Design of a Lunar Volatiles Miner

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Lecture 14

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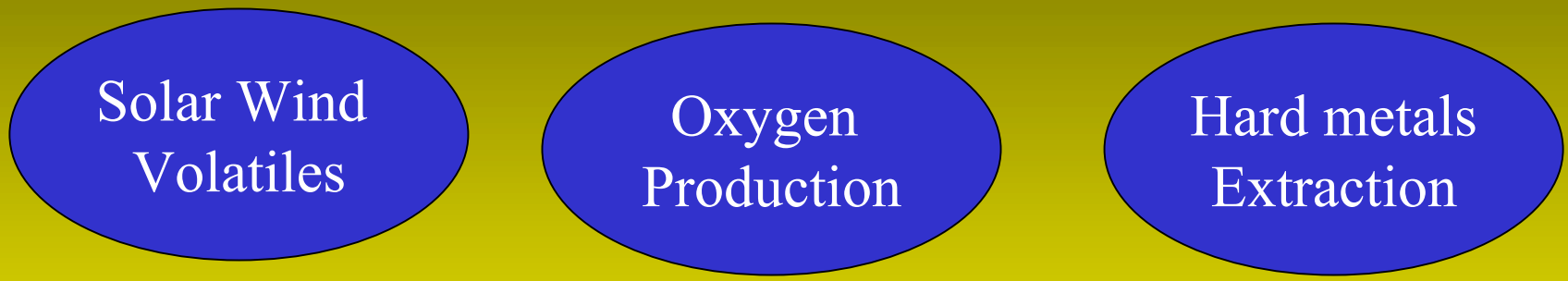
There Have Been Relatively Few Comprehensive Mining Equipment Studies for Lunar Resources

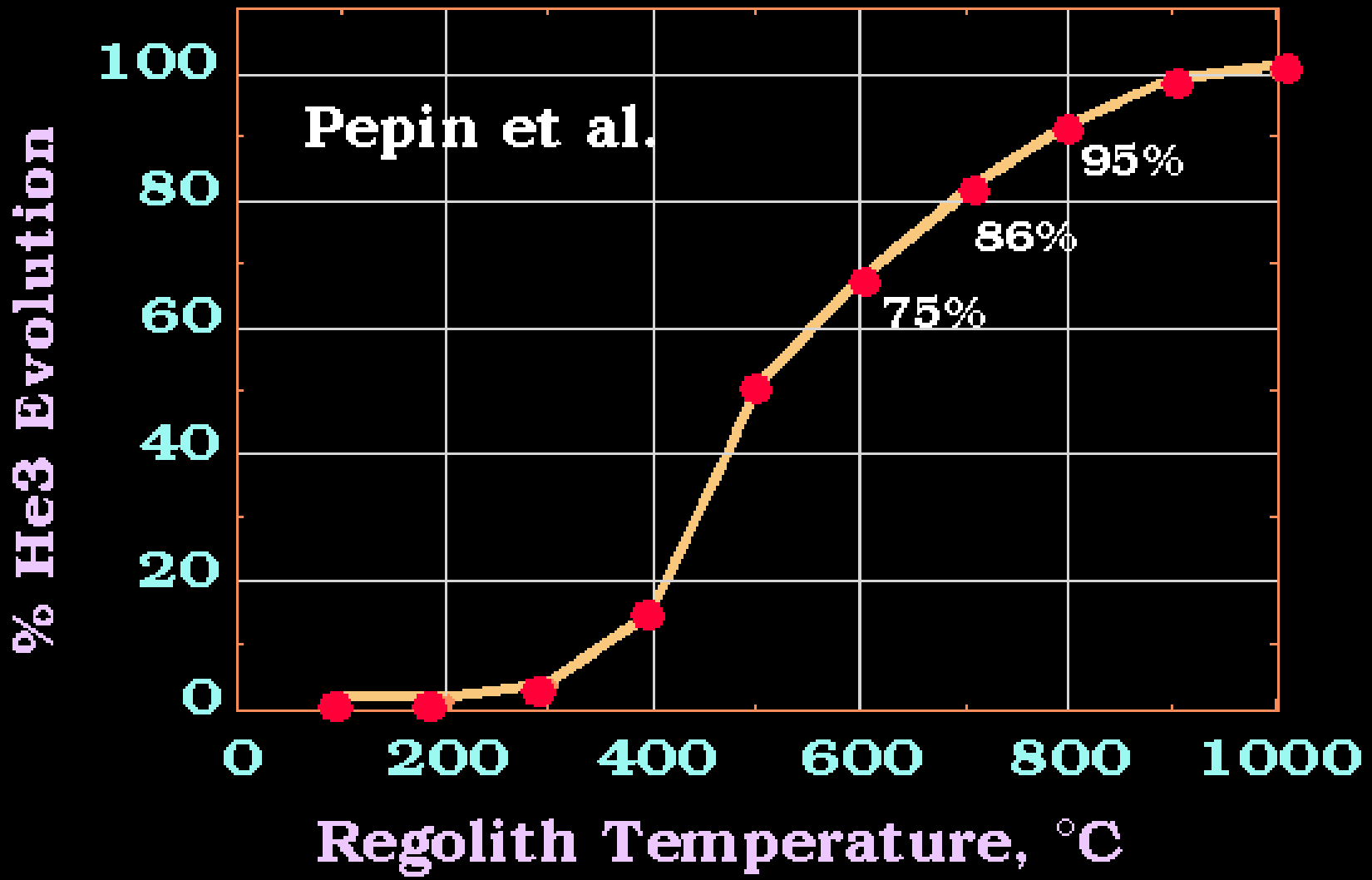


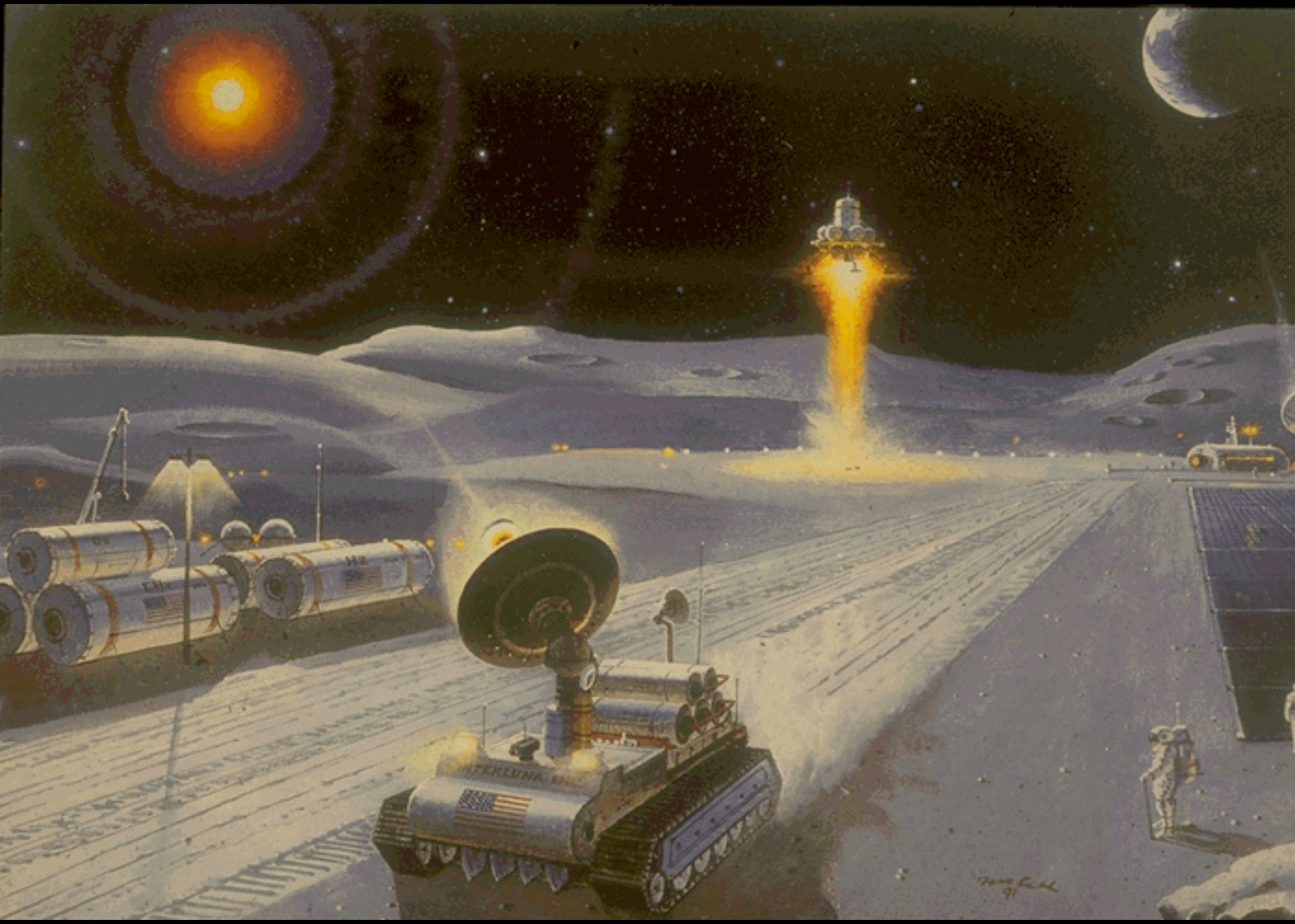
- University of Wisconsin

- Carbotek/JSC
- Bureau of Mines
- Shimizu

- Bureau of Mines
- Los Alamos National Laboratory

Helium-3 Evolution from Lunar Regolith



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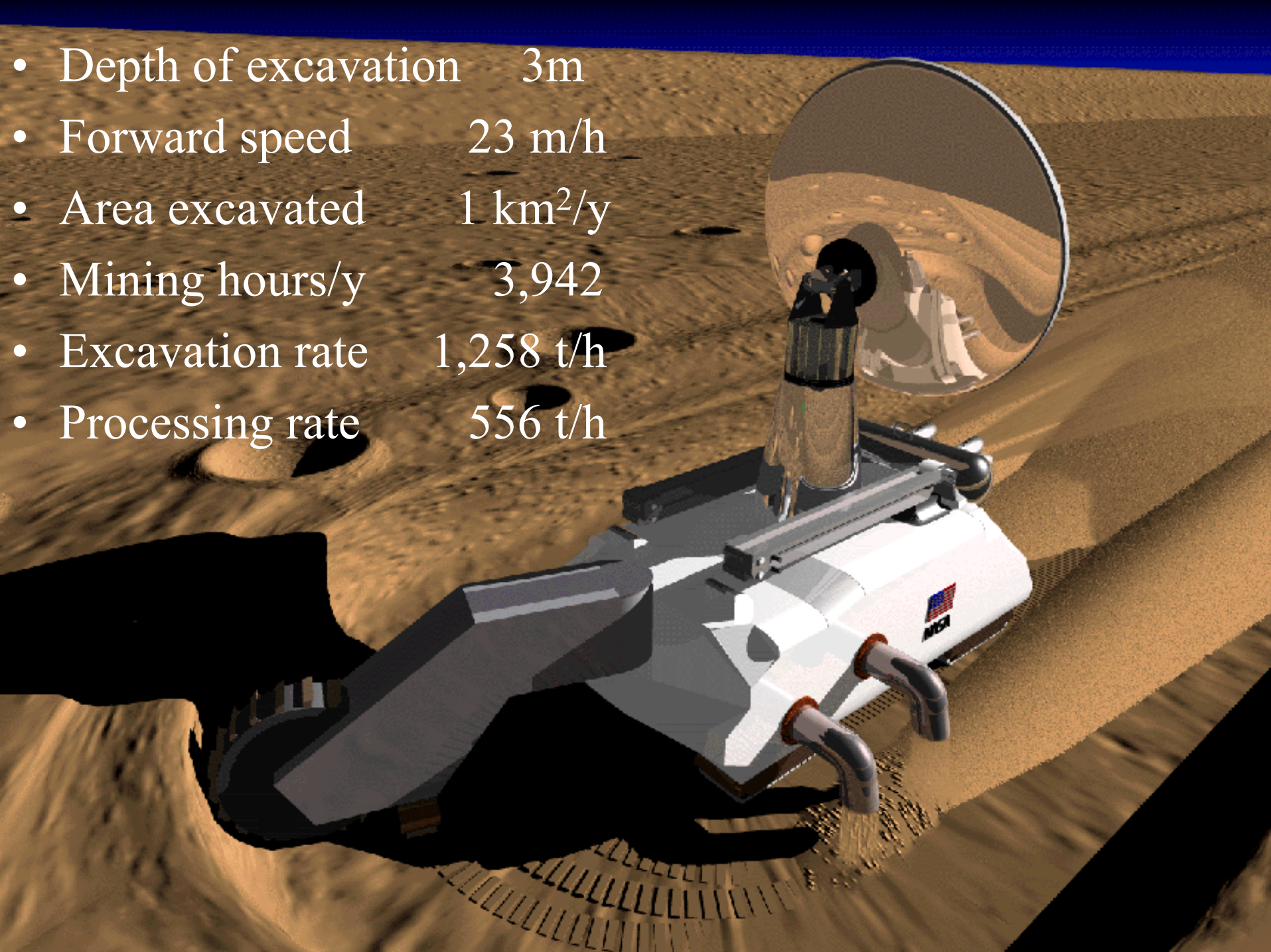
Miner Movie


• Depth of excavation 3m
• Forward speed 23 m/h
• Area excavated 1 km²/y
• Mining hours/y 3,942
• Excavation rate 1,258 t/h
• Processing rate 556 t/h

Process for Extracting Helium-3 from Lunar Regolith

300 °K → Radiator/ Condenser → 50 °K → Isotopic Separation → 1.5 °K → 1 tonne Helium-3

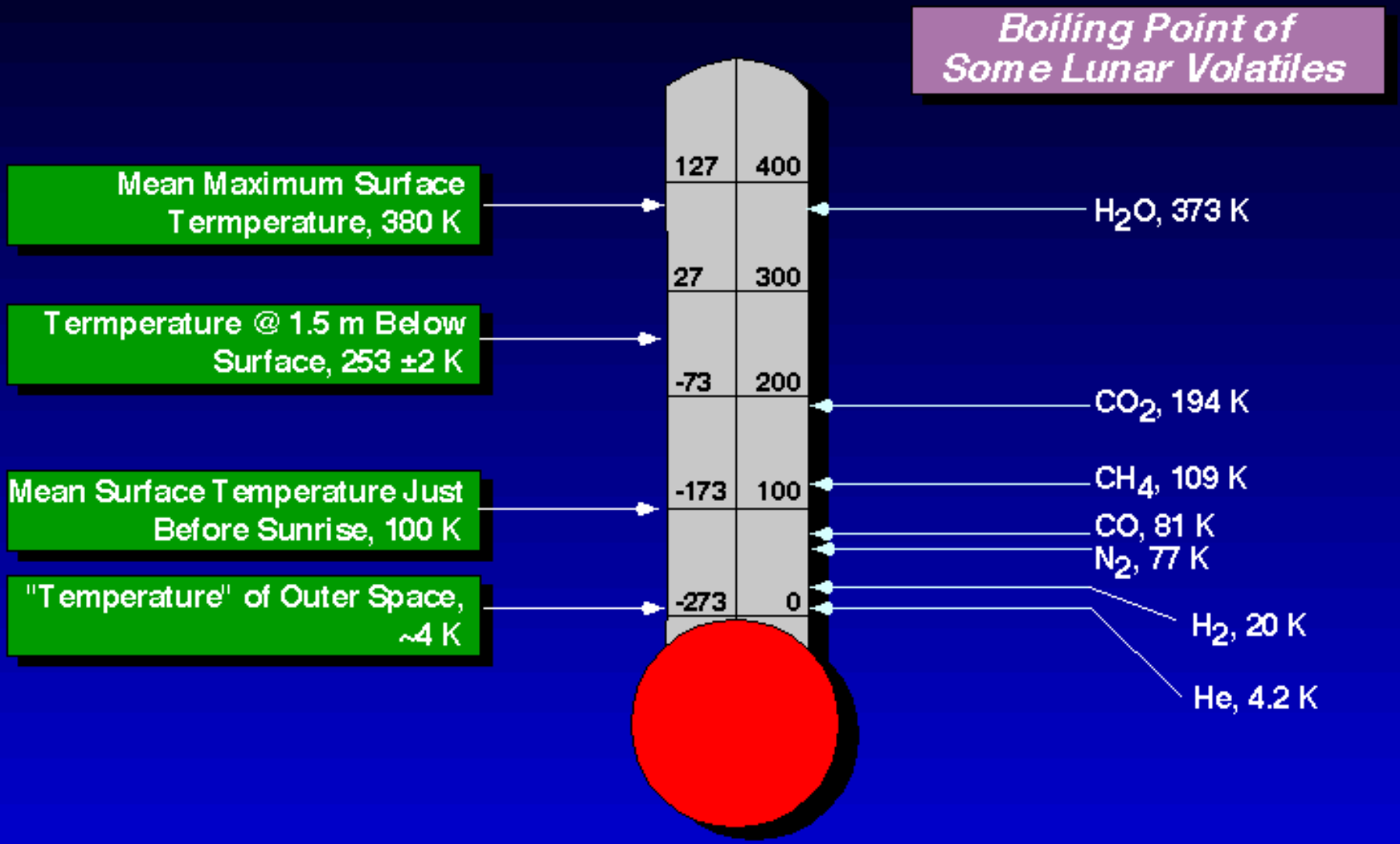
6100 tonnes

H_2	H_2O	N_2	CO_2	CH_4	CO	Helium-4
	3300	500	1700	1600	1900	3100

Fuel *Life Support* *Cryogenics*

Clean Fusion Energy on Earth

The "Coldness" of Outer Space Can Be Used to Separate the Lunar Volatiles



One Mark II Miner Can Provide Enough ^{3}He to Power a 330 MW_e Fusion Power Plant for a Full Year

- Earth mass of miner 18 t
- Thermal energy 12.3 MW_t
- Operating power 200 kW_e

- Annual Production ^{3}He 33/y

- Volatile by-prod 600 t/y

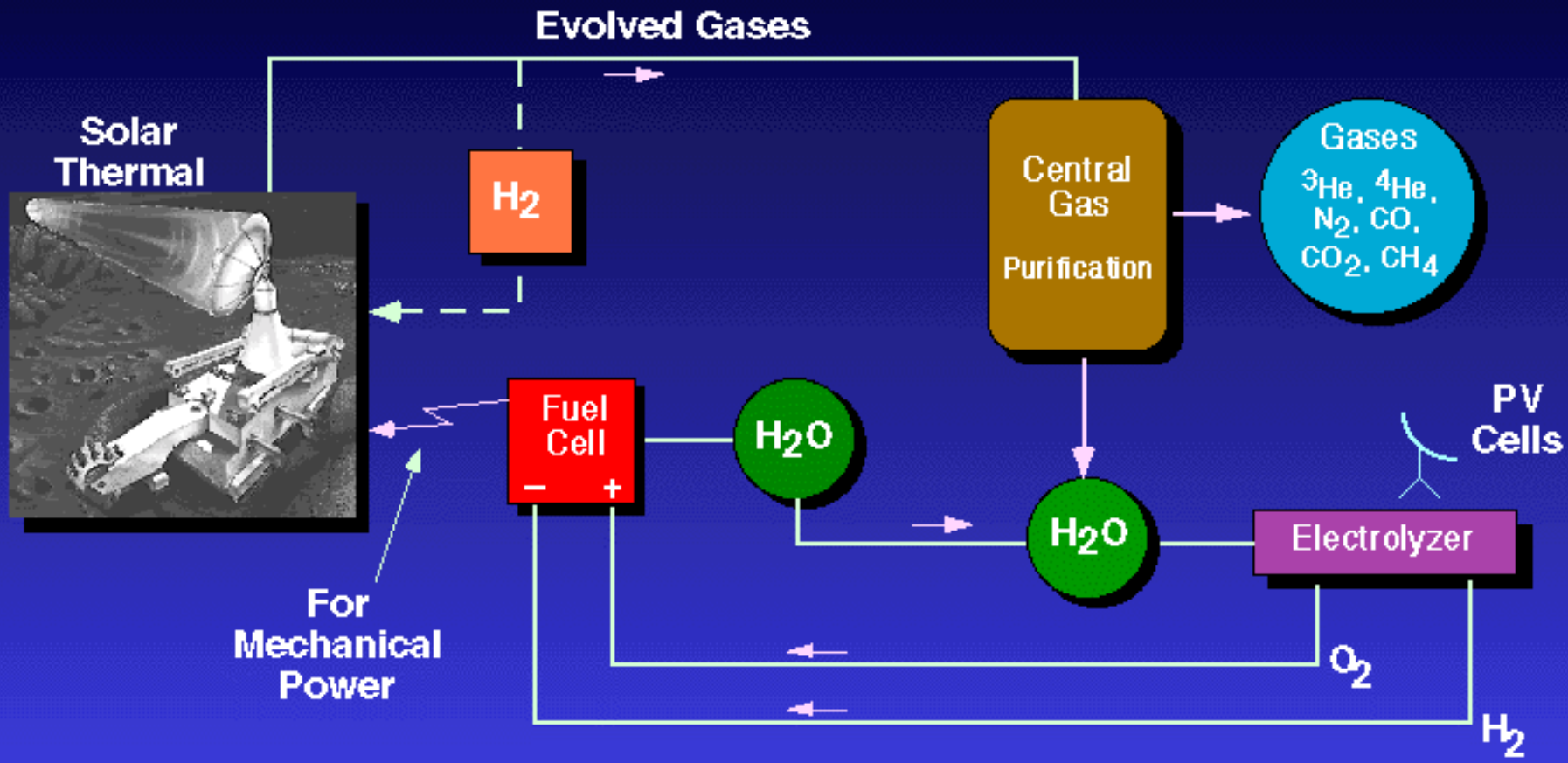
There Are at Least Three Major Applications for the Volatile By-products from Lunar ^{3}He Mining

1) Fuel Cells
   - (H_2, O_2)
2) Life Support
   - (N_2, O_2, H_2O, CO_2)
3) Propulsion
   - (H_2, O_2, ^{4}He)

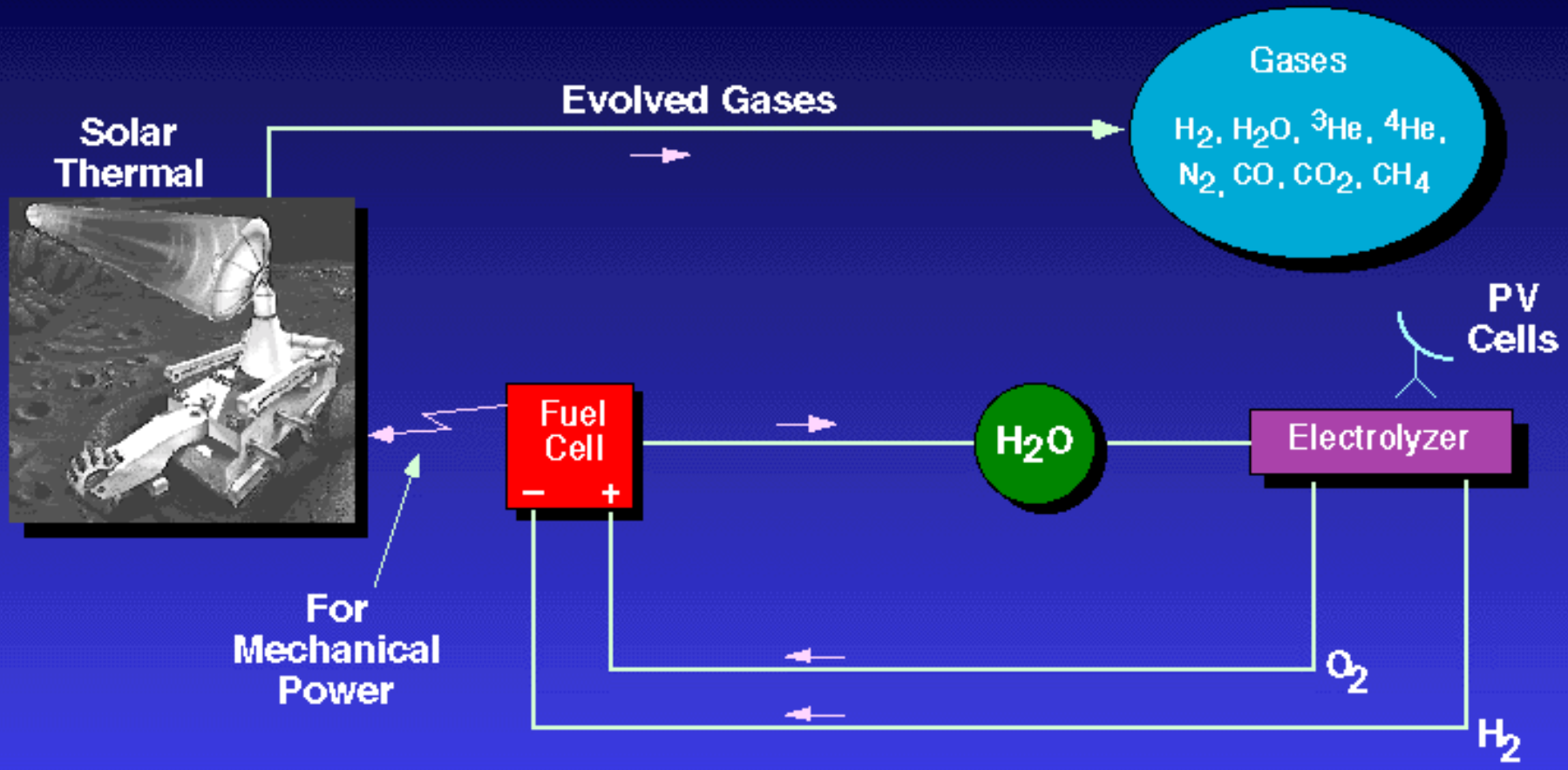
The Mark-II Miner Could be Powered by a 200 kW_e Fuel Cell

- Operation Schedule
  - During lunar day only (≈14 earth days)
  - Assume 90% availability to account for sunrise and sunset as well as component failure
- Fuel Input
  - 200 kWe requires
    - 17.1 g O_2/s
    - 2.1 g H_2/s
  - Total O_2 & H_2 is 23.2 tonnes/lunar day
  - PV array for electrolysis ≈ 250 kW_e

In 1/3 of a Lunar Day, the Mining Unit Can Extract Enough H_2 and O_2 to Fill the 200 kWe Fuel Cell/Electrolyzer Loop

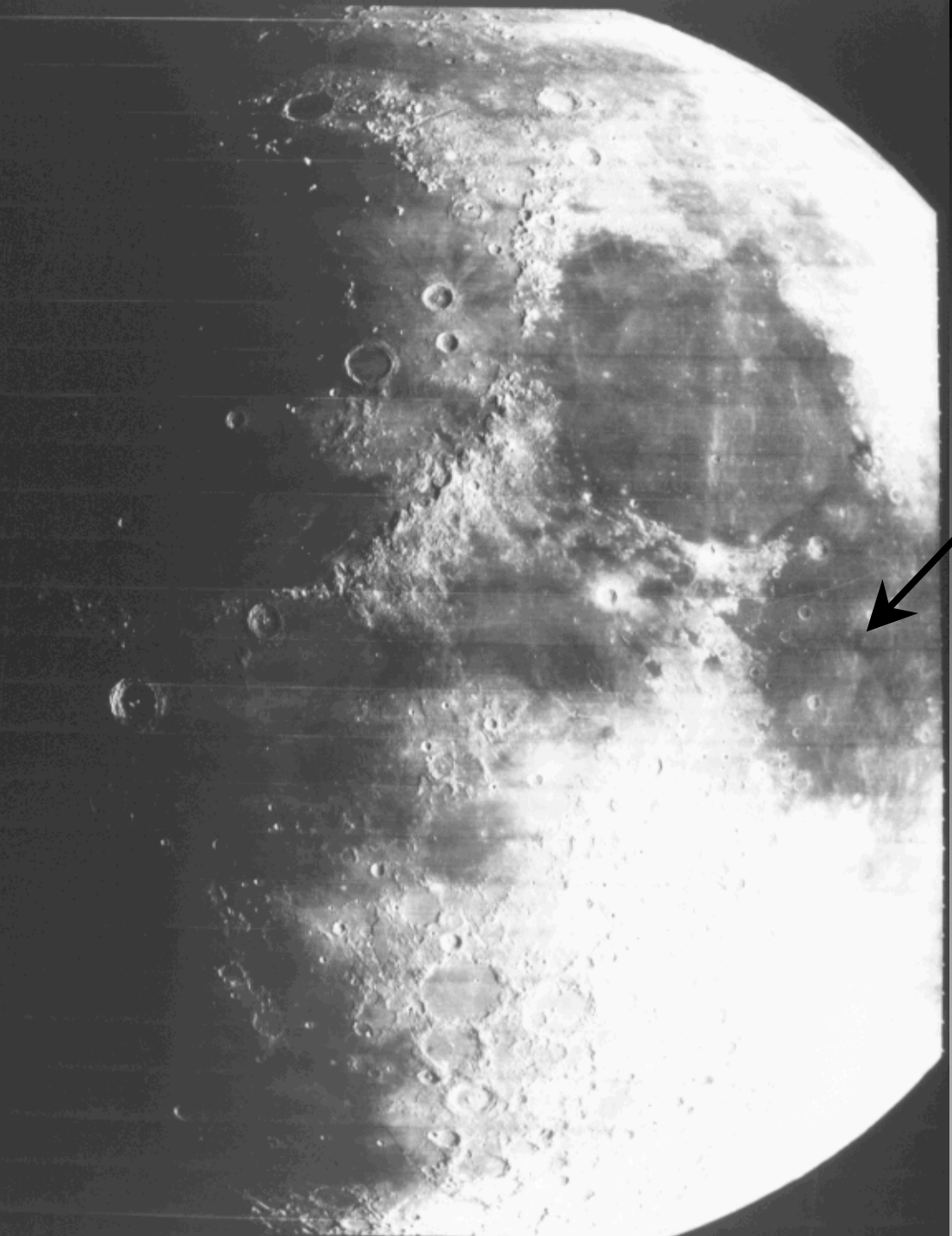


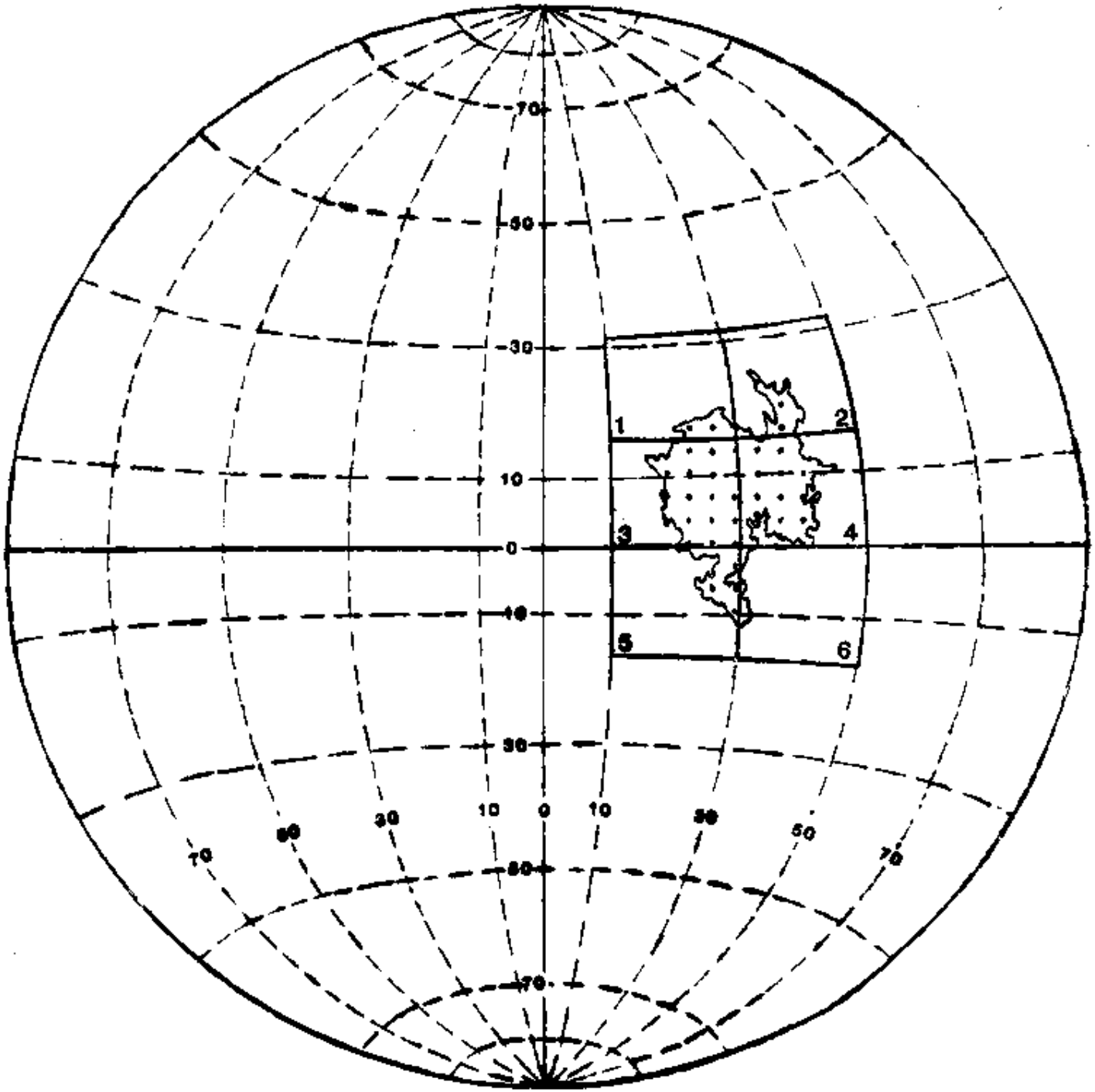
After the First Lunar Day, the Entire Output of Volatiles Can Be Used For Support of the Lunar Settlement



An Example of How a Solar Wind Volatiles "Mine' Might be Identified

-Mare Tranquillitatis-


Mare Traquillitatus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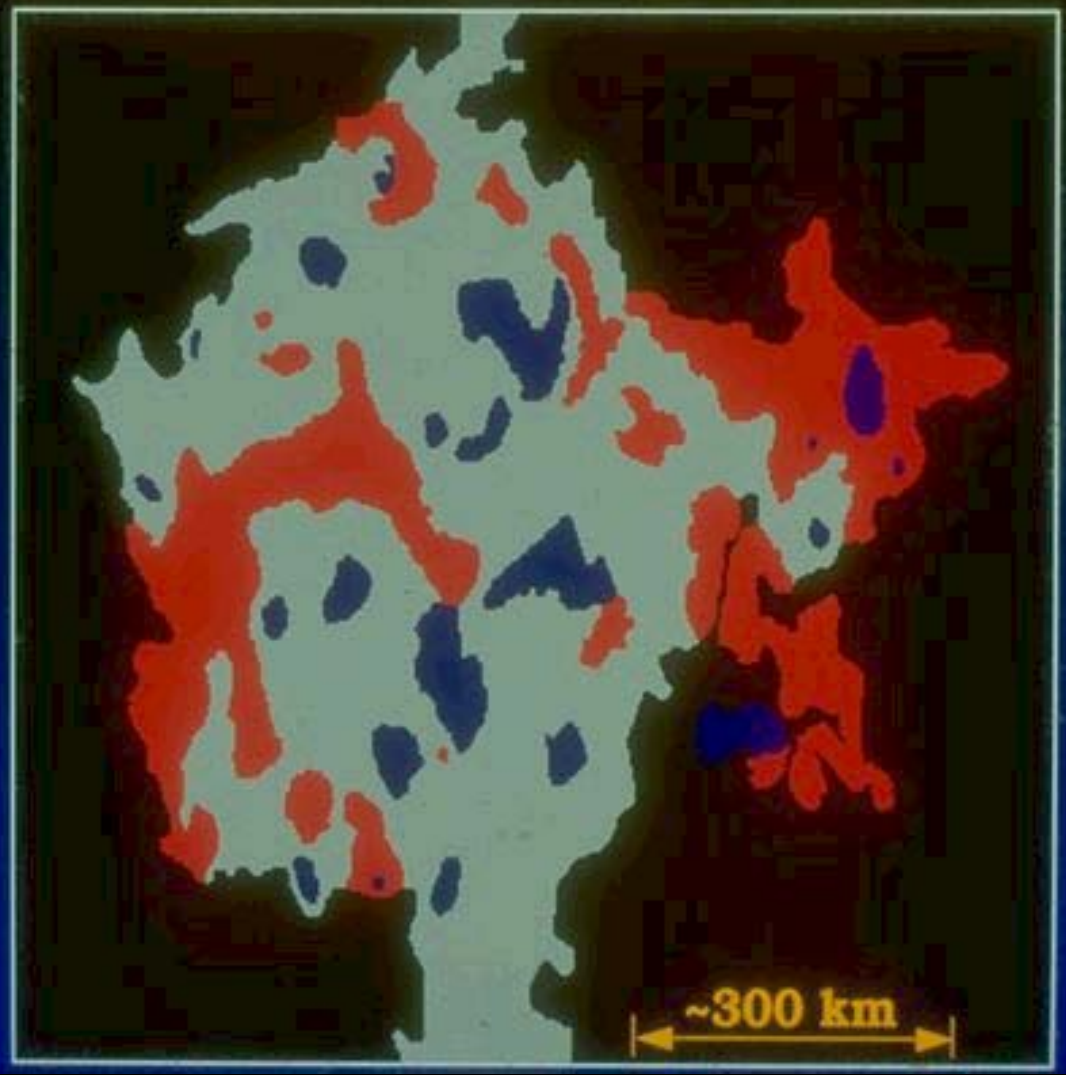
6

How Much of the Regolith in Mare Tranquillitatis can be Mined?

1) What is the depth of regolith?
2) How much of Tranquillitatis is covered by high-Ti regolith?
3) What percentage of Tranquillitatis is minable?
4) How much ^{3}He is present in minable regolith?

Inferred Titanium Content of Regolith of Mare Tranquillitatis



After G. Cameron

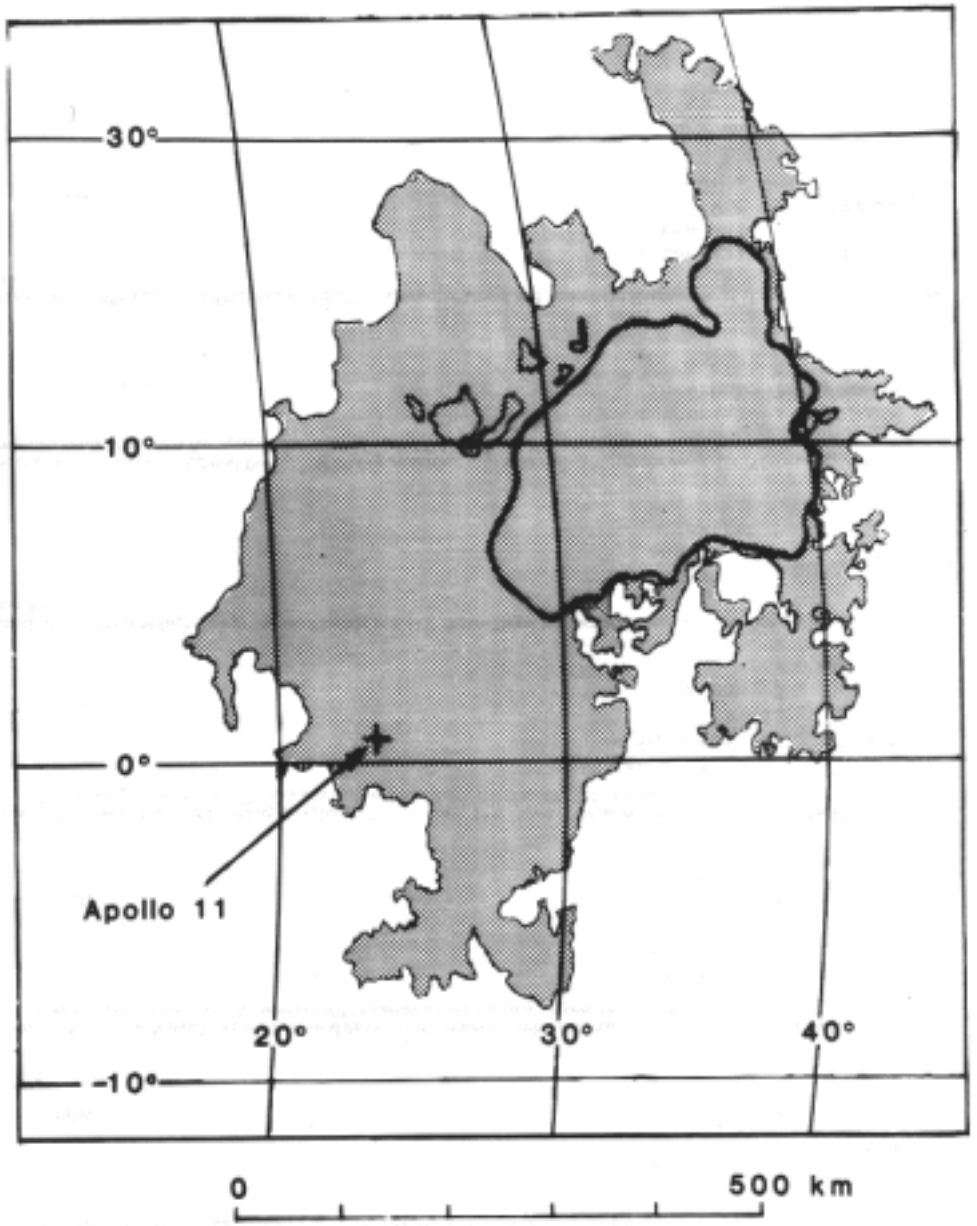


Figure 15. Map of Mare Tranquillitatis. Major structural features are less numerous in the area bounded by the area bounded by the heavy black line than in the remainder of the mare (cf. Figs. 5 and 6).

After G. Cameron

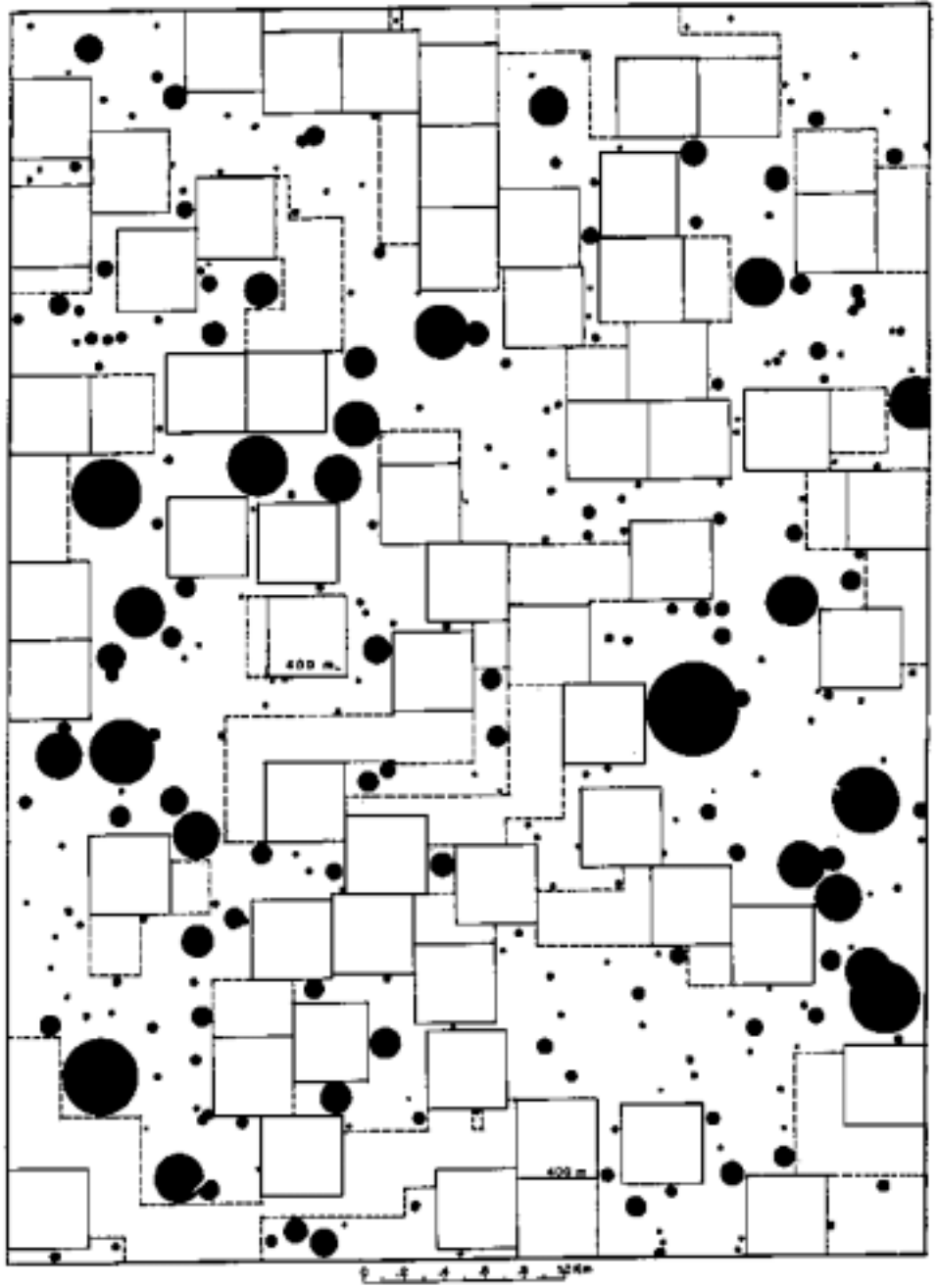


Figure 6. Reduced overlay of original of Figure 5. Craters 23.4 m or more in diameter (including ejecta halos where observed or inferred) shown by solid black circles. Minable area plotted in terms of 400-meter square blocks (bounded by solid lines) and extensions (bounded by dashed lines).

After G. Cameron

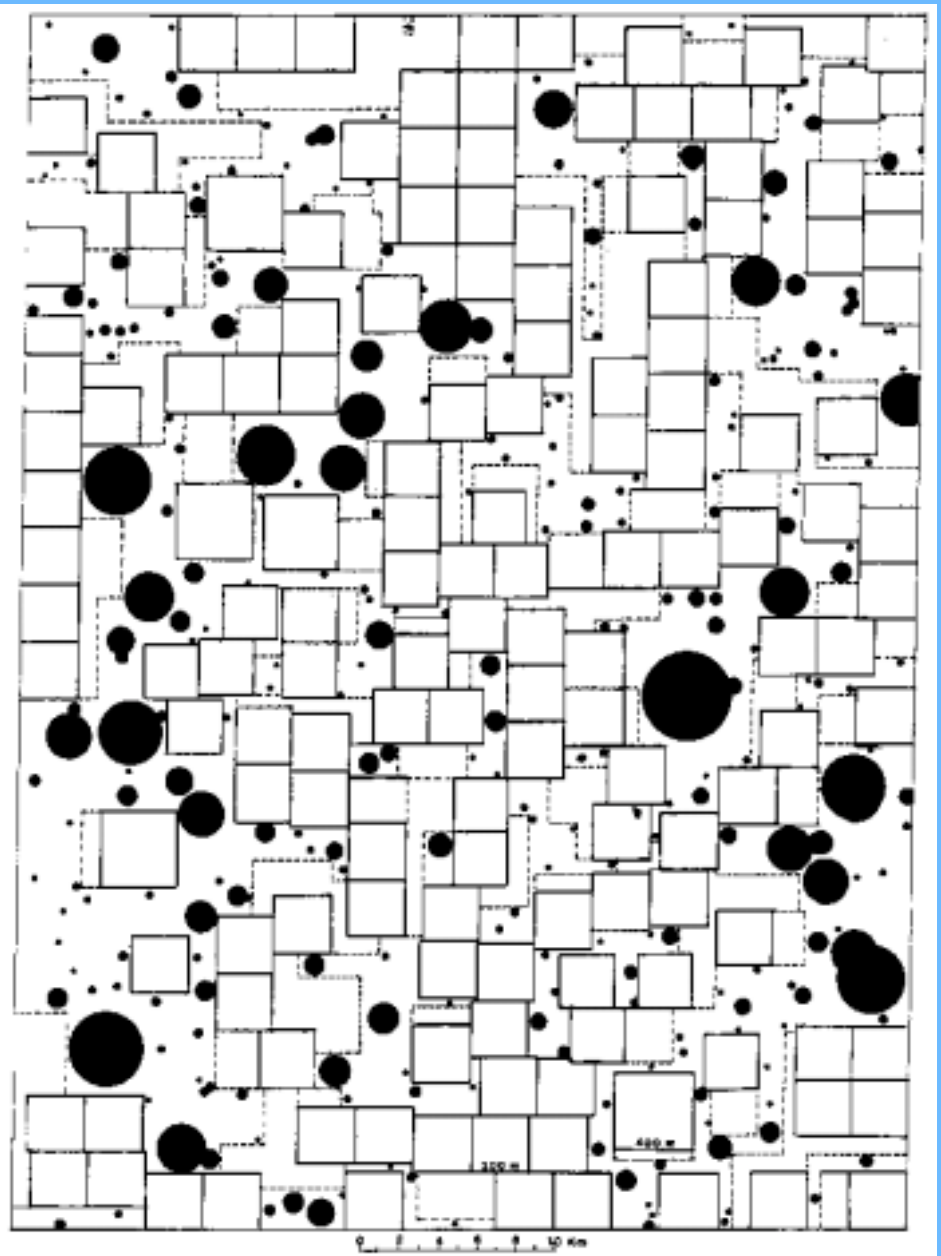


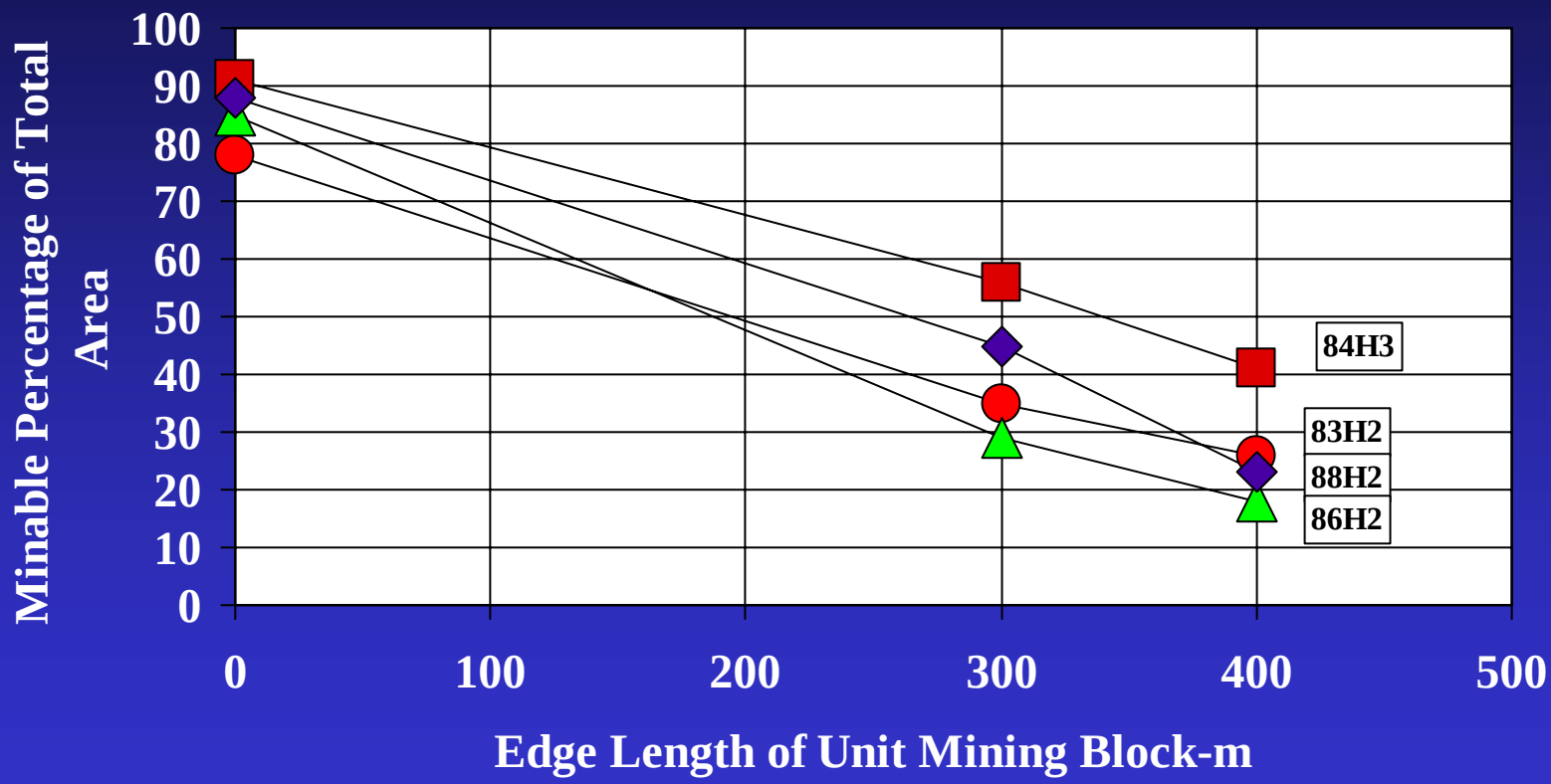
Figure 7. Reduced overlay of original of Figure 5. Craters 23.4 m or more in diameter (including ejecta halos where observed or inferred) shown by solid black circles. Minable area plotted largely in terms of 300-meter square blocks (bounded by solid lines) and extensions (bounded by dashed lines).

After G. Cameron

Approximately 1/5 of the Total Area of Mare Tranquillitatis is Occupied by Features that May Be Unminable

• Domes	0.6%
• Ridges	5.6%
• Craters	4.2%
• Rilles	0.6%
• Basement materials	2.0%
• Ray materials	5.6%
• Misc. non-mare features	3.4%
• Total	22.0%

The Smaller the Unit Mining Block the Larger the Percentage of Minable Area



Minable Regolith and Helium Content of Mare Tranquillitatis

Regolith Category	Area km^2	Ave. He Content-wppm	Minable Regolith, tonnes	Helium tonnes	Helium-3 tonnes
A	84,000	38	252×10^9	9,580,000	3,625
B	195,000	25	598×10^9	14,960,000	5,754
Totals	279,000		850×10^9	24,540,000	9,439

Note: He-3 content based on $^4He/^3He = 2600$ and average depth of regolith is 3 m

Another Approach to Lunar Volatiles Mining

-Spiral Mine Plots-

Spiral Mining System for Lunar Volatiles

Mobile Miner

Solar Thermal Receiver

SA

New Road

VR

HS

PS

Mined Area

New Road

Wheel Track

LP

Old Road

Temporary Road

VR: Volatile refining subsystems
HS: Habitat and crew work section
LP: Launch and landing platform
PS: Power subsystems
SA: Mobile Miner support arm

Solar Concentrators and Reflectors

Crane

Regolith Filled Shield

Sealed SA Bearing

VR HS PS HS VR

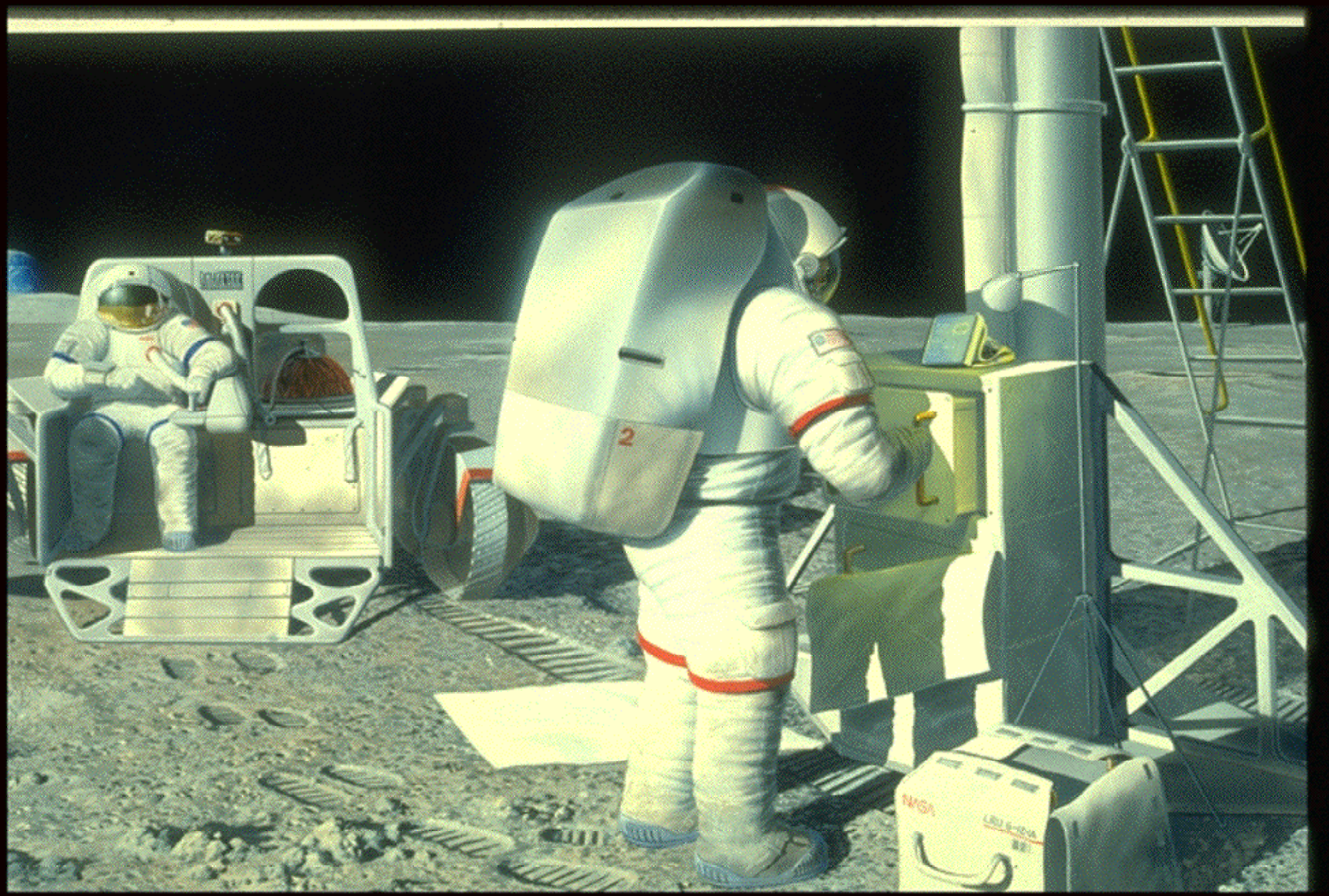
SA

Adjustable Skirt

Parking and Storage

Cryogenic Storage Center

Mobility Subsystem (1 of 4)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Spiral Miner Concepts (1)

- Mobile miner similar to Wisconsin Mark-II
- Power received from central station
- Daylight operation or nighttime with fuel cells
- Volatiles piped to central station
- Routine telerobotic operation
- Backup manual operation

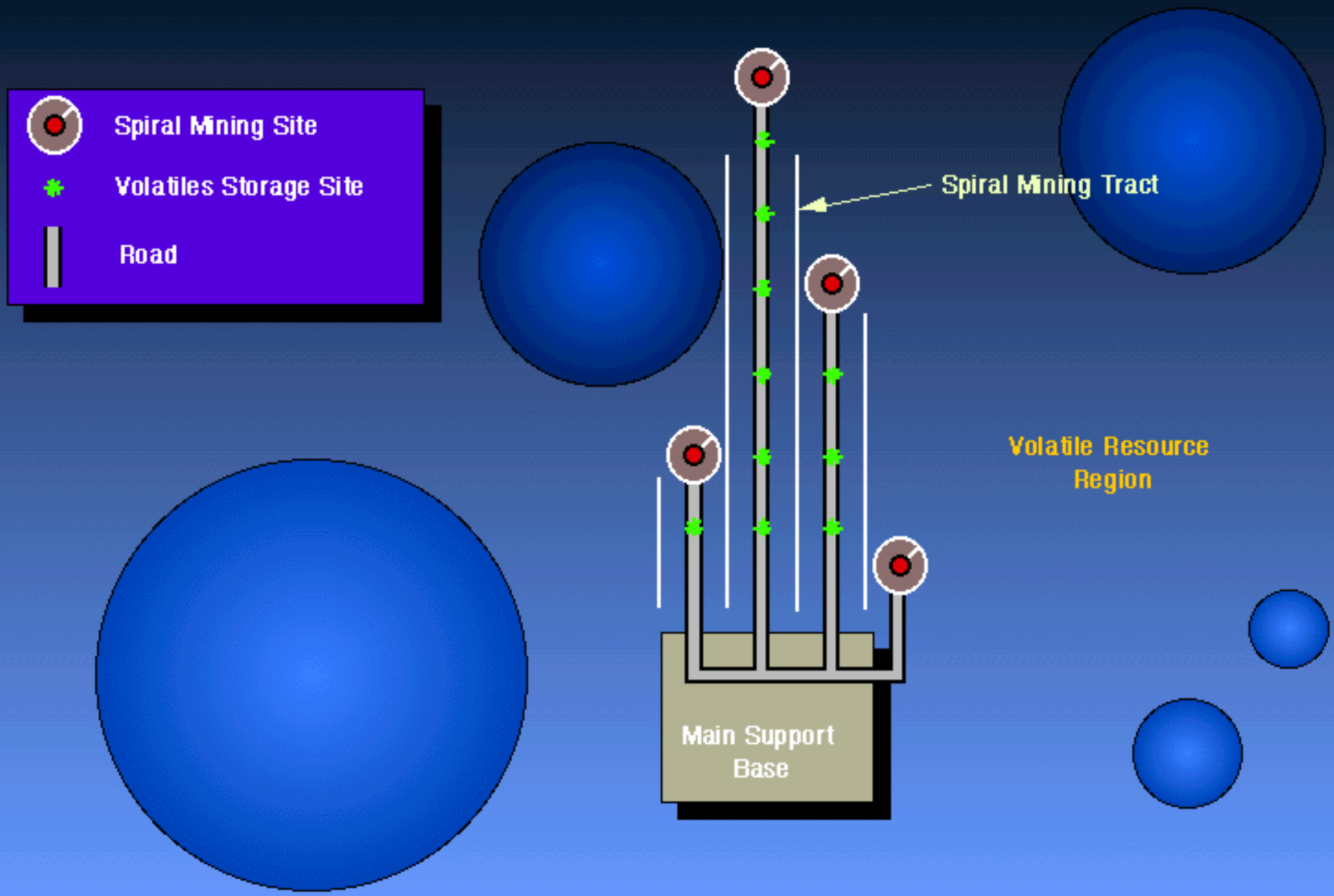
Spiral Miner Concepts (2)

- Maintenance and repair at central station
- Possible transport of regolith through pipe to central station
- Look ahead radar to identify hidden boulders
- Unminable areas avoided by extending or contracting arm.

Spiral Mining/Central Station

- Could provide thermal and electrical power generation
- Command and control functions
- Processing of extracted volatiles
- Refined volatiles tanked for export or storage
- Regolith filled insulating shell

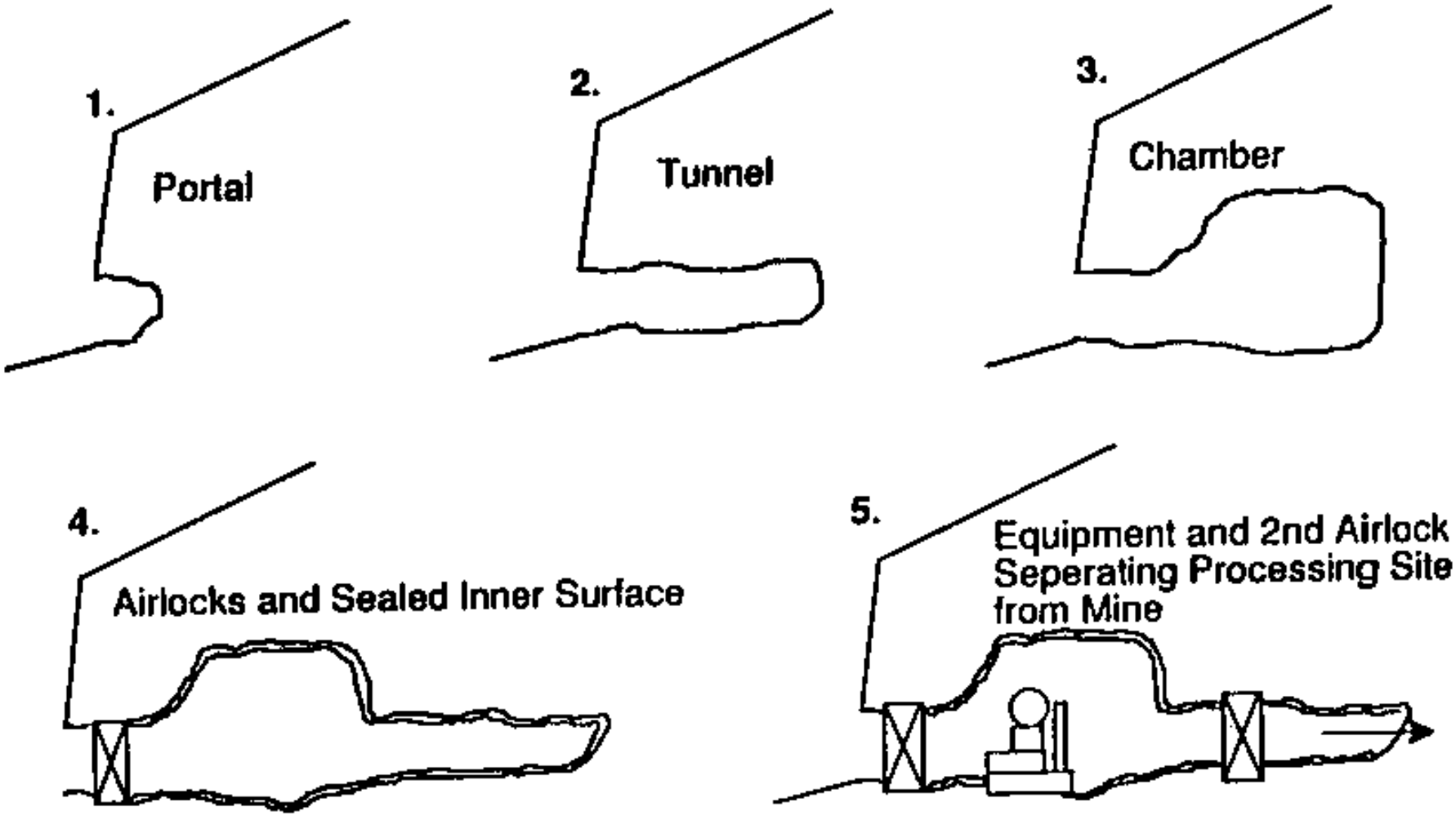
Regional Mining Plan Utilizing Spiral Mining Systems

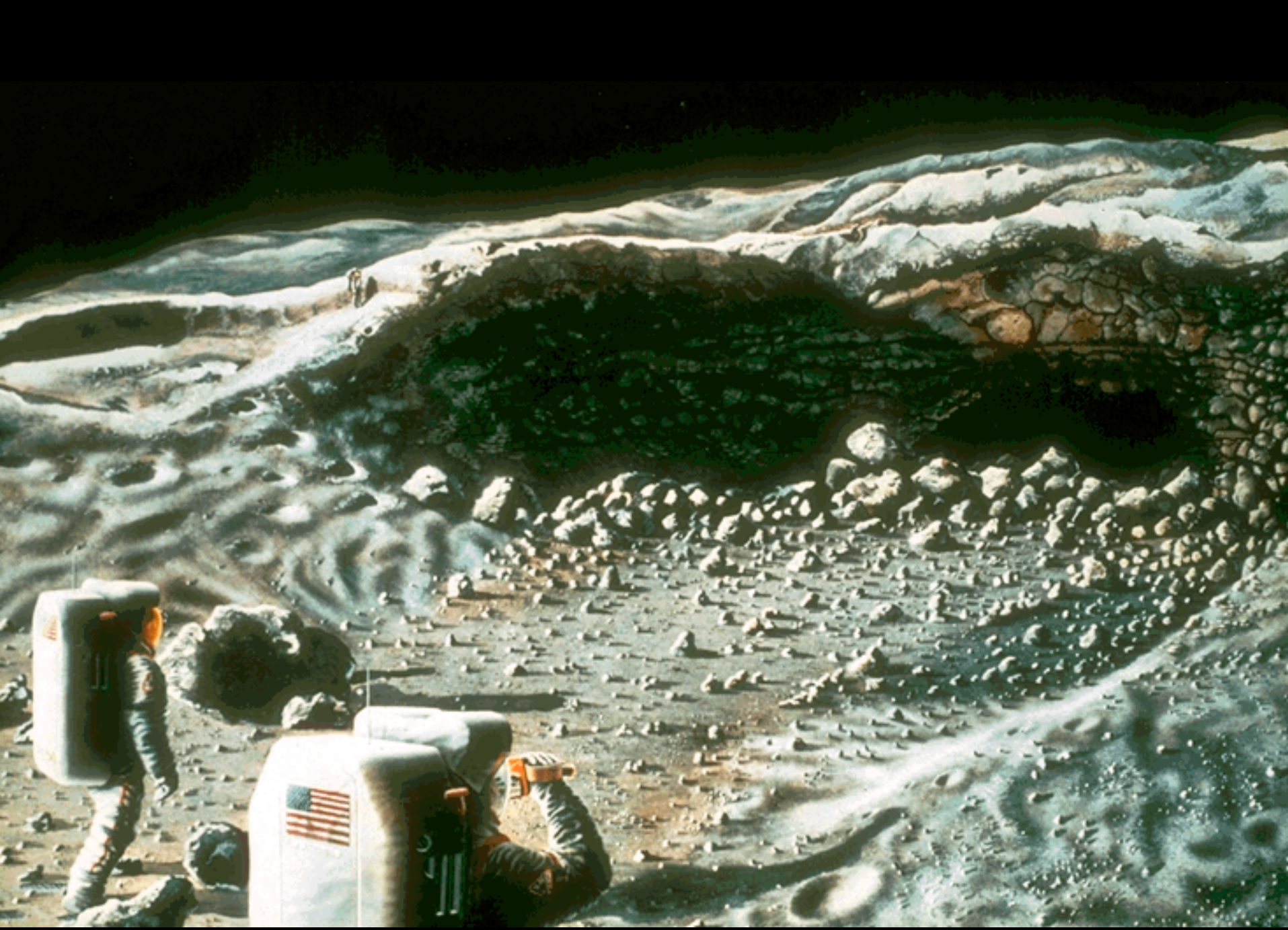


Spiral Mining/Permanent Support Base

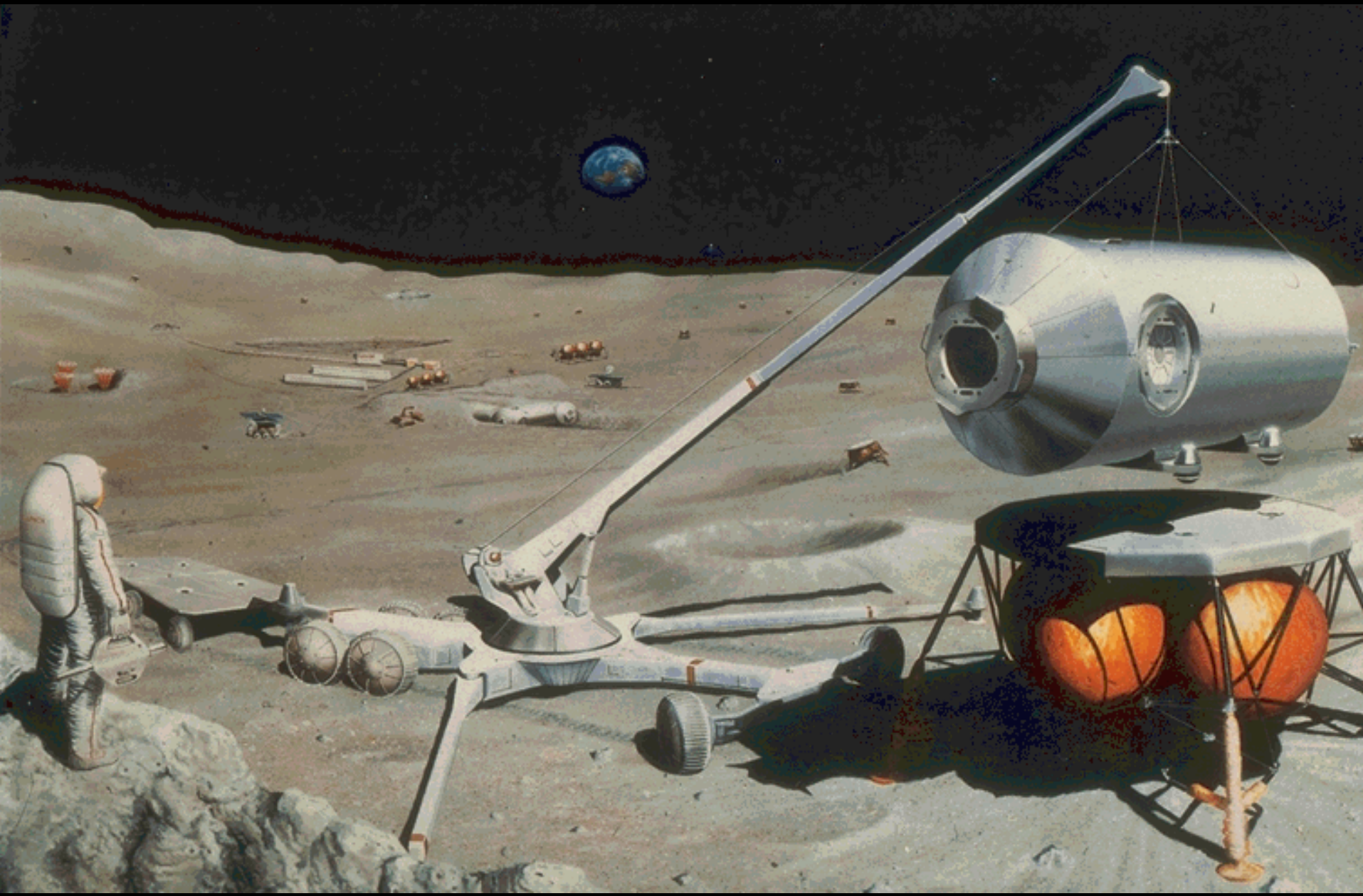
- Administration and long term planning
- Volatile export planning
- Consumable import planning
- Region launch and landing coordination
- Agricultural production
- Manufacturing and shop support
- Major medical support
- Regional recreation center

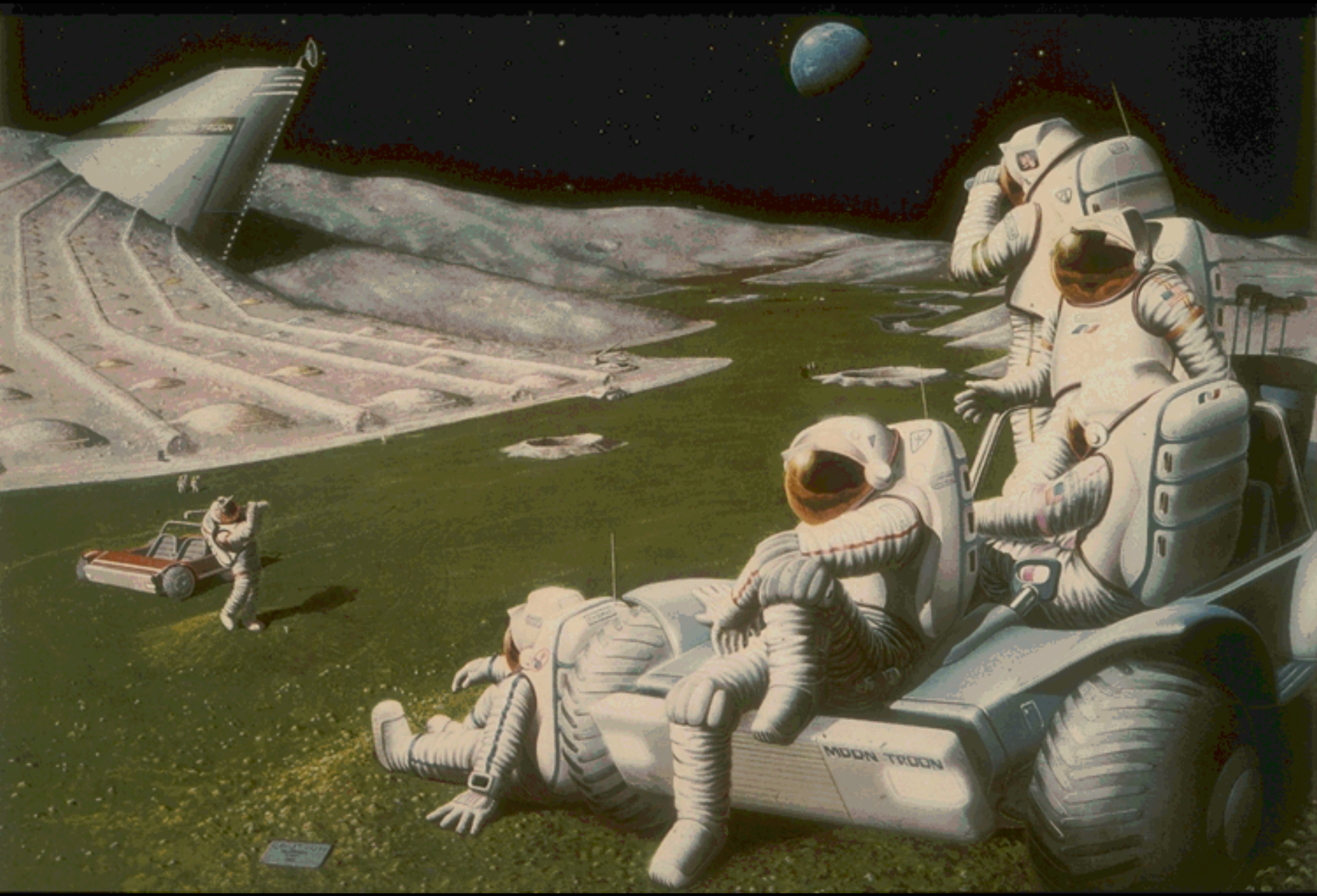
Chamberlain et. al., (1993) Have Proposed Have Proposed an Underground Mining and Sealing Concept






LUNOX
Pat Rawlings




MOON TROON

Conclusions

- The mining of Solar Wind Volatiles is feasible via several approaches.
- Considerable planning for mining operations could be done on the Earth once “ground truth” is obtained on resource distribution.
- Economic geology and transportation costs will play an important role in the determination of the profitability of Lunar resource recovery.