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Indigenous Lunar Construction Materials

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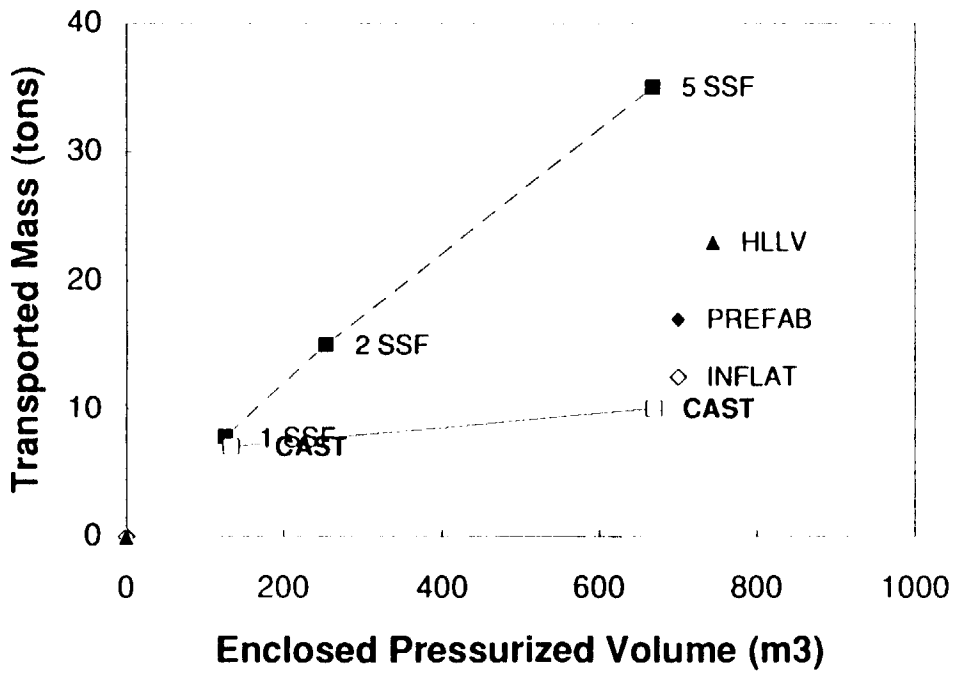
Motivation

The utilization of local resources for the construction and operation of a lunar base can significantly reduce the costs of transporting materials and supplies from Earth.

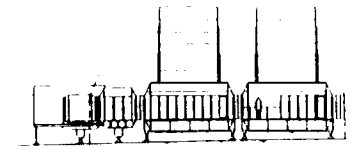
- Primary examples of utilization of lunar resources: radiation shielding, oxygen extraction, water production, helium-3 mining.
- **Construction materials** are excellent candidates for utilization of local resources: they are relatively simple, heavy, and available. Raw materials may be by-product of other operations such as oxygen extraction.

Why	Why not
Pay-load weight savings	Unfamiliar technologies
Long term manned presence in space	Significant infrastructure

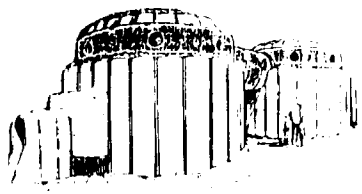
Comparison of Various Lunar Structures



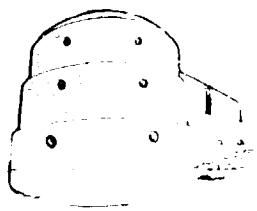
SFF
Space Station
Freedom Module



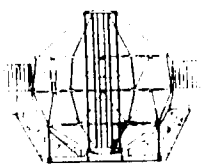
HLLV
Heavy Lift Launch
Vehicle Module



PREFAB
Deployable Module



INFLAT
Inflatable Sphere



CAST Cast Regolith Structure

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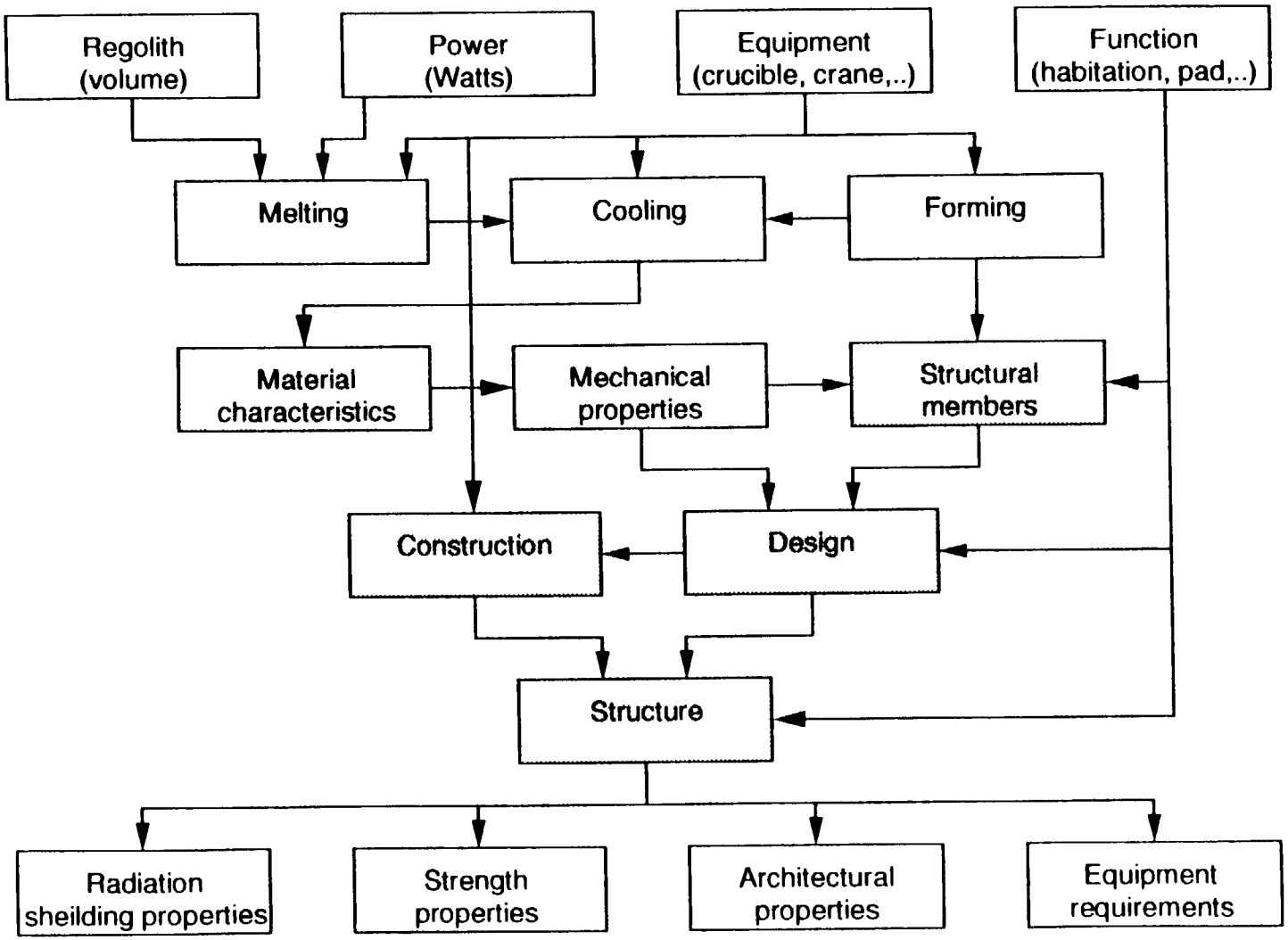
Processing - material - construction - structure relationships



Objectives

- Investigate the *feasibility* of the the use of local lunar resources for construction of a lunar base structure.
- Develop a material processing method and integrate the method with design and construction of a pressurized habitation structure.
- Estimate specifications of the support equipment necessary for material processing and construction.
- Provide parameters for systems models of lunar base constructions, supply and operations.

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Indigenous Lunar Construction Materials

- **Minimally processed materials**: lunar rocks, regolith mortar, compressed regolith, free flowing molten regolith, for domes, roads, and landing pads (Khalili SCIA). *Materials do not have good mechanical properties.*
- **Solar power fused regolith** for large layered slabs (Clifton). *Solar power is not sufficient to melt large quantities of regolith in reasonable lengths of time.*
- **Sintered and hot pressed regolith** for bricks, plates, columns (Simonds, NASA LSI; Meek, UT; Vaniman, LANL; Sullivan, Battelle). *Small structural components. Not suited to tensile (pressurized) loading conditions or automated construction.*
- **Concrete**: traditional steel reinforced concrete structure using columns, beams, and slabs (Lin, CTL). *Lack of water.*
- **Iron and Steel**, high quality construction materials (UA). *Complex processing methods with high energy requirements.*
- **Cast basalt:** liquified regolith cast into large slab forms (Capps and Wise, Boeing; Binder, Lockheed)

Guidelines for Material Processing Method

- Material processing method should be applicable to a variety of structural element geometries and sizes.
- Processing method should produce a material with good, consistent mechanical properties.
- Amount of material processing-specific support equipment should be minimized.
- Material processing method should be integrated with structural design and construction operations.
- Processing and construction steps should be simple in order to accommodate robotic automation.

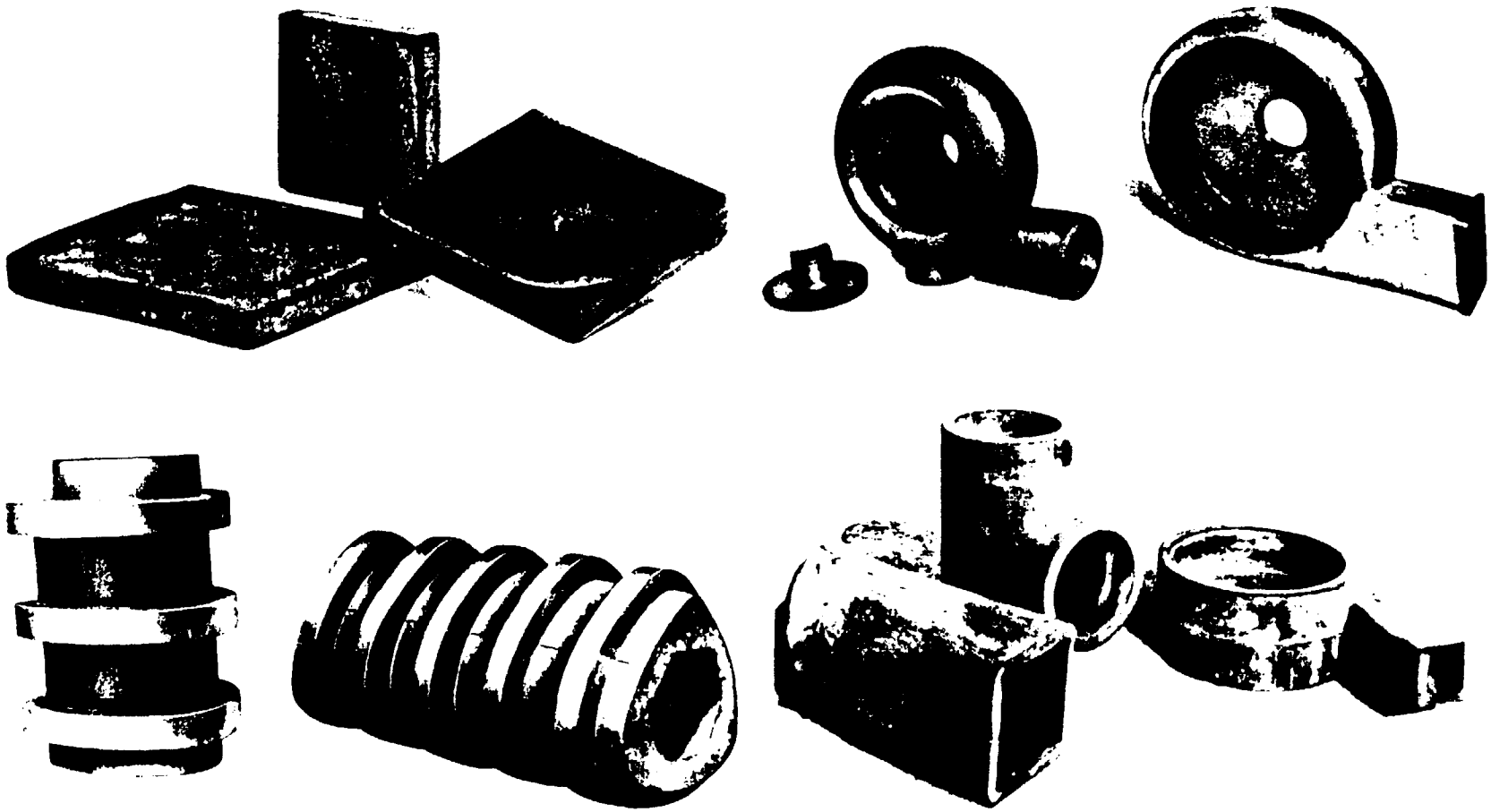
Assumptions

- Material processing method is intended for **far-term lunar base**. *A certain level of infrastructure must be in place.*
- **Power source** of 100 kW is available (SP-100 nuclear reactor). *This places tight constraints on processing time and structural component size.*
- **Earth moving equipment** is available. *All scenarios include plans for regolith shielding which requires earth moving.*
- **Lunar crane** with 10 ton capacity is available. *Near-term lunar base construction is likely to require lunar crane.*

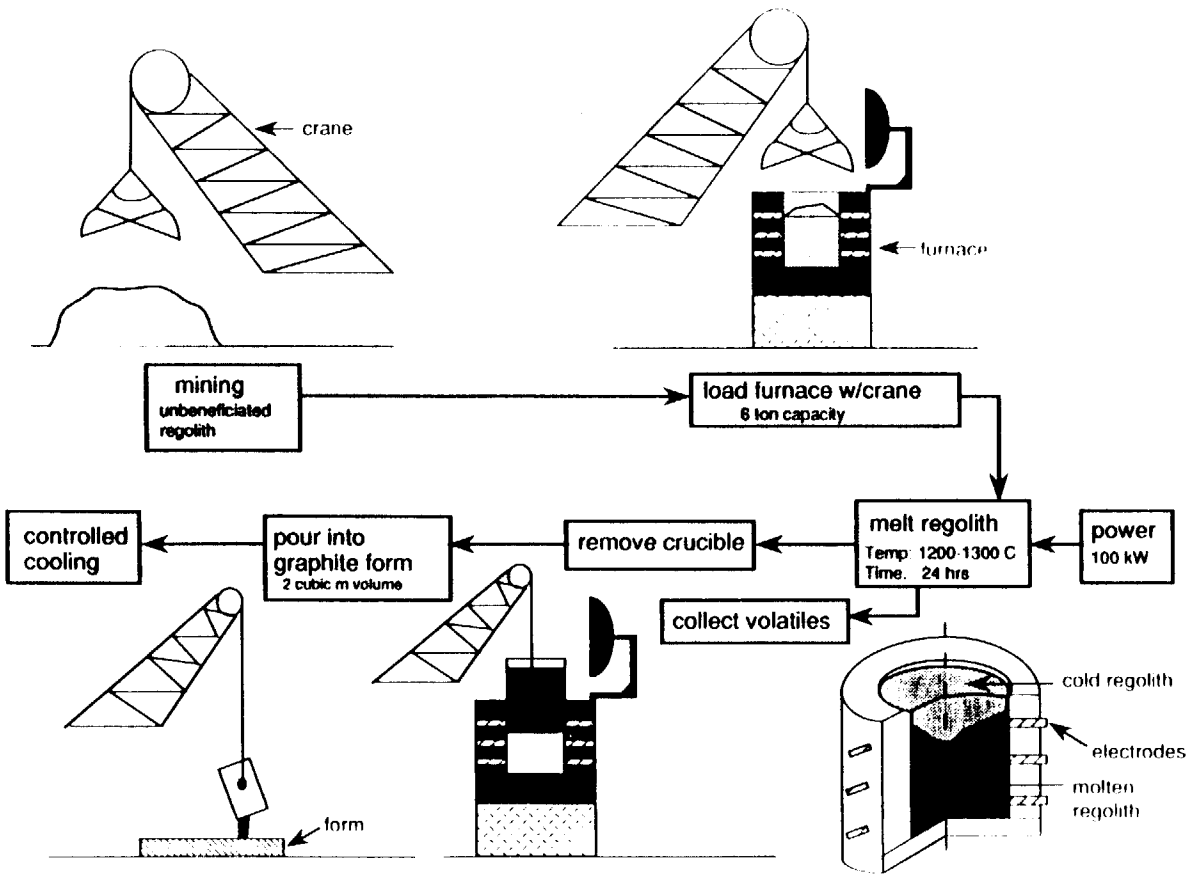
Cast Lunar Regolith

- **Raw materials**: regolith is abundant over the lunar surface. Chemical composition of regolith is very similar to terrestrial basalts.
- **Terrestrial cast basalt** processing methods are moderately well established. Cast basalt has good mechanical properties and can be formed into complex geometries.
- **Proposed cast regolith** process is a simplification of terrestrial cast basalt suited to the lunar environment. Benificiation, grinding, homogenization steps are unnecessary. High vacuum and low gravity pose no unusual problems.
- Material processing may be integrated with oxygen production.

Examples of Cast Basalt Components



Cast Regolith Process



Processing Equipment

- **Furnace**: batch operation, electrical resistance, 1300°C capability, 90% efficiency, 3 ton weight, enclosed heating chamber for recovery of volatiles (hydrogen, nitrogen,...). At 100 kW, melting cycle lasts 24 hrs for 6 ton regolith capacity.
- **Ladle**: heating chamber of furnace is removable to act as a ladle for the transfer of molten regolith to casting forms.
- **Casting forms**: reinforced graphite panels, 1500°C capability, 0.5 ton weight. Reflective surfaces reduce radiative heat transfer for controlled cooling and recrystalization over a 24 hr period.

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Mechanical Properties of Cast Basalt

	Cast Regolith	Concrete	Cast Iron	Aluminum
Density (g/cc)	2.9	2.4	7.1	2.8
Elastic Modulus (GPa)	110	21	160	70
Tensile Strength (MPa)	>35	7	125	100*
Fracture Tough. (MPa$\sqrt{m}$)	2	2	15	25
Thermal Expan. (x10^{-6}/°C)	7.8	13	11	22
Melting Point (°C)	1200	-	1400	600

* yield

Material Properties and Structural Design

- **Brittle material**. Design must minimize tensile and bending stresses and stress concentrations. Compression loading is ideal but unrealistic for pressurized structure.
- **Joining** introduces stress concentrations so the minimum number of structural components should be used. The maximum size of a structural element is dictated by the capacity of the batch furnace, casting capabilities, and constructibility.
- **Net shape forming** is necessary because cutting is very difficult.
- Large factors of safety must be avoided to reduce mass of structure and time required for material processing.
- Earth-based structural elements are necessary for joining, reinforcement, and air-locks. Design should minimize these.

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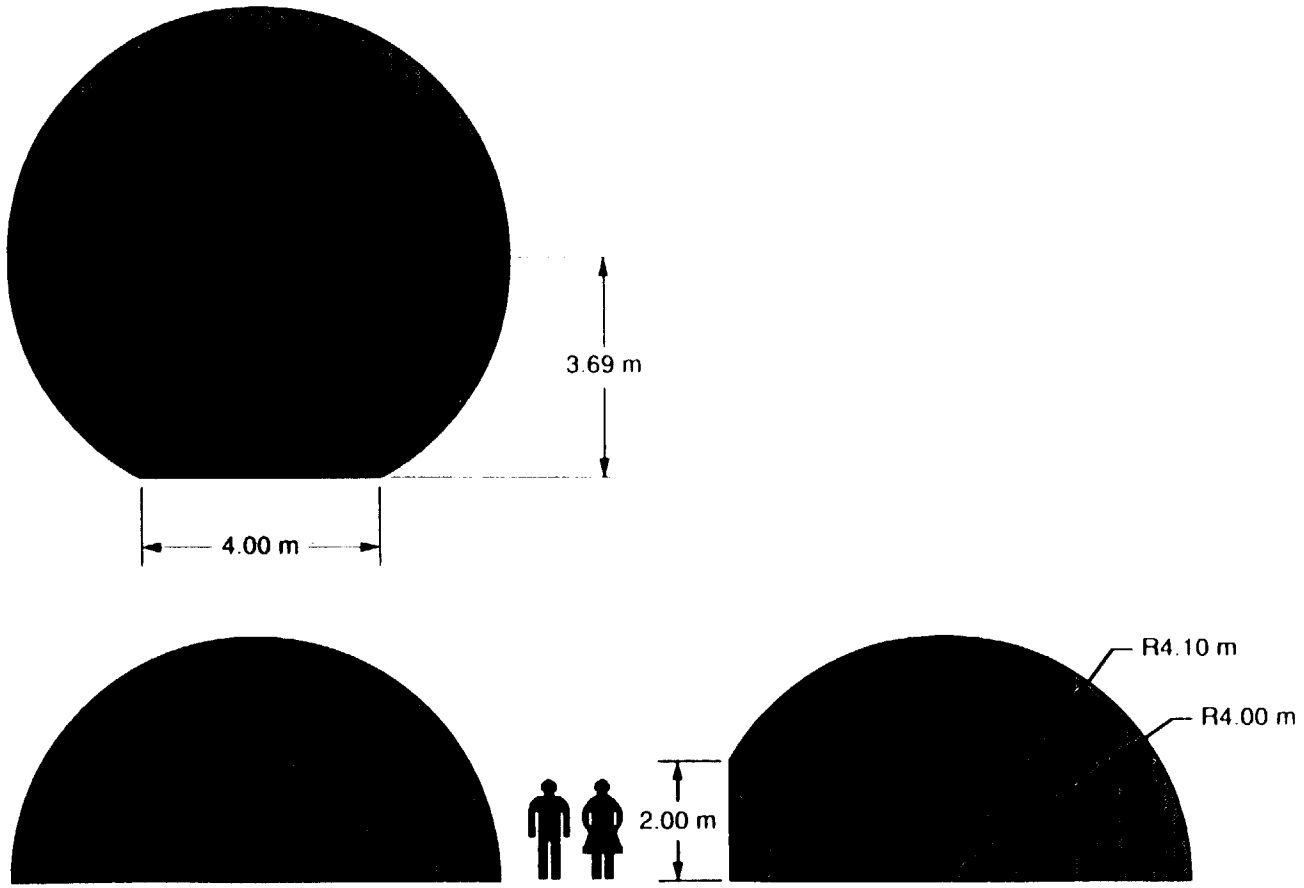

Future Work

- **Material processing demonstration**. Demonstrate liquification, casting characteristics, viscosity, cooling and recrystalization, environmental effects.
- **Material property evaluation**: density, elastic moduli, fracture toughness, statistical measures of strength.
- **Structural design**. Develop a point estimate of a pressurized lunar habitation structure based on cast regolith.
- **Construction methods**. Establish integrated material processing and construction steps. Investigate potential for robotic automation.
- **Scale structural testing**. Validate design models and demonstrate structural reliability of point design.