



# WPI

## Lunar Colony Phase 1

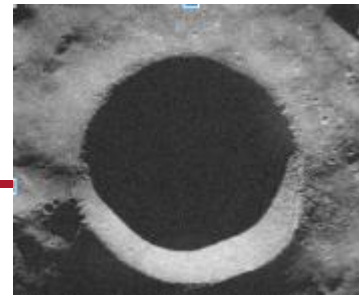
Weston Schlack, Mykalin Jones,  
Flah Ilyas, Dan Pelgrift

# Phase I Goals

---

- Establish small outpost capable of housing 6 astronauts
- Perform preliminary research:
  - Study effects of lunar gravity on human and plant growth
  - Study lunar regolith: composition, plant growth, material extraction
- Test automated technology and construction techniques
- Survey lunar landscape for future development sites:
  - Equatorial settlement
  - NEO telescope
  - Launch pad
  - Maglev track
- Begin construction for Phase 2

# Location of main site



- Phase 1: surface structure at the Shackleton crater
- Controlled convergence method trade study:
  - Key: 1=poor, 2=neutral, 3=excellent

Location	Features					Rating
	Radiation Protection	Temperature Fluctuation	Escape Velocity	Sunlight	Good for Overseeing Phase 3	
<b>Pit in Mare Tranquillitatis</b>	3	1	3	1	1	9
<b>Shackleton Crater (surface outpost)</b>	1	3	1	3	3	11
<b>Pit in Mare Fecunditatis</b>	3	1	2	2	2	10

- Results: for Phase 1, build surface outpost at shackleton crater. Place a permanent outpost in a lava tube near the equator along with a launch pad and space elevator in Phase 2. Phase 3 will expand on both locations.

# Additional Sites

---

- Rovers will be used to survey the parameters of the chosen location and to find the optimal locations for the following sites:
  - Equatorial launch pad, space elevator and permanent outpost
  - Far side location for telescope
- The mare tranquillitatis pits described in the trade study could provide a good permanent equatorial outpost.

# Rovers for surveying additional sites

---

- 3 rovers: south pole, equatorial, far side
- 2 relay satellites in L2 and L4 will be established to maintain contact with the far side rover

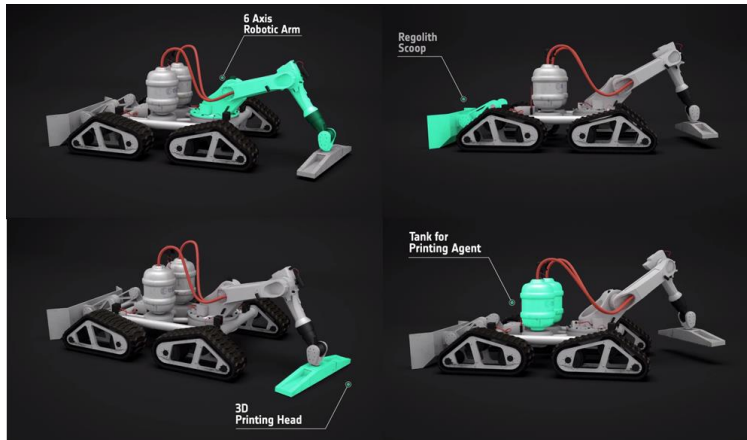
# Structure

- Base inflatable structure, covered with lunarcrete or mass produced regolith blocks
  - Could have multiple connected structures
- Separate solar & nuclear power facilities
- Robotic maintenance facility
- Food, Water, Equipment, Power Storage
- Living Quarters
- Laboratory
- Excavated emergency shelter under base
  - Radiation protection from solar flare



# Construction

- Robots survey site and test Lunarcrete creation
- Specialized robots collect regolith, process into Iron, Silicon, Aluminum, Titanium, & water, then water into Hydrogen & Oxygen, store in removable tanks or deposit in central storage location
- Nuclear reactor landed, construction of solar plant begins
- Underground shelter excavated
- Inflatable base structure lands and self-deploys
  - Outside coated with regolith
- Final supplies delivered, astronauts arrive and finish setting up



# Power

For early development phase: Three nuclear fission reactors were compared. Of the three types under consideration, the Space Molten Salt Reactor design will be used.

<b>SP-100</b>	<b>HOMER-25</b>	<b>Space Molten Salt Reactor</b>
Solid Uranium fuel	Solid Uranium fuel	Liquid Fluoride Thorium fuel (thorium 3 times more abundant than Uranium)
At 4500kg, it can be stowed and taken to the moon as a single payload.	At 1385kg, multiple reactors could be carried as a single payload	Conceptual stages. Simplistic design could lead to lightweight model
Capacity of 100 KWe to 400KWe; one reactor will be enough to meet the power demands of the base	Capacity of 25 KWe; 4 reactors will be required to meet power demand of 100KWe	Capacity of 100KWe to 15MWe Could be expanded to meet growing energy demands
415.2 Million invested until withdrawal of funding, ground testing yet to begin	Low-cost may be a possibility, but costs may rise as time goes on	100 MWe Terrestrial MSR projected to cost \$200 Million, so 100KWe model could cost significantly less
Life span: 7 years	Life span: 5 years	Not Predicted



# Lunar Solar Plant (LSP)

---

- Location:
  - Located at the “Peak of Eternal Light” at the rim of the Shackleton crater at the South Pole, which has sunlight incident on it for 84% of the time on an annual basis.
- Design:
  - Gallium arsenide photovoltaic cells will be used due to high conversion efficiency and temperature resistance.
  - Each array measures 33.528 m by 11.5824 m, consists of 32,800 solar cells, and generates 11 KWe.
  - 10 such arrays will provide a nominal power capacity of about 100 KWe during daytime covering 3883 square meters.
  - Triangular 60° self-deploying arrays, placed 15m apart in 5 rows to keep them overshadowing each other.

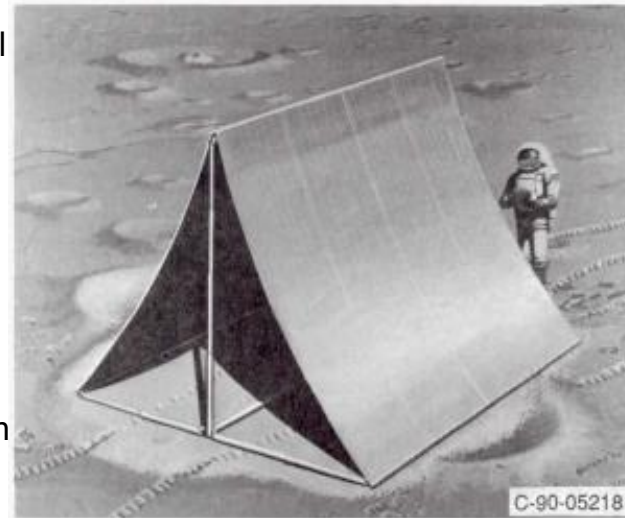


Figure 4.—Self-deploying tent array.

# Lunar Solar Plant (LSP) continued

---

- **Storage:**

- Regenerative Fuel Cells (RFC) using hydrogen and oxygen will store power for use during lunar night, lasting a maximum of 7 earth days or 168 hours.
- The RFCs will operate at 50 KWe or lower during lunar night so night power usage will be minimized.
- A power management and distribution system will control power supply. Power will be transmitted at a high voltage to minimize transmission losses.
- The excess heat from all power systems will be removed by radiators.
- Lithium ion batteries will be used as backup power for life support system.

- **Research:**

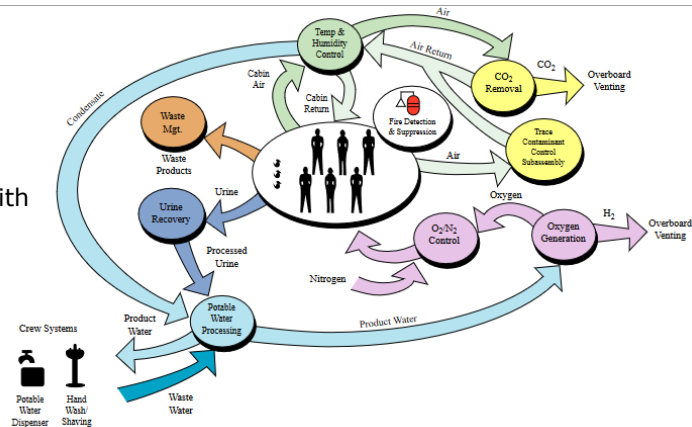
The crew will carry out test studies into:

- Solar sails (based on JAXA IKAROS)
- Free-flying mirrors (based on Formation-Flying SPS)
- Tracking array technology
- Quantum dot technology

These may be used in the later phases to increase sunlight flux and power generation.

# Life Support

- Water
  - Recycled from waste water & liquid waste
  - Collected from humidity
  - Generated by reaction of Hydrogen w/ regolith (full of oxides)
  - Generated by fuel cells
- Oxygen
  - Air Revitalization System
    - Carbon Dioxide Removal
    - Trace Contaminant Control
    - Air Composition Analysis
  - Oxygen Generation
    - Electrolysis of water generated w/ regolith
    - Oxygen pumped to habitat
    - Hydrogen reused for water generation
  - Chemical Generation
    - In event of emergency
- Waste Management
  - Water removed, remaining waste dumped



# Temperature Control

---

- Shackleton average temperature is around 90K.
- The main structure will be covered with a multilayer insulation (MLI) consisting of many thin layers coated with reflective material that are separated by minute spaces. This will provide insulation from radiation.
- Regolith coating of 2 meter thickness will also offer good insulation.
- The combination of MLI and regolith coating will lower heat gains during the day to 0.08KWe and heat losses during the night to 0.17KWe, a negligible level.
- Habitat could be coated in darker material to better absorb heat from sunlight.
- Ground near site could be coated for increased ambient heat.
- The internal temperature will be maintained at 21° Celsius by air conditioning, forced convection cooling and ceiling panel cooling systems.

# Crew: Research Team

---

- Will carry out the research described in Phase I goals
- Composition:
  - Medical Doctor
    - Provide medical care to crew
    - Research effects of lunar environment on humans and human development
  - Geologist
    - Study lunar regolith and research methods for extracting materials
    - Conduct surveys of sites for future construction
  - Botanist
    - Study plant growth in the lunar environment with a focus on aeroponics

# Crew: Engineering Team

---

- Composition:
  - Space Systems Engineer
    - Maintain specialized equipment (life support, space suits, rovers, etc.)
  - Electrical Engineer
    - Oversee construction and operation of solar power facility
    - Oversee operation of nuclear reactor
    - Design and troubleshoot electrical systems
  - Mechanical Engineer
    - Troubleshoot robotic hardware and facility equipment
- In addition to troubleshooting, the Engineering Team will use the Research Team's results and their direct experience with lunar living to design new technologies that will benefit future phases

# Logistics

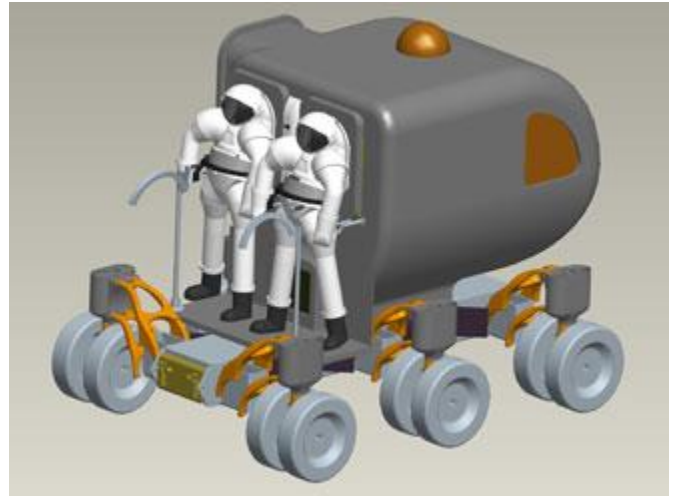
---

- Day/night cycles: 24 hour cycles on GMT
- Food will be supplied from earth for Phase 1
- Daily exercise will be mandatory to protect against bone and muscle degeneration
- Crew will be rotated in groups of three every six months

# Surface Transportation

---

- Two rovers based on NASA's Lunar Electric Rover
- Used to survey the local area, collect regolith samples, and move away from the habitat in case of emergency
- Radiation shielded, pressurized cabins typically crewed by 2 astronauts, can hold 4 maximum
- Can travel up to 240 km away from base
- Can function independently for 72 hours
- Designed to traverse steep terrain





# Space Suits

- Hybrid design chosen – works with rover

Design	Desired Features					Rating
	presurization	ease of don/doff	manuverability	durability	weight	
hard suit	3	2	2	3	1	11
Soft suit	3	1	1	2	1	8
Hybrid suit	3	3	3	2	2	13
Mechanical counter pressure suit (MCP)	1	1	3	3	3	11

Key:  
1 = poor  
2 = neutral  
3 = excellent

# Backups Systems/Contingency Plans and Maintenance

Considerations	Possible Solutions
Radiation/space weather	In Phase 1, a thick regolith wall on the outside will protect inhabitants in the pod.
Micrometeorites	Regolith wall. Robots used to print wall will be repurposed to make repairs and maintain wall.
Medical emergency	A medical doctor will be a part of the crew. All crew will have mandatory extensive first aid training.
Dust mitigation	Materials that repel dust will be explored. Gears and gaps in equipment will have to be maintained or designed with the abrasive dust in mind. Acoustic levitation, blasting with compressed air, or possibly power washing will be tested and a combination of these may be used.

Considerations	Possible Solutions
Power failure	Nuclear will be used initially. Solar panels will be regularly maintained in case of damage, nuclear power system will be used as back up. Fuel cells and lithium ion batteries will be used for further backup.
Fire	All crew will receive fire fighting training. Supplies for fighting all types of fires will be sent with the crew in case of emergency. The structure will have an inner lining of beta cloth.
Catastrophic event during phase 1	The crew lander will be able to launch and meet up with an orbiter to go back to Earth in case of a catastrophic event.

# Schedule

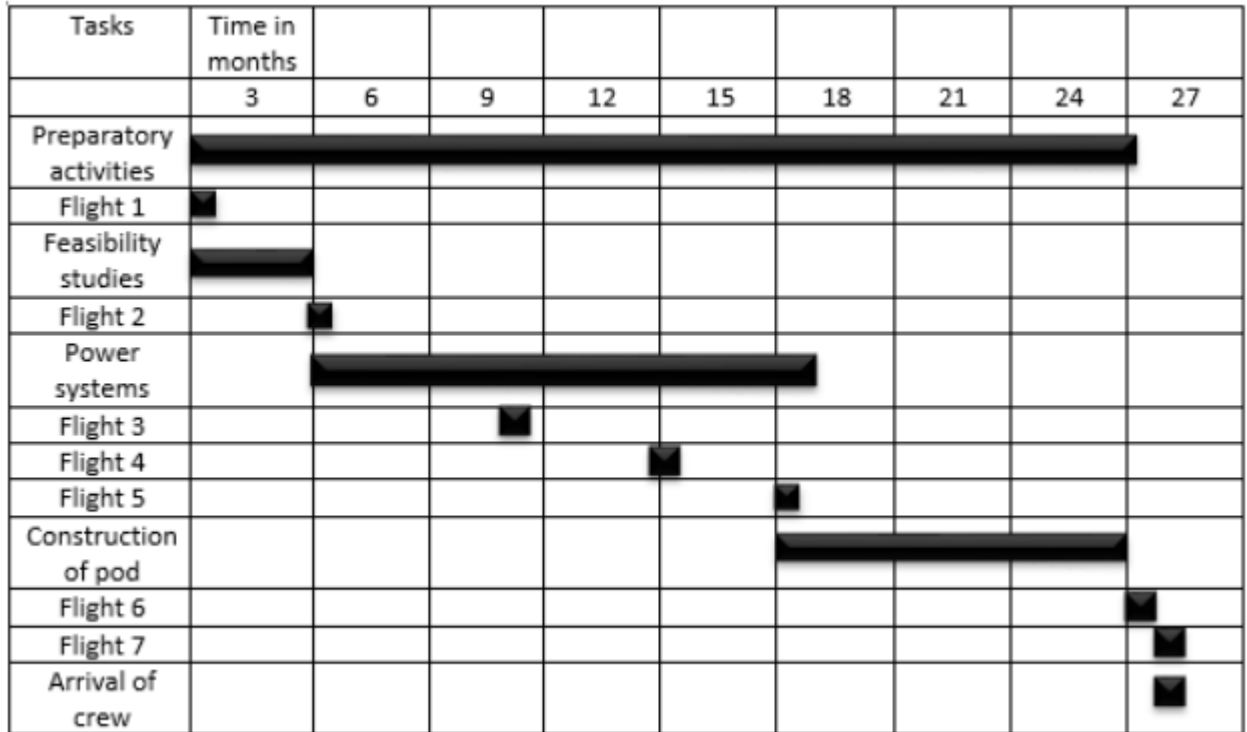
---

- Remote rovers will carry out feasibility studies of various sites for: (Months 0-3)
  - Outpost/bunker - shackleton crater
  - nuclear reactors - 1km away from outpost
  - solar power station - peak of eternal light
- Power systems: (Months 3-16)
  - Nuclear reactors are installed- (Months 3-6)
  - Construction on 100 KWe solar power plant begins- (Months 6-12)
  - Power management and distribution system, and fuel cells are installed- (Months 12-16)
- Construction of pod: (Months 18-24)
  - Dig underground reservoir (Months 18-19)
  - Inflate pod and print regolith shield over structure (Month 20)
  - immediately after completing shield: tweak atmosphere to 1 atm 20% oxygen with rest being nitrogen.
  - check infrastructure for functionality (Months 21-24)
- Phase I, Months 1-3
  - Complete the base
  - Research
  - Surveys:
    - pits for permanent equatorial outpost - sea of tranquility
    - launch pad - equator
    - space elevator - equator
    - telescope- the far side - 2 relay satellites in L3 and L2
- Phase 1, Month 4 - Year 2:
  - Begin construction: Maglev, equatorial outpost, launch pad, telescope, space elevator

# Flight Schedule (Using SLS)

---

Flight no.	Cargo	Total Weight/kg
1	Robonaut 2 teleoperated rover (150 kg)	150
2	Nuclear reactors (5000kg) Power management and distribution system at 19kg/KWe (4000kg) Lithium-ion batteries (100kg) 10 Solar Arrays (4000kg)	13100
3&4	Regenerative Fuel Cell Storage and radiator system - (45000kg)	45000
5	2 Roving Space Exploration Vehicles (at 3000 kg each) Inflatable habitat and robots to set up (estimated 10,000 kg)	16000
6&7	Two Options: <ul style="list-style-type: none"><li>• 2 Modified Dragon capsules (15,000kg)<ul style="list-style-type: none"><li>• One would carry crew, the other supplies and both could be reused as escape vehicles</li></ul></li><li>• 2 Orion Capsules: (at 20,000 kg each)<ul style="list-style-type: none"><li>• Could carry both crew and supplies in each</li><li>• Could work better for rotations of 3 crew at a time</li></ul></li></ul>	30000 - 40,000



# Cost

---

- One-time: ~\$65.5 billion
  - Construction of outpost: ~ \$35 billion
  - SLS launch of Flight 1: ~\$0.5 billion
  - SLS launches of Flights 2-7: ~ \$30 billion
- Annual upkeep: ~\$11 billion:
  - Crew rotation + supplies (2 launches/year): ~ \$10 billion
  - Support and services equipment: ~ \$1 billion
- 2 year total: ~ \$87.5 billion

# Works Cited

---

- All references and pictures cited in project report