APPENDIX B: RISK DATA SHEETS

Risk Title: Accelerated Bone Loss and Fracture Risk

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Bone Loss
Risk Number :	1
Risk Description :	Failure to recover bone lost during mission coupled with age-related bone loss can lead to osteoporotic fractures at a younger age. Important for long duration missions for crew health and for designing rehabilitation strategies.
Context/Risk Factors :	Age ; Baseline BMD ; Gender ; Muscle loss ; Nutrition
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** TBD **Lunar:** TBD **Mars:** TBD
Current Countermeasures :	**ISS :** Bisphosphonate ; Gravity-related exercise activity ; Nutrition ; Resistive exercise **Lunar :** Bisphosphonate ; Gravity-related exercise activity ; Nutrition ; Resistive exercise **Mars :** Bisphosphonate ; Gravity-related exercise activity ; Nutrition ; Resistive exercise
Projected Countermeasures :	**ISS :** TBD **Lunar :** TBD **Mars :** TBD
Enabling Questions [With Mission Priority]:	

No.	Question
1a	What is the relative risk of sustaining a traumatic and/or stress fracture for a given decrement in bone mineral density or alteration in bone geometry in an astronaut-equivalent population who are physically active? **[ISS 3, Lunar 5, Mars 1]**
1b	Will a period of rapid bone loss in hypogravity be followed by a slower rate of loss approaching a basal bone mineral density? What are the estimated site-specific fracture risks as one approaches this minimal BMD? **[ISS 2, Lunar 5, Mars 1]**
1c	Is there an additive or synergistic effect of gonadal hormone deficiency in men or women on bone loss during prolonged exposure to hypogravity? **[ISS 1, Lunar 5, Mars 5]**
1d	What pharmacological agent(s) will most effectively minimize the decrease in bone mass with extended exposure to hypogravity? **[ISS 1, Lunar 5, Mars 1]**
1e	What are the specifics of the optimal exercise regimen with regard to mode, duration, intensity and frequency, to be followed during exposure to hypogravity so as to minimize decreases in bone mass? Is impact loading an essential element and, if so, how can it be produced in hypogravity? **[ISS 1, Lunar 3, Mars 1]**
1f	What combination of exercise and a pharmacological agent(s) will prevent bone loss during exposure to hypogravity? **[ISS 1, Lunar 5, Mars 1]**

	1g	What are the important predictors for estimating site-specific bone loss and fracture risk during hypogravity exposure, especially with reference to ethnicity, gender, age, baseline bone density and geometry, nutritional status, fitness level and prior microgravity exposure? **[ISS 1, Lunar 5, Mars 1]**
	1h	Does the hypogravity environment change the nutritional requirements for optimal bone health? **[ISS 3, Lunar 3, Mars 2]**
	1i	What diagnostic tools can be utilized during multi-year missions to monitor and quantify changes in bone mass and bone strength? **[ISS 2, Lunar 5, Mars 1]**
	1j	What systemic adaptations to hypogravity are important contributory factors to bone loss, evaluations of which are essential to effective countermeasure development (e.g., fluid shifts, altered blood flow, immune system adaptations)? **[ISS 3, Lunar 5, Mars 2]**
	1k	Are hypogravity-induced changes in bone density, geometry and architecture reversible upon encountering partial Gravity exposure, or on return to full gravity (1-G)? **[ISS 1, Lunar 5, Mars 1]**
	1l	What regimen (exercise, pharmacological or biomechanical including impact loading or artificial gravity exposure) will most effectively hasten restoration of bone mass and bone strength (geometry and architecture) to pre-flight values in returning crewmembers? **[ISS 2, Lunar 5, Mars 2]**
Related Risks :		

Important References :	Bikle DD, Sakata T, Halloran BP. The impact of skeletal unloading on bone formation. Gravit Space Biol Bull. 2003 Jun;16(2):45-54. Review. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12959131
	Cancedda R, Muraglia A. Osteogenesis in altered gravity. Adv Space Biol Med. 2002;8:159-76. Review. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12951696
	Cena H, Sculati M, Roggl C. Nutritional concerns and possible countermeasures to nutritional issues related to space flight. Eur J Nutr. 2003 Apr;42(2):99-110. Review.
	Heer M, Kamps N, Biener C, Korr C, Boerger A, Zittenman A, Stehle P, Drummer C. Calcium metabolism in microgravity. Eur J Med Res. 1999 Sep 9;4(9): 357-60 Review. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10477499
	Jennings RT, Bagian JP. Musculoskeletal injury review in the U.S. space program. Aviat Space Environ Med. 1996 Aug; 67(8): 762-6. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8853833
	Schneider SM, Amonette WE, Blazine K, Bentley J, Lee SM, Loehr JA, Moore AD Jr, Rapley M, Mulder ER, Smith SM.. Training with the International Space Station interim resistive exercise device. Med Sci Sports Exerc. 2003 Nov;35(11):1935-45. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=14600562
	Shapiro JR, Schneider V. Countermeasure development: future research targets.J Gravit Physiol. 2000 Jul;7(2):P1-4. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12697548

Risk Title: Impaired Fracture Healing

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Bone Loss

Risk Number :	2
Risk Description :	Bone fractures incurred during and immediately after long duration space flight can be expected to require a prolonged period for healing, and the bone may be incompletely restored, owing to the changes in bone metabolism associated with space flight.
Context/Risk Factors :	Nutritional environment ; Rapid bone loss is progressive ; Risk factors will differ for major skeletal fracture vs. minor ; Stress related fractures ; Work environment
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Mars:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.
Justification :	**ISS:** Major fracture-Operational disruption for prolonged time. Minor fracture site-Minor operational disruption. **Lunar:** Major fracture-Operational disruption for prolonged time. Minor fracture site-Minor operational disruption. **Mars:** Major fracture-Operational disruption for prolonged time, fracture- related complications including immobility might risk death.Minor fracture site-Minor operational disruption Minor fracture site-Minor operational disruption
Current Countermeasures :	**ISS :** Major fracture-return crew (ISS and Moon) ; Minimize bone loss to lessen fracture risk ; Orthopedic procedures ; Rehabilitation procedures ; Ultrasound and electrical stimulation **Lunar :** Major fracture-return crew (ISS and Moon) ; Minimize bone loss to lessen fracture risk ; Orthopedic procedures ; Rehabilitation procedures ; Ultrasound and electrical stimulation **Mars :** Minimize bone loss to lessen fracture risk ; Orthopedic procedures ; Possibly biochemical/pharmacological intervention to hasten fracture healing for Mars ; Rehabilitation procedures ; Ultrasound and electrical stimulation
Projected Countermeasures :	**ISS :** Biomechanical measure to promote healing in relatively short time frame **Lunar :** Application of novel locally active agents to facilitate fracture healing in concert with biomechanical stimulation **Mars :** Application of novel locally active agents to facilitate fracture healing in concert with biomechanical stimulation
Enabling Questions [With Mission Priority]:	

No.	Question
2a	Is the rate of fracture healing and the integrity of the healed fracture altered under microgravity or unloaded conditions? **[ISS 1, Lunar 1, Mars 1]**
2b	Are there site-specific differences, or differences in healing diaphyseal bone versus metaphyseal bone under microgravity or partial-gravity conditions? **[ISS 3, Lunar 3, Mars 3]**
2c	Which cellular and biochemical changes in bone cell biology alter fracture healing under microgravity conditions? **[ISS 4, Lunar 4, Mars 4]**
2d	Does the presence of microgravity-induced alteration in bone remodeling and/or osteoporosis affect fracture callus remodeling? **[ISS 2, Lunar 2, Mars 2]**
2e	How does altered muscle biology contribute to altered fracture healing in microgravity? **[ISS 4, Lunar 4, Mars 4]**
2f	Do biophysical modalities play a role in improving fracture healing in a microgravity environment? **[ISS 2, Lunar 2, Mars 2]**

	2g	Do biophysical modalities play a role in improving fracture healing in the presence of bone loss in a microgravity environment? **[ISS 2, Lunar 2, Mars 2]**
	2h	Are there anabolic agents, growth factors or cytokines that will speed fracture repair during microgravity, in combination with active bone loss due to unloading? **[ISS 1, Lunar 1, Mars 1]**
	2i	What technologies will be used to diagnose fractures of the axial and appendicular skeleton in a space environment? **[ISS 1, Lunar 1, Mars 1]**
	2j	Will different technologies be needed to treat either open or closed fractures in a space environment? **[ISS 1, Lunar 1, Mars 1]**
Related Risks :		
Important References :		Durnova GN, Burkovskaia TE, Vorotnikova EV, Kaplanskii AS, Arustamov OV. [The effect of weightlessness on fracture healing of rats flown on the biosatellite Cosmos-2044]. Kosm Biol Aviakosm Med. 1991 Sep-Oct;25(5):29-33. Russian. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8577136
		Kaplansky AS, Durnova GN, Burkovskaya TE, Vorotnikova EV. The effect of microgravity on bone fracture healing in rats flown on Cosmos-2044. Physiologist. 1991 Feb;34(1 Suppl):S196-9. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2047441
		Kirchen ME, O'Connor KM, Gruber HE, Sweeney JR, Fras IA, Stover SJ, Sarmiento A, Marshall GJ.. Effects of microgravity on bone healing in a rat fibular osteotomy model.Clin Orthop. 1995 Sep;(318):231-42. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=7671522

Risk Title: Injury to Joints and Intervertebral Structures

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Bone Loss
Risk Number :	3
Risk Description :	Fascia, tendon and ligament overuse or traumatic injury, joint dysfunction upon return to normal/partial gravity. Hypogravity changes to intervertebral discs may increase risk of rupture, with attendant back pain, possible neurological complications.
Context/Risk Factors :	Age ; Muscle and tendon loss of mechanical strength ; Prior conditioning status ; Prior history of injuries ; Work related impact on intervertebral disc structures
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** High likelihood/Moderate consequence. **Lunar:** High likelihood/Moderate consequence. **Mars:** High likelihood/Moderate consequence.
Current Countermeasures :	**ISS :** Musculoskeletal Fitness ; Post-injury Rehabilitation ; Work injury avoidance patterns **Lunar :**

<table>
<tr><td></td><td>Musculoskeletal Fitness ; Post-injury Rehabilitation ; Work injury avoidance patterns
Mars :
Musculoskeletal Fitness ; Post-injury Rehabilitation ; Work injury avoidance patterns</td></tr>
<tr><td>Projected Countermeasures :</td><td>ISS :
Coordinated muscle/tendon/ligament conditioning program
Lunar :
Coordinated muscle/tendon/ligament conditioning program
Mars :
Coordinated muscle/tendon/ligament conditioning program</td></tr>
<tr><td>Enabling Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>3a</td><td>What is the cause of the back pain commonly experienced by crewmembers upon return to 1-G? [ISS 2, Lunar 3, Mars 2]</td></tr>
<tr><td>3b</td><td>Is damage to joint structure or intervertebral discs incurred during or following hypogravity exposure? [ISS 2, Lunar 3, Mars 1]</td></tr>
<tr><td>3c</td><td>What countermeasures will protect joint and intervertebral soft tissues from microgravity or partial Gravity-related damage? [ISS 2, Lunar 2, Mars 1]</td></tr>
<tr><td>3d</td><td>What rehabilitative measures will hasten recovery of soft tissue damage in a partial Gravity environment or upon return to Earth's gravity? [ISS 2, Lunar 2, Mars 1]</td></tr>
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</td></tr>
<tr><td>Related Risks :</td><td></td></tr>
<tr><td>Important References :</td><td>
<table>
<tr><td>Foldes I, Kern M, Szilagyi T, Oganov VS. Histology and histochemistry of intervertebral discs of rats participated in space flight. Acta Biol Hung. 1996;47(1-4):145-56.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9123987</td></tr>
<tr><td>Foldes I, Szilagyi T, Rapcsak M, Velkey V, Oganov VS. Changes of lumbar vertebrae after Cosmos-1887 space flight. Physiologist. 1991 Feb;34(1 Suppl):S57-8.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2047467</td></tr>
<tr><td>Hutton WC, Malko JA, Fajman WA. Lumbar disc volume measured by MRI: effects of bed rest, horizontal exercise, and vertical loading. Aviat Space Environ Med. 2003 Jan;74(1):73-8.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12546302</td></tr>
<tr><td>LeBlanc AD, Evans HJ, Schneider VS, Wendt RE 3rd, Hedrick TD. Changes in intervertebral disc cross-sectional area with bed rest and space flight. Spine. 1994 Apr 1;19(7):812-7.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8202800</td></tr>
<tr><td>Maynard JA. The effects of space flight on the composition of the intervertebral disc. Iowa Orthop J. 1994;14:125-33.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=7719767</td></tr>
<tr><td>Oganov VS, Cann C, Rakhmanov AS, Ternovoi SK. [Study of the musculoskeletal system of the spine in humans after long-term space flights by the method of computerized tomography] Kosm Biol Aviakosm Med. 1990 Jul-Aug;24(4):20-1. Russian.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2214660</td></tr>
<tr><td>Pedrini-Mille A, Maynard JA, Durnova GN, Kaplansky AS, Pedrini VA, Chung CB, Fedler-Troester J. Effects of microgravity on the composition of the intervertebral disk. Appl Physiol. 1992 Aug;73(2 Suppl):26S-32S

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=1526953</td></tr>
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	Stupakov GP, Mazurin YuV, Kazeikin VS, Moiseyev YB, Kaliakin VV. Destructive and adaptive processes in human vertebral column under altered gravitational potential. Physiologist. 1990 Feb;33(1 Suppl):S4-7. Review. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2196601

Risk Title: Renal Stone Formation

<table>
<tr><td>Theme :</td><td>Human Health and Countermeasures (HH&C)</td></tr>
<tr><td>Discipline :</td><td>Bone Loss</td></tr>
<tr><td>Risk Number :</td><td>4</td></tr>
<tr><td>Risk Description :</td><td>Urine calcium concentration is increased due to increased bone resorption during hypogravity and to decreased urine volume during periods of dehydration.</td></tr>
<tr><td>Context/Risk Factors :</td><td>Altered renal function ; Calcium loss from bone ; Fluid and mineral imbalance ; Impact of extended environmental features regarding mineral/fluid alterations ; Individual propensity for urine calcium oxalate solubility patterns</td></tr>
<tr><td>RYG Risk Assessment :</td><td>ISS: Green
Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space.
Lunar: Green
Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space.
Mars: Green
Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space.</td></tr>
<tr><td>Justification :</td><td>ISS:
TBD
Lunar:
TBD
Mars:
TBD</td></tr>
<tr><td>Current Countermeasures :</td><td>ISS :
K Citrate ; Maintained hydration
Lunar :
K Citrate ; Maintained hydration
Mars :
K Citrate ; Maintained hydration</td></tr>
<tr><td>Projected Countermeasures :</td><td>ISS :
K Mg Citrate currently in testing in flight ; Ultrasound of renal status to anticipate renal stone formation ; Urine solubility testing in flight
Lunar :
K Mg Citrate currently in testing in flight ; Ultrasound of renal status to anticipate renal stone formation ; Urine solubility testing in flight
Mars :
K Mg Citrate currently in testing in flight ; Ultrasound of renal status to anticipate renal stone formation ; Urine solubility testing in flight</td></tr>
<tr><td>Enabling Questions [With Mission Priority]:</td><td><table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>4a</td><td>What diagnostic measures permit detection of renal calcification during extended-duration space flight? [ISS 4, Lunar 1, Mars 1]</td></tr>
<tr><td>4b</td><td>What nutritional and/or pharmacological countermeasures adequately minimize risk of stone formation in-flight and upon return to 1G? [ISS 3, Lunar 2, Mars 2]</td></tr>
<tr><td>4c</td><td>What is the time course of increased risk for renal stone formation abating upon return to 1G? [ISS 3, Lunar 3, Mars 2]</td></tr>
</table></td></tr>
<tr><td>Related Risks :</td><td></td></tr>
</table>

Important References :	Pak CY, Hill K, Cintron NM, Huntoon C. Assessing applicants to the NASA flight program for their renal stone-forming potential. Aviat Space Environ Med. 1989 Feb;60(2):157-61. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2930428
	Whitson PA, Pietrzyk RA, Morukov BV, Sams CF. The risk of renal stone formation during and after long duration space flight. Nephron. 2001 Nov;89(3):264-70. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11598387
	Whitson PA, Pietrzyk RA, Pak CY, Cintron NM. Alterations in renal stone risk factors after space flight. J Urol. 1993 Sep;150(3):803-7. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8345588
	Whitson PA, Pietrzyk RA, Pak CY. Renal stone risk assessment during Space Shuttle flights. J Urol. 1997 Dec;158(6):2305-10. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9366381
	Whitson PA, Pietrzyk RA, Sams CF. Space flight and the risk of renal stones. J Gravit Physiol. 1999 Jul;6(1):P87-8. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11543039
	Whitson PA, Pietrzyk RA, Sams CF. Urine volume and its effects on renal stone risk in astronauts. Aviat Space Environ Med. 2001 Apr;72(4):368-72. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11318017
	Zerwekh JE. Nutrition and renal stone disease in space. Nutrition. 2002 Oct;18 (10):857-63. Review. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12361779

Risk Title: Occurrence of Serious Cardiovascular Dysrhythmias

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Cardiovascular Alterations
Risk Number :	5
Risk Description :	Cardiac dysrhythmias pose a potentially lethal risk during long-duration space flight. Cardiac dysrhythmias may also cause hypotension and syncope. Cause is unknown.
Context/Risk Factors :	Altered neural and hormonal regulation ; Diminished cardiac mass and cardiac remodeling, flight duration ; Gender ; Possible risk factors include fluid and electrolyte imbalance ; Pre-existing cardiovascular disease ; Radiation exposure
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** Serious cardiac rhythm disturbances including ventricular tachycardia have been observed on several occasions during space flight including a documented 14-beat run of ventricular tachycardia during a

	Mir mission. Recent flight and ground-based data demonstrate alterations in cardiac electrical activity, which may indicate altered cardiac electrical stability. If space flight increases the risk of serious cardiac dysrhythmias this could lead to syncope and/or death posing risk both to crewmembers and to the mission. **Lunar:** Serious cardiac rhythm disturbances including ventricular tachycardia have been observed on several occasions during space flight including a documented 14-beat run of ventricular tachycardia during a Mir mission. Recent flight and ground-based data demonstrate alterations in cardiac electrical activity, which may indicate altered cardiac electrical stability. If space flight increases the risk of serious cardiac dysrhythmias this could lead to syncope and/or death posing risk both to crewmembers and to the mission. **Mars:** Serious cardiac rhythm disturbances including ventricular tachycardia have been observed on several occasions during space flight including a documented 14-beat run of ventricular tachycardia during a Mir mission. Recent flight and ground-based data demonstrate alterations in cardiac electrical activity, which may indicate altered cardiac electrical stability. If space flight increases the risk of serious cardiac dysrhythmias this could lead to syncope and/or death posing risk both to crewmembers and to the mission.
Current Countermeasures :	**ISS :** Resuscitation equipment including defibrillator on board **Lunar :** Resuscitation equipment including defibrillator on board **Mars :** Resuscitation equipment including defibrillator on board
Projected Countermeasures :	**ISS :** Electrical cardioversion (Equipment currently on board, efficacy not demonstrated in space environment) ; Nutritional countermeasure ; Pharmaceutical countermeasure ; Pre-flight and in-flight testing of astronauts to assess altered susceptibility to dysrhythmias **Lunar :** Electrical cardioversion (Equipment currently on board, efficacy not demonstrated in space environment) ; Nutritional countermeasure ; Pharmaceutical countermeasure ; Pre-flight and in-flight testing of astronauts to assess altered susceptibility to dysrhythmias **Mars :** Electrical cardioversion (Equipment currently on board, efficacy not demonstrated in space environment) ; Nutritional countermeasure ; Pharmaceutical countermeasure ; Pre-flight and in-flight testing of astronauts to assess altered susceptibility to dysrhythmias
Enabling Questions [With Mission Priority]:	

No.	Question
5a	Does space flight increase susceptibility to serious cardiac dysrhythmias? **[ISS 1, Lunar 1, Mars 1]**
5b	What conditions of space flight (e.g., Microgravity, disruption of physiological rhythms, nutrition, environmental factors and radiation) may be responsible? **[ISS 1, Lunar 1, Mars 1]**
5c	What mechanisms are involved? **[ISS 1, Lunar 1, Mars 1]**
5d	Can risk of serious cardiac dysrhythmias be predicted for individual crewmembers? **[ISS 1, Lunar 1, Mars 1]**
5e	What countermeasures may prevent or reduce the occurrence of serious cardiac dysrhythmias during long-term space flight? **[ISS 1, Lunar 1, Mars 1]**
5f	Can susceptibility to and occurrence of serious cardiac dysrhythmias be effectively diagnosed and treated during space flight? **[ISS 1, Lunar 1, Mars 1]**
5g	Which cardiovascular diseases are likely to be aggravated by space flight? **[ISS 1, Lunar 1, Mars 1]**
5h	What mechanisms are involved? **[ISS 1, Lunar 1, Mars 1]**
5i	What improved screening methods on the ground and in-flight might identify crewmembers with underlying cardiovascular disease, which may be aggravated by space flight? **[ISS 1, Lunar 1, Mars 1]**
5j	What countermeasures may be effective in mitigating the risk? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :	**ISS :** **Cardiovascular Alterations** Occurrence of Serious Cardiovascular Dysrhythmias Diminished Cardiac and Vascular Function **Clinical capabilities** Monitoring & Prevention Major Illness & Trauma Pharmacology of Space Medicine Delivery Ambulatory Care Return to Gravity/Rehabilitation Insufficient Data/Information/Knowledge Management & Communication Capability Skill Determination and Training Palliative, Mortem, and Post-Mortem Medical Activities **Lunar :** **Cardiovascular Alterations** Occurrence of Serious Cardiovascular Dysrhythmias Diminished Cardiac and Vascular Function **Clinical capabilities** Monitoring & Prevention Major Illness & Trauma Pharmacology of Space Medicine Delivery Ambulatory Care Return to Gravity/Rehabilitation Insufficient Data/Information/Knowledge Management & Communication Capability Skill Determination and Training Palliative, Mortem, and Post-Mortem Medical Activities **Mars :** **Cardiovascular Alterations** Occurrence of Serious Cardiovascular Dysrhythmias Diminished Cardiac and Vascular Function **Clinical capabilities** Monitoring & Prevention Major Illness & Trauma Pharmacology of Space Medicine Delivery Ambulatory Care Return to Gravity/Rehabilitation Insufficient Data/Information/Knowledge Management & Communication Capability Skill Determination and Training Palliative, Mortem, and Post-Mortem Medical Activities
Important References :	Charles JB, Bungo MW, Fortner GW. Cardiopulmonary Function. In: Nicogossian A, Huntoon C. Pool S. and (editors). Space Physiology and Medicine. 3rd ed. Philadelphia, PA: Lea & Febiger, 286-304, 1994.

	Hawkins WR, Zieglschmid JF. Clinical Aspects of Crew Health. In: Biomedical Results of Apollo (NASA SP-368). Johnston RS Dietlein LF, Berry CA, editors. Washington, DC: U.S. Government Printing Office, 43-81, 1975.
	Smith RF, Stanton K, Stoop D, Brown D, Januez W, King P. Vectorcardiographic Changes During Extended Space flight (M093): Observations at Rest and During Exercise. In: Biomedical Results of Skylab (NASA SP-377). Johnston RS and Dietlein LF, editors. Washington, DC: NASA 339-350, 1977.

Risk Title: Diminished Cardiac and Vascular Function

<table>
<tr><td>Theme :</td><td>Human Health and Countermeasures (HH&C)</td></tr>
<tr><td>Discipline :</td><td>Cardiovascular Alterations</td></tr>
<tr><td>Risk Number :</td><td>6</td></tr>
<tr><td>Risk Description :</td><td>Short-duration space flight has been associated with a decrease in cardiac mass. Long-duration space flight may result in greater decrease in cardiac mass and additional alterations that may diminish cardiac function, aggravate underlying cardiovascular disease (e.g., arterial atherosclerosis) leading to myocardial infarction, stroke or heart rhythm disturbances that could be irreversible.</td></tr>
<tr><td>Context/Risk Factors :</td><td>Altered neural and hormonal regulation ; Flight duration ; Gender</td></tr>
<tr><td>RYG Risk Assessment :</td><td>ISS: Yellow
High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Lunar: Yellow
High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Mars: Yellow
High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.</td></tr>
<tr><td>Justification :</td><td>ISS:
Ground based and flight data in humans and animals suggest that prolonged exposure to microgravity may lead to the reduction of cardiac mass and reduced cardiac function, although different studies have come to different conclusions in this regard. Carefully controlled studies from very long-duration to microgravity are required to definitively resolve this issue.
Lunar:
Ground based and flight data in humans and animals suggest that prolonged exposure to microgravity may lead to the reduction of cardiac mass and reduced cardiac function, although different studies have come to different conclusions in this regard. Carefully controlled studies from very long-duration to microgravity are required to definitively resolve this issue.
Mars:
Ground based and flight data in humans and animals suggest that prolonged exposure to microgravity may lead to the reduction of cardiac mass and reduced cardiac function, although different studies have come to different conclusions in this regard. Carefully controlled studies from very long-duration to microgravity are required to definitively resolve this issue.</td></tr>
<tr><td>Current Countermeasures :</td><td>ISS :
Exercise
Lunar :
Exercise
Mars :
Exercise</td></tr>
<tr><td>Projected Countermeasures :</td><td>ISS :
Artificial G exposure ; Drugs that affect cardiac mass and function
Lunar :
Artificial G exposure ; Drugs that affect cardiac mass and function
Mars :
Artificial G exposure ; Drugs that affect cardiac mass and function</td></tr>
<tr><td>Enabling Questions [With Mission Priority]:</td><td><table><tr><th>No.</th><th>Question</th></tr><tr><td>6a</td><td>Does long-duration space flight lead to diminished cardiac function? [ISS 1, Lunar 1, Mars 1]</td></tr></table></td></tr>
</table>

6b	What mechanisms are involved? **[ISS 1, Lunar 1, Mars 1]**
6c	Is the process reversible? **[ISS 1, Lunar 1, Mars 1]**
6d	What is the extent of reduction in cardiac function and/or mass associated with long-duration space flight? Can susceptibility to reduced cardiac function be predicted for individual crewmembers? **[ISS 1, Lunar 1, Mars 1]**
6e	Can susceptibility to reduced cardiac function be predicted for individual crewmembers? **[ISS 2, Lunar 2, Mars 2]**
6f	What countermeasures may be effective in mitigating the risk? **[ISS 1, Lunar 1, Mars 1]**
6g	What are the physiological and environmental factors by which space flight decreases orthostatic tolerance? **[ISS 1, Lunar 1, Mars 1]**
6h	How does duration of space flight affect the severity and time course of orthostatic intolerance and what are the mechanisms? **[ISS 2, Lunar 2, Mars 2]**
6i	Is orthostatic intolerance likely to develop on the surface of Mars or the moon? **[ISS 1, Lunar 1, Mars 1]**
6j	Can space flight-induced orthostatic intolerance be predicted for individual crewmembers? **[ISS 1, Lunar 1, Mars 1]**
6k	What countermeasures can be developed to overcome or prevent orthostatic intolerance? **[ISS 1, Lunar 1, Mars 1]**
6l	What are the physiological and environmental factors by which space flight decreases aerobic exercise capacity? **[ISS 1, Lunar 1, Mars 1]**
6m	How does duration of space flight affect the severity of limitation of exercise capacity? **[ISS 1, Lunar 1, Mars 1]**
6n	Can aerobic exercise capacity limitation be predicted for individual crewmembers? **[ISS 1, Lunar 1, Mars 1]**
6o	What countermeasures can be developed to overcome aerobic exercise capacity limitation? **[ISS 1, Lunar 1, Mars 1]**
6p	What are the physiological and environmental factors by which space flight decreases orthostatic tolerance? **[ISS 1, Lunar 1, Mars 1]**
6q	Is orthostatic intolerance likely to develop on the surface of Mars or the moon? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

ISS :

Cardiovascular Alterations
Occurrence of Serious Cardiovascular Dysrhythmias
Diminished Cardiac and Vascular Function
Clinical capabilities
Monitoring & Prevention
Major Illness & Trauma
Pharmacology of Space Medicine Delivery
Ambulatory Care
Return to Gravity/Rehabilitation
Insufficient Data/Information/Knowledge Management & Communication Capability
Skill Determination and Training
Palliative, Mortem, and Post-Mortem Medical Activities

Lunar :

Cardiovascular Alterations
Occurrence of Serious Cardiovascular Dysrhythmias

	Diminished Cardiac and Vascular Function
	Clinical capabilities
	Monitoring & Prevention
	Major Illness & Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Return to Gravity/Rehabilitation
	Insufficient Data/Information/Knowledge Management & Communication Capability
	Skill Determination and Training
	Palliative, Mortem, and Post-Mortem Medical Activities
	Mars :
	Cardiovascular Alterations
	Occurrence of Serious Cardiovascular Dysrhythmias
	Diminished Cardiac and Vascular Function
	Clinical capabilities
	Monitoring & Prevention
	Major Illness & Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Return to Gravity/Rehabilitation
	Insufficient Data/Information/Knowledge Management & Communication Capability
	Skill Determination and Training
	Palliative, Mortem, and Post-Mortem Medical Activities
Important References :	Blomqvist CG, Lane LD, Wright SJ, et al. Cardiovascular regulation at microgravity. In: Scientific Results of the German Spacelab Mission D-2, Proceedings of Symposium at Norderney, Sahm PR, Keller MH and Schiewe B, editors. Wissenschaftliche Projektfuhrung D2, RWTH Aachen, Care of DLR, Koln, pp. 688-690.

Risk Title: Define Acceptable Limits for Contaminants in Air and Water

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Environmental Health
Risk Number :	7
Risk Description :	Lack of information needed to set requirements for air and water quality. This includes inadequate information about: 1) sources of contaminants; 2) identification of potential contaminants; and 3) bases for setting acceptability limits for individual contaminants and combinations of contaminants.
Context/Risk Factors :	Remoteness: Crew health/susceptibility to degree of system closure
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.

Justification :	**ISS:** Excessive pollutant levels (including microbial contaminants) can jeopardize crew health and/or impair mission success. The severity and likelihood of any adverse effects depends on the specific pollutant and its measured concentration. **Lunar:** Excessive pollutant levels (including microbial contaminants) can jeopardize crew health and/or impair mission success. The severity and likelihood of any adverse effects depends on the specific pollutant and its measured concentration. **Mars:** Excessive pollutant levels (including microbial contaminants) can jeopardize crew health and/or impair mission success. The severity and likelihood of any adverse effects depends on the specific pollutant and its measured concentration.
Current Countermeasures :	**ISS :** TBD **Lunar :** TBD **Mars :** TBD
Projected Countermeasures :	**ISS :** TBD **Lunar :** TBD **Mars :** TBD

Enabling Questions [With Mission Priority]:

No.	Question
7a	What are the most likely sources of severe air pollution specific to ISS, lunar, and Mars missions and what methods can be used to control these sources over long periods of time? **[ISS 1, Lunar 1, Mars 1]**
7b	What are the tolerance limits in terms of quantity and type of microorganisms in air, water, and food and on surfaces? **[ISS 1, Lunar 1, Mars 1]**
7c	What approaches to setting exposure standards may be used when insufficient data are available to allow prediction of acceptable exposure levels? **[ISS 1, Lunar 1, Mars 1]**
7d	What is the requirement for determining how rapidly acceptable air quality can be recovered after a severe pollution condition and what effect that recovery has on humidity condensate and the water recovery system? **[ISS 1, Lunar 1, Mars 1]**
7e	Can automated real-time systems be used to monitor air quality for lunar and Mars missions and can the crew interpret results without ground support? **[ISS 1, Lunar 1, Mars 1]**
7f	How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation exposures to single chemicals and/or to mixtures? **[ISS 2, Lunar 2, Mars 2]**
7g	What impact do space flight-induced biological, physiological, and immunological changes have on the susceptibility of crewmembers to infectious agents and toxic substances in the air? **[ISS 2, Lunar 2, Mars 2]**
7h	What are the effects of exposure to ultra fine and larger (respirable and non-respirable) particles (e.g., lunar dust) on crew health, safety and performance? **[Lunar 2, Mars 2]**
7i	What are the interactions of microbes, chemicals and plants in CELSS on air quality? **[Lunar 2, Mars 2]**
7j	To the extent that plants are critical to mission success, will the potential for phytotoxicity be adequately addressed in the evaluation of air quality? **[Mars 2]**
7k	Is there the potential for increased heterogeneity in terms of the distribution of air contaminants in the relatively larger lunar and Mars habitats? If so, what additional monitoring resources and/or strategies are necessary to protect crew health? **[Lunar 2, Mars 2]**

Related Risks :	

Important References :	Huntoon, C.L., Toxicological Analysis of STS-40 Atmosphere, NASA/JSC Memorandum, SD4/01-93-251, July 6, 1991; Toxicological Analysis of STS-55 Atmosphere, NASA/JSC Memorandum SD4-93-251, July 6, 1993. James, J.T Toxicological Assessment of Air Samples Taken after the Oxygen-Generator Fire on Mir, NASA/JSC Memorandum SD2-97-513, April 10, 1997 James, J.T., Toxicological Assessment of Air Contaminants during the Mir 19 Expedition, 1996 Nicogossian, A.E., et al. Crew Health in the Apollo-Soyuz Test Project Medical Report, NASA SP-411, 1977 Pool, S.L. Ethylene Glycol Treatise. NASA/JSC Memorandum SD2-97-542, September 15, 1997.

Risk Title: Immunodeficiency / Infection

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Immunology, Infection & Hematology
Risk Number :	8
Risk Description :	It is possible that space flight may suppress immune function, a newly designated form of secondary immunodeficiency disease. Secondary immunodeficiency causes an unusual number of infections, with greater severity and duration. Secondary immunodeficiency leads to reactivation of latent virus infections with organisms that lay dormant until immune resistance is lowered and virus replication begins.
Context/Risk Factors :	Extreme environments ; Microbial contamination ; Microgravity isolation ; Nutritional deprivation ; Radiation ; Sleep deprivation ; Stress
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** The contributing risk factors of space flight collectively have a powerful effect upon the cells of the immune system: T cells, particularly CD4+ (helper) T cells, B cells, NK cells, monocyte/macrophages/dendritic cells and hematopoietic stem cells. Every component of immune resistance to infection is compromised under space flight conditions, particularly the ability of the central immune cell, the CD4+ T cell. **Lunar:** The experience of the lunar surface would create the same general risks as those of the ISS. The effects of microgravity would be slightly reduced and radiation would be greater than that on the ISS. The relatively short time of the lunar mission (10-44 days) would tend to reduce the risk of developing immunodeficiency and infection. **Mars:** The long-term exposure (>1 year) to deep-space radiation and prolonged exposure to microgravity (> 2 years), length of separation from humans, constant sleep deprivation and other conditions of space flight would offer the greatest challenge to the host immune system in protecting space travelers from the development of secondary immuno-deficiency and reactivated latent viral infections.
Current Countermeasures :	**ISS :** Anti-viral agents ; Air and water monitoring ; Onboard antibiotics ; Pre-flight Quarantine (Health Stabilization Program) ; Replacement intravenous immunoglobulins ; Routine immunizations ; Use of clean vehicles **Lunar :** Anti-viral agents ; Air and water monitoring ; Onboard antibiotics ; Pre-flight Quarantine (Health Stabilization Program) ; Replacement intravenous immunoglobulins ; Routine immunizations ; Use of clean vehicles Because of the shorter duration of the lunar mission, the use of these countermeasures may be minimal. **Mars :**

Anti-viral agents ; Air and water monitoring ; Onboard antibiotics ; Pre-flight Quarantine (Health Stabilization Program) ; Replacement intravenous immunoglobulins ; Routine immunizations ; Use of clean vehicles

The Martian mission would be expected to produce the greatest need for these countermeasures, particularly monoclonal antibodies to pathogens and even autologous bone marrow stem cell transplants (technology to preserve these bone marrow stem cells in-flight for up to 3 years would need to be developed).

Projected Countermeasures :

ISS :
Detection systems for assessment of immune function ; Molecular detection systems for water and airborne pathogens ; Monoclonal antibodies to viral, bacterial and fungal pathogens and inflammatory mediators, such as TNF-; cytokines such as IFN- and bone marrow stem cells ; Pathogen-specific immunizations ; Anti-viral agents

Lunar :
Detection systems for assessment of immune function ; Molecular detection systems for water and airborne pathogens ; Monoclonal antibodies to viral, bacterial and fungal pathogens and inflammatory mediators, such as TNF-; cytokines such as IFN- and bone marrow stem cells ; Pathogen-specific immunizations ; Anti-viral agents

Because of the shorter time exposure to space conditions on a lunar mission, the use of treatment countermeasures would be less.

Mars :
Detection systems for assessment of immune function ; Molecular detection systems for water and airborne pathogens ; Monoclonal antibodies to viral, bacterial and fungal pathogens and inflammatory mediators, such as TNF-; cytokines such as IFN- and bone marrow stem cells ; Pathogen-specific immunizations ; Anti-viral agents

The long-duration and difficult living conditions of a Martian mission would stress the ability of countermeasures to remain effective (e.g., the development of bacteria, fungi, or viruses that are resistant to the anti-microbial agents brought on-board).

Enabling Questions [With Mission Priority]:

No.	Question
8a	What are the molecular and cellular mechanisms of innate and acquired immunity that become compromised with space flight conditions of radiation, microgravity, isolation, stress, microbial contamination, sleep deprivation, extreme environments and nutritional deficiency? **[ISS 1, Lunar 1, Mars 1]**
8b	Is it possible to predict the summary effects of each component condition and duration (1 year SSS, 30-day lunar, 18 month Martian) of space flight that compromises the immune system? **[ISS 1, Lunar 1, Mars 1]**
8c	What types of infections are likely to occur in astronauts exposed to space flight conditions of different missions and durations? **[ISS 1, Lunar 1, Mars 1]**
8d	Are there detection systems that can assess surrogate markers of immune function so that therapeutic interventions could be planned/during space flight? **[ISS 2, Lunar 2, Mars 2]**
8e	Will it be possible to use immune protection measures to prevent infection aboard spaceships and to use antimicrobial therapies and immunological treatments to cure infections and prevent their complications? **[ISS 2, Lunar 2, Mars 2]**
8f	Will nutritional supplements be able to boost immune responses in space flight to counteract the infectious complication of compromised immune function? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

ISS :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Nutrition
Inadequate Nutritional Requirements
Clinical capabilities
Monitoring & Prevention

	Major Illness & Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Return to Gravity/Rehabilitation
	Insufficient Data/Information/Knowledge Management & Communication Capability
	Skill Determination and Training
	Palliative, Mortem, and Post-Mortem Medical Activities
	Human Behavior & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Poor Psychosocial Adaptation
	Human Performance Failure Due to Neurobehavioral Problems
	Mismatch between Crew Cognitive Capabilities and Task Demands
	Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
	Radiation Health
	Carcinogenesis
	Acute and Late CNS Risks
	Other Degenerative Tissue Risks
	Heredity, Fertility and Sterility Risks
	Acute Radiation Syndromes
	Lunar :
	Environmental Health
	Define Acceptable Limits for Contaminants in Air and Water
	Nutrition
	Inadequate Nutritional Requirements
	Clinical capabilities
	Monitoring & Prevention
	Major Illness & Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Return to Gravity/Rehabilitation
	Insufficient Data/Information/Knowledge Management & Communication Capability
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	Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
	Radiation Health
	Carcinogenesis
	Acute and Late CNS Risks
	Other Degenerative Tissue Risks
	Heredity, Fertility and Sterility Risks

	Acute Radiation Syndromes
	Mars :
	Environmental Health
	Define Acceptable Limits for Contaminants in Air and Water
	Nutrition
	Inadequate Nutritional Requirements
	Clinical capabilities
	Monitoring & Prevention
	Major Illness & Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Return to Gravity/Rehabilitation
	Insufficient Data/Information/Knowledge Management & Communication Capability
	Skill Determination and Training
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	Radiation Health
	Carcinogenesis
	Acute and Late CNS Risks
	Other Degenerative Tissue Risks
	Heredity, Fertility and Sterility Risks
	Acute Radiation Syndromes
Important References :	Aviles H, Belay T, Fountain K, Vance M, Sonnenfeld G. Increased susceptibility to Pseudomonas aeruginosa infection hindlimb unloading conditions. J Appl Physiol 95:73-80, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12626488
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Risk Title: Virus-Induced Lymphomas and Leukemia's

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Immunology, Infection & Hematology
Risk Number :	9
Risk Description :	This risk occurs in humans who are immunosuppressed and develop latent virus reactivation. Since the astronauts all carry many latent viruses in their bodies because of universal exposure, it is possible that if their immune resistance is lowered to a critical level, they may be subject to B-cell lymphomas and T-cell leukemias.
Context/Risk Factors :	Host genetics ; Immunodeficiency due to space flight conditions ; Latent virus reactivation
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Green Health and performance consequences are known or suspected, but will not affect mission success

<table>
<tr><td></td><td>due to effective mitigation strategies that have been validated in space.
Mars: Yellow
High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.</td></tr>
<tr><td>Justification :</td><td>ISS:
Due to severe immunosuppression caused by several space flight conditions (radiation, microgravity, isolation, stress, microbial contamination, sleep deprivation, extreme environments, nutritional deprivation), latent viruses (e.g., Epstein-Barr virus, polyomaviruses) become active and favor the selection of escape mutant lymphoid cells, which lack replication controls. These clones of lymphoid cells become oligoclonal and finally monoclonal and grow without inhibition. The nests of these clones grow into tumors that disrupt normal tissue and architecture, sap the energy of normal cells and kill the host in a short period of time.
Lunar:
The relatively short exposure of astronauts to space flight conditions in the lunar mission may not yield the final development of malignancy. However, Alan Shepard, the fifth man to step on the moon (and one of 12 to do so) surface died of T-cell leukemia. It is possible that the premalignancy is triggered in the appropriate genetic host years before oncogenic transformation occurs. Publication of the long-term health consequences of NASA’s space pioneers will prove an important source of clinical evidence.
Mars:
The length and severity of space flight conditions of the Martian Mission are expected to pose the most dangerous risk for the development of immune cell-mediated leukemias and lymphomas. Animal model studies are the only means, at present, by which to assess the risk of virus-induced tumors in an immunosuppressed host.</td></tr>
<tr><td>Current Countermeasures :</td><td>ISS :
Cytotoxic anti-EBV T cells ; Monitor exposure to radiation and other environmental factors ; Monoclonal anti-B cell (tumor) antibody (Rituximab) ; Ongoing health status monitoring ; Radiation shielding
Lunar :
Cytotoxic anti-EBV T cells ; Monitor exposure to radiation and other environmental factors ; Monoclonal anti-B cell (tumor) antibody (Rituximab) ; Ongoing health status monitoring ; Radiation shielding

Use of countermeasures may not be needed on short voyages to the Moon, but in later years if tumors develop.
Mars :
Cytotoxic anti-EBV T cells ; Monitor exposure to radiation and other environmental factors ; Monoclonal anti-B cell (tumor) antibody (Rituximab) ; Ongoing health status monitoring ; Radiation shielding

Need to develop radiation-proof container for autologous stem cell transplants. The other countermeasures can be delivered in deep-space.</td></tr>
<tr><td>Projected Countermeasures :</td><td>ISS :
Autologous stem cell transplants ; Fusion proteins to block virus reinfection ; Specific antiviral drugs
Lunar :
Autologous stem cell transplants ; Fusion proteins to block virus reinfection ; Specific antiviral drugs

Use of monoclonal anti-B cell tumor antibodies and cytotoxic anti-EBV T cells may not be necessary on the short Moon mission, but they may be necessary after return to Earth.
Mars :
Autologous stem cell transplants ; Fusion proteins to block virus reinfection ; Specific antiviral drugs

Technology needs to be developed to preserve autologous cytotoxic anti-EBV T cells on board the spacecraft in the Martian mission. The other countermeasures could presently be delivered in deep-space.</td></tr>
<tr><td>Enabling Questions [With Mission Priority]:</td><td><table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>9a</td><td>What are the molecular and genetic mechanisms of host defense cells and latent virus genomes that become altered with immunosuppression produced by space flight conditions and latent virus reactivation, leading to lymphoid tumor production? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>9b</td><td>Will the degree of immune compromise, latent virus reactivation and lymphoid malignancy vary with the space mission and its duration (1-year ISS, 30-day lunar, 18 month Martian)? [ISS 1, Lunar 1, Mars 1]</td></tr>
</table></td></tr>
</table>

	9c	Is it possible to predict the summary effects of each component condition and duration of space flight that produce lymphoid malignancies? **[ISS 1, Lunar 1, Mars 1]**
	9d	What are the types of lymphoid malignancies (lymphomas, leukemias) that are likely to occur in immunosuppressed astronauts with reactivated latent viral infections? **[ISS 1, Lunar 1, Mars 1]**
	9e	Are there virus quantitation assays to predict those astronauts who will develop malignancies and who would benefit from immune intervention? **[ISS 2, Lunar 2, Mars 2]**
	9f	Will it be possible to use anti-viral and anti-tumor agents aboard spaceships to reduce viral burden and abort forbidden clone development? **[ISS 2, Lunar 2, Mars 2]**
	9g	Will it be possible to develop nutritional supplements to augment anti-viral and anti-tumor therapy? **[ISS 2, Lunar 2, Mars 2]**
	9h	Will it be possible to restore immunity in a severely immunocompromised astronaut with autologous stem cell transplants? **[ISS 3, Lunar 3, Mars 3]**

Related Risks :

ISS :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Nutrition
Inadequate Nutritional Requirements
Clinical capabilities
Monitoring & Prevention
Major Illness & Trauma
Pharmacology of Space Medicine Delivery
Ambulatory Care
Return to Gravity/Rehabilitation
Insufficient Data/Information/Knowledge Management & Communication Capability
Skill Determination and Training
Palliative, Mortem, and Post-Mortem Medical Activities
Radiation Health
Carcinogenesis
Acute and Late CNS Risks
Other Degenerative Tissue Risks
Heredity, Fertility and Sterility Risks
Acute Radiation Syndromes

Lunar :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Nutrition
Inadequate Nutritional Requirements
Clinical capabilities
Monitoring & Prevention
Major Illness & Trauma
Pharmacology of Space Medicine Delivery
Ambulatory Care

	Return to Gravity/Rehabilitation Insufficient Data/Information/Knowledge Management & Communication Capability Skill Determination and Training Palliative, Mortem, and Post-Mortem Medical Activities **Radiation Health** Carcinogenesis Acute and Late CNS Risks Other Degenerative Tissue Risks Heredity, Fertility and Sterility Risks Acute Radiation Syndromes **Mars :** **Environmental Health** Define Acceptable Limits for Contaminants in Air and Water **Nutrition** Inadequate Nutritional Requirements **Clinical capabilities** Monitoring & Prevention Major Illness & Trauma Pharmacology of Space Medicine Delivery Ambulatory Care Return to Gravity/Rehabilitation Insufficient Data/Information/Knowledge Management & Communication Capability Skill Determination and Training Palliative, Mortem, and Post-Mortem Medical Activities **Radiation Health** Carcinogenesis Acute and Late CNS Risks Other Degenerative Tissue Risks Heredity, Fertility and Sterility Risks Acute Radiation Syndromes
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Risk Title: Anemia, Blood Replacement & Marrow Failure

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Immunology, Infection & Hematology
Risk Number :	10
Risk Description :	There is loss of plasma and red blood cells due to exposure to microgravity and a there is a decrease of RBCM of 15% in the first week in space (2 units of blood). This can lead to problems with spaceflight anemia, or hemorrhage.
Context/Risk Factors :	Age ; Baseline ; Decreased production ; Gender ; Marrow stores ; Need during surgery ; Nutrition ; Trauma – loss & destruction
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** TBD **Lunar:** TBD **Mars:** TBD
Current Countermeasures :	**ISS :** Blood replacement ; Hormonal & stem cell therapy ; Nutrition ; Pharmaceutical **Lunar :** Blood replacement ; Hormonal & stem cell therapy ; Nutrition ; Pharmaceutical **Mars :** Blood replacement ; Hormonal & stem cell therapy ; Nutrition ; Pharmaceutical
Projected	**ISS :**

Countermeasures :	TBD **Lunar :** TBD **Mars :** TBD
Enabling Questions [With Mission Priority]:	**No.** / **Question** 10a — What are the methods for space based therapy for blood replacement? What new technologies are needed for blood replacement in space? **[ISS 3, Lunar 2, Mars 1]** 10b — What are the nutritional requirements for adequate red cell production in microgravity? What are the contributory factors and how do they inter-relate in the development of space anemia (radiation, unloading, nutrition, fluid shift, changes in sex hormones, etc.)? **[ISS 2, Lunar 2, Mars 2]** 10c — How can aplastic anemia be treated during space missions? **[ISS 5, Lunar 5, Mars 3]**
Related Risks :	
Important References :	

Risk Title: Altered Host-Microbial Interactions

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Immunology, Infection & Hematology
Risk Number :	11
Risk Description :	The balance between human host and microbes found on Earth may be altered in space because of responses associated with microgravity, stress, radiation, or other space flight factors.
Context/Risk Factors :	Extreme environments ; Isolation ; Microbial contamination ; Microgravity ; Nutritional deprivation ; Radiation ; Sleep deprivation ; Stress
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** Changes in microflora; novel microbial ecosystems; genetic changes/mutations of microorganisms; alterations in host microbe interaction; alterations in host susceptibility. **Lunar:** The short-duration of the lunar mission might not provide sufficient time for significant alterations in the host: microbe relationship. **Mars:** The long-duration and severe nature of space flight conditions on a Mars mission would favor the alterations in the host: microbe relationship. Possibly, evolution of a supermicrobe that overpowers the human immune response would be favored.
Current Countermeasures :	**ISS :** In-flight environmental monitoring and bioburden reduction procedures **Lunar :** In-flight environmental monitoring and bioburden reduction procedures **Mars :** In-flight environmental monitoring and bioburden reduction procedures
Projected Countermeasures :	**ISS :** Comprehensive microbial identification technology based on mass spectrometry and/or hybridization ; In-flight antibiotic susceptibility testing capability ; Pre-flight screening ; Routine In-flight microbial identification/monitoring capability **Lunar :** Comprehensive microbial identification technology based on mass spectrometry and/or hybridization

	; In-flight antibiotic susceptibility testing capability ; Pre-flight screening ; Routine In-flight microbial identification/monitoring capability **Mars :** Comprehensive microbial identification technology based on mass spectrometry and/or hybridization ; In-flight antibiotic susceptibility testing capability ; Pre-flight screening ; Routine In-flight microbial identification/monitoring capability
Enabling Questions [With Mission Priority]:	see table below

Enabling Questions [With Mission Priority]:

No.	Question
11a	What diagnostic and environmental monitoring laboratory technologies need to be developed for the detection and diagnosis of infectious disease in space? **[ISS 1, Lunar 1, Mars 1]**
11b	Does the spacecraft environment exert a selective pressure on environmental microorganisms that presents the crew with increased health risks (e.g., Helicobacter and ulcers)? **[ISS 1, Lunar 1, Mars 1]**
11c	Does space flight alter microbial growth rates, mutation rates, or pathogenicity? **[ISS 1, Lunar 1, Mars 1]**
11d	Does space flight alter the exchange of genetic material between microorganisms? **[ISS 1, Lunar 1, Mars 1]**
11e	Does space flight alter host-microbe balance? **[ISS 1, Lunar 1, Mars 1]**
11f	Can molecular and genetic testing of pathogenetic microbial organisms during space flight be accomplished on a real-time basis to prevent development of infections in astronauts? **[ISS 2, Lunar 2, Mars 2]**
11g	Do microorganisms associated with biological life support systems or biological waste treatment systems enter the general spacecraft environment with consequent increase in health risks? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

ISS :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Clinical capabilities
Monitoring & Prevention
Major Illness & Trauma
Pharmacology of Space Medicine Delivery
Ambulatory Care
Return to Gravity/Rehabilitation
Insufficient Data/Information/Knowledge Management & Communication Capability
Skill Determination and Training
Palliative, Mortem, and Post-Mortem Medical Activities

Lunar :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Clinical capabilities
Monitoring & Prevention
Major Illness & Trauma
Pharmacology of Space Medicine Delivery
Ambulatory Care
Return to Gravity/Rehabilitation
Insufficient Data/Information/Knowledge Management & Communication Capability
Skill Determination and Training

	Palliative, Mortem, and Post-Mortem Medical Activities **Mars :** **Environmental Health** Define Acceptable Limits for Contaminants in Air and Water **Clinical capabilities** Monitoring & Prevention Major Illness & Trauma Pharmacology of Space Medicine Delivery Ambulatory Care Return to Gravity/Rehabilitation Insufficient Data/Information/Knowledge Management & Communication Capability Skill Determination and Training Palliative, Mortem, and Post-Mortem Medical Activities
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Risk Title: Allergies and Autoimmune Diseases

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Immunology, Infection & Hematology
Risk Number :	12
Risk Description :	Genetic inheritance and environmental insults are the two factors that trigger development of allergic and autoimmune diseases. Failure of immunologic tolerance due to malfunction of regulatory immune mechanisms leads to immune-mediated diseases in life. Space flight conditions have been shown to upset immune regulation and produce immunologic disease in experimental systems.
Context/Risk Factors :	Extreme environments ; Isolation ; Microbial contamination ; Microgravity ; Nutritional deprivation ; Radiation ; Sleep deprivation ; Stress
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** In contrast to immunodeficiency where a lowered immune response looks to a predilection for opportunistic infection and malignancy, a heightened immune response leads to allergic and autoimmune diseases, which are part of the spectrum of hypersensitivity reactions mediated by IgE (Type I), antibody-cell receptor interactions (Type II), immune complexes (Type III) and T-cell mediated diseased (Type IV). Central to all of these paradoxical over-reactions of the immune system is the immunoregulatory T cell (CD4+DC25+)" Space flight conditions have the potential to affect this cell and other immunoregulatory cells that networks to produce all of our types of hypersensitivity: Allergy (Type I) and Autoimmune Diseases (Types II, III, IV). **Lunar:** Although the lunar mission is short in duration, there may be sufficient loss of fine control of immune tolerance to produce immune diseases later in life. **Mars:** It is very likely that severe allergies and autoimmune diseases will result from a Martian mission, unless specific counter-measures are developed. The length and severity human exposure to

<table>
<tr><td></td><td>environmental insults will most likely result in allergic and immunologic diseases.</td></tr>
<tr><td>Current Countermeasures :</td><td>ISS :
Toxicological/Environmental/Microbiological standards for spacecraft atmosphere
Lunar :
Toxicological/Environmental/Microbiological standards for spacecraft atmosphere

Use of these countermeasures may not be needed in the lunar mission but may be needed later in life.
Mars :
Toxicological/Environmental/Microbiological standards for spacecraft atmosphere

These countermeasures must be ready for use in a Mars mission.</td></tr>
<tr><td>Projected Countermeasures :</td><td>ISS :
Antigen peptide immunotherapy ; Dendritic cell-antigen vaccines ; Monoclonal anti-IgE antibody ; Monoclonal antibody to CD52+ cells, TNF-, C3+ T cells, CD19+/20+ B cells; soluble receptors (7) for TNF-, IL-1, IL-2 ; Th1 immunostimulants (e.g., CpG)
Lunar :
Antigen peptide immunotherapy ; Dendritic cell-antigen vaccines ; Monoclonal anti-IgE antibody ; Monoclonal antibody to CD52+ cells, TNF-, C3+ T cells, CD19+/20+ B cells; soluble receptors (7) for TNF-, IL-1, IL-2 ; Th1 immunostimulants (e.g., CpG)
Mars :
Antigen peptide immunotherapy ; Dendritic cell-antigen vaccines ; Monoclonal anti-IgE antibody ; Monoclonal antibody to CD52+ cells, TNF-, C3+ T cells, CD19+/20+ B cells; soluble receptors (7) for TNF-, IL-1, IL-2 ; Th1 immunostimulants (e.g., CpG)</td></tr>
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<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>12a</td><td>What are the molecular and genetic mechanisms of loss of immunoregulation and immune tolerance in that occur with the exposure to the space flight conditions of radiation, microgravity, isolation, stress, microbial contamination, sleep deprivation, extreme environments and nutritional deficiency? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>12b</td><td>Is it possible to predict the summary effects of each component condition on duration of space flight (1-year ISS, 30-day, 18-month Martian) that leads to immune dysregulation and loss of immune tolerance? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>12c</td><td>What are the allergies and autoimmune diseases that are likely to occur in astronauts exposed to space flight conditions of different missions and durations? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>12d</td><td>Are there detection systems that can detect the first alterations in immune regulatory networks so that therapeutic intervention could be planned? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>12e</td><td>Will it be possible to use new immune regulatory agents to prevent immune imbalance with the expressions of allergies and autoimmune conditions? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>12f</td><td>Will it be possible to use nutritional supplements to boost the immunoregulatory agents used therapeutically? [ISS 2, Lunar 2, Mars 2]</td></tr>
</table>
</td></tr>
<tr><td>Related Risks :</td><td>ISS :
<table>
<tr><td>Environmental Health</td></tr>
<tr><td>Define Acceptable Limits for Contaminants in Air and Water</td></tr>
<tr><td>Nutrition</td></tr>
<tr><td>Inadequate Nutritional Requirements</td></tr>
<tr><td>Clinical capabilities</td></tr>
<tr><td>Monitoring & Prevention</td></tr>
<tr><td>Major Illness & Trauma</td></tr>
<tr><td>Pharmacology of Space Medicine Delivery</td></tr>
<tr><td>Ambulatory Care</td></tr>
<tr><td>Return to Gravity/Rehabilitation</td></tr>
<tr><td>Insufficient Data/Information/Knowledge Management & Communication Capability</td></tr>
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	Skill Determination and Training
	Palliative, Mortem, and Post-Mortem Medical Activities
	Radiation Health
	Carcinogenesis
	Acute and Late CNS Risks
	Other Degenerative Tissue Risks
	Heredity, Fertility and Sterility Risks
	Acute Radiation Syndromes
	Lunar :
	Environmental Health
	Define Acceptable Limits for Contaminants in Air and Water
	Nutrition
	Inadequate Nutritional Requirements
	Clinical capabilities
	Monitoring & Prevention
	Major Illness & Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
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	Palliative, Mortem, and Post-Mortem Medical Activities
	Radiation Health
	Carcinogenesis
	Acute and Late CNS Risks
	Other Degenerative Tissue Risks
	Heredity, Fertility and Sterility Risks
	Acute Radiation Syndromes
	Mars :
	Environmental Health
	Define Acceptable Limits for Contaminants in Air and Water
	Nutrition
	Inadequate Nutritional Requirements
	Clinical capabilities
	Monitoring & Prevention
	Major Illness & Trauma
	Pharmacology of Space Medicine Delivery
	Ambulatory Care
	Return to Gravity/Rehabilitation
	Insufficient Data/Information/Knowledge Management & Communication Capability
	Skill Determination and Training
	Palliative, Mortem, and Post-Mortem Medical Activities

	Radiation Health
	Carcinogenesis
	Acute and Late CNS Risks
	Other Degenerative Tissue Risks
	Heredity, Fertility and Sterility Risks
	Acute Radiation Syndromes
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Risk Title: Skeletal Muscle Atrophy Resulting in Reduced Strength and Endurance

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Muscle Alterations & Atrophy
Risk Number :	13
Risk Description :	Given that deficits in sensory-motor regulation of muscle-force generation capacity and movement skill occur in space flight, this deficiency could result in an inability or reduced ability/fidelity in performing mission-directed physical activities (especially when the system becomes loaded), as well

	as cause a proneness for muscle/connective tissue (muscle fiber; fiber-tendon; tendon-bone interfaces) damage and soreness, further exacerbating intrinsic muscle performance capacity.
Context/Risk Factors :	Muscle atrophy is the result of sarcopenia or net protein catabolism associated with skeletal muscle unloading and this alteration likely increases compliance of the muscle vascular bed which could impair venous return (i.e., muscle pump) and contribute to orthostatic intolerance upon re-exposure to a gravitational environment and accelerate bone loss due to reductions in muscle tone and the force generating capacity of the muscle and the corresponding reduction of force at the tendon/bone interface
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** Growing database demonstrating that skeletal muscles, particularly postural muscles of the lower limb, undergo atrophy and undergo structural and metabolic alterations during space flight. **Lunar:** Growing database demonstrating that skeletal muscles, particularly postural muscles of the lower limb, undergo atrophy and undergo structural and metabolic alterations during space flight. **Mars:** Growing database demonstrating that skeletal muscles, particularly postural muscles of the lower limb, undergo atrophy and undergo structural and metabolic alterations during space flight.
Current Countermeasures :	**ISS :** Cycle ergometer ; Moderate resistance exercise ; Treadmill **Lunar :** Cycle ergometer ; Moderate resistance exercise ; Treadmill **Mars :** Cycle ergometer ; Moderate resistance exercise ; Treadmill
Projected Countermeasures :	**ISS :** Artificial gravity (e.g., centrifuge with exercise capabilities) ; New programs of heavy resistance exercise (e.g., expanded exercise and loading capabilities) ; Pharmacological interventions **Lunar :** Artificial gravity (e.g., centrifuge with exercise capabilities) ; New programs of heavy resistance exercise (e.g., expanded exercise and loading capabilities) ; Pharmacological interventions **Mars :** Artificial gravity (e.g., centrifuge with exercise capabilities) ; New programs of heavy resistance exercise (e.g., expanded exercise and loading capabilities) ; Pharmacological interventions

Enabling Questions [With Mission Priority]:

No.	Question
13a	What is the time course of skeletal muscle atrophy during an ISS, lunar, and Mars mission? **[ISS 1, Lunar 1, Mars 1]**
13b	Does muscle atrophy of the lower extremity muscles contribute to orthostatic hypotension due to deficiencies in the muscle pump? **[ISS 1, Lunar 1, Mars 1]**
13c	Does skeletal muscle atrophy contribute to the accelerated rate of bone loss in the central and peripheral skeleton because of reduced forces at the tendon insertion sites during long-duration space missions? **[ISS 1, Lunar 1, Mars 1]**
13d	What hardware and/or technologies are currently available, or need to be developed for an ISS, lunar, or Mars mission in order to simulate the type of musculoskeletal loading experienced here on Earth to preserve muscle structure and function? **[ISS 3, Lunar 3, Mars 3]**
13e	What are the effects of skeletal muscle atrophy on whole body metabolism (e.g., insulin and glucose tolerance)? **[ISS 1, Lunar 3, Mars 1]**
13f	Are the deleterious changes that occur in skeletal muscle (atrophy, alterations in contractile phenotype, etc.) during long-duration space flight missions completely reversible upon return to Earth? **[ISS 3, Lunar 3, Mars 3]**

	13g	What combination of exercise and/or hormonal/pharmacological, nutritional and micronutrient supplements are effective in preserving muscle structure and function during ISS, lunar, and Mars missions? **[ISS 1, Lunar 1, Mars 1]**
	13h	What are the appropriate prescription modalities (exercise regimens, artificial gravity, etc.) and the compliance factors needed during an ISS, lunar, and Mars mission to minimize losses in muscle mass and strength? **[ISS 1, Lunar 1, Mars 1]**
	13i	What are the effective resistance exercise modalities (contraction modes) and exercise prescriptions (frequency, intensity, duration) needed to maintain skeletal muscle structure and function during an ISS, lunar, and Mars mission? **[ISS 1, Lunar 1, Mars 1]**
	13j	What are the appropriate prescription modalities (exercise regimens, physical therapy, etc.) and the compliance factors needed to facilitate skeletal muscle rehabilitation in crewmembers returning from microgravity, 1/3-gravity, or 1/6-gravity to Earth gravity? **[ISS 1, Lunar 1, Mars 1]**
	13k	What cellular processes/signaling pathways in skeletal muscle can be identified and targeted (pharmacological, gene therapy, hormones, etc.) to prevent or attenuate fiber atrophy during ISS, lunar, or Mars missions? **[ISS 3, Lunar 3, Mars 3]**
	13l	What practical diagnostic tools (e.g., biochemical markers, ultrasound) can be used during ISS, lunar, and Mars missions to monitor and quantify changes in muscle structure and function? **[ISS 3, Lunar 3, Mars 3]**
	13m	Is the capacity of skeletal muscle to grow or regenerate (satellite cells) compromised during or after a mission because of conditions (e.g., radiation exposure, reduced muscle tension) associated with an ISS, lunar, and Mars mission? **[ISS 3, Lunar 2, Mars 1]**
	13n	What are the temporal relationships between the changes in structure and function of the tendon, muscle and muscle-tendon interface? **[ISS 2, Lunar 2, Mars 2]**
	13o	How do the deficits in skeletal muscle strength associated with long-duration space flight affect the structural/functional properties of the sensory system and motor nerves? **[ISS 1, Lunar 1, Mars 1]**
	13p	Can those resistance exercise paradigms and other activity modalities aimed at counteracting atrophy processes maintain those deficits in muscle strength that appear to occur independent of the atrophy process? **[ISS 1, Lunar 1, Mars 1]**
	13q	What are the bioenergetic, metabolic and substrate-processing factors that contribute to the reductions in skeletal muscle endurance associated with muscle atrophy? **[ISS 1, Lunar 1, Mars 1]**
	13r	Can endurance exercise activities that normally enhance skeletal muscle endurance under weight bearing conditions effectively maintain this property in atrophying muscle when they are performed in microgravity environments? **[ISS 2, Lunar 2, Mars 2]**
	13s	How does the atrophy processs affect the structural and functional properties of connective tissue (tendons), the fiber-tendon interface and the tendon-bone interface? **[ISS 2, Lunar 2, Mars 2]**
	13t	Do resistance-training paradigms that counteract muscle atrophy processes improve the structure-function properties of connective tissue systems? (countermeasure) **[ISS 2, Lunar 2, Mars 2]**
	13u	Do strength-training programs that minimize atrophy processes and strengthen muscle tendon properties that are performed in states of unloading prevent injury from occurring during the return to normal weight bearing states? **[ISS 1, Lunar 1, Mars 1]**
	13v	What are the appropriate prescription modalities (exercise regimens, physical therapy, etc.) and the compliance factors needed to facilitate skeletal muscle rehabilitation in crewmembers returning from the ISS, Moon, or Mars to Earth gravity? **[ISS 1, Lunar 1, Mars 1]**
	13w	What combination of exercise and/or hormonal/pharmacological, nutritional and micronutrient supplements are effective in preserving muscle structure and function during missions to the ISS, Moon, and Mars? **[ISS 2, Lunar 2, Mars 2]**

13x	What hardware and/or technologies are currently available, or need to be developed for an ISS, lunar, and Mars mission in order to simulate the type of musculoskeletal loading experienced here on Earth to preserve muscle structure and function? **[ISS TBD, Lunar TBD, Mars TBD]**
13y	To what extent should transcutaneous electrical stimulation be used as a countermeasure for preserving skeletal muscle structure and function during space flight? **[ISS TBD, Lunar TBD, Mars TBD]**
13z	If a muscle injury occurs during a space flight mission, what criteria will be used to determine when it is safe for a crewmember to resume exercise? **[ISS TBD, Lunar TBD, Mars TBD]**
13aa	Are there assistance devices/technologies that can compensate for losses in muscle mass and strength and prevent injury during a space mission? **[ISS TBD, Lunar TBD, Mars TBD]**
13bb	What are the effects of skeletal muscle atrophy on whole body metabolism? **[ISS TBD, Lunar TBD, Mars TBD]**
13cc	What are the effects of muscle atrophy on thermoregulation? **[ISS TBD, Lunar TBD, Mars TBD]**

Related Risks :

ISS :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Impaired Fracture Healing
Injury to Joints and Intervertebral Structures
Renal Stone Formation
Cardiovascular Alterations
Occurrence of Serious Cardiovascular Dysrhythmias
Diminished Cardiac and Vascular Function
Nutrition
Inadequate Nutritional Requirements

Lunar :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Impaired Fracture Healing
Injury to Joints and Intervertebral Structures
Renal Stone Formation
Cardiovascular Alterations
Occurrence of Serious Cardiovascular Dysrhythmias
Diminished Cardiac and Vascular Function
Nutrition
Inadequate Nutritional Requirements

Mars :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Impaired Fracture Healing
Injury to Joints and Intervertebral Structures
Renal Stone Formation

	Cardiovascular Alterations Occurrence of Serious Cardiovascular Dysrhythmias Diminished Cardiac and Vascular Function **Nutrition** Inadequate Nutritional Requirements
Important References :	Adams GR, Caiozzo VJ, Baldwin KM. Skeletal muscle unweighting: spaceflight and ground-based models. J Appl Physiol 95:2185-201, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=14600160 Antonutto G, Capelli C, Girardis M, Zamparo P, di Prampero PE. Effects of microgravity on maximal power of lower limbs during very short efforts in humans. J Appl Physiol 86: 85-92, 1999. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9887117 Baldwin KM, Edgerton VR, Roy RR. Muscle loss in space: physiological consequences. Encyclopedia of Space Sciences and Technology. Vol. 2; H. Mark, M. Salkin and A. Yousef (eds). John Wiley & Sons, Inc. Hoboken NJ, 2003, pp. 149-166. Convertino VA, Doerr DF, Stein SL. Changes in size and compliance of the calf after 30-days of simulated microgravity. J Appl Physiol. Mar; 66(3):1509-12, 1989. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=2708266 di Prampero PE, Narici MV. Muscles in microgravity: from fibers to human motion. J Biomech.;36(3):403-412, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12594988 Edgerton VR, Zhou MY, Ohira Y, Klitgaard H, Jiang B, Bell G, Harris B, Saltin B, Gollnick PD, Roy RR, et al. Human fiber size and enzymatic properties after 5 and 11 days of space flight. J Appl Physiol May; 78(5):1733-9, 1995 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=7649906 Fitts RH, Riley DR, Widrick JJ. Physiology of a microgravity environment invited review: microgravity and skeletal muscle. J Appl Physiol 89: 823-39, 2000 (Review). http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10926670 LeBlanc A, Lin C, Shackelford L, Sinitsyn V, Evans H, Belichenko O, Schenkman B, Kozlovskaya I, Oganov, V, Bakulin, A, Hedrick T and Feeback, D. Muscle volume, MRI relaxation times (T2) and body composition after space flight. J. Appl. Physiol. 89: 2158-2164, 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11090562 McCall GE, Goulet C, Boorman GI, Roy RR, Edgerton VR. Flexor bias of joint position in humans during spaceflight. Exp Brain Res 152: 87-94. 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12844202 Narici M, Kayser B, Barattini P, Cerretelli P. Changes in electrically evoked skeletal muscle contractions during 17-day space flight and bed rest. Int. J. Sports Medicine 18: S290-S292, 1997. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9391835

	NASA, Space Life Sciences, Final Report Task Force on Countermeasures, (Chair, Kenneth M. Baldwin) May 1997. Appendix E-26.
	Zhou MY, Klitgaard H, Saltin B, Roy RR, Edgerton VR, Gollnick PD. Myosin heavy chain isoforms of human muscle after short-term space flight. J Appl Physiol May; 78(5):1740-4, 1995. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=7649907

Risk Title: Increased Susceptibility to Muscle Damage

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Muscle Alterations & Atrophy
Risk Number :	14
Risk Description :	Given that muscle fiber atrophy and corresponding contractile protein phenotype shifts occur in response to space flight, this deficiency could result in an inability or reduced ability/fidelity in performing mission-directed physical activities, as well as cause a proneness for muscle/connective tissue damage and soreness further exacerbating one's performance.
Context/Risk Factors :	Given the reductions in skeletal muscle size, strength and endurance that result from space flight exposure, there is a greater likelihood of sustaining muscle and/or connective tissue damage and soreness that could result in an inability or reduced ability/fidelity in performing mission-directed physical activities
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** Growing database based on space flight and ground based studies demonstrating that muscle atrophy processes are associated with changes in structural proteins and connective tissues, which could impair performance of various activities during and after ISS, lunar, or Mars missions. **Lunar:** Growing database based on space flight and ground based studies demonstrating that muscle atrophy processes are associated with changes in structural proteins and connective tissues, which could impair performance of various activities during and after ISS, lunar, or Mars missions. **Mars:** Growing database based on space flight and ground based studies demonstrating that muscle atrophy processes are associated with changes in structural proteins and connective tissues, which could impair performance of various activities during and after ISS, lunar, or Mars missions.
Current Countermeasures :	**ISS :** Cycle ergometer ; Moderate resistance exercise ; Treadmill **Lunar :** Cycle ergometer ; Moderate resistance exercise ; Treadmill **Mars :** Cycle ergometer ; Moderate resistance exercise ; Treadmill
Projected Countermeasures :	**ISS :** Artificial gravity (e.g., centrifuge with exercise capabilities) ; New programs of heavy resistance exercise (e.g., expanded exercise and loading capabilities) ; Pharmacological interventions **Lunar :** Artificial gravity (e.g., centrifuge with exercise capabilities) ; New programs of heavy resistance exercise (e.g., expanded exercise and loading capabilities) ; Pharmacological interventions **Mars :** Artificial gravity (e.g., centrifuge with exercise capabilities) ; New programs of heavy resistance exercise (e.g., expanded exercise and loading capabilities) ; Pharmacological interventions

Enabling Questions [With Mission Priority]:	

No.	Question
14a	If a muscle injury occurs during an ISS, lunar or Mars mission, what criteria can be used to determine when it is safe for a crewmember to resume exercise or perform dynamic activities associated with the mission (e.g., EVA/exploration)? **[ISS 1, Lunar 1, Mars 1]**
14b	Do strength-training programs that minimize atrophy processes and strengthen muscle tendon properties that are performed in states of unloading prevent injury from occurring during a mission and upon return to weight bearing states (e.g., 1-G)? **[ISS 1, Lunar 1, Mars 1]**
14c	Do resistance-training paradigms that counteract muscle atrophy processes improve the structure-function properties of connective tissue systems? **[ISS 2, Lunar 2, Mars 2]**
14d	How does the atrophy processes affect the structural and functional properties of connective tissue (tendons), the fiber-tendon interface and the tendon-bone interface? **[ISS 3, Lunar 3, Mars 3]**
14e	Are the deleterious changes that occur in skeletal muscle (atrophy, alterations in contractile phenotype, etc.) during long-duration space flight missions completely reversible upon return to Earth? **[ISS 3, Lunar 3, Mars 3]**
14f	Do the deficits in skeletal muscle associated with long-duration space flight affect the structural/functional properties of the sensory system and motor nerves (e.g., motor unit recruitment strategies within a muscle, altered muscle recruitment strategies for a given joint)? **[ISS 1, Lunar 1, Mars 1]**
14g	What are the appropriate ground-based space flight analog environments that can be used as test beds for evaluating neurological adaptation time constants, adverse operational implications, countermeasures and impacts of adaptation on other anatomical and physiological systems? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

ISS :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Impaired Fracture Healing
Injury to Joints and Intervertebral Structures
Renal Stone Formation

Lunar :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Impaired Fracture Healing
Injury to Joints and Intervertebral Structures
Renal Stone Formation

Mars :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Impaired Fracture Healing
Injury to Joints and Intervertebral Structures
Renal Stone Formation

Important References :

Adams GR, Caiozzo VJ, Baldwin KM. Skeletal muscle unweighting: spaceflight and ground-based models. J Appl Physiol 95:2185-201, 2003.

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	di Prampero PE, Narici MV. Muscles in microgravity: from fibers to human motion. J Biomech.;36(3):403-412, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12594988
	Edgerton VR, Zhou MY, Ohira Y, Klitgaard H, Jiang B, Bell G, Harris B, Saltin B, Gollnick PD, Roy RR, et al. Human fiber size and enzymatic properties after 5 and 11 days of space flight. J Appl Physiol May; 78(5):1733-9, 1995 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=7649906
	Fitts RH, Riley DR, Widrick JJ. Physiology of a microgravity environment invited review: microgravity and skeletal muscle. J Appl Physiol 89: 823-39, 2000 (Review). http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10926670
	LeBlanc A, Lin C, Shackelford L, Sinitsyn V, Evans H, Belichenko O, Schenkman B, Kozlovskaya I, Oganov, V, Bakulin, A, Hedrick T and Feeback, D. Muscle volume, MRI relaxation times (T2) and body composition after space flight. J. Appl. Physiol. 89: 2158-2164, 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11090562
	McCall GE, Goulet C, Boorman GI, Roy RR, Edgerton VR. Flexor bias of joint position in humans during spaceflight. Exp Brain Res 152: 87-94. 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12844202
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	Tidball JG, Quan DM. Reduction in myotendinous junction surface area of rats subjected to 4-day space flight. J Appl Physiol. Jul; 73(1):59-64, 1992. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=1506399
	Zhou MY, Klitgaard H, Saltin B, Roy RR, Edgerton VR, Gollnick PD. Myosin heavy chain isoforms of human muscle after short-term space flight. J Appl Physiol May; 78(5):1740-4, 1995. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=7649907

Risk Title: Vertigo, Spatial Disorientation and Perceptual Illusions

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Neurovestibular Adaptation

Risk Number :	15
Risk Description :	When astronauts transition between gravitational environments, head movements and/or vehicle maneuvering can cause spatial disorientation, perceptual illusions and/or vertigo. Should any of these occur in flight deck crewmembers during critical entry or landing phases it could lead to loss of vehicle. In-flight spatial disorientation can cause operational difficulties during docking and remote manipulation of payloads that can (and has) caused dangerous collisions, while in-flight frame-of-reference illusions, direction vertigo, or navigation problems could cause reaching errors, spatial memory failures, difficulty locating emergency egress routes and/or fear of falling during EVA (height vertigo). While rotational artificial gravity (AG) has great potential as a bone, muscle, cardiovascular and vestibular countermeasure, head movements out of the plane of rotation will produce illusory spinning sensations about an axis orthogonal to the head motion, which may lead to spatial disorientation.
Context/Risk Factors :	Landing0-G exposure duration. (Vertigo is an aftereffect of neurovestibular adaptation to 0-G, which may require several weeks.) ; Manual or supervisory control of vehicle by crewmember during critical phase of flight ; Non-zero gravitational level ; Pilot head movements, especially large or rapid ones. (Head movement contingent vertigo reported in early phases of entry. Orbiter crews routinely make slow practice head movements during entry to initiate re-adaptation) ; Poor visual reference to runway environment. (e.g., approaches at night or with low ceilings or poor visibility or to unfamiliar runway) ; Turbulence or wind shear in approach area ; Vehicle maneuvers (e.g. deceleration on inner glide slope; flare) In-FlightTeleoperations requiring user to cognitively integrate several different views of a work area, or transform commands to a different reference frame ; Physical orientation of 1-G training modules ; Ambiguous visual orientation cues (interior architectural symmetries, rack orientation and labeling, EVA visual cues) ; Inconsistent visual verticals (within and between modules) ; Individual ability differences (mental rotation, perspective taking, and sense of direction)
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** Problem has been with us throughout Shuttle program (e.g. perhaps as early as STS-3), and became recognized after multi-week shuttle missions in late 90s (cf. McCluskey, et al 2001). Currently constrains time on orbit of shuttle pilots, and night and low visibility approaches. Shuttle auto-land capability has not been operationally verified, and contingency landing sites do not have required microwave landing system. Skylab and Shuttle crews described almost universal incidence of occasional in-flight spatial disorientation and frame-of-reference illusions. Mir and ISS crews report susceptibility continues throughout long missions, and are exacerbated by complex 3D station architectures, inconsistent interior visual verticals, and perhaps by physical orientation of their ground trainers. Shuttle crews visiting Mir and ISS occasionally became lost, a concern in case emergency egress was required. EVA crewmembers occasionally report disorientation and disabling fear of falling to Earth. Reference frame integration problems have been noted by Shuttle and ISS teleoperators, and contributed to Mir-Progress collision, and complicated several other emergencies NASA Man System Integration Standard 3000 required locally consistent cue orientation and lighting, but did not address consistency between modules or work areas. However ISS (SSP5005) deleted many MSIS requirements. ISS modules have symmetric cross section and dual visual verticals. **Lunar:** Some degree of manual control and maneuvering will be required for landing at unprepared lunar landing sites. Effects on crew capability of 7 day 0-G transits and 30 day adaptation to lunar 1/6 g, and are currently unknown. Apollo mission durations were less than 15 days. Crews' 1/6 g exposure on lunar surface was limited to 75 hours. No vertigo reported during lunar landing or EVA. Lunar Module did not have auto-land. Command module auto-landed in Earth's ocean. Significant exposure to this risk in 0-G areas of Lunar transit vehicles and 0-G EVA. Teleoperator frame of reference integration problems potentially a factor in Lunar surface operations. **Mars:** Even if Earth and Mars landings are nominally auto-landed, some degree of maneuvering and contingency manual control will be needed for landing at unprepared or contingency sites. Effects of 4-6 month adaptation to 0-G during transit to Mars on astronaut's ability to transition to Mars 1/3 g are unknown. However, large radius continuous AG may be possible. On return to Earth, pilot will

	have adapted to 0-G for 4-6 months, and ISS experience indicates many will experience strong landing vertigo. Significant exposure to this risk in 0-G areas of Mars transit vehicles and 0-G EVAs. Teleoperator frame of reference integration problems potentially a factor in Mars surface operations
Current Countermeasures :	**ISS :** **Landing** CDRs are space flight veterans. CDR flies approach, PLT assists. Previous flight experience may help pilots cope with vertigo ; Re-adaptation head movements during entry. No formal procedure exists. Efficacy is unknown ; Restrictions on night and low ceiling/visibility approaches. Visual approach aids and runway lighting ; Shuttle pilot's 0-G exposure currently limited to 2-3 weeks **In-Flight** Luminous exit placards, and module surface labels ; Pre-flight EVA training using virtual reality techniques ; Pre-flight training in 1-G modules and neutral buoyancy **Lunar :** None **Mars :** None
Projected Countermeasures :	**ISS :** **Landing** Implement shuttle auto-land capability at landing sites ; Correlate shuttle approach flight technical error, vehicle accelerations, head movements, display legibility, post-flight visual acuity, gaze stability, OTTR, and G-excess illusions ; Determine efficacy of re-adaptation head movements during entry ; Evaluate landing vertigo effect on pilots supervisory control capability. ; Evaluate pre-flight or in-flight neurovestibular g-context-specific pre-adaptation techniques (e.g. short radius artificial gravity) and in-flight landing rehearsal simulators. ; Improved standards for workstation and spacecraft interior architecture ; Improved teleoperator displays ; Quantitative metrics for visual symmetry and polarity cues ; Redesign cockpit procedures and displays (e.g. flight director) to minimize head movements and accelerations, and to improve legibility during vertigo ; Validated spatial ability tests to predict and improve individual performance ; Pre-flight visual orientation training for IVA activities using VR techniques[CRL 2-5] **Lunar :** **Landing** Auto-land capability on lunar or Mars landing and return vehicles ; Pre-flight or in-flight g-specific pre-adaptation techniques, (e.g. artificial gravity) **Mars :** **Landing** Auto-land capability on lunar or Mars landing and return vehicles ; Pre-flight or in-flight g-specific pre-adaptation techniques, (e.g. artificial gravity)
Enabling Questions [With Mission Priority]:	(see table below)

No.	Question
15a	What are the physiological bases for spatial disorientation, perceptual illusions, and vertigo? **[ISS 1, Lunar 1, Mars 1]**
15b	What combinations of visual, vestibular, and haptic cues cause spatial disorientation, perceptual illusions, and vertigo during and after g-transitions? **[ISS 2, Lunar 2, Mars 2]**
15c	Can g-transition-related spatial disorientation, perceptual illusions, and vertigo be predicted from mathematical models? **[ISS 3, Lunar 3, Mars 3]**
15d	What individual physiological and behavioral characteristics contribute to the large inter-individual differences in neurovestibular symptoms and signs? **[ISS 1, Lunar 1, Mars 1]**
15e	What individual physiological and behavioral characteristics will best predict susceptibility and adaptability **[ISS 3, Lunar 3, Mars 3]**
15f	What is the physiological basis for context-specific-adaptation? **[ISS 1, Lunar 1, Mars 1]**
15g	To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context-specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness? **[ISS 2, Lunar 2, Mars 2]**
15h	What preflight training techniques (e.g. virtual reality simulations, parabolic flight) can be used to alleviate the risks of spatial disorientation, perceptual illusions, and vertigo as astronauts launch, enter, and adapt to 0-G? **[ISS 2, Lunar 2, Mars 2]**

	15i	What in-flight training techniques (e.g. virtual reality simulations, treadmill with vibration isolation system, artificial gravity) can be used to alleviate the risks of vertigo, disorientation, and perceptual illusions as astronauts land and (re)adapt to Earth, Moon, or Mars gravity? **[ISS 3, Lunar 3, Mars 3]**
	15j	How can voluntary head movements during entry and landing be used to accelerate re-adaptation? **[ISS 3, Lunar 3, Mars 3]**
	15k	Is adaptation to the lunar gravity environment sufficient to reduce incidence of landing vertigo upon return to Earth? **[Lunar 3]**
	15l	What artificial gravity exposure regimens (g level, angular velocity, duration, and repetition) will ameliorate the bone, muscle, cardiovascular, and vestibular deconditioning associated with hypogravity during surface operation phases of a mission? **[Lunar 5, Mars 5]**
	15m	What artificial gravity exposure regimens (g level, angular velocity, duration, and repetition) will ameliorate the bone, muscle, cardiovascular, and vestibular deconditioning associated with hypogravity during transit phases of a mission? **[Lunar 5, Mars 5]**
	15n	What level of supervisory control will mitigate the landing vertigo risk in landing on the Moon, Mars, and Earth? **[ISS 4, Lunar 4, Mars 4]**
	15o	How can traditional clinical vestibular rehabilitation techniques be employed to usefully accelerate readaptation following g-transitions? **[ISS 3, Lunar 3, Mars 3]**
	15p	What objective assessment techniques can be used to determine crew readiness to return to normal activities following g transitions? **[ISS 2, Lunar 2, Mars 2]**
Related Risks :	**ISS :**	
		Space Human Factors Engineering
		Mismatch between Crew Physical Capabilities and Task Demands
		Mis-assignment of Responsibilities within Multi-agent Systems
	Lunar :	
		Space Human Factors Engineering
		Mismatch between Crew Physical Capabilities and Task Demands
		Mis-assignment of Responsibilities within Multi-agent Systems
	Mars :	
		Space Human Factors Engineering
		Mismatch between Crew Physical Capabilities and Task Demands
		Mis-assignment of Responsibilities within Multi-agent Systems
Important References :		Baldwin, et al (1997) NASA Task Force on Countermeasures, Final Report. Appendix E
		Guedry, F.E. and A.J. Benson. Coriolis cross-coupling effects: Disorienting and nauseogenic or not? Aviation, Space, and Environmental Medicine 49(1): 29-35, 1978. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=304719
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Risk Title: Impaired Movement Coordination Following G-Transitions

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Neurovestibular Adaptation
Risk Number :	16
Risk Description :	When astronauts adapt to 0-G transition to an Earth, Moon, or Martian gravitational environment, balance, locomotion and eye-head coordination are transiently disrupted. Some symptoms may be masked by sensory substitution, only to emerge unexpectedly in response to changing sensory affordance contexts. Muscle atrophy and orthostatic hypotension may also contribute to post-flight balance and locomotion impairment. Some long-duration crewmembers have been unable to egress the spacecraft unassisted in 1-G, so affected crew are at an increased risk of emergency at or soon after landing. There are large individual differences, but recovery of normal abilities requires several days to weeks. Recovery time increases as the 0-G exposure time increases. Lower extremity coordination is often the slowest to return. Post-flight rehabilitation currently employs only traditional methods and may not be optimal. Sensory-motor changes on long-duration flights increases the potential risk of post-landing falls and bone fractures and delays safe return to normal daily activities (running, driving and flying).
Context/Risk Factors :	Cardio-regulatory changes or reduced blood volume increasing susceptibility to fainting ; Muscle alterations and atrophy due to lack of appropriate 0-G exercise ; Physical activity leading to head movement, or requiring visual acuity (e.g. running, operation of a vehicle or aircraft) ; The longer a crewmember is exposed to 0-G, generally the more profound and long lasting the post-flight symptoms ; Zero-g exposure duration
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** Shuttle post-landing emergency egress requires crew to stand up, operate a hatch, attach and lower themselves on a tether, and run away from the vehicle. Cardiovascular and musculo-skeletal countermeasures have mitigated the incidence of muscle weakness, fatigue, and fainting, but many returning crews still exhibit clinically and operationally significant post-flight neurovestibular signs. Long duration crews currently undergo a post-flight physical rehabilitation program based on traditional techniques. Flight surgeons have taken a conservative clinical approach, and no NASA crewmembers have had post-flight fractures or auto accidents. However, none have been able to run 1000 feet on a treadmill on landing day. Animal experiments indicate the vestibular system may play a role in cardiovascular orthostatic regulation. **Lunar:** Apollo EVA crews adopted a loping gait in the 1/6 g lunar environment. No reported vertigo and coordination problems. Fracture risks in 1/6 g likely minimal. Primary risks are after return to Earth after long duration (44 day) missions. **Mars:** Mars landings may be in unprepared areas, so posture and locomotion ability in 1/3 g immediately after landing is potentially important in emergencies. Fracture risk in 1/3 g not yet determined, and will depend on countermeasures available in transit vehicle. Mars transit vehicles may use

	intermittent or continuous AG to pre-adapt crews for Mars surface operations, and to prepare crews for return to Earth.
Current Countermeasures :	**ISS :** Quantitative post-flight tests of spontaneous, positional and positioning nystagmus, postural stability, dynamic visual acuity, and gait (TRL/CRL8) ; Traditional clinical rehabilitation techniques **Lunar :** None **Mars :** None
Projected Countermeasures :	**ISS :** General or G-specific pre-adaptation techniques, (e.g. in-flight or pre-flight artificial gravity; sensory -motor generalization training techniques ; 1-G balance prostheses (e.g. tactile vest, TRL/CRL6) ; Quantitative post-flight tests of gaze stability, and locomotion and corner turning stability (TRL 6, CRL 6) **Lunar :** Pre-flight or in-flight g- specific pre-adaptation techniques, (e.g. artificial gravity) (CRL2, TRL1) **Mars :** Improved EVA suits designed to mechanically mitigate fracture risk in the event of falls ; G-specific pre-adaptation for Mars landing (e.g. short radius intermittent or large radius continuous artificial gravity) and return to Earth
Enabling Questions [With Mission Priority]:	(see table below)

No.	Question
16a	What are the physiological bases for disruption of balance, locomotion, and eye-head coordination following g-transitions? **[ISS 1, Lunar 1, Mars 1]**
16b	Can disruption of balance, locomotion, and eye-head coordination following g-transitions be predicted from mathematical models? **[ISS 3, Lunar 3, Mars 3]**
16c	What individual physiological and behavioral characteristics contribute to the large inter -individual differences in neurovestibular symptoms and signs? **[ISS 1, Lunar 1, Mars 1]**
16d	What individual physiological and behavioral characteristics will best predict susceptibility and adaptability? **[ISS 3, Lunar 3, Mars 3]**
16e	What is the physiological basis for context-specific-adaptation? **[ISS 1, Lunar 1, Mars 1]**
16f	To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context-specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering impaired balance control and/or movement coordination? **[ISS 2, Lunar 2, Mars 2]**
16g	What in-flight training techniques (e.g. virtual reality simulations, treadmill with vibration isolation system, artificial gravity) can be used to alleviate the risks of impaired balance control and movement coordination as astronauts land and (re)adapt to Earth, Moon, or Mars gravity? **[ISS 3, Lunar 3, Mars 3]**
16h	Is adaptation to the lunar gravity environment sufficient to reduce incidence of sensory-motor balance and coordination problems upon return to Earth? **[Lunar TBD]**
16i	What artificial gravity exposure regimens (g level, angular velocity, duration, and repetition) will ameliorate the bone, muscle, cardiovascular, and vestibular deconditioning associated with hypogravity during surface operation phases of a mission **[Lunar TBD, Mars TBD]**
16j	What artificial gravity exposure regimens (G level, angular velocity, duration, and repetition) will ameliorate the bone, muscle, cardiovascular, and vestibular deconditioning associated with hypogravity during transit phases of a mission? **[Mars TBD]**
16k	How can traditional clinical vestibular rehabilitation techniques be employed to usefully accelerate readaptation following g-transitions? **[ISS TBD, Lunar TBD, Mars TBD]**
16l	What objective assessment techniques can be used to determine crew readiness to return to normal activities following g transitions? **[ISS TBD, Lunar TBD, Mars TBD]**
16m	How can preflight or in-flight sensory-motor training or sensory aids improve post-landing postural and locomotor control and orthostatic tolerance? **[ISS TBD, Lunar TBD, Mars TBD]**

16n	To what extent can crew "learn how to learn" by adapting to surrogate sensory-motor rearrangements? **[ISS TBD, Lunar TBD, Mars TBD]**
16o	What are the relative contributions of sensory-motor adaptation, neuromuscular deconditioning, and orthostatic intolerance to postflight neuro-motor coordination, ataxia, and locomotion difficulties? **[ISS TBD, Lunar TBD, Mars TBD]**
16p	What posture, locomotion and gaze deficits result from transition to Mars gravity and Moon gravity? **[ISS TBD, Lunar TBD, Mars TBD]**

Related Risks :

ISS :

Cardiovascular Alterations
Occurrence of Serious Cardiovascular Dysrhythmias
Diminished Cardiac and Vascular Function
Neurovestibular Adaptation
Vertigo, Spatial Disorientation and Perceptual Illusions
Impaired Movement Coordination Following G-Transitions
Motion Sickness
Nutrition
Inadequate Nutritional Requirements

Lunar :

Neurovestibular Adaptation
Vertigo, Spatial Disorientation and Perceptual Illusions
Impaired Movement Coordination Following G-Transitions
Motion Sickness

Mars :

Neurovestibular Adaptation
Vertigo, Spatial Disorientation and Perceptual Illusions
Impaired Movement Coordination Following G-Transitions
Motion Sickness

Important References :

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Risk Title: Motion Sickness

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Neurovestibular Adaptation
Risk Number :	17
Risk Description :	Motion sickness symptoms frequently occur in crewmembers during and after G-transitions. Symptoms include nausea, stomach awareness, gastrointestinal stasis, anorexia, dehydration and less overt but operationally significant symptoms such as "space stupids," irritability, profound fatigue ("sopite" syndrome) and changes in sleep-wake cycle. Motion sickness symptoms decrease crew work capacity, vigilance and motivation, impair short-term memory and increase the likelihood of cognitive error. Although only 10-20% of Shuttle crews vomit, 75% experience symptoms for the first 2-4 days in 0-G and many experience similar symptoms for hours to days after landing. Several crewmembers have remained symptomatic during flight for up to two weeks. Current anti-motion sickness drugs are only partially effective. Though they appear to reduce symptoms and delay onset, they have significant side effects that prevent regular prophylactic use. While rotational AG has great potential as a bone, muscle, cardiovascular and vestibular countermeasure, head movements out of the plane of rotation may lead to motion sickness. How provocative the AG stimulus is at levels between 0 and 1-G and how rapidly and completely humans can adapt is largely unknown and cannot be fully determined in ground laboratories. If motion sickness drives an EVA crewmember to vomit in the extant extravehicular mobility unit (EMU), a complete shutdown of the primary and secondary oxygen supplies could occur, leaving only a few minutes of residual oxygen in the suit, creating a serious emergency. Vomit on the faceplate could also block vision. Even if the crewmember survives, vomit is biologically active, so the EMU cannot be reused and must be returned to the ground for refurbishment.
Context/Risk Factors :	Initial week of exposure to altered gravity ; Head movements and visual cues causing frame-of-reference illusions ; Diseases, conditions or drugs which cause nausea and vomiting (gastroenteritis, contaminated food or water, certain medications, pregnancy)
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Mars:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space.
Justification :	**ISS:** Mercury and Gemini crews were restrained in their capsules, and did not report sickness. Primary stimuli are clearly head movements and frame-of-reference illusions resulting from 3D movement. Crews move slowly and stay upright to limit symptoms. Prior space flight experience reduces susceptibility. Apollo, Skylab and early Shuttle crews took prophylactic oral scopolamine/dexedrine or promethazine/ephedrine, with limited effectiveness, and sometimes objectionable side-effects. Symptoms are currently treated with intramuscular promethazine and sleep/rest, but injections leave a painful sore spot. Early US and Russian programs implemented aerobatic flight and various forms

	of extreme vestibular stimulation as pre-flight countermeasures, and use of Coriolis induced sickness susceptibility as a predictor, without demonstrable success, though many crew believe aerobatic and parabolic flight practice should be helpful. NASA developed TransdermScop patch in early 80s, but effectiveness and side effects were too variable for deployment. Russians deployed neck restraints and foot-pressure-inducing boots, but there is no data showing effectiveness. Biofeedback/autogenic training techniques can be effective against laboratory induced sickness, but flight evaluations have been equivocal, and techniques may not be usable by everyone. **Lunar:** Several Apollo crews retrospectively reported symptoms in Earth orbit, and on the way to the moon. No symptoms reported on lunar surface. One report of symptoms during 0-G return. **Mars:** Crew will be potentially susceptible to motion sickness for several days after each major G-level change during the mission (1-G to 0-G to AGto 0-G to 0-G to Martian-g to 0-G to artificial-g to 0-G to Earth-g.)
Current Countermeasures :	**ISS :** Head and body movement restriction ; Intramuscular promethazine injection ; Oral Promethazine/Ephedrine ; Oral Scopolamine/Dexedrine **Lunar :** Head and body movement restriction ; Intramuscular promethazine injection ; Oral Promethazine/Ephedrine ; Oral Scopolamine/Dexedrine **Mars :** Head and body movement restriction ; Intramuscular promethazine injection ; Oral Promethazine/Ephedrine ; Oral Scopolamine/Dexedrine
Projected Countermeasures :	**ISS :** New administration methods for rapid, reliable relief with fewer side effects ; Techniques to quantify cognitive deficits **Lunar :** **Mars :** Large radius continuous or short radius intermittent AG

Enabling Questions [With Mission Priority]:

No.	Question
17a	What are the physiological mechanisms that trigger vomiting in space motion sickness? **[ISS 1, Lunar 1, Mars 1]**
17b	What is the physiological basis of the emetic linkage between vestibular and emetic centers? **[ISS 2, Lunar 2, Mars 2]**
17c	What individual physiological and behavioral characteristics contribute to the large inter -individual differences in neurovestibular symptoms and signs? **[ISS 1, Lunar 1, Mars 1]**
17d	What individual physiological and behavioral characteristics will best predict susceptibility and adaptability? **[ISS 3, Lunar 3, Mars 3]**
17e	What is the physiological basis for context-specific-adaptation? **[ISS 1, Lunar 1, Mars 1]**
17f	To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context-specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness? **[ISS 3, Lunar 3, Mars 3]**
17g	What preflight training techniques (e.g. virtual reality simulations, parabolic flight) can be used to alleviate the risks of space motion sickness? **[ISS 4, Lunar 4, Mars 4]**
17h	What in-flight training techniques (e.g. virtual reality simulations, treadmill with vibration isolation system, artificial gravity) can be used to alleviate the risks of space motion sickness as astronauts land and (re)adapt to Earth, Moon, or Mars gravity **[ISS 4, Lunar 4, Mars 4]**
17i	Is adaptation to the lunar gravity environment sufficient to reduce incidence of motion sickness upon return to Earth? **[Lunar 4]**
17j	Is adaptation to the lunar gravity environment sufficient to reduce incidence of motion sickness upon return to Earth? **[Lunar 5, Mars 5]**
17k	What artificial gravity exposure regimens (g level, angular velocity, duration, and repetition) will ameliorate the bone, muscle, cardiovascular, and vestibular deconditioning associated with hypogravity during transit phases of a mission? **[Mars 5]**

17l	How does susceptibility to motion sickness due to Coriolis forces and cross-coupled canal stimuli vary as a function of g-levels between 0-G and 1-G, and also on RPM, radius, and head orientation during AG? **[Lunar 1, Mars 1]**
17m	What are the best methods for quantifying the symptoms and signs of motion sickness and associated performance decrements and drug side effects in a non-intrusive way? **[ISS 2, Lunar 2, Mars 2]**
17n	What better ways can be found to administer anti-motion sickness drugs to provide more rapid and reliable relief, with fewer objectionable side effects? **[ISS 3, Lunar 3, Mars 3]**
17o	Do scopolamine and promethazine prevent or impair sensory-motor adaptation to 0-G? **[ISS 4, Lunar 4, Mars 4]**
17p	What new drugs will more specifically prevent nausea, fatigue, memory and vigilance deficits without side effects? **[ISS 4, Lunar 4, Mars 4]**
17q	Can drugs be developed to effectively block the emetic linkage without unacceptable side effects? **[ISS 4, Lunar 4, Mars 4]**
17r	Can operationally practical, non-pharmacologic techniques be developed that are effective against motion sickness? **[ISS 4, Lunar 4, Mars 4]**
17s	Is 1/6-G lunar gravity or 3/8-Mars gravity adequate to prevent all cases of motion sickness? **[ISS 4, Lunar 4, Mars 4]**

Related Risks :

ISS :

Human Behavior & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems

Lunar :

Human Behavior & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems

Mars :

Human Behavior & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems

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Risk Title: Inadequate Nutritional Requirements

Theme :	Human Health and Countermeasures (HH&C)
Discipline :	Nutrition
Risk Number :	18
Risk Description :	Without scientifically supported nutritional requirements, a food system cannot be developed to support astronaut health. Nutritional requirements for space include fluids, macronutrients, micronutrients and compounds or elements that may be essential and may include compounds that may be required to optimize health status such as lipids, energy distribution (e.g., % calories from carbohydrate), fiber, and non-nutritive factors such as various phytochemicals, etc. Requirements must take into account any changes in the sensory system that might influence taste and smell influence intake, and the role of countermeasure-induced alterations on nutrient requirements.
Context/Risk Factors :	For missions where in situ food production are required, failure of this system would be an associated risk as well ; Psychosocial factors, elevated stress and boredom all contribute to this risk ; Undefined nutritional requirements causing inability to provide nutritional foods, exacerbate substandard food intakes, countermeasure-induced alterations in nutrient requirements leading to poor countermeasure performance; e.g., bone, muscle, immune system and radiation protection
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** Essentially all US crews have experienced nutritional deficiencies. Limited foods, physiological

<table>
<tr><td></td><td>changes, stress and other factors may have consequences for physical and cognitive performance. Inadequate micronutrient or vitamin intake could adversely affect crew health, making determination of all required nutrients (absorption, metabolism, excretion) a priority. Furthermore, nutrition/nutrients may play a role in counteracting the negative effects of space flight (e.g., radiation, bone and muscle loss). These have yet to be fully explored.
Lunar:
Essentially all US crews have experienced nutritional deficiencies. Limited foods, physiological changes, stress and other factors may have consequences for physical and cognitive performance. Inadequate micronutrient or vitamin intake could adversely affect crew health, making determination of all required nutrients (absorption, metabolism, excretion) a priority. Furthermore, nutrition/nutrients may play a role in counteracting the negative effects of space flight (e.g., radiation, bone and muscle loss). These have yet to be fully explored.
Mars:
Essentially all US crews have experienced nutritional deficiencies. Limited foods, physiological changes, stress and other factors may have consequences for physical and cognitive performance. Inadequate micronutrient or vitamin intake could adversely affect crew health, making determination of all required nutrients (absorption, metabolism, excretion) a priority. Furthermore, nutrition/nutrients may play a role in counteracting the negative effects of space flight (e.g., radiation, bone and muscle loss). These have yet to be fully explored.</td></tr>
<tr><td>Current Countermeasures :</td><td>ISS :
The countermeasure is the provision of adequate diet to maintain health and to provide correct nutrient and non-nutrient proportions to prevent problems due to bone and muscle loss, radiation and potential changes in immune function. This has not been implemented (e.g., food system limitations), utilized (e.g., inadequate intake), or evaluated (e.g., lack of research) fully to determine whether the current provisions are fully meeting requirements
Lunar :
The countermeasure is the provision of adequate diet to maintain health and to provide correct nutrient and non-nutrient proportions to prevent problems due to bone and muscle loss, radiation and potential changes in immune function. This has not been implemented (e.g., food system limitations), utilized (e.g., inadequate intake), or evaluated (e.g., lack of research) fully to determine whether the current provisions are fully meeting requirements
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<tr><td>Projected Countermeasures :</td><td>ISS :
Food, nutrients, improved dietary compliance and counseling, enhanced food system. Provide diet and nutritional supplementation that ensures and/or enhances the effectiveness of other countermeasures. Nutritional requirements must include the role of food in psychosocial needs. Refined nutritional requirements, understanding and implementing an acceptable food system and understanding the psychological benefits of food all may serve as potential countermeasures [TRL/CRL TBD]
Lunar :
Food, nutrients, improved dietary compliance and counseling, enhanced food system. Provide diet and nutritional supplementation that ensures and/or enhances the effectiveness of other countermeasures. Nutritional requirements must include the role of food in psychosocial needs. Refined nutritional requirements, understanding and implementing an acceptable food system and understanding the psychological benefits of food all may serve as potential countermeasures [TRL/CRL TBD]
Mars :
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<tr><td>Enabling Questions [With Mission Priority]:</td><td><table><tr><th>No.</th><th>Question</th></tr><tr><td>18a</td><td>What are the nutritional requirements for extended stay ISS missions, including (but not limited to): calories, protein, calcium, iron, antioxidants, iodine, vitamin D, sodium, potassium? [ISS 1, Lunar 1, Mars 1]</td></tr></table></td></tr>
</table>

18b	What are the potential impacts of countermeasures on nutritional requirements or nutritional status? **[ISS 1, Lunar 1, Mars 1]**
18c	What are the decrements in nutritional status due to long-term LEO, lunar, and exploration missions? **[ISS 1, Lunar 1, Mars 1]**
18d	What are the means of monitoring nutritional status during the mission? **[ISS 3, Lunar 3, Mars 3]**
18e	What monitoring (biochemical, anthropometric, clinical assessments) during rehabilitation is required? **[ISS 3, Lunar 3, Mars 3]**
18f	What level of dietary counseling is needed for crewmembers during rehabilitation? **[ISS 3, Lunar 3, Mars 3]**
18g	Can general nutrition or specific nutrient countermeasures mitigate the negative effects of space flight on bone, muscle, cardiovascular and immune, systems and protect against damage from radiation? **[ISS 1, Lunar 1, Mars 1]**
18h	What is the role of adequate nutrition/weight maintenance on crew health (specifically bone, muscle and cardiovascular adaptation)? **[ISS 1, Lunar 2, Mars 1]**
18i	What level of dietary counseling is needed for crewmembers pre-flight? **[ISS 1, Lunar 2, Mars 1]**
18j	How does on-orbit exercise affect nutritional requirements and vice versa? **[ISS 1, Lunar 2, Mars 1]**
18k	Can nutrition mitigate radiation induced cataractogenesis and carcinogenesis? **[ISS 1, Lunar 1, Mars 1]**
18l	Are there long-term effects of disease risk post-flight and can nutritional countermeasures be preventative? **[ISS 1, Lunar 2, Mars 1]**

Related Risks :

ISS :

Bone Loss
Accelerated Bone Loss and Fracture Risk
Impaired Fracture Healing
Renal Stone Formation
Cardiovascular Alterations
Diminished Cardiac and Vascular Function
Muscle Alterations & Atrophy
Skeletal Muscle Atrophy Resulting in Reduced Strength and Endurance
Increased Susceptibility to Muscle Damage
Neurovestibular Adaptation
Motion Sickness
Radiation Health
Carcinogenesis
Acute and Late CNS Risks
Other Degenerative Tissue Risks
Heredity, Fertility and Sterility Risks
Acute Radiation Syndromes
Advanced Life Support (ALS)
Manage Waste
Provide and Maintain Bioregenerative Life Support Systems
Provide and Recover Potable Water
Cross Discipline

	Inadequate Mission Resources for the Human System
	Lunar :
	Bone Loss
	Accelerated Bone Loss and Fracture Risk
	Impaired Fracture Healing
	Renal Stone Formation
	Cardiovascular Alterations
	Diminished Cardiac and Vascular Function
	Muscle Alterations & Atrophy
	Skeletal Muscle Atrophy Resulting in Reduced Strength and Endurance
	Increased Susceptibility to Muscle Damage
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	Motion Sickness
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	Acute and Late CNS Risks
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	Acute Radiation Syndromes
	Advanced Life Support (ALS)
	Manage Waste
	Provide and Maintain Bioregenerative Life Support Systems
	Provide and Recover Potable Water
	Cross Discipline
	Inadequate Mission Resources for the Human System
	Mars :
	Bone Loss
	Accelerated Bone Loss and Fracture Risk
	Impaired Fracture Healing
	Renal Stone Formation
	Cardiovascular Alterations
	Diminished Cardiac and Vascular Function
	Muscle Alterations & Atrophy
	Skeletal Muscle Atrophy Resulting in Reduced Strength and Endurance
	Increased Susceptibility to Muscle Damage
	Neurovestibular Adaptation
	Motion Sickness
	Radiation Health
	Carcinogenesis
	Acute and Late CNS Risks
	Other Degenerative Tissue Risks
	Heredity, Fertility and Sterility Risks

	Acute Radiation Syndromes **Advanced Life Support (ALS)** Manage Waste Provide and Maintain Bioregenerative Life Support Systems Provide and Recover Potable Water **Cross Discipline** Inadequate Mission Resources for the Human System
Important References :	NASA Johnson Space Center. Nutritional Requirements for International Space Station Missions Up To 360 Days. JSC-28038; 1996. Nutrition 18:793-936, 2002. (volume dedicated to nutrition and space, >20 articles)

Risk Title: Monitoring & Prevention

Theme :	Autonomous Medical Care (AMC)
Discipline :	Clinical capabilities
Risk Number :	19
Risk Description :	Monitoring and Prevention (Health Tracking, Prophylaxis & Disease Prevention). The primary means to reduce the risk of life and/or mission-threatening medical conditions is to prevent those conditions from happening. The second most effective means to reduce such risk is to monitor for medical conditions so as to catch them at an early stage to treat.
Context/Risk Factors :	Family history ; Medical history ; Pre-flight screening ; Pre-mission screening
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.
Justification :	**ISS:** TBD **Lunar:** TBD **Mars:** TBD
Current Countermeasures :	**ISS :** Annual comprehensive physical exam ; In-flight examination ; Selection criteria for astronauts to become active and to be selected for a mission **Lunar :** Annual comprehensive physical exam ; In-flight examination ; Selection criteria for astronauts to become active and to be selected for a mission **Mars :** Annual comprehensive physical exam ; In-flight examination ; Selection criteria for astronauts to become active and to be selected for a mission
Projected Countermeasures :	**ISS :** Additional screening criteria ; Better equipment to monitor and track health in-flight **Lunar :** Additional screening criteria ; Better equipment to monitor and track health in-flight **Mars :** Additional screening criteria ; Better equipment to monitor and track health in-flight

Enabling Questions [With Mission Priority]:

No.	Question
	Health Tracking
19a	Define the key parameters for health screening and early detection. **[ISS 4, Lunar 2, Mars 1]**
19b	Identify what resources and technologies are required for routine health monitoring, including examination, laboratory, imaging and adaptation for operation in reduced-G environments **[ISS 4, Lunar 2, Mars 1]**
19c	What diagnostic imaging technologies and procedures need to be developed and/or adapted to support the primary, secondary and tertiary prevention of illness and injury? **[ISS 3, Lunar 2, Mars 1]**
19d	Identify the parameters and sensors needed to monitor health and performance in crewmembers performing EVA **[ISS 4, Lunar 2, Mars 2]**
19e	Identify the investigations needed to discriminate between terrestrial and space flight norms in order to allow early detection of illness and injury. **[ISS 3, Lunar 2, Mars 2]**
19f	What is space-normal physiology? **[ISS 4, Lunar 3, Mars 3]**
19g	What are the signs, symptoms or abnormal examination findings (including laboratory) associated with illness and injury in reduced-G? **[ISS TBD, Lunar TBD, Mars TBD]**
19h	How do alterations in space flight-associated physiology interact across body systems? **[ISS 4, Lunar 3, Mars 3]**
19i	Identify the appropriate informatics tools to automate monitoring crew health (i.e., prompting screening evaluations, off-nominal value detection, intelligent diagnostic work-up), in order to free-up crew time. **[ISS 2, Lunar 1, Mars 1]**
	Prophylaxis/Disease Prevention
19j	Identify the ideal set of nutritional and medical prophylaxis and primary and secondary preventive measures to reduce the risk of space illness. (such as medical countermeasures for known conditions e.g., bisphosphonates for loss of BMD). **[ISS 3, Lunar 2, Mars 2]**
19k	Identify the primary, secondary and tertiary prevention strategies needed to mitigate the risk of anticipated environmental exposures to toxic substances and radiation.(i.e., shielding, nutritional and medical prophylaxis such as agents to augment cellular defenses, immune surveillance, etc.). **[ISS 2, Lunar 1, Mars 1]**
19l	What are the essential technologies, resources, procedures, skills and training necessary to provide effective primary prevention strategies to mitigate each of the conditions listed in the SMCCB-approved Space Medicine Condition List (catalogued in the online Patient Condition Database)? **[ISS 4, Lunar 3, Mars 2]**
19m	What are the essential technologies, resources, procedures, skills and training necessary to provide effective secondary prevention strategies to mitigate each of the conditions listed in the SMCCB-approved Space Medicine Condition List (catalogued in the online Patient Condition Database)? **[ISS 4, Lunar 3, Mars 2]**

Related Risks :

ISS :

Human Behavior & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems

Lunar :

Human Behavior & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands

	Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Mars :** **Human Behavior & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
Important References :	

Risk Title: Major Illness & Trauma

Theme :	Autonomous Medical Care (AMC)
Discipline :	Clinical capabilities
Risk Number :	20
Risk Description :	Major Illness & Trauma (Diagnosis, Management, CPR, BCLS, ACLS, BTLS, ATLS, DCS, Toxic Exposure- Detection and Management, Surgical Management, Medical Waste Management). There is a risk of major illness that increases with length of mission. There is always a risk of trauma, which can vary according to activities (e.g. construction, vehicle driving, etc.) Lack of capability to treat these major illnesses and injuries poses a threat to life and mission.
Context/Risk Factors :	TBD
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth. **Mars:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.
Justification :	**ISS:** TBD **Lunar:** **Mars:**
Current Countermeasures :	**ISS :** Transport to terrestrial care facility ; Ventilator ; Defibrillator ; ISS Medical Kit **Lunar :** Transport to terrestrial care facility ; Ventilator ; Defibrillator ; ISS Medical Kit **Mars :** Transport to terrestrial care facility ; Ventilator ; Defibrillator ; ISS Medical Kit
Projected Countermeasures :	**ISS :** TBD **Lunar :** TBD **Mars :** TBD
Enabling Questions [With Mission Priority]:	

No.	Question
20a	What are the essential technologies, resources, procedures, skills and training necessary to provide effective tertiary prevention strategies to mitigate each of the conditions listed in the SMCCB-approved Space Medicine Condition List (catalogued in the online Patient Condition Database)? **[ISS 3, Lunar 1, Mars 1]**

20b	Identify the technologies for employing decision support techniques for diagnostic assistance of the crew medical personnel, emphasizing autonomy in decision-making from ground resources and based on known space flight illnesses and injuries and expedition analog experience. **[ISS 2, Lunar 1, Mars 1]**
20c	Define the appropriate role and resources required for telemedical consultation for the diagnosis and management of major illnesses. **[ISS 3, Lunar 2, Mars 1]**
Major Illness Treatment	
20d	Identify and adapt for reduced-G operation the resources, procedures and technologies are required for treatment of major illnesses, emphasizing autonomy from ground resources and based on known space flight illnesses and injuries and expedition analog experience. **[ISS 2, Lunar 1, Mars 1]**
20e	Identify appropriate synergistic and alternative management strategies for reducing the morbidity of major illnesses during space flight. **[]**
20f	What procedures and protocols are necessary for rehabilitation after an acute medical illness or trauma? **[ISS 4, Lunar 3, Mars 1]**
CPR/BCLS/ACLS (Cardiac Life Support)	
20g	What is the most effective means of conducting life support operations in the space flight milieu, to include identification and modification of the resources and procedures for reduced-G? **[ISS 3, Lunar 2, Mars 1]**
20h	Identify the optimal resources and procedures for post-resuscitation management of the ill/injured crewmember and modify for reduced-G operations. **[ISS 2, Lunar 1, Mars 1]**
Decompression Illness (DCS) & Other Environmental Illness	
20k	What is the most effective pre-EVA DCS prevention strategy to include pre-breathe with various gases, exercise and other medical measures? **[ISS 5]**
20l	What are the appropriate screening procedures to minimize predispositions for DCS? **[ISS 4]**
20m	Identify the resources and techniques for early diagnosis of DCS signs and symptoms, including the use of Doppler U/S and other bubble detection technologies. **[ISS 4]**
20n	What are the best methods for predicting DCS risk and for reducing the risk, based on understanding of the physiological mechanism for bubble formation and propagation, employing best available knowledge from flight and analog environment experience? **[ISS 4]**
20o	Identify and adapt for reduced-G operations the most effective yet energy and space-efficient, as well as safe means of managing DCS in the space flight milieu, including the use of hyperbaric oxygen delivery and other promising technology. [ISS 3, moon 2, Mars 1] **[ISS 3, Lunar 2, Mars 1]**
20p	What is the actual risk of space-related DCS? (from both de novo physiological causes and through acute environmental insult - e.g., leaking module or damaged EMU etc.?) **[ISS 3, Lunar 3, Mars 3]**
20q	What are the operational and medical impacts of off-nominal performance of DCS countermeasures? **[ISS 4, Lunar 3, Mars 3]**
20r	What are the risk factors that can increase the likelihood of DCS, such as the presence of Patent Foramen Ovale (PFO)? **[ISS 4, Lunar 3, Mars 2]**
20s	What is the likelihood of surviving an acute environmental insult severe enough to cause damage to the vehicle or spacesuit? **[ISS 2, Lunar 2, Mars 2]**
20t	Is it possible and what are the DCS risk mitigation options for interplanetary EVA (e.g., moon and Mars) given that a tri-gas breathing mixture including argon is present? **[ISS 4, Lunar 4, Mars 4]**
20u	What is the role of individual susceptibility, age and gender on the risk of DCS during NASA operations involving decompression? **[ISS 4, Lunar 3, Mars 3]**
20v	What are the available and new technologies needed to provide hyperbaric treatment options on the ISS and future habitats (or vehicles) beyond LEO (e.g., on the moon or Mars)? **[ISS 3, Lunar 2, Mars 1]**

20w	What is the correlation between the detection/existence of gas phase creation in the bloodstream and development of clinically significant DCS? **[ISS 4, Lunar 3, Mars 3]**
	Toxic Exposure Detection
20x	Identify the signs and symptoms secondary to toxic chemical exposure and radiation in reduced-G environments. **[ISS 2, Lunar 1, Mars 1]**
	Toxic Exposure/Management
20y	What are the resources and procedures for the mitigation of toxic exposures? **[ISS 3, Lunar 1, Mars 1]**
20z	What primary prevention strategies (such as crew screening and selection criteria) should be developed and implemented to identify individuals who are at increased risk for developing hypersensitivity or allergies to space flight compounds, exposures, or payloads? **[ISS 3, Lunar 2, Mars 2]**
20aa	What secondary prevention strategies (i.e., countermeasures) should be developed and implemented to prevent adverse reactions to toxic exposures (e.g., sleep, nutritional, medications, stress reduction, shielding, protective equipment, etc.)? **[ISS 3, Lunar 2, Mars 2]**
	Surgical Management
20bb	What are the resources and procedures needed for surgical management of illness and injury and major trauma? **[ISS 3, Lunar 1, Mars 1]**
20cc	What are the appropriate roles and resources required for telemedical consultation for the surgical management of major illnesses? **[ISS 3, Lunar 2, Mars 1]**
20dd	What are the issues surrounding wound care? **[ISS 4, Lunar 2, Mars 2]**
	Medical Waste Management
20ee	What are the most effective means of management and disposal of medical waste within the surgical milieu? **[ISS 2, Lunar 1, Mars 1]**
	Drug Stowage/Utilization/Replenishment
20i	What are the resources and procedures needed to perform basic and advanced management of trauma? **[ISS 3, Lunar 1, Mars 1]**
20j	What are resources required for telemedical consultation for the diagnosis and management of major trauma? **[ISS 3, Lunar 2, Mars 1]**

Related Risks :	
Important References :	

Risk Title: Pharmacology of Space Medicine Delivery

Theme :	Autonomous Medical Care (AMC)
Discipline :	Clinical capabilities
Risk Number :	21
Risk Description :	Pharmacology of Space Medication Delivery (Space flight Physiology Effects – Pharmacodynamics/Pharmocokinetics, Drug Stowage/Utilization/Replenishment, Drug Use Optimization), . If issues relating to pharmaceutical stowage, generation, effectiveness, and administration methods are not solved then we may be unable to treat some medical conditions during flight, resulting in a threat to both life and mission.
Context/Risk Factors :	Limited or no resupply ; Micro-gravity ; Radiation environment
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.

	Mars: Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.
Justification :	**ISS:** TBD **Lunar:** TBD **Mars:** TBD
Current Countermeasures :	**ISS :** Resupply **Lunar :** Resupply **Mars :** Resupply
Projected Countermeasures :	**ISS :** TBD **Lunar :** TBD **Mars :** TBD
Enabling Questions [With Mission Priority]:	(see table below)

No.	Question
	Pharmacodynamics/Pharmacokinetics
21a	What are the effects of space flight and reduced-G on the absorption, distribution, metabolism, clearance, excretion, clinical efficacy, side effects and drug interactions for medications used in primary, secondary and tertiary prevention of conditions stated in the Space Medicine Condition List? **[ISS 2, Lunar 2, Mars 1]**
21b	How should the crew and medical team be trained and prepared to recognize and deal with side effects and interaction effects of commonly used medications? **[ISS 3, Lunar 3, Mars 2]**
21c	What diagnostic, therapeutic and laboratory technologies are necessary to predict (model) and manage medication side effects, interactions and toxicity during space flight? **[ISS 3, Lunar 3, Mars 3]**
21d	What effect does space adaptation have on drug bio-availability and how can efficacy be enhanced? **[ISS 2, Lunar 2, Mars 1]**
	Drug Stowage/Utilization/Replenishment
21e	What is the effect of long-duration space flight on drug stability and what measures can be employed to extend the duration of drug efficacy? **[ISS 3, Lunar 1, Mars 1]**
21f	Identify appropriate on-orbit/on-station means of drug and intravenous (IV) fluid replenishment appropriate for space operations **[ISS 3, Lunar 1, Mars 1]**
21g	What are Biomedical models for drug efficacy? **[ISS 4, Lunar 3, Mars 3]**
	Drug Use Optimization
21h	Define the optimal dosages and routes of administration for space flight/ reduced-G clinical effectiveness. **[ISS 3, Lunar 2, Mars 2]**
21i	Identify efficient means of monitoring drug levels for therapeutic effect and toxicity and to minimize cross-reaction and negative synergy. **[ISS 4, Lunar 3, Mars 3]**

Related Risks :

ISS :

Human Behavior & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems

	Radiation Health Carcinogenesis Acute and Late CNS Risks Other Degenerative Tissue Risks Heredity, Fertility and Sterility Risks Acute Radiation Syndromes **Lunar :** **Human Behavior & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Radiation Health** Carcinogenesis Acute and Late CNS Risks Other Degenerative Tissue Risks Heredity, Fertility and Sterility Risks Acute Radiation Syndromes **Mars :** **Human Behavior & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Radiation Health** Carcinogenesis Acute and Late CNS Risks Other Degenerative Tissue Risks Heredity, Fertility and Sterility Risks Acute Radiation Syndromes
Important References :	

Risk Title: Ambulatory Care

Theme :	Autonomous Medical Care (AMC)
Discipline :	Clinical capabilities
Risk Number :	22
Risk Description :	Ambulatory Care (Minor Illness-Diagnosis, Management; Minor Trauma – Management) The risk of not being able to diagnose and treat minor illnesses and minor trauma can lead to more significant conditions that may threaten limb, life and mission.
Context/Risk Factors :	
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success

	due to effective mitigation strategies that have been validated in space. **Lunar:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** TBD **Lunar:** TBD **Mars:** TBD
Current Countermeasures :	**ISS :** ISS Medical Kit **Lunar :** ISS Medical Kit **Mars :** ISS Medical Kit
Projected Countermeasures :	**ISS :** TBD **Lunar :** TBD **Mars :** TBD

Enabling Questions [With Mission Priority]:

No.	Question
	Minor Illness Diagnosis
22a	Identify and adapt for reduced-G operations the resources for establishing the diagnosis of minor illnesses, emphasizing autonomy in decision-making from ground resources and based on known space flight illnesses and injuries and expedition analog experience. **[ISS 4, Lunar 2, Mars 1]**
22b	Define the appropriate role and resources required for telemedical consultation for the diagnosis and management of minor illnesses. **[ISS 4, Lunar 3, Mars 2]**
	Minor Illness Management
22c	Identify and adapt for reduced-G operation the resources and procedures required for treatment of minor illnesses, emphasizing autonomy from ground resources and based on known space flight illnesses and injuries and expedition analog experience. **[ISS 4, Lunar 3, Mars 2]**
22d	Identify appropriate synergistic and alternative management strategies for reducing the morbidity of minor illnesses during space flight. **[]**
	Minor Trauma Management
22e	Identify and adapt for reduced-G operations the resources and procedures required for the treatment of minor trauma, emphasizing autonomy from ground resources and based on known space flight illnesses and injuries and expedition analog experience. **[ISS 3, Lunar 1, Mars 1]**

Related Risks :

ISS :

Clinical capabilities
Monitoring & Prevention

Lunar :

Clinical capabilities
Monitoring & Prevention

Mars :

Clinical capabilities

	Monitoring & Prevention
Important References :	

Risk Title: Return to Gravity/Rehabilitation

Theme :	Autonomous Medical Care (AMC)
Discipline :	Clinical capabilities
Risk Number :	23
Risk Description :	Return to Gravity/Rehabilitation. Possibility of deconditioning during space flight to another gravitational body entails the need for rehabilitation once a crewmember returns to gravity. Otherwise the crewmember may not be able to function as needed.
Context/Risk Factors :	TBD
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.
Justification :	**ISS:** TBD **Lunar:** TBD **Mars:** TBD
Current Countermeasures :	**ISS :** Exercise during flight ; Ground rehabilitation facilities ; Ground support personnel **Lunar :** Exercise during flight ; Ground rehabilitation facilities ; Ground support personnel **Mars :** Exercise during flight ; Ground rehabilitation facilities ; Ground support personnel
Projected Countermeasures :	**ISS :** TBD **Lunar :** TBD **Mars :** TBD

Enabling Questions [With Mission Priority]:

No.	Question
23a	What are the primary, secondary and tertiary preventive strategies needed to ensure post-landing performance for all DRMs? **[ISS 4, Lunar 4, Mars 1]**
23b	What are the essential technologies, resources, protocols, skills and training necessary for post landing rehabilitation (including psychological, cardiovascular, neurosensory, musculoskeletal and nutritional)? **[ISS 4, Lunar 4, Mars 1]**

Related Risks :	
Important References :	

Risk Title: Insufficient Data/Information/Knowledge Management & Communication Capability

Theme :	Autonomous Medical Care (AMC)
Discipline :	Clinical capabilities

Risk Number :	24
Risk Description :	Insufficient Data/Information/Knowledge Management & Communication Capability. The risk of not being able to get the right data/information/knowledge to the right place at the right time.
Context/Risk Factors :	TBD
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.
Justification :	**ISS:** TBD **Lunar:** TBD **Mars:** TBD
Current Countermeasures :	**ISS :** TBD **Lunar :** TBD **Mars :** TBD
Projected Countermeasures :	**ISS :** TBD **Lunar :** TBD **Mars :** TBD
Enabling Questions [With Mission Priority]:	(see table below)

No.	Question
24a	What decision support technologies are needed to support clinical care? **[ISS 4, Lunar 2, Mars 1]**
24b	What informatics systems and technology are needed, both for crew and ground support, to optimize medical care? **[ISS 3, Lunar 1, Mars 1]**
24c	What are the impacts of communication latency on the ability to provide primary, secondary and tertiary prevention during space flight? **[ISS 4, Lunar 4, Mars 1]**

Related Risks :	
Important References :	

Risk Title: Skill Determination and Training

Theme :	Autonomous Medical Care (AMC)
Discipline :	Clinical capabilities
Risk Number :	25
Risk Description :	Skill determination and Training. Risk of not having crewmembers with the right medical skills and training to perform the medical procedures needed. Assumption: For Mars, there will be at least one physician, assisted by non-physician space medical care providers.
Context/Risk Factors :	TBD
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success

<table>
<tr><td></td><td>due to effective mitigation strategies that have been validated in space.
Lunar: Yellow
High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Mars: Red
Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.</td></tr>
<tr><td>**Justification :**</td><td>**ISS:**
TBD
Lunar:
TBD
Mars:
TBD</td></tr>
<tr><td>**Current Countermeasures :**</td><td>**ISS :**
TBD
Lunar :
TBD
Mars :
TBD</td></tr>
<tr><td>**Projected Countermeasures :**</td><td>**ISS :**
TBD
Lunar :
TBD
Mars :
TBD</td></tr>
<tr><td>**Enabling Questions [With Mission Priority]:**</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>25a</td><td>What are the necessary clinical skills/knowledge for a space medicine physician? **[ISS 4, Lunar 1, Mars 1]**</td></tr>
<tr><td>25b</td><td>How can the clinical skills and knowledge of space medical care providers be maintained during missions? **[ISS 2, Lunar 2, Mars 1]**</td></tr>
<tr><td>25c</td><td>What is the optimum crew complement (size, skill sets, etc.) to provide the appropriate medical care for the primary, secondary and tertiary care for the conditions in the Space Medicine Condition List? **[ISS 4, Lunar 3, Mars 1]**</td></tr>
<tr><td>25d</td><td>What techniques can be used to train and maintain the skills of the crew medical personnel to perform specific medical procedures when needed? **[ISS 3, Lunar 1, Mars 1]**</td></tr>
</table>
</td></tr>
<tr><td>**Related Risks :**</td><td></td></tr>
<tr><td>**Important References :**</td><td></td></tr>
</table>

Risk Title: Palliative, Mortem, and Post-Mortem Medical Activities

Theme :	Autonomous Medical Care (AMC)
Discipline :	Clinical capabilities
Risk Number :	26
Risk Description :	Palliative, Mortem and Post-Mortem Medical Activities. As the length of mission and distance from Earth increase, the likelihood that a crewmember will become so ill or injured that he/she cannot survive increases.
Context/Risk Factors :	TBD
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.

Mars: Red
Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.

Justification :	**ISS:** TBD **Lunar:** TBD **Mars:** TBD
Current Countermeasures :	**ISS :** Medical evacuation of ISS **Lunar :** **Mars :**
Projected Countermeasures :	**ISS :** TBD **Lunar :** TBD **Mars :** TBD

Enabling Questions [With Mission Priority]:

No.	Question
	Palliative Care
26a	What are the specific techniques, resources, protocols, training curricula, skills and equipment (technology) necessary to implement palliative care protocols for in-flight use? **[ISS 4, Lunar 2, Mars 1]**
26b	What is the policy and procedure for determining a "Do Not Resuscitate" (DNR) status on a Martian mission? **[ISS 3, Lunar 1, Mars 1]**
	Declaring Death
26c	What are the criteria for death during missions? **[ISS 4, Lunar 3, Mars 2]**
26d	What are procedures for pronouncing death during missions? **[ISS 4, Lunar 3, Mars 2]**
26e	What resources and procedures are needed to determine cause of death during a mission? **[ISS 4, Lunar 3, Mars 3]**
26f	What is the policy and procedure for termination of a "Code" on a Martian mission? **[ISS 3, Lunar 1, Mars 1]**
	Cadaver Management
26g	What resources, procedures, protocols and technology are required to handle deceased crewmembers? **[ISS 3, Lunar 1, Mars 1]**
	Managing Remaining Crew
26h	Identify the strategies for psychological stress management and maintaining morale and acceptable functioning and safety of the remaining crewmembers **[ISS 3, Lunar 1, Mars 1]**

Related Risks :

ISS :

Human Behavior & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems

Lunar :

Human Behavior & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems

	Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Mars :** **Human Behavior & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
Important References :	

Risk Title: Human Performance Failure Due to Poor Psychosocial Adaptation

Theme :	Behavioral Health and Performance (BH&P)
Discipline :	Human Behavior & Performance and Space Human Factors (Cognitive)
Risk Number :	27
Risk Description :	Human performance failure due to problems associated with adapting to the space environment; poor interpersonal relationships and/or group dynamics; inadequate team cohesiveness; and poor pre-mission preparation.
Context/Risk Factors :	Boredom with available foodstuffs ; Crew autonomy and increased reliance on each other ; Crowding ; Distance from family and friends ; Duration of flight ; Incompatible crewmembers ; Interpersonal tensions ; Mechanical breakdowns ; Poor communications ; Scheduling constraints and requirements ; Sleep disturbances ; Social isolation
RYG Risk Assessment :	**ISS:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.
Justification :	**ISS:** Moderate likelihood/high consequence risk with low risk mitigation status; Need to reduce probability of human error, performance and/or mission failure. Serious interpersonal conflicts have occurred in space flight. The failure of flight crews to cooperate and work effectively with each other or with flight controllers has been a periodic problem in both US and Russian space flight programs. Interpersonal distrust, dislike, misunderstanding and poor communication have led to potentially dangerous situations, such as crewmembers refusing to speak to one another during critical operations, or withdrawing from voice communications with ground controllers. Such problems of group cohesiveness have a high likelihood of occurrence in prolonged space flight and if not mitigated through prevention or intervention, they will pose grave risks to the mission. Lack of adequate personnel selection, team assembly, or training has been found to have deleterious effects on work performance in organizational research studies. **Lunar:** Moderate likelihood/high consequence risk with low risk mitigation status; Need to reduce probability of human error, performance and/or mission failure. Serious interpersonal conflicts have occurred in space flight. The failure of flight crews to cooperate and work effectively with each other or with flight controllers has been a periodic problem in both US and Russian space flight programs. Interpersonal distrust, dislike, misunderstanding and poor communication have led to potentially dangerous situations, such as crewmembers refusing to speak to one another during critical operations, or withdrawing from voice communications with ground controllers. Such problems of group cohesiveness have a high likelihood of occurrence in prolonged space flight and if not mitigated through prevention or intervention, they will pose grave risks to the mission. Lack of adequate personnel selection, team assembly, or training has been found to have deleterious effects on work performance in organizational research studies. **Mars:**

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<tr><td></td><td>Moderate likelihood/high consequence risk with low risk mitigation status; Need to reduce probability of human error, performance and/or mission failure. Serious interpersonal conflicts have occurred in space flight. The failure of flight crews to cooperate and work effectively with each other or with flight controllers has been a periodic problem in both US and Russian space flight programs. Interpersonal distrust, dislike, misunderstanding and poor communication have led to potentially dangerous situations, such as crewmembers refusing to speak to one another during critical operations, or withdrawing from voice communications with ground controllers. Such problems of group cohesiveness have a high likelihood of occurrence in prolonged space flight and if not mitigated through prevention or intervention, they will pose grave risks to the mission. Lack of adequate personnel selection, team assembly, or training has been found to have deleterious effects on work performance in organizational research studies.</td></tr>
<tr><td>Current Countermeasures :</td><td>ISS :
In-flight psychological support ; Language and cultural training, ; Personal in-flight communications with Earth ; Post-flight debriefs ; Pre-flight training and teambuilding, ; Select-in criteria ; Self-report monitoring of adaptation during mission with private psychological conference
Lunar :
In-flight psychological support ; Language and cultural training, ; Personal in-flight communications with Earth ; Post-flight debriefs ; Pre-flight training and teambuilding, ; Select-in criteria ; Self-report monitoring of adaptation during mission with private psychological conference
Mars :
In-flight psychological support ; Language and cultural training, ; Personal in-flight communications with Earth ; Post-flight debriefs ; Pre-flight training and teambuilding, ; Select-in criteria ; Self-report monitoring of adaptation during mission with private psychological conference</td></tr>
<tr><td>Projected Countermeasures :</td><td>ISS :
Development of individual performance enhancement plan for each crewmember ; Individual and team selection for long-duration missions ; Monitoring & early detection of adaptation problems ; Predictive model of adaptability to long-duration missions
Lunar :
Development of individual performance enhancement plan for each crewmember ; Individual and team selection for long-duration missions ; Monitoring & early detection of adaptation problems ; Predictive model of adaptability to long-duration missions
Mars :
Development of individual performance enhancement plan for each crewmember ; Individual and team selection for long-duration missions ; Monitoring & early detection of adaptation problems ; Predictive model of adaptability to long-duration missions</td></tr>
<tr><td>Enabling Questions [With Mission Priority]:</td><td><table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>27a</td><td>What are the fundamental behavioral and social stressors during long-duration missions that will most likely affect crew performance, both individual and team and how can they be tested in Earth analogue environments, to be eliminated or accommodated? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>27b</td><td>What factors contribute to the breakdown of individual and team performance and team coordination with mission support with regard to scheduling, prioritization of work activities and control of timelines? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>27c</td><td>What behaviors, experiences, personality traits and leadership styles in crewmembers most contribute to optimal performance? How are these factors related to performance of individuals and teams? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>27d</td><td>What criteria can be identified during the selection process and be used to select and assemble the best teams for long-duration missions? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>27e</td><td>What factors in crew design, composition, dynamics and size will best enhance the crew's ability to live and work in the space environment? How are these factors different from shorter duration missions? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>27f</td><td>How can attitudes and behaviors of agency management, ground controllers, crewmembers and their families be modified to maintain and improve individual and group performance? [ISS 2, Lunar 2, Mars 2]</td></tr>
</table></td></tr>
<tr><td>Related Risks :</td><td>ISS :<table>
<tr><th>Human Behavior & Performance and Space Human Factors (Cognitive)</th></tr>
<tr><td>Human Performance Failure Due to Poor Psychosocial Adaptation</td></tr>
<tr><td>Human Performance Failure Due to Neurobehavioral Problems</td></tr>
</table></td></tr>
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	Mismatch between Crew Cognitive Capabilities and Task Demands
	Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
	Lunar :
	Human Behavior & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Poor Psychosocial Adaptation
	Human Performance Failure Due to Neurobehavioral Problems
	Mismatch between Crew Cognitive Capabilities and Task Demands
	Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
	Mars :
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	Kanas, N. Psychiatric issues affecting long-duration space missions. Aviation Space & Environmental Medicine 69:1211-1216, 1998. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=9856550
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	Wood, J. A., Hysong, S. J., Lugg, D. J., & Harm, D. L. (2000). Is it really so bad? A comparison of positive and negative experiences in Antarctic winter stations. Environment and Behavior, 32(1), 85-110. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11542948

	Wood, J. A., Lugg, D. J., Hysong, S. J., Eksuzian, D. J., & Harm, D. L. (1999). Psychological changes in hundred-day remote Antarctic field groups. Environment and Behavior, 31(3), 299-337. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11542387

Risk Title: Human Performance Failure Due to Neurobehavioral Problems

Theme :	Behavioral Health and Performance (BH&P)
Discipline :	Human Behavior & Performance and Space Human Factors (Cognitive)
Risk Number :	28
Risk Description :	Human performance failure during missions due to such conditions as depression, anxiety, trauma or other neuropsychiatric, cognitive problems
Context/Risk Factors :	Clinical capabilities ; Concern about health or loss of life or mission failure ; Crowdedness ; Differential vulnerability to neurobehavioral problems ; Duration of flight ; Environmental health ; Immunodeficiency issues ; Loneliness and worry about family ; Neurovestibular problems ; Nutrition ; Prolonged isolation and confinement ; Radiation exposure ; Trauma from unexpected event
RYG Risk Assessment :	**ISS:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.
Justification :	**ISS:** Although infrequent, serious neurobehavioral problems involving stress and depression have occurred in space flight, especially during long-duration missions. In some of these instances, the distress has contributed to performance errors during critical operations, such as the collision of Progress into Mir during manual docking. In other instances, emotional problems led to changes in motivation, diet, sleep and exercise—all critical to behavioral and physical health in-flight. No matter how prepared crews are for long-duration flights, the US and Russian experiences reveal that at least some subset of astronauts will experience problems with their behavioral health, which will negatively affect their performance and reliability, posing risks both to individual crewmembers and to the mission. The IOM report, Safe Passages, notes that Earth analogue studies show an incidence rate ranging from 3 – 13 percent per person per year. The report transposes these figures to 6-7 person crew on a 3-year mission to determine that there is a not insignificant likelihood of psychiatric problems emerging (p.106). **Lunar:** Although infrequent, serious neurobehavioral problems involving stress and depression have occurred in space flight, especially during long-duration missions. In some of these instances, the distress has contributed to performance errors during critical operations, such as the collision of Progress into Mir during manual docking. In other instances, emotional problems led to changes in motivation, diet, sleep and exercise—all critical to behavioral and physical health in-flight. No matter how prepared crews are for long-duration flights, the US and Russian experiences reveal that at least some subset of astronauts will experience problems with their behavioral health, which will negatively affect their performance and reliability, posing risks both to individual crewmembers and to the mission. The IOM report, Safe Passages, notes that Earth analogue studies show an incidence rate ranging from 3 – 13 percent per person per year. The report transposes these figures to 6-7 person crew on a 3-year mission to determine that there is a not insignificant likelihood of psychiatric problems emerging (p.106). **Mars:** Although infrequent, serious neurobehavioral problems involving stress and depression have occurred in space flight, especially during long-duration missions. In some of these instances, the distress has contributed to performance errors during critical operations, such as the collision of Progress into Mir during manual docking. In other instances, emotional problems led to changes in motivation, diet, sleep and exercise—all critical to behavioral and physical health in-flight. No matter how prepared crews are for long-duration flights, the US and Russian experiences reveal that at least some subset of astronauts will experience problems with their behavioral health, which will negatively affect their performance and reliability, posing risks both to individual crewmembers and to the mission. The IOM report, Safe Passages, notes that Earth analogue studies show an incidence

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<tr><td>Current Countermeasures :</td><td>ISS :
Crew medical officer behavioral medicine training pre-flight ; Detection at the time of failure ; Emergency response protocol on orbit ; Individual pre-flight and post-flight evaluations ; Individual pre-flight evaluations ; Medication therapy, including during space flight on-board ; Opportunity for crewmember to communicate with crew medical officer or health provider on ground ; Select-in and select-out criteria ; Self monitoring of cognition on orbit and post-flight ; Self-report monitoring during mission with private psychological conference
Lunar :
Crew medical officer behavioral medicine training pre-flight ; Detection at the time of failure ; Emergency response protocol on orbit ; Individual pre-flight and post-flight evaluations ; Individual pre-flight evaluations ; Medication therapy, including during space flight on-board ; Opportunity for crewmember to communicate with crew medical officer or health provider on ground ; Select-in and select-out criteria ; Self monitoring of cognition on orbit and post-flight ; Self-report monitoring during mission with private psychological conference
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<tr><td>Projected Countermeasures :</td><td>ISS :
Greater interaction and observation by behavioral specialist during astronaut professional training ; Improved ability to safely and effectively manage an uncooperative crewmember during mission ; Improved capability for remote diagnosis ; Improved diagnostic cognitive self-assessment ; Individualized treatment algorithm developed pre-flight ; On-board information technologies as astronaut aids for management of stress reactions and cognitive or emotional problems ; On-board modalities of therapy ; On-board unobtrusive technologies as astronaut aids for valid detection of stress reactions and cognitive or emotional problems ; Predictive model for risk of neurobehavioral illness in-flight ; Self monitoring of mood pre-flight, in-flight and post-flight ; Updated behavioral medicine aeromedical standards
Lunar :
Greater interaction and observation by behavioral specialist during astronaut professional training ; Improved ability to safely and effectively manage an uncooperative crewmember during mission ; Improved capability for remote diagnosis ; Improved diagnostic cognitive self-assessment ; Individualized treatment algorithm developed pre-flight ; On-board information technologies as astronaut aids for management of stress reactions and cognitive or emotional problems ; On-board modalities of therapy ; On-board unobtrusive technologies as astronaut aids for valid detection of stress reactions and cognitive or emotional problems ; Predictive model for risk of neurobehavioral illness in-flight ; Self monitoring of mood pre-flight, in-flight and post-flight ; Updated behavioral medicine aeromedical standards
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<tr><td>Enabling Questions [With Mission Priority]:</td><td><table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>28a</td><td>What are the best select-out tools of astronaut candidates and best select-out tools for selection of individuals to teams for specific missions to avoid possible neuropsychiatric and psychological incompatibility with the mission and fellow team members? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>28b</td><td>What are the long-term effects of exposure to the space environment (microgravity, isolation, stress) on human neurocognitive and neurobiological functions (from cellular to behavioral levels of the nervous system)? [ISS 2, Lunar 2, Mars 2]</td></tr>
</table></td></tr>
</table>

28c	What are the long-term effects of exposure to the space environment on human emotion and psychological responses, including emotional reactivity, stress responses, long-term modulation of mood and vulnerability to affective and cognitive disorders? **[ISS 3, Lunar 3, Mars 3]**
28d	What objective techniques and technologies validly and reliably identify when astronauts are experiencing distress that compromises their performance capability in space? **[ISS 1, Lunar 1, Mars 1]**
28e	What are the best behavioral, technological and pharmacological countermeasures for managing cognitive dysfunction, neuropsychiatric and behavior problems in space? **[ISS 3, Lunar 3, Mars 3]**
28f	What are the best behavioral, psychological, technological and pharmacological countermeasures for managing emotional and stress-related problems in space? **[ISS 3, Lunar 3, Mars 3]**
28g	What are the best techniques and technologies for identification and treatment of cognitive disorders, neuropsychiatric and behavior problems in space? **[ISS 4, Lunar 4, Mars 4]**

Related Risks :

ISS :

Human Behavior & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Human Performance Failure Due to Neurobehavioral Problems
Mismatch between Crew Cognitive Capabilities and Task Demands
Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems

Lunar :

Human Behavior & Performance and Space Human Factors (Cognitive)
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Mars :

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Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems

Important References :

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Risk Title: Mismatch between Crew Cognitive Capabilities and Task Demands

Theme :	Behavioral Health and Performance (BH&P)
Discipline :	Human Behavior & Performance and Space Human Factors (Cognitive)
Risk Number :	29
Risk Description :	Human performance failure due to inadequate accommodation of human cognitive limitations and capabilities. If human cognitive performance capabilities are surpassed due to inadequate design of tools, interfaces, tasks or information support systems, mission failure or decreased effectiveness or efficiency may result. Identifying, locating, processing or evaluating information to make decisions and perform critical tasks in short time-frames in nominal and emergency situations, with limited crew size, relying on strictly local resources is extremely subject to human error.
Context/Risk Factors :	Blackouts ; Communications lags ; Mission duration ; Required levels of autonomy ; Time since training, time since last performing a task and level of support available from mission control on Earth are major factors that increase the probability of human error ; Very long crew return times requiring a 'stand and fight' response to any malfunction on the lunar or Martian surface are expected to increases the likelihood and severity of consequences of error due to forgetting knowledge, losing skills, or failing to find information and training materials in databases
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.
Justification :	**ISS:** Crews require refresher training and information support systems for numerous tasks during 6 month missions. (Ev. Level 4) Psychological literature documents increases in error with time since learning and decreases in error with correctly practicing the task. (Evidence level 1) Failure to correctly follow procedures has leads to fatal accidents in commercial aviation, even with greatly over learned tasks. (NTSB Reports-Level 2?) **Lunar:** Crews require refresher training and information support systems for numerous tasks during 6 month missions. (Ev. Level 4) Psychological literature documents increases in error with time since learning and decreases in error with correctly practicing the task. (Evidence level 1) Failure to correctly follow procedures has leads to fatal accidents in commercial aviation, even with greatly over learned tasks. (NTSB Reports-Level 2?) **Mars:** Crews require refresher training and information support systems for numerous tasks during 6 month missions. (Ev. Level 4) Psychological literature documents increases in error with time since learning and decreases in error with correctly practicing the task. (Evidence level 1) Failure to correctly follow procedures has leads to fatal accidents in commercial aviation, even with greatly over learned tasks. (NTSB Reports-Level 2?)
Current Countermeasures :	**ISS :** Crew resilience is the countermeasure for schedule and interface problems ; Crewmembers absorb task and schedule impacts ; Mission Control provides training, information, procedures, etc. as required to support crew actions and decision-making **Lunar :** Crew resilience is the countermeasure for schedule and interface problems ; Crewmembers absorb task and schedule impacts ; Mission Control provides training, information, procedures, etc. as required to support crew actions and decision-making **Mars :** Crew resilience is the countermeasure for schedule and interface problems ; Crewmembers absorb task and schedule impacts ; Mission Control provides training, information, procedures, etc. as required to support crew actions and decision-making

<table>
<tr><td>Projected Countermeasures :</td><td>ISS :
Design requirements for communications systems among crewmembers, between crew and mission control and among crew and intelligent agents that reduce risk of mission failure ; Onboard training systems that enable successful readiness to perform ; Tools for analyzing tasks to identify critical skills and knowledge ; Tools for enabling crew autonomy with respect to information retrieval ; Tools to enable self-assessment of readiness to perform

There is inadequate data to enable developing realistic workloads and schedules for tasks to be performed in space contexts
Lunar :
Design requirements for communications systems among crewmembers, between crew and mission control and among crew and intelligent agents that reduce risk of mission failure ; Onboard training systems that enable successful readiness to perform ; Tools for analyzing tasks to identify critical skills and knowledge ; Tools for enabling crew autonomy with respect to information retrieval ; Tools to enable self-assessment of readiness to perform

There is inadequate data to enable developing realistic workloads and schedules for tasks to be performed in space contexts
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Design requirements for communications systems among crewmembers, between crew and mission control and among crew and intelligent agents that reduce risk of mission failure ; Onboard training systems that enable successful readiness to perform ; Tools for analyzing tasks to identify critical skills and knowledge ; Tools for enabling crew autonomy with respect to information retrieval ; Tools to enable self-assessment of readiness to perform

There is inadequate data to enable developing realistic workloads and schedules for tasks to be performed in space contexts</td></tr>
<tr><td>Enabling Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>29a</td><td>What crew size and composition is required to provide the amount of information, variety of skills, etc. required to accomplish the design reference mission? [ISS 2, Lunar 1, Mars 1]</td></tr>
<tr><td>29b</td><td>What is required to counteract the negative effects of communications lags on human performance? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>29c</td><td>What information systems, interface designs, intelligent systems and other tools to enable autonomy are required to enable human performance to be maintained at an acceptable level over the design reference missions (Shared - Integrated Testing supports)? [ISS 2, Lunar 1, Mars 1]</td></tr>
<tr><td>29d</td><td>What types and techniques of training are required and within what timeframes, to enable the crewmembers to accomplish the mission with increased effectiveness, efficiency and safety? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>29e</td><td>What principles of task design, procedures, job aids and tools and equipment, are required to enable crewmembers to accomplish nominal and emergency perceptual and cognitive tasks [ISS 2, Lunar 1, Mars 1]</td></tr>
<tr><td>29f</td><td>How can crewmembers and ground support personnel detect and compensate for decreased cognitive readiness to perform? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>29g</td><td>What scheduling constraints are required to reduce the risk of human error due to fatigue? (Share with Sleep and Circadian Rhythm) [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>29h</td><td>What tools and techniques will maintain the crew's situational awareness at a level sufficient to perform nominal and emergency tasks? [ISS 2, Lunar 1, Mars 1]</td></tr>
<tr><td>29i</td><td>What characteristics of equipment, tool and computer displays; instructions, procedures, labels and warning; and human-computer interaction designs will maintain critical sensory and cognitive capabilities? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>29j</td><td>What approaches to human computer interactions will maintain crew critical capabilities to assess, control and communicate? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>29k</td><td>What decision-support systems are required to aid crew decision-making? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>29l</td><td>What design considerations are needed to accommodate effects of changes in gravity on perception (Launch, lunar landing, lunar launch, Earth return)? [Lunar 1, Mars 1]</td></tr>
</table>
</td></tr>
</table>

Related Risks :	**ISS :** **Human Behavior & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Lunar :** **Human Behavior & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems **Mars :** **Human Behavior & Performance and Space Human Factors (Cognitive)** Human Performance Failure Due to Poor Psychosocial Adaptation Human Performance Failure Due to Neurobehavioral Problems Mismatch between Crew Cognitive Capabilities and Task Demands Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems
Important References :	Ellis SR. Collision in space. Ergonomics in Design 8(1): 4-9, 2000 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12162316 Handbook of Human Factors and Ergonomics (2nd ed), G. Salvendy, ed. John Wiley and Sons, Inc. 1997. Handbook of Human Factors Testing and Evaluation, 2nd ed. S. G. Charlton, T.G. O'Brien, eds. 2002. Human Space flight: Mission Analysis and Design, eds. W.J. Larson, L.K. Pranke. McGraw Hill Space Technology Series. 1999. Sleep, performance, circadian rhythms and light-dark cycles during two spaceShuttle flights. Dijk DJ, Neri DF, Wyatt JK, Ronda JM, Riel E, Ritz-De Cecco A, Hughes RJ, Elliott AR, Prisk GK, West JB, Czeisler CA. Am J Physiol Regul Integr Comp Physiol. 2001 Nov; 281(5):R1647-64. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11641138 Woolford, B., Hudy, C. E., Whitmore, M., Berman, A., Maida, J. and Pandya, A. (2002). In Situ Training Project: LMLSTP Phase III Report. In Lane, H.W., Sauer, R.L. and Feeback, D.L. (Eds.), ISOLATION: NASA Experiments in Closed Environment Living. Advanced Human Life Support Enclosed System Final Report. San Diego, CA: American Astronautical Society.

Risk Title: Human Performance Failure Due to Sleep Loss and Circadian Rhythm Problems

Theme :	Behavioral Health and Performance (BH&P)
Discipline :	Human Behavior & Performance and Space Human Factors (Cognitive)
Risk Number :	30
Risk Description :	Human performance failure due to disruption of circadian phase, amplitude, period or entrainment and/or human performance failure due to acute or chronic degradation of sleep quality or quantity
Context/Risk Factors :	Artificial and transmitted ambient light exposure ; Individual differences in vulnerability to sleep loss and circadian dynamics ; Work shift and sleep schedules

RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Mars:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** High likelihood/high consequence risk with high risk mitigation status; Need to reduce probability of human error, performance and/or mission failure. Loss of circadian entrainment to Earth-based light-dark cycles and chronic reduction of sleep duration in space result in fatigue and jeopardize astronaut performance. Fatigue is a common symptom in prolonged space flight and every study of sleep in space, including those on US, Russian and European astronauts, has found that daily sleep is reduced to an average of 6 hours and even less when critical operations occur such as during nighttime Shuttle docking on ISS or during an emergency (e.g., equipment failure). Astronaut sleep in space is also physiologically altered and the most frequent medications taken in-flight by astronauts are hypnotics for sleep disturbances. Extensive ground-based scientific evidence documents that circadian disruptions and restriction of sleep at levels commonly experienced by astronauts can severely diminish cognitive performance capability, posing risks to individual astronaut safety and mission success. **Lunar:** High likelihood/high consequence risk with high risk mitigation status; Need to reduce probability of human error, performance and/or mission failure. Loss of circadian entrainment to Earth-based light-dark cycles and chronic reduction of sleep duration in space result in fatigue and jeopardize astronaut performance. Fatigue is a common symptom in prolonged space flight and every study of sleep in space, including those on US, Russian and European astronauts, has found that daily sleep is reduced to an average of 6 hours and even less when critical operations occur such as during nighttime Shuttle docking on ISS or during an emergency (e.g., equipment failure). Astronaut sleep in space is also physiologically altered and the most frequent medications taken in-flight by astronauts are hypnotics for sleep disturbances. Extensive ground-based scientific evidence documents that circadian disruptions and restriction of sleep at levels commonly experienced by astronauts can severely diminish cognitive performance capability, posing risks to individual astronaut safety and mission success. **Mars:** High likelihood/high consequence risk with high risk mitigation status; Need to reduce probability of human error, performance and/or mission failure. Loss of circadian entrainment to Earth-based light-dark cycles and chronic reduction of sleep duration in space result in fatigue and jeopardize astronaut performance. Fatigue is a common symptom in prolonged space flight and every study of sleep in space, including those on US, Russian and European astronauts, has found that daily sleep is reduced to an average of 6 hours and even less when critical operations occur such as during nighttime Shuttle docking on ISS or during an emergency (e.g., equipment failure). Astronaut sleep in space is also physiologically altered and the most frequent medications taken in-flight by astronauts are hypnotics for sleep disturbances. Extensive ground-based scientific evidence documents that circadian disruptions and restriction of sleep at levels commonly experienced by astronauts can severely diminish cognitive performance capability, posing risks to individual astronaut safety and mission success.
Current Countermeasures :	**ISS :** Bright light entrainment pre-flight (only prior to launch) ; Individual active noise cancellation at sleep ; Medications ; Scheduling constraints in Ground Rules & Constraints document ; Self report monitoring during mission with personal physician conference **Lunar :** Bright light entrainment pre-flight (only prior to launch) ; Individual active noise cancellation at sleep ; Medications ; Scheduling constraints in Ground Rules & Constraints document ; Self report monitoring during mission with personal physician conference **Mars :** Bright light entrainment pre-flight (only prior to launch) ; Individual active noise cancellation at sleep ; Medications ; Scheduling constraints in Ground Rules & Constraints document ; Self report monitoring during mission with personal physician conference
Projected Countermeasures :	**ISS :** Ability to monitor sleep, circadian and lighting parameters unobtrusively in order to predict physiological and behavioral responses ; Develop flight rule limits on critical operations during sleep period ; Model of performance deficit based on sleep and circadian data ; Personal lighting device (e.g., light visor) ; Sleep/circadian rhythm non-photic adjustment tools pre- in- and post-flight ;

	Sleep/circadian rhythm pharmacological interventions pre- in- and post-flight. ; Sleep/circadian rhythm photic adjustment tools pre- in- and post-flight **Lunar :** Ability to monitor sleep, circadian and lighting parameters unobtrusively in order to predict physiological and behavioral responses ; Develop flight rule limits on critical operations during sleep period ; Model of performance deficit based on sleep and circadian data ; Personal lighting device (e.g., light visor) ; Sleep/circadian rhythm non-photic adjustment tools pre- in- and post-flight ; Sleep/circadian rhythm pharmacological interventions pre- in- and post-flight. ; Sleep/circadian rhythm photic adjustment tools pre- in- and post-flight **Mars :** Ability to monitor sleep, circadian and lighting parameters unobtrusively in order to predict physiological and behavioral responses ; Develop flight rule limits on critical operations during sleep period ; Model of performance deficit based on sleep and circadian data ; Personal lighting device (e.g., light visor) ; Sleep/circadian rhythm non-photic adjustment tools pre- in- and post-flight ; Sleep/circadian rhythm pharmacological interventions pre- in- and post-flight. ; Sleep/circadian rhythm photic adjustment tools pre- in- and post-flight

Enabling Questions [With Mission Priority]:

No.	Question
30a	What are the acute and long-term effects of exposure to the space environment on biological rhythmicity on sleep architecture, quantity and quality and their relationship to performance capability? **[ISS 1, Lunar 1, Mars 1]**
30b	Which countermeasures or combination of behavioral and physiological countermeasures will optimally mitigate specific performance problems associated with sleep loss and circadian disturbances during the design reference missions? **[ISS 1, Lunar 1, Mars 1]**
30c	What are the long-term effects of countermeasures employed to mitigate pre, - in- and post-flight performance problems with sleep loss and circadian disturbances? **[ISS 3, Lunar 4, Mars 2]**
30d	What are the best methods for in-flight monitoring of the status of sleep, circadian functioning and light exposures for assessing the effects of sleep loss and circadian dysrhythmia on performance capability that are also portable and non-intrusive in the space flight environment? (e.g., actigraphy) **[ISS 2, Lunar 2, Mars 2]**
30e	What work, workload and sleep schedule(s) will best enhance crew performance and mitigate adverse effects of the space environment? **[ISS 1, Lunar 1, Mars 1]**
30f	What individual biological and behavioral characteristics will best predict successful adaptation to long-term space flight of sleep, circadian physiology and the neurobehavioral performance functions they regulate? **[ISS 4, Lunar 5, Mars 1]**
30g	What mathematical and computational models should be used to predict performance associated with sleep-wake, schedule, work history, light exposure and circadian rhythm status and also provide guidelines for successful countermeasure strategies? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

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Risk Title: Carcinogenesis

Theme :	Radiation Health
Discipline :	Radiation Health
Risk Number :	31
Risk Description :	Unacceptable levels of increased cancer morbidity or mortality risk in astronauts caused by occupational radiation exposure or the combined effects of radiation and other space flight factors. These risks would be expressed following the mission (late).
Context/Risk Factors :	Microgravity ; Physiological changes ; Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation with other space flight factors including stress
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth. **Mars:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.

Justification :	**ISS:** Crew Health and Performance Post-Mission **Lunar:** Crew Health and Performance Post-Mission **Mars:** Crew Health and Performance Post-Mission
Current Countermeasures :	**ISS :** Polyethylene shielding **Lunar :** Polyethylene shielding **Mars :** Polyethylene shielding
Projected Countermeasures :	**ISS :** Hydrogenous shielding ; Anti-oxidants ; Gene therapy ; Pharmaceuticals **Lunar :** Hydrogenous shielding ; Anti-oxidants ; Gene therapy ; Pharmaceuticals **Mars :** Hydrogenous shielding ; Anti-oxidants ; Gene therapy ; Pharmaceuticals

Enabling Questions [With Mission Priority]:

No.	Question
31a	What are the probabilities for increased carcinogenesis from space radiation as a function of NASA's operational parameters (age at exposure, age, latency, gender, tissue, mission, radiation quality, dose rate and exposure protraction)? **[ISS 1, Lunar 1, Mars 1]**
31b	How can tissue specific probabilities for increased carcinogenesis risk from space radiation be best evaluated and what molecular, genetic, epigenetic and abscopal (effect that irradiation of a tissue has on remote non-irradiated tissue) or other factors contribute to the tissue specificity of carcinogenic risk? **[ISS 1, Lunar 1, Mars 1]**
31c	How can the individual's sensitivity to radiation carcinogenesis be estimated? **[ISS 2, Lunar 2, Mars 1]**
31d	How can effective biomarkers of carcinogenic risk from space radiation be developed and validated? **[ISS 3, Lunar 3, Mars 2]**
31e	What are the most effective biomedical or dietary countermeasures to mitigate cancer risks? By what mechanisms are the countermeasures expected to work and do they have the same efficiency for low- and high-LET radiation? **[ISS 3, Lunar 3, Mars 1]**
31f	How can animal models (including transgenics) of carcinogenesis be developed to improve estimates of cancers from space radiation and what longitudinal studies are needed? **[ISS 2, Lunar 2, Mars 1]**
31g	What improvements can be made to quantitative procedures or theoretical models in order to extrapolate molecular, cellular, or animal results to determine the risks of specific cancers in astronauts? How can human epidemiology data best support these procedures or models? **[ISS 3, Lunar 3, Mars 2]**
31h	Are there significant combined effects from other space flight factors (microgravity, stress, altered circadian rhythms, changes in immune responses, etc.) that modify the carcinogenic risk from space radiation? **[ISS 5, Lunar 5, Mars 3]**
31i	What are the probabilities that space radiation will produce damage at specific sites on DNA including clustered DNA damage? **[ISS 3, Lunar 3, Mars 2]**
31j	What mechanisms modulate radiation damage at the molecular level (e.g., repair, errors in repair, signal transduction, gene amplification, bystander effects, tissue microenvironment, etc.) that significantly impact the risk of cancers and how can the understanding of mechanisms be used to predict carcinogenic risks from space radiation? **[ISS 2, Lunar 2, Mars 1]**
31k	What space validation experiments could improve estimates of carcinogenic risks for long-term deep-space missions? **[ISS 5, Lunar 5, Mars 3]**
31l	What are the most effective shielding approaches to mitigate cancer risks **[ISS 1, Lunar 1, Mars 1]**
31m	What new materials or active shielding methods can be used for reducing space radiation cancer risks? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :	
Important References :	Alpen, E.L., Powers-Risius, P, Curtis, S.B. and DeGuzman, R. Tumorigenic potential of high-Z, high-LET charged-particle radiations. Radiation Research 136: 382-391. 1993. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8278580 Berrington, A., et al., 100 Years of observation of British radiologists: mortality from cancer and other causes 1897-1997. BrJ Radio 74:507-519. 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12595318 Boice, J.D., et al. Radiation Dose and Leukemia Risk in Patients Treated for Cancer of the Cervix. J. National Cancer Institute 79, 1295-1311, 1987. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=3480381 Cucinotta, F.A., Schimmerling, W; Wilson, J.W.; Peterson, L.E., Badhwar, G.D.; Saganti, P.; and Dicello, J.F., Space Radiation Cancer Risks And Uncertainties For Mars Missions. Radiation Research 156, 682-688, 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11604093 National Academy of Sciences Space Science Board, Report of the Task Group on the Biological Effects of Space Radiation. Radiation Hazards to Crews on Interplanetary Mission National Academy of Sciences, Washington, D.C., 1997. National Council on Radiation Protection and Measurements, Recommendations of Dose Limits for Low Earth Orbit. NCRP Report 132, Bethesda MD, 2000. National Council on Radiation Protection and Measurements, Uncertainties in Fatal Cancer Risk Estimates used in Radiation Protection, NCRP Report 126, Bethesda MD, 1997. Preston, D.L., et al., Radiation Effects on Breast Cancer Risk: A Pooled Analysis of Eight Cohorts. Radiation Research 158: 220-235, 2002. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12105993 Preston, D.L., et al. Studies of mortality of atomic bomb survivors Report 13: Solid cancer and noncancer disease mortality: 1950-1997. Radiation Research 160, 381-407, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12968934 Thompson, D.E., et. al. Cancer Incidence in Atomic Bomb Survivors. Part II: Solid tumors, 1958-1987. Radiation Research 137: S17-S67, 1994. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8127952 Weiss, H.A., et. al. Leukemia mortality after X-ray treatment for ankylosing spondylitis. Radiation Research 142, 1-11, 1995. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=7899552 Wing, S., et al., Mortality Among Workers of the Oak Ridge National Laboratories- Evidence of Radiation Effects in Follow Up Through 1984. Journal of the American Medical Association 265, 1397-1402, 1991.

Risk Title: Acute and Late CNS Risks

Theme :	Radiation Health
Discipline :	Radiation Health
Risk Number :	32

Risk Description :	Damage to the central nervous system (CNS) leading to unacceptable levels of risk for changes in motor function and behavior, or neurological disorders caused by occupational radiation exposure or the combined effects of radiation and other space flight factors. These risks can be manifested during an extended mission (acute), or following return to Earth (late).
Context/Risk Factors :	Microgravity ; Physiological changes ; Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation with other space flight factors including stress
RYG Risk Assessment :	**ISS:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Lunar:** Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space. **Mars:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.
Justification :	**ISS:** Crew Health and Performance In-Flight and Post-Mission **Lunar:** Crew Health and Performance In-Flight and Post-Mission **Mars:** Crew Health and Performance In-Flight and Post-Mission
Current Countermeasures :	**ISS :** Polyethylene shielding **Lunar :** Polyethylene shielding **Mars :** Polyethylene shielding
Projected Countermeasures :	**ISS :** Hydrogenous shielding ; Anti-oxidants ; Gene therapy ; Pharmaceuticals **Lunar :** Hydrogenous shielding ; Anti-oxidants ; Gene therapy ; Pharmaceuticals **Mars :** Hydrogenous shielding ; Anti-oxidants ; Gene therapy ; Pharmaceuticals
Enabling Questions [With Mission Priority]:	

No.	Question
32a	Is there a significant probability that space radiation would lead to immediate or acute functional changes in the CNS due to a long-term space mission and if so what are the mechanisms of change? **[ISS 3, Lunar 3, Mars 1]**
32b	Is there a significant probability that space radiation exposures would lead to long-term or late degenerative CNS risks? If so what are the mechanisms of change? **[ISS 3, Lunar 3, Mars 1]**
32c	How does individual susceptibility including hereditary pre-disposition (Alzheimer's, Parkinson's, apoE) and prior CNS injury (concussion or other) alter significant CNS risks? **[ISS 3, Lunar 3, Mars 1]**
32d	What are the most effective biomedical or dietary countermeasures to mitigate CNS risks? By what mechanisms do the countermeasures work? **[ISS 4, Lunar 4, Mars 1]**
32e	How can animal models of CNS risks, including altered motor and cognitive function, behavioral changes and late degenerative risks be best used for estimating space radiation risks to astronauts? **[ISS 4, Lunar 3, Mars 1]**
32f	Are there significant CNS risks from combined space radiation and other physiological or space flight factors (e.g., bone loss, microgravity, immune-endocrine systems or other)? **[ISS 5, Lunar 5, Mars 3]**
32g	What are the molecular, cellular and tissue mechanisms of damage (DNA damage processing, oxidative damage, cell loss through apoptosis or necrosis, changes in the extra-cellular matrix, cytokine activation, inflammation, changes in plasticity, micro-lesion (clusters of damaged cells along heavy ion track, etc.) in the CNS? **[ISS 4, Lunar 3, Mars 1]**

	32h	What are the different roles of neural cell populations, including neuronal stem cells and their integrative mechanisms in the morphological and functional consequences of space radiation exposure? **[ISS 2, Lunar 2, Mars 1]**
	32i	Are there biomarkers for detecting damage or susceptibility to/for radiation-induced CNS damage? **[ISS 4, Lunar 3, Mars 2]**
	32j	What quantitative procedures or theoretical models are needed to extrapolate molecular, cellular, or animal results to predict CNS risks in astronauts? How can human epidemiology data best support these procedures or models? **[ISS 4, Lunar 3, Mars 2]**
	32k	What are the most effective shielding approaches to mitigate CNS risks? **[ISS 1, Lunar 1, Mars 1]**
	32l	What space validation experiments could improve estimates of CNS risks for long-term deep-space missions? **[ISS 5, Lunar 5, Mars 3]**
Related Risks :		
Important References :		Joseph, J.A., Hunt, W.A., Rabin, B.M. and Dalton, T.K. Possible “Accelerated Striatal Aging” Induced by 56Fe Heavy Particle Irradiation: Implications for Manned Space flights. Radiat. Res. 130: 88-93, 1992. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=1561322
		Lett, J.T. and Williams G.R., Effects Of LET On The Formation And Fate Of Radiation Damage To Photoreceptor Cell Component Of The Rabbit Retina: Implications For The Projected Manned Mission To Mars. In Biological Effects Of Solar And Galactic Cosmic Radiation, Part A (C.E. Swenberg, G. Horneck and e.g., Stassinopoulos, Eds.) 185-201, Plenum Press, NY, NY: 1993.
		National Academy of Sciences Space Science Board, HZE Particle Effects in Manned Space flight, National Academy of Sciences U.S.A. Washington D.C., 1973.
		National Academy of Sciences, NAS. National Academy of Sciences Space Science Board, Report of the Task Group on the Biological Effects of Space Radiation. Radiation Hazards to Crews on Interplanetary Mission National Academy of Sciences, Washington, D.C., 1997.
		Rabin, B.M., Joseph, J.A., Shukitt-Hale, B. and McEwen, J. Effects of Exposure to Heavy Particles on a Behavior Medicated by the Dopaminergic System. Adv. Space Res. 25, (10) 2065-2074, 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11542858
		Surma-aho, O., et al. Adverse Long-Term Effects of Brain Radiotherapy in Adult Low-Grade Glioma Patients. Neurology 56, 1285-1290, 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11376174
		Todd P. Stochastics of HZE-Induced Microlesions. Adv. in Space Res. 9 (10) 31-34, 1981. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11537310
		Tolifon P.J. and Fike, J.R. The radioresponse of the Central Nervous System: A Dynamic Process. Radiat. Res. 153: 357-370. 2000. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10798963

Risk Title: Other Degenerative Tissue Risks

Theme :	Radiation Health
Discipline :	Radiation Health
Risk Number :	33
Risk Description :	Unacceptable levels of morbidity or mortality risks for degenerative tissue diseases (non-cancer or

<table>
<tr><td></td><td>non-CNS) such as cardiac, circulatory or digestive diseases or cataracts caused by occupational radiation exposure or the combined effects of radiation and other space flight factors.</td></tr>
<tr><td>Context/Risk Factors :</td><td>Microgravity ; Physiological changes ; Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation ; Stress</td></tr>
<tr><td>RYG Risk Assessment :</td><td>ISS: Yellow
High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Lunar: Yellow
High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Mars: Red
Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.</td></tr>
<tr><td>Justification :</td><td>ISS:
Crew Health and Performance Post-Mission
Lunar:
Crew Health and Performance Post-Mission
Mars:
Crew Health and Performance Post-Mission</td></tr>
<tr><td>Current Countermeasures :</td><td>ISS :
Polyethylene shielding
Lunar :
Polyethylene shielding
Mars :
Polyethylene shielding</td></tr>
<tr><td>Projected Countermeasures :</td><td>ISS :
Hydrogenous shielding ; Anti-oxidants ; Gene therapy ; Pharmaceuticals
Lunar :
Hydrogenous shielding ; Anti-oxidants ; Gene therapy ; Pharmaceuticals
Mars :
Hydrogenous shielding ; Anti-oxidants ; Gene therapy ; Pharmaceuticals</td></tr>
<tr><td>Enabling Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>33a</td><td>What are the probabilities for degenerative tissue risks from protons and HZE ions as a function of NASA's operational parameters (age at exposure, age and time after exposure, gender, tissue, mission, radiation quality, dose rate)? [ISS 2, Lunar 2, Mars 1]</td></tr>
<tr><td>33b</td><td>What are the mechanisms of degenerative tissues risks in the heart, circulatory, endocrine, digestive, lens and other tissue systems? [ISS 2, Lunar 2, Mars 1]</td></tr>
<tr><td>33c</td><td>How can the latency period for degenerative tissue risks, including sub-clinical diseases, following space radiation exposures be estimated? [ISS 3, Lunar 3, Mars 1]</td></tr>
<tr><td>33d</td><td>What are the most effective biomedical or dietary countermeasures to degenerative tissue risks? By what mechanisms do the countermeasures work? [ISS 3, Lunar 3, Mars 1]</td></tr>
<tr><td>33e</td><td>What quantitative procedures or theoretical models are needed to extrapolate molecular, cellular, or animal results to predict degenerative tissue risks in astronauts? How can human epidemiology data best support these procedures or models? [ISS 4, Lunar 4, Mars 2]</td></tr>
</table>
</td></tr>
<tr><td>Related Risks :</td><td></td></tr>
<tr><td>Important References :</td><td>Berrington, A., et al., 100 Years of observation of British radiologists: mortality from cancer and other causes 1897-1997. BrJ Radio 74:507-519. 2001.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12595318</td></tr>
</table>

	Boivin, J.F., et al. Coronary Artery Disease Mortality in Patients Treated for Hodgkins Disease. Cancer 69: 1241-1247, 1992. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=1739922
	Cucinotta, F.A., Manuel, F., Jones, J., Izsard, G., Murray, J., Djojonegoro, B. and Wear, M. Space Radiation and Cataracts in Astronauts. Radiation Research 156: 460-466, 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11604058
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	National Academy of Sciences Space Science Board, Report of the Task Group on the Biological Effects of Space Radiation. Radiation Hazards to Crews on Interplanetary Mission National Academy of Sciences, Washington, D.C., 1997.
	National Council on Radiation Protection and Measurements, Recommendations of Dose Limits for Low Earth Orbit. NCRP Report 132, Bethesda MD, 2000.
	Otake, M., Neriishi, K. and Schull, W.J. Cataract in atomic bomb survivors based on a threshold and the occurrence of severe epilation. Radiation Research 146: 339-348, 1996. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=8752314
	Preston, D.L., et al. Studies of mortality of atomic bomb survivors Report 13: Solid cancer and noncancer disease mortality: 1950-1997. Radiation Research 160, 381-407, 2003. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=12968934
	Schimizu, Y., et. al. Studies of the Mortality of Atomic Bomb Survivors. Report 12, Part II: Non-cancer mortality: 1950-1990. Radiation Research 152: 374-389, 1999. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10477914
	Stewart, J.R. and Faiardo, L.F. Radiation-induced heart disease. Clinical and experimental aspects. Radiological Clinical Journal of North America 9, 511-531, 1971. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=5001977

Risk Title: Heredity, Fertility and Sterility Risks

Theme :	Radiation Health
Discipline :	Radiation Health
Risk Number :	34
Risk Description :	Unacceptable levels of increased hereditary, fertility, or sterility risk caused by occupational radiation exposure or the combined effects of radiation and other space flight factors. These decrements can be following return to Earth (late), or in the progeny of astronauts (for hereditary risks).
Context/Risk Factors :	Microgravity ; Physiological changes ; Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation ; Stress
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space.

	Mars: Yellow High risk of serious health or performance consequences; there is no mitigation strategy that has been validated in space.
Justification :	**ISS:** Crew Health and Performance Post-Mission **Lunar:** Crew Health and Performance Post-Mission **Mars:** Crew Health and Performance Post-Mission
Current Countermeasures :	**ISS :** Family counseling ; Polyethylene shielding **Lunar :** Family counseling ; Polyethylene shielding **Mars :** Family counseling ; Polyethylene shielding
Projected Countermeasures :	**ISS :** Hydrogenous shielding ; Anti-oxidants ; Gene therapy ; Pharmaceuticals **Lunar :** Hydrogenous shielding ; Anti-oxidants ; Gene therapy ; Pharmaceuticals **Mars :** Hydrogenous shielding ; Anti-oxidants ; Gene therapy ; Pharmaceuticals
Enabling Questions [With Mission Priority]:	see below
Related Risks :	
Important References :	see below

Enabling Questions [With Mission Priority]:

No.	Question
34a	What are the risks of hereditary, fertility or sterility effects as a result of exposure to space radiation? **[ISS 4, Lunar 3, Mars 2]**
34b	Is there a transmissible risk for neurodegenerative or other non-cancer/non-CNS diseases to the offspring of those exposed to radiation? **[ISS 3, Lunar 3, Mars 3]**

Important References :

Beir V, Health Effects of Exposure to Low Levels of Ionizing Radiation. NRC, National Academy of Sciences Press, 1990.
Bridges BA. Radiation and Germline Mutation at Repeat Sequences: Are We in the Middle of a Paradigm Shift? Radiation Research 156: 631-641, 2001. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11604085
National Academy of Sciences Space Science Board, Report of the Task Group on the Biological Effects of Space Radiation. Radiation Hazards to Crews on Interplanetary Mission National Academy of Sciences, Washington, D.C., 1997.
National Council on Radiation Protection and Measurements, Recommendations of Dose Limits for Low Earth Orbit. NCRP Report 132, Bethesda MD, 2000.
Schull, W.J., Otake, M. and Neel, J.V. Genetic Effects of the Atomic Bombs: A Reappraisal. Science 213, 1220-1227, 1981. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=7268429

Risk Title: Acute Radiation Syndromes

Theme :	Radiation Health
Discipline :	Radiation Health
Risk Number :	35
Risk Description :	Any increased risk of clinically significant acute radiation syndromes caused by occupational radiation exposure or the combined effects of radiation and other space flight factors. These decrements can be manifested during an extended mission (acute), or following return to Earth (late)
Context/Risk Factors :	Microgravity ; Physiological changes ; Radiation (space, medical diagnostic, atmospheric, experimental and nuclear sources including propulsion systems) and synergistic effects of radiation ;

	Stress
RYG Risk Assessment :	**ISS:** Green Health and performance consequences are known or suspected, but will not affect mission success due to effective mitigation strategies that have been validated in space. **Lunar:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth. **Mars:** Red Unacceptable risk of serious adverse health or performance consequences; there is no mitigation strategy that has been validated in space or demonstrated on Earth.
Justification :	**ISS:** Crew Health and Performance In-Flight and Crew Health and Performance Post-Mission **Lunar:** Crew Health and Performance Post-Mission **Mars:** Crew Health and Performance Post-Mission
Current Countermeasures :	**ISS :** Polyethylene shielding **Lunar :** Polyethylene shielding **Mars :** Polyethylene shielding
Projected Countermeasures :	**ISS :** Hydrogenous shielding ; Anti-oxidants ; Gene therapy or bone marrow transplant ; Pharmaceuticals **Lunar :** Hydrogenous shielding ; Anti-oxidants ; Gene therapy or bone marrow transplant ; Pharmaceuticals **Mars :** Hydrogenous shielding ; Anti-oxidants ; Gene therapy or bone marrow transplant ; Pharmaceuticals

Enabling Questions [With Mission Priority]:

No.	Question
35a	How can predictions of acute space radiation events be improved? **[ISS 5, Lunar 3, Mars 3]**
35b	Are there synergistic effects arising from other space flight factors (microgravity, stress, immune status, bone loss, damage to intestinal cells reducing their ability to absorb medication? etc.) that modify acute risks from space radiation including modifying thresholds for such effects? **[ISS 4, Lunar 3, Mars 3]**
35c	What are the molecular, cellular and tissue mechanisms of acute radiation damage (DNA damage processing, oxidative damage, cell loss through apoptosis or necrosis, cytokine activation, etc.)? **[ISS 4, Lunar 3, Mars 3]**
35d	Does protracted exposure to space radiation modify acute doses from SPEs in relationship to acute radiation syndromes? **[ISS 4, Lunar 3, Mars 3]**
35e	What are the most effective biomedical or dietary countermeasures to mitigate acute radiation risks? By what mechanisms do the countermeasures work? **[ISS 4, Lunar 3, Mars 3]**
35f	What quantitative procedures or theoretical models are needed to extrapolate molecular, cellular, or animal results to predict acute radiation risks in astronauts? How can human epidemiology data best support these procedures or models? **[ISS 4, Lunar 3, Mars 3]**
35g	What are the most effective shielding approaches to mitigate acute radiation risks? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

Important References :

Ainsworth, E.J. Early and late mammalian responses to heavy charged particles. Advances in Space Research 6: 153-165, 1986.

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=11537215

National Council on Radiation Protection and Measurements, NCRP. Guidance on Radiation Received in Space Activities, NCRP Report 98, NCRP, Bethesda (MD), 1989.

	National Council on Radiation Protection and Measurements, Recommendations of Dose Limits for Low Earth Orbit. NCRP Report 132, Bethesda MD, 2000. Todd, P., Pecautt, M.J., Fleshner, M. Combined effects of space flight factors and radiation on humans. Mutation Res. 430: 211-219, 1999. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10631335

Risk Title: Monitor Air Quality

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control (AEMC)
Risk Number :	36
Risk Description :	Lack of timely information about the buildup of chemicals, pre-combustion reaction products, malfunction of life support equipment, or other events (e.g., accidental release from an experiment) can lead to delayed response by crew or by automated equipment resulting in a hazard to the crew.
Context/Risk Factors :	Accidental event such as fire or leak ; Malfunction in life support system which may be gradual or sudden
RYG Risk Assessment :	**ISS:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Lunar:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements. **Mars:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:** The time constant for measurement varies widely depending on the cause. Gradual buildup of toxic chemicals may take months, calling for highly sensitive detection at slow intervals, perhaps daily. Leakage or pre-combustion events are expected to occur more rapidly, requiring more rapid detection (minutes), though less sensitive detection may be necessary. Localized information is needed to identify the problem source. Existing technology for ground-based measurement is massive, power hungry and requires significant crew skill and time. No single technology currently can address all Space Maximum Allowable Concentration SMAC chemicals. Combustion in micro, lunar and Martian gravity is very different from combustion on Earth and has different pre-combustion indicators. Harmful foreign matter may be inadvertently brought in following extravehicular activity (EVA) and should be monitored prior to cabin entry as well as inside the habitat. The same monitoring technology may be useful for helping diagnose crew health by providing breath monitoring data. **Lunar:** The time constant for measurement varies widely depending on the cause. Gradual buildup of toxic chemicals may take months, calling for highly sensitive detection at slow intervals, perhaps daily. Leakage or pre-combustion events are expected to occur more rapidly, requiring more rapid detection (minutes), though less sensitive detection may be necessary. Localized information is needed to identify the problem source. Existing technology for ground-based measurement is massive, power hungry and requires significant crew skill and time. No single technology currently can address all Space Maximum Allowable Concentration SMAC chemicals. Combustion in micro, lunar and Martian gravity is very different from combustion on Earth and has different pre-combustion indicators. Harmful foreign matter may be inadvertently brought in following extravehicular activity (EVA) and should be monitored prior to cabin entry as well as inside the habitat. The same monitoring technology may be useful for helping diagnose crew health by providing breath monitoring data. **Mars:** The time constant for measurement varies widely depending on the cause. Gradual buildup of toxic chemicals may take months, calling for highly sensitive detection at slow intervals, perhaps daily. Leakage or pre-combustion events are expected to occur more rapidly, requiring more rapid detection (minutes), though less sensitive detection may be necessary. Localized information is needed to identify the problem source. Existing technology for ground-based measurement is massive, power hungry and requires significant crew skill and time. No single technology currently can address all Space Maximum Allowable Concentration SMAC chemicals. Combustion in micro, lunar and Martian gravity is very different from combustion on Earth and has different pre-combustion

<table>
<tr><td></td><td>indicators. Harmful foreign matter may be inadvertently brought in following extravehicular activity (EVA) and should be monitored prior to cabin entry as well as inside the habitat. The same monitoring technology may be useful for helping diagnose crew health by providing breath monitoring data.</td></tr>
<tr><td>Current Countermeasures :</td><td>ISS :
Compound Specific Combustion Product Analyzer ; Crew indicators such as reports of odor, nausea ; Ground analysis of returned samples ; Major Constituent Analyzer (currently not functioning) ; Volatile Organic Analyzer (currently not functioning)
Lunar :
Compound Specific Combustion Product Analyzer ; Crew indicators such as reports of odor, nausea ; Ground analysis of returned samples ; Major Constituent Analyzer (currently not functioning) ; Volatile Organic Analyzer (currently not functioning)
Mars :
Compound Specific Combustion Product Analyzer ; Crew indicators such as reports of odor, nausea ; Ground analysis of returned samples ; Major Constituent Analyzer (currently not functioning) ; Volatile Organic Analyzer (currently not functioning)</td></tr>
<tr><td>Projected Countermeasures :</td><td>ISS :
Distributed network of rapid, smaller detectors ; Highly sensitive somewhat slower analyzer suite
Lunar :
Distributed network of rapid, smaller detectors ; Highly sensitive somewhat slower analyzer suite
Mars :
Distributed network of rapid, smaller detectors ; Highly sensitive somewhat slower analyzer suite</td></tr>
<tr><td>Enabling Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>36a</td><td>What technologies can be used to detect slow, gradual changes in the chemical and microbial environment (work with Environmental Health)? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>36b</td><td>What set of technologies and data can be used to make the diagnosis of potentially hazardous event from chemical data quickly (work with Environmental Health, ALS)? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>36c</td><td>How can environmental information be used to assist in-flight biomonitoring for health and performance of the astronauts (supporting Biomedical monitoring)? [ISS 3, Lunar 3, Mars 3]</td></tr>
<tr><td>36d</td><td>What technologies must be developed to rapidly detect and address fire in space? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>36e</td><td>How can technology help make appropriate response to a hazardous event be achieved in a timely manner (needed for automated systems)? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>36f</td><td>What set of technologies and data can be used to detect and diagnose hardware malfunction, in such systems as life support or in situ resource utilization by assessment of environmental (air, water, or surfaces) changes (work with ALS)? [ISS 2, Lunar 2, Mars 2]</td></tr>
</table>
</td></tr>
<tr><td>Related Risks :</td><td>ISS :
<table>
<tr><td>Environmental Health</td></tr>
<tr><td>Define Acceptable Limits for Contaminants in Air and Water</td></tr>
<tr><td>Advanced Life Support (ALS)</td></tr>
<tr><td>Maintain Acceptable Atmosphere</td></tr>
<tr><td>Provide and Maintain Bioregenerative Life Support Systems</td></tr>
<tr><td>Provide and Recover Potable Water</td></tr>
</table>
Lunar :
<table>
<tr><td>Environmental Health</td></tr>
<tr><td>Define Acceptable Limits for Contaminants in Air and Water</td></tr>
<tr><td>Advanced Life Support (ALS)</td></tr>
<tr><td>Maintain Acceptable Atmosphere</td></tr>
<tr><td>Provide and Maintain Bioregenerative Life Support Systems</td></tr>
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	Provide and Recover Potable Water **Mars :** **Environmental Health** Define Acceptable Limits for Contaminants in Air and Water **Advanced Life Support (ALS)** Maintain Acceptable Atmosphere Provide and Maintain Bioregenerative Life Support Systems Provide and Recover Potable Water
Important References :	"Cabin Air Quality Dynamics on Board the International Space Station" J. Perry, B. Peterson, 33rd International Conference on Environmental Systems, SAE#2003-01-2650, July 2003. "Toxicological Assessment of the International Space Station Atmosphere with Emphasis on Metox Canister Regeneration" J. James, 33rd International Conference on Environmental Systems, SAE#2003-01-2647, July 2003. Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf http://peer1.nasaprs.com/peer_review/prog/nap.pdf NASA/JSC Toxicology Group Home Page http://www.jsc.nasa.gov/toxicology/ http://www.jsc.nasa.gov/toxicology/

Risk Title: Monitor External Environment

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control (AEMC)
Risk Number :	37
Risk Description :	Failure to detect hazards external to the habitat can lead to lack of remedial action and poses a hazard to the crew.
Context/Risk Factors :	TBD
RYG Risk Assessment :	**ISS:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Lunar:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements. **Mars:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:** null **Lunar:** null **Mars:** null
Current Countermeasures :	**ISS :** Trace Gas Analyzer (TGA) using miniature quadrupole mass spectrometry technology **Lunar :** Trace Gas Analyzer (TGA) using miniature quadrupole mass spectrometry technology **Mars :** Trace Gas Analyzer (TGA) using miniature quadrupole mass spectrometry technology
Projected Countermeasures :	**ISS :** Realtime radiation monitor ; Second generation TGA **Lunar :**

	Real-time radiation monitor ; Third generation TGA to include particulate measurement **Mars :** Real-time radiation monitor ; Third generation TGA to include particulate measurement
Enabling Questions [With Mission Priority]:	<table><tr><th>No.</th><th>Question</th></tr><tr><td>37a</td><td>What sensors are required to monitor hazardous conditions in the extra-vehicular environment (work with AEVA)? [ISS 1, Lunar 1, Mars 1]</td></tr></table>
Related Risks :	
Important References :	"Trace Gas Analyzer for Extra-Vehicular Activity" T. Abbasi, M. Christensen, M. Villemarette, M. Darrach, A. Chutjian, 31st International Conference on Environmental Systems, SAE#2001-01-2405, July 2001.

Risk Title: Monitor Water Quality

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control (AEMC)
Risk Number :	38
Risk Description :	Lack of timely information about the build-up of chemicals or microbial growth in the crew water supply, or elsewhere in the water reclamation system, can lead to a delayed response by the crew or the automated response equipment posing a hazard to the crew.
Context/Risk Factors :	Accidental event such as leak of ammonia from cooling system into water supply through heat exchanger ; Malfunction in life support system which may be gradual or sudden
RYG Risk Assessment :	**ISS:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Lunar:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements. **Mars:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:** The time constant for measurement varies widely depending on the cause. Gradual buildup of toxic chemicals may take months, calling for highly sensitive detection at slow intervals, perhaps daily. Leakage events are expected to occur more rapidly, requiring more rapid detection (minutes), though less sensitive detection may be necessary. Localized information is needed to identify the problem source. Existing technology for ground-based measurement is massive, power hungry, needs hazardous reagents, requires significant crew skill and time and is sensitive to micro, lunar, or Martian gravity multiphase issues. **Lunar:** The time constant for measurement varies widely depending on the cause. Gradual buildup of toxic chemicals may take months, calling for highly sensitive detection at slow intervals, perhaps daily. Leakage events are expected to occur more rapidly, requiring more rapid detection (minutes), though less sensitive detection may be necessary. Localized information is needed to identify the problem source. Existing technology for ground-based measurement is massive, power hungry, needs hazardous reagents, requires significant crew skill and time and is sensitive to micro, lunar, or Martian gravity multiphase issues. **Mars:** The time constant for measurement varies widely depending on the cause. Gradual buildup of toxic chemicals may take months, calling for highly sensitive detection at slow intervals, perhaps daily. Leakage events are expected to occur more rapidly, requiring more rapid detection (minutes), though less sensitive detection may be necessary. Localized information is needed to identify the problem source. Existing technology for ground-based measurement is massive, power hungry, needs hazardous reagents, requires significant crew skill and time and is sensitive to micro, lunar, or Martian gravity multiphase issues.
Current Countermeasures :	**ISS :** Crew report of odor or taste ; Ground analysis of returned samples ; Manual plate culturing at ambient temperature with visual estimate ; Total Organic Carbon (currently not in use due to difficulty in bubble removal) ; Water conductivity **Lunar :**

<table>
<tr><td></td><td>Crew report of odor or taste ; Ground analysis of returned samples ; Manual plate culturing at ambient temperature with visual estimate ; Total Organic Carbon (currently not in use due to difficulty in bubble removal) ; Water conductivity
Mars :
Crew report of odor or taste ; Ground analysis of returned samples ; Manual plate culturing at ambient temperature with visual estimate ; Total Organic Carbon (currently not in use due to difficulty in bubble removal) ; Water conductivity</td></tr>
<tr><td>Projected Countermeasures :</td><td>ISS :
Compact online chemical water analyzer suite ; Microbial analysis instrument
Lunar :
Compact online chemical water analyzer suite ; Microbial analysis instrument
Mars :
Compact online chemical water analyzer suite ; Microbial analysis instrument</td></tr>
<tr><td>Enabling Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>38a</td><td>What technologies can be used to detect slow, gradual changes in the chemical and microbial environment (work with ALS and Environmental Health)? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>38b</td><td>What set of technologies and data can be used to make the diagnosis of potentially hazardous event from chemical data quickly (work with ALS and Environmental Health)? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>38c</td><td>How can technology help make appropriate response to a hazardous event be achieved in a timely manner (needed for developing automated system)? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>38d</td><td>What set of technologies and data can be used to detect and diagnose hardware malfunction by assessment of environmental (air, water, or surfaces) changes (work with ALS)? [ISS 1, Lunar 1, Mars 1]</td></tr>
</table>
</td></tr>
<tr><td>Related Risks :</td><td>
ISS :
<table>
<tr><td>Environmental Health</td></tr>
<tr><td>Define Acceptable Limits for Contaminants in Air and Water</td></tr>
<tr><td>Advanced Life Support (ALS)</td></tr>
<tr><td>Maintain Acceptable Atmosphere</td></tr>
<tr><td>Provide and Maintain Bioregenerative Life Support Systems</td></tr>
<tr><td>Provide and Recover Potable Water</td></tr>
</table>
Lunar :
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<tr><td>Provide and Recover Potable Water</td></tr>
</table>
</td></tr>
</table>

Important References :	"ISS Potable Water Sampling and Chemical Analysis: Expeditions 4-6" D. Plumlee, P. Mudgett, J. Schultz, J. James, 33rd International Conference on Environmental Systems, SAE#2003-01-2401, July 2003. Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf http://peer1.nasaprs.com/peer_review/prog/nap.pdf AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html http://peer1.nasaprs.com/peer_review/prog/prog.html Characterization and Monitoring of Microbial Species in the International Space Station Drinking Water," M. LaDuc, 33rd International Conference on Environmental Systems, SAE#2003-01-2404, July 2003. NASA/JSC Toxicology Group Home Page http://www.jsc.nasa.gov/toxicology/ http://www.jsc.nasa.gov/toxicology/

Risk Title: Monitor Surfaces Food and Soil

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control (AEMC)
Risk Number :	39
Risk Description :	Lack of timely information, or failure to detect the presence of harmful chemicals or microbial growth on surfaces, food supplies or soil required for plant growth can pose a crew health hazard.
Context/Risk Factors :	Low or microgravity allows for greater accumulation of liquids on surfaces by surface tension and longer persistence of matter suspended in air, increased the likelihood of surface impact
RYG Risk Assessment :	**ISS:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Lunar:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements. **Mars:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:** The area of contamination of surfaces in the space environment has received relatively little attention to date. The risk is essentially unknown. **Lunar:** The area of contamination of surfaces in the space environment has received relatively little attention to date. The risk is essentially unknown. **Mars:** The area of contamination of surfaces in the space environment has received relatively little attention to date. The risk is essentially unknown.
Current Countermeasures :	**ISS :** Occasional manual plate culturing of samples from swabbed surfaces **Lunar :** Occasional manual plate culturing of samples from swabbed surfaces **Mars :** Occasional manual plate culturing of samples from swabbed surfaces
Projected Countermeasures :	**ISS :** Detection and identification of surface contamination by optical interrogation ; Reliable, repeatable sampling methods taking minimal crew time **Lunar :** Detection and identification of surface contamination by optical interrogation ; Reliable, repeatable sampling methods taking minimal crew time **Mars :** Detection and identification of surface contamination by optical interrogation ; Reliable, repeatable

	sampling methods taking minimal crew time

Enabling Questions [With Mission Priority]:

No.	Question
39a	What technologies can be used to detect slow, gradual changes in the chemical and microbial surface environment? (work with Environmental Health and ALS) **[ISS 1, Lunar 1, Mars 1]**
39b	What set of technologies and data can be used to make the diagnosis of potentially hazardous event involving surfaces quickly? (work with Environmental Health and Life Support) **[ISS 1, Lunar 1, Mars 1]**
39c	What technologies are required to meet the radiation monitoring requirements of a mission? **[ISS TBD, Lunar TBD, Mars TBD]**
39d	What sample acquisition and preparation technologies can meet the requirements of the gaseous, aqueous and solid-phase matrices monitoring? **[ISS TBD, Lunar TBD, Mars TBD]**
39e	What research is required to validate design approaches for multiphase flow for monitoring systems in varying gravity environments? **[ISS TBD, Lunar TBD, Mars TBD]**

Related Risks :

ISS :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Advanced Life Support (ALS)
Maintain Acceptable Atmosphere
Provide and Maintain Bioregenerative Life Support Systems
Provide and Recover Potable Water

Lunar :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Advanced Life Support (ALS)
Maintain Acceptable Atmosphere
Provide and Maintain Bioregenerative Life Support Systems
Provide and Recover Potable Water

Mars :

Environmental Health
Define Acceptable Limits for Contaminants in Air and Water
Advanced Life Support (ALS)
Maintain Acceptable Atmosphere
Provide and Maintain Bioregenerative Life Support Systems
Provide and Recover Potable Water

Important References :

Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf http://peer1.nasaprs.com/peer_review/prog/nap.pdf
AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html http://peer1.nasaprs.com/peer_review/prog/prog.html

Risk Title: Provide Integrated Autonomous Control of Life Support Systems

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Environmental Monitoring & Control (AEMC)
Risk Number :	40
Risk Description :	Lack of stable, reliable, efficient process control for the life support system.
Context/Risk Factors :	Decreasing life support system mass by decreasing air or water buffer sizes (an economically desirable objective) increases potential for system to become unstable ; Longer mission time such as Martian scenario means greater potential for life support system to become unstable
RYG Risk Assessment :	**ISS:** Green Minimum or limited potential for improvement in mitigation efficiency **Lunar:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Mars:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:** Automated control of life support is needed to minimize the crew workload. Industrial process control technology is manufacturing-oriented (input/output) with a narrow range of time constants. Space life support is an endless loop-recycling environment, with time constants ranging from fast accidental incidents to life cycles of plant crops (months). Advances in process control technology are needed for safe, efficient control of the life support system. **Lunar:** Automated control of life support is needed to minimize the crew workload. Industrial process control technology is manufacturing-oriented (input/output) with a narrow range of time constants. Space life support is an endless loop-recycling environment, with time constants ranging from fast accidental incidents to life cycles of plant crops (months). Advances in process control technology are needed for safe, efficient control of the life support system. **Mars:** Automated control of life support is needed to minimize the crew workload. Industrial process control technology is manufacturing-oriented (input/output) with a narrow range of time constants. Space life support is an endless loop-recycling environment, with time constants ranging from fast accidental incidents to life cycles of plant crops (months). Advances in process control technology are needed for safe, efficient control of the life support system.
Current Countermeasures :	**ISS :** Manual and low level process control **Lunar :** Manual and low level process control **Mars :** Manual and low level process control
Projected Countermeasures :	**ISS :** Automated control of life support, integrated with monitoring system **Lunar :** Automated control of life support, integrated with monitoring system **Mars :** Automated control of life support, integrated with monitoring system
Enabling Questions [With Mission Priority]:	

No.	Question
40a	How do we design an effective control system with flexibility, modularity, growth potential, anti-obsolescence and accommodate varied, new, & unknown test articles, taking advantage of standards (work with Integrated Testing)? **[ISS 1, Lunar 1, Mars 1]**
40b	How does a control system manage and plan for the long time constants of certain biological processes that lead to changes days, months later; and reconciles between discrete events, continuous processing and varying time constants (work with Integrated Testing)? **[ISS 1, Lunar 1, Mars 1]**
40c	How do we assure that human situation awareness is at a high level when needed, while offloading the crew workload for most of the time (work with SHFE and Integrated Testing)? **[ISS 2, Lunar 2, Mars 2]**
40d	How can a control system support strategic decisions; launch readiness/abort/return home decisions and procedures (work with SHFE and Integrated Testing)? **[ISS 1, Lunar 1, Mars 1]**

	40e	How can we develop real time prognostic capabilities to predict failures before they occur and degradations before they have impact (work with ALS and Integrated Testing)? **[ISS 1, Lunar 1, Mars 1]**
	40f	How do we allocate efficiently and safely between space-based control and ground-based control (work with SHFE and Integrated Testing)? **[ISS 1, Lunar 1, Mars 1]**
	40g	In very large and complex systems, how can we synchronize system states across subsystems (work with Integrated Testing)? **[ISS 1, Lunar 1, Mars 1]**
	40h	How do we trade between buffers and controls to ensure safe and reliable system (work with ALS and Integrated Testing)? **[ISS 1, Lunar 1, Mars 1]**
	40i	How can understanding process control help determine which sensors may be missing and where sensors should be placed (work with Integrated Testing)? **[ISS 1, Lunar 1, Mars 1]**
Related Risks :	**ISS :**	
	Environmental Health	
	Define Acceptable Limits for Contaminants in Air and Water	
	Advanced Life Support (ALS)	
	Maintain Acceptable Atmosphere	
	Lunar :	
	Environmental Health	
	Define Acceptable Limits for Contaminants in Air and Water	
	Advanced Life Support (ALS)	
	Maintain Acceptable Atmosphere	
	Mars :	
	Environmental Health	
	Define Acceptable Limits for Contaminants in Air and Water	
	Advanced Life Support (ALS)	
	Maintain Acceptable Atmosphere	
Important References :	Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable from http://peer1.nasaprs.com/peer_review/prog/nap.pdf http://peer1.nasaprs.com/peer_review/prog/nap.pdf	
	AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html http://peer1.nasaprs.com/peer_review/prog/prog.html	
	Final Report, Workshop on Advanced System Integration and Control for Life Support (ASICLS) Monterey Plaza Hotel , 26 – 28 August 2003, Monterey, CA	
	NASA Advanced Environmental Monitoring and Control (AEMC) Program Review, Final Report, USRA, August 1999. Also, AEMC review response sent to HQ Sept 1999.	

Risk Title: Provide Space Suits and Portable Life Support Systems

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Extravehicular Activity (AEVA)
Risk Number :	41
Risk Description :	Inability to provide a robust EVA system that provides the life support resources, mobility and ancillary support, including robotics interactions and airlock design, to perform defined mission EVA tasks.

Context/Risk Factors :	Accommodation for waste including potential for emisses ; CO_2 removal system consumption ; Dust contamination ; Power consumption ; Suit pressure ; Thermal comfort consumables, increased carry weight
RYG Risk Assessment :	**ISS:** Green Minimum or limited potential for improvement in mitigation efficiency **Lunar:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Mars:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:** Long-duration in Martian partial Gravity leads to increased hardware use. Hardware failures could occur without the capability for equipment servicing and overhaul. Dust contamination leads to equipment failures and decreased suit mobility from contaminated bearings and joints. **Lunar:** Long-duration in Martian partial Gravity leads to increased hardware use. Hardware failures could occur without the capability for equipment servicing and overhaul. Dust contamination leads to equipment failures and decreased suit mobility from contaminated bearings and joints. **Mars:** Long-duration in Martian partial Gravity leads to increased hardware use. Hardware failures could occur without the capability for equipment servicing and overhaul. Dust contamination leads to equipment failures and decreased suit mobility from contaminated bearings and joints.
Current Countermeasures :	**ISS :** Dedicated water ; Limited maintenance ; Longer life rechargeable batteries ; Regenerable CO_2 removal systems **Lunar :** Apollo Era dust mitigation ; Dedicated water ; Limited maintenance ; Longer life rechargeable batteries ; Regenerable CO_2 removal systems **Mars :** Apollo Era dust mitigation ; Dedicated water ; Limited maintenance ; Longer life rechargeable batteries ; Regenerable CO_2 removal systems
Projected Countermeasures :	**ISS :** Cleaning and maintenance of soft goods (e.g., LCVG) ; Increased on-orbit space suit service life ; Longer shelf and service life batteries ; Non-venting heat rejection system ; Regenerable closed loop CO_2 removal systems **Lunar :** Cleaning and maintenance of soft goods (e.g., LCVG) ; Dust removal and dust prevention ; Increased on-orbit space suit service life ; Longer shelf and service life batteries ; Non-venting heat rejection system ; Reduced mass of suit and PLSS ; Regenerable closed loop CO_2 removal systems **Mars :** Cleaning and maintenance of soft goods (e.g., LCVG) ; Dust removal and dust prevention ; Increased on-orbit space suit service life ; Longer shelf and service life batteries ; Non-venting heat rejection system ; Reduced mass of suit and PLSS ; Regenerable closed loop CO_2 removal systems
Enabling Questions [With Mission Priority]:	

No.	Question
41a	What EVA system design can be developed to reduce the pre-breath requirement? **[Lunar 1, Mars 1]**
41b	What suit and PLSS technology must be developed to meet mission requirements for EVA mobility? **[Lunar 1, Mars 1]**
41c	How do we protect against planetary surface dust through suit and airlock system design? **[Lunar 1, Mars 1]**
41d	How do we protect against toxic fluids and contaminants? **[ISS 2, Lunar 2, Mars 2]**
41e	How do we design space suits to fit multiple crewmembers of various sizes and shapes? **[ISS 1, Lunar 1, Mars 1]**
41f	How do we improve glove dexterity? **[ISS 1, Lunar 1, Mars 1]**
41g	What technologies can be developed to provide passive or active thermal insulation in various environments, including deep-space and lunar vacuum? **[Lunar 1, Mars 1]**
41h	What technologies must be developed to meet mission non-venting and non-contaminating requirements? **[Lunar 2, Mars 2]**

41i	How do we provide and manage increased information to EVA crewmember, including suit parameters, systems status, caution and warning, video, sensor data, procedures and text and graphics? **[Lunar 2, Mars 2]**
41j	How do we achieve EVA and robotic interaction and cooperation? **[Lunar 1, Mars 1]**
41k	What biomedical sensors are needed to enhance safety and performance during EVAs? **[Lunar 2, Mars 2]**
41l	How can space suit design accommodate crewmember physical changes after long time in microgravity? **[Lunar 1, Mars 1]**
41m	What technology can be developed to monitor EVA crewmember thermal status and provide auto-thermal control? **[Lunar 1, Mars 1]**
41n	Can a practical EMU containment receptacle for emesis be developed? If a vomiting episode occurs, is there a way of refurbishing the suit during the mission? How can suit life support systems be designed to be more resistant to vomiting episode? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

ISS :

Human Behavior & Performance and Space Human Factors (Cognitive)
Mismatch between Crew Cognitive Capabilities and Task Demands
Advanced Environmental Monitoring & Control (AEMC)
Monitor Air Quality
Monitor External Environment
Monitor Water Quality
Monitor Surfaces Food and Soil
Provide Integrated Autonomous Control of Life Support Systems
Advanced Life Support (ALS)
Provide and Recover Potable Water
Space Human Factors Engineering
Mismatch between Crew Physical Capabilities and Task Demands
Mis-assignment of Responsibilities within Multi-agent Systems

Lunar :

Human Behavior & Performance and Space Human Factors (Cognitive)
Mismatch between Crew Cognitive Capabilities and Task Demands
Advanced Environmental Monitoring & Control (AEMC)
Monitor Air Quality
Monitor External Environment
Monitor Water Quality
Monitor Surfaces Food and Soil
Provide Integrated Autonomous Control of Life Support Systems
Advanced Life Support (ALS)
Provide and Recover Potable Water
Space Human Factors Engineering
Mismatch between Crew Physical Capabilities and Task Demands
Mis-assignment of Responsibilities within Multi-agent Systems

Mars :

Human Behavior & Performance and Space Human Factors (Cognitive)

	Mismatch between Crew Cognitive Capabilities and Task Demands **Advanced Environmental Monitoring & Control (AEMC)** Monitor Air Quality Monitor External Environment Monitor Water Quality Monitor Surfaces Food and Soil Provide Integrated Autonomous Control of Life Support Systems **Advanced Life Support (ALS)** Provide and Recover Potable Water **Space Human Factors Engineering** Mismatch between Crew Physical Capabilities and Task Demands Mis-assignment of Responsibilities within Multi-agent Systems
Important References :	Advanced Technology for Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.

Risk Title: Maintain Food Quantity and Quality

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Food Technology (AFT)
Risk Number :	42
Risk Description :	If the food system is inadequate for the mission, then crew nutritional requirements may not be met and crew health and performance will suffer. An inadequate food system is one that is unsafe provides food that fails to meet nutritional requirements or is unacceptable from a sensory standpoint.
Context/Risk Factors :	Below standard food intakes ; Chemical or microbial contamination of food ; Crew psychological and physiological changes ; Elevated stress and boredom ; Inadequate food packaging ; Inadequate food processing/preservation ; Inadequate quantity of food ; Inadequate shelf life ; Inadequate storage conditions and environmental control ; Inadequate variety ; Product formulation ; Undefined nutritional requirements
RYG Risk Assessment :	**ISS:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Lunar:** Green Minimum or limited potential for improvement in mitigation efficiency **Mars:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:** Food provides the crew with the required nutritional daily intake. In addition, food through its variety and acceptability provides a psychosocial component by decreasing stress during a mission. An inadequate food supply will lead to unhealthy crewmembers hence resulting in a compromised mission through reduced crew performance. **Lunar:** Food provides the crew with the required nutritional daily intake. In addition, food through its variety and acceptability provides a psychosocial component by decreasing stress during a mission. An inadequate food supply will lead to unhealthy crewmembers hence resulting in a compromised mission through reduced crew performance. **Mars:** Food provides the crew with the required nutritional daily intake. In addition, food through its variety and acceptability provides a psychosocial component by decreasing stress during a mission. An inadequate food supply will lead to unhealthy crewmembers hence resulting in a compromised mission through reduced crew performance.
Current Countermeasures :	**ISS :** Hazard analysis critical control point processing ; Increased menu cycle ; Increased variety of menu

items ; Menu developed based on daily nutritional requirements ; Testing and evaluation ; Vitamin D supplementation

Lunar :

Hazard analysis critical control point processing ; Increased menu cycle ; Increased variety of menu items ; Menu developed based on daily nutritional requirements ; Testing and evaluation ; Vitamin D supplementation

Mars :

Hazard analysis critical control point processing ; Increased menu cycle ; Increased variety of menu items ; Menu developed based on daily nutritional requirements ; Testing and evaluation ; Vitamin D supplementation

Projected Countermeasures :

ISS :

Assessment of food psychosocial importance ; Determine effects of radiation on food ; Development of extended shelf life food through improved food preservation technologies ; Enhanced food system with increased variety and acceptability ; Hazard analysis critical control point processing ; High barrier and low mass food packaging materials ; Refined nutritional requirements

Lunar :

Assessment of food psychosocial importance ; Determine effects of radiation on food ; Development of extended shelf life food through improved food preservation technologies ; Enhanced food system with increased variety and acceptability ; Hazard analysis critical control point processing ; High barrier and low mass food packaging materials ; Refined nutritional requirements

Mars :

Assessment of food psychosocial importance ; Determine effects of radiation on food ; Development of extended shelf life food through improved food preservation technologies ; Enhanced food system with increased variety and acceptability ; Hazard analysis critical control point processing ; High barrier and low mass food packaging materials ; Refined nutritional requirements

Enabling Questions [With Mission Priority]:

No.	Question
42a	What procedures (e.g., storage, processing, preparation, clean-up), such as HACCP, need to be developed to assure a safe food system? **[ISS 1, Lunar 1, Mars 1]**
42b	What are the allowable limits of microbial and chemical contamination in the food? **[ISS 1, Lunar 1, Mars 1]**
42c	How does space radiation affect the functionality and nutritional content of the stored staple ingredients for food processing? **[Lunar 1, Mars 1]**
42d	What food processing technologies are required when using stored staple ingredients to ensure a food system that is nutritious, safe and acceptable? **[Lunar 1, Mars 1]**
42e	What food packaging materials will provide the physical and chemical attributes, including barrier properties, to protect the food from the outside environment and assure the 3-5 year shelf life? **[ISS 1, Lunar 1, Mars 1]**
42f	What food packaging material will be biodegradable, easily processed, or be lighter in mass than the current packaging and can still provide the physical and chemical attributes including barrier properties to protect the food from the outside environment and assure the 3-5 year shelf life? **[ISS 1, Lunar 1, Mars 1]**
42g	What food preservation technologies will provide prepackaged food items with a shelf life of 3-5 years? **[ISS 2, Lunar 2, Mars 2]**
42h	What are the impacts of reduced Gravity and atmospheric pressure on the food processing activities? **[Lunar 2, Mars 1]**
42i	What are the impacts of reduced Gravity and atmospheric pressure on the food preparation activities? **[ISS 3, Lunar 2, Mars 1]**
42j	What nutritional content and sensory attributes changes (including radiation induced effects) in the prepackaged food items will occur over the shelf life of the food? **[ISS 2, Lunar 2, Mars 2]**
42k	What food system technology selection criteria will be used to effectively reduce critical resources such as air, water, thermal, biomass and solid waste processing, during a mission? **[ISS 2, Lunar 2, Mars 2]**
42l	What are the changes (taste, odor, etc.) that occur in crewmember's sensory perceptions during space flight that would affect food acceptability? **[ISS 3, Lunar 3, Mars 3]**

	42m	What are the physical and chemical requirements for each of the stored staple ingredient items to assure effective processing into acceptable, safe and nutritious food ingredients? **[Lunar 2, Mars 2]**
	42n	What level of acceptability in the food system is required to provide psychosocial well being of the crew? **[ISS 3, Lunar 3, Mars 2]**
	42o	What level of variety (e.g., number of food items, length of menu cycle) in the food system is required to provide psychosocial well being of the crew? **[ISS 3, Lunar 3, Mars 2]**
	42p	What modeling techniques can be used to measure the subjective portions of the food system such as palatability, nutrition, psychological issues and variety? **[ISS 3, Lunar 3, Mars 2]**

Related Risks :

ISS :

Immunology, Infection & Hematology
Allergies and Autoimmune Diseases
Muscle Alterations & Atrophy
Skeletal Muscle Atrophy Resulting in Reduced Strength and Endurance
Nutrition
Inadequate Nutritional Requirements
Human Behavior & Performance and Space Human Factors (Cognitive)
Human Performance Failure Due to Poor Psychosocial Adaptation
Mismatch between Crew Cognitive Capabilities and Task Demands
Radiation Health
Carcinogenesis
Acute and Late CNS Risks
Other Degenerative Tissue Risks
Acute Radiation Syndromes
Advanced Environmental Monitoring & Control (AEMC)
Monitor Air Quality
Monitor External Environment
Monitor Water Quality
Monitor Surfaces Food and Soil
Provide Integrated Autonomous Control of Life Support Systems
Advanced Life Support (ALS)
Maintain Acceptable Atmosphere
Maintain Thermal Balance in Habitable Areas
Manage Waste
Provide and Maintain Bioregenerative Life Support Systems
Provide and Recover Potable Water
Space Human Factors Engineering
Mis-assignment of Responsibilities within Multi-agent Systems

Lunar :

Immunology, Infection & Hematology
Allergies and Autoimmune Diseases
Muscle Alterations & Atrophy

	Skeletal Muscle Atrophy Resulting in Reduced Strength and Endurance
	Nutrition
	Inadequate Nutritional Requirements
	Human Behavior & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Poor Psychosocial Adaptation
	Mismatch between Crew Cognitive Capabilities and Task Demands
	Radiation Health
	Carcinogenesis
	Acute and Late CNS Risks
	Other Degenerative Tissue Risks
	Acute Radiation Syndromes
	Advanced Environmental Monitoring & Control (AEMC)
	Monitor Air Quality
	Monitor External Environment
	Monitor Water Quality
	Monitor Surfaces Food and Soil
	Provide Integrated Autonomous Control of Life Support Systems
	Advanced Life Support (ALS)
	Maintain Acceptable Atmosphere
	Maintain Thermal Balance in Habitable Areas
	Manage Waste
	Provide and Maintain Bioregenerative Life Support Systems
	Provide and Recover Potable Water
	Space Human Factors Engineering
	Mis-assignment of Responsibilities within Multi-agent Systems
	Mars :
	Immunology, Infection & Hematology
	Allergies and Autoimmune Diseases
	Muscle Alterations & Atrophy
	Skeletal Muscle Atrophy Resulting in Reduced Strength and Endurance
	Nutrition
	Inadequate Nutritional Requirements
	Human Behavior & Performance and Space Human Factors (Cognitive)
	Human Performance Failure Due to Poor Psychosocial Adaptation
	Mismatch between Crew Cognitive Capabilities and Task Demands
	Radiation Health
	Carcinogenesis
	Acute and Late CNS Risks
	Other Degenerative Tissue Risks
	Acute Radiation Syndromes
	Advanced Environmental Monitoring & Control (AEMC)
	Monitor Air Quality

	Monitor External Environment
	Monitor Water Quality
	Monitor Surfaces Food and Soil
	Provide Integrated Autonomous Control of Life Support Systems
	Advanced Life Support (ALS)
	Maintain Acceptable Atmosphere
	Maintain Thermal Balance in Habitable Areas
	Manage Waste
	Provide and Maintain Bioregenerative Life Support Systems
	Provide and Recover Potable Water
	Space Human Factors Engineering
	Mis-assignment of Responsibilities within Multi-agent Systems
Important References :	Isolation NASA Experiments in Closed-Environment Living Advanced Human Life Support Enclosed System Volume 104SCIENCE AND TECHNOLOGY SERIES; A Supplement to Advances in the Astronautical Sciences Edited by: Helen W. Lane, Richard L. Sauer, and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198 web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf. web:%20%20http://lsda.jsc.nasa.gov/books/ground/chambers.pdf
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	U. S. Food and Drug Administration. Kinetics of Microbial Inactivation for Alternative Food Processing Technologies. http://vm.cfsan.fda.gov/~comm/ift-toc.html. June 2000. http://vm.cfsan.fda.gov/~comm/ift-toc.html

Risk Title: Maintain Acceptable Atmosphere

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support (ALS)

Risk Number :	43
Risk Description :	Inability to control atmosphere concentration CO_2, O_2 and trace contaminants in habitable areas (excessive airborne chemical pollutants e.g., formaldehyde, ethylene glycol, freon from leaks, fires, etc.) including microbial contaminants (microbial degradation of biological wastes).
Context/Risk Factors :	Complexity of systems and increase in the number of systems (e.g., additional solid waste processing, plant growth, food processing, etc. for what?) ; Insensitivity of control system to contaminants leading to toxic build ups due to a closed system ; Remoteness ; Severely constrained resources (such as mass, power, volume, thermal, crew time)
RYG Risk Assessment :	**ISS:** Green Minimum or limited potential for improvement in mitigation efficiency **Lunar:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Mars:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:** The inability to control and condition the atmosphere and maintain the makeup & composition, limits the ability of the crew to perform basic functions and can present an immediate threat to the health, life and success of crew and mission. **Lunar:** The inability to control and condition the atmosphere and maintain the makeup & composition, limits the ability of the crew to perform basic functions and can present an immediate threat to the health, life and success of crew and mission.No rapid return capability (days) **Mars:** The inability to control and condition the atmosphere and maintain the makeup & composition, limits the ability of the crew to perform basic functions and can present an immediate threat to the health, life and success of crew and mission. No rapid return capability (months)
Current Countermeasures :	**ISS :** Looking at potentially more robust methods of removing CO_2 and combining functions for air management ; Regenerable Trace Contaminant Control System (TCCS) development (testing, modeling) ; Resupply ; Technology development to further close the air loop and increase carbon dioxide reduction. This includes testing, modeling and analysis **Lunar :** Development in new sorbent technology, application in CO_2 Moisture Removal System (CMRS), an open loop system ; Limited resupply ; Model and analysis trade of technology ; Regenerable Trace Contaminant Control System (TCCS) **Mars :** Analysis to identify projected contaminant sources from other systems ; Compressor technology applicable also for ISRU ; Extremely limited resupply ; Looking at potentially more robust methods of removing CO_2 and combining functions for air management ; Regenerable Trace contaminant control (testing, modeling) ; Technology development to further close the air loop and increase carbon dioxide reduction. This includes testing, modeling and analysis
Projected Countermeasures :	**ISS :** Regenerable TCCS ; Improved Carbon Dioxide Removal and Reduction System– [TRL 3, 4] **Lunar :** Bioregenerative Life Support ; ISRU ; Look to have better models identifying contaminant load ; CMRS **Mars :** Bioregenerative Life Support ; ISRU ; Regenerable TCCS ; Improved Carbon Dioxide Removal and Reduction System [TRL 3, 4]

Enabling Questions [With Mission Priority]:

No.	Question
43a	What system will meet all the requirements for controlling atmospheric pressure, O_2 and CO_2 partial pressure? **[ISS 1, Lunar 1, Mars 1]**
43b	What method for recovering O_2 from CO_2 is most effective in an integrated ECLS? **[ISS 2, Lunar 2, Mars 2]**
43c	What is the proper trace contaminant load and performance model to drive the design and operation of a trace contaminant system? **[ISS 2, Lunar 2, Mars 2]**
43d	What sensors are required to provide environmental data, monitor performance and provide inputs to control systems (AEMC)? **[ISS 2, Lunar 2, Mars 2]**

	43e	What monitoring and control system can provide semi-to-total autonomous control of Life Support Systems (AEMC)? **[ISS 2, Lunar 2, Mars 2]**
	43f	How can microbes and candidate crop species be engineered to perform better and fulfill multiple functions in a bioregenerative system? **[Lunar 3, Mars 1]**
	43g	What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? **[Lunar 3, Mars 1]**
	43h	Can viability and genetic integrity of the biological components be maintained for the duration of different missions? **[Lunar 3, Mars 2]**
	43i	What are the effects of radiation on biological components of the life support system? **[Lunar 3, Mars 1]**
	43j	What research is required to validate design approaches for multiphase flow and particulate flows for air revitalization systems in varying gravity environments? **[Lunar TBD, Mars TBD]**
Related Risks :		**ISS :** **Advanced Life Support (ALS)** Maintain Thermal Balance in Habitable Areas **Lunar :** **Advanced Life Support (ALS)** Maintain Thermal Balance in Habitable Areas **Mars :** **Advanced Life Support (ALS)** Maintain Thermal Balance in Habitable Areas
Important References :		Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1324, 1994 Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf http://lsda.jsc.nasa.gov/books/ground/chambers.pdf Space flight Life Support and Biospherics, Eckart, 1996

Risk Title: Maintain Thermal Balance in Habitable Areas

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support (ALS)
Risk Number :	44
Risk Description :	Inability to acquire, transport and reject waste heat from life support systems reliably and efficiently with minimum power, mass and volume. Capability is crucial to enabling extended human exploration of space.
Context/Risk Factors :	Location on planetary surface ; Orientation of the vehicle during flight ; Orientation of vehicle and/or habitat on planetary surface ; Planetary environment (temperature ranges & extremes, dust, seasonal variations, etc.) ; Sources of heat from other elements of the mission ; Use or availability of local planetary resources
RYG Risk Assessment :	**ISS:** Green Minimum or limited potential for improvement in mitigation efficiency **Lunar:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Mars:** Red

<table>
<tr><td></td><td>Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.</td></tr>
<tr><td>Justification :</td><td>ISS:
Humans cannot live and work on Mars without a thermally controlled environment.
Lunar:
Humans cannot live and work on Mars without a thermally controlled environment.
Mars:
Humans cannot live and work on Mars without a thermally controlled environment.</td></tr>
<tr><td>Current Countermeasures :</td><td>ISS :
Thermal control systems have been a mandatory system on every space vehicle that has ever flown
Lunar :
Thermal control systems have been a mandatory system on every space vehicle that has ever flown
Mars :
Thermal control systems have been a mandatory system on every space vehicle that has ever flown</td></tr>
<tr><td>Projected Countermeasures :</td><td>ISS :
Several advances are underway to improve the reliability and life, or decrease the mass, volume, or power required for thermal control system hardware. [TRL 3-6]
Lunar :
Several advances are underway to improve the reliability and life, or decrease the mass, volume, or power required for thermal control system hardware. [TRL 3-6]
Mars :
Several advances are underway to improve the reliability and life, or decrease the mass, volume, or power required for thermal control system hardware. [TRL 3-6]</td></tr>
<tr><td>Enabling Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>44a</td><td>What heat transport fluids meet the requirements for specified missions? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>44b</td><td>What materials and designs will meet the heat acquisition (cold plates, heat exchangers, cooling jackets, etc.) requirements for specified missions? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>44c</td><td>What materials and designs will meet the heat transport (pumps, two-phase loops, heat pumps, etc.) requirements for specified missions? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>44d</td><td>What materials and designs will meet the heat rejection (radiators, sublimators, evaporators, etc.) requirements for specified missions? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>44e</td><td>What materials and designs will meet the humidity control requirement requirements for specified missions? [ISS 1, Lunar 1, Mars 1]</td></tr>
<tr><td>44f</td><td>What thermal system sensors will meet the requirements to provide monitoring and data collection for specified missions? [ISS 2, Lunar 2, Mars 2]</td></tr>
<tr><td>44g</td><td>What monitoring and control system hardware and design will meet the requirements for specified missions? (AEMC) [ISS 2, Lunar 2, Mars 2]</td></tr>
</table>
</td></tr>
<tr><td>Related Risks :</td><td></td></tr>
<tr><td>Important References :</td><td>
<table>
<tr><td>Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997</td></tr>
<tr><td>Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1234, 1994</td></tr>
<tr><td>Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf

http://lsda.jsc.nasa.gov/books/ground/chambers.pdf</td></tr>
<tr><td>Space flight Life Support and Biospherics, Eckart, 1996</td></tr>
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</table>

Risk Title: Manage Waste

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support (ALS)
Risk Number :	45
Risk Description :	Inability to adequately process solid wastes reliably with minimum power, mass, volume and consumables can harm to crew health and safety. Inadequate waste management can also lead to contamination of planetary surfaces or significant increases in mission costs in terms of system mass, power, volume and consumables.
Context/Risk Factors :	Crew health/susceptibility to degree of system closure, mission duration, microgravity environment ; Failure of other systems such as diminished or failed power supply ; Remoteness
RYG Risk Assessment :	**ISS:** Green Minimum or limited potential for improvement in mitigation efficiency **Lunar:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Mars:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:** Inadequate waste management can lead to harm to crew health and safety including reduced performance, sickness and death. Inadequate waste management can also lead to contamination of planetary surfaces or significant increases in mission costs in terms of system mass, power, volume and consumables. **Lunar:** Inadequate waste management can lead to harm to crew health and safety including reduced performance, sickness and death. Inadequate waste management can also lead to contamination of planetary surfaces or significant increases in mission costs in terms of system mass, power, volume and consumables. **Mars:** Inadequate waste management can lead to harm to crew health and safety including reduced performance, sickness and death. Inadequate waste management can also lead to contamination of planetary surfaces or significant increases in mission costs in terms of system mass, power, volume and consumables.
Current Countermeasures :	**ISS :** Adsorbents are used for odor control ; Crew manually compacts waste and/or stores waste in bags ; Feces is mechanically compacted ; Waste is returned in the Shuttle for disposal or returned in logistics modules to be destroyed on entry **Lunar :** Adsorbents are used for odor control ; Crew manually compacts waste and/or stores waste in bags ; Feces is mechanically compacted ; Return of waste is unlikely and overboard disposal is not currently developed as an option for a Lunar or Mars mission. Other countermeasures are not currently developed **Mars :** Adsorbents are used for odor control ; Crew manually compacts waste and/or stores waste in bags ; Feces is mechanically compacted ; Return of waste is unlikely and overboard disposal is not currently developed as an option for a Lunar or Mars mission. Other countermeasures are not currently developed
Projected Countermeasures :	**ISS :** Current practice though less than optimum may be adequate for the life of ISS **Lunar :** Provide a system for adequately collecting waste . ; Provide a system for adequately transporting waste ; Provide a system for processing waste for storage , resource recovery or disposal of trash generated (including clothing) throughout the mission, reliably and efficiently with minimum power, mass and volume. **Mars :** Provide a system for adequately collecting waste . ; Provide a system for adequately transporting waste ; Provide a system for processing waste for storage , resource recovery or disposal of trash generated (including clothing) throughout the mission, reliably and efficiently with minimum power, mass and volume.
Enabling Questions [With Mission Priority]:	

No.	Question
45a	What system will meet the storage and/or disposal requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**

	45b	What system will meet requirements for processing wastes to recover resources for specified missions? **[ISS 1, Lunar 1, Mars 1]**
	45c	What waste management will handle complex waste streams such as packaging, paper, etc. in order to meet mission requirements? **[ISS 2, Lunar 2, Mars 2]**
	45d	What waste management will handle medical wastes such as blood, tissues and syringes etc. in order to meet mission requirements? **[Lunar 2, Mars 2]**
	45e	What system will separate wastes (inedible plant biomass, trash and/or paper, feces, etc.) in order to meet compatibility mission requirements for waste management? **[ISS 1, Lunar 1, Mars 1]**
	45f	What system will meet the requirements for managing residuals for planetary protection? **[Lunar 2, Mars 2]**
	45g	How can microbes and candidate crop species be engineered to perform better and fulfill multiple functions in a bioregenerative system? **[Lunar 3, Mars 1]**
	45h	What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? **[Lunar 3, Mars 1]**
	45i	Can viability and genetic integrity of the biological components be maintained for the duration of different missions? **[Lunar 3, Mars 2]**
	45j	How do partial and microgravity affect biological waste processing? **[Lunar 3, Mars 1]**
	45k	What are the effects of radiation on biological components of the life support system? **[Lunar 3, Mars 1]**
	45l	What sensors are required to monitor performance and provide inputs to control systems (AEMC)? **[ISS 2, Lunar 2, Mars 2]**
	45m	What monitoring and control system can provide semi to total autonomous control to relieve the crew of monitoring and control functions to the extent possible (AEMC)? **[ISS 2, Lunar 2, Mars 2]**
	45n	Could any of the solid waste be recycled in such a way to provide building material for habitability features needed in subsequent phases of the mission? **[Lunar 3, Mars 3]**
	45o	What research is required to validate design approaches for multiphase flows for solid waste management and resource recovery in varying gravity environments. **[Lunar TBD, Mars TBD]**
	45p	What resources are required to manage waste disposal as an environmental risk during long and remote missions (from EH)? **[ISS TBD, Lunar TBD, Mars TBD]**
Related Risks :		
Important References :	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997	
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1324, 1994	
	Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf http://lsda.jsc.nasa.gov/books/ground/chambers.pdf	
	Space flight Life Support and Biospherics, Eckart, 1996	

Risk Title: Provide and Maintain Bioregenerative Life Support Systems

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support (ALS)
Risk Number :	46

<table>
<tr><td>Risk Description :</td><td>Inability (with minimal or no re-supply) to provide adequate fresh food products, assimilate carbon dioxide, produce oxygen and recycle solid and liquid wastes at the levels of performance required for a specified mission due to lack of bio-regenerative subsystems integrated with other physical and chemical life support systems.</td></tr>
<tr><td>Context/Risk Factors :</td><td>Effect of radiation on plants ; For some scenarios, reduced atmospheric pressure ; For some scenarios, reduced sunlight ; Limited availability of water ; Limits on power availability for artificial lighting ; Reduced gravity ; Remoteness</td></tr>
<tr><td>RYG Risk Assessment :</td><td>ISS: Green
Minimum or limited potential for improvement in mitigation efficiency
Lunar: Yellow
Considerable potential for improvement in mitigation efficiency in a few areas.
Mars: Red
Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.</td></tr>
<tr><td>Justification :</td><td>ISS:
Risk to mission success relatively low. Resupply line is short and resources limited for bioregenerative systems. Possible decrease in crew performance without biological systems.
Lunar:
Necessary to sustain long-term habitats on Lunar surface due to distance required for resupply.
Mars:
Risk to mission success is high. Very high life support requirement masses necessary for Martian habitat. Bioregenerative systems only means of producing food and primary contributor for CO_2 removal, O_2 production and H_2O purification and achieving high degree of autonomy</td></tr>
<tr><td>Current Countermeasures :</td><td>ISS :
Development of Vegetable Production Unit ; Fresh fruit and vegetables included on current resupply missions to ISS ; Screen acceptable cultivars for space systems
Lunar :
Closed system testing (BPC) to identify area requirement for food, water, O_2. Screen / develop acceptable cultivars ; Development of Vegetable Production Unit for use with partial Gravity ; Telescience and robotic management of cropping systems
Mars :
Atmospheric pressure limitations to production being determined ; Conduct long-duration tests to assess reliability ; Develop surface deployable systems ; Materials for Martian greenhouse being evaluated ; Mixed cropping systems for continuous production under long-duration missions being tested ; Screen / develop acceptable cultivars ; VPU for salad crop production during transit</td></tr>
<tr><td>Projected Countermeasures :</td><td>ISS :
Provide Vegetable Production Unit for ISS
Lunar :
Mixed cropping systems for continuous production evaluated ; Scale gravity based salad production module to meet all water and partial O_2 and food requirements for surface mission
Mars :
Integrated Bioregenerative / PC test bed ; Low pressure Martian greenhouse ; Scale system to meet all O_2, CO_2 requirements for surface habitat and meet partial food requirements</td></tr>
<tr><td>Enabling Questions [With Mission Priority]:</td><td>
<table>
<tr><th>No.</th><th>Question</th></tr>
<tr><td>46a</td><td>What are the optimal methods of plant growth for a specified mission, including development of appropriate hardware, management of light, water, nutrients, gas composition and pressure, trace contaminants, horticultural procedures and disease risks? [ISS 2, Lunar 2, Mars 1]</td></tr>
<tr><td>46b</td><td>How can microbes and candidate crop species be engineered to perform better and fulfill multiple functions in a bioregenerative system? [Lunar 3, Mars 1]</td></tr>
<tr><td>46c</td><td>What mechanized or automated systems are required for planting and harvesting crops and monitoring and control for a specified mission? [Lunar 3, Mars 2]</td></tr>
<tr><td>46d</td><td>Can viability and genetic integrity of the biological components be maintained for the duration of different missions? [Lunar 3, Mars 2]</td></tr>
<tr><td>46e</td><td>What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? [Lunar 3, Mars 1]</td></tr>
<tr><td>46f</td><td>How do partial and microgravity affect plant growth and crop yield? [Lunar 3, Mars 1]</td></tr>
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	46g	What are the effects of radiation on biological components of the life support system? **[Lunar 3, Mars 1]**
	46h	What percentage of crew food needs should be attributed to ALS plant products for specified missions? **[Lunar 3, Mars 2]**
	46i	What capabilities and associated hardware are required for processing and storing plant products for a specified mission? **[Lunar 3, Mars 2]**
	46j	Can the plant production rates and ALS functions be sustained for the duration of the mission? **[Lunar 3, Mars 1]**
	46k	Can plant yields and ALS functions measured during low TRL (fundamental) testing be scaled up for large bioregenerative systems? **[Lunar 3, Mars 1]**
	46l	What sensors and monitoring systems will be required to measure environmental conditions and crop growth parameters and health for a specified mission (AEMC)? **[ISS 3, Lunar 3, Mars 2]**
	46m	What control system hardware and software technologies will be required to monitor and control crop systems for a specified mission (AEMC)? **[ISS 3, Lunar 3, Mars 2]**
Related Risks :		
Important References :	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997.	
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1324, 1994	
	Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf http://lsda.jsc.nasa.gov/books/ground/chambers.pdf	
	Space flight Life Support and Biospherics, Eckart, 1996	
	Wheeler, R.M. and C. Martin-Brennan. 2000. Martian greenhouses: Concept and Challenges. Proceedings from a 1999 Workshop. NASA Tech. Memorandum 208577.	
	Wheeler, R.M., C.L. Mackowiak, G.S. Stutte, N.C. Yorio, L.M. Ruffe, J.C. Sager, R.P. Prince, B.V. Peterson, G.D. Goins, W.L. Berry, C.R. Hinkle and W.M. Knott. 2003. Crop production for Advanced Life Support Systems. Observations from the Kennedy Space Center Breadboard Project. NASA Tech. Mem. 2003-211184. (58 pages).	
	Wheeler, R.M., G.W. Stutte, G.V. Subbarao and N.C. Yorio. 2001. Plant growth and human life support for space travel. In: M. Pessarakli (ed.), 2nd Edition. Handbook of Plant and Crop Physiology. pp. 925-941. Marcel Dekker Inc., NY	

Risk Title: Provide and Recover Potable Water

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Advanced Life Support (ALS)
Risk Number :	47
Risk Description :	If there is an inability to provide and recover potable water from human-generated wastewaters, then a potable water shortage may exist. Lack of potable water is a risk to crew health.
Context/Risk Factors :	Crew health/susceptibility to degree of system closure ; Remoteness
RYG Risk Assessment :	**ISS:** Green Minimum or limited potential for improvement in mitigation efficiency **Lunar:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Mars:** Red

	Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:** Lack of potable water is a health risk. **Lunar:** Lack of potable water is a health risk. Lack of immediate resupply and increased reliance on water recovery systems compounds risk. **Mars:** Lack of potable water is a health risk. Lack of resupply and increased reliance on water recovery systems greatly compounds risk.
Current Countermeasures :	**ISS :** Resupply possible ; Stored potable water ; Water recovery system performance monitored **Lunar :** Minimal stored potable water ; Water recovery system performance monitored **Mars :** Minimal stored potable water ; Water recovery system performance monitored
Projected Countermeasures :	**ISS :** Possibility of in situ resource utilization (cannot assign TRL until presence of water is confirmed) ; Biological systems ; Redundant systems **Lunar :** Possibility of in situ resource utilization (cannot assign TRL until presence of water is confirmed) ; Biological systems ; Redundant systems **Mars :** Possibility of in situ resource utilization (cannot assign TRL until presence of water is confirmed) ; Biological systems ; Redundant systems

Enabling Questions [With Mission Priority]:

No.	Question
47a	What system meets all requirements for supplying potable water needs? **[ISS 1, Lunar 1, Mars 1]**
47b	What mechanisms to collect and transport wastewater meet the mission requirements? **[ISS 1, Lunar 1, Mars 1]**
47c	What methods for the removal of organic, inorganic and microbial contaminants in wastewater meet all mission requirements for efficiency and reliability? **[ISS 1, Lunar 1, Mars 1]**
47d	What method to store and maintain portability of recycled water meets all requirements for specified missions? **[ISS 1, Lunar 1, Mars 1]**
47e	What sensors are required to provide water quality parameters, monitor performance and provide inputs to a control system (AEMC)? **[ISS 2, Lunar 2, Mars 2]**
47f	What control system meets all mission requirements (AEMC)? **[ISS 2, Lunar 2, Mars 2]**
47g	How can microbes be engineered to perform better and fulfill multiple functions in a bioregenerative system? **[Lunar 3, Mars 1]**
47h	What are the interfaces between the biological and physical chemical life support subsystems for a specified mission? **[Lunar 3, Mars 1]**
47i	Can viability and genetic integrity of the biological components be maintained for the duration of different missions? **[Lunar 3, Mars 2]**
47j	How do partial and microgravity affect biological water processing? **[Lunar 3, Mars 1]**
47k	What are the effects of radiation on biological components of the life support system? **[Lunar 3, Mars 1]**
47l	What research is required to validate design approaches for multiphase flows for Water recovery systems in varying gravity environments? **[ISS 1, Lunar 1, Mars 2]**

Related Risks :	
Important References :	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington DC, 1997

	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA RP-1234, 1994 Isolation, NASA Experiments in Closed-Environment Living, Advanced Human Life Support Enclosed System Final Report, Volume 104, Science And Technology Series, A Supplement to Advances in the Astronautical Sciences, Edited by Helen W. Lane, Richard L. Sauer and Daniel L. Feeback. Published for the American Astronautical Society by Univelt, Incorporated, P.O. Box 28130, San Diego, CA 92198. web: http://lsda.jsc.nasa.gov/books/ground/chambers.pdf http://lsda.jsc.nasa.gov/books/ground/chambers.pdf Space flight Life Support and Biospherics, Eckart, 1996

Risk Title: Inadequate Mission Resources for the Human System

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Cross Discipline
Risk Number :	48
Risk Description :	Lack of low mass, low power, low consumable, highly reliable, low maintenance solutions to human support systems can lead to excessive mission costs.
Context/Risk Factors :	
RYG Risk Assessment :	**ISS:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Lunar:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements. **Mars:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:** Human support and monitoring equipment must be sufficiently low in mass and power requirements to be affordable to launch. Reagents and other system consumables needs must be low and nonhazardous. Crew training and maintenance must be low, or the human support technology will not be used properly, increasing the risks. Anecdotal evidence suggests that crew training may be behind the difficulties in water sampling and analysis—some are able to figure out how to remove bubbles; others are not. **Lunar:** Human support equipment must be sufficiently low in mass and power requirements to be affordable to launch. Reagent and other consumable needs must be low and nonhazardous. Crew training and maintenance must be low, or the technology may not be used properly. Analytical capability must be provided in situ, because samples can't be returned to Earth readily **Mars:** Human support equipment must be sufficiently low in mass and power requirements to be affordable to launch. Reagent and other consumable needs must be low and nonhazardous. Crew training and maintenance must be low, or the technology may not be used properly. Analytical capability must be provided in situ, because samples can't be returned to Earth .
Current Countermeasures :	**ISS :** The Electronic Nose is an attempt to develop a rugged, small, reagentless easy to use monitor, which is intended to be useful without trying to duplicate the capabilities of a laboratory analytical bench instrument **Lunar :** The Electronic Nose is an attempt to develop a rugged, small, reagentless easy to use monitor, which is intended to be useful without trying to duplicate the capabilities of a laboratory analytical bench instrument **Mars :** The Electronic Nose is an attempt to develop a rugged, small, reagentless easy to use monitor, which is intended to be useful without trying to duplicate the capabilities of a laboratory analytical bench instrument
Projected Countermeasures :	**ISS :** Med checklist ; Second Generation Electronic Nose Sabatier ; VPCAR

	Lunar : Med checklist ; Second Generation Electronic Nose Sabatier ; VPCAR **Mars :** Med checklist ; Second Generation Electronic Nose Sabatier ; VPCAR
Enabling Questions [With Mission Priority]:	

No.	Question
48a	What technologies can meet expected mission requirements for both monitoring and efficiency? **[ISS 1, Lunar 1, Mars 1]**
48b	How is the total mass of the EVA system reduced significantly (portable life support system and the pressure garment)? **[ISS 2, Lunar 2, Mars 2]**
48c	What is the best method for minimizing space suits consumables through advanced subsystems designs (thermal control, CO2 removal, humidity control, trace contaminants)? **[ISS 2, Lunar 2, Mars 2]**
48d	How do we increase reliability and maintainability of space suits? **[ISS 1, Lunar 1, Mars 1]**
48e	What levels of hardware, software and operations commonality are desirable and feasible to enhance likelihood of mission success and reduce mission mass, risk and cost? **[ISS 2, Lunar 2, Mars 2]**
48f	How can the effectiveness, efficiency and safety of integrated human systems in space missions be measured and analyzed (Supports SHFE)? **[ISS 1, Lunar 1, Mars 1]**
48g	What food system technology selection criteria will be used to effectively reduce critical resources such as air, water, thermal, biomass and solid waste processing, during a mission? **[ISS 2, Lunar 2, Mars 2]**

Related Risks :	
Important References :	Advanced Technology for Human Support in Space, National Research Council Report, 1997. Downloadable fromhttp://peer1.nasaprs.com/peer_review/prog/nap.pdf http://peer1.nasaprs.com/peer_review/prog/nap.pdf
	AEMC Technology Development Requirements (1998) downloadable from http://peer1.nasaprs.com/peer_review/prog/prog.html http://peer1.nasaprs.com/peer_review/prog/prog.html

Risk Title: Mismatch between Crew Physical Capabilities and Task Demands

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Space Human Factors Engineering
Risk Number :	49
Risk Description :	Human performance failure due to habitats, work environments, workplaces, equipment, protective clothing, tools and tasks, not designed to accommodate human physical limitations, including changes in crew capabilities resulting from mission and task duration factors, leading to loss of mission, crew injury or illness or reduced effectiveness or efficiency in nominal or predictable emergency situations.
Context/Risk Factors :	Design constraints ; Gravitational loads ; Human physical performance capability deteriorates with lack of stimulation (such as gravity and practice), under adverse physical contexts (stabilization, restrictive clothing, thermal stress etc.) and under task stress conditions that lead to fatigue, sleep loss etc ; Lack of exercise and specific training countermeasures ; Temporal factors
RYG Risk Assessment :	**ISS:** Green Minimum or limited potential for improvement in mitigation efficiency **Lunar:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Mars:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:**

	Crew accommodations are designed based primarily on volume and mass considerations. Anecdotal information from crew reports and extrapolations from physiological studies is available on impacts of habitats, work environments, workplaces, equipment, protective clothing, tools and tasks on human performance in space contexts. There is inadequate data on physical performance changes in strength, stamina and motor skill as functions of time in micro-g. Returning crewmembers usually exhibit substantial physical and motor deficits. **Lunar:** Very limited anecdotal information is available on impacts of habitats, work environments, workplaces, equipment, protective clothing, tools and tasks on human performance in lunar contexts. There is inadequate data on physical performance changes in strength, stamina and motor skill as functions of time in reduced G and while wearing protective clothing. **Mars:** No information is available on impacts of habitats, work environments, workplaces, equipment, protective clothing, tools and tasks on human performance in long-duration space contexts. There is minimal data on physical performance changes in strength, stamina and motor skill as functions of time in reduced-g.
Current Countermeasures :	**ISS :** Appropriate mission design ; Crew ‘resiliency ; Crew training **Lunar :** Appropriate mission design ; Crew ‘resiliency ; Crew training **Mars :** Appropriate mission design ; Crew ‘resiliency ; Crew training
Projected Countermeasures :	**ISS :** Measurement, analysis, modeling and design tools for optimizing environment , habitat, workplace, equipment, protective clothing and task design. ; Tools for analyzing physical tasks to determine allocations of functions between humans and machines. **Lunar :** Measurement, analysis, modeling and design tools for optimizing environment , habitat, workplace, equipment, protective clothing and task design. ; Tools for analyzing physical tasks to determine allocations of functions between humans and machines. **Mars :** Measurement, analysis, modeling and design tools for optimizing environment , habitat, workplace, equipment, protective clothing and task design. ; Tools for analyzing physical tasks to determine allocations of functions between humans and machines.
Enabling Questions [With Mission Priority]:	(see table below)
Related Risks :	

Enabling Questions [With Mission Priority]:

No.	Question
49a	What are the effects of microgravity, 1/6-gravity, or 1/3-gravity on requirements for habitable volume and architecture? **[ISS 2, Lunar 2, Mars 2]**
49b	What designs of workspace, equipment, tool and clothing will accommodate differences in crew anthropometry? **[ISS 2, Lunar 2, Mars 2]**
49c	What are the effects of duration of exposure to microgravity, 1/6-gravity, 1/3-gravity on human physical performance? **[ISS 1, Lunar 1, Mars 1]**
49d	What tools, equipment and procedures will enable crew physical performance to accommodate the effects of exposure to different gravity levels? **[ISS 2, Lunar 2, Mars 2]**
49e	How can crewmembers and ground support personnel detect and compensate for decreased physical readiness to perform during a mission? **[ISS 2, Lunar 3, Mars 3]**
49f	What scheduling constraints are required to reduce the risk of human performance failure due to physical fatigue to an acceptable probability? **[ISS 2, Lunar 2, Mars 2]**
49g	What principles of task design and function allocation will result in operations concepts that meet crew performance requirements for the mission? **[ISS 2, Lunar 2, Mars 2]**
49h	What limitations are required on physical workload to enable crewmembers to complete physical tasks with an acceptable probability? **[ISS 1, Lunar 1, Mars 1]**
49i	What crew size, composition and task allocations are required to accomplish the design reference missions? **[ISS 1, Lunar 1, Mars 1]**
49j	What design considerations are needed to accommodate effects of changes in gravity, including launch, reentry, lunar landing, lunar launch, Mars landing, Mars launch, and Earth return? **[ISS 1, Lunar 1, Mars 1]**

Important References :	An Ergonomics Case Study: Manual Material Handling in Microgravity. M. Whitmore & T. D. McKay. Advances in Industrial Ergonomics and Safety VI. London: Taylor & Francis. 1994. Ergonomic Evaluation of a Spacelab Glovebox. M. Whitmore, T. D. McKay, & F. E. Mount. International Journal of Industrial Ergonomics, 16, pp. 155-164. 1995. Human Space flight: Mission Analysis and Design, eds. W.J. Larson, L.K. Pranke. McGraw Hill Space Technology Series. 1999. Set Phasers on Stun, S. Casey, Agean Publishing, 1993. Thornton, W.E. and Rummel, J.A. (1977). "Muscular Deconditioning and its Prevention in Space flight," Biomedical Results from Skylab, pp. 175-182, NASA SP-377. Webb Associates, (1978), Anthropometric Source Book, Vol. I. Anthropometry for Designers, pp. 1-76, NASA RP 1024 West, J. B. (2000). Physiology in microgravity. Journal of Applied Physiology, 89(1): 379-384. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=10904075

Risk Title: Mis-assignment of Responsibilities within Multi-agent Systems

Theme :	Advanced Human Support Technologies (AHST)
Discipline :	Space Human Factors Engineering
Risk Number :	50
Risk Description :	If multi-agent systems, including ground support, crewmembers and intelligent devices are designed and assigned functions and responsibilities without due regard to human capabilities and limitations, mission degradation or failure will result. Various combinations of agents are required to accomplish mission objectives.
Context/Risk Factors :	Lag times of 20 minutes, or communications blackout, can remove one potential agent (Mission Control) ; Risk of failure to successfully perform multi-agent tasks increases with time since training, and with decrements in communications ; Very long crew return times requiring a 'stand and fight' response to any malfunction on the lunar or Mars surface increases the likelihood and severity of consequences of failure to complete tasks due to inadequate task design and planning
RYG Risk Assessment :	**ISS:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Lunar:** Yellow Considerable potential for improvement in mitigation efficiency in a few areas. **Mars:** Red Considerable potential for improvement in mitigation efficiency in many areas; proposed missions may be infeasible without improvements.
Justification :	**ISS:** Inadequate design of human-automation systems is known to leads to human error, based on analysis of incidents in the nuclear power industry and commercial aviation. (Ev. Level 3) "Mode error" has resulted in fatal accidents in commercial aviation. (Ev Level 2) At least two critical collisions between ISS and SRMS have been avoided only by real-time monitoring and intervention by MCC. (Level 4) **Lunar:** Inadequate design of human-automation systems is known to leads to human error, based on analysis of incidents in the nuclear power industry and commercial aviation. (Ev. Level 3) "Mode error" has resulted in fatal accidents in commercial aviation. (Ev Level 2) At least two critical collisions between ISS and SRMS have been avoided only by real-time monitoring and intervention by MCC. (Level 4) **Mars:** Inadequate design of human-automation systems is known to leads to human error, based on analysis of incidents in the nuclear power industry and commercial aviation. (Ev. Level 3) "Mode error" has resulted in fatal accidents in commercial aviation. (Ev Level 2) At least two critical collisions between ISS and SRMS have been avoided only by real-time monitoring and intervention by MCC. (Level 4)
Current Countermeasures :	**ISS :** None **Lunar :**

None
Mars :
None

Projected Countermeasures :

ISS :
Reliability measures and data for human performance ; Requirements for use of automated systems and for human-centered system design ; Tools for analyzing task requirements
Lunar :
Reliability measures and data for human performance ; Requirements for use of automated systems and for human-centered system design ; Tools for analyzing task requirements
Mars :
Reliability measures and data for human performance ; Requirements for use of automated systems and for human-centered system design ; Tools for analyzing task requirements

Enabling Questions [With Mission Priority]:

No.	Question
50a	What crew size and composition is required to accomplish the design reference mission (Shared - Integrated Testing supports)? **[ISS 2, Lunar 1, Mars 1]**
50b	What principles and algorithms for allocating tasks to human crewmembers, ground support and onboard automated systems will reduce the probability of significant errors (Shared - Integrated Testing supports)? **[ISS 1, Lunar 1, Mars 1]**
50c	What automated tools and equipment are required to enable the crewmembers to accomplish the mission? **[ISS 2, Lunar 2, Mars 2]**
50d	How do crew size, communications restrictions, crew skills, scheduling constraints and design reference mission task requirements affect the requirements for automation? **[ISS 1, Lunar 1, Mars 1]**
50e	What combinations of crew, ground and on-board automation capabilities will increase the likelihood of a successful mission (Shared - Integrated Testing supports)? **[ISS 1, Lunar 1, Mars 1]**
50f	What training and operational readiness assurance processes and implementations will increase likelihood of mission success? **[ISS 2, Lunar 2, Mars 2]**
50g	What principles of task assignment workload and automation need to be developed to facilitate critical team performance? **[ISS 2, Lunar 2, Mars 2]**
50h	What tools and procedures are needed to determine the appropriate level of automation and crew control for the various tasks in the DRM? **[ISS 1, Lunar 1, Mars 1]**

Related Risks :

Important References :

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