Determining the relative criticality of diverse exploration risks in NASA's Human Research Program

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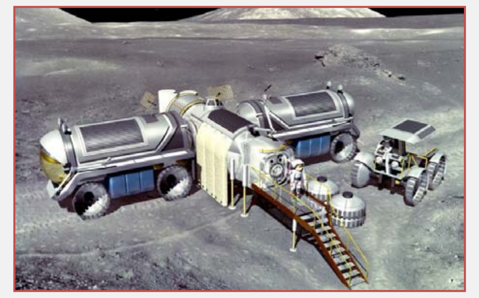
Abstract

The mission of NASA's Human Research Program (HRP) is to understand and reduce the risk to crew health and performance in exploration missions. The HRP addresses 27 specific risks[1], primarily in the context of Continuous Risk Management. Each risk is evaluated in terms of two missions (a six month stay on the Moon and a thirty month round trip to Mars) and three types of consequences (in-mission crew health, in-mission performance, and post-mission crew health). The lack of a common metric between the three consequence categories, such as financial costs or quality adjusted life years lost, makes it difficult to compare the relative criticality of the risks. We are, therefore, exploring the use of a ternary metric of criticality based on the common metric of influencing an operational decision. The three levels correspond to the level of concern the risk generates for a "go/no-go" decision to launch a mission: 1) no-go; 2) go with significant reservations; 3) go. The criticality of each of the 27 risks is scored for the three types of consequence in both types of mission. The scores are combined to produce an overall criticality rating for each risk. The overall criticality rating can then be used to guide the prioritization of resources to affect the greatest amount of risk reduction.

Mission Types

Moon- 4-person crews, 180 days

Mars- 6-person crews, up to 1000 days



Consequence Types

The Office of the Chief Health and Medical Officer at NASA is concerned with three types of consequences:

1. **Short Term Health**- during the mission and within one year of return.
2. **In-Mission Performance**- the ability of the crew to perform mission tasks
3. **Long Term Health**- one year after return and later.

Metrics can be readily developed for each type of consequence. Sick days, mission objectives accomplished, quality adjusted life years lost are examples. It is more difficult to identify a metric, however, that applies to all three types of consequence.

A Common Metric: The Criticality Metric

Before a space flight mission is launched, several organizations within NASA are polled for a "Go/No-Go" status. The Office of the Chief Health and Medical Officer is one such organization. A common metric, then, between the three types of consequence of concern to OCHMO is the impact of a risk's status on the "Go/No-Go" recommendation. This metric consists of three values:

C

• **Critical-** Absence of additional data or risk mitigation countermeasures would likely delay Lunar Outpost or Mars Missions, even if all other elements of the mission were ready (e.g., if the launch systems, Extravehicular Activity (EVA) systems, landing and life support systems were ready). The lack of this data or an adequate additional mitigation would leave NASA with unacceptable uncertainty in the risk, and/or with unacceptable absolute risk to human health and performance, thus precluding NASA's ability to embark on the mission.

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• **Important-** Absence of additional data or risk mitigation countermeasures in this area would likely not delay lunar outpost or Mars missions, if all other elements of the mission were ready. This would leave the mission with significant or unknown risk however. Mission loss or major impact to crew health (in-mission or post-mission) could occur if this risk is not quantified and reduced.

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• **Desirable-** The absence of data or risk mitigation countermeasures in this area would not delay the lunar outpost or Mars missions if all other elements of the mission were ready. However, quantifying the risk and implementing risk mitigation strategies could reduce the risk for that particular discipline. Engineering or operational workarounds/ constraints could be avoided if this risk were quantified and/or reduced.

The HRP has used this metric in its Integrated Research Plan[2]. Each risk is scored on this metric, once for the lunar mission and once for the martian mission. The IRP mission scores are officially approved by the HRP.

For this work, a more detailed scoring was conducted. Each risk was scored for each type of consequence within the mission type (Table 1) such that at least one score equaled the IRP mission score and none exceeded the IRP mission score. These scores are not officially approved by the HRP.

Example: the risk of inability to treat an ill or injured crew member.

Table 1

	Lunar Consequences			Martian Consequences		
Risk/Risk Factor of:	STH	IMP	LTH	STH2	IMP2	LTH2
Acute or Late Central Nervous System Effects from Radiation Exposure	I	I	I	C	C	C
Inability to Adequately Treat an Ill or Injured Crew Member	I	I	D	C	C	D
Behavioral and Psychiatric Conditions	D	D	D	C	C	D
Inadequate Nutrition	D	D	D	C	C	D
Inadequate Food System	D	D	D	C	C	D
Radiation Carcinogenesis	D	D	C	D	D	C
Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity	D	I	D	D	C	D
Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance	D	I	D	D	C	D
Degenerative Tissue or other Health Effects from Radiation Exposure	D	D	I	D	D	C
Acute Radiation Syndromes Due to Solar Particle Events	I	I	D	I	I	D
Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems	D	I	D	I	I	D
Intervertebral Disc Damage	D	D	D	I	I	D
Cardiac Rhythm Problems	D	D	D	I	I	D
Orthostatic Intolerance During Re-Exposure to Gravity	D	D	D	I	I	D
Crew Adverse Health Event Due To Altered Immune Response	D	D	D	I	I	D
Therapeutic Failure Due to Ineffectiveness of Medication	D	D	D	I	I	D
Adverse Health Effects Due to Alterations in Host-Microorganism Interactions	D	D	D	I	I	D
Performance Errors Due to Poor team Cohesion and Performance, Inadequate Selection/Team Composition, Inadequate Training, and Poor Psychosocial Adaptation	D	D	D	D	I	D
Accelerated Osteoporosis	D	D	D	D	D	I
Impaired Ability to Maintain Control of Vehicles and Other Complex Systems	D	D	D	D	I	D
Reduced Safety and Efficiency Due to Poor Human Factors Design	D	D	D	D	I	D
Associated with Poor Task Design	D	D	D	D	I	D
Error Due to Inadequate Information	D	D	D	D	I	D
Adverse Health Effects from Lunar Dust Exposure	D	D	I			
Performance Errors Due to Sleep Loss, Circadian Desynchronization, Fatigue, and Work Overload	D	D	D	D	D	D
Bone Fracture	D	D	D	D	D	D
Renal Stone Formation	D	D	D	D	D	D

Comparing Risks: The Criticality Score

The Criticality Score, CS, for each risk is the sum of weights (Table 2) over each mission type (lunar and martian) and consequence type (STH, IMP, and LTH). For example, the CS of the risk of inability to treat an ill or injured crew member is 1 + 1 + 0.1 + 10 + 10 + 0.1 = 22.2

Table 2

	Weighting					
	Lunar			Martian		
	STH	IMP	LTH	STH	IMP	LTH
Critical	10.0	10.0	10.0	10.0	10.0	10.0
Important	1.0	1.0	1.0	1.0	1.0	1.0
Desirable	0.1	0.1	0.1	0.1	0.1	0.1

For simplicity in this work, the lunar and martian missions were weighted equally (Table 2).

This weighting scheme allows the Criticality Score to reflect the rank order criticality of the risks with the assumption that no number of Desirable scores can equal or exceed an Important score and no number of Important scores can equal or exceed a Critical score.

The Criticality Scores are depicted in Figure 1 (linear scale) and Figure 2 (logarithmic scale).

Figure 1

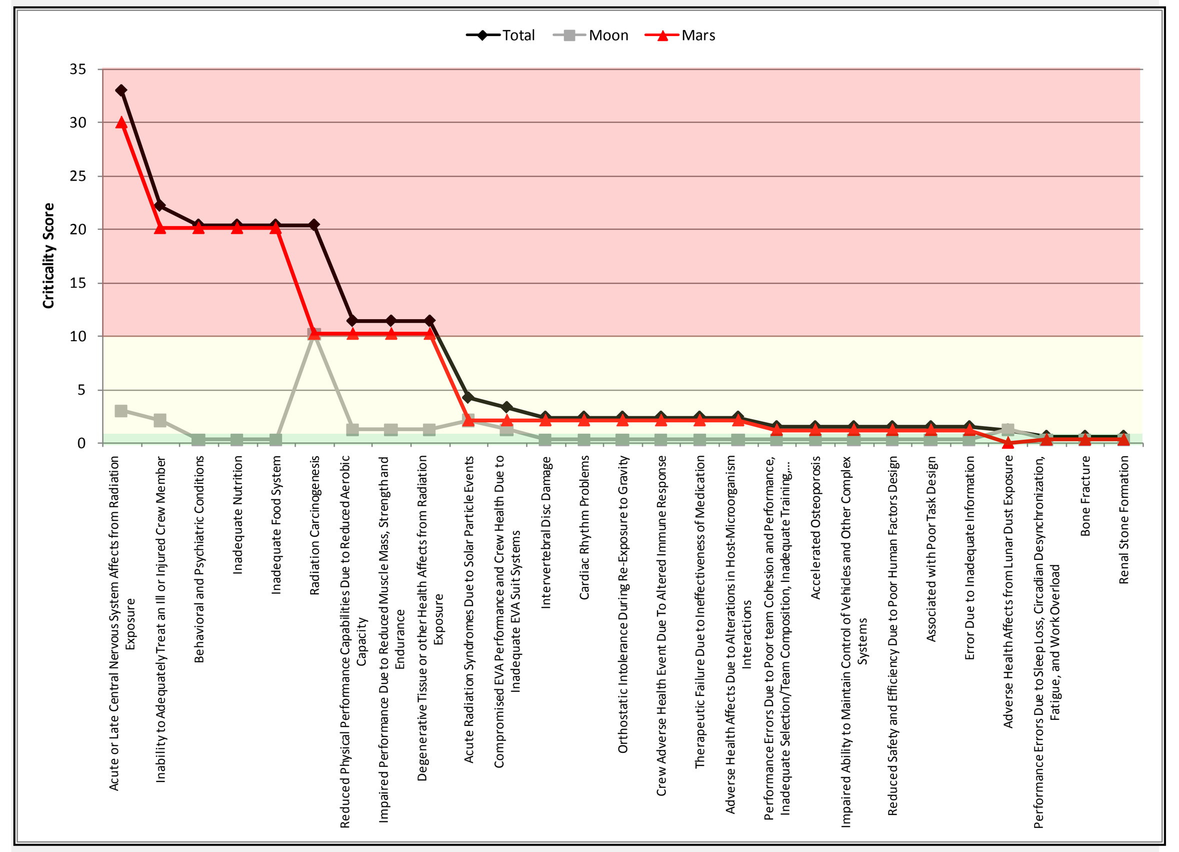
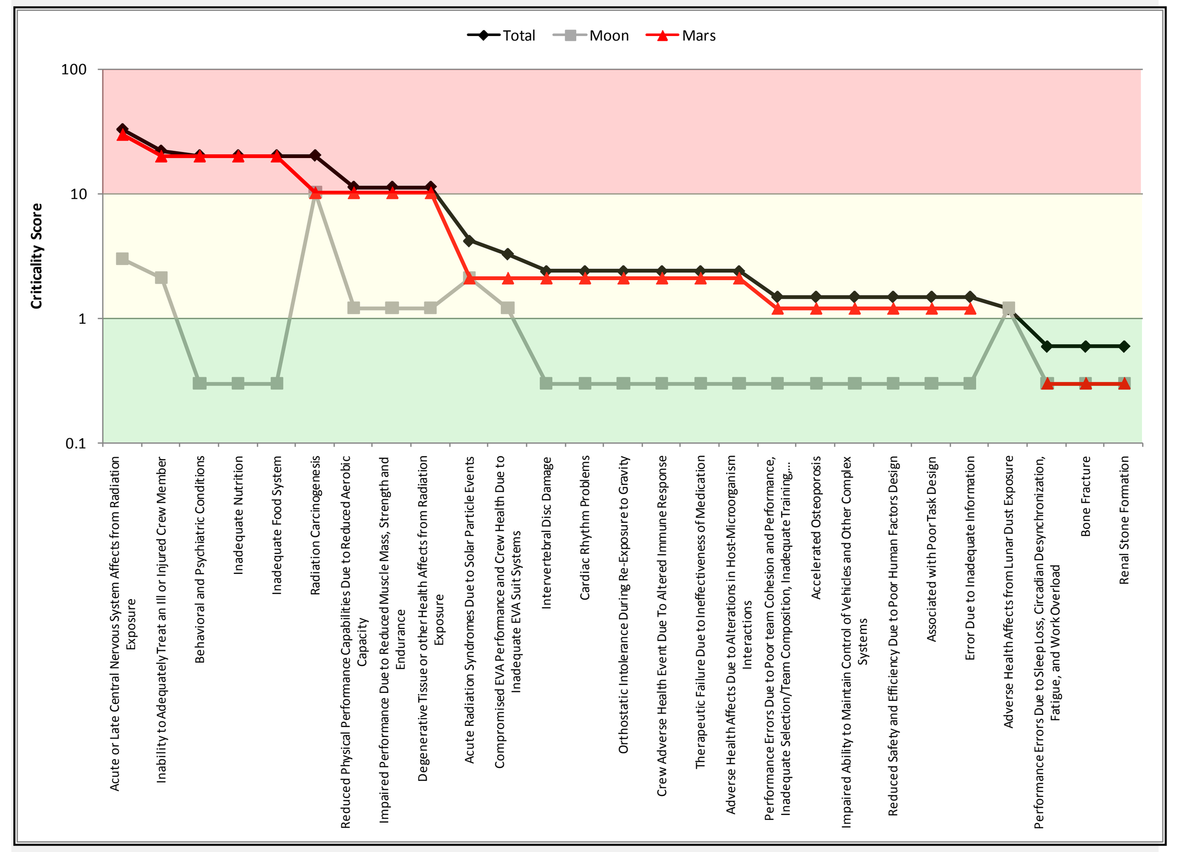


Figure 2



Discussion

This approach provides a basis for comparing the 27 risks being addressed by the HRP.

The Criticality Score, CS, allows risks to be rank ordered based on their relative importance to the missions (Moon or Mars) and types of consequences (short term health, in-mission performance, or long term health). Arithmetic operations on the CS (e.g., addition, multiplication) to calculate quantities such as averages are not meaningful.

The rank ordering and graphical display provide an overall view of the risks: the degree of total criticality, the relative contribution from the different missions, groupings of comparable criticality. It provides a qualitative tool for the risk manager to analyze the portfolio of risks and to guide the allocation of resources to control the risks.

The CS guides, but does not dictate, funding priorities. The cost per unit risk reduction and the timeframe in which the risk must be addressed are among the other factors that must be considered for funding priorities.

The current approach provides a common metric for consequences of interest to NASA's Office of the Chief Health and Medical Officer. However, it does address not another important goal of HRP: reduce human systems resource requirements (mass, volume, power, data, etc.). The resource savings can be achieved in design phases as well as operational phases. An even broader metric is required to enfold the need to reduce resource requirements.

The risks for the martian mission are more critical than the lunar missions. The only lunar mission risk with a criticality comparable to martian mission criticality is the risk of radiation carcinogenesis.

Conclusion

The Criticality metric described here provides a useful tool for making rank order comparisons between risks using risk properties of interest to NASA's Office of the Chief Health and Medical Officer.

References

1. PRD
2. IRP