Operation of the Urine Collection and Pretreatment System in the ISS US Segment Waste & Hygiene Compartment (WHC)

D. Layne Carter[1], Darren Riggle[2], and Stephanie Walker[3]
NASA ISS ECLS Subsystem Managers, Houston TX

Petr Andreychuk[4], Galina Karaseva[5] and Aleksandr Zheleznyakov[6]
RSC Energia, Korolev, Russia

Leonid Bobe[7], Alexey Kochetkov[8] and Nicolay Rykhlov[9]
NIIChimmash, Moscow, Russia

Andrew Gleich[10]
The Boeing Company, Houston TX

Christopher Zahner[11]
The Boeing Company, Houston TX

and

Katie Spicer[12] and Mike Berrill[13]
NASA ISS Operations Support Office, Houston TX

The US Segment Waste & Hygiene Compartment (WHC) provides the capability to collect crew urine for subsequent delivery to the Urine Processor Assembly (UPA). Urine collection in the WHC is accomplished with the urine collection and pretreatment system designed by RSC "Energia" and NIICHIMMASH and integrated into the WHC by Boeing and NASA. The WHC was installed in the US Laboratory Module in November 2008 and later transferred to the Node 3 in February 2010. As of February 1st 2021, the WHC has collected 25855 liters of pretreated urine. The system collects urine from astronauts, adds required pretreatment chemicals to maintain chemical and microbial control of the urine, and delivers the pretreated urine to the Urine Processor Assembly. This paper will summarize the twelve years of operation of the WHC on ISS, significant anomalies, and lessons learned from its operation.

[1] ISS Water Subsystem Manager, NASA Marshall Space Flight Center
[2] ISS WHC Subsystem Manager, NASA Johnson Space Center
[3] ISS Subsystem Manager, NASA Johnson Space Center
[4] Head of Sector, LSS Department, Russia,.141670 Korolev, Lenin street, 4a.
[5] Lead Engineer, LSS Department, Russia,.141670 Korolev, Lenin street, 4a.
[6] Head of Science Center, Russia, 141670 Korolev, Lenin street, 4a.
[7] Head of Laboratory, Life Support ivision, 14 B.Novodmitrovskaya str., 125017, Moscow.
[8] Head of Division, Life Support Division, 14 B.Novodmitrovskaya str., 125017, Moscow.
[9] Head of Sector, Life Support Laboratory, 14 B.Novodmitrovskaya str., 125017, Moscow.
[10] ISS Water Recovery and Management Team, The Boeing Company
[11] NASA Johnson Space Center, Wyle Laboratories
[12] NASA ISS Operations Support Office, Houston TX
[13] NASA ISS Operations Support Office, Houston TX

ACY = Waste Collection System
ВК = liquid level sensor in urine separator
COT = Passive Separator
EDV = Russian fluid container
EDV-CB = flush water tank
EDV-U = urine collection tank
ISS = International Space Station
LED = Light Emitting Diode
PTBQL = Pretreat Bad Quality Light
RS = Russian Segment
UPA = Urine Processor Assembly
WHC = Waste & Hygiene Compartment
WPA = Water Processor Assembly

I. Introduction

The US Segment Waste & Hygiene Compartment (WHC) has been collecting crew urine on the International Space Station (ISS) since November 2008. This subsystem represents a unique collaboration between NASA, Boeing, Energia and NIIChimmash in that the WHC uses the АСУ hardware initially developed by Energia and NIIChimmash for use on the MIR Space Station and subsequently in the ISS Russian Segment (RS). During the development of the ISS life support systems in the late 1990s, NASA determined to procure the АСУ hardware due to schedule constraints associated with the development of an inhouse system and to take advantage of component commonality between the two segments for this critical function.

II. Integration

NASA, Energia and NIIChimmash personnel completed the initial assessment to determine the ACY (Russian toilet) would properly interface to the Urine Processor Assembly (UPA). This assessment included confirming the АСУ separator could generate enough pressure to deliver pretreated urine to the UPA waste tank without exceeding the Maximum Design Pressure (maximum pressure after two failures) of the tank or the maximum flow rate the tank could tolerate. In parallel, NASA performed ground tests to confirm the pretreatment solution used by the АСУ was compatible with the UPA treatment process. Pretreatment chemicals are required to maintain microbial control of urine after collection and to inhibit precipitation during the urine distillation process. The UPA was initially developed with oxone and sulfuric acid for urine pretreatment[1], which was used by the Shuttle program to ensure microbial control of urine collected during a mission. During ground testing, it was determined that potassium benzoate would also be required for ISS to ensure adequate fungal control. However, the Russian АСУ uses chromium trioxide and sulfuric acid for urine pretreatment, based on development research initially performed by Umpqua Research Company[2]. Extensive ground testing was performed by NASA to verify this pretreatment was compatible with the UPA, specifically that it supported 85% recovery of the water from urine during the distillation process, and provided adequate microbial control of the pretreated urine during processing and storage. This testing showed the pretreatment to be more effective at fungal and bacterial control than oxone and sulfuric acid, eliminating the need for potassium benzoate. Furthermore, chromium trioxide and sulfuric acid produced a lower pH, which inhibits precipitation and therefore was beneficial for the UPA distillation process. Unfortunately, after operations began on ISS, the UPA experienced precipitation of calcium sulfate in the distillation process[3] due to the elevated levels of calcium in crew urine in microgravity. This issue was resolved by replacing sulfuric with phosphoric acid[4,5,6], thus reducing the amount of sulfate available for precipitation with calcium. Though this modification was relatively straightforward to implement (pretreatment tanks were simply filled with the new pretreatment solution on the ground), there were two modifications required to WHC. First, the revised pretreatment solution requires a minimum dose quantity of 3.3 ml to ensure effectiveness, compared to a minimum of 3.0 ml for the pretreatment solution using sulfuric acid. This required selecting dose pumps (based on ground data) that nominally delivered at least 3.3 ml for use in the WHC. In addition, this modification required adjusting the conductivity setpoint used to verify pretreatment quality prior to addition to the urine stream, since the phosphoric acid has a lower conductivity than the sulfuric acid.

The integration of the АСУ hardware into the WHC was led by Boeing, with support from NASA, Energia and NIIChimmash. Since the internal layout of the hardware in the Russian segment was fundamentally different than the available volume in the WHC rack (utilizing a standard International Standard Payload Rack, or ISPR), the hardware had to be repackaged to properly fit in the available volume with the required interfaces. In addition, hardware was added for the additional interfaces associated with the WHC in the US Segment, specifically the potable bus (for flush water) and the delivery of urine to the UPA instead of an EDV-U as is done in the RS Segment.

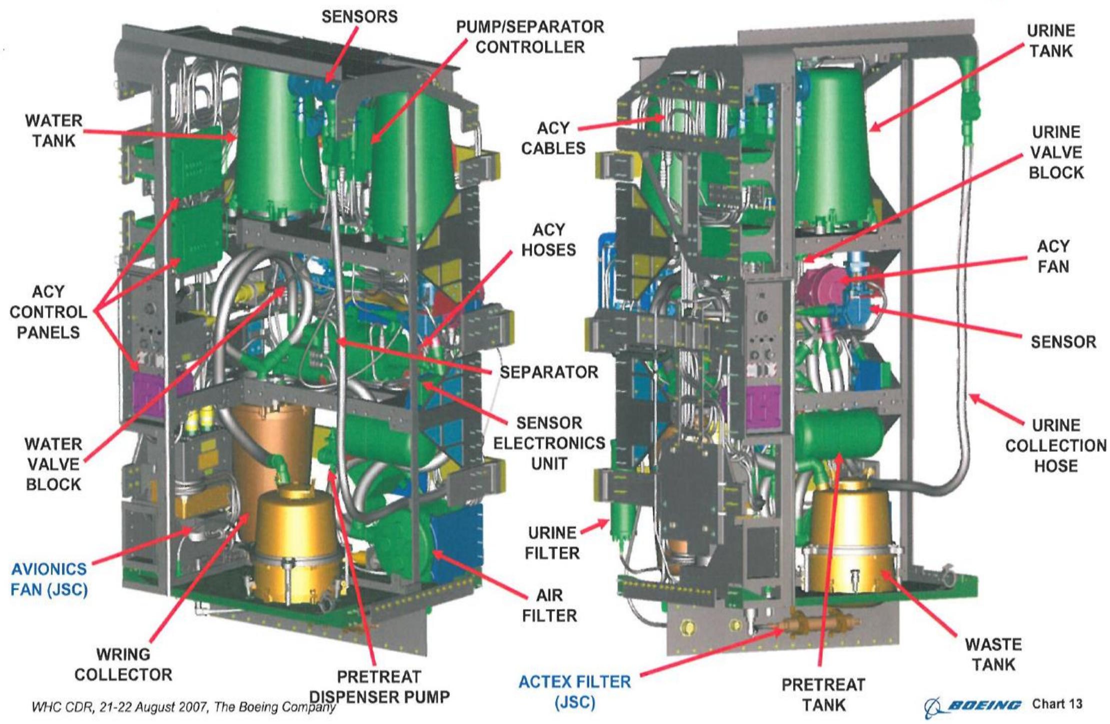

Figure 1. Integrated Waste & Hygiene Compartment (WHC)

III. System Description

The АСУ system is responsible for urine and fecal collection on ISS, on both the Russian and US Segments. The operation of the system in the Russian Segment is described in papers[7,8,9]. This paper will address the collection of urine (not fecal collection), which is subsequently processed by the UPA to reduce water resupply required for the US Segment. Figure 2 provides a functional diagram of the system. The system is activated when the crew opens the urine receptacle valve, initiating operation of the separator, the fan, and the dose pump that delivers pretreatment to the urine. The fan pulls air at 250 to 300 L/min from the urine funnel (to draw urine into the funnel), through the urine separator, through a static separator (referred to as the "COT") and then vented into the cabin. The COT is filled with water-retentive adsorbent to remove impurities before venting. Before the urine is delivered to the separator, the dose pump injects the pretreatment chemicals to ensure the residual fluid in the separator has adequate microbial control. The pretreatment chemicals are added using a dose pump that injects 50 ml of flush water and 3.0 to 3.6 ml of pretreatment (chromium trioxide and the inorganic acid). As noted previously, dose pumps are selected on the ground for the WHC application that deliver a minimum of 3.3 ml of the phosphate-based pretreatment solution. The flush water comes from a Russian EDV that is periodically filled from the ISS potable bus, and the pretreatment is pumped from a pretreatment tank filled on the ground with the proper ratio of chromium trioxide and inorganic acid. A conductivity sensor monitors the quality of the pretreatment and annunciates a Pretreat Bad Quality Light (PTBQL) indicator if the conductivity is below the acceptable setpoint. The separator provides the motive force to deliver the pretreated urine to the UPA waste tank for subsequent processing.

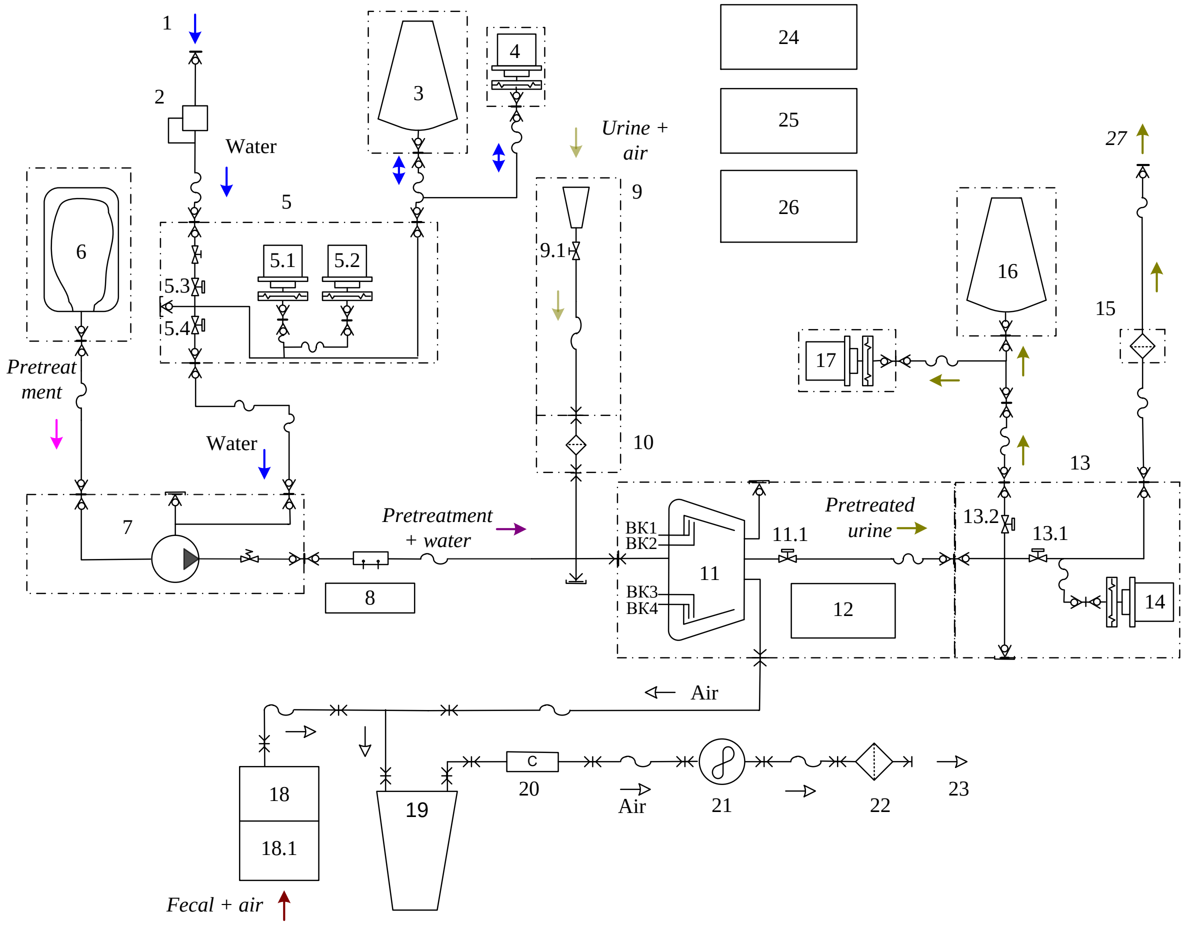

Figure 2. Waste & Hygiene Compartment (WHC) functional diagram

1. Flush water from potable bus. 2. Reducing valve. 3. Flush water tank (EDV-CB). 4. Pressure sensor. 5. Water valve interface unit (5.1, 5.2 – pressure sensors; 5.3; 5.4 - solenoid valves). 6. Pretreatment chemicals tank. 7. Dose Pump. 8. Pretreat conductivity sensor. 9. Urine Receptacle (9.1 - valve with electrical contact). 10. Insert Filter. 11. Rotary pump separator (11.1 - solenoid valve). 12. Rotary Pump-separator control unit. 13. Urine valve interface unit (13.1, 13.2 – solenoid valves). 14. Pressure sensor. 15. Urine filter. 16. Urine feed tank (EDV-U). 17. Pressure sensor. 18. Fecal Container (KTO). 19. Static Separator (COT). 20. Liquid Indicator. 21. Fan. 22. Air filter. 23. Air outlet. 24. Control Panel. 25. Hydraulic Interface Control Panel. 26. Fan Control Panel. 27. Urine to UPA.

IV. Performance on ISS

The WHC was installed in the US Laboratory Module in November 2008, along with the Regenerative ECLS racks required for water recovery and oxygen generation in the US Segment. Since initial installation, approximately 25855 liters of urine have been collected in the WHC. Data of WHC operation and its technical characteristics are shown in the table below.

Table 1. WHC operation and its technical characteristics

Item number	Parameters	From 9th August 2012 up to 1st February 2021
1	Duration of the work period, days	4437
2	Number of uses of the system, units	87497
3	Quantity of accepted urine with pretreatment and flush water, l	25855
4	Spent pretreatment, l	297
5	Specific mass of the WHC: kg of the system hardware per one liter of accepted urine with pretreatment and flush water, kg/l	0.07
6	Power consumed in the mode of receiving urine, Watts	120
7	Average daily power consumption for a crew of 3 people, Watts	5

A. Nominal Operation

WHC (Figure 2) is operated automatically by control panels (24), (25 – fan control panel), (26) and the separator control unit (12). The LEDs and signals described below refer to the ACY control panel (24), unless other panels are specified. WHC operation is initiated by removing the urine funnel (9) from its stowed location, removing its lid (a press-fit cover), and turning the urine receptacle valve (9.1) to the "OPEN" position. The urine receptacle valve will activate the system by sending a command to actuate the rotary pump-separator (11) as well as the Separator Control Unit (12) timer which monitors the separator's internal pressure sensors during operation.

After the initial spin-up of the separator, the separator transitions to the operation mode to confirm the internal volume of the separator has not leaked out. Once the required number of revolutions is achieved, LED "SEPARATOR" is lit up on the ACY control panel by a command from its built-in BK-1 pressure sensor along with a command to switch on the pretreat & water dose pump (7) and the fan (21). The internal pressure sensors monitor the pressure of the pretreated urine fluid ring that is created by the centrifugal motion of the separator, separating the liquid from the air stream.

Assuming a nominal activation, the dose pump is commanded to deliver pretreat. Power is supplied to a 15-second timer monitoring the dose pump, to the pretreat conductivity sensor (8), and to the 5-second timer for unpowering the sensor (8). On the ACY control panel, the "DOSE PUMP" LED illuminates as well as "BLOWER POWER" on the Fan Control Panel (26). The fan operation is confirmed by the crewmember by checking for air suction at the urine funnel on the urine receptacle. Upon activation, the dose pump pulls approximately 50 ml of water from flush water tank EDV-CB (3) and 3.6 ml of pretreat from the pretreatment tank, then delivers the dose to mix with the urine as introduced to the pump-separator. Once a water and pretreat dose is fed downstream, the dose pump is disabled on a command from its built-in sensor, and the "DOSE PUMP" light on ACY control panel fades out. The 5-second timer unpowers the conductivity sensor. The conductivity sensor downstream of the dose pump monitors the pretreat to water ratio to ensure acceptable pretreatment quality, otherwise a red “PRETREAT BAD QUALITY” LED will light up when the dose pump is disabled (this light is often referred to as a PTBQ). If the “PRETRT BAD QUALITY” LED is illuminated, the use can be competed, though the separator actuation is inhibited until the off-nominal pretreat:water ratio is corrected.

The control logic monitors the dose pump operation for 15 seconds, after which the dose pump operation monitoring is done. If the dose pump sensor fails to complete the dosing operation, the dose pump will be unpowered and a red “CHECK DOSE PUMP” LED on the ACY control panel will be illuminated.

After the urine receptacle cover is removed and the valve position is turned to the “OPEN” position, the separator will begin nominal operation mode. In this mode, if the separator does not spin fast enough to trigger the BK1 pressure sensor within 28±5 seconds, the separator triggers a red “CHECK SEPARATOR” LED on the ACY control panel. Once the separator’s green LED fades, the separator is powered off. The red “Check Separator” on the control panel will inhibit operations until it is cleared.

Fan (21) pulls air through the urine receptacle and separator, providing the suction to also pull urine into the urine funnel. A filter screen (10) at the base of the urine receptacle protects the separator from Foreign Object Debris (FOD) in the urine/air stream. Pretreatment solution from the dose pump is added to the urine/air stream at the piping (8) before the entire solution flows into the separator. In the separator, the liquid phase is separated from the air stream, while also ensuring proper mixing of the urine and pretreatment solution. Air exits the separator through the air line and through the COT (19), which is a back-up, passive separator using sponges to trap any residual liquid that is not effectively removed by the separator (11). Next, air passes through the fan (21), the air filter (22), and flows into the cabin atmosphere.

When the liquid level in the separator (11) reaches the pressure setpoint monitored by sensor BK3 (corresponding to 350-450 ml of liquid in the separator bowl), the electromagnetic outlet valve (11.1) is opened. Under pressure, the liquid is discharged through the urine interface valves to the UPA under nominal conditions. If the UPA is not available, liquid flow may be directed to the internal EDV-U. When the liquid level in the separator drains to the setpoint monitored by pressure sensor BK2, the separator electromagnetic outlet valve is closed, leaving roughly 150 ml of liquid in the pump-separator. Upon completion of urination, the crew puts the urine receptacle valve on the urine hose into the CLOSED position, and a command is sent to disable the fan, the dose pump (if it has not been disabled earlier), and the separator. After all operations are complete and no air flow is felt, the urine funnel lid is reinstalled.

If the separator is commanded off before the BK2 sensor indicates it is properly drained, or it is not emptied within 28±5 seconds after the BK-2 sensor response, a command is given to disable the separator’s motor. The “CHECK SEPARATOR” light is annunciated and the “SEPARATOR” light fades out on the ACY control panel. If liquid floods the separator during operation, indicating more than 500 ml of liquid is in the pump-separator, a command for an emergency disconnection of the separator and the fan is sent from the internal pressure-sensor BK4. In addition, the “CHECK SEPARATOR” light is annunciated and the “SEPARATOR” light fades out.

If there is an operational constraint against delivering the urine to the UPA, the WHC urine interface valves can be reconfigured by manual control on the Hydraulic Interface Control Panel (26) to route the urine into an internal storage tank, the EDV-U, which uses an internal Teflon bladder with a capacity of approximately 22 L. When pressure in the EDV-U indicates it has been filled, the “Full” pressure sensor (17) unit (+900±200 mm water column) lights up a “UR TK FULL” light on the ACY control panel and the Hydraulic Interface control panel. Any subsequent actuation of the separator is inhibited. If the “UR TK FULL” lights up during ACY usage, the urination can be completed, but further usage of the system is prohibited.

Solid wastes are collected into special inserts, with a breathable bottom installed in the solid waste receptacle. Wastes are transported to the solid waste tank KTO (18) by an air flow generated by the fan. Air from the solid waste tank KTO (18) is directed through the back-up, passive separator COT (19) and the fan (21) to a charcoal air filter (22) where trace contaminants and unpleasant odors are removed, and then discharged into the cabin atmosphere. A KTO solid waste insert, after defecation is complete, is pulled off from its attach point and transported by an air flow into the replaceable solid waste tank. As the tank is filled (after 20 individuals/day), it is sealed tight, and then replaced with a new one.

Operation of ACY interface units

The water interface valves unit (5). Flush water for urine collection is provided by the ISS potable water bus, which is fed from the US Segment Water Processor Assembly (WPA). The WPA product water contains iodine biocide, which is removed by an ACTEX cartridge (containing adsorbent and ion exchange media for removal of both iodine and iodide) before it is used by the WHC. Water from the potable bus goes initially through a reducing valve (2) to ensure a pressure not more than 0.8 kgf/cm^2 (11.3 psig). Next, the water interface valves unit (5) provides the fluid interface for the delivery of flush water to the flush water tank and the dose pump (see Figure 2). The water interface valves direct flow from the potable bus to the flush water tank EDV-CB (3) (protecting against an overpressure of 0.99-2.1 kgf/cm^2 (14 to 30 psig)) by closing valve (5-4) and opening valve (5-3). Under automated operation, water transfer to EDV-CB (3) is continued until a pressure increase to 900 mm water is observed, at which time valve (5-3) is closed and, with a 10-second delay, valve (5-4) is opened for the delivery of flush water from the flush water tank (EDV-CB) to the dose pump (7). Also under automated operation, once the flush water tank is emptied, a signal from pressure sensor (4) closes valve (5-4) and, with a 20-second delay, opens valve (5-3) to refill the flush water tank as described above. The delay of valve opening ensures the dose pump is not exposed to the pressure from the potable bus (0.99-2.1 kgf/cm^2). In all cases, both in automatic and manual modes, if one valve is open, the other is closed. In the event the potable bus is not available to fill the flush water tank, the EDV-CB may be remove from WHC and filled manually from another source.

If valve (5.3) fails to close and the pressure increases to 0.35 kgf/cm^2, the pressure (5.2) provides a signal to close valves (5.3) and (5.4) and to annunciate an off-nominal situation by illuminating the “H2O HIGH PRESSURE” light on control panel (25).

The ACY hydraulic interface for urine supply (13).

The ACY hydraulic interface for urine supply to the Urine Processor Assembly (UPA) is provided by the urine interface valves unit (БК УИ). In a nominal operation mode, urine received by WHC is fed from the pump-separator (11) via the urine interface valves unit (5) to UPA, with the electromagnetic valve (13.1) open and valve (13.2) closed. The available backpressure during urine supply to UPA can reach up to 0.35 kgf/cm2. For mechanical filtration, a 100 micron filter is incorporated in the WHC pretreat urine output line. If the pressure drop across the filter exceeds 0.35 kgf/cm2, then valve (13.1) is automatically closed by urine interface sensor unit (14) and valve (13.2) is opened to divert flow to the EDV-U (16). In this scenario, the «UPA NOT RECEIVE » indicator is illuminated.

B. Maintenance

WHC maintenance is accomplished by replacement of the various functional blocks as listed in Figure 2. All components were initially replaced on a schedule, but the dose pump was eventually transitioned to “run to failure” as ground personnel developed sufficient operational experience to determine when available data provided sufficient information to determine when the useful life was consumed. Though this approach impacts crew time associated with troubleshooting and unscheduled maintenance, it was deemed necessary to reduce the resupply costs associated with those specific components. The pump-separator was once maintained as a run to failure item until 2016 when a downstream hydraulic connector failed and a significant pool of pretreated urine escaped the fluid lines. After this, it has essentially defined that all hardware pressurized by the pump-separator is replaced annually, including the pump-separator itself. The term for this activity is correctly identified as Preventive Maintenance (PM).

C. Lessons Learned

Though the ACY hardware is used similarly in the WHC and the RS Segment, there are differences in the US Segment that have impacted the optimal operational approach for WHC. During the operation of WHC on ISS, multiple lessons have been learned regarding these interfaces, as well as the correct approach to maintain system functionality in response to the limited data available on the ground.

1. As noted previously, WHC differs from the ACY in that the EDV-CB flush water tank (Item 3 in Figure 2) is automatically filled from the potable bus. This function was added to WHC to reduce crew time, but some nuances have impacted WHC functionality. The initial plan for the flush water tank was to use the pressure sensor in the water valve block to detect when the EDV was empty to automatically trigger a refill. During initial WHC operations, the crew was instructed to manually actuate the dose pump by using the control panel to “drain” the last water in the EDV-CB, Unfortunately this manual dosing was thought to contribute to early failure of the dose pump as the piston-style pump was drawing from an empty tank. Additionally, it was ultimately determined that repeated uses of the EDV flush water tank resulted in the accumulation of free gas in the EDV bladder. Since the bladder is Teflon, gas will permeate through the bladder and saturate the flush water, allowing free gas to form in response to pressure fluctuations initiated by flow to the dose pump. This free gas would be pumped out of the tank as it is emptied and subsequently fed to the dose pump. The dose pump uses a piston technology to accurately deliver the

required quantity of pretreatment and flush water. This technology tends to be sensitive to free gas. The presence of gas reduced the electrical conductivity of the flush water flow with the pretreatment and led to a false signal about the poor quality of the pretreatment. This phenomenon was not observed in the Russian segment, so a decision was made to manually initiate flush tank fills before the EDV was emptied.

2. The subsequent issue with the automated flush tank fill was associated with completely filling the EDV-CB. When the EDV is filled, a pressure sensor detects when the bladder is fully inflated, stopping the fill and reconfiguring the valves such that the EDV flush tank is hydraulically connected to the dose pump. However, this sequence did not occur quickly enough due to the control response of the regulator and electromagnetic valves, resulting in elevated pressure in the EDV-CB. When the dose pump was subsequently activated, the elevated pressure from the fill would often impact dose pump function, sometimes resulting in a failure of the dose pump. This problem was further exacerbated by the presence of free gas in the EDV-CB, which would provide a sustained pressure on the dose pump until sufficient water was removed to reduce the system pressure to ambient. This issue was resolved in March 2015 by installing a 1 Liter Teflon sample bag at a test port (PY3) on the dose pump (see Figure 3), such that the pressure from the flush tank fill can relieve into the "burp" bag and thus ensure the dose pump would only see flush water at ambient pressure when activated. This modification to the flush tank operation has eliminated the dose pump failures associated with the flush tank fill.

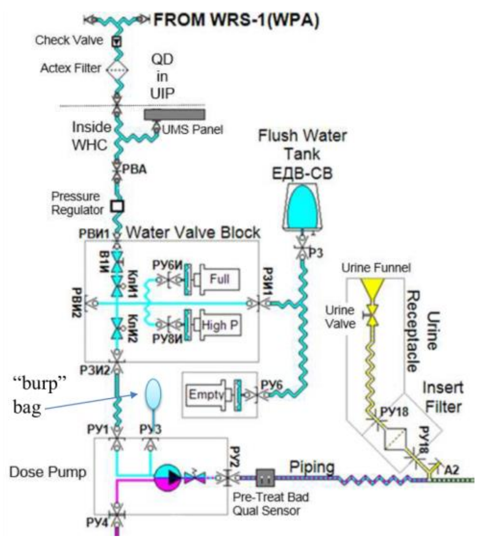

Figure 3. Schematic for the Automatic Fill of the Flush Water Tank

3. The interface with the UPA has created a separate problem associated with backflow of pretreated urine. When pretreated urine is delivered to the separator, approximately 350 to 450 ml must be present in the bowl to trip the BK3 sensor and open the outlet solenoid valve to allow from to the UPA waste tank. Once the separator drains below the BK2 quantity, the outlet solenoid valve is closed and the separator is deactiviated. However, if the solenoid valve does not close, the positive pressure from the UPA waste tank (maintained at 0.1 to 1 psig) will push pretreated urine back to the separator (which is vented to the cabin and thus at ambient pressure when not spinning). On three occasions on ISS, a loss of power to the WHC during use has resulted in this condition (separator off and solenoid valve remaining in the open position). Operational controls are now in place to detect this condition as quickly as possible and either power WHC to close the solenoid valve or have crew demate a quick disconnect between WHC and UPA to stop the back flow.

4. As stated previously, a conductivity sensor is used to monitor the quality of the pretreatment added to the urine. Insufficient pretreatment is a critical issue for the WHC and UPA, as it may result in microbial growth or precipitation in the UPA. While ground personnel addressed operational issues associated with the dose pump (especially in response to the issues previously discussed related to flush tank fills), insufficient pretreatment was periodically added to the urine. This would result in the annunciation of the Pretreatment Bad Quality Light (PTBQL), requiring a specific crew response to continue operation of the WHC urinal. Due to a miscommunication between engineering and operations personnel at NASA, the WHC was initially allowed to operate for up to 20 uses (urine input) with the PTBQL annunciated while the crew attempted to recovery functionality. During 2014, the

dose pump function was consistently degraded, resulted in the delivery of a significant quantity of urine to the UPA that was not effectively pretreated. This resulted in degraded UPA function[10], including elevated system pressure associated with microbial activity. The UPA function was recovered by processing pretreated urine transferred from the Russian Segment АСУ. In parallel, the WHC system was flushed with pretreated water to recover functionality, and modifications were made to the flight rules to clarify that the dose pump could be actuated for 20 doses to clear a PTBQL annunciation, but no urine input would be accepted until the PTBQL was cleared.

5. The pretreatment tank is filled with approximately 5 liters of pretreatment solution. The pretreatment solution is maintained inside a bladder that is vented to the atmosphere, thus there is no positive pressure to feed the pretreatment solution to the dose pump. The dose pump is capable of pumping the needed pretreatment from the tank as long as there is adequate solution in the tank. As the bladder is emptied, there may not be sufficient hydraulic connectivity to pump out the required dose volume. This may result in damage to the dose pump, therefore the pretreat tank is replaced with approximately 500 milliliters remaining in the bladder. Unfortunately, there have still been instances in which the PTBQL has annunciated as the tank approaches this empty limit. Over the years, as additional lessons have been learned to protect the dose pump from overpressurization, the instances of unexpected PTBQL have been reduced. However, during initial WHC operations on ISS, when the pretreatment tank would near empty and a PTBQL was persistent, the removal and replacement of the pretreatment tank would sometimes cause the dose pump to fail. Other early failures involving either the pretreatment tank/PTBQL indication and/or the dose pump were also attributed to incorrect configuration of the fluid connections and or the tank venting caps. When fluid connections from the pretreatment tank to the dose pump were not carefully mated and tightened in an incremental pattern to ensure even compression of the internal fluid seals, a number of leaks at those fluid connections were observed. Corrections to procedures to clarify correct mating technique, along with additional inspections, have considerably dropped the number of observed leaks around the dose pump/pretreatment tank connections. The WHC dose pump is located in a location that is not readily accessible, and thus requires special tools and mirrors to perform the connector mate. Since 2020, the protocol of allowing the connecting hose (referred to as the E-K hose) to remain installed for up to 200 days has limited the need for difficult mating of the hydraulic connectors between the pretreat tank and the dose pump. This maintenance modification has reduced the frequency of this challenging effort by 60%, and also reduced crew time required for each occurrence. In summary, improvements to both operational products and hardware configurations have decreased the number of PTBQL and early dose pump failure over the past six years.

6. Manual operation of the WHC has also introduced challenges to WHC function. Initially, the ACY Control Panel circuitry was not well understood by NASA personnel, and sometimes the misunderstanding/misinterpretation of the operational details would result in early corrective maintenance. The control panels have an internal capacitor that must be bled off after power is removed from the panel, to ensure proper safing before performing maintenance. The use of “holding down” the lamp test buttons to bleed off the capacitor was learned through crew observations and further discussion with the Russian specialists. Additionally, the manual buttons to operate the individual major components of the WHC, the separator, the dose pump, and the ACY Fan (also referred to as the “Blower”), was not well understood in conjunction with the electrical connection from the Urine Receptacle. Manual control of the individual components, if required for troubleshooting failures, will require an electrical connection demate to prevent the automatic activation feature from taking over the ACY logic.

7. The urine receptacle has a valve that serves as both an electrical connection to activate the system and a butterfly valve that opens the liquid/air flow path to permit waste collection. The urine receptacle valve is closely integrated with the ACY control panel and separator control logic. Past failures of the electrical valve have contributed to the system exhibiting both failure signatures: the inability to turn the system ON and the inability to turn the system OFF when it is running. Additional mechanical failures of the valve actuation itself has lent to failures with intermittent signals being sent to and received from the ACY control panel. Urine receptacles have exhibited workmanship issues that have led to “sticky” urine receptacle valves, which have been difficult to turn and complete a full travel of the valve, leading to intermittent signals of on/off/on being sent to the ACY Control Panel. The intermittent on/off/on has shown a variety of failure signatures including PTBQL and Check Separators.

8. The separator has additional logic that works in conjunction with the urine receptacle valve and ACY control panel. Various lessons learned have been identified over the years in working with the separator. The separator is flown dry and therefore the internal pressure sensors that would identify a leak (or a dry separator) must be masked during the initial activation after a separator is replaced. This mask is controlled through a manual switch on the ACY control panel and can only be completed by the crewmember during installation and initial checkout. Procedures and training have improved in relaying the masking step to ensure a new separator would not be mistakenly viewed as not operating nominally. As the separator spins up, there is a vent to allow air pressure

equalization between the inner and outer shells of the Pump Separator. Bearings exist between the outer and inner shells that have lubricant. ISS crewmembers have been trained to communicate detection of off-nominal sounds and airflow observations during use to provide an early indication of a hardware misconfiguration. The vents have been known to still be capped or covered, causing air flow degradation, and lead to leaks of the lubricant pretreated urine. The earlier description of the UPA backflow of pretreated urine during a WHC power loss during a use (reference Issue#3 above) have been connected with WHC separator failures, where the separator has stalled or degraded, causing a current spike above the WHC trip limits. (There are current limiting circuit breakers on the ACY control panel, as well as on the WHC power control panels, and trip limits provided by the ISS power source.) The separator's internal logic to alert the crew and ground operators of a possible misconfiguration or general degradation will place a red LED on the ACY control panel called a "Check Separator," The Check Separator logic will identify if the separator bowl has a possible leak (see Figure 4 for visual of external leak on ISS), if there is a slower than normal drain duration out of the separator, and if there is a blockage downstream that won't permit draining and starts to fill up the separator internal volume. While over the years the ISS crew have gained expertise on operational nuances to help the separator run smoothly (e.g., letting the WHC run after final urination is complete, ensuring full travel of the urine receptacle valve as to not have intermittent on/off, and to mitigate Foreign Object Debris (FOD) contamination).

Figure 4. Photograph of Pretreated Urine Leak from Urine Separator

9. Dose pump failures have been experienced when the manual operation of the dosing command buttons on the ACY control panel are not strictly followed. The dose pump nominally operates in Dose 2 mode, which delivers the correct amount of pretreatment downstream to the UPA by completing two strokes of the dose pump. The dose pump will only operate for about ~8seconds for the pistons to deliver the correct water:preatreat ratio downstream into the separator, and the "Dose Pump" LED will turn on the ACY control panel during this dosing. If the lights are not fully off and the command button is pushed to activate the dose pump while the dose pump is completing its internal logic, the dose pump has been seen to fail in the ON mode, dosing more pretreat and water than just the correct Dose 2 volume. The dose pump internal watchdog timer is confirming the pistons are operating nominally, and if the dose pump fails to complete the piston actuations, either due to mechanical failures or fluid flow blockages/deadhead, the red "Check Dose Pump" light will illuminate on the ACY control panel. Finally, a failed internal inductive sensor, monitoring the piston motion, can contribute to a failed dose pump. Dose pumps have seen internal leakage across the pretreat and water chambers with the water overpressure configuration noted in Issue#2 above.

D. Future Work

The experience accumulated during the WHC operation allows personnel at Energia and NIIChimmash to formulate a number of recommendations for further improvement of the equipment and methods of operation of the system.

To address the issue associated with overpressurizing the EDV-CB flush water tank during the automated fill (reference Issue#2), it is necessary to reduce the free gas present in the EDV before installing it in the WHC and, if possible, reduce the pressure of the water supplied from the potable bus. The WPA has also been evaluated for delivering subsaturated water, which reduces the likelihood of air evolving during the filling and pressure reduction phases which occurs in the WHC fluid lines. In addition, tests should be carried out on a ground stand to assess the working speed of the reducing valve and flow-limiting controls.

As the E-K Pretreat Tank (6) is the launch and on-orbit stowage container for the concentrated alternate pretreat solution, it is highly desired to minimize the quantity of pretreatment remaining in the tank when it is replaced. In an effort to allow further fluid extraction from each tank (initial capacity of approximately 5 liters), Energia and NIIChimmas are evaluating and testing a new tank design. As a side benefit, if complexity and possible failure modes can be reduced, this leads to higher reliability and efficiency of the effective launch mass.

Pretreated urine produced by the phosphate-based pretreatment approach has shown to produce suspended solids that must be filtered prior to delivery to the UPA. In addition, it has been noted that airborne contaminants are also ingested in the urine receptacle and pass into the pretreated urine fluid stream. The loading factor of the current filter and the allowable installation duration (yearly) must be evaluated and possibly updated. As filter loading increases, it also provides additional loading on the pump-separator function, while reducing the pressure available to flow against the UPA backpressure. The effect of the additional backpressure on the performance and life of the urine separator should be evaluated, and used to determine if more frequent replacement of the filter is worthwhile.

The operational status of the separator is determined by the induced pressure on the rubber membranes of the built-in pressure sensors ВК1, ВК2, ВК3, and ВК4. Currently, an improvement of the membranes has been implemented. In all cases, it is necessary to carefully monitor the mating of hydraulic connectors and internal seals, since incorrect mating may lead to flooding the separator with pretreated urine and the premature failure of the dose pump.

V. Conclusion

Operation of the WHC with the ACY hardware has been successfully implemented on ISS. This system has illustrated the collaborative effort between NASA, Boeing, Energia, and NIIChimmash to integrate and operate Russian hardware in the US Segment, providing an essential function to enable crew presence on ISS. WHC is expected to continue nominal operation in the US Segment for the duration of ISS.

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