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ABSTRACT

Hamilton Standard Space Systems International, Inc. (HSSSI) is under contract to NASA Marshall Space Flight Center (MSFC) to develop a Water Processor Assembly (WPA) for the International Space Station (ISS) Water Processor Assembly. The WPA produces potable quality water from humidity condensate, carbon dioxide reduction water, water obtained from fuel cells, reclaimed urine distillate, shower, handwash and oral hygiene waste waters. This paper describes the WPA integration into the ISS Node 3. It details the substantial development history supporting the design and describes the WPA System characteristics and its physical layout.

INTRODUCTION

A regenerative life support system is being developed for the International Space Station (ISS) United States On-orbit Segment (USOS) to reduce the logistics burden of providing potable water and oxygen to the crew and biological specimens. The basic architecture of the system is depicted in Figure 1. A Water Recovery System (WRS) and an Oxygen Generation System (OGS) combine to provide the capability to produce potable water and oxygen from waste waters generated by the crew and biological specimens. Crew urine, cabin humidity condensate (including condensate evaporated from liquid animal wastes), and waste hygiene water is processed to ISS potable water quality specifications by the WRS. The major components of the WRS are a Urine Processor Assembly (UPA) and a Water Processor Assembly (WPA). Because of its relatively high contaminant load, crew urine is processed separately from all other waste waters via the UPA, which is based on the process of Vapor Compression Distillation (VCD). Distillate from the UPA is combined with remaining waste waters for processing by the WPA. Product potable water from the WPA is available for direct reuse by the crew and animal payloads and as the feed water to the OGS for the production of oxygen via an Oxygen Generator Assembly (OGA). The potential for the future enhancement of the OGS to enable the recovery of additional water via the reduction of carbon dioxide is also provided via appropriate scarring of the OGS.

The general architecture of the WRS has evolved throughout a development program begun during the Space Station Freedom program (1-5). Originally designed as a two-loop system in which potable water was reclaimed from humidity condensate separately from other waste waters reclaimed for hygiene reuse, the WRS now provides a single potable-grade product that is reusable for all purposes. This single loop architecture, which greatly simplifies the architecture and minimizes the size of the WRS, has been made possible due to the confidence gained in the capability of the WPA to reliably produce potable-grade water from a variety of waste water sources.

The WRS will be deployed in two (2) dedicated International Standard Payload Racks (ISPR) to be located within the ISS Node 3. The racks, referred to as WRS Rack #1 and WRS Rack #2, include all the major components of the UPA and WPA along with additional standard outfitting equipment.

This paper presents the WPA requirements followed by a system overview. Component and system development history follow and then the paper finishes with a package description.

WPA REQUIREMENTS

Primary requirements that drive the design of the WPA fall into the categories of Water Quality, Function, Physical Characteristics, Reliability/Safety and Sterilization compatibility. Water Quality drives the particular processes included in the system and the configuration of those processes in the flow train. The functional requirements along with the physical limitations size the individual components in the system. Reliability, Safety and Fault Detection/Isolation drive non-control instrumenta-

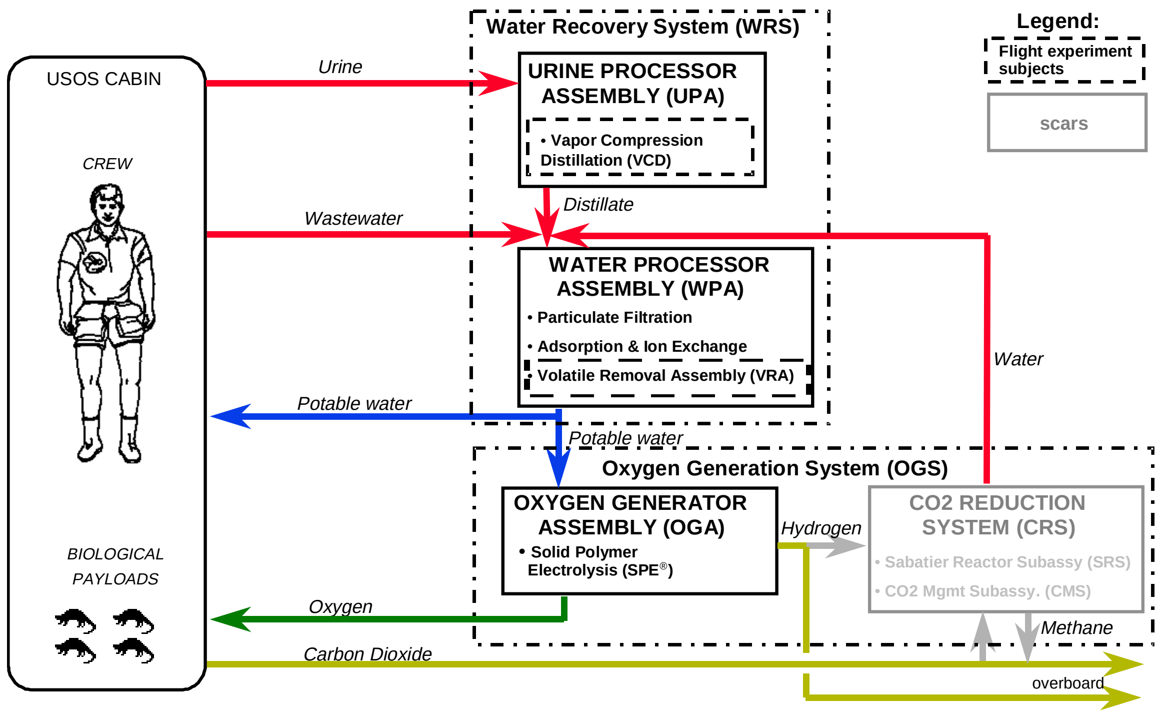


Figure 1. General Architecture of the U.S. Regenerative Life Support System

tion and additional valves. The materials and processes selected must be compatible with the techniques that might be used for On-Orbit Sterilization should the WPA need to recover from on-orbit microbiological upsets. The following are the core requirements in each of these categories.

WATER QUALITY

- Produce Potable water to the water quality standards of Table 1 from the waste water model of Table 2
- Remove gas such that there is no free gas at 98.6°F and 14.7 psia.
- Impart an iodine dose such that the residual iodine in the delivered water is 1-4 mg/l

Functional Requirements

- Operate at a maximum of 18 hours per day to process the WRS design load quantities of Table 3
- Four man crew, process and deliver at the profiles of Figure 2
- Backpressure the waste water bus to no more than 8 psig while accepting 500 pph waste water flow
- Deliver product water at 15 – 30 psig at a rate up to 500 pph with a maximum delivery slug of 6 pounds
- Energy consumption shall average no more than 805 watt-hours/hour while processing and 405 watt-hours/hour in standby
- Maximum gas usage is 0.3 lb/day of oxygen and 0.2 lb/day of nitrogen

Physical Requirements

- Envelope is slightly less than 1½ ISPR racks (1 full rack plus share a second rack with the Urine Processing Assembly)
- Wet weight shall be less than 1450 lbs.
- Resupply weight, including expendables and limited life items shall be less than 1100 lbs./year
- Utilize less than 26 mean maintenance crew-hours per year.

Reliability/Safety

The WPA shall be designed to be:

- zero fault tolerant for functional requirements
- one fault tolerant for critical hazards
- two fault tolerant for catastrophic hazards

On-Orbit Sterilization Compatibility

The WPA shall be compatible with both of the following on-orbit sterilization methods

- 180°F flowing water
- 30 mg/l iodine in water

Table 1. Delivery Water Quality Requirements

Parameter	Specification
Physical	
Total Solids	100 mg/l
Particulates	40 u max.
pH	4.5 – 8.5
Turbidity	1 NTU
Free gas	0 @ 14.7 psia, 98.6°F
Inorganic Constituents	
Ammonia	0. 5 mg/l
Arsenic	0.01 mg/l
Barium	1.0 mg/l
Cadmium	0.005 mg/l
Calcium	30 mg/l
Chlorine (total)	200 mg/l
Chromium	0.05 mg/l
Copper	1.0 mg/l
Iodine (total)	15 mg/l
Iron	0.3 mg/l
Lead	0.05 mg/l
Magnesium	50 mg/l
Manganese	0.05 mg/l
Mercury	0.002 mg/l
Nickel	0.05 mg/l
Nitrate	10 mg/l
Potassium	340 mg/l
Selenium	0.01 mg/l
Silver	0.05 mg/l
Sulfate	250 mg/l
Sulfide	0.05 mg/l
Zinc	5 mg/l
Conductivity	15 umho/cm
Bactericide	
Residual Iodine	1-4 mg/l
Aesthetics	
CO_2	15 mg/l
Microbial	
Bacteria/Fungi	100 CFU/100ml
Total Coliform	Non-detectable
Virus	Non-detectable
Organic Parameters	
Total acids	500 ug/l
Cyanide	200 ug/l
Volatile Organics	< EPA MCL
Semivolatile Organics	< EPA MCL
Total Alcohols	500 ug/l
TOC	500 ug/l

Table 2. Waste Water Model

Parameter	Value
Particulate size	Prefiltered to 100u
TOC	210 mg/l
PH	6.0 to 8.2
Conductivity	600 umho/cm max.
Microbes	10^9 cfu/100 ml
Free gas	18% by volume

Table 3. WRS Design Loads (Lb/day)

Waste Water	Nominal (4 Crew)	Maximum (7 Crew)
Waste shower	0-22.9	0-40.1
Waste handwash	0-34.4	0-69.2
Waste oral hygiene	0-3.2	0-5.6
Crew latent	0-20.1	0-35.1
Pretreated urine	0-13.8	0-24.0
Urine flush water	0-4.4	0-7.6
EHS waste (2.6 lb/7days)	0-0.4	0-2.6
Biological specimen latent	0-7.9	0-7.9
Hygiene and food prep latent	0-3.3	0-5.7
EVA wastewater (7.0lb/7days)	0-1.0	0-7.0
CO_2 reduction water	0	0-9.5
TOTAL	**111.4**	**205.3**

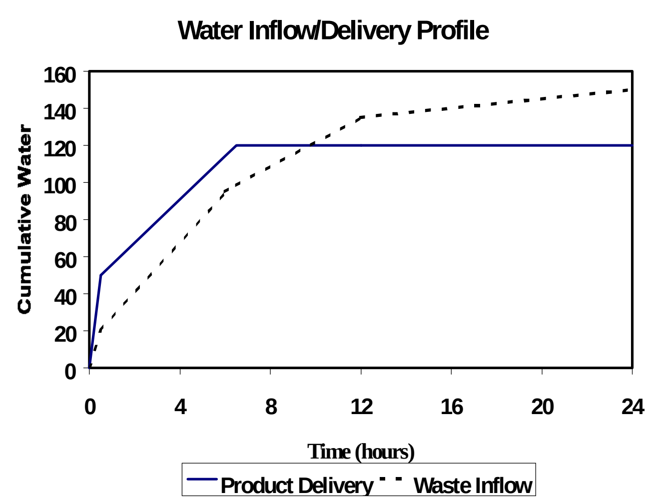


Figure 2.

WATER PROCESSOR ASSEMBLY SYSTEM OVERVIEW

A simplified schematic is shown in Figure 3. Waste water from the bus enters the processor and is stored in the waste water tank. Prior to entering the tank, the waste water flows through an inlet isolation valve. This valve isolates the WPA from the waste bus. Water processing begins by flowing the waste water through a MLS (Mostly Liquid Separator) which removes free gas from the water prior to entering the main pump. This pump provides the necessary head rise to flow water through the processing components and fill the outlet storage tanks. The waste water is first pumped through a particulate filter which protects the multifiltration beds. The multifiltration beds remove non-volatile organic and inorganic impurities from the water. To maximize bed utilization, there are two multifiltration beds in series, with a conductivity sensor between the beds. The beds are designed to breakthrough on inorganic species before organic species and this conductivity sensor provides the necessary detection to determine the replacement time for the first bed. At replacement, the second bed replaces the first, and a new bed is placed in the second bed's position. Water flows through a regenerative heat exchanger to minimize power consumption and maintain proper temperature for gas separation in the gas separator. The water enters a pair of heaters; one to preheat the water up to its setpoint temperature and the second to maintain that temperature. The catalytic reactor then oxidizes the remaining organics with injected gaseous oxygen. The water is cooled in its return flow through the regenerative heat exchanger and then flows through the gas separator that removes excess oxygen and evolved gas. The water then enters the ion exchange bed that removes any remaining by-products (bicarbonates and acetic acid) produced in the catalytic reactor. Conductivity sensors in a bleed stream downstream of the reactor ORU and in the main stream downstream of the ion exchange bed infer acceptability of the water. Water is delivered to the water storage tank where it is made available for use. A three-way solenoid valve returns water back to the processing loop when unacceptable water is detected. A mechanical and microbial check valve is located between the storage tank and the waste water tank to act as a barrier between the two. Water is delivered to the product water bus by a high flow rate pump with the flow rate buffered by a delivery water accumulator. The WPA also contains a firmware controller which provides all the necessary software control to command the effectors within the system and provide fault detection/isolation logic.

Water Processor Assembly

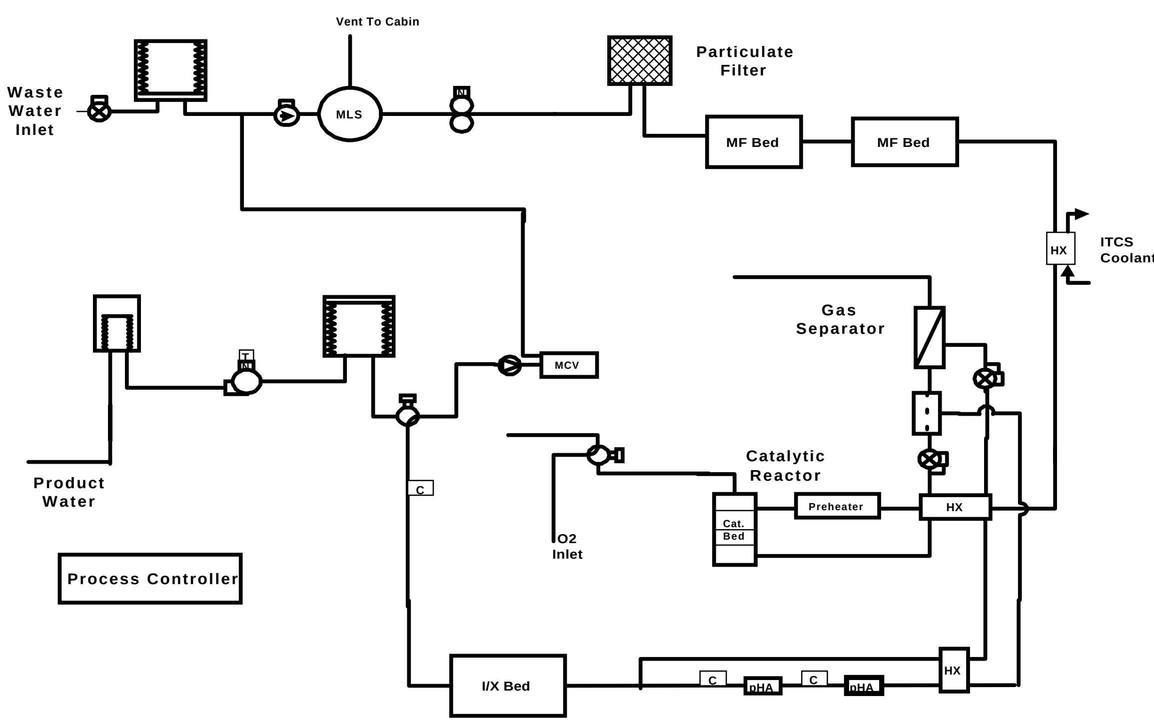


Figure 3.

WPA TECHNOLOGY DEVELOPMENT

Since the fall of 1992, when the effort on the flight Water Processor for Space Station Freedom was suspended, development programs on several key WPA components were conducted. These programs were conducted by HSSSI under funding from both ION Electronics and Boeing Aerospace sponsored by NASA MSFC. The objective of these programs was to mitigate the risks to their eventual use in the ISS WPA. The programs were conducted on the four components: Process Pump, Mostly Liquid Separator (MLS), Volatile Removal Assembly (VRA), and Gas Liquid Separator (GLS).

PROCESS PUMP – The Process Pump is an integral component in the Pump/Separator ORU in the WPA. The function of this ORU is remove any free gas from the waste water prior to processing, and then provide the processing flow and system head pressure. The function of the Process Pump is to provide the system flow and head pressure, 15 lb/hr and nominal 70 psig respectively.

Other key requirements are:

Operating life: 4000 hours minimum (1 year of operation)
Particulate size: 0 - 100 µm
Operating pressure: 0 – 125 psig

Background – As part of the SSF Water Processor program, a gear pump was tested at HSSSI through the first and second quarter of 1992. The results of this testing revealed that improvements in corrosion resistance would be necessary to achieve the pump's performance and life requirements. (Reference 6)

The initial development program was conducted under contract NAS8-38250-12 for Ion Electronics from March 1994 through July 1995. The objective of this program was to continue the development of originally procured pumps (HFS M/N 2992) and to significantly improve the pump corrosion resistance while still meeting the pump performance requirements.

A follow-on program was conducted under contract NAS8-50000-JC6104 for Boeing Aerospace from November 1995 through July 1997. This program was conducted in two phases. Phase I was conducted from November 1995 through August 1996, which included a trade study of all available pump technologies suitable for the WPA application along with a selection of suppliers. Phase II was conducted from August 1996 through July 1997, which included procurement and test of four different pump technologies. Refer to HSSSI Report SVHSER18280 dated July 31, 1997 for complete program details. (reference 9)

The trade study in Phase I concluded with the following positive displacement technology recommendations for pump development and testing: Gear, Vane, Piston and Diaphragm. Positive displacement pumps were selected due to requirements for potential gas ingestion along with the low flow and high-pressure head requirements.

During Phase II, the four pumps were procured, performance mapped and life tested over several months. The conclusion of the testing indicated that the Gear and Piston pumps met the minimum performance life of 4000 hrs with only slight performance reduction. A recommendation of this program was to continue life test on the three remaining pumps, Gear, Vane and Piston, for further evaluation. The Diaphragm pump experienced a housing failure during the test phase and was eliminated from further evaluation.

The current Node 3 WPA Program, along with NASA-MSFC agreement, re-evaluated the previous pump program recommendations. The decision was to continue testing on the Gear and Vane pumps while eliminating the Piston. This pump was dropped as a result of technical complexity, development cost and schedule. An additional recommendation was to develop an alternate Gear pump.

The two existing pumps (Gear and Vane) were put back on test at HSSSI in 4^{th} Quarter 1998. The Vane pump was significantly modified by original manufacturer under a contract directly from NASA-MSFC. This modified Vane pump was provided to HSSSI for further testing.

The Gear pump continued operation and accumulated 7500 hrs of operation prior to a motor failure. As of this writing, the failure investigation has not reached a conclusion as to a specific cause. The Vane pump is still operating with approximately 4300 hrs accumulated.

A new Gear pump supplier is currently under contract to deliver their pump in June 1999. This pump will incorporate several key features that will improve operating performance and life. Some of the key features include ceramic-coated Inconel 718 housings, lower operating speed with larger diameter ceramic gears and larger ceramic journal bearings.

MOSTLY LIQUID SEPARATOR (MLS) – The MLS is an integral component in the Pump/Separator ORU in the WPA. The function of this ORU is remove free gas from the waste water prior to processing. A pump then provides the processing flow and system pressure head. The function of the MLS is to remove free gas from the waste water. To accomplish this, HSSSI developed a patented concept that uses a series of rotating disks to create a gravity field by spinning the water against the inside diameter of the separator housing and by collecting and venting the gases from the center. The development of this separator was unique since there were no other known zero-gravity separator technologies that could handle the combination soap, particulates, and biomass.

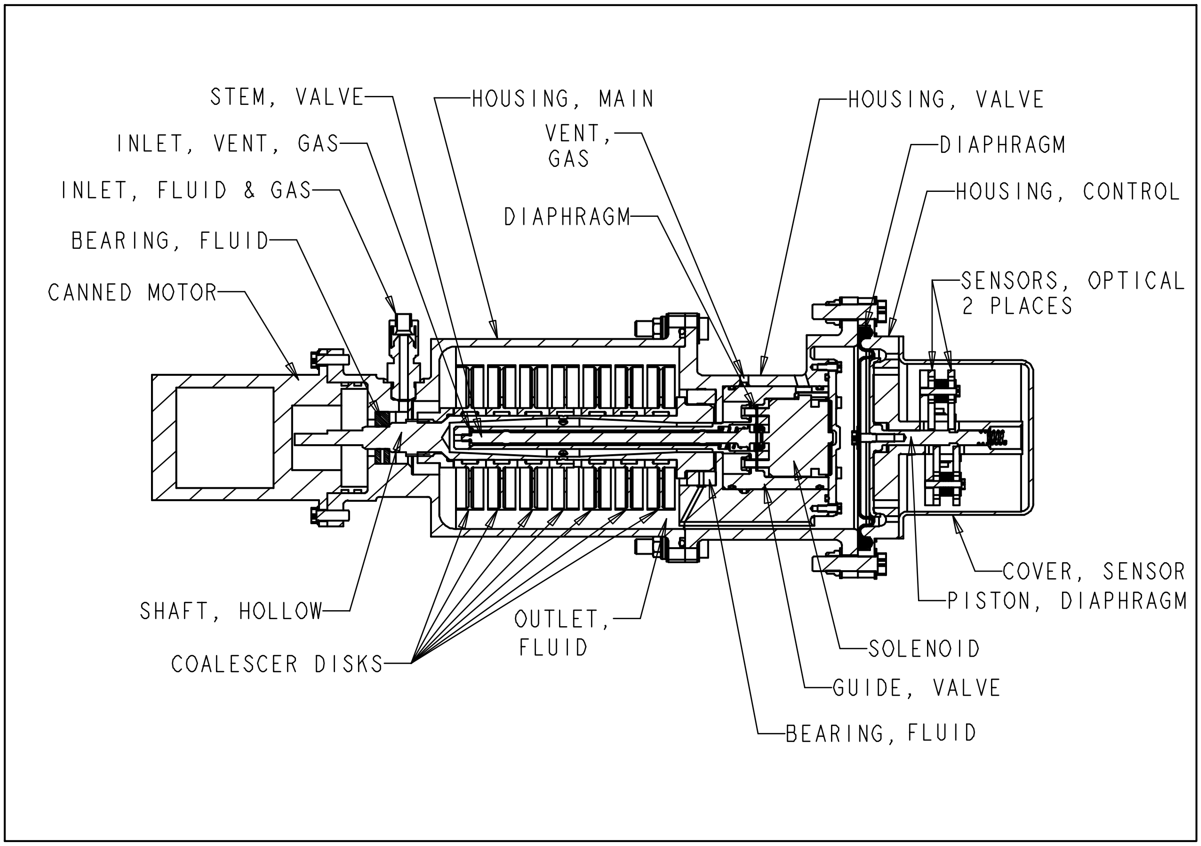


Figure 4.   MLS Cross-section

MLS Key Requirements

Water Flow Rate: 13 – 19 lb/hr
Inlet Free Gas: 0% - 100% min/max
0% - 10% average
Particulate Size: 0 – 100 µm

Fluid – Combination of waste hygiene, humidity condensate and urine distillate

Operating Pressure: 0 – 8 psig
Operating Temperature: 63 - 113°F

Background – As part of the SSF Water Processor Program, a prototype MLS was developed for initial application within the Potable Water Processor. After the Space Station Freedom (SSF) System modification that combined the potable and hygiene waters into a single water loop, the MLS was evaluated for use in the SSF WP.

The initial development program was conducted under contract NAS8-38250-12 for Ion Electronics from March 1994 through July 1995. The objective of this program was to develop a full-scale MLS for the International Space Station (ISS) Water Processor. Two development units were fabricated for evaluation. One unit, utilizing clear plastic housings, was used for a series of performance tests, while the second unit, fabricated using stainless steel housings, was used for extended duration tests.

A series of performance evaluations were conducted on the plastic MLS. These included performance maps for air and water carryover on clean, virgin soap and real shower waste waters. The metal MLS was performance tested before and after 300 hrs of operation with real waste water. The conclusions from this program indicated both the units met the key performance requirements, and that the extended duration test had no impact on the MLS performance. In addition, further development was needed for the integral control mechanism.

A follow-on program was conducted under contract NAS8-50000-JC6104 for Boeing Aerospace from November 1995 through July 1997. The objective of this program was to improve performance and operational control. Specific improvements included a new internal control valve within the MLS center shaft and improved sizing for both water and gas flow.

Conclusions from this latest program included:

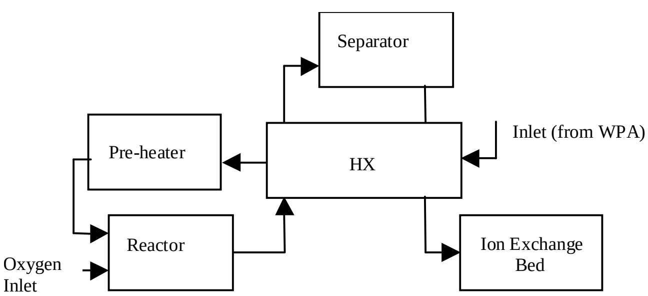
- MLS exceeded requirements for liquid/gas separation
- Control mechanism, although improved was still inadequate to perform fault override (flooding operation and draining prevention)

The current Node 3 WPA program is continuing MLS development by concentrating on simplification of the override control mechanism as well as incorporating flight design features (e.g.: Bearings, motors, seals). A cross-section of the current MLS is shown in Figure 4.

The development test program is being conducted in two phases. In Phase I, the objective was to evaluate an internal back-pressuring device, pitot tube, aimed at control simplification. The testing was conducted in the first quarter of 1999 and was found to have partial success. The requirement for back-pressure was to generate up to 5 psig. The test results indicated only 3 psig was generated at MLS operating speeds greater than desired. The WPA schematic was then modified to incorporate an external solenoid valve for MLS operational control. As of this writing, this solenoid valve will be operated by optical sensors located in the MLS. The MLS has been modified and will be tested as part of Phase II during the second quarter of 1999.

VOLATILE REMOVAL ASSEMBLY (VRA)

Multifiltration beds remove the higher molecular weight organics, but are not efficient at removing volatile organics, e.g., ethanol, acetone, isopropyl alcohol. The VRA is a HSSSI patented device whose function is to oxidize those organics and provide a sterilization barrier for the WPA. A simplified schematic of the VRA is shown as follows:



Water enters into the regenerative heat exchanger and preheater for heating prior to entering the reactor. The reactor is the main component within the assembly and is responsible for oxidizing the organics. By-product gases and chemicals are subsequently removed by the separator and Ion Exchange Bed respectively.

Reactor and catalyst development has continued at HSSSI which has resulted in improvements in both catalyst performance and reactor configuration. A substrate change has improved operational life, while improvements in catalyst formulation have enhanced performance. The catalayst now permits treatment of additional chemicals, primarily acetone, which was challenging the reactor.

During the same time, a VRA Flight Experiment program was initiated in July 1995 under contract NAS8-40343 from NASA-MSFC. The purpose was to design and develop an experiment to evaluate microgravity performance of the VRA and its components. In doing so, the reactor configuration was changed from a single 2.5" diameter canister to a two-canister design. Test results indicated a smaller diameter canister would provide improved performance. The same flow residence time was maintained in the two-canister configuration to provide a consistent basis of microbial barrier. This new configuration along with the new catalyst was evaluated at NASA-MSFC as part of Stage 10 testing. The results indicated that the reactor met the chemical performance requirements while not affecting its operating life or microbial reduction performance.

The initial launch of the VRA Flight Experiment onboard STS-89 in January was unable to provide any reactor chemical performance data due to a regulator anomaly. A reflight aboard STS-96 is scheduled for May 1999.

In addition to the flight experiment, efforts on analytical predictions of the reactor's microgravity performance have been conducted. Since the analytical predictions are extremely difficult for microgravity operation of a two-phase flow within packed bed, additional testing is being conducted. This testing includes flow visualization evaluations of a packed bed in one gravity which have been conducted at both MSFC and HSSSI. The final stage of these flow tests will be a series of experiments onboard the NASA KC-135 airplane currently scheduled for June 1999.

GAS/LIQUID SEPARATOR (GLS) – The GLS is located just downstream of the catalytic reactor. The function of the GLS is to remove any excess oxygen, reactor gas by-products or other gases in the WPA product water. The GLS is operated at high temperature and low pressure to improve the separator operation.

GLS Key Requirements
Water Flow Rate: 13 – 19 lb/hr
Operating Temperature: 160 - 190°F
Operating Pressure: 4 – 6 psig
Outlet Gas: No free gas @ 14.7 psia, 100°F

Background – Several variations of separators have been used through out the different water processing systems developed at HSSSI. These have included commercial hollow fiber membranes and custom designed hydrophobic/hydrophilic separators. The commercial separators are not capable of the required operating temperatures while the custom designed separators have shown limited operating life.

As a result of unacceptable life performance of the hydrophobic/hydrophilic GLS in stage 10 testing at NASA-MSFC, a development program at HSSSI was conducted. This program was conducted for ION Electronics under contract NAS8-40369-4376 from February 1998 to January 1999. The objective of this program was to conduct a detailed evaluation of available technologies for the WPA application.

The program was conducted in two phases. In the first phase, a trade study was conducted to select the best technologies for the GLS. The primary conclusion of the trade study was that passive separators based on hydrophobic membranes were best suited for the application.

The second phase evaluated several hydrophobic membrane configurations. Selected membranes were then ranked to identify the best membranes for the application.

The conclusions from Phase II of this program recommend the use of the following:

- Hollow fiber module using TFE based Millipore proprietary membrane
- Flat sheet hydrophobic PVDF coated with Teflon AF2400
- Flat sheet membrane of solid Teflon AF2400
- Hollow fiber membranes using solid Teflon AF2400

The current Node 3 WPA program has continued the GLS development following the completion of the ION Electronic program. Two flight-sized GLS prototypes have been designed. One uses a Millipore hollow fiber membrane, while the other uses a series of flat hydrophobic PVDF sheets coated with Teflon AF2400. Both separators are being fabricated to evaluate the separators performance. Development testing of these separators is planned for the second and third quarter of 1999. The test results, along with other factors (i.e., weight, volume, cost & fabrication complexity) will be evaluated to select the flight concept of the GLS.

LESSONS LEARNED

The general architecture of the WRS has evolved throughout a development program begun during the Space Station Freedom program (1-5). Many lessons learned from that development activity through the 1990s have been incorporated into the present design. Some examples of those lessons are detailed in Table 4.

Table 4. Lessons Learned

Lesson Learned	**Implementation**
Volatile Removal Catalytic Reactor reduces virus by 12 log units	Virus control verified
Multifiltration bed performance was not affected by removal of the upstream pre-sterilizer	Eliminated from schematic
Baseline system maintained microbial control for duration of testing	Bacterial control verified
250°F hot water sterilization for one hour in tanks and 30 minutes for tubing achieves adequate microbial control	Equivalent criteria used for ground sterilization
Bacterial control - dead legs are not a problem as long as they are initially sterile; 180°F is ok for stagnant water	Start-up filter dead leg is ok
Particulate filter (0.5u) loaded only on surface	Various filter configurations (especially 5u) being assessed in integrated system test
To meet product water free gas requirements, the gas/liquid separator needs to be operated at temperatures above 130°F	Located at mid-temperature tap of regenerative heat exchanger
Acetone detected in water exiting the multifiltration beds	VRA catalyst reformulated and tested in subsequent integrated system testing
Reactor catalyst fines generated during launch vibration impacted performance of downstream components	Filter incorporated downstream of reactor
Packed beds generated fines during vibration testing	Final 40u filter at IX bed outlet. Also, filtration at multifiltration bed outlet.
Leachates affect water acceptability at outlet of Ion Exchange Bed for approximately 1 volume time if system off for 4 hours	Schedule recycle timing coming out of Standby Reduced bed volume by ½ Assessing chemical control Keeping bed cool to reduce thermal degradation
Automatic calibration intervals of PCWQM interfered with processing	Calibrations and active bit during Standby
PCWQM internal lags causes PCWQM to signal everything ok when not	PCWQM TOC measurement in bypass for timed interval on startup
Iodine poisons VRA catalyst - need to protect against inadvertent iodine contamination	Schematic, maintenance procedures, QD keying
Backpressure regulator needs to be set 10 psig above pump on/off band to control pump cycling during Standby	Set at 55 - 59 psig

Table 4. Lessons Learned

Lesson Learned	Implementation
Consistent evidence of start-up thermal instability of preheater and reactor in stage 9 and stage 10. The cold slug from the preheater would cause wild oscillations of heater control for ½ to 1 hour with the resulting cycling temperatures.	Preheater in Hot Box. Regenerative HX thermally coupled
Preheater control sensor location on outer shell was a problem (inaccurate reading due to location). It read and controlled to 230 - 232°F when actual temperature read 250°F.	Control by immersion sensor downstream
Process flow control needs to be more timely than tank control – must have real time flow measuring device	Incorporated delta P sensor across heat exchanger for flow control
There were water delivery (lack of water) problems: 1) during maintenance, 2) when total system water quantity was low, 3) when the tank control logic wanted to fill a tank to completion when delivery was needed., 4) at low pump flow. Part of the problems were attributed to the PDR logic of demanding that the fill tank be completely filled before switching to delivery.	Modifying control logic to provide product water availability 100% of time.
Hydrophobic/Hydrophilic GLS has 30 day life	Development effort on “Hydrophobic only” design.
Gravity sensitivity of two phase reactor suspected	Evaluation tests include ground assessment/ evaluation tests, KC135 testing and VRAFE orbital test.
Process feed pump life unacceptably short	Pump development program – now 7000 hours
Waste water characterization	System design basis
Hygiene and Potable water processing can be accomplished in one unit. Significant Space Station equipment and plumbing savings offset expendable impact	Hygiene WPA and Potable WPA combined into one process
Reactor health can be inferred by measuring downstream conductivity	Replaced PCWQM with Reactor Health Sensor

PACKAGING

The WPA consists of a total of 15 ORUs (Orbital Replaceable Units), of which six are expendable ORUs which require changeout on a regular basis, and two are limited life items which require replacement as they wear out. WPA has been allocated one full ECLSS Equipment Rack plus most of the right side of a second rack. It shares the second rack with the Urine Processing Assembly (UPA) whose distillate is one of the waste water sources feeding the WPA. An Avionics Air Assembly (AAA), a smoke detector and a rack maintenance switch are part of the Rack #1 package. Mechanically, functionally and pragmatically, the ECLSS Equipment Rack is structurally identical to an International Standard Payload Rack (ISPR). The full rack, Rack #1, is a five-post configuration, while the shared rack, Rack #2, is the six-post configuration. Major constraints in locating ORUs within the rack are the bowed back surface, the intercostal bracket, and the structural closeout panel.

The package arrangement was driven by a number of considerations as follows:

- Frontal access is required for expendable ORU’s
- Frontal access is a goal for non-expendable ORU’s
- Tilt out of rack is allowed for maintenance of non-expendable ORU’s
- Removal of one ORU to gain access to another ORU is not preferred
- Use of slides and guides facilitates maintenance
- One full rack plus 40% of a second rack available for packaging
- Maximize expendable bed life
- Minimize inter-rack plumbing lines
- 25 Hz minimum rack natural frequency
- ORUs are mounted to structural shelves with corner brackets attaching the shelves to vertical rack posts
- ORU weight must be evenly distributed throughout rack
- Avionics air cooling of Rack 1
- Convective cooling of product water
- Hot section of Rack #1 (Catalytic Reactor ORU & Gas Separator ORU) requires shielding from convective cooling losses
- Smoke detection within Rack 1

- Continuous air flow around components and throughout Rack 1
- Interfaces at Rack #1 and #2 front panel required to vent system gasses

The resulting design is shown in Figure 5 for Rack #1 and Figure 6 for Rack #2. Table 5, which is organized to follow the process water flow in the system, identifies the rack location and defines the life for each ORU. From the table, it is apparent that, except for the particulate filter, all of the waste water end of the system is packaged in Rack 2. The remainder is packaged in Rack #1. This, to the largest extent practical, keeps the waste water with the UPA and minimizes inter-rack plumbing. Functions are co-located with the Waste Water ORU and the Pump/MLS ORU adjacent to each other. Locating the Multifiltration ORUs adjacent to each other simplifies expendable changeout from the front of the rack. When Multifiltration Bed #1 is expended, it is removed. Multifiltration Bed #2 is then removed and replaced in the Bed #1 location. A new bed is then inserted in the Bed #2 location.

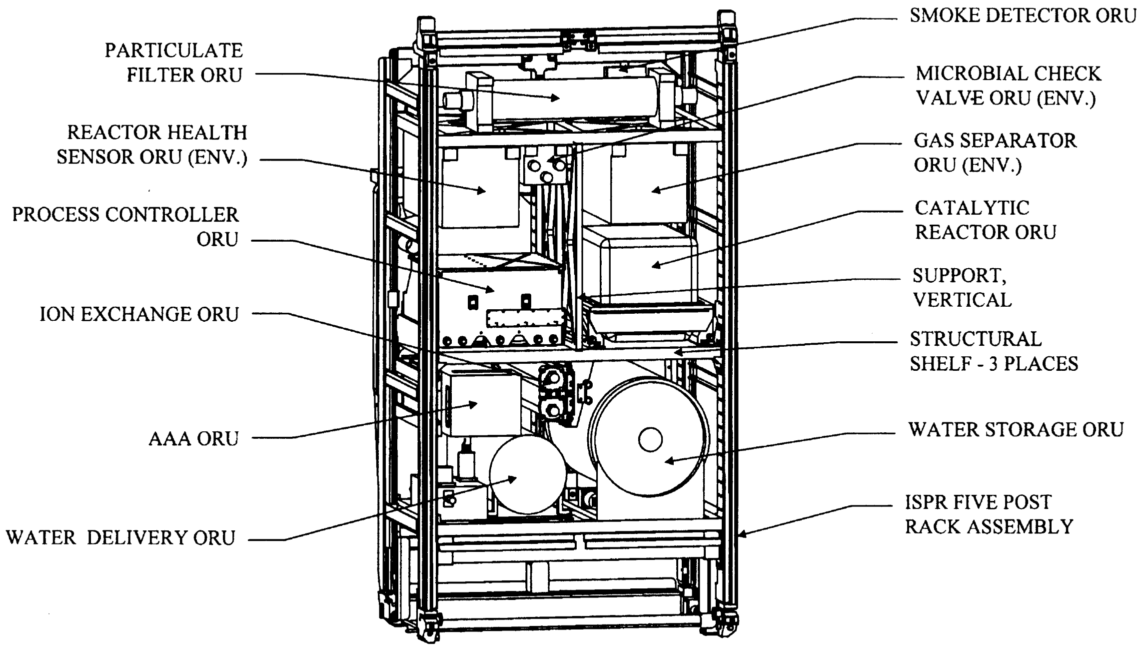
In Rack #1, the particulate filter ORU is tucked in the top of the package. ORUs associated with volatile organic control (catalytic reactor, gas separator and reactor health sensor ORUs) are located in the middle of the package, while the final delivery equipment (ion exchange, water storage and water delivery ORUs) are located in the bottom of the package. The AAA is located at the bottom of the package with the process controller and MCV ORU located in the remaining volume in the package center. It was highly desirable to locate the AAA at the package bottom for air flow circulation throughout the package, for thermal control and for smoke detection. A parallel network of inlet ducts throughout the package feed the AAA. Flow from the AAA exhausts radially from the outlet, bathing the water delivery equipment in cool air to cool the water for crew consumption. The flow then washes upward through the package to the inlet ducts. With the smoke detector ORU located at the very top of the package, the air entering it has swept over the full package to insure detection of smoke from all sources. The hot elements of the WPA, namely, the catalytic reactor ORU and the gas separator ORU, are located to the right of the package middle with a vertical panel separating that section from the remainder of the package. AAA flow to that area is small to minimize heat leak and therefore conserve power. To minimize maintenance time, expendables are changed out without allowing the rack to cool down. The panels and package arrangement serve to prevent the crew from being near the hot areas during changeout of the particulate filter, ion exchange and MCV ORUs. These ORUs are easily accessible from the front of the rack to facilitate expendable changeout.

Table 5. ORU Identifications and Characteristics

ORU	Rack	Life Category	Life (days)
Waste Water	2		
Pump/MLS	2	Limited	720
MLS Filter	2	Expendable	120
Particulate Filter	1	Expendable	40
Sensor	2		
Multifiltration Bed #1	2	Expendable	66
Multifiltration Bed #2	2	Expendable	66
Catalytic Reactor	1		
Gas Separator	1	Limited	360
Reactor Health Sensor	1		
MCV (Microbial Check Valve)	1	Expendable	360
Ion Exchange	1	Expendable	60
Water Storage	1		
Water Delivery	1		
Process Controller	1		
Rack #1 Resident Heat Exchanger	1		
Avionics Air Assembly (GFE)	1		
Smoke Detector (GFE)	1		
Rack Maintenance Switch (GFE)	1		

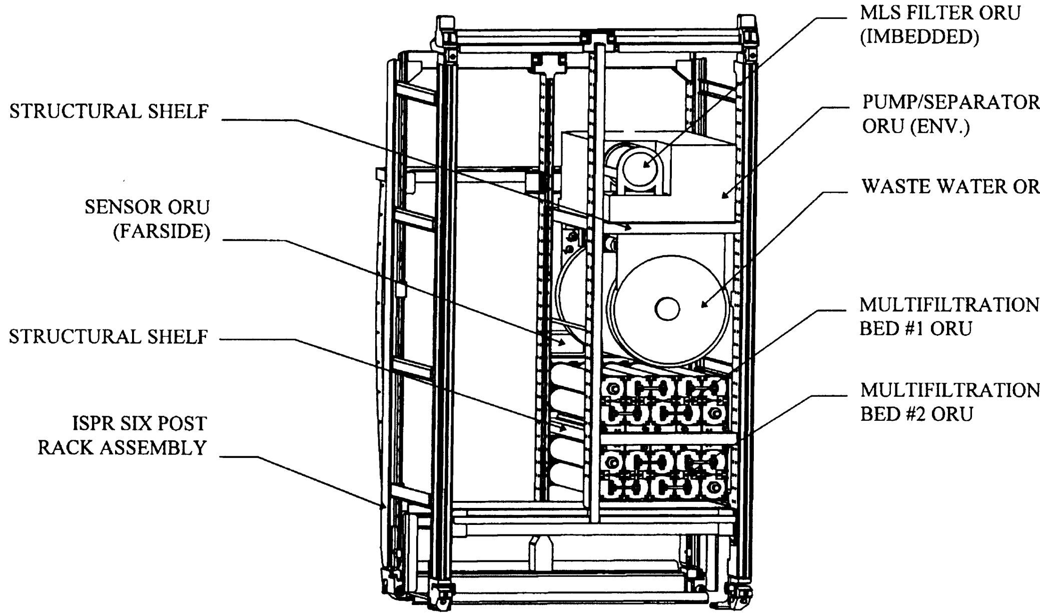
CONCLUSION

HSSSI is developing a WPA as part of the ISS Node 3 Regenerative Life Support System for MSFC. The WPA is required to store and process various waste waters collected to potable standards for crew consumption. The capabilities of the base technologies utilized, filtration, ion exchange, and catalytic oxidation have been demonstrated through a series of water recovery tests at MSFC and development tests at HSSSI. The ISS WPA requirements have been defined, system schematic finalized, package developed and detailed designs are in process.



WPA RACK #1 ASSEMBLY
FRONT ISOMETRIC VIEW

Figure 5.



WPA RACK #2 ASSEMBLY
FRONT ISOMETRIC VIEW

Figure 6.

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