

Chemical Analysis Results for Potable Water Returned from ISS Expeditions 14 and 15

John E. Straub II, Debrah K. Plumlee and John R. Schultz
Wyle

ABSTRACT

The Johnson Space Center Water and Food Analytical Laboratory (WAFAL) performed detailed ground-based analyses of archival water samples for verification of the chemical quality of the International Space Station (ISS) potable water supplies for Expeditions 14 and 15. During the 12-month duration of both expeditions, the Space Shuttle docked with the ISS on four occasions to continue construction and deliver additional crew and supplies; however, no Shuttle potable water was transferred to the station during Expedition 14. Russian ground-supplied potable water and potable water from regeneration of humidity condensate were both available onboard the ISS for consumption by the Expeditions 14 and 15 crews. A total of 16 chemical archival water samples were collected with U.S. hardware during Expeditions 14 and 15 and returned on Shuttle flights STS-116 (12A.1), STS-117 (13A), STS-118 (13A.1), and STS-120 (10A) in December 2006, and June, August, and November of 2007, respectively. The average return sample volume of 0.73 liters was sufficient to allow full chemical characterization to be performed. This paper reports the analytical results for the condensate-regenerated and ground-supplied/stored potable water archival samples that were returned from Expeditions 14 and 15, and compares these results to ISS water quality standards. Potable water samples collected in-flight with Russian hardware and pre-flight samples of Rodnik potable water delivered to the Station on the Russian Progress vehicle during Expeditions 14 and 15 were also received from the Russian side and analyzed by the WAFAL. Analytical results for these additional ISS potable water samples are also reported and discussed in this paper.

INTRODUCTION

Onboard the International Space Station (ISS) there are 3 different sources of potable water that can be made

available to the crews: Russian ground-supplied water, Shuttle-transferred water, and condensate reclaimed water. The Russian side periodically prepares filtered groundwater from Korolev, Russia that is stored in two 210-liter Rodnik tanks and launched on the Progress vehicle for delivery to the ISS. Electrolytically-generated silver is added to this water during ground preparation to inhibit microbial growth during transport and storage. During Expedition 15, both the Progress 25 and 26 vehicles delivered Rodnik potable water to the station.

Potable water can also be transferred from the Shuttle to the ISS in contingency water containers (CWC's). During the 12-month duration of Expeditions 14 and 15, the Space Shuttle docked with the ISS on four occasions to continue construction and deliver additional crew and supplies. Shuttle potable water was transferred to the station during Expedition 15. Shuttle potable water consists of fuel cell generated water to which 2 to 4 mg/L iodine has been added. Iodine is removed and silver and minerals are added to Shuttle water during the filling of each CWC to be transferred to the station [1]. Either Rodnik water or Shuttle-transferred potable water can be used as the water supply for the stored potable water system (SVO-ZV) located in the Service Module (SM). The SVO-ZV system consists of a 22-liter bladder tank (EDV) connected to a manual air pump for pressurization of the bladder and a dispenser for crew access.

Atmospheric humidity condensate is recovered from cabin air and processed into potable water in the Russian condensate water recovery system (SRV-K) (see Figure 1). The SRV-K is designed to process either humidity condensate coming directly from the SM cabin air heat exchanger or condensate collected in the U.S. Laboratory (Lab) module and stored in a CWC. A Condensate Feed Unit is available to transfer the condensate from the CWC for processing. After it is



Documents

Document Sharing Hub

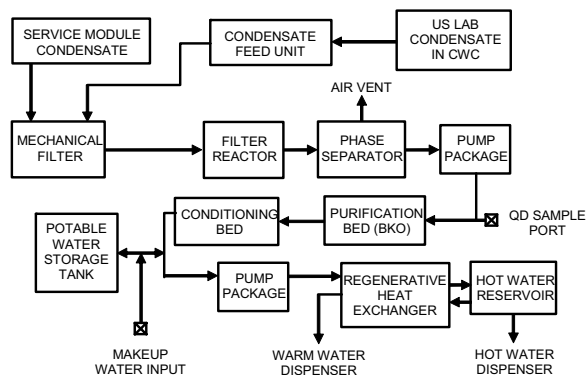


Figure 1. SRV-K condensate water recovery system

filtered to remove particulate matter, the condensate flows through a catalytic filter reactor, phase separator, and multifiltration beds (BKO) for removal of organic and inorganic contaminants. A conditioning bed then adds silver biocide, as well as minerals (calcium, magnesium, and fluoride) to improve palatability. The conditioned product water is stored in a tank that feeds the SRV-K galley (see Figure 2), where it is finally pasteurized and dispensed to the crews from either a hot or warm port. Whenever demand for drinking water exceeds the availability of condensate, the SRV-K system is also designed to use stored potable water for makeup. The source water can be either Shuttle-transferred potable water or Rodnik water. Since formate is not normally found in Rodnik water, its presence in either the SRV-K or SVO-ZV water samples is considered an indicator that the source is Shuttle-transferred potable water.



Figure 2. SRV-K Galley Located in Service Module

Requirements for water quality and monitoring of the ISS potable water supplies can be found in the ISS Medical Operations Requirements Document (MORD) [2]. The monitoring requirements specify the collection of chemical archival water samples from the SRV-K hot and warm ports and the SVO-ZV port for return and ground-based analyses. The Johnson Space Center (JSC) Water and Food Analytical Laboratory (WAFAL)

performs detailed chemical analyses and coordinates sharing of samples and analytical data with International Partners. Analytical results for archival potable water samples collected during Expeditions 1-13 have been previously reported [3,4,5,6,7,8]. The results for samples collected during Expeditions 14 and 15 are discussed herein.

COLLECTION OF POTABLE WATER SAMPLES

Collection of water samples from either the SRV-K or SVO-ZV ports during Expeditions 14 and 15 using U.S. hardware involved the use of similar procedures. The port was first disinfected using a benzalkonium chloride wipe before a sampling adapter was connected. A 300-mL FEP (fluorinated ethylene propylene) small waste water bag was then attached to the adapter and 50-mL of water was collected in the bag to flush any dead volume prior to the actual sample collection. Chemical archive samples were then collected by attaching a 1-liter FEP sample bag to the port and dispensing a target volume of 750-mL into the bag. Figure 3 is a photo taken during a SVO-ZV water sampling session.



Figure 3. SVO-ZV Flush Water Sample Collection

EXPEDITION 14

Soyuz 13 launched on September 18, 2006 carrying the two-man Expedition 14 crew to the ISS. During the seven month expedition the Space Shuttle docked with

the ISS only once on December 12, 2006, when the STS-116 (12A.1) mission delivered cargo and a third expedition member. A total of 8 chemical archive potable water samples were collected with U.S. hardware during Expedition 14. On October 13, 2006 the crew collected the first set of chemical archive samples in 1-liter FEP samples bags from SRV-K warm and SVO-ZV ports. A second set of 1-liter bag samples was collected on December 5, 2006 from the SRV-K hot and SVO-ZV ports. All four samples were returned on STS-116 (12A.1). The crew also collected two more sets of 1-liter samples using U.S. sampling hardware on January 16, 2007 (SRV-K warm and SVO-ZV) and March 8, 2007 (SRV-K warm and SVO-ZV). These 4 samples remained onboard until they could later be returned during Expedition 15 on STS-117 (13A). In addition to the U.S. samples, the Expedition 14 crew also collected one SVO-ZV sample on April 3, 2007 in a Russian drink bag that was returned on Soyuz 13.

RODNIK POTABLE WATER TANKS

On April 2, 2007, Russian water specialists collected two preflight samples of ground-prepared potable water that was later loaded into the two Rodnik storage tanks on the Progress 25 vehicle and delivered to ISS during Expedition 15. The U.S. side received small aliquots of each sample for chemical analysis on May 14, 2007. Again on June 20, 2007, the Russian side collected a preflight sample of Rodnik water loaded on Progress 26 and delivered during Expedition 15. The U.S. portion of this sample was received for analysis on July 31, 2007.

EXPEDITION 15

Expedition 15 began in April of 2007 with the arrival of the two-man ISS crew on Soyuz 14. During this 6-month expedition, three Shuttle flights, STS-117 (13A), STS-118 (13A.1), and STS-120 (10A) docked with the ISS in June, August, and October of 2007, respectively. A third expedition crew member was transported to the ISS on STS-117 (13A). Chemical archival sample collections with U.S. hardware were scheduled approximately every month in accordance with the ISS MORD requirements. A total of 8 chemical archive potable water samples were collected with U.S. hardware during Expedition 15. The U.S. chemical archive samples were collected into 1-L FEP sample bags with target volumes of 750-milliliters each. On May 23, 2007 the crew collected samples from the SRV-K hot and SVO-ZV ports. These two samples were returned on STS-117(13A) along with 4 other U.S samples collected earlier during Expedition 14. Later, on July 6, 2007, two more samples were collected from the SRV-K hot and SVO-ZV ports. These two samples were returned on STS-118 (13A.1). The crew also collected SRV-K warm and SVO-ZV samples on September 4, 2007 and SRV-K hot and SVO-ZV samples on October 1, 2007. These four samples were returned on STS-120

(10A). In addition to the U.S. samples, the Expedition 15 crew also collected 4 potable water samples (2 SRV-K hot, 1 SRV-K warm and 1 SVO-ZV) using Russian sampling hardware on October 10, 2007. These 4 samples returned with the crew on Soyuz 14.

SAMPLE ALLOCATION & ANALYSES

The WAFAL sent a representative to the Kennedy Space Center in Florida to retrieve the ISS potable water samples that returned on Shuttle flights STS-116 (12A.1), STS-117 (13A), STS-118 (13A.1), and STS-120 (10A) on December 22, 2006, June 22, 2007, August 21, 2007, and November 7, 2007, respectively. These samples were packed into coolers along with ice packs and transported to Houston via commercial airlines. The ISS water samples that returned on Soyuz 13 and Soyuz 14 on April 21, 2007 and October 21, 2007, respectively, were received by Russian water specialists and portions transferred into FEP sample bottles provided by the WAFAL. NASA representatives packed these samples inside coolers with ice packs and transported them to Houston on a NASA jet.

Once the samples arrived at the Johnson Space Center, allocation was done in the WAFAL based upon return sample volume. The samples collected into U.S. 1-L FEP sample bags usually contained sufficient sample volume (>500 milliliters) to support full characterization using standard and custom analytical methods as shown in Table 1.

Table 1. Potable Water Analytical Methods	
PARAMETER	METHOD
pH & conductivity	Potentiometric
Turbidity	Nephelometric
Total Dissolved Solids	Gravimetric
Metals/Minerals	Inductively coupled plasma-mass spectrometry (ICP/MS)
Inorganic anions & cations	Ion chromatography (IC)
Iodine & iodide	Leuco crystal violet (LCV)
Fluoride	Ion selective electrode (ISE)
Total organic carbon (TOC)	Ultraviolet or heated persulfate oxidation
Semi-volatile organics	GC/MS after liquid/liquid extraction (modified EPA method 625)
Volatile organics	GC/MS with a purge & trap concentrator (EPA method 524.2)
Alcohols & glycols	Direct Injection gas chromatography/mass spectrometry (GC/MS)
Organic acids & amines	Capillary electrophoresis (CE)
Urea/Caprolactam	Liquid chromatography (LC) with UV diode array detector
Formaldehyde	GC/MS after derivatization & extraction

As a part of data analysis and reporting, the analytical results for each archival water sample were compared against the Russian Segment potable water quality requirements from the ISS MORD (see Table 2).

Table 2. Russian Segment Potable Water Quality Requirements

Parameter	Units	SVO-ZV (Supplied)	SRV-K (Regenerated)
PHYSICAL:			
pH	-	5.5 - 9.0	5.5 - 9.0
Turbidity	mg/L	1.5	1.5
Total Dissolved Solids	mg/L	1000	100
Color	degree	20	20
Taste	grade	2	2
Odor	grade	2	2
Total gas@1atm,20°C	%	5	5
INORGANIC:			
Ammonia (NH ₃ -N)	mg/L	2	2
Arsenic	mg/L	0.01	0.01
Barium	mg/L	1	1
Cadmium	mg/L	0.005	0.005
Calcium	mg/L	100	100
Chloride	mg/L	250	250
Chromium	mg/L	0.1	0.1
Copper	mg/L	1	1
Cyanide	mg/L	0.2	0.2
Fluoride	mg/L	1.5	1.5
Iodine-total	mg/L	0.05	0.05
Iron	mg/L	0.3	0.3
Lead	mg/L	0.05	0.05
Magnesium	mg/L	50	50
Manganese	mg/L	0.05	0.05
Mercury	mg/L	0.002	0.002
Nickel	mg/L	0.1	0.1
Nitrate (NO ₃ -N)	mg/L	10	10
Selenium	mg/L	0.01	0.01
Silver	mg/L	0.5	0.5
Sulfate	mg/L	250	250
Total Hardness	meq/L*	7	7
Zinc	mg/L	5	5
ORGANIC:			
Total Organic Carbon**	mg/L	20	20
Ethylene Glycol	mg/L	N/A	12
Phenol	mg/L	1	1

*meq=milliequivalent

**TOC contribution from formate excluded for mineralized CWC water

DISCUSSION OF ANALYTICAL RESULTS

Appendices 1 and 2 contain the analytical results for the SRV-K (regenerated) and SVO-ZV (supplied/stored) archival potable water samples returned from Expeditions 14 and 15. The results for the Rodnik potable water samples collected pre-flight from the water supplies loaded on the Progress 25 and 26 vehicles have also been included in Appendix 2. Specific maximum contaminant levels from either the ISS MORD requirements or the U.S. Environmental Protection Agency [9], as well as NASA Spacecraft Water Exposure Guidelines (SWEGs) developed specifically for spaceflight have been included in the tabulations in both appendices where applicable.

EXPEDITION 14

The Expedition 14 crew collected a total of 9 chemical archival potable water samples (3 SRV-K warm, 1

SRV-K hot, and 5 SVO-ZV). All samples were collected into U.S. 1-liter FEP sample bags except for one SVO-ZV sample that was collected in a Russian drink bag on April 3, 2007. The Russian drink bag sample had insufficient volume to allow full chemical characterization per Table 1, so it was not analyzed for turbidity, total dissolved solids, or total iodine and the volatile organics were analyzed by direct injection GC/MS. Due to a leak in the sample bag that occurred after receipt in the laboratory, total dissolved solids and semi-volatile organics analyses were not performed on the SRV-K warm sample collected October 13, 2006.

SRV-K Potable Water Samples

All chemical parameters measured for the four SRV-K hot and warm samples collected during Expedition 14 and returned on STS-116 (12A.1) and STS-117 (13A) were within the ISS MORD potable water quality requirements. An updated plot of historical TOC levels, including both formate and non-formate TOC, measured in SRV-K archive samples is shown in Figure 4. TOC levels in the 4 samples ranged from 0.22 to 0.45 mg/L, all well below the ISS MORD limit of 20 mg/L. Formate was not detected in any of the samples, confirming that Shuttle-transferred potable water was not being used as SRV-K makeup water at the times of the sample collections. The only specific organic compound identified was chloroform at levels of 0.9 to 6.4 µg/L in all 4 samples. There is no specific limit for chloride in the ISS MORD; however, all levels were well below the U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) of 80 µg/L for trihalomethanes and the 1000-day Spacecraft Water Exposure Guideline (SWEG) for chloroform of 6,500 µg/L [10]. Nickel levels ranged from 20 to 77 µg/L, all well below the ISS MORD limit of 100 µg/L. An updated plot of historical nickel levels detected in SRV-K archive samples is shown in Figure 5. Total silver levels in the 4 samples ranged from 30 to 138 µg/L, all well below the ISS MORD limit of 500 µg/L. Zinc levels in these samples ranged from 38 to 94 µg/L. Figure 6 is an updated historical plot of zinc in the SRV-K archive samples, showing that the zinc levels found in the Expedition 14 SRV-K samples were all below the 5000 µg/L ISS MORD limit. Manganese ranged from 12 to 29 µg/L, also below the ISS MORD limit of 50 µg/L.

SVO-ZV Potable Water Samples

All chemical parameters measured in the 5 SVO-ZV water samples collected during Expedition 14 met the ISS MORD potable water quality requirements for all parameters except turbidity. Turbidity ranged from 0.4 to 5.4 NTU, with 2 samples exceeding the ISS MORD limit of 1.5 NTU. These elevated turbidity levels were not considered to be a toxicological concern; however, particulate matter causing the turbidity can shelter microorganisms that could be a health concern. Figure 7 is an updated plot of historical values for turbidity.

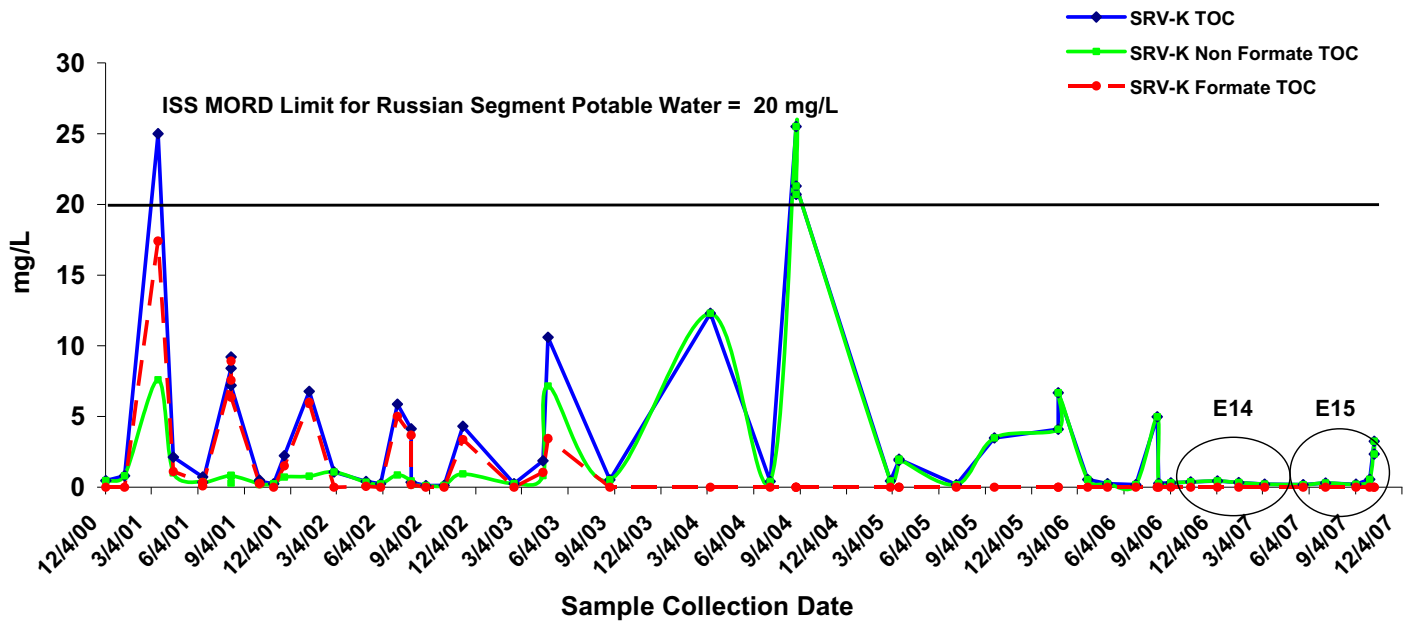


Figure 4. Total, Formate, & Non-formate Organic Carbon in SRV-K Potable Water
ISS Flights 4A to Soyuz 14

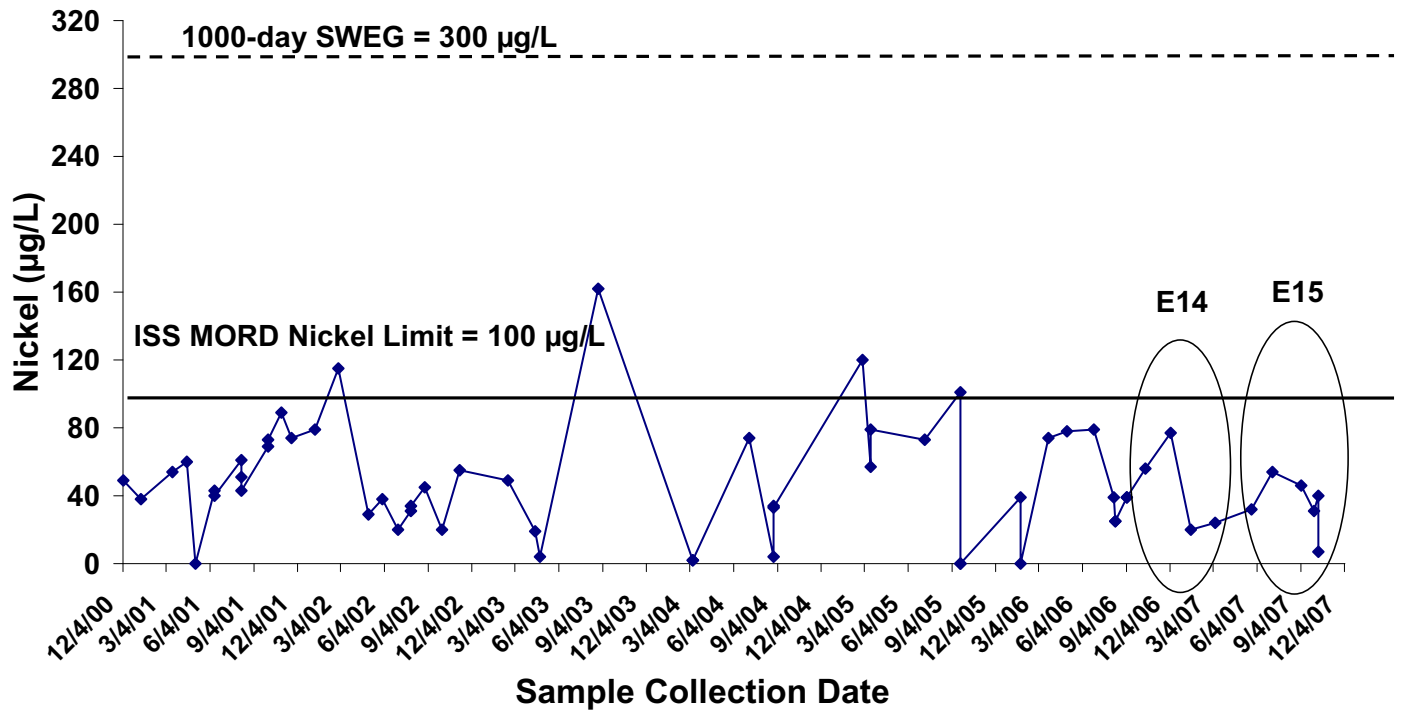


Figure 5. Nickel Levels in SRV-K Potable Water Samples
ISS Flights 4A to Soyuz 14

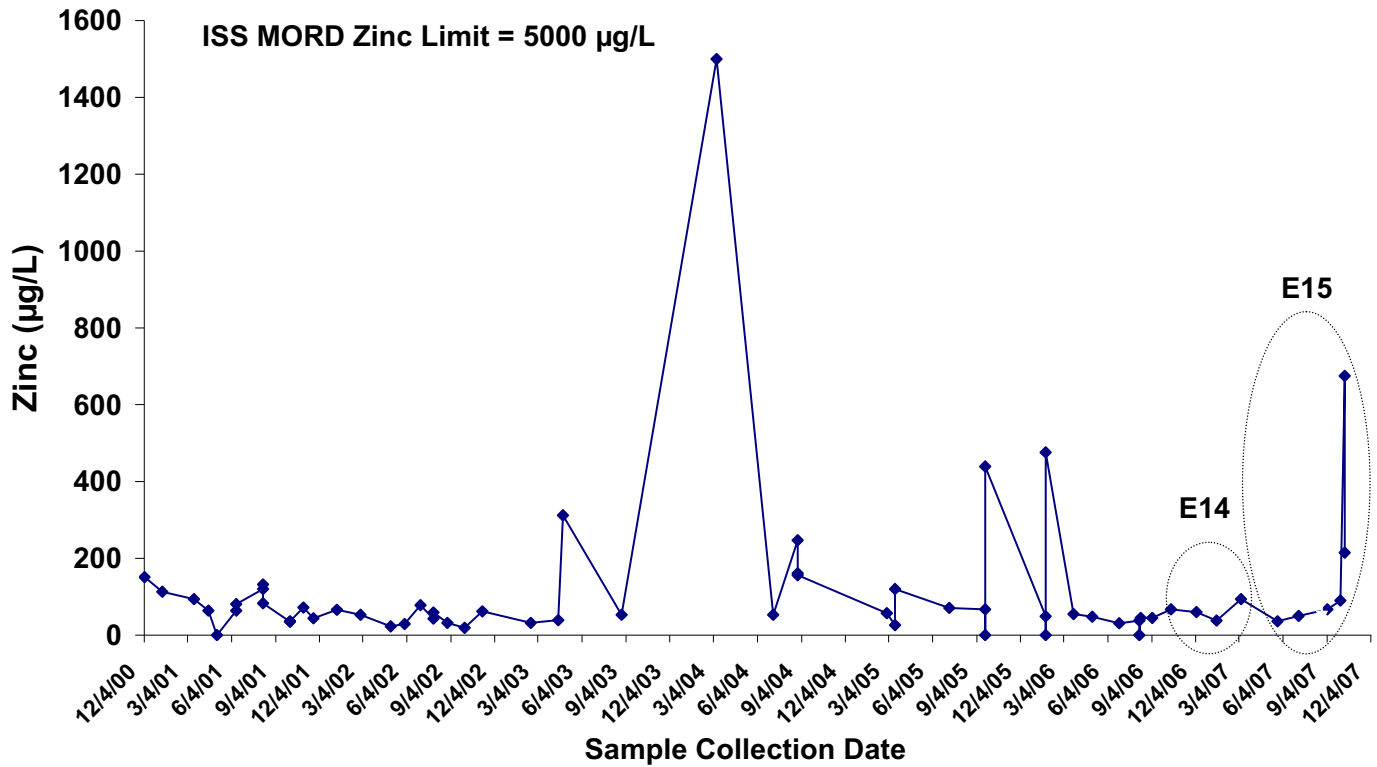


Figure 6. Zinc Levels in SRV-K Potable Water Samples
ISS Flight 4A to Soyuz 14

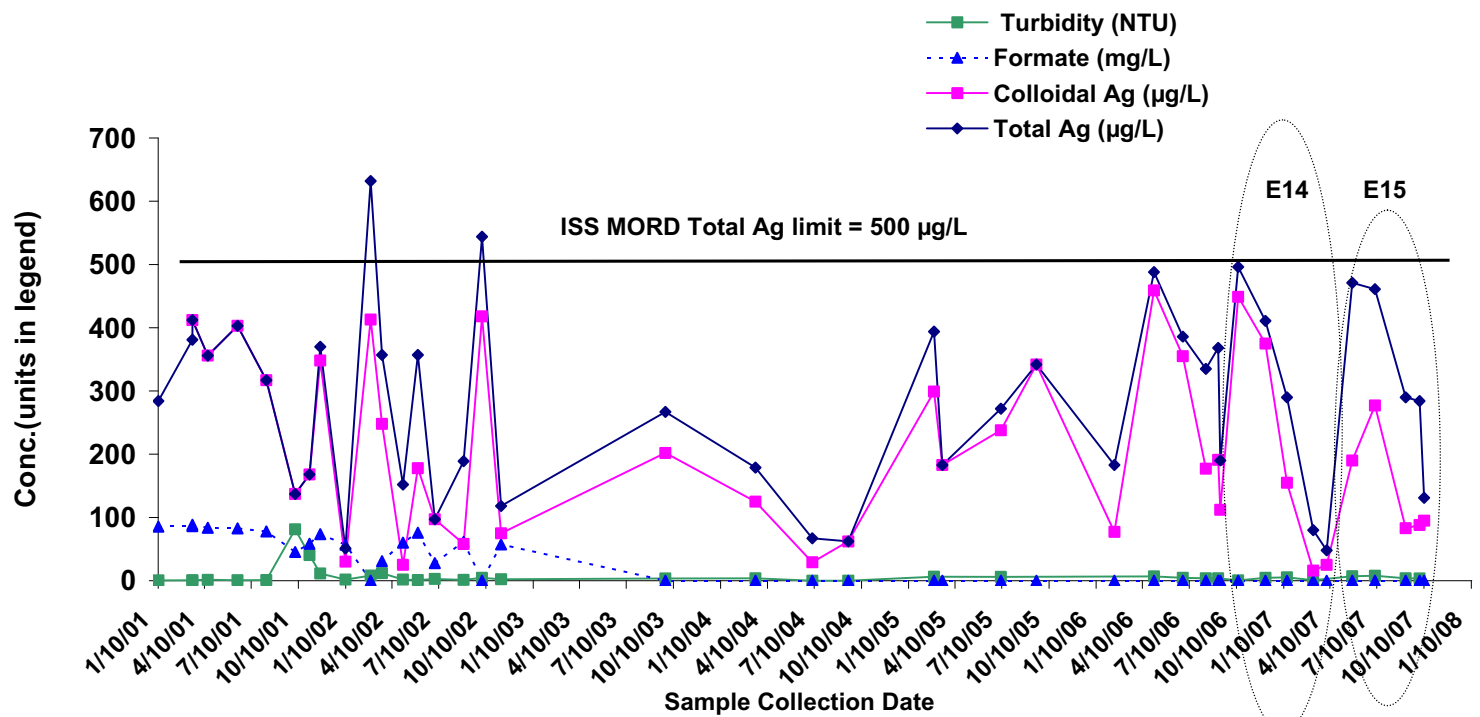


Figure 7. Turbidity, Formate, Total & Colloidal Silver in the SVO-ZV Water Samples
ISS Flights 5A to Soyuz 14

formate, and total and colloidal silver in SVO-ZV archival samples. Formate was not detected in any of the Expedition 14 SVO-ZV samples confirming that Shuttle-transferred potable water was not in use at the times of the sample collections. Total and dissolved silver levels ranged from 48 to 496 µg/L and 23 to 135 µg/L, respectively, with all samples below the ISS MORD limit of 500 µg/L. These levels were sufficient to control microbial growth as confirmed by in-flight microbial analyses results. Figure 8 is an updated historical plot of manganese in the SVO-ZV archive water samples. Manganese levels in the 5 Expedition 14 SVO-ZV samples ranged from 24 to 45 µg/L, all below the ISS MORD limit of 50 µg/L. TOC levels detected ranged from 0.25 to 1.22 mg/L, also all well below the ISS MORD limit of 20 mg/L. Detailed organic analyses found chloroform in 3 samples at levels from 1.4 to 6.1 µg/L. These levels were all well below the U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) of 80 µg/L for trihalomethanes and the 1000-day Spacecraft Water Exposure Guideline (SWEG) for chloroform of 6,500 µg/L [10]. The January 16, 2007 SVO-ZV water sample contained 5 µg/L of bis-2-ethylhexyl phthalate, which was below both the EPA MCL of 6 µg/L and the 1000-day SWEG of 20,000 µg/L [11]. The March 8, 2007 sample contained 11 µg/L of acetone but the level was well below the recently established 1000-day SWEG of 15,000 µg/L [12]. The January 16, 2007 sample also contained 0.9 µg/L of ortho-xylene, well below the EPA limit of 10,000 µg/L for total xylenes.

The April 3, 2007 SVO-ZV sample collected in a Russian drink bag was found to contain 25.5 µg/L of carbon tetrachloride, which exceeded the EPA MCL of 5 µg/L. Carbon tetrachloride is not routinely found in ISS potable water samples. A previous case of carbon tetrachloride contamination in a Rodnik ground-supply water sample suggests that the source was most likely contamination during sample allocation and storage in the laboratory.

Cadmium was not detected in any of the Expedition 14 SVO-ZV samples. A plot of historical cadmium levels for SVO-ZV archive samples is shown in Figure 9 for reference. Previous samples collected during Expeditions 1, 2, 11, and 12 contained cadmium above the ISS MORD limit of 5 µg/L. Those exceedances were determined to have resulted from contact with a metallic spring within the SVO-ZV dispenser and were subsequently resolved by replacing the dispenser during Expedition 2 and again during Expedition 13 [3,8]. The Expedition 14 crew was asked to return the October 13, 2006 SVO-ZV flush water sample along with the actual sample in order to confirm the success of the Expedition 13 dispenser change out in resolving this situation.

SVO-ZV Flush Water Sample

The Expedition 14 crew returned both the SRV-K and SVO-ZV flush water samples bags from the October 13,

2006 sample collection session on STS-116 (12A.1). Unfortunately the two sample bags were not labeled on-orbit; therefore, both flush samples were analyzed. Only minerals and metals were measured in order to monitor leaching of metals within the SVO-ZV dispenser. All parameters measured in the two samples were below the ISS MORD limits. Flush bags 1 and 2 contained 107 µg/L and 19 µg/L total silver and 759 µg/L and 87 µg/L zinc, respectively. Based upon comparison of these silver and zinc results to those found in the actual samples, it was determined that flush bag 1 most likely contained the SVO-ZV flush sample. Cadmium was detected in flush bag 1 at a level of 2 µg/L while no cadmium was found in flush bag 2, thereby confirming that replacement of the SVO-ZV dispenser by the Expedition 13 crew had resolved the issue.

RODNIK TANK WATER SAMPLES

The U.S. side received allocations of preflight samples of the Russian ground-prepared potable waters that were loaded into the Progress 25 and Progress 26 Rodnik tanks and subsequently delivered to ISS during Expedition 15. These samples were received and analyzed in the WAFAL on May 14, 2007 and July 31, 2007. All sample volumes were sufficient to support full chemical characterization. All chemical parameters for the Progress 25 (Tanks 1 & 2) samples and the Progress 26 sample met the ISS MORD requirements except for turbidity, manganese, and total silver. The Progress 26 sample had turbidity of 1.7 NTU that exceeded the ISS MORD limit of 1.5 NTU; however, slightly elevated turbidity was not considered to be toxicologically significant as discussed previously for SVO-ZV samples.

Manganese levels ranged from 37 to 104 µg/L in the 3 samples. Although the manganese level in the Progress 26 sample of 104 µg/L was above the ISS MORD limit of 50 µg/L, it was well below the recently established 1000-day SWEG value of 300 µg/L [13]. It was therefore considered to not be toxicologically significant. Figure 10 is an updated historical plot of manganese levels in Rodnik samples for reference.

Total silver ranged from 200 to 875 µg/L in the 3 Rodnik samples. The Progress 25 Tank 2 sample contained 875 µg/L, which exceeded the ISS MORD limit of 500 µg/L. Given that the stored water only contributes a portion of the ISS potable water (other water sources typically represent 50% or more of the inventory) the elevated silver level was not considered a health threat. Nevertheless, it has prompted forward actions to closely evaluate causes and help ensure lower silver levels for future flights. The dissolved silver levels in the 3 samples ranged from 46 to 101 µg/L, indicating a majority of the silver was in colloidal form. Chloride levels ranged from 6.8 to 9.0 mg/L. The presence of both chloride and colloidal silver suggests that silver chloride particles or colloids may have precipitated.

