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Urine Removal from Suited Crew in Orion Vehicle Depressurization Scenario

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Humankind wants to continually venture deeper into space, but there are many hazards of deep space exploration. NASA's Orion Program seeks to incrementally identify these hazards and begin addressing the difficulties of such long-duration missions. One of the largest risks and areas of program focus is crew survival in a vehicle cabin depressurization scenario. As part of proactive mitigation efforts, contingency operations and associated hardware are being developed to sustain crew members for up to 6 days. While the Orion launch and entry suit would provide the crew a pressurized safe haven for that duration, additional systems are needed to handle crew waste while within the suit. NASA's Orion Crew Survival Systems (OCSS) and Collins Aerospace are working together to develop and test an external suit system to aid in the evacuation of urine from pressurized suits to ensure crew health and safety. This paper describes the recent and on-going design and testing that is driving evolution of hardware and requirements towards eventual flight certification.

Nomenclature

4WV = switching valve
CUD1 = Contingency Urine Device 1
FI1 = flow indicator
mil = milli-inch (one thousandth of an inch)
ONWM = Off-Nominal Waste Management System
OCSS = Orion Crew Survival Systems
pH = measure of acidity or basicity
ppm = parts per million
QD = quick disconnect
SW1 = switch
UCTA = Urine collection transfer assembly

I. Introduction - Orion Mission Cabin Depress Scenario

The Orion Crew Survival Systems (OCSS) off-nominal waste management (ONWM) system is designed to address an emergency scenario during an Orion mission where there is a loss of vehicle pressure, thereby forcing the crew members to don their launch and entry suits for phsyiologic protection. As pressure is lost, crew members must quickly dress for the contingency, get into their launch and entry suits, then pressurize the suits to a habitable pressure. The astronauts would be forced to remain inside their suit until landing back on Earth. Based on initial Orion mission profiles, the longest return trip from the initiation of cabin depressurization could take up to six days. During this time, crew members will not have access to the Orion toilet, and will be unable to change out of any short-term diapers. The ONWM system is designed to remove crew member urine from their suits and the vehicle for the maximum six day contingency duration, helping to prevent any health issues associated with long-term exposure of urine on skin.

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II. Legacy Solutions

In the past, multiple human spaceflight programs have had to solve waste-management related problems within a pressurized suit. For urine, Mercury and Gemini solutions utilized a solution of temporary storage with an in-suit collection bag[1]. This provided suitable containment for short missions or mission phases such as ascent/reentry. Currently, the International Space Station (ISS) uses a Maximum Absorbancy Garments (MAGs), similar to adult diapers, for urine collection during ExtraVehicular Activities (EVAs). MAGs are intended for use no greater than 12 hours. As mission lengths are extended in time and distance from Earth, more complex solutions required the capability to remove urine from the in-suit collection bag by having an external suit port and pump.

The Orion program's cabin depress mission scenario is similar to proactive mitigation efforts done in the Apollo program. Apollo therefore had a similar need for in-suit waste management hardware. Apollo missions used a Urine Collection and Transfer Assembly (UCTA) to allow crew members to urinate while in a pressurized flight suit, for both nominal and contingency operations[1]. The system and hardware of the UCTA is shown in Figure 1. The crew member would urinate into a bladder worn inside the pressure suit, that would then be emptied by using suit pressure to squeeze the bladder and push the urine into a collection bag or directly overboard[2].

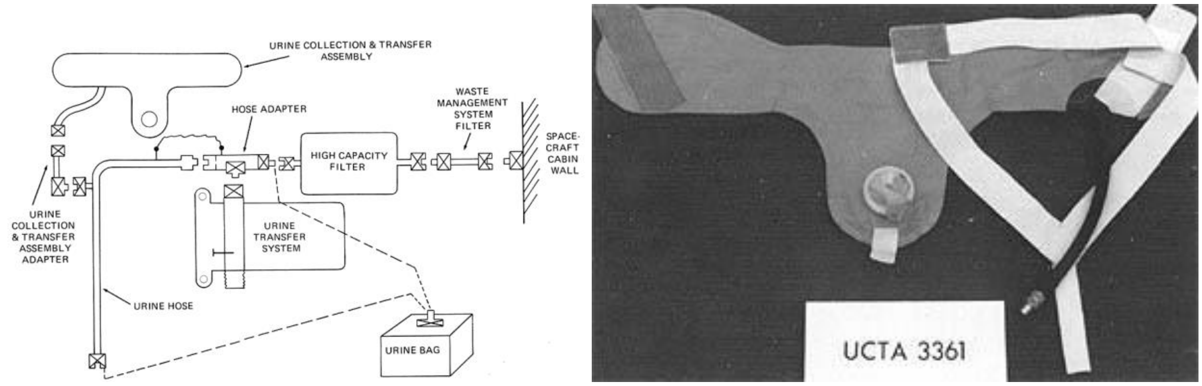

Figure 1. Apollo Urine Collection System and Urine Collection Transfer Assembly[2]

Whether in the Apollo crew module or lunar module, any suited urination events would utilize a pressure differential between the suit and the vehicle collection system to move the urine away from the crewmember and out of their suit, while protecting the crewmember from direct exposure to that pressure differential using relief valves or pressure-sensitive shutoff valves[3].

III. ONWM External-Suit Hardware Concept

To manage urine output from a flight crew, the ONWM system focuses on urine removal from both the OCSS suit and Orion vehicle to the vacuum space environment, instead of collection and containment inside the suit. Over a 6 day period, removal of urine from the suit is key to maintaining the health of the crew. This design decision drives an ONWM system architecture with both suit-external and suit-internal hardware components, of which the external system will be the focus of discussion.

The driving concept of operations for the suit-external hardware is to allow the user to urinate and immediately evacuate any expelled urine from the suit using the pressure differential between the OCSS suit (pressurized up to 4.3 or 8.0 psid) and space vacuum as the driving force. The external hardware functionality is shaped by some of the key design drivers for an off-nominal waste management system, including:

- The management of 1 liter of urine per crewmember per day, assuming up to 6 urinations per day per crewmember, and with a total of 4 crewmembers. Over a 6 day period, this totals to 24 liters of urine that must be collected and routed.
- Allowing for crewmembers to watch the progress of urine flow out of the suit and into the tank. Because crewmembers won't have adequate sensory indications about urine flow from their body, seeing the urine flow into the tank can provide confidence that the system is working and is not backing up onto the body or into the suit.
- The system shall be designed for handling to the capabilities of a pressurized suit crewmember. Because pressurized suits have lower mobility and less tactile ability, any system operations need to be verified by a pressurized, suited subject.
- To minimize mass, the external system shall be shared by all 4 crewmembers during a cabin depress scenario.

- Materials shall be compatible with 6-day vacuum exposure and urine exposure.
- The system shall be utilized only for off-nominal operations, and will otherwise be in vehicle stowage.

To fulfill the operational use and requirements as specified above, the system is designed to use a series of flex hoses and QDs to provide a flow path from the OCSS suit urine passthrough to the vehicle's contingency urine device system, CUD1. The CUD1 acts as the overboard dump line for urine, and provides the constant reference to vacuum needed for pressure-driven urine flow to occur out of the suit. The image below, Figure 2 provides the system level view of the external ONWM system.

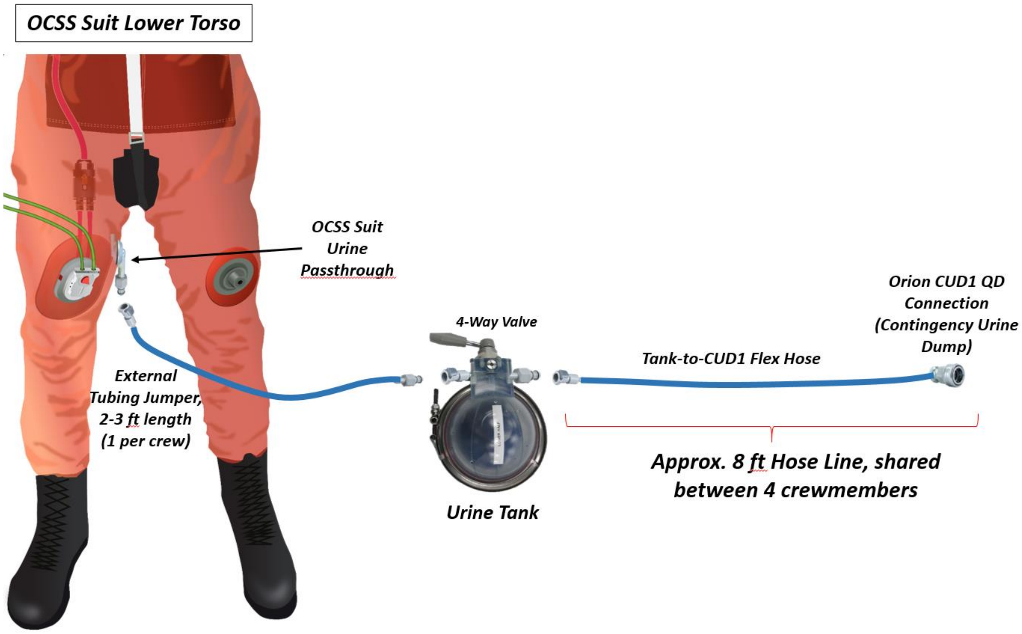

Figure 2. External Portion of the OCSS Off-Nominal Waste Management System

In addition to the flex hoses and QDs, a unique piece of equipment called the urine bladder tank is used to regulate the amount of urine flow out of the suit. The urine tank is designed to be 1 liter in volume, and acts as the primary mechanism to draw urine away from the body and suit, while providing a controllable barrier between the user and the vacuum environment. The tank's ability to operate is dependent on the internal flexible bladder, which separates the sphere into two halves and provides the barrier between the suit and vacuum. One half of the tank is exposed to either the OCSS suit's pressure environment or the CUD1 vacuum at any given time, and a 4-way valve is used to control and alter which side of the tank is exposed to what reference source or sink. See Figure 3 for the urine tank flow path schematic.

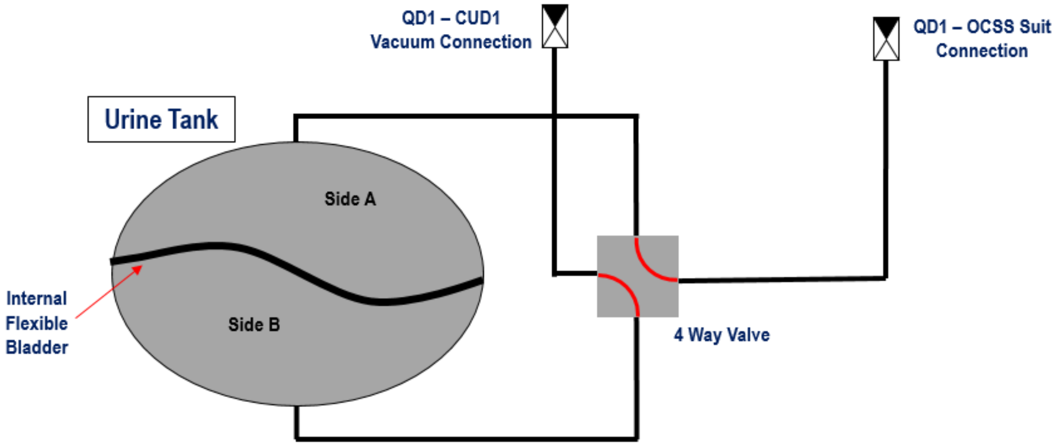

Figure 3. Urine Tank Design Concept Schematic

Use of the urine tank by a suited crewmember begins when the crewmember connects the tank to their suit's urine passthrough, and positions the 4-way valve from a Closed position to a position referencing each tank half to either the OCSS suit or CUD1 vacuum. The vaccum exposure would then cause the flexible bladder to travel towards that side of the tank, creating a suction force and additional volume for the tank side referenced to the suit. Because of the suit's pressure and tank's suction action, urine and gas begin flowing into the urine tank from the suited crewmember. When one side of the urine tank becomes full with urine and gas, the crewmember is able to swap the position of the 4-way valve to reference the side full of urine and gas to vacuum (allowing it to dump to space) while the other half is now referenced to the suit, and begins collecting a secondary set of fluids. This process continues almost seamlessly, until all urine is removed. When the urine has been sufficiently removed, the crewmember can disconnect their suit's passthrough from the tank and can then be used by other crewmembers.

IV. Design Iterations

A. Generation 0 System

The first design iteration, or Generation 0, was quickly developed as a proof of concept to test the operation of a flexible bladder tank and the valving system. A tank was constructed from a section of PVC pipe using a rubber balloon as a bladder sandwiched in using a pipe cap. A commercially available 4-way crossover switching valve was used to provide flow selection to and from the tank. Figure 4 depicts the design with an initial test setup.

The Generation 0 design successfully proved the design concept, and pointed to areas that needed improvement. The cylindrical tank with the bladder installed at the end caused the bladder to be stretched thin on one end and crumpled on the other during cycling. The latex rubber bladder tore after a couple uses around the location that tended to extrude through the outlet ports. Trying to determine flow using the rotary flow indicator was difficult because the air-water mixed flow did not reliably turn the vanes. The focus moving into the Generation-1 design was to improve the tank and bladder design, and focus on reducing the size of valves and components into a single hand-held unit.

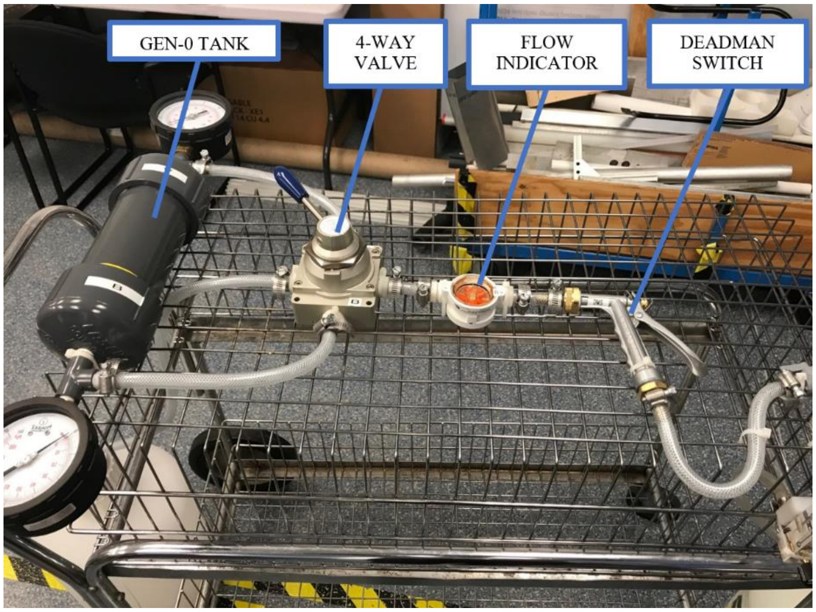

Figure 4. Generation 0 OCWMS System

B. Generation 1 System

The Generation 1 design for the external ONWM system was the first time the system was packaged into a single unit for testing. A spherical tank and a hemispherical bladder were designed to eliminate stresses on the bladder at the end of each cycle. The tank was designed as two halves, and additively manufactured using a clear material so that the behavior of the bladder could be easily observed during cycles. Clear, polyurethane bladders of two varying thickness were designed and formed to match the hemispherical shape of the tank. The 4-way valve was reduced down in size, and packaged around the tank. Flexible tubing was used to make connections between the valve and tank body and allow for easy plumbing routing and flexible positioning of the valve.

The Generation 1 tank was the first major leap from commercially available parts proof of concept to a purpose-built tank and system design. The clear tank design showed how the bladder folded over during the transition from one side of the tank to the other. The spherical geometry of the tank reduced stresses on the internal bladder, by providing continuous support of the bladder in either orientation. Being able to see inside the tank gave a clear indication that the current design resulted in the bladder trapping off the outlet port, trapping water and air from exiting. This prevented using the full volume of the tank during each cycle. The 4-way switching valve was operable by a suited test subject, but were challenging.

Results from the assessment of the Generation 1 design led to a focus on bladder visibility, tank manufacturability, controls simplification, and overall size and weight reduction for the Generation-2 design.

C. Generation 2 System

The Generation 2 design involved the development of two prototype urine tanks to investigate various design approaches, including COTS mechanism and valve options along with system weight reduction. The first prototype was designed using a spring-return switching toggle valve, a bolted flange design for the tank mating, and uses hard plumbing for connections. The second prototype design sought to improve upon the original 4-way valve by integrating the valve plumbing directly to the tank and using a flange clamp to mate the tank halves together.

Improving the bladder design was also completed. Initially, increasing the visibility of the bladders was approached by forming a more visible, colored bladder material. However, the colored polymers ended up being difficult to form and would not maintain shape over time. Therefore, new bladders were made using the original Generation 1 bladder material, and the tip of the hemisphere was dyed after vacuum forming in order to produce a more visible indication.

Both prototype tanks moved the outlet ports closer to the equator of the tank to prevent early entrapment of the bladder. Grooves were made in the interior surface of the tank to help all the water drain out effectively. One tank design incorporated a flattened dome, while the other used a spherical dome to experiment the effect on trapped water and bladder cycling. Testing of the Generation 2 systems is currently being completed, and investigation of the extended benefits of the different designs is currently ongoing.

V. Testing

A. Cycle Testing (Generation 1)

Initial testing completed focused on assessing the Generation I tank design for functionality after multiple cycles of the system valve and bladder The test configuration included a pressurized air and water supply that was metered prior to entering the urine tank, and maintain pressure within the tank to 5 psig. This allowed any of the possible fluid mediums, either air, water, or an air-water mixture to be tested with the system. An interchangeable orifice was also added to the outlet of the OCWMS to assess the impact of the pressure drop caused by the Orion CUD1 exit nozzle. Various bladders were tested to observe the impact of bladder strength and flexibility.

While waiting for Generation-1 bladders to be manufactured, a latex rubber balloon was cut to size and installed in the tank as a temporary bladder. This setup was cycle tested with water, checking out the bladder behavior and the tank design. The dual o-ring configuration provided a leak-tight seal at the tank equator. The flexible, thin rubber bladder cycled easily with the water flow. However, the bladder trapped off the outlet early, preventing all the water on one side from evacuating each cycle. When under the design pressure, the tip of the bladder slightly extruded through the tank outlet. This fully reversed cyclic extrusion eventually caused the bladder to rupture before 100 cycles.

Following the rubber balloon bladder testing, the Generation-1 bladders were installed for testing. The two thicknesses of bladders were tested independently and exhibited no difference in operation, except for a slight reduction in water trapped in the emptying tank half after each cycle. With the designed bladders installed, the whole system was assessed. The bladders were cycled greater than 100 times during testing, with no change in functionality observed. In addition, the thicker bladders did not extrude through the outlet ports of the tank.

Flow testing was performed, switching between orifice sizes, and measuring the pressure drop and flow rate across the system at different supply pressures. When the orifice was reduced the flow started to be restricted, and at very small orifice sizes the flow rate was determined entirely by the outlet orifice, showing that the Orion CUD1 exit nozzle would be the largest contributor to pressure drop and therefore have the biggest impact on the integrated ONWM system flow rate.

The unit was then packaged into a hand-held unit to allow a user to operate the 4-way valve as if they were using the ONWM system in-flight. The valve operations were determined to be relatively simple, but required both hands to be performing independent operations, one for switching tank sides. The rotary flow indicator and the bubble sight flow indicator did not provide a good indication to the user of when they should switch tank sides. The clear tank provided the best indication of when the valve should be switched to start filling the other side of the tank, by allowing the user to see where the bladder was with regards to each side of the tank.

The results of this testing fed into the configurations for the second generation designs. Therefore, the second generation of designs focused on packaging, tank clamping mechanism, bladder material, tank outlet design, valve simplification, and weight/mass reduction.

B. Urine Cycle Testing (Generation-1)

The purpose of Generation-1 urine cycle testing was to evaluate the material compatibility of the bladder and tank assembly with urine over the duration of a cabin depress scenario. Additionally, the valves and tubing lines were to be observed for any buildup that may cause a malfunction or reduce performance of the ONWM system. The test configuration consisted of a pressurized urine supply, a pressurized air supply at 5psig, and the ONWM Generation I urine tank with the thinner, 30 mil Generation-1 bladder. Fresh urine was collected twice a day for use in the cycle testing. The system was cycled for 4 times the contingency duration for a total of 24 days. The urine was sampled for total dissolved solids and pH during collection, after cycling through the system, and after dwelling in the tank for a period of time to track the inputs and outputs. Change in urine pH and total dissolved solids was gathered as secondary information in case tank functionality issues were encountered over the test duration. Pressure drop of the system was monitored to identify any potential harmful residue buildup within the OCWMS. Urine was left in the OCWMS tank overnight, alternating sides, to give a worst-case use scenario simulating crew sleep cycles.

Over the first 6 days representing the contingency scenario, the tank, hoses, and valves remained clear, showing no evidence of particulate build-up. The pressure drop across the system was consistent, and outlet urine samples were similar to the collected urine samples. After an additional 10 days of cycle testing, the bladder started to show a film of residue, and the clear tank and fluid lines started to become visibly cloudy. The pressure drop across the system remained consistent with the first 6 days of testing, indicating no significant flow restriction buildup. The outlet urine samples remained consistent with the collected urine samples.

At the end of 24 days of cycle testing, one side of the tank had developed a particulate coating, and one side of the bladder had become coated with residue, as well. The bladder remained flexible, and no leaks, tears, or thinned locations were noted. The pressure drop of the system remained unchanged. Over 24 days, there was a slight upward trend in the pH of the urine dwelling overnight from about 5.5 to 6.5, becoming more neutral over time. The total dissolved solids also had an upward trend in for the overnight dwelling urine from about 5500 parts per million (ppm) to 9000 ppm, showing more particulates in the outlet flow. Figure 5 shows the pH measurement of the urine after each overnight dwell for the duration of the test. Figure 6 shows the total dissolved solids in parts per million after each overnight dwell for the duration of the test.

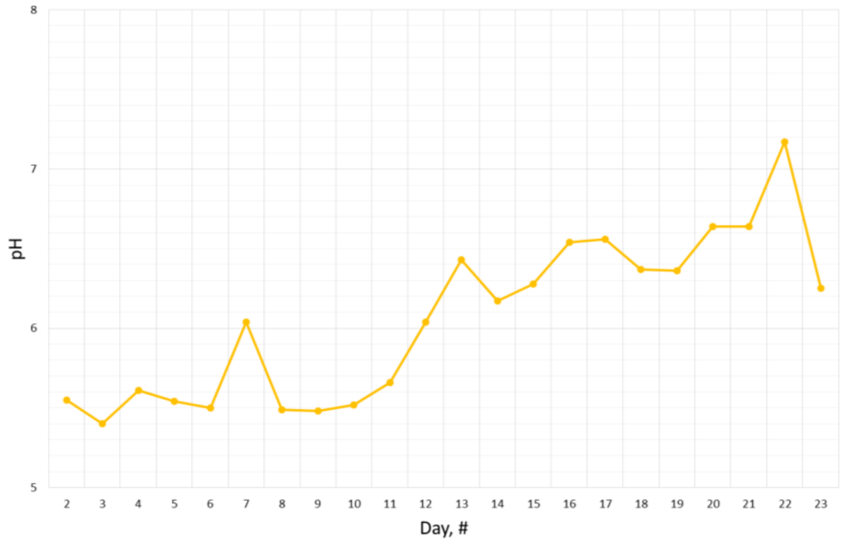

Figure 5. Overnight Dwell Urine pH over Test Duration

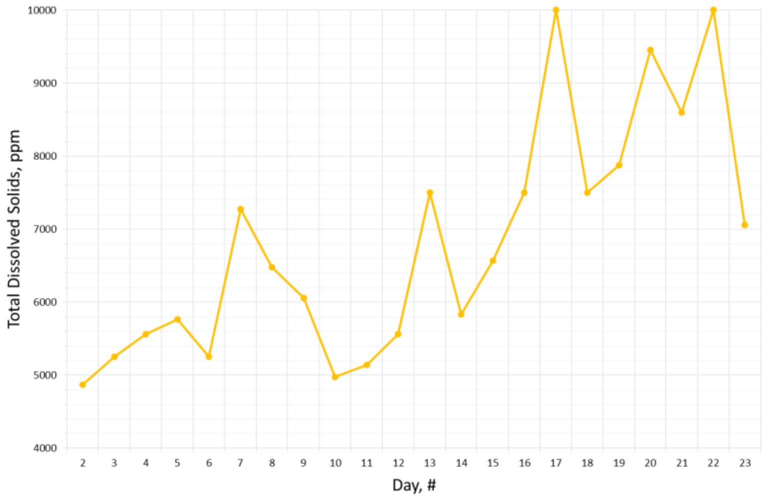

Figure 6. Overnight Dwell, Urine Total Dissolved Solids over Test Duration

The results showed that the Generation 1 bladder material could withstand the expected contingency duration cycles being continuously exposed to urine. The pressure drop testing along with visual examination of valves and plumbing showed that the thin urine residue buildup over the extended duration testing did not interfere with the operation and flow characteristics of the OCWMS.

C. Suited Testing (Generation 1)

The Generation 1 urine tank assembly was also functionally tested by test subjects inside a OCSS launch and entry suit when pressurized up to 4.3 psig. Both males and females were utilized as subjects, and were asked to evaluate the urine tank from a human factors and handling perspective, while also assessing functionality by urinating into the urine tank and operating the tank components accordingly. Figure 7 below shows a snapshot from some of the testing that was completed with the Generation 1 urine tank and willing test subject.

Figure 7. Pressurized, Suited OCSS ONWM Functionality Evaluation

The system successfully evacuated urine from the suit during micturition, with no backup of urine experienced by the test subject. The suit-internal waste management hardware used did allow for gas to flow out of the pressurized suit, in addition to urine, causing test subjects to cycle the tank multiple (2-3) times to remove 200-300 mL of urine. The test subjects did not use any flow indicator to determine when to cycle the tank, but rather the motion and location of the internal bladder. The operation of the 4-way valve was manageable, but the limited mobility of the suit arms and fingers when pressurized required repositioning the 4-way valve for easier reach.

D. Concerns for 1G and Non-Vacuum Testing

To start feasibility testing of the system, some simplifying measures were taken for the initial testing, including testing in standard earth gravity and using a one atmosphere outlet pressure instead of a vacuum. The testing was also performed in a lab atmosphere, whereas in flight, the cabin will be depressurized to a vacuum, impacting the thermal environment. Air was used for testing in lieu of the suit’s 100% oxygen environment.

Microgravity significantly changes the physical behavior of liquids to that in a standard gravity environment. In microgravity, surface tension becomes the overriding force that determines the shape of the flow and the behavior of the liquid inside the urine tank. The effects of microgravity are expected to impact how the bladder may trap urine from leaving the tank and where urine could become trapped and dwell in the system. These could contribute to an icing issue.

Using standard pressure, instead of a true vacuum, impacts the mass and density of air flowing through the system. In flight, this will result in a larger mass of urine per mass of air. The pressure drop of the less dense air through the orifice will therefore be less.

During testing, the environment outside the tank was a standard lab atmosphere, where the surrounding environment kept the tank at a consistent temperature. During an actual cabin depress scenario, though, there will be a vacuum in the cabin surrounding the ONWM system. With only internal vehicle radiative effects to keep the urine tank and flex hoses above a freezing temperature level, and a drop in sensible heat of any residual urine due to liquid vaporization when exposed to vacuum, there are some concerns that ice build up could occur internal to the system over a 6 day period. On-going thermal analyses are being completed at the vehicle level, and future testing efforts will be tailored based on the finalized thermal environment.

VI. Future Developments (Conclusion)

As the design continues to mature, more complex testing will be performed, aimed at more accurately representing the contingency flight environment, including vacuum and thermal effects. Suited crew testing will also continue to assess the mechanisms and useability considering the dexterity and range of motion limitations of being in a pressurized suit. Future design of the external ONWM system will look to address manufacturability and mechanisms. Transitioning from additive manufacturing to machining the tank from clear material is currently being researched, allowing future users to watch the bladder during operation.

The ONWM waste management system will complete its Critical Design Review with the Orion Program in September 2019. Qualification testing will start soon after, and continue through FY2020 and part of FY2021. OCSS off-nominal waste management hardware will begin flying on the first Orion manned mission, EM-2, slated for 2023.

For note, the internal set of hardware use for the ONWM waste management system will be discussed at the International Conference on Environmental Systems in future conference papers.

References

[1] Kemmerer, W. W. and Moran, Jon W., "A Review of Spacecraft Waste-Management Systems," *National Aeronautics and Space Administration,* Technical Memorandum, NASA TM S-1851, 1969.

[2] Sauer, R. L. and Jorgensen, G. K., "Biomedical Results of Apollo" NASA SP-368, 1975.

[3] McAllister, Fred A., "Apollo Experience Report – Crew Provisions and Equipment Subsystem," *National Aeronautics and Space Administration,* Technical Note, NASA TN D-6737, URL: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19720013196.pdf [cited 28 February 2019].