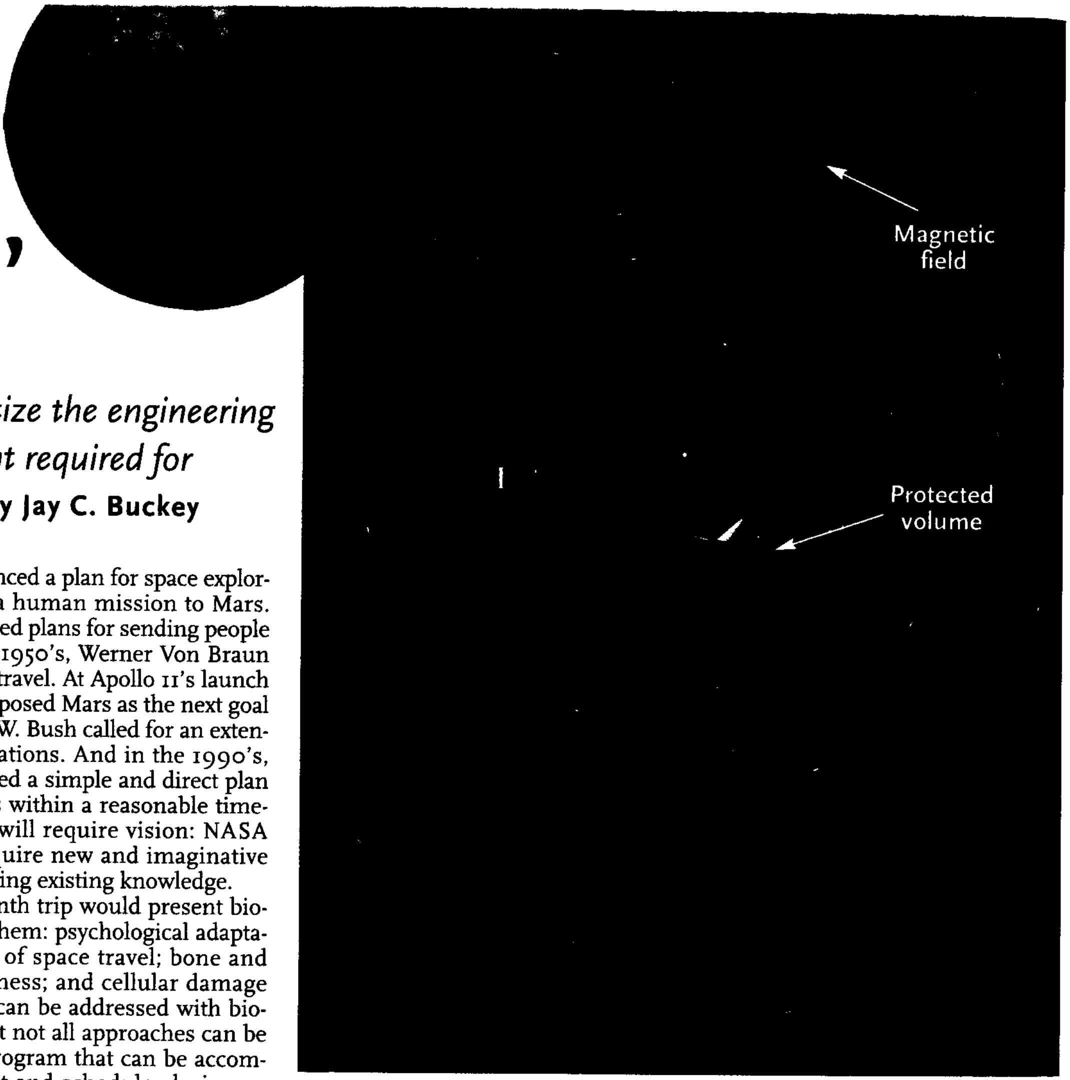
Next Stop, MARS

| VISION | *NASA must prioritize the engineering and biomedical development required for humans to explore space* | **By Jay C. Buckey**



A SUPER COIL: Although engineering challenges exist, unpacking a large superconductive coil in space could allow for a magnetic radiation shield with a low current (I) requirement. The concept is being developed at Creare in Hanover, NH.

This past year President Bush announced a plan for space exploration that includes preparing for a human mission to Mars. Although the initiative is new, detailed plans for sending people to Mars have existed for decades. In the 1950's, Werner Von Braun outlined a comprehensive plan for Mars travel. At Apollo 11's launch in 1969, Vice President Spiro Agnew proposed Mars as the next goal for NASA. In 1989, President George H.W. Bush called for an extensive program of Moon and Mars explorations. And in the 1990's, author and engineer Robert Zubrin offered a simple and direct plan for Mars exploration. But reaching Mars within a reasonable timeframe will require more than plans; it will require vision: NASA must distinguish the problems that require new and imaginative research from those that can be solved using existing knowledge.

Beyond technical barriers, the 30-month trip would present biomedical risks to the crew. Chief among them: psychological adaptations to the confinement and isolation of space travel; bone and muscle loss associated with weightlessness; and cellular damage from cosmic radiation exposure. These can be addressed with biomedical and engineering approaches, but not all approaches can be pursued simultaneously. To provide a program that can be accomplished within reasonable limits on cost and schedule, designers must choose which problems to solve with biomedical research and which to address with an engineering approach. These choices, which must be made with less than complete information, are essential for the program to move forward.

PSYCHOSOCIAL STRESSORS Small crews isolated together for long periods of time are susceptible to conflict and depression. Evidence suggests that psychosocial factors are leading contributors to mission termination on long-duration space flights ended prematurely.[1] These problems could be addressed by developing the engineering capability needed to send a large crew on a faster or more spacious craft, or by intensely focusing on psychological training and selection.

Perhaps such issues will prove less worrisome than many perceive. Humans have proven quite adaptable and psychologically tough in a variety of demanding situations. Fridtjof Nansen spent nine months above the Arctic Circle in a two-person hut with colleague Hjalmar Johansen. Nansen returned and later received the Nobel Prize for other work. He not only survived, he flourished. The crew on Sir Ernest Shackleton's unsuccessful trip across Antarctica survived two years lost in the Antarctic ice. These examples suggest that with proper training and selection, a Mars crew could complete the almost three-year mission. Certainly, a large habitat and a short journey made possible through better propulsion would make the journey easier, but even without these, a successful mission is possible.

WEIGHTLESS WORRIES Bone loss has been a serious issue. Crewmembers in space can lose approximately 1.5% of bone mass per month in certain load-bearing areas such as the hip.[2] This loss occurs despite an aggressive, exercise-based countermeasure program.

The problem of bone loss can be approached in two ways. One is to understand how bones sense loading and to uncover the signaling pathways involved. This knowledge likely would lead to intervention through more effective exercises or drugs. Moreover, genetic factors might predispose individuals to above-average bone loss in weightlessness. The research would result in a set of exercises, interventions, and screening guidelines that could be used to enable long trips in weightlessness.

Another approach would be to minimize biological research and instead build a spacecraft with artificial gravity. Research would be devoted to solving the engineering problems associated with rotating large structures in space. But an engineering solution to this problem may not be essential.

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Knowledge about bone biology has grown dramatically in recent years, and new methods for maintaining bone mass, such as low-level vibration, high-impact loading, and drugs (e.g., parathyroid hormone and bisphosphonates) could make bone loss a much less-serious problem in space than it has been in the past.

SHIELDING SOLUTIONS? Radiation exposure presents a different kind of challenge. Galactic cosmic radiation consists of atomic nuclei traveling at high speed with high energy. Earth's magnetic field and atmosphere deflect or block most of it terrestrially, but a spacecraft in interplanetary space would not have this protection. Modeling studies have shown that with typical shielding, ions with an atomic number (z) ≥ 15 would hit approximately 6%–12% of the entire population of neuronal nuclei (depending on size and location) in the brain.[3] Hits would occur outside of the nucleus as well. Many of these strikes are likely to be lethal to the cells. While it is not known if any functional capability would be lost due to brain-cell loss from ion strikes, the data do show that the number of brain cells hit would be significant.

Developing a thorough understanding of radiation-induced DNA damage and repair could minimize the damage. For bone loss, however, there aren't many good biomedical countermeasures. Antioxidants and radioprotective drugs are not useful against lethal damage. At present, the best strategy is to keep the ions from hitting the cells in the first place, which means shielding.

Unfortunately, this type of radiation is hard to shield against due to the high energies of the individual particles. For example, high-energy iron nuclei encountering an aluminum shield might stop in the metal. In the process, an iron particle might collide with an aluminum atom. When this happens, the nuclei can fragment into lighter nuclei that will continue traveling, and these fragments can then have other collisions. The net result is production of secondary radiation entering the spacecraft.

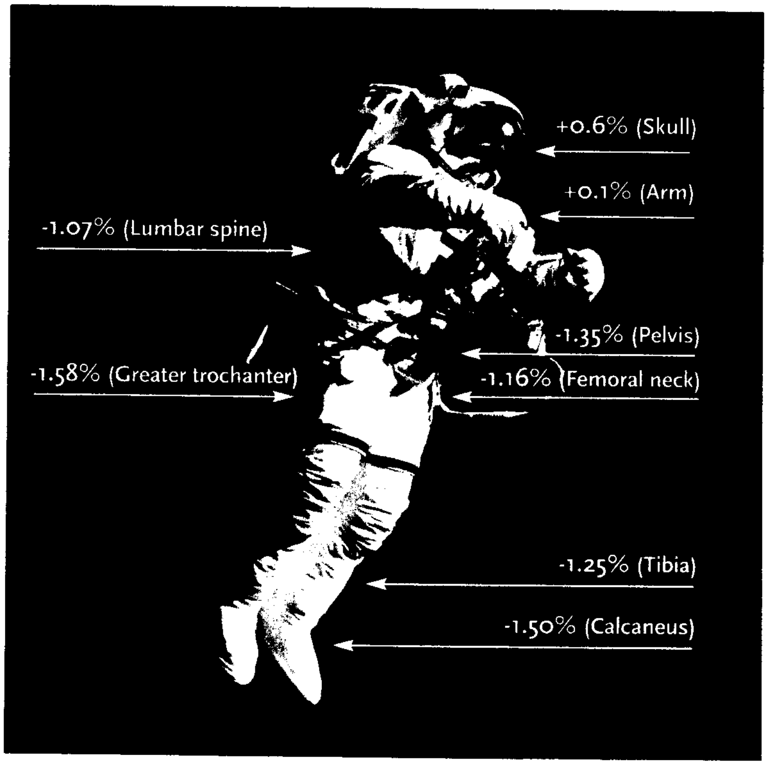
Dense materials such as lead, which shield effectively against gamma rays and X-rays, are poor shields for galactic cosmic radiation. These dense materials create more secondary radiation than do lighter materials such as hydrogen or water. Shields would need to be extremely thick to bring galactic cosmic radiation into more acceptable ranges. Such thick shields, however, would make a Mars mission nearly impossible to accomplish due to the weight of the spacecraft. Another alternative is to accept a higher level of radiation exposure, but, as missions lengthen, this problem eventually must be solved.

Fortunately, however, an engineering solution to this problem may exist. Just as a magnetic field protects Earth, it might be possible to put a magnetic field around a spacecraft. A coil of a superconducting material could produce a substantial magnetic field, which could, in turn, deflect the energetic galactic cosmic radiation. For a small-coil radius, the magnetic field would have to be quite strong (several Tesla) to be effective. A field of this size presents major structural and safety issues. The larger the coil, however, the weaker the magnetic field needs to be. A wire wrapped on a spool could be unwound in space into a large coil. As the radius of the coil approaches a kilometer or so, the field strength and current that is needed will drop to reasonable levels. This approach to shielding, called active shielding, potentially could keep radiation levels within the spacecraft at any desired level.

This idea is not new: It was first proposed in the early 1960s. What is new, however, is the ability to make a practical active shield. High-temperature superconductors now exist that could be formed into large coils. Active and passive methods to keep the coil cool are also possible. Despite these advances, though, creating a functioning active shield would be a significant engineering effort and would require a concentrated research program.

This leads us back to the tradeoffs that must be made to make a Mars mission possible. I would argue that we should not devote key engineering resources to rotating spacecraft or making exotic propulsion systems. Instead, we should create a practical active shield. This would solve a biomedical problem that is unlikely to have a biomedical solution, and would open up travel in interplanetary space. Reducing trip time through better propulsion would reduce radiation exposure, as would addition of passive shielding to the spacecraft. But these solutions serve only to minimize and not solve the problem. With an active shield the crew and mission planners would not have to worry about radiation exposure.

Mars is an achievable goal, but to be successful the research and development program has to stay within politically acceptable bounds. Not every engineering and biomedical problem can be addressed with an aggressive research program. A focus on a few key areas, however, might open up Mars to exploration sooner rather than later. My vision: We solve most of the physiologic problems such as bone loss through biomedical research; address the psychological stresses with proper training and selection; and devote our engineering efforts to making an active radiation shield. ⊗



○ **LOST IN SPACE:** Bone losses (and slight gains) per month associated with extended space travel (Adapted from *Space Biology and Medicine*, A.E. Nicogossian, O.G. Gazenko, eds. American Institute of Aeronautics and Astronautics, Reston, Va., 1996, and A. LeBlanc et al., "Bone mineral and lean tissue loss after long duration spaceflight," *Bone*, 11:S323, 1996.)

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