Breaking the Pressure Barrier: A History of the Spacesuit Injection Patch

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The spacesuit assembly has a fascinating and complicated history dating back to the early 1930s. Much has been written on this history from an assembly perspective and, to a lesser extent, a component perspective. However, little has been written or preserved specifically on smaller, lesser-known aspects of pressure suit design. One example of this is the injection patch—a small 2–in.-diameter disk on the leg of the Apollo suit that facilitated a medical injection when pressurized, and the only known implementation of such a feature on a flight suit. Whereas many people are aware this feature existed, very little is known of its origin, design, and use, and the fact that the Apollo flight suit was not the only instance in which such a feature was implemented. This paper serves to tell the story of this seeming "afterthought" of a feature, as well as the design considerations heeded during the initial development of subsequent suits.

Nomenclature

EMU	=	Extravehicular Mobility Unit
ETFE	=	ethylene tetrafluoroethylene
EVA	=	extravehicular activity
FEP	=	fluorinated ethylene propylene
ILC	=	International Latex Corporation
IM	=	intramuscular (injection)
IO	=	intraosseal (injection)
IV	=	intravascular (injection)
LCG	=	liquid cooling garment
NASA	=	National Aeronautics and Space Administration
PGS	=	pressure garment subsystem
TMG	=	thermal micromediorite garment
UTC	=	urine transfer connector

I. Introduction

The earliest efforts in pressure suit design were driven by the need to survive high altitudes during attempts to break speed or height flight records. At first, these efforts were propelled by daredevil aviators such as Wiley Post; however, the most aggressive pressure suit development period arguably occurred between the early 1940s and the mid 1960s, beginning with parallel and often competing efforts funded by the US Air Force and the US Navy, and culminating in the design of the Apollo Extravehicular Mobility Unit (EMU).

Although differences abound between early flight suits and spacesuits used during the Mercury and Gemini programs, one common factor differentiates them from the Apollo suit: For Apollo, the ability to get back to the safety of Earth relatively quickly was precluded. The fact that Apollo represented a change from being able to get home within hours to not being able to get home for days drove the program to consider additional risks, and the requirements to address those risks.

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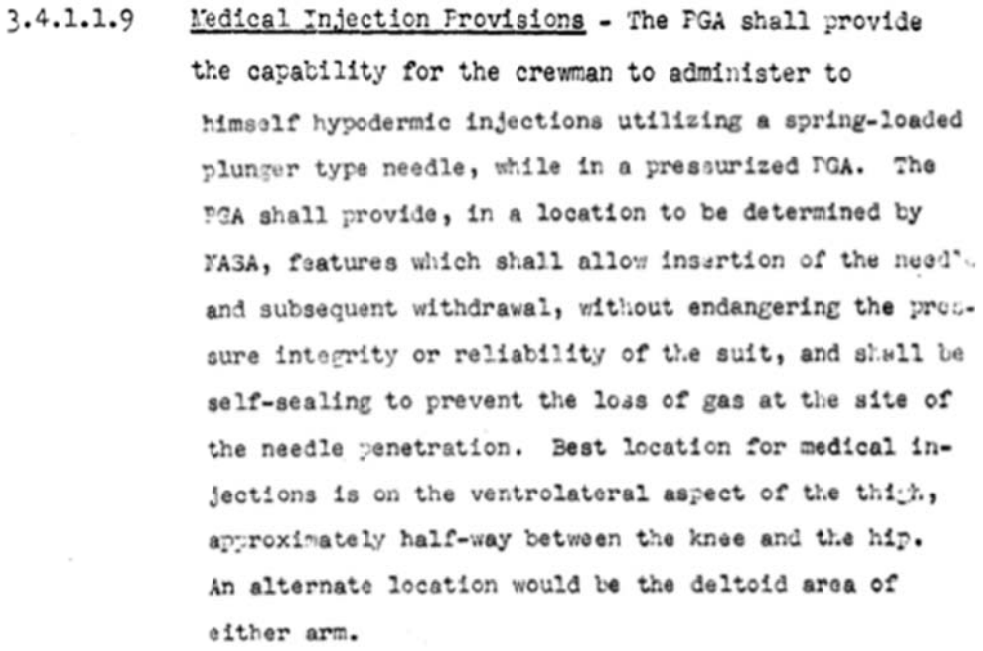
One of these identified risks was the potential need, in a contingency, to return to the crew module from an extravehicular activity (EVA) on the lunar surface in an unpressurized cabin or from lunar orbit back to Earth in an unpressurized cabin, or both. In such cases, it might be necessary to administer medication to the crewmember in the event of illness. In a pressurized cabin, it is of little consequence to doff the suit (as was typically done during the Apollo Program, regardless) and administer a medical injection as would normally be done on Earth. However, while in a pressurized suit, this becomes a bit more problematic. The Apollo Program identified a requirement for the Apollo EMU to have a biomedical injection patch to facilitate such an injection. This paper serves to document the design of this patch and, moving forward, design considerations for future EVA suits that may have comparable requirements.

II. Early Apollo Efforts

As was typical for Apollo suit requirements, the requirement levying an injection patch on the contractor for the EMU partially dictated design but lacked in other specific details (Fig. 1).



3.4.1.1.9 Medical Injection Provisions - The PGA shall provide the capability for the crewman to administer to himself hypodermic injections utilizing a spring-loaded plunger type needle, while in a pressurized PGA. The PGA shall provide, in a location to be determined by NASA, features which shall allow insertion of the needle and subsequent withdrawal, without endangering the pressure integrity or reliability of the suit, and shall be self-sealing to prevent the loss of gas at the site of the needle penetration. Best location for medical injections is on the ventrolateral aspect of the thigh, approximately half-way between the knee and the hip. An alternate location would be the deltoid area of either arm.

Figure 1. Apollo Suit Injection Requirement. Source: Apollo Space Suit Assembly Design and Performance Specification, October 12, 1964.[1]

Note that the requirement does not state the size of the needle or the number of injections for which the patch must provide. Little can be found regarding early development efforts by International Latex Company (ILC), the ultimate contractor for the EMU pressure garment assembly. Considering the injection patch was a minor component that was not required for early testing and, furthermore, not evaluated in any of the several competitive "suit-offs" at the Manned Spaceflight Center in the early to mid 1960s (suit-offs that are now legend), it is not unreasonable to assume that little or no development occurred during this time. It was not until training suits of the A7L, the name designated for the final ILC design, that injection patches started to appear on hardware delivered to NASA.

One notable exception—the Apollo Block 1 suit entrant, the A-1C (David Clark Company, Inc., Worcester, MA) (Fig. 2)—did include an injection patch on the upper right thigh. Little is known about this hardware. In fact, the hardware was only recently "rediscovered" thanks in part to the X-ray images of the A-1C suit in Amanda Young's book titled *Spacesuits*[2] (although this discovery occurred 2 years after publication, as a result of research by the author and a keen eye by an engineer at David Clark).

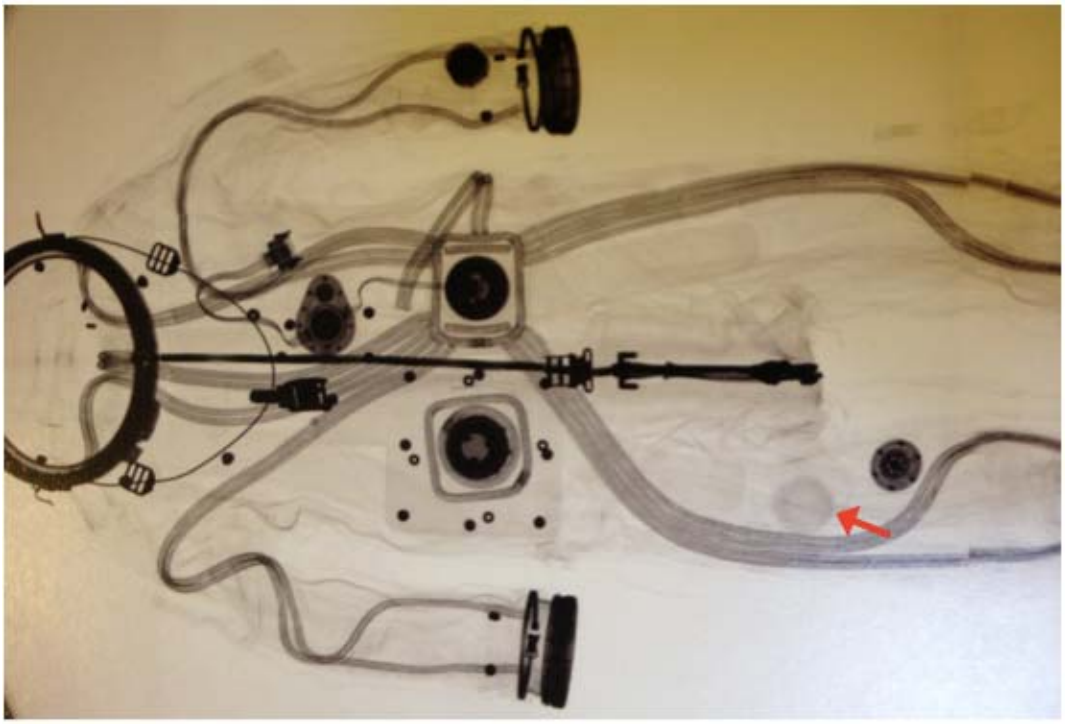


Figure 2. X-ray image of David Clark A-1C suit. Source: Smithsonian Institute Image 2009-0965.

Based on the Apollo Block 1 Spacesuit Assembly, Model A-1C Technical Manual,[3] the injection patch was added on version A-1C-6 (Fig. 3). Based on this information, Cathy Lewis at the Smithsonian Institute performed a comprehensive survey of the 15 David Clark A-1C suits in their possession. Of these, 11 suits were available for evaluation; of these, 10 suits had injection patches intact (Fig. 4). Interestingly enough, although they were constructed and integrated similar to the ILC A7L injection patches (as illustrated in the next section), there are varying levels of integration. For example, compare the injection patches from A-1C serial number 114 to serial numbers 133 and 125.

Whereas serial numbers 114 and 125 were well integrated to the back side of the cover layer using different applications of loop tape, serial number 133 has exposed Link-Net and bladder. As this injection hardware was likely never designed to be tested, it is of little consequence as far as safety is concerned, but it does provide interesting insight into the varied construction methods that were tried across different assemblies within a relatively short period of time.

CHARACTERISTIC DIFFERENCES

The Models A-1C-6 and up are basically similar to Models A-1C-2 thru A-1C-5 except for the modifications, additions or deletions of the following parts and assemblies: (see figure 5-1)

a. The weight of the entire PGA will not exceed 25 pounds, including torso, helmet, gloves, helmet communication harness, constant wear garment, and neck seal.

b. The electrical connector of the Bio-Medical fitting now has a flat oriented at the 12 o'clock position.

c. A pressure sealing closure is now used on the main slide fastener used to relieve pressure.

d. The closure tie bar has been removed in this configuration.

e. A medical injection assembly has been added to the right thigh area.

f. The helmet hold down is now attached to the closed end of the entry closure.

g. Flange mounted wrist disconnects (suit side) with compatible vent channelization are used on this configuration.

Figure 3. Text Excerpt noting addition of injection hardware to David Clark A-1C. Source: Apollo Block 1 Spacesuit Assembly, Model A-1C Technical Manual, November 1, 1965.

It should be mentioned that little else is known, with certainty, regarding these injection discs—e.g., what material they were made of, if they were tested, etc. However, it can be said with some confidence that other than the ILC design that flew for Apollo, the David Clark A-1C is the only other known pressure suit with a functional injection patch.

Figure 4. Various David Clark A-1C injection patches. Left to right: Injection patches from A-1C serial numbers 114, 133, and 125.

III. Flight Apollo Design

Based on conducted research, it appears that the first implementation of the A7L injection patch was included in training suits delivered to NASA in early 1968. These "bio-medical injection patches" were located on the right thigh cone, as indicated by item 166 on the Apollo suit patent number 3,751,727[4] (Fig. 5).

Anecdotcal evidence by engineers at ILC indicate that the injection patch was actually tested by a test subject at ILC who injected himself with saline while the suit was at full pressure. Little is known regarding the specifics of this evaluation, as no documentation can be readily obtained, to date.

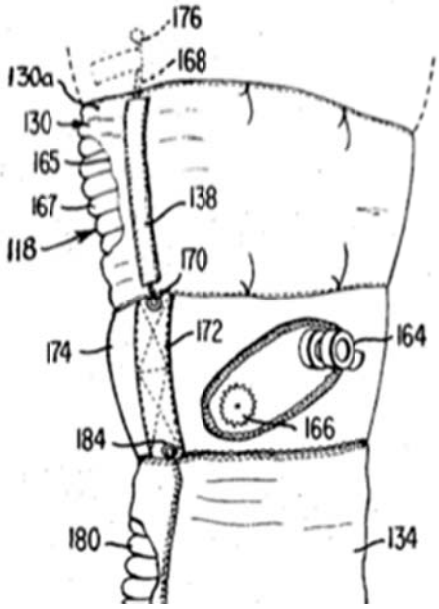


Figure 5. Patent drawing showing A7L suit injection patch. Source: US Patent Number 3,751,727.

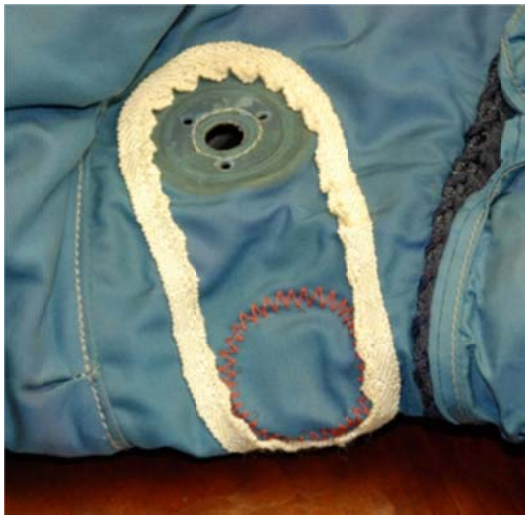


Figure 6. Injection Patch from A7L SN 053. Injection patch from Frank Borman's A7L suit as viewed with the TMG removed.

As for the specific construction, and based on visual observation, the injection patches were sewn to the restraint layer using a zigzag pattern (Fig. 6), which provides visual confirmation of the injection site. The injection disc was integrated between the bladder and restraint. When the patch was to be used, the needle would puncture the restraint, then the injection disc, then the bladder before entering the suit cavity.

The tubing was strategically routed away from the injection site on the right thigh to avoid puncturing the water lines running through the liquid cooling garment (LCG). This can be clearly seen by comparing photos of the injection site location on the suit with the LCG (Fig. 7).

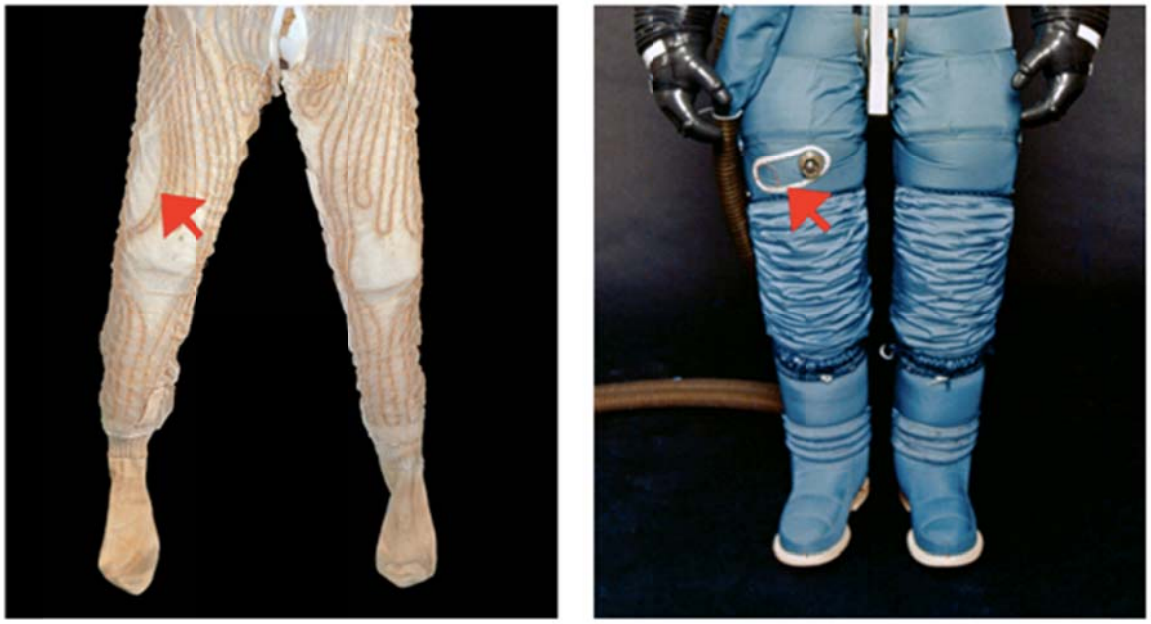


Figure 7. A7L LCG (left) and suit with TMG removed (right). The LCG tubing of the A7L suit was strategically routed to avoid needle puncture if the injection patch was used.

Later, the injection patch was relocated to the left thigh for the A7LB (Fig. 8). This was a result of a cascade of changes initiated by the relocation of the pressure gauge, which was initially on the right wrist of the A7L but was relocated to the left wrist for the A7LB. This forced the pressure relief valve (originally on the left wrist of the A7L) down to the injection patch location and, finally, the injection patch from its original location to its symmetrical location on the left thigh. The final lower-torso configuration of the A7LB is shown at left. The loop tape around the injection patch can clearly be seen on the left thigh.

Figure 8. A7L/B injection patch. The patch was relocated from the right to the left thigh for the A7L/B.

Figure 9. Ed Mitchell's A7L suit from Apollo 14. Shown is injection flap, UTC, and edge of injection patch.

To integrate the thermal micrometeorite garment (TMG), a large "biomedical injection flap" was added, and was kept in place by buttons and Velcro (Fig. 9). Opening the flap allowed direct access not only to the injection patch but also to the urine transfer connector (UTC).

Given the lack of documented technical details on the design of the injection patch, it was decided to remove the patch from the Borman suit and perform nondestructive evaluations on it to determine its geometry and composition.

The bladder was cut at the injection site from the inside of the suit and the patch was removed, as shown in Fig. 10. The patch was measured to be 2” in diameter and 0.1” in thickness (Fig. 11).

The injection patch consists of two sides with differing materials. A transparent yellow side, and an opaque, white side. Nondestructive spectroscopy was performed to determine the content of the injection patch.) A quick examination by infared spectroscopy determined that the main component of patch is silcone.

X-ray spectroscopy (Philips PW2400, Westborough, MA) was performed on both sides to better charactize chemical makeup. The chemical composition is shown in Fig. 12. Both sides are made primarily of silicone. The clear side has clorine (Cl) as the second highest concentration element, and the white side has titanium (Ti) as the next highest concentration element. It is unknown why a two-part injection disk was created, but we speculate that titanium dioxide was used as a filler material on the white side. This could have given the disk stiffer structural properties, or it could have provided less friction on the surface to facilitate insertion between the restraint later and the bladder.

Figure 10. Removal of injection patch from A7L suit. An incision was made from inside the bladder, as shown on the left. The injection patch can be clearly seen in the photo on the right.

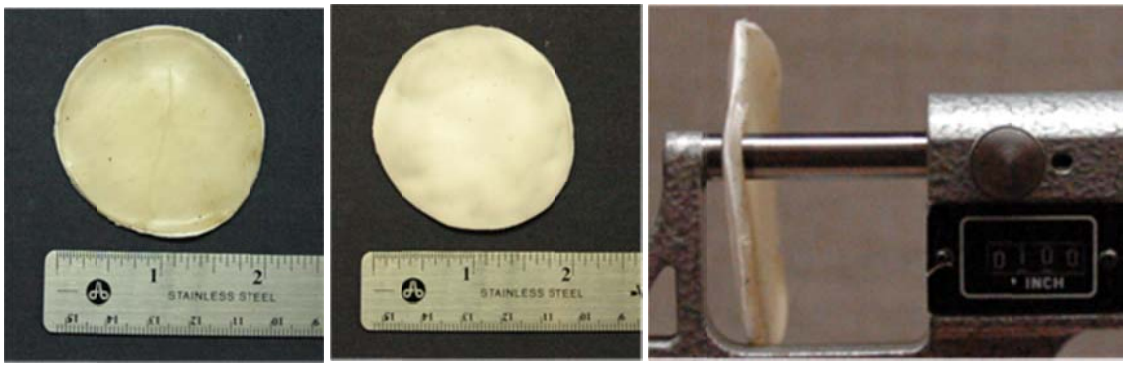


Figure 11. Removed A7L Injection Patch. Left to right: clear side facing body (97.1% Si; 1.6% Cl); white side facing outward (97.9% Si; 1.5% Ti); thickness measurement.

CLEAR SIDE (FACING BODY)

Compound	Conc. (%)
Si	97.057
Cl	1.606
Ca	0.304
Zn	0.291
Mg	0.288
S	0.232
Al	0.108
K	0.062
Ti	0.052

WHITE SIDE (FACING OUT)

Compound	Conc. (%)
Si	97.937
Ti	1.535
Cl	0.316
Mg	0.072
S	0.062
Zn	0.026
Ca	0.024
K	0.010
W	0.008
Pd	0.007
Sr	0.002

Figure 12. Chemical composition of A7L injection patch. Left to right: clear side of the injection Patch; white side of the injection patch. All compositions are normalized to 100%.

IV. Apollo Injection Hardware

Specific details on the engineering design of the Apollo medical injector are scarce. Engineering drawings, specifications, requirements, or internal pictures of the devices have not been found. Several of the injectors are on display at the Smithsonian National Air and Space Museum in Washington D.C., but the internal structure of these injectors has not been examined. Pictures of the medical kit and the injectors are shown in Figs. 13 and 14.

Several people who had first-hand experience of the Apollo design were contacted during the course of the search for information. Dr. Sam Pool joined NASA in 1969 and served as a flight surgeon during the Apollo Program. From his description, the injectors housed pre-filled medical syringes inside a pressurized aluminum tube. This tube was placed flush with the outside of the resraint layer, and was activiated by pressing a button at the top of the device. Once the button was depressed, a spring performed two actions. First, the syringe and needle were displaced, driving the needle through the seal on the device, through the injection patch in the EVA suit, and into the muscle on the upper thigh. The spring continued its action to depress the plunger on the syringe, delivering the medication into the muscle of the crewmember. The time from depressing the button on the injector to complete delivery of the medication was fast (less than 1 second) to prevent the crewmember being injected from reflexively pulling away before the injection was finished.

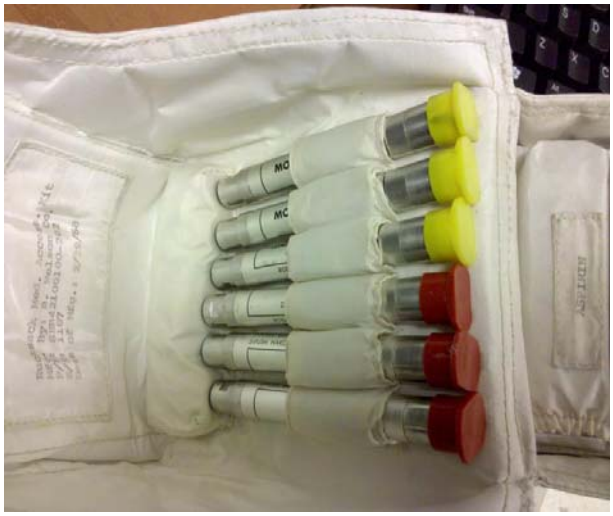


Figure 13. Apollo Medical Kit. Six injectors shown.

Figure 14. Motion Sickness Injector from Apollo Medical Kit. Other injectors labeled: XXX.

V. Post-Apollo Development

Likely due to the operational concept of the the Space Shuttle Program, the Shuttle EMU did not carry an injection patch; therefore, development of in-suit injection hardware languished for the better part of 4 decades. However, with the Constellation Program looking to enable a human lunar return came a renewed interest and the need to provide injection capability through the suit.

Most of the development during the Constellation suit project focused on risk and requirements definition. Looking at this work provides a microcosm of the different risk posture of the Constellation Program as compared to the Apollo Program. For example, one of the largest driving contingency scenarios defined in Constellation was the so-called “144-hour return” case, where a pressurized suit would need to protect its occupant from the lunar surface and all the way back to Earth during a contingency. In theory, this is no different from the Apollo risk; however, the Constellation Program set out to specifically protect for this scenario. Driving requirements included 144 hours of in-suit waste management, 144 hours of nutrition and hydration, and 144 hours of emergency medical care. Regarding the latter, Constellation Medical Operations identified a list of possible medical scenarios needing protection during this contingency return. Among the scenarios was the pushing of fluids in the event the crewmember became ill and was unable to maintain hydration using a feeding tube (Fig. 15).

[CSSE1XXX] **Hypodermic Interface for Intraosseous (IO) Injections**

The PGS shall meet its leakage requirements after one (1) IO injection with a 15-gauge hypodermic needle, leaving the needle in for up to 48 hours, to a suited crewmember at a (TBD-CSSE-XXX) location.

Rationale: Current operational concepts include administration of medications via hypodermic injection. The hypodermic needle will be left in to ensure that fluids and drugs can be administered via a standard intravenous (IV) set. The 48 hours limitation for the needle staying in is due to the potential for infection. The area of injection could be self-sealing to ensure that PGS leakage rates do not exceed standard leak requirements after use.

[CSSE1013] **Hypodermic Interface for Intramuscular (IM) Injections**

The PGS shall meet its leakage requirements after a minimum of 40 IM injections with an 18-gauge hypodermic needle to a suited crewmember at a muscular mass location.

*Rationale: Current operational concepts include repeated administration of medications via hypodermic injection. The number of 40 injections is based on giving two antibiotics four times per day for five days (2*4*5). The area of injection could be self-sealing to ensure that PGS leakage rates do not exceed standard leak requirements after use.*

Figure 15. Constellation Program Injection requirements (Constellation Space Suit Element Elements Requirement Document[5] [CSSE]). Both instramuscular (IM) and intraosseal (IO) requirements were originally considered.

This quickly became an issue, as previous implementations of in-suit injection patches were meant for instramuscular (IM) injections. To push fluids, either an intravascular (IV) or intraosseal (IO) injection would be required. The former would likely need a permanently installed IV in the crewmember, something not considered practical or acceptable, especially for something meant to be used only in a contingency; the latter would require an injection directly into the bone—relatively difficult and painful as compared to an IM injection. On top of that, imposing IO injections limited the candidate injection sites to only a handful of locations. However, for a short time during development, IO injection was a requirement levied on the Constellation suit (along with the IM injection requirement).

In assessing the feasability of meeting the above requirements, engineers identified three candidate locations for the IO injection patch: the proximal tibial (knee), the distal tibial (ankle), and the proximal humerus (shoulder). However, none of these locations were attractive from a suit design perspective as they are all areas limited in real estate, taken up by important mobility elements. In the end, the IO injection requirement was removed, and a definite location was never identified.

Similarly, little development occurred on the IM injection patch before it was removed from the requirement set with a reduction in scope to an International Space Station-based mission. Plans were to leverage experience gained from the Apollo legacy design and perhaps update with new materials. Due to the flexibility of IM injection sites, no location was ever identified. However, for ease of pressurized use and the need for a crewmember to inject himself/herself as well as others, the injection site likely would have been placed on the thigh, similar to the Apollo design.

Prior to the removal of the injection requirements, limited work was completed to determine the most effective way of delivering liquid medication through the spacesuit to an injured or ill crewmember. Limited testing was completed on the suit side to determine what types of materials would work best to ensure an adaqate seal after injection. The main component of the Apollo-era injection patches was silcone, which is also the main component of medicinal vial caps. The project obtained different silcone materials in varying thicknesses and coatings. A needle was attached to a force gauge, and the septa material was punctured numerous times to evaluate the ingretity of the

seal. Testing was performed on the benchtop in ambient conditions, in a vacuum environment, and in a cold chamber. After this testing, NASA concluded that the septum used for a suit interface should be either a fluorinated ethylene propylene (FEP [Teflon® FEP] or an ethylene tetrafluoroethylene (ETFE [Tefzel ®]) coated silicone septum with a thickness of 0.075" or greater.

Figure 16. Gloved assessment of syringes. Different syringes were manipulated with EVA gloves in a simulated pressure environment to determine how the geometry and size of a potential injection device affects a gloved operator's ability to provide an injection.

In addition to testing of the septa materials, the team performed work to determine optimal parameters for the syringe. The design of an injection device for continegency space operations presents many challenges. Among them are how to maintain the temperature and pressure of the liquid medication without an operational environmental control and life support system. Also, with the crewmembers in their EVA suits during the contingency, what is the best form for the injector to take for ease of use. The EVA gloves inhibit dexterity and motion; in an emergency medical situation, the injector needs to be simple to operate. Testing was performed in a flight glove simulator to examine this parameter. The testing consisted of simulating operation of various forms and sizes of syringes to determine ease of operation while wearing pressurized EVA gloves. Using three different test operators, a 0.87-in.-diameter syringe was unanimously agreed upon to be the easiest syringe to operate with a gloved hand. This helped constrain the possible geometries for future injection devices.

Acknowledgments

The authors would like to thank Cathleen Lewis at the Smithsonian Institute for her help investigating the A1C suits for possible injection hardware, and Dr. Shane Jacobs at David Clark Company for his help in discovering the same. Additional thanks to Cathleen Lewis for her help in obtaining photos of the Apollo Medical Kit.

References

[1]Apollo Space Suit Assembly Design and Performance Specification, October 12, 1964
[2]Spacesuits book (Smithsonian)
[3]Apollo Block 1 Spacesuit Assembly, Model A-1C Technical Manual, November 1, 1965
[4]US Patent Number 3,751,727
[5]Constellation Space Suit Element Elements Requirement Document