

# Microgravity Evaluation of Colorimetric-Solid Phase Extraction for the Measurement of Total I in Spacecraft Drinking Water

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## ABSTRACT

We are developing a drinking water test kit based on colorimetric-solid phase extraction (C-SPE) for use onboard the International Space Station (ISS) and on future Lunar and/or Mars missions. C-SPE involves measuring the change in diffuse reflectance of indicator disks following their exposure to a water sample. We previously demonstrated the effectiveness of C-SPE in measuring iodine in microgravity. This analytical method has now been extended to encompass the measurement of total I (i.e., iodine, iodide, and triiodide). This objective was accomplished by introducing an oxidizing agent to convert iodide and triiodide to iodine, which is then measured using the indicator disks previously developed for iodine. We report here the results of a recent series of C-9 microgravity tests of this method. The results demonstrate that C-SPE technology is poised to meet the total I monitoring requirements of the international space program.

## INTRODUCTION

The anticipated delivery to the International Space Station (ISS) of the water processing assembly (WPA), with its requirement for monitoring the level of total iodine (total I, i.e., iodine, iodide, and triiodide) in ISS drinking water, has created an urgent need for an onboard total I test kit. To meet this need, we devised an analytical method to convert iodide and triiodide to iodine, which can then be measured by colorimetric-solid phase extraction (C-SPE). Our research team has been exploring the development of C-SPE as an approach to

meet the biocide monitoring needs of space exploration.<sup>1-5</sup> C-SPE is a spectrophotometric technique based on measuring the change in diffuse reflectance of indicator disks after exposure to a water sample. C-SPE extracts and concentrates analytes on a solid-phase extraction membrane, yielding concentration factors approaching 1000 or more.<sup>6</sup> A hand-held diffuse reflectance spectrophotometer is used to quantify membrane-bound analytes using the Kubelka-Munk function.<sup>7-9</sup> The Kubelka-Munk function relates the diffuse reflectance of an opaque sample to its absorption coefficient  $k$ , and scattering coefficient  $s$ , as given by the following equation:

$$F(R) = \frac{(1-R)^2}{2R} = \frac{k}{s} \quad (1)$$

where  $F(R)$  is the Kubelka-Munk function and  $R$  is the relative reflectance of the sample (i.e., reflectance measured relative to a nonabsorbing standard). When measuring the reflectance of an absorbing species diluted in a nonabsorbing matrix, relative to the reflectance of the matrix, the absorption coefficient  $k$  may be replaced by the product  $2.303\epsilon C$ , where  $\epsilon$  is the extinction coefficient and  $C$  is the molar concentration. Then

$$F(R) = \frac{2.303\epsilon}{s} C. \quad (2)$$

To determine analyte concentrations, spectra are transformed to obtain the value of the Kubelka-Munk function at the appropriate analytical wavelength. This

value is then used to quantify the analyte via a standard response curve.

The measurement of iodine by C-SPE uses extraction membranes impregnated with poly(vinylpyrrolidone) (PVP), which serves as the colorimetric reagent.<sup>1</sup> Iodine is determined as the yellow iodine-PVP complex. We have also extended our iodine test method to the determination of total I by employing an oxidative pretreatment of the sample solution with Oxone®, a commercially available potassium monopersulfate salt. Oxone® converts iodide and triiodide to iodine, which can then be measured using the indicator disks previously developed for iodine. These disks are insensitive to iodide and triiodide.<sup>1,4,5</sup>

The oxidative pretreatment step is implemented by filling sample syringes through a reagent cartridge containing Oxone®. Dead space in the reagent cartridge results in the introduction of air into the sample syringe. Previous microgravity testing has shown that air bubbles suspended in water samples can cause uncertainty in precisely knowing the volume of liquid passed through the indicator disks, leading to errors in the determination of analyte concentrations. We report herein the results of a recent series of C-9 experiments designed to evaluate our C-SPE method for total I in microgravity.

The broad goals of these tests were to: (1) evaluate the effectiveness of oxidation of iodide to iodine by Oxone®, introduced by filling a sample syringe through a cartridge containing solid Oxone® in a glass fiber filter matrix; and (2) determine a simple and effective method to remove the air bubbles introduced into the sampling syringe by the reagent cartridge. The achievement of these goals was demonstrated by determining the accuracy and precision of measurements in microgravity of solutions of various iodide concentrations.

To verify the functionality of sample collection procedures and C-SPE test methods in microgravity, analyses for total I were performed using water samples prepared from standard solutions of potassium iodide (KI), which were also analyzed by ground tests using the Leuco Crystal Violet (LCV) method to certify total I concentrations. This process was carried out over a series of four C-9 flights. The following list the objectives of each flight.

#### Flight 1: Syringe filling and bubble mitigation for total I Analysis of I<sub>2</sub> and I<sub>2</sub> + KI samples

- Evaluate syringe filling strategies for 10.0-mL water sample collection through an Oxone® cartridge.
- Determine a procedure for manual bubble mitigation and expulsion of air and excess sample prior to passing 10.0 mL of bubble-free sample through a C-SPE membrane.
- Evaluate the use of a three-way valve connected to a syringe, sample bag, and waste bag as a means of simplifying sample handling.

#### Flight 2: Test total I analysis as KI

- Use methods developed in Flight 1 to compare ground and flight data from total I analyses.

#### Flight 3: Refine total I analysis via repetitive tests of single concentration of KI

- Determine if 10.0 mL of sample can be drawn accurately into a syringe through an Oxone® cartridge present in-line between the sample collection bag and syringe by comparing multiple in-flight determinations of a single KI concentration to the certified ground measurement value.
- Evaluate reproducibility of new and existing sample collection and manipulation methods by comparing the results from multiple runs using only one KI concentration.

#### Flight 4: Evaluate Oxone® introduction and sampling procedures for total I analysis as KI

- Analyze a range of KI concentrations for total I using procedures developed in previous flights.
- Construct calibration curves and determine precision of the method using certified ground analysis concentrations.
- Tabulate results and compare to ground measurements to determine accuracy of the method under microgravity conditions.

The results of these flight experiments illustrate the development of procedures for effectively collecting 10.0-mL bubble-free water samples through an Oxone® cartridge in microgravity, thereby allowing for the in-flight determination of total I.

## **MATERIALS AND METHODS**

**INSTRUMENTATION** - Both in-flight and ground-based C-SPE measurements were made using BYK Gardner Color Guide spin d/8° diffuse reflectance spectrophotometers. All mass measurements were performed using a calibrated, certified Mettler Toledo model AG205 analytical balance.

**IODINE-SENSITIVE MEMBRANES** - A solution was prepared by dissolving 14.988 g poly(vinylpyrrolidone) (PVP: MW = 10,000) in 250 mL of 1:1 methanol:water in a 500-mL volumetric flask. The solution was brought to volume with 1:1 methanol:water. An Empore SDB-XC 47-mm extraction membrane was placed into a Millipore glass filter holder assembly, and 10.0 mL of the PVP solution was pipetted into the funnel. Next, a vacuum pump was used to apply a pressure differential (~3.5 in Hg) across the membrane to force this solution through the membrane. Once the solution had passed through the membrane, the pressure difference was maximized by setting the vacuum valve to its full-open position for 30 s to remove residual solvent. The prepared membranes were allowed to air dry for ~12 h and stored

in Ziploc bags in the dark before being cut into 13-mm disks.

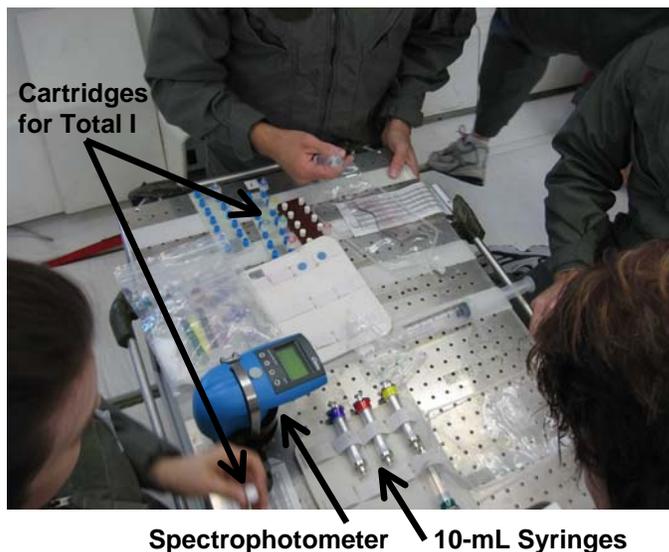
**OXONE® GLASS FIBER FILTERS** - Oxone® (Aldrich) was used as an oxidizing agent to convert iodide and triiodide to iodine. An Oxone® solution was prepared by weighing 7.4977 g in a weighing boat, transferring to a 25-mL volumetric flask and bringing to volume with DI water. Glass fiber filters (Millipore AP20047000) were placed in 60 × 15 mm (Dia × H) glass Petri dishes, and 1.0 mL of Oxone® solution was pipetted onto the center of each filter to ensure wetting of the entire filter. The dishes containing the treated filters were heated in an oven at 110°C for 2 h, after which the filters were removed and stored in Ziploc bags before being cut into 13-mm reagent chads just prior to use.

**C-SPE CARTRIDGES** - All C-SPE membranes and Oxone® coated glass fiber filters were prepared the day before their corresponding flight. A few hours prior to flight, the PVP-treated membranes and Oxone®-treated filters were cut into 13-mm disks and loaded into separate Swinnex polypropylene cartridges. One end of the filter holder cartridge has a Luer fitting that readily forms a leak-tight connection with a syringe; the opposite end of the cartridge has a slip fit that mates with the sample or waste collection bag. A Teflon gasket contained in the cartridge forms an internal seal and defines the area of the membrane disk exposed to the water sample.

**STANDARD SOLUTIONS** - A 50-ppm standard iodide stock solution was prepared by dissolving 0.0696 g KI in deionized water in a volumetric flask and diluting to 1.00 L. The stock solution for iodine and total I was prepared by diluting one ampoule of FIXANAL® standard (Riedel-de Haen, #38060, containing 12.690 g I<sub>2</sub> and 20 g KI) to 1.00 L with deionized water, producing 0.1 N iodine. Working solutions of iodide, iodine, and total I were prepared by appropriate dilutions of the stock with deionized water. The actual solution concentrations of I<sub>2</sub> and total I were certified by Wyle Laboratory using the LCV method.<sup>10</sup>

**SAMPLE AND WASTE BAGS** - All sample and waste bags were acquired from American Fluoroseal. Sample bags (#1P-0072-K) that hold approximately 72 mL and waste bags (#1PF-0270) that hold ~1.0 L were used for sample-passing (through the membrane) and membrane-drying steps, respectively. The bag (#1P-0012) used for sampling in conjunction with a 3-way valve holds ~12 mL.

**MICROGRAVITY WORKBENCH SETUP** - The positions of fliers and analytical accessories on and around the flight bench are shown in Figure 1.



**Figure 1.** Photograph taken during flight illustrating the layout of the workbench and positioning of four flyers.

## PROCEDURES, RESULTS, AND DISCUSSION

**GENERAL OBSERVATIONS** - All flight experiments were performed aboard NASA's Reduced Gravity Office's C-9 aircraft. Each flight consisted of 4 sets of 10 parabolas (40 total parabolas) that created alternating high gravity and microgravity environments. Efforts were taken to design experiments that could be broken into discrete steps that could be completed in a single microgravity segment.

During the first two flights of this series, challenges were encountered in accurately filling syringes with 10.0 mL of sample during the ~25 s microgravity period of each parabola. Careful reassessment of the test procedures during the third flight resulted in a marked reduction in the measurement error. By identifying problem areas and making corrections on the fourth flight, the team was able to demonstrate the use of C-SPE methodology for total I analysis in microgravity. It is important to note that we expect even better performance on ISS, since many of the challenges encountered on these flights resulted from the limitation of the 25 s microgravity simulation time. This time constraint will not be applicable on ISS.

### FLIGHT 1: SYRINGE FILLING AND BUBBLE MITIGATION FOR TOTAL I ANALYSIS OF I<sub>2</sub> AND I<sub>2</sub> + KI SAMPLES

**Procedures.** Various sampling manipulations were evaluated on the first half (20 parabolas) of Flight 1. 10.0-mL glass syringes (SGE International Pty, Ltd.) were fitted with either: (1) an Oxone® cartridge connected to a 72-mL Teflon sample bag filled with colored water to enhance air bubble visualization; or (2) a three-way valve with attached 12-mL waste bag incorporated in-line between the syringe and sample bag. In either case, the syringe was first overfilled by withdrawing the plunger to the end of the syringe and then detaching the sample bag. The syringe was then

swung in an arc to separate the entrapped air from the water by driving the liquid to the plunger end and the air to the tip end of the syringe where the air could be expelled into the waste bag, along with any excess liquid. In tests devoid of the three-way valve, the syringe with a cartridge attached to the port end was affixed to a waste bag and the plunger was depressed to expel air and excess liquid. This step was not required when the three-way valve was used, since a small, 12-mL waste bag was already attached to one port of the valve. The two experimental procedures appeared to produce comparable results.

To confirm that all prior developmental procedures were working effectively, the third set of 10 parabolas were used for measurements at five different iodine concentrations using procedures verified on previous C-9 flights. For the last set of 10 parabolas, the total I procedures tested earlier in the flight were used for a total I analysis, using dilutions of the FIXANAL® standard as a simulant for iodinated water. To maximize the number of samples handled (5), each of the four fliers had multiple tasks. Syringe filling required fliers to work in teams of two in order to complete each task in the microgravity portion (~25 s) of each parabola. The task/test matrix is shown in Table 1.

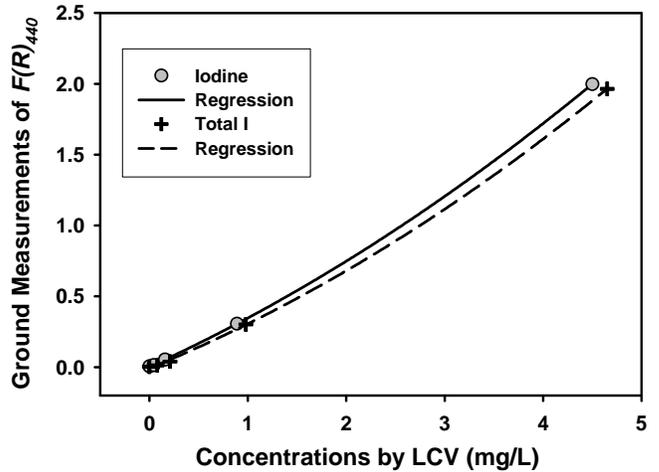
**Table 1.** Test matrix for Flight 1 showing flier tasks.

Parabola	Flier 1	Flier 2	Flier 3	Flier 4
1	Open	Open	Fill 1	Fill 1
2	Pass 1	Open	Fill 2	Fill 2
3	Pass 2	Dry 1	Fill 3	Fill 3
4	Pass 3	Dry 2	Measure 1	Record 1
5	Open	Dry 3	Measure 2	Record 2
6	Fill 4	Fill 4	Measure 3	Record 3
7	Pass 4	Open	Fill 5	Fill 5
8	Pass 5	Dry 4	Open	Open
9	Open	Dry 5	Measure 4	Record 4
10	Open	Open	Measure 5	Record 5

Procedurally, one member of the team held the syringe, and another held the sample bag to ensure the Luer slip fitting of the cartridge remained connected to the sample bag. After filling, debubbling, and expelling air and excess liquid, the syringe was handed to a second flier, who metered the liquid sample through the PVP membrane; a third flier dried the membrane, and a fourth flier measured spectral response and recorded the data.

Concurrent with the flight, samples taken from the same solutions used on the flight were analyzed by Wyle Life Sciences. Both I<sub>2</sub> and total I concentrations were determined using the LCV method.<sup>10</sup> These solutions

were also analyzed in the lab by C-SPE for I<sub>2</sub> and total I. Calibration curves for each analyte were constructed by plotting the value of the Kubelka-Munk function at 440 nm ( $F(R)_{440nm}$ ) vs. LCV values for iodine. These curves were fit to a second order polynomial, which was subsequently used to determine the concentration of samples measured in flight from their  $F(R)$  values. The calibration curves are shown in Figure 2.



**Figure 2.** Calibration curves for iodine and total I.

**Results:** The results from four I<sub>2</sub> samples measured on this flight are shown in Table 2 and the results for total I as I<sub>2</sub> + KI are given in Table 3. The experimental error lies well within the target error for each concentration of I<sub>2</sub> analyzed by C-SPE, except for the highest concentrations. The target error above concentrations of 2.5 ppm has been set at ±1.25 ppm, while for lower concentrations the target error has been set at ±50%.

**Table 2.** Comparison of Flight 1 results with laboratory determination of I<sub>2</sub>.

Number of Samples	Total I Conc. (mg/L)		Error	Target Error
	Ground LCV	C-9 Flight		
1	0.080	0.076	-5.5%	±50%
1	4.65	3.27	-1.38 mg/L	±1.25 mg/L

**Table 3.** Comparison of flight results with laboratory determination of total I from standard solutions containing I<sub>2</sub> + KI.

Number of Samples	Iodine Conc. (mg/L)		Error	Target Error
	Ground LCV	C-9 Flight		
1	0.046	0.035	-24%	±50%
1	0.16	0.095	-41%	±50%
1	0.89	0.58	-35%	±50%
1	4.5	3.08	-1.42 mg/L	±1.25 mg/L

*Discussion:* Although use of an Oxone® cartridge had the effect of introducing large (~1-mL) volumes of air into the syringe, the process of overfilling the syringe and separating the entrapped air from the liquid sample proved highly effective. However, maintaining a leak-tight connection between the sample bag and syringe proved difficult because the outlet end of the Oxone® cartridge, which mated the cartridge to the sample bag, was a Luer slip fitting as opposed to the Luer Lock fitting. The procedure of using teams of two fliers to fill syringes proved helpful in stabilizing the position and alignment of the sample bag with the syringe. In this arrangement, the flier holding the sample bag also had to ensure that the cartridge did not begin to detach from the sample bag. Unfortunately, the additional effort and maneuvering required to conduct this portion of the procedure proved difficult to complete in the time available in the microgravity segment of a parabola. This new set of procedures challenged the ability of even our most experienced fliers. As a consequence, the number of samples fully worked up in this portion of flight was less than originally planned. The errors in measurements for the high concentration samples were also beyond the targeted level of acceptability.

Note that the calibration curve in Figure 2 indicates that the diffuse reflectance response is not linearly dependent on iodine concentration, being fitted more effectively by a second order polynomial equation. Although the fundamental origin for such dependence remains to be determined, we suspect that the optical characteristics of the membrane used to support the PVP reagent play an important role.<sup>11</sup>

#### FLIGHT 2: TEST TOTAL I ANALYSIS AS KI

*Procedures:* The procedure for Flight 2 was essentially that used for the second half of Flight 1. For this experiment, total I was determined as KI. Again, teams of two fliers were used for filling syringes following the

test matrix in Table 1. Syringes were overfilled and air and excess sample were expelled before handing off the syringe for the subsequent steps of passing the sample through the reagent cartridge, drying the membrane, measuring spectral response, and recording the data. An observer was also present on this flight.

*Results.* This new flight procedure also proved problematic with the introduction of larger than expected volumes of air into the sample syringe. As a result, only three of the planned 20 samples contained the required 10.0 mL specified in the protocol.

*Discussion.* This test matrix was judged unacceptable, since its successful execution required a high level of coordinated activity in the zero-g and 2-g segments of each parabola as well as during flight turnarounds.

#### FLIGHT 3: REFINE TOTAL I ANALYSIS FROM TESTS OF SINGLE CONCENTRATION OF KI

*Procedures.* To overcome the problems experienced on the previous two flights and to ensure that a viable test procedure for microgravity analysis could be developed, only one concentration of KI (5 ppm) was used on this flight and the test matrix was modified. Efforts focused on: (1) optimizing syringe filling; (2) debubbling; and (3) air and excess sample expulsion. Only correctly filled syringes (i.e., those containing 10.0-mL of the iodide sample) were subsequently analyzed. Furthermore, the workup of a new sample was initiated only after the preceding sample was completely processed. An additional flier was also added (total of five team members) during this flight to improve the efficiency of the process. A detailed record was maintained to track the possible importance of timing during each processing step.

*Results:* A total of 11 attempts (3 using the three-way valve and 8 without) were made to fill syringes with 10.0 mL of water through an Oxone® cartridge. The outcome of each attempt to obtain a bubble-free 10-mL sample is given in Table 4, which also indicates whether or not a three-way valve was used.

Three of the first four samples analyzed on this flight involved the use of the three-way valve. Of these three attempts, two failed to yield the required 10.0-mL samples. A decision was made to abandon the use of this accessory. Of the next seven attempts made without the valve, only one attempt failed. The results presented in Table 5 reflect measurements made on the successfully filled syringes (7 without the three-way valve, 1 with the valve). The table also includes data reflecting the precision and accuracy of the method developed on this flight.

**Table 4.** Flight 3: Evaluation of three-way valve.

Sample #	Valve (Y/N)	Successful (Y/N)
1	Y	N
2	N	Y
3	Y	Y
4	Y	N
5	N	Y
6	N	Y
7	N	Y
8	N	N
9	N	Y
10	N	Y
11	N	Y

**Discussion:** Terminating use of the three-way valve resulted in boosting the percentage of successfully filled syringes from ~30 to 70%. The higher success rate was attributed to the ability of fliers to manipulate sample accessories in a more efficient manner, thereby preventing excess air from entering the syringe. With a resulting relative standard deviation of 4.1% and an error of 3.0%, the precision and accuracy of these results were well within the targeted level of acceptability. In addition, the length of time between sample filling and data recording had no observable effect on the precision and accuracy of these measurements.

**Table 5.** Results from Flight 3: Replicate total I analysis of a single concentration of KI solution.

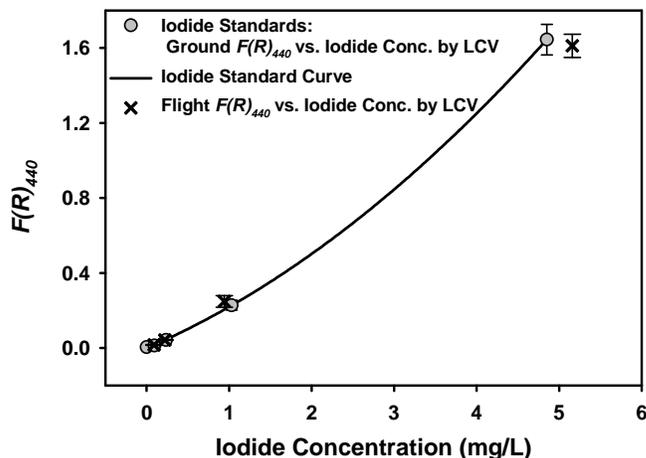
Number of Samples	Iodide Conc. (mg/L)		Standard Deviation C-9 Flight	RSD	Error
	Ground LCV	C-9 Flight			
8	4.85	4.97	0.21	4.1%	3.0%

**FLIGHT 4: EVALUATE OXONE® INTRODUCTION AND SAMPLING PROCEDURES FOR TOTAL I ANALYSIS AS KI**

**Procedures.** Based on experience gained in the previous three flights, it was decided that a fifth flier was needed on Flight 4 to aid in the syringe filling process. Three-way valves were not used, since it was previously determined that the valves contributed to problems associated with accurate syringe filling. Only one syringe was filled during a given parabola, and two fliers worked in teams; one flier held the sample bag while the other extracted a sample through an Oxone® cartridge. After

separating the entrapped air from the liquid sample by the previously described procedure, air and excess sample were expelled into a waste bag. The syringe was handed to the next flier (sample pass step) for extraction of the sample through a PVP-modified membrane, followed by removal of the membrane cartridge. The cartridge was handed to the next flier (sample dry step) for membrane drying by forcing 60 mL of air through the cartridge. The cartridge was then disassembled (sample measure step) and the lower half of the cartridge containing the membrane was placed in the spectrophotometer for measurement and data recording.

**Results:** Results from Flight 4 are presented in Figure 3 and Table 6. A total of 12 samples, taken from freshly prepared solutions of 5.0, 1.0, 0.25 and 0.10 ppm KI, were analyzed. In Table 6, concentrations determined from C-9 flight data are compared with laboratory LCV data for an assessment of accuracy and precision for the newly-developed microgravity analytical method. Errors are well within the target error of ±50%, attesting to the feasibility of using C-SPE for total iodine analysis in onboard flight management of biocidal concentrations in drinking water.



**Figure 3.** Flight 4 measurements of iodide solutions. The circles are the  $F(R)$  values measured in flight plotted against the known concentration from LCV analysis. The solid line is the calibration curve measured on the ground during flight 2. This curve was used to find the flight concentrations from  $F(R)$  values measured in flight.

**Table 6.** Results from Flight 4: Total I analysis of a range of KI Solutions.

Number of Samples	Iodide Conc. (mg/L)		Standard Deviation C-9 Flight	RSD	Error
	Ground LCV	C-9 Flight			
3	0.09	0.091	0.0094	10%	1.1%
3	0.22	0.223	0.0048	2.1%	1.6%
3	0.94	1.1	0.12	11%	19%
3	5.16	4.8	0.13	2.7%	7.0%

**Discussion:** The results from this flight demonstrate that experience gained from the previous three flights allowed us to modify and refine our total I analytical method to readily meet the targeted levels of performance listed in Table 2. This reduction in error is attributed to the ability of the fliers to more accurately meter a 10.0-mL sample for C-SPE analysis. Four factors contributed to this improvement: (1) eliminating the use of three-way valves, which were cumbersome in flight and allowed excess air to enter the syringe; (2) working in teams of two fliers to fill each syringe with the sample; (3) overfilling the syringe to allow expulsion of air in conjunction with excess sample; and (4) increasing the number of fliers involved in the analysis procedure from four to five.

## CONCLUSION

By identifying problem areas and making corrections, the team demonstrated the use of C-SPE methodology for total I analysis in microgravity environments. Once verified by additional microgravity testing to further refine the analytical procedure, this methodology will place C-SPE in a strategic position for onboard flight as a means to strictly manage biocidal iodine concentration levels in drinking water on ISS and future Lunar and/or Mars missions.

## REFERENCES

1. Arena, M. P.; Porter, M. D.; Fritz, J. S. *Analytical Chemistry* 2002, 74, 185-190.
2. Arena, M.; Porter, M.; Fritz, J.; Mudgett, P.; Rutz, J.; Schultz, J. 32th International Conference on Environmental Systems, San Antonio, TX, 2002.

3. Arena, M. P.; Porter, M. D.; Fritz, J. S. *Analytica Chimica Acta* 2003, 482, 197-207.
4. Gazda, D. B.; Lipert, R. J.; Fritz, J. S.; Porter, M. D.; Rutz, J.; Mudgett, P.; Schultz, J. 33th International Conference on Environmental Systems, Vancouver, B.C., Canada, 2003.
5. Gazda, D. B.; Lipert, R. J.; Fritz, J. S.; Porter, M. D. *Analytica Chimica Acta* 2004, 510, 241-271.
6. Fritz, J. S. *Analytical Solid-Phase Extraction*; Wiley-VCH: New York, 1999.
7. Wendlandt, W. W.; Hecht, H. G. *Reflectance Spectroscopy*; Inter-science: New York, 1966.
8. Kortum, G.; Springer-Verlag: New York, 1969, p 106-116.
9. Blitz, J. P. In *Modern Techniques in Applied Molecular Spectroscopy*; Mirabella, F. M., Ed.; John Wiley & Sons, Inc.: New York, 1998, p 185-219.
10. Eaton, A. D.; Clesceri, L. S.; Greenberg, A. E.; Franson, M. A. H.; American Public Health Association.; American Water Works Association.; Water Environment Federation. *Standard methods for the examination of water and wastewater*; American Public Health Association: Washington, 1998.
11. Dmitrienko, S. G.; Sviridova, O. A.; Pyatkova, L. N.; Senyavin, V. M. *Analytical and Bioanalytical Chemistry* 2002, 374, 361-368.

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## DEFINITIONS, ACRONYMS, ABBREVIATIONS

**C-SPE:** colorimetric-solid phase extraction  
**F(R):** Kubelka-Munk function  
**LCV:** Leuco Crystal Violet  
**Total I:** iodine, iodide, and triiodide  
**PVP:** poly(vinylpyrrolidone)  
**ISS:** International Space Station  
**WPA:** water processing assembly