One Small Step for Man, One Giant Leap for Moon Microbes? Interpretations of Risk and the Limits of Quarantine in NASA's Apollo Program

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Abstract: As NASA prepared to land astronauts on the Moon in the 1960s, scientists and federal officials came to fear that they could bring lunar microorganisms back to Earth, with potentially grave consequences for human, plant, and animal life. To prevent this "back contamination," representatives from NASA and a network of federal departments and services developed a protocol to quarantine astronauts, equipment, samples, and spacecraft exposed to lunar dust. Yet although NASA assured policy makers and an anxious public that it had implemented impermeable safeguards against the escape of lunar microorganisms, it had in fact prioritized likely risks to astronauts over unlikely risks to American society. To a degree previously unknown, the Apollo quarantine protocol suffered from numerous containment breaches that would likely have exposed the terrestrial biosphere to contamination—had lunar microorganisms actually existed.

In the 1960s, a network of American scientists, officials, and civil servants mobilized to protect the Earth against extraterrestrial contamination. Their efforts, which consumed well over $100 million, confronted the possibility that NASA's Apollo missions to the Moon could expose the Earth to microorganisms from the lunar surface.[1] This backward or back contamination, some feared, threatened the wholesale degradation of Earth's biosphere—and perhaps a pandemic that rivaled the worst in human history.

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[1] All figures in this article are in 2020 USD.

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The quest to prevent back contamination rarely enters the historiography of the Apollo program, even as the biological dimensions of the "space race" between America and the Soviet Union receive increasing attention. The two most important publications that investigate the effort conclude that, overall, NASA and its partners effectively addressed the threat.[2] Articles written for a popular audience frame the back-contamination issue as little more than an amusing sideshow to the real drama of the Apollo missions.[3] The Moon, after all, seems so obviously bereft of life.

To imagine otherwise requires an intellectual return to the 1960s, when little was known about the possibilities for life on other worlds. Since the seventeenth century, assumptions that the solar system was widely inhabited—an idea known as the "plurality of worlds"—led astronomers to identify evidence for life on the Moon, Mars, and Venus. By the early twentieth century, the most sensational of these ideas seemed implausible, or at least unprovable, and biologists temporarily refrained from speculating about extraterrestrial life. Yet midway through the century biochemists proposed, and through experimentation seemed to verify, that basic chemical reactions in Earth's primordial atmosphere had given rise to the first complex organic molecules. Precisely as the maturation of radio astronomy and rocketry opened new possibilities in the search for extraterrestrial life, it seemed that life would emerge on any world with chemistry similar to that of the early Earth.[4]

In 1960, scientists undertook the first Search for Extra-Terrestrial Intelligence (SETI) initiative at Green Bank Observatory. In the following year, another group of scientists coined a new field: exobiology, the study of life as it had evolved beyond Earth.[5] By discovering microbial life on other worlds, exobiologists hoped eventually to develop a "true general biology," with universal laws that could distinguish the contingent from the necessary in Earth's living systems.[6] Yet prominent scientists ridiculed exobiology for being a discipline that had not yet found its subject: science fiction, more than science. In response, exobiologists argued that only their field could mitigate the gravest risks and exploit the greatest opportunities of the new Space Age. Echoing proponents of the plurality of worlds, they stressed that microbial life could be ubiquitous across the solar system. Missions to other worlds therefore had to guard against both forward contamination, which could jeopardize the detection of extraterrestrial life, and back contamination, which could threaten life—including human life—on Earth.[7]

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[2] Michael Meltzer, *When Biospheres Collide: A History of NASA's Planetary Protection Programs* (Washington, D.C.: U.S. Government Printing Office, 2012); and Susan Mangus and William Larsen, "Lunar Receiving Laboratory Project History," NASA/CR-2004-208938 (hereafter cited as **Mangus and Larsen, "Lunar Receiving Laboratory Project History"**). For recent work on the biological dimensions of the space race see Neil M. Maher, *Apollo in the Age of Aquarius* (Cambridge, Mass.: Harvard Univ. Press, 2017); David P. D. Munns and Kärin Nickelsen, "To Live among the Stars: Artificial Environments in the Early Space Age," *History and Technology*, 2017, 33:272–299; and Leah V. Aronowsky, "Of Astronauts and Algae: NASA and the Dream of Multispecies Spaceflight," *Environmental Humanities*, 2017, 9:359–377.

[3] A recent exception is a popular article that chronicles spills at the Lunar Receiving Laboratory: Dagomar Degroot, "A Lunar Pandemic," *Aeon*, 2020 (hereafter cited as **Degroot, "Lunar Pandemic"**). For the usual story see Kent Carter, "Moon Rocks and Moon Germs: A History of NASA's Lunar Receiving Laboratory," *Prologue*, 2001, 33(4):233–250 (hereafter cited as **Carter, "Moon Rocks and Moon Germs"**), esp. p. 237; and Brian Duff, "The Great Lunar Quarantine," *Air and Space*, Feb./Mar. 1994, pp. 38–43 (hereafter cited as **Duff, "Great Lunar Quarantine"**).

[4] Michael J. Crowe, *The Extraterrestrial Life Debate, 1750–1900: The Idea of a Plurality of Worlds from Kant to Lowell* (Cambridge: Cambridge Univ. Press, 1986), p. 21; and Steven J. Dick, *The Biological Universe: The Twentieth-Century Extraterrestrial Life Debate and the Limits of Science* (Cambridge: Cambridge Univ. Press, 1996), pp. 18, 348, 351.

[5] Duncan H. Forgan, *Solving Fermi's Paradox* (Cambridge: Cambridge Univ. Press, 2019), p. 7 (SETI); Gavriil A. Tikhov, *Astrobiology* (Moscow: Molodaya Gvardia, 1953); and Joshua Lederberg, "Exobiology: Approaches to Life beyond the Earth," *Science*, 1960, *132*(3424):393–400, esp. p. 400.

[6] In this quest lie the origins of today's astrobiology, a field that considers how life emerged, evolved, and spread across the universe (including on Earth). See Charles S. Cockell, *Astrobiology: Understanding Life in the Universe* (New York: Wiley, 2020), p. 13.

[7] Joshua Lederberg, "Signs of Life," *Nature*, 1965, 207(4992):9–13, esp. p. 9; Audra J. Wolfe, "Germs in Space: Joshua Lederberg, Exobiology, and the Public Imagination, 1958–1964," *Isis*, 2002, 93:183–205; Dick, *Biological Universe* (cit. n. 4), pp. 5, 322; and National Research Council, *Biology and the Exploration of Mars* (Washington, D.C.: National Academies Press, 1966), p. 5.

Since early efforts to minimize forward contamination raised the cost and apparently reduced the reliability of those missions, NASA ultimately invested little effort in sterilizing its Moon-bound spacecraft.[8] Yet the correspondence, press briefings, confidential reports, operational manuals, congressional testimonies, periodicals, oral histories, and science fiction examined in this essay all reveal that the threat of back contamination prompted serious and sustained concern across the federal government and among the general public. Eventually, the success of the Apollo missions seemed to depend on a rigorous quarantine protocol that could isolate astronauts, spacecraft, and lunar samples from Earth's biosphere. At its heart was the Lunar Receiving Laboratory (LRL), an unprecedented facility that in theory allowed bioscientists to detect and, if necessary, contain microorganisms returned from the Moon.

Yet by explaining how the Apollo quarantine protocol was designed, tested, promoted, and ultimately implemented, this essay argues that, had lunar microorganisms actually existed, the protocol would have failed. In all probability, the microorganisms that seemed most likely to evolve on the Moon would have infected the astronauts, contaminated their spacecraft, escaped into the Pacific Ocean, and breached containment in the LRL, just as tests on plants—and bacteria apparently returned from the Moon—made headlines across the United States. The quarantine protocol looked like a success only because it was not needed. Luckily, there were no microorganisms discovered during the Apollo missions that were indigenous to the Moon.

In 1961, when John F. Kennedy proposed that NASA land a man on the Moon "by the end of the decade," the agency had not yet launched a single astronaut into orbit. NASA accomplished Kennedy's goal ahead of schedule by elaborating a model of systems management originally developed in the U.S. Air Force and at the Jet Propulsion Laboratory.[9] Effective management allowed NASA to organize the labor of three hundred thousand people employed by twenty thousand contractors and in two hundred universities. It enabled NASA to control the development of technological artifacts that demanded the integration and testing of millions of components, many created within distinct cultural, social, and disciplinary frameworks that had to meet unprecedented standards of precision and cleanliness. Systems management in the crewed space program generally worked well when tightly controlled by NASA Headquarters. Yet the history of the Apollo quarantine protocol reveals that NASA's managerial model could lead to potentially catastrophic flaws in the design, integration, and operation of novel technologies and practices when federal departments and services with goals contradictory to those of NASA challenged the authority of NASA administrators but could not fully control them.[10]

The most important source of dissension between NASA and other federal bodies involved distinct perceptions of risk in different disciplinary communities. NASA had explicitly rejected relatively new, quantitative approaches to assessing risk because they gave a low probability to successfully returning an astronaut from the Moon. Until the *Challenger* disaster in 1986, NASA would instead use (and thereby popularize) qualitative Failure Mode and Effects Analysis, a step-by-step method that helped its engineers understand and control risks in complex technical systems. NASA managers, engineers, and geoscientists directly involved in landing astronauts on the Moon and returning lunar samples to Earth accordingly focused on technical risks that, if left unaddressed,

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[8] PS5/M1125, "Lunar Surface Contamination," Apollo 076-11, HIS 25353; and "Biologic Contamination of the Lunar Surface," Apollo 076-11, HIS 26191: Johnson Space Center History Collection, University Archives, Neumann Library, University of Houston–Clear Lake, Houston (hereafter **JSC Archives**). See also Meltzer, *When Biospheres Collide* (cit. n. 2).

[9] Charles Fishman, *One Giant Leap: The Impossible Mission That Flew Us to the Moon* (New York: Simon & Schuster, 2019), p. 8; Asif A. Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington, D.C.: NASA, 2000); and Stephen Johnson, *The Secret of Apollo: Systems Management in American and European Space Programs* (Baltimore: Johns Hopkins Univ. Press, 2006), p. 6.

[10] Johnson, *Secret of Apollo*, pp. 3, 8, 117, 122.

had a high likelihood of endangering the well-being of astronauts, the completion of their missions, and the integrity of their retrieved samples. Federal regulators, bioscientists, and a small group of scientists in universities, by contrast, used diverse qualitative understandings of risk to concentrate on low-frequency, high-consequence threats to American ecosystems and populations.[11]

Neither group could ignore the other. Yet given the size of the Apollo program, the money invested in it, the magnitude of popular interest it inspired, the scale of federal support for it, the opaque nature of the technical challenges it faced, and, above all, the compressed timetable it followed, there were limits to the extent to which regulators and bioscientists could delay or complicate the Moon landing effort. This meant that NASA managers and engineers were eventually able to prioritize high-probability risks to individual astronauts and machines over low-probability risks to American society. That prioritization seriously undermined the design, implementation, and operation of the Apollo quarantine protocol, especially as it was carried out by technicians in the LRL.

Popular pressure and, in turn, elected policy makers, rather than scientists or regulators, might have compelled NASA to evaluate risk differently. Admittedly, NASA's risk prioritization reflected the demands of the Kennedy, Johnson, and Nixon presidential administrations, and congressional policy makers played a key role in forcing the agency to take the threat of back contamination seriously. Yet the design and implementation of the quarantine protocol was left almost entirely to unelected officials, engineers, and scientists, some of whom concealed the true nature of the back-contamination threat from elected policy makers. NASA officials assured policy makers, journalists, and, therefore, the American public that they could manage the threat, even as they privately agreed that any lunar microorganisms returned to Earth would inevitably escape into the terrestrial biosphere. There is no evidence that NASA officials briefed policy makers on the shortcomings of their quarantine protocol in the weeks and months before the launch of *Apollo 11*. NASA representatives attempted to calm popular fears of back contamination, even as they concealed containment failures and acknowledged to one another that the quarantine protocol was flawed and could never offer complete protection. In general, NASA managers regarded public and political pressure over back contamination as a nuisance that had to be managed, rather than an expression of popular will that required a serious response.

DESIGNING THE QUARANTINE PROTOCOL

While the Moon remained a mysterious world in the 1950s, most astronomers assumed that it was biologically and geologically inert. Yet by the end of the decade, reputable reports of "transient lunar phenomena"—episodes of apparent outgassing from the lunar surface—challenged that consensus. In 1960, the planetary scientist Carl Sagan proposed that since the early Moon had likely resembled the primordial Earth, microbial life could have arisen on both worlds. On the Moon, it could persist just under the irradiated surface.[12] Other scientists suggested that the carbon of ancient lunar life accounted for the dark tint of lunar lowlands or that "astroplankton"—microorganisms from other star systems—coated the lunar landscape. The influential Space Science Board of the National Academy of Sciences (NAS) concluded that samples of the lunar regolith could harbor microorganisms capable of contaminating Earth's biosphere. In 1962, scientists convened by the NAS issued a report warning that missions returning from other worlds risked "the introduction into the Earth's biosphere of destructive alien organisms," with the potential for "a

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[11] Karin Zachmann, "Risk in Historical Perspective: Concepts, Contexts, and Conjunctions," in *Risk—A Multidisciplinary Introduction*, ed. Claudia Klüppelberg, Daniel Straub, and Isabell M. Welp (Heidelberg: Springer, 2014), pp. 3–35, esp. p. 22.

[12] N. A. Kozyrev, "Volcanic Activity on the Moon," *International Geology Review*, 1959, *1*(10):40–44 ("transient lunar phenomena"); Carl Sagan, "Biological Contamination of the Moon," *Proceedings of the National Academy of Sciences of the United States of America*, 1960, *46*:396–402, esp. p. 400; and Sagan, "Indigenous Organic Matter on the Moon," *ibid.*, pp. 393–396, esp. p. 395.

disaster of enormous significance to mankind." Sagan then announced that astronauts returning from the Moon could bring these organisms to Earth.[13]

While Sagan had not yet acquired widespread fame, he was already influential enough for a March 1963 congressional staff memo to repeat his claims that "hardy microorganisms that have survived throughout the ages on the Moon might multiply and spread rapidly in the rich environment of the Earth." The memo stressed that Sagan had compared the possible consequences "to the violence of the venereal disease epidemics that raged through Europe in the Middle Ages, or to the measles that took a heavy death toll when it was introduced into Polynesia." In April and May, during high-stakes congressional debates over NASA's funding in fiscal year 1964, senators bombarded agency officials with questions about their efforts to mitigate the risk of both forward and back contamination. "Studies will be made of the possibilities of back-contamination and appropriate actions taken," NASA assured them.[14]

In situ tests for life on the lunar surface, ideally using robotic landers, provided an obvious first step to minimizing the risk of back contamination. The pioneering exobiologist Wolf Vishniac had developed a device—the "Wolf Trap"—that seemed capable of revealing the existence of microbial life on planetary surfaces. Vishniac and Sagan later joined two other scientists in proposing that the Apollo astronauts conduct such tests before returning to Earth. Yet faced with the daunting challenge of beating the Soviets to the Moon, there was little appetite within NASA for anything that could slow the progress of the Apollo program.[15]

Nevertheless, by July 1964 the threat of back contamination had assumed such scientific and political importance that the Life Sciences Committee of the Space Science Board convened thirty representatives from the Department of Agriculture, the Army, the National Institutes of Health, the Public Health Service (PHS), major universities, and, of course, NASA for a two-day conference devoted to the topic. Conferencegoers agreed that the threat of back contamination had been ignored for too long. Seeking to "forecast the worst conditions that might be faced," they echoed Sagan by drawing on "innumerable examples of the harmful spread of biological agents," including past "pandemics of plague, smallpox, and yellow fever." Even organisms that seemed innocuous on other worlds could overgrow Earth's "comparatively lush environment" and hence alter "the physical or commercial characteristics of the biosphere."[16]

Astronauts who traveled to the Moon therefore needed training "in clean-and-sterile techniques," and any samples they collected had to be sealed within airtight containers. Conference attendees acknowledged, however, that decontamination could never eliminate all microorganisms stowed away on returning spacecraft. Nor could any facility contain them indefinitely. "If infection of the earth by extraterrestrial organisms is possible," they concluded, "it will occur."

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[13] J. J. Gilvarry, "The Possibility of a Pristine Lunar Life," *Journal of Theoretical Biology*, 1964, 6:325–346; Gilvarry, "Observability of Indigenous Organic Matter on the Moon," *Icarus*, 1966, 5(1–6):228–236; National Research Council, *A Review of Space Research* (Washington, D.C.: National Academies Press, 1962), pp. 9–13; and Carl Sagan, "The Search for Indigenous Lunar Organic Matter," *Space Life Sciences*, 1972, 3:484–489, esp. p. 484.

[14] Committee on Science and Astronautics, U.S. House of Representatives, Hearings on H.R. 5466 (1964 NASA Authorization), 88th Cong., 1st sess., 4 and 5 Mar. 1963, p. 1088; and Degroot, "Lunar Pandemic." Sagan had learned about historical epidemics while taking an undergraduate course with William McNeill, a pioneer of world and environmental history. Conversation with John McNeill, 20 May 2020.

[15] Harold J. Morowitz, Carl Sagan, Richard S. Young, and Wolf Vishniac, "Biology Training Program for Apollo Astronauts: Proposal," 1967, p. 13, Seth Macfarlane Collection of the Carl Sagan and Ann Druyan Archive, Library of Congress, Washington, D.C.; "The Wolf Trap," in Freeman Henry Quimby, *Concepts for Detection of Extraterrestrial Life* (Washington, D.C.: NASA Science and Technical Information Division, 1964), p. 39; and Vishniac, "Extraterrestrial Microbiology," *Aerospace Medicine*, 1960, *31*:678–680, esp. p. 678.

[16] Mangus and Larsen, "Lunar Receiving Laboratory Project History," p. 6; and National Research Council, *Conference on Potential Hazards of Back Contamination from the Planets* (Washington, D.C.: National Academies Press, 1964), p. 1.

All that could be done was to "protect the earth from *immediate* infection" by quarantining everything returned to Earth from an extraterrestrial environment until some "specific, effective weapon," such as a vaccine, could be developed.[17]

Conference representatives agreed that subsurface organisms from the Moon could also travel to Earth in the bodies of astronauts. Even if astronauts stayed healthy during the three-day journey home, they might still harbor dangerous alien organisms that could sicken them over longer intervals, infect other people, or contaminate plants and animals. Conferencegoers decided that returning astronauts needed to stay within their spacecraft until it could be sealed behind an impermeable "biological barrier." After exiting the spacecraft, the astronauts then had to be quarantined behind that barrier for at least three weeks. Any samples they had recovered needed to join them in quarantine and be introduced to plants and animals that were then monitored for signs of disease. Conference attendees stressed that the success of the whole effort depended on the weakest link in a quarantine chain that stretched from the Moon to Earth.[18]

The 1964 conference helped ensure that the threat of back contamination had the attention of both the congressional representatives who controlled NASA's budget and the regulators who could complicate or prohibit the return of astronauts to the United States. NASA's Office of Space Science and Applications (OSSA) quickly assembled an "ad hoc committee" composed of representatives from across the federal government. The committee was charged with developing a shared vision for a facility that could protect Moon rocks from terrestrial contamination as geoscientists studied them while also protecting the Earth from anything that had been exposed to the lunar surface. Yet meetings devolved into arguments over the scope of the committee's authority, the location of the planned facility, and even the very need for protection against back contamination, all of which were secretly reported to officials at the PHS. As the committee's deliberations dragged on, NASA administrators decided that the PHS should be responsible for designing and enforcing protective measures against back contamination. James Goddard, Director of the Centers for Disease Control and Prevention (CDC), and William Lovelace, NASA's Director of Space Medicine, agreed that the new facility should be located far from most Americans, preferably on an island where an accidental release of lunar microorganisms could not immediately endanger the public. Yet in March the priority now given to back contamination led the committee to propose a quarantine facility in Houston, at the Manned Spacecraft Center (MSC; now the Johnson Space Center), where isolated astronauts could stay on-location to help plan future missions.[19]

On 31 July four senior NASA representatives—including Hugh Dryden, the agency's deputy administrator—convened with four representatives from the PHS, led by Goddard and Allen Pond, the assistant Surgeon General. Both parties agreed that the PHS was responsible for "any potential threat" to the health of the nation "from extraterrestrial life, particularly from back contamination." The Department of Agriculture and the Fish and Wildlife Service, they acknowledged, had similar responsibilities for America's crops and animals but would likely go along with the decisions of the PHS. NASA's representatives managed to convince their counterparts that the new facility could be located in the continental United States, rather than at some "isolated forward receiving station."[20]

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[17] National Research Council, *Conference on Potential Hazards of Back Contamination from the Planets*, p. 5 (the italicized word was underlined in the NRC report).

[18] *Ibid.*, p. 8.

[19] NASA, "Integrated Quarantine Operations Plan," NASA MSC, 15 May 1969, NASA HQ Archives, Washington, D.C. (hereafter **NASA HQ Archives**); Lawrence Hall, "Primary Barrier for Lunar Quarantine," Back Contamination and Quarantine, Apollo 076-11, HIS 23837, JSC Archives; and Mangus and Larsen, "Lunar Receiving Laboratory Project History," p. 13.

[20] Orr Reynolds, "Summary of Meeting between Representatives of the National Aeronautics and Space Administration and the Public Health Service, July 31, 1965," Back Contamination and Quarantine, Apollo 076-11, HIS 25063, JSC Archives; and Degroot, "Lunar Pandemic."

Roughly two months later, representatives of the MSC, the PHS, and the Department of Agriculture met in Houston for an informal conference on back contamination. After everyone agreed that Apollo astronauts would be exposed to lunar contaminants, Goddard expressed astonishment that the MSC had developed no plans to isolate the astronauts as soon as they returned to Earth—before they entered a quarantine facility. This prompted a "very extended and somewhat heated discussion" in which an MSC representative directly asked whether the PHS would allow Apollo astronauts to enter the continental United States if they were treated in the same way as Gemini astronauts who had only orbited the Earth. According to Lawrence Hall, the Planetary Quarantine Officer at OSSA, "the Public Health Service representative of the Division of Foreign Quarantine emphatically replied that they would refuse such entry."[21]

By October 1965, it had dawned on managers at MSC and NASA Headquarters that senior officials in regulatory agencies feared "viable lunar surface organisms." The success of the entire Apollo program now seemed to depend on isolating everything that had been on the Moon as soon as it reached Earth and then quarantining it within a secure facility.[22] NASA officials looked to the Army biological research facilities at Fort Detrick, the Naval Biological Laboratories in Washington, D.C., and the Public Health Service laboratories in Atlanta for examples, but nothing like the facility they needed had ever been imagined, let alone built. That October, the Technical Working Committee for the Design of the Lunar Sample Receiving Laboratory submitted plans to NASA Headquarters for a mammoth, 86,000-square-foot complex that would cost nearly $75 million to build, nearly $60 million to equip, and over $13 million annually to operate.[23]

The complex, later named the Lunar Receiving Laboratory, ultimately consisted of three parts, each with a different function. The Crew Reception Area in the southwest corner of the facility isolated astronauts, spacecraft, and any personnel exposed to lunar contaminants behind a biological barrier. The Sample Operations Laboratory in the northwest corner included a biotesting wing where technicians exposed individual cells and over a hundred organisms to crushed lunar rocks behind a separate biological barrier. The entire eastern half of the facility encompassed a Support and Administrative Area, housing offices and laboratories that posed no risk of back contamination. All three sections of the LRL were surrounded by a third barrier: the sealed perimeter of the complex (see Figure 1).[24]

That November, Surgeon General William Stewart called for the creation of a new Interagency Advisory Committee on Back Contamination (ICBC) to oversee NASA's efforts to prevent back contamination directly. NASA administrators agreed, and in March 1966 the committee included three representatives from PHS (two from CDC), eight from NASA (four from MSC), and two each from NAS, the Department of Agriculture, and the Department of the Interior. Since the PHS representatives included the director and assistant director of the CDC, they had outsized influence. In theory, they would establish the procedures that NASA had to follow to protect the Earth.[25]

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[21] Lawrence Hall, "Informal Conference on Back Contamination Problem," Back Contamination and Quarantine, Apollo 076-11, HIS 25726, JSC Archives.

[22] Owen Maynard, "Earth Contamination from Lunar Surface Organisms," Back Contamination and Quarantine, Apollo 076-11, HIS 25830, JSC Archives.

[23] Carter, "Moon Rocks and Moon Germs," p. 239; Mangus and Larsen, "Lunar Receiving Laboratory Project History," p. 7; and *Eighteenth Semiannual Report to Congress: July 1–December 31, 1967* (Washington, D.C.: NASA, 1968), https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19690006381.pdf, p. 42.

[24] James C. McLane *et al.*, "Lunar Receiving Laboratory," *Science*, 1967, *155*(3762):525–529, esp. p. 525; "Apollo 11 Recovery and Quarantine News Briefing, June 16, 1969," Washington, D.C., Col. John E. Pickering, USAF, Director, Lunar Receiving Operations, Office of Manned Space Flight, NASA HQ Archives; "Lunar Receiving Laboratory, MSC Building 37, Facility Description, Preliminary," NASA MSC, 9 Dec. 1966, NASA HQ Archives.

[25] G. Biggs Phillips was PHS liaison to MSC; here he is included within PHS. See J. H. Allton, J. R. Bagby, Jr., and P. D. Stabekis, "Lessons Learned during Apollo Lunar Sample Quarantine and Sample Curation," *Advances in Space Research*,

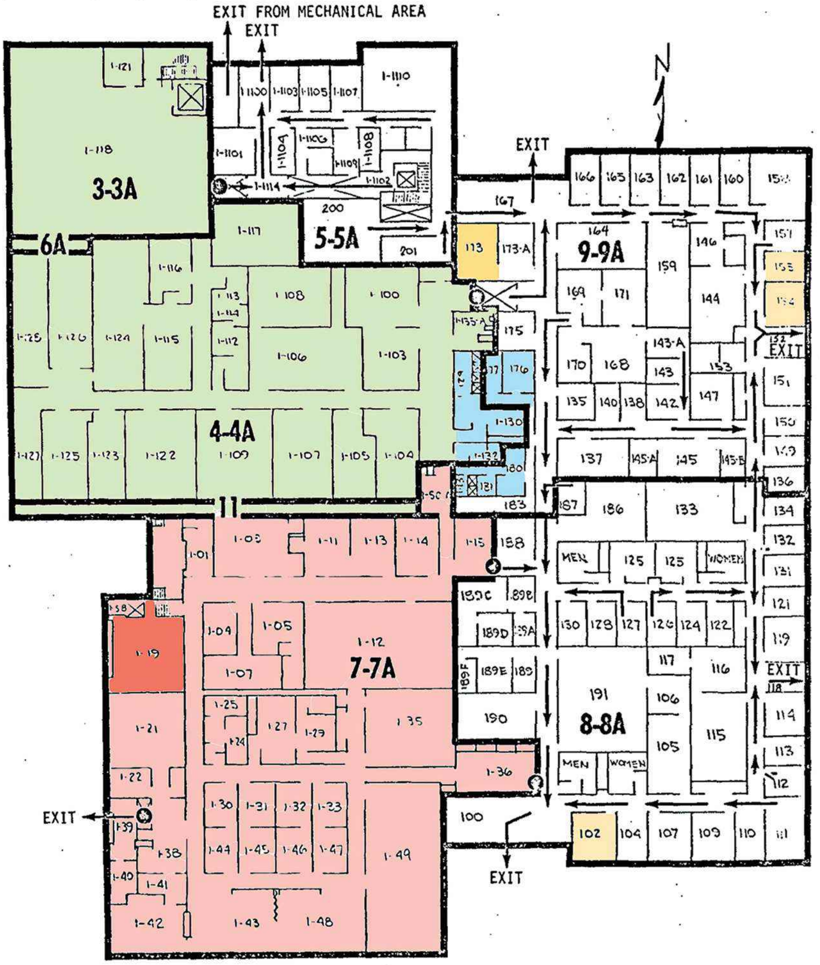

Figure 1. An exit plan of the completed LRL (up is north). The Crew Reception Area (red, with the room housing the command module in darker red) and the Sample Operations Laboratory (green, for biological and chemical testing facilities featured in this essay) were both surrounded by separate biological barriers. The changing rooms are shaded blue; the offices for the six quarantine officers are yellow (darker yellow for the Central Status Station). Source: "Handout for Biological Safety Training in the LRL (Lunar Receiving Laboratory)," 31 Oct. 1969, Apollo 076-26, HIS 39905, Johnson Space Center History Collection, University Archives, Neumann Library, University of Houston–Clear Lake, Houston.

At last, NASA was ready to ask Congress for the money required to build the LRL. With costs soaring for both the Vietnam War and the Johnson administration's War on Poverty, NASA's

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1998, 22:373–382, esp. p. 374; Carter, "Moon Rocks and Moon Germs," p. 239; Mangus and Larsen, "Lunar Receiving Laboratory Project History," p. 16; Meltzer, *When Biospheres Collide* (cit. n. 2), p. 139; and Maynard, "Earth Contamination from Lunar Surface Organisms" (cit. n. 22). From the JSC Archives see "Role of USPHS (United States Public Health Service) in Return of Men and Materials from the Moon," Back Contamination and Quarantine, Apollo 076-11, HIS 26264; "Agenda NASA–PHS (United States Public Health Service) meeting Nov 12," Back Contamination and Quarantine, Apollo 076-11, HIS 25961; "Proposed Letter from NASA to USPHS (United States Public Health Service)," Lunar Receiving Center, Apollo 076-11, HIS 25871; "Proposal from the Public Health Service to NASA," Back Contamination and Quarantine, Apollo 076-11, budget was poised to plummet in 1967. Congressional representatives questioned whether a facility that NASA officials had never mentioned before deserved urgent and substantial funding. Yet in response to every concern George Mueller, NASA's Associate Administrator for Manned Spaceflight, reminded Congress that the PHS had deemed the facility essential for protecting American health and agriculture. The threat of back contamination had become the major rationale for the new laboratory, and it was PHS recognition of this threat that won over Congress. The House Science and Astronautics Committee approved funding for the LRL—at nearly $8 million below NASA's original asking price.[26]

BUILDING AND TESTING THE LRL

Congress, however, delayed final approval for the LRL until August 1966. With time running out before the first planned Moon landing, the design for the LRL had to be finalized as the facility was built. Yet the design depended on the primary purpose of the LRL, and this remained a matter of bitter debate—despite NASA's assurances to Congress. Geoscientists and bioscientists, for example, argued over whether the facility's air pressure should be high (to push terrestrial contaminants outside, away from lunar samples) or low (to keep lunar contaminants inside). To the consternation of chemists, geologists, and physicists, the biologists prevailed. In late 1966, however, PHS bioscientist and ICBC representative G. Briggs Phillips, a leading authority on microbial containment, confided to his ICBC colleagues that the MSC was still not prioritizing biological or medical science. Indeed, while NASA officials agreed during a meeting at the CDC that the LRL's primary purpose was to protect against back contamination, senior NASA administrators privately admitted that quarantine was just one of the facility's functions—and only "initially."[27]

In August 1967, MSC Director Robert Gilruth assigned management of the LRL to a physicist, Persa Bell, who focused on preparations for radiological testing of lunar samples. Gilruth also gave Charles Berry, MSC Director of Medical Research and Operations, total authority over all biological aspects of the LRL, and Berry in turn granted Walter Kemmerer, chief of the facility's Biomedical Specialties Branch, day-to-day control over its back-contamination efforts. In that role, Kemmerer reported not only to NASA but also to the ICBC and the PHS, an independent power base that granted him and the bioscience community outsized clout within LRL. It was a recipe for infighting.[28]

Nevertheless, the LRL was built in only eleven months, leaving sixteen months to equip, staff, test, and certify the complex. From the start, that effort too was embroiled in controversy. The ICBC had designed its contamination safeguards around what Berry called "one of the nastiest earthly organisms known to man": *Yersinia pestis*, the pathogenic bacterium responsible for the bubonic plague. It was a superficially impressive but ill-conceived choice. Even work with infectious clinical cultures of *Y. pestis* currently requires researchers to adhere to only the second of four "biosafety level" (BSL) procedures. Yet the PHS clearly intended the LRL to function as a BSL-4

HIS 24098; and "Statutory Authority for Planetary Quarantine on the Part of the Public Health Service Dept (Department) of Agriculture Dept of Interior and NASA," Back Contamination and Quarantine, Apollo 076-11, HIS 14098.

[26] Mangus and Larsen, "Lunar Receiving Laboratory Project History," p. 20; Carter, "Moon Rocks and Moon Germs," p. 240; and Committee on Aeronautical and Space Sciences, United States Senate, *Hearings on S. 2909, NASA Authorization for Fiscal Year 1967*, 89th Cong., 2nd sess. (Washington, D.C.: U.S. Government Printing Office, 1966), p. 139.

[27] G. Briggs Phillips, "Quarantine Personnel Needed for the LRL (Lunar Receiving Laboratory)," Back Contamination and Quarantine, Apollo 076-14, HIS 28561, JSC Archives; George Mueller, "LRL (Lunar Receiving Laboratory) Certification Testing of Containment and Operational Capability," Apollo 076-15, HIS 30075, JSC Archives; Phillips and Joseph V. Jemski, *Microbiological Safety Bibliography* (Frederick, Md.: Army Biological Labs, 1965); and Carter, "Moon Rocks and Moon Germs," p. 236.

[28] Mangus and Larsen, "Lunar Receiving Laboratory Project History," p. 31; and Allton *et al.*, "Lessons Learned during Apollo Lunar Sample Quarantine and Sample Curation" (cit. n. 25), p. 375.

facility.[29] *Y. pestis* is also a complex bacterium, sensitive to environmental conditions and adapted to a specific organism: *Xenopsylla cheopis*, the tropical rat flea. The obvious absence of complex life on the Moon meant that any lunar pathogen would have radically different sensitivities and proclivities. *Y. pestis*, moreover, spreads zoonotically from fleas to humans—precisely the kind of transmission that bioscientists did not anticipate for lunar microorganisms. Only when a bubonic plague victim develops secondary pneumonic plague can transmission occur by aerosols, which is how scientists assumed that lunar pathogens were most likely to enter the bodies of astronauts. Nor does *Y. pestis* generate bacterial spores, protective layers around DNA that allow some bacteria to endure extreme environmental conditions. Yet the OSSA's Planetary Quarantine Officer, Lawrence Hall, understood that such spores presented the most realistic threat from the Moon, since they could best survive the harsh lunar surface.[30]

In early 1968, the chemist John Hodge therefore suggested using a different, live pathogen to test the LRL: *Coxiella burnetii*, the tiny bacterium that causes Q fever in humans. *C. burnetti* forms spores, is highly infectious, and spreads easily through aerosol transmission. Hodge understood that the deadliness of the pathogen used to prepare the LRL was ultimately irrelevant. What mattered was how easily the pathogen could endure conditions reminiscent of the lunar surface and how readily it could breach containment.[31]

Senior MSC managers were aghast. A test using *C. burnetti* would motivate a concerted effort to prepare the LRL for a lunar pathogen—but at the risk of sickening thousands of NASA employees on the eve of the first lunar landing. In May, Gilruth used Hodge's proposal to argue that the ICBC should propose policy but not actually oversee its implementation, which should be left to MSC professionals who better understood the facts on the ground. As Gilruth no doubt understood, this distinction had the potential to severely limit the ICBC's oversight of NASA's quarantine program. It was now clear that whereas Hodge and other bioscientists joined regulatory agencies in prioritizing the unlikely but potentially catastrophic threat to Earth's biosphere, many NASA managers and engineers were more concerned with likelier—but potentially less calamitous—threats to the progress of the Apollo program. By June, a meeting at the MSC concluded that LRL testing would use harmless "biological analogs" rather than "hazardous substances."[32]

Nobody had worked out a process for testing and certifying the LRL, however—in fact, MSC officials sometimes had difficulty even contacting ICBC members—and with only a year left before the planned takeoff of *Apollo 11* the process of installing equipment was months behind schedule. The LRL was in a "continuing state of flux" throughout 1968, as a team of thirteen engineers struggled to implement countless last-minute modifications. Meanwhile, dysfunction persisted at the highest levels. In July, for example, Berry sent an irate memo to senior MSC managers to excoriate the "totally unacceptable" restraints MSC Science and Applications Director Wilmot Hess had attempted to impose on the use of Class III biological agents in the LRL. By August, it was clear that a first round of testing, scheduled for October, could not be completed owing to persistent

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[29] Duff, "Great Lunar Quarantine," p. 39. Berry publicly acknowledged that the LRL adhered to more stringent procedures than were used to contain bubonic plague: "Lunar Microbe Hunters," *Newsweek*, 16 June 1969.

[30] Duff, "Great Lunar Quarantine," p. 39; Robert D. Perry and Jacqueline D. Fetherston, "Yersinia pestis—Etiologic Agent of Plague," *Clinical Microbiological Reviews*, 1977, *10*:35–66, esp. pp. 37, 54; "Biosafety Levels," U.S. Department of Health and Human Services, https://www.phe.gov/s3/BioriskManagement/biosafety/Pages/Biosafety-Levels.aspx; and "Purchase of Reference Material for Use by the Planetary Quarantine Program," 17 Aug. 1966, NASA HQ Archives.

[31] Carter, "Moon Rocks and Moon Germs," p. 247; and Thomas J. Marrie and Didier Raoult, "Coxiella burnetii (Q Fever)," in *Mandell, Douglas, and Bennett's Principles and Practice of Infectious Diseases*, 9th ed. (Philadelphia: Elsevier, 2019), p. 260.

[32] Wilmot Hess, "Initiation of Monthly Review Meetings on LRL (Lunar Receiving Laboratory)," Apollo 076-11, HIS 33278; G. S. Trimble, "Relations between Groups Involved in LRL (Lunar Receiving Laboratory) Operation," Apollo 076-21, HIS 33491; and "Minutes of the Monthly LRL (Lunar Receiving Laboratory) Review," Apollo 076-21, HIS 33721: JSC Archives.

problems in the autoclave systems needed to heat and thereby sterilize materials passing through the facility's biological barriers. Nevertheless, "every effort will be made to shorten the length of tests and to reduce the time required of each participant," Hess promised.[33]

Far from the rubber stamp Hess appears to have expected, the tests were a disaster. In October, a Preliminary Examination Team uncovered no fewer than eighty-two problems in the LRL. The most serious involved the vacuum chamber in the Lunar Sample Laboratory, where glove boxes—sealed "biocabinets" with supposedly impermeable gloves—in theory allowed technicians to manipulate Moon rocks safely in conditions that resembled the near-vacuum of the lunar surface. The gloves, however, cracked and leaked when exposed to the pressure difference in the biocabinets. In December, Hodge led a new Operational Readiness Inspection Team that found some 140 deficiencies, which Hodge blamed on "sloppy management." NASA hurriedly identified military medical facilities that could, perhaps, be used for quarantine if the LRL was not certified in time. ICBC chair David Sencer warned that the MSC should concentrate its efforts on back contamination to prevent that possibility. Berry and then Gilruth requested emergency funding to build a 3,150-square-foot Biomedical Support Facility beside the LRL that would house many of the organisms that bioscientists planned to expose to Moon dust in the Sample Operations Laboratory. It went up at a breakneck pace.[34]

With time running out, Gilruth sidelined Bell and eventually appointed his chief lieutenant, Richard Johnston, to oversee preparations at the LRL. In February Richard Wieland, chief of NASA's legal branch, drafted legislation that allowed the agency's administrator to quarantine any organisms or materials that could harbor "germs, virus, or disease of any kind." Meanwhile, advisors from regulatory agencies joined George Mueller to test the LRL. This time, every laboratory in the facility suffered a containment failure. Every mouse died, "even without being intentionally infected with any pathogenic agent," according to Wolf Vishniac, who was now NAS representative to the ICBC, while "routine apparatus does not seem to work properly." Autoclaves, for example, regularly filled with water, and there seemed to be "no way of carrying out rapid minor emergency repairs." Air Force Colonel John Pickering, Director of Lunar Receiving Operations, reported that "our LRL is not yet ready." Not only was it "short of people," but the personnel it had "are not yet trained."[35]

In March and April, a thirty-day "full scale" simulation circulated mock lunar samples through the LRL and included tests for back contamination. With just months remaining before the first lunar landing, the results were alarming. In late March, a memo from Bell listed no fewer than

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[33] From the JSC Archives see Charles Berry, "Use of Class III Biological Agents in the LRL (Lunar Receiving Laboratory)," Apollo 076-21, HIS 34279; Wilmot Hess and Anthony Calio, "Preliminary Examination Team Simulation Tests and Full Scale LRL (Lunar Receiving Laboratory) Simulation," Apollo 076-21, HIS 34628 ("every effort"); "Minutes of Monthly LRL (Lunar Receiving Laboratory) Review, Sept 16," Apollo 076-22, HIS 34976; and "LRL (Lunar Receiving Laboratory) Operational Readiness Inspection Nov. 18," Apollo 076-22, HIS 35748. See also Mangus and Larsen, "Lunar Receiving Laboratory Project History," p. 28; "Plans on Handling Lunar Sample Stir Bitter Scientific Controversy," *Washington Post*, 3 Mar. 1969; and "Lunar Receiving Laboratory, MSC Building 37, Facility Description, September 1968," NASA MSC, NASA HQ Archives.

[34] "LRL (Lunar Receiving Laboratory) Equipment and System Problems," Apollo 076-22, HIS 35638, JSC Archives; "Request for Approval of Project #72-9056 LRL (Lunar Receiving Laboratory) Biomedical Support Facility," Apollo 076-22, HIS 35747, JSC Archives; and Meltzer, *When Biospheres Collide* (cit. n. 2), p. 186.

[35] "Proposed Legislation to Provide Statutory Basis for Restrictive Ingress and Egress to the LRL (Lunar Receiving Laboratory) and Other Purposes," Apollo 076-21, HIS 36720, JSC Archives ("germs, virus, or disease of any kind"); Wolf Vishniac to Fred Seitz, 5 Mar. 1969, NASA HQ Archives; John Pickering, "LRL (Lunar Receiving Laboratory) Bioprotocol Readiness Review and Certification Procedures," Back Contamination and Quarantine, Apollo 076-23, HIS 36891, JSC Archives; Howard Eckles, "Dept (Department) of Interior Observations on the LRL (Lunar Receiving Laboratory) Procedures Relative to Invertebrate and Fish Species Feb 12-14," Back Contamination and Quarantine, Apollo 076-24, HIS 37092, JSC Archives; and Meltzer, *When Biospheres Collide*, p. 187.

thirteen problems that urgently needed fixing "if Laboratory operations are to fulfill major mission needs," including—once again—finding and correcting "autoclave flooding trouble." Days later, Sencer warned NASA Administrator Thomas Paine that regulatory agencies could not certify the LRL as a "biologically-safe containment system" unless "drastic changes are made." These changes included fixing the malfunctioning autoclaves and designing "emergency or disaster procedures" that had a "fall-back position for abnormal and catastrophic events." Tellingly, NASA had not yet planned for these contingencies. MSC officials asked NASA Headquarters for over $15 million to cover cost overruns associated with unexpected testing—they received approximately half as much—and scrambled to develop plans for quarantining and then sustaining all personnel within the LRL in the event of a catastrophic containment failure. Nevertheless, Sencer worried that LRL staff saw quarantining procedures as nothing more than "an imposed operation to be done the easiest way possible while hoping that it would go away."[36]

In late May, G. Briggs Phillips led a team that inspected the LRL according to the "most stringent biological containment requirements of the U.S. Army biological laboratories" at Fort Detrick. If the team suggested any last-minute changes, NASA promised to make those changes and certify that they had been made. ICBC representatives who belonged to the government's regulatory agencies would then sign the certification—without checking to see whether the changes had actually been implemented. During the inspection, the team was surprised to find that the autoclaves were still not steam-certified. Team member Louis Locke of the Department of the Interior Fish and Wildlife Service warned Richard Johnston that the "failure to have these autoclaves fully operational by the time the Lunar Samples are returned would nullify the entire project." He worried that with *Apollo 11* just weeks away the team had not had time to conduct "an on-site investigation during a full-scale Mission Simulation." Now, he could "only hope that we gave the LRL a thorough evaluation." After the team submitted their report, LRL personnel struggled to implement its changes and simulate containment faults. While they coped with several equipment failures, it was only on 23 July that major problems reemerged. "Liquid effluent" spilled into the Sample Operations Laboratory, owing to a "pressure problem," while the autoclave in the men's change room stopped working and needed lengthy repairs. Nevertheless, on the following day ICBC representatives signed the last of NASA's certifications, and the *Apollo 11* capsule splashed down in the Pacific Ocean.[37]

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[36] Mangus and Larsen, "Lunar Receiving Laboratory Project History," p. 47 ("imposed operation"); Baylor University College of Medicine, "Comprehensive Biological Protocol for the Lunar Sample Receiving Laboratory," p. iii; and Meltzer, *When Biospheres Collide*, p. 194. From the JSC Archives see Persa Bell, "Problems Identified in Feb and Mar LRL (Lunar Receiving Laboratory) Simulations," Apollo 076-24, HIS 37265; David Sencer, "LRL (Lunar Receiving Laboratory) can not be certified by the regulatory agencies unless drastic changes are made in priority of activities and operations of the laboratory," Apollo 076-24, HIS 37372; "LRL (Lunar Receiving Laboratory) Simulation Mar–Apr 1969," Apollo 076-24, HIS 37662; "Emergency Delivery of Foods to LRL (Lunar Receiving Laboratory) in Event of Quarantine," Apollo 076-24, HIS 38000; and "Request for Additional FY 1969 (Fiscal Year 1969) Funding," reimbursement for cost overruns associated with achievement of LRL (Lunar Receiving Laboratory) readiness, Apollo 076-24, HIS 37681.

[37] Carter, "Moon Rocks and Moon Germs," p. 247; "Lunar Receiving Laboratory, MSC Building 37, Facility Description," NASA MSC, Mar. 1969, NASA HQ Archives; and NASA, "Integrated Quarantine Operations Plan" (cit. n. 19). From the JSC Archives see John E. Pickering, "Standards for Certification of LRL (Lunar Receiving Laboratory)," Apollo 076-15, HIS 29425; "Minutes of Monthly LRL (Lunar Receiving Laboratory) Review July 1," Apollo 076-21, HIS 33981; Louis Locke, "Recent Visit to LRL (Lunar Receiving Laboratory) on Behalf of the ICBC (Interagency Committee on Back Contamination)," Apollo 076-24, HIS 38076 (autoclaves, "nullify the entire project," "thorough evaluation"); "LRL (Lunar Receiving Laboratory) Daily Summary Report #1, June 10," Apollo 076-24, HIS 38187; "LRL (Lunar Receiving Laboratory) Daily Report #2, June 11," Apollo 076-24, HIS 38204; "LRL (Lunar Receiving Laboratory) Daily Report #4," Apollo 076-24, HIS 38242; "LRL (Lunar Receiving Laboratory) Daily Summary Report #5," Apollo 076-24, HIS 38247; "June 17 LRL (Lunar Receiving Laboratory) Staff Meeting Action Items," Apollo 076-24, HIS 38297; and "LRL (Lunar Receiving Laboratory) Activities Report July 22–23," Apollo 076-25, HIS 38811.

PANDEMICS, THE PUBLIC, AND GAPS IN THE QUARANTINE CHAIN

Until 1968, journalists and in turn the public largely ignored NASA's efforts to prevent back contamination. Yet in summer 1968, the arrival in Hong Kong of a novel influenza virus, H3N2, spurred widespread concern. The spread of the virus created a pandemic that, by February 1969, had killed tens of thousands of Americans. For NASA, it provided another reason to quarantine Apollo astronauts. "We don't want someone coming down with Asian Flu [*sic*] two weeks after he returns," an agency official confided to *Newsweek* just before the *Apollo 11* mission, "and starting a moon plague panic."[38] Indeed, in October 1968 the already cantankerous crew of *Apollo 7* contracted painful head colds while in orbit around Earth. In December 1968, during the first crewed flight to the Moon, *Apollo 8* astronauts all suffered from what NASA doctors called a "celestial illness": an intestinal virus that made headlines when NASA only belatedly revealed it to the press. The *Apollo 11* crew was therefore kept in semi-isolation for three weeks before liftoff. "If they caught something preflight," Charles Berry mused, "we would spend forever trying to convince everybody [after the mission] that this was not some lunar organism."[39]

As a real pandemic swept through America, popular attention turned to the possibility of a contagion with a more distant origin. A series of articles on the Lunar Receiving Laboratory and the threat of a lunar plague now appeared in America's major newspapers and magazines. On 2 November, for example, a glossy feature in the *Saturday Evening Post* mentioned the risk that "if moon life does exist . . . it could be hostile to earth life, and . . . so different from anything on earth that neither plant, animal, nor human life would have any resistance against it." On 29 December 1968—two days after *Apollo 8* returned to Earth—*Time* reported "nagging fear" at NASA "that alien organisms might hitch a ride aboard the [*Apollo 11*] spacecraft, in the bodies of the astronauts or in moon rocks that they will carry back." The result could be a "catastrophic plague on earth."[40]

Popular science fiction had long explored the possibility of contamination from space—for example, in the BBC's 1953 broadcast of *The Quatermass Experiment*. Yet what really focused public attention on the threat of back contamination was the publication, just months before *Apollo 11*, of Michael Crichton's *The Andromeda Strain*. In the book, a biophysicist proposes that the Moon might harbor microbial life and is widely ridiculed by other scientists. Nevertheless, the Department of Defense uses the construction of the LRL to justify building its own facility for a program, "Wildfire," capable of containing alien pathogens introduced to Earth.[41] Crichton connected the risk of back contamination to that of forward contamination; one of his characters fears that Earth organisms on inadequately sterilized spacecraft could mutate in space and come back "different."

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[38] "Lunar Microbe Hunters," *Newsweek*, 16 June 1969. That official confused the so-called Asian Flu of 1957 (H2N2) with the Hong Kong Flu (H2N3) of 1968–1970. Both names had and have racist connotations. See Patrick R. Saunders-Hastings and Daniel Krewski, "Reviewing the History of Pandemic Influenza: Understanding Patterns of Emergence and Transmission," *Pathogens*, 2016, 5(4):66. For more on the pandemic see also Edwin D. Kilbourne, "Influenza Pandemics of the Twentieth Century," *Emerging Infectious Diseases*, 2006, *12*:9–14, esp. p. 12.

[39] "Lunar Microbe Hunters"; "Flu Perils Apollo's Orbits of the Moon," *Chicago Tribune*, 23 Dec. 1968; Marvin Miles, "Apollo 8 Crew Fights Off Flu," *Los Angeles Times*, 23 Dec. 1968; Duff, "Great Lunar Quarantine," pp. 40 (quoting Berry), 41; Cécile Viboud, Rebecca F. Grais, Bernard A. P. Lafont, Mark A. Miller, and Lone Simonsen, "Multinational Impact of the 1968 Hong Kong Influenza Pandemic: Evidence for a Smoldering Pandemic," *Journal of Infectious Diseases*, 2005, *192*:233–248, esp. p. 234; and A. Strickland, "Rigid Quarantine Awaits Apollo 11 Return," *Aviation Week and Space Technology*, 7 July 1969, p. 18.

[40] James Atwater, "Welcome Home from the Moon!" *Saturday Evening Post*, 2 Nov. 1968; and "Quarantine for Moon Travelers," *Time*, 29 Dec. 1967.

[41] Peter Hutchings, "1945–55: From *Dead of Night* to *The Quatermass Experiment*," in *Hammer and Beyond*, ed. Johnny Walker (Manchester: Manchester Univ. Press, 2021), pp. 55–88, esp. p. 55; and Michael Crichton, *The Andromeda Strain* (1969; New York: Vintage, 2017). Crichton referenced A. Morley *et al.*, "Preliminary Criteria for a Lunar Receiving Laboratory," NASA *Field Reports*, No. 7703A.

In any case, a meteoroid harboring an alien organism triggers the Wildfire Protocol by contaminating a satellite, which in turn crashes into and infects an American town. In the end, a crack team just barely manages to contain the organism within the Wildfire facility.[42]

The Andromeda Strain rocketed up the *New York Times* bestseller list and inspired another wave of articles in American periodicals. "It has a certain basis in fact," *Time* concluded, since "an everyday childhood disease like measles has caused devastating epidemics when spread by Westerners to the inhabitants of Pacific islands never before exposed to the rubeola virus." Could Americans suffer the same fate? The effect of *The Andromeda Strain*, Berry remembered, "was horrible." It inspired "all kinds of furor and . . . thousands of letters which we had to answer." NASA had meticulously cultivated its image in popular media, and now the agency's administrators felt compelled to arrange a press conference. In June 1969 John Pickering—who weeks earlier had fretted that "we, in all likelihood, are going to try to do things beyond our capability" at the LRL—confidently assured the media that NASA had partnered with the ICBC to develop "facilities and procedures" that were "well beyond the current state-of-the-art," with capabilities that "have never previously existed" and "exhaustive test programs . . . unparalleled in scope and complexity."[43]

In fact, confusion persisted in the U.S. government over the ICBC's exact purpose and authority. By now, key managers at MSC and NASA Headquarters assumed that the committee existed only to inspect the LRL and offer broad recommendations. ICBC representatives who were not also in the agency, however, insisted that they needed to approve every aspect of the Apollo program that posed a risk of back contamination. After more than a year of negotiation, the two sides settled on an uneven compromise. The ICBC would not take action that affected the lunar program without the unanimous consent of its members (which included NASA employees), while NASA would approach the ICBC before undertaking actions that risked contamination—unless it considered those actions necessary to protect its astronauts and spacecraft. The agreement seemed to establish that the ICBC was little more than an advisory body, as Gilruth had intended. Yet participating agencies retained their regulatory powers under federal law, so NASA could not completely ignore them.[44]

In the months before the launch of *Apollo 11*, this tense and uncertain arrangement broke down, jeopardizing the first Moon landing. Since 1965, NASA and the PHS had agreed that the LRL was only the most visible component of a broader quarantine protocol that extended all the way from the Moon to Houston. The interior of the command module, the capsule that returned Apollo astronauts to Earth, needed to be sealed as soon as it encountered Earth's atmosphere and until it was behind quarantine at the LRL (see Figure 2). In a "sensitive" memo from 1965, Owen Maynard, chief of the System Engineering Division at the Apollo Spacecraft Program Office, confided to his subordinates that this requirement posed an enormous problem, for "the spacecraft has not been designed to preclude . . . environmental exposure," and "in fact, opening the cabin environment to the earth's atmosphere, allowing waste water tanks to burst on impact, transferring the crew to life rafts, and helicopter rescue of the crew have been assumed to be a part of the standard operation procedures." Yet because the command module would likely be contaminated with lunar organisms "capable of multiplying in the earth environment,"

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[42] Crichton, *Andromeda Strain*, pp. 41, 48, 133; and Degroot, "Lunar Pandemic."

[43] "Defenseless?" *Time*, 4 Aug. 1965; Duff, "Great Lunar Quarantine," p. 39 (quoting Berry); "Apollo 11 Recovery and Quarantine News Briefing, June 16, 1969" (cit. n. 24); "Apollo 11 Mission Director's Briefing for News Media, 16 June 1969," NASA HQ Archives; and Pickering, "LRL (Lunar Receiving Laboratory) Bioprotocol Readiness Review" (cit. n. 35).

[44] Carter, "Moon Rocks and Moon Germs," p. 242; and Allton *et al.*, "Lessons Learned during Apollo Lunar Sample Quarantine and Sample Curation" (cit. n. 25), p. 374.

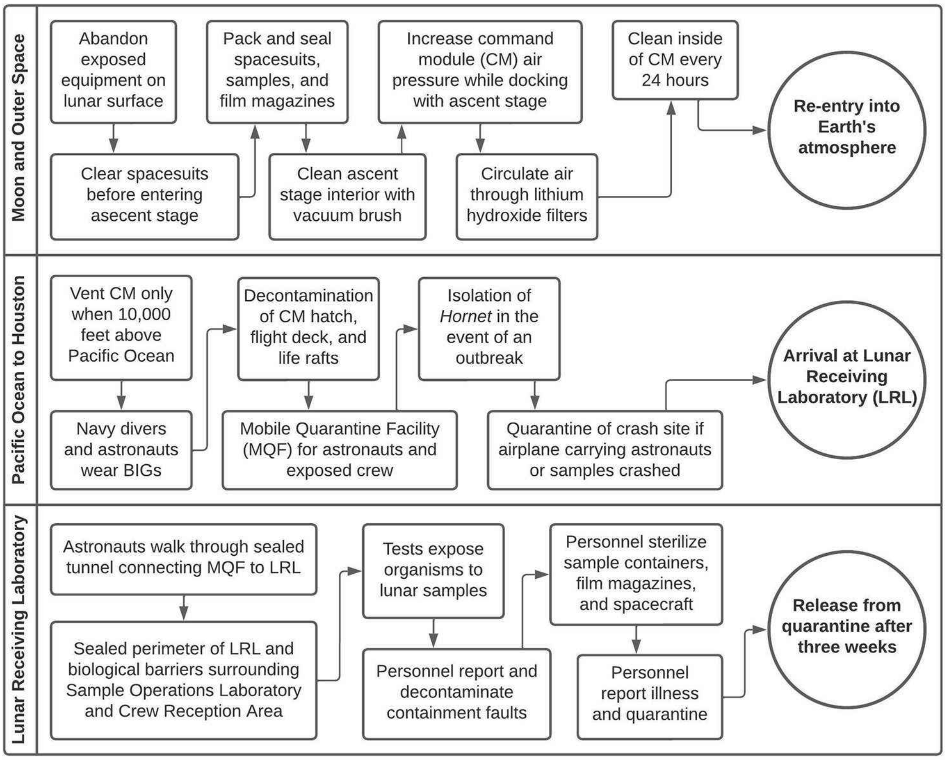

Figure 2. The *Apollo 11* quarantine protocol, showing the steps taken by the federal government to avoid back contamination from the Moon. Author's rendering.

Maynard emphasized, NASA engineers were "morally obligated to prevent any possible contamination of the earth." Maynard was clear: "rather than assume the standard answer that no changes can be made within present weight, cost and schedule limitations," his engineers had to review every subsystem in the command module so no "components can be exposed to earth's atmosphere following reentry."[45]

Yet when the ICBC first met, NASA was planning to ventilate the command module as it touched down in the Pacific Ocean. "Venting" lowered the risk of overheating and carbon dioxide poisoning within the module. It also greatly increased the odds that any lunar organisms onboard would escape, so the ICBC instructed NASA to investigate whether it could install biological filters in the air vents. NASA engineers determined that these filters were too heavy and needed more power than the command module could provide. According to Vishniac, the ICBC and NASA worked out a compromise whereby Navy divers would hastily install powered filters over the command module vents just after splashdown. Only then would the astronauts vent their capsule.[46]

On 13 February 1969, however, NASA informed the ICBC that it had not worked out any such procedure and that the command module would be vented according to the original plans. PHS and Department of Agriculture representatives were not overly concerned, but Howard Eckles, program manager of Marine Resources Development at the Department of the Interior, feared that

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[45] Maynard, "Earth Contamination from Lunar Surface Organisms" (cit. n. 22).

[46] Carter, "Moon Rocks and Moon Germs," p. 247; and Degroot, "Lunar Pandemic."

the ocean environment would be contaminated. Vishniac sent a letter to Frederick Seitz, President of the NAS. “My own reaction is based entirely on whether we consider back contamination a matter of concern or not,” he explained. Since “this question has been answered in the affirmative,” it was “irresponsible to leave a large breach in the biological barrier in any part of the recovery procedure.” The PHS and the Department of Agriculture should be more concerned, Vishniac concluded, since pathogenic organisms that entered the ocean could also “spread to land and become . . . a very great concern.”[47]

Seitz would later become an outspoken denier of global warming, yet in 1969 he took the less likely threat of back contamination seriously. After receiving Vishniac’s letter, he forwarded it to NASA’s new Administrator, Thomas Paine, and attached a note that suggested a meeting between Vishniac and a NASA representative—perhaps Paine himself. Paine responded one month later, writing that he had also received a letter from ICBC Chairman Sencer and that the Apollo Program Office would work to develop “a satisfactory solution.” It was now just three months before the first Moon landing.[48]

In the meantime, another possible containment breach troubled the ICBC. The committee had pressed NASA to keep the command module sealed until it could be hoisted by crane aboard a waiting aircraft carrier. An impervious tunnel would then be hastily installed between the command module and the Mobile Quarantine Facility (MQF), a travel trailer sealed by a biological barrier (see Figure 2). Yet MSC Director of Flight Crew Operations Deke Slayton remembered that in 1961 the *Mercury-Redstone 4* capsule had flooded right after splashdown and that astronaut Gus Grissom had only narrowly escaped. If the command module suffered a similar fate, the *Apollo 11* astronauts had to be able to evacuate. Moreover, NASA and Navy officials concluded that the aircraft carrier charged with recovering the astronauts—the thirty-thousand-ton *USS* Hornet—could not pull up alongside the command module without swamping it. In fact, no “manrated” crane existed on any carrier, and even if it did such a crane could not lift the capsule without damaging the carrier’s deck plates. Only a helicopter could lift the command module onto the carrier—and only if no astronauts were on board to add weight. The astronauts needed to disembark after splashdown, opening another breach in containment.[49]

“It is clear,” Vishniac wrote, that “the Apollo Program is moving at a pace which we cannot stop” and that “this irresistible progress is being used to brush aside the inconvenient restraints which the Interagency Committee has considered to be an essential part of the Quarantine Program.” ICBC representatives felt they had no option but to tap into rising popular fears of a lunar pandemic by approaching the press. In May—less than a week after the publication of *The Andromeda Strain*—a *New York Times* article warned that if NASA let its astronauts emerge from their capsule before entering quarantine, the world could face “the depredations of . . . extraterrestrial pathogens.” An article in the *Washington Post* explained that while the risk of back contamination was low, it had become a concern now that NASA planned to allow its astronauts to exit their capsule at sea.[50]

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[47] Vishniac to Seitz, 5 Mar. 1969 (cit. n. 35); and Eckles, “Dept (Department) of Interior Observations” (cit. n. 35).

[48] Seitz to T. O. Paine, 24 Mar. 1969; and Paine to Seitz, 25 Apr. 1969: NASA HQ Archives. Regarding global warming denial see Naomi Oreskes and Erik M. Conway, *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming* (New York: Bloomsbury, 2010), p. 5.

[49] J. R. Bagby, Jr., “Back Contamination: Lessons Learned during the Apollo Lunar Quarantine Program,” in *Contract #560226 Report* (Jet Propulsion Laboratory, California Institute of Technology, 1975); Allton *et al.*, “Lessons Learned during Apollo Lunar Sample Quarantine and Sample Curation” (cit. n. 25), p. 376; and William E. Burrows, *This New Ocean: The Story of the First Space Age* (New York: Modern Library, 2010), p. 407.

[50] Vishniac to Seitz, 5 Mar. 1969 (cit. n. 35); “Danger from the Moon,” *New York Times*, 18 May 1969; Victor Cohn, “Lunar Contamination: Growing Worry,” *Washington Post*, 28 May 1969; and Degroot, “Lunar Pandemic.”

In response to mounting pressure from federal regulators and the press, NASA officials hastened to appease the ICBC. New plans stipulated that the two astronauts who landed on the Moon—in the case of *Apollo 11*, Neil Armstrong and Buzz Aldrin—abandon any equipment that had been on the lunar surface that did not need to be returned to Earth. When climbing back into their lander, the lunar module, they had to brush and kick Moon dust off their spacesuits. After lifting off from the Moon in the module's ascent stage, they needed to pack their spacesuits, samples, and film magazines carefully into sealed storage bags, then use a vacuum brush to clean the inside of their spacecraft. Once they docked with the orbiting command and service modules, the astronaut who had remained in the command module—Michael Collins, during *Apollo 11*—had to engage a flow of oxygen to raise the command module's air pressure relative to the lunar module. Air would flow from the command to the lunar module, keeping possible contaminants within the latter. After the three astronauts crowded into the command module, undocked from the lunar module, and began their voyage back to Earth, they needed to vacuum and wipe the inside of their spacecraft every twenty-four hours. Meanwhile, the air they breathed would continually circulate through lithium hydroxide filters capable of trapping bacteria. Upon reentering Earth's atmosphere, the astronauts had to vent the command module while ten thousand feet above the Pacific. Navy divers would now wear Biological Isolation Garments (BIGs) while recovering the command module. They had to scrub the hatch and vent with a sterilizing "iodine preparation"—an acid—and then open the hatch before tossing in three BIGs. The astronauts would pull on the BIGs before exiting, and the divers would then close and again sterilize the hatch. Navy personnel were to use the acid to disinfect the divers, the flight deck, and the life rafts that had carried the astronauts to the *Hornet*. If an outbreak occurred aboard the ship, it would remain at sea for the entire quarantine period, and if any of the crew were exposed they had to isolate within a second MQF. To teach the astronauts the new procedures and why they mattered, Berry drafted twenty-two hours of last-minute instruction. Under pressure from Slayton, he shortened it to a four-hour lecture.[51]

Not all were convinced. Locke at Interior informed Johnson that he was "personally concerned about" the "extremely serious break in the idea of containment" in plans for the astronauts to exit their command module in the Pacific Ocean. "Should an astronaut fall into the water while making the transfer onto the raft," Locke argued, "he would effectively nullify some important quarantine procedures as far as the exposing of aquatic life is concerned." The ICBC approved the new procedures, however, and after it did NASA officials launched a public relations offensive. "All precautions are being taken," one press release assured readers, to prevent the "remote" chance of alien contamination. Sencer supported these efforts. "We pounded the table and we have gotten results," he assured the *New York Times*.[52]

Yet as Sencer no doubt knew, a small group of scientists, including Carl Sagan, had already flagged yet another weak point in the quarantine procedures. The MSC's Integrated Quarantine Operations Plan stipulated that if an astronaut suffered a medical emergency that could not be handled at the LRL, "the quarantine may be broken and the individual transported to the nearest appropriate medical facility." This meant that if a pathogen was dangerous enough to make an

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[51] NASA, "Integrated Quarantine Operations Plan" (cit. n. 19); "Spacecraft Quarantine and Release Plan," NASA MSC, 21 May 1969; "Apollo 7 to 11: Medical Concerns and Results: Presented at XVIII International Congress of Aerospace Medicine: 18 Sept. 1969"; and "Lunar Receiving Laboratory Apollo Spacecraft Cleaning and Housekeeping Procedures Manual," NASA MSC, 12 May 1969: NASA HQ Archives. See also Mangus and Larsen, "Lunar Receiving Laboratory Project History," p. 46; Carter, "Moon Rocks and Moon Germs," p. 246; and Meltzer, *When Biospheres Collide* (cit. n. 2), p. 219.

[52] Locke, "Recent Visit to LRL (Lunar Receiving Laboratory) on Behalf of the ICBC (Interagency Committee on Back Contamination)" (cit. n. 37); "Splashdown Procedures," NASA Press Release, 9 July 1969; and Harry Schwartz, "NASA Steps Up Effort to Avert Contamination from the Moon," *New York Times*, 2 June 1969.

astronaut truly sick, NASA would remove that astronaut from quarantine and allow the pathogen to escape.[53]

Other potential containment failures went entirely unnoticed. An LRL training handbook, for example, stipulated that in the event of a major injury, emergency personnel could enter and exit the Sample Operations Laboratory without following decontamination procedures. The same handbook outlined procedures whereby the entire LRL—including the sections behind biological barriers—would be evacuated in the event of a fire. Moreover, while NASA drafted plans to quarantine a crash site if an airplane holding samples or astronauts crashed, it never considered whether microorganisms could escape if the command module burned up in the atmosphere or if its parachutes failed to open and it broke apart upon impacting the ocean. Even the breaches that were known left some scientists feeling defeated. John Hodge believed that once NASA modified its procedures for venting and astronaut egress, it was "really kind of a game after that."[54]

SPILLS AND THRILLS: OPERATING THE LRL

Some two hundred technicians worked in the LRL during *Apollo 11*, alongside approximately a hundred NASA employees and visiting scientists. To pass through a biological barrier, they walked to a change room (see Figure 1); deposited jewelry and other personal items with a security guard; replaced their street clothing with laboratory clothes and clogs; walked briskly through "ultraviolet light airlocks" (loitering caused burns); and, finally, replaced their clogs with laboratory socks and shoes (see Figure 3). To leave, personnel deposited their laboratory clothes within an ultraviolet "irradiated contaminated clothing receptacle," showered, walked nude through ultraviolet locks, and, finally, dressed in street clothes. It was considerably harder to leave the Sample Operations Laboratory or Crew Reception Area than it was to enter, enshrining—in theory—the primacy of concern over back contamination within the facility.[55]

Since moving lunar samples and potentially contaminated equipment through the LRL presented "a hazard of possible exposure of laboratory personnel to extraterrestrial infectious agents," scientists developed no fewer than seven sterilization methods for the facility, most importantly the autoclaves. Meanwhile, all personnel adhered to a Mission Personnel Surveillance System that allowed a CDC representative quickly to identify a containment failure that could have infected laboratory workers with a lunar pathogen. Everyone filled out a Personnel Surveillance Form that required them to list their work room, address, and physician. At the beginning of every shift, absences were reported by each Area Test Director to one of six Quarantine Control Officers (QCOs), who entered the information into a Surveillance System monitored by the CDC representative. To determine the significance of absences, the system established background levels of illness and absence using a control group of personnel in another building. Any reported illness prompted a thorough "medical and epidemiologic" investigation, potentially at an employee's home. The results were compared with records at a local clinic and shared with the employee's personal physician. The CDC representative provided summaries of the surveillance results and recommendations to the Occupational Medicine Contract Technical Manager's Representative for Clinical Operations, who in turn forwarded the information to LRL and NASA management.[56]

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[53] NASA, "Integrated Quarantine Operations Plan" (cit. n. 19); and Mangus and Larsen, "Lunar Receiving Laboratory Project History," p. 31.

[54] "Handout for Biological Safety Training in the LRL (Lunar Receiving Laboratory)," 31 Oct. 1969, Apollo 076-26, HIS 39905, JSC Archives; Carter, "Moon Rocks and Moon Germs," p. 248; and Mangus and Larsen, "Lunar Receiving Laboratory Project History," p. 42 (quotation).

[55] "Handout for Biological Safety Training in the LRL (Lunar Receiving Laboratory)."

[56] *Ibid.*

Figure 3. Biological (left) and chemical (right) testing in the Lunar Receiving Laboratory. Top left: "Biological Test Laboratory, Sample Operations Area," NASA, https://images-assets.nasa.gov/image/S68-25213/S68-25213~orig.jpg. Bottom left: "Saturn Apollo Program," NASA, https://images-assets.nasa.gov/image/6901320/6901320~orig.jpg. Right: "Technicians examine largest lunar rock sample collected," NASA, https://images-assets.nasa.gov/image/S71-21244/S71-21244~orig.jpg.

LRL managers distinguished between containment faults—"a degradation of the biological containment system which may or may not result in the exposure of personnel to the returned lunar sample or pathogenic terrestrial materials"—and spills, a containment fault that definitely caused exposure. When a technician or scientist noticed a containment fault in the Sample Operations Laboratory, they had to immediately slip on a face mask and activate the spill alarm. Everyone in the room where the containment fault occurred walked to a shower in a change room behind the biological barrier, everyone in the Sample Operations Laboratory pulled on their masks, and a security guard locked the change room doors. The QCO—who was usually in the Central Status Station on the other side of the biological barrier (see Figure 1)—announced the containment fault over the intercom and ordered all affected personnel to shower and then call him to describe the incident. After the call had been made and a health and safety team had donned protective gear, the QCO relayed the description to them. The team decontaminated the area and then walked to the change rooms behind the biological barrier, where they deposited all their equipment and clothing in an emergency bag along with that of the affected personnel. Finally, the QCO determined whether an actual spill had occurred. It could be difficult to discern whether a containment fault had in fact caused a spill, and only in obvious cases did a QCO decide that it had. He could in theory quarantine the entire Sample Operations Laboratory. In practice, after clear spills QCOs opted to unlock the door between the laboratory and the Crew Reception Area, and affected personnel then entered quarantine with the astronauts. To the extent that they could, QCOs chose to minimize disruptions to the lives of LRL personnel and to operations within the facility, rather than to reduce the risk of back contamination to the maximum possible extent.[57]

LRL technicians agreed that if they were exposed to lunar contaminants and quarantined, they would not attempt to escape. If exposure killed them, their relatives could not claim their bodies. Rough plans drafted by NASA officials imagined that, in the event of a dangerous breach of lunar organisms that threatened to spill beyond the LRL, guards would seal the facility at gunpoint. If all else failed, the entire facility and everyone inside it would be buried under a mountain of dirt and concrete.[58]

These arrangements were in force on 20 July 1969, when Buzz Aldrin and Neil Armstrong landed on the lunar surface and stepped into what—for all they knew—could be an alien biosphere. When they returned to the lunar lander, they removed their helmets and immediately smelled "wet ashes," according to Armstrong. Moon dust was everywhere. Because it irritated the skin and lungs, both astronauts slept in their helmets and gloves that night. Removing all the dust was clearly impossible. If it had harbored a pathogen, it would easily have infected the astronauts. This was only the first of many scares, spills, and containment failures in NASA's efforts to protect Earth from back contamination during the Apollo program (see Figure 4).[59]

"Keep the mice healthy," command module pilot Michael Collins joked on 24 July, just before entering Earth's atmosphere. President Nixon flew to the *Hornet* to meet the returning astronauts. Had they fallen sick, the presidential party planned to evacuate. It might not have done any good; the astronauts found salt water in their BIGs, suggesting that they leaked. Around noon on 25 July, lunar samples and film magazines arrived at the LRL, along with a sample of seawater from the vicinity of the command module that was soon tested for lunar microorganisms.[60]

LRL managers had originally planned to quarantine film magazines collected by the *Apollo* astronauts. Yet by late 1968 they had decided that these magazines should be processed outside of the laboratory, so that the public could see the images more quickly. Unlike everything else exposed to lunar dust, the magazines spent only hours behind the biological barrier at the LRL. The plan was to sterilize the film with ethylene oxide gas in an autoclave, then perform the same procedure on a control film contaminated with *Bacillus globigii* bacteria (which was used at Fort Detrick as a substitute for *B. anthracis*, the spore-creating bacterium responsible for anthrax). If the procedure killed the terrestrial bacteria, it was assumed, then the Apollo film must also be sterile. Yet by March 1969 LRL technicians were still working out the details.[61]

On 24 July NASA photo technician Terry Slezak simulated the procedure to prepare for the imminent arrival of the *Apollo 11* magazines. To his surprise, "the ethylene oxide gas somehow had condensed at the top of the autoclave and . . . gotten on the film, and it melted it." In response, Slezak remembered, "they had some plumbers come in, and they re-plumbed the autoclave, and they put some kind of a shield up at the top." On 25 July, they had only just finished and run another simulation when the magazines arrived. Minutes after midnight on 26 July, Slezak opened a

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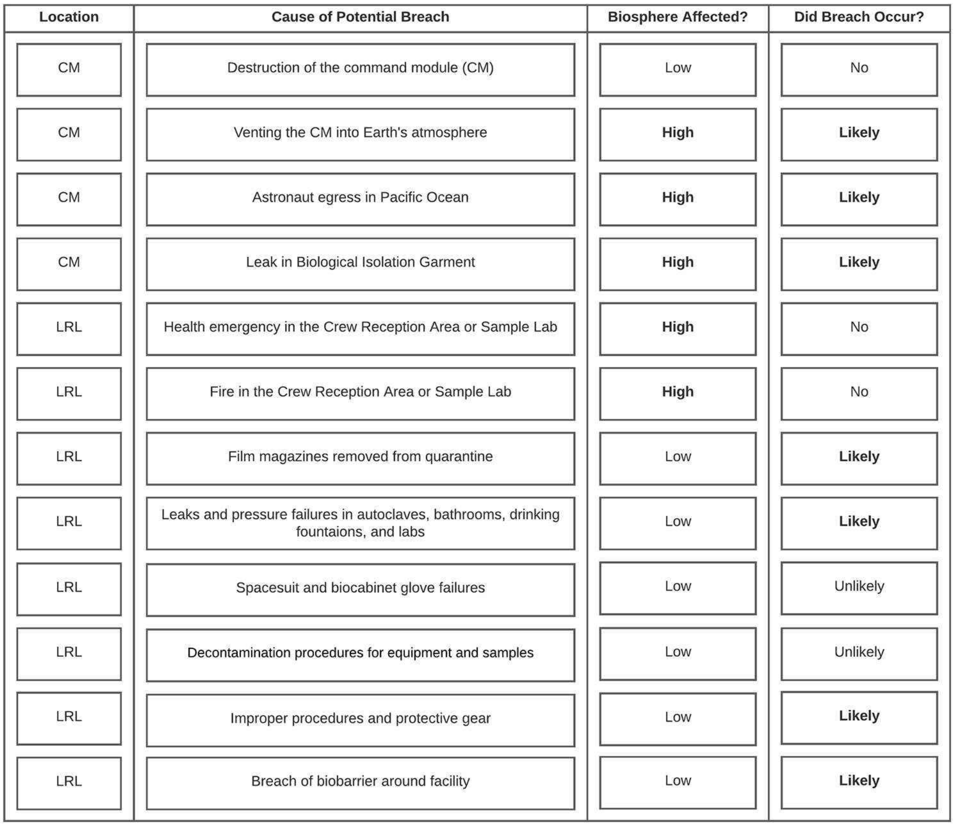
[57] *Ibid.*

[58] Carter, "Moon Rocks and Moon Germs," pp. 244, 247; Allton *et al.*, "Lessons Learned during Apollo Lunar Sample Quarantine and Sample Curation" (cit. n. 25), p. 377; and Degroot, "Lunar Pandemic."

[59] Fishman, *One Giant Leap* (cit. n. 9), p. xi; Donald A. Beattie, *Taking Science to the Moon: Lunar Experiments and the Apollo Program* (Baltimore: Johns Hopkins Univ. Press, 2003), p. 19; and "Transcript of EASEP Deployment and Closeout," *Lunar Surface Journal: Apollo 11*, https://www.hq.nasa.gov/alsj/a11/a11.clsout.html.

[60] "LRL (Lunar Receiving Laboratory) Apollo 11 Daily Summary Report July 24–25," Apollo 076-25, HIS 38855, JSC Archives; and Duff, "Great Lunar Quarantine," p. 41.

[61] "LRL (Lunar Receiving Laboratory) Operational Readiness Inspection Nov. 18" (cit. n. 33); and "Sterilization of Film in LRL (Lunar Receiving Laboratory)," Back Contamination and Quarantine, Apollo 076-23, HIS 36109, JSC Archives.



Location	Cause of Potential Breach	Biosphere Affected?	Did Breach Occur?
CM	Destruction of the command module (CM)	Low	No
CM	Venting the CM into Earth's atmosphere	**High**	**Likely**
CM	Astronaut egress in Pacific Ocean	**High**	**Likely**
CM	Leak in Biological Isolation Garment	**High**	**Likely**
LRL	Health emergency in the Crew Reception Area or Sample Lab	**High**	No
LRL	Fire in the Crew Reception Area or Sample Lab	**High**	No
LRL	Film magazines removed from quarantine	Low	**Likely**
LRL	Leaks and pressure failures in autoclaves, bathrooms, drinking fountaions, and labs	Low	**Likely**
LRL	Spacesuit and biocabinet glove failures	Low	Unlikely
LRL	Decontamination procedures for equipment and samples	Low	Unlikely
LRL	Improper procedures and protective gear	Low	**Likely**
LRL	Breach of biobarrier around facility	Low	**Likely**

Figure 4. Potential back contamination "breaches," or spills, during *Apollo 11* and *Apollo 12*. Containment problems are categorized by their location, cause, likelihood of contaminating the biosphere (had lunar microorganisms actually existed), and likelihood of having resulted in a genuine breach. Author's rendering.

magazine and found a note from Aldrin.[62] It warned him that Armstrong had dropped this "most important" magazine on the lunar surface. Suddenly Slezak realized that his left hand was covered with something "very black . . . like graphite" with "some kind of sparkly substance." It was Moon dust. Slezak and four other technicians had been exposed.[63]

Slezak wiped the magazine with a damp towel and put it through the decontamination procedure. After two hours, the five technicians stripped, washed their hands and arms in sodium hypochlorite (a disinfectant), showered for five minutes (the water drained into isolated septic tanks), and finally joined the quarantined astronauts in the Crew Reception Area. "The only thing I was concerned about," Slezak later recollected, was that the "abrasive" dust could have scratched the film. As ICBC members feared, even some technicians responsible for implementing and perfecting

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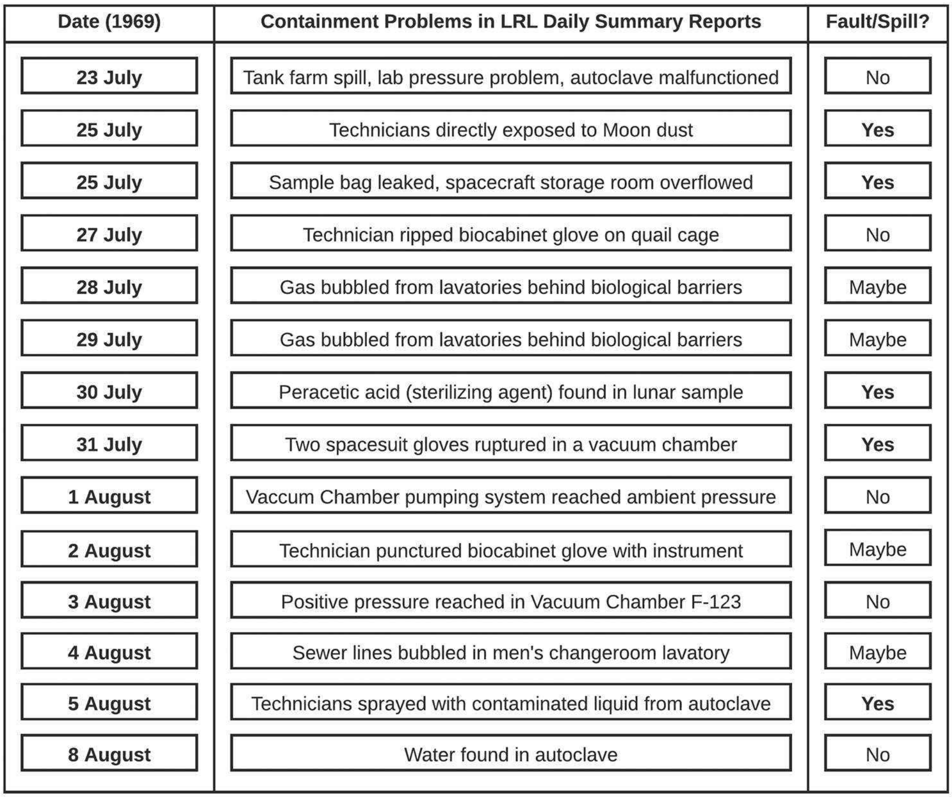
[62] "Lunar Receiving Laboratory (LRL)—Slezak, Terry—Moon Dust—MSC," NASA, https://images.nasa.gov/details-s69-40054; Thomas O'Toole, "Photo Worker Gets Moon Dust on Hands," *Washington Post*, 27 July 1969; "LRL Daily Summary Report # 3," 26 July 1969, Apollo 076-25, HIS 38868, JSC Archives; and "Terry Slezak interviewed by Rebecca Wright," 29 July 2009, NASA Johnson Space Center Oral History Project, oral history transcript, https://historycollection.jsc.nasa.gov/JSCHistoryPortal/history/oral_histories/SlezakTR/SlezakTR_7-29-09.htm.

[63] O'Toole, "Photo Worker Gets Moon Dust on Hands"; Carter, "Moon Rocks and Moon Germs," p. 247; "Moon Dust Gets Six Men Showers." *Baltimore Sun*, 27 July 1969; and "Terry Slezak interviewed by Rebecca Wright."



Date (1969)	Containment Problems in LRL Daily Summary Reports	Fault/Spill?
23 July	Tank farm spill, lab pressure problem, autoclave malfunctioned	No
25 July	Technicians directly exposed to Moon dust	**Yes**
25 July	Sample bag leaked, spacecraft storage room overflowed	**Yes**
27 July	Technician ripped biocabinet glove on quail cage	No
28 July	Gas bubbled from lavatories behind biological barriers	Maybe
29 July	Gas bubbled from lavatories behind biological barriers	Maybe
30 July	Peracetic acid (sterilizing agent) found in lunar sample	**Yes**
31 July	Two spacesuit gloves ruptured in a vacuum chamber	**Yes**
1 August	Vaccum Chamber pumping system reached ambient pressure	No
2 August	Technician punctured biocabinet glove with instrument	Maybe
3 August	Positive pressure reached in Vacuum Chamber F-123	No
4 August	Sewer lines bubbled in men's changeroom lavatory	Maybe
5 August	Technicians sprayed with contaminated liquid from autoclave	**Yes**
8 August	Water found in autoclave	No

Figure 5. Containment problems at the LRL over approximately two weeks during *Apollo 11*. The command module splashed down in the Pacific Ocean on 24 July. Film magazines and samples arrived at the facility on 25 July and astronauts on 27 July. Author's rendering.

sterilization procedures at the LRL did not take the threat of back contamination seriously. Yet the facility's procedures for interpreting illnesses and limiting exposure to containment faults depended in large part on the willingness of its personnel to self-report illness or enter quarantine.[64]

During *Apollo 11*, the Quarantine Control Manager and Test Director of the LRL wrote daily reports that described all containment faults and spills for regulatory agencies in the ICBC. These reports reveal that the LRL suffered from almost daily containment failures or near-failures that were largely hidden from the public (see Figure 5). By 3 August, twenty-four people had been quarantined—and the LRL's malfunctioning autoclaves were largely responsible. For almost a year, tests and simulations had uncovered critical problems with the autoclaves, and federal officials had repeatedly warned that they urgently needed fixing. Yet there had not been enough time to prepare them for the arrival of the *Apollo 11* astronauts, the command module, film magazines, and samples. Had *Apollo 11* returned microorganisms from the Moon, they would likely have escaped.[65]

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[64] "Terry Slezak interviewed by Rebecca Wright."

[65] From the JSC Archives see "LRL (Lunar Receiving Laboratory) Summary Report #4," Apollo 076-25, HIS 38877; "LRL (Lunar Receiving Laboratory) Summary Report #5," Apollo 076-25, HIS 38901; "LRL (Lunar Receiving Laboratory) Summary Report #6," Apollo 076-25, HIS 38925; "LRL (Lunar Receiving Laboratory) Summary Report #7," Apollo 076-25, HIS 38938; "LRL (Lunar Receiving Laboratory) Summary Report #8," Apollo 076-25, HIS 38961; "LRL (Lunar Receiving Laboratory) Summary Report #9,"

On 21 August, scientists in the LRL's Botanical Laboratory noticed something strange. Seedlings exposed to Moon dust "look better than controls," a summary report noted, as though the "lunar soil" was "behaving as a source of nutrients." NASA announced that plants and plant cells showed "definite" and "unexpected" responses to lunar material. When exposed liverwort saplings grew to three times the size of control saplings, press speculation mounted that organisms from the Moon could be reacting to terrestrial life. The cause turned out to be mundane: elemental nutrients in the dust had never encountered water and so were more easily absorbed by the plants (see Figure 6).[66]

When scientists and technicians uncovered no sign of lunar microorganisms in the dust returned by *Apollo 11*, the ICBC allowed the astronauts to leave quarantine in three weeks. Geoscientists and many NASA managers hoped that the quarantine requirement would now be lifted and biological testing removed entirely from the Sample Operations Laboratory. The ICBC did agree that *Apollo 12* astronauts Richard Gordon, Alan Bean, and Pete Conrad no longer needed to wear BIGs after splashdown. Yet because one landing at one location could not rule out life on the lunar surface, the ICBC upheld the quarantine protocol.[67]

On 19 November 1969, *Apollo 12* settled down within sight of a robotic lander, *Surveyor* 3, that had arrived on the Moon more than two years earlier. Conrad detached the probe's camera so scientists on Earth could study how equipment endured the lunar environment (see Figure 6). "Al and I look just like a couple of bituminous coal miners," he quipped after the astronauts returned to the lunar module. Both men quickly came down with hay fever symptoms. More than even the *Apollo 11* crew, they had saturated their spacecraft—and their lungs—with Moon dust.[68]

When the astronauts entered quarantine in the LRL, more containment breaches troubled the facility. Engineers had implemented dozens of changes since *Apollo 11* to help prevent, identify, and control containment faults and spills in the LRL. Yet human error was harder to avoid. "Inappropriate procedures" soon led a technician to tear open a glove in a biocabinet, exposing eleven technicians who were then quarantined in the Crew Reception Area. By coincidence, one fell ill and isolated in the MQF for seventy-two hours. On 11 December, another "improper procedure" in an autoclave exposed four technicians to "potentially contaminated fluid." Although they were "followed closely" for three weeks, they were not quarantined. That decision reflected a more relaxed attitude toward back contamination at the LRL. Daily reports that identified every potential breach had given way to less detailed weekly summaries.[69]

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1 Aug. 1969, Apollo 076-25, HIS 39005; "LRL (Lunar Receiving Laboratory) Summary Report #10," Apollo 076-25, HIS 39015; "LRL (Lunar Receiving Laboratory) Summary Report #11," Apollo 076-25, HIS 39025; "LRL (Lunar Receiving Laboratory) Summary Report #12," Apollo 076-25, HIS 39038; and "LRL (Lunar Receiving Laboratory) Summary Report #15," Apollo 076-25, HIS 39082. From the NASA HQ Archives see "LRL Summary Report No. 3," 26 July 1969; "LRL Summary Report No. 13," 7 Aug. 1969; "LRL Summary Report No. 14," 8 Aug. 1969; "LRL Summary Report No. 15," 9 Aug. 1969; "LRL Summary Report No. 16," 11 Aug. 1969; "LRL Summary Report No. 17," 21 Aug. 1969; and "LRL Summary Report No. 18," 21 Aug. 1969.

[66] Lunar Sample P-I Summary Conference, Apollo News Center, Houston, 30 Apr. 1969, NASA HQ Archives; Henry C. Dethloff, *Suddenly, Tomorrow Came: A History of the Johnson Space Center* (Washington, D.C.: NASA, 1993), p. 180; and "Plants Thrive on Moon Dust," *Washington Post*, 30 Aug. 1969.

[67] Carter, "Moon Rocks and Moon Germs," p. 248; Duff, "Great Lunar Quarantine," p. 42; and "LRL (Lunar Receiving Laboratory) Situation Is Almost Desperate with Regard to Sample Handling and Processing," Lunar Samples, Apollo 076-26, HIS 39804, JSC Archives.

[68] A quarantined engineer later observed "considerable dust" in the interior of the spacecraft: Philip J. Stooke, *The International Atlas of Lunar Exploration*, 1st ed. (Cambridge: Cambridge Univ. Press, 2007), p. 224. See also "EVA-1 Closeout," "Post EVA Activities in the LM," and "Return to Orbit," *Lunar Surface Journal: Apollo 12*, https://www.hq.nasa.gov/alsj/a12/a12.html; George Lardner, "Conrad Finds Surveyor Turned Color on Moon," *Washington Post*, 21 Nov. 1969, p. A17; and "LRL (Lunar Receiving Laboratory) Operational Summary Apollo 12 Dec 6–13," Apollo 076-31, HIS 40443, JSC Archives.

[69] NASA, "Integrated Quarantine Operations Plan" (cit. n. 19). From the JSC Archives see "LRL (Lunar Receiving Laboratory) Operational Summary Apollo 12 Nov 24 to Dec 6 1969," Apollo 076-31, HIS 40339; "LRL (Lunar Receiving Laboratory) Operational Summary Apollo 12 Dec 6–13"; and "LRL (Lunar Receiving Laboratory) Weekly Activity Report Dec 14–20," Apollo 076-31, HIS 40532, JSC Archives.

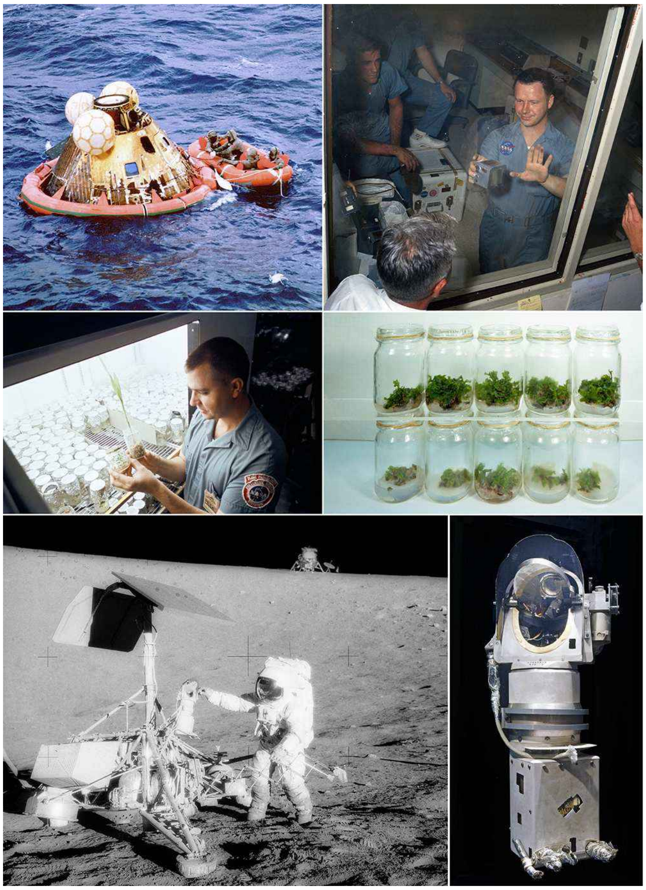

Figure 6. Back contamination scares and tests during *Apollo 11* and *Apollo 12*. Top left: *Apollo 11* astronauts and Navy divers in their BIGs, after splashdown. Source: “Saturn Apollo Program,” NASA, https://images-assets.nasa.gov/image/6900604/6900604~orig.jpg. Top right: Slezak shows Moon dust on his hand and the film cassette responsible for it. Source: “Lunar Receiving Laboratory (LRL)—Slezak, Terry—Moon Dust—MSC,” NASA, https://images.nasa.gov/details-s69-40054. Middle left: Botanist Charles Walkinshaw examines sorghum and tobacco plants exposed to Moon dust in the LRL’s Plant Laboratory, following the return of *Apollo 11*. Source: “Examination—Plants—Lunar (Germ Free) Soil—Plant Laboratory—MSC,” NASA, https://images-assets.nasa.gov/image/S69-53894/S69-53894~orig.jpg. Middle right: Liverwort treated in the LRL with *Apollo 11* Moon dust (top row) grew faster than untreated plants (bottom row). Source: “Progress Photograph of Sample Experiments Being Conducted with Lunar Material,” NASA, https://images-assets.nasa.gov/image/S69-53126/S69-53126~orig.jpg. Bottom left: Pete Conrad examines the *Surveyor* 3 camera housing before detaching it. Source: “Apollo 12 Mission Image—Astronaut Alan L. Bean, Lunar Module Pilot, and Two U.S. Spacecraft,” NASA, https://images.nasa.gov/details-AS12-48-7134. Bottom right: The housing after sampling. Source: *Surveyor* 3 camera housing, Smithsonian National Air and Space Museum, Washington, D.C.

Then, in early 1970, two discoveries at the laboratory made headlines across the United States. On 7 January, all samples returned by the *Apollo 12* astronauts, including the *Surveyor* 3 camera housing, left quarantine. On the following day, laboratory personnel used dry swabs to sample the camera. They placed each sample into a thioglycolate broth and spread the broth across blood agar plates. After four days of incubation, one of the plates showed signs of modest growth and, thus, multiplying bacteria. This was precisely the result some scientists and ICBC members had feared. Technicians quickly injected the bacteria into a germ-free mouse, with no observed effect. With help from the PHS, on 15 January they identified a single bacterium within the plate: alpha hemolytic *Streptococcus mitis*, a typically benign species that resides in the human respiratory system. Scientists speculated that a technician had contaminated *Surveyor* 3 before it was launched and that the bacteria survived for years on the lunar surface. Samples collected in the International Space Station have since revealed that bacteria can evolve into new species while in the extreme environment of outer space, as Crichton first proposed. The *S. mitis* in the camera housing, however, had apparently survived unchanged. Even skeptical geologists and astronauts now confessed that the quarantine protocol had been "a damn good idea," as Conrad put it at the time. "I always thought the most significant thing that we ever found on the whole goddamn Moon," he reflected in 1991, "was that little bacteria who came back and lived and nobody ever said shit about it."[70]

Yet *S. mitis* does not form spores, and later some scientists argued that it could not have survived the extreme temperature swings of the lunar surface. *S. mitis* had been isolated from the *Apollo 12* astronauts in testing at the LRL, suggesting that the astronauts could have contaminated the camera housing after collecting it. Grainy video also reveals that technicians at the LRL disassembled the housing in short sleeves, without gloves. *Surveyor* project scientist Leonard Jaffe later remembered a definite "breach of sterile procedure" when a technician placed an implement for collecting samples on a nonsterile bench. The detection of *S. mitis*, Jaffe concluded, "looks suspiciously like a lab error rather than a lunar germ colony." Yet fresh contamination of the camera would have produced a fast-growing sample of diverse bacteria scattered across the blood agar plate: precisely the opposite of what LRL technicians observed. Moreover, bacteria were not found on the surface of the housing, which was presumably easier to contaminate, but, rather, deep within the camera, which was shielded from the worst temperature extremes of the lunar surface. Studies subsequently revealed that even non-spore-forming bacteria remain viable at the edge of space, in Earth's upper atmosphere. It seemed clear, as NASA administrator Thomas Paine acknowledged, that "there has been some" forward contamination of the lunar surface—and that back contamination remained a genuine threat.[71]

Just two months later, microbiologists in the LRL exposed pathogenic bacteria to Moon dust exhumed from below the lunar surface by the *Apollo 11* astronauts. The bacteria they selected were resistant to antibiotics, and all three could easily endure environmental extremes. Yet within ten hours of exposure, NASA announced, all were dead. Walter Kemmerer, *Time* reported, judged that

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[70] Roger D. Launius, "Can We Colonize the Solar System? Human Biology and Survival in the Extreme Space Environment," *Endeavour*, 2010, *34*(3):122–129, on p. 122 (quoting Conrad); Duff, "Great Lunar Quarantine," p. 42; Carter, "Moon Rocks and Moon Germs," p. 248; Mangus and Larsen, "Lunar Receiving Laboratory Project History," p. 42; "Earth Germ Survives Three Years in Camera on Moon," *Los Angeles Times*, 23 May 1970, p. 1; "'Benign Bacteria' Survives 950 Days on a Hostile Moon," *Baltimore Sun*, 23 May 1970, p. A8; Launius, *Reaching for the Moon: A Short History of the Space Race* (New Haven, Conn.: Yale Univ. Press, 2019), p. 181; F. J. Mitchell and W. L. Ellis, "Surveyor III: Bacterium Isolated from Lunar-Retrieved TV Camera," in *Lunar and Planetary Science Conference Proceedings* (Cambridge, Mass.: MIT Press, 1971), Vol. 2, p. 2721; Swati Bijlani *et al.*, "Methylobacterium ajmalii sp. nov., Isolated from the International Space Station," *Frontiers in Microbiology*, 2021, *12*:1; and Degroot, "Lunar Pandemic."

[71] John D. Rummel, J. H. Alton, and Don Morrison, "A Microbe on the Moon? Surveyor III and Lessons Learned for Future Sample Return Missions," Conference for Solar System Sample Return Missions, Lunar and Planetary Institute, 2011; Dale W. Griffin, "Non–Spore Forming Eubacteria Isolated at an Altitude of 20,000 m in Earth's Atmosphere: Extended Incubation Periods Needed for Culture-Based Assays," *Aerobiologia*, 2008, *24*:19–25, esp. p. 19; Leonard Jaffe, in *Planetary Report*, Nov.–Dec. 1994, p. 3; and Ronald Kotulak, "Man Has Contaminated Moon, NASA Chief Dr. Paine Says," *Chicago Tribune*, 27 Nov. 1969, p. B10.

the "unknown killer in the moon soil" posed no threat to life on Earth, though NASA officials now agreed to continue the quarantine protocol for *Apollo 13*. The *Chicago Tribune* took a different tack. "This dirt from another world," the paper announced, clearly had "strange powers of being able to destroy earthly infectious bacteria and cause some plants to act as if they were the magic beans that sprouted into the clouds in Jack and the Beanstalk." Far from a threat, it now seemed as though lunar soil could be used to develop revolutionary "moon drugs" and "super fertilizer."[72]

Although the lunar surface seemed more biologically relevant than ever, NASA and the ICBC soon curtailed their efforts to defend against back contamination. *Apollo 13* never reached the lunar surface, and because the astronauts of *Apollo 14* drilled deep into the lunar landscape—precisely where Sagan had predicted that life could exist—they too entered quarantine upon returning to the Earth. Yet after they left the LRL and biological testing uncovered no microorganisms, NASA lifted the quarantine protocol for its final Apollo missions.[73]

CONCLUSION: RISK AND REWARD

As NASA prepared to land its astronauts on the Moon, there was no way for scientists to know whether microbial life had evolved on or beneath the lunar surface. If it had, federal officials privately agreed, the Apollo missions would release it into Earth's biosphere. NASA could have delayed crewed landings until it had conducted a robotic search for lunar life. Not four years after the final Apollo mission, the agency's Viking landers seemed to rule out life on the surface of Mars.[74] Yet NASA managers feared that any delay would allow Soviet cosmonauts to reach the Moon first. Above all, it was this fear that encouraged the development of a flawed quarantine protocol that would have accelerated—rather than delayed—the release of lunar microorganisms on Earth.

The tendency in scientific and technical endeavors to overlook low-probability but potentially existential risk was not unique to the Apollo program. Scholars and journalists have revealed that federal bureaucracies in the United States have mismanaged nuclear weapons and deadly pathogens, often by prioritizing expediency or geopolitical competition over public safety. Climate specialists may have systematically understudied social responses to environmental transformations under unlikely but plausible worst-case climate scenarios. Companies and governments continue breakneck development of artificial intelligence in the wake of a recent deep learning revolution, partly because the risk of not acquiring powerful software seems more pressing than the arguably low but real risk of the eventual emergence of general or super artificial intelligence. Similar pressures and assumptions have long informed the development and recent democratization of gene-editing technology. Efforts at SETI and METI—Messaging Extra-Terrestrial Intelligence—have historically discounted the potential risks of uncovering, let alone contacting, alien civilizations. Space agencies and corporations have planned to bring samples to Earth from the surface or subsurface of Mars and the atmosphere of Venus, environments far more likely than the Moon to harbor microbial life.[75]

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[72] *Arabidopsis thaliana* plants recently grown entirely in lunar regolith were less robust than plants grown in terrestrial soil. See George Getze, "Certain Earth Elements Killed by Moon Dust," *Los Angeles Times*, 12 Mar. 1970, p. 3; Ronald Kotulak, "Soil of Moon May Be Boon to Man," *Chicago Tribune*, 3 May 1970, p. D32; "Menace in Moon Soil?" *Time*, 30 Mar. 1970; Victor Cohn, "Lunar Soil Kills Three Kinds of Bacteria," *Washington Post*, 12 Mar. 1970, p. A1; and Anna-Lisa Paul, Stephen M. Elardo, and Robert Ferl, "Plants Grown in *Apollo* Lunar Regolith Present Stress-Associated Transcriptomes That Inform Prospects for Lunar Exploration," *Communications Biology*, 2022, 5(1):382.

[73] "Apollo Quarantine Discontinued," NASA Press Release, 28 Apr. 1971, NASA HQ Archives; and Allton *et al.*, "Lessons Learned during Apollo Lunar Sample Quarantine and Sample Curation" (cit. n. 25), p. 377.

[74] Admittedly, the Viking tests may have been inconclusive. See Robert Markley, *Dying Planet: Mars in Science and the Imagination* (Durham, N.C.: Duke Univ. Press, 2005), p. 34.

[75] Eric Schlosser, *Command and Control: Nuclear Weapons, the Damascus Accident, and the Illusion of Safety* (London: Penguin, 2013); Sara Reardon, "NIH Finds Forgotten Smallpox Store," *Nature*, 2014, *10*, https://doi.org/10.1038/nature.2014

The failures of the Apollo quarantine protocol demonstrate the extent to which poor oversight, unclear lines of authority, and schedule pressure brought about by vague political imperatives can encourage institutions to prepare inadequately for and even conceal unlikely but possibly catastrophic risks. Yet as historians have only begun to chronicle, similar approaches to risk seem widespread in the history of science, and they appear to have had diverse motivations. As improbable but potentially existential risks proliferate today, further histories of science may reveal why they have often been ignored. They may suggest how institutions can more effectively manage, and more transparently communicate, the gravest threats facing humanity.

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