

Adapting Disease Prevention Protocols for Human Spaceflight During COVID-19

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- BACKGROUND:** The National Aeronautics and Space Administration (NASA) Flight Crew Health Stabilization Program (HSP) was historically implemented to minimize infectious disease transmission to astronauts in the immediate prelaunch period. The first ever commercial application and adaptation of the NASA HSP was implemented during the Crew Demo-2 mission in the time of the Coronavirus disease 2019 (COVID-19) pandemic. This article details and discusses the first commercial implementation and adaptation of the HSP prior to the Crew Demo-2 launch.
- METHODS:** This is a retrospective descriptive analysis of the application of NASA disease prevention protocols for human spaceflight during the COVID-19 pandemic. In the context of the pandemic, extra precautions added to the HSP included daily symptom surveys completed by Primary Contacts of the crew, COVID-19 RT-PCR testing, and improved quarantine protocols.
- RESULTS:** Of the 91 SpaceX Primary Contacts who completed a total of 2720 daily symptom surveys prior to launch, 22 individuals (24.2%) and 198 surveys (7.3%) returned positive for potential symptoms of COVID-19. Two individuals were removed due to symptoms indistinguishable from COVID-19. Through this survey, systematic quarantine, and PCR testing, the Crew Demo-2 mission was successful with no known infectious diseases transmitted.
- CONCLUSIONS:** Overall, the commercial implementation of the NASA Health Stabilization Program by SpaceX with adjustments required during the COVID-19 pandemic was a success, with protocols allowing identification and removal of potentially infectious persons from the program. The principles of the HSP may provide an adequate infectious disease playbook for commercial spaceflight operations going forward.
- KEYWORDS:** NASA, disease prevention, health stabilization, human spaceflight, COVID-19.

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The NASA Flight Crew Health Stabilization Program (HSP) was designed to minimize infectious disease transmission to astronauts during the immediate prelaunch period by instituting quarantine protocols. Initially conceived during the Gemini era (1961–1966), early measures to isolate crew from infectious exposures prior to launch met with varying levels of success. During that period, all three Apollo 7 crewmembers contracted an upper respiratory infection in flight, and one Apollo 8 crewmember manifested recurrent gastroenteritis. After a primary crewmember for Apollo 13 was replaced for lack of immunity to rubella following exposure, the HSP was officially implemented prior to Apollo 14⁵ and continued throughout the Space Shuttle era (1981–2011). No crewmember illness was reported for the missions for which the program was in effect (Apollo 14–17). Statistics recorded

for prior Apollo missions indicated that 57% of the prime crewmembers experienced some illness during the 21 d prior to launch, as well as illness events in flight and postflight.⁹ The

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NASA HSP continued to evolve with spaceflight programs and missions and was last revised in March of 2017.

The HSP is designed to maintain the health of the crew by maximizing primary prevention and minimizing contact to infectious material or persons. This is accomplished by quarantining the flight crew in a controlled environment starting 14 d before launch (L–14), limiting the number of people with potential exposure to the crew, crew quarters, and crew work areas. Individuals with access to crew work areas after initiating quarantine are termed Primary Contacts (PC), and a subset of those individuals with direct access to the crew were termed the Operational Group (OG).

Early planning of the first commercial application of the HSP took place prior to the Coronavirus Disease 2019 (COVID-19) pandemic. Caused by SARS-CoV-2, COVID-19 was initially reported on December 31, 2019, to the World Health Organization (WHO), which would designate COVID-19 as a global pandemic on March 11, 2020.¹ The diagnostic and operational dilemma of a crewmember COVID-19 diagnosis would be dangerous to other crewmembers, result in large economic consequences, and jeopardize ongoing research and scientific efforts on the International Space Station. The 14-d quarantine encompasses the upper incubation limit of most respiratory viruses, including SARS-CoV-2, capturing 99% of symptomatic individuals.⁴ Due to concerns for morbidity, mortality, and rapid spread to crewmembers aboard enclosed spacecraft, extra precautions were deemed necessary for successfully implementing the HSP.

This paper aims to provide a retrospective descriptive analysis of the steps taken for the first ever commercial application of the NASA Health Stabilization Program during the SpaceX Crew Demo-2 mission in the midst of the COVID-19 pandemic. This description will highlight the steps taken by the joint NASA and SpaceX medical operations teams to protect astronauts prior to launch, identify the challenges faced during implementation, and suggest areas for future improvement. Though some protocols discussed are unique to aerospace medicine, this program has implications for other industries where protection of a subset of individuals is necessary. Examples of similar productions include sporting “bubbles”, political events, military centers, governmental organizations, correctional facilities, and many others.

METHODS

Potential PCs and OG members were identified by the SpaceX launch operations team, the commercial flight surgeon, and NASA. They aimed to adequately cover critical job functions while minimizing contacts. Before launch minus 45 d (L–45), health screening questionnaires were distributed to potential PCs and immunization records were requested from the OG. These records were reviewed by the NASA HSP flight surgeon and individuals who passed the initial health screening and vaccination requirements entered into the SpaceX HSP program. Of note, NASA had an additional 36 members of their

OG and an additional 78 PCs. The OG and PC figures in this paper focus only on the SpaceX PCs and OG members due to the slight variation in SpaceX HSP implementation and NASA HSP as discussed. The study protocol was approved by the Western IRB (study number 1,282,913).

In response to COVID-19, additional precautions were taken to ensure crew safety prior to entering the HSP regulated 14-d quarantine, as an infection would impact the training/launch schedule and crew participation. These precautions included a closed-loop system for NASA crew interactions with SpaceX. When visiting SpaceX facilities, crew traveled only by NASA agency aircraft. Crew and support personnel were then transported in sterilized vehicles from the airport to their training facility. Crew entered the safe and access-controlled “Training Center” via a private entrance. This center was cleaned twice daily per CDC guidelines, with common surfaces being wiped down, and was limited to operationally critical personnel with badge access and temperature <100.4°F. Everyone was required to wear face masks at all times. All SpaceX OG members underwent SARS-CoV-2 RT-PCR testing 48 h prior to close contact with crew.

Protocols were designed to reduce crew contact with high-risk or uncontrolled areas (e.g., restaurants, hotels, rental cars, grocery stores) for the entire duration of crew training. A dedicated “crew house” was procured to provide safe housing and mitigate the risk of staying at public hotels. The property was cleaned per CDC guidelines prior to crew arrival and after departure.⁶ Dedicated electric vehicles were provided upon arrival to avoid rental cars and gas stations. In addition, all snacks, beverages, and meals were provided by SpaceX at the training center and crew house.

Initially planned for L–28 to L–14, PCs were screened for infectious disease symptoms to screen out any potential disease or COVID-19 exposure prior to entering into the final 2-wk quarantine using a custom Qualtrics survey (**Table I**). Although the original HSP does not require symptom tracking of mission personnel, it was implemented by NASA as a COVID-19 mitigation protocol and continued by SpaceX. Though symptom monitoring was only intended through L–14, the decision was made to extend the survey through the first two potential launch scrub dates for SpaceX PCs (**Table II**). Given an eventual launch date of May 30, 2020, SpaceX PCs were screened for the 32 d prior to the launch of Crew Demo-2. One of the few differences between NASA HSP and SpaceX HSP was that NASA PCs only completed the survey from L–28 to L–14.

This morning survey was sent automatically with the results reviewed nightly by the SpaceX HSP flight surgeon. Those that did not fill out the survey were reminded by the flight surgeon and those with new symptoms were contacted for further history taking. If the symptoms were concerning for infectious disease, PCs were instructed to quarantine at home and undergo a physical examination with COVID-19 PCR testing if needed.

Employees were encouraged to work from home when possible. Though Personal Protective Equipment (PPE) (i.e., masks and gloves) were initially only intended for use while working around crew during the quarantine period, COVID-19 policy

Table I. Symptom Tracking Survey Questions and Response Options.

QUESTION	RESPONSE OPTIONS
Are you currently working?	"Yes" or "No"
Are you currently working remotely?	"No, not at all," "Yes, sometimes," or "Yes, all the time."
Have you been in close contact with anyone with CONFIRMED coronavirus in the past 24 h? (Face-to-face within 6 ft for ≥10 min)	"Yes" or "No"
Have you been in close contact with anyone that you SUSPECT had coronavirus in the past 24 h? (Face-to-face within 6 ft for ≥10 min)	"Yes" or "No"
How would you rate your energy level in the past 24 h?	"Worse than usual," "As usual," "Better than usual," or "Much better than usual."
Have you experienced any of the following over the past 24 h? - Fever (>100.0°F or >37.7°C)	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Feverish but no measured fever	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Chills	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Headache	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Red eyes/eyelids	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Neck pain or stiffness	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Runny/stuffy nose	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Decreased sense of smell	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Decreased sense of taste	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Sneezing	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Cough	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Sore throat	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - No appetite	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Feel like vomiting	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Vomiting	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Abdominal pain	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Diarrhea	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Body or muscle aches	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Joint pain	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - General weakness	"Yes" or "No"
Have you experienced any of the following over the past 24 h? - Feel more tired than usual	"Yes" or "No"

changes made masking with surgical or N95 masks mandatory on site. Social distancing and hand hygiene were repeatedly encouraged and disposable gloves were provided while working with the crew or in the capsule. The facilities were disinfected twice daily. Alcohol-based hand sanitizer was stationed in high-traffic areas and doors had disinfecting wipes positioned nearby or had foot openers. Security personnel performed temperature checks at guard stations prior to permitting entry to facilities.

Updated medical histories and physical exams were performed on the OG prior to L-14 to confirm lack of infectious

disease prior to entering into the formal self-quarantine. Upon completion of exams, the OG were provided HSP badges, PPE education, and HSP quarantine procedure reminders. Those living locally performed home quarantine. Travelers from remote sites used private aircraft and quarantined at a local hotel with an isolated floor. Starting L-14, the Qualtrics survey was updated to include a specific temperature question and PCs were reminded to perform temperature monitoring even when working remotely. Additional PC temperature checks were performed and logged by security personnel in a secure electronic form.

The OG was screened for COVID-19 with RT-PCR nasopharyngeal swabs on days L-12 and L-9 with the intent to have results prior to crew arrival on L-7. If negative on both screens, they were cleared to work with the crew.

If an HSP member was exposed to a suspected or confirmed COVID-19 positive individual, they were quarantined and tested with a single nasopharyngeal RT-PCR at least 72 h after exposure. If negative, they would be allowed to return to work with mandatory masking. The timeline of HSP events is shown in **Fig. 1**.

RESULTS

A total of 91 SpaceX employees initially entered into SpaceX HSP monitoring as PCs. There were 35 individuals in the OG

Table II. Commercial Space HSP Population Characteristics.

VARIABLE	DESCRIPTIVE STATISTIC
Total commercial HSP participants	91
Enrolled at the beginning	89
Added after the start	2
HSP classification	
OG	35
Non-OG PC	56
Gender	
Male	76
Female	15
Living location	
Locally	75
Remote	16

HSP: Health Stabilization Program; OG: operational group; PC: primary contacts.

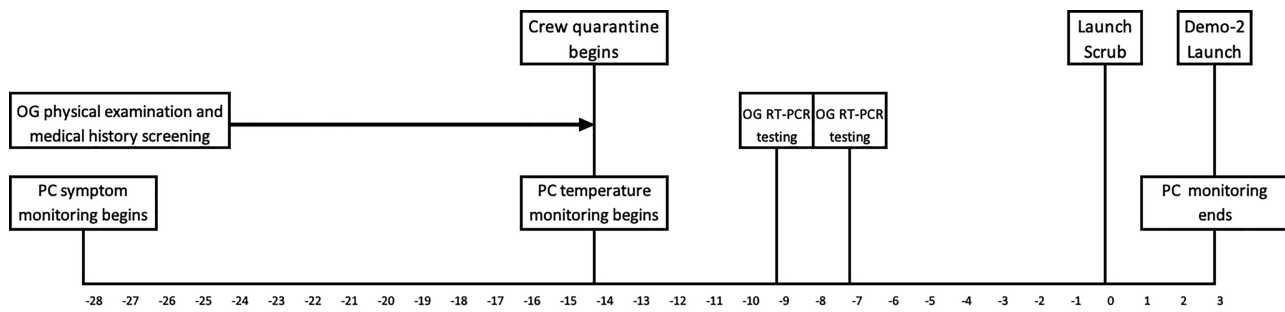


Fig. 1. Timeline of HSP procedures.

for whom direct contact with the crew would be necessary to ensure launch safety. More employees lived locally (75, 82.4%) than remotely (16, 17.6%) and 83.5% were men while 16.5% were women.

The survey was implemented on L-28 and it had a 93.4% average daily response rate. During the survey reporting period, 22 employees (24.2%, 12 OG, 10 Non-OG) reported symptoms and all were contacted by the commercial flight surgeon for symptom clarification. Symptom clarification identified 5 of 22 HSP participants with symptoms (23%) concerning for infectious disease. All five were re-examined, with one employee being examined twice. All exams were unremarkable and additional COVID-19 RT-PCR testing was performed on two of the five individuals, who tested negative and returned to duty. Two individuals who reported concerning symptoms, both non-OG, were removed from the commercial HSP program for potential infectious disease. Both had chronic medical conditions which were difficult to distinguish from infectious disease. The frequency of symptoms reported can be seen in **Table III**.

Of the 2720 surveys, 198 surveys (7.3%) returned positive for symptoms. The most common symptoms were joint pain (30, 15.2% of positive surveys), cough (28, 14.1% of positive surveys), sneezing (20.1, 10% of positive surveys), abdominal pain (20, 10.1% of positive surveys), and headache (19, 9.6% of positive surveys). The symptoms most commonly reported by multiple individuals were headache (10, 45.5% of symptomatic participants), diarrhea (6, 27.3% of symptomatic participants), cough (5, 22.7% of symptomatic participants), and sore throat (5, 22.7% of symptomatic participants). Multiple symptoms were reported in 25 d (12.6% of all positive surveys), with 12 of these 25 surveys (48%) coming from the 2 individuals removed from the HSP.

Of 35 SpaceX OG members, 34 received clearance exams at L-14. A single individual was initially cleared but did not proceed with OG duties after the quarantine started. No signs of infectious disease were identified and all continued prelaunch quarantine procedures. All were provided HSP badges denoting they were able to interact with crew. Active temperature checks implemented on L-14 via the security team did not identify a single fever, recording temperatures on an average of 31 individuals per day.

A total of 67 nasopharyngeal swabs were performed on the SpaceX OG members on L-12 and on L-9 for a 96%

completion rate. One person received only one swab due to travel, and the other individual did not proceed with OG duties after the quarantine started. All nasopharyngeal swabs were negative for SARS-CoV-2 infection.

There were 22 individuals (16 PCs and 6 OGs) who were identified as secondary contacts to 1 known COVID-19 positive individual in a large exposure. The 16 PCs were negative for SARS-CoV-2 on a single nasopharyngeal swab, and the 6 OG members were tested through the OG L-12 and L-9 protocol and were found to be negative as well. All 22 returned to HSP duties after this incident.

DISCUSSION

Since Apollo 14, a formal Flight Crew Health Stabilization Program has been implemented by NASA Medical Operations prior to launch to reduce infectious disease risk and resulting mission impact. While the risk cannot be reduced to zero, a

Table III. Symptom Survey Frequencies.

SYMPTOM	TOTAL COUNT (DAYS WITH SYMPTOMS)	INDIVIDUALS WHO REPORTED THIS SYMPTOM
Fatigue	0	0
Objective fever	0	0
Subjective fever	2	2
Chills	0	0
Headache	19	10
Red eyes/eyelids	13	3
Neck pain or stiffness	17	2
“Runny stuffy nose”	6	4
Decreased sense of smell	0	0
Decreased sense of taste	0	0
Sneezing	20	4
Cough	28	5
Sore throat	15	5
Decreased appetite	0	0
Nausea	2	2
Vomiting	0	0
Abdominal pain	20	3
Diarrhea	9	6
Body or muscle aches	6	1
Joint pain	30	1
General weakness	4	2
Feel more tired than usual	7	4

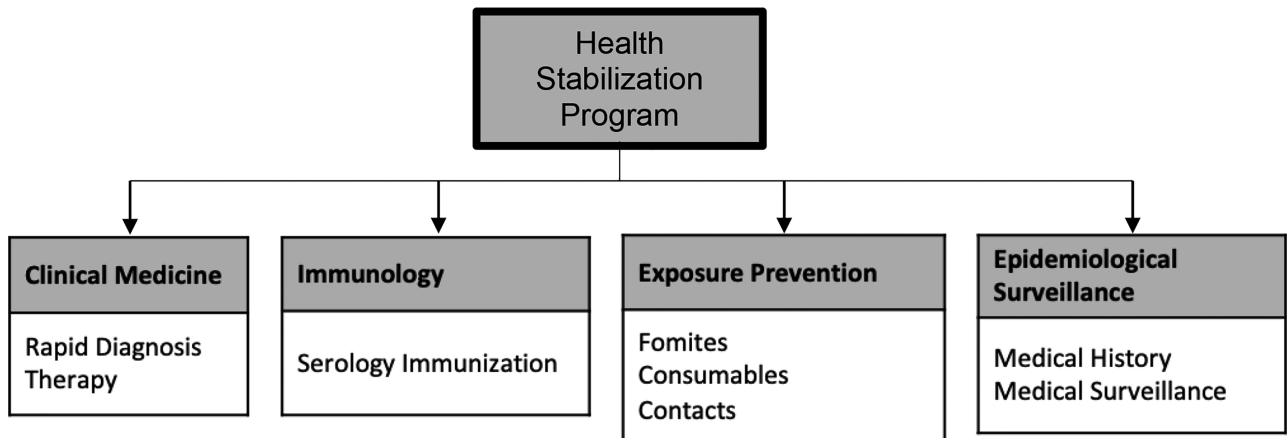


Fig. 2. Health stabilization program components.

comprehensive HSP platform based on four pillars (clinical medicine, immunization, exposure prevention, and epidemiological surveillance; **Fig. 2**) presents a way to significantly reduce hazard.

The first pillar, clinical medicine, is implemented through astronaut annual certification exams and prequarantine medical evaluations to rapidly detect and treat any illness. This ensures a healthy crew prior to entering premission quarantine. The NASA flight surgeons at the Johnson Space Center Flight Medicine Clinic provide this service. Due to the COVID-19 pandemic, flight surgeons and the rest of the SpaceX medical team had to adjust some of the protocols set forth by the NASA HSP, including the symptom survey, subsequent physical exams, and RT-PCR testing, as discussed. The COVID-19 pandemic was caused by a novel coronavirus and, as such, flight surgeons had to stay up to date with frequent changes in the latest prevention, testing, and treatment guidelines as set forth by the CDC and other medical organizations.

The second pillar, immunization, involves vaccinating the crew and their family members. This promotes primary prevention of disease and is extended to potential close contacts in the preflight period. As the OG was in close contact with the crew, NASA vaccination requirements were extended to these personnel. Immunizations required for crew and PCs included measles, mumps, rubella, diphtheria, pertussis, polio, varicella, and hepatitis A & B. Given the lack of available vaccine, immunization was not an option for the SARS-CoV-2 virus.

Exposure prevention, the third pillar of the HSP, involves reducing exposure to contaminated fomites, consumables, and infectious individuals. Traditionally, the HSP targets fomite transmission by implementing high efficiency bacterial filters in air supply ducts, providing positive air pressure in areas inhabited by the crew to prevent inward air movement, and rigorous decontamination of all areas with potential crew contact. Contaminated consumables were avoided by limiting and regulating the food and water consumed by crew with daily microbiological evaluations of samples. Finally, controlling for any contact of potentially infectious individuals was accomplished through minimizing personal contacts during critical preflight

periods, isolating crewmembers from potential carriers (visitors, children, uncontrolled contacts), and regular evaluation of individuals with critical mission-related responsibilities who had contact with the crew.¹

Due to the COVID-19 pandemic, certain additional actions were taken for this third pillar, including noncommercial plane travel, limiting interaction with the public, and mandatory mask wearing. Recent studies have shown a reduction in risk of COVID-19 transmission by 82% with mask use and maintaining physical distance of 1 m in both health care and community settings.⁷ Surgical and N95 masks were required because they have also been shown to be more effective than cloth masks.³ Ultimately, the most effective mitigation strategy is a combination of multiple methods, including testing and tracing, social distancing, community containment including travel restrictions, personal hygiene with handwashing and sanitizer, surface disinfection, and face coverings.⁸ All of these strategies were implemented with the HSP for the Crew Demo-2 mission.

The final pillar is epidemiological surveillance, where the health of all individuals interacting with crew or crew quarters prior to launch is monitored to rapidly detect and remove individuals developing infectious diseases. Expanding on this principle, surveillance strategies taken for this mission included a daily symptom survey completed by PCs as well as RT-PCR testing of all OG members prior to crew arrival. This regimented daily tracking provided reassurance that all potentially symptomatic cases of COVID-19 were identified, tested, and quarantined. Combined with PCR testing and thorough medical evaluations, the L-12 and L-9 surveys represented a highly effective way to ensure symptomatic COVID-19 was not being spread throughout the crew within quarantine.

COVID-19 risk was assessed by monitoring the surrounding county statistics as well as by performing internal COVID-19 screenings to assess company-specific prevalence. The Kennedy Space Center and nearby Cape Canaveral launch and landing complexes are located within Brevard County, FL. Prior to launch, there were 409 cases in a population of 576,808, representing a recorded prevalence of 70.9:100,000.² Greater than 87% (87.9%) of the PCs were living in the local area. Internal

prevalence was estimated by RT-PCR screening of certain mission critical and high-risk groups, including the OG, mission control, and those scheduled for recovery operations of crew and capsule upon their return. There were no active cases identified throughout this screening and, therefore, programmatic risk of COVID-19 was identified to be low. The amount of COVID-19 testing was another difference identified in the NASA and SpaceX protocols. In contrast to the SpaceX testing protocols mentioned, NASA limited its testing to two tests for crew, families, and key close contacts which were defined as those who stayed in crew quarters (17 individuals in total).

Overall, the strategies implemented in the first commercial application of the NASA HSP were successful in preventing infectious disease (including COVID-19) spread among the OG, PCs, and crew. The daily symptom survey which helped identify two individuals with symptoms concerning for potential infection who were removed from the commercial HSP program was very helpful. Because of the novelty, lack of vaccination, variable symptoms, and unknown prevalence of COVID-19, RT-PCR was also an essential tool to this mission in the time of a pandemic.

Areas for future improvement include improved monitoring of areas that were accessible to personnel not under HSP protocol. For example, the launch pad 39A tower was accessed by certain personnel who were not participating in the HSP program, providing a potential point of transmission. In addition, further research is needed to adapt HSP protocols for pandemic environments when the prevalence of disease in the community is high.

In conclusion, the first commercial application of the NASA Flight Crew Health Stabilization Program, though complicated by a global pandemic, was successful in minimizing risk of infectious disease transmission to the mission personnel and crew. Necessary adjustments were made due to the COVID-19 pandemic which allowed for prevention and early detection of disease, leading to identification and removal of potentially infectious persons from the program. The principles of the HSP, with allowed flexibility to account for any ongoing local or broad health crises such as the COVID-19 pandemic, provided an adequate infectious disease playbook for commercial spaceflight operations as we move toward an increasing number of commercial space launches.

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