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ꝺ	TAKE OUT CHARACTER INDICATED	ꝺ Your proo~~f~~f.
∧	LEFT OUT, INSERT	u Yo∧r proof.
#	INSERT SPACE	# Your∧proof.
9	TURN INVERTED LETTER	Your p∧ɹoof.
×	BROKEN LETTER	× Your pr/of.
ˇˇ eq #	EVEN SPACE	eq # A ˇgood ˇproof.
⁐	CLOSE UP: NO SPACE	Your pro⁐of.
tr	TRANSPOSE	tr A (proof)(good).
wf	WRONG FONT	wf Your pro/f.
lc	LOWER CASE	lc Your /Proof.
≡ caps	CAPITALS	Your proof. caps (Your) proof.
ital	ITALIC	Your proof. ital Your proof.
rom	ROMAN, NON ITALIC	rom Your (*proof.*)
bf	BOLD FACE	Your proof. bf (Your) proof.
...... stet	LET IT STAND	~~Your~~ proof. stet ~~Your~~ proof.
out sc.	DELETE, SEE COPY	out sc. She∧Our proof.
spell out	SPELL OUT	spell out Queen (Eliz.)
¶	START PARAGRAPH	¶ read. [Your
no ¶	NO PARAGRAPH: RUN IN	no ¶ marked.→ ⊂Your proof.
⊔	LOWER	⊔ ⌊Your proof.⌋

MARK	EXPLANATION	EXAMPLE
⊓	RAISE	⊓ ⌈Your proof.⌉
[	MOVE LEFT	[Your proof.
]	MOVE RIGHT	] Your proof.
‖	ALIGN TYPE	‖[Three dogs. ‖Two horses.
═	STRAIGHTEN LINE	═ Your proof.
⊙	INSERT PERIOD	⊙ Your proof∧
,/	INSERT COMMA	,/ Your proof∧
:/	INSERT COLON	:/ Your proof∧
;/	INSERT SEMICOLON	;/ Your proof∧
∨'	INSERT APOSTROPHE	∨' Your man∧s proof.
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=/	INSERT HYPHEN	=/ A proof∧mark.
!/	INSERT EXCLAMATION MARK	!/ Prove it∧
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[/]	INSERT BRACKETS	[/] The∧ Smith∧ girl
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Human Health and Performance for Long-Duration Spaceflight

AD HOC COMMITTEE OF MEMBERS OF THE SPACE
MEDICINE ASSOCIATION AND THE SOCIETY OF NASA
FLIGHT SURGEONS

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AD HOC COMMITTEE OF MEMBERS OF THE SPACE MEDICINE ASSOCIATION AND THE SOCIETY OF NASA FLIGHT SURGEONS. ***Human health and performance for long-duration spaceflight.*** **Aviat Space Environ Med 2008; 79:1–7.**

Future long-duration spaceflights are now being planned to the Moon and Mars as a part of the "Vision for Space Exploration" program initiated by NASA in 2004. This report describes the design reference missions for the International Space Station, Lunar Base, and eventually a Mars Expedition. There is a need to develop more stringent preflight medical screening for crewmembers to minimize risk factors for diseases which cannot be effectively treated in flight. Since funding for space life sciences research and development has been eliminated to fund program development, these missions will be enabled by countermeasures much like those currently in use aboard the International Space Station. Artificial gravity using centrifugation in a rotating spacecraft has been suggested repeatedly as a "universal countermeasure" against deconditioning in microgravity and could be an option if other countermeasures are found to be ineffective. However, the greatest medical unknown in interplanetary flight may be the effects of radiation exposure. In addition, a Mars expedition would lead to a far greater level of isolation and psychological stress than any space mission attempted previously; because of this, psychiatric decompensation remains a risk. Historically, mortality and morbidity related to illness and injury have accounted for more failures and delays in new exploration than have defective transportation systems. The medical care system on a future Mars expedition will need to be autonomous and self-sufficient due to the extremely long separation from definitive medical care. This capability could be expanded by the presence of a physician in the crew and including simple, low-technology surgical capability.

ON JANUARY 14, 2004, the United States put forth a Vision for Space Exploration, setting a long-term direction for the return of humans to the Moon, followed by robotic and human exploration of Mars.

This vision is bold and forward-looking, yet practical and responsible – one that explores answers to long-standing questions of importance to society, develops revolutionary technologies and capabilities, fosters international cooperation and scientific exchange for the future, while maintaining good stewardship of taxpayer dollars. The specific reasons for taking the necessary steps of extended microgravity stays on the International Space Station and then extended stays on the Moon to achieve a planetary outpost were recently delineated by NASA at a conference held in Houston, TX, organized by the American Institute of Aeronautics and Astronautics. These are summarized in the following:

1. Fulfill our human nature to explore the unknown beyond the bounds of our planet, with extended missions to the Moon providing the operational training ground for future planetary outposts such as Mars;
2. Establish a permanent Moon outpost to conduct experiments and studies to answer questions about how the solar system was formed and is evolving. The Moon, devoid of any atmosphere, is an ideal site for such astronomical observations and research and the necessary first step for the development of a planetary outpost;
3. Develop commercial operations such as mineral mining and microgravity materials development;
4. Improve international cooperation among nations and inspire the commonality of cultures;
5. Inspire young people to pursue careers in science and engineering; and
6. Eventually extend the settlement of humankind and preserve our species from extinction due to a catastrophic asteroid event or eventual sun death.

Carrying out this vision will challenge the medical profession to protect the human crewmembers from the hostile environments of interplanetary space and the surfaces of the Moon and Mars, and to provide the best medical care possible on these remote journeys.

Future design reference missions (DRMs) for the stepwise exploration of space are listed in **Table I** with target dates. These DRMs will require remote space outposts on the International Space Station (ISS), Lunar, and Mars Outposts and illustrate the daunting tasks ahead.

Outposts on the lunar surface will be several days away from Earth, and both medical personnel and

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This Position Paper was adopted by the Aerospace Medical Association. The following members of the Space Medicine Association and the Society of NASA Flight Surgeons contributed to this report: Drs. Denise L. Baisden, Gary E. Beven, Mark R. Campbell, John B. Charles, Joseph P. Dervay, Estrella Foster, Gary W. Gray, Douglas R. Hamilton, Dwight A. Holland, Richard T. Jennings, Smith L. Johnston, Jeffrey A. Jones, Joseph P. Kerwin, James Locke, James D. Polk, Philip J. Scarpa, Walter Sipes, Jan Stepanek, and James T. Webb.

This Position Paper is intended to update the membership of the Aerospace Medical Association on the current plans for Long-Duration Spaceflight (specifically Lunar Outpost and Mars expedition). As detailed plans are dynamic and evolutionary, there was an attempt to concentrate on general concepts.

This manuscript was received for review in March 2008. It was accepted for publication in April 2008.

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TABLE I. CHARACTERISTICS OF SELECTED DESIGN REFERENCE MISSIONS (DRM).

	1-yr ISS	Lunar	Mars DRM
Crew Size	2+	4	6
Launch Date	2010	2018-2020	2025-2030
Mission Duration	1 yr	10-44 d	30 mo
Outward Transit	2 d	3-7 d	4-6 mo
On-site Duration	1 yr	4-30 d	18 mo
Return Transit	2 d	3-7 d	4-6 mo
1-way Communication Lag	0+	1.3 s+	3-20 min
g Transitions	2	4	4
Hypogravity	0 g	1/6 g for 30 d	1/3 g for 18 mo
Spacecraft Internal Environment	14.7 psi 21% O_2	TBD	TBD
EVA Schedule	0-4 per mission	2-3 per week ~4-15 EVA per person	2-3 per week ~180 EVA per person
Deep Space Radiation Exposure	~0	~6-14 d	~8-12 mo

equipment will be quite limited. But on travel to Mars, these limitations will be multiplied; crews and their supplies will be absent from Earth with no possibility of rapid return for many months at a time. Competition for space and weight will require state-of-the-art monitoring, diagnostic, and treatment hardware, while limiting the training needed to use it. This is the ultimate challenge to the concept of telemedicine, which was fostered by NASA, and must evolve into real-time, simulator-based, onboard instruction and training. It will also push the envelope in the principles of preventive medicine and necessitate the development of screening techniques beyond the present scope and capabilities.

This paper will summarize the views of a panel of members selected from the Space Medicine Association (an Aerospace Medical Association constituent organization) and the Society of NASA Flight Surgeons (an AsMA affiliate organization) on the vision's principal challenges to space medicine and the approaches to meeting them. Specifically the critical life science technologies and capabilities needed in the areas of medical screening risk mitigation, life support and habitability design, and microgravity countermeasures and health care.

Pre-mission Medical Screening

The first step in the medical risk mitigation for missions to Moon and Mars will require a significant effort in research and development in primary prevention screening capabilities. There needs to be an inverse relationship between access to medical care and the physical qualifications demanded of explorers. In planetary exploration, the rigors and unknowns of the environment amplify this relationship. Medical standards for travelers to the Moon, and most especially to Mars, should utilize the latest screening methods to minimize risk factors for diseases which cannot be effectively treated during the missions. Chronic diseases for which medication is required on a regular basis might be disqualifying as they would affect the total volume of the medical care system adversely. Genetic factors, which predispose crewmembers to disease, must be taken into consideration. This is currently undefined, but is expected to become more important in the future as research in this area is rapidly progressing.

Life Support and Habitability

Mission designers are well aware of the challenges of providing a safe, extremely reliable, and habitable environment during extended space missions. Their efforts will involve trading off these considerations with weight, power, volume, and other operational requirements. One example is the pressure and composition of the atmosphere chosen. Here, the safe medical choice must compete with engineering and logistics factors (e.g., leak rate, mass and volume of gases, flammability, and equipment cooling) and the need to protect the crew from decompression illness during EVA (extravehicular activities). The space medicine community must not only provide valid medical requirements but must work very closely with the designers and operators as the spacecraft are developed and tested, participating in any necessary compromises.

Microgravity Countermeasures

Countermeasures are under development to mitigate the risks of prolonged spaceflight on the human body. Some of these countermeasures may be pharmacological, and may have side effects and/or risks of their own. In any event, residual medical risks will always remain. The nature of such risks will vary, from short term illness or injury, which cannot be treated during the mission, to permanent tissue and organ damage (e.g., from radiation or bone demineralization) which may result in morbidity and mortality during the mission or later in life.

Because of their experimental nature, space countermeasures will not have been subject to the lengthy and very extensive testing for safety and efficacy that the Food and Drug Administration requires to certify almost all treatments (e.g., drugs, surgical procedures, etc.) for use in the general population. This is acceptable because the countermeasures are not to be used in the general population. They are considered to be experimental (off label use), yet they will be taken and used by informed subjects. Safety and efficacy will be tested, but on smaller numbers of subjects and in analog environments as well as in space.

Due to the limitations placed on such testing, there will be a necessity to accept countermeasures that, at the time, are not fully developed, and thus are neither as efficient nor efficacious as might otherwise be possible. It is expected that the countermeasure effectiveness will be routinely monitored on lunar and Mars expedition missions to insure maximum benefit to the crewmember. This will also permit continued refinement of the various countermeasure modalities. Thus, the complete countermeasure development will actually be deferred into the operational setting, with expected resulting impacts on mission resources and countermeasure improvements.

Countermeasure testing will be limited because of practical, and perhaps unavoidable, decisions made in the early years after the pronouncement of the Vision for Space Exploration. The requirement to develop a crew-carrying spacecraft as a replacement for the Space Shuttle, in parallel with continued Space Shuttle and International Space Station operations, all without a significant increase in overall NASA funding, necessitate other portions of the NASA's program—including space life sciences research and development— to bear the sacrifice. The deferred research and development would have included a larger suite of more efficient and effective physiological countermeasures. These countermeasures especially include those which might have developed from the low technical readiness level (TRL) activities and which might have borne fruit in later years had they not been preferentially targeted for reduction or elimination. Thus, NASA's Lunar Outposts and eventual Mars missions will most likely be enabled by countermeasures and protocols not fundamentally different from those currently in use aboard the International Space Station.

The eliminated research would have investigated the physiological mechanisms underlying the potentially deleterious changes observed in crewmembers during long-duration spaceflight The study of these physiologic adaptive mechanisms of spaceflight would have created the opportunity to devise risk mitigation measures that could have served to maintain, restore or enhance physiologic function of the crew. In the absence of either historical or contemporary insights into the mechanisms of these deleterious changes, mission designers are forced to make decisions for future operational support based on imprecise and incomplete knowledge.

Radiation: The greatest medical unknown in interplanetary flight may be the quality, intensity, and effects of radiation. A radiation shelter can afford protection against occasional solar flares. However sheltering against extremely energetic "galactic cosmic radiation" may be impossible and even harmful, due to the biological effects of a large number of secondary particles generated by interaction of a few energetic primary (such as Galactic Cosmic Radiation or GCR) particles with the atoms in the shielding. NASA and its international partners have embarked upon an aggressive program of research and measurement to characterize this radiation more accurately, and to estimate better its threat to human health. Physicians, physicists, and materials experts will work together to reduce the risk for space exploration, with the prospect that improved knowledge and understanding of shielding techniques will also help to make radiation therapy, nuclear reactors and other hazardous environments on Earth safer.

Artificial Gravity Countermeasures: Exposure of the crew to "artificial gravity," that approximates Earth-normal gravity loads, via centrifugation in a rotating spacecraft has been suggested repeatedly as a "universal countermeasure" against deconditioning in microgravity. Such an approach has profound and extensive engineering implications, and current mission scenarios do not incorporate it. Furthermore, the proposed benefits are unproven. However, it is worth the effort to determine whether artificial gravity "works," what g levels are necessary, and what rotation velocities are acceptable. Such a determination will provide both fundamental knowledge of biological processes and a valuable insurance policy against unacceptable risks from exposure to weightlessness. We endorse ground-based and, if possible, space-borne studies of animals in a centrifuge large enough to provide continuous exposure to a variety of g levels. We also endorse human experiments on a short-radius centrifuge, both on the ground and in a spacecraft. Eventually, prolonged habitation on the Moon will expose astronauts to 1/6th of Earth's surface gravity for weeks or even months, permitting detailed study of human physiological responses to extended exposure to an additional gravitational environment (the two others being Earth's surface gravity and weightlessness). It is important to endorse provisions to acquire this knowledge on the Moon during the course of lunar missions, to benefit future planetary surface architecture planning and design of future deep-space vehicles.

In-flight Medical Care

Medical care arrangements on the lunar surface for the longer duration Lunar Base missions should include the presence of a physician; and on a Mars expedition mission, depending on crew size, having two physicians should be seriously considered and surgical training should be mandatory. As complete a suite of monitoring and diagnostic equipment as technology can provide should be onboard. This capability should provide for thorough periodic evaluations of crew health and will double as experiment equipment. This mission will be one of great medical significance, and should be planned to yield a comprehensive set of medical data. The benefits of increasing the capability of the medical care system are obvious. The risks of not having enough capability include mission abort, not being able to accomplish the goals of the mission, and in-flight morbidity and mortality. There are also risks as the capabilities (hardware and crew training) are increased as they will affect other aspects of the mission. The volume, weight, power requirements, and crew training time are all severely limited. Any additional capability in one area (the medical care system) will require decreased capability in another area.

Our clinical experience in space at this time is very limited and a surgical procedure has never been required or performed during spaceflight. However, there will be a rapid increase in both crew size and mission duration with the exploration class missions to follow, and with it the likelihood of surgical events will increase. Current weight and volume restrictions on spacecraft severely limit the availability of surgical and anesthetic equipment to cover all but the most likely situations. Due to limits on crew size and capabilities, it is currently not possible to have crew medical officers with the necessary intensive training to handle major surgical procedures. A significant surgical event will greatly impact the mission and require a large amount of resources in order to be treated successfully.

Historically, mortality and morbidity related to illness and injury have accounted for more failures and delays in expeditions and new exploration than have defective transportation systems. There are numerous ways in which the environment of a long-duration spaceflight such as a Mars expedition will affect the ability to provide medical and surgical care. These include long communication delays (8 to 56 min depending on the orbital configuration of the Earth and Mars), limited medical care resources, the abnormal pathophysiology of spaceflight, limited crew training and experience, radiation exposure, operating in an enclosed environment, and long definitive medical care times. The medical care system on a future Mars expedition will need to be very autonomous and self-sufficient due to the extremely long separation from definitive medical care. The time to reach definitive medical care is only 24 to 36 h for the International Space Station, but is 4 to 7 d for a Lunar Base and over 9 mo for a Mars expedition.

The minimal capabilities for the International Space Station, Lunar outpost, and Mars mission are listed in **Table II**.

The paradigm for the surgical component of the medical care system for long-duration flight is not a highly technological system (such as robotic surgery with stored memory), ultra sophisticated hardware, or surgical procedures which require specialized training. Instead, the paradigm is more likely to resemble the surgical care of the 1960s. It was not uncommon then for a general practitioner to perform an appendectomy, a cholecystectomy, or even more advanced surgical procedures. The Crew Medical Officer will need to be skilled in many areas and yet also be as surgically capable as the common family doctor of the past (in the 1960 era, these physicians commonly performed open abdominal cases). The experience onboard the International Space Station has shown that hardware will need to be simple and reliable, or at least easily repairable. Advanced technology hardware that has a high failure rate or a low rate of maintainability will be a liability. It is very hard to break a hemostat, a scalpel, or a pair of scissors.

There will be an increased emphasis on converting surgical conditions to medical illness. Examples include dis-

TABLE II. PROJECTED MEDICAL CAPABILITIES FOR LOW EARTH ORBIT AND BEYOND.

Advanced Life Support Capabilities	Time to Definitive Medical Care	Crew Medical Officer Training
Low Earth Orbit (LEO) / ISS	24 h	
Specialized Restraint Systems		Trained EMT (< 100 h training)
IV/IM Medications		
Oral & Endotracheal Airway / Cricothyroidotomy		
Automated Pneumatic Ventilator		
BP Monitoring		
Pulse Oximetry		
Ultrasonography (Abdominal, Cardiac, Thoracic)		Paramedic Level (2)
Informatics/Telemedicine		
Limited Hyperbaric Treatment		
Defibrillator with External Cardiac Pacing		
ECG Monitoring		
Modified ACLS & ATLS Protocols		
Minor Surgical Care		
Lunar Base Missions / Stable Lagrangian Platforms	Days to weeks	
LEO / ISS, plus augmented supplies:		Physician & Paramedic or Paramedic & Paramedic with Advanced Training
More sustainable ACLS and ATLS		
Hyperbaric Chamber		
Advanced Diagnostic Tools		
Diagnostic Imaging (?)		
Radiation Shelter		
Mars Expeditionary Missions	9 to 30 mo	
Lunar, plus augmented supplies and stand-alone capabilities:		Physician (limited surgical capability) & Paramedic
IV Fluids, Antibiotics, and Nutrition		
Limited Surgical Intervention		
Banked or Synthetic Blood / Banked Bone Marrow		
Informatics/Expert Systems/Clinical Decision-Support Tools		
Radiographic / MRI Diagnostic Imaging		
Recuperation and Convalescence Capabilities		
Radiation Shelter		

solving urinary or biliary calculi, percutaneously draining fluid collections (such as an intra-abdominal abscess), treating an ectopic pregnancy with Methotrexate, and treating malignancies (such as breast cancer) nonsurgically until return to Earth. Prophylactic surgery (cholecystectomy or appendectomy) will be considered, but represent preventing specific diseases of low incidence instead of providing for general medical/surgical capabilities.

The requirement to limit mass, volume, power, and onboard medical expertise will be judiciously traded off with the need for comprehensive medical and surgical care capability including the need for operative intervention. A system with more surgical capability than has been present in past space medical care systems will be necessary due to the increased risk and the need to reduce mission and health impact. This capability may be provided through a mixture of traditional resources and some newer innovative technologies currently in development such as “smart” medical systems, medical informatics, telemedicine, imaging, monitoring, artificial blood, and the miniaturization of laparoscopic equipment. Virtual reality refresher training for surgical procedures is also not far away. Of most importance, the surgical capability of any medical care system ultimately will be limited by the surgical capability and training of the crew medical officer. When and if a surgical procedure is performed, then the same variable will occur as in conventional surgery concerning the innate surgical skills of the operator. An operator with poor surgical skills on the ground will have poor surgical skills in space.

Behavioral Health

Providing adequate behavioral health services to astronauts on a long-duration lunar or Mars mission will require NASA psychiatrists and psychologists with extensive experience working with astronauts and their families during the missions. Such personnel will require an in-depth knowledge and familiarity with the expedition crew and their family members, as well as a true working knowledge of all aspects of the mission pertaining to the spaceflight environment, habitability, sleep/wake schedules, workload, medical support capabilities, and risks.

Regular private communication with crewmembers will be required throughout the mission. During the initial and very late stages of a Mars mission, private psychological conferences (PPC) can be held using audio and visual communication in real time. However, most of the mission will occur at such a distance that the communication delay would make this impossible. PPC’s will then need to occur via e-mail or perhaps through recorded video response to a written query or a standard interview questionnaire. Such a barrier will render the interpersonal human interaction and give-and-take of any needed counseling or psychotherapy useless and will make psychological assessment and potential treatment far more difficult. A long-duration lunar expedition would be an excellent test-bed for the monitoring and communication challenges of a Mars expedition mission.

Such communication challenges will also mandate the existence of an autonomous method of psychological/psychiatric self assessment and diagnosis for disorders of mood, anxiety, thought, cognition, and level of fatigue. A comprehensive battery of self-administered or crew medical officer- (CMO) administered psychological diagnostic tests will be required. The results may then be sent to the crew surgeon and the ground consultant psychiatrist/psychologist for review and recommended therapeutic response. In this regard, the CMO will require a much greater level of training in behavioral medicine issues than is currently required for Low Earth Orbit (LEO) missions. A computer- delivered, interactive, self-guided psychotherapy tool to aide in the treatment of depression, anxiety, and interpersonal conflict would also be highly beneficial. Antarctica, the ISS, and long-duration lunar missions would provide venues for the testing of such a psychological treatment tool.

A 2.5-yr Mars expedition would lead to a far greater level of isolation and psychological stress than any space mission attempted previously. Because of this, a risk of psychiatric decompensation would remain despite the most careful genetic and personality screening. If a serious psychiatric disorder were to develop during the mission, there would be no realistic opportunity for evacuation. As a consequence, there would need to be an ample range of medications to treat psychiatric disorders. Such medications would need to be effective in emergency and chronic psychiatric conditions, including severe mood, anxiety, and psychotic disorders. The choice of psychiatric medications for such a mission will require a great deal of forethought and the mission CMO would require significant education in their use.

Safe Passage

This paper has summarized this panel’s views on the Vision’s principal challenges to space medicine. The following compilation of critical technologies and capabilities were identified by a NASA life sciences technology working group and the Institute of Medicine and listed in the book, “Safe Passage: Astronaut Care for Exploration Missions” (Ball HR, Evans CH, eds. Washington, DC: National Academies Press, 2001). The approaches to meeting them lies in the will and funding of the U.S. Congress and other governments and the implementation by NASA and its international partners. Specifically the critical life science technologies and capabilities needed in the areas of medical screening risk mitigation, life support and habitability design, and microgravity countermeasures and health care are listed below.

1) Space Radiation Modeling

- A space weather simulation/visualization system for assessing developing radiation conditions
- Model(s) to describe the dynamic behavior of the trapped radiation belts
- Model(s) of the geomagnetic cutoff, including diurnal, seasonal, and solar cycle activity dependence
- Technologies for quantitative assessment of radiation risks

- Model(s) of the interaction of the heavy ions in galactic cosmic rays with spacecraft, planetary atmospheres, and regoliths
- Improved radiation transport and shielding codes
- Evaluation of new materials, composites, and planetary regoliths as shielding media

2) Radiobiology

- Models, sensors, and systems to measure and predict the effects of radiation upon humans
- Determination of RBE (radiobiological equivalents) for neoplastic transformation of human cells
- Determination of RBE for lung and mammary cancers
- Radiophysical models for neoplastic transformation
- Method(s) of calculating probabilities of cancer induction at the organ level
- Methods for determining the human genetic effects of High LET (linear energy transfer) radiation
- Models of performance and quality of life impairment
- Strategies for determining and evaluating potential microgravity-radiation synergism
- Operational measures (e.g., mission planning and operations, safe shelters, etc.)
- Chemical and biological modifiers and radioprotectants

3) Space Radiation Monitoring

- Space-based neutron monitor (spectrometer/dosimeter) which can measure neutron energies to at least 20 MeV in the presence of high levels of protons
- Early warning system for predicting Solar Particle Events (SPE) and their size, based on the X-ray and gamma-ray spectral characteristics of observed solar flares
- Small, portable electronic dosimeter, which can be used in EVA suits and habitable volumes (provides dose and dose-equivalent rates and integrated values)
- New and advanced/improved techniques and materials for passive dosimetry, including biological radiation sensors

4) Skeletal Integrity

- Inflight, compact, light weight dual energy X-ray absorption to perform hip, spine, and heel bone mineral density (BMD) measurements
- Automated urine collection, measurement, and sample storage/analysis equipment
- Load cells in pedals for cycle ergometer and angle measurement for hub and pedals
- Dynamometers for hip, knee, and ankle measurements in space
- Finite element analysis methods and equipment for skeleton measurements/analysis with minimal radiation (model incorporates bone morphology and bone density)

5) Physical Performance Maintenance

- Means to monitor the effectiveness of nutrition and pharmacological agents, exercise and electro-myostimulation
- Means to assess lean body mass, aerobic/anaerobic capacity, muscle endurance/strength, thermal regulation, neuromuscular (coordination control), and compliance in applying countermeasures

6) Environmental Physiology/Biophysics

- Sensors and systems to determine the effects of pressure and changes in pressure, especially in decompression illness (DCI)
- Systems to determine the effects of temperature on the health and performance of the crew in spacecraft and during EVA
- Systems to measure metabolic rates, especially during EVA, and to relate them to fatigue and risk of DCI
- Systems to measure the effects of different gas species such as oxygen, water, carbon dioxide, and ionized particles
- Methods of treating of DCI, such as hyperbaric therapy for DCI and hyperbaric/oxygen therapy
- Tools for understanding how spacecraft bioelectromagnetic fields and nonionizing radiation affects the crew
- In-flight/in-suit Doppler systems
- Methods for treating decompression illness

7) Calcium Deposition (Stones)

- Systems that measure the changes in calcium during spaceflight and how it affects the neurosensory, cardiac, muscle, or other systems
- Countermeasures (procedures and pharmacologic/nutritional agents) that prevent ectopic calcium deposition in 99% of the population

8) Orthostatic Tolerance

- Hardware for an integrated countermeasures program to maintain orthostatic tolerance for landing, planetary excursion, emergency, entry, egress, and postflight rehabilitation
- Technologies for exercise, pharmacologic agents (e.g., mineral corticosteroid, fluid augmentation), fluid therapy, neurostimulation, compression garment

9) Artificial Gravity Countermeasures

- Hardware to assess artificial gravity as a countermeasure
- Systems to determine the most efficient combination of g-level and exposure duration for intermittent centrifuge operation
- Systems to determine the most effective combination of radius and rotation rates for continuous centrifuge operation
- Systems to verify centrifuge effectiveness in maintaining skeletal integrity, calcium metabolism, physical performance, orthostatic tolerance, neurosensory function, and other physiological functions, identifying positive and negative side effects
- Systems to verify the effect of intermittent and continuous centrifuge exposure on humans at several gravity values, including near 0-g, 1/6-g (lunar surface), 3/8-g (Mars) and 1 g

10) Neurosensory and Sensorimotor Function

- Ultra-lightweight binocular 3-D video eye movement monitoring
- Ultra-lightweight 6-degree-of-freedom head movement monitoring
- Nonhead coupled visual display system
- Wide field stereo head mounted display (HMD) with eye and head movement monitoring and see through capability
- Dynamic visual acuity testing and analysis system; 3-D video eye movement capture and analysis software
- Mathematical models of visual-vestibular integration and adaptation
- Head-body tracking system
- Mathematical models of postural and locomotor control
- Dynamic posturography system
- Ways to evaluate the role of proprioceptive and somatosensory information in sensorimotor functions
- Human-rated angular and linear whole-body acceleration devices
- Techniques for measuring orientation and perceptual disturbances
- Tests/devices for evaluating ability to perform mental rotation on Earth and in space
- Tests/devices for evaluating adaptive changes in spatial orientation during spaceflight
- Improved preflight and in-flight adaptation to altered vestibular, proprioceptive and somato sensory inputs
- Means to evaluate changes in sensory-motor performance
- Sensory substitution using electrical and/or magnetic stimulation

11) Countermeasures for Neurosensory and Sensorimotor Disturbances

- Means for preflight adaptation to altered sensory inputs to reduce sensorimotor disturbances, spatial orientation and perceptual disturbances, and space motion sickness
- Means for inflight maintenance of Earth gravity sensorimotor and perceptual function (adaptation), including a short-arm centrifuge, 3-d eye-head movement monitoring system with visual display system, and foot pressure (somatosensory) input device
- Vibrotactile orientation system/device for inflight maintenance of spatial orientation - specifically during EVA

12) Diagnostic/Physiological Monitoring & Telemedicine

- Laboratory diagnostics (clinical chemistry, hematology, pathology, microbiology, etc.); imaging diagnostics (radiographic, magnetic resonance, ultrasound, etc.)
- Advanced monitoring and sensors

- Non- or minimally-invasive monitors (ECG, BP, SpO_2, HR, T, etc.)
- Implantable/injectable/ingestable biomedical sensors
- Telemetry to/from sensors and processing systems
- Autonomous/expert systems (monitoring, diagnosis, treatment, and surgical assistance)
- Multimedia medical record technologies
- Advanced user interfaces for medical diagnosis, treatment and training (VR, haptic, etc.)
- Advanced computer-based medical training and simulation techniques and systems
- Robotic (autonomous) and teleoperated medical assistance systems

13) Immune Protection

- Means to determine maximal acceptable decrements of cellular and humoral protective mechanisms, relation of the immune system dysfunction to the incidence of infection, cancer induction, allergy, and autoimmune disease manifestations
- Pharmacological agent(s) as a countermeasure
- Means to decrease "stress response;" means to improve the current Preflight Health Stabilization Program
- In-flight cytometer, delayed type hypersentitivity test device ("skin test"), in-flight Enzyme-Linked Immunoassay (ELISA) system, in-flight blood collection and distribution system, and a cell culture and challenge system

14) Medical Intervention

- Systems for emergency surgery and critical care
- Systems for rescue, resuscitation, stabilization, and transport
- Fluid therapy systems, with infusion pumps, on-site production of sterile fluids, nutritional support, blood and blood component replacement
- Extended (3 yr) shelf-life pharmaceuticals
- Medical waste management system
- Advanced medical storage systems (samples, pharmaceuticals, etc.)
- Microsurgery/microtherapeutics equipment and protocols
- Planetary surface and microgravity hyperbarics
- Portable (inflatable) hyperbaric chamber

15) Psychosocial Stability

- An integrated countermeasures program for Psychosocial Stability with preflight training, group support, self help, pharmacologic treatment, exercise, etc.
- Systems designed to measure, evaluate and preserve psychosocial stability

16) Crew Productivity

- Technology tools and models for determining acceptable performance ranges for different types of tasks
- Tools for modeling complex missions with multiple participants, assessing predicted vs. actual productivity, and updating the model status to identify potential problems or failures

17) Maintenance of Proficiency

- Tools for design-time information collection/capture in developing training materials
- Authoring tools optimized for computerized training for unique or unusual skills or tasks
- Nonintrusive technologies for monitoring individual and group performance over time
- Advanced virtual reality systems with low power, volume, and mass requirements, which provide position tracking, wide field-of-view head mounted displays, and haptic feedback for onboard refresher training and skill monitoring
- Authoring languages for VR training systems that incorporate error feedback to the user, prompting, and tools for data collection and performance assessment

18) Crew Accommodations

- New methods of trash disposal which reclaim useful materials while minimizing or eliminating disposal volume, such as plastic recycling
- Technologies for 0-g/partial-g washing and drying of clothes
- Technologies for providing crew consumables such as food supplies and so on, in a wide variety of emergency situations with the least possible mass
- Advanced technologies to repair systems without Earth support
- Means for analyzing spares requirements, documenting repair procedures at very low level (e.g., components rather than boards), and developing multipurpose troubleshooting tools
- Improved cleaning technologies
- A method of tracking the location and status (e.g., health, functional state, etc.) of items (e.g., by embedding a small microchip with integral microtransmitter into every object)

19) Food and Galley

- Shelf life extension to store a complete and acceptable diet for the 3 to 5 yr required by Mars mission scenarios
- Advanced food packaging
- Means for food preparation for crew
- Reduction in waste generated (both food and packaging wastes)
- Enhancements in acceptability, palatability, and variety

20) Food Development from Chamber Grown Plants

- Harvesting technologies
- Processing (e.g., drying, grinding, making bread from wheat flour)
- Sugar and oil production compatible with manned chambers

21) Habitability

- Measurement techniques to determine personal space, time, and privacy requirements
- Measurement tools to determine actual and preferred levels of habitability factors such as volume and area, noise, vibration, odor, temperature, and humidity, and their relationship to crew performance and productivity in long-duration missions
- Tools to measure personal preference for habitability factors in individual crewmembers

22) Contingencies

- Model that can continuously estimate the likelihood of potential critical events
- Analytical model that identifies and evaluates potential responses to critical events for a Decision Support System
- Advanced and/or improved models of human decision making that provide assistance in predicting and resolving contingencies or critical events in human/human or human/system situations

CONCLUSIONS

Planetary missions are going to be inherently risky. It is the task of the medical profession to estimate and explain the medical risks clearly, so that NASA and all those involved can weigh them against the overall risks and benefits of the mission and decide whether to accept them. Thus there is no definite threshold short of which we are not ready, and beyond which we are ready, to go to Mars. We will always be ready, if the risks are deemed worth taking; and we will never stop learning how to reduce them. Perhaps the biggest challenge will be <u>execution</u> – implementing what we know with excellence – in medical crew selection and training, in countermeasures, in remote medical care. This must be done in stepwise approach, utilizing the ISS and then the Moon, toward our foreseeable goal, the journey to Mars.

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Author Query sheet–ASEM2314

Q1 : Query Author: is is ok to call this an ad hoc committee? Members are listed in the footnote.