Reducing the Risk of Long-Duration Spaceflight

BY MARIANNE DYSON

Volunteers are ready to rush off to Mars as soon as a ship is ready. But the international medical community urges patience while they gather data on the space station and determine ways to prevent and treat medical issues sure to develop during long-duration spaceflights.

"Anybody that thinks we are ready to go to Mars right now, I'm here to tell you is wrong," said Dr. John Charles, the associate manager for international science in NASA's Human Research Program. "To do a real round trip to Mars, we're talking about at least 600 days, and probably 900 days," he noted at a recent meeting at Johnson Space Center. "We have most of our experience in the four to six month duration missions."

To remedy that, NASA and its partners are planning what they hope will be the first of multiple one-year missions on the space station. To oversee the science and coordinate investigations from different countries, they formed the Multilateral Human Research Program Panel for Exploration, abbreviated MHRPE. (Charles noted it is pronounced mur-pee, not Murphy.) Charles co-chairs the panel along with a senior Russian medical specialist. "Its sole purpose is to facilitate multilateral in-flight investigations," he said. "We're supposed to use the space station as its title implies, and make it a truly international space station."

The panel first identified a set of risks. "These are the risks that the best and brightest of your space life sciences community around the world have decided are the most important risks that need to be resolved before astronauts can safely go on exploration class missions beyond low-Earth orbit," Charles said.

1. Musculoskeletal: Long-term health risk of early onset osteoporosis. Mission risk of reduced muscle strength and aerobic capacity.

2. Sensorimotor: Mission risk of sensory changes/dysfunction.

3. Autonomous medical care: Mission and long-term health risk due to inability to provide adequate medical care throughout the mission (includes onboard training, diagnosis, treatment, and presence/absence of onboard physician).

4. Behavioral health and performance: Mission and long-term behavioral health risk.

5. Autonomous emergency responses: Medical risks due to life support system failure and other emergencies (fire, depressurization, toxic atmosphere, etc.), crew rescue scenarios.

6. Ocularsyndrome: Mission and long-term health risk of microgravity induced visual impairment and/or elevated intracranial pressure (VIIP).

7. Nutrition: Mission risk of behavioral and nutritional health due to inability to provide appropriate quantity, quality, and variety of food.

8. Radiation: Long-term risk of carcinogenesis and degenerative tissue disease due to radiation exposure, largely addressed with ground-based research.

9. Toxicity: Mission risk of exposure to a toxic environment without adequate monitoring, warning systems or understanding of potential toxicity (dust, chemicals, infectious agents).

10. Hypogravity: Long-term risk associated with adaptation during IVA and EVA on the Moon, asteroids, Mars (vestibular and performance dysfunction), and post-flight rehabilitation.

Credit: MHRPE Risk Chart (25 Sept. 2014)

After the 10 risk categories were identified, the panel did a risk assessment, assigning one of four color codes to indicate the status of each one. Charles stressed that "The color assignments are more qualitative than quantitative and are not universally accepted." Specifically, he noted the complex nature of risk assessments and that labeling one risk green and another yellow for example "is not meant to undervalue or over-simplify any particular risk."

Green means the panel is mostly good to go with current knowledge. Yellow means they are probably okay to proceed with that level of known risk. Charles said red means "we think that the risk is too high to proceed safely, effectively, and efficiently with current knowledge." Gray means there is insufficient knowledge to make an assessment.

The risk changes with the duration and distance of the mission from Earth. "So for ISS missions, most of it is green. There are a few yellow because there are still some outstanding categories of concern, especially the ocular syndrome (see VIIP sidebar). For lunar surface missions lasting six months, there's a lot of yellow," Charles said. "But we could do it if we accept and appreciate that level of risk. For near-Earth asteroids, there is a lot of red, but some areas that we feel moderately comfortable about. Finally, for going to Mars with the knowledge that we have now, there is a lot more red."

Then the panel looked at what they could accomplish with a research effort focused on reducing these risks. "We tried to estimate what kind of progress we can make on the space station, which is the world's only first-class weightless facility, to understand the effects of weightlessness and other effects on astronauts," Charles said. "We predict we can reduce the risk in these areas from fewer red to yellow, and even some green if we keep the space station functioning long enough."

Risk Status Table

Risk	ISS	Moon	NEA	Mars Now	Mars 2024
Musculoskeletal	Green	Green	Yellow	Red	Yellow
Sensorimotor	Green	Yellow	Red	Red	Yellow
Autonomous Medical Care	Green	Yellow	Red	Red	Yellow
Behavioral Health & Performance	Green	Yellow	Red	Gray	Yellow
Autonomous Emergency Response	Yellow	Yellow	Red	Yellow	Yellow
Ocular Syndrome	Yellow	Yellow	Red	Red	Green
Nutrition	Green	Green	Yellow	Red	Yellow
Radiation	Green	Yellow	Red	Red	Red
Toxicity	Yellow	Yellow	Red	Gray	Green
Hypogravity	Green	Green	Yellow	Red	Yellow

Charles emphasized, “We are not talking about gee-whiz, nice-to-have medical research. We’re not even talking about research that will benefit life on Earth. We are focused on the human research program specifically, exclusively, with laser-like focus on the risks to astronauts of long-duration spaceflight.”

One of the key measures of risk is the incidence rate. This measure is particularly important to reducing the autonomous medical care and emergency response risks. They asked the question, “How do we make sure we’ve anticipated the problems that might develop gradually?”

Based on data from previous space missions and also including Antarctic, submarine, and aviation data, in a one-year period, one out of 16 people in these dangerous environments will have an injury or illness that would require emergency room care. “So if you assume six astronauts on a 2.5-year mission,” Charles said, “that means about once per mission, something bad is going to happen to one of the six astronauts that would send you or me to the emergency room. Every third mission, there is going to be something bad enough happen that you’re going to wish you had an intensive care unit.”

Illness/Injury Incidence Chart

Incidence requiring ER	Incidence requiring ICU	Deaths (20% of ICU)
6 percent/year	2 percent/year	0.04 percent/year
Almost 1 of 6 crew/one 2.5-year Mars’ mission	About 1 of 18 crew/3 (2.5-year) Mars’ missions	About 1 of 90 crew/15 (2.5-year) Mars’ missions

*Based on U.S. and Russian space flight data; U.S. astronaut longitudinal data; and submarine, Antarctic winter-over, and military aviation experience. Source: R. Bilica, January 1998, & D. Hamilton, June 1998.

Furthermore, based on normal activities in a risky environment, one in 15 missions to Mars (assuming six-person crews on 2.5-year missions) is going to have a fatality. Charles said, “We, as a society, when we talk about sending astronauts to Mars—we, as the people who are doing it or encouraging others to do it, need to be comfortable with the idea that not everybody is going to come back.”

To reduce these risks, and also to develop and test prevention and treatment options, the MHRPE science teams are coordinating their investigations for the upcoming one-year mission of American Scott Kelly and Russian Mikhail Kornienko that is planned to run from March 2015 to March 2016 on the International Space Station.

Charles said, “I think we can make a reasonable case for the fact that we can acquire most of the knowledge we need about physiology and medical aspects of long-duration spaceflight in flights that are just a few months long.” He believes this because most adaptations that occur to the human body are a result of weightlessness and happen fairly quickly. “You reach a new set point within a few days,” he said. Some systems, like the cardiovascular system, take days to weeks to plateau. Even lean body mass, which includes the bones and muscles, changes predictably and levels out. Scientists now know what level and type of exercise and diet are needed to keep bone and muscles strong.

The one-year mission of American Astronaut Scott Kelly and Russian Cosmonaut Mikhail Korenienko, shown here at the Gargarin Cosmonaut Training Center in Star City, Russia in September 2014, will help lower the risk of future long-duration trips to Mars.

Red Alert

However, radiation effects continue to accumulate with time in space. “So it is not going to reach a peak effectiveness or a peak of damage and then level off,” Charles said. “It’s going to keep happening as long as you’re exposed to radiation.”

Another parameter that appears to accumulate with time is psychological stress. To measure stress’s impact on the mission, one ongoing ISS investigation has crewmembers log incidents of conflict with other crewmembers and with the ground team in a journal.

Data shows conflicts increase sharply during the fourth quarter of a six-month mission. Also, crew ratings of how well the group is getting along drop significantly during the last quarter. Do these trends level off or continue with increased mission duration? “Without any interventions, it suggests that there will be a high level of stress which has effects on your physiology, metabolism, and on your getting along with others,” Charles said. “We’d better be able to provide the appropriate therapy, the appropriate countermeasures, and appropriate selection so we hire people who don’t get stressed or respond to stress differently.”

The lower body negative pressure device in the Russian Zvezda module, shown here in use by Expedition 30 Cosmonaut Oleg Kononenko in February of 2012, is used to pull fluid back down to the legs during freefall. This device will be used during the one-year mission to test the effects of fluid shifts on vision.

Another recently identified risk is the ocular ischemic syndrome. A NASA report published in 2012 found that 29 percent of short-duration (less than 30 days) and 60 percent of long-duration crew members reported degradation of long distance or near-visual acuity, which, in some long-duration cases, did not resolve in the years after the mission.

These three areas will be getting particular scrutiny during the one-year mission, not just for the one-year crew, but also for the short-term and six-month crewmembers on the station. "If we continue to see change from the six-month missions to the one-year missions, [that is, if] the [trend] line does not flatten out for that particular parameter, then this is one we've got to pay attention to while we have a continued space station working."

Increasing Sample Size

"We don't know what might be out there that's going to surprise us with longer duration flight," Charles said. "We don't really know if we've seen the full expression of the changes that occur."

The first joint year-long mission will help, but won't be enough to get us ready for Mars. Charles said, "We can't reasonably expect to understand the effects of space physiology with just one or two people.…We need large numbers of test subjects to understand the effects of the phenomena we're trying to study and differentiate those effects from the effects of random biological variability. We're all built to the same plan, but we all have different blood pressures, different heights. We all have different shoe sizes. We need a large number of subjects and measurements to give us what that average is, to determine the baseline."

Thus Charles said that, "we're trying to convince the Russians to do up to five more one-year missions." By 2024, Charles expects to have turned many of the risks of heading to Mars from red to yellow or green. "I am confident that we will be able to reduce the risks to astronauts in long-duration spaceflight."

Marianne Dyson is an award-winning author and a former NASA flight controller. She and Buzz Aldrin just completed a children's book about Mars for National Geographic. She is on the NSS board of advisors, chairman of the NSS publications committee, and a founder of the Clear Lake Area/Houston NSS chapter. http://www.mdyson.com.

Ocular Syndrome a.k.a. VIIP

NASA astronaut Karen Nyberg uses a fundoscope to image her eye while in orbit.

Astronauts have reported visual impairments associated with spaceflight for more than 40 years. Until recently, these changes were thought to be temporary. But a comparison of eyesight pre- and post-flight has now identified a potential risk of permanent visual changes as a result of spaceflight. An "Evidence Report" published by NASA in July 2012 stated, "Data show that there is a subset of crewmembers that experience visual performance decrements, cotton-wool spot formation, choroidal fold development, optic-disc edema, optic nerve sheath distention, and/or posterior globe flattening with varying degrees of severity and permanence. These changes define the visual impairment/intracranial pressure (VIIP) syndrome."

Although the effects vary with the individual, a decreased ability to see up close is the most common complaint. "For short-duration spaceflight, it is a bit of a nuisance," Charles said. "If you need reading glasses, you take an extra pair along with you that have a slightly stronger prescription. This phenomenon became more serious when astronauts on the space station were saying after three to four months that they used up all their glasses and still had difficulty seeing."

One astronaut reported he could not read the checklist during reentry on the Soyuz. "His arms were not long enough and the cabin not big enough for him to hold the checklist far enough away to be able to call out the right events for the pilot," Charles said. Imagine the consequences of not being able to see the instruments during a landing on Mars.

Measurements using ultrasound and ocular computer topography (to build 3-D cross sections of the eye) in space have shown that the eye changes shape in astronauts. "It is flatter on the back side which changes your focal length," Charles said. This data led to the hypothesis that the shift of body fluids towards the head in freefall increases pressure behind the eye that changes its shape, thus altering vision.

To test this hypothesis, one investigation planned for the one-year mission involves using the Lower Body Negative Pressure (LBNP) device located in the Russian Zvezda module. The LBNP "acts to reduce the fluid volume in the upper body and move it back to the lower body. By putting somebody inside this LBNP device, we reduce that fluid shift for a few minutes, and see if the eyeball goes back to its previous shape."

"With any luck, we can correlate those changes with what else is going on in spaceflight. Is it simply a matter of time in flight, a function of the environment? Is it perhaps carbon dioxide levels which are higher on space station? Is it a function of viral reactivation, which is another stress response to spaceflight? Is it an effect of exercise? Are they pushing too hard? All of those are hypotheses. We don't know what the answer is right now," Charles admitted.

NASA's Chief Medical Officer Dr. Jeffrey Davis is responsible for all the medical operations for spaceflight. At a meeting in late 2013, when asked if deteriorating vision was a show stopper for Mars, he said, "Right now we're kind of on the fence. We don't think so. We're thinking that for flights maybe up to a year that we are planning, we should be okay…But for two and a half years, we can't really say."

That's why VIIP is one of the yellow risks for space station. But Charles expects the one-year missions will reduce this risk. "We'll be able to see whether or not the effect on the eyeball plateaus between six months and one year. And if it does, if data acquired at six months and data acquired at one year don't look appreciably different, then we're going to start feeling a little more confident that we don't expect any further changes for 1.5, or 2.5, or 3 years. We can then call that risk yellow or even green.

"This is right now one of our most serious concerns. It's also one we expect fully to be able to address over the next couple of years with some focused, dedicated research."