Astronautical hygiene

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Astronautical hygiene is the application of science and technology to the recognition and evaluation of hazards, and the prevention or control of risks to health, while working in low-gravity environments.[1]

Space medicine has developed as a science since 1948 when Dr. Hubertus Strughold predicted many of the medical problems of working in low gravity for example, neurovestibular disturbances, red blood cell changes. The discipline of astronautical hygiene includes such topics as the use and maintenance of life support systems, the risks of extravehicular activity, the risks of exposure to chemicals or radiation, the characterisation of hazards, human factor issues and the development of risk management strategies. Astronautical hygiene works side by side with space medicine to ensure that astronauts will be healthy and safe when working in space. This is especially critical with the planned manned expeditions to the Moon and Mars.

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Overview

When astronauts return to the Moon and travel farther to Mars, or even other planets, they will be exposed to a number of hazards e.g. radiation, microbes in the spacecraft, planetary surface toxic dust. An "astronautical hygienist" or an astronaut with knowledge of the discipline would provide invaluable data during the voyage on for example, how to assess the risks to health from exposure to chemicals within the spacecraft and the appropriate measures to mitigate exposure. Once on the surface of the Moon or planet the astronautical hygienist would provide information on the nature of the dust, measure the potential levels of exposure while exploring the surface terrain, assess the likely risks to health and thereby determine how to prevent or control exposure. Applying astronautical hygiene knowledge and expertise from the gathered intelligence during the journey would ensure that the health of the astronauts was protected at all time.

The main roles of the astronautical hygienist are:

1. To initiate and participate in research where a competent assessment of the risks to health are critical e.g. in the development of effective dust mitigation strategies for lunar exploration.

2. To be actively involved in designing hazard mitigation techniques e.g. spacesuits with low dust retention/release and ease of movement.
3. To provide in-flight trouble shooting e.g. for identifying the hazard, assessing the health risks and for determining the mitigation measures.
4. To advise governments such as the UK Space Agency on the most cost effective risk mitigation measures for a manned spaceflight.
5. To act as a central link between the other space science disciplines.
6. To provide information, instruction and training on for example, standard setting, on exposure health effects, on hazard identification and on the use of controls.
7. To provide an holistic approach to protecting an astronaut's health.

As manned spaceflight programmes develop over the years and include missions to the Moon, Mars and asteroids, then the expertise and knowledge of the astronautical hygienist will be crucial.

The Space Shuttle is to be replaced in 2014 by a new spacecraft, the Orion Multi-Purpose Crew Vehicle, to carry astronauts to the International Space Station. Orion will contain potentially hazardous material such as ammonia, hydrazine, freon, nitrogen tetroxide, volatile organic compounds and it will be necessary to prevent or control exposure to these substances during flight. Astronautical hygienists in the United States together with colleagues in the European Union and individual United Kingdom astronautical hygienists and space medicine experts are developing the measures that will mitigate exposure to these substances.

Dr. John R. Cain (a UK government health risk management expert) was the first scientist to define the new discipline of astronautical hygiene. The establishment of the UK Space Agency and the UK Space Life and Biomedical Sciences Association (UK Space LABS) should see the development and application of the principles of astronautical hygiene as an important means to protect the health of astronauts working (and eventually living) in space.

Hygiene in space

Issues arise when dealing with low gravity environments. On the International Space Station, there are no showers, and astronauts instead take short sponge baths, with one cloth used to wash, and another used to rinse. Since surface tension causes water and soap bubbles to adhere to the skin, very little water is needed.[2][3] Special non-rinsing soap is used, as well as special non-rinsing shampoos.[4] Since a flush toilet would not work in low gravity environments, a special toilet was designed, that has suction capability.[5] While the design is nearly the same, the concept uses the flow of air, rather than water. In the case of the space shuttle, waste water is vented overboard into space, and solid waste is compressed, and removed from the storage area once the shuttle returns to earth.[6] The current toilet model was first flown on STS-54 in 1993, and features an unlimited storage capacity, compared to only 14-day capacity of the original shuttle toilets, and the new model has an odor-free environment.[4]

Control of gases in spacecraft

Toxic gases are produced as an off-gassing from the astronauts, non-metallic materials e.g. surface coatings, adhesives, elastomers, solvents, cleaning agents, heat exchanger liquids etc. The gases if inhaled above specific concentrations could affect the ability of the crew to carry out their duties effectively[7]

Most of the toxicological data on gas exposure is based on the 8-hour work period of the terrestrial worker and is therefore unsuitable for spacecraft work. New exposure times (astronautical hygiene data) have had to be established for space missions where exposure can be uninterrupted for up to 2 weeks or longer with no daily or weekend periods.

Exposure limits are based on:

- "Normal" spacecraft operating conditions.
- An "emergency" situation.

In the normal conditions there are found trace contaminant gases such as ammonia from normal off-gassing at ambient temperatures and at elevated temperatures. Other gases arise from the breathing gas supply reservoirs and crew members themselves. In emergencies gases can arise from overheating, spills, a rupture in the coolant loop (ethylene glycol) and from the pyrolysis of non-metallic components. Carbon monoxide is a major concern for space crews; this was evident during the Apollo missions. The emitted trace gases can be controlled using lithium hydroxide filters to trap carbon dioxide and activated carbon filters to trap other gases.

Gases in the cabin can be tested using gas chromatography, mass spectrometry and infra-red spectrophotometry. Samples of air from the spacecraft are examined both before and after flight for gas concentrations. The activated carbon filters can be examined for evidence of trace gases. The concentrations measured can be compared with the appropriate exposure limits. If the exposures are high then the risks to health increase. The on-going sampling of the hazardous substances is essential so that appropriate action can be taken if exposure is high.

A large number of volatile substances have been detected during flight mostly within their threshold limit values and NASA Spacecraft Maximum Allowable Concentration Limits. If spacecraft cabin exposure to specific chemicals is below their TLVs and SMACs then it is expected that the risks to health following inhalation exposure will be reduced.

Spacecraft maximum allowable concentrations

SMACs provide guidance on chemical exposures during normal as well as emergency operations aboard spacecraft. Short-term SMACs refer to concentrations of airborne substances such as a gas and vapor that will not comprise the performance of specific tasks by astronauts during emergency conditions or cause serious toxic effects. Long-term SMACs are intended to avoid adverse health effects and to prevent any noticeable changes in the crews performance under continuous exposure to chemicals for as long as 180 days.[8]

Astronautical hygiene data needed for developing the SMACs include:

- chemical-physical characterization of the toxic chemical
- animal toxicity studies
- human clinical studies
- accidental human exposures
- epidemiological studies
- *in-vitro* toxicity studies

Application of astronautical hygiene principles to control exposure to lunar dust

Hazard

Lunar dust or regolith is the layer of particles on the Moon's surface and is <100 um.[9] The grain shapes tend to be elongated. Inhalation exposure to this dust can cause breathing difficulties because the dust is toxic. It can also cloud astronauts' visors when working on the Moon's surface. Furthermore, it adheres to spacesuits both mechanically (because of barbed shapes) and electrostatically. During Apollo, the dust was found to cause wear in the fabric of the spacesuit.[10]

Evaluation of risks

During lunar exploration it will be necessary to evaluate the risks of exposure to the moon dust and thereby instigate the appropriate exposure controls. Required measurements may include measuring exospheric-dust concentrations, surface electric fields, dust mass, velocity and charge and its plasma characteristics.

Control

The use of high-gradient magnetic separation techniques should be developed to remove dust from the spacesuits following exploration as the fine fraction of the lunar dust is magnetic.[11] Furthermore, vacuums can be used to remove dust from spacesuits.

Mass spectrometry

Mass spectrometry has been used to monitor spacecraft cabin air quality.[12] The results obtained can then be used to assess the risks during spaceflight for example, by comparing the concentrations of VOCs with their SMACs. If the levels are too high then appropriate remedial action will be required to reduce the concentrations and the risks to health.

Deposition of inhaled particles of lunar dust

The extent of the inflammatory response in the lung will depend on where the lunar dust particles are deposited. In 1G deposition in the more central airways will reduce the transport of the fine particles to the lung periphery. On the Moon with fractional gravity, the inhaled fine particles will be deposited in more peripheral regions of the lung. Therefore, because of the reduced sedimentation rate in lunar gravity, fine particles of dust will deposit in the alveolar region of the lung. This will exacerbate the potential for lung damage.[13]

Microbial hazards in space

During spaceflight there will be the transfer of microbes between crew members. Microbial exchange commonly occurs amongst astronauts. Several bacterial associated diseases were experienced by the crew in Skylab 1. The microbial contamination in the Skylab was found to be very high. *Staphylococcus aureus* and *Aspergillus* spp have commonly been isolated from the air and surfaces during several space missions. The microbes do not sediment in microgravity which results in persisting airborne aerosols and high microbial densities in cabin air in particular if the cabin air filtering systems are not well maintained. During one mission an increase in the number and spread of fungi and pathogenic streptococci were found.

Urine collection devices build up the bacterium *Proteus mirabilis*, which is associated with urinary tract infection. For this reason, astronauts may be susceptible to urinary tract infection. An example is the Apollo 13 mission, during which the lunar module pilot experienced an acute urinary tract infection which required two weeks of antibiotic therapy to resolve.[14]

Biofilm that may contain a mixture of bacteria and fungi have the potential to damage electronic equipment by oxidising various components e.g. copper cables. Such organisms flourish because they survive on the organic matter released from the astronaut's skin. Organic acids produced by microbes, in particular fungi, can corrode steel, glass and plastic. Furthermore, because of the increase in exposure to radiation on a spacecraft there are likely to be more microbial mutations.

Because of the potential for microbes to cause infection in the astronauts and to be able to degrade various components that may be vital for the functioning of the spacecraft it is important that the risks are assessed and where appropriate the levels of microbial growth controlled by the use of good astronautical hygiene. For example, by frequently sampling the spacecabin air and surfaces to detect early signs of a rise in microbial contamination, keeping surfaces clean by the use of disinfected clothes, by ensuring that all equipment is well maintained in particular the life support systems and by regular vacuuming of the spacecraft to remove dust etc. It is likely that during the first manned missions to Mars that the risks from microbial contamination will be underestimated unless the principles of good astronautical hygiene practice are applied. Further research in this field is therefore especially important so that the risks of exposure can be evaluated and the necessary measures to mitigate microbial growth are developed.

Microbes and microgravity in space

There are over one hundred strains of bacteria and fungi that have been identified from manned space missions. These microorganisms survive and propagate in space.[15] Much effort is being made to ensure that the risks from exposure to the microbes are significantly reduced. Spacecraft are sterilized as good control practice by flushing with antimicrobial agents such as ethylene oxide and methyl chloride; and astronauts are quarantined for several days prior to a mission. However, these measures only reduce the microbe populations rather than eliminate them. Microgravity may increase the virulence of specific microbes. It is therefore important that the mechanisms responsible for this problem are studied and the appropriate controls are implemented to ensure that astronauts, in particular those that are immunocompromised, are not affected.

Humans in space

The work of Cain ("Spaceflight" Dec 2007) and others[16] have seen the need to understand the hazards and risks of working in a low gravity environment. The general effects on the body of space flight or reduced gravity for example, as may occur on the Moon or during the exploration of Mars include changed physical factors such as decreased weight, fluid pressure, convection and sedimentation. These changes will affect the body fluids, the gravity receptors and the weight bearing structures. The body will adapt to these changes over the time spent in space. There will also be psychosocial changes caused by traveling in the confined space of a spacecraft. Astronautical hygiene (and space medicine) needs to address these issues in particular the likely behavioral changes to the crew otherwise the measures developed to control the potential health hazards and risks will not be sustained. Any decrease in communication, performance and problem solving for example, could have devastating effects.

During space exploration there will be the potential for contact dermatitis to develop in particular if there is exposure to skin sensitisers such as acrylates. Such skin disease could jeopardise a mission unless appropriate measures are taken to identify the source of the exposure, to assess the health risks, and thereby determine the means to mitigate exposure.[17]

Noise

Fans, compressors, motors, transformers, pumps etc. on the International Space Station (ISS) all generate considerable noise. As more equipment is required on the space station, then more noise will be generated.

The Russian space program has never given a high priority to the noise levels experienced by its cosmonauts (e.g. on Mir the noise levels reached 70–72 dB). Such noise levels may cause a temporary reduction in hearing but not a full hearing loss. This could result in hazard warning alarms not being heard against the background noise. To reduce the noise risks NASA engineers are building hardware with inbuilt noise reduction. A depressurized pump producing 100 dB can have the noise levels reduced to 60 dB by fitting four isolation mounts. For future space programs it is essential that the noise levels are reduced. The use of hearing protectors are not encouraged because they block out alarm signals. More research is necessary in this field as well as in other astronautical hygiene areas e.g. measures to reduce the risks of exposure to radiation, methods to create artificial gravity, more sensitive sensors to monitor hazardous substances, improved life support systems and more toxicological data on the Martian and lunar dust hazards.

Hazards of radiation in space

Space radiation consists of high energy particles such as protons, alpha and heavier particles originating from such sources as galactic cosmic rays, energetic solar particles from solar flares and trapped radiation belts. Space station crew exposures will be much higher than those on Earth and unshielded astronauts may experience serious health effects if unprotected. Galactic cosmic radiation is extremely penetrating and it may not be possible to build shields of sufficient depth to prevent or control exposure.

Trapped radiation

The Earth's magnetic field is responsible for the formation of the trapped radiation belts that surround Earth. The ISS orbits at between 200 nautical miles (370 km) and 270 nautical miles (500 km), known as a Low Earth Orbit (LEO). Trapped radiation doses in LEO decrease during solar maximum and increase during solar minimum. Highest exposures occur in the South Atlantic Anomaly region.

Galactic cosmic radiation

This radiation originates from outside the solar system and consists of ionized charged atomic nuclei from hydrogen, helium and uranium. Due to its energy the galactic cosmic radiation is very penetrating. Thin to moderate shielding is effective in reducing the projected equivalent dose but as shield thickness increases, shield effectiveness drops.

Solar Particle Events

These are injections of energetic electrons, protons, alpha particles into interplanetary space during solar flare eruptions. During periods of maximum solar activity, the frequency and intensity of solar flares will increase. The solar proton events generally occur only once or twice a solar cycle.

The intensity and spectral disruption of SPEs have a significant impact on shield effectiveness. The solar flares occur without much warning so they are difficult to predict. SPEs will pose the greatest threat to unprotected crews in polar, geo-stationary or interplanetary orbits. Fortunately, most SPEs are short lived (less than 1 to 2 days) which allows for small volume "storm shelters" to be feasible.

Other

Radiation hazards may also come from man-made sources for example, medical investigations, radio-isotopic power generators or from small experiments as on Earth. Lunar and Martian missions may include either nuclear reactors for power or related nuclear propulsion systems. Astronautical hygienists will need to assess the risks from these other sources of radiation and take appropriate action to mitigate exposure.

Laboratory tests reported in the Journal of Plasma Physics and Controlled Fusion[18] indicate that a magnetic "umbrella" could be developed to deflect harmful space radiation away from the spacecraft. Such an "umbrella" would protect astronauts from the super-fast charged particles that stream away from the Sun. It would provide a protective field around the spacecraft similar to the magnetosphere that envelops the Earth. This form of control against solar radiation will be necessary if man is to explore the planets and reduce the health risks from exposure to the deadly effects of radiation. More research is necessary to develop and test a practical system.

See also

- Effect of spaceflight on the human body
- Bioastronautics
- International Space Station

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