Lunar Settlement Calculator
Spreadsheet Basis for Calculations

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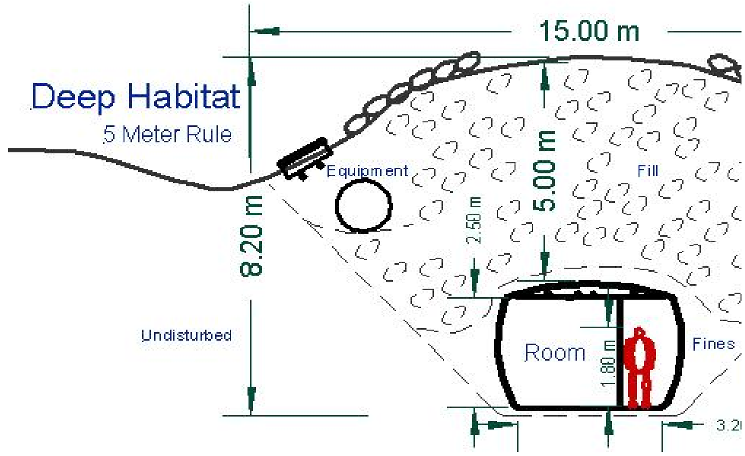
File: BMDSettlementCalmmddyy.xls



Purpose:

This spreadsheet is the basis of the "Big Moon Dig, Lunar Settlement Calculator" and the 5 Meter Rule.

Developing a Settlement Design of your own:

1. Physical constants

		Acceleration			SI	Ratio
Earth Gravitation Constant	g	9.81	**m/s^2**	9.81	**N/kg**	1.00
Moon Gravitational Constant	g	1.63	**m/s^2**	1.63	**N/kg**	6.02
Mars Gravitations Constant	g	3.75	**m/s^2**	3.75	**N/kg**	2.62

Air on Earth at STP

Pressure		101.32	**kPa**	101323	**N/m^2**
Density		1.22	**kg/m^3**		
Nitrogen	at STP	1.25	**kg/m^3**		

2. Conversion Constants: (See Note 1)

m^2 / cm^2	0.0001
kg / g	0.001
ft/m	3.28084
psi / kPa	6.894757293
(lbs/in^3)/(kg/m^3)	3.61272E-05
kPa/(N/m^2)	0.001
lbs/kg	2.2046

3. Regolith Densities from real Apollo Data (See Note 2)

Core #	Mission	Landmark	Bulk Density g/cm^3	kg/cm^3	kg/m^3	Weightm Newton/m^3
10004			1.59	0.00159	1590.00	2591.70
10006			1.71	0.00171	1710.00	2787.30
12025	Apollo 12	Halo Crater	1.98	0.00198	1980.00	3227.40
12026			1.74	0.00174	1740.00	2836.20
12028	Apollo 12	Halo Crater	1.96	0.00196	1960.00	3194.80
14210	Apollo 14	Weird Crater	1.75	0.00175	1750.00	2852.50

14211	Apollo 14	Weird Crater	1.73	0.00173	1730.00	2819.90
14220	Apollo 14	Triplet	1.60	0.0016	1600.00	2608.00
15001			1.93	0.00193	1930.00	3145.90
15002			1.64	0.00164	1640.00	2673.20
15003			1.74	0.00174	1740.00	2836.20
15004			1.74	0.00174	1740.00	2836.20
15005			1.78	0.00178	1780.00	2901.40
15006			1.58	0.00158	1580.00	2575.40
15007	Apollo 15	St. George Crater	1.69	0.00169	1690.00	2754.70
15008	Apollo 15	St. George Crater	1.36	0.00136	1360.00	2216.80
15009	Apollo 15	Apennine Front	1.30	0.0013	1300.00	2119.00
15010	Apollo 15	Hadley Rille	1.91	0.00191	1910.00	3113.30
15011	Apollo 15	Hadley Rille	1.69	0.00169	1690.00	2754.70
60001			1.67	0.00167	1670.00	2722.10
60002			1.81	0.00181	1810.00	2950.30
60003			1.67	0.00167	1670.00	2722.10
60004			1.62	0.00162	1620.00	2640.60
60005			1.58	0.00158	1580.00	2575.40
60006			1.62	0.00162	1620.00	2640.60
60007			1.58	0.00158	1580.00	2575.40
60008			1.44	0.00144	1440.00	2347.20
60009			1.72	0.00172	1720.00	2803.60
60010			1.47	0.00147	1470.00	2396.10
64001	Apollo 16	Stone Mountain	1.66	0.00166	1660.00	2705.80
64002	Apollo 16	Stone Mountain	1.40	0.0014	1400.00	2282.00
68001	Apollo 16	South Ray Crater	1.74	0.00174	1740.00	2836.20
68002	Apollo 16	South Ray Crater	1.67	0.00167	1670.00	2722.10
70001	Apollo 17	Camelot Crater	1.66	0.00166	1660.00	2705.80
70002	Apollo 17	Camelot Crater	1.84	0.00184	1840.00	2999.20
70003	Apollo 17	Camelot Crater	1.84	0.00184	1840.00	2999.20
70004	Apollo 17	Camelot Crater	1.86	0.00186	1860.00	3031.80
70005	Apollo 17	Camelot Crater	1.83	0.00183	1830.00	2982.90
70006	Apollo 17	Camelot Crater	1.85	0.00185	1850.00	3015.50
70007	Apollo 17	Camelot Crater	1.80	0.0018	1800.00	2934.00
70008	Apollo 17	Camelot Crater	2.07	0.00207	2070.00	3374.10
70009	Apollo 17	Camelot Crater	1.75	0.00175	1750.00	2852.50
70012			1.77	0.00177	1770.00	2885.10
73001	Apollo 17	Lara Crater	1.73	0.00173	1730.00	2819.90
73002	Apollo 17	Lara Crater	1.60	0.0016	1600.00	2608.00
74001	Apollo 17	Shorty Crater	2.29	0.00229	2290.00	3732.70
74002	Apollo 17	Shorty Crater	2.04	0.00204	2040.00	3325.20
76001	Apollo 17	North Massif	1.57	0.00157	1570.00	2559.10
79001	Apollo 17	Van Serg Crater	1.74	0.00174	1740.00	2836.20
79002	Apollo 17	Van Serg Crater	1.67	0.00167	1670.00	2722.10
Max Apollo			2.29	0.00229	2290.00	3732.70
Min Apollo			1.30	0.0013	1300.00	2119.00

Aver Apollo		1.72	0.00172	1719.60		**2802.95**

Reference:

Water		1.00	0.001	1000.00	**kg/m^3**	1630.00

4. Possible Habitat Air Pressures

Historic examples:		**kPa**	**(psi)**	Pa	N/m^2	**% STP**
Apollo Capsule	Pure O2	32.20	4.67	32200	32200	31.82%
Apollo Suits	Pure O2	32.40	4.70	32400	32400	32.02%
ISS Habitat	Air	101.30	14.20	101300	101300	100.10%
ISS Suites	Pure O2	29.60	4.30	29600	29600	29.25%
Mir Habitat	Air	101.20	14.20	101200	101200	100.00%

Earth examples:						
Sea Level	Air	101.20	14.20	101200	101200	100.00%
Denver	Air	84.00	12.17	84000	84000	83.00%
Mexico City	Air	81.40	11.74	81400	81400	80.43%
Open Airplane	Air	74.00	10.20	74000	74000	73.12%
Mt. Everest	Air	26.00	3.65	26000	26000	25.69%

Partial pressure of Oxygen:		**kPa**	**(psi)**	**atm**
Oxygen at Sea Level	O_2	21.25	2.98	0.21

Questions for Settlement Calculator:

Input: Name
Input: E-mail address

1. The origin of the 5 meter rule (See Note 3)

"How much lunar regolith is needed to equal the mass of the air above your head?"

"Think through converting the height of water supported by the Earth's atmosphere into meters of lunar regolith

input: Density of regolith to use (expected range 1.6 to 2.3 g/cm^3)

Density H2O

g/cm^3	**kg/cm^3**	**kg/m^3**
1	0.001	1000

DensityRegolith

g/cm^3	**kg/cm^3**	**kg/m^3**
1.72	0.00172	1719.6

Air Pressure				
kPa	**N/m^2**	**Earth Gravity N/kg**	**Pressure kg/m^2**	**Column H2O m**
101.32	101323	9.81	10328.54	10.33
			Denver	8.57

Mexico Cit	8.31

Then to match the mass over people's heads in places where they now live, we will need between 5 and 6 meter
The 5 Meter Rule is then the minimum, and is **not** an acceptable average.

This is only an estimate for the needed shielding but it is a good place to start.

2. Roof Support Calculation

"Will your chosen habitat air pressure support the roof?"

Input: Air pressure to use for your habitat (expected range 70 to 102 kPa)

Calculate thickness of regolith supported.

Habitat Press		Moon g	Pressure	Roof support		
kPa	**N/m^2**	**N/kg**	**kg/m^2**	**regolith**		
101.32	101323	1.63	62161.35	36.15	m	Sea level
84.00	84000	1.63	51533.74	29.97	m	Denver

Input: Thickness of regolith over your habitat (expected range 5 to 6 meters)

Calculate: Margin of safety (give warning if < 150%)

Roof Safety Percentage

3. Mass of Nitrogen needed

"What mass of nitrogen do you need to ship from Earth for every 100 m^3 of living space or 10 m of your tube?"

Input: Diameter of cross-section of habitat (expected range 2.5 to 4 meters)

Calculate cross-section area. Assume length of 1 meter.
Calculate proportion taken up by Nitrogen.
Calculate the mass of Nitrogen at STP.
Calculate the mass of Nitrogen at given internal pressure assuming standard temperature.

		Pressure	Vol	N2		
		kPa	**m^3**	**Partial**	**kg/m^3**	**100m^3**
ISS Habitat	Air	101.30	100	80.05	0.99	98.82
Denver	Air	84.00	100	62.75	0.93	93.42
Mexico City	Air	81.40	100	60.15	0.92	92.41
Apollo Suits	Pure O2	32.40				
Oxygen at Sea Level	O_2	21.25				
Nitrogen	at STP	1.25	**kg/m^3**			

Output: Mass of nitrogen per 100 m^3.
Output: Mass of nitrogen per 10 meters of tube.

4. Decompression Time Estimator

"About how long will a person have to wait in a room at suit pressure before making an EVA?"
Reference:

The ISS pre-breathe protocol involves breathing pure oxygen for a total of 2 hours and 20 minutes and includes a short period of high-intensity exercise at the beginning of the pre-breathe

		Pressure	Time	
		kPa	minutes	hours
ISS Habitat	Air	101.30	140	2.33
Denver	Air	84.00	105	1.75
Mexico City	Air	81.40	100	1.66
Apollo Suits	Pure O2	32.40	0	0.00

Equation from chart: Time =2.0349*(Pres) -65.95

Output: Time you must wait before EVA.

5. Boiling Point of Water Estimator

"What is the boiling point of water in this habitat?"

Boiling Point of Water vs. Pressure

kPa	deg C
3.45	26.40
6.90	38.70
13.79	52.20
20.69	60.80
27.58	67.20
34.48	72.30
41.37	76.70
48.27	80.40
55.27	83.80
62.06	86.80
68.95	89.60
76.85	92.10
82.74	94.40
89.64	96.60
96.53	98.70
101.30	100.00

Equation from chart: Temp = 22.169 ln(Pres) -4.4516

Pressure	oiling Point
kPa	C

Sea Level	Air	101.20	100.00		Cal to 100C
Denver	Air	84.00	95.88		
Mexico City	Air	81.40	95.18		
Apollo Suits	Pure O2	32.40	74.76		

Reference:

Human body temperature	1.28	36.8	**C**

Output: Boiling point of water in habitat
"This parameter strongly effects the inhabitants ability to cook.

6. Volume to Dig

"How much regolith do we need to dig for each meter of habitat buried?"

Use input on habitat diameter from above.
Input: Maximum slope allowed (expected range 30 to 50 degrees)

	Diameter	Shield	Slope	Depth	Top Width
	m	m	degree	m	m
Example	3	5.5	45	8.5	20.00

Calculate depth and width of bottom flat.
Calculate width at top given slope restriction.
Calculate volume of material to be moved.

Output: Volume of material to be moved

Calculating Score:

Rate the reasonableness of design against current norms.

Test pressure range.
Test shield depth range.
Test EVA time range.
Test mass from Earth range.
Test for warning is anything is out of range.

Test to rate risk as to: (1) over all risk, (2) radiation protection, (3) EVA ease, and (4) mass from Earth.

Output: Overall rating and rating in three categories
Output: Notes on what is good and what is bad about the design.
Export: form with design e-mailed to BMD.bigmoondig.com.

Notes:

1 The preferred calculations for all Moon work are done in the SI (metric) system.

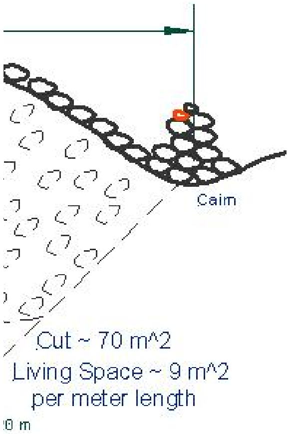
2 NASA, "*Lunar Sourcebook* , Chapter 7, The Lunar Regolith"

3 Notes on Radiation Protection:

The recent space missions Lunar Reconnaissance Orbiter (LRO) [3] and Curiosity carried instruments specifically designed to measure the danger of space radiation to human beings. Their results are now in and not what we wanted to hear at all. The radiation danger for humans in space is much worse than we foresaw, in fact, about it is about twice as bad.

There are two separate radiation dangers for a manned space mission, Coronal Mass Ejections (CME) or solar storms, and Galactic Cosmic Rays (GCR). Our old lunar settlement design considered CME's to be the worst problem and was designed to deal with them, but this turned out to be wrong, dead wrong.

The real problem is GCR. Galactic cosmic rays are not as concentrated as a CME at its peak, but they are very penetrating. They are present 24/7/365 and they will go through a space suit, they will go through a spacecraft skin, and they will go through a meter of lunar regolith. To make matters worse, insufficient radiation shielding will work against you. A thin shield only increases deadly secondary radiation.



Percent
100%
17%
38%

29.92 **inHg** 33.78 **ftWater**

Weighte (lbs/in^3)	**Weightm (lbs/in^3)**
0.057	0.009544
0.062	0.010265
0.072	0.011886
0.063	0.010445
0.071	0.011765
0.063	0.010505

0.063	0.010385
0.058	0.009604
0.070	0.011585
0.059	0.009845
0.063	0.010445
0.063	0.010445
0.064	0.010685
0.057	0.009484
0.061	0.010145
0.049	0.008164
0.047	0.007804
0.069	0.011465
0.061	0.010145
0.060	0.010025
0.065	0.010865
0.060	0.010025
0.059	0.009725
0.057	0.009484
0.059	0.009725
0.057	0.009484
0.052	0.008644
0.062	0.010325
0.053	0.008824
0.060	0.009965
0.051	0.008404
0.063	0.010445
0.060	0.010025
0.060	0.009965
0.066	0.011045
0.066	0.011045
0.067	0.011165
0.066	0.010985
0.067	0.011105
0.065	0.010805
0.075	0.012426
0.063	0.010505
0.064	0.010625
0.063	0.010385
0.058	0.009604
0.083	0.013746
0.074	0.012246
0.057	0.009424
0.063	0.010445
0.060	0.010025

0.083	0.013746
0.047	0.007804

N/m^3	0.062	0.010322	(lbs/in^3)

N/m^3	0.036	0.006003	(lbs/in^3)

Regolith supported

SI		(English)		Check Ratio
11.49	m	37.70	(ft)	1.00
11.56	m	37.94	(ft)	1.00
36.14	m	114.64	(ft)	1.03
10.56	m	34.71	(ft)	1.00
36.10	m	114.64	(ft)	1.03
36.10	m	114.64	(ft)	1.03
29.97	m	98.25	(ft)	1.00
29.04	m	94.78	(ft)	1.01
26.40	m	82.35	(ft)	1.05
9.28	m	29.47	(ft)	1.03

ı."

	Column Regolith	
(ft)	**m**	**(ft)**
33.89	6.01	19.71
28.13	4.99	16.36

27.26	4.83	15.85

s of lunar regolith.

			Save	
kg	217.9	**(lbs)**	0.00	**kg**
kg	206.0	**(lbs)**	5.40	**kg**
kg	203.7	**(lbs)**	6.41	**kg**

Volume		
m^3	**kg**	**mton**
34.00	58466	58.5