President Harry Truman asked the engineers when they presented the concept of a manned space program that neglected a plumbing system. The engineers stumbled for an answer and replied, “Uh, sir, they don’t.” The late Alan Shepard laughed when telling me this story,¹ which was also included in the book he co-authored, called “Moon Shot.”

Author’s Note: This is the first in a series of articles that I intend to write covering Plumbing Biospherics. These articles are intended to spark the imagination of plumbing engineers on how future plumbing system technology will develop—by copying the Earth’s sustainable biosphere, and, as a result, increase our basic sustainable standard of living here on Earth.

This first article discusses the future demand and criteria for designing plumbing in space, and on Mars and Earth; Earth-based sustainable-building concerns, and sustainable building requirements and guidelines. An extensive sidebar provides a detailed review of the history of space-plumbing technology.

¹ President Harry Truman asked the engineers when they presented the concept of a manned space program that neglected a plumbing system.
Shepard continued the story, saying the problem/question posed by President Truman was never resolved. Shepard's contemporaries later said the Cape Canaveral's nurse had gone to Sears and bought an extra-thick pair of underwear—or as astronaut Virgil “Gus” Grissom called them, “nappies”—for Shepard to wear during the Freedom 7 mission, which landed him in the history books as the first American launched into space. Shepard also said it took several hours to get into the sealed space suits (which have no flies like men's pants) and that he was forced to lie in an uncomfortable position for several hours due to many delays before the Freedom 7 launch.

Eventually, he had the desire to relieve himself. Werner Van Braun, preoccupied with more pressing issues, would not allow Shepard to leave the capsule to answer nature’s call. As a result, Shepard relieved himself in the suit. “There was 100% oxygen flowing through my suit so my pants quickly dried. This is a case where 100% oxygen helped out,” he said, laughing.

Russian Cosmonaut Yuri Gagarin, the first person in space, faced a similar situation in 1961. Legend has it that the morning of his launch on the way to the rocket, Yuri, dressed in his space suit, needed to answer the call of nature. He walked out of the bus and relieved himself through a tube from his space suit against one of the bus’s rear wheels. Since then, all cosmonauts, including women, have stuck to this unique Russian Space Program tradition before their launch.

As for President Truman, he had his own plumbing problem. This occurred in the late 1940s when he noticed that his bathtub at the White House was sinking into the floor. After a study, it was discovered that the plumbing system added in 1912 had deteriorated and was in unsanitary condition. As a result, the entire White House was reconstructed in 1948.

**A Look Back…and Ahead**

Looking back in history, we can see how drastically plumbing technology has changed; as proof, compare plumbing systems in the White House in 1912 to the self-sustaining plumbing system used in today’s International Space Station (ISS). Looking into the future, we must ask some tough questions: What are the demands of future plumbing technology in space and on Earth for the next 50 to 100 years? Can future space habitats sustain life with thick underwear? Can modern life sustain itself with current plumbing technology?

To answer these questions, all the building engineering disciplines (including plumbing) will need to study the Earth’s self-sustaining biosphere and then apply this knowledge to real applications. Like those on the ISS, future plumbing systems on Earth will need to be more self sustaining and operate more like a “ship in a bottle,” reducing or eliminating the plumbing connections to the outside world.

Nevertheless, living in a bottle is different than living in a bubble. Future plumbing technologies must take into account that humans are using these systems and do not always follow the rules of engineers. Future plumbing technologies will need to encompass Earth-friendly systems that people will actually use. These technologies will also need to mimic the Earth’s biosphere’s methods of recycling and reusing water, air, and wastes to sustain life.

**Demand for Future Plumbing Technology**

**On Mars/Lunar Missions.** The plumbing system in the ISS is a showcase of current plumbing technology. The ISS “is kind of an ecologist’s dream house,” says Dave Williams, system manager for Environmental Control and Life Support Systems (ECLSS) at Johnson Space Center in Houston, Texas. “If you built a house this way you would be reclaiming as much water as possible.” Between Shuttle visits to deliver supplies, the ISS runs on a fixed amount of air and water.

Efficient, leak-free recycling of everything that flows through the pipes is essential for the Station.

Research and testing are now underway to develop the next level of plumbing technology for use on long-term Mars/Lunar missions. Several scenarios under discussion include a Mars station, a Mars colony, and even introducing plants into the Mars atmosphere that could create an atmosphere much like the Earth. The need to recycle and reuse, and create self-sustaining environments, will remain an important factor in all these developments in plumbing technology.

**On Earth.** The need to recycle and reuse will remain important factors in the development of Earth-based plumbing technology. These trends are developing today with the growth of “sustainable” and “green” construction practices. These trends will affect the way plumbing systems conserve water and energy, and recycle and reuse storm water and sewer systems. Plant systems are being introduced into plumbing technology with the addition of “green roof” systems. [Editor’s Note. Penn State researchers have developed a microbial fuel cell that they hope will turn human waste into electricity and clean water. More details at http://www.nsf.gov/od/lpa/newsroom/pr.cfm?ni=49.]

**Criteria for Future Plumbing Technology**

**Closed and Open Ecological/Sustainable Systems.** To send material into low orbit costs approximately $10,000 per pound, notes a recent article in Business Week magazine. This cost would increase with a Mars mission. On short-term space-shuttle flights (those not involved with Space-Station re-supply), water is brought along for the crew and waste is brought back without recycling. Long-term missions on the ISS or a Mars mission would make this approach impractical.

Many short-term flights by aircraft or spacecraft would release waste outside the craft based on the theory that it would break apart in the Earth’s atmosphere.
space applications. Precise, small, use little energy, and are reliable for current and distilled and pasteurization processes. These systems are to treat and monitor waste (sewer) streams. Early tests for chemical systems, which use machines or chemicals from showers and urine.

Mir water systems would clean and reuse cabin air condensation. For example, the ISS and systems and subsystems and be self-sustaining. Unlike most municipal systems, the ISS system recycles the urine of both the crew and the laboratory animals and returns it to the drinking water supply. The health of the crew is of particular concern in space. Microbes are a danger even to the Station itself, as exemplified by the problems on Mir with fungal growth. Keeping the microbe levels in the water supply to an absolute minimum is an important part of ensuring the longevity of the Station.²

As the need to recycle and reuse increases, plumbing systems will need to close or partially close ecological systems and subsystems and be self-sustaining. For example, the ISS and Mir water systems would clean and reuse cabin air condensate water. Other systems would reuse and recycle water from showers and urine.

**Physical, Chemical, and Biological Systems.** Most of the water-reclamation systems now used in space are physical chemical systems, which use machines or chemicals to treat and monitor waste (sewer) streams. Early tests for space-station water-reclamation systems included filtration, and distilled and pasteurization processes. These systems are precise, small, use little energy, and are reliable for current space applications.

They also have limitations when dealing with the other functions of a station in terms of food preparation and psychological well-being of the crew. Scientists and engineers like working with machines; people, on the other hand, are not as comfortable using machines to sustain their life.

Future plumbing technologies will need to start using biological means to clean and treat black water and gray water waste by using both microorganisms and plants. The advantage to using plants is that they can provide food, clean air, and raise the standard of living in a sterile habitat.

NASA states, “A life support system that would perform these regenerative functions is included in the goals of the NASA Advanced Life Support Program. Such a system would be a closed-loop system, in which the growth of crop plants would contribute to the life-support functions.”³

**Earth-Based Sustainable-Building Concerns**

Future Earth-based plumbing systems, like those for space plumbing, will develop ways to close the plumbing-system loop. For years, the basic concept of plumbing systems was to bring in clean drinking water and carry out the waste. This basic technology to clean drinking water was developed during the time of the Roman Empire.

Water entered settling ponds from a river, where solids would settle to the bottom while the clean water would flow from the top. Later, systems would inject chemicals such as chlorine into the water. Lead pipes were used to distribute the water to the different users. While today’s water treatment systems are more complex, the basic technology remains the same.

Like most major cities in the world, Washington, D.C., has a system that, for the most part, was built in the 1800s and uses the basic technology described above to get citizens their drinking water. The main problems with this ancient design are that it will not remove many of the contaminants in drinking water and can even add contaminants such as lead into drinking water.

According to the city’s Chief Engineer, quoted in an article in the Washington Post, “A substitute must be found for lead pipes. The general fear that such pipes might cause lead poisoning, under certain conditions makes them a menace to the health of the people.” Interestingly, the article is dated June 9, 1893.

Fast forward to this year. On April 2, 2004, the Post reported, “The D.C. Water and Sewer Authority violated federal law by failing to properly notify city residents of high lead levels in the drinking water and to adequately protect public health, regulators at the U.S. Environmental Protection Agency said yesterday.”⁵

However, lead in pipes is just one concern for future Earth-based plumbing systems. Other concerns include potable-water efficiency, energy reduction, storm-water retention, storm-water reuse, sewer-waste reduction, sewer pre-treatment, and safe piping materials. Taking these concerns into account, plumbing engineers will construct future plumbing systems on Earth that are more self-sustaining and resemble a “ship in a bottle” (like the ISS).

...continued on page 40
Space-Plumbing Technology of the Past

Research for space-plumbing technology has been done for many years using different approaches. A common approach, taken by Russia and the United States in the 1950s, was to rely on the aerospace industry because it was ultimately responsible for building spacecraft. Unfortunately, the aerospace industry at the time considered space-plumbing technology an afterthought. Not surprisingly, when aerospace engineers were developing manned space flights, President Truman felt the need to ask them, “How the hell do these guys take a leak?” Their response: “They don’t.”

Around the same time, the U.S. military (including the Navy) began adding a very basic plumbing system into its aircraft and ships. The military was used to having people in risky environments (pushing the envelope, so to speak) and understood people in risky environments (pushing the envelope, so to speak) and understood

some type of plumbing system

when aerospace engineers were developing manned space flights, President Truman felt the need to ask them, “How the hell do these guys take a leak?” Their response: “They don’t.”

research at the time was limited and

technologies. Case in point: Plastic-bag waste-collection bags were still being used when the Shuttle program began in the late 1970s.

During the 1980s, the U.S. space program developed a Waste Collection System (WCS) for the later Shuttle flights. This system looked more like a conventional toilet and needed straps and thigh bars to hold the astronauts to the seat in zero gravity. A vacuum would pull both air and feces from the cabin into the collection device. The feces would be stored in space and disposed after returning to Earth.

Today and Tomorrow: No More Nappies

In the early 1990s, during the Mir program, the Russians developed a space toilet that used a storage tank with flexible hoses, including a different-shaped end for women and men. While this device was better, it was still cumbersome to use. There also were cultural conflicts between the crew. For example, the Russians would complain that Americans drank too much water; as a result the Mir urine-recovery systems would be overloaded.

In 1998, the first two modules of the International Space Station were launched and joined together in orbit. Other modules soon followed, and the first crew arrived in 2000. By studying the Earth’s biosphere, the ISS designers have developed a plumbing system that is not connected to the Earth. Dave Williams, system manager for Environmental Control and Life Support Systems (ECLSS) at Johnson Space Center in Houston says the ISS operates as a “ship in a bottle,” cut off from the outside world. A WCS similar to that used on the later Shuttle flights (from the late ’90s) is still planned for the ISS.

An Extended Stay

The length of time humans can stay in space for a particular mission continues to grow with each passing decade. By the late 1970s, the Russians were conducting experiments with long-term space flights, and in 1980, Soyuz 35 cosmonauts Leonid Popov and Valery Ryumin spent a total of six months in space. From January 8, 1994, to March 22, 1995, Valeri Polyakov spent 438 days in space on Mir.

Improved spacecraft construction (with space plumbing) is the main reason longer space flights occur. For example, Mir’s first modules were launched in 1986 and remained in service until 2000. The ISS is scheduled to remain in service until 2018.

Equally important, however, is biologically based research that began during the Cold War using biology in closed systems. The reason? People would need to live for long periods of time in a closed biological ecosystem in the event of a nuclear holocaust. One such large research project took place in Russia and was called Bios-3. This 4x9x2.5-meter (46x30x8-foot) enclosed stainless-steel structure only received outside electricity and light. It was a 100% biologically closed system that did not use physical chemical methods for life support. Different crews lived in the structures for different periods of time. The longest was 6 months in 1972.

Closed-system research continues today, motivated by a need to study the environment, not out of fear of a possible nuclear holocaust. One such organization is the Japan Society for Controlled Ecological Life Support Systems, which is conducting limited closed biological research in a facility in Japan.

This is a schematic representation of the Waste Management System (WMS) elements within the Apollo Command Module. The function of the WMS was to control the disposition of solid and liquid wastes and waste-stowage gases.

Sources:
Sustainable-building practices follow the motto: I made the mess and I will clean it up, just don’t make me clean up the other person’s mess. When workers produce products, they do not want to have the waste stream of that product harm themselves or others outside the work place. Why should one building place waste into the sewer, which another community would have to pay to remove?

In addition, sustainable-building practices seek to create a healthy environment for each person: A workspace with natural light, clean water, and fresh air to enhance their productivity and creativity.

**Sustainable-Building Requirements and Guidelines**

Over the past few years, sustainable building has grown into a discipline of study with its own requirements and guidelines. Motivations vary for facility owners and operators to build and conform to sustainable-building standards. Some facilities are required to meet standards to meet regulatory requirements, while others voluntarily follow these requirements in an effort to be a good neighbor to the community. Still others conform to the requirements in an effort to overcome negative public perceptions of their projects.

The following is a list of some of the organizations with sustainable-building standards and recommendations.

**LEED®**. The Leadership in Energy and Environmental Design (LEED®) Green Building Rating System is a priority program of the U.S. Green Building Council. It is a voluntary rating system with 69 possible points that can be obtained for a building with four different levels of certification. Projects that earn less than 26 points are ineligible for LEED® certification. A building receiving 26 to 32 points reach the Certified level, 33 to 38 points reach the Silver level, 39 to 51 points reach the Gold level and 52 or more points are the platinum level. Points can be earned when applying sustainable practices in the areas of sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation and design process. Plumbing technologies apply to each of these areas. As a result, sustainable plumbing systems can help a facility obtain several points for certification. For more information on the Green Building Council and the LEED® program go to the website at http://www.usgbc.org.

**Energy Star Label for Buildings**. Similar to the familiar Energy Star rating on appliances, the EPA has set up a program to rank energy-efficient buildings. Buildings with benchmark scores of 75 or higher are eligible for the Energy Star label for buildings. This program is different than LEED’s because it is only concerned with energy use. As a result, energy-efficient plumbing systems such as water heaters will help the building obtain this rating. Many federal buildings or buildings receiving federal funds are required to meet these standards. Refer to this site for a PDF copy of the guidelines: http://www.energystar.gov/ia/business/evaluate_performance/pm_pe_guide.pdf.

**Greening Federal Facilities**. This EPA guidebook is a federal EPA program that is mandated for some federal facilities. The purpose of these guidelines is to make government

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**The Origins of Closed-Ecological-System Thought**

When studying plumbing technology and its relationship to the Earth and other planets, it is important to know about Konstantin Tsiolkovsky (1857-1935).

In the late 19th century there were several rocket societies developing around the world to facilitate serious discussions about future space travel. The person credited with being the first to put serious thought to this idea was Tsiolkovsky. He started writing and developing concepts that were later used in the space program, including the use of liquid oxygen and liquid hydrogen or liquid oxygen and kerosene for propulsion; spinning space stations for artificial gravity; mining asteroids for materials; space suits; and the problems of eating, drinking, and sleeping in weightlessness. By 1932, he was discussing the need for closed-cycle biological systems to provide food and oxygen for space colonies.

“The Earth is the cradle of the mind, but we cannot live forever in a cradle,” Tsiolkovsky wrote in a letter in 1911.

While the language of the time was different than ours, he also thought about the concept of how the Earth’s biosphere is vulnerable to humans, and how humans can use the knowledge of the Earth’s biosphere and travel to distant planets and live a higher quality of life on this planet.


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Men are weak now, and yet they transform the Earth’s surface. In millions of years their might will increase to the extent that they will change the surface of the Earth, its oceans, the atmosphere, and themselves. They will control the climate and the Solar System just as they control the Earth. They will travel beyond the limits of our planetary system; they will reach other Suns, and use their fresh energy instead of the energy of their dying luminaries.

—Konstantin Tsiolkovsky
buildings cost less and to use the Federal government’s purchasing power to stimulate markets for U.S. energy and environmental technologies. As a result, this saves taxpayer money by reducing the cost of materials, waste disposal, and energy. This is a very detailed guideline that covers many plumbing systems. It also makes recommendations such as using waterless plumbing fixtures. For a PDF copy of the guidelines, refer to this site: http://www.eere.energy.gov/femp/pdfs/29267-0.pdf.

**Green Guidelines for Healthcare Construction (GGHC).** The GGHC provides the healthcare sector with a self-certifying metric tool that designers, owners, and operators can use to evaluate their progress towards high-performance healing environments. GGHC follows the credit structure of LEED® 2.1 and, for many credits, incorporates identical language. The total number of possible points in the draft GGHC is 106, compared to the 69 possible points in the LEED. For more information check the GGHC website at: http://www.gghc.org.

**Conclusion**

Wherever humans live and work—whether in space, on Mars, or on Earth—there are three basic trends that should be applied to influence future plumbing technology:
1. The need to recycle and reuse;
2. The need to apply the Earth’s biosphere method of recycling and reusing waste into plumbing systems;
3. The need to include the human factor in the plumbing technology.

**References**


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