Science and in situ resources utilization (ISRU): Design reference mission for the First Lunar Outpost

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Science and Payloads Team

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1. Requirements and themes

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DISCLAIMER:

- All science activities and payloads in this reference mission are to be considered *strawmen only*.

- Actual science activities and payloads as well as the FLO landing site will be chosen by appropriate committees, panels, and representatives from the respective science disciplines after due deliberation and agreement.

- However, the following activities are believed to be reasonably representative of a set which may finally be chosen.

- These activities provide necessary information on masses, dimensions, EVA activities, power, etc. as required for planning and designing other parts of the FLO reference mission.

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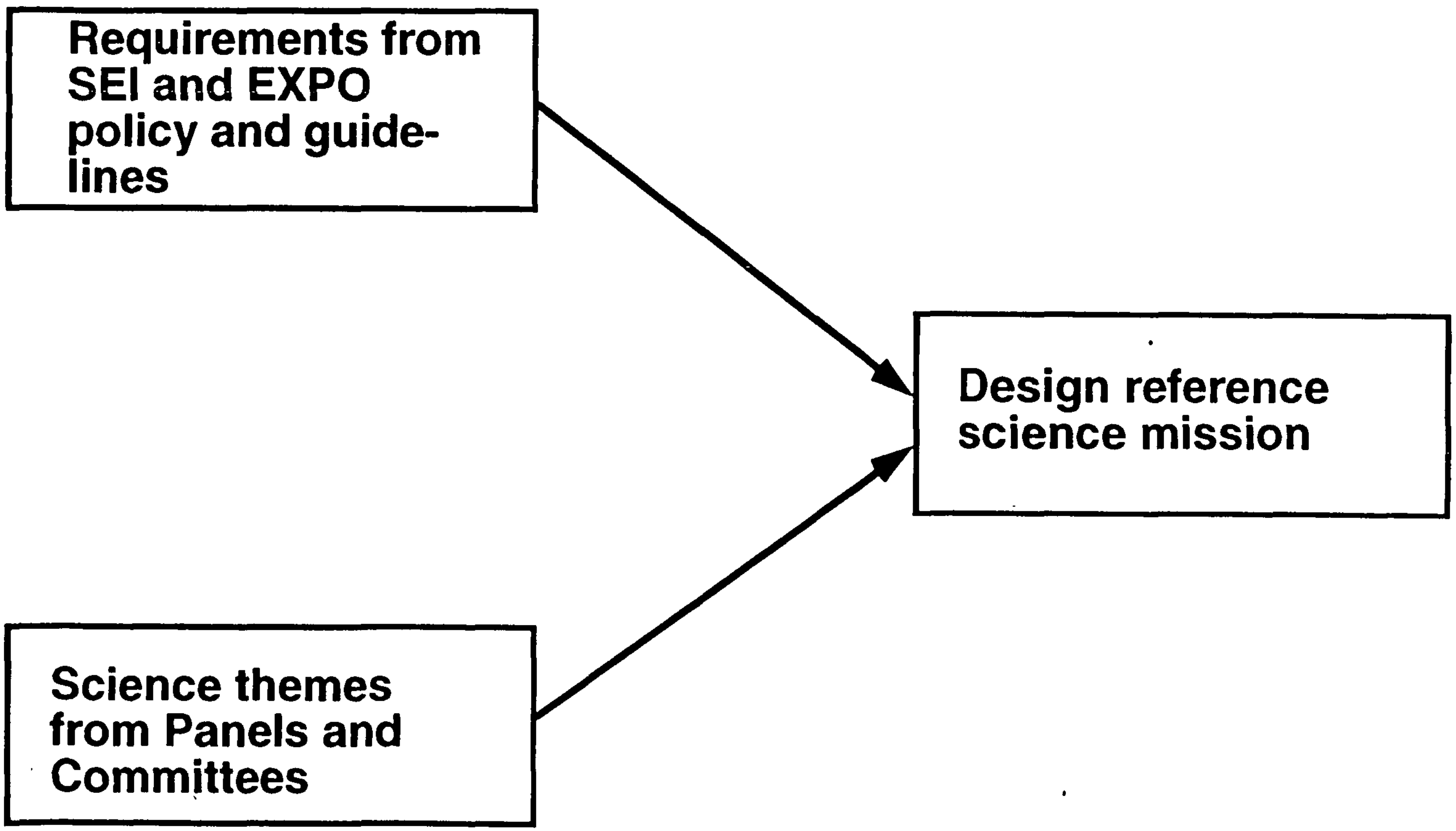

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Science objectives of the first lunar outpost are derived from several top level goals of the SEI program as listed in the First Lunar Outpost Requirements and Guidelines (FLORG):

- The SEI shall expand knowledge of the solar system and the universe.
- The SEI shall establish continual human presence on the Moon.
- The SEI shall research the utilization of space resource.

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Science Themes

- A series of science themes and first order scientific questions has been developed for each major science discipline

- These science themes and questions are mostly traceable to major reports of the scientific community and their representative bodies such as the National Academy of Science.

- The strawman science activities and payloads are designed to address these major science themes and questions

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Comparison to Apollo:

- An additional scientific objective is to provide more and better scientific data from FLO than from all Apollo missions combined

- It is judged that this is achievable in most disciplines

- FLO science is designed to provide much better geologic and geophysical coverage of a local area than any Apollo mission, both laterally and vertically
- FLO science will provide pioneering new science in astronomy

- FLO science will provide basic new information on planetary life support and human performance

- FLO science combined with robotic orbiter and Artemis science will provide a significantly better understanding of the moon as a planetary body and as detector and recorder for events in the solar system and the universe

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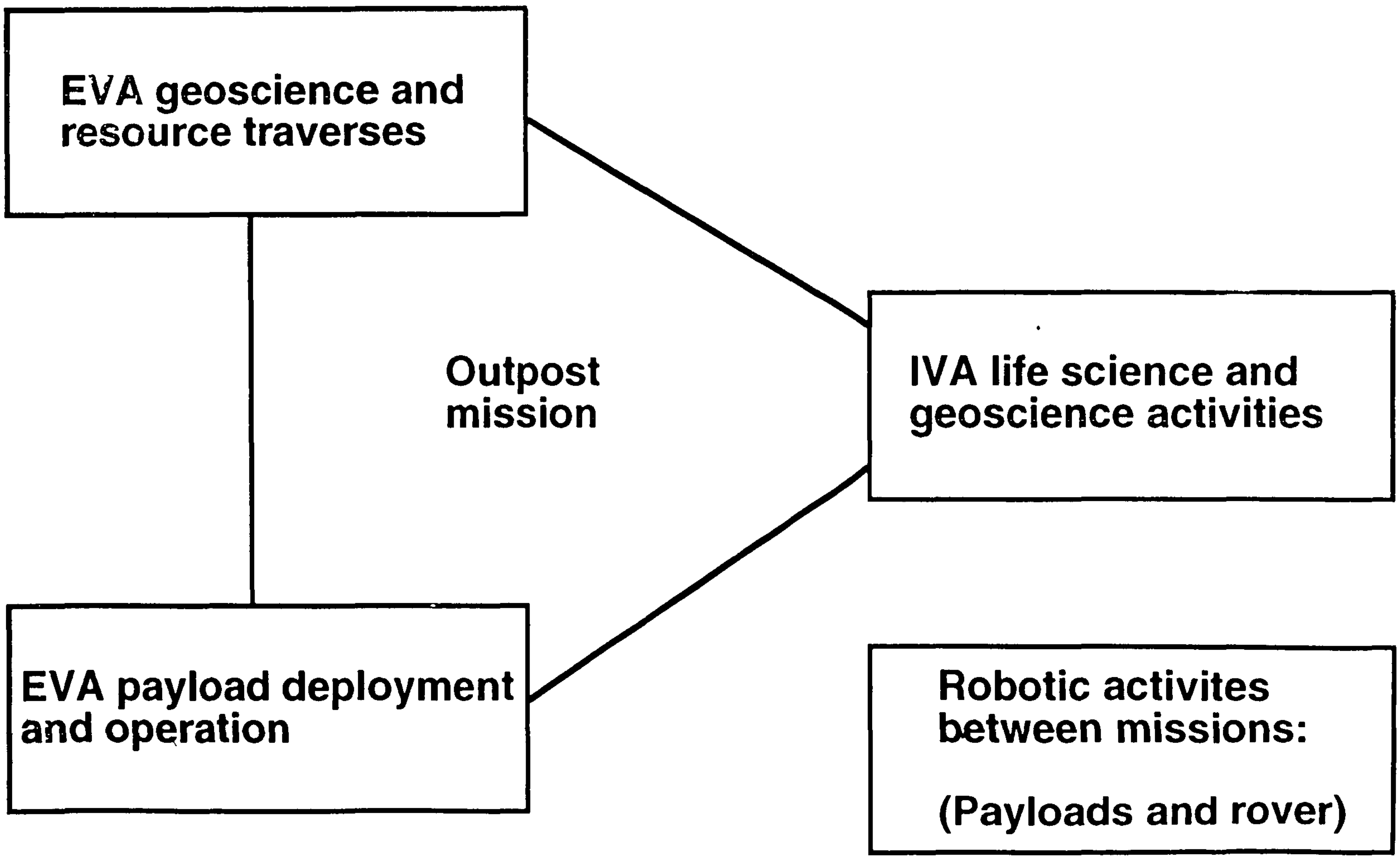
Science and ISRU Activities



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General Approach:

Science activities consist of four components:

1. EVA crew activities: performing life science, geologic, geophysical, and geochemical investigations

2. EVA crew activities: deploying and activating experiments

3. IVA crew activities: performing life science investigations, and analyzing, sorting, and packaging geologic and life science samples for return to earth

4. Complementary robotic activities including operation of deployed payloads and additional experiment deployment and sample analysis, collection, and return done by the rover in robotic mode.

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Strawman sites

- **An initial strawman site (Mare Smythii near the equator on the eastern limb) has been chosen for specific science planning, including traverse layouts for EVAs**

- **An alternate strawman (Aristarchus Plateau at 23 N, 48 W) was chosen to determine if it made significant difference in the design reference mission**

- **It was found that the alternate site made no significant difference in the reference mission in terms of payloads and EVAs. Detailed differences in the timelines resulted from a different set of preplanned traverse stations**

The overall conclusion is that, except for some specialized sites (lunar poles, crater bottoms, unusual features, etc.) the mission science payload and EVA activities will not change much from site to site.

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Geoscience and Resource ExplorationTraverses

- For the Mare Smythii site, 9 looping traverses were laid out which ranged out to a maximum of about 25 km from the outpost
- The traverse were designed to visit all major features and to provide detailed geologic recon of an area about 50 km in diameter around the outpost
- Each traverse was divided into segments suitable for one 8-hr EVA on the rover
- Initial timelines indicate that about 5 to 6 of the traverses could be completed on one mission leaving the rest for future missions
- The number of traverses is flexible and can adapt to available EVA time

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Experiment Packages

- A number of experiment packages are deployed on the lunar surface
- Some experiment packages are "set and forget"
- Some experiment packages require interactive crew participation
- Four major scientific disciplines plus ISRU are represented by the experiment packages:
  - Astronomy
  - Geophysics
  - Life sciences
  - Space and solar system physics

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Strawman Payload	Mass (kg)	Dimensions (folded)
Geophysical Monitoring Package	200	1m x 1m x 1m
Solar System Physics Expt Package	200	0.25m x 0.25m x 0.25m
Traverse Geophysical Package	400	0.5m x 0.5m x1m
Lunar Geologic Tool Set	400	0.5m x 1m x 1m
Lunar Transit Telescope	230	2.7m x 1.1m
Small Research Telescope	200	2m x 1m x 1m
Small Solar Telescope	100	0.5m x 0.5m x 1.5m
ISRU Demo Package	700	1.4m x 1.4m x 1m
Robotic Package for Rover	300	1m x 1m x 2m (initial est.)
Life Science Package (EVA)	200	0.2m x 0.3m x 0.3m(initial est.)
Total	2930	

Note: Habitat laboratory equipment *not* included in this payload budget

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Geophysical Monitoring Package

- Measures values of a number of geophysical parameters
- Provides information on lunar heat flow, magnetic strength, seismic activity, micrometeorite and secondary ejecta flux, and precise distance measurements to earth
- Has ALSEP heritage and will contain very similar instruments
- Powered by central station, possible photovoltaic and batteries, or possibly RTG
- Must be deployed by crew and activated; robotically operated thereafter from earth

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Solar System Physics Experiments Package

- Contains instruments to particles and fields
- Contains instruments to analyze the lunar atmosphere and its variations
- Also has ALSEP heritage and will contain some similar instruments
- Powered by central station, possible photovoltaic and batteries, or possibly RTG
- Must be deployed by crew and activated; robotically operated thereafter from earth
- FLO package may be identical to one designed for Artemis landing

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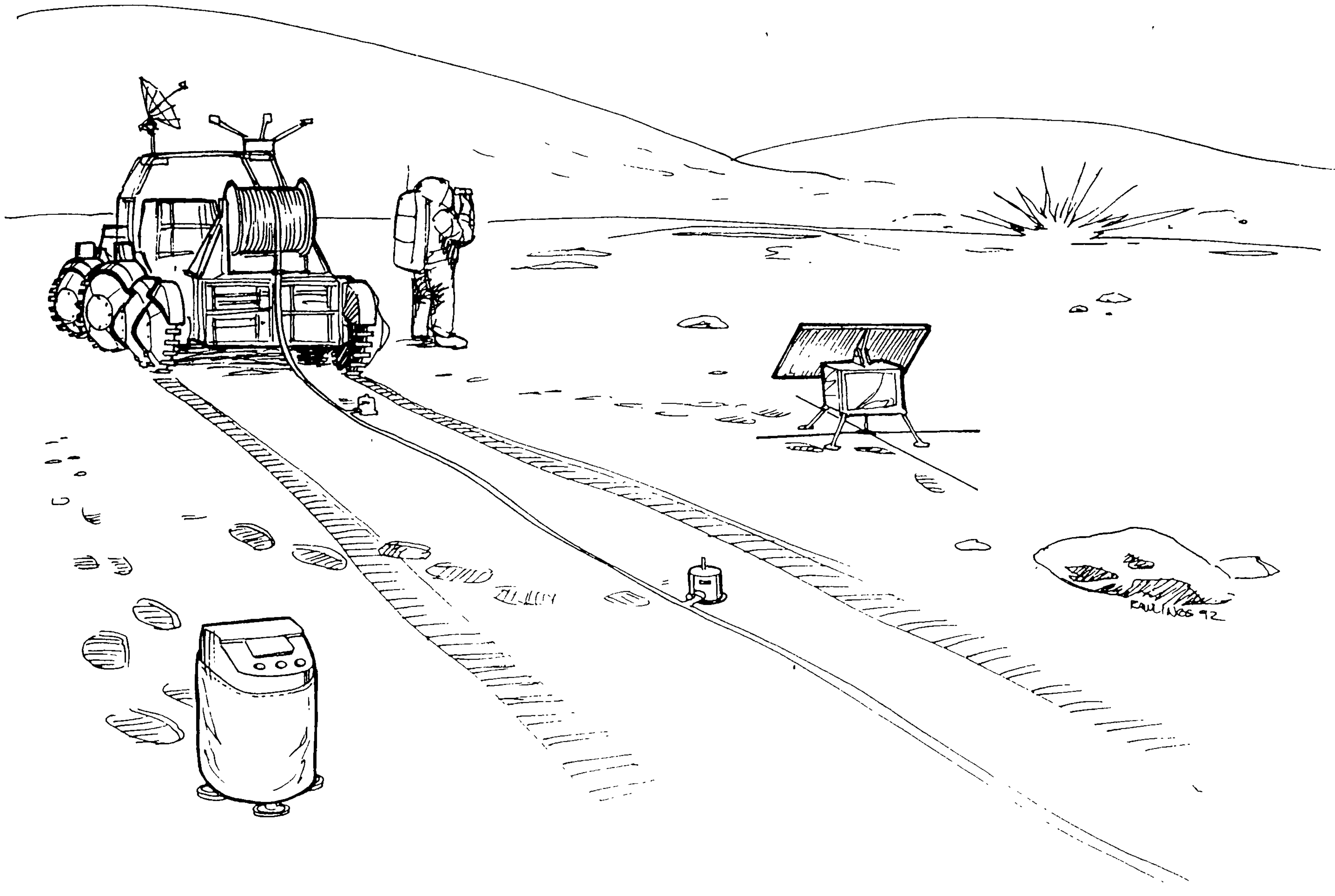
Traverse Geophysical Package

- Contains instruments which can be operated from the rover
- Instrument package includes:
  - Electromagnetic sounder for subsurface data collection
  - Active Seismic Experiments for data on upper few kilometers
  - Traverse Gravimeter to track variations in lunar gravity from place to place
  - Electrical Properties Experiment to help determine subsurface structure
  - Profiling Magnetometer to measures local variations in magnetic field
- Instruments will be operated by crew and powered by rechargeable batteries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Lunar Geologic Tool Set

- Contains tools, cameras, and sample containers required for geologic investigations and exploration
  - Apollo-type 3-m drill
  - Hammers
  - Rake
  - Soil sampler
  - Scoops
  - Tongs
  - Drive tubes
  - Cameras/digital imaging
  - Sample containers
- Will be carried on traverses and used for collecting and documenting samples

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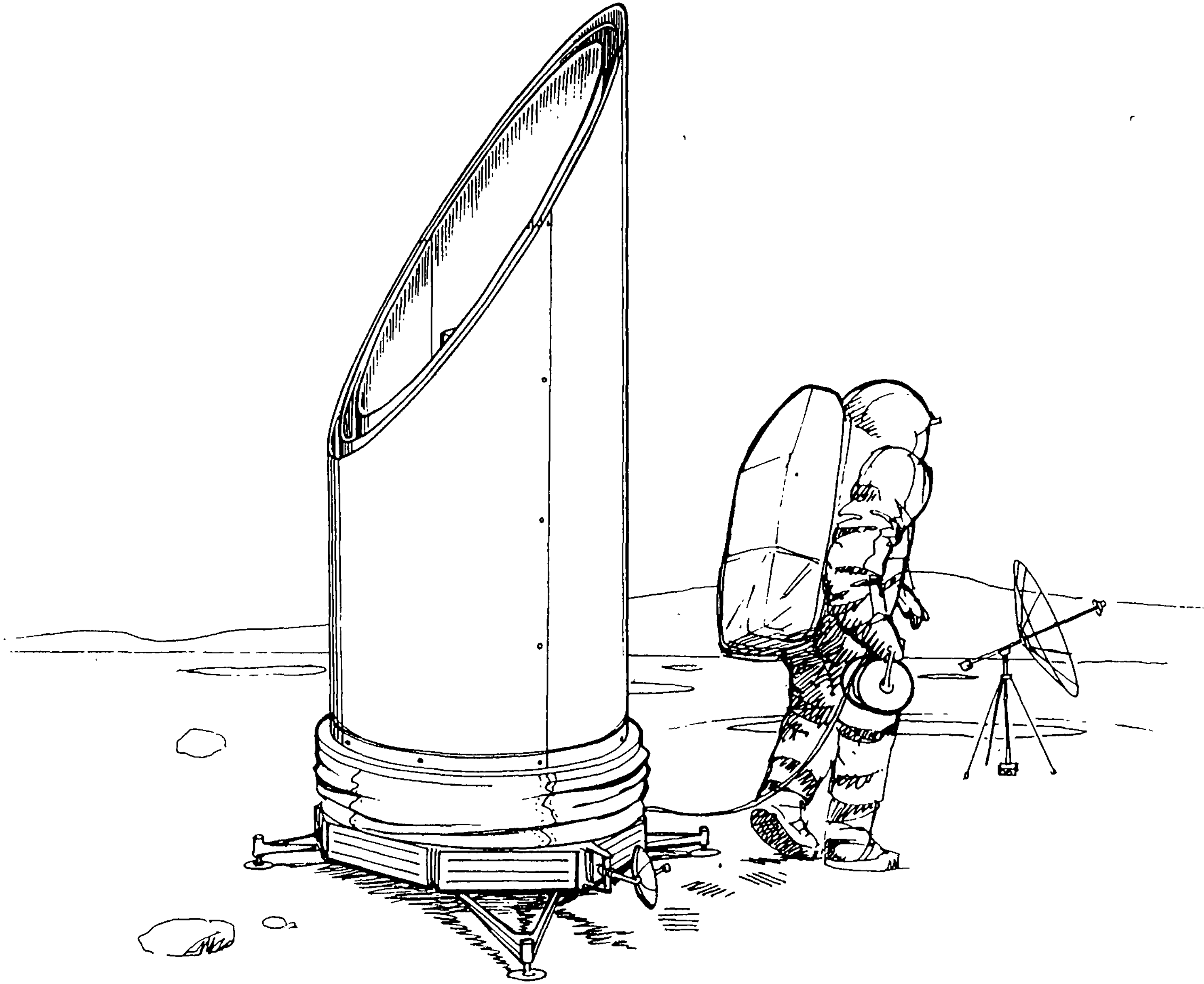
Lunar Transit Telescope

- Will take advantage of minimal lunar atmosphere to survey the sky in the UV spectral range

- Will provide images of stars, galaxies, clusters, and the interstellar medium in the UV

- Deployed by crew at Telescope Farm and operated remotely from earth

- Can be powered by solar cells for lunar daytime operation only



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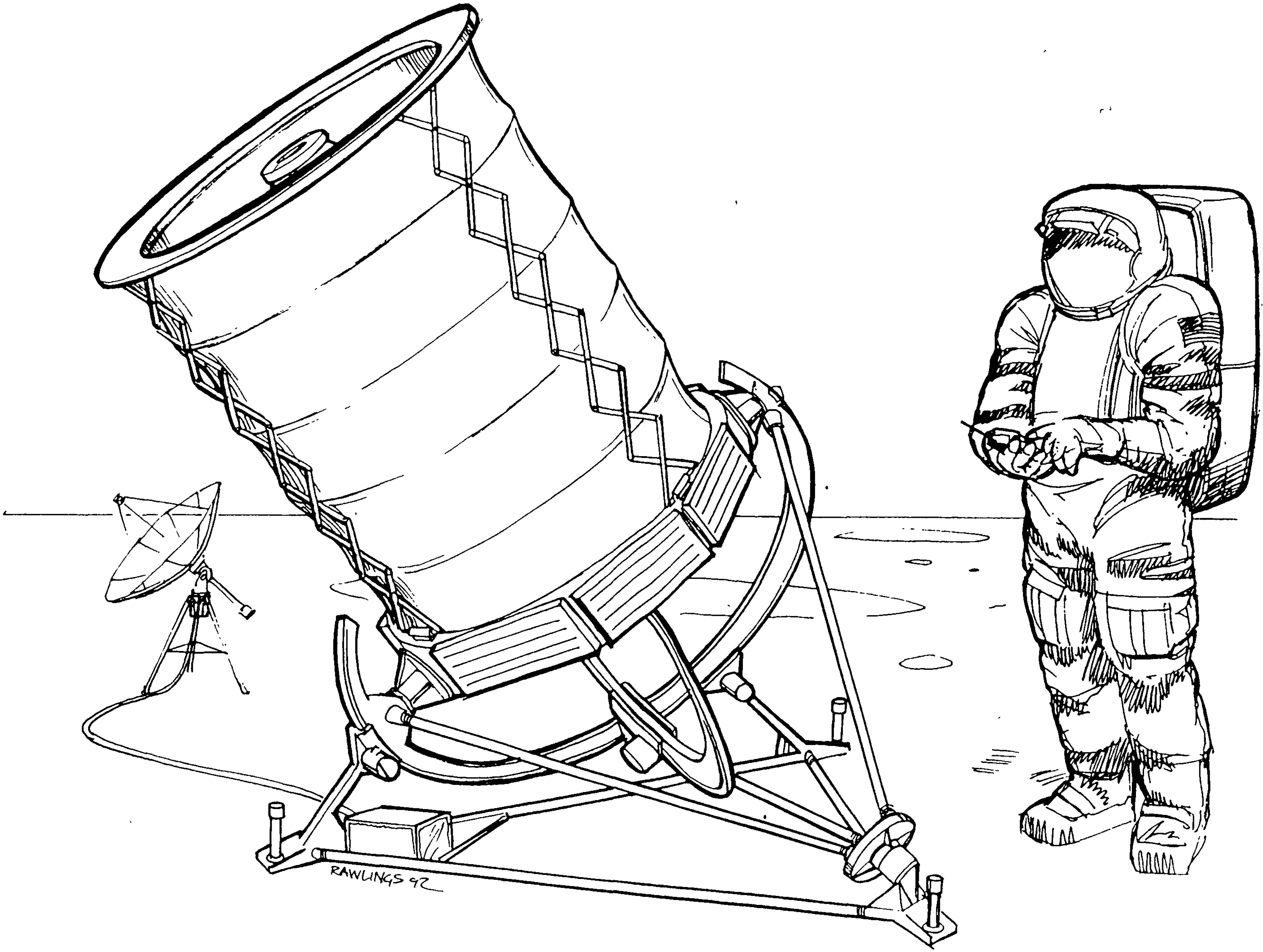
Small Research Telescope

- Pointable telescope for various astronomy objectives
- To be deployed by crew at 10 km or more from habitat: Telescope Farm
- Will be operated and pointed from earth and will transmit data to earth
- Will provide valuable engineering and operating data for future telescopes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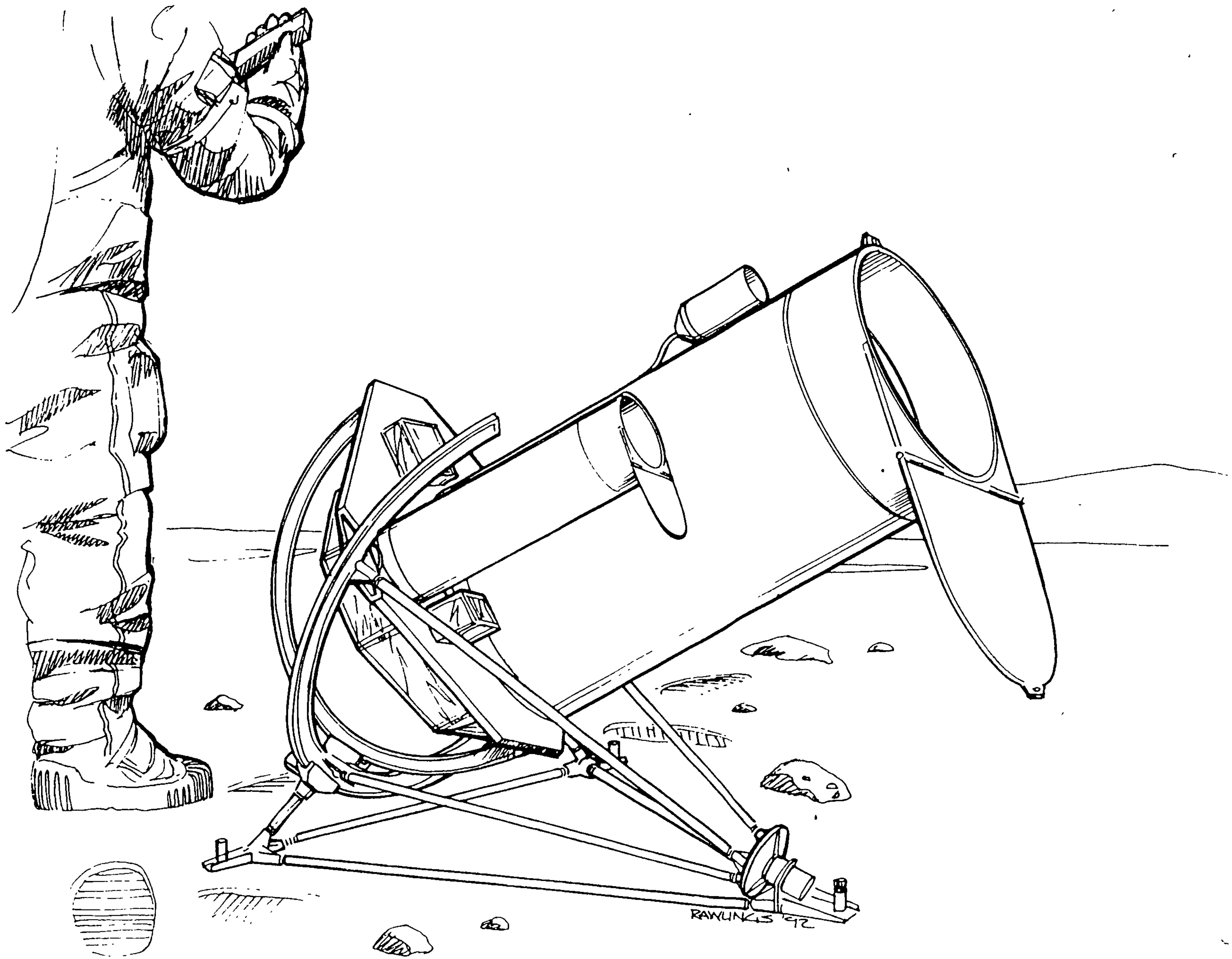
Small Solar Telescope

- Will provide high resolution images of sun to support solar flare tracking and other solar process investigations
- Will typically make on solar image every 30 seconds
- Operates only during lunar day
- Will be deployed by crew at Telescope Farm (10 km from outpost)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Life Science Packages (EVA):

- Monitoring equipment for human performance during EVA

- Will allow specialized testing for such attributes as vision, locomotion, balance, orientation, etc.

- Data will be collected for later analysis

- Exobiology experiment may consist of cosmic dust collector deployed on lunar surface to be returned on a later mission for analysis

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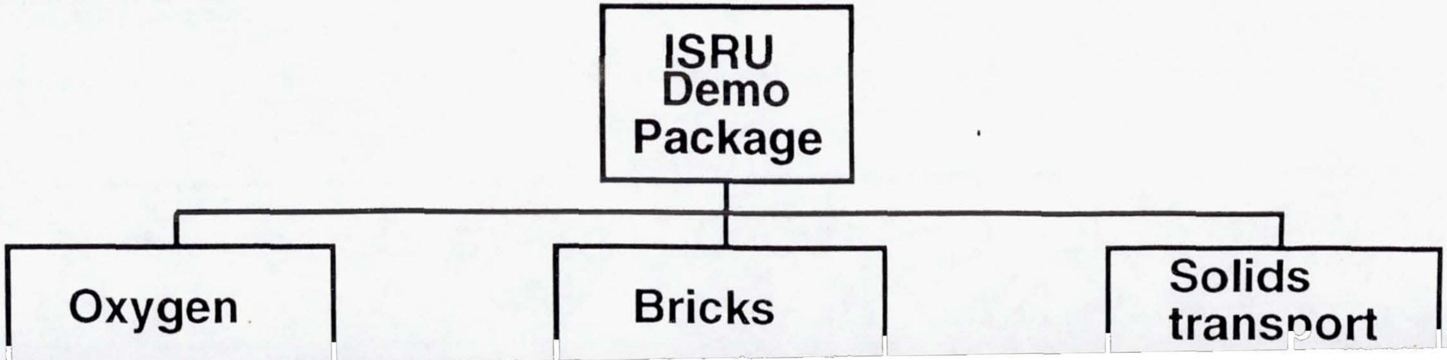
ISRU Demo Package

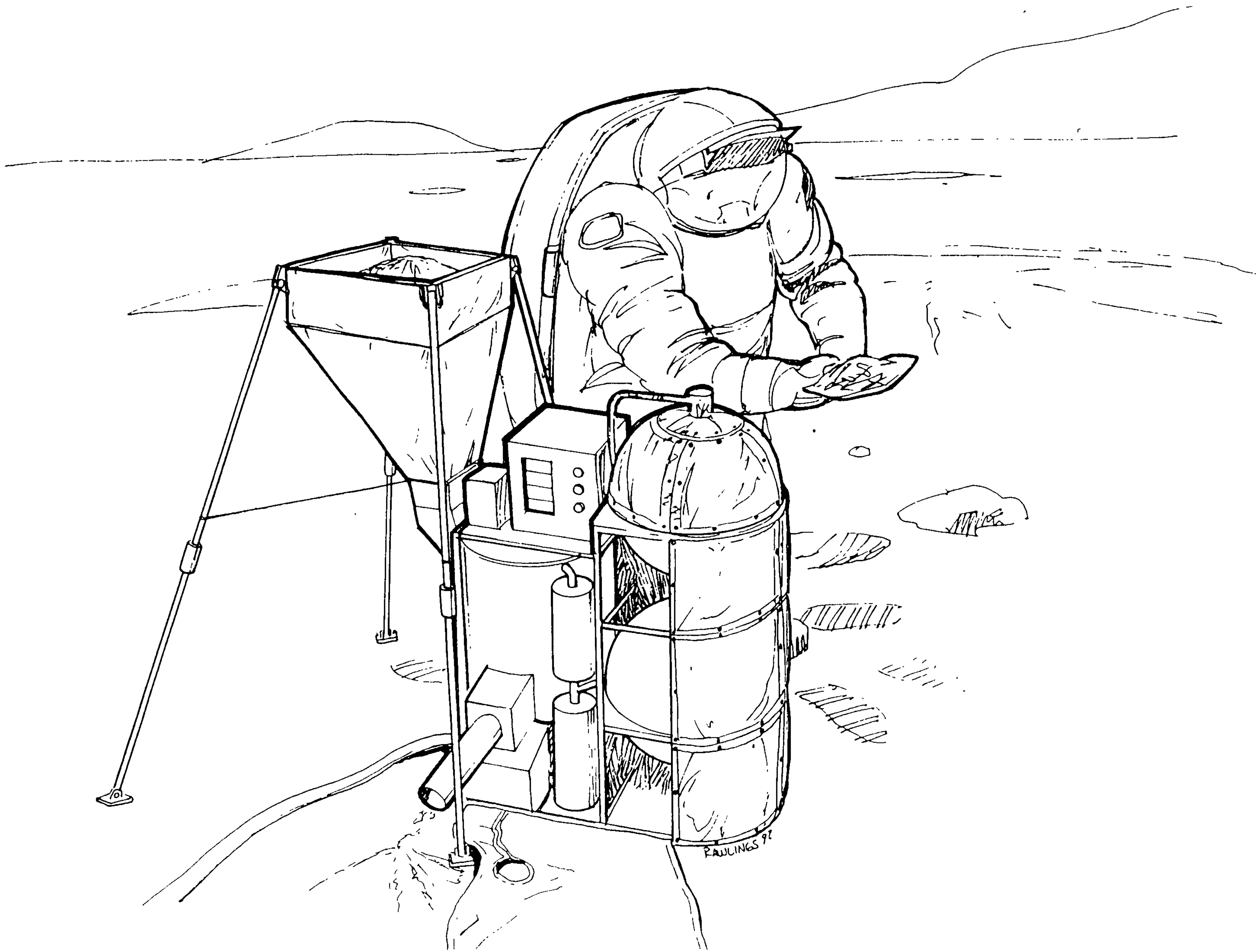
- Enables early ISRU demonstration and validation
- Allows testing of basic processes
- Will provide operational experience for later production units
- Contain three basic subsystems:

1. Oxygen extraction unit which uses imported hydrogen and makes water from lunar oxygen testing various feedstocks and parameters

2. Brick making unit which investigates a number of variables for optimizing brick/block fabrication by sintering of lunar soil

3. Gas-solid flow unit which tests pneumatic transport and pneumatic size sorting methods

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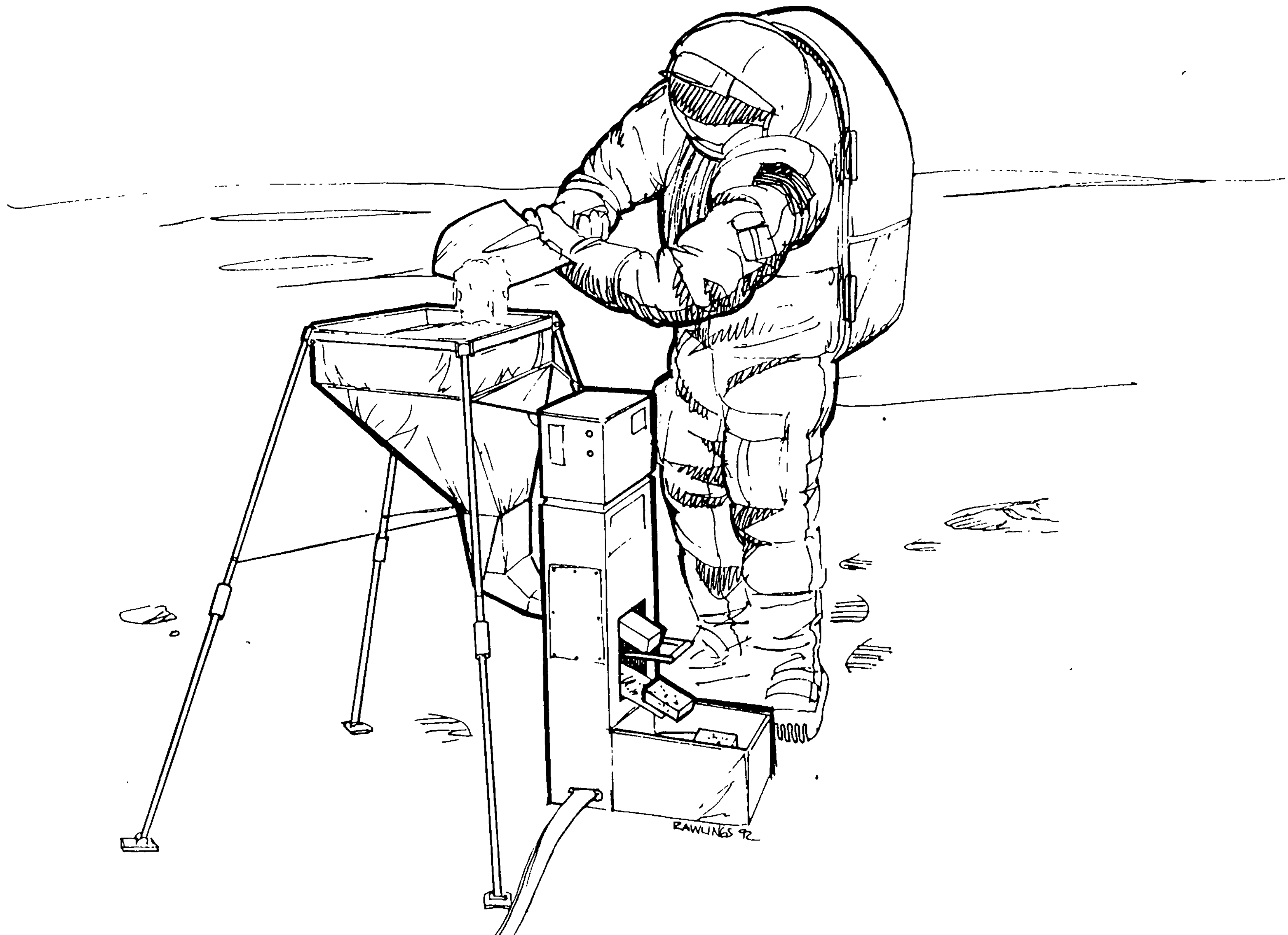
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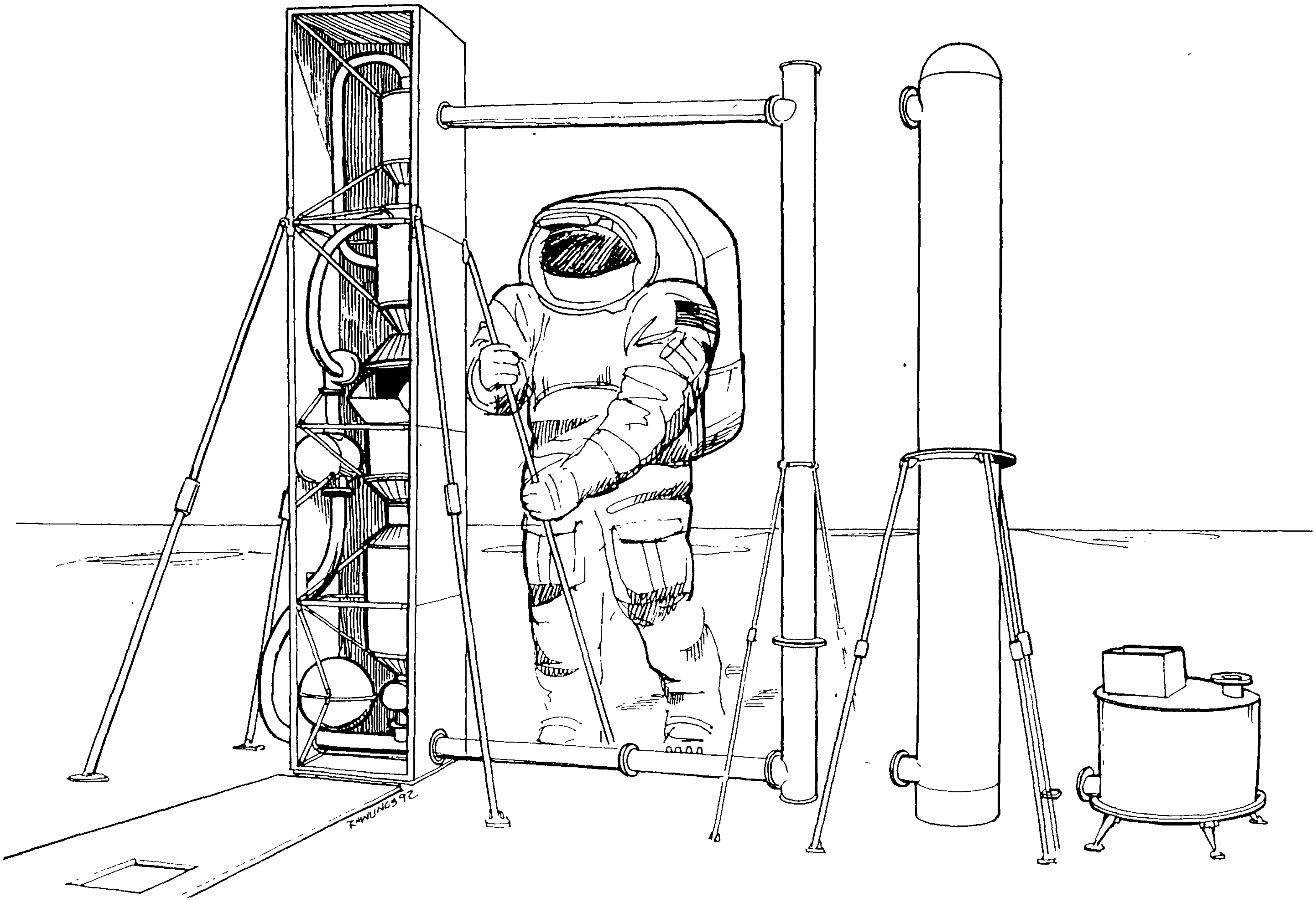

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IVA Science

- Will include basic analysis, sorting, and packaging of samples for return to earth, including lunar samples and biosamples

- Will include gravitational biology experiments
  - Mutagenicity of cosmic radiation
  - Chloroplast movement

- Will include physiological experiments
  - Central nervous system
  - Thermoregulation
  - Body fluid analysis

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Robotic Package for Rover Operations:

Current concept is an add-on package for manned rover which will allow robotic (mainly teleoperated) operation

- Provide capability for continuing robotic activity between missions
  - Allows for teleoperation from outpost or earth
  - Includes manipulator arm with ability to dig, scoop, and sample
  - Contains set of basic analysis instruments
- Explore out to 100 km from outpost and return
  - Return samples to outpost for collection, analysis and return
  - Return samples from beyond human range for ISRU demo feedstock
  - Up to 4 round trips per year (outpost site to 100 km and return)

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Strawmen Science Payload Summary (kg)

Discipline	EVA	IVA	Total	Percent
Geophysics	600		600	18
Space Physics	200		200	6
Lunar Geology	400	50	450	13
Astronomy	530		530	16
ISRU	700		700	21
Rover Robotic Package	300		300	9
Life Science	200	400	600	18
Total	2930	450	3380	100

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Some trade studies and issues which are being addressed:

- Appropriate mix of science among represented disciplines
- Use of EVA time and capability vs IVA time and capability
- Demo and validation of ISRU vs. use of products on FLO
- Initial evolution of science
- Initial evolution path for ISRU
- Rover range vs. assured crew walkback
- Frequency of EVA: every day using alternating crews vs every third day with all crew members staying in habitat every third day
- Radiation storm shelter using local materials vs transported materials
- Effect of site selection on science payloads and activities

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Science on the second mission:

1. Continue original detailed reconnaissance traverses not completed on first mission.

    • Estimate that 5 or 6 of 9 planned traverses at Smythii would be completed on first mission leaving 3 to 4 for second mission.

    •This would complete the mapping of the general geology and chemistry of an area about 20-25 km diameter around the outpost.

2. Begin a detailed drilling program with 10 meter drill (300 kg) using data from the traverses to determine optimum drilling locations within 20 km of outpost. Number of drill holes would be determined by EVA time available.

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Science on the second mission (continued)

3. Bring and deploy initial elements of radio telescope array (300 kg).

4. Revisit optical telescope site and switch detectors as an operational test.

5. Analyze and sort samples returned by robotic science rover between missions.

6. Perform additional life science experiments with hardware on hand.

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Science Evolution:

Over a series of missions to the same outpost, including the transition to permanent occupancy, science studies might be expected to evolve in the following ways:

Astronomy:

- Evolution will be toward bigger observatories, more observatories using different wavelengths (UV, IR, X-Ray, radio frequencies, and visible)
- Radiotelescopes will be added and array size can be increased

Space Physics and Geophysics:

- Evolution will be toward network emplacement to provide information on variations of many properties from place to place.
- Instruments may not change much or grow significantly larger

Life Sciences:

Additional and more elaborate experiments would be delivered

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Geology and geochemistry:

Evolution may be in two directions:

1. A need for broader coverage of the lunar surface may require *longer and longer traverses* which will in turn require a pressurized rover.

(An alternative approach is to use *Sorte* missions instead of very long traverses).

2. *Much more detailed studies* in close to the outpost may be undertaken.

- May include trenching into the regolith as deep as possible and in several directions.
- Very detailed study of local features such as large craters, rilles, or volcanic vents might also occupy considerable time.

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ISRU Evolution:

Evolution will be toward producing larger amounts of oxygen, volatiles, and construction materials which can be used to support the outpost and the transportation system.

- Early production plant in 4-5 years with capacity of 10-15 MT oxygen/yr
- First real use of oxygen or water in infrastructure and outpost support
- Full production plant with capacity 100 MT/yr (8-10 years?)
- Transition to heavy use of lunar propellant and volatiles in infrastructure and transportation support

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General: Evolution Philosophy:

- Allow payload room for new experiments
- Plan for new and different activities
- Stay flexible enough to take advantages of new discoveries

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What are we doing now?

- Refining concept design and costing of strawmen payloads
- Iterating timeline planning and day to day activities
- Looking at synergy with robotic orbiter and Artemis program
- Working on design concepts and operations concepts for rover in robotic mode
- Planning science evolution
- Planning ISRU evolution
- Designing technology development plan for ISRU
- Preparing to plan for technology development for other science payloads

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Where do we go from here?

- Startup of development programs for science and ISRU payloads
- Organize workshops and committees on science priorities and site selection
- Organize mapping and mission planning activity
- Write plan for payload command and control and data flow and analysis
- Write plan for science management
  - Payload selection and integration
  - Payload command and operation
  - Data flow and analysis
- Prepare detailed science and ISRU evolution trees with options, waypoints, and decision points leading to additional lunar-based science and to Mars science and ISRU activities