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EDITORIAL COMMENT

The authors have provided an informative and entertaining summary of the challenges of micturition in microgravity. They have thoroughly captured many of the technologic evolutions for managing the most basic of human functions-elimination. Employing space vacuum seemed an easy approach to the problem, but was offset for the potential for vehicle decompression, through valve failure, as which induced ebullism and killed the crew of Soyuz 11-Georgi Dobrovolski, Vladislav Volkov, and Viktor Patsayev on June 30, 1971.

Voiding dynamics, access to collection means and the collection process itself have all been barriers to an activity we take for granted in 1-g, on planet Earth. The engineering for waste management without gravity has proven to be somewhat complex, especially when there is a desire to preserve a highly needed and heavy to launch consumable, water. The Soviet Union preceded the United States in space toilet design and implementation. The USSR's first orbital toilets were custom-made, such that cosmonauts G. Titov, A. Nikolayev, P. Popovich, V. Bykovsky, and A. Leonov had their buttocks measured for their personal toilets. A research institute in Moscow still has the bronze toilet bowl, used by the first woman in space, V. Tereshkova.

Zvezda, built the 35 lb potty for the Soyuz and Mir space station, noted for its clever and reliable simplicity, but lack of personalizable interface, and unpleasant emptying. Cleaning the ACY (Assenizationno Sanitarnaya Ustanovka, aka Russian space toilet) typically ranks up with the astronauts' and cosmonauts' least favorite mission tasks. As mentioned in the manuscript, urine collection devices and bags were used for many missions, including the last Mercury flight in 1963, when Gordon Cooper wore a UCD that attached to his space suit. Cooper's mission had many failures, several of which required him to manually pilot the spacecraft for reentry. He returned safely, but even a small error could have resulted in disaster. Investigative teams, later determined that Gordon's urine bag leaked and disabled several automated electronic guidance and control systems. During Apollo, each fecal collection bag came with a "finger cot" to allow the astronauts to manually move things along-thereby separating man from his product. Then, after capture, the Apollo crew had to squeeze a germicide into their excrement, so that gas-producing bacteria would not multiply inside the sealed bag and cause it to explode!

Shuttle waste management systems were initially fraught with unpleasant failures, as early as STS-3, requiring multiple system redesigns, which were precipitated by the infamous and

odiferous In-Flight Maintenance of a previously utilized Waste Collection System onboard orbiter Atlantis, during STS-46, by the first Swiss ESA astronaut, Claude Nicollier. There was also a space toilet scandal on ISS in 2007 when, after several failed attempts of their own, NASA bought a Russian toilet for \$19 million to install in the US segment, but would not let Russian crew members use it. In 2018, that very toilet broke and US crew members had to borrow the Russian segment toilet while asking RSS Energia for repair parts.

Although, the device worn in NASA's Launch and Entry and Extravehicular Activity space suits-the Maximal Absorbency Garments, aka "space diapers" were made famous for a "discommoding" reason, this technology reduced the morbidity of many with earthbound incontinence; just as much of spaceflight technology has improved the lives of terrestrial people worldwide. The chemical powder absorbent, sodium polyacrylate (SPA) is embedded into the fabric of the undergarment. SPA can absorb approximately 300 times its weight in fluid, (~2L), so the crew can go 10-12 hours without changing, and the water-SPA gel created by use, wicks liquid away from the skin, preventing irritation. The hope will also be that improvements in recycling technology, being employed on the International Space Station and Orion vehicle, as in the Universal Waste Management System, will not only enable human exploration class missions to destinations such as Mars, but also possibly help conserve a precious resource on our planet-potable water.

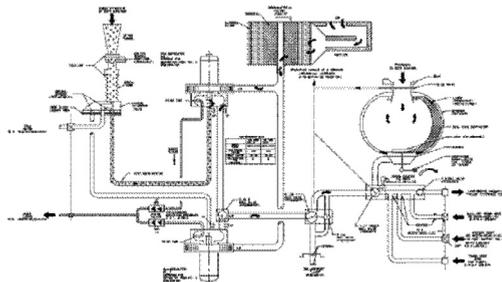
We cannot leave the topic of space-related urination without mentioning a famous Russian tradition of stopping the crew transfer bus headed to the Soyuz launch facility at the Baikonur Cosmodrome, and voiding onto the starboard, after tire. This tradition began with the first human into space, Yuri Gagarin, who needed to relieve himself before the first spaceflight and did not want to have to go into his spacesuit, like Alan Shepherd had to do a month later, May 5, 1961 on Friendship 7. Thus, Gagarin took liberties in wetting the bus' right, rear tire on April 12, 1961, shortly before he launched into space. There is no indication he intended to start a tradition, and likely was done out of pure necessity; but since he is a national hero of the motherland, other cosmonauts have perpetually emulated him exactly, many out of superstition. And now 50 years later, they are still boldly "going". In case you were wondering, female crew members, are not obligated to participate, due to anatomic considerations, however they often bring a collection cup full of their urine and ceremoniously dump it onto the tire instead!

Photos if there is space or desire by the editors to use them, complementary to the photos selected by the authors.

ISS-Service Module "Zvezda" Toilet-ACY.



ACY-schematic.



Shuttle toilet trainer.



Honoring Yuri Gagarin tradition before Soyuz launch.



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AUTHOR REPLY



We sincerely appreciate the thoughtful comment accompanying our manuscript. We wholeheartedly agree that physiological changes in microgravity require sophisticated technology, despite the seeming simplicity of voiding.

As highlighted in the commentary, the discoveries that help astronauts eat, drink, and “pee merry” have had direct translations for the earth-bound. Innovations in water recycling and high absorbency space diapers have been translated into applications on earth.

The greatest success of the space program is not only the technological advancements but also the human collaboration. The Space Race started as a competition between the Soviet Union and the United States to secure national security and gain global influence. Even the engineering for waste management echoed the tone of the Space Race; advancements in waste management in space were notable for firsts from both the Soviets and Americans. However, the change in political climate after the fall of the Soviet Union sparked increased areas of cooperation, including strategic partnerships in space. For example, Russian cosmonauts barter their urine with the American astronauts in exchange for solar energy. Today, the International Space Station represents strong “pee-ceful,” international collaboration, transcending political barriers.

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