NUCLEAR FISSION AND FUSION MICROREACTORS FOR LUNAR AND PLANETARY TUNNELING APPLICATIONS

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Introduction

- We are going for the long-term development of the Moon and beyond. Mankind must become a space faring species!
- Lunar and deep space bases, missions and the successful development of the solar system and beyond requires energy-intensive bases, mining, research and construction activities.
- Subsurface bases on the Moon and beyond would be preferable to surface—easier to protect from Lunar and planetary environments
- Tunneling with tunnel boring machines (TBM's) can be used
- Preliminary design of LTBM's reactor will be in the 1 to 2 MWe size range, for a 4-meter diameter tunnel.
- Tunneling and other construction activities requires a lot of power, in the multiples of MWe range
- New advancement of thermonuclear peacetime technologies are an ideal solution
- *Simply seeking of "free trade" monetary profit, based on existing "cartel" mining arrangements, and controlling access to space through hybrid warfare to "control terms of trade", will lead to the rapid failure of space development efforts.*

Potential LTBM Configurations

- Forces are self-contained
- Can excavate rock, soil or mix
- Suggested size is 3 – 4 meters
- Requires about 1 MWe at this size [15]
- Weight reduction may include composite frame and tube

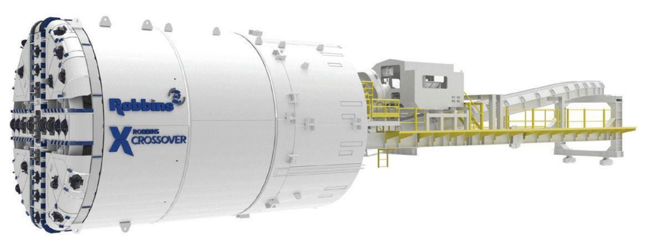
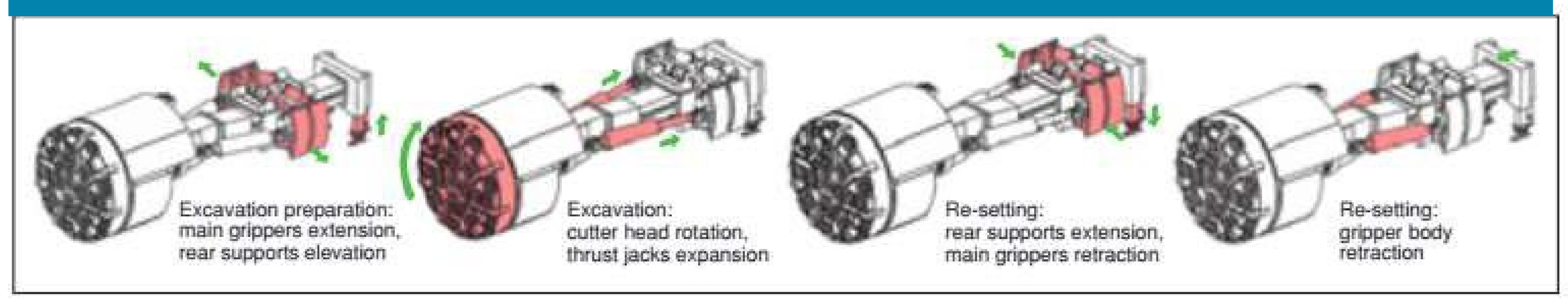


Figure 1: Conceptual terrestrial design for tunnel boring machines that could be modified for Lunar use. Weight reduction will have to be made for the system to be deliverable. [1]



Brief Reactor Design History

Numerous microreactors for space and ocean navigation were designed and deployed by Naval reactor designers, DOE and other agencies since the 1950's. The Army launched the ML-1 500 kWe portable system in 1960. Other space designs ranged from SNAP 1 (500 We, Ce 144 plant with Hg Rankine heat exchangers to the 100 We MMRTG's aboard *Curiosity* and *Perseverance* on Mars. SNAP 50, a 1200 kWe system, was cancelled in 1973. SP-100 system 2500 kWt prototype for lunar power was terminated.

All SNAP designs used UZrH fuel, cooled with NaK mixture and powered Hg Rankine or thermoelectric generators.

A few designs are indicated, below:

- ML-1, 500 kWe, portable, deployed in 1960 and shelved in 1964, Figure 2
- SNAP-10A, 500 We, weighed less than 950 lbs, launched April 1965, Figure 3
- Project Prometheus, 200 kWe nuclear space propulsion, shelved 2006 after final design released, Figure 4
- KILOPOWER, developed by 2018, 10kWe, mass of 1,500 kg. commercial versions under development. Figure 5

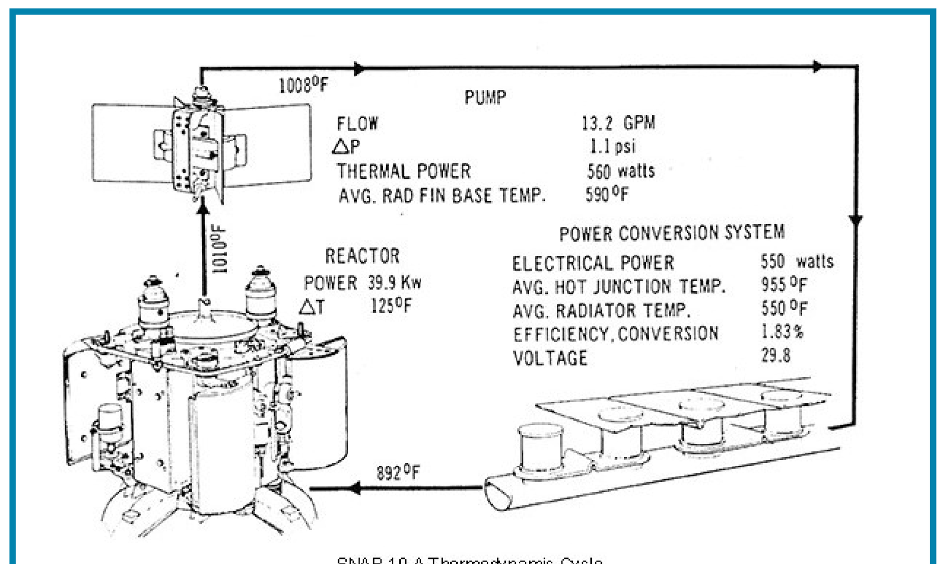


Figure 3: SNAP-10A Thermodynamic Cycle and Machine. SNAP-10A weighed less than 950 lbs, produced 500 We, 2 Be reflectors, liquid NaK coolant, Te thermocouples. Launched on 3 April 1965, produced power for 43 days before faulty command receiver shut it down. Still orbits aboard Agena-D satellite. [6]

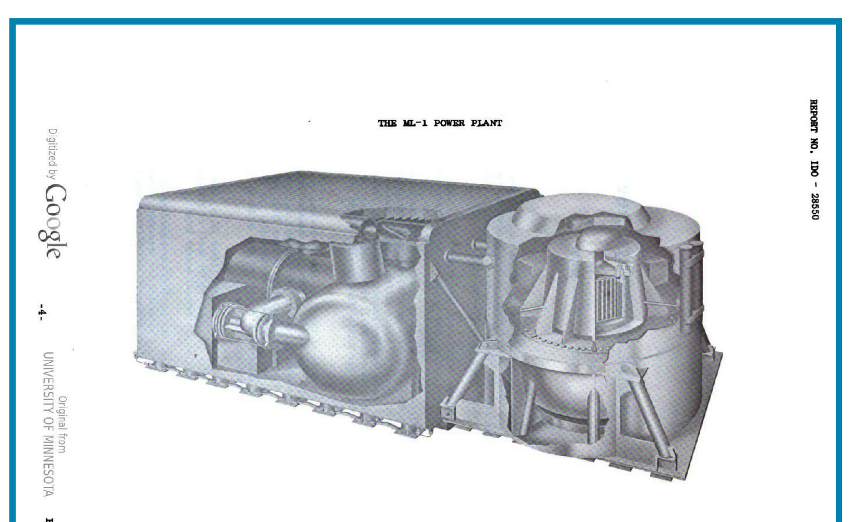


Figure 2: ML-1 Nuclear Power Plant, cutaway view. POWER: Up to 500 kWe, cycle efficiency 133%, power density 700 kW/ft³, N2 coolant, 22,000 rpm axial flow compressor, water-moderated, enriched UO2. TRANSPORT: Total weight 40 tons, in 3 15-ton packages, for aircraft, truck trailer or barge transport. [2]

Figure 4: Project Prometheus was a 200 kWe nuclear reactor powered space craft, designed to reduce travel time from Earth to Mars to weeks. The project was abandoned in 2006, after significant development. [11]

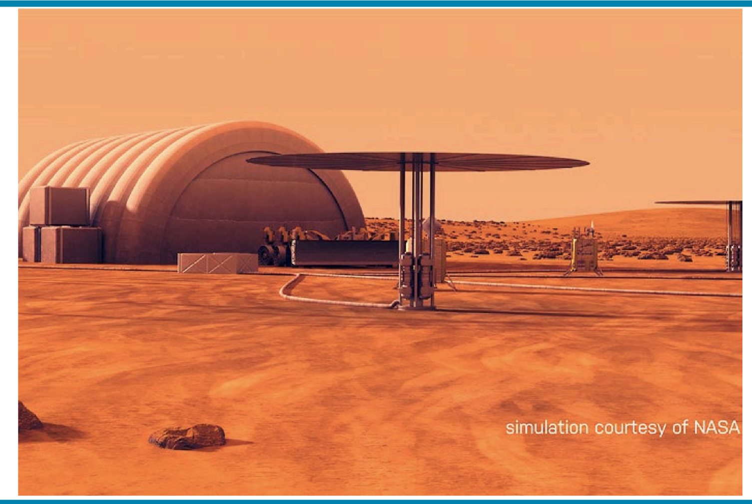


Figure 5: Artist's conception of "KiloPower" type Stirling Cycle nuclear reactors on the Martian surface [8]

Energy Flux Density

Energy Density and Energy Flux Density are Keys to Successful Development of the near Solar System and Ensure Growing Relative Potential Population Density.

Energy sources must offer high power-to-weight ratio, ability to withstand delivery, years of maintenance-free service, steady supply, increased surplus energy of the system (thermodynamic efficiency), durability in the Lunar environment, and modularity.

Energy Density can be measured in kWe/kg. Energy Flux Density is a different construct. It is a measure of the organization of the energy supplied. For example, a high-temperature fusion plasma has higher energy flux density than a nuclear fission power plant with the same power output.

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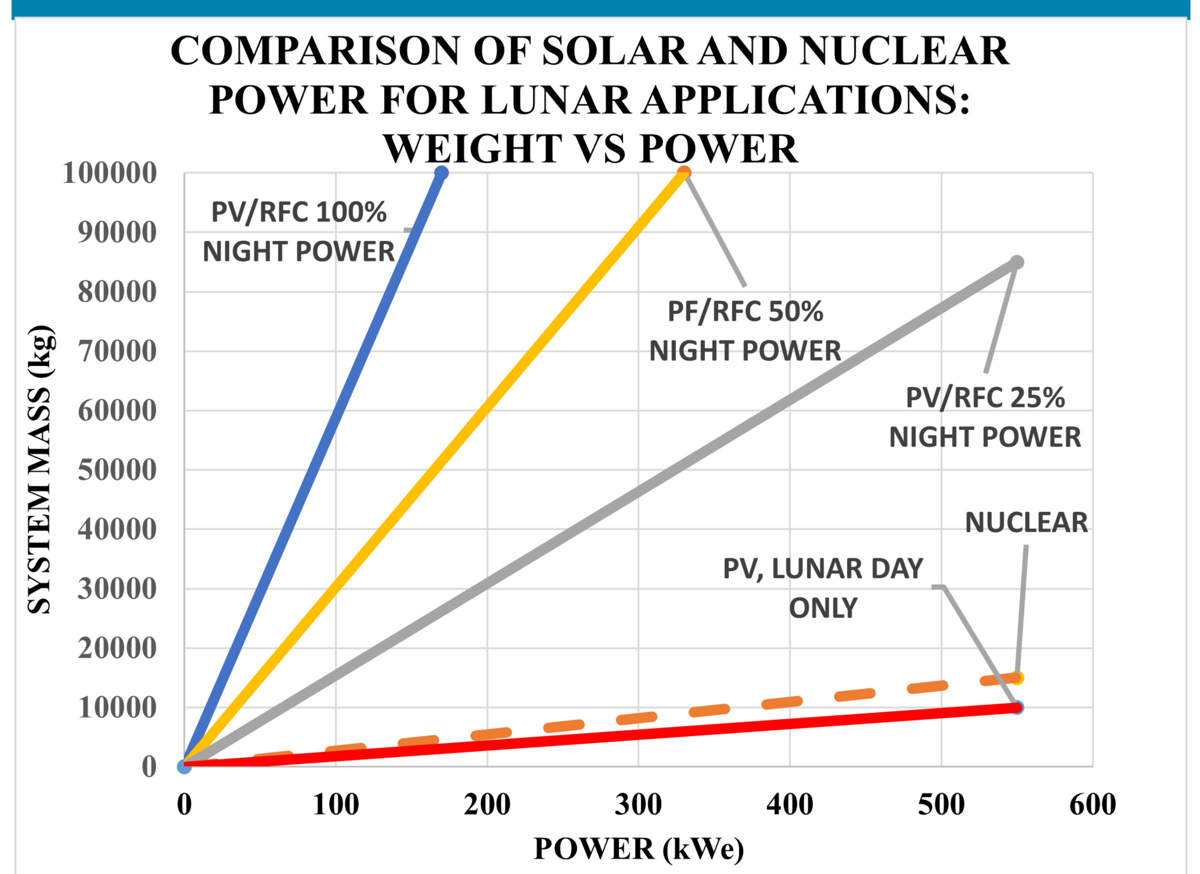
The Moon currently supports no human populations with in-site resources or development. Large amounts of power will be needed quickly for construction of tunnel and underground spaces, as well as the Lunar economy in general.

Relative Potential Population Density is a measurement of the amount of land, with physical improvements, that can support a given number of people. Energy sources must be sufficient to support a growing scientifically and industrial population.

Figure 6: Comparison of Weight vs Power ("Energy Density) Between Solar and Nuclear Power for Lunar Applications [6]



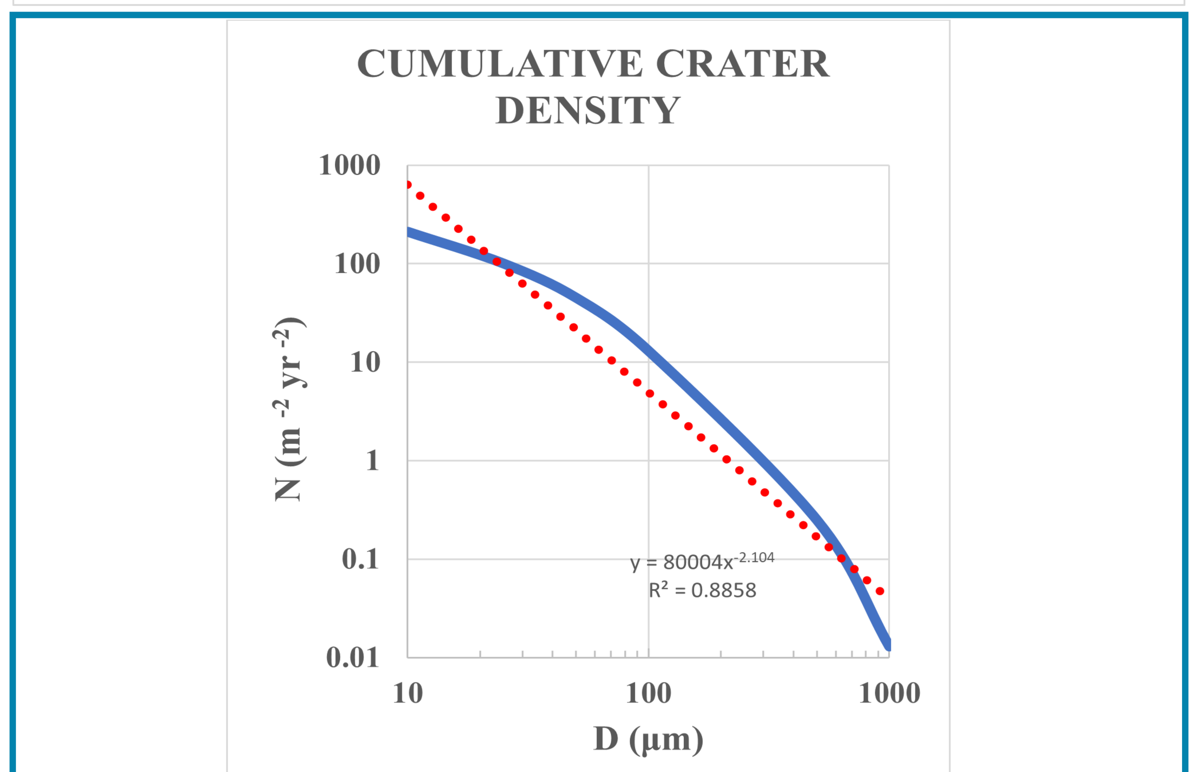


Figure 7: Vulnerability: Hypothetical Flat Aluminum Alloy Target Exposed on Lunar Surface for One Year: Expected Cumulative Crater Density [14]

Table 1: Some existing and proposed designs for space and planetary nuclear fission reactors

	SNAP-10 US	SP-100 US	Romashka Russia	Bouk Russia	Topaz-1 Russia	Topaz-2 Russia-US	SAFE-400 US
dates	1965	1992	1967	1977	1987	1992	2007?
kWt	45.5	2000	40	<100	150	135	400
kWe	0.65	100	0.8	<5	5-10	6	100
converter	t'electric	t'electric	t'electric	t'electric	t'ionic	t'ionic	t'electric
fuel	$U\text{-}ZrH_x$	UN	UC_2	U-Mo	UO_2	UO_2	UN
reactor mass, kg	435	5422	455	<390	320	1061	512
neutron spectrum	thermal	fast	fast	fast	thermal	thermal/ epithermal	fast
control	Be	Be	Be	Be	Be	Be	Be
coolant	NaK	Li	none	NaK	NaK	NaK	Na
core temp. °C, max	585	1377	1900	?	1600	1900?	1020

Table 2: Summary of Some Projected Fusion Power Plants in the 1 MWe Power Range

COMPANY	LOCATION	SIZE	FUEL	GENERAL APPROACH	PROJECTED DATE
Avalanche Energy	Tukwila, WA	0.005 MWe/module	D-T	Hybrid electrostatic confinement	2025/Q4
Blue Laser Fusion, Inc.	Palo Alto, CA		$H\text{-}^{11}B$	Inertial confinement	2030
Crossfield Fusion LTD	London, UK	10kW	D-D	Closed orbit, velocity resonant	Not disclosed
Deutelio	Gavirate, Italia	10 MWt	D-D	Magnetic confinement	2027
Electric Fusion Systems, Inc.	Broomfield, CO	5 kWe	$H\text{-}^{7}Li$	Rydberg matter fuel-based	2030
Helicity Space Corporation	Pasadena, CA	300 MWe	D-D	Magneto-inertial	(included because space-oriented)
Helion	Everett, WA	50 MWe	$D\text{-}^{3}He$	Pulsed non-ignition	2028
Horne Technologies, Inc	Longmont, CO	1 MWe	$H\text{-}^{11}B$	Magneto-electrostatic confinement	2028
LPP Fusion, Inc.	Middlesex, NJ	5 MWe	$H\text{-}^{11}B$	Magnetic confinement	2025
Novatron Fusion Group AB	Stockholm, Sweden	1 MWe	D-T	Magnetic confinement	2030
NT-TAO Ltd	Hod Hasharon, Israel	10 MWe	D-T	Magnetic confinement	2030
Princeton Fusion	Plainsboro, NJ	1 MWe	$D\text{-}^{3}He$	Field	2030
Systems				reversed	
				magnetic	
				confinement	
Shine Technologies	Janesville, Wisconsin	1 MWe (Phase 2)	D-T	Magnetic-electrostatic	2024

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