Radiation Monitoring and Shielding Capability Gaps

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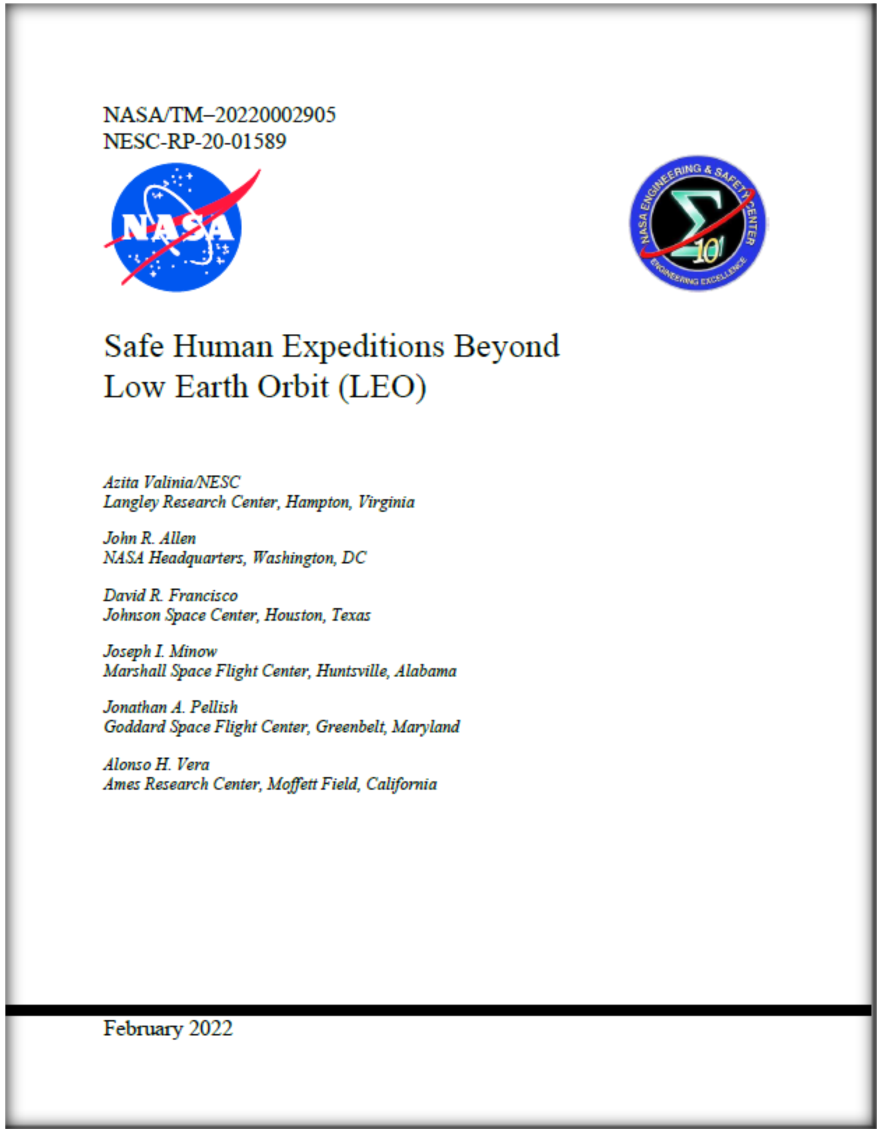
Introduction

- NASA's Engineering and Safety Center (NESC) recently completed a study that included findings on space weather and space environments that impact human exploration in general and radiation monitoring and radiation shielding in particular:
  - Valinia, A., J.R. Allen, D.R. Francisco, J.I. Minow, J.A. Pellish, and A.H. Vera, ***Safe Human Expeditions Beyond Low Earth Orbit (LEO)***, NASA/TM-20220002905, February 2022.
  - URL: https://ntrs.nasa.gov/citations/20220002905

- This presentation summarizes selected radiation monitoring and shielding results from the report relevant to the "*SWx Support for Human Exploration*" topic of today's panel discussion



NASA/TM–20220002905
NESC-RP-20-01589

Safe Human Expeditions Beyond Low Earth Orbit (LEO)

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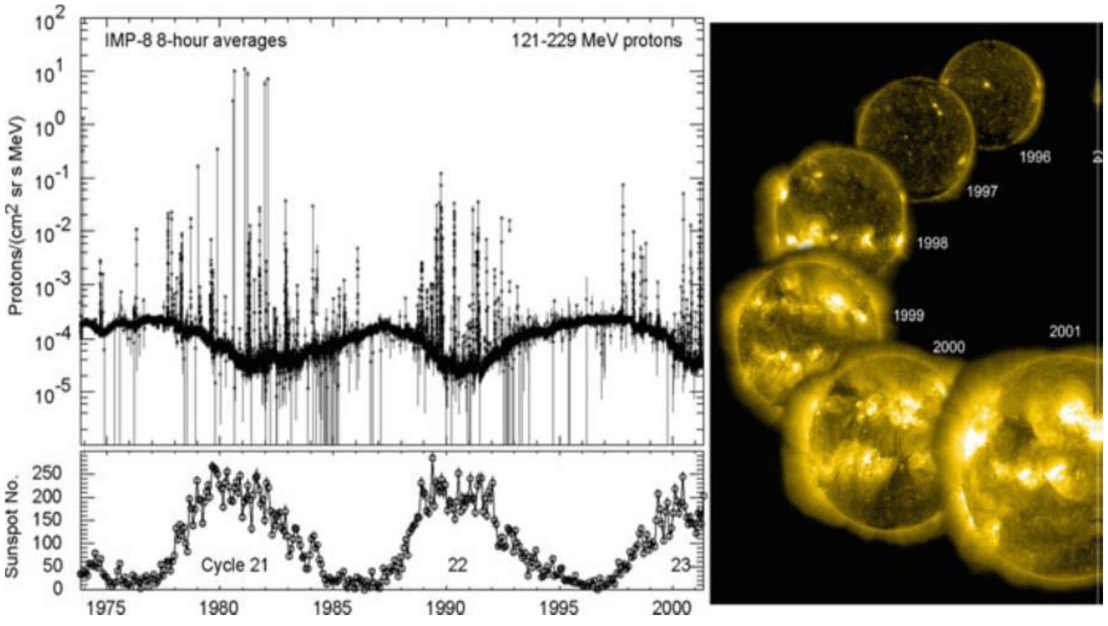
February 2022

Knowledge of Radiation Environments



(top left) Flux of 121–229 MeV protons for Cycles 21, 22, and 23
(bottom left) Monthly sunspot numbers provide phase in solar cycle
(right) EUV images of Sun during rising phase of Cycle 23
[source: Reames 2021]

Trapped Radiation Belts

- Knowledge of long-term mean and statistical variations in the trapped radiation belts is sufficiently advanced to support design of crewed spacecraft that transit the belts on trajectories between LEO and the Moon and Mars, as long as the time spent in the belts is <24 hours
- Knowledge of long-term mean and statistical variations in the trapped radiation belts is sufficiently advanced to support design and operations of robotic missions that spend long periods of time in the radiation belts, such as the Gateway Power and Propulsion Element (PPE) and future uncrewed logistics vehicles using solar electric power to operate ion engines for gradual orbit raising through the belts
- The ability to forecast the state of the radiation belts for specific short periods of time (i.e., on the order of days to several weeks) is currently limited due to the lack of nowcast data and predictive models

Solar Particle Events

- Capability to nowcast (monitor) SEP events is sufficient to support crew warnings for onset of radiation events in time to implement radiation mitigation strategies
- Capability to predict the onset of solar energetic particle events in advance is limited

Galactic Cosmic Rays

- GCR models are sufficiently advanced that they can be reliability (within ±15%) used to specify the proton and heavy ion flux of importance to crew health and single event effects if the solar cycle activity is known
- The ability to predict future GCR environments is limited by the ability to predict future solar activity for periods of time beyond the minima in activity between two cycles

Mission GCR Radiation Exposures

NASA-STD-3001, Rev B., Vol. 1, Section 4.8.2: Career Space Permissible Exposure Limit for Space Flight Radiation

An individual astronaut's total career effective radiation dose due to space flight radiation exposure shall be less than 600 mSv. This limit is universal for all ages and sexes.

Shielding:
0, 20, 40 g/cm^2
spherical Al shield

GCR environment:
Solar min 2009
Solar max 2001

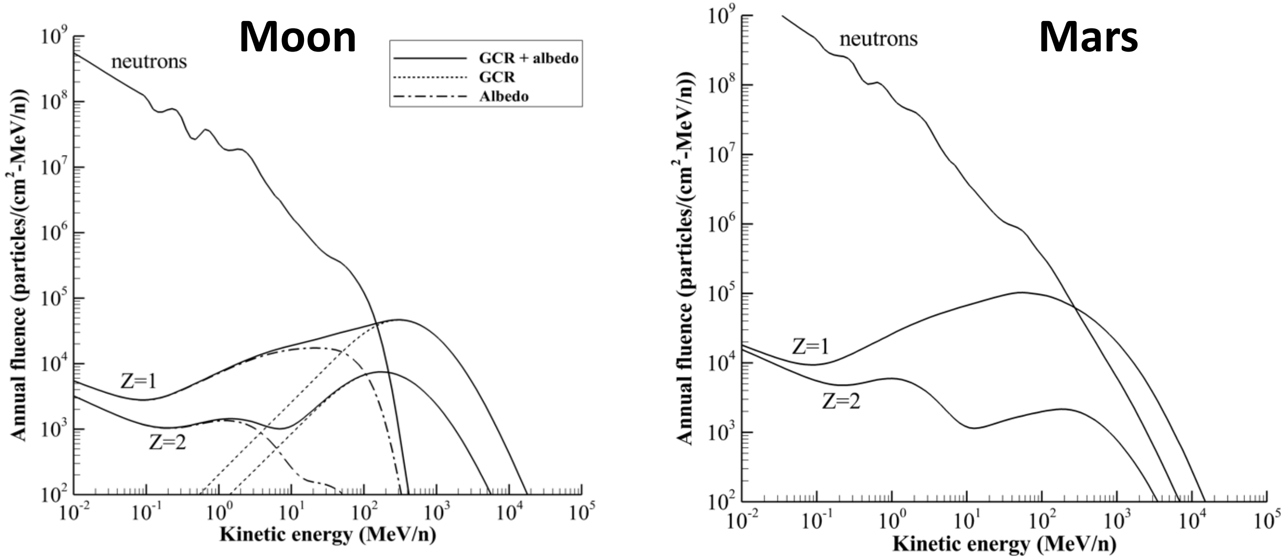
X/Y duration format:
X days in free space
Y days on surface

Effective dose ≥600 mSv

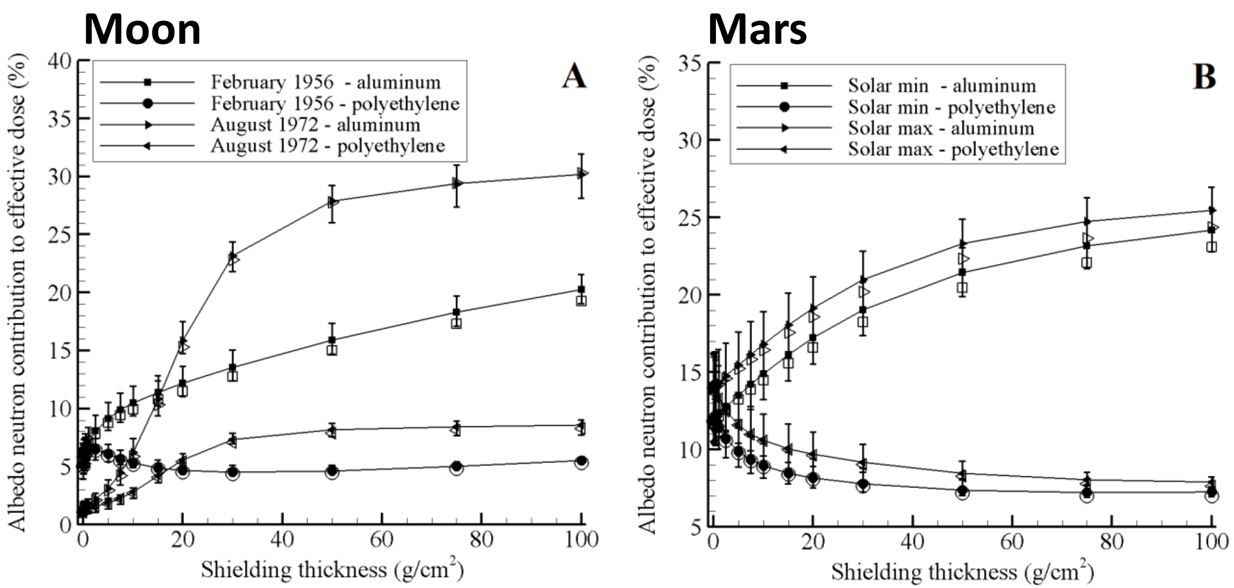
	Mission	Duration (days)	Dose (mGy)			Dose equivalent (mSv)			Effective dose (mSv)		
			0	20	40	0	20	40	0	20	40
solar maximum	Artemis II	10	1.5	2.1	2.5	10.2	6.9	5.9	6.3	5.1	5.3
	Artemis III	30	4.6	6.4	7.6	30.5	20.7	17.6	19.0	15.4	15.8
	Artemis III (surface)	23.5/6.5	4.2	5.8	6.9	27.7	18.7	16.0	17.4	14.1	14.4
	Gateway – 6 month	183	28	39	46	186	126	108	116	94	96
	Gateway – 12 month	365	56	78	92	372	252	215	232	188	192
	Mars DRM	621/40	99	137	163	644	440	377	405	331	339
	Mars DRM	840	128	178	213	855	580	494	533	432	442
solar minimum	Artemis II	10	4.6	5.2	5.6	28.5	15.0	12.2	14.6	10.9	10.7
	Artemis III	30	13.8	15.5	16.7	85.5	44.9	36.5	43.8	32.8	32.1
	Artemis III (surface)	23.5/6.5	12.6	14.0	15.0	77.1	40.5	33.0	39.8	29.9	29.2
	Gateway – 6 month	183	84	95	102	522	274	223	267	200	196
	Gateway – 12 month	365	168	189	203	1040	546	445	533	399	391
	Mars DRM	621/40	295	332	356	1795	950	779	929	702	688
	Mars DRM	840	386	434	466	2395	1256	1023	1228	918	899

Lunar Neutron Environments

- Past efforts to measure lunar albedo neutrons have only extended to energies of 15 or 20 MeV
- In-situ measurements of the secondary neutron environment on the lunar surface extending beyond tens to hundreds of MeV to GeV energies are needed to support dose estimates for long-term lunar exploration
- A single mission is adequate to characterize the albedo environment since the goal is primarily to validate the nuclear interaction models used to simulate the production of neutrons from the GCR source and GCR flux varies slowly over time
- Lunar albedo neutron measurements are not required for the near-term missions to Gateway and the lunar surface since the current plan is to keep the mission durations sufficiently short such that GCRs and any albedo neutron contributions to crew dose are small compared with the NASA lifetime radiation exposure limit of 600mSv



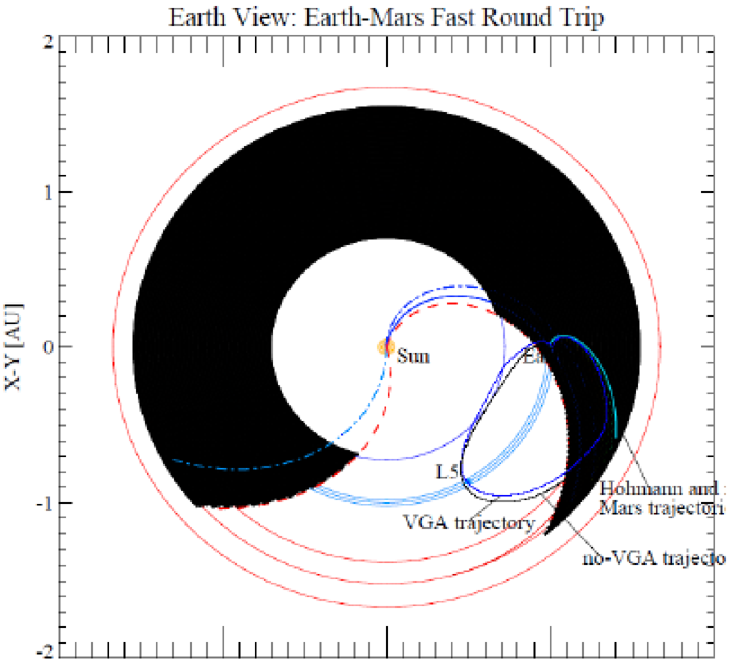
2009 Solar Minimum GCR Environments



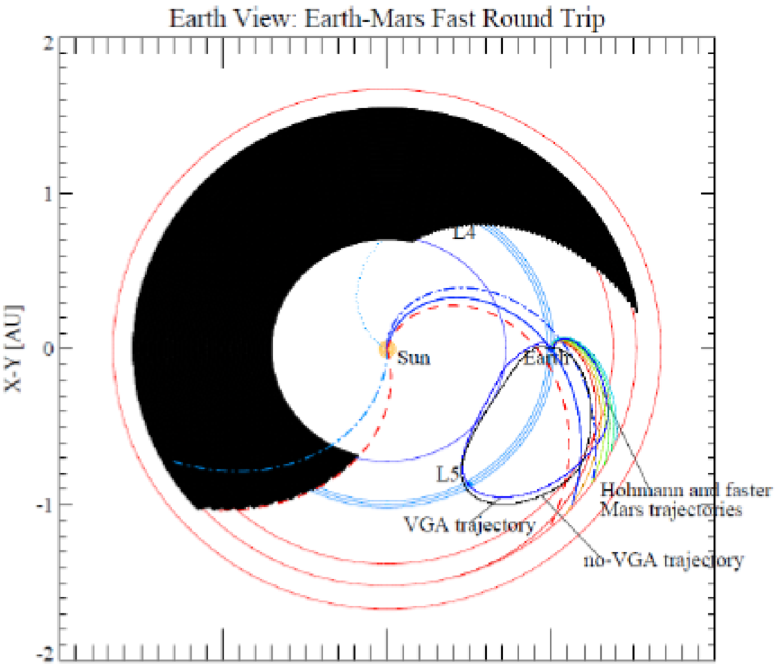
Lagrange Point SWx Monitoring Platforms

- In-situ monitoring and assets at Sun-Earth L1 provide adequate coverage for near term missions to the Moon
- Additional space weather monitoring assets (i.e., solar coronagraph and particle detector suites) at Sun-Earth Lagrange point L4 and L5 provide additional opportunities to monitor SWx for lunar missions and short-term missions to Mars
- Sun-Mars L1 and L4/L5 can enable sufficient early warnings for Mars missions during transit and stay.
- The Sun-Mars L4/L5 assets would also provide a communications relay solution for when the Earth line of sight to Mars is behind or close to the Sun, leading to a 2-week blackout period every 2 years.

Fast Mars Round Trips and SWx Safety Zones



SWx Safety Zone supported by L1 only



SWx Safety Zone supported by L1 and L4[1]

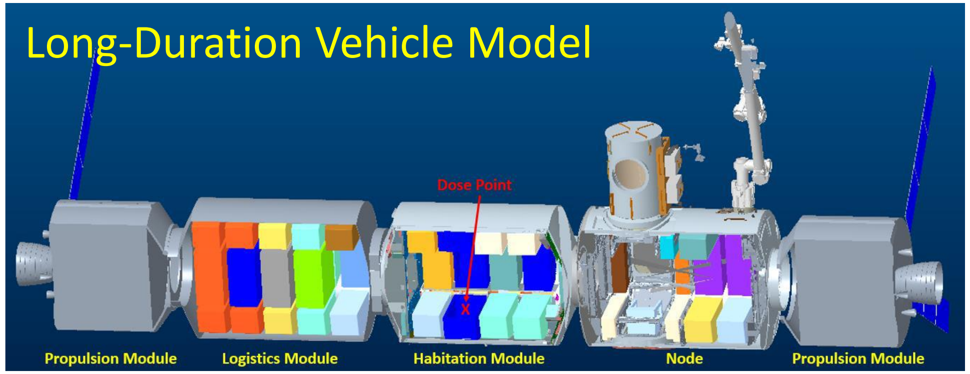
Passive GCR Shielding for a Mars Mission

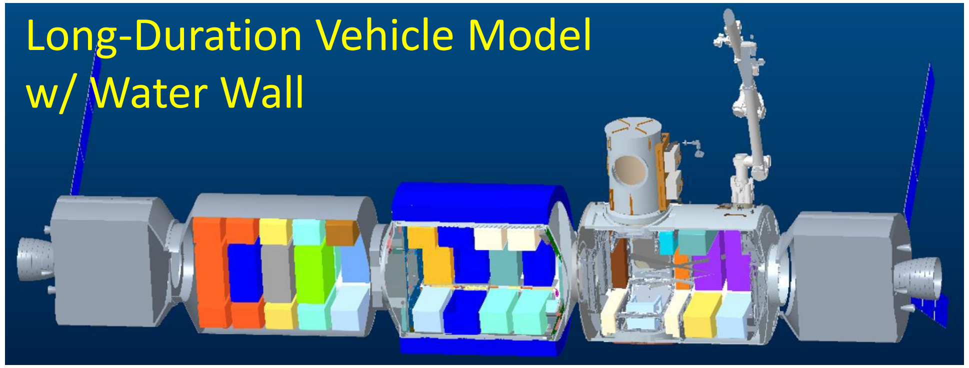
- Radiation shielding as a function of a water-wall thickness evaluated for GCR environment

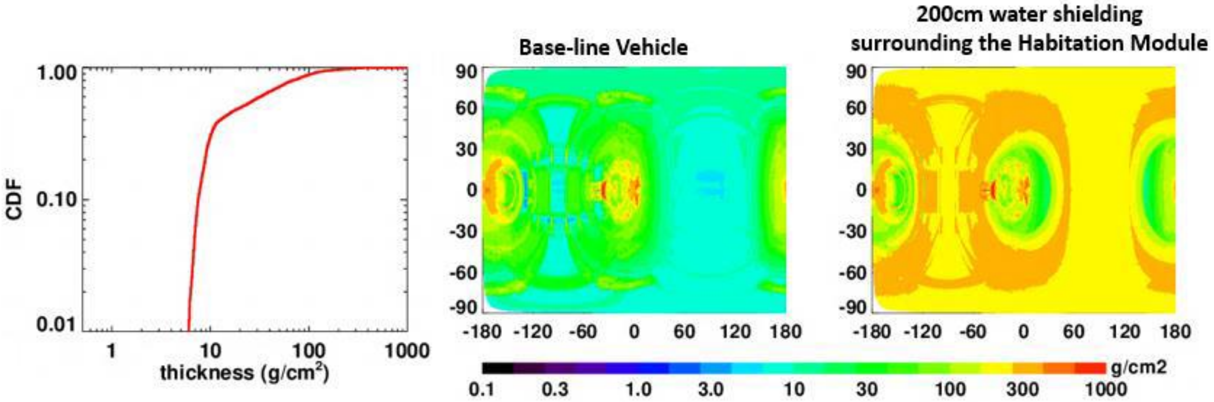
- Radiation shielding design needs to be part of the early design process of any vehicle or habitat, to maximize the shielding provided by the required vehicle mass as opposed to the incorporation of additional parasitic shielding mass

- Baseline (no supplemental water-wall shielding):
  - Solar minimum 1.08 mSV/day
  - Solar maximum 0.55 mSV/day

- Demonstrates the advantage of traveling to/from Mars at solar maximum assuming ability to adequately shield SPEs with passive shielding







Passive GCR Shielding for a Solar Minimum Mars Mission

- Large water-shielding thickness on the order of 1000 cm may be needed to reduce the exposure of solar minimum GCR environment to the exposure level for solar maximum GCR

- The uncertainty in transport codes used to study the shielding efficacy is largely unquantified at material thicknesses greater than ~100 g/cm2, additional work needs to be done to quantify the uncertainty in transport codes for these large shielding values

- Table shows number of launches required to deliver water mass to initial LEO orbit
  - Examples provided for three launch vehicle classes: small, medium, and large
  - Arbitrary color scale to emphasize when water mass is
    Less than 20% of payload mass
    20% to 100% of payload mass
    1 to 2 launches
    More than 2 launches

Water-wall Thickness (cm)	Dose Equivalent (mSv/day)	Reduction in Dose Equivalent (%)	Water-Wall Mass (kg)	Number of Launches		
				10,000 kg per launch[a]	50,000 kg per launch[b]	100,000 kg per launch[c]
0	1.08	0	0.0	**0**	**0**	**0**
20	1.06	1.9	1,900	**0.19**	**0.038**	**0.019**
50	1.10	-1.9	4,700	**0.47**	**0.094**	**0.047**
100	1.10	-1.9	9,300	**0.93**	**0.19**	**0.093**
200	0.96	10.7	18,700	**1.87**	**0.37**	**0.19**
300	0.83	23.6	28,000	**2.80**	**0.56**	**0.28**
400	0.72	33.7	37,300	**3.73**	**0.75**	**0.37**
500	0.65	40.0	46,700	**4.67**	**0.93**	**0.47**
1000	0.55	49.0	93,000	**9.30**	**1.86**	**0.93**

Launch vehicle payload to LEO classification (within about 2x):
[a]Atlas V, Falcon 9, Antares, Delta IV
[b]Falcon Heavy, New Glenn
[c]Saturn V, SLS, Starship

Launches < 0.20 0.2 < L < 1.0 1.0 < L < 2.0 L > 2.0

Questions?