# Comparing Crew Operations in Extreme Environments: Arctic Shipping vs. Outer Space

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## ABSTRACT

Working in extreme environments presents serious challenges to crewmembers. This paper compares and contrasts various aspects of the working environments of outer space and cold climate (i.e., Arctic) shipping, looking at similarities and differences between the two, as well as lessons that might be transferable from one to the other. These transferable lessons might be found in the arenas of tools, equipment, protective gear, crew health, safety, habitability, ergonomics, operations, or some combination of the above. The two industries both stand to benefit from a deliberate comparison of challenges, technologies and lessons learned.

**KEY WORDS:** crew operations, human performance, extreme conditions/environments, personal protection gear, habitability, ergonomics.

## INTRODUCTION

As humankind contemplates ever further exploration and exploitation of the extreme frontiers our world (whether on or off of the planet), many questions come to mind regarding the practicalities of these endeavors. How far can we go and how long can we stay? Will our bodies and minds remain healthy during the course of our travels in extreme environments? Can humans be productive throughout a long trip to the remote reaches of our world? Many of these questions have yet to be fully addressed.

Living and working within the extreme environments of either outer space or cold climate[1] shipping present significant challenges to crewmembers (as well as to ship design, operations and support personnel) in accomplishing both daily duties and mission objectives. Both "job sites" are isolated from the rest of human civilization, and confined to the ship that transports and shelters the crewmembers within an otherwise hostile environment, lacking the basic support infrastructure that most of us have come to take for granted. This paper compares and contrasts various aspects of each working environment, looking at similarities and differences between the two, as well as the lessons that might be transferable from one to the other. These transferable lessons might be found in the arenas of tools, equipment, protective gear, crew health, safety, habitability, ergonomics, operations, or some combination of the above. For example, both environments are very hazardous for external, extravehicular operations, and protective gear must be worn by the crewmembers whenever they venture outside either type of ship. A closer look reveals that the protective gear worn in each environment serves similar purposes (e.g., thermal control, debris impact protection) and encounters similar challenges (e.g., simultaneously protecting while still allowing flexibility and mobility), and some sharing of operational "trade secrets" or technology transfers may be worthy of consideration. In fact, it has been suggested by some in the aerospace community that Antarctica could serve as a valuable analogous training site for lunar or planetary missions (Waller, 2010).

Cold climate shipping operations have a substantially longer history than human spaceflight operations, but due to a variety of factors, the types of technologies used by crewmembers in each environment are quite different. On the one hand, because of high public visibility, federal priority, and widely acknowledged risks, technologies associated with - indeed developed for - human spaceflight missions (particularly in the West) have tended to push the state of the art of technology, then trickle down to other lower profile, yet often just as risky, operations. On the other hand, many historically tried and true techniques and technologies from the shipping industry may in fact be the most appropriate approach to reliably accomplishing a given task.

This paper provides an overview of extreme workplace challenges, technologies, and lessons learned from the perspective of an aerospace crew systems (i.e., human factors) engineer.

## BACKGROUND

From the very beginning of our ventures into space, scientists and physicians have wondered whether the human body is well suited for spaceflight. The original issue was whether humans could merely survive even a short flight into space, let alone remain healthy during a long trip. Because of this fundamental concern, both the Russians and the Americans first sent animals (primarily dogs and primates) into space prior to sending humans. When most of the animals returned alive and without any major health problems, both countries proceeded with sending humans on very short trips.

The unique conditions of spaceflight - such as microgravity, high radiation levels, isolation and confinement, vibration, acceleration, and noise levels, as well as the external environment of low pressure and extreme temperature variations - produce a variety of physiological and psychological effects in humans. These effects manifest themselves throughout the body and mind, and range in time of onset, duration, and recovery from minutes to months.

Likewise, the Arctic shipping environment presents hazardous working conditions of its own. Some are similar to those of spaceflight (e.g., isolation and confinement, lack of nearby support infrastructure, extreme temperatures), while others are quite different (e.g.,

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[1] For the purposes of this paper, "cold climate" and "Arctic" will be used interchangeably, since the majority of cold climate shipping traffic operates in the Arctic region.

encounters with ice, inclement weather and wildlife). Either way, the physical and psychological stressors of each environment can have a profound effect on the performance and productivity of the crew.

### Problem Statement

The primary concern to be addressed in preparing for extended human missions in extreme environments is that of keeping the crew healthy, safe, and as productive as possible during all phases of the mission, as well as upon their reintroduction to a more conventional, habitable earth environment.

The discussion that follows compares the effects of environmental hazards on human performance that must be addressed in planning and preparing for successful human missions in the extreme environments of spaceflight or cold climate shipping. Crew protective gear and human factors design considerations are examined, and potential physiological and psychological countermeasures are proposed.

## DISCUSSION

### Environmental Hazards

As mentioned previously, both the spaceflight environment and the cold climate shipping environment present hazards to human crews. In the case of spaceflight, the most persistent of these can generally be categorized as remoteness/isolation/confinement, desynchronosis (disruption of circadian day-night time cycles), high radiation levels, microgravity, extreme temperatures, and low external pressure. In the case of cold weather shipping, the persistent hazards are again remoteness/isolation/confinement, desynchronosis, higher (seasonal) radiation levels, and extreme temperatures (lower range), with the added dangers of inclement weather, icebergs, and untimely encounters with large and/or endangered wildlife or other humans. Although not necessarily extreme enough to be considered hazardous, noise levels are also a concern in both environments. Since the purpose of this paper is ultimately to share lessons learned, the focus will be on the most similar issues.

#### *Remoteness/Isolation/Confinement*

Few places accessible to humankind could be considered as remote as the Arctic Ocean or outer space. The lack of easily accessible support infrastructure (resupply logistics, rescue/evacuation vehicles, medical facilities and resources, 24/7 communications/information, hazardous materials resources, emergency response teams, etc.) in these environments necessitates that crewmembers and their ships be extremely self-sufficient. There is virtually no possibility for "shore leave" to boost crew morale in either of these situations.

Compared to concern for the crewmember's physical safety, relatively little consideration has been given to the psychological and cognitive impacts and adjustments associated with working in remote environments. Yet as we prepare for more frequent and more remote operations, the full spectrum of human psychological and social requirements must be fully addressed.

Some kinds of psychological effects are to be expected on any remote mission, especially one of extended duration and in confined quarters. On submarine missions, evacuations for psychiatric disturbances rank just behind evacuations for trauma and surgery. Many of the following factors are found in remote habitats. Some factors are territorial issues, while some are sensory stimulation issues:

- Isolation
- Confinement
- Limited habitation volume
- Compromised quality/conditions of habitation environment
- Absence of fresh air
- Reduced sensory stimulation
- Boredom
- Regimented work/rest schedules
- Strangeness of environment
- Awareness of risk

Each factor can contribute to mood disturbances, impaired intellectual function, problems with work, interpersonal conflicts, loss of sleep, apathy, depression, and withdrawal. If interpersonal conflicts or work problems lead to withdrawal or feelings of being outcast by the group, being an exiled member of an isolated group can be very stressful, and can lead to more serious semi-psychotic indications such as hallucinations, crying, loss of appetite, silence, paranoia, and lethargy (Wickman, 2006).

Some behavioral research suggests that remote mission adaptation progresses through several distinct sequential phases (Atkov and Bednenko, 1992). The first phase might last for 60 days or more, and may be characterized as a high motivation period of adjustment to a new and exciting environment, with the crew adapting an "us" (crewmembers) and "them" (non-crewmembers) mentality. The next phase might last from about the 60-day mark to the mission midpoint, characterized by a loss of energy, error-prone performance, and psychosomatic illnesses. Sometime during this phase the "us versus them" evolves into a "me versus the rest of you" mentality. The third phase would last from mission midpoint through third quarter, characterized by apathy, withdrawal, depression, and declining productivity. The final phase would extend from the third quarter through the end of the mission, and would be considered the "home stretch", characterized by renewed motivation, increased energy, improved productivity, and enhanced mood.

In the shipping community, isolation-induced low morale in remote icy regions has been observed to negatively impact productivity and teamwork (Palinkas, 2001). Crewmembers suffering this type of experience may be less likely to offer their services for future cold climate voyages. Therefore personnel retention rates decline and valuable cold climate shipping experience is lost (Sillitoe et al, 2010).

In the spaceflight community, personnel retention is less of a problem, partially due to the societal prestige of being an astronaut. However, the stress of isolation, confinement and separation from earth continue throughout each flight, and may be exacerbated by interpersonal stressors and homesickness (Sandal, 1999). These high levels of sustained stress can produce various effects during long duration spaceflight missions, such as decreased energy, intellectual impairment, decreased productivity, increased hostility, anxiety, sleep disorders, miscommunication, and impulsive behavior (Levine, 1991).

#### *Desynchronosis*

Desynchronosis, or disruption of the circadian day-night cycles, typically occurs in circumstances wherein the usual daylight-waking/darkness-sleeping pattern is interrupted. In the endless daylight of Arctic summer, or the 90-minute day-night cycles of low earth orbit, or even in night-shift work, this is often the case. During low earth orbit spaceflight, astronauts practically ignore the 90-minute light-dark cycles and maintain a schedule in synch with Mission Control. The endless darkness of Arctic winter will become a similar concern as shipping activities move toward year-round operations in order to become more economically viable. Even in between the winter and summer solstice extremes of the Arctic, the often lop-sided day-night cycles can be harmful to crew performance (Sillitoe et al, 2010). Desynchronosis can lead to sleep loss/disruption, chronic insomnia, irritability, depression, inattentiveness, diminished performance, loss of productivity, and immune system suppression. This can be an even bigger problem for a ship's watchkeepers, who have to deal with the odd hours of shift work in addition to strange light-dark cycles (Palinkas, 2001). Spotting ice or other traffic in the dark can be difficult enough without the added challenge of desynchronosis.

### *Increased Radiation*

Radiation exposure limits for interplanetary missions have yet to be established. Increased radiation exposure (from galactic cosmic rays, solar particles, trapped belt radiation, or other ionized particles) outside the earth's protective atmosphere and magnetic field may manifest effects somatically in cellular damage or genetically in reproductive defects. Radiation exposure at the earth's surface is less than 0.6 percent of that received in low earth orbit (LEO), and less than 0.3 percent of that received in an interplanetary transit mission (e.g., to Mars) (NRC, 1996).

Likewise, radiation exposure within the Arctic region is higher for several reasons: diminished ozone layer; global fallout from atmospheric nuclear tests; liquid discharges from nuclear reprocessing plants in Western Europe; and Chernobyl nuclear plant failure fallout (Strand et al, 2002). In addition, fresh white snow can reflect all but ten percent of incoming sunlight (NSIDC, 2010). This glare can diminish vision (problematic for viewing external surroundings as well as internal displays and controls), or in extreme cases cause permanent snow blindness. The long summer days in the Arctic are accompanied by increased amounts of ultraviolet radiation, as well as increased potential for sunburn and eye damage (Sillitoe et al, 2010).

### *Ambient Noise*

In spaceflight, noise and vibrations associated with normal vehicle systems operations, fear of equipment failure, and the rigors of adjusting to microgravity are consistent sources of stress (Levine, 1991). Noise exposure levels on the International Space Station typically range from 65 to 71 dBA (Barratt and Pool, 2008).

In cold climate shipping, the sometimes unexpected noise and vibrations that occur when various parts of the ship (whether the hull, propeller, or shaft line) come in contact with ice can disrupt normal communications, disturb rest and sleep patterns, and cause stress and fatigue (Sillitoe et al, 2010). Ships encountering ice may experience noise level increases of 4-12 dBA for wave-ice interaction, and as much as 30 dBA for cracking ice (Diachok and Winokur, 1974).

Acoustic requirement limits are very similar between the two regimes. Working area limits are 85 dBA onboard ships, and 70-85 dBA for spaceflight, while sleeping area limits are 60 dBA on ships and 60-65 for spaceflight (ISO, 1996; NASA, 2011).

### *Extreme Temperatures*

The propensity for extreme cold temperatures (together with accompanying inclement weather) is perhaps the hallmark of perceived difficulties of working in the cold climate shipping environment. In the polar regions, average winter temperatures of -20 degrees C are to be expected, and extremes as low as -50 degrees C are fairly common (Sillitoe et al, 2010). Indeed, cold temperatures are the source (whether directly or indirectly) of many of the problems associated with cold climate shipping in general. Extreme cold is the single most significant factor necessitating heavy-duty protective outdoor gear for the crew. Extreme cold is the factor that dictates that much of crew time be spent indoors. Extreme cold (together with wintertime darkness) is what makes the Arctic such a remote and isolated, yet alluring and pristine location in the first place.

As cold weather shipping operations experts Andrew Sillitoe, Desmond Upcraft, and their colleagues from Lloyd's Register and Scandpower write in their 2010 paper, *"Supporting Human Performance in Ice and Cold Conditions"*:

> *"Humans have adapted physically and behaviourally to life in widely differing climates, but the range of body temperatures within which we remain healthy is narrow. Environmental temperatures or disease raise or lower our core body temperature through the physics of heat transfer, such as conduction and evaporation. In extremely cold environments the steep temperature gradient between our body core and the outside world increases the risk of heat loss. Extreme or extended body heat loss can lead to hypothermia. This is an abnormally low body temperature, which can be fatal. It affects brain and cardiac function at 35°C and becomes life-threatening at 32°C, below which point loss of consciousness is likely. Freezing cold injuries, known as frostbite, can develop if bodily fluids freeze within the tissue… Unprepared seafarers are also at risk of debilitating non-freezing cold injuries such as frost nip or trench foot. The effect of wind passing the body reduces body temperature through convection. Without proper protection, wind chill can severely affect performance and safety by drastically reducing the exposure time needed for frostbite to start. If bare skin comes into contact with cold metal structures or equipment it may adhere to the surface and be torn off. Freezing or non-freezing injuries can also result. Even the act of breathing can present difficulty and risk, as the low humidity of cold air can cause the respiratory passages to narrow… The body's efforts to reduce temperature loss in cold tissues by vasoconstriction influence the work that those tissues can support. Manual dexterity declines substantially when the skin temperature on the hands falls to 12-16°C… The body's natural counterbalances to cold conditions, such as shivering, use high levels of energy. If this is not replaced then performance will quickly degrade. Because of this, extremely low temperatures can adversely affect psychological processes as well as physical capability. This includes cognitive tasks such as decision-making and judgement, including risk perception. The stresses of a cold environment also place high demands on attention capacity… In relatively mild hypothermia, with a core body temperature of around 34°C, cognitive effects such as amnesia can be seen. However, it is likely that some aspects of performance will be impaired long before this relatively low core temperature is reached… This effect [of cold as opposed to heat on the performance of various cognitive tasks] is particularly pronounced for tasks involving reasoning, learning and memory..."* (Sillitoe et al, 2010).

In a region such as the Arctic where communications and navigation aids and infrastructure is sparse, ship navigation requires more cognitive attention than in more populated regions, so the prospect of cold-degraded cognitive performance carries with it an even higher risk.

From the spaceflight perspective, extreme temperatures (both hot and cold) together with low pressure (near-vacuum) are the primary factors necessitating heavy-duty protective "outdoor" gear (i.e., the pressurized spacesuit, or "extravehicular mobility unit") for the crew.

In either location, whether the Arctic or outer space, the heavy gear that must be worn in the external environment affords significant protection, while simultaneously presenting challenges of its own. The heavy protective gear is big and bulky, limiting crew mobility, flexibility, and accessibility into tight spaces. Dexterity is also greatly reduced, especially in the gloved hands and fingers. Oversized helmets and/or protective hats and goggles limit visual capabilities as well.

### Countering the Challenges

In the spaceflight arena, a major objective of both Russian and American space programs has been to minimize the time and energy devoted to overcoming environmental challenges, so that more time can be freed up to perform useful space science or other productive work. Likewise, to enhance crew productivity in both of these extreme work environments (the Arctic and outer space), it is important to find efficient (time and cost effective) methods of countering all of the challenges identified above. It is typically the role of the human factors or crew systems profession to address these challenges.

The primary purposes of the human factors discipline are to proactively:

1) optimize performance of "human-machine" systems;
2) optimize human health and safety;
3) minimize human error

Human factors programs can be divided into two components: the human-operator part, and the machine-operations part. The human-operator component can be summarized as a "human resource management" matter, to be addressed primarily proactively through crew selection and training, and retroactively through provision for treatment or resolution of health and interpersonal issues. The machine-operations component is multi-faceted, with elements that vary from one work environment to another. The central elements that are shared across industries operating in extreme/remote environments are sometimes referred to by different labels, but generally include the following three broad categories:

1) ***crew health and safety:*** includes protective clothing/gear/equipment, food/diet, physical and mental fitness programs;
2) ***habitability:*** includes design of living, sleeping, working, and recreation spaces;
3) ***human-machine/system interface:*** includes user-friendliness, anthropometry, kinematics, cognition, accessibility, maintainability, etc.

Components and elements from each of these categories will be applied in the discussion and recommendations that follow.

#### *Countering the Challenge of Remoteness/Isolation/Confinement*

There are two basic options available to alleviate the symptoms of stress: 1) remove or diminish the causes of stress; or 2) introduce countermeasures to relieve stress. Given that the environmental stressors of isolation and separation from one's familiar environment are unavoidable in long duration remote missions, a two-stage approach is recommended. First, it is important to select crewmembers who are less susceptible to the stressors specific to the environment, and second, it is just as important to train crewmembers in stress relief techniques to alleviate stress despite the ongoing presence of its causes.

Due to the unpredictable nature of psychological crises, a little effort expended on prevention is far preferable to the great amount more that would otherwise be required for management or treatment. The list of recommendations below represents a variety of measures that can be implemented to prevent psychological problems from occurring.

- Vehicle/habitat design: should be as "homey" as possible, with familiar scenes on video and art; allow for privacy, personal touches and reminders of home.
- Mission/work design: give crewmembers a sense of control of their own work, schedules, decisions, or at least some input into decisions affecting them; allow creative use of free time; moderate workload to avoid extremes of hypo- and hyper-stress.
- Home-base support: provide frequent two-way communication with support network of professionals, friends and family.
- Crew selection and composition: select mature, stable crewmembers that are most psychologically and physiologically suited to long duration remote missions in extreme conditions, with self-awareness and sensitivity to potential problems. Crew mix must consider personality attributes and group dynamics.
- Crew training: train crew in team social dynamics, enabling them to handle problems as they arise; instill realistic expectations; view the mission as a chosen lifestyle, not an endurance race to be survived.
- Awareness training: train in relaxation, meditation, biofeedback and autogenic techniques to help with sleep, reduce anxiety, increase calmness, focus attention, decrease stress, increase awareness.
- Exercise and recreation: provide space for regular physical fitness sessions and recreation to increase energy and reduce stress.
- Allocate daily 8-hour sleep period in all crew schedules.
- Provide full-body showers onboard the ship.
- Implement practical yet effective "creature comforts" to ease psychological and physiological stress.
- Psychotherapy: encourage psychological assessment on a regular basis with professional assistance.
- Designate an on-board counselor: assign a counselor who is respectable and respectful, empathetic, understanding, consistent, and unconditionally caring.

If a psychological crisis should occur, treatment and/or management possibilities include pharmaceuticals, crisis intervention, psychiatric evaluation and therapy, restraint and/or quarantine. In the case of a space mission, evacuation is probably not a feasible option (Wickman, 2006).

#### *Countering the Challenge of Desynchronosis*

Desynchronosis can be minimized by providing black out shades for outside windows, coupled with the use of seemingly natural interior lighting to emulate a normal 24-hour cycle of daylight and darkness. In spaceflight, personal eyeshades coupled with interior lighting may be a more practical approach, since viewing the earth from space is a favorite job perk among astronauts. A daily routine including consistent mealtimes and exercise sessions will also help to restore the body's normal circadian cycle.

#### *Countering the Challenge of Increased Radiation*

Radiation exposure may be mitigated to some extent through the use of shielding materials for protection while inside the ship, and to a lesser extent in protective outdoor or extravehicular suits. Radioprotectant ingestible substances may also be useful. As with any outdoor exposure to snow and ice conditions, sunglasses or goggles should be worn to prevent the possibility of snow blindness (Sillitoe et al, 2010).

Antibiotics may be used to treat or prevent infections when radiation exposure has compromised a crewmember's immune system. In extreme cases of lethal doses of radiation exposure, bone marrow transplants have been shown to improve patients' chances of survival.

### *Countering the Challenge of Ambient Noise*

As mentioned above, the noise and vibrations associated with normal vehicle systems operations can disrupt all forms of normal shipboard communications, disturb rest/sleep patterns, and cause consistent stress and fatigue. All reasonable efforts should be made to isolate the crew sleep and rest quarters from known sources of noise and vibration, such as engines, thrusters, large fans, and external hull structures susceptible to impacts (e.g., with ice). Hearing protection may be used to mitigate noise exposure during non-resting periods, as long as it does not interfere with job performance and situational awareness.

### *Countering the Challenge of Extreme Temperatures*

The challenge of extreme temperatures is probably the most difficult to address in terms of its far-reaching and pervasive impact on work in extreme environments. In both spaceflight and cold climate shipping environments, protective clothing and gear is needed when working outside the vehicle. Whether in the Arctic or outer space, the heavy extravehicular gear affords significant protection, while simultaneously presenting challenges of its own. The heavy protective gear is big and bulky, limiting crew mobility, dexterity, flexibility, vision, and accessibility into tight spaces. Once again, crew selection plays a significant role in choosing individuals possessing strength, persistence, mental toughness, and adaptability to working in the extreme conditions of the specific environment. For example, crewmembers hailing from cold climates may fare better than those hailing from the tropics for work in the Arctic shipping environment.

The protective gear should be as streamlined as possible, imposing minimal constraints and restrictions on the crewmember's capabilities, while still providing full protection of all body parts from the harsh external environment including standard human-rated factors of safety. The fit of protective suits and gloves is especially important in order to enhance the body joints' ranges of motion, hand and finger dexterity, general flexibility and overall performance. In addition, ill-fitting clothing or boots can increase the likelihood of cold-related injuries by restricting circulation to the extremities (Sillitoe et al, 2010).

Depending on individual level of physical fitness and strength, force-imparting capability while wearing heavy protective gear in the harsh external environment of the Arctic or outer space is very likely to be significantly less than it would be in normal shirtsleeve conditions on the earth, due to the reduction in leveraging capabilities correlated with low gravity levels and slippery surfaces (Wickman, 1994). Task demands should be limited to correspond with operator strength, stamina, agility and dexterity.

Due to the dangers and difficulty of working outside, extravehicular task procedures should be planned as efficiently as possible. Crewmembers must be adequately trained to safely accomplish outside tasks in a thorough and timely manner. Crew aids such as electronic checklists should be considered for complex and/or critical tasks. Simulator training is often appropriate for extreme environment work, where on the job training is usually not practical.

Ship designers must provide adequate volume in passageways and at all worksites to accommodate the full anthropometric size range of crew body and hand (including protective suit, headwear/helmet, and gloves), visual and tool access, along with full ranges of motion within the optimum crew work volume (around the head and chest). If the crew is unable to access the site or the interfaces, the task will not get done (HSE, 2004).

Crew diet and personal health awareness training are also very important components in countering the challenges of extreme temperatures. As Sillitoe, et al, report:

> *"A high-energy, nutritionally balanced diet and good hydration are important. Appetite and food intake can decrease in the cold despite energy requirements increasing (US Army, undated). An alcohol policy may be required as the adverse diuretic and circulatory effects of drinking it are exacerbated by the cold, as they are for excessive caffeine (BOHS, 1996). The effects of alcohol can increase the risk of frostbite and hypothermia, and despite the commonly held belief alcohol has no known preventative or management benefits for cold injury (US Army, undated)… Personal health awareness is important to enable personnel to minimise further harm if danger signs become apparent. Training and awareness-raising should address both physical and mental health, to help people meet their responsibilities in protecting their own health and that of the people around them. As an example, hypothermia can develop gradually even to a severe stage without the sufferer being aware of its onset (BOHS, 1996). Minor injuries such as cuts and abrasions must be treated promptly."* (Sillitoe et al, 2010).

## CONCLUSIONS AND RECOMMENDATIONS

If crewmembers are expected to perform at peak levels in extreme environments, serious efforts must be applied toward keeping them healthy, safe and productive. The design and operational guidelines summarized here are worth considering for application in a variety of extreme environments.

Vehicle designers and mission planners must consider crew capabilities and limitations based on physiological and psychological factors and conditioning levels in designing hardware and mission activities. Tasks should be simplified and human interfaces with hardware and software should be user-friendly. Crew health and safety must be the number one priority in planning, operations, and design.

The crew is already operating under tenuous conditions, and should never be intentionally placed in harm's way. Mission planners and designers should work together to protect the crew from all potential electrical, thermal, pyrotechnic, radioactive, chemical, mechanical, and pressure hazards. All structural corners, edges, and protrusions must be rounded and de-burred; all snag and tripping hazards eliminated.

User-friendly design implies designing well within crew capabilities and constraints. Task demands should be limited relative to circumstantial impacts on strength, stamina, agility, dexterity and simultaneous actions. Crewmembers will often be using one hand to stabilize themselves while working in microgravity, or on an icy ship in stormy conditions, leaving at best one hand free to do useful work. Thus, interfaces must be designed for actuation with one hand and minimal tools. Interfaces should be standardized in order to minimize requirements for unique tools and training. Alignment aids and capture features should be implemented for assembly or replacement equipment wherever practical. Crew stability and mobility aids (such as handrails and foot restraints) must be provided as necessary to accomplish tasks.

Realistic task timelines should be developed based on human simulations, with extra time added for contingencies. Unexpected problems or delays can very quickly obliterate a timeline schedule.

Have back-up plans for every operation. For example, in case of problems or equipment failures, determine how each task could be accomplished with one crewmember rather than two, or using manual instead of power tools. Also, all mission-related tools and equipment must be fit-checked with mission hardware ahead of time.

The following account summarizes the primary human factors design considerations for any remote mission in an extreme environment.

- Prioritize first crew then equipment safety
- Ensure accessibility to worksite and interfaces; physically, visually, and with tools
- Implement "user-friendly" design; make it fool-proof
- Solicit experienced crewmember input early in the ship/work interface design process
- Design for full anthropometric crew size ranges and body postures normative to the specific environment
- Design outside tasks to be performed within protective extravehicular suit mobility ranges
- Design tasks to be performed within the crews' optimum work volume (chest area)
- Consider reach envelope limitations
- Consider crew force application capabilities for each working environment (e.g., capabilities may be reduced in zero-gravity or icy/slippery conditions)
- Map out realistic task timelines
- Identify and protect against potential hazards
- Provide integral structural crew aids wherever practical
- Provide crew stability/mobility aids as necessary
- Strategize support equipment and tool requirements and logistics
- Provide replacement equipment alignment/capture aids
- Provide standard, captive fasteners
- Use wing-tabbed connectors for extravehicular interfaces
- Implement adequate lighting provisions
- Use easily identifiable labels and color-coding
- Be aware of and accommodate for indoor/outdoor work constraints
- Always have backup plans/procedures

Another important consideration is the fact the crew may very well arrive back home in a partially compromised physical and/or psychological state. Considering the range of possible environmental conditions of the mission, potential adaptive alterations in some physiological systems may affect the function of other systems. For example, changes in physical conditioning may alter the cardiovascular or muscular responses, leading to loss of muscle strength and coordination. We must strive to understand how alterations in multiple systems may result in performance decrements or increased risk of injury, and to identify and implement preventative or rehabilitation strategies for facilitating post-mission recovery of function and performance.

## REFERENCES

Atkov, O.Y. and Bednenko, V.S., *Hypokinesia and Weightlessness: Clinical and Physiologic Aspects*, International Universities Press, 1992.

Barratt, M., and Pool, S., editors, *Principles of Clinical Medicine for Space Flight*, New York, Springer, 2008.

Diachok, O. I. and Winokur, R.S., Spatial variability of underwater ambient noise at the Arctic ice-water boundary, *Journal of the Acoustic Society of America,* 55(4): 750-753, 1974.

Health and Safety Executive, *Manual Handling*, Colegate, HMSO, ISBN 9-780717-628230, http://www.hse.gov.uk/index.htm, 2004.

ISO 2923, *Acoustics: Measurement of noise on board vessels*, International Organization for Standardization, http://www.iso.org/iso/home.htm, 1996.

Levine, A.S., "Psychological Effects of Long-Duration Space Missions and Stress Amelioration Techniques," *From Antarctica to Outer Space: Life in Isolation and Confinement*, New York, Springer-Verlag, 305-315, 1991.

National Snow and Ice Data Center, "Northern Hemisphere Snow Extent," http://nsidc.org/sotc/snow_extent.html, 2010.

*NASA-STD-3001 Space Flight Human-System Standard*, National Aeronautics and Space Administration, Washington, D.C., http://www.nasa.gov/centers/johnson/slsd/about/divisions/hefd/standards/index.html, 2011.

NRC Space Studies Board Task Group on the Biological Effects of Space Radiation, *Radiation Hazards to Crews of Interplanetary Missions – Biological Issues and Research Strategies,* National Academy Press, Washington, D.C., 1996.

Palinkas, L., "Mental and Cognitive Performance in the Cold," *International Journal of Circumpolar Health*, 60, 430-439, 2001.

Sandal, G.M., Endresen, I.M., Vaernes, R., and Ursin, H., "Personality and coping strategies during submarine missions," *Military Psychology*, 11, 381-404, 1999.

Sillitoe, A., Upcraft, D., Rich, K., LaRoche, M., Røed, B.K., and Huse, J.R., "Supporting Human Performance in Ice and Cold Conditions," Norwegian Maritime Authority website, http://www.sjofartsdir.no/en/, 2010.

Strand, P., Howard, B.J., Aarkrog, A., Balonov, M., Tsaturov, Y., Bewers, J.M., Salog, A., Sickela, M., Bergman, R., and Rissanen, K., "Radioactive contamination in the Arctic: sources, dose assessment and potential risks," *Journal of Environmental Radioactivity*, 60: 5-21, 2002.

*Technical Guide No.12: The Thermal Environment (Second Edition)*, British Occupational Hygiene Society, ISBN 0-948237-29-5, 1996.

US Army Research Institute of Environmental Medicine, *Medical Aspects of Cold Weather Operations: A Handbook for Medical Officers*, Report TN93-4, Natick, Massachusetts (undated).

Waller, W.H., "Moon Bases: Lessons from Antarctica," *Sky & Telescope*, 86, November 2010.

Wickman, L., *The Influence of Reduced Gravity on Human Load-Carrying and Preferred Load Placement,* doctoral dissertation, Stanford University, 1994.

Wickman, L., "Human Performance Considerations for a Mars Mission," *Proceedings of the 2006 IEEE Aerospace Conference*, Big Sky, Montana, USA, 2006.

Wickman, L., Tsai, A., and Walters, R., *"Isolation & Confinement Issues in Long Duration Spaceflight," Proceedings of the 2006 IEEE Aerospace Conference*, Big Sky, Montana, USA, 2008.