Radiation Effects on Astronautic Fertility in Space: Deep Space Policy

Seth T. Barbrow
United States Military Academy, Department of Physics and Nuclear Engineering, West Point, NY
Corresponding author: seth.t.barbrow@gmail.com
Keywords: radiation; deep space; fertility

Executive Summary: Long-term manned missions for deep space exploration prompt the examination of humans' prolonged cohabitation. Male and female astronauts risk exposure to austere conditions that will have physiological effects and gender-unique biological responses (Ronca et al. 2014). In addition, cohabitation may initiate intimate relations that could result in the conception and birth of the first humans in space. Therefore, the environmental factor of space radiation is a concern to the sexual and reproductive health of astronauts (Tou et al. 2002). Through an examination of the space environment's effect on reproductive cells, this article considers the possibilities of birth defects and probability of conception in space (Dekaban 1968). To protect astronaut's fertility, policy recommendations are presented towards age-restrictions, mandating the wear of protective garments, and on-board reproductive exams.

I. Introduction

Space organizations attempt to maintain basic levels of privacy for astronauts (Casper and Moore 1995). This level of personal privacy, and regulations guarding against experiments on humans for ethical concerns, has prevented astronauts from becoming the subjects of gender and fertility experiments (Rhawn 2010). Long-term missions will require new policies that ease privacy expectations in order to closely monitor the sexual and reproductive health of astronauts due to heightened concerns of space radiation effects on sexual organs. Interplanetary travel will encompass greater periods of seclusion for deep-space teams and a heightened amount of interactions among male and female astronauts – although there is no assurance that astronauts will engage in sexual activity. Therefore, this paper covers irradiated reproductive organ risks regarding short-term and long-term fertility, as well as risks to accidental pregnancies in outer space.

II. Environmental analysis

This article focuses on environmental threats to fertility due to radiation caused sterility. The largest concern for astronauts involves long-term exposure to radiation in the form of gamma rays and charged particles (Cucinotta 2007). Solar particle events occur on the Sun's surface due to its turbulent magnetic field causing solar flares and coronal mass ejections (CMEs) (Rask et al. 2008). Both solar flares and CMEs jettison streams of charged particles and radiation out into space with energies up to 30×10^6 electron volts (eV) (Cucinotta 2007). These solar particle events tend to occur in 11-year cycles corresponding to solar maximums when the Sun's surface increases magnetic field activity.

The heightened magnetic field of solar maximums also works to dampen interstellar charged particles, which originate from other galaxies or solar systems, called galactic cosmic radiation (Cucinotta 2007). Galactic cosmic radiation (GCR) occurs more frequently than solar particle events, carrying up to 50×10^9 eV of energy, but is most prevalent during solar minimums where the Sun's magnetic field activity is reduced for an eleven year period (Rask et al. 2008). Traveling near the speed of light, the charged protons and alpha particles of galactic cosmic radiation tend to pass through thinly shielded spacecraft and tissue, even creating secondary particles after colliding with a spacecraft's shell that can cause astronauts molecular-level damage. Therefore, hydrogen-based materials are often used for shielding GCR given their ability to attenuate radiation without secondary adverse effects (Vuolo et al. 2017). Spacecraft are equipped with extra hydrogen-based shielding in high-trafficked areas for astronauts (Rask et al. 2008).

Solar particle events and galactic cosmic radiation are forms of ionizing radiation (Rask et al. 2008). As ionizing radiation, including gamma rays and high-energy neutrons, passes unhindered through atomic structures, a transfer of energy strips electrons from atoms causing significant molecular damage. Low energy, non-ionizing electromagnetic radiation does not pose the same magnitude of threat because spacecraft are often better equipped to block the exposure to astronauts (Rask et al. 2008). However, current missions onboard the International Space Station benefit from the protection of Earth's magnetosphere, deflecting low-energy charged particles and reducing an astronaut's exposure to a manageable 108 mSv (milli-Sieverts) over a six-month period (Ronca et al. 2014). In perspective, the average U.S. citizen receives a total background radiation dose of between 2 mSv to 6 mSv per year (Murray and Holbert 2015, 144). Future deep space missions to Mars will require astronauts to leave low-Earth orbit, traveling beyond the protection of the magnetosphere. It is estimated that annual exposure could reach 1,070 mSv which crosses the threshold of 500 mSv linked to increased cancer risk (Ronca et al. 2014).

III. Biological analysis

There are three categories of biological effects observed from radiation exposure: genetic, somatic, and teratogenic (NRCC 1988). First, genetic effects impact the offspring of individuals whose gametes sustained damage to their DNA sequences before conception. Gametes contain half the chromosomes required for reproduction in the form of male sperm and female ova (Miko 2008). If ionizing radiation altered their chromosomes' genetic sequence, the mutation would exist after conception when the newly formed zygote reproduces. This mutation will replicate in the proceeding generations of the cell, carrying into the fetus development.

Second, somatic effects are the physical reactions of radiation limited to an exposed individual and not subsequent generations (NRCC 1988). Astronauts on-board a spacecraft are subject to acute doses of increased radiation due to galactic cosmic rays and solar particle events. Acute dose refers to a large exposure to radiation over a short period of time (NRCC 1988). Radiation has a direct effect on organs and the body does not have enough time to adapt to the highly irradiated environment. As a result, the irradiated organs may produce cancer (NRCC 1988). Similarly, prolonged dose accounts for radiation exposure distributed over a longer period of time such as year-long mission in space (NRCC 1988). The effects of prolonged exposure take longer to materialize.

Reproductive organs are the most susceptible to radiation doses causing somatic effects and infertility (Ronca et al. 2014). Male and female reproductive organs respond the two types of doses differently, with ovaries being more radiation resistant (Rhawn 2010). Women are less prone to undergo temporary sterility while men are more likely to experience temporary sterility with an acute dose of 1500 mSv or a prolonged dose of 400 mSv/year directly to the reproductive organs (NRCC 1988). Permeant sterility, for both men and women, starts to occur at 2 Sv/year. Astronauts on the previously stated Mars mission may receive an estimated 1070 mSv, which accounts for a round trip journey of six months each way and eighteen months on the planet's surface for a total of two and a half years (Rask et al. 2008). This means that humans on a trip to Mars will receive a dose of around 425 mSv/year to their whole body. Since this is not a direct dose to the reproductive organs, this likely will not cause sterility. However, factors such as high solar activity or an individual's sensitivity to radiation may cause temporary sterility (Cheung 2009).

Third, teratogenic effects are the result of radiation exposure during embryonic and fetal development which produce irregularities throughout a pregnancy and at birth (Ronca et al. 2014). Here, radiation permeates the developing fetus which leads to physical deformities after birth (Dekaban 1968). Studies conducted on expecting mothers and test animals showed a correlation between radiation exposure during gestational periods and irradiation caused abnormalities. The study on these mothers was a byproduct of either cancer/disease treatment or attempted irradiated abortions which often failed (Dekaban 1968). After birth, most children exhibited some form of stunted growth including microcephaly, microphthalmos, or other brain malformations causing mental retardation. It is important to note that not all irradiated children portrayed these characteristics, but the probability of intellectual deficits is strongly correlated with increasing radiation dose inside the womb (Rhawn 2010).

Teratogenic effects can be examined in five stages of gestation while the fetus is in the mother's womb (Dekaban 1968). Pregnant mice were irradiated at periods corresponding to a human pregnancy at: less than 3 weeks of gestation (stage one), 3-7 weeks (stage two), 8-16 weeks (stage three), 17-24 weeks (stage four), and longer than 25 weeks (stage five). Subjecting the mice to a radiation dose, equivalent to exposing human fetuses at 1.8 Sv per gestation period, the study found a fetus in stages one, two, and three to be the most vulnerable (Dekaban 1969). For a majority of fetuses irradiated in stage one, death was the normal result. Stages two and three saw a drastic increase in intellectual deficit along with brain and organ abnormalities which often caused mental retardation (Dekaban 1968). However, stage four saw a declining trend of deformities up until 24 weeks. Once the fetus reached stage five, abnormalities approached naturally expected levels and mental deficits were less often noted (Straume et al. 2010). Although these teratogenic effects were observed with doses larger than deep space astronauts would expect, they portray a correlated hazard that should be considered when forming precautionary policy.

IV. Policy recommendations

Conservative time predictions suggest that the first manned Mars mission will occur in the late-2030s (Foust 2019). This gives NASA the time to enact new policies regarding both reproductive health and radiation protection. Due to the highly irradiated environment, exposure limits dependent on age are already enforced on astronauts (Rask et al. 2008). In accordance with the United States Nuclear Regulatory Commission, Code of Federal Regulations Title 10 sets the yearly dose limit at 50 mSv per year for worker on Earth in a radiation environment (Nuclear Regulatory Commission 2001). NASA sets career radiation exposure limits on astronauts by age and gender (Rask et al. 2008). For example, a twenty-five-year-old male astronaut should not exceed an average of 1500 mSv in his career, while astronauts in their fifties are allowed to receive up to 4000 mSv (Rask et al. 2008). This limit difference is due to younger astronauts having more of their life to live, and subsequently a larger time span for cancer to occur.

The first recommendation for NASA policy is to bar young astronauts from deep-space missions. Deep space missions to Mars should contain a majority of personnel age forty and older. The immediate consequence of this policy will be a smaller pool of candidates, but these astronauts will be able to carry out more missions while staying within the bounds of career dose limits. Younger astronauts with higher levels of irradiation might have trouble reproducing due to radiation caused infertility or experience greater rates of cancer.

The second recommendation for NASA policy is to mandate the use of personal radiation protection garments (PRPG). Lead aprons are commonly used on the surface to protect against low-energy radiation from medical radiology. However, lead is not a viable option for PRPG shielding since secondary particles are produced when high-energy radiation collides with the lead. Instead, adapting hydrogen-based materials for personal shielding could provide a lightweight yet effective option for everyday wear (Vuolo et al. 2017). Astronauts do not currently wear protective space suits while traveling in space. However, policy should mandate wearing pelvic protection while sleeping or for a certain number of hours a day to incrementally reduce radiation exposure over long periods of deep space travel. As a precautionary measure, PRPG should be designed specifically for the off-event of pregnancy.

The third recommendation for NASA policy is to mandate periodical on-board exams focused on reproductive health. Part of this exam should require the use of contraceptives such as birth control pills for astronauts on-board deep-space missions. This measure will help prevent pregnancy within spacecraft. On-board exams for deep space missions need to be self-sufficient due to communication lag caused by the large distance between astronauts and Earth. New biosensors that conduct on-the-spot testing of astronaut bio-samples should be carried by on spacecraft to allow for Earth-based doctors to diagnose their patients (Roda et al. 2018). Consistent monitoring should discover health problems early, allowing for the medical mitigation of their effects.

V. Conclusion

Mars missions will offer scientists a first look at long term cohabitation of male of females in space. Radiation poses the largest threat to reproductive health of astronauts. With limited human-centered studies, many of the biological effects of space radiation are projected from animal experiments or observing effects of medical irradiance. Although astronauts are held as professionals, long term missions beginning at two and a half years open possibilities for potential conception. We recommend NASA implement responsible policy regarding astronaut age restrictions, protective garments, and reproductive health monitoring to ensure the biological effects of radiation over this extended duration of time are mitigated.

References

Casper, Monica and Lisa Moore. 1995. "Inscribing Bodies, Inscribing the Future: Gender, Sex, and Reproduction in Outer Space," *Sociological Perspectives* 38(2): 311-33. www.jstor.org/stable/1389295

Cheung, Vivian. 2009. "Genetic Clues to Radiation Sensitivity." *Howard Hughes Medical Institute.* Last modified April 6, 2009. https://www.hhmi.org/news/genetic-clues-radiation-sensitivity

Cucinotta, Francis. 2007. "Space Radiation Organ Doses for Astronauts on Past and Future Missions." *Space Physiology and Medicine* 5. https://ntrs.nasa.gov/search.jsp?R=20070010704

Dekaban, Anatole. 1968. "Abnormalities in Children Exposed to X-Radiation During Various Stages of Gestation: Tentative Timetable of Radiation Injury to the Human Fetus, Part I." *Journal of Nuclear Medicine* 9(9): 471-77. http://jnm.snmjournals.org/content/9/9/471.full.pdf+html

Dekaban, Anatole. 1969. "Effects of X-Radiation on Mouse Fetus During Gestation: Emphasis on Distribution of Cerebral Lesions, Part II," *Journal of Nuclear Medicine* 10(2): 68-77. http://jnm.snmjournals.org/content/10/2/68.full.pdf

Foust, Jeff. 2019. "Independent Report Concludes 2033 Human Mars Mission is Not Feasible." *Space News.* April 18, 2019. https://spacenews.com/independent-report-concludes-2033-human-mars-mission-is-not-feasible/

Murray, Raymond L. and Keith E. Holbert. 2015. *Nuclear Energy: An Introduction to the Concepts, Systems, and Applications of Nuclear Processes*, Elsevier, Inc.

Nuclear Regulatory Commission . 2001. "Standards for Protection Against Radiation." *Code of Federal Regulations,* Title 10, part 20. https://www.nrc.gov/about-nrc/radiation/healtheffects/info.html

National Research Council Committee (NRCC) on the Biological Effects of Ionizing Radiation. 1988. *Health Risks of Risks of Radon and Other Internally Deposited Alpha-Emitters: Beir IV*. The National Academies Press. https://doi.org/10.17226/1026

Miko, Ilona. 2008. "Mitosis, Meiosis, and Inheritance." *Nature Education* 1(1): 206. https://www.nature.com/scitable/topicpage/mitosis-meiosis-and-inheritance-476/

Rask, Jon, Wenonah Vercoutere, Barbara Navarro, and Al Krause. 2008. *Space Faring: The Radiation Challenge.* NASA, EP-2008-08-120-MSFC, Accessed October 4, 2019. https://www.nasa.gov/pdf/284277main_Radiation_MS.pdf

Rhawn, Joseph. 2010. "Sex on Mars: Pregnancy, Fetal Development, and Sex in Outer Space," *Journal of Cosmology* 12: 4034-50. https://www.journalofcosmology.com/Mars144.html

Roda, Aldo, Mara Mirasoli, Massimo Guardigli, Martina Zangheri, Cristiana Caliceti, Donato Calabria, and Patrizia Simoni. 2018. "Advanced biosensors for monitoring astronauts' health during long-duration space missions." *Biosensors and Bioelectronics* 111: 18-26. https://doi.org/10.1016/j.bios.2018.03.062

Ronca, April, Ellen S. Baker, Tamara G. Bavendam, Kevin D. Beck, Virginia M. Miller, Joseph S. Tash, and Marjorie Jenkins 2014."Effects of Sex and Gender on Adaptations to Space: Reproductive Health," *Journal of Women's Health* 23 (11): 967-74, https://dx.doi.org/10.1089%2Fjwh.2014.4915

Straume, Tore, Steve Blattnig, and Cary Zeitlin. 2010. "Radiation Hazards and the Colonization of Mars: Brain, Body, Preganancy, In-Utero Development, Cardio, Cancer, Degeneration," *Journal of Cosmology* 12 (October): 3992-4033 https://www.journalofcosmology.com/Mars124.html

Tou, Janet, April Ronca, Richard Grindeland, and Charles Wade. 2002. "Models to Study Gravitational Biology of Mammalian Reproduction," *Biology of*

Reproduction 67(6): 1681-87. https://doi.org/10.1095/biolreprod.102.007252

Vuolo, M., G. Baiocco, S. Barbieri, L. Bocchini, M. Giraudo, T. Gheysens, C. Lobascio, and A. Ottolenghi. 2017. "Exploring Innovative Radiation Shielding Approaches in Space: A Material and Design Study for a Wearable Radiation Protection Spacesuit," *Life Sciences in Space Research* 15: 69-78. https://doi.org/10.1016/j.lssr.2017.08.003

Seth Barbrow is a space science major at the United States Military Academy. During his time at West Point, Seth studied Chinese abroad in Taiwan where he also conducted research with a cube-satellite team working on orbital propagation. Bringing this knowledge back to the Academy, Seth has researched ionospheric scintillation to predict the effects of solar weather on everyday life which he presented at the Space Weather Workshop in Boulder, CO. As an Army Aviation officer, Seth will learn to fly helicopters for the military and hopes to continue his studies of outer-space in graduate school after the Army.