Transitioning Sixty Years of NASA Spacesuit Knowledge Capture Lessons Learned to Searchable Knowledge Transfer Databases

Thomas Reuland[1], Vladenka Oliva[2], Zoe Nuhfer[3]
Jacobs Technology, Inc, 2224 Bay Area Blvd, Houston, TX 77058

and

Cinda Chullen[4]
NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX, 77058

Sixty years of spacesuit knowledge capture and lessons learned by spacesuit subject matter experts are documented on videos and presentations and archived with the NASA Engineering and Safety Center (NESC) Academy. The NESC Academy is a web-based platform that hosts online courses by technical experts. A process is underway to transition these decades of lessons learned from the U.S. Spacesuit Knowledge Capture Program Library into more quicky searchable databases and to proactively provide this information to those working on spacesuit projects. Hundreds of lessons learned from Project Mercury, Gemini, Apollo, Apollo-Soyuz Test Project, Skylab, Space Shuttle, International Space Station, and Artemis have been captured in a format that can be quickly searched, enabling users to find information directly applicable to their needs. Transitioning this information to a NASA wiki page will further enhance search and retrieval of data immediately useful to users. This paper provides information about how the lessons learned were determined and how to access them.

Nomenclature

AI	= Artificial Intelligence
ASTP	= Apollo-Soyuz Test Project
ChatGPT	= Chat Generative Pre-Trained Transformer
CM	= Crew Module
CSM	= Crew/Service Module
DAA	= Document Availability Authority
EVA	= Extravehicular Activity
FY	= Fiscal Year
HLS	= Human Landing System
ISS	= International Space Station
JSC	= Johnson Space Center
LiOH	= lithium hydroxide
LM	= Lunar Module
MS	= Microsoft
mxEMU	= Mars Exploration EMU
NASA	= National Aeronautics and Space Administration
NESC	= NASA Engineering and Safety Center
NDE	= nondestructive evaluation
NTR	= New Technology Report

[1] Systems Engineer, Exploration Extravehicular Activity Services Collaboration, Bay Area Blvd, Houston, TX 77058
[2] U.S. Spacesuit Knowledge Capture Program Administrator and Technical Editor, Science and Exploration Department, Bay Area Blvd, Houston, TX 77058/JE6WA
[3] U.S. Spacesuit Knowledge Capture Program Administrative Specialist, Science and Exploration Department, Bay Area Blvd, Houston, TX 77058/JE6WA
[4] Project Engineer, Space Suit and Crew Survival Systems Branch, Crew and Thermal Systems Division, NASA Parkway, Houston, TX 77058/EC5

RCU = Remote Control Unit
SKC = Spacesuit knowledge capture
SME = Subject matter expert
STI = Scientific and Technical Information
STRIVES = Scientific, Technical and Research Information DiscoVEry System
U.S. = United States
xEMU = Exploration Extravehicular Mobility Unit
xEVAS = Extravehicular Activity Services

I. Introduction

POPULATING lessons learned on easy-to-use searchable databases can provide access to valuable data that otherwise may have been unknown, may not have been found, or would not be found in time to avoid project impacts. U.S. Spacesuit Knowledge Capture (SKC) videos archived on the NASA Engineering and Safety Center (NESC) Academy website contain captured lessons learned on the design, development, manufacturing, testing, qualification, certification, production, and operations of dozens of spacesuit models. These lessons learned are valuable for present and future spacesuit projects, but extracting these data requires time to identify, find, and watch the videos and to remember or document the lessons learned. Transitioning this information into searchable knowledge transfer databases would enable users to quickly identify and find information while providing references to the source material for more detail in the NESC Academy SKC Program Library. The landing page for the NESC Academy SKC Program Library provides a brief overview of the U.S. Spacesuit Knowledge Capture program and its impacts:

> The NASA U.S. Spacesuit Knowledge Capture (SKC) Program has existed since the beginning of 2007 and was designed to share historical spacesuit information with engineers and other technical team members to augment their understanding of the spacesuit, its evolution, limitations, and capabilities. Many subject-matter experts have provided lectures, and some were interviewed to help bring the spacesuit to life to ensure lessons learned will never be lost. Also, expert engineers and scientists have shared their challenges and successes to be remembered. The SKC Program topics have included lessons learned from some of the most prominent spacesuit experts and spacesuit users including current and former astronauts. The events have enriched the spacesuit legacy knowledge from the Gemini, Apollo, Skylab, Space Shuttle, and International Space Station programs. As the SKC Program identifies needs and opportunities to broaden its scope, it expands its roles to capture spacesuit-related knowledge. At the onset of 2022, more than 165 events have captured spacesuit history and knowledge, and over 90 events have been released to the public.[1]

The NESC Academy website continues to add events to its archives. The paper "U.S. Spacesuit Knowledge Capture"[2] provides a thorough description of the philosophy, background, importance of systematic knowledge capture and use for the future and going about the business of systemizing knowledge capture.

NASA has owned and operated Extravehicular Activity (EVA) spacesuits for more than 50 years. An EVA spacesuit is specifically designed to protect a crew member during an EVA outside the space vehicle without using an umbilical. NASA's EVA spacesuits are known as Extravehicular Mobility Units (EMUs). The first EMU, designed in the 1960s, was the Apollo EMU, which established a baseline for EVA spacesuits for decades. After Apollo and as the Space Shuttle program was being concepted, so was an EVA spacesuit design for the missions. The development of the Shuttle EMU was greatly influenced by the Apollo EMU. The Shuttle EMU continued to be progressively upgraded and became the baseline to an evolutionary enhanced EMU design for the International Space Station (ISS) Program. The ISS EMU has had over 30 years of active operation on the ISS and is still in operation as of the publication of this paper.[3]

In Fiscal Year (FY) 2022, NASA began a significant transition to embrace a new commercial model for acquiring EVA services under the NASA Extravehicular Activity Services (xEVAS) procurement. Through decades of in-house spacesuit design, development, manufacturing, and test of the xEMU government reference design spacesuit, NASA provided a foundation of knowledge to facilitate the xEVAS vendors. NASA continues to use the xEMU government reference design suit for continuing spacesuit development. Two American companies were awarded the xEVAS contracts to provide NASA with spacesuit services for spacewalks planned on the ISS and for lunar spacewalks during a return to Earth's Moon for the first time since the Apollo Program. Prior to the xEVAS contract, NASA was pursuing an Exploration EMU (xEMU) configuration to serve as an ISS demonstration with features for a lunar application. However, the NASA xEMU government reference design is not being pursued. Instead, NASA is committed to facilitating the new xEVAS vendors. NASA has provided both xEVAS contractors with information to help them be successful in their spacesuit development. In 2024, NASA is embarking on a Mars Exploration EMU (mxEMU) for the pursuit of a Mars schematic study for a portable life support system design.[3]

To support NASA's goal of a lunar landing in the mid-2020s, a project was undertaken to transition the most directly applicable spacesuit knowledge from subject-matter experts (SMEs) in video recordings and presentations to formats that can be more readily searchable. Furthermore, the goal was to pursue a proactive method of identifying those who can most quickly benefit from this knowledge and to provide access to them. The immediate beneficiaries of the lessons learned from NASA's 60 plus years of spacesuit history are likely the NASA and contractors' xEMU teams and the new xEVAS contractors. Therefore, as part of an FY 2023 NASA-funded project called xEVAS Collaboration, SKC data from the NESC Academy video recordings and presentations were reviewed and documented to capture lessons learned. These data were first collected in a Microsoft (MS) Excel equivalent database.

Key lessons learned from the videos have been documented in searchable workbooks. Uploading these data into a NASA wiki page is planned to better provide access to NASA users and customers. Transferring this knowledge could help achieve spacesuit project success by avoiding problems encountered in previous spacesuit projects and by leveraging successful techniques. This approach could help avoid impacts to project schedule and budget along with helping produce successful spacesuit designs that meet the needs of the key stakeholders and mission operations.

II. Step 1: Researching, Selecting, and Prioritizing Videos

At the onset of this project, the NESC Academy website contained over 800 videos, 102 of which were videos and presentations specific to SKC (including both publicly available videos and those restricted to NASA employees and contractors). The NESC Academy home page includes the following description of the website's features and content:

> The NESC Academy presents live and on-demand content from researchers, engineers, and field experts in 19 technical disciplines relevant to the design, development, test, and operation of NASA programs and projects. It hosts more than 800 videos containing interviews, tutorials, lectures, and lessons learned in an engaging format that features side-by-side video and slides, powerful search capabilities, downloadable course materials, and more.

The 19 technical discipline categories on the NESC Academy website are: Aerosciences, Avionics, Cryogenics, Electrical Power, Environmental Control/Life Support, Flight Mechanics, Guidance Navigation & Control, Human Factors, Loads and Dynamics, Materials, Mechanical Systems, Nondestructive Evaluation (NDE), Propulsion, Sensors & Instrumentation, Software, Space Environments, Structures, Systems Engineering, and Thermal Control and Protection. There is a 20th category labeled "Other." The 102 SKC videos archived on the NESC Academy website include content in the following six technical disciplines:

1) Environmental Control/Life Support (93)
2) Electrical Power (3)
3) Space Environments (2)
4) Thermal Control and Protection (2)
5) Loads and Dynamics (1)
6) Other (1)

For this project, the primary author, a systems engineer on the xEVAS collaboration project, chose 24 of the 102 SKC videos as most directly addressing the spacesuits used for the major NASA space projects and programs, plus two addressing failure investigation, root cause and corrective action. Table 1 lists the NASA projects, programs, and videos chosen for the initial spacesuit lessons learned project.

Table 1. List of the NASA projects, programs, and videos chosen for the initial spacesuit lessons learned project.

Project/Program	NESC SKC Video Title
Project Mercury	U.S. Spacesuit Development and Qualification for Project Mercury
Project Gemini	Spacesuit Development and Qualification for Project Gemini
Apollo Program	Apollo Block I - Spacesuit Development and Apollo Block II Spacesuit Competition
	Apollo A-7L Spacesuit Certification and Mission Operations Details
	Early Apollo Spacesuit Development, A-7L Suit Requirements, and Design Details
	Apollo A-7LB Spacesuit Development for Apollo 15 through 17 Missions
	Apollo Lunar Surface Operations and Extravehicular Activity Suit Issues
Skylab Program	Skylab A-7LB Spacesuit Development for Skylab SL-2 through SL-4 Missions
Apollo-Soyuz Test Project (ASTP)	Apollo Spacesuit Modifications for the Apollo-Soyuz Project
Space Shuttle Program & International Space Station (ISS) Program	Space Shuttle Extravehicular Mobility Unit Spacesuit Development for Initial Space Shuttle Missions
	Shuttle Extravehicular Mobility Unit (EMU) Lessons Learned, Part 1 - Development
	Shuttle Extravehicular Mobility Unit (EMU) Lessons Learned, Part 2 - Development
	Shuttle Extravehicular Mobility Unit (EMU) Lessons Learned, Part 3 - Communications Subsystem Development
	Extravehicular Mobility Unit (EMU) Certification Workshop Day 1, Part 1
	Extravehicular Mobility Unit (EMU) Certification Workshop Day 1, Part 2
	Extravehicular Mobility Unit (EMU) Certification Workshop Day 1, Part 3
	Extravehicular Mobility Unit (EMU) Certification Workshop Day 1, Part 4
	Extravehicular Mobility Unit (EMU) Certification Workshop Day 2, Part 1
	Extravehicular Mobility Unit (EMU) Certification Workshop Day 2, Part 2
	Extravehicular Mobility Unit (EMU) Certification Workshop Day 2, Part 3
	Extravehicular Mobility Unit (EMU) Certification Workshop Day 2, Part 4
	Post-Shuttle EVA Operations on ISS
Generic	Failures, Part 1 (What I've Learned in 50 Years About Hardware and People, 50+ Years in EVA Life Support)
	Failures, Part 2 (What I've Learned in 50 Years About Hardware and People, 50+ Years in EVA Life Support)

III. Step 2: Transition from Videos to Searchable Files

The videos listed in Table 1 were viewed and studied. Some also had corresponding presentations. A study of these data resulted in a decision to categorize the information and data sources in a table database format in six columns. The columns used are noted in Table 2.

Table 2. Columns used in the table database and their descriptions.

Project / Program	Spacesuits / Missions / Crew / Photos	Mission Objective(s) or Spacesuit Design Objective(s)	Significant Design Changes	Keywords and Phrases	References and DAA
The project or program for which the spacesuit was designed and used.	A listing of spacesuit model designators and photos of the suits. In some Missions(s)/Crew cases the mission designation and crew were listed.	The primary and secondary objectives of the mission, often including a description of the primary, modified, and/or new spacesuit design features.	A list of the spacesuit design and/or operational features different from previous spacesuit(s) and what was learned.	A list of words and phrases to help categorize the contents of each section.	SKC class video title and the DAA# (Document Availability Authority) issued by Export Control authorizing release type, following the NASA process for publishing Scientific and Technical Information (STI).

The lessons learned extracted from the two dozen NESC SKC videos and presentations were documented in six files with the following file names:

1. NESC SKC Lessons Learned, from Mercury to Artemis, Part 1 - Mercury, Gemini, Apollo
2. NESC SKC Lessons Learned, from Mercury to Artemis, Part 2 - Apollo Program
3. NESC SKC Lessons Learned, from Mercury to Artemis, Part 3 - Skylab
4. NESC SKC Lessons Learned, from Mercury to Artemis, Part 4 - Space Shuttle + ISS EMU, 1 of 2
5. NESC SKC Lessons Learned, from Mercury to Artemis, Part 5 - Space Shuttle + ISS EMU, 2 of 2
6. NESC SKC Lessons Learned, from Mercury to Artemis, Part 6 - Failures, Root Cause

Table 3 displays a portion of the table database and examples of lessons learned from Project Mercury, extracted from the video, "U.S. Spacesuit Development and Qualification for Project Mercury." Photos and a listing of spacesuit models from other sources were added to the Excel spreadsheets to supplement the information contained in the videos. The additional information is shown below in the column titled, "Spacesuits / Mission(s) / Crew".

Table 3. An example of lessons learned from Project Mercury, from the video, "U.S Spacesuit Development and Qualification for Project Mercury."

Program	Spacesuits / Mission(s) / Crew	Mission Objective(s)	Significant Design Changes and Lessons Learned	Key Words & Phrases	References & DAA#
Mercury	Mercury Pressure Suits Mark IV, Model 3, Type 1 (XN-1 through XN-4)  	1) Orbit a manned spacecraft around Earth. 2) To investigate man's ability to function in space. 3) To recover both man and spacecraft safely.	LESSONS LEARNED - Mercury Pressure Suits Suit Assembly A) New requirement identified to add pre-flight low pressure leakage testing Torso: A) Excessive bladder leakage i) Repetitive re-rolling and re-bonding of adhesive bonded seams ii) Frequent leakage testing necessary B) Frequent factory replacement of pressure sealing slide closure i) Reinforcement gussets added at closure ends C) Excessive low-pressure leakage during on-pad capsule ECS test i) Wrist-bearing seal installed backwards D) Flotation necessary for post landing water survival i) Added on-suit worn life preserver and deployable neck dam	Mercury, pressure suit, suit assembly, pre-flight, low-pressure, leakage testing, torso, excessive bladder leakage, repetitive re-rolling and re-bonding, adhesive bonded seams, frequent leakage testing, frequent factory replacement, pressure sliding slide closure, reinforcement gussets added, excessive low-pressure leakage, on-pad capsule ECS test, wrist-bearing seal, installed backwards, flotation necessary, post landing water survival, on-suit worn life preserver, deployable neck dam	1) NASA NESC SKC class: "U.S. Spacesuit Development and Qualification for Project Mercury", by James McBarron II, May 2015. DAA #29301, November 6, 2012 2) http://www.astronautix.com/m/mercuryspacesuit.html

The example above illustrates how users can get a summary of the information provided in an SKC video, enabling them to identify which lessons learned are of interest and then to identify the reference video from which to get more information. The SME(s) in the videos provide context and more detailed descriptions of the lessons learned and other pertinent information. A column is included to provide photos and descriptions of spacesuit models, missions, and crews. The column includes photos and illustrations from the original videos plus additional photos and information from other sources.

IV. Step 3: Results of a Lessons Learned Search on Lunar Dust

With the Artemis program planning return missions to the Moon with hardware now being designed, developed, and tested, it is important to consider lessons learned to enable hardware to avoid repeating issues experienced in the Apollo program. In order to help better enable new spacesuits to operate in a lunar dust environment without unacceptable degradation, a search of the lessons learned files using the key word "dust" quickly identifies two NESC Academy/SKC videos:

1. "Apollo A-7L Spacesuit Certification and Mission Operations Details" by James McBarron II, October 2015. DAA #33683, Approved 8/3/2015[5]
2. "Apollo Lunar Surface Operations and EVA Suit Issues" by Dr. Richard Scheuring, February 2017. DAA #29309, Approved 12/1/2016[6]

A. Apollo A-7L Spacesuit Certification and Mission Operations Details

The presentation for this video summarizes four succinct points from Apollo 13-14 and another four from missions Apollo 7-17. Although the points are short and simple, new spacesuit design and test programs should carefully consider them. The effects of lunar dust were not limited to the spacesuits but also to astronaut health and performance and to lunar ascent vehicle systems. These are risks to Artemis astronauts, Human Landing System (HLS) vehicles and vehicles to which they will dock and transfer astronauts, atmosphere, and equipment. These are also risks to surface habitation modules, pressurized and unpressurized rovers, and to all hardware in the lunar environment.

These lessons were extracted from James McBarron II's "Apollo A-7L Spacesuit Certification and Mission Operations Details" video and recorded in the "Significant Design Changes and Lessons Learned" column of the lessons learned spreadsheet table database. The Apollo 7-17 Summary Lessons Learned chart included a specific recommendation as shown below. The Apollo 13–14 lessons learned were presented in the video and the presentation charts without a specific recommendation. This process and format are described in Section III. The following lunar dust lessons learned are quoted in their entirety from the charts presented in the video:

Lessons Learned - Apollo 13–14 Missions

A. Lunar Dust Particles Contamination:
   1. Suit disconnects and connectors found difficult to actuate upon LM [Lunar Module] entry and next EVA preparation.
   2. RCU [Remote Control Unit] readout lens visually obscured.
   3. Mostly on lower suit surfaces, lunar module cabin surfaces and atmosphere.
   4. Design future spacesuits to provide dust contamination protection.

Summary Lessons Learned: Apollo 7–17

A. Lunar Dust Particles Contamination:
   1. Spacesuit disconnects and connectors found difficult to actuate on Lunar Module entry and preparation for next lunar surface EVA.
   2. Chest-mounted Remote Control Unit read-out lens was visually obscured by lunar dust.
   3. Dust contamination occurred mostly on lower spacesuit legs and boot surfaces.
   4. Lunar Module cabin surfaces and atmosphere breathing concerns.

B. Recommendation:
   1. Develop effective dust protection method for future Lunar or other surface dust-prone missions.

B. Apollo Lunar Surface Operations and EVA Suit Issues

Lessons learned were extracted from a second NESC Academy/SKC video, Dr. Richard Scheuring's "Apollo Lunar Surface Operations and EVA Suit Issues," and recorded (either by quote or summary) in the Apollo table database. The following lunar dust lessons learned are portions of actual entries identified in the Apollo table database:

Apollo Medical Operations Project

Lessons Learned: EMU/EVA Suit:

A. Protect the suit zipper function:
   1. The A-7LB was a single zipper system.
   2. Lunar dust was difficult to clear from the zipper and impaired normal function on each subsequent lunar EVA.

B. Suit donning/doffing; dust management and pressure integrity on lunar surface may be facilitated by a rear-entry suit mated to a suit port.

Lunar Surface Operations

C. An airlock would be a good idea in the next lunar lander design.

D. An airlock may make ingress/egress easier and will also help with dust control.

Lunar Surface Operations Observations

A. "Lunar dust particles floated everywhere in the LM upon return to microgravity."
   1. Dust particles got into crew members eyes, nose, & chest.
   2. This prompted crews to keep helmets on before docking with CSM [Crew/Service Module].
   3. Dust did not appear to be filtered from the environment through ventilation/LiOH [lithium hydroxide] system.

B. Dust is slowly cleared in the cabin by lithium hydroxide.
   1. Dust is very abrasive and there are jagged fragments. The dust on the surface was a problem because it covered all your gear, visors, etc.

Lunar Dust - Why are we concerned?

A. Dust particles levitated at the lunar terminator, perhaps due to polarity changes (Criswell 1972). 0.16 G at lunar surface, where there is a layer of fine particles that are easily disturbed and placed into suspension. These particles cling to all surfaces & pose serious challenges for the utility of construction equipment, air locks, and all exposed surfaces (Slane 1994).

B. After, lunar EVA crewmen and samples they had collected were covered with fine lunar material. Despite attempts at clean-up and packaging in the LM, transfer of crew and materials back to the CM [Crew Module] resulted in contamination of the CM atmosphere (Brady et. al 1975).

C. Apollo astronauts were not in the lunar environment long enough to develop clinically significant, dust-related symptoms. However, during upcoming missions, crews will be on the Moon for months at a time.

Properties

A. Size, shape, impacts with space, not terrestrial weathering, metal content.

B. Possible reactivity- volatiles, solar protons, unsatisfied chemical bonds—passivation rate?

The "Apollo Lunar Surface Operations and EVA Suit Issues" presentation includes photos and illustrations, a selection of which accompany the above entries in the table database and are highlighted here. One visual from the presentation illustrates a suggested risk mitigation design (Figure 1).

A photo of Apollo 17 Commander Gene Cernan in the Lunar Module after EVA #2 shows the extent of lunar dust contamination on the upper portion of his spacesuit and on his face (Figure 2).

Figure 3 displays several other graphics from the video (from top to bottom): an illustration of lunar dust being transported from the Moon's surface onto the lunar roving vehicle; heavy lunar dust contamination on a spacesuit glove in comparison to the white surfaces of a wrist-mounted checklist; the structure of lunar dust under an electron micrograph; and a lung cross section and x-ray from a non-astronaut individual who had repeated exposure to dust. These visuals demonstrate and emphasize some of the issues behind the lessons learned.

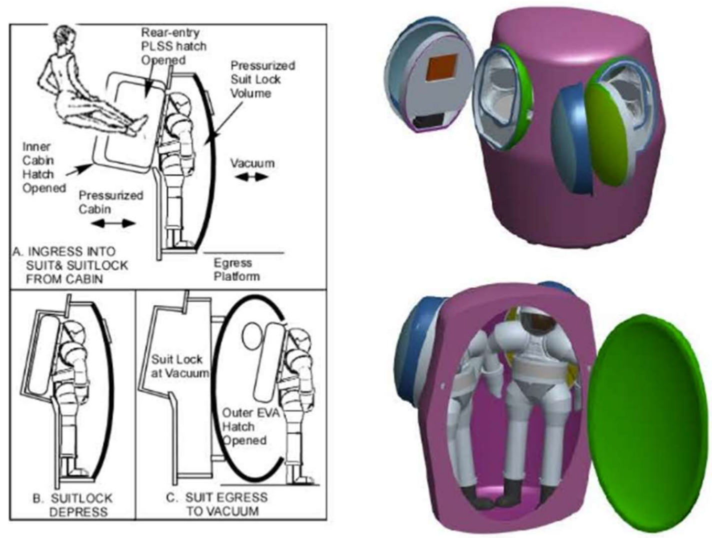

Figure 1. An illustration of a suggested risk mitigation design for a spacesuit and suit lock for operations on the lunar surface.

Figure 2. Apollo 17 Commander Gene Cernan in the Lunar Module following the second of three EVAs on the lunar surface.

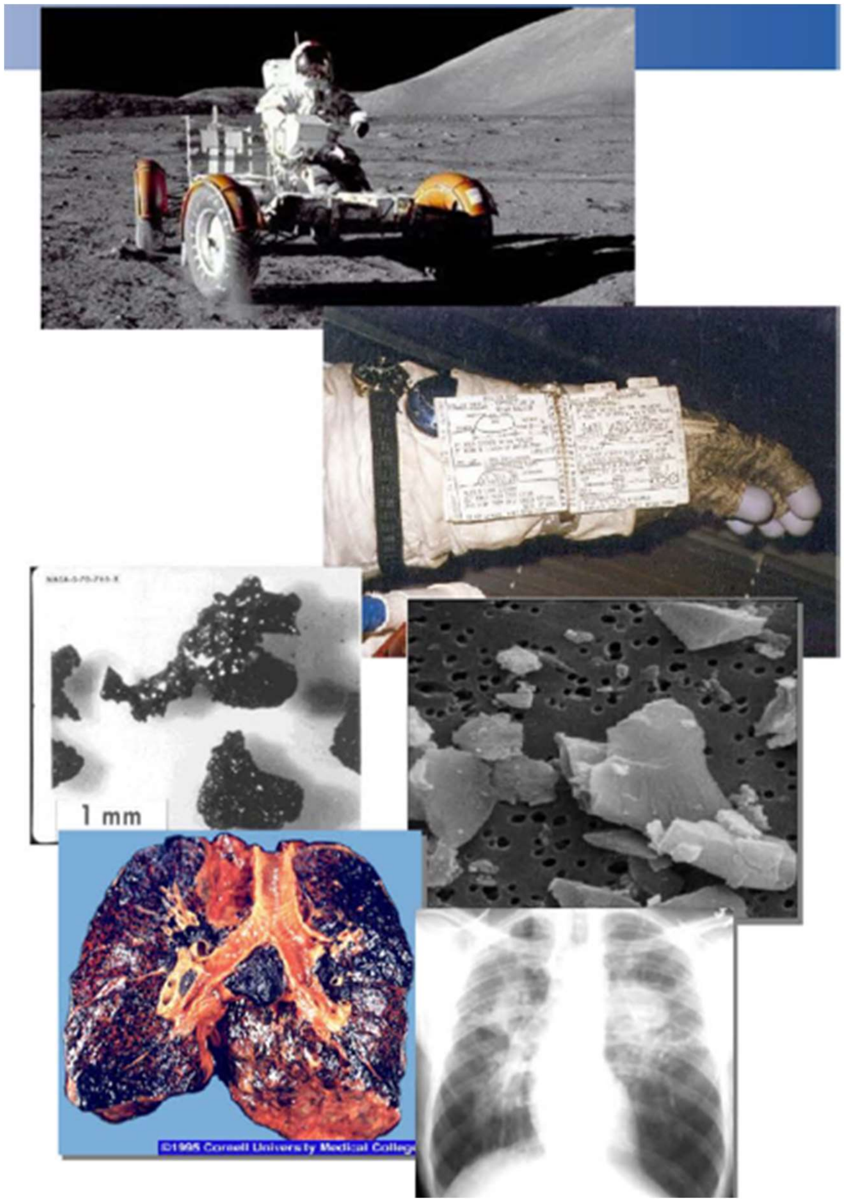

Figure 3. Additional graphics from "Apollo Lunar Surface Operations and EVA Suit Issues."

V. Step 4: Transitioning from Searchable Files to the Exploration Wiki Page

NASA has a general wiki page, group wiki pages, and vehicle wiki pages, which provide teams with the ability to input, reference, and update information of value to their team. The Flight Wiki page, which incorporates data originally on an EVA Wiki page provides those involved in real time mission operations for the ISS with data for their team. The development of the EVA Wiki page and its benefits is described in the ICES-2016-405 paper, "EVA Wiki: Transforming Knowledge Management for EVA Flight Controllers and Instructors," by Stephanie S. Johnston and colleagues.[7] That paper reached the following conclusion: "The EVA Wiki amplifies JSC's goals to promote knowledge transfer and collaborative sharing, which is required for the success of NASA missions."[7] The paper further states that, "…the EVA Wiki has become a powerful knowledge management tool for both the EVA Operations branch and the ISS EVA community."[7]

The same goals are being pursued for this spacesuit lessons learned knowledge management project: to promote knowledge transfer and collaborative sharing. Additionally, this new project is intended not only to help enable the success of NASA missions, but also to help contractors to provide spacewalk services to NASA and non-NASA customers to be successful.

The lessons learned extracted from the SKC Program videos and documented in the database can be uploaded in a single operation when formatted to match the fields on the desired destination Exploration Wiki page. The Exploration Wiki page includes a page for Lessons Learned, with many fields. The 16 fields intended to be populated with the spacesuit lessons learned information are shown below. The wiki page also includes fields to add groups of images and free text. A new field to the wiki page could be added to address risk. Mapping the information for each of these fields from the SKC Program lessons learned documented in the database enables a bulk upload to these fields on the Exploration Wiki page, which would otherwise require thousands of manual entries.

1) Title
2) Lessons Learned Type
3) Status
4) Event Type
5) Organization
6) Applicable Mission(s)
7) Author
8) SME
9) Intended Audience
10) Related Articles
11) Executive Summary
12) Background
13) Resolution
14) Recommendations
15) Actions
16) Is this a recurrence of a lesson learned?

After the data are populated in the Exploration Wiki, users can simply use the Search window to query the Lessons Learned database using key words and phrases to quickly find all entries containing those words. Each record will include a reference to the source video in the NESC Academy SKC Library, enabling users to learn more information about the lesson by watching the video or by reading the presentation linked to the SKC link for that video or both.

VI. Step 5: Plans to Identify Key Spacesuit Project Stakeholders & Transfer Knowledge

Some of the key personnel in the NASA and EVA community were participants in NESC Academy SKC real-time presentations. The recordings of these sessions provide an appreciation for the depth of knowledge and the amount of information provided by the SME presenters. Because it has been several years since these videos were recorded, it is believed that the extraction of lessons learned from the videos will be beneficial to those who originally attended the presentations as well as to new team members.

The key stakeholders, now working with the xEVAS suppliers, were provided with the database documenting the lessons learned from this project. As a result of continuously high workload and schedule priorities, spacesuit personnel availability to view lessons learned is extremely limited. Thus, a knowledge transfer methodology in which data can be quickly retrieved using key words and phrases can help make retrieval of information pertinent to present and near-term work scope valuable. A proactive approach to providing spacesuit team members with data timely to their present and planned work can help establish use of lessons learned data retrieval a normal part of work activity. The intent of lessons learned is to avoid not only technical performance impacts but also to avoid schedule and cost impacts, thus saving time and allowing time for lessons learned to be periodically reviewed as well as for new lessons to be documented.

The next priority customers for spacesuit lessons learned are the xEVAS contractors. These companies are under even greater project schedule deadlines and budget limitations, and their spacesuits must meet the technical requirements of the xEVAS contract. Thus, a proactive approach to identifying those with access to the NASA network who can best benefit from these lessons learned is needed. Contractual relationships called xEVAS Collaboration and xEVAS Insight may provide an avenue for communication of these documented and searchable lessons learned to be accessed. A presentation to these customers providing examples of how lessons learned apply to work scope now being performed and planned is hoped to initiate a process whereby these contractors begin referencing these lessons and avoid lessons relearned if the advice of NASA spacesuit SMEs is not heeded.

VII. Export Control

The plethora of lessons learned being added to quicky searchable databases are derived from the SKC Program's collected knowledge that is archived with the NESC Academy website. The SKC Program recognizes that sharing pertinent knowledge with the public (American taxpayers and NASA stakeholders) is important to encourage public support for NASA's missions. For this reason, the SKC Program aims to distribute its captured knowledge to the widest extent possible, as appropriate. However, to protect national security interests, export control is imposed before NASA releases its knowledge to the public or to NASA contractors and vendors who do not have the proper credentials to access sensitive information.

Export control determines what knowledge can be disseminated and to whom. To identify export-controlled content and determine the range of distribution, the NASA DAA system is a mechanism used. The Scientific, Technical and Research Information DiscoVEry System (STRIVES) is the tool used as the STI Program's system for STI submission, review, and dissemination. The DAA system uses STRIVES to review and process content before distributing it.

Before an SKC Program event is archived with the NESC Academy, it is processed through the NASA JSC export control system and approved for public or internal release. LaunchPad credentials are required for anyone to retrieve NESC Academy files with restricted access. LaunchPad is an online tool that grants authorized users special access privileges.

Although the SKC Program's targeted beneficiaries are NASA employees and contractors, the public can also benefit from lessons learned. When applied, lessons learned can prevent repeated mistakes and push space exploration further. Knowledge gained from NASA's human space exploration programs has also contributed to many technologies that benefited the public. For the curious or those who question the benefits of space exploration, the NASA Spinoff website (*https://spinoff.nasa.gov*) reveals more than 2,000 valuable spinoffs developed from NASA technologies since 1976.[8] During FY 2023, more than 1,500 new technology reports (NTRs) were filed at NASA. NTRs record the inventions, discoveries, improvements, and innovations conceived of or first reduced to practice in the performance of NASA work, help ensure that new technologies can be used and disseminated appropriately.[9] During that same period, 140 patent licenses were executed.[9] These licenses grant outside entities permission to use, manufacture, and sell inventions patented by NASA.

NASA's decades of incremental learning and knowledge sharing have been valuable. However, there is an overwhelming collection of useful knowledge of which users are unaware. To encourage learning and applying these lessons, this new searchable database will help lead users to this knowledge and promote its application. The lessons learned database is in the process of going through export control.

VIII. Conclusion

A transition is being made from capturing NASA spacesuit knowledge and archiving the videos and presentations on the NESC Academy website to more accessible knowledge management databases. Work is underway to transfer the information to spacesuit manufacturers and users in increasingly easier ways. The first step in the process was to extract lessons learned from the videos and presentations into a series of searchable files. The files cover hundreds of lessons learned from Project Mercury through the beginning of the Artemis Program. The next step planned is to upload the data to the NASA Exploration Wiki page. The Exploration Wiki page will return a listing of all spacesuit lessons learned, from the first 24 videos initially selected, with a single query using a key word or phrase.

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The authors would like to acknowledge the SMEs who took the time to share their knowledge with the SKC Program over the years. Without these efforts, the lessons learned would remain undocumented and lost forever. For their efforts, we are eternally grateful.

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