Double Containment Transfer Tool for Liquid Sample Manipulation on the International Space Station

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ABSTRACT

With the termination of flights of the U. S. space shuttle there has been an abrupt reduction in experimental sample return capabilities from the International Space Station (ISS). There is an immediate need for an increase in on-orbit analysis capabilities and therefore for sample-transfer capabilities. We have therefore designed and fabricated prototypes of transfer tools capable of removing and doubly containing up to 1.0 mL and up to 5.0 mL of Tox-Level-1 fluids between devices on ISS. The Double Containment Transfer Tool accommodates commercially available syringe bodies and off-the-shelf needle-less luer fixtures in isolation from the spacecraft atmosphere. Experimental vessels can be modified with female connectors so they can be sampled by or can receive fluids from the Transfer Tool. Prototypes have been subjected to leakage, pressure, vacuum, and performance testing, and prototypes are available for testing in experimenters' laboratories.

INTRODUCTION

With the termination of flights of the U. S. space shuttle, which has historically returned life sciences and fluids materials to Earth for post-flight analysis, there is an immediate need for on-orbit analysis capabilities. In many life sciences, fluids, and human research projects it will be necessary to transfer fluids from an experiment facility to an analytical facility. This requirement is often in conflict with the NASA requirement that fluids classified as Toxicity Level-1 must be always doubly contained. In view of this need we have designed, fabricated, and tested prototypes of transfer tools capable of removing and doubly containing fluids without necessarily requiring a glovebox.

FEATURES

The Double Containment Transfer Tool transfers up to 1.0 mL and up to 5.0 mL of Tox-Level-1 fluids from and to appropriately equipped experimental devices on ISS. The capacity depends on the size of a sterile, off-the-shelf commercial syringe that is installed in the Double Containment Transfer Tool housing. The transfer tool accommodates commercially available syringe bodies and utilizes an off-the-shelf needle-less luer fixture and septum. These elements are enclosed so as to prevent their contact with the spacecraft atmosphere. Various experimental cassettes, vessels, and sample carriers can be modified with female connectors so they can be sampled by or can receive fluids from the Transfer Tool.

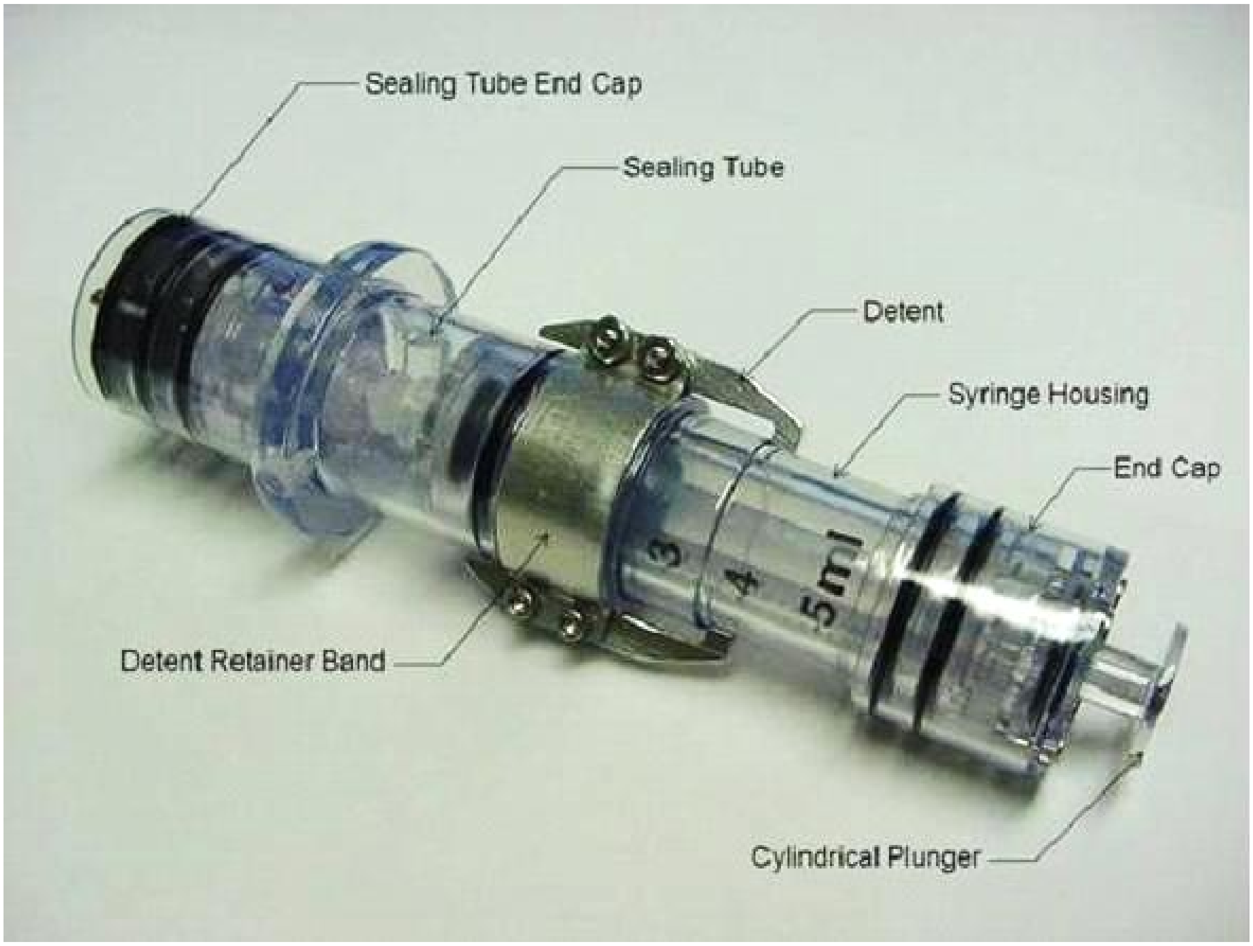

Figure 1. Photograph of one embodiment of the *Double Containment Transfer Tool*. The upper half (right) is the housing for a commercial syringe. It is coupled to a sealing tube by a retainer band, which seals the syringe housing to the coupling and transfer mechanism that provides double containment during transfer and allows disassembly for the insertion of the inner syringe. A cylindrical plunger glides through an O-ring seal to prevent fluid escape. The sealing tube terminates with a slitted rubber aperture sweep that prevents the escape of drops into the cabin atmosphere. The sealing tube end cap is protective only and does not provide a level of containment; it is normally tethered to the body of the sealing tube.

Several detailed features have been incorporated in anticipation of safety certification requirements for crewed orbital flight. During transport a simple package will secure and protect the Transfer Tool during transport or storage. If the plunger is accidentally depressed the sample that is ejected will be contained within the Sealing Tube (see Figure 1). Two levels of containment are required through all phases of operations. Double containment between the Sealing Tube and the ISS transfer site is maintained through design of the target mating port. The target hardware is required to have a female port that contains a needleless septum. When not in use this septum remains protected with a tethered cap or plug. When a transfer is to be made the cover is removed from the female port and the tip of the tool is inserted. Once mated within the female port the Transfer Tool is rotated clockwise to lock the threaded male luer fitting on the end of the tool with the needleless septum within the female port. Upon internal luer engagement the syringe housing is pushed forward and twisted clockwise to engage the needleless septum and syringe housed within the tool. Once engaged, the double o-rings on the front of the tool provide and maintain a seal through the transfer process. Once the selected volume has been transferred by pushing the plunger, the syringe housing is rotated counterclockwise within the sealing tube to disengage the internal luer seal within the tool. The sealing tube is then rotated counterclockwise within the mating female port to disengage the connection at the sample transfer site. Once disengaged, the Transfer Tool is removed from the female port, the end cap is placed over the end of the tool, and the cap reattached to the female port. Both end caps are tethered to their respective devices. An o-ring ring seal provides containment around the plunger, which has a cylindrical shaft. The "stock" syringe plunger provides the primary fluid containing seal, while the o-ring prevents leakage in the event of a plunger seal failure or fluid ejection into the Sealing Tube.

The appearance and main features of the Double Containment Transfer Tool are illustrated in Figure 1. Prototypes of this tool are available for ground-based laboratory testing in user applications.

TEST METHODS AND RESULTS

Extensive performance testing was conducted on the Double Containment Transfer Tool prototype. The battery of tests conducted on the initial prototype is summarized by the following categories:

Test 1: Mate and De-Mate with needle-less septum port (off-the-shelf Becton-Dickinson "BD Q-Syte Septum, 385100").

Result: Mate and De-Mate connection performed as designed

Test 2: Sample input/ withdrawal from experiment cassette

Result: Sample of water containing green food coloring was successfully injected into a cassette ("Light Microscopy Module Dynamic Stage" (LMM-DS)) and was also withdrawn from the cassette as designed. The test procedure is seen in the Figure 2 photographs.

Test 3: Containment testing

Result: A leak path was found around End Cap fasteners. This leak was avoided by a modification that was successfully retested in a second prototype with a design modification to the seal.

Test 4: Rapid depressurization/ re-pressurization

Result: The Transfer Tool prototype was subjected to rapid depressurization and repressurization in both the filled and empty states in accordance with NASA Document SSP 5200-IDD-ERP Rev. H (NASA, 2009). In both the filled and empty states the Transfer Tool prototype experienced no leakage or structural failure.

Test 5: Rapid temperature cycling

Result: A water-filled Double Containment Transfer Tool prototype was temperature cycled between 71^o C and -40^o C with a soak period of 3 hours. During the cycling from 71^o C to – 40^o C, the Protective End Cap softened and deformed around the end of the Double Containment Transfer Tool. This occurrence was remedied in the second prototype design with addition of a thicker Protective End Cap that features a pressure relieving breather.

Test 6: Freeze/thaw cycling (empty and filled)

Result: When tested in the empty state the Double Containment Transfer Tool prototype experienced no damage or failure from temperature cycling from 24^o C to -40^o C. In the filled state the prototype did produce a 10 µL drop of fluid within the Sealing Tube. This drop was the result of fluid expansion during freezing and the drop was completely contained within the Sealing Tube.

All testing was documented for the sponsor, and any design deficiencies found through the initial testing process were addressed with the fabrication and testing of a second generation prototype. Testing of the second generation Double Containment Transfer Tool proved the design updates to be successful and these results have been formally recorded as reports to the sponsor.

DISCUSSION

Fabrication and testing efforts to date are consistent with the Double Containment Transfer Tool becoming available for exercises in users' laboratories in 2012 and prepared for flight certification in 2013. Figure 3 shows an example of how the Double Containment Transfer Tool would find applications by transferring samples among specific life science facilities that might exist aboard ISS.

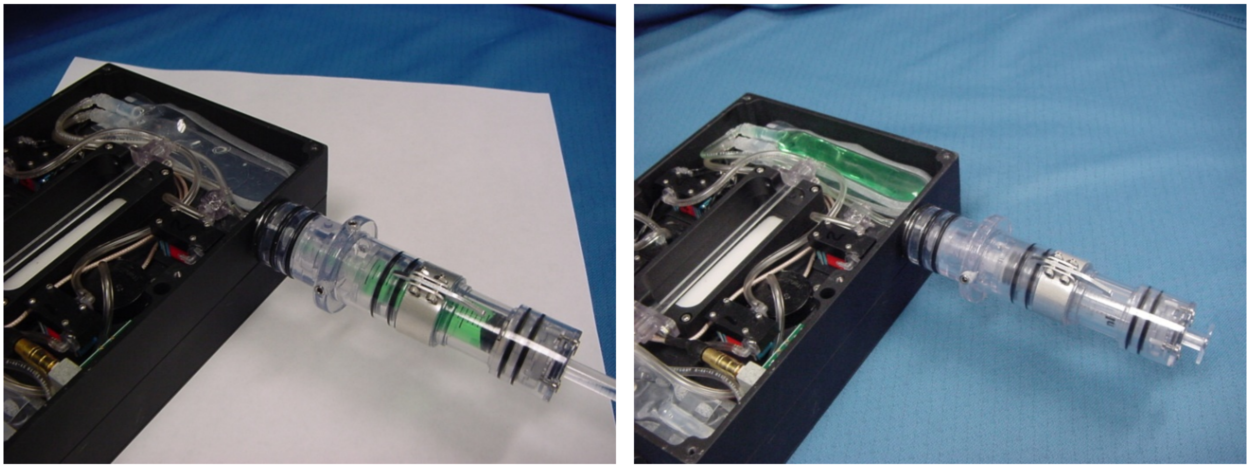

Figure 2. Left: a photograph of the Transfer Tool engaged to the Needle-less Septum Port prior to the sample input (see also image in Figure 3). Right: After being emptied into the cassette bag.

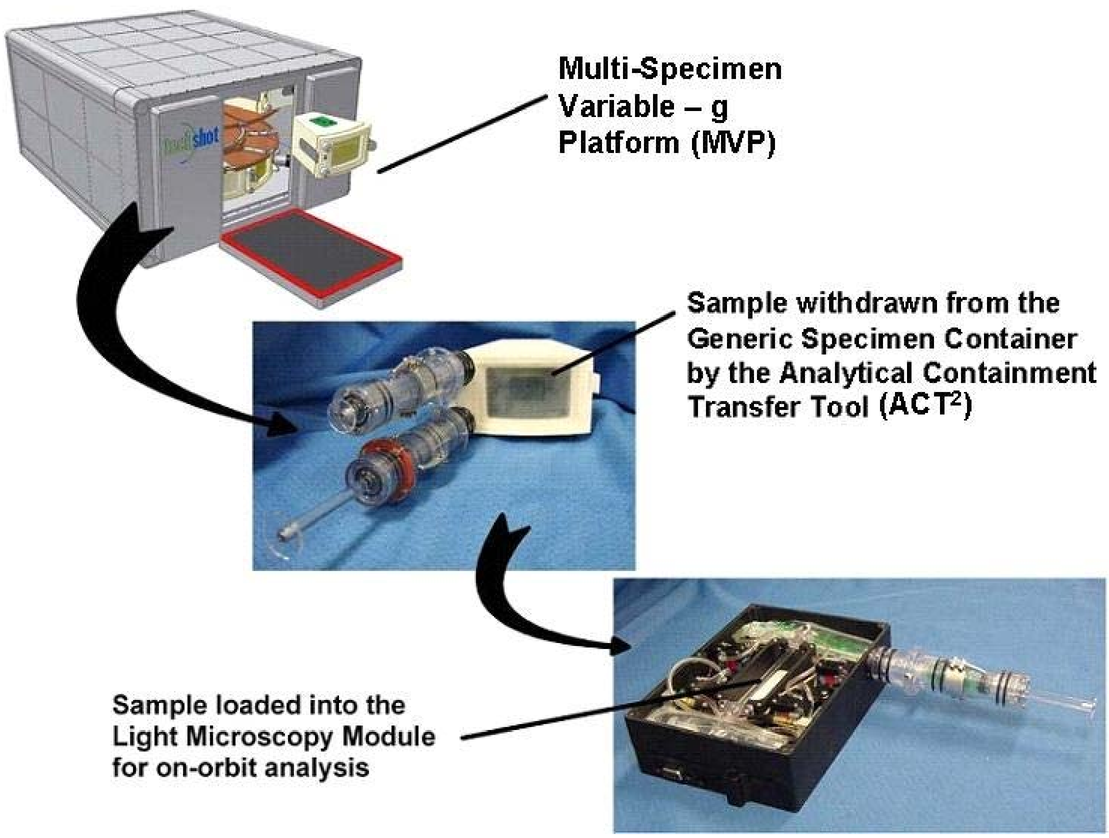

Figure 3. Example of an application of the Double Containment Transfer Tool: Transfer of biological suspensions between an experiment facility, such as a variable-*g* centrifuge with culture modules equipped with a needle-less septum port, and a receiving cassette for microscopy.

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