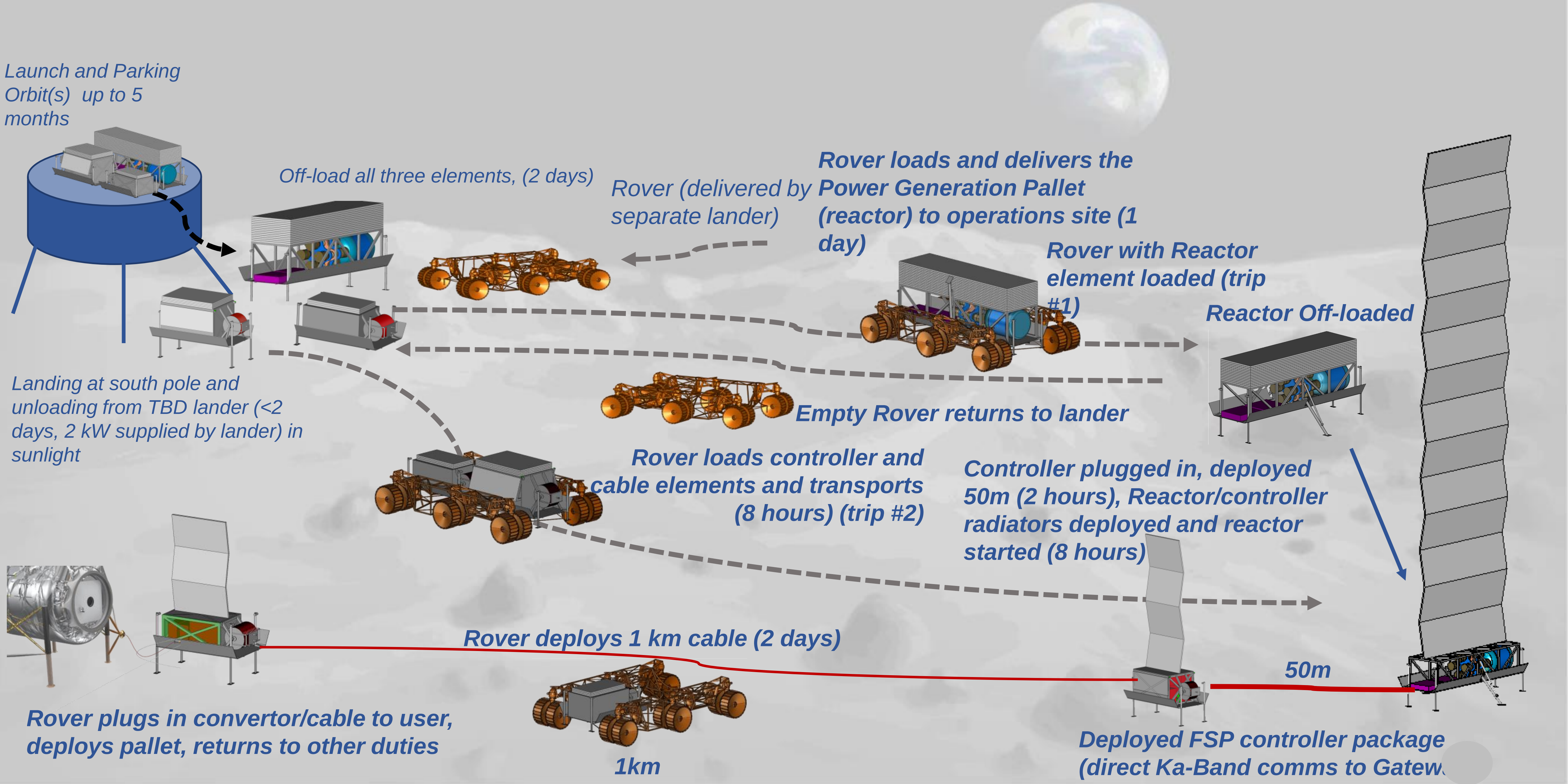
Top Level Requirements/Design Goals

- ✓ 40 kWe for 10 years on Lunar South Pole
- ✓ *Low Enriched Uranium (LEU) reactor includes shielding to keep radiation to 5 Rem/year at 1 km*
- ✓ *Stow in 4 m Diameter cylinder x 6 m length*
- *Maximum 6000 kg*
  - ✓ *(design showed a ~10,000 kg landed mass required – excluding mobility system)*
- ✓ *Commanded and autonomous on/off*
- ✓ *Up to 100% shunting of power*
- ✓ *Single fault tolerant with a minimum provided power of 5 kWe*
- *Operable from*
  - *lander deck OR*
  - ✓ *be removed and transported by a separate mobile system (focus of study)*
- ✓ *Assumed minimal crew interaction*

Top Level Schematic

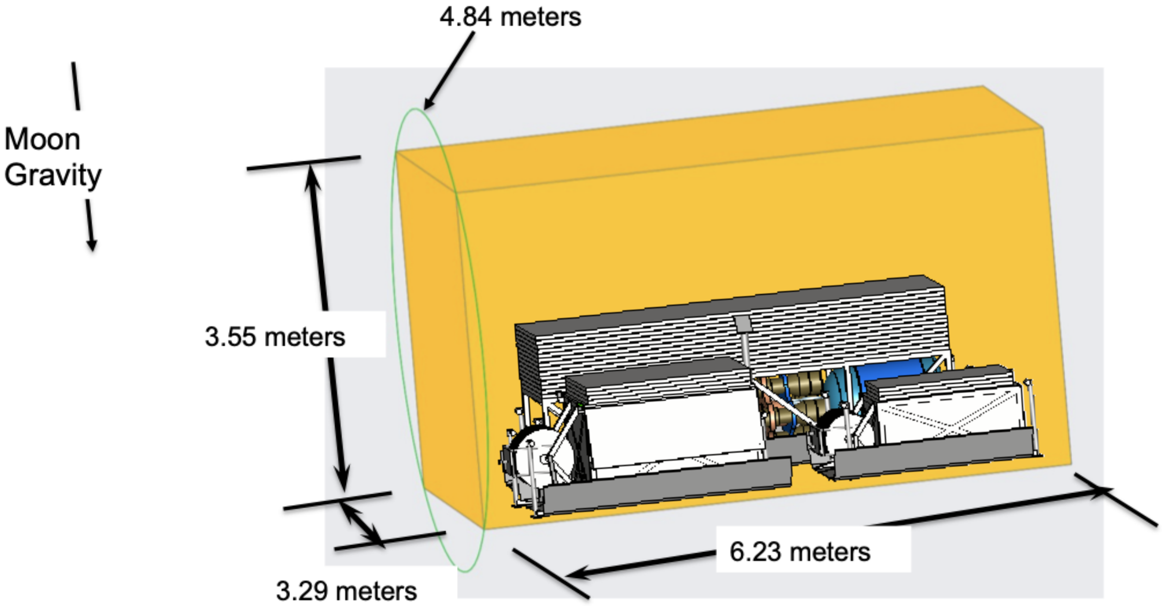


Top Level CONOPs



Rover and FSP Envelope

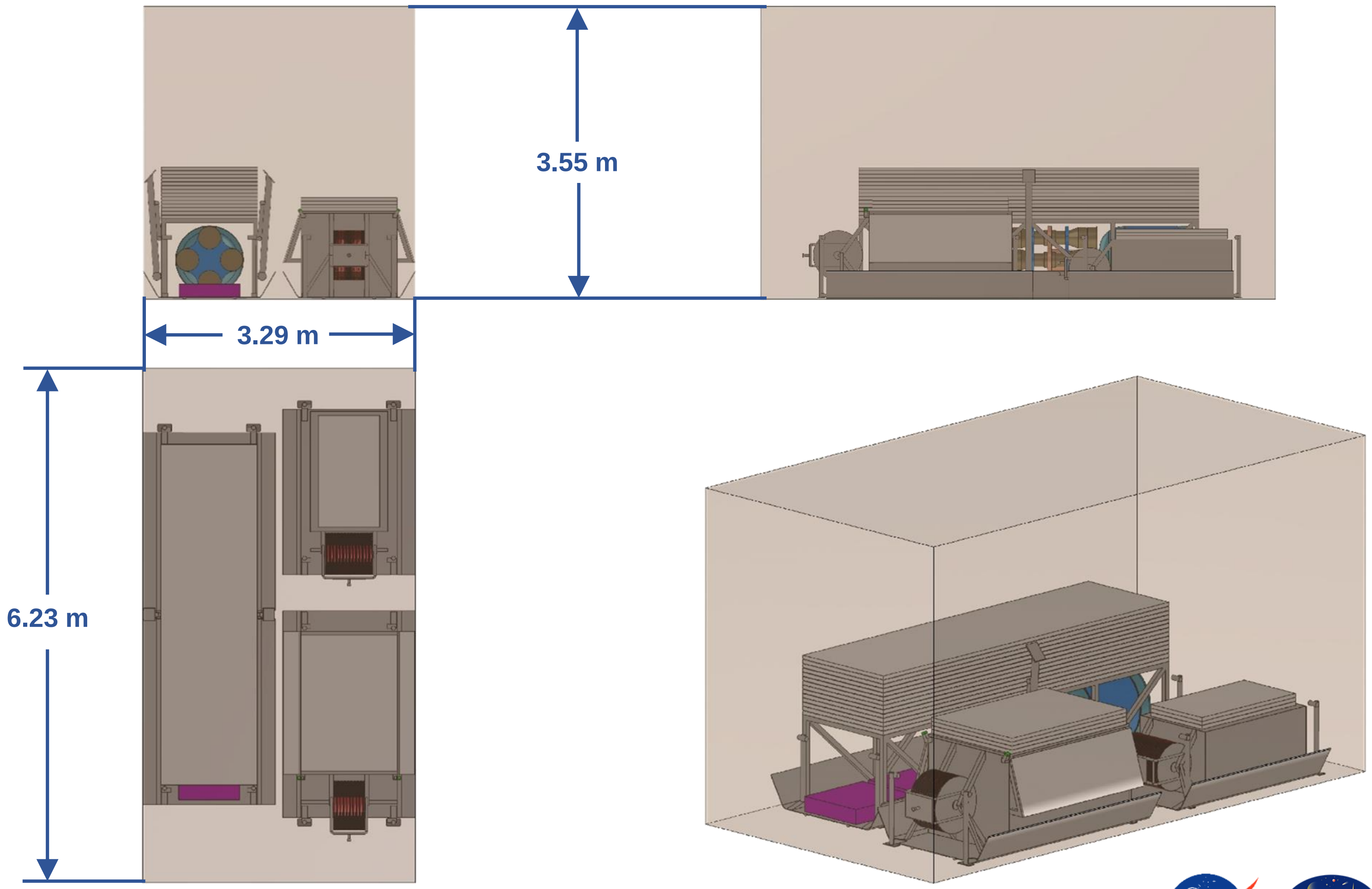
Pressurized Rover (PR): Volume and Orientation



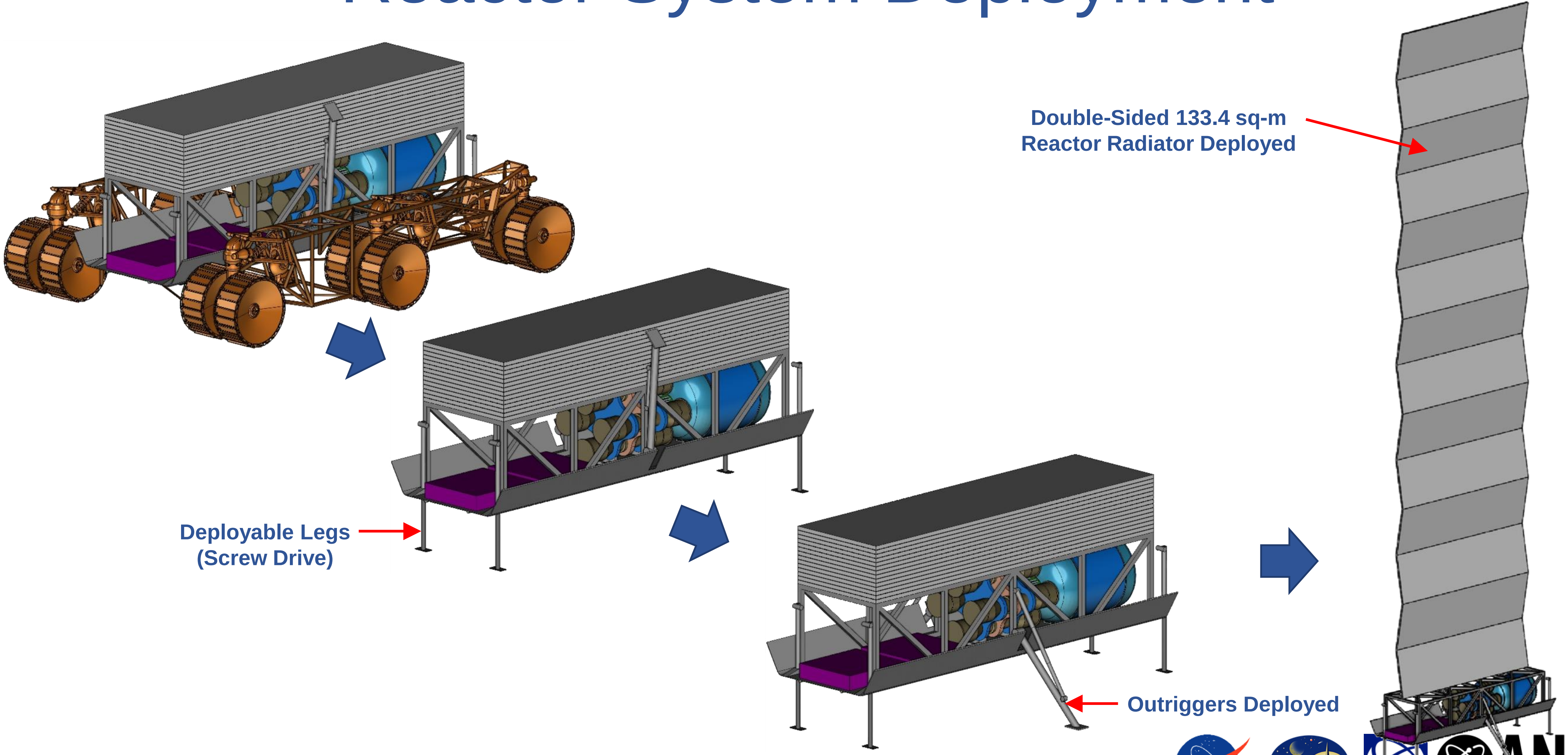
Design Constraints / Parameters	
Length	6.23 m
Width	3.55 m
Height	3.29 m

From: HUMAN Class Cargo LUnar Lander (HCCLL) SYstem to Cargo Interface Requirements Document (IRD)

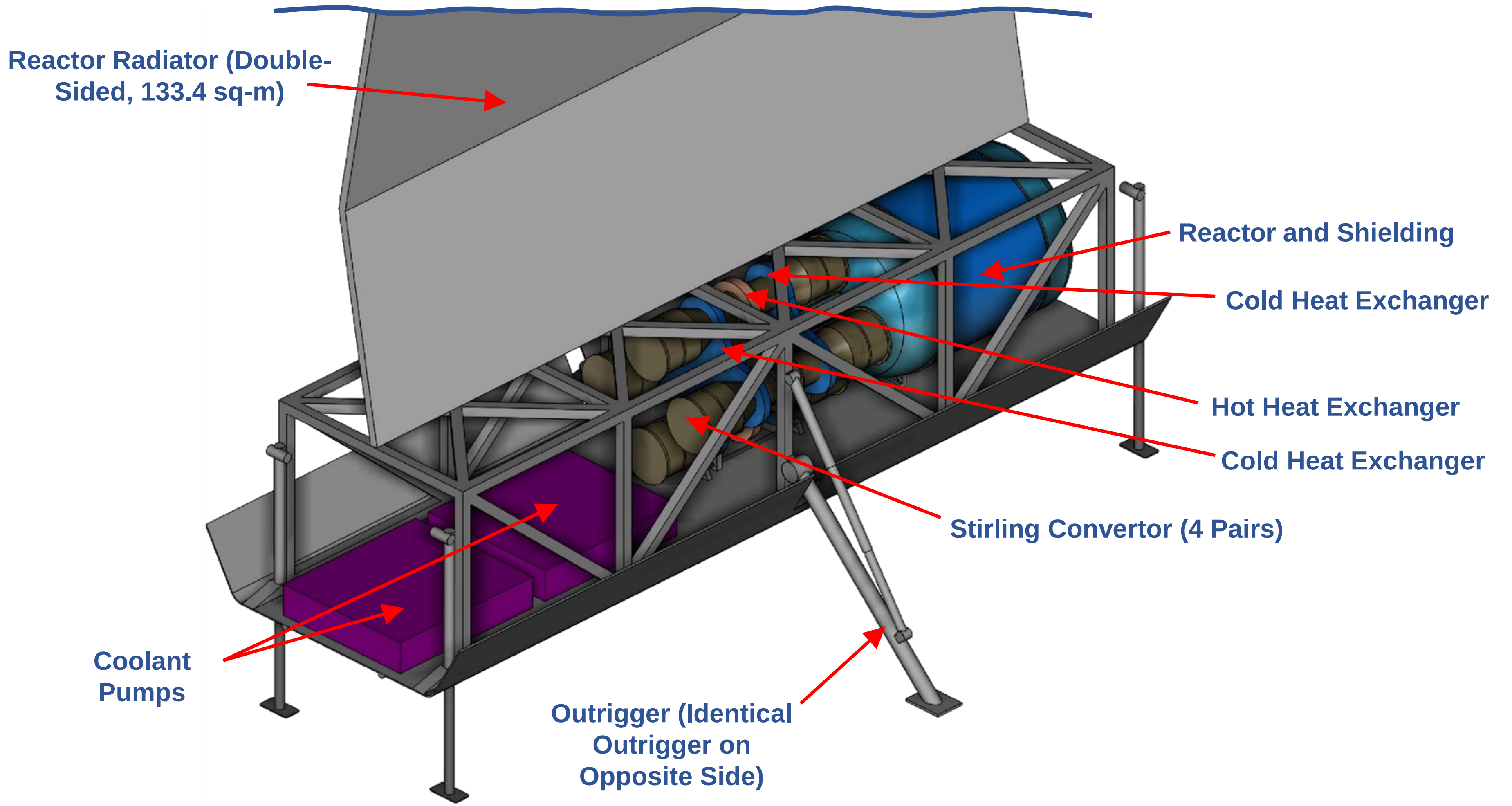
FSP 40 kW Transportability Concept Within the Lander Envelope

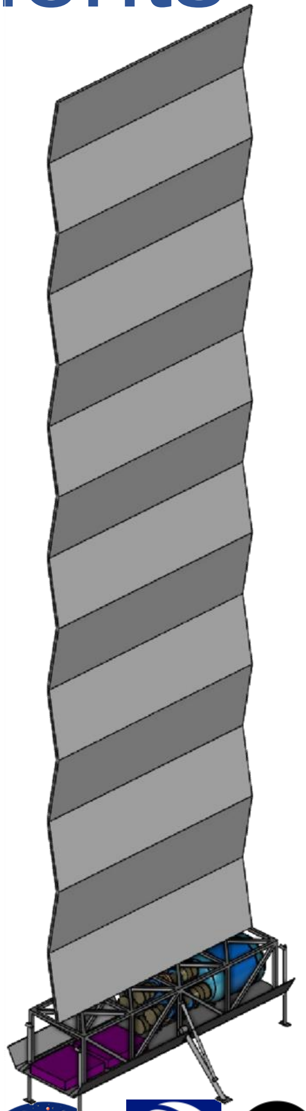


FSP 40 kW Transportability Concept Reactor System Deployment



FSP 40 kW Transportability Concept Reactor System External Components





‘SPYDER’ Design: HALEU Fueled YH Moderated Heat Pipe Reactor

<u>Nuclear Features</u>

K_{eff} (BOL): 1.06

Burnup: 250 kWt for 10-yr

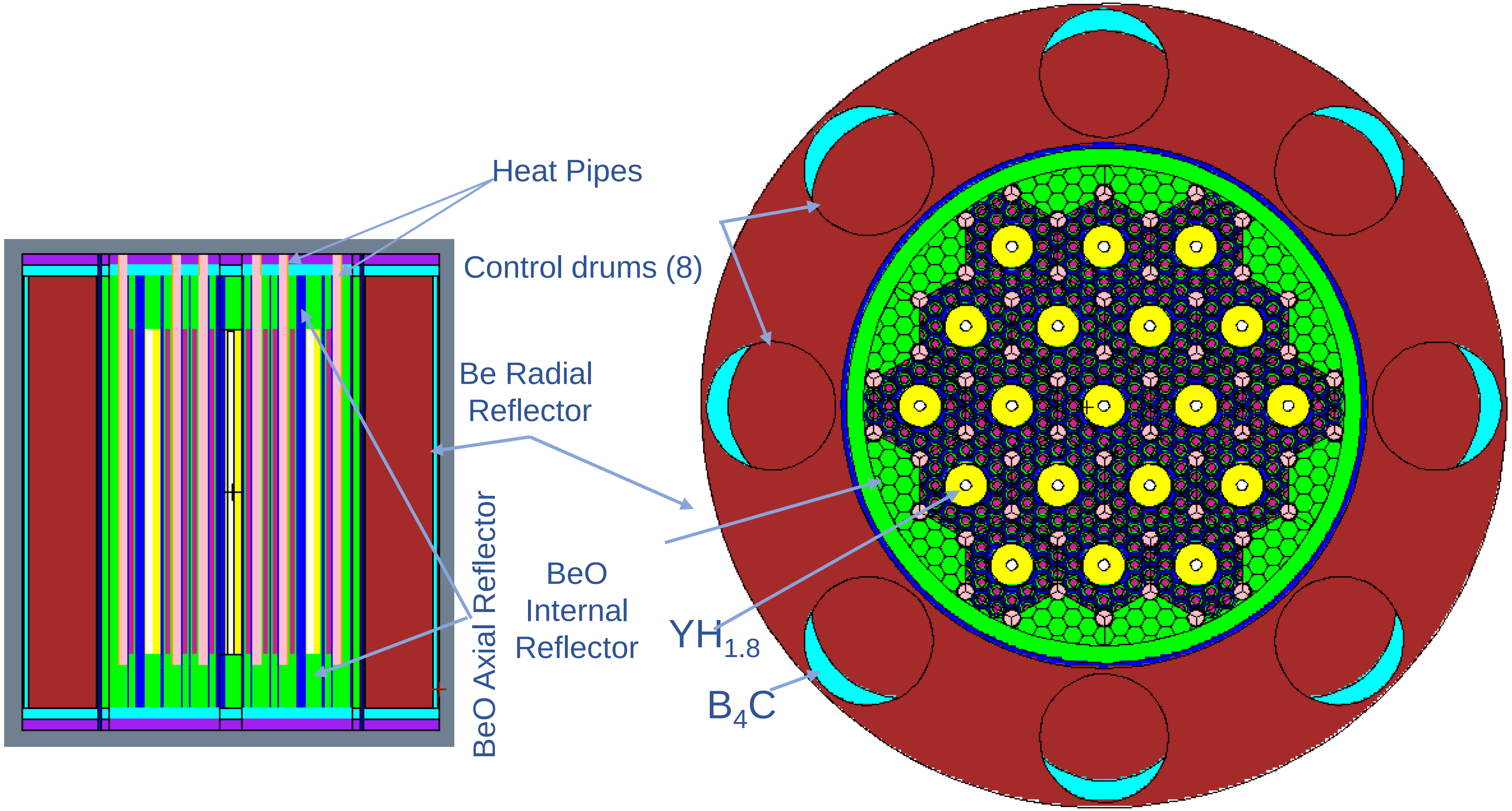
Fuel: UN pellets

Enrichment: 19.75%

Monolith: Graphite

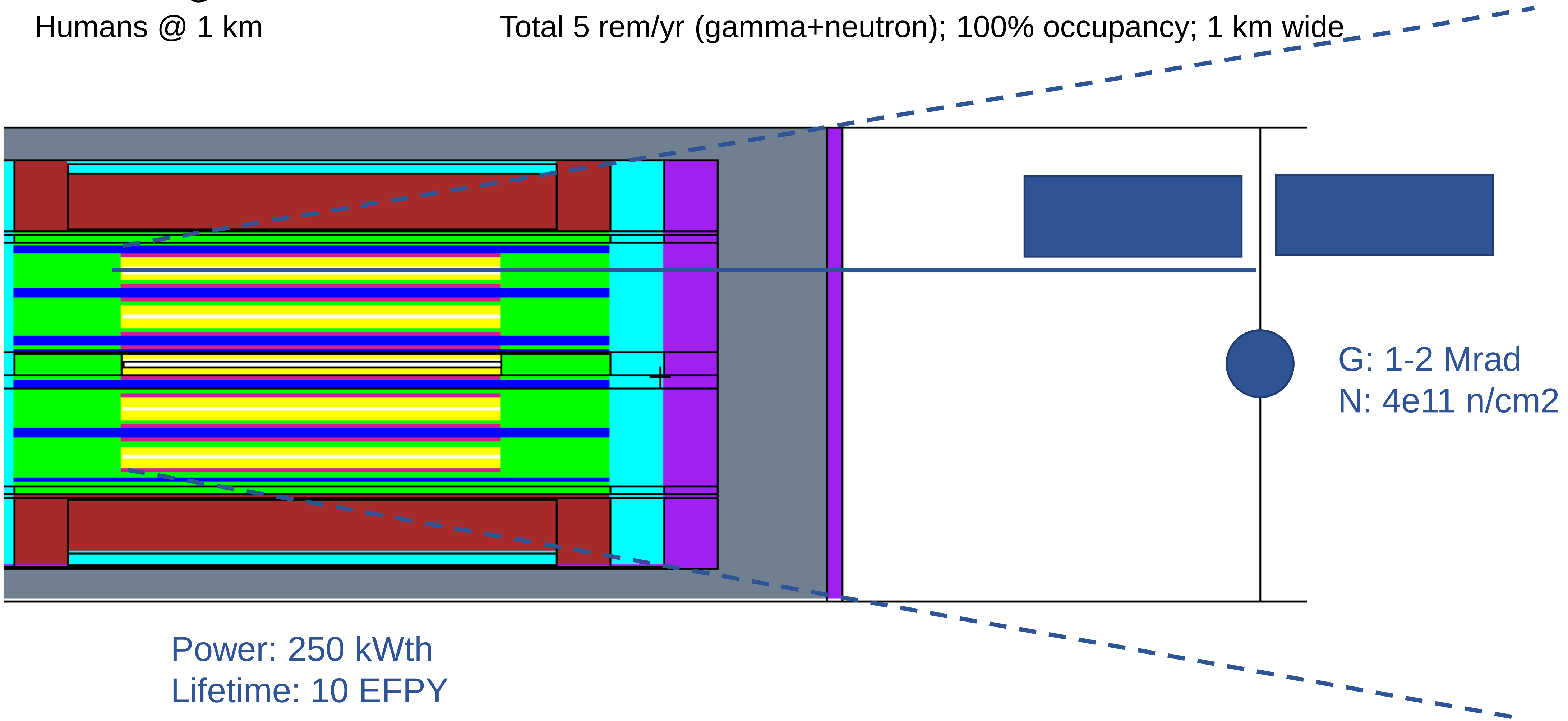
Heat Pipes: Na-Mo

Moderator: $YH_{1.8}$



Shielding Requirements

1. Stirling Components (1 m) — n: 5×10^{14} n/cm^2 (>100 keV) and Gamma: 25 MRad (Rad Si)
2. Electronics @10 m — n: 5×10^{11} n/cm^2 and Gamma: 25 kRad
3. Humans @ 1 km — Total 5 rem/yr (gamma+neutron); 100% occupancy; 1 km wide



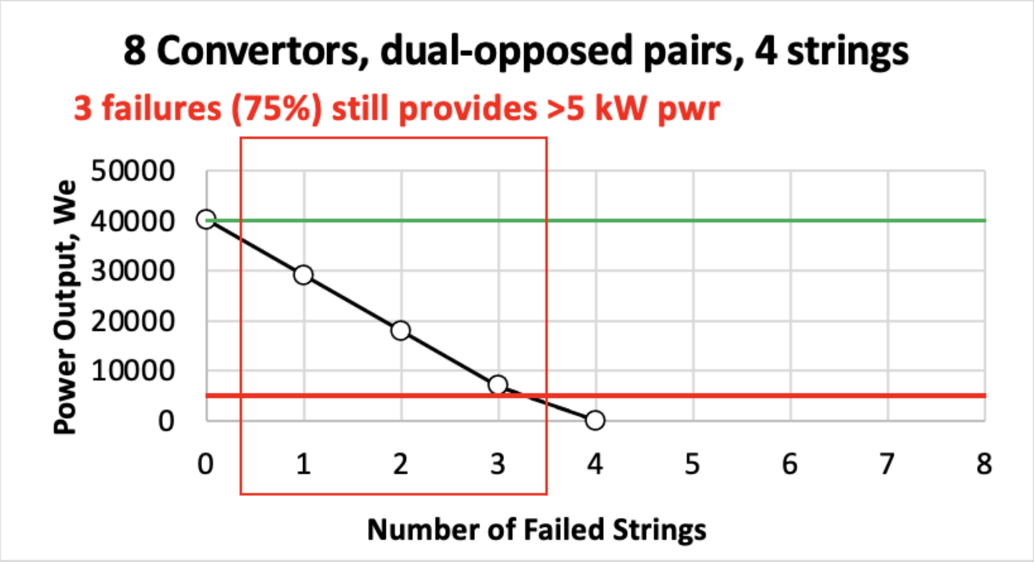
Power: 250 kWth
Lifetime: 10 EFPY

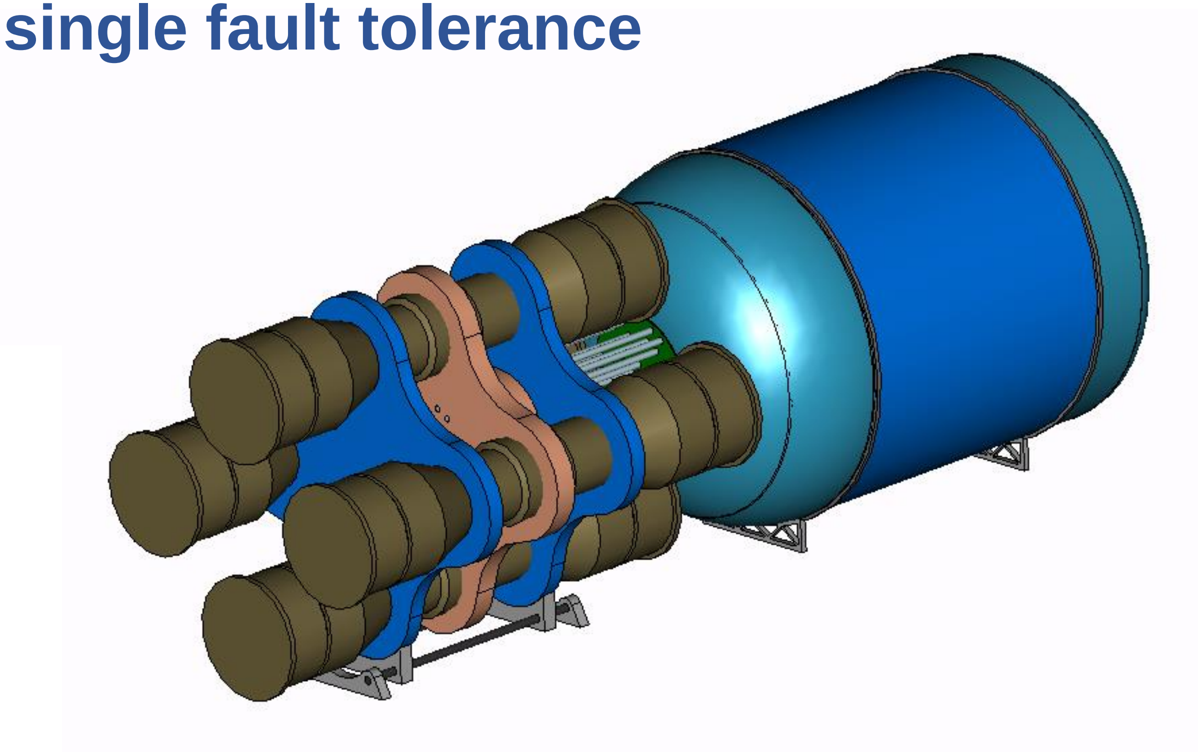
Stirling-Based PCS Power

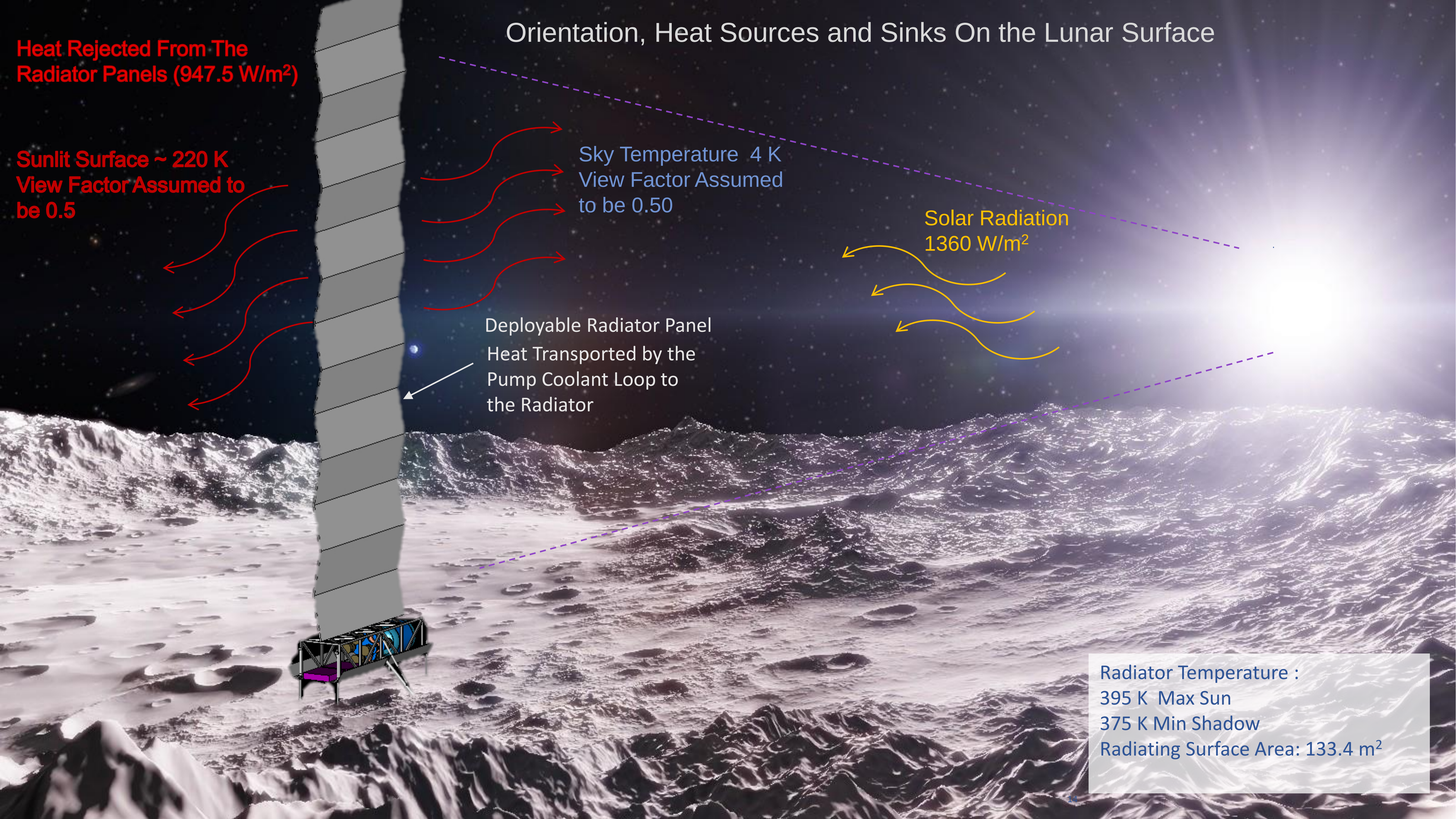
8 Convertor Case, 4 Strings: Dual-opposed pairs, no balancers, no single fault tolerance

8 Convertors:

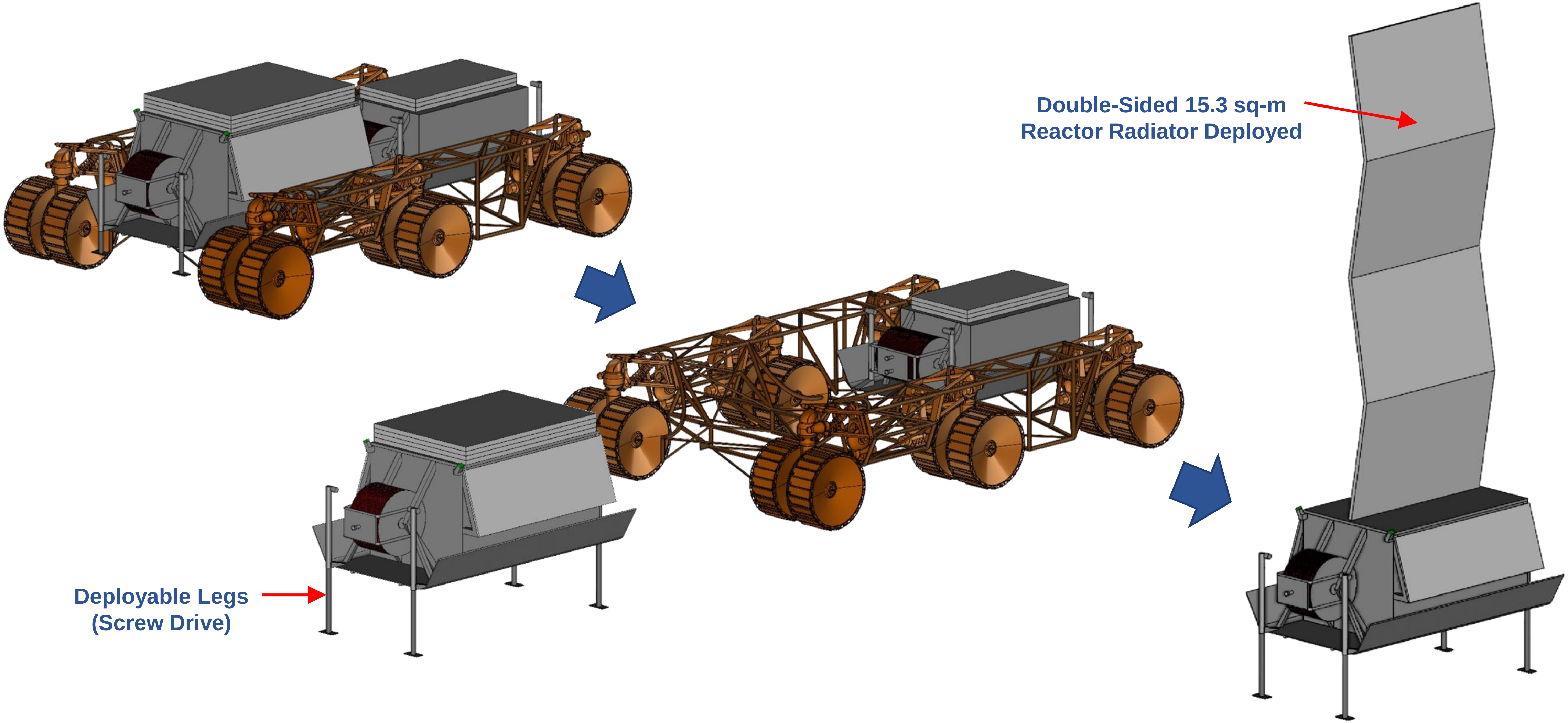
- Synchronized pairs
- Not single fault tolerant
- High reliability: able to meet minimum power requirement >5 kW_e after 3 of 4 string failures



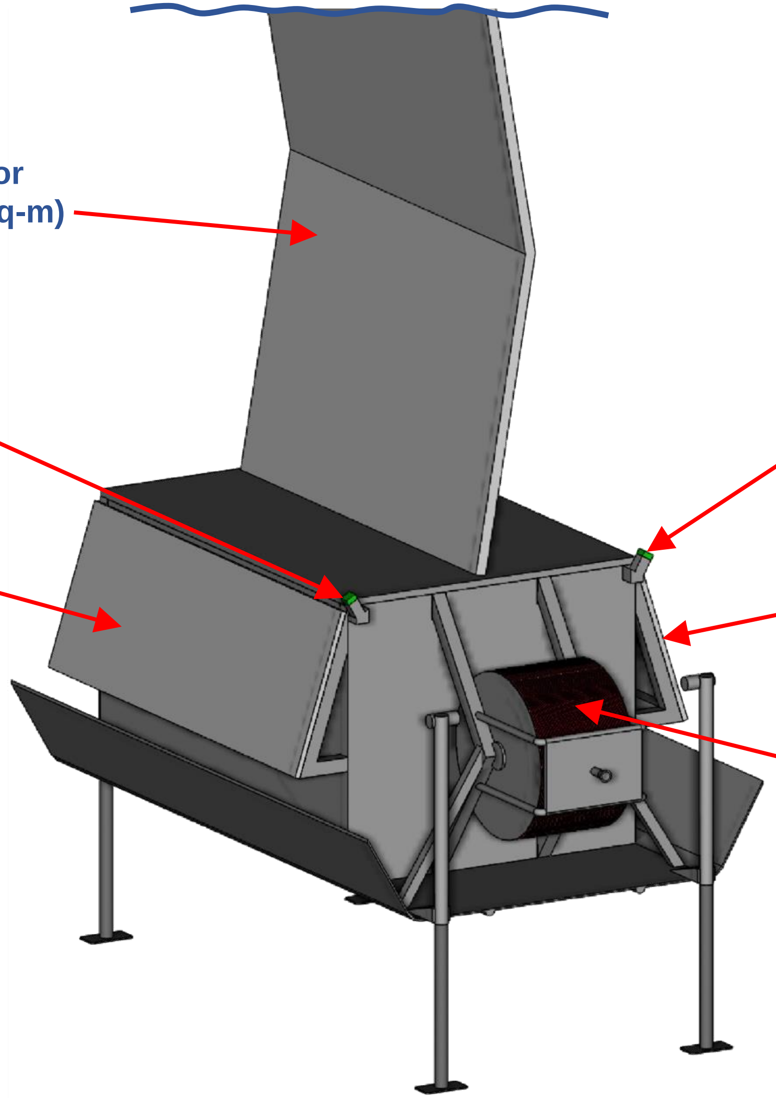



Orientation, Heat Sources and Sinks On the Lunar Surface
Heat Rejected From The Radiator Panels (947.5 W/m2)
Sunlit Surface ~ 220 K View Factor Assumed to be 0.5
Sky Temperature 4 K View Factor Assumed to be 0.50
Solar Radiation 1360 W/m2
Deployable Radiator Panel
Heat Transported by the Pump Coolant Loop to the Radiator
Radiator Temperature :
395 K Max Sun
375 K Min Shadow
Radiating Surface Area: 133.4 m2

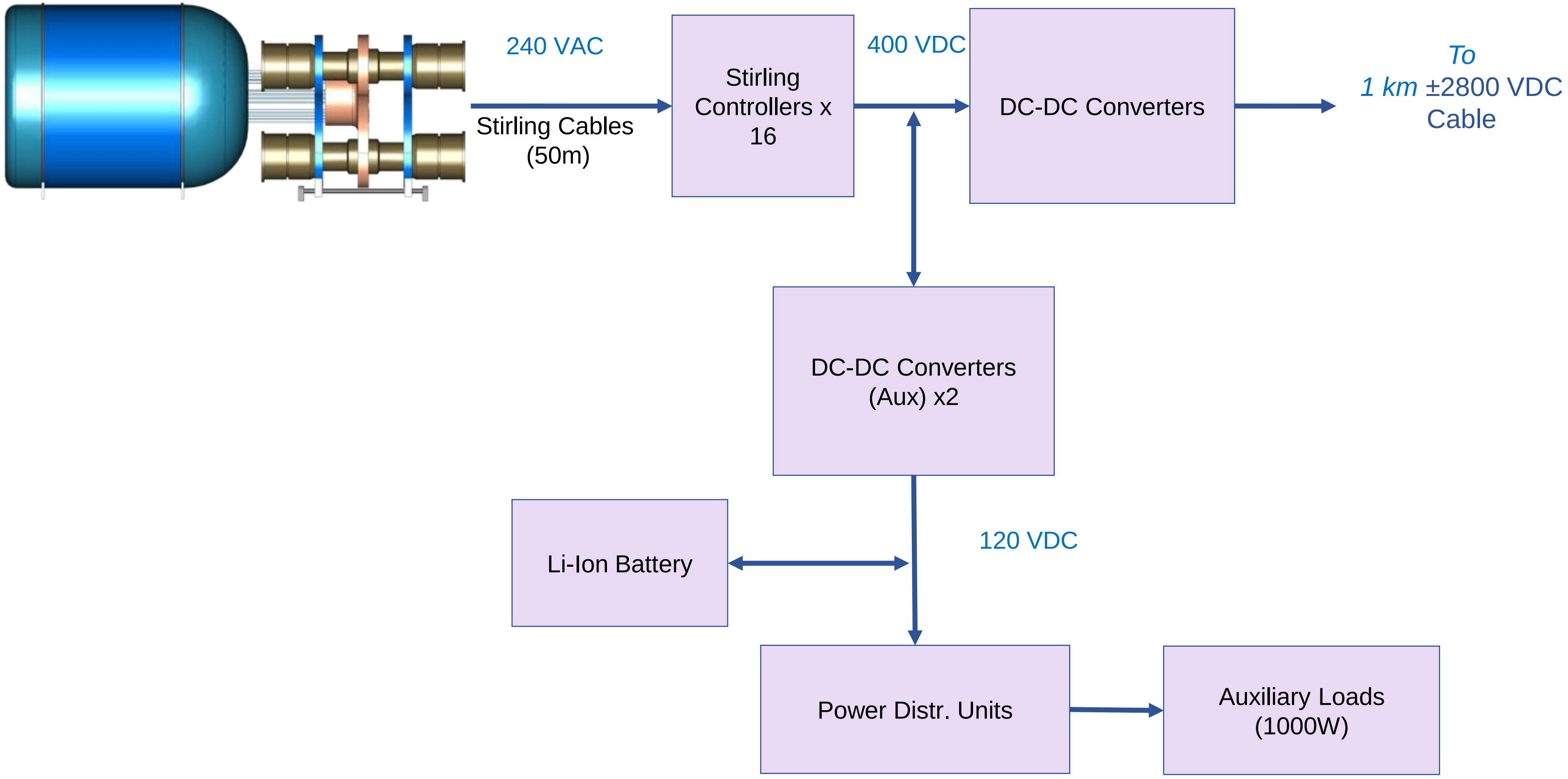
FSP 40 kW Transportability Concept Control Systems Deployment



FSP 40 kW Transportability Concept Control Systems External Components

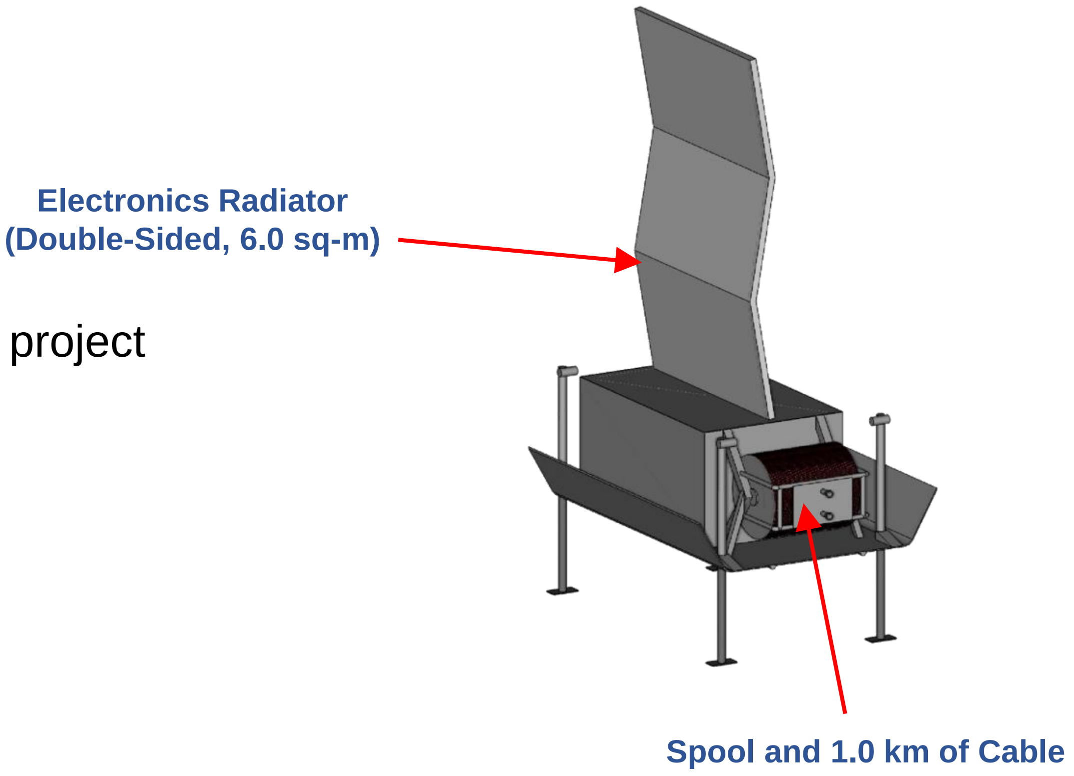


Power System Design – Control Systems

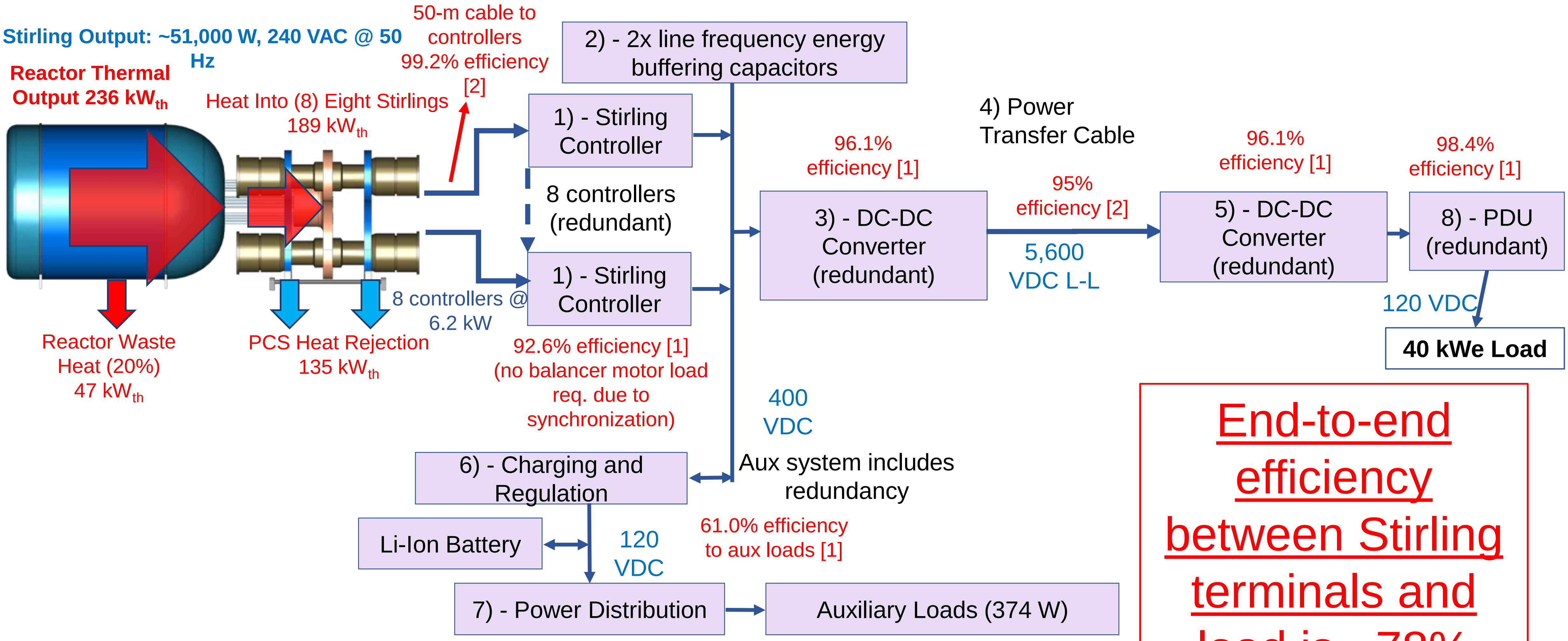


Power Transfer Spool Downconverter and Cable Design

- HabiaCable high voltage cables for electric aircraft/aeronautics
  - Design specification per Fission Surface Power (FSP) project
- Cable Design Assumptions:
  - Cable Length: 1 km
  - Cable Output Power: 43.5 kW
  - Cable Efficiency: >95% (2.2 W/m max losses)
- Selected *Aluminum Bipolar Pair* cable design
  - Operating voltage: +/-2800 VDC
  - Total cable mass: 73 kg
  - Cable outer diameter: 6.5 mm
  - Conductor area: 1.9 mm^2
- Reference "Lunar Cables for Fission Surface Power Project (FSP)". Adapted for 40 kW, 1 km by Christopher Barth (GRC/LET).
- Downconverter to return power to 120VDC



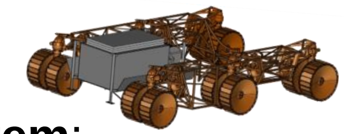
Power System Block Diagram



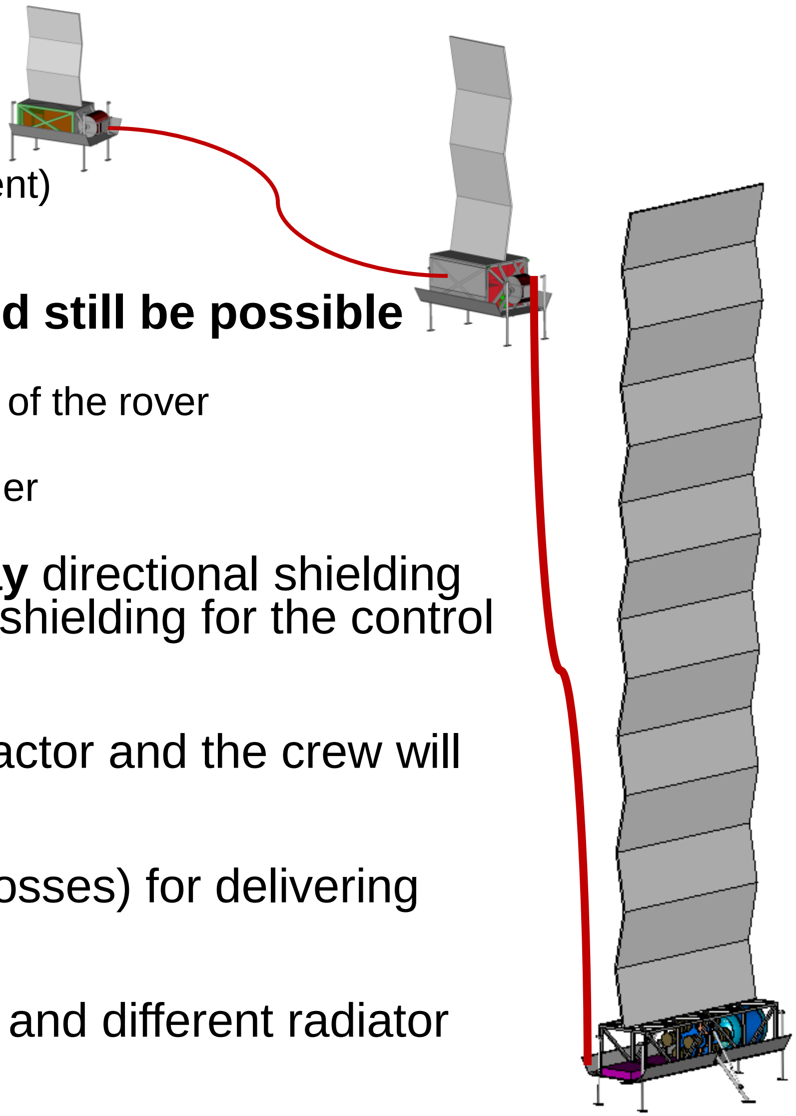
End-to-end efficiency between Stirling terminals and load is ~78%

[1] Metcalf design models
[2] Designed efficiency

Lessons Learned



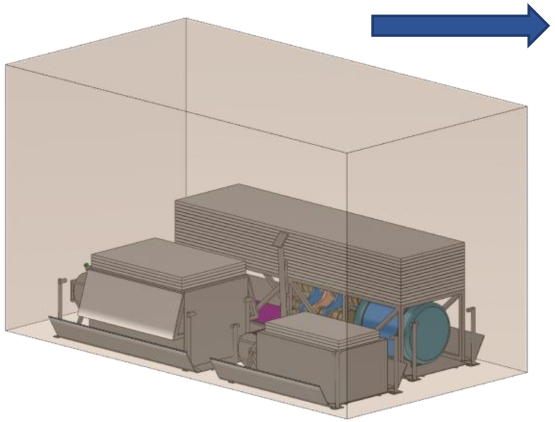
- **Increasing to a 40 kWe (from a 10 kWe) power system**:
  - Almost breaks the 12t limit for planned cargo landers
  - Cannot be landed with the mobility system (it will need to be landed with other equipment)
  - Does fit the volume limit
- **Using the pressurized rover chassis to deploy the 40 kWe system should still be possible BUT**
  - It now must be deployed as three separate pieces due to volume and mass constraints of the rover
    - A new, dedicated rover could be developed but at added cost
  - The three separate pieces add complexity, mass, and an additional trip to/from the lander
- **By laying down the reactor and placing the control electronics 50m away** directional shielding can be optimized to provide the 5 rem/year for the crew and eliminate added shielding for the control electronics.
- In the current configuration, adding distance/over the horizon between the reactor and the crew will not reduce shield mass
- **High, DC voltage found more mass efficient** (even with conversion mass/losses) for delivering power to users 1 km away
- **Modifying the design for equatorial use** requires ~60% more radiator area and different radiator configurations for all elements
- **On-Lander option**: Assuming the lander could be placed >1 km from the crew the current reactor pallet could be kept on the lander **– just the controller/cable pallet unloaded and deployed**
  - Further work to assess radiation and any interactions with the TBD lander



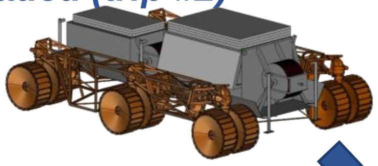
Lunar 40 kWe Fission Power System Demonstrator: Smart Buyer Executive Summary

- **Purpose: Develop a deployable 40 kWe Lunar Fission Surface Power System Concept**
- **Users: Human lander, Night-time survival, Science, ISRU, communications**
- **Total FSP Mass ~ 10,000 kg (~2t rover not included)**
- **Power: 40 kWe reactor 1km cable to users**
  - **Eight, 6 kWe Stirlings ensure ~ 5kWe at 10 years**
  - **Radiation tolerance set to 100 krad in controller**
  - **Radiation at Stirlings set to 25 Mrad**
  - **<5 mrem/hr at >1 km from habitat**
  - **Utilize same rover to deploy 1km, +/- 2800VDC cable**
- **Lander:**
  - **Provides transit and delivery to lunar surface (up to 12,000 kg capability)**
  - **Provides structure for mounting FSP and carrier rover**
  - **Deploys FPS/Rover to surface in the same was as the PR**
- **Rover: based on Pressurized rover (PR) (up to ~8 t carrying capability) and skid based off-loadable cargo concepts. Landed separately.**
- **Comms: Reactor Package: shielded Ka-Band link to 70,000 km Gateway (almost continuous commlink)**
- **C&DH: Reactor Package: Shielded controllers for reactor and Stirlings, interface to Gateway**
- **Thermal:**
  - **Deployable Reactor Package: 133 m^2 radiator for Stirlings, sized for polar operations**
    - **Use at equator adds 60% radiator area**
- **Mechanical:**
  - **Deployable jacks to lift FSP pallets off of rover**
  - **Deployable radiators**
  - **50m 240VAC (@50Hz) and 1 km 3000 VDC cable/spools**
  - **Stability legs for reactor element**

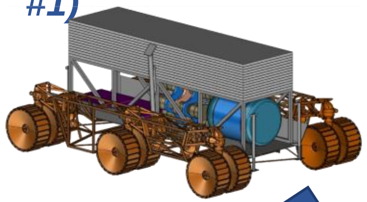
40 kWe FSP system packaged in lander envelope

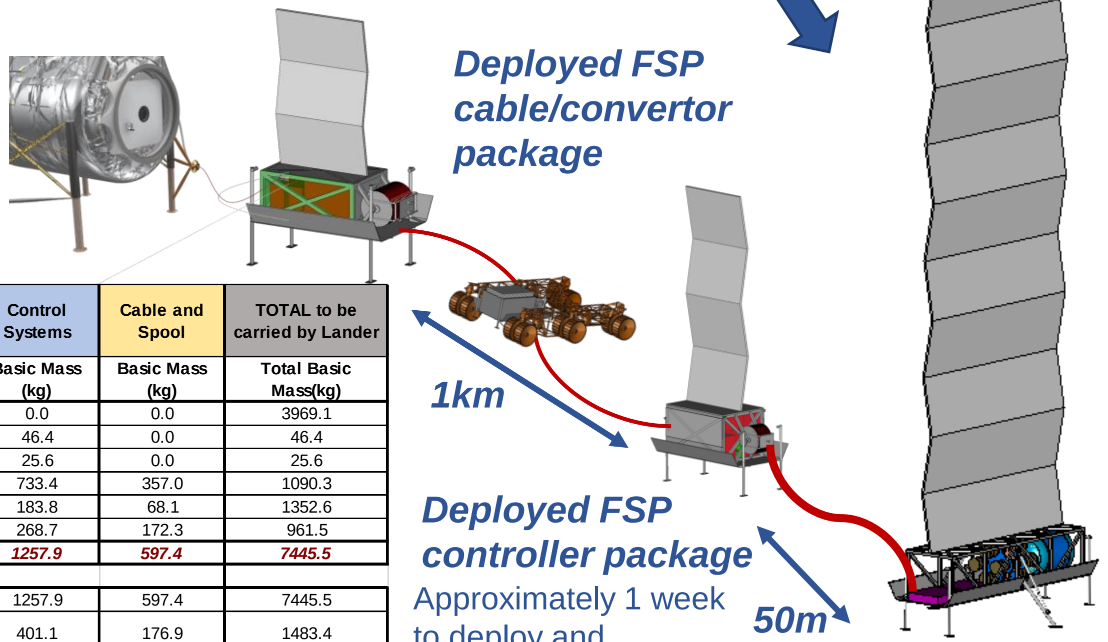


Rover with controller and cable elements loaded (trip #2)



Rover with Reactor element loaded (trip #1)





Deployed FSP cable/convertor package

1km

Deployed FSP controller package

Approximately 1 week to deploy and commission reactor and provide user power

50m

Deployed 40 kWe FSP system packaged in lander envelope

MEL Summary: 40kW_Case 2_FSPS Deployability CD-2021-187	Fission Surface Power System	Control Systems	Cable and Spool	TOTAL to be carried by Lander
Main Subsystems	**Basic Mass (kg)**	**Basic Mass (kg)**	**Basic Mass (kg)**	**Total Basic Mass(kg)**
Fission Power System	3969	0.0	0.0	3969.1
Command & Data Handling	0.0	46.4	0.0	46.4
Communications and Tracking	0.0	25.6	0.0	25.6
Electrical Power Subsystem	0.0	733.4	357.0	1090.3
Thermal Control (Non-Propellant)	1100.6	183.8	68.1	1352.6
Structures and Mechanisms	520.4	268.7	172.3	961.5
Element Total	*5590.2*	*1257.9*	*597.4*	*7445.5*
Element Dry Mass (no prop,consum)	5590.2	1257.9	597.4	7445.5
Element Mass Growth Allowance (Aggregate)	905.4	401.1	176.9	1483.4
MGA Percentage	16%	32%	30%	20%
Predicted Mass (Basic + MGA)	6495.6	1659.1	774.3	8928.9
System Level Mass Margin	838.5	188.7	89.6	1116.8
System Level Growth Percentage	15%	15%	15%	15%
Element Dry Mass (Basic+MGA+Margin)	7334.1	1847.8	863.9	10045.8
Element Inert Mass (Basic+MGA+Margin)	7334.1	1847.8	863.9	10045.8
Total Wet Mass (Allowable Mass)	*7334.1*	*1847.8*	*863.9*	*10045.8*
	Mobility System Trip 1	Mobility System Trip 2		

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