Hazards and Countermeasures on Extended Space Missions

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Abstract

Humanity has always been fascinated with the stars and planets; and with advancing technology most of the myths were replaced with the realities of space science; and curiosity is leading to exploration of our solar system and even considering colonization of our nearby planet. The objective is landing humans on planet Mars.

The technology of getting into deep space beyond the protective layers of the Van Allen belts are available for inanimate objects, but not yet fully developed for humans. The main drawback and limiting factor is galactic radiation effects over long time periods, since space travel has become synonymous with radiation dose and its associated risk, namely latent cancer.

This presentation discusses the various hazards of space travel, practical and psychological, reviews the countermeasures that are currently being researched in reducing the duration of travel by faster propulsion, improved shielding to minimize the radiation dose, and by forestalling the onset of cancer through enhancement of the immune system by nutrition or by drugs, for astronaut protection and survival.

KEYWORDS:* *Radiation Protection, Hazards in Space Missions

1. Introduction

Current space missions are probing into space for longer durations to explore the origins of our solar system and of the universe with the clear intent of sending humans initially on trial missions to asteroids but with the purpose of landing on planet Mars. The few successful orbiters and landers that arrived on Mars have provided a wealth of data, but not quite sufficient, on what the first astronauts would endure on that planet.

2. What to Expect on Mars

Mars is a planet of extremes and though there are similarities with Earth, it is cold and arid with a mean surface temperature of -63ºC, and -140ºC during polar winters, compared to −89.2°C the lowest temperature ever recorded on Earth at the Soviet Vostok Research Station in Antarctica on July 21, 1983. Summer temperatures at its equator can reach +20 ºC. It is debatable whether there is, or was, life on Mars. Interestingly, Mars temperature has increased by 0.5 ºC since 1970 and this is similar to the increase on Earth. The atmosphere is predominantly carbon dioxide, a global warming gas and there is speculation that the warming trend is Universal, or that large Martian dust storms absorbed surface heat and then radiated it back to its atmosphere, causing the observed dust devils, Fig.1 by NASA's Phoenix Lander at about 11:53 a.m. on day 104 Martian time (Sept. 9, 2008). These are whirlwinds that occur when the Sun heats the surface of Mars and the adjacent air rises as a miniature tornado but only about 5 m in diameter.

Geographically, Mars has the highest volcano in the solar system as well as the deepest canyon. But geologically, the Martian surface is similar to the Ubehebe Crater in Death Valley, Nevada, USA, Fig.2. This similarity is seen when compared with the Victoria crater, Fig. 3. Mars has no global magnetic field comparable to Earth's, and, combined with a thin atmosphere, permits a significant amount of ionizing radiation to reach the Martian surface.

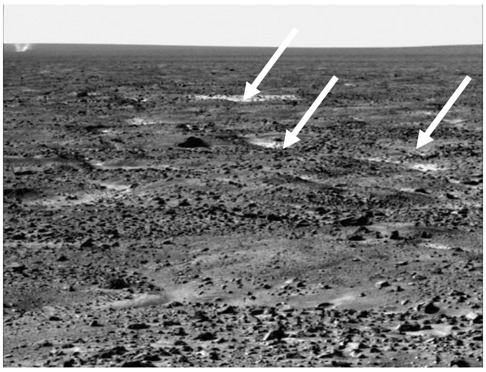

Fig.1 Dust Devils on Mars

Fig.2 The Ubehebe Crater in Death Valley,

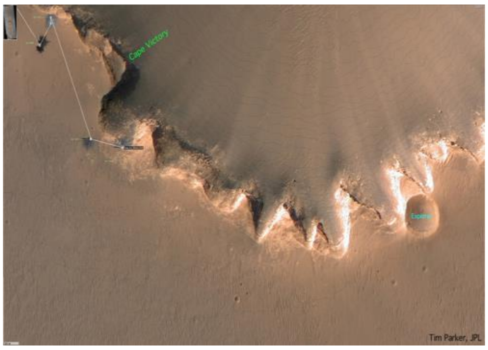

Fig.3 Victoria Crater on Mars Explored by Opportunity Rover

3.0 The Known Hazards

The limiting factors are coping with the radiation levels and the provision of radiation protection to astronauts before long term visits can be considered leading to the eventual colonization of the planet.

3.1 Levels of Radiation

In 2001 Mars Odyssey was launched, a spacecraft that carried an instrument dubbed MARIE [Mars Radiation Environment

Table 1 GCR Fluence In Outer Space, Summarized Data From MARIE, During 2001-2002. [Refs.1 and 2]

	Ion Energy	On Route to Mars	In Orbit Around Mars
	MeV	$(cm^2\text{-}sr\text{-}s\text{-}MeV/n)^{-1}$	
Proton Flux	45–75	2×10^{-5}	$\sim 2\text{-}4 \times 10^{-5}$
	75- 105	7×10^{-5}	$\sim 7\text{-}9 \times 10^{-5}$
Helium Flux	50-150	6×10^{-6}	$5\text{-}7 \times 10^{-6}$
	150-250	1.5×10^{-5}	$1\text{-}1.7 \times 10^{-5}$
HZE >2 Flux	125-225	$1\text{-}2 \times 10^{-6}$	5×10^{-7} - 2×10^{-6}
	225-325	$\sim 4 \times 10^{-6}$	$2\text{-}5 \times 10^{-6}$
Neutron Flux Ref.3	10^{-2} - 10^{-1} MeV	6×10^7 n/cm^2 .MeV total neutron fluence	
(By calculation)	10^{-1} MeV	$\sim 4 \times 10^7$ n/cm^2.MeV backscattered neutrons	

Experiment], to measure the galactic cosmic radiation fluence, and the radiation levels on-route to Mars as well as in near orbit of Mars Table 1, [Ref.1 & 2]. The dose levels are about the same. MARIE found that radiation average dose were ~1.28 mSv/day in orbit above Mars. This is 2.7 times higher than that at the International Space Station dose is 0.48 mSv/day [Ref.3]. On Mars surface the detected radiation levels are ~ 0.22 mSv/day due to the albedo neutrons that abound on the surface due to galactic particle bombardment on the surface.

Table 2 Hypothetical 2.7 Year Mission to Mars e.g. [18 Sept.2007 – 20 May 2010]

Phase Mission	Time Spent (days)	Effective Dose (seiverts)
Earth to Mars	280	0.88 GCR + 0.17 SEP
On Mars	439	0.41 (GCR)
Mars to Earth	256	0.8 GCR
Totals	975	2.26
GCR= galactic cosmic radiation	SEP= solar energetic particles	

In a simulated mission to Mars, [Ref.4] a round trip can take as long as 975 days as in Table 2 with the caveats of time on Mars for orbital alignment with Earth. Allowing for one solar proton event contributing 0.17 Sv to the dose, this would produce a total dose of 2.26 Sv that exhausts the lifetime limit for exposure set by the NCRP at 1 to 4 Sv career limits for LEO (Low Earth Orbit) activities. It also adds 2.4% to the risk of fatal cancer for male astronauts aged 55-64, and 16.7% for women astronauts within ages 25-34. Such a dose exposure defies the safety limits set by NASA.

3.2 Radiation Effects

The critical factors in prolonged space missions are the detrimental effects of galactic cosmic radiation (GCR) comprising high energy heavy nuclei (HZE), and from solar particle events (SPE) both of which limit the mission time. SPE's are directional which makes it difficult to warn distant astronauts early enough. At the NASA Space Radiation Lab (Brookhaven Labs) a Booster accelerator simulates the effects of high energy heavy nuclei particles on tissue and on shielding techniques [NASA-BNL-AGS Program], by using beams of heavy ions, such as iron, silicon and gold with energies from 0.6 to 10 GeV/u. The objective is to increase our understanding of the biological effects of low fluence HZE nuclei on tissue, since there is no human data. Estimates are that unshielded humans in interplanetary space are likely to receive annually some 400 to 900 mSv compared to 2.4 mSv on Earth, (3 mSv if human made sources are included). About 35% of the astronaut's DNA would also be badly affected.

Earlier notions considered that DNA damage was the primary target for radiation response. But recent studies and subsequent advances in the cellular molecular biology indicate several response mechanisms to ionizing radiation that have consequential biological effects in multiple neighbouring cells (the bystander effect) through free radical triggered mechanisms. These cause cellular radio-sensitivity modifications, and genomic instability, [Ref 5]. Genomic instability means the persistent production of genomic changes in the progeny of the surviving cells after irradiation, resulting in cell mutations, chromosome aberrations, neoplastic transformations, and delayed reproductive cell death.

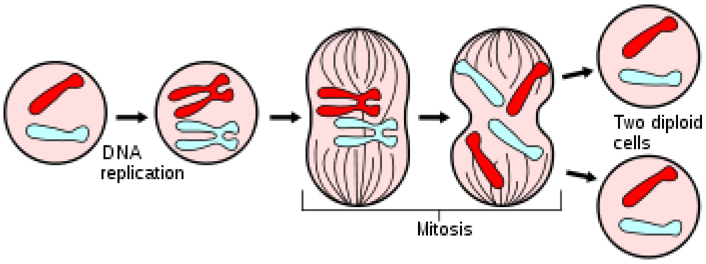

Fig.4 DNA Cell Cycle Replication Fidelity

However, The DNA remains an important target for radiation induced damage. Whether the cell survives or dies remains the study of these end points Radiation damage is initiated through signal transduction cascades in the plasma membrane, [Ref 6], by reactive oxygen and nitrogen species immediately after radiation exposure. Later consequences show up as changes in gene expression, resulting in cell survival or death, within hours or days of exposure. DNA damage is most severe with the double strand breaks that occur by ionizing radiation including the cluster breaks that are prevalent with galactic particle radiation. A cellular protein TP53 (tumor suppressor protein 53) is crucially affected since it regulates the cell cycle and functions in cancer prevention by maintaining replication fidelity.

Altered cell cycle and the activation of checkpoint pathways via other proteins (such as ATM Ataxia Telangiectasia Mutated) inhibit the progression of DNA repair through its different phases (viz. G1, G2 and S-phases) which all converge to the probability of cell survival or death. These effects synergize towards radiation carcinogenesis which appears much later.

The risk to induce stochastic biological effects is based on the Linear No Threshold (LNT) hypothesis which presumes that radiation exposure risk increases linearly from around 0.2 Gy. The contributions from non-DNA radiation targets and the contributions of extra-cellular components of irradiated neighbouring cells would ultimately decide the fate of the radiation exposed cells at the low dose range. By considering these factors, a more realistic dose-response "curve" can be rendered.

3.3 Microgravity Effects

3.3.1 Physiological

Human physiological adaptation to the conditions of space is a challenge faced in the development of human spaceflight. During the NASA-Mir program experiments were carried out to investigate the underlying adaptive alterations that contribute to the observed post-flight loco-motor and postural equilibrium disturbances. Previous assessments focused on the vestibulo-ocular and otolith-spinal reflexes during adaptation to weightlessness and re-adaptation to 1-g. These included eye and head control mechanisms required to maintain gaze stability during terrestrial locomotion and whether these and head-trunk coordination were modified during prolonged space flights.

The results showed that after landing, all astronauts had altered head-trunk coordination strategies, and modified lower limb kinematics with reduced Dynamic Visual Acuity during locomotion that did not revert to normality within the 9-day period after landing. The obtained data has become part of the Space Medicine and Countermeasure Program at NASA.

3.3.2 Serious and Debilitating Effects

- *Fluid Redistribution and Loss:* in the absence of gravity body fluids tend to migrate to the abdomen, the cephalic area and the central veins dilate. The body interprets this as an increase in the total fluid volume and counteracts by increasing the excretory mechanism causing calcium loss and bone demineralization. Blood volume may decrease by as much as 10% which elicits cardiovascular deconditioning. This also causes electrolyte imbalances in sodium and potassium when the autonomic regulatory system is disturbed.
- *Cardiovascular Effects:* The fluid redistribution thus causes an increase in the left ventricular cardiac volume and the body excretes the fluids to balance. This causes orthostatic hypotension where blood pools in the lower extremities which, in turn, compromises the venous return, a decrease in cardiac output and a subsequent drop in arterial pressure upon return. To countermeasure, an equivalent (to Earth's gravity) physiologic stress is induced by applying suction to the legs and abdominal region, and by ingesting isotonic solutions (similar to salt concentration of body fluids) prior to landing.
- *Loss of Red Blood Cells:* Microgravity may alter the spleenic functions causing the premature destruction of red blood cells. This was noticed in Soviet and American astronauts where blood samples taken before and after flights showed a loss of 0.5 liter of red blood cells. An on-board centrifugal blood analyzer Fig.5, is used to perform some 80-100 blood tests from a single drop of whole blood.
- *Muscular Atrophy:* The anti gravity muscles, those that support body weight are composed of slow twitch fibres which rapidly degenerate into fast twitch fibre muscles that do functions other than weight. The countermeasure is exercise; not of intensive short duration, but of long duration of over 2h per 24h where the muscles expend less than 30% of maximum power.

Fig.5. Portable Blood Analyzer

- *Bone Loss/Damage:* when bones are least stressed in microgravity, they resorb at a rate of 1.5% per month especially in the lower vertebrae, hip and femur. Initially, the loss is about 3.2% in the first 10 days of microgravity via urine and feces. This rapid loss may induce kidney stones and bone fractures. Losses in trabecular (spongy) bone may be irreversible but losses in cortical bone (more dense) can be regenerated.
- *Hematologic and Immunologic System:* is affected by the transformation of some red blood cells from normal erythrocytes (cells shaped like a doughnut without a hole) into spheroid shapes causing anemia within 4 days of spaceflight. Red blood cells decrease by about 15% after a 3 month spaceflight. The activity lymphocytes that counteract any bodily invasion of microorganisms, though slightly reduced, cause no practical problems. These effects are reversible upon re-entering gravity.
- *Immune System:* damage to the T-Cells was observed aboard Spacelab flights (1981 – 2000). Loss of T-Cell function reduces the body's resistance to cancer. This is further exacerbated by the higher radiation levels in space.

- *Spatial Disorientation:* without a gravitational up-down reference rendering verticality, the brain adapts to visual references only becoming less reliant on positioning and sensing motion.
- *Effects on Medical Procedures:* bacterial cell membranes were noted to become thicker reducing the effectiveness of antibiotics should surgery be required. Some organs may drift and blood would globulate such that a mechanical means may be necessary should transfusions be required.

3.3.3 Inconveniencing Effects

The worst of these are adapting to space. The symptoms are nausea and vomiting, anorexia, headaches, drowsiness and asthenia. Fortunately, these subside within 1-3 days. If not, promethazine hydrochloride is prescribed. Sweating will form as globules and remain where they are secreted. There is a gain in height of up to 7 cm (reversible when back on Earth), with changes in posture. Other effects are flatulence and a degraded sense of smell. Disturbance of the circadian rhythm induces poor sleep patterns.

3.3.4 Microgravity Effects on Bacteria

Experiments aboard the ISS (International Space Station) indicated that bacteria grow better in space. Those that produce antibiotics were up to three times more prolific than on earth. This was attributed to microgravity where no nutrient fluid convection nor sedimentation occurs, and the bacteria get the full nutrient value. But this also applies to the harmful bacteria that become more pernicious. Space flight showed that bacterial gene expression and virulence is altered [Ref. 7]. It seems that bacteria express a different set of genes, and to ensure their survival activate a genetic regulator switch Hfq, a binding protein that acts as a regulator switch, when in microgravity [Ref.8]. This increase in pathogenecity is attributed to biofilm formation since the immune system cannot clear the bacteria effectively and neither do antibiotics.

To-date, microbial physiology and behaviour under spaceflight conditions is still fragmentary and these effects have only been recently discovered. The effects of hypervelocity, cosmic radiation, vibration and microgravity on microbial behaviour is yet to be resolved [Ref.9].

3.40 Psychological Effects

Being in a confined space for prolonged periods with virtually no privacy, and with a probable multicultural heterogeneous crew, compounded with the above-mentioned inconveniences can be very stressful and may jeopardize the mission and the safety of the crew [Ref.10]. These are likely to lead to asthenia, decreased crew cohesiveness, depression and anxiety analogous to those on Arctic-Antarctic research stations, or with submariners.

4.0 Possible Countermeasures

To counteract the mentioned hazards and for the radiation safety of future space travelers, the protection areas to focus on are:

4.1 Revised Paradigm for Dose Limits

With new knowledge on radiation effects and new experimental data it became prudent to derive a more accurate methodology to reduce the uncertainties in estimating the health risk and to modify the previous paradigm/model. NASA has pioneered and revised the previous model with a different approach that departs from NCRP 132 as in Table 3 (on next page), [Ref.11].

Using the revised paradigm and the latest data from the Space Radiation Lab, a new estimate of astronaut safe days in space can be derived. These are shown in Table 4.

Table 4. Revised NASA Estimates of maximum safe days in deep space, 95% Confidence level, and below the NASA imposed 3% of Risk of Exposure Induced Death (REID), at solar minimums, with 20 g/cm^2 Aluminum shielding. (US Data)

Age	NASA 2005 Based on NCRP		NASA 2010 Average US Population				NASA 2010 Never Smokers			
	Male	Female	Male		Female		Male		Female	
	Safe days in space		Safe days in space				Safe days in space			
35	158	129	140	(186)	88	(120)	180	(239)	130	(172)
45	207	173	150	(200)	97	(129)	198	(263)	150	(196)
55	302	259	169	(218)	113	(149)	229	(297)	177	(231)

Data in (parenthesis) uses an alternate uncertainty assessment that presumes a high level of constraint on the radiation quality of cancer risk for solid cancer or for leukemia as determined by existing radiobiological data. Never Smokers defined as those who have never smoked, or have smoked less than 100 cigarettes in their lifetime. [Source: Ref .11]

Table 3. NASA Revised Paradigm for Dose Limits

NASA revised model uses	Previous model uses
• Using the incidence rates from exposed cohorts (BEIR Vll approach).	• Uses the mortality rate transport (NCRP 132)
• Ratio of mortality to incidence are then used to convert REIC to REID estimates, then arithmetic weightings multiplicative risk transfer models are used to transfer to US population. Adjusted for never smokers (i.e. < 100 cigarettes in early lifetime)	• The transfer methodology as per NCRP 132
• Analysis of smoking attributable cancer for the never smokers shows a significant cancer risk reduction of 20% for males and 30% for females.	• The breakdown for smokers and never smoked is not featured.
• Cancer - mortality REID based career limits • Gender specific career limits calculated for individual astronaut mission.	• Based on overall health detriment includes hereditary risks and non-lethal cancers.
• Revised values of low LET risk coefficients for tissue specific cancer incidence.	• LET (Linear Energy Transfer) alone to describe the Relative Biological Risk (RBE).
• Biological effects depend on particle charge number and its kinetic energy and not on LET alone.	
• Lifetime cancer risk projections to model the uncertainties.	• Risk assessments are population based.
• Risk projection modeling to define dose limits and mission risks, that considers age, gender, shielding used and any other countermeasures.	• Based on age where age groupings to set the dose limits with higher dose at a higher age.
• Emphasis on particle track to describe energy deposition at the molecular/cellular tissue level depending on the element with a high Z and its kinetic energy E.	
• Cancer risk assessments for each tissue/organ for greater accuracy by a factor of 2 from ICRP.	• Single weighting factor for all organs.
• Gender specific tissue weighting factors to define Effective Dose, and tissue specific incident calculations offer improved representation of cancer risks from SPE exposures.	• ICRP averages tissue weightings over gender, age, and organ dose equivalents including for pre-adults since the intended use is for public and occupational exposures.
• More restrictions for astronauts aged greater than 40 y	
• Monte Carlo simulations where the uncertainties are taken from multiple contributors.	

The never smoked have different weighting factors due to lower contributions from smoking. But the never smoked data did not consider the influence of second hand smoke nor of former smokers. Similarly, the effective dose can be determined for a 1-y mission as shown in Table 5. The aim is to achieve < 50% error on risk projections for a Mars mission.

Table 5. Effective Dose Limits for a 1-y mission With a 3% Risk of Exposure Induced Death (REID) Assuming Organ Dose Equivalents. Units are in Sv

Age	NASA 2006		BEIR Vll		NASA 2010		NASA 2010 Never Smokers	
	Male	Female	Male	Female	Male	Female	Male	Female
30	0.6	0.5	0.97	0.55	0.73	0.49	0.93	0.68
40	0.8	0.6	0.80	0.59	0.79	0.52	1.04	0.76
50	1.15	0.9	0.83	0.64	0.87	0.57	1.17	0.84
60	2.0	1.6	0.94	0.73	1.0	0.66	1.38	0.97

4.2 Enhancing the Immune System

Another line of research is the development of drugs that mimic and/or enhance the body's natural capacity to repair damage caused by radiation. Such an idea is enticing, but is proving somewhat elusive since the immune system is a system not a single entity. Which cells should be boosted and to what number? Immune cells, lymphocytes, are continuously being generated in quantities more than the body can use. The extra cells die through apoptosis even before they are called upon. But it is still not known how many cells are needed for optimum functionality of the immune system, [Ref.12].

NASA’s Space Radiation Health Project in Houston has involved scientists, universities and medical centers on how space radiation damages cells and tissues such as the eyes, brain and internal organs. Effective medical treatments can then be initiated to limit the radiation exposure damage. However, drugs that are being considered are mainly antioxidants:

Retinoids: which are chemically related to vitamins, (vitamin A) with antioxidant properties. The molecules retard cell division giving the body time to fix damage before harmful mutations can be duplicated. They are also used in medicine to regulate the epithelial (tissue) cells, cell proliferation, growth of bone tissue, and the immune system functions by activation of tumor suppressor genes. The downside to retinoids is its toxic effects after prolonged high dosage.

Bowman-Birk Inhibitor Concentrate (BBIC): is a chemoprevention drug that may keep cancer from forming, but is however toxic. Research work at the National Cancer Institute, (NCI), [Ref.13] is in the trial phase, June 2007 to December 2009, to ascertain the best dose of BBIC for minimum side effects. The outcomes, to quote:

Primary Outcome(s)

- Safety, including description of dose-limiting toxicity (i.e., any grade 3 event) and expansion of doses observed to be safe in humans, as measured by NCI Common Toxicity Criteria.
- Recommended dose of Bowman-Birk Inhibitor Concentrate (BBIC) for a phase I multiple-dose BBIC study

Secondary Outcome(s)

- Pharmacokinetics of BBIC as measured by a sandwich enzyme-linked immunosorbent assay.

Selenium incorporates into proteins to make selenoproteins, which are important antioxidant enzymes. They help prevent cellular damage from free radicals, a natural byproduct of oxygen metabolism that contributes to the development of chronic diseases such as cancer and heart disease. Selenoproteins also have a role in the immune system. It is toxic in large amounts.

Selenomethionine is an amino acid containing selenium. It is also an antioxidant since it has the ability to deplete reactive species. Being an organic form of selenium it is easily absorbed by the body than it inorganic format selenite by 19%.

4.3 Better Shielding Materials

For optimum shielding in space applications, the nuclear and atomic interactions in materials are of paramount consideration, as well as the average distance a cosmic particle penetrates before losing all its kinetic energy and comes to a stop, i.e. its MeV. Materials in current usage are aluminum, (Al) whose density ρ is 2.7. High density polyethylene has a ρ of 0.96, whereas human tissue the ρ is taken as 1. Considering the above, the required shielding thickness becomes a few g/cm^2 of Al for particle energies of 50 MeV/u (per nucleon for particles in the vicinity of the International Space Station ISS). The shielding becomes more than 100 g/cm^2 of Al for particles of 1000 MeV/u (particles from Solar Particle Events SPE in outer space whose energies can reach humanly dangerous levels), Table 1. Increasing the shielding is problematical as the overall payload increases and so does the overall cost by about $10000/kg. Furthermore, high energy galactic radiation/particles causes secondary radiation, primarily neutron, Fig.6

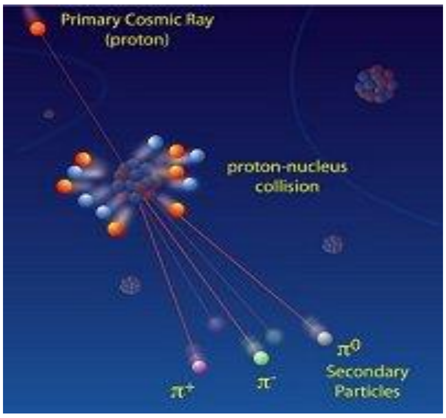

Fig.6 Cosmic ray fragmenting Nucleus, releasing secondary radiation

However, newer methodologies or strategies are being pursued in shielding at the Space Radiation Laboratory at Brookhaven National Laboratory where materials rich in hydrogen e.g. polyethylene offer enhanced radiation protection Fig.7. Hydrogen rich plastics, or even biological samples, are placed in the path of a beam of protons or heavy ions generated by accelerators, of similar energy levels found in space. Measurements are taken as to how well it blocks or absorbs the particles. Plastic composites produce far less secondary radiation.

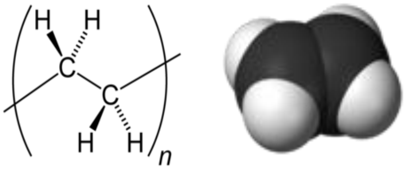

Fig.7 A repeating molecule of polyethylene. The bonding angles are at 110° since the Carbon atom is tetrahedral

A newly invented polyethylene composite material RXF1 is stronger than aluminum (3 times the tensile strength) and lighter than aluminum (2.6 times lighter), is 50% better at shielding solar flares and 15% better at shielding cosmic rays. It can be used in the construction of spacecraft since it fragments (absorbs and disperses) radiation thus producing less secondary radiation than the heavier materials in current use, Fig.8..The material invented is primarily a flexible fabric and can be draped, or molded. It is cut and layered in a mould, vacuum pumped, compressed and autoclaved and thus formed into a spacecraft component that can even deflect micrometeorites. This has been used aboard the ISS. If it is found structurally inadequate for a space craft, it can still be used to shield the crew quarters. The drawback is that polyethylene is very flammable and may melt in direct sunlight for long periods. Basic research is on-going to alleviate these issues.

Computer simulations comparing the cancer risk of going to Mars using an aluminum ship vs. a polyethylene ship were done by. Dr. Cucinotta and his NASA colleagues and found no significant difference. Hence it now depends on the on-going research on a biological model to estimate the effects of radiation on the human tissue and enhance the body's resistance to radiation damage. Due to the above-mentioned uncertainties, dose limits for astronauts on a Mars mission have not yet been set. When set, and they turn out to be similar to the ISS limits, then the RXF1 shielding may hypothetically provide adequate shielding for a mission to Mars.


Fig.8 Composite Shielding Material RXF1

Other speculative shielding alternatives are under consideration viz.

- Pure liquid hydrogen that is carried on board for fuel can block galactic radiation by a factor of 2.5 times better than aluminum, and it hardly produces secondary radiation. Hydrogen fuel tanks can surround the living quarters, but this shielding reduces as the hydrogen is consumed along the journey.
- The water on board also can provide shielding, but that too gets consumed; unless waste recycling is adopted.
- Shelter behind an asteroid. But that requires taking the asteroid along and would depend on its size and whether it can be made to tag along.
- Magnetic deflection of charged radiation particles by electrostatic or by magnetic repulsion can be a hypothetical alternative to conventional mass shielding. Superconductors or plasma currents would produce the magnetic shielding with required fields of up to 10-20 Tesla. This is higher than the Tesla in MRI (Magnetic Resonance Imaging) machines in hospitals that are at about 5 Tesla. MRI machines have produced migraines and severe headaches in patients. Long term exposure to such machines have not yet been studied.

4.4 Nutrition

Nutrition plays a critical role in space travel and must be adequately provided for on long term and must cater to the astronauts' physiological changes that occur during the mission. [Ref.14].

Bone loss is significant in missions of longer than 30 days. Calcium is administered to astronauts but has tended to be slightly below the required daily dose of 1000-1200 mgm. However the rate of absorption into the blood stream from the intestines decreases during spaceflight and there is bone loss even when the administered quantities are increased. Actual losses from long term mission data are in Table 6.

Table 6. Bone Mineral Density % Loss per Month	
Lumbar Spine	1.1
Femur Neck	1.2
Trochanter	1.6
Pelvis	1.4
Legs	0.3
Whole Body	0.4
Calcium Changes mg/day	
Spaceflight	-250
Postflight	100
Source: Helen W. Lane PhD, NASA, Johnston Space Centre, Houston, TX	

Vitamin D is also provided in the astronauts' diet. On Earth it is produced by the skin when exposed to sunlight ultraviolet rays. In space there is so much ultraviolet that spacecraft are shielded against UV. Sodium is also a concern requiring dietary control and tends to exceed the 3500 mgm normal daily intake. This is attributed to feeding the astronauts with off the shelf items purchased locally. Back on Earth it is not clear Whether bone loss is fully replenished.

Muscle atrophy and loss of adipose (fat) tissue contribute to loss of body mass from 1-5%, but can reach up to 15% due to metabolic stress associated with space flight as muscles weaken during prolonged unloading. This atrophy is similar to severely traumatized people on earth or burn patients. Aerobic (treadmill, stationary bicycle) are only partially effective; and resistance exercises are proposed where the weight of another person to exercise against is proposed. This is being conducted aboard the International Space Station (ISS) for effectiveness.

However, administering BBIC was found to diminish antigravity muscle atrophy and oxidative stress in the hind limbs of mice [Ref.15] and established that BBIC directly buffers the reactive oxygen and inhibits serine protease activity. Dietary supplements of BBIC promotes the redox homeostasis (reduction of oxidation buffer, i.e. an antioxidant) in muscle fibers and blunts muscle atrophy, free radicals, antioxidants and hence microgravity.

Blood plasma decreases without changes in blood composition by about 10-15% from pre-flight levels as the body adapts to space flight. Red blood cells that are not needed in a smaller blood volume are destroyed until a new steady state condition is reached and the surplus iron is processed and stored. Too much iron can be harmful and is of concern in long missions. More so, iron intakes have been 50-60% above the 10 mgm per day requirement in space flights, due to pre-packaged diets and iron fortification of food items.

Nutrition aboard the ISS is a four meals per day menu comprising freeze-dried and/or canned foods, with very few fresh foods. The aim is to develop products from plants grown in space viz. high protein bread, soy foods e.g. soy milk and tofu [Ref.16]. Future plans for the ISS is to include a galley module with refrigerators, freezers, and a microwave oven.

Constipation has also affected some astronauts due to interference with normal peristalsis, the contraction of the intestinal wall that directs the food down the digestive tract.

4.5 Psychological Countermeasures

The Russian Institute of Medical and Biological Problems isolated 7 potential men cosmonauts from Russia, Japan Austria and a female Canadian, in 1999 for 110 days to study group dynamics during space voyages. The accommodation comprised 3 rooms connected by narrow tunnels as in a space craft, and catering was bad food and no hot water. Tensions developed to the point of injurious fist fights and advances on the female. Yet a more recent experiment in Moscow that ended November 2011, isolated 7 men (international) for some 17 months with no ill effects, physical nor psychological.

Further studies are in the Canadian High Arctic, Fig.9, where a “Habitat”, a cylinder 7.7m tall, 8.3m in diameter is used to simulate possible accommodation on Mars. It is more comfortable than the Russian experiment and features more storage space, a toilet, a shower and a kitchen equipped with a stove, refrigerator, a microwave, an oven and a sink. Psychological compatibility is imperative as conflicts arose after about 30 days in space even to the extent of the crew going on strike with ground control! Democratic leadership proved better, and 2-way audio-video communication with family members; and even private counseling.

Fig.9 Heighton Crater On Devon Island Northern Canada, Latitude 75° 25’ 52.75” N
Credit: The Mars Society

4.6 Possible Protection From Microgravity

The NAUTILUS-X [**N**on **A**tmospheric **U**niversal **T**ransport **I**ntended for **L**engthy **U**nited **S**tates –**X**ploration], Figs. 10 and 11 is a conceptual spaceship.. It is a reusable Multi-Mission Transport for deep space exploration designed for a crew of 6 for journeys of up to 2 years. It is self powered and self sustaining. To impart artificial gravity for prolonged journeys it incorporates a centrifuge to impart artificial gravity for prolonged journeys to avoid microgravity effects. It will include a docking facility with the ISS. NAUTILUS may take up to 5 years to build at a cost of around $20 B. It may even be used as a nearby space station, or in deep space.

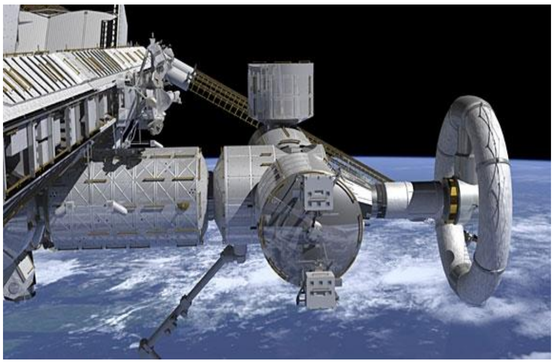

Fig.10 The NAUTILUS as a Space Station

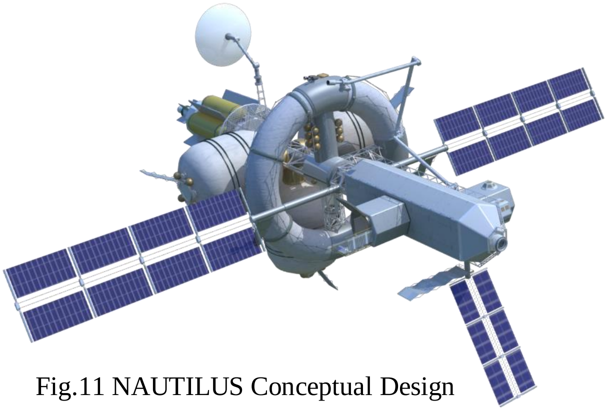

Fig.11 NAUTILUS Conceptual Design

4.7 Propulsion

Travel time can be reduced by innovative rocket engines. Ion, or plasma engines are considered as thrusters once the space ship is in Earth orbit. Ion propulsion is a technology where electrons are emitted from a cathode to strike atoms of the propellant gas (Xenon or Argon) in a chamber knocking away an electron from e.g. Xenon’s 54 orbiting electrons. Having lost an electron, the gas atoms become charged particles, or ions. Oppositely charged grids accelerate these ions to a velocity of about 60000 mph (96000 km/h) to provide the engine thrust (as in aircraft jet engines, Newton's third law).

Table 7 Test Data Comparisons of Some Ion Thrusters

Engine	Propellant	Required Power (kW)	Specific Impulse (I_{sp}) (s)	Thrust (mN)
NEXT	Xenon	7.7	4,300	236 max.
HiPEP	Xenon	25-50	6,000-9,000	460-670
Hall effect	Bismuth	140	8,000	2,500
Hall effect	Xenon	75	2,900	2,900
VASIMR	Argon	200	3,000-30,000	~5000
Dawn Spacecraft	Xenon	Solar Panels	3100	90

Specific Impulse (I_{sp}) is a way to describe the efficiency of a rocket. It represents the impulse (change in momentum) per unit amount of propellant fuel used. The higher the specific impulse, the less propellant needed to gain a given amount of momentum. Its units come out as time, i.e. in seconds.

However, this requires high electrical power from its solar panels, and becomes a limiting factor. Each impulse is hardly the weight of a sheet of paper Table 7, but with continuous impulses over time, tremendously high spacecraft velocity is achievable. Even greater thrust is obtained if the propellant gas is preheated and ionized by using radio waves, then electromagnets to accelerate it and eject it out. This principle is used in the VASIMIR, Variable Specific Impulse Magneto-plasma Rocket engine under development by the Ad Astra Rocket Co. Texas, USA, Fig. 13. The technology inherently requires high power of >100kW where the plasma stream of electrons and ions in the engine become highly magnetized enabling strong radial confinement to produce higher power densities of greater than 1 MW/m^2 . Ad Astra's current design [Ref. 17] of their VX-200 engine has an Isp = 4900 ±300s. and a power of 5.8 ± 0.4 N without indication of saturation. Development is on-going.

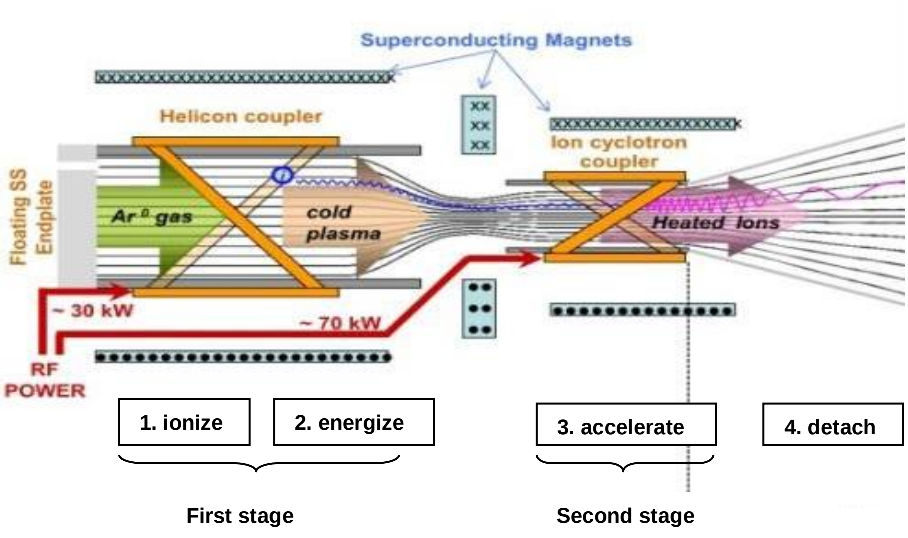

Fig.13 Schematic of Ad Astra's VASIMIR VX-200

Extrapolating to a 10 to 20 MW engine, VASIMR claims to propel human missions to Mars in 39 days, compared to 6-8 months by conventional rocketry. It would accelerate out of Earth's orbit, to a speed of 10 km/s then decelerate into the Martian orbit, Fig.14. Then chemical rocketry would be used for landing.

Currently being tested, is the Orion spacecraft, to replace the shuttles that were just retired. It is to carry astronauts to the ISS by 2015, and then to asteroids by around 2018, and a possible journey to the Moon by 2020. It can stay aloft for up to 6 months. In September 2011, NASA unveiled its giant Space Launch System (SLS), comprising of a rocket with a thrust of some 10-20 greater than the Saturn V. To develop, the estimated costs are at $18 billion and first flight is scheduled for 2017. It will be nearly 103 m. tall with a lift capability of 130 tons.

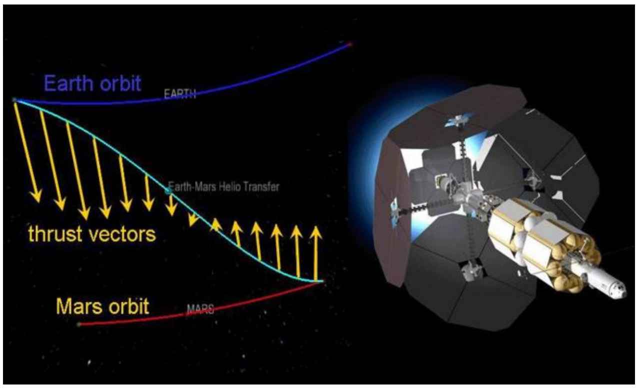

Fig.14 Proposed method by Ad Astra of using VASIMR engine to reach Mars in 39 days

5.0 What is Next?

Unmanned exploration will continue on distant planets, and countermeasures against the adverse biological and psychological effects on humans will be researched until it is safe enough to send humans.

Due to arrive shortly on planet Mars, estimated on 6 August 2012, is the Curiosity Rover Fig.15, that was launched 25 November 2011. Curiosity is to collect Martian soil, analyze them for organic compounds and check on the environmental conditions that may/could support microbial life. Curiosity carries a neutron based hydrogen detector for locating water (Russian Federal Space Agency), a spectrometer (Canadian Space Agency), and a meteorological package (Spanish Ministry of Education and Science).

Fig.15 Space Mars Science Lab. The Curiosity Rover

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7.0 Acknowledgments:

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