180 DAY PRELIMINARY SCIENCE REPORT
Mir 22/NASA 3/STS 81
E592 Collecting Mir Source and Reclaimed Water for Postflight Analysis

U.S. Principal Investigator: Richard Sauer, P.E. NASA/Johnson Space Center

Russian Principal Investigator: Yuri Sinyak, M.D. Institute of Biomedical Problems

Co-Investigator: John Schultz, Ph.D. Krug Life Sciences

Co-Author: Lizanna M. Pierre, Krug Life Sciences

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I. Introduction

A portion of the potable water supplied to the Russian cosmonauts, American astronauts, and other occupants of the current Russian Mir Space Station is produced by the direct recycle of water from humidity condensate. Additional supplies come from ground supplied potable water that is delivered on a Progress resupply spacecraft, or fuel cell water transferred from the Shuttle. Because of offnominal conditions, stored water supplies have been the predominant source of potable water used onboard Mir since Mir 21 which began in February, 1996. This project is being conducted to determine the potability of the water supplied on Mir, to assess the reliability of the water reclamation and distribution systems and to aid in developing water quality monitoring standards for International Space Station.

A. Hypothesis

Detailed analysis of reclaimed and other Mir supplied potable waters will confirm that the design of the Mir purification and distribution systems are adequate to maintain the concentrations of potentially harmful contaminants at acceptably safe levels.

B. Objectives of Investigation

1. Characterize the chemical composition of Mir humidity condensate to support development and testing of the water recycling and monitoring systems for the International Space Station (ISS)
2. Characterize the chemical composition of the ground-resupply water prior to launch and on orbit
3. Characterize the chemical composition of Mir recycled water to evaluate the efficiency of onboard water processors and aid in the development of ISS water processing and monitoring technology
4. Compare the chemical composition of Mir and Shuttle humidity condensate
5. Provide inflight testing of water collection hardware being developed to collect water samples on ISS

C. Background/History of Project

Historically, water provided for crew consumption during U.S. space missions has either been launched from the ground or produced as a byproduct of fuel cell operation. Reclamation and purification of spacecraft wastewaters as practiced on the Russian Space Station Mir, will be required for supplying crewmembers of the International Space Station with potable and hygiene water.

This experiment has flown during the Mir 18/NASA 1/STS-71, Mir 19, Mir 20/STS-74, and Mir 21/NASA2/STS-79 missions.

II. Methods/ Research Operations

A. List & Description of All Functional Objectives

FO1. Preflight collection of ground-supplied water at RSC Energia, Korolov, Russia
FO2. Water Sampling Hardware Setup
FO3. Inflight collection of hot, cold, and SVO-ZV (ground-supplied) water
FO4. Inflight collection of humidity condensate
FO5. Postflight analysis of samples

B. List & Description of All Hardware Items Used

Major hardware items used inflight for this experiment:

HW1. Water Experiment Kit - NASA provided
HW2. Disinfectant/Antiseptic Wipes - NASA provided
HW3. Potable Water Samplers (with Mir port adapter interfaces) - NASA provided
HW4. Waste bags and Postflight Chemical Sample Bags - NASA provided
HW5. Self Sealing Storage Bags - NASA provided
HW6. Atmospheric Condensate Sampler - RSA provided

Major hardware items used postflight for this experiment:

HW7. HP 5890 Gas Chromatograph (GC) with HP5971A Mass Spectrometer (MS) - NASA provided
HW8. Waters Quanta 4000 Capillary Electrophoresis System - NASA provided
HW9. OI 700 Carbon Analyzer - NASA provided
HW10. Sievers Model 800 Total Organic Carbon Analyzer - NASA provided
HW11. HP 7694 Headspace sampler with a HP 5890 GC and 5972 Mass Selective Detector - NASA provided
HW12. HP 5989 Mass Spectrometer (MS) with a 1090 Liquid Chromatograph with Particle beam & Thermospray interfaces - NASA provided
HW13. pH meter - RSA and NASA provided
HW14. Conductivity meter - RSA provided

C. Sessions/Functional Objectives (FO) Table

See Table 1.

D. Discussion of Method/Protocol

During inflight water sampling sessions on board Mir, the water experiment kit was unstowed from its storage location. The water experiment kit contained the disinfectant wipes, potable water samplers, waste bags, chemical archive sample bags, and storage bags needed for water sampling. A prepackaged disinfectant wipe containing 1 ml of benzalkonium chloride in 250 ml of water, was retrieved from the kit and used to disinfect the Mir galley-hot, galley-cold, or SVO-ZV water port. Next, a potable water sampler was connected to the port. A waste bag was then connected to the potable water sampler. Using the waste bag, 50 ml of water was collected and discarded. Next, 750 ml of water was collected into the chemical archive sample bag. The chemical archive sample bag was placed in a self sealing storage bag and stowed for return on the Shuttle. These procedures were used to collect galley-hot, galley-cold, and SVO-ZV (ground-supplied) water for postflight chemical analysis for this experiment. Following the collection of the chemical samples, microbiological samples were obtained for a separate experiment. The procedures used for microbiological sample collection, analysis, and preliminary results are reported elsewhere in “Microbiological Investigations of the Mir Station and Flight Crew” [4].

Postflight chemical analysis of samples occurred at Johnson Space Center (JSC) and the Institute for Biomedical Problems (IBMP). Following recovery of the samples on the ground, the samples were allocated (See Table 2) for distribution to the water analysis laboratories at JSC and IBMP. Parameters tested at JSC included total carbon (total inorganic carbon, purgeable organic carbon, nonpurgeable organic carbon and total organic carbon), specific organics (alcohols, organic acids, semivolatiles, volatiles, nonvolatiles, formaldehyde), and silver. Parameters tested by IBMP included conductivity, pH, color, chemical oxygen demand, total solids, calcium, magnesium, total hardness, and silver.

III. Results

A. List of Pre-, In-, Post-flight Anomalies

Preflight Anomalies
Not applicable to this experiment

Inflight Anomalies
On 9/8/96, it was reported that the condensate recovery system, which produces regenerated potable water from humidity condensate, was turned off. The crewmembers relied on Russian ground supplied and American stored water for drinking until the system could be repaired. In addition, there were also reports of at least two incidents of thermal coolant loop leaks on 10/14/96 and 11/25/96 which also necessitated the use of stored water instead of regenerated water. Therefore Mir 22/NASA 3 crewmembers were not using regenerated water from the condensate recovery system for their primary source of water until 12/14/96. Because of this, the source of water collected from the SVO-ZV on 11/6/96 is not known. This water sample may be a result of the use of Russian ground supplied water or American stored water, or a combination of both.

One additional session for water collection was performed on 12/4/96. This session was completed before the changeout of the condensate recovery system multifiltration beds and the installation of the ambient temperature catalytic oxidation system (filter reactor). Water samples were also collected after the multifiltration beds were changed (12/14/96). Data from the analysis of these samples are critical in determining the operational efficiency of the condensate recovery system with the replacement of the multifiltration beds and the installation of the catalytic oxidation system.

Although not requested, three additional water samples were collected during this mission. They include one cold and one SVO-ZV collected on 11/6/96. Also, one sample of partially processed condensate (recovered condensate) stored in a Russian EDV container was collected on 12/4/96.

Postflight Anomalies
Two humidity condensate samples collected previously during Mir 21/NASA 2/STS-79 were found and returned on STS-81.

B. Completeness/Quality of Data

Data for this experiment are derived from analysis of water samples returned from the mission. Sample analyses are in progress.

C. Tables, Graphs, Figures

See attachments

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IV. Discussion

A. Status of Data Analysis

Chemical analyses of the potable water and humidity condensate samples are in progress. Analyses completed to date include conductivity, pH, turbidity, total organic carbon (TOC), trace metals, urea, volatile organics, formaldehyde, alcohols, carboxylates, and glycols. Analyses yet to be completed include color, taste, odor, total hardness, total solids, chemical oxygen demand (COD), anions, cations, amines, semivolatile organics, and the identification of unknown compounds.

B. Preliminary Research Findings

Eleven samples were collected during the Mir-22 mission and returned on STS-81 in January, 1997 (Table 1). During this mission, leaks from the thermal control system in the Mir core, the Kvant, and the Kvant II modules required shutting down the condensate recovery system (CRS), which reclaims potable water from humidity condensate [5,6,7], because of possible contamination of the potable water by the thermal coolant, 1,2-ethanediol (ethylene glycol). The first thermal-coolant leak aboard Mir was reported during the Mir-20 mission in November 1995, when 1.8 L of 1,2-ethanediol leaked in the Kvant module [2]. In addition, several problems with CRS hardware such as line blockage and pump failures were also reported. Crewmembers relied on stored water, either Russian ground-supplied water or U.S.-supplied fuel-cell water, when the CRS was inoperable.

Regenerated Water Results

Preliminary results of potable water samples collected on 11/6/96, 12/4/96, 12/14/96, and 1/18/97 show that the regenerated water continues to meet the Russian potable water specification of 25 mg/L of Total Organic Carbon (TOC), however not meeting the U.S. maximum contaminant level (MCL) of 0.5 mg/L for TOC. Also, turbidity exceeded the U.S. MCL of 1 NTU. The TOC levels in these samples ranged from 1.06 mg/L - 7.25 mg/L, as compared to the range of 1.3 -25.1 mg/L for thirteen samples collected from Mir 18-Mir 21. It is noted that samples collected after the changeout of the condensate recovery system (CRS) multifiltration beds (i.e 12/14/96, 1/18/97) had less total organic carbon as compared to those samples collected before changeout of the beds (11/6/96, 12/4/96). Turbidity levels in the regenerated water samples returned on STS-81 ranged from 0.7 - 6.58 NTU; samples collected from Mir 18 - Mir 21 had turbidity levels ranging from 0.95 - 5.50 NTU.

In addition, one sample of hot water collected on 12/4/96 slightly exceeded the Joint U.S./Russian potable water specification (Table 3) for manganese and total phenols. This sample had 51.7 µg/L of manganese; the U.S./Russian specification for manganese is 50 µg/L. Manganese was not analyzed in samples received from Mir 18-Mir 20, but samples collected during Mir 21 did not exceed this specification. Values for Mir 21 samples ranged from 1.6-4.8 µg/L. Total phenols in this sample included the presence of phenol only at 1.3 µg/L. The U.S./Russian specification for total phenols is 1.0 µg/L. No other phenolic compounds were detected in the other Mir 22 samples returned on STS-81. However, phenol was detected at concentrations ranging from nondetectable - 6.0 µg/L in Mir 18-Mir 21 samples.

This hot water sample also had 177.2 µg/L of chloroform; the U.S. Environmental Protection Agency (EPA) maximum contaminant level for chloroform is 100 µg/L. Levels of chloroform previously seen in Mir 18 - Mir 21 samples range from nondetectable - 31.79 µg/L. Levels of chloroform in the other Mir 22 samples returned on STS-81 ranged from nondetectable - 26.39 µg/L.

Stored Water Results

Two stored water samples were returned on STS-81. Results from the analysis of these samples reveal that the stored water samples did not meet U.S. standards for turbidity and total phenols and the joint U.S./Russian standards for TOC and manganese. U.S. EPA standards were also exceeded for chloroform. Turbidity levels in the two stored water samples returned on STS-81 were 6.43 NTU and 6.58 NTU. Stored water samples collected during Mir 21 were analyzed for turbidity and their values were 7.74 NTU and 7.68 NTU, respectively. Stored water samples continue to exceed the U.S. specification of 0.5 mg/L of TOC. One sample, collected on 11/6/97, which contained 54.8 mg/L of TOC exceeded both the U.S. standard and the Russian standard of 25 mg/L for TOC. Because of the presence of formate (40.5 mg/L) and ethanol (86.6 mg/L) in this sample, it is believed that this water originated as fuel cell water supplied by the U.S. shuttle since preflight servicing and mineralization of the U.S. water prior to transfer to Mir adds formate and ethanol to the water. The other sample, collected on 1/18/97 measured 7.14 mg/L of TOC, which exceeded the U.S. standard only.

The manganese levels in the two samples were nondetectable for the 11/6/96 sample and 62.7 µg/L for the 1/18/97 sample which exceeds the joint U.S./Russian specification of 50 µg/L. Other stored water samples had manganese levels which ranged from 5.5-23.7 µg/L in five samples tested, three of which were collected prior to launch of the water on a Progress resupply spacecraft, and two collected during the Mir 21 mission. The joint U.S./Russian potable water specification for total phenols (1 µg/L) was also exceeded in one of the stored water samples. This sample, collected on 11/6/97 contained 16.6 µg/L of phenol. No data are available yet for the 1/18/97 sample. Only one sample collected during Mir 21 showed detectable levels of phenol. This sample, collected on 8/15/96 has 1.2 µg/L of phenol.

The only EPA standard exceeded in the stored water samples was for chloroform, whose MCL is 100 µg/L. The stored water sample collected on 1/18/97 has 243.59 µg/L of chloroform. Chloroform levels have been exceeded in the past in both samples collected prior to Progress launch and in samples collected during a mission. Previous levels of chloroform ranged from non-detectable - 205.5 µg/L.

Humidity Condensate Results

Three humidity condensate samples were collected during this mission. Of these, one sample had been incompletely processed through the CRS ; this sample is known as recovered condensate. Analytical results on these condensate samples have identified a variety of compounds. Some of the compounds identified to date in the humidity condensate samples include manganese, zinc, mercury, carbon disulfide, tetrahydrofuran, n,n-dimethylacetamide, 3-t-butylphenol, tetramethylthiourea, acetaldehyde, caprolactam, and 4-ethylmorpholine. No ethylene glycol or propylene glycol, which are components of the thermal coolant that leaked onboard Mir were detected in these samples. These samples had TOC levels of 3.37 - 27.0 mg/L.

C. Conclusions

Preliminary findings from the analysis of the reclaimed and stored water samples show that the Mir water generally met all requirements of the Joint U.S./Russian spacecraft water quality standards. It is noted, however, that the NASA requirements for TOC and turbidity were exceeded in these samples. Other parameters in the reclaimed and stored water that exceeded the joint U.S./Russian standards included total phenols and manganese, in addition to the EPA standard for chloroform. The exceeding of these specifications is not a concern, since EPA Long term health advisories for phenol and chloroform have not be exceeded. These health advisories define the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects up to approximately 7 years in an individual's lifetime of exposure [11]. The EPA long term health advisory for phenol is 20 mg/L and the long term health advisory for chloroform is 400 µg/L.

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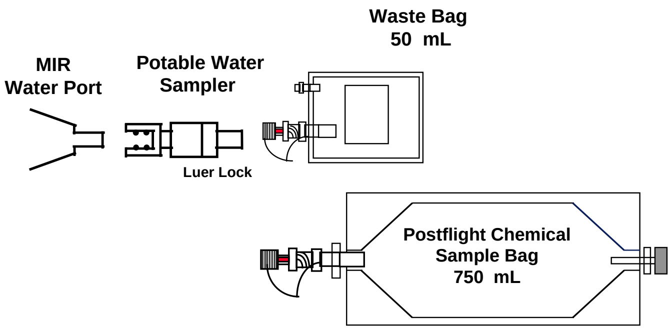

Figure 1. Sample Collection Methodology

Table 3: Joint /Russian Potable Water Specifications for International Space Station

Water Parameter	U.S. Maximum Contaminant Level (MCL)	Russian Maximum Contaminant Level (MCL)
pH[1]	5.5-9.0 pH units	5.5-9.0 pH units
Color[2]	15 Pt-Co units	20 degrees
Taste[2]	3 TTN	2 points
Odor[2]	3 TON	2 points
Total Dissolved Solids[3]	100-1,000 mg/L	100-1,000 mg/L
Turbidity[2]	1 NTU	1.5 mg/L
Total Gas	5% volume @1 ATM, 20^{o}C	5% volume @1 ATM, 20^{o}C
Ammonia (NH3-N)	2 mg/L	2 mg/L
Arsenic	0.01 mg/L	0.01 mg/L
Barium	1 mg/L	1 mg/L
Cadium	0.005 mg/L	0.005 mg/L
Calcium	100 mg/L	100 mg/L
Chlorine-total (includes Cl-)	250 mg/L	250 mg/L
Chromium	0.1 mg/L	0.1 mg/L
Copper	1 mg/L	1 mg/L
Fluorine	1.5 mg/L	1.5 mg/L
Iodine-total (includes I-)	15 mg/L	15 mg/L
Iodine-residual[4]	1.0-4.0 mg/L	1.0-4.0 mg/L
Iron	0.3 mg/L	0.3 mg/L
Lead	0.05 mg/L	0.05 mg/L
Magnesium	50 mg/L	50 mg/L
Manganese	0.05 mg/L	0.05 mg/L
Mercury	0.002 mg/L	0.002 mg/L
Nickel	0.1 mg/L	0.1 mg/L
Nitrate (NO_3-N)	10 mg/L	10 mg/L
Selenium	0.01 mg/L	0.01 mg/L
Silver	0.5 mg/L	0.5 mg/L
Sulfate	250 mg/L	250 mg/L
Zinc	5 mg/L	5 mg/L
Total Hardness (Ca & Mg)	7 meq/L	7 meq/L
Total Bacteria[2]	100 CFU/100 ml	10,000 CFU/100 ml
Coliform Bacteria	<1 CFU/100 ml	<1 CFU/100 ml
Virus	<1 PFU/100 ml	<1 PFU/100 ml
Cyanide	200 µg/L	200 µg/L
Total Phenols	1 µg/L	1 µg/L
Total Organic Carbon (TOC)	500 µg/L	25,000 µg/L
Uncharacterized TOC	100 µg/L	no limit
Oxygen Consumption-COD	no limit	100 mg/L

[1]pH range applies only before iodination
[2]Parameters have different values for U.S. and Russian supplied water because of different analytical methods used

[3]The 100 mg/L limit applies to the water before mineralization. After mineralization, this parameter will not exceed 1,000 mg/L
[4]Range of required level if iodine is used as a biocide