water

MDPI

Article

Investigating the Leaching of Organic Compounds from Polyethylene and the Formation of Iodinated Disinfection Byproducts in the International Space Station Potable Water

Conor T. Gowan [1,*], Bailey A. M. Gordon [2], Judy Westrick [2] and Shawn P. McElmurry [1]

[1] Department of Civil and Environmental Engineering, Wayne State University, Detroit, MI 48202, USA; s.mcelmurry@wayne.edu
[2] Lumigen Instrument Center, Wayne State University, Detroit, MI 48202, USA; baileygordon@wayne.edu (B.A.M.G.); judy.westrick@wayne.edu (J.W.)
* Correspondence: conorgowan@wayne.edu

Abstract

Ensuring safe and palatable drinking water is critical for long-duration space travel and part of NASA's 2022 strategic goals. This study investigated whether the formation of iodoform occurred when iodine reacts with trace levels of dissolved organic carbon (DOC) leaching from spacecraft water system components. A simplified model of the International Space Station's Environmental Control and Life Support System was constructed, focusing on disinfection. The system included water storage in low-density polyethylene (LDPE) bags followed by activated carbon block filtration. Three scenarios were tested: iodine treatment in the storage tank, iodine treatment in-line after storage, and a control with no iodine. Preliminary results showed I_2 concentrations of 0.1–5.42 mg/L prior to filtration, which decreased below detection after filtration. DOC concentrations ranged from below detection to 1.1 mg/L. Concentrations of iodoform, determined by gas chromatography–mass spectrometry, were assessed to observe potential risks to spacecraft drinking water quality. Iodine-based disinfection did result in significant iodoform formation or increased leaching of DOC. This study supports that long-term water storage can be achieved using iodine disinfection and LDPE storage. These results also inform the use of iodine disinfection in emergency situations by drinking water managers when water supply is interrupted in disaster situations.

Keywords: water storage; iodine; iodoform; dissolved organic carbon; human health

Check for updates

Academic Editors: Enedir Ghisi and Stavroula Tsitsifli

Received: 14 April 2026
Revised: 11 June 2026
Accepted: 13 June 2026
Published: 16 June 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

Since mankind began its quest to travel beyond the limits of Earth into space, the ability to ensure the health and safety of astronauts has been imperative. Though creature comforts are limited due to weight and limited storage capacity, necessities to support human life, such as safe, palatable drinking water, have always been provided. Strict water quality standards have been implemented on space missions and the disinfectants used have evolved with advances in scientific understanding. This study focuses on the disinfection and storage presently used on the International Space Station (ISS), which can also provide valuable information for practices that could be used in drinking water treatment on Earth.

On board the ISS, an Environmental Control and Life Support System (ECLSS), which utilizes a Water Recovery System (WRS) and Water Process Assembly (WPA), produces

potable water for crew members [1]. Presently, iodine (I_2) is used on the ISS in the final stages of disinfection within the WPA and is removed by the Potable Water dispenser (PWD) before water is consumed by crew [2]. An illustration of this looped system is shown in Figure 1.

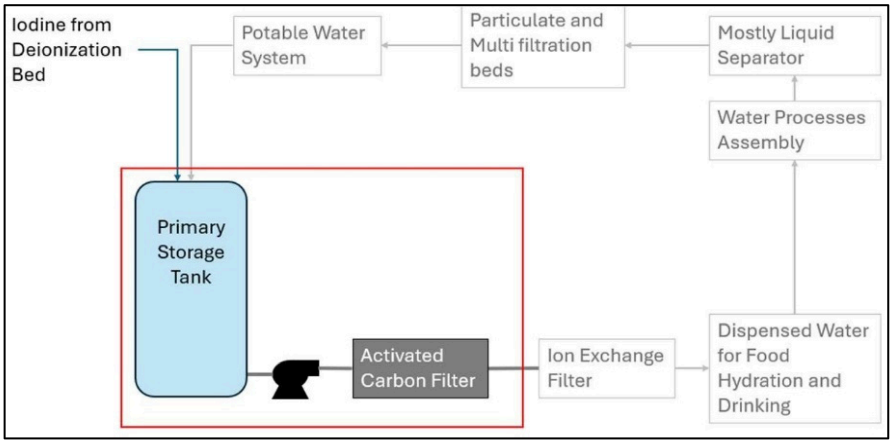


Figure 1. Overview of the ECLSS on board the ISS. The proposed research focuses on the area in red, concerning the storage of potable water, peristaltic pump, and activated carbon filtration.

The main storage tank utilizes combitherm®, a composite material with a polyethylene layer that interacts directly with the water [3]. To suppress microbial growth, an iodine concentration of 1.0–4.0 mg/L is maintained using I_2 in the primary storage tank [4]. Activated carbon and ion exchange filters (ACTEX) are then used to remove free iodine before water is dispensed. The entire system is linked with stainless steel tubing to resist corrosion, and water is pumped through the system using peristaltic pumps [5].

Though ACTEX is used to remove iodine to <0.2 mg/L [6], organic carbon can leach from the polyethylene layer used in the combitherm® vessels [7]. Leaching of organic carbon can potentially form iodinated disinfection byproducts (I-DBPs), leading to long-lasting health implications to crew members if consumed over time [8]. Although I-DBPs are not considered a significant threat to public health due to the widespread use of chlorine-based disinfection methods, they may still pose potential health risks to crew members. While I-DBPs are not heavily regulated in the United States, they have drawn increasing concern due to their greater cytotoxic and genotoxic properties compared to regulated trihalomethanes derived from chlorine and bromine at lower concentrations [9–16]. Currently, there are only 11 DBPs that are regulated and they fall into four major groups, trihalomethanes, haloacetic acids, bromate and chlorite, none of which are iodine-based DBPs [8,17]. Due to the lack of regulation, the formation of I-DBPs may not have been considered when creating the water system for the ISS. By using iodine as a disinfectant, it increases the likelihood of the formation of harmful I-DBPs in the water supply, unlike Earth-bound drinking water systems where other halogen-based disinfection are more commonly used. The inherent health risks of exposure to iodoform are neurological problems as well as toxic effects to the liver and brain due to long-term exposure [18]. Strict requirements are needed to ensure that the long-term health impacts on crew members are minimized on extended-duration exploration of our solar system. The goal of this specific research is to assess the leaching of organic carbon and quantify the formation of harmful I-DBPs in the WPA and removal by activated carbon in the PWD.

This study assesses drinking-water-related risk by observing leaching dissolved organic molecules from the storage vessels during long mission durations and their interactions with iodine disinfectants on the ISS. With an improved understanding of risk, additional improvements to drinking water systems may be necessary. Ultimately, this

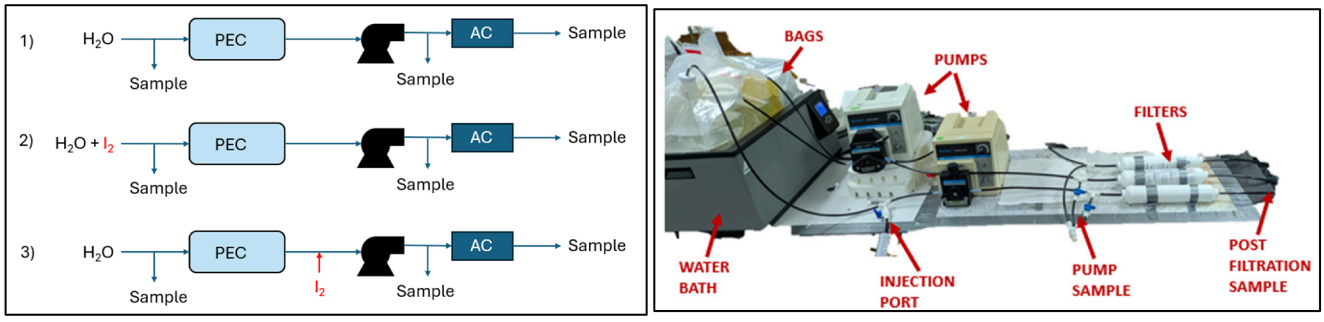
research can help to ensure the health of crew members on long voyages to the moon as well as aid in water safety planning for emergency situations.

Innovations put forth by the scientific community for space travel have become commonplace in society (e.g., Velcro, memory foam, emergency blankets, etc.) and innovations in water disinfection could be used in society through water safety planning and risk-based management approaches in emergency situations. By better understanding long-term storage effects in low-density polyethylene (LDPE)-based containers in conjunction with iodine-based disinfection, it can improve the understanding of storing and disinfecting water that could be used when water emergencies occur, like those caused by the California wildfires [19] and during water crises in Flint, Michigan [20] and Toledo, Ohio [21]. Access to potable water in emergency situations is critical to human health, especially as drinking water becomes scarce for prolonged periods and trust in public water systems dwindles [22].

To meet the goal of improving and maintaining long-term crew member health on extended missions as a part of NASA's 2022 strategic goals [23], this project aims to: (1) quantify organic carbon that leaches from the potable water storage vessels/tubing, and (2) quantify I-DBPs in the storage tank and removal by the activated carbon filter. By improving upon the understanding of I-DBP formation and long-term storage of potable drinking water utilizing iodine, this research can aid drinking water scientists in using effective, safe doses of disinfectants in LDPE storage units that could be utilized in emergency situations in local communities.

2. Materials and Methods

To assess the leaching of organics and possible formation of halogenated DOCs, the focus was placed on the PWD portion of the cycle, where iodine and organic carbon could potentially interact. Therefore, the experimental design focused on water quality following the drinking water storage tank and activated carbon filter, where I-DBPs can be removed (the encircled red section of Figure 1). The proposed experimental design (Figure 2) mimicked PWD conditions using a polyethylene storage container, stainless steel tubing, peristaltic pumps, and an activated carbon filter.



(**a**) (**b**)

Figure 2. The experiment comprised three separate systems, each composed of LDPE bag containers (PEC), peristaltic pump heads, polyethylene tubing, and an activated carbon filter (AC) (**a**). A photo of the experimental setup (**b**).

The PEC storage bags and activated carbon filters are the two most likely sources of organic compounds required for I-DBP formation. The inner layer of Combitherm® that is in direct contact with water is LDPE. Therefore LDPE bags (KRW Packaging Machinery Inc., Weaverville, NC, USA) were placed in an incubator with temperature set to 30 °C, representing the heating of water within the PWD, which can provide a temperature range of 18–93 °C [6]. Three paired treatment systems were run to assess organic carbon

leaching and I-DBP formation: System 1 served as a DBP control and had nano-pure water (>18 MΩ/cm) flowing through the system, System 2 resembled what takes place on the ISS and contained nano-pure water and up to 4 mg/L iodine (Sigma-Aldrich Inc., Saint Louis, MO, USA) entering the system, and System 3 had nano-pure water flowing to the storage tank with iodine added to achieve a maximum concentration of 4 mg/L prior to entering the activated carbon filter (General Electric, Boston, MA, USA).

Two hydraulic retention times in the storage tank were tested: 48 h and 18 days. These retention times were expected to bound the exposure risk that could be experienced in the ISS (48 h) or during extended space travel. Though it is not expected for the 18-day water stagnation period to be experienced on board the ISS, it was done as a "worst case scenario" to see if it were possible to cause sufficient leaching and time for the formation of iodoform. For the 48 h retention time, the system was run for four weeks to reach a steady state and then sampled weekly for three weeks. For the 18-day retention time, sampling was performed once on day 18. Samples were collected at each step of the treatment train to assess the formation and removal of I-DBPs. DOC and I-DBP samples were collected and filtered using a 0.45 µm PTFE (VWR International, Radnor, PA, USA) syringe directly into trace carbon clean amber vials (40 mL) with acid washed Teflon septa. Free iodine samples were also filtered in the same manner, though collected in sterile 50 mL centrifuge tubes and were assessed within 1 h of collection. The total number of samples collected for free iodine, I-DBP, and organic carbon analysis were 204, 27 and 204, respectively.

To assess if I-DBPs were present in samples, a modified methyl tert-butyl ether (MTBE) Liquid to Liquid extraction method developed by Cuthbertson et al. [24] was used. I-DBP samples were collected at 80 mL volumes in head space free bottles, free iodine was quenched using 3% sodium thiosulfate (Thermo Fisher Scientific, Hampton, NH, USA), and pH was adjusted to 3–5 using sulfuric acid. Extractions were completed within 48 h (chilled at 4 °C). The sample pH was adjusted to below 1 using 1 M sulfuric acid (Millipore Corporation, Darmstadt, Germany), followed by an addition of 5 g of sodium sulfate. The sample was then placed in a 250 mL separation funnel with 15 mL of MTBE (Thermo Scientific Chemicals, Waltham, MA, USA) and shaken. Samples were then allowed to settle to allow for the organic layer to separate and the top layer was then extracted to a 15 mL glass test tube. Samples were then dried by passing through a sodium sulfate column (made with glass wool, sodium sulfate, and pasteur pipette) and then evaporated to <500 µL under a gentle stream of nitrogen using the nitrogen blowdown concentration method. The sample was then brought up to 1 mL using MTBE, transferred to an amber GC vial with a screw down cap with a PTFE-lined silicone septum, and an internal standard (0.01 mL of 1,2-dibromopropane) (TCI Chemicals, Tokyo, Japan) was added.

The I-DBP samples were assessed using a Thermo Scientific TSQ™ 9610 Triple Quadrupole GC-MS (Thermo Scientific, Waltham, MA, USA) with electron ionization in scan mode. The GC was equipped with a Restek VMS capillary column (30 m, 0.25 mm ID, 1.40 µm). The GC temperature ramp is described in Table S1. The MS was used to scan a range of masses, 40–400, and the target compound was assessed using reference mass spectrum and retention time. The calibration curve ranging from 10 to 1000 µg/L was constructed using an iodoform standard (MilliporeSigma, Burlington, MA, USA). The target I-DBP for this study was iodoform ($HC\text{-}I_3$) due to trihalomethanes typically having the highest prevalence in drinking water distribution systems compared to other chlorinated disinfection byproducts [25]. Due to the limitations of this study, we do acknowledge that there could be other I-DBPs forming at concentrations below detection. The iodoform ions we extracted for the MS scans were 267 m/z and 127 m/z with a retention time of 29.16 minutes. Seven replicates of the lowest calibration standard with a 3:1 signal-to-noise ratio, 20 µg/L, were prepared and the limit of detection was calculated as the mean plus

three times the standard deviation of those replicates. Based on this validation, the limit of detection was determined to be 24 µg/L.

Samples were assessed for free iodine concentrations using Standard Method 4500-I.B [26], Leuco Crystal Violet Method. This method has a detection limit of 10 µg/L according to the World Health Organization (WHO) [27]. This method requires the use of a spectrophotometer and a standard curve using I_2 in the range of 0.1 to 6 mg/L. Samples (50 mL) were treated with 1.0 mL of a citric acid buffer solution and 1.0 mL of leuco crystal violet indicator (Thermo Scientific, Waltham, MA, USA) and were diluted to a total volume of 100 mL using iodine-free water. Samples were then transferred into a 1.0 cm light path cuvette and assessed using a Thermo Scientific Evolution 200 series spectrophotometer (Thermo Scientific, Waltham, MA, USA) at 592 nm. Concentrations were then assessed based on the standard curve and Beer–Lambert law.

Dissolved organic carbon (DOC) was analyzed using a wet oxidation technique using phosphoric acid (VWR International, Radnor, PA, USA) and sodium persulfate (Thermo Scientific, Waltham, MA, USA) (ASTM 5310.C) [28], utilizing an Aurora 1030 Wet Oxidation TOC Analyzer. Due to the expected low concentration of DOC, the calibration curve consisted of concentrations of 0.5 to 25 mg/L from a DOC Standard (RICCA, Arlington, TX, USA). A check standard of 2 mg/L was created to ensure the accuracy of the analysis within 5%.

All statistical analyses, tables, and figures were assessed and generated using R software (version 4.4.0) in RStudio (version 2023.090+463.pro11).

3. Results and Discussion

3.1. DOC Analysis

DOC concentrations ranged from non-detect to 0.3 mg/L over the 10-week experimental period. The average weekly DOC concentrations can be seen in Figure 3.

DOC concentrations varied throughout the experiment; the average concentrations were below both Code of Federal Regulations (40 CFR) limits (2.0 mg/L) [29] and NASA target goals on board the ISS (0.5 mg/L) [4]. Even after extending the stagnation period to about three weeks, there was no significant increase in DOC concentration in the PEC bags, in-line, or post-filtration. This leads to the conclusion that the PEC liner (LDPE) within combitherm® is a stable storage vessel for long-term water storage that can withstand leaching into the WPA and shows that after extended use, even in disaster scenarios, long-term water storage can be achieved using current potable water systems with minimal harmful health effects. The leaching of organic carbon from LDPE was not detected at levels likely to pose a risk to crew members over a seven-week period. The average concentration of DOC detected was an order of magnitude below the threshold of 2.0 mg/L suggested by the USEPA to discourage the formation of disinfection byproducts [30]. These results are in agreement with similar studies that assessed the leaching of DOC from polyethylene microplastic into various types of water, including tap water [31,32]. Although some DOC leaching was observed over a 14-day period, it was an insignificant amount. It also suggests that the introduction of iodine as a disinfectant does not significantly increase the amount of leached organic carbon in storage, further suggesting minimal harmful effects of long-term water storage (7.5 weeks) with iodine. This low concentration of DOC also limits the formation of iodinated trihalomethanes, as DOC has been reported to be a key factor in the formation of I-DBPs [33].

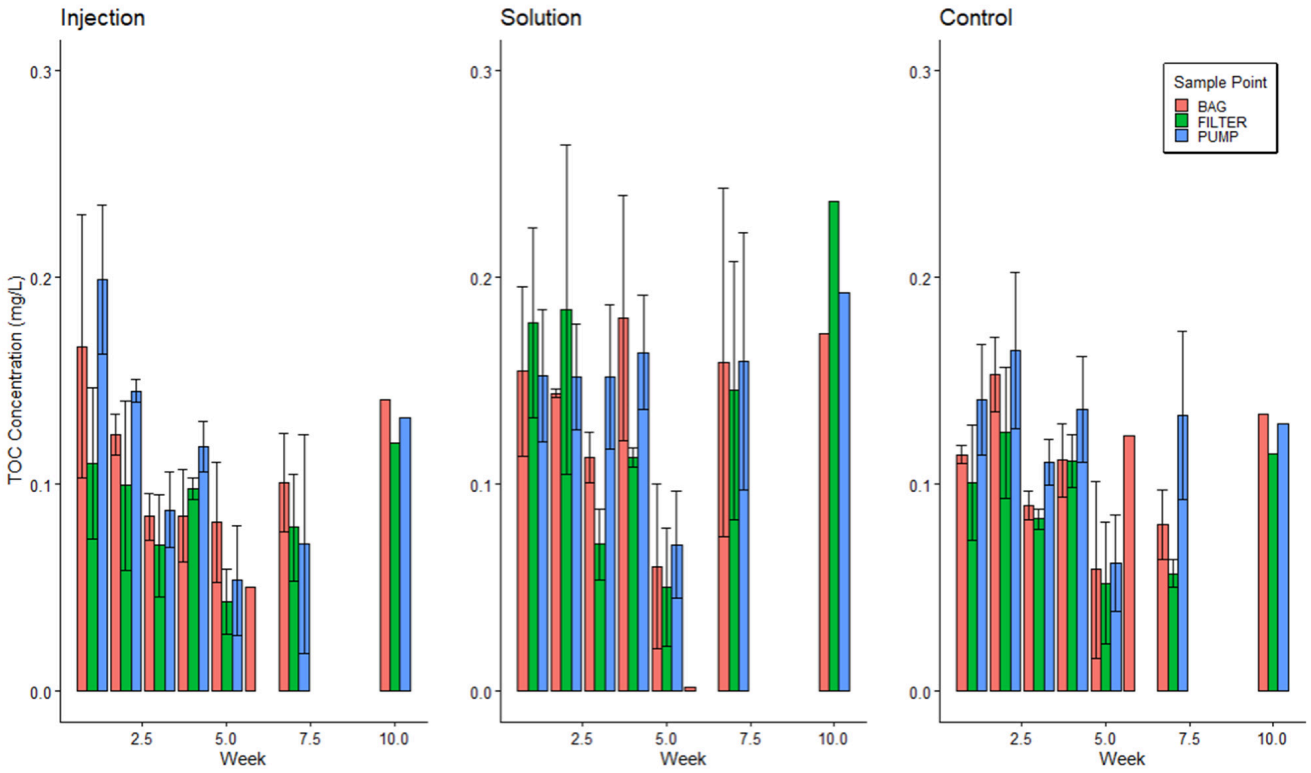


Figure 3. The average DOC concentrations (mg/L) in the three treatment scenarios. Samples were assessed for the storage bag (red), pump (blue), and post-filtration (green). Averages that do not include error bars had only one sample above detection limit. Missing data represents sample concentrations below the detection limit or occurred during the 18-day retention period where no collections were made (starting week 7.5).

3.2. Residual Iodine Analysis

Residual iodine measurements were between method non-detect (<10 µg/L) and 5.42 mg/L prior to filtration. The changes in concentration and redosing of iodine in the appropriate systems over the course of the experiment are shown in Figure 4.

After monitoring the 2-day retention time over the 7.5-week period, the filters remain effective at removing free iodine. Post-filtration data show that the maximum iodine concentration was 0.152 mg/L, below the removal goal of <0.2 mg/L [6]. Iodine decay and removal continued to be observed over the three-week extended retention time (18 days). Through showing the presence of iodine in systems 1 and 2 and the removal of I_2 post-filtration, the systems can operate for extended periods of time and reduce the effects of iodine consumption by the crew. The finding is consistent with Pan et al. [34], that reported powdered activated carbon filters are highly effective at removing free iodine from drinking water prior to subsequent disinfection steps in drinking water treatment processes. Even if low concentrations of iodine (<0.1 mg/L) were able to flow through the activated carbon filtration, it would most likely be removed by the second filtration step in the ACTEX system, the ion exchange filter, before being ingested by the members of the ISS. The activated carbon filtration is efficient at removing free iodine, ensuring minimal effects on the palatability of water for the crew.

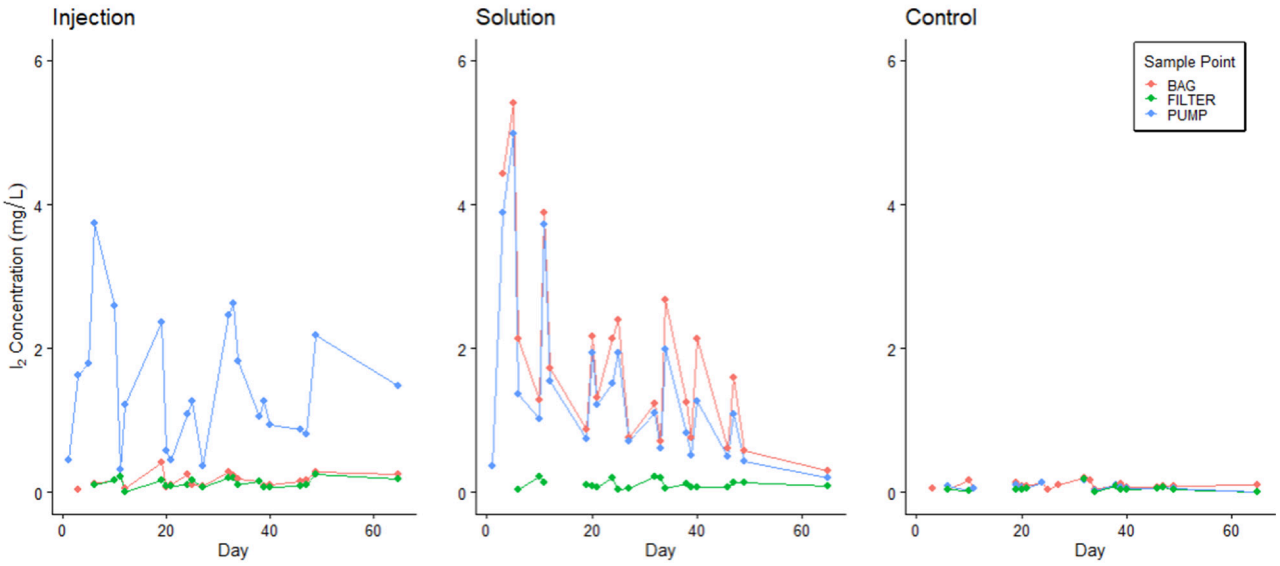


Figure 4. Concentration of I_2 in the three treatment scenarios over 65 days. Samples were assessed for the storage bag (red), pump (blue), and post-filtration (green). Averages that do not include error bars had only one sample above detection limit. Missing data represents sample concentrations below the detection limit or occurred during the 18-day retention period where no collections were made (starting week 7.5).

3.3. Disinfection Byproduct Analysis

No discernible peaks were detected via GC-MS for samples collected after 48 h of storage (Table S2). Small peaks consistent with iodoform were identified in water that had been stored for 18 days. For these samples, iodoform was detected (58.7 µg/L) in the bag that contained iodine in solution as well as in-line, after the pump (53.2 µg/L). Post-filtration, iodoform was below the detection limit (24 µg/L). All other samples assessed at 18-day storage showed that iodoform was below the detection limit. This is consistent with previous studies demonstrating that PAC and other activated carbon filters can reduce the formation of I-DBPs, particularly trihalomethanes, during drinking water treatment [34,35]. These findings further indicate that even if I-DBPs were to form in the system prior to filtration, they would likely be effectively removed by carbon filtration. Based on current disinfection byproduct regulations [36], the low concentration of residual iodine post-filtration is below the lowest observed toxic concentration for iodoform (1.0×10^{-5} M) [14] and I-DBPs are not likely to negatively impact crew health for long-term space travel based on our current understanding of risk. The use of LDPE containers with iodine disinfectants can be applied in emergency situations on Earth for long-term potable water storage when significant stagnation may occur (up to 7.5 weeks). Since the levels of iodoform observed were below harmful concentrations, this suggests a minimal risk to human health.

4. Conclusions

Over the course of this study, it was shown that:

(1) There is little evidence of substantial leaching of DOC species from the LDPE bags, and minimal to no formation of I-DBPs was observed under both the 2-day retention time associated with typical water usage and the extended 18-day retention period. Any I-DBPs formed remained below harmful thresholds and were effectively removed by activated carbon filters.

(2) DOC concentrations were less than 0.3 mg/L on average throughout the 7-week incubation period, well below the acceptable 2 mg/L in drinking water on Earth and 0.5 mg/L on the ISS.

(3) Filters were effective at removing free iodine to target concentrations (<0.2 mg/L).

Future studies can explore the potential for extended stress tests on the PEC bags, such as drastic temperature changes (greater than 30 °C) and increased storage times (10–31 weeks) to observe if these external factors would affect leaching of DOC species from the PEC bags, the formation of I-DBPs, and breakthrough of free iodine post-filtration. Through this research, it was shown that iodine disinfection did not lead to significant and harmful formation of I-DBPs and did not lead to an increase in leached DOC, impacting water quality. This study showed that long-term water storage could be achieved using iodine disinfection, stored in LDPE, and filtered with low-cost activated carbon filters, which could be utilized in emergency situations by drinking water managers when water supply is interrupted during disasters.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w18121479/s1, Figure S1. Experiment sample analysis schema. All samples were assessed for free I2, DOC, and I-DBPs. Figure S2. Chromatographic peaks with a retention time of ~29.15 min were identified and quantified through calibration standards as iodoform. Table S1. GC Oven Ramp. Table S2. Raw data for the 65 days of sample collection for DOC, free I_2, and iodoform.

Author Contributions: Conceptualization, C.T.G.; methodology, C.T.G.; software, C.T.G.; validation, C.T.G. and S.P.M.; formal analysis, C.T.G. and B.A.M.G.; investigation, C.T.G.; resources, C.T.G., J.W. and S.P.M.; data curation, C.T.G.; writing—original draft preparation, C.T.G.; writing—review and editing, C.T.G., B.A.M.G., J.W. and S.P.M.; visualization, C.T.G. and S.P.M.; supervision, C.T.G. and S.P.M.; project administration, C.T.G. and S.P.M.; funding acquisition, C.T.G. All authors have read and agreed to the published version of the manuscript.

Funding: Funding for this award is made possible by a Cooperative Agreement with National Aeronautics and Space Administration (NASA) to the Michigan Space Grant Consortium (MSGC) via the Office of STEM Engagement (OSTEM) and is subject to the same terms and conditions required of MSGC to maintain good standing and compliance with evolving guidance provided by NASA in response to current Executive Orders and contingent upon the Federal Government's continued funding for the National Space Grant College and Fellowship Program. Research reported in this publication was supported in part by funding provided by the National Aeronautics and Space Administration (NASA), under award number 80NSSC25M7087, Michigan Space Grant Consortium (MSGC). The Center for Urban Responses to Environmental Stressors (CURES) voucher, NIEHS award P30 ES036084, provided funding for the gas chromatography analyses.

Data Availability Statement: The original contributions presented in this study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

NASA	National Aeronautics and Space Administration
I-DBP	Iodinated Disinfection Byproduct
DOC	Dissolved Organic Carbon
LDPE	Low-Density Polyethylene
ISS	International Space Station
ECLSS	Environmental Control and Life Support System
WRS	Water Recovery System
WPA	Water Process Assembly
PWD	Potable Water Dispenser
ACTEX	Activated Carbon and Ion Exchange Filters

PEC	Polyethylene Bag Containers
AC	Activated Carbon Filter
MTBE	Methyl Tert-Butyl Ether
WHO	World Health Organization
TOC	Total Organic Carbon

References

1. Gaskill, M. NASA Achieves Water Recovery Milestone on International Space Station—NASA. 2023. Available online: https://www.nasa.gov/missions/station/iss-research/nasa-achieves-water-recovery-milestone-on-international-space-station/ (accessed on 14 October 2024).
2. Tobias, B.; Garr, J.; Erne, M. International Space Station Water Balance Operations. In *41st International Conference on Environmental Systems*; American Institute of Aeronautics and Astronautics: Portland, OR, USA, 2011. [CrossRef]
3. Rutz, J.A.; Schultz, J.R. *Identification of an Organic Impurity Leaching from a Prototype ISS Water Container*; SAE International: Orlando, FL, USA, 2001. [CrossRef]
4. Carter, L.; Tabb, D.; Tatara, J.D.; Mason, R.K. *Performance Qualification Test of the ISS Water Processor Assembly (WPA) Expendables*; 2005-01–2837; SAE International: Rome, Italy, 2005. [CrossRef]
5. Steele, J.; Wilson, M.; Makinen, J.; Ott, C.M. Antimicrobials for Water Systems in Manned Spaceflight—Past, Present, and Future Applications and Challenges. In Proceedings of the 48th International Conference on Environmental Systems, Albuquerque, NM, USA, 8–12 July 2018.
6. Shaw, L.A.; Barreda, J.L. *International Space Station USOS Potable Water Dispenser Development*; SAE International: Warrendale, PA, USA, 2008.
7. Birmele, M.; Roberts, M.; McCoy, L. Disinfection of Spacecraft Potable Water Systems by Passivation with Ionic Silver. In *41st International Conference on Environmental Systems*; American Institute of Aeronautics and Astronautics: Portland, OR, USA, 2011. [CrossRef]
8. Dong, H.; Qiang, Z.; Richardson, S.D. Formation of Iodinated Disinfection Byproducts (I-DBPs) in Drinking Water: Emerging Concerns and Current Issues. *Acc. Chem. Res.* **2019**, *52*, 896–905. [PubMed]
9. Pan, Y.; Zhang, X.; Li, Y. Identification, toxicity and control of iodinated disinfection byproducts in cooking with simulated chlor(am)inated tap water and iodized table salt. *Water Res.* **2016**, *88*, 60–68. [CrossRef] [PubMed]
10. Smith, E.M.; Plewa, M.J.; Lindell, C.L.; Richardson, S.D.; Mitch, W.A. Comparison of Byproduct Formation in Waters Treated with Chlorine and Iodine: Relevance to Point-of-Use Treatment. *Environ. Sci. Technol.* **2010**, *44*, 8446–8452. [CrossRef] [PubMed]
11. Richardson, S.D.; Fasano, F.; Ellington, J.J.; Crumley, F.G.; Buettner, K.M.; Evans, J.J.; Blount, B.C.; Silva, L.K.; Waite, T.J.; Luther, G.W.; et al. Occurrence and Mammalian Cell Toxicity of Iodinated Disinfection Byproducts in Drinking Water. *Environ. Sci. Technol.* **2008**, *42*, 8330–8338. [CrossRef] [PubMed]
12. Wei, X.; Chen, X.; Wang, X.; Zheng, W.; Zhang, D.; Tian, D.; Jiang, S.; Ong, C.N.; He, G.; Qu, W. Occurrence of Regulated and Emerging Iodinated DBPs in the Shanghai Drinking Water. *PLoS ONE* **2013**, *8*, e59677. [CrossRef]
13. Woo, Y.-T.; Lai, D.; McLain, J.L.; Manibusan, M.K.; Dellarco, V. Use of mechanism-based structure-activity relationships analysis in carcinogenic potential ranking for drinking water disinfection by-products. *Environ. Health Perspect.* **2002**, *110*, 75–87. [CrossRef] [PubMed]
14. Plewa, M.J.; Wagner, E.D. Mammalian Cell Cytotoxicity and Genotoxicity of Disinfection By-Products. 2009. Available online: https://repository.library.noaa.gov (accessed on 12 May 2026).
15. Sayess, R.; Khalil, A.; Shah, M.; Reckhow, D.A.; Godri Pollitt, K.J. Comparative Cytotoxicity of Six Iodinated Disinfection Byproducts on Nontransformed Epithelial Human Colon Cells. *Environ. Sci. Technol. Lett.* **2017**, *4*, 143–148. [CrossRef]
16. Plewa, M.J.; Wagner, E.D.; Richardson, S.D. TIC-Tox: A preliminary discussion on identifying the forcing agents of DBP-mediated toxicity of disinfected water. *J. Environ. Sci.* **2017**, *58*, 208–216. [CrossRef] [PubMed]
17. United States Environmental Protection Agency. Stage 2 DBPR QRG for Schedule 1 Systems. Available online: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100A2D4.txt (accessed on 13 May 2026).
18. Iodoform—An Overview | ScienceDirect Topics. Available online: https://www-sciencedirect-com.proxy.lib.wayne.edu/topics/immunology-and-microbiology/iodoform (accessed on 11 May 2026).
19. Public Policy Institute of California. *The Challenges of Fighting Wildfires with Urban Water Systems*; Public Policy Institute of California: San Francisco, CA, USA, 2025. Available online: https://www.ppic.org/blog/the-challenges-of-fighting-wildfires-with-urban-water-systems/ (accessed on 10 May 2026).
20. Masten, S.J.; Davies, S.H.; McElmurry, S.P. Flint Water Crisis: What Happened and Why? *J. Am. Water Works Assoc.* **2016**, *108*, 22–34. [CrossRef] [PubMed]

21. Jetoo, S.; Grover, V.I.; Krantzberg, G. The Toledo Drinking Water Advisory: Suggested Application of the Water Safety Planning Approach. *Sustainability* **2015**, *7*, 9787–9808. [CrossRef]
22. Brooks, S.K.; Patel, S.S. Psychological Consequences of the Flint Water Crisis: A Scoping Review. *Disaster Med. Public Health Prep.* **2022**, *16*, 1259–1269. [CrossRef] [PubMed]
23. NASA. *NASA Strategic Plan 2022*; NASA: Washington, DC, USA, 2022. Available online: https://www.nasa.gov/wp-content/uploads/2023/09/fy-22-strategic-plan-1.pdf?emrc=ff1a1e (accessed on 10 October 2024).
24. Cuthbertson, A.A.; Liberatore, H.K.; Kimura, S.Y.; Allen, J.M.; Bensussan, A.V.; Richardson, S.D. Trace Analysis of 61 Emerging Br-, Cl-, and I-DBPs: New Methods to Achieve Part-Per-Trillion Quantification in Drinking Water. *Anal. Chem.* **2020**, *92*, 3058–3068. [PubMed]
25. Waller, K.; Swan, S.H.; DeLorenze, G.; Hopkins, B. Trihalomethanes in drinking water and spontaneous abortion. *Epidemiology* **1998**, *9*, 134–140. [CrossRef] [PubMed]
26. *4500-I IODINE*; Standard Methods for the Examination of Water and Wastewater. APHA Press: Washington, DC, USA, 2023. Available online: https://www.standardmethods.org/doi/10.2105/SMWW.2882.083 (accessed on 10 October 2024).
27. World Health Organization. Iodine in Drinking-water. *Health Criteria Support. Inf.* **1996**, *2*, 1–10.
28. American Public Health Association. 5310 total organic carbon. In *Standard Methods for the Examination of Water and Wastewater*; American Public Health Association: Washington, DC, USA, 2017.
29. CFR 141.135—Treatment Technique for Control of Disinfection Byproduct (DBP) Precursors. Available online: https://www.ecfr.gov/current/title-40/part-141/section-141.135 (accessed on 12 May 2026).
30. United States Environmental Protection Agency. Disinfectants and Disinfection Byproducts Rules (Stage 1 and Stage 2) What Do They Mean to You? Available online: https://www.epa.gov/sites/default/files/2020-06/documents/dbpr_plain_english_guide_final_508.pdf (accessed on 12 May 2026).
31. Koh, K.Y.; Chen, Z.; Lin, S.; Mohan, K.S.; Luo, X.; Chen, J.P. Leaching of organic matters and formation of disinfection by-product as a result of presence of microplastics in natural freshwaters. *Chemosphere* **2022**, *299*, 134300. [CrossRef] [PubMed]
32. Lee, Y.K.; Romera-Castillo, C.; Hong, S.; Hur, J. Characteristics of microplastic polymer-derived dissolved organic matter and its potential as a disinfection byproduct precursor. *Water Res.* **2020**, *175*, 115678. [CrossRef] [PubMed]
33. Allard, S.; Tan, J.; Joll, C.A.; von Gunten, U. Mechanistic Study on the Formation of Cl-/Br-/I-Trihalomethanes during Chlorination/Chloramination Combined with a Theoretical Cytotoxicity Evaluation. *Environ. Sci. Technol.* **2015**, *49*, 11105–11114. [CrossRef] [PubMed]
34. Pan, R.; Lin, Y.L.; Zhang, T.Y.; Wei, X.L.; Dong, Z.Y.; Hu, C.Y.; Tang, Y.L.; Xu, B. Sequential combination of pre-chlorination and powdered activated carbon adsorption on iodine removal and I-THMs control in drinking water. *Chemosphere* **2023**, *313*, 137529. [CrossRef] [PubMed]
35. MacKeown, H.; Gyamfi, J.A.; Schoutteten, V.M.K.; Dumoulin, D.; Verdickt, L.; Ouddane, B.; Criquet, J. Formation and removal of disinfection by-products in a full scale drinking water treatment plant. *Sci. Total Environ.* **2020**, *704*, 135280. [CrossRef] [PubMed]
36. US EPA. Stage 1 and Stage 2 Disinfectants and Disinfection Byproducts Rules. 2015. Available online: https://www.epa.gov/dwreginfo/stage-1-and-stage-2-disinfectants-and-disinfection-byproducts-rules (accessed on 11 May 2026).

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.