The Impact of Apollo-Era Microbiology on Human Space Flight

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Abstract

The microbiota of crewmembers and the spacecraft environment contributes significant risk to crew health during space flight missions. NASA reduces microbial risk with various mitigation methods that originated during the Apollo Program and continued to evolve through subsequent programs: Skylab, Shuttle, and International Space Station (ISS).

A quarantine of the crew and lunar surface samples, within the Lunar Receiving Laboratory following return from the Moon, was used to prevent contamination with unknown extraterrestrial organisms. The quarantine durations for the crew and lunar samples were 21 days and 50 days, respectively.

A series of infections among Apollo crewmembers resulted in a quarantine before launch to limit exposure to infectious organisms. This Health Stabilization Program isolated the crew for 21 days before flight and was effective in reducing crew illness.

After the program developed water recovery hardware for Apollo spacecraft, the 1967 National Academy of Science Space Science Board recommended the monitoring of potable water. NASA implemented acceptability limits of 10 colony forming units (CFU) per mL and the absence of viable *E. coli*, anaerobes, yeasts, and molds in three separate 150 mL aliquots.

Microbiological investigations of the crew and spacecraft environment were conducted during the Apollo program, including the Apollo-Soyuz Test Project and Skylab. Subsequent space programs implemented microbial screening of the crew for pathogens and acceptability limits on spacecraft surfaces and air.

Microbiology risk mitigation methods have evolved since the Apollo program. NASA cancelled the quarantine of the crew after return from the lunar surface, reduced the duration of the Health Stabilization Program, and implemented acceptability limits for spacecraft surfaces and air. While microbial risks were not a main focus of the early Mercury and Gemini programs, the extended duration of Apollo flights resulted in the increased scrutiny of impact of the space flight environment on crew health. The lessons learned during that era of space flight continue to impact microbiology risk mitigation in space programs today.

Introduction

Microbiological studies in space predated the Apollo program by several decades, starting with experiments on-board high altitude balloons and sounding rockets. These studies continued through the early days of space exploration on satellites, such as Sputnik, and manned flights, including Vostok, Mercury, and Gemini (1). The control of microbial risk became a principal concern during the Apollo Program with possibility of back contamination of Earth with unknown microbes from the lunar surface (2). Currently, microbiology continues to be a concern and the lessons learned in the Apollo Program impact microbiology operations occurring in human space flight today.

Lunar Quarantine Program

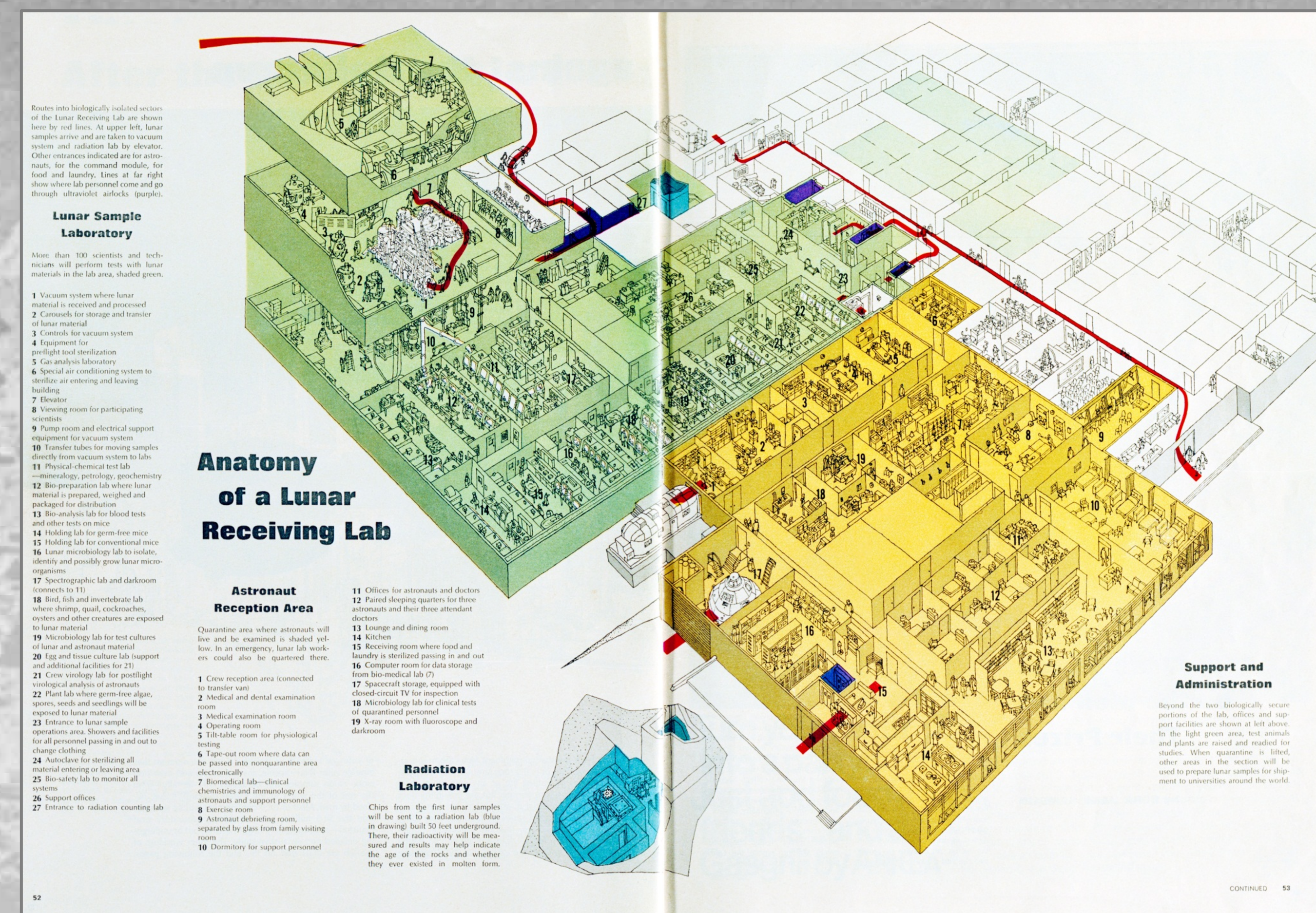
- Established to mitigate the risk of biological hazards returning from the lunar surface. (2)
- Consisted of the isolation and biological assessment of lunar samples, spacecraft, and crew after return from the lunar surface.
  - Crewmembers were isolated for 21 days after closing the hatch on the lunar surface.
  - Lunar samples were released 50 to 80 days after closing the hatch
- Housed in the Lunar Receiving Laboratory, a containment facility at the Manned Space Center (Johnson Space Center) in Houston, TX.
- After exhaustive microbial analysis of Apollo 11, 12, and 14, NASA and the Inter-agency Committee on Back-Contamination (ICBC) concluded that there was no hazard from lunar samples and that post-lunar quarantine should be discontinued. (2)
- Lunar samples are currently stored at the Lunar Sample Laboratory Facility and other locations.
- The Lunar Receiving Laboratory currently houses biomedical operations and research facilities that support ISS and the Human Research Program.

The Apollo 11 crewmen wear biological isolation garments as they walk toward the Mobile Quarantine Facility.

Richard M. Nixon welcomes the Apollo 11 astronauts confined to the Mobile Quarantine Facility (MQF).

The crewmen of Apollo 11 go through their post flight debriefing session in the Lunar Receiving Laboratory at the Manned Spacecraft Center.

The first direct exposure to Lunar material occurred when a technician was removing film magazines.



"Anatomy of a Lunar Receiving Lab" appeared in LIFE magazine, 07/04/69

A scientist examines lunar material in a sieve from the bulk sample container which was opened in the Biopreparation Laboratory of the Lunar Receiving Laboratory.

The incubation laboratory of the Sample Operations Area of the Lunar Receiving Laboratory, Bldg 37.

Flight Crew Health Stabilization Program

After a series of preflight, and in-flight clinical infections, NASA established the Flight Crew Health Stabilization Program to prevent future infectious disease incidences which could endanger a lunar mission (3).

Preventable occurrences included:

- Viral gastroenteritis was contracted at a formal dinner where several other guests suffered symptoms
- Exposure of a prime crewmember to rubella

Components included:

- Rapid diagnosis and therapy of crew and families
- Immunization of crew and families
- Exposure prevention
- Epidemiological surveillance

The Apollo-era Flight Crew Health Stabilization Program was considered to be a success in preventing pre-flight and in-flight infectious disease

The Health Stabilization Program continues today to protect crew members prior to ISS missions using a similar strategy (4):

Program	Pre-Flight (days)	Post-Flight (days)
Apollo	21	0
Skylab	21	7
Shuttle	7	0
ISS	7	0

Table 1: Durations of Flight Crew Health Stabilization Programs: The Apollo Flight Crew Health Stabilization Program was instituted after Apollo 13. The Skylab Health Stabilization Program consisted of a 7 day post-flight quarantine to protect the crew from any increased susceptibility to infection disease. The Shuttle and ISS programs utilized a 7 day pre-flight quarantine.

Before Stabilization Program				After Stabilization Program			
Mission	**Illness**	**# Crew**	**Time**	**Mission**	**Illness**	**# Crew**	**Time**
Apollo 7	Upper respiratory infection	3	inflight	Apollo 14	-	-	-
Apollo 8	Viral gastroenteritis	3	pre/inflight	Apollo 15	-	-	-
Apollo 9	Upper respiratory infection	3	preflight	Apollo 16	-	-	-
Apollo 10	Upper respiratory infection	2	preflight	Apollo 17	Skin infection	1	preflight
Apollo 11	-	-	-	Skylab 2	-	-	-
Apollo 12	Skin infection	2	inflight	Skylab 3	Skin infection	2	inflight
Apollo 13	Rubella exposure	1	preflight	Skylab 4	Skin infection	2	inflight

Table 2: Effect of the Flight Crew Health Stabilization Program on the Occurrence of Illness in Prime Crewmen: There was a high occurrence of infectious disease early in the Apollo Program until the implementation of the Flight Crew Health Stabilization Program during Apollo 14. (5)

Potable Water Acceptability Limits

In 1967, the Space Science Board of the National Academies of Science appointed an ad hoc panel to set chemical, physical, and biological standards for reclaimed potable water on spacecraft. (6) These recommendations were used to set microbiological requirements for potable water which have evolved since the Apollo program.

	Heterotrophic	E. coli	Coliforms	Anaerobic	Yeasts and Molds
Apollo	< 1 CFU / 150mL	< 1 CFU / 150mL	n/a	< 1 CFU / 150mL	< 1 CFU / 150mL
Shuttle [a]	< 1 CFU / 100mL	n/a	< 1 CFU / 100mL	< 1 CFU / 100mL	< 1 CFU /100mL
Shuttle [b]	< 100 CFU / 100mL	n/a	< 1 CFU / 100mL	< 1 CFU / 100mL	< 1CFU / 100mL
Shuttle [c]	<50 CFU / mL	n/a	< 1 CFU / 100mL	n/a	n/a
ISS	<50 CFU / mL	n/a	< 1 CFU / 100mL	n/a	n/a

Table 3: Potable Water Acceptability Limits of Spacecraft: The microbiological limits of potable water evolved between Apollo and ISS. During the Shuttle Program, the potable water limits evolved three times; before 1981 [a], around 1987 [b], and again around 2005 [c]. (7) Currently, potable water is also filtered through a 1 micron filter to exclude protozoa.(8)

The Coliform Detection Packet is used to detect *E. coli* and coliforms in potable water on ISS.

The Microbial Capture Device is used to enumerate heterotropic bacteria in potable water on ISS.

Surface and Air Monitoring

Analysis of crew microbiology was required as part of the Lunar Quarantine Program recommended by the Interagency Committee on Back-Contamination:

- Provided a baseline of crew microbiota in the determination of possible lunar contamination (9).
- Revealed a number of opportunistic pathogens in the crew microbiota (10).

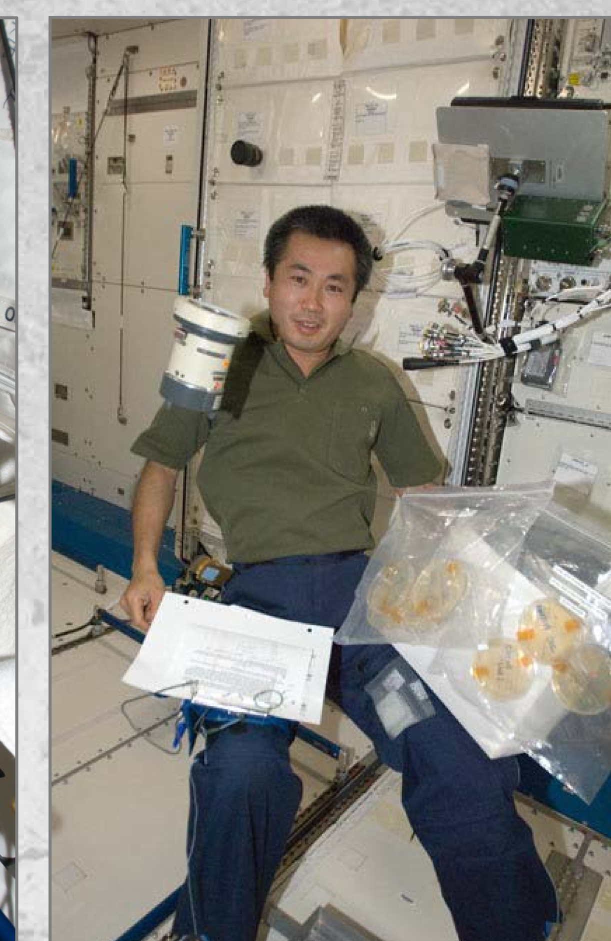
Studies in Apollo, Skylab, and the Apollo-Soyuz Test Project found (11, 12):

- Transfer of *Staphylococcus aureus* between crew members
- Transfer of *Candida albicans* between crew members
- Contamination of Skylab with *Serratia marcenscens* that persisted in crew after return
- Transfer of microorganisms from crewmembers to command module environmental surfaces, including:
  - *Klebsiella pneumoniae*
  - *Proteus mirabilis*
  - *Streptococcus faecalis*
  - *Bacillus* species

Surface and air monitoring was used for the pre-flight validation of the Space Shuttle as a part of its Contamination Control Program.

Currently, inflight surface and air monitoring is used to measure the environmental microbiology of ISS.

The Microbiology Surface Sampling Kit (SSK) is used to enumerate bacteria and fungi on ISS surfaces.



The Microbial Air Sampler is used to enumerate bacteria and fungi in ISS air.

	Maximum for Bacteria	Maximum for Fungi
Pre-flight Air	300 CFU / m3	50 CFU / m3
Pre-flight Surfaces	500 CFU / 100 cm2	10 CFU / 100 cm2
Inflight Air	1000 CFU / m3	100 CFU / m3
Inflight Surfaces	10,000 CFU / cm2	100 CFU / 100 cm2

Table 4: Current Microbial Acceptability Limits for Pre-flight and Inflight Spacecraft Air and Surfaces: Pre-flight and Inflight microbial acceptability limits for Shuttle and ISS were established to provide requirements to engineering to monitor microbial levels (8).

Conclusions

- Many valuable lessons were learned during the Apollo-era of human space flight. These lessons were built on knowledge gathered through scientific experimentation and medical diagnosis
- The knowledge from the Apollo-era shaped microbial operations of current space programs, such as ISS and commercial vehicles, and will have a continued effect on future exploration.

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