The Boice Report #55

John D. Boice, Jr., NCRP President
ICRP Main Commissioner
UNSCEAR U.S. Alternate Representative
Vanderbilt Professor of Medicine

The Martian Brain

I just watched the movie *The Martian* and was thrilled, again, about the opportunities of actually going to Mars, cultivating the soil, and living there for long periods. The National Council on Radiation Protection and Measurements (NCRP) has a long-standing relationship with the National Aeronautics and Space Administration (NASA) and recently published a commentary on the potential central nervous system (CNS) effects, primarily on the human brain, following galactic cosmic-ray and other space exposures. We have now embarked on a new venture (Phase 2) to be more detailed in our evaluations and to make recommendations to the extent possible on what might happen to the brain when traveling to the red planet. In November, NCRP Scientific Committee (SC) 1-24 met at the Johnson Space Center (JSC) in Houston with NASA scientists and astronauts to learn about the multiple insults that would affect astronauts during long-term space flight.

Why is there a concern about CNS effects?
NASA is particularly interested in behavioral and cognitive impairments due to effects of space irradiation on CNS, especially those of high-velocity heavy ions (e.g., ^{56}Fe) zipping through space like cosmic bullets fired from the explosion of a supernova. The key issues: will the astronauts complete the mission and, if so, will they remember where they were? Animal studies show detrimental early and late effects of high-atomic-number, high-energy (HZE) irradiation on behavioral and cognitive performance as well as neurological disorders. SC 1-24 is charged with integrating data over all biological scales, including mechanisms of damage, experimental animal responses, and human data, as well as evaluating the interactions of radiation with other aspects of the space environment that may result in CNS effects.

What do we know about CNS effects following human exposures?
Not very much. There is no evidence that moderate doses of low linear-energy-transfer (LET) radiation causes dementia or lasting cognitive dysfunction. The occurrence of a range of CNS effects following radiation therapy clearly demonstrates that high doses of low-LET (x and gamma ray) radiation can initiate both prompt and delayed damage. However, the minimum absorbed doses that result in significant cognitive decrement are much larger than would be received during three years in space (time for a round-trip to Mars). High-dose radiotherapy to treat childhood leukemia in past years increases the risk of brain cancer, but the relevance to space travel is minimal at best. Since no human data currently exist for radiations that simulate the space environment, we must rely on animal experiments that use simulated space radiation, primarily the particle beams available at the NASA Space Radiation Laboratory. These experiments have produced mixed results, with no clear indication of the relative biological effectiveness of different components of the radiation environment in space, but they indicate that there is a possibility of significant damage at doses that are in the range of likely exposures to individuals involved in exploration outside the protection of Earth's magnetic field.

Is there a possibility for research to contribute new knowledge on high-LET exposures to the human brain and CNS effects?
The Million Person Study of radiation workers and veterans includes cohorts of workers with intakes of radionuclides that provide a high-LET dose to brain tissue from alpha-particle emitters amid a low-LET dose from external gamma rays (somewhat similar to the fields in outer space). Intakes of radionuclides that provide a high-LET dose to the brain include polonium, radium, and uranium. SY Tolmachev suggested to me in November 2016 that plutonium and americium also provide a high-LET dose to the brain. Intakes of these radionuclides occurred at the Mound Facility, Rocketdyne, Los Alamos National Laboratory, Rocky Flats, and Mallinckrodt, among others. Further validation that these radionuclides cross the blood-brain barrier and deposit energy in brain tissue is ongo-

ing in a collaboration between Northwestern University and the U.S. Transuranium and Uranium Registries. They are studying brain tissue from workers exposed to these radionuclides using synchrotron-based hard x-ray fluorescence microscopy for two- and three-dimensional trace element mapping—cool stuff and colorful images. Polonium was previously measured in brain tissue during the Litvinenko autopsy. Workers with these unique exposures are being combined in a study to look at dementia, Alzheimer's disease, Parkinson's disease, and motor neuron disease. Stay tuned to learn whether alpha-particle dose to the brain affects dementia and associated conditions.

November 2016 meeting at JSC.

During the JSC meeting, SC 1-24 received updates on NASA research on CNS effects and information on how the limits of cognitive ability, response time and accuracy, and tolerance of adverse circumstances (communication delay, sleep deprivation, excessive workload, etc.) are handled in the design of equipment and operational procedures for space exploration. There were eight marvelous talks and two tours, including one of the Human Exploration Research Analog (HERA).

- Talk 1 described the skills needed and tasks performed, as well as work and living environments, by and for crews on long-duration missions.
- Talk 2 focused on understanding what engineering and operational interfaces have been developed to accommodate healthy living and productivity in the space environment.
- Talk 3 provided a perspective on sensorimotor reactions to spaceflight.
- Talk 4 considered how behavioral or neurocognitive changes may be affected by elevated CO_2 levels.
- The first day ended with a tour of the HERA ground analog to illustrate firsthand what aspects of the living and working environment are like. The facilities planned for space exploration are remarkable, but it would still be a challenge (for me at least) to handle three years aboard a vehicle to Mars. But then given my age and brain-matter state, there would be no risk of late effects and the acute ones have already occurred!
- Talk 5 was a perspective by flight surgeons on what behavioral and performance parameters are actually observed in reaction to the space environment. SC 1-24 heard directly the experiences of performance impairments and the efficacy of mitigation or coping strategies.
- Talk 6 reviewed observations and assessments of different neurocognitive domains on the International Space Station and ground analogs.
- Talk 7 reviewed altered circadian and sleep-deprivation effects on performance. Having sleep apnea, I was wide awake for this presentation!
- Talk 8 addressed the question of "what is a significant behavioral effect" using measures of error that have been employed in the aerospace industry.

It is exhilarating to work with NASA and to have some of the magic rub off from their vision for civilization, how to accomplish the vision, and to boldly go where no man (or woman) has gone before. So whether there is or is not a "Martian brain" problem, I'm certain that NASA will resolve it and then it will be "second [star] to the right, and straight on 'til morning."

Thanks to Les Braby and Janice Huff for providing and reviewing much of the text for this report.

November 2016 meeting of NCRP SC 1-24 at the Johnson Space Center

Top to bottom, left to right: Jacob Raber (vice chair, Oregon Health and Science University), Larry Townsend (University of Tennessee, staff consultant), Susanna Rosi (University of California, San Francisco), James Root (Memorial Sloan Kettering), Janice Huff (NASA, observer), Peter Winsauer (Louisiana State University), Kerry O'Banion (University of Rochester), Greg Nelson (NASA, Loma Linda, observer), Kevin Krull (St. Jude), Angela Harrivel (NASA Langley Research Center), Les Braby (chair, Texas A&M), Dudley Goodhead (Medical Research Council, United Kingdom), "Q" Qin (Naval Submarine Medical Research Lab), Kathy Held (NCRP), and John Boice (NCRP). Not in photo: Polly Chang (SRI International), David Dinges (University of Pennsylvania), David Herr (Environmental Protection Agency), Tom MacVittie (University of Maryland), and John Hopewell (Oxford).
Photo courtesy of John Boice