PANEL S-065: APOLLO 1 MISHAP: ITS CAUSES AND ITS CONSEQUENCES FROM THE AEROMEDICAL PERSPECTIVE

[327] BIOMEDICAL RESEARCH DEFERRED IN THE AFTERMATH OF THE APOLLO FIRE: IMPACT TO PROGRESS IN HUMAN SPACEFLIGHT

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I have no financial relationships to disclose.

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Overview

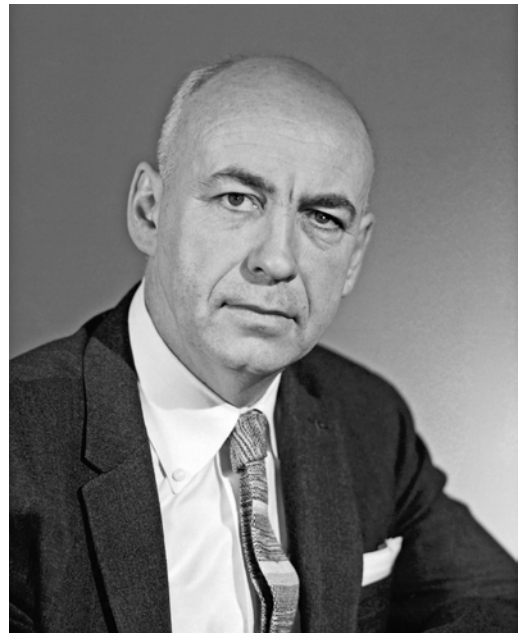
- Before *Apollo* fire, early *Apollo* missions were expected to continue pattern established in *Gemini* program of accommodating significant scientific and biological experimentation, including human biomedical studies, during flights
  - *Apollo* 1 and *Apollo* 2, both 2-week engineering test flights, were to carry almost as many biomedical studies as Gemini 7, a 2-week medical test mission

NASA Headquarters position on in-flight science (June 1965)

"Although the principal objective of Apollo is to land astronauts on the lunar surface (...), we are also performing considerable in-flight experimentation as well, particularly on the developmental flights leading up to the lunar landing. **Some of these are experiments to determine man's physical functioning in space and the medical effects of the space environment on man.** These investigations contribute directly to the lunar landing capability. However, **we will also perform other medical inflight experiments whose purpose is to add to the store of man's knowledge**. (...) Many important scientific investigations in the fields of biology, physics and astronomy are also included in the Apollo Program."

Samuel C. Phillips, Brig. Gen., USAF, Director of the Apollo Program, memo dated June 30, 1965, to Dr. George E. Mueller, Assoc. Admin. for Manned Space Flight, "Points for the Wood's Hole Talk"

NASA Manned Spacecraft Center position on in-flight science (May 1965)



"The main goal of the early Apollo Earth orbital missions is the certification of the spacecraft design and development of operational procedures for the lunar landing mission. The program policy is also, to accommodate, whenever possible, significant in-flight experiments. [...] Although the ground rule has been that [these] experiments will be carried out on a 'noninterference' basis, **each added requirement interferes**, hopefully to only a small degree, **with the main task of early development of the lunar system**. For this reason, the experiments to be flown on the Earth orbital Apollo missions should meet **one** of the following criteria:

1. Contribute directly to the body of data needed for the lunar mission; and
2. Be of such importance to the scientific community that deferral to later Apollo flights is clearly undesirable."

Dr. Robert Gilruth, director of MSC, memo dated May 5, 1965, to Dr. George E. Mueller, NASA Assoc. Admin. for Manned Space Flight, "Reassignment of Apollo onboard experiments."

The *Apollo* Program in early 1966

Date	Mission	Duration	Objectives
January 1966	AS-201		Test Block 1 CSM, Saturn IB unmanned
June 1966	AS-203		Test Block 1 CSM, Saturn IB unmanned
July 1966	AS-202		Test S-IVB stage to destruction
October 1966	AS-204, *Apollo* 1	14 days	1st manned test flight
December 1966	AS-205, *Apollo* 2	14 days	2nd manned test flight
December 1966	AS-501		Test Saturn V unmanned
March 1967	AS-206		Test LM unmanned
April 1967	AS-502		Test Saturn V unmanned
June 1967	AS-207/208, *Apollo* 3	10 days	1st manned Block 2 CSM, LM test flight
September 1967	AS-503, *Apollo* 4	8-10 days	1st manned Saturn V; LM test in LEO
January 1968	AS-504, *Apollo* 5	8 days	Manned lunar mission simulation in HEO
April 1968	AS-505, *Apollo* 6	8 days	Possible first manned lunar landing

Comparison of General Mission Characteristics of *Apollo* 1 and *Apollo* 2 (as of September 1965)

Mission	*Apollo* 1 (AS-204)	*Apollo* 2 (AS-205)
Spacecraft	CSM-012, LES-12, SLA-5	CSM-014, LES-14, SLA-6
Launch date	Early 1967	Mid-1967
Maximum duration	13.8 days	13.8 days
SPS firings	8	4
Primary objectives	1. Verify spacecraft/crew operations 2. Determine CSM subsystem performance 3. Evaluate S-IVB and IU checkout in orbit 4. Demonstrate S-IVB attitude control 5. Demonstrate crew/CSM/launch vehicle/mission support facilities performance	Same as Apollo 1 plus: 1. CSM/S-IVB maneuvering for IMU alignment, tracking of stars and earth landmarks 2. CSM transposition, simulated docking with S-IVB 3. Separation, re-rendezvous, simulated docking 4. S-IVB LH2 venting (6 times) and LO2 venting (twice)
Secondary objectives	11 experiments 5 medical (1 pre/post only) 4 scientific 1 technological	15 experiments 8 medical 7 scientific

Gemini and Planned *Apollo* Biomedical Experiments (January 1966)

Experiment		Gemini 4 4 days 2 men	Gemini 5 8 days 2 men	Gemini 7 14 days 2 men	Apollo 1 14 days 3 men	Apollo 2 14 days 3 men
M-1	Cardiovascular Deconditioning		✓	✓		
M-3	In-flight Exerciser	✓	✓	✓	X	
M-4	In-flight Phonocardiogram	✓	✓	✓	X	
M-5	Bioassays Body Fluids	✓		✓	X	X
M-6	Bone Demineralization		✓	✓	X	X
M-7	Calcium Balance			✓		X
M-9	Human Otolith Function		✓	✓	X	X
M-12	Exercise Ergometer				X	X
M-20	Pulmonary Function					X
T-3	In-flight Nephelometer				X	
T-4/S-14	Frog Otolith Experiment					X
S-15	Zero G Single Human Cells					X
S-16	Trapped Particle Asymmetry					X

Evolution of Planned *Apollo 1* Biomedical Experiments

Experiment		May 1965	June 1965	Aug 1965	Sep 1965	Jan 1966	June 1966	Sep 1966
M-1	Cardiovascular Deconditioning	X	X	X	X			
M-3	In-flight Exerciser					X	X	X
M-4	In-flight Phonocardiogram			X	X	X	X	X
M-5	Bioassays Body Fluids	X	X	X	X	X		
M-6	Bone Demineralization	X	X	X	X	X	X	X
M-7	Calcium Balance							
M-9	Human Otolith Function	X	X	X	X	X	X	X
M-12	Exercise Ergometer	X	X	X	X	X		
M-17	Thoracic Blood Flow	X						
M-18	Vectorcardiogram	X						
M-19	Metabolic Rate Measurement	X						
M-20	Pulmonary Function	X						
M-48	Cardiovascular Reflex Deconditioning						X	X
T-3	In-flight Nephelometer					X	X	X

Evolution of Planned *Apollo 2* Biomedical Experiments

Experiment		May 1965	Aug 1965	Jan 1966	Apr 1966	Aug 1966
M-4	In-flight Phonocardiogram	X	X		X	X
M-5A	Bioassays Body Fluids		X	X		
M-6	Bone Demineralization	X	X	X	X	X
M-7	Calcium Balance	X	X	X	X	X
M-9	Human Otolith Function	X	X	X	X	
M-11	Cytogenic Blood Studies	X	X		X	X
M-12	Exercise Ergometer	X	X	X	X	X
M-19	Metabolic Rate Measurement	X	X		X	X
M-20	Pulmonary Function	X	X	X	X	X
M-23	Lower Body Negative Pressure				X	X
T-4/S-14	Frog Otolith Experiment	X	X	X	X	X
S-15	Zero G Single Human Cells	X	X	X	X	X
S-16	Trapped Particle Asymmetry	X	X	X	X	X

The *Apollo* Program in late 1966

Date	Mission	Duration	Objectives
February 1967	AS-204, *Apollo* 1	14 days	1st manned test flight
~~December 1966~~	~~AS-205, *Apollo* 2~~	~~14 days~~	~~2nd manned test flight~~
~April 1967	AS-501		Test Saturn V unmanned
~July 1967	AS-206		Test LM unmanned
~August 1967	AS-502		Test Saturn V unmanned
~October 1967	AS-205/208, *Apollo* 2	10 days	1st manned Block 2 CSM, LM test flight
1968	AS-503, *Apollo* 4	8-10 days	1st manned Saturn V; LM test in LEO
1968	AS-504, *Apollo* 5	8 days	Manned lunar mission simulation in HEO
1968	AS-505, *Apollo* 6	8 days	Possible first manned lunar landing

Evolution of Biomedical Experiments Planned For *Apollo* 3 (AS-207/208), later (after Nov. 1966) *Apollo* 2 (AS-205/208)

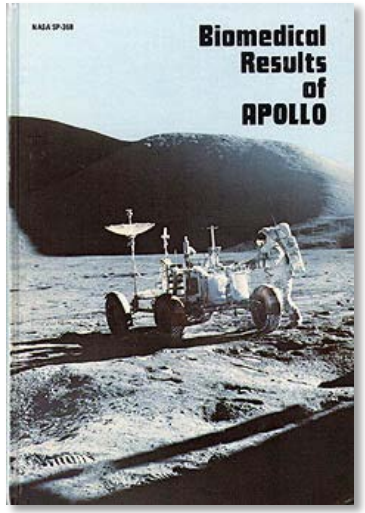
Experiment		May 1965	Aug. 1965	Dec. 1965	Mar. 1966	Apr. 1966	Aug. 1966	Nov. 1966
M-3A	In-flight Exerciser	NF						
M-4A	In-flight Phonocardiogram	(X)						
M-5A	Bioassays Body Fluids						X	**X**
M-6A	Bone Demineralization*						X	**X**
M-8	In-flight Sleep Analysis	(X)						
M-9	Human Otolith Function	(X)						
M-11	Cytogenic Blood Studies						X	**X**
M-12	In-flight Ergometer	(X)						
M-17	Thoracic Blood Flow	(X) NF						
M-18	Vectorcardiogram	(X) NF						
M-22	Red Blood Cell Survival	(X)						
M-23	Lower Body Negative Pressure*			**X**	X	**X**	X	**X**
T-3	In-flight Nephelometer		**X**					
D-8A	Radiation in Spacecraft	X	**X**	**X**	X	X	**X**	**X**

( ) under consideration
NF evaluated but judged not feasible
* pre- and postflight only
x [bold] explicit
x inferred

After the Apollo Fire: biomedical data

Crew health and inflight monitoring

- Clinical care
- Microbial investigations
- Radiation monitoring
- Metabolism and heat dissipation
- Environmental factors
- Toxicology



Biomedical Results of Apollo
Johnston, Dietlein and Berry
NASA SP-368, 1975

Pre/postflight medical testing

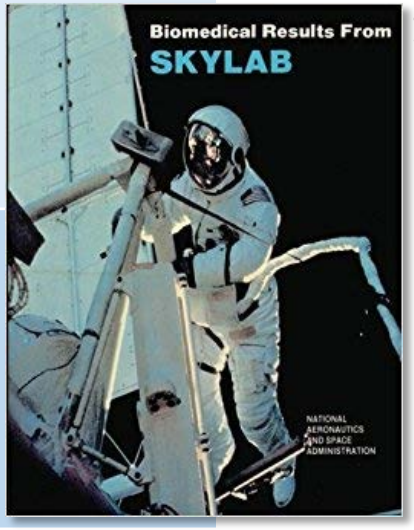
- Endocrine, electrolyte and fluid volume changes
- Clinical biochemistry
- Hematology and immunology
- Cardiovascular assessment
- Exercise responses
- Nutritional studies
- Skeletal response
- Vestibular assessment

After the Apollo Fire

Apollo experiment		Skylab experiment	
M-5	Bioassays Body Fluids	M073	Bioassay of Body Fluids
M-11	Cytogenic Blood Studies	M111	Cytogenic Blood Studies
M-22	Red Blood Cell Survival	M110	Hematology, Immunology
M-6	Bone Demineralization	M078	Bone Mineral Measurement
M-7	Calcium Balance	M071	Mineral Balance
M-8	In-flight Sleep Analysis	M133	Sleep Monitoring
M-9	Human Otolith Function	M131	Human Vestibular Function
M-18	Vectorcardiogram	M093	Vectorcardiogram
(M-4	In-flight Phonocardiogram)		
(M-17	Thoracic Blood Flow)		
M-19	Metabolic Rate Measurement	M171	Metabolic Activity
M-20	Pulmonary Function		
M-12	Exercise Ergometer		
(M-3	In-flight Exerciser)		
M-23	Lower Body Negative Pressure	M092	Lower Body Negative Pressure
(M-48	Cardiovascular Reflex Conditioning)		
(M-1	Cardiovascular Deconditioning)		

( ): subsumed or OBE

Biomedical Results from Skylab
Johnston and Dietlein
NASA SP-377, 1977

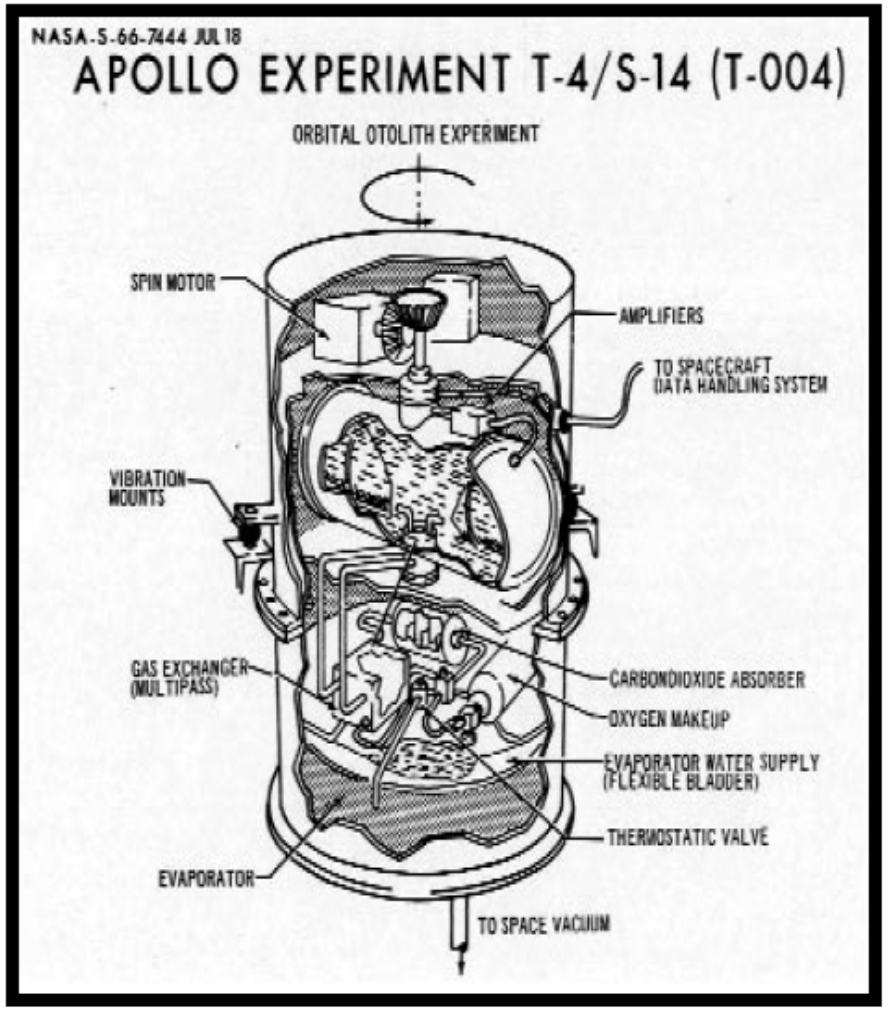


S-15, Zero G Single Human Cells

S015, The Response of Single Human Cells to Zero- Gravity

After the Apollo Fire: biological experiments

- Weightlessness
  - Frog Otolith Experiment
    - demanifested from Apollo program
    - added to OWS Airlock Module (AAP-2) in June 1967
    - transferred to AAP-1A—cancelled June 1968
    - flew as Orbiting Frog Otolith, launched by a Scout rocket into LEO Nov. 9, 1970.
    - Functioned for over 6 days, frogs acclimated after ~ 5 days

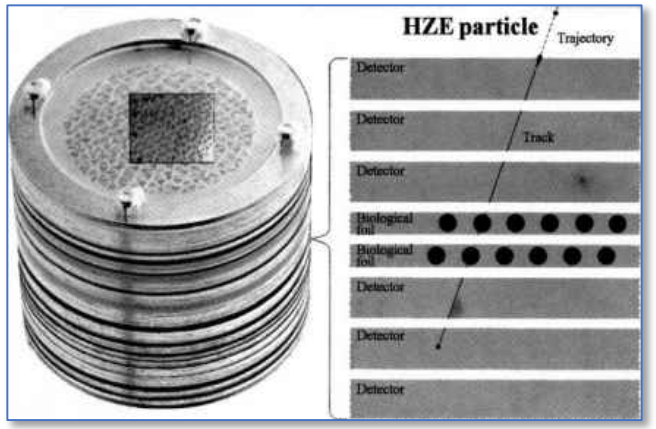


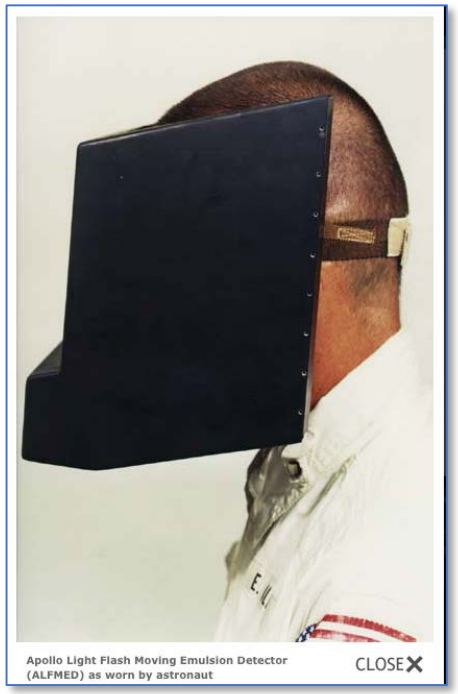
The Frog Otolith Experiment Package provided a self-contained life supporting environment for two bull frogs carried inside a small centrifuge.

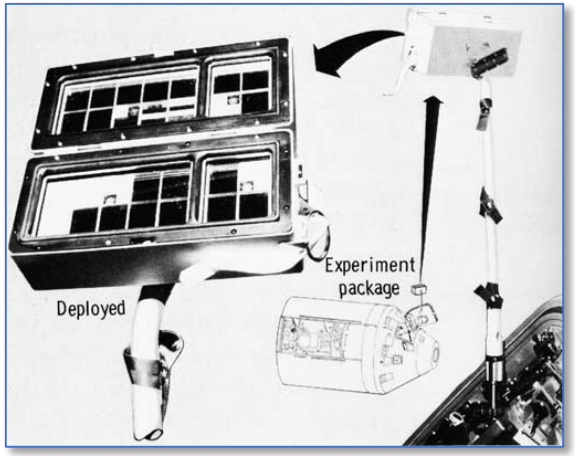
Image courtesy of NASA (image S-66-7444).

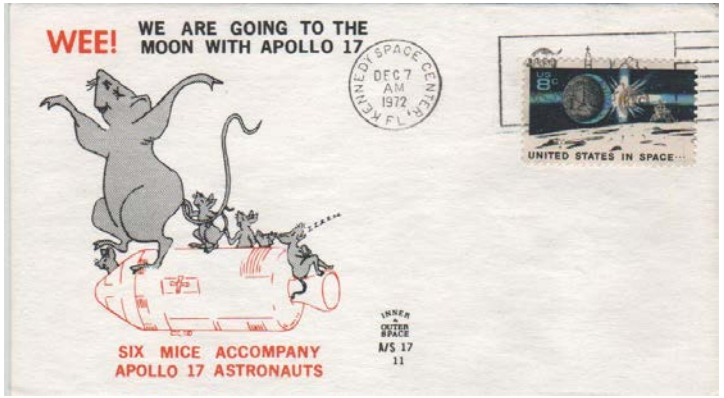
After the Apollo Fire: biological experiments

- Space Radiation
  - BIOSTACK (Apollo 16 and 17): spores, seeds, animal eggs
  - Apollo Light Flash Investigation (Apollo 14, 15, 16 and 17)
  - Microbial Response to Space Environment Experiment (Apollo 16)
  - BIOCORE Pocket Mouse Experiment (Apollo 17)









Results

- After Apollo fire, early Apollo missions were scrubbed of all in-flight biomedical experiments, other non-operational evaluations
    - Prioritized checkouts of spacecraft components to accomplish manned lunar landing, safe return
- After goal was attained and sufficient confidence had been established in spacecraft functionality, small number of human and biological experiments were accommodated
- However, even earliest Apollo missions flown saw extensive pre- and postflight biomedical studies in support of operational medical certification of astronaut capacity for substantial workloads of lunar surface
- Apollo lunar surface crewmembers were sparsely instrumented but creatively monitored using data provided by their life support systems
- Biomedical, biological research deferred from Apollo were largely acquired on Skylab under well-controlled circumstances with larger number of crewmen participants
- These data formed basis for more intensive studies on Space Shuttle, established foundation for continuing investigations on International Space Station

Resources

- Charles JB. “The First Apollo 2: Science and Operations Planned for the 'Leaping Green Frog." *Quest* 9:2, 26-42 (available from author).
- Johnston, R.S., L.F. Dietlein and C.A. Berry, eds., Biomedical Results of Apollo (NASA SP-368), NASA, Washington, D.C., 1975, https://history.nasa.gov/SP-368/contents.htm (accessed Apr. 24, 2017).
- Johnston, R.S., and L.F. Dietlein, eds., Biomedical Results from Skylab (NASA SP-377), NASA, Washington, D.C., 1977, https://lsda.jsc.nasa.gov/books/skylab/biomedical_result_of_skylab.pdf (accessed Apr. 24, 2017).

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