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Survey of Frontier Technologies and Approaches to Enable Humans-Mars Both Safe and Affordable

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Abstract: Frontier technologies and systems that could reduce costs and improve human health and safety for human missions to Mars. Overall cost reductions increase funding opportunities for addressing serious radiation and reduce gravity health impacts for human-mars class missions. Major cost reduction/health improvement opportunities include fast transit via either starship due to low-cost chemical fuels in space, or high thrust electric propulsion, Isp of 6,000, enabled by lightweight megawatt class weak force nuclear batteries. Additional approaches include dark foods, ditch and bury habitats vice surface constructions, autonomous robotic ISRU, and in-transit artificial gravity.

Keywords: Interplanetary, Energetics, Radiation Protection, Fast Transits, ISRU

Introduction

Human society is now beset with a variety of serious existential threats, both natural and anthropogenic (Snead, 2017). Serious natural threats include solar storms that could degrade essential societal electron utilization and asteroid impacts and supervolcanoes which could nearly destroy the ecosystem upon which humans depend. Serious anthropogenic threats include climate change writ large, Artificial Intelligence (AI) developing into superintelligence, pandemics, and ecosystem degradation. Wikipedia (n.d.) has a collection of expert projections of societal collapse and human extinction probabilities, including one by Martin Rees of a 50% probability of the collapse of civilization by 2100. Other such projections range from 1 to some 25%. Concomitantly, there is rapid frontier technological development across a spectrum of Information Technology/AI (IT), bio, nano/quantum, and energetics that could be applied to deep space-faring. The design characteristics of space include dark, cold, nearly perfect vacuum, 30-50 Giga Electron Volts (GEV) of particle radiation Galactic Cosmic Rays (GCR), and microgravity. To ensure the survival of the human species and its culture, there is emerging interest in becoming a two-planet society (Reuter, 2021) enabled by ongoing technological progress. Given the state of energetics and in-space propulsion, initial second-planet possibilities are limited to those nearby in the solar system. Choices include the poles of Mercury, the atmosphere of Venus and Mars. Due to its plentiful natural resources, Mars is the apparent current choice (Wikipedia, n.d.). Mars has a tenuous atmosphere, significant water resources, and a large number of minerals and other favorable attributes. There are sufficient resources on Mars to possibly establish a successful human colony and provide resources and equipment for exploration of the rest of the outer solar system's moons and planets.

The basic enabling metrics for humans-Mars exploration, pioneering, and colonization are cost/ affordability and human safety/health. The major health concerns, aside from those that can be engineered via suits and habitats, including very low temperatures and pressures and a CO_2 atmosphere, are 38% of earth's gravity (g) and radiation. We know very little concerning the effects upon humans of .38 g, but the hope is that living on Mars humans would evolve to become "Martians", acclimatized to reduced g. The radiation levels on the Mars surface are less than in deep space, due to presence on a large surface providing radiation protection from much of space writ large. However, since GCR is up to 30-50 Giga Electron Volts (GEV) of particle radiation, fully ionized iron atoms, humans would have to be protected from radiation both in transit, full GCR and on the planet, some half GCR. The most efficacious on planet radiation protection is ditch and bury, living under some 4 m of regolith on Mars. This would probably be different, very different, from living on Earth. On Mars, the most economical and safe approach is living underground, or under thick low cost radiation protection in a "fail-safe" artificial pressure, temperature, and chemical atmosphere. Ultimately, the massive Martian resources would enable the development of a two-planet human society and the commercialization of deep space.

While humans have years ago journeyed to the earth's moon and are slated to return in the near term, humans have not yet visited Mars. The plans to visit Mars are in the early stage of development, enabled by many concomitant frontier technologies. For decades now, studies of humans-mars have resulted in delays due to cost and safety/health issues. Cost reductions are needed to enable serious and detailed provisions for human safety/health. Relatively recent technological advances by space-X, which drastically reduced the cost of space access, along with the ongoing development of their revolutionary "starship" and other frontier technologies worldwide, proffer possibilities for major human cost reductions and human safety/health improvements. The purpose of this study is to explore, examine, and project the possibilities going forward for humans-Mars exploration, pioneering, and colonization that is both affordable and safe/healthy for humans (Kehrl and Steele, 2013; Wikipedia, (n.d.); Prince, 2022; Mackwell, 2022; Heldmann, *et al*., 2022; Bushnell, 2022b; Zubrin, 2021; Klaus, 2014; Mankins, 2002; Hofstetter *et al*., 2005; Moktar *et al*., 2001; Goldstein, 2010) document previous studies of reducing costs for humans-mars and robotic Martian science missions (Biswal *et al*., 2021) provides a comprehensive summary of the spectrum of human challenges.

Approach

This report is based upon 60 years of aerospace experience at NASA starting with Gemini and Apollo through planning for human exploration, pioneering, and colonization of Mars, along with the realization that, currently, for humans what is affordable is not safe and what is safe is not affordable. Given that realization and knowledge of the serious potential health effects of human Martian missions, summarized the frontier technologies and systems/architecture approaches that could combinatorially reduce mission cost to enable increased human health and safety. The approaches sought and included cover the entire TRL range.

Societal Technological Context in the Time of Humans-Mars

‘We change our technology and then our technology changes us” (Bushnell and Gross, 2023). Frontier technologies proffer increases in human life, health, wealth, and knowledge. The recent developments regarding AI exhibit emergent behaviors and are closing in on human level and beyond intelligence, creativity, and knowledgeability, along with providing autonomous robotics capabilities and direct brain-machine connectivity. The overall major impacts of the frontier techs going forward upon society provide context for the exploration, pioneering, and colonization of Mars. Regarding energetics, the emerging capabilities of Japanese weak force nuclear batteries sans radiation and ever less costly renewables and storage applied to distributed, point-of-use energy generation could obviate central generation and the electric grid, reducing costs to the consumer and solving the existential issue of Electro Magnetic Pulse (EMP) from solar storms. To mitigate climate, including via sequestering major amounts of CO_2 in their deep desert roots, halophytes could be grown in deserts and wastelands, competing with fresh water-grown food. This would reduce costs across the board and release much fresh water now used to grow food for direct human use, thereby providing mitigations for fresh water and food issues and producing massive amounts of biomass for chemical feedstock and biofuels. The current “tele-everything” is providing the foundation for the development of the virtual age, reducing physical presence and physical travel. Electric, Vertical Takeoff and Landing (VTOL) personal air vehicles operating from driveways and the local street or holding could largely replace automobiles, enabling the population to live wherever it chooses to, including off roads and with distributed energy generation, off wires. Brain chips and direct machine-to-brain communication will provide vast increases in knowledgeability, aided by the evolving global brain. The machines/AI/AGI will provide seriously improved creativity, generating wealth that when taxed could provide a guaranteed annual income. Virtual, tele-everything, Personal Air Vehicles (PAVs), and distributed energy generation along with the bio revolution enabling food production in limited spaces create possibilities for folks to live wherever they desire, off roads and wires, decentralized versus the urban and suburban concentrations required in the industrial age. The bio revolutions will enable serious increases in life span. The energetics revolution and the virtual age lifestyle changes and tech enablers could produce a shift to a green circular economy and mitigate climate and ecosystem issues. Printing manufacture and biological approaches will subsume much of manufacturing and produce a partial shift to Do It Yourself (DIY) manufacture. Such frontier technologies and resultant technology-based societal changes going forward will create fertile technical ground to support Mars exploration, pioneering, and colonization over the next decades.

Results and Discussion

Approaches for Aerospace Cost Reductions

There are two fundamental approaches to cost reduction, conventional and unconventional. The conventional approach is often incremental, and evolutionary and involves examining all aspects of supply, production, and operation in a process usually termed "continuous improvement". The unconventional approach involves ideating, innovating solution spaces

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with often greater-to-far greater performance, and functionality at the same or lower cost. Typically, the unconventional approach, which requires risk embracing and courage yields far greater effective cost reduction and often the creation of whole new markets. Analyses of major determiners of costs, both wrt production and product, indicate that 80-90% of the cost is "designed in" at the initial 10% conceptual, design stage (Leithem and Soden, 2017; Wertz, 2023). This necessitates serious early efforts involving a multiplicity of concepts, and ideas that are triaged for the major, real-world metrics, one of the most important of which is cost. That in turn requires superb knowledgeability wrt worldwide technology, marketability, real-world metrics, and societal requirements-to-desirements, along with raw ideation, and inventiveness.

Usual cost reduction approaches include economies of scale. Unconventional approaches include ideation, invention, and development of advanced technologies for both approach efficiency and cost reduction. There is a rich literature on conventional cost-reducing approaches (Hammelburger, 2021). The purpose of this report is to consider various unconventional, non-incremental, non-orthogonal approaches to reduce costs for humans to mars going forward. It is increasingly important to shift to an approach variously known as cost as an independent variable, design to cost, should cost, and competitive costing.

Mod-sim vice physical experiments: The computing machines and AI are becoming fast enough and large enough and inexpensive enough to very rapidly evaluate proffered concepts including mission architectures at increasing levels of fidelity. Also, the machines are increasingly writing and executing the requisite software to do so. In general, computation is less costly and time-saving compared to experiment.

Machine ideation: Machine-assisted human creativity began decades ago initially via the availability of an ever-increasing magnitude of information writ large on the web and the search engines to access such. As AI has developed there has been progress on 'intelligent search agents", which, after being instructed wrt what is of interest, or via monitoring user search patterns/content, can continually widely search, summarize, and increasingly analyze web content for the human user. What is now evolving is actual machine creativity (Kurman, 2017; McAfee and Brynjolfsson, 2017). Problems are posed by humans, or can be sent from machines and the machines create and can increasingly triage solution spaces. The basic enabler is evolutionary algorithms. Thaler was an early applier with his imagination engine/creativity machine (Home of The Creativity Machine, n.d.). His approach was to train a neural net and then deprive it of rational input. The neural net was observed to dream, apparently much like humans dream and, in the process, produces new combinatorials. These were then evaluated at the systems level for application to various problems and metrics. This fundamental approach to machine ideation has been quite successful over the years, producing new capabilities and products. The process of generating multitudes of applicable combinatorial is analogous to the human ideation process where after putting information into the subconscious it is conjectured that it tries various combinatorials and reports back to the conscious regarding those that it evaluates as useful. The machines have now greatly exceeded human brain speed and knowledge and are utilizing the information from the web and the emerging global sensor grid. There are several, related, machine ideation approaches, Thalers' creativity machine, one by Koza/genetic algorithms (Koza, 1994), and the now very successful Generative Adversarial Networks (GANS) (Salehi, 2020). There is a mid-spectrum/ alternative machine ideation capability, data analytics, which ideates by inference from data, extracting trends, and producing projections. The latest ChatGPT AI and ongoing improvements exceed human ideation/ creativity on the tests for such.

A research center on the desktop: Given serious modeling and simulation and machine ideation, researchers can, on their desktop and perhaps within a few days, ideate and triage for marketability a large number of possible solution spaces/products, accelerating and improving the research process and reducing research costs.

Major Humans-Mars Cost and Safety Issues/Centers

The major issues for human-mars are cost and safety, health, and reliability. The major cost issues can be broken down into those associated with space access, space round trips, habitats, on-surface operations and development, facilities, operations, and support (Bushnell, 2022a). For cost reduction considerations, these cost centers can be addressed individually and combinatorially at the systems, configuration, and architecture levels. Some technologies and approaches can reduce the trip/on the planet per se costs, some can reduce the costs of approaches to ensure greater crew health and safety and some can do both. As currently identified, the major human crew health issues are related to reliability, reduced gravity, and space radiation, with these health impacts amplified by increasing time in space and overall affecting nearly every physiological and neurological aspect of human health (Moses, 2018). The basic differences in health-related parameters between the ISS in Low Earth Orbit (LEO) and the missions to and from Mars include a far longer time frame for the current projected three-year roundtrip duration versus 6 months on ISS, spacecraft exposed to full GCR vice some 45% on ISS in LEO and attendant increased time-related reliability, safety, psychological issues and other health concerns. The detailed nature of the potential clinical health impacts at Mars mission conditions and their potential synergistic effects are largely unknown. Where the impacts are known, the effects appear to scale in severity with the exposed time in space to and from Mars. The potential effects of the .38 g on Mars are unknown. GCR, longer time at higher levels of radiation exposure, and the combinational effects of all the myriad adverse health stressors are the greatest overall human-mars human health and safety concerns, along with equipage reliability. In general, as stated, mission cost reductions could provide the cost margins to enable improved human health and safety approaches and equipment. Mission cost breakdowns change depending upon mission architectures, but in general, LEO access is some 28% of the usual historic mission projected costs, space transportation is some 39% [to/from Mars] and on-planet operations are some 20%. This breakdown is for historical capabilities and approaches involving lofting some 900 metric tons into LEO and non-reusable chemical rockets.

Frontier Technologies and Approaches to Foster Safe and Affordable Humans-Mars

Energetics: High levels of power and energy are necessary for space-faring, including space exploration, commercialization, and colonization. Space energetics applications include in-space and on-body propulsion, habitats and transportation, INSITU Resource Utilization (ISRU), manufacturing, life support, robotics, satellites, sensors, and construction. Lower cost, lighter energetics technology would reduce costs for nearly all aspects of humans-mars. Current space energetics include solar energy, chemical fuels, Radioisotope Thermoelectric Generator (RTG) nuclear batteries, and fission nuclear reactors (Bushnell, 2021). Issues with these include cost, decreasing solar intensity farther from the Sun, mobility, storage, and transfer of chemical fuels, weight, energy density, and safety for current nuclear approaches. Alternative energy sources in development proffer cost and weight reductions and include high energy density, low weight weak force nuclear batteries that have orders of magnitude greater energy density than RTGs and order of magnitude less weight than reactors with scalability from watts to tens of megawatts. These may be capable of powering nearly everything space-related, from small sensors to in-space propulsion. Other frontier energy approaches include regeneration of heat losses and heat rejection via ultra -ow weight multi-phase space radiators. Beyond these are positrons, with two orders of magnitude greater energy density than fission and no residual radiation.

Ongoing development of two advanced scalable weak force nuclear batteries with an alpha, [Kgs/Kw] of order one, and lasting for years could revolutionize space power and energy. The NASA version is the Nuclear Thermionic Avalanche Cell (NTAC) (Bushnell, 2022a; Choi, 2022), which releases inner shell electrons via the impact of high-energy photons. NTAC scales from watts to tens of megawatts. The Japanese have scaled up versions of Low Energy Nuclear Reactions (LENR), a heat battery with no radiation and scalable from watts to high kilowatts thus far utilizing small amounts of nickel and regular hydrogen with an alpha of 2 (Kaeko, 2022). These new nuclear weak force battery designs could power In Situ Resource Utilization (ISRU) and on-body and in-space propulsion and habitats. Additional potential utilization includes powering satellites, terrestrial and deep space mining, ships, manufacturing. Utilizing nuclear fission waste as fuel, NTAC could generate the electricity for the grid for a century. During Entry Descent and Landing [EDL] on Mars, the weak force nuclear batteries could provide the power to execute powered EDL via ingestion of atmospheric CO_2/retropulsion. These scalable weak-force nuclear batteries would obviate the need for on-planet central fission nuclear power stations and attendant energy distribution and the cost, weight, and energy level issues associated with solar on Mars.

Space transportation: A major cost center for human's mars is space transportation, both to space and in space. To space, LEO access, under development since the 1950s, employs the high thrust-to-weight capabilities of chemical rockets. The most efficient fuel is hydrogen/oxygen, with a specific impulse [Isp] of some 460 sec. Other chemical fuels with less performance are also used. Until relatively recently the cost of LEO access, using one-time use rockets was in the range of thousands of dollars per Kg to orbit and relatively stable. The cost of human-rated rockets for space access was much greater, with space shuttle costs in the range of $32,000 dollars a Kg to orbit and the under-development Space Launch System (SLS) system some twice that. Space X has pioneered unique space access rocket systems using reusable rockets, advanced manufacturing, robust designs, and robotics proffering revolutionary LEO cost reductions. For the case of humans-mars class missions, the projected cost of the Space X starship rocket is up to three orders of magnitude less than the SLS. Such a low cost for LEO access enables low-cost chemical fuels in space proffering faster earth-mars transits which reduce the health concerns associated with both microg and GCR radiation and provides many other system-level benefits for both human health aspects and cost/reliability. Such much-reduced space access costs could also possibly enable powered EDL at Mars and the affordable launch of a reusable thick material spacecraft overcoat to provide viable GCR protection during transit.

In-space propulsion options include increasing fuel efficiency [Isp], chemical rockets, fission nuclear rockets, and high-thrust electrics (Bushnell, 2021; 2022a-b). Fission nuclear is some factor of 2 greater Isp than chemical, whereas high thrust electrics, such as Vasimr, are an order of magnitude or greater Isp than chemical.

The issue with nuclear and electricity is energetic weight and cost, including development cost. The much lower weight of the developing new weak force nuclear batteries would enable low-cost, fast-thrust electric transits with lower weight in LEO.

Reduced mission up-mass/requisite Mass in LEO: Mission cost scales directly with requisite up-mass to space/resultant transit mass to Mars. Up-mass consists of crew, equipment, and supplies to keep the crew healthy, on body equipage such as habitats, rovers, and fuels. The approaches to reducing cost for up-mass include higher ISP/reduced fuel requirements to/from mars, reusability/closed cycle food and environmental systems, in-situ resource utilization/printing manufacture making it there vice taking it there, synbio, rigidizable inflatables/ditch and bury vice surface habitats, dark food/chemotropic/cellular food, fast transits enabling reduced in space supplies, aerocapture at Mars, weak force nuclear batteries for energy-rich/CO_2 breathing on planet propulsion, distributed energy generation and robotization.

Human health: The major human health issues for humans-mars are low microgravity, space radiation [GCR and solar particles], psychological issues, sleep and diet changes, toxic exposures, and toxic dust on mars (Moses, 2018; Moses and Bushnell, 2016). Microg and space radiation combinatorially adversely impact nearly every human physiological system. At this point the health impacts of partial g on Mars are unknown. Astronaut ISS experience, 6 months to one-year duration exposures to some half of full GCR and micro g provides some guidance but does not accurately predict the effects of longer stays in space. In general, as stated adverse human health effects of space-faring increase in severity with duration of exposure. Mitigation approaches involving exercise can reduce some of the physiological effects of microg, but for long-duration travel exposed to microg, artificial gravity via spinning would be efficacious. GCR is the greatest radiation human health issue in space. GCR adversely impacts the central nervous system, heart/blood circulation system, carcinogenesis, and much else. Mitigation for radiation health effects includes fast transits/reduced exposure time, use of a 3 m thick reusable overcoat composed of low atomic number materials over the inhabited portion of the spacecraft, on the planet living/working under some 4-5 m of regolith and, under study, using small curved silicon crystals to redirect the radiation away from the body/spacecraft and, also under development, biological countermeasures to "rad-harden" humans. Psychological health issues can be addressed via the metaverse/virtual living and holographic crew members with the latest earth news, etc.,

Autonomous robotics/AI/AGI: Given the now rapid development of both AI and robotics, going forward they could be considered adjunct crew members with the following attributes compared to human capabilities (Bushnell and Gross, 2023):

- Know far more
- Less expensive
- Exclude operational human error
- Far less latency
- Provide new functionalities
- Far longer duty cycles
- Provide size reductions
- Faster, more durable, and more patient
- As or more creative
- Operate at conditions and perform functions where and in a manner humans cannot

For initial operational effectiveness and human safety, robots and requisite equipment could be sent to Mars initially to set up and operate ISRU and prepare for human arrival. That enables ISRU processes to be established, checked out, and operated at Martian conditions and ensures the production/availability of earth return fuel. Also, once humans arrive, pioneer, and colonize, robotics can be used for operations on the surface vice exposing humans to high levels of GCR. Overall, compared to humans, robotics writ large are orders of magnitude less costly than humans for space-faring.

Synbio, dark/laboratory foods: Synthetic biology is being studied for many Martian ISRU applications including food, materials, electronics, bio-cement, biopolymers, bio-adhesives, life support, biofuels, biomining, bio-photovoltaics, bio-composites, biorefining and pharma for both bioproduction and bio-functionalism (Rothschild, 2016; Berliner, 2021). Then there is the related developing cellular agriculture, including "dark foods" (Nord and Bryson, 2022). This is a seriously major shift/revolution in human nutrition and enables large decreases in the cost, time, energy, and water to produce food. These technologies utilize molecular biologics, synthetic biology [synbio], bacteria, chemotropic single-celled organisms, and precision fermentation and are tailoring the mouth feel, taste "eatability" and variety of food offerings. Their development was motivated initially as a way to mitigate the many adverse climate and ecological impacts on the earth of conventional agriculture. Insects and fungi are also being considered as food for humans, as are spirulina and duckweed. It is even becoming possible to craft food from the microbes extracted from the air in the habitat.

Membranes/inflatables: Weight reduction is a key cost reducer. "Ditch and bury", living under some 4 m of regolith or in lava tubes as available is an approach for protection from GCR radiation, meteoroids and provides thermal insulation along with much reducing the cost of surface habitats. Such underground habitats could employ either "brought there" or ISRU-produced inflatables with

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much of the requisite functionality included. Membranes and inflatables (Mattick and Hertzberg, 1981) could also be employed as solar collectors, radiators, sunshades, concentrators, antennas, sails, waveguides, reflectors, sensors/imaging, filtration, and condensers. Mirrors and separators both in space and on the planet. Membrane/inflatable materials developments include self-healing, embedded sensors/actuators, increased strength, tailored permeability, and robustness for environmental conditions including atomic oxygen.

On planet mobility: Mars has of yet no roads, bridges, or railroads and a highly variegated, complex topography created by meteoroid impacts, volcanism, and other geological forces. Ground transportation has to be capable of traversing problematic terrain locally, but much transportation, including longer distances and traverse of multitudinous obstacles, would have to be via flight. Energetics is the first order issue wrt on planet transportation. Historically, fuel cells, solar, and chemical batteries have been benchmarked for on-body vehicle power and energy. Considering the new, developing, scalable from watts to megawatts weak force nuclear batteries, at some 10,000 times chemical energy density and an alpha of one to two, one of these with no radiation discussed herein revolutionizes the functionality of on-planet transportation, making it "energy-rich" and greatly increasing the capabilities of both driving and flying machines. Possibilities include CO_2 breathing for propulsion and lift, ground effect machines, and long ranges.

Thermal managemen: Managing waste heat involves three major issues, recuperation/regeneration, using it and disposing of it. In-space, radiation is the sole heat disposal approach, historically requiring large radiators. There is another class of radiators, which utilize multiphase fluids (Mattick and Hertzberg, 1981). These particle/droplet radiators have much greater heat-radiating surfaces and thus enable lighter radiators. There exists a plethora of approaches for heat regeneration, converting waste heat into usable electricity, a recent one being a direct thermal-electric concept that is factors more efficient than conventional thermal-electric conversion approaches. An advanced solution to the cryogenic fluid thermal boiloff/fuel storage problem is a refrigeration system powered by the new weak force nuclear batteries to suppress boiloff.

Materials: There are several major frontier options to reduce weight via advanced materials. Obviously more, better composites and from nano, including carbon nano tubes. From printing, less material used, more intricate designs enabled and printing at the nano scale for much reduced dislocations and grain boundary problems, improved microstructure. The utilization of AI to rapidly sort through millions of candidates' optimization possibilities for application-specific tailored materials is now ongoing.

The Major Approaches to Enable Humans-Mars Both Safe and Affordable

The approaches that would most seriously reduce the costs of Humans-Mars include the huge projected cost reductions of the reusable space X starship for both LEO access and Mars transits, along with ISRU [make it on Mars vice taking it there]. The major approaches to ensure humans-Mars health and safety include fast transits, artificial gravity during transit, radiation protection by several means, and the hoped for human evolution to accommodate the .38 g gravity on Mars. Overall, recycling of everything, liquids, solids, gases, and materials is efficacious. A major enabler for nearly all of these is the recent development of scalable, lightweight weak-force nuclear batteries.

Fast Transits

The major health/safety human-mars issue is GCR radiation exposure over the long, conventional, earth-mars transits. One way to reduce that exposure is faster transits. There are two possibilities to affordably enable fast transits, cheap chemical fuel in orbit to power longer transit chemical rocket burns and high thrust electric propulsion with much higher Isp. The Space X starship is projected to reduce the cost of putting chemical fuel in orbit by large factors and faster transits are under consideration. The high thrust electric Vasimr propulsion approach has an Isp of 12X chemical but requires a lightweight energy source. The developing NASA and Japanese weak force scalable nuclear batteries could supply such light weight energy for Vasimr. Vice the usual nearly three-year conventional humans-mars missions, these fast transit approaches could enable round trips as short as 200 days (Moses, 2018). Fast transits as stated could much alleviate the GCR health concerns and those, nearly as serious health-wise, from microg. The benefits of fast transits include, in addition to reduced radiation, reduced costs overall, reduced microg, increased reliability due to reduced "duty time", reduced durability concerns, less 'boil off", fewer consumables, fewer human psychological issues, and enhanced currency wrt public relations.

ISRU

Humans-Mars mission costs scale as the mars-earth transit payload size. Mars has huge resources. These could be harvested and worked to provide for humans-Mars missions habitats, fuels, life support [water, O_2, N_2, food], radiation protection, devices, and equipage of all manner from regolith and atmospheric constituents via physical, chemical, and biological processing, expedited by advanced weak force scalable nuclear batteries (Moses and Bushnell, 2016). There are massive amounts of water near the poles, adsorbed in the regolith and chemically bound up in sulfates and silicates. Microwaving the regolith would release water. Cooling a surface would condense CO_2 from the atmosphere. With C, H, and O could make plastics and fuels. Minerals on Mars include nickel, titanium, iron, sulfur, magnesium, calcium, phosphorus, chlorine, bromine, aluminum, silicon, sodium, manganese, potassium, and chromium. The resources are present on Mars to both "make it there" for human colonization and provide supplies for exploration of the solar system beyond Mars, developing in the process a true deep space economy, space-for-space. For the initial Humans-Mars missions, autonomous robotics could be deployed to Mars years before human missions to, via ISRU, make and store the return fuel if necessary and in general "prepare the ground" equipage for human arrival, checked out at Martian conditions. Overall, ISRU on Mars including synbio, printing, and recycling proffers large cost reductions including much-reduced earth-mars transit payload weight.

Frontier Human Health for Humans-Mars

The major Human health and safety issues after the overarching issue of reliability/fail-safe are GCR radiation, microg/low g, Mars dust [sulfur, chlorine, perchlorate, hexavalent chromium], sleep, diet and psychological issues (Moses, 2018). Radiation effects include carcinogenesis, radiation sickness, tissue degeneration, central nervous system and cardiovascular impacts, immune system degeneration, anemia, DNA damage, and cataracts. Microg effects include vision changes, motion/balance issues, DNA damage, Chromosome mutations, weakened T cells/immune system, weakened bones and musculature, skin irritation, heart degeneration, liver damage, kidney stones kidney damage, and sensory dysfunctions. The health effects of these health stressors/impacts for a nearly three-year humans-mars mission are currently unknown, including their combinatorial effects. The health effects of the Mars .38 g level are unknown.

The options for GRC protection include biological countermeasures, diet, and supplements, etc., to ruggedize human physiology to GCR-level particle radiation. Other radiation mitigation approaches include fast transits to minimize exposure time to full GCR, utilization of spacecraft components as partial radiation shielding, on Mars ditch and bury or in lava tubes under some 4-5 m of regolith and in space a 3 plus meter thick reusable polyethylene spacecraft covering overcoat. The latter is nearly the weight of the spacecraft. Also, there is current research on the potential for using small, curved silicon crystals to redirect the particle radiation away from the crew which may have application to spacesuits that currently are not GCR protective. Protective measures for microg include spacecraft artificial gravity and various exercise protocols, many proven out on ISS. For the .38 g on Mars, there is hope for human evolution on Mars, becoming "Martians". Additional in space/on Mars health concerns include the observations that in space 'bugs" are prone to turn more virulent and the unknown health impacts of regolith at the oxygen and water content, temperature, and pressure conditions inside the Habitats.

Conclusions

To become a multi-planet society and develop space-to-space commercial deep space requires humans that are both affordable and safe with large positive margins. The ongoing development of the space X star ship with its' huge LEO access cost reductions, the ongoing development of new scalable to megawatts and lightweight weak force nuclear batteries and the massive resources on Mars, along with other frontier technologies and their system/architecture applications should result in affordable and safe Mars exploration, pioneering and colonization. Some residual concerns include the health impacts of Martian dust at the increased temperature, pressure and oxygen content of the habitats and the effects of the Martian 38 g. Many of the cost reduction precepts herein require some decade of increasing TRL research. Overall, the major keys to affordable/healthy Mars for humans going forward are the space X cheap LEO access, the development of scalable from watts to megawatts lightweight weak force nuclear batteries, extensive ISRU, the biological technology revolution, and autonomous robotic

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