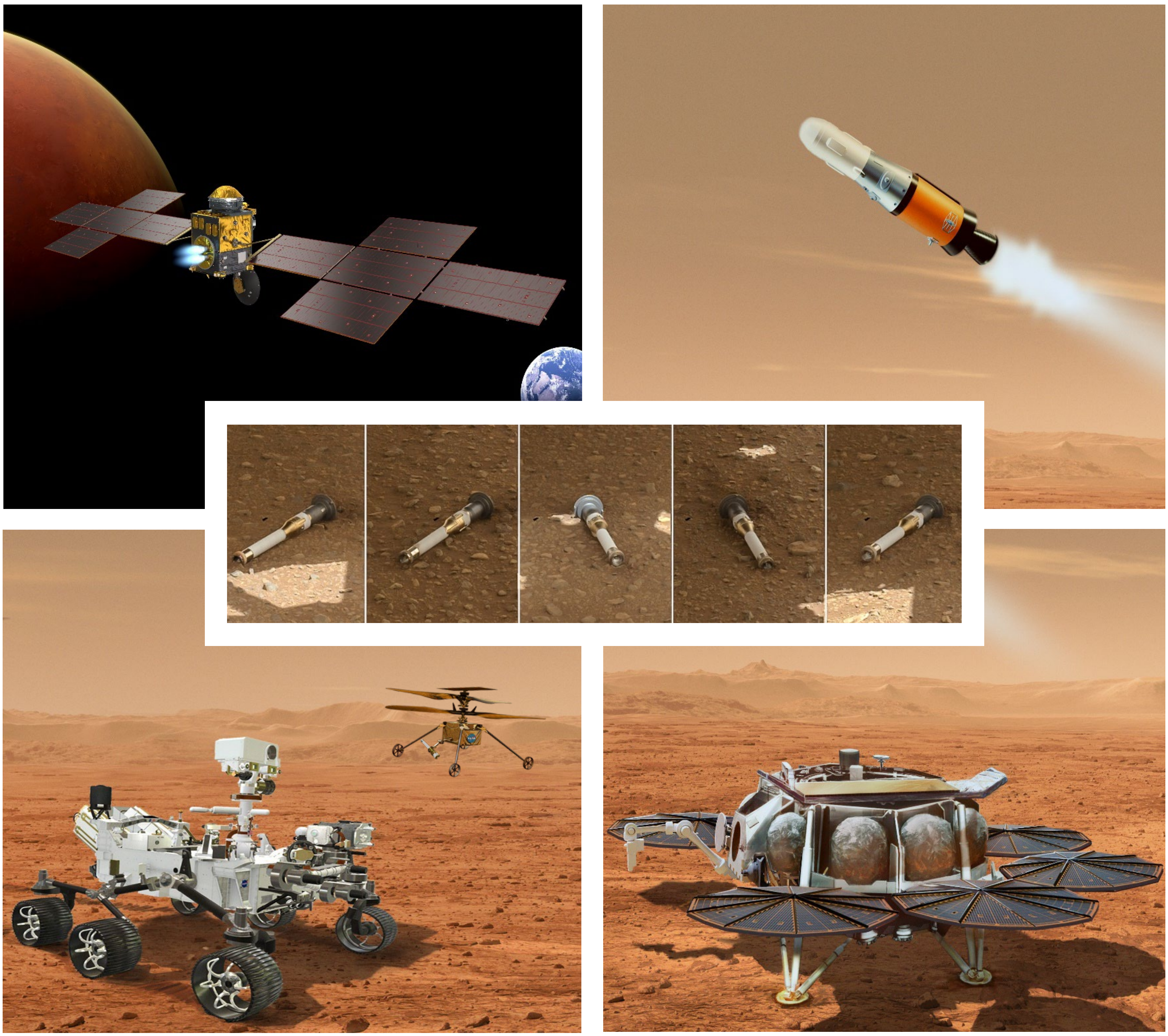
NASA
Office of Inspector General

Audit of the Mars Sample Return Program



February 28, 2024

IG-24-008

Office of Inspector General

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PHOTO CREDITS: Earth Return Orbiter (top left) is from ESA/ATG Medialab. Mars sample tubes (center), Mars Ascent Vehicle (top right), Sample Retrieval Lander (bottom right), and Perseverance rover with Sample Recovery Helicopter (bottom left) are from NASA/JPL-Caltech.

RESULTS IN BRIEF

Audit of the Mars Sample Return Program

February 28, 2024 IG-24-008 (A-23-01-00-SARD)

WHY WE PERFORMED THIS AUDIT

The Mars Sample Return (MSR) Program is a partnership between NASA and the European Space Agency (ESA) to return Martian geological samples to Earth for scientific study. One of the most technically complex, operationally demanding, and ambitious robotic science missions ever undertaken by NASA, the MSR Program consists of two major flight projects: the Earth Return Orbiter (ERO) and Sample Retrieval Lander (SRL). The MSR Program represents the second and third phases of the four-phased MSR Campaign: (1) collecting of samples by the Mars Perseverance rover, (2) landing a sample retrieval vehicle on Mars, (3) sending an orbiter to return samples to Earth, and (4) examining the samples.

The ERO is scheduled to launch in fall 2027 and arrive in Mars' orbit in late 2029. The SRL is scheduled to launch in spring/summer 2028 and land on the surface of Mars in 2030. The SRL and its components will transfer samples from the Perseverance rover or a sample depot into an Orbiting Sample container, where it will be launched from Mars aboard the Mars Ascent Vehicle rocket into orbit in early 2031. The ERO will rendezvous with the sample container in orbit, where the ERO's Capture, Containment, and Return System (CCRS) will capture and sterilize the sample container and deliver it back to Earth via the Earth Entry System in late 2033. ESA is developing and funding the ERO and Sample Transfer Arm component of the SRL, with NASA developing and funding the remaining components.

The MSR Program is approaching its next Key Decision Point (KDP) review (KDP-C) planned for March 2024 at which time NASA will evaluate Program plans, establish cost and schedule baseline commitments, and determine whether it should proceed from formulation to development. In this audit we evaluated NASA's management of the MSR Program to determine whether the Program (1) is on track to develop a stable design prior to proceeding to development, (2) is poised to establish a realistic life-cycle cost estimate at KDP-C, (3) is prepared to establish realistic launch schedule dates for the ERO and SRL projects at KDP-C, and (4) has identified and is addressing programmatic and technical issues and risks to accomplish its formulation goals. To complete this work, we obtained an understanding of the MSR Program's management, costs, schedules, issues and risks, technology readiness, business and procurement processes, and coordination with ESA. In addition, we reviewed MSR Program and project reports; key NASA and Center documents, procedures, and handbooks; scientific studies and independent board reports; agreements with ESA; and risks identified in NASA databases. We also interviewed NASA and ESA officials involved with the MSR Program.

WHAT WE FOUND

The MSR Program is facing significant obstacles completing its Formulation Phase—establishing a stable design with realistic cost and schedule estimates—in a timely and effective manner. As the Program prepares to recommend a life-cycle cost and schedule baseline at KDP-C, those obstacles include schedule and design/architecture issues with the CCRS. The CCRS's Preliminary Design Review—which demonstrates the design is complete and meets all system requirements—was scheduled for October 2022 but was not completed until December 2023. To simplify the CCRS's design, changes were made to its sample container sterilization system; however, the new system's effectiveness must be studied, and the technology matured, before it can be used in space.

These schedule and design issues, adding about $200 million to the budget and resulting in one year of lost schedule, can be attributed in part to inadequate guidance during the Pre-Formulation Phase, a problem experienced by several

NASA large flagship missions. NASA completed a Large Mission Study in October 2020 that noted while large missions require greater priority, resources, and attention during pre-formulation when key architecture decisions are made, little guidance exists to guide activities during this period. NASA has yet to incorporate the study's results into its practices for these missions. Considering the CCRS's schedule and design issues, the MSR Program is at least 7 months behind schedule in completing its Formulation Phase as its KDP-C, originally scheduled for August 2023, will not occur until at least March 2024.

The trajectory of the MSR Program's life-cycle cost estimate, which has grown from $2.5 to $3 billion in July 2020, to $6.2 billion at KDP-B in September 2022, to an unofficial estimate of $7.4 billion as of June 2023 raises questions about the affordability of the Program. Characteristics intrinsic to big and complex missions like the MSR Program are hard to quantify in estimates but can drive project costs upwards throughout development. These include fully understanding the mission's complexity, initial over-optimism, a less than optimal design/architecture, and the team's ability to perform to expectations. When developing its cost and schedule estimate for KDP-C, and as the MSR Program addresses its architecture issues, Program management must consider these intrinsic characteristics and not attribute past cost growth to just the COVID-19 pandemic, inflation, or supply chain issues.

Additionally, MSR Program formulation is impacted by coordination challenges between NASA and ESA. While communication processes are formally documented and being followed, NASA and ESA are experiencing issues related to schedule transparency, asynchronous design progress, and mass allocation, which appear to stem from differing operational approaches, acquisition strategies, and agency funding mechanisms. The CCRS project team noted that significant progress has been made addressing interface issues between the two entities.

The MSR Program recently acknowledged it likely cannot meet the life-cycle cost estimate and launch dates established at KDP-B. A September 2023 report by an Independent Review Board recommended the Program consider modifications to specific mission designs. Accordingly, it is critical that before the MSR Program is approved to proceed from formulation into development, viable alternatives to the Program's mission architecture are considered—including mission launch and sample return alternatives—as well as the value of the samples returned, the Program's schedule, life-cycle cost estimate, and the Agency's historic leadership position in space exploration.

WHAT WE RECOMMENDED

To provide the Agency Program Management Council with the necessary information to make an informed decision at KDP-C, we recommended the Associate Administrator for Science Mission Directorate (1) ensure the MSR Program establishes a stable CCRS design prior to establishing the life-cycle cost and schedule estimate at KDP-C, (2) ensure the life-cycle cost and schedule estimates properly incorporate MSR Program complexity and performance, and (3) ensure the Agency Program Management Council is provided with a set of potential launch scenarios by KDP-C, including life-cycle cost and schedule estimates and an associated Joint Cost and Schedule Confidence Level for each. In addition, we recommended NASA's Chief Program Management Officer (4) assess the efficacy of large mission pre-formulation guidance and develop a corrective action plan that addresses the concerns and recommendations of the October 2020 Large Mission Study.

We provided a draft of this report to NASA management who concurred or partially concurred with our recommendations and described planned actions to address them. We consider management's comments responsive to Recommendations 2 and 3, and therefore both are resolved and will be closed upon completion and verification of the proposed corrective actions. Regarding Recommendations 1 and 4, while we consider management's comments responsive, we will require further discussions and documentation from management before deciding whether to close them as requested.

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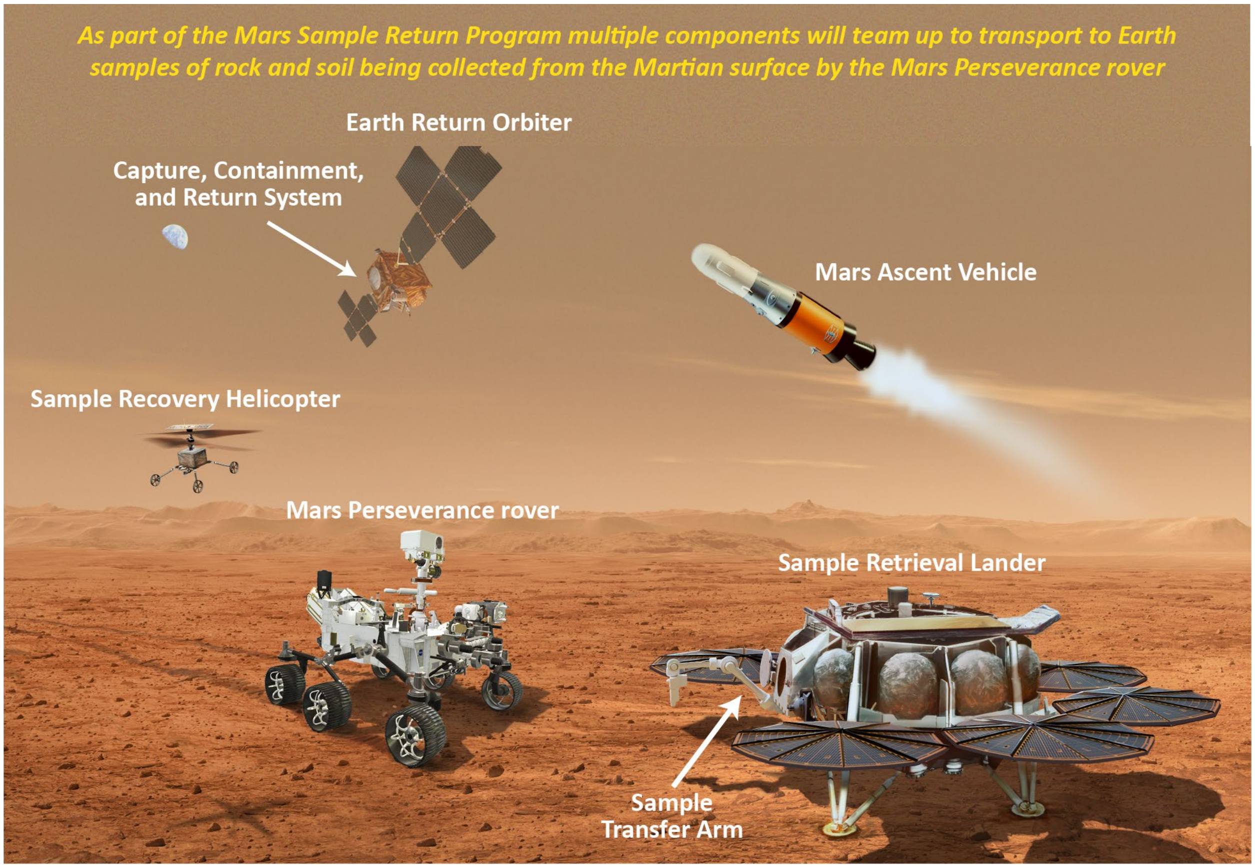
Acronyms

CCRS	Capture, Containment, and Return System
ERO	Earth Return Orbiter
ESA	European Space Agency
FY	fiscal year
IRB	Independent Review Board
JPL	Jet Propulsion Laboratory
KDP	Key Decision Point
MAV	Mars Ascent Vehicle
MEP	Mars Exploration Program
MSR	Mars Sample Return
OIG	Office of Inspector General
PDR	Preliminary Design Review
SRB	Standing Review Board
SRL	Sample Retrieval Lander

INTRODUCTION

The Mars Sample Return (MSR) Program is a partnership between NASA and the European Space Agency (ESA) designed to return Martian geological samples to Earth for scientific study in the early 2030s. A part of NASA's MSR Campaign, the MSR Program is one of the most technically complex, operationally demanding, and ambitious robotic science missions ever undertaken by NASA (see Figure 1).

Figure 1: Mars Sample Return Concept Illustration



Source: NASA Office of Inspector General (OIG) presentation of Agency information.

The potential for discovering evidence of life on other planets as well as the desire to understand the geology and history of Earth's closest planetary neighbor has inspired exploration efforts on Mars for several decades. Recommendations from the National Academies of Sciences, Engineering, and Medicine spanning nearly 30 years identified these efforts among the highest priorities of the planetary science research community. Since the 1960s NASA has invested billions of dollars in exploring the Red Planet with satellites, landers, and rovers culminating in the creation of the MSR Campaign. As the first phase of that campaign, NASA's Perseverance rover is currently operating on Mars and collecting samples on the planet's surface.[1]

NASA will soon review the MSR Program's plan for retrieving and returning the samples to Earth and determine whether to authorize the Program to proceed into development. To this end, MSR Program management is currently assessing the stability of its mission design and seeking to develop realistic cost and schedule estimates as part of the Program's Formulation Phase. However, since NASA approved the MSR Program to proceed into formulation in December 2020, the Program has faced significant challenges finalizing the design of one of its key flight components, leading to schedule delays that may ultimately result in the loss of one or more potential launch window opportunities. In addition, the unofficial life-cycle cost estimate of $7.4 billion as of June 2023 is almost 20 percent above the top of the preliminary life-cycle cost estimate of $5.9 to $6.2 billion established in September 2022 during the Program's Formulation Phase. An independent review of the MSR Program released in September 2023 recommended the Program evaluate alternative mission architectures, including options that delay launch dates and could lead to cost estimates in the range of $8 to $11 billion.

Because of highly constrained launch windows associated with planetary science missions, environmental conditions affecting operations on the surface of Mars, and other constraints that need to be considered in planning a mission schedule, changes to the MSR Program's architecture and timing could impact the quantity and quality—and ultimately the scientific value—of any samples returned. Additionally, considering the constrained budget environment NASA is likely to find itself in for the next several fiscal years, budget increases required for the MSR Program to maintain its current funding profile will most likely come at the expense of other projects in the Agency's science portfolio.

Until the MSR Program design is stable, a realistic cost and schedule baseline commitment cannot be established. MSR is approaching its next Key Decision Point (KDP) review (KDP-C) at which time NASA will evaluate Program plans and determine whether the Program should proceed into development. NASA must be able to conduct this review based on a stable design and realistic cost and schedule commitments while considering the interests of its various stakeholders. This review process will assist the Agency in making an informed decision regarding the future of the MSR Program that could include options such as (1) approving the Program to proceed into development and targeting more immediate launch opportunities, (2) delaying Program development and launch, or (3) canceling the Program outright.

In this audit, we evaluated NASA's management of the MSR Program relative to established cost, schedule, technological goals, and risks. Specifically, we determined whether the Program (1) is on track to develop a stable design prior to proceeding to development, (2) is poised to establish a realistic life-cycle cost estimate at KDP-C, (3) is prepared to establish realistic launch schedule dates for the Earth Return Orbiter (ERO) and Sample Retrieval Lander (SRL) projects at KDP-C, and (4) has identified and is adequately addressing programmatic and technical issues and risks to effectively accomplish its formulation goals. Details of the audit's scope and methodology are outlined in Appendix A.

[1] The Mars 2020 mission's Perseverance rover launched in July 2020 and continues to operate, having already completed its minimum planned operating life of 1.25 Mars years (28 Earth months).

Background

Planetary Science Decadal Survey

NASA solicits guidance from the National Academies of Sciences, Engineering, and Medicine on planning and prioritizing planetary exploration missions and research through the Academies' Planetary Science Decadal Survey process. Updated approximately every 10 years, the Decadal Survey identifies what the Academies believe are the most pressing planetary science and astrobiology questions based on input from the wider planetary science community.

In its 2003 Decadal Survey, the Academies noted that the underlying motivation for exploration of Mars is "the possibility that conditions favorable for life may have existed there in the past."[2] Therefore, a sample return mission would be required because it is unlikely that examination of the Martian atmosphere, soil, and rock conducted on the surface of Mars (i.e., an *in situ* examination) could perform the requisite analysis at an acceptable level of scientific certainty to thoroughly answer questions about the planet's geochemistry and climate and ultimately establish whether life does now or did previously exist on Mars. In addition to supporting smaller Mars exploration efforts, the Decadal Survey noted that its Mars Panel "attaches the greatest importance to Mars Sample Return" with its eye on a launch "early in the next decade (2013-2020)."

Similarly, the 2013 Decadal Survey recommended a high-priority focus on Mars exploration efforts, supporting a "Mars Astrobiology Explorer-Cacher" mission as "the first of three components of the Mars Sample Return campaign."[3] The cacher mission was recommended as the "highest priority flagship mission for the decade 2013-2022," intended to perform *in situ* science on the surface of Mars as well as collect samples for future return to Earth as "fundamental advances in addressing the important questions [related to planetary science] will come only from analysis of returned samples."

The 2023 Decadal Survey stated that "the highest scientific priority of NASA's robotic exploration efforts this decade should be completion of Mars Sample Return," noting that the mission "is of fundamental strategic importance to NASA, U.S. leadership in planetary science, and international cooperation and should be completed as rapidly as possible."[4] It also stated that costs needed to be contained so as to not undermine the balance of the planetary portfolio. Specifically, if costs increased by 20 percent or more above $5.3 billion or annual budget requests exceeded approximately 35 percent of the total Planetary Science Division budget, then NASA should work with the Administration and Congress to secure additional funding.

[2] National Research Council of the National Academies, *New Frontiers in the Solar System: An Integrated Exploration Strategy* (2003). The National Research Council was the research arm of the National Academy of Sciences, and in 2015 the institution became the National Academies of Sciences, Engineering, and Medicine.

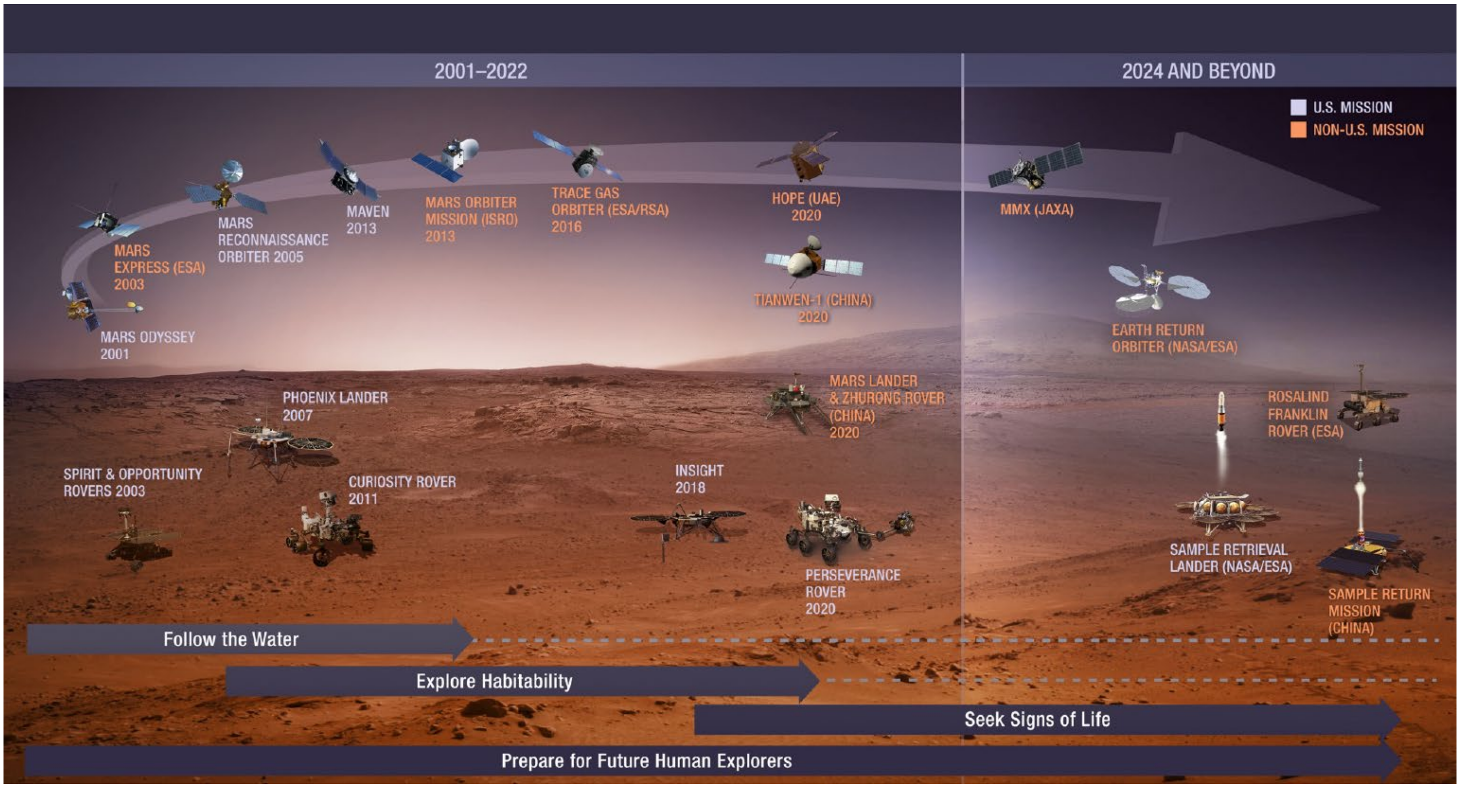
[3] National Research Council of the National Academies, *Vision and Voyages for Planetary Science in the Decade 2013-2022* (2011).

[4] National Academies of Sciences, Engineering, and Medicine, *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032* (2022).

Mars Exploration Program Overview

Since 1994, NASA's efforts to explore Mars through robotic exploration have been led by the Mars Exploration Program (MEP), originally referred to as the Mars Surveyor Program. Figure 2 illustrates MEP missions as well as Mars-related missions from non-U.S. entities since 2001.

Figure 2: Timeline of U.S. and International Mars Missions (as of January 2024)



Source: NASA.

Note: Indian Space Research Organisation (ISRO), Roscosmos (RSA), United Arab Emirates (UAE), and Japan Aerospace Exploration Agency (JAXA).

MEP's long-term science goals are to (1) determine whether life ever existed on Mars, (2) characterize the climate of Mars, (3) characterize the geology of Mars, and (4) prepare for human exploration of Mars. To accomplish these goals, MEP has designed missions to support four science strategies: (1) follow the water, (2) explore habitability, (3) seek signs of life, and (4) prepare for future human explorers. Each mission is intended to inform and support subsequent missions in multiple ways, including the following:

- Scientific discoveries from one mission can drive the formulation of the scientific focus of future missions, for example by acquiring information crucial for the execution of future missions.
- Missions that develop and demonstrate new engineering capabilities can enable future missions, for example new entry-descent-landing capabilities or helicopter flights on other planets.
- Orbiters can enhance the scientific return of landed missions by serving as telecommunication relays for those missions, enabling significant increases in data return.

This linked approach helps MEP achieve a benefit greater than that attained through a series of disconnected, unrelated missions. While some missions contribute to the success of the missions that come after it, this linkage can create a potential vulnerability if the success of a future planned mission relies on the success of preceding missions.

Although the primary goal of the MSR Program is to collect and return Martian samples to Earth, the Program is also an important part of NASA's long-term plans to eventually land humans on Mars and return them safely to Earth. The processes established for a sample return mission will help to address the possible environmental and planetary protection concerns related to one day returning humans from extraterrestrial environments.

Mars Sample Return Campaign

The MSR Program is part of a four-phase campaign to collect, retrieve, return, and examine samples from the surface of Mars. The first phase is currently being accomplished by the Mars 2020 mission and its Perseverance rover which landed on Mars in 2021 and began collecting and caching samples of the Martian surface (see Figure 3).

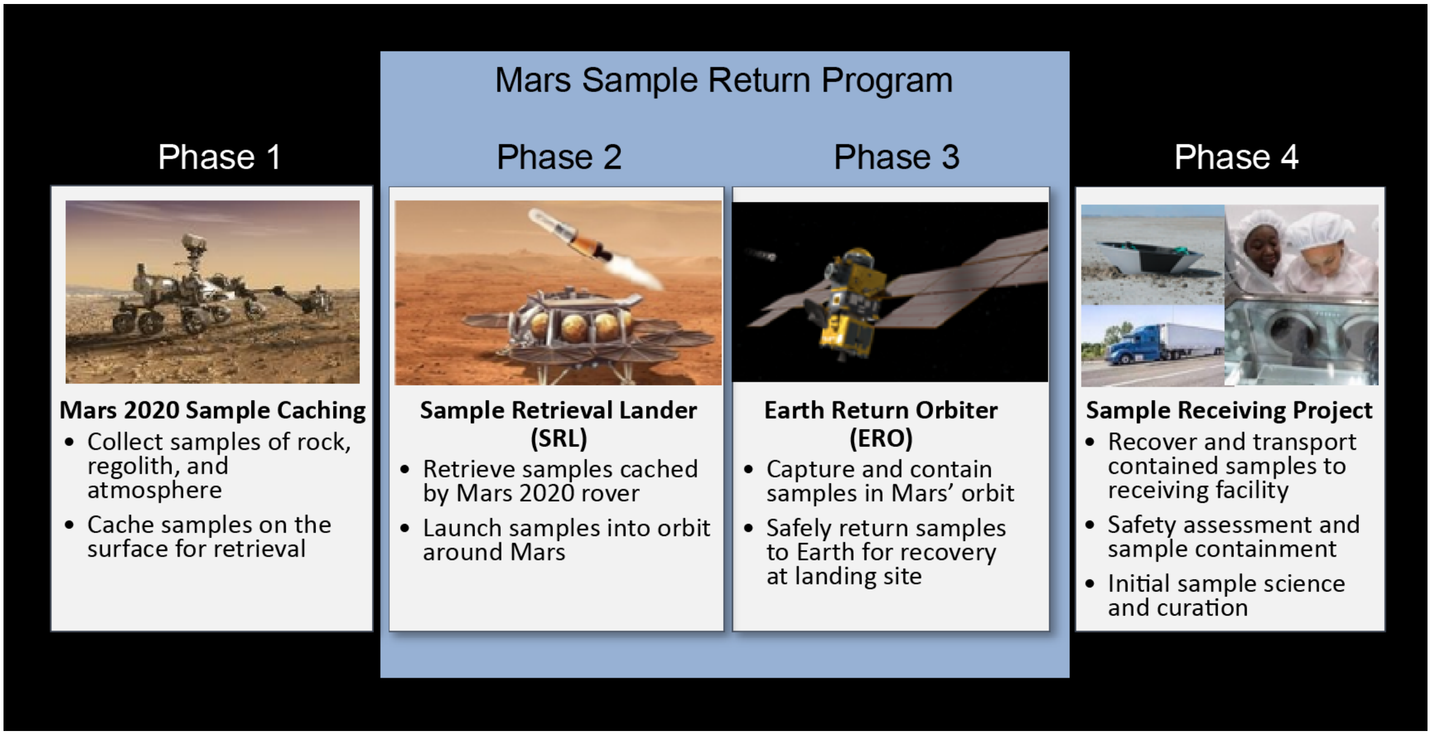
Figure 3: Collection and Cache of Martian Surface Samples by the Perseverance Rover

NASA's Perseverance rover includes 43 sample tubes for the collection of materials for return to Earth. 38 of these tubes are for collecting Mars surface samples, and 5 are "witness tubes" designed to document the cleanliness of the sampling system throughout the mission. To collect each surface sample, the rover drills into a selected area, breaks off a sample, and caps and hermetically seals the sample in a collection tube. Each sealed tube is either stored on board the rover or deposited in a "depot cache" on the planet's surface. The sample tubes can each hold up to 16 grams of material, and not all of the tubes will be filled to capacity. The rover began to collect samples on the surface of Mars in 2021, has already deposited 10 tubes in the sample depot, and continues to collect and store additional samples in its internal cache. See https://mars.nasa.gov/mars-rock-samples/ for additional information regarding the samples collected.

Source: NASA.

The MSR Program represents the second and third phases of the campaign—landing a sample retrieval vehicle on Mars and sending an orbiter to enable the return of the samples to Earth. The final phase will include curation and examination of the samples in laboratories on Earth. Figure 4 outlines the four phases of the MSR Campaign.

Figure 4: Mars Sample Return Campaign (as of January 2024)



Source: NASA.

Mars Sample Return Program

The MSR Program consists of two major flight projects: the Sample Retrieval Lander (SRL) and Earth Return Orbiter (ERO). The SRL includes the components and backups necessary to land on the surface of Mars, transfer samples from either the Perseverance rover or sample depot to the Mars Ascent Vehicle (MAV), and launch the sample container into orbit for return to Earth. The ERO includes the orbiter as well as the Capture, Containment, and Return System (CCRS), which will retrieve the sample container in orbit and return it to Earth. ESA is developing and funding the ERO and Sample Transfer Arm component of the SRL, with NASA developing and funding the remaining components. See Appendix B for a detailed description of the MSR Program's components.

NASA and ESA will separately launch the SRL and ERO, respectively, and then coordinate activities once the payloads arrive at Mars as follows:

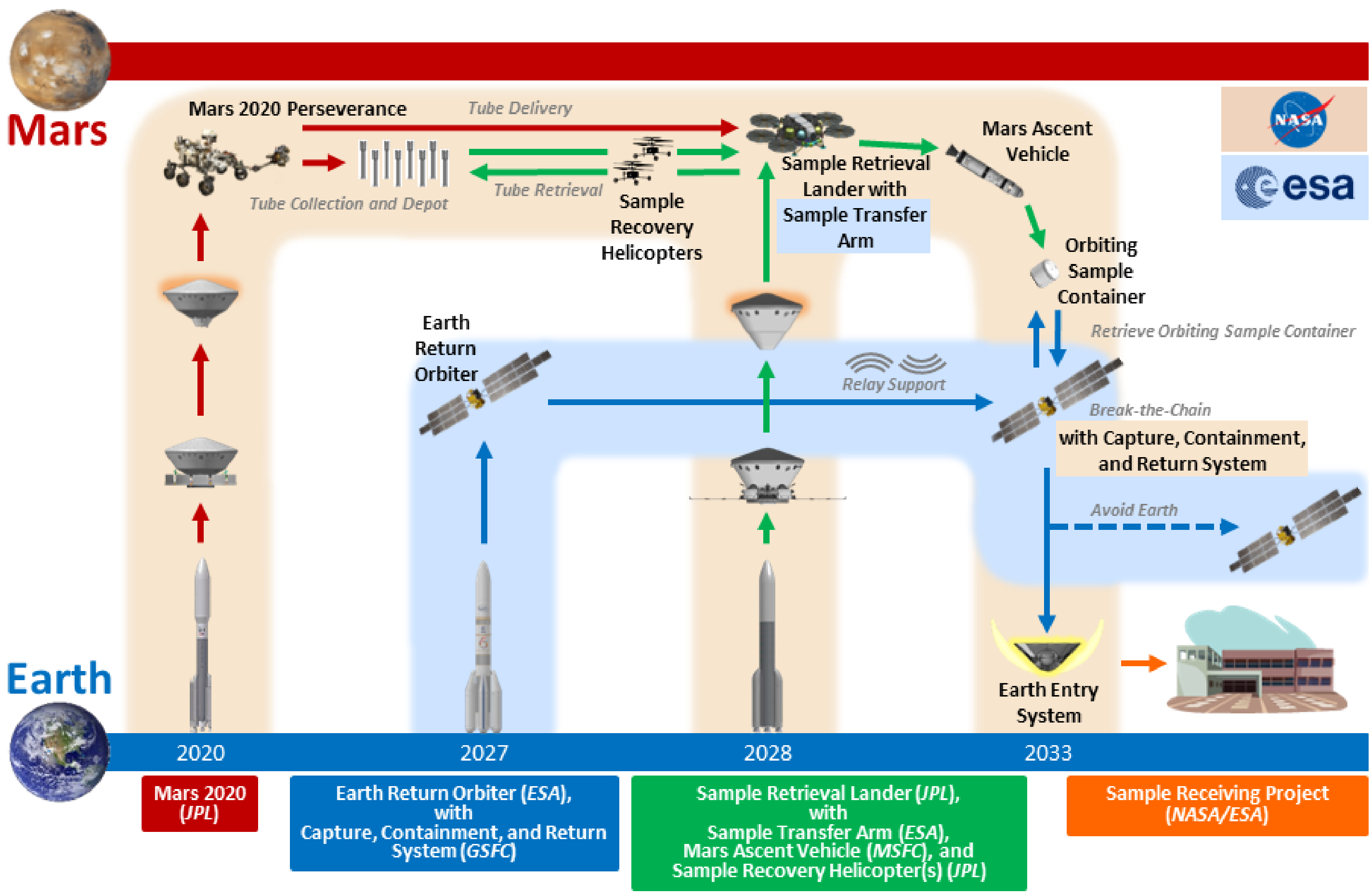
- ERO is scheduled to launch in fall 2027 and arrive in Mars' orbit in late 2029.
- SRL is scheduled to launch in spring/summer 2028 and land on Mars in 2030, transfer samples into the sample container, and then launch the container on the MAV in early 2031. The Perseverance rover is the primary method of delivering samples to the SRL, but Sample Recovery Helicopters will serve as the backup method in the event Perseverance is unable to accomplish this mission.

- ERO will rendezvous with the Orbiting Sample container in orbit. CCRS will capture the container, sterilize its exterior, and deliver it back to Earth via the Earth Entry System in late 2033.

Mission success requires returning samples from Mars and maintaining scientific integrity and containment until the samples are secure on Earth. See Figure 5 for the MSR Campaign's mission architecture and Appendix C for a timeline of significant modifications to date to the SRL and CCRS design architectures.

From a risk perspective, the MSR Program is categorized as a Class A mission. NASA has four risk classifications for its missions, Classes A through D, where Class A are missions with the highest priority, complexity, and cost. See Appendix D for further information on the mission risk classifications.

Figure 5: Mars Sample Return Campaign Mission Architecture (as of July 2023)



Source: NASA.

Note: Goddard Space Flight Center (GSFC), Jet Propulsion Laboratory (JPL), and Marshall Space Flight Center (MSFC).

Planetary Protection

The MSR Program will bring back to Earth the first material samples from another planet.[5] Accordingly, any materials collected on Mars must be returned to Earth in a manner that maintains their integrity for scientific analysis and adheres to international commitments intended to protect Earth's biosphere from extraterrestrial contamination, referred to as backward planetary protection. The most direct way to ensure that protection is achieved is to securely contain the samples during their return to Earth using a "safety first" engineering approach, which is the basis of NASA-ESA planning for the MSR Program. Multiple engineering steps are being designed and tested to "break the chain" of contact between Mars and Earth, shielding Earth's environment from any material from Mars that has not been contained or sterilized.

The legal basis for NASA's current planetary protection requirements is the Outer Space Treaty adopted by the United Nations in 1967, which states that: "Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose."[6]

The Committee on Space Research provides the implementation guidance for the planetary protection requirements outlined in Article IX of the Outer Space Treaty.[7] Both the international community and NASA categorize the MSR Program as a Category V "Restricted Earth Return Mission." For missions in this category, the Committee's guidance places the highest priority on "the absolute prohibition of destructive impact upon return, the need for containment throughout the return phase of all returned hardware which directly contacted the target body or unsterilized material from the body, and the need for containment of any unsterilized sample collected and returned to Earth," with additional requirements for the post-return handling of samples that will impact subsequent phases of the MSR Campaign.[8]

Mars Sample Return Organizational Structure and Governance

NASA's MSR Program Office sits within the Science Mission Directorate at NASA Headquarters. This office is responsible for making Program decisions; determining which MSR projects and components will be designed and built by the Jet Propulsion Laboratory (JPL), NASA Centers, and ESA; and managing planetary protection. JPL has the lead role for implementing MEP's Mars missions and is responsible for managing the MSR Program and ensuring mission success.[9] These MSR activities include coordination

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[5] NASA has retrieved samples from the Moon and an asteroid, but the MSR Program will be the first planetary sample return. Specifically, between 1969 and 1972 six Apollo missions brought back 842 pounds of rocks, core samples, pebbles, sand, and dust from the lunar surface.

[6] The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies—known as the Outer Space Treaty—provides the basic framework on international space law.

[7] Based out of Paris, France, the Committee on Space Research was established in 1958 to promote at an international level scientific research in space, with an emphasis on the exchange of results, information, and opinions, and to provide a forum, open to all scientists, for the discussion of problems that may affect scientific space research. The Committee's objectives are achieved through the organization of scientific assemblies, publications, and other means.

[8] Committee on Space Research, Panel on Planetary Protection, *COSPAR Policy on Planetary Protection* (June 3, 2021).

[9] The California Institute of Technology is a not-for-profit educational institution that operates JPL, a federally funded research and development center.

with ESA, NASA Centers, and their contractors to plan, design, build, test, and integrate MSR components and meet the launch dates.

NASA partnered with ESA by signing a Memorandum of Understanding agreement for the MSR Program in October 2020 which defines each party's responsibilities for the MSR Program and their coordination efforts. ESA's Mars Exploration Group is responsible for the completion and launch of the ERO project and delivery of the Sample Transfer Arm to the SRL project along with other ground and flight components. JPL is developing the SRL project while NASA's Goddard Space Flight Center (Goddard) and Marshall Space Flight Center (Marshall) are developing the CCRS and MAV, respectively. NASA's Launch Services Program is responsible for procuring a launch vehicle for the SRL.

Optimal Launch Schedule and Planetary Conditions

The transit time between Earth and Mars depends on the two planets' relative proximity at the time of launch as well as payload mass and orbital approach requirements. Transit times from previous Mars missions averaged from 144 days (Mariner 6 and 7, 1969) to 348 days (Viking 1 and 2, 1975).[10] Recent Mars missions like the Mars Reconnaissance Orbiter and Mars 2020 averaged just over 200 days.[11] The optimal time to launch an object from Earth to Mars is when the orbits of the two planets are most closely aligned with each other, known as "opposition," as this proximity reduces the amount of fuel and time required to reach the destination. Earth and Mars come into opposition approximately every 26 months.

In addition, operations on the surface of Mars are limited by positional and weather-related factors. For example, when missions include solar powered components, the orientation of Mars and the location of operations on the surface in relation to the Sun is a key element to ensuring that seasons where the Sun is not directly striking the relevant surface of the planet (similar to winter in Earth's northern hemisphere) are avoided. Most significantly, during surface operations it is extremely important to prevent any buildup of dust on the solar panels that might interfere with solar energy collection. Mars has a predictable dust storm season during which operations would be impaired or impossible.[12] Mars' position in space relative to Earth also affects mission communications and data transfer during transit and surface operations since signals can be lost or degraded over longer distances or if obstructed by other celestial bodies.

The MSR Program determined that for a solar-powered SRL, if the 2028 launch date is not met, the next best launch window to retrieve the same quantity of samples is in 2035.[13] This is due to planetary alignment and conditions on Mars that would negatively affect surface operations. However, extending launch dates too far into the future may result in a launch date at or beyond the end of the useful life of

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[10] Running from 1962 to 1973, the Mariner missions consisted of 10 spacecraft designed to explore and visit for the first time Venus, Mars, and Mercury. Launched separately in 1969, Mariner 6 and 7 completed a flyby over Mars' equator and south polar region, analyzed the Martian atmosphere and surface with remote sensors, and recorded and relayed hundreds of pictures. Launched separately in 1975, Viking 1 and 2 were the first U.S. missions to land on Mars. The landers took photographs, collected science data on the Martian surface, and conducted experiments to look for possible signs of life.

[11] Launched in 2005, the Mars Reconnaissance Orbiter has studied the Martian atmosphere and terrain from orbit since 2006 while also serving as a key data relay station for other Mars missions.

[12] The most significant environmental concern for missions operating on Mars during its dust storm season is the degree to which dust suspended in the atmosphere or built up on the solar panels reduces the amount of solar radiation received by the panels, thereby reducing available electrical power for the equipment.

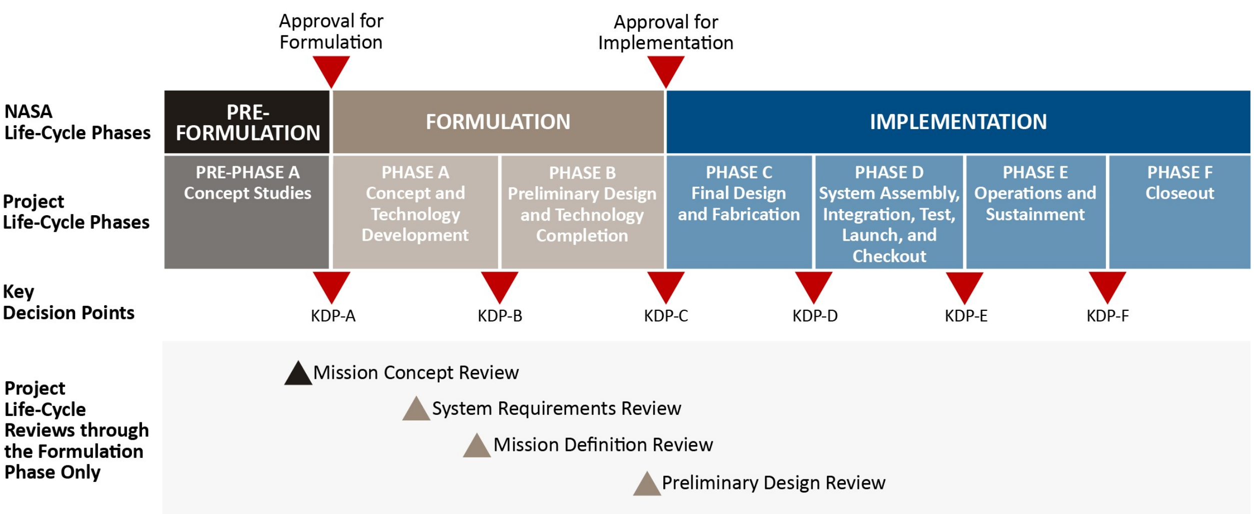
[13] Other options for SRL operations, including the use of a radioisotope power system, could enable other launch opportunities.

the Perseverance rover, shifting more of the burden for sample recovery onto the two Sample Recovery Helicopters which are currently intended as a backup system. If the helicopters become the primary retrieval method, it may be necessary to incorporate an additional backup system—requiring additional design effort, development time, and cost—to enhance the probability of mission success.

NASA's Program/Project Life Cycle

NASA's standard program and project life cycle, illustrated in Figure 6, includes three fundamental phases: Pre-Formulation (preceding Phase A), Formulation (Phases A and B), and Implementation (Phases C through F). To proceed from one phase to the next, programs and projects must receive approval from the appropriate Decision Authority at designated Key Decision Points (KDP) that serve as checkpoints (or "gates") through which programs and projects must pass during their development.

Figure 6: NASA Program and Project Life Cycle



Source: NASA OIG presentation of information from NASA Procedural Requirements 7120.5F, *NASA Space Flight Program and Project Management Requirements w/Change 2* (August 3, 2021).

Pre-Formulation. This phase allows programs and projects to conduct initial feasibility studies—including identification and assessment of key technologies and development of initial budgets and schedules—and examines the proposed mission's objectives and concept for meeting those objectives.

Formulation. During this phase, programs and projects develop and complete the requirements for a successful System Requirements Review and Mission Definition Review, ensuring proposed requirements, system architecture, and all functional elements will satisfy the mission. At KDP-B, programs and projects with an estimated life-cycle cost of $1 billion or greater establish cost and schedule estimates. To establish these estimates, programs and projects conduct a probabilistic analysis of development cost and schedule risks to produce a Joint Cost and Schedule Confidence Level that measures the likelihood of completing all remaining work at or below the budgeted levels.[14]

[14] NASA generally requires programs and projects to develop budgets consistent with a 70 percent Joint Cost and Schedule Confidence Level—in short, a 70 percent likelihood the program or project will launch on cost and on the planned schedule.

Additionally, a Preliminary Design Review (PDR) demonstrates the intended design is correct and complete and meets all system requirements within acceptable risk, cost, and schedule constraints. To proceed to the start of the Implementation Phase, NASA programs and projects must pass through KDP-C including a final assessment of the preliminary design, a determination of whether the program or project is sufficiently mature, and the establishment of cost and schedule baselines.[15]

NASA's Space Flight Program and Project Management Requirements include the following developmental efforts during the Formulation Phase:[16]

- Identifying how the program or project supports the Agency's strategic goals.
- Assessing feasibility, technology, and concepts.
- Performing trade studies.
- Assessing and possibly mitigating risks based on risk-informed decision-making and continuous risk management processes.
- Maturing technologies.
- Building teams.
- Developing system-level preliminary designs.
- Developing operations concepts and acquisition strategies.
- Establishing high-level requirements, requirements flow down, and success criteria.
- Assessing the relevant industrial base and supply chain to ensure program or project success.
- Preparing plans, cost estimates, budget submissions, and schedules essential to the success of a program or project.
- Establishing control systems to ensure performance of those plans and alignment with current Agency strategies.

Implementation. This final phase is focused on preparing vehicles and payloads for launch and space flight, conducting operations, and closing out programs and projects.

The SRL and CCRS projects are required to satisfy NASA's various reviews and gate requirements but each may do so on its own schedule, independent of the other project. The overall MSR Program moves from one phase to the next when all projects within the Program have successfully met their individual milestone requirements. Consistent with this approach, NASA has not required the projects to develop, nor has it approved, individual project cost and schedule baselines; only an MSR Program-level cost and schedule baseline will be developed and approved.

With substantial effort expended in developing the MSR Program's plans and approach during the Pre-Formulation Phase from fiscal years (FY) 2016 through 2021, the Program was authorized to proceed into Formulation Phase A (Concept Development) following a Mission Concept Review in

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[15] These baselines are referred to as the Agency Baseline Commitment, which is the cost and schedule baseline committed to Congress and the Office of Management and Budget against which a program or project is measured.

[16] NASA Procedural Requirements 7120.5F, *NASA Space Flight Program and Project Management Requirements w/Change 2* (August 3, 2021).

October 2020 and an Agency Program Management Council meeting in December 2020.[17] A System Requirements Review/Mission Definition Review was conducted in July 2022. Following another meeting with the Council in September 2022, the MSR Program was authorized to proceed into Formulation Phase B (Preliminary Design) with a preliminary life-cycle cost estimate of $5.9 to $6.2 billion and launch windows in October 2027 for ERO and June to July 2028 for SRL.

Mars Sample Return Program Funding

Historically, Congress has demonstrated strong financial support for the MSR Program. The Program was first given its own section in NASA's annual budget request in FY 2022, and beginning that year, congressional appropriations language noted the level of funding "provides no less than the request level for Mars Sample Return" even though the Agency as a whole received less than its full requested amount.[18] Similar language was included in NASA's FY 2023 appropriation. See Appendix E for funding information on the MSR Program, as well as other related funding requests and allocations, for FYs 2021 to 2024.

Recent events, however, suggest that this level of congressional support is unlikely to continue in future years. For example, an agreement reached between the White House and Congress in June 2023 to raise the federal debt ceiling proposed to cap federal FY 2024 non-defense spending at no more than the FY 2023 level and then increase it by up to 1 percent in FY 2025.

In the FY 2024 President's budget request submitted to Congress in March 2023, NASA requested $949.3 million for MSR, a 15.4 percent increase over its FY 2023 funding level. Additionally, FY 2024 appropriations language proposed by the Senate expressed concern about the current cost and status of the MSR Program and its potential impact on other NASA missions. Instead of the $949.3 million NASA requested, the Senate Appropriations Committee's recommended funding level for FY 2024 was "not less than $300,000,000 for MSR," noting that if NASA cannot execute the MSR Program "within the $5,300,000,000 budget profile, NASA is directed to either provide options to descope or rework MSR or face mission cancellation."[19] For NASA to provide full funding to the MSR Program in a year when the Agency receives less than its overall full funding request, other programs will be required to make up the difference through reductions, potentially impacting the spending plans, schedules, and related success of other science projects in the Agency's portfolio. For example, the delay in the Psyche mission

[17] The Agency Program Management Council serves as the Agency's senior decision-making body regarding the integrated Agency mission portfolio and provides oversight over the programmatic and technical capabilities needed to execute NASA's mission. NASA's Associate Administrator chairs the Council.

[18] Consolidated Appropriations Act, 2022, Pub. L. No. 117-103 (2022).

[19] S. No. 118-62, at 151 (2023). $5.3 billion is the cost limit outlined in the 2023 Decadal Survey for MSR. While we have not extensively reviewed the National Academies' cost estimating process, we note several issues with this estimate. For example, it was developed from 2020 to late 2021 and includes an assumption of inflation at 2 percent which is far below actual inflation rates in the range of 5 to almost 9 percent from mid-2021 to early 2023. The Decadal Survey's estimate also includes a sample receiving facility, which is not included in the MSR Program's scope or cost estimates, and assumes an ESA-provided Sample Fetch Rover (not included in the Decadal Survey cost), which was descoped in the summer of 2022 and replaced by NASA-developed Sample Recovery Helicopters. Additionally, the $5.3 billion funding level is not a life-cycle cost estimate as it includes only those costs incurred during the 2023 to 2032 Decadal Survey period and not costs incurred outside this period.

affected the Venus Emissivity, Radio Science, InSAR, Topography and Spectroscopy mission, resulting in a postponement of that mission's launch of at least 3 years from 2027.[20]

As of February 2024, the total amount of funding for MSR in FY 2024 remains uncertain. Congress passed multiple appropriations bills allowing NASA to continue operating in FY 2024 at its FY 2023 funding level, first through November 17, 2023, then through February 2, 2024, and most recently through March 8, 2024.[21] However, an additional appropriation will be required to provide funding for operations after March 8, and the amount, duration, and any other potential requirements or restrictions associated with that appropriation are currently unknown. Because of the funding environment noted above, a reduction below the FY 2023 level for the remainder of FY 2024 is anticipated. As a result of the current budget uncertainty and to preserve funding until a final FY 2024 appropriation is enacted, NASA recently directed the MSR Program to reduce its spending as much as possible and plan for an orderly stand down of the CCRS following completion of that project's PDR in December 2023.

Relevance of Mars-Related International Exploration Efforts

Science Mission Directorate officials acknowledged that maintaining a leadership position in space exploration generally and Mars exploration specifically is an important consideration in the timing of, and investment in, the MSR Program. Accordingly, ongoing activities by other countries such as China are relevant to the Program's mission schedule, particularly missions intending to retrieve Martian surface samples.

In May 2021, China landed a rover on the surface of Mars that operated until May 2022 when it was placed into hibernation; however, it did not wake up in December 2022 as intended.[22] It is believed that dust storms and the Martian winter reduced temperatures and sunlight below levels where the rover could function, and as of January 2024 it is unclear if the rover could become operational again at some point in the future. China's future Mars exploration efforts appear to include a lander and sample collector with a launch possible in the 2028- to 2030-time frame.[23] It would be logical to assume that the same surface environment conditions the MSR Program is facing would also impact China's plans to launch a Mars sample retrieval mission. Moreover, some scientists question China's ability to retrieve samples comparable in scientific value to the MSR Program. Specifically, NASA senior leadership's understanding of China's concept for a Mars sample return mission would limit it to collecting and retrieving material within the immediate reach of the lander, compared to NASA's scientifically-selected

[20] The Psyche mission launched in October 2023 to visit a unique metal-rich asteroid orbiting the Sun between Mars and Jupiter. The 2023 Psyche Mission Independent Review Board determined that an imbalance between the workload and available resources at JPL was a root cause of issues contributing to the mission's launch delay and adversely affected all flight project activity at the Center. The Venus Emissivity, Radio Science, InSAR, Topography and Spectroscopy mission will explore Venus to gather data on how the evolutionary paths of Venus and Earth diverged.

[21] The Continuing Appropriations Act, 2024 and Other Extensions Act, Pub. L. No. 118-15 (2023) provided funding for NASA's operating expenses through November 17, 2023. The Further Continuing Appropriations and Other Extensions Act, 2024, Pub. L. No. 118-22 (2023) provided additional funding through February 2, 2024. The Further Additional Continuing Appropriations and Other Extensions Act, 2024, Pub. L. No. 118-35 (2024) provided additional funding through March 8, 2024.

[22] Tianwen-1 is China's first Mars mission, consisting of an orbiter and a rover named Zhurong. The mission intended to search for pockets of water using a radar on the rover.

[23] Josh Dinner, *Space.com*, "China just might add a helicopter and 6-legged robot to Mars sample-return mission" (April 28, 2023).

approach. Therefore, China's mission requirements would be less complex than NASA's, allowing them to take advantage of earlier launch windows with more restrictive surface environment conditions.

The next missions expected to arrive at Mars are India's Mars Orbiter Mission 2 and ESA's ExoMars Rosalind Franklin mission, planned to launch in 2024 and 2028, respectively.[24] Neither mission is designed to retrieve samples.

A Uniquely Challenging and Complex Mission

All aspects of the MSR Program's intricate architecture and multiple interdependent components make it one of the most technically challenging missions NASA has ever undertaken, not only compared with other planetary missions but relative to all science and human space flight missions. Whereas a typical NASA science mission gathers data, the MSR Program is primarily an engineering endeavor where mission success is based solely on successfully returning surface samples from Mars to Earth for analysis. To maximize the quality and quantity—and thereby value—of samples returned, NASA is undertaking an aggressive schedule to take advantage of optimal launch windows and Martian surface conditions; but as a result, any delays will significantly impact cost and potentially the number of samples returned. An already compressed 5-year development time frame, when compared with other NASA flagship missions that average 7 years, leaves the MSR Program little flexibility to address significant challenges that may arise during formulation and development.[25] With a development end date constrained by limited launch windows for Mars missions, any additional time spent in formulation further reduces the amount of time available for development.

NASA and ESA are working towards an unprecedented number of first-of-its-kind undertakings in this one program. These include the following:

- A high-precision touch down of the largest lander on Mars to date.
- A sample collection with transfer of sample tubes from one vehicle to another on the Martian surface.
- The first rocket launch from another planet.
- A partially autonomous Mars orbital rendezvous and capture, described by one Program official as "catching a football in space."
- Robotic sample handling and sealing to break-the-chain standards (i.e., anything coming from Mars is sealed within a container whose exterior is free of dust).
- Departure from Mars' orbit on an Earth-return trajectory.
- Safe atmospheric entry and landing on Earth under restricted return constraints (i.e., backward planetary protection).
- The most powerful electric propulsion system to date for an interplanetary mission.
- The largest spacecraft to ever orbit Mars.

[24] A follow-on to the Indian Space Research Organisation's first Mars mission, the Mars Orbiter Mission 2 spacecraft will study the Martian atmosphere, environment, and interplanetary dust on the planet. The ExoMars program consists of two missions, the first of which launched in 2016, to search for evidence of atmospheric gases and signs of life on Mars.

[25] Flagship missions are the highest costing and most capable large strategic science missions designed to answer the most compelling and challenging questions.

Moreover, the MSR Program is producing seven significant engineering developments and one critical technology along with a number of component interfaces required for mission success—as depicted by the red, green, blue, and orange arrows in Figure 5. These challenges, in conjunction with external factors such as operational and funding considerations, make MSR a uniquely complex mission.

Successfully carrying out these and other mission-critical events, in many cases using newly developed systems based on not-yet-proven technologies with stringent design and performance requirements, highlights the substantial technical challenges and risks facing the MSR Program.

Lack of a Stable Design Is Impairing the MSR Program's Ability to Establish a Realistic Life-Cycle Cost and Schedule Estimate

NASA programs and projects often face challenges in rightsizing their scope and establishing realistic life-cycle cost and schedule estimates during mission formulation. A properly executed Formulation Phase ensures programs and projects proceed into development with a stable design and realistic cost and schedule. However, the MSR Program is facing significant obstacles to accomplishing this in a timely and effective manner. As it prepares to recommend a life-cycle cost and schedule baseline in the coming months at KDP-C, the Program is faced with a series of significant challenges:

- The ongoing effects of questionable early architecture and design decisions.
- At least a 7-month delay in completing its Formulation Phase.
- Acknowledgement that it will likely not meet its launch schedule of 2027 for the ERO and 2028 for the SRL.
- Significant growth in cost estimates during formulation, specifically increases from a life-cycle cost estimate of $6.2 billion at KDP-B in September 2022 to an unofficial estimate of $7.4 billion as of June 2023.
- Operational differences with ESA that are impacting MSR Program execution.
- The need to address recommendations made by an Independent Review Board (IRB) in September 2023 regarding modifications to specific mission designs.

Until the MSR Program design is stable, a realistic cost and schedule baseline commitment cannot be established.

Capture, Containment, and Return System Design Issues Delayed Completion of Program Formulation Phase

CCRS Preliminary Design Review Was Delayed

The CCRS is designed to capture and sterilize the Orbiting Sample container, seal it in a secondary container, and return the samples to Earth. CCRS is being integrated into and launched as part of ESA's ERO project. The MSR Program delayed the PDR for CCRS to simplify the design and address technical challenges including backward planetary protection strategy, containment assurance, ERO mechanical interfaces, and changes to the Orbiting Sample container. Originally scheduled for October 2022, CCRS's PDR was delayed several times and was held in December 2023. A partial PDR, PDR-1, was conducted in

December 2022; however, the MSR Program could not complete formulation and proceed to KDP-C until the CCRS design successfully passed PDR-2.[26]

Mars Sample Return Orbiting Sample Container Concept Model

NASA's Orbiting Sample container will hold tubes of Martian rock and soil samples that will be returned to Earth through the Mars Sample Return Campaign. At right is the lid and at bottom left is a model of the sample holding tube. The sample container, at top left, will hold the tubes and help keep its contents at less than about 86° Fahrenheit to preserve the Mars material in its natural state.

Source: NASA/JPL-Caltech.

In January 2023, based on the results of CCRS PDR-1, the Goddard Standing Review Team raised a key concern regarding the CCRS design, noting "[t]he objective evidence indicates that the current delivery dates cannot be achieved without further simplification of the design and without taking significant development work out of the baseline."[27] In January 2023, CCRS project management reported that CCRS was in a highly constrained position when considering technical, cost, and schedule issues, and that the baseline architectural design was not achievable, particularly at a risk level appropriate for the Program. They advised the architectural redesign must be accomplished quickly and may require a combination of actions determined jointly by the CCRS project, the MSR Program, the Science Mission Directorate, and ESA to identify a path forward for a successful CCRS PDR-2 in December 2023.

The CCRS's design initially incorporated a complex aseptic heat sterilization system to meet backward planetary protection requirements.[28] Specifically, a small amount—less than 0.02 grams—of Martian dust on the outside of the Orbiting Sample container will need to be sterilized before the container and its samples are returned to Earth. To simplify the design, in March 2023 the MSR Program changed the sterilization system requirements from aseptic heat treatment to one that instead utilizes ultraviolet radiation (see Figure 7 for an illustration of the CCRS's initial simplified design).[29] While the MSR Program Director approved this change, the ultraviolet method must be scientifically studied to determine sterilization effectiveness and the specific ultraviolet technology selected by CCRS project management must be matured by engineering assessment before space application.

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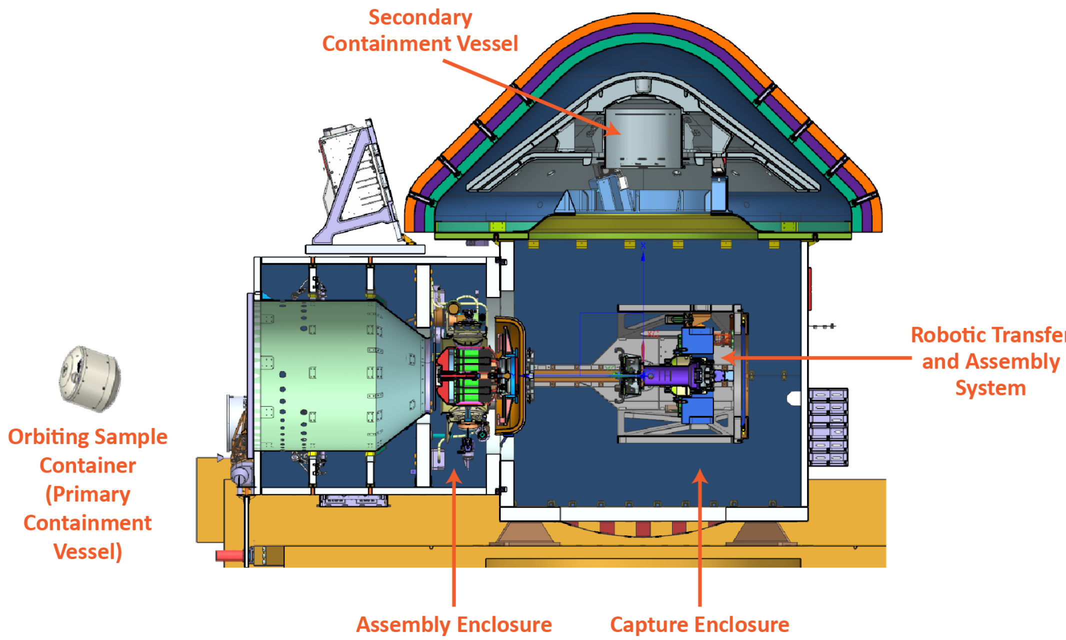
[26] NASA split the CCRS PDR into two parts, PDR-1 and PDR-2.

[27] The Goddard Standing Review Team, different from the Program's Standing Review Board, is the review board for the CCRS PDR.

[28] Sterilization is the process used to eliminate—through removal, inactivation, or destruction—all living microorganisms and viruses. Aseptic sterilization utilizes heat for a prescribed period to destroy all microorganisms present on the surface of an article such as hardware or substances returned to Earth from another planet.

[29] Ultraviolet light is a type of electromagnetic radiation transmitted in waves and falls on the spectrum between visible light and x-rays. The radiation emitted by ultraviolet light can be used to destroy the structure of microorganisms and inactivate living cells. This type of sterilization reduces risk to sample integrity compared to using heat, but its effectiveness can be influenced by multiple factors including its wavelength, the temperature, the type of microorganism, and ultraviolet intensity.

Figure 7: Initial Simplified Design of the Capture, Containment, and Return System (as of March 2023)



Source: NASA OIG presentation of Agency information.

In CCRS project management's judgment, the delayed PDRs for both CCRS and the MSR Program resulted from multiple factors, the most significant being inadequate concept maturity development during pre-formulation related to the CCRS's complex architecutural design and the lack of an adequate scientific study and engineering assessment to comply with NASA's backward planetary protection requirements.

From CCRS project management's perspective, both CCRS and the MSR Program would have benefitted by beginning the current backward planetary protection study at least 4 years earlier during pre-formulation rather than in 2023. CCRS estimates the delayed PDR due to technical issues and the restructuring of the project's architecture will add approximately $200 million to the budget and result in one year of lost schedule. This delay also threatens the MSR Program's ability to proceed into development, which will likely significantly delay the launch schedule.

Ongoing Pre-Formulation Guidance Issues with NASA's Flagship Missions Also Affect MSR Program

The problems currently experienced by the MSR Program that are due to inadequate guidance during pre-formulation are an example of an ongoing issue also experienced by several of NASA's previous flagship missions. Historically, NASA's largest missions have presented the Agency significant challenges in managing cost growth and schedule delays. Accordingly, the Science Mission Directorate conducted an internal study of its large missions from October 2019 to October 2020 to examine how NASA makes critical decisions that impede or support mission and programmatic success. Two of the lessons identified by this study have relevance to CCRS's technical issues and the project's delayed formulation:

- First, large strategic missions require greater priority, resources, and attention during the pre-formulation period when key architecture decisions are made.
- Second, whereas practices and processes for Phases A through F are well-defined in existing Agency/Science Mission Directorate documentation, comparatively little guidance exists to guide activities undertaken during the pre-formulation period.

The Large Mission Study was completed in October 2020 during the MSR Program's Pre-Formulation Phase which ended in December 2020. Therefore, the results and recommendations from the study were not available during the MSR Program's pre-formulation process. However, since the study's completion, NASA has yet to incorporate the results and recommendations into its practices and guidance for executing flagship missions. While there are differing opinions in the project management and execution community regarding the level of guidance and resources that should be applied to large missions during pre-formulation, the results of the Large Mission Study and the ongoing issues with the MSR Program suggest that NASA should formally reconsider its current practices.

Schedule Delays in Completing Formulation

The MSR Program is currently at least 7 months behind schedule in completing its Formulation Phase. The KDP-B Decision Memorandum set a KDP-C date for MSR of August 2023, but CCRS did not complete its PDR until December 2023. Following the CCRS PDR, the MSR Program needs to complete a Program-level PDR and then proceed to KDP-C where its cost and schedule baseline commitments will be established. The Program's current master schedule anticipates 1 month between the CCRS PDR and the Program-level PDR followed by 2 months until KDP-C. Applying these lead times to the December 2023 CCRS PDR date results in a Program-level KDP-C no earlier than March 2024 (or 7 months later than planned). Changes in the Program's major milestones have been reflected each year in the Agency's annual budget requests (see Table 1).

Table 1: Key MSR Program Milestone Dates from NASA's Annual Budget Requests

Event	FY 2022 Request	FY 2023 Request	FY 2024 Request
Mission Concept Review	October 2020	N/A	N/A
Key Decision Point A	December 2020	N/A	N/A
System Requirements Review	August 2021	April 2022	April 2022
Key Decision Point B	September 2021	June 2022	September 2022
Preliminary Design Review	August 2022	May 2023	No earlier than June 2023
Key Decision Point C	September 2022	July 2023	No earlier than Quarter 1, FY 2024
Critical Design Review	September 2023	April 2024	No earlier than June 2024
Key Decision Point D	July 2024	November 2025	No earlier than January 2026
SRL Launch	July 2026	July 2028	No earlier than June 2028
ERO Launch	August 2026	August 2027	No earlier than October 2027

Source: NASA OIG presentation of NASA annual budget requests.

Initial plans for the MSR Program included launches for both the SRL and ERO in 2026. However, analysis conducted by an IRB in late 2020 determined that "[t]he current 2026 launch schedules for SRL and ERO are judged by the IRB to not be consistent with Class A/Category 1 missions. The program should be replanned for SRL and ERO launches in 2028, with the potential of a 2027 ERO launch."[30] During the Program's December 2020 KDP-A review by the Agency Program Management Council, these launches remained planned for 2026 although the Science Mission Directorate leadership described the schedule as "challenging." By the Program's System Requirements Review in July 2022, planned launch dates were adjusted to reflect an ERO launch in October 2027 with SRL following in June 2028. Even considering these changes, the Standing Review Board (SRB) conducting that review reported its concerns about the Program's schedule in its findings: "Schedules seem aggressive and optimistic" and "Schedule challenges could drive cost growth."[31] As of January 2024, this launch schedule has yet to be adjusted.

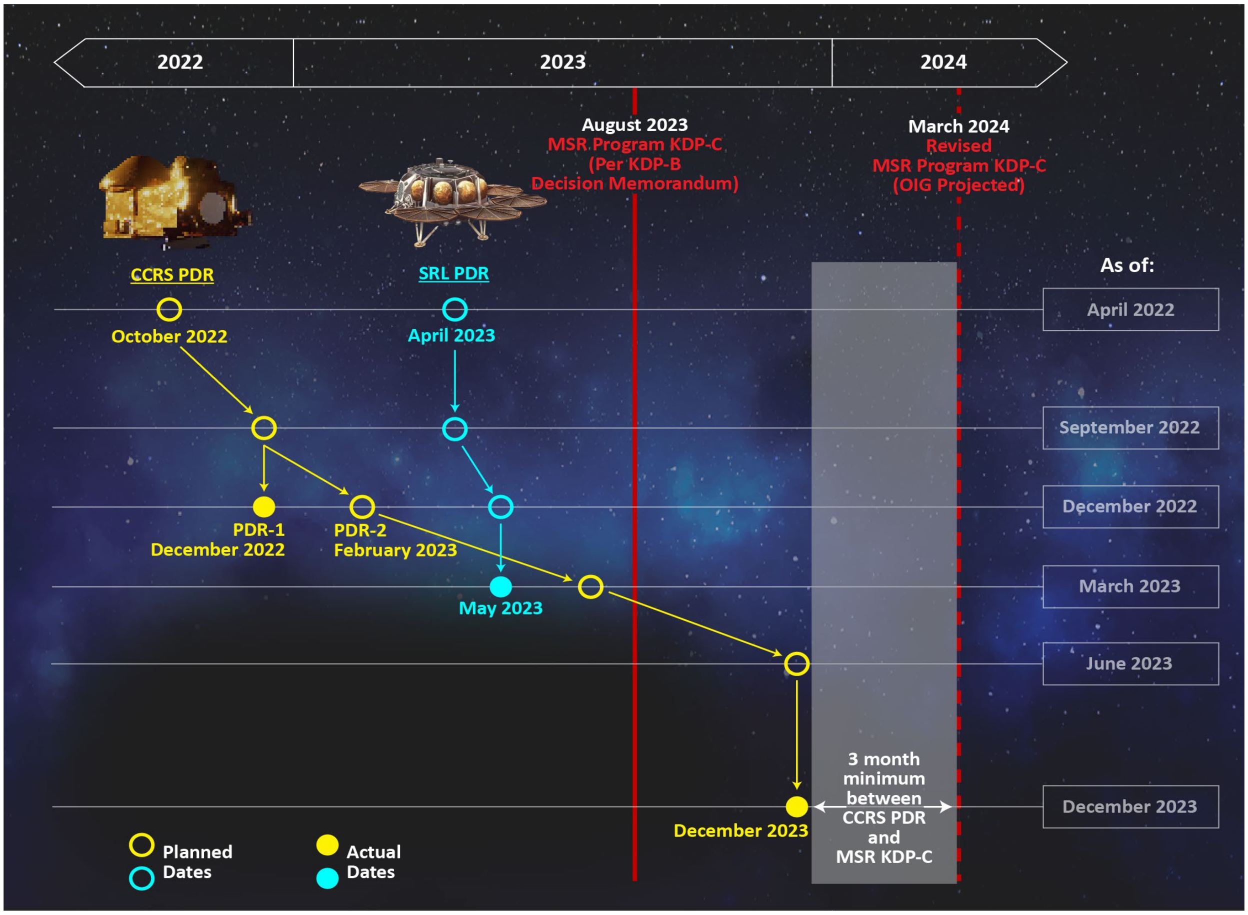
However, milestones for the MSR Program's projects have shifted as they consumed available schedule margin to accommodate changes in design plans and architecture.[32] Although the SRL has experienced some minor schedule shift, the majority of the shift is with CCRS (see Figure 8).

[30] NASA established the IRB in August 2020 to evaluate the technical, cost, and schedule plans prior to confirmation of the mission's design.

[31] An SRB is composed of independent experts who provide assessments of a program's or project's technical and programmatic approach, risk posture, and progress against the program or project baseline and offer recommendations to improve performance or reduce risk from formulation through development. An SRB differs from an IRB in that an SRB is an advisory body that follows a project through its life cycle and is responsible for conducting life-cycle reviews while an IRB is commissioned by a Convening Authority with a specific scope and finite duration to evaluate specific concerns about a project.

[32] Space flight programs and projects routinely encounter technical difficulties during development that cause delays, and therefore it is a best practice to build extra time or margin into the schedule to accommodate for these delays.

Figure 8: Schedule Shift over Time for CCRS and SRL Projects (as of December 2023)



Source: NASA OIG presentation of Agency data.

The CCRS PDR consistent with a 2027 ERO launch date was previously scheduled for October 2022. After conducting status reviews in the fall of 2022, Science Mission Directorate leadership decided to split what is typically a single PDR into two. The first session (PDR-1) was held in December 2022 and focused on systems engineering and related project elements. The second session (PDR-2) was scheduled for February 2023 to focus on flight segment and programmatic items. But before the second PDR took place a report from the Goddard Standing Review Team evaluating CCRS's progress stated that the current delivery dates could not be achieved, postponing the PDR-2 until December 2023.

Even though both NASA and ESA pushed forward on development tasks for non-CCRS components (ERO, SRL, and MAV) while CCRS worked towards its PDR, overall the MSR Program has experienced inefficiencies as components have grown out of phase with each other (e.g., the ERO is significantly ahead of development compared to CCRS). Moreover, by proceeding with development activities prior to establishing a baseline commitment at KDP-C, the Program further commits the Agency to spending development funds on a program that has yet to receive authorization to proceed from the Formulation Phase to the Implementation Phase.

Latest Life-Cycle Cost Estimate Is Not Realistic

Of particular concern is the trajectory of the life-cycle cost estimates for the MSR Program. At a July 2020 press conference just prior to the launch of the Mars 2020 mission, NASA reported an early cost estimate for the MSR Program of $2.5 to $3 billion, noting this amount would likely be adjusted as the result of additional analysis that would be conducted during the Program's formulation.[33] Since that time, the Program's estimated cost has steadily increased. By Mission Concept Review in October 2020, the estimate had grown to $3.6 billion, and by KDP-B in September 2022 the estimate was revised to $6.2 billion. As of June 2023, MSR Program officials acknowledged a life-cycle cost estimate of $7.4 billion to stay on the launch schedules planned at KDP-B. This figure is nearly three times NASA's July 2020 cost estimate and more than double the amount estimated at Mission Concept Review.

While the MSR Program provided us the rough life-cycle cost estimate of $7.4 billion, they did not provide details explaining the $1.2 billion increase from the $6.2 billion estimate established at KDP-B. According to Program management, the $7.4 billion figure is a pre-PDR estimate based on multiple rounds of "grass roots" estimates.[34] Absent an accurate breakdown of the differences between the two figures—which was not available during the course of our audit—we were not able to assess the accuracy of the $7.4 billion figure. However, given the number and significance of cost increase indicators to date, we are concerned that the $7.4 billion estimate is premature and may be insufficient.[35] These cost increase indicators include the following:

- Unpredictable and unanticipated high levels of inflation and supply chain price increases stemming from the COVID-19 pandemic.
- An additional $250 million in funding for FY 2024 and FY 2025 as requested by the MSR Program.
- A $200 million cost increase identified by the CCRS team.
- An increase of at least $45 million requested by one of the MAV rocket contractors.
- A $180 million increase to provide two Sample Recovery Helicopters. Costs for a backup sample retrieval method were shifted from ESA to NASA when ESA's fetch rover, initially planned for sample retrieval on the Martian surface, was removed in 2022 and replaced by two helicopters to be provided by NASA.
- Higher than typical cost margins requested by the CCRS (38 percent) and SRL (33 percent) teams when establishing their cost estimates for PDR.[36] Per Center guidelines, projects based at Goddard (CCRS) and JPL (SRL) should carry a minimum cost margin of 25 percent.[37]

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[33] MSR Program cost estimates do not include costs related to ESA investments or a future sample receiving facility.

[34] Grass roots estimating establishes a more detailed cost estimate by providing costs for each activity in the project schedule.

[35] The September 2023 IRB report stated that the complexity of the MSR mission would drive costs to between $8 billion to $11 billion.

[36] Cost margins are the allowances carried in a program's or project's budget to account for unexpected issues and risks. Margins are allocated in the formulation process based on assessments of risks and are typically consumed as the program/project proceeds through the life cycle.

[37] Goddard Procedural Requirements 7120.7B, *Funded Schedule Margin and Budget Margin for Flight Projects* (September 17, 2018), and Jet Propulsion Laboratory Document 58032, *Flight Project Practices, Rev. 14* (April 20, 2022).

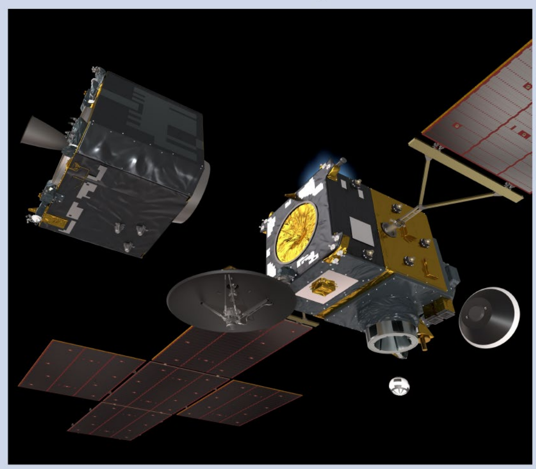
- Increased cost margin requests from CCRS and SRL, along with delays in the Program-level PDR that further compress the development time, indicate increased uncertainty about the costs by the Program, reducing their confidence level of staying within the KDP-B cost and schedule estimates. In a Joint Cost and Schedule Confidence Level calculation, increasing the confidence level results in increased costs when the schedule and scope remain fixed. The actual cost impact will not be determined until a new Joint Cost and Schedule Confidence Level is run at PDR and KDP-C.

In addition, characteristics intrinsic to big and complex missions like MSR are hard to quantify in estimates but can drive costs upwards throughout development. These include, for example, a full understanding of the mission's complexity, initial over-optimism, a less than optimal design/ architecture, and the team's ability to perform to expectations. When developing its cost and schedule estimate to proceed to development, and as the MSR Program addresses issues with its architecture, it is important that these intrinsic characteristics be given proper consideration and that management does not simply attribute past cost growth to the COVID-19 pandemic, inflation, or supply chain issues.

Enhanced Coordination Needed between NASA and ESA

ESA is providing the ERO and Sample Transfer Arm components, a significant portion of the MSR Program, estimated at 15 to 20 percent of NASA's KDP-B life-cycle cost estimate (or $900 million to $1.2 billion).[38] Therefore, ESA expects and continually advocates for a role commensurate with its investment as a partner rather than just a contributor to the MSR Campaign. Although communication processes are formally documented and being followed, NASA and ESA are nonetheless experiencing coordination challenges that are affecting Program formulation as they work toward establishing a development baseline at KDP-C. As early as October 2020, an IRB's assessment of the MSR Program reported both NASA and ESA should bridge their differing management approaches and development cultures to avoid future friction between their teams. The IRB recommended NASA and ESA scrutinize their business practices to identify adjustments needed to maximize Program success. The CCRS team reported in March 2023 that improving working relations with ESA ERO project personnel and restoring confidence was a programmatic issue.[39] Ongoing challenges related to schedule transparency, asynchronous design progress, and mass allocation appear to stem from differing operational approaches, acquisition strategies, and agency funding mechanisms.

Earth Return Orbiter Components



This artist's impression shows the Earth Return Orbiter's components including the Capture, Containment, and Return System; Orbiting Sample container; and Earth Entry System.

Source: ESA.

[38] ESA's contribution is not included in NASA's cost estimate.

[39] Since that time, a dedicated ERO-CCRS Interface Co-Engineering Tiger Team was put in place to perform co-engineering activities between the CCRS and ERO teams. The CCRS project team noted that significant progress has been made addressing interface issues between the two organizations.

NASA and ESA Operational Differences

NASA and ESA have fundamental differences in their operating approaches and funding mechanisms. For example, with respect to contracting, NASA primarily utilizes cost-type contracts and determines what work to outsource on a mission-by-mission basis.[40] On the other hand, according to an ESA official, ESA primarily utilizes firm-fixed-price contracts and they are required to allocate about 80 percent of their funding to contractors.[41] Consequently, ESA has less flexibility to execute contract changes without renegotiating contract terms. Also impacting the MSR Program is the differing funding and approval processes of NASA's and ESA's governing bodies. NASA's funding is approved annually by Congress and often with months long delays in finalizing appropriations, whereas ESA's funding is approved by its multi-member countries on a 3-year appropriation cycle with an inflation adjustment provided annually.[42] According to the ESA official, ESA's MSR components are adequately funded through a 2028 launch date and any changes to the launch date and associated funding would require the member countries' approval.

Integrated Master Schedule

An Integrated Master Schedule constitutes the framework for time phasing and coordinating all program and project efforts into a master plan to ensure that objectives are accomplished within approved commitments. NASA is utilizing the MSR Program's Integrated Master Schedule as a core tool for the integration, control, and analysis of all Program work scope. MSR Program management expected ESA would provide more detailed schedule information than is currently available. According to Program management, this creates challenges for managing the critical path and identifying risks early.[43] However, according to ESA, detailed contractor schedule and process information is proprietary and cannot be shared with NASA. On the other hand, an ESA official stated they also need additional details about CCRS issues from NASA to effectively manage the ERO using its Joint Receivables and Deliverables List. ESA manages NASA's milestones via a Joint Receivables and Deliverables List; however, MSR Program management said this does not provide the same level of detail as an Integrated Master Schedule. While it appears ESA is meeting the agreement requirements outlined in their Joint Management and Implementation Plan with NASA, it is critical to the success of the MSR Program that both agencies continue to work toward a common approach that effectively supports execution of their respective responsibilities.

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[40] Under a cost-type contract, the contractor is paid on the basis of the actual, allowable costs it incurs plus any fee or profit for which the contract provides.

[41] A firm-fixed-price contract provides for a price that is not subject to adjustment based on the contractor's cost experience in performing the contract. This contract type places upon the contractor maximum risk and full responsibility for all costs and resulting profit or loss.

[42] ESA consists of 22 member states: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland, and the United Kingdom.

[43] The critical path refers to the sequential series of tasks in a schedule that represents the longest overall duration from the present time through project completion. Any slippage of these tasks will increase the project's duration.

ERO and CCRS Design Maturity

ESA's development of the ERO is on schedule but significantly ahead of CCRS, a component of the ERO. While ERO has already entered the development phase which continues in Phase C (Final Design and Fabrication) as it nears its Critical Design Review, the CCRS project just recently completed the second part of their PDR (PDR-2) in December 2023. Having a more mature and stable design makes it more difficult for the ERO to accommodate requested changes. Any design adaptations the CCRS needs as a result of its PDR will have to be made primarily on their side, resulting in schedule and cost implications for NASA. Nonetheless, ESA will also be impacted if delays from CCRS cause cost impacts to ERO contractors.

Mass Margin

Another significant challenge that NASA and ESA must address is the mass of the CCRS and ultimately the ERO. The mass of a spacecraft, once designed for a specific launch vehicle, is one of its most important constraints as every launch vehicle has a limit to the mass it can carry. ERO is launching on ESA's new Ariane 64 launch vehicle which as of January 2024 had not yet flown a space flight mission. Accordingly, ESA manages the mass allocation and any margins therein.[44] According to CCRS project management, the mass allocation received from ESA was not adequate to accommodate its changing needs as they tried to stabilize their design to procced into the second PDR (PDR-2), despite receiving a 25 percent increase (from 500 to 625 kilograms) from ESA prior to its first PDR (PDR-1) in December 2022. However, the ESA official also indicated that ERO's mass margin going into the Critical Design Review is already close to half the recommended level, down to 5.6 percent when NASA and ESA standards recommend 10 percent.

Ariane 6 Rocket at Europe's Space Port in French Guiana on September 5, 2023

Source: ESA/ArianeGroup/CNES - Optique vidéo du CSG.

As of May 2023, the CCRS project was tracking mass as a major risk. As of July 2023, ESA was also tracking mass as a high-level risk for the ERO spacecraft and is working with NASA to resolve CCRS's mass margin challenge. Nonetheless, given that mass is a hard constraint, mass allocation must be carefully managed between the ESA and CCRS teams.

[44] Mass margin is the mass available for in-scope changes calculated by the difference between the space system's allowable mass (the established requirement) and the predicted mass (estimate of the final mass at system delivery). Mass margin is meant to mitigate potential mass increases from omissions or refinement of existing design requirements that exceed mass growth allowance allocations (predicted changes to the current mass of an item based on an assessment of the hardware category, design maturity, fabrication status, and an estimate of the in-scope design changes that may still occur throughout the life cycle).

Other Factors to Consider in Establishing a Stable Design and Reliable Cost and Schedule Estimate

The MSR Program has recently acknowledged that it likely cannot meet the life-cycle cost estimate and launch dates established at KDP-B. Additionally, an IRB report released in September 2023 included recommendations that the Program consider modifications to specific mission designs, issues that are beyond the scope of this audit.[45] NASA is currently reviewing the report's recommendations and developing a response. Accordingly, it is critical that the MSR Program, Science Mission Directorate, and Agency Program Management Council consider all viable alternatives to the Program's mission architecture—including mission launch and sample return alternatives—before the Program is approved to proceed from formulation into development. Specifically, as NASA and the MSR Program work to finalize the stability of mission architecture and project design while balancing the interests of a diverse set of stakeholders, we believe the following factors need to be considered:

- **Value of Samples Returned**. NASA should strive to return the highest value sample collection by maximizing the quantity, quality, and diversity of samples returned from those collected. Fewer samples are stored in the depot cache than in the Perseverance rover and the 10 samples in the depot cache are the less desirable of the initial sample pairs. Additionally, the Perseverance rover continues to collect samples, potentially resulting in the collection of different geological sample types than those already included in the sample depot.
- **Program Schedule**. Any delays in the MSR Program's launch dates will likely result in comparable delays in sample return dates. Additionally, although the optimal planetary alignment for missions to Mars occurs approximately every 26 months, mission planning must also account for surface conditions and related factors that differ during these alignments that could potentially compromise mission length and negatively impact samples returned. Later launch opportunities also increase the risk that Perseverance will not be capable of direct sample delivery during the surface mission, increasing reliance on the recovery helicopters.
- **Life-Cycle Cost Estimate**. With a minimal number of descopes available, the overall cost of the MSR Program is likely to increase regardless of the final mission design selected. However, although deferring launches to later launch windows will increase overall mission cost estimates, that could also reduce annual funding requirements, thereby reducing potential negative impacts (e.g., funding availability, schedule delays) on other missions in the Science Mission Directorate portfolio.
- **Relationship with Partners**. ESA has expressed a strong desire to be an involved partner in the MSR Campaign, and some architectural decisions may inherently enhance or diminish the extent of that involvement. These impacts could play a role in efforts to develop partnerships with ESA and other international space agencies for future missions.
- **National Leadership**. The United States takes great pride in maintaining its historic leadership in space exploration. Other nations are currently developing plans that could challenge this leadership position, and delays in executing the MSR Program and returning Mars samples to Earth for analysis could impact that leadership position.

[45] NASA established the IRB in May 2023 to evaluate the MSR Program's technical, cost, and schedule plans prior to confirmation of the mission's design and cost and schedule baselines.

Any analysis of alternatives by NASA needs to include life-cycle cost estimates based on full and accurate information that takes into account Program complexity and performance. Since it is unlikely the MSR Program will receive the same level of funding from Congress as it has in the past given the relatively flat budget anticipated over at least the next two fiscal years, any shifts in funding for the Program will likely come at the cost of other Science Mission Directorate missions. It is critical that the MSR Program, Science Mission Directorate, and Agency Program Management Council establish a realistic cost and schedule baseline at KDP-C.

CONCLUSION

NASA is in the process of formulating one of the most significant and complex missions it has ever undertaken. The MSR Program is the culmination of decades of Mars missions that have aggregated knowledge and capabilities to enable the retrieval of the first-ever samples from another planet. Beyond the scientific value of potentially answering the question of whether life has or can exist outside our planet, the MSR Program is also important in supporting the United States in its quest to land humans on Mars in the coming decades.

However, the MSR Program recently acknowledged that it likely cannot meet the life-cycle cost and schedule estimates it set for the Program when it started formulation. The Program has already experienced significant cost growth and delays to its formulation timeline, and in September 2023 an IRB made significant recommendations that could affect the current mission design. While adjustments to cost, schedule, and scope during formulation are typical in complex missions, as NASA moves to establish a stable design with the optimal samples to be retrieved and optimal launch dates, it is critical not to underestimate the corresponding cost and schedule when it sets its baseline commitment at KDP-C.

Due to the scale of the MSR Program and the resources required for its successful completion, the potential magnitude of adjustments to its design or cost and schedule commitments after formulation likely will have consequences to other NASA science missions. To maximize the potential for MSR's success while also minimizing the risk of negative impacts outside of the MSR Program, it is vital that NASA review the Program as a comprehensive plan including a variety of mission scenarios and incorporate stakeholder interests. Only with a stable design and reliable cost and schedule estimates can NASA evaluate MSR and commit to a realistic path forward for this Program with a full understanding of the potential requirements and consequences of its decision at KDP-C.

RECOMMENDATIONS, MANAGEMENT'S RESPONSE, AND OUR EVALUATION

To provide the Agency Program Management Council with the necessary information to make an informed decision at KDP-C in the best interest of stakeholders regarding development of the MSR Program, we recommended NASA's Associate Administrator for Science Mission Directorate:

1. Ensure the MSR Program establishes a stable CCRS design prior to establishing the life-cycle cost and schedule estimate at KDP-C, incorporating recommendations from the 2023 IRB as appropriate.
2. Ensure the life-cycle cost and schedule estimates properly incorporate MSR Program complexity and performance as factors and do not only focus on external cost growth impacts and ongoing design issues.
3. Ensure the Agency Program Management Council is provided with a set of potential launch scenarios by KDP-C, including life-cycle cost and schedule estimates and an associated Joint Cost and Schedule Confidence Level for each.

In addition, we recommended NASA's Chief Program Management Officer:

4. Assess the efficacy of large mission pre-formulation guidance and develop a corrective action plan that addresses the concerns and recommendations of the October 2020 Large Mission Study.

We provided a draft of this report to NASA management who concurred or partially concurred with our recommendations and described planned actions to address them. We consider management's comments responsive to Recommendations 2 and 3, and therefore both are resolved and will be closed upon completion and verification of the proposed corrective actions. Regarding Recommendations 1 and 4, while we consider management's comments responsive, we will require further discussions and documentation from management before deciding whether to close them as requested.

Management's comments are reproduced in Appendix F. Technical comments provided by management and revisions to address them have been incorporated as appropriate.

Major contributors to this report include Ray Tolomeo, Science and Aeronautics Research Audits Director; Adrian Dupree, Acting Science and Aeronautics Research Audits Director; Gerardo Saucedo, Assistant Director; L. Scott Collins; Bryan McGloin; Lynette Westfall; and Lauren Suls.

If you have questions about this report or wish to comment on the quality or usefulness of this report, contact Laurence Hawkins, Audit Operations and Quality Assurance Director, at 202-358-1543 or laurence.b.hawkins@nasa.gov.

George A. Scott Digitally signed by George Scott Date: 2024.02.27 11:03:04 -05'00'

George A. Scott
Acting Inspector General

Appendix A: Scope and Methodology

We performed this audit from November 2022 through January 2024 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

During our audit survey period, we obtained an understanding of the MSR Program's management, costs, schedules, issues and risks, technology readiness, business and procurement processes, and coordination with ESA. We interviewed NASA Headquarters, JPL, Goddard CCRS, and Marshall MAV program and project managers, lead scientists, and lead engineering officials involved with the MSR Program. In addition, we interviewed ESA's ERO Project Manager.[46]

The scope of the audit focused on the MSR Program Formulation Phase prior to the PDR. We reviewed key NASA and JPL documents from 2020 through 2023, as well as federal fiscal laws, Government Accountability Office guidelines, and NASA and JPL procedures and handbooks as criteria for the audit steps and findings. We also reviewed scientific studies and NASA independent board reports; NASA and JPL program and project planning and management documents; decision documents; monthly and quarterly reports for the MSR Program, multiple projects (SRL, ERO, CCRS, and MAV), flight programs, and the Joint Steering Committee; agreements with the California Institute of Technology and ESA; procurement instruments; and the risks identified in JPL, Goddard, and Marshall databases.

Assessment of Data Reliability

The findings in this report do not rely on computer-generated data.

Review of Internal Controls

We assessed internal controls necessary to satisfy the audit's objectives during the audit. We performed a high-level review of NASA's and JPL's internal controls associated with the MSR Program's Formulation Phase. JPL has procedures in place and followed NASA's program and risk management requirements. JPL created planning documents and used monthly and quarterly reports to manage the Program. We determined internal controls for JPL's procurement and risk processes were adequately employed; therefore, no findings were identified based on the limited audit work performed. We identified weaknesses in NASA's pre-formulation requirements for complex missions, as was previously reported in a prominent NASA study. Our recommendation, if implemented, will improve NASA's program and project Formulation Phase.

[46] As of February 2023, the ERO Project Manager was also ESA's Mars Exploration Group Leader in the Human and Robotic Exploration Directorate.

Prior Coverage

The NASA Office of Inspector General and the Government Accountability Office have issued 17 reports of significant relevance to this report. These reports can be accessed at https://oig.nasa.gov/audits/auditReports.html and https://www.gao.gov, respectively. In addition, NASA and the scientific community have issued 9 reports of importance to our findings.

NASA Office of Inspector General

2023 Report on NASA's Top Management and Performance Challenges (MC-2023, November 2023)

NASA's Management of the Artemis Supply Chain (IG-24-003, October 19, 2023)

NASA's Electrified Aircraft Propulsion Research and Development Efforts (IG-23-014, May 17, 2023)

2022 Report on NASA's Top Management and Performance Challenges (MC-2022, November 2022)

NASA's Cost Estimating and Reporting Practices for Multi-Mission Programs (IG-22-011, April 7, 2022)

2021 Report on NASA's Top Management and Performance Challenges (MC-2021, November 15, 2021)

NASA's Management of the Artemis Missions (IG-22-003, November 15, 2021)

*NASA's Plans for Human Exploration Beyond Low Earth Orbi*t (IG-17-017, April 13, 2017)

NASA's Mars 2020 Project (IG-17-009, January 30, 2017)

NASA's Management of the Mars Science Laboratory Project (IG-11-019, June 8, 2011)

Government Accountability Office

NASA: Assessments of Major Projects (GAO-22-105212, June 23, 2022)

NASA: Lessons from Ongoing Major Projects Could Improve Future Outcomes (GAO-22-105709, February 9, 2022)

NASA Human Space Exploration: Significant Investments in Future Capabilities Require Strengthened Management Oversight (GAO-21-105, December 15, 2020)

Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects (GAO-20-48G, January 7, 2020)

NASA Human Space Exploration: Persistent Delays and Cost Growth Reinforce Concerns over Management of Programs (GAO-19-377, June 19, 2019)

Schedule Assessment Guide: Best Practices for Project Schedules (GAO-16-89G, December 22, 2015)

GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs (GAO-09-3SP, March 2, 2009)

Other Reports

NASA, *Mars Sample Return (MSR) Independent Review Board-2 Final Report* (September 1, 2023)

NASA, *Psyche Independent Review Board Report* (November 4, 2022)

National Academies of Sciences, Engineering, and Medicine, *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032* (2022)

NASA, *Mars Sample Return (MSR) Program Final Report of the Independent Review Board (IRB)* (October 29, 2020)

NASA Science Mission Directorate, *Large Mission Study Report* (October 2020)

NASA, *Planetary Protection Independent Review Board Report to NASA/Science Mission Directorate* (2019)

National Research Council of the National Academies, *Vision and Voyages for Planetary Science in the Decade 2013-2022* (2011)

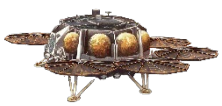
National Research Council of the National Academies, *Assessment of Planetary Protection Requirements for Mars Sample Return Missions* (2009)

National Research Council of the National Academies, *New Frontiers in the Solar System: An Integrated Exploration Strategy* (2003)

APPENDIX B: MARS SAMPLE RETURN PROGRAM COMPONENTS

The MSR Program includes multiple components within the SRL and ERO projects. Table 2 describes these components along with the Mars 2020 Perseverance Rover, their mission description, and the organization supporting them.

Table 2: Mars Sample Return Program Architectural Component Description (as of January 2024)

Architectural Component	Component Description	Supporting Organization
Mars 2020 Perseverance Rover 	Having collected and stored a variety of samples, the Mars 2020 Perseverance Rover will be the primary means of transporting samples to the Sample Retrieval Lander (SRL).	NASA - Jet Propulsion Laboratory
Sample Retrieval Lander (SRL) 	The SRL will touch down on Mars and remain in place to receive a diverse collection of scientifically-selected samples of Martian rock already collected and cached by the Mars 2020 Perseverance Rover. The lander will be the first to bring along a rocket—the Mars Ascent Vehicle (MAV)—and two helicopters as backup options to the rover for sample retrieval. In addition, the lander will carry the Sample Transfer Arm to load the sample tubes into the MAV.	NASA - Jet Propulsion Laboratory
Sample Transfer Arm (STA) 	The Sample Transfer Arm will be carried to Mars by the SRL to retrieve the sample tubes the Mars 2020 Perseverance Rover has collected from the surface. The arm will identify, pick up, and transfer the tubes into the MAV. After the arm closes the sample container's lid, the Martian samples will be launched for rendezvous with the Earth Return Orbiter (ERO), which will bring the material back to Earth.	European Space Agency
Sample Recovery Helicopters (SRH) 	A pair of helicopters will provide a secondary capability to pick up additional samples stashed on the surface by the Mars 2020 Perseverance Rover and bring them back to the SRL for transfer onto the MAV rocket. The Sample Recovery Helicopters are modeled after the Ingenuity Mars Helicopter, which was carried to Mars by Perseverance. Perseverance, which has already collected a diverse set of scientifically-selected samples for potential safe return to Earth, is planned as the primary method of delivering samples to the SRL. The Sample Recovery Helicopters will expand on Ingenuity's design, adding wheels, gripping capabilities, and lift capacity to pick up cached sample tubes left on the surface by Perseverance and transport them to the SRL.	NASA - Jet Propulsion Laboratory

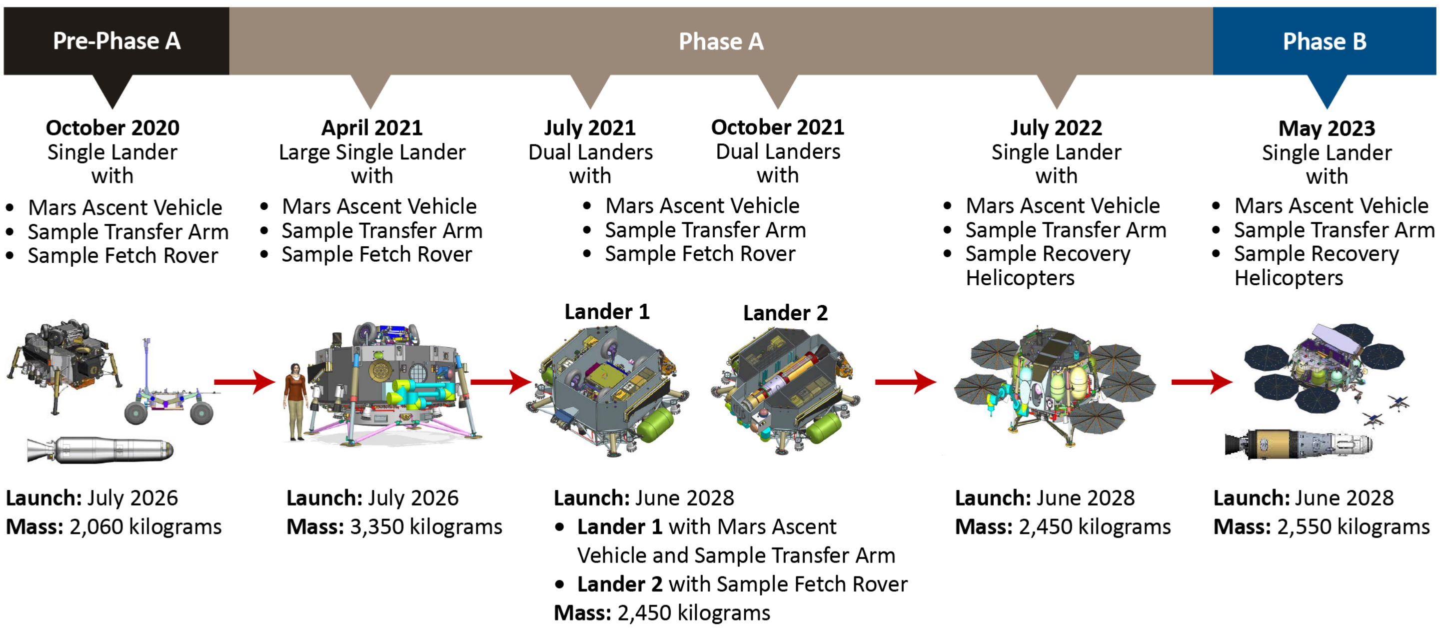
Architectural Component	Component Description	Supporting Organization
Mars Ascent Vehicle (MAV) 	The MAV will be the first rocket to launch off the surface of another planet. A lightweight rocket, it will transport the Orbiting Sample container—which is the container of sample tubes containing Martian rock, atmosphere, and loose surface material—into orbit around Mars. The rocket and enclosed sample container will initially travel to Mars inside the SRL and will remain aboard until loaded with samples and prepped for launch. Once the sample container reaches Mars' orbit, the ERO will capture and store it in a secure containment capsule for safe delivery to Earth.	NASA - Marshall Space Flight Center
Earth Return Orbiter (ERO) 	The ERO spacecraft will locate, intercept, and capture the Orbiting Sample container—a volleyball-sized capsule launched from the surface of Mars carrying samples of Mars' rocks and atmosphere previously collected by the Mars 2020 Perseverance Rover. Once the orbiter has completed rendezvous, it will perform a maneuver to capture the Orbiting Sample container and place it within the Capture, Containment, and Return System (CCRS) onboard the orbiter, housed on the upper deck of the spacecraft. After flying back to Earth, the Earth Entry System will separate from the orbiter and fly a precision trajectory through the atmosphere down to the landing site. In addition to the rendezvous and return mission, the orbiter will provide critical Mars-Earth communications coverage for the Perseverance and sample retrieval missions.	European Space Agency
Capture, Containment, and Return System (CCRS) 	The CCRS aboard the ERO will capture the Orbiting Sample container in orbit, orient and double seal it, and transfer it into the Earth Entry System—a clean zone—for its journey to Earth.	NASA - Goddard Space Flight Center
Earth Entry System (EES) 	The Earth Entry System will contain the Orbiting Sample container inside a disk-shaped vehicle with a heat shield for safe entry through the Earth's atmosphere to safely return the samples to the Earth's surface.	NASA - Ames Research Center and Langley Research Center

Source: NASA OIG presentation of Agency information.

APPENDIX C: EVOLUTION OF SRL AND CCRS DESIGN ARCHITECTURES

Below are timelines of the significant modifications made to the design architectures of both the SRL (Figure 9) and CCRS (Figure 10).

Figure 9: Evolution of the Sample Retrieval Lander's Design Architecture



Source: MSR Program presentation to the NASA Planetary Advisory Committee (June 21, 2023).

Figure 10: Evolution of the Capture, Containment, and Return System's Design Architecture

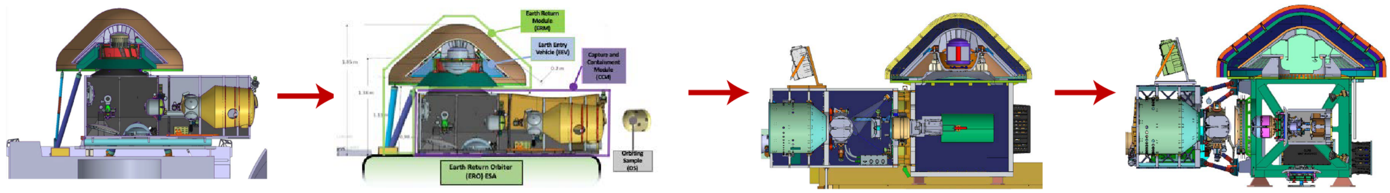
Pre-Phase A | **Phase A** | **Phase B**

October 2020

April 2021

October 2021
Post System
Requirements Review
Rearchitecture

May 2023
Post Preliminary
Design Review (PDR-1)
Rearchitecture



Risks
- Brazing technology →
- Full jettison architecture not viable →
- Numerical containment assurance not viable

Addressed in New Design By
- Different approach to Heated Shrink Fit
- Partial jettison architecture

Risks
- Insufficient Robotic Assembly Force →
- Numerical containment assurance not viable →
- Earth Entry System mass margin →
- Kickstand I/F
- Mass margin

Addressed in New Design By
- Simplified robotics/ containment configuration
- Subcellular descope/ultraviolet sterilization approach to backward planetary protection
- Dual containment/ Orbiting Sample

Risks
- Kickstand I/F →
- Shrink Fit/Aseptic Transfer and Encapsulation System →
- Landing impact structural margins →
- Mass margin

Addressed in New Design By
- Removed kickstand I/F
- Removed Aseptic Transfer and Encapsulation System, now an ultraviolet system
- Deformable structure

Current Risks
- Mass margin
- Subcellular descope/ ultraviolet sterilization
- Thermal Protection System performance

Source: MSR Program presentation to the NASA Planetary Advisory Committee (June 21, 2023).

APPENDIX D: NASA MISSION RISK CLASSIFICATIONS

NASA missions are designated as Class A, B, C, or D. Multiple factors—the mission's level of priority, years of operation, complexity and challenges, and life-cycle cost—are treated holistically with each factor taken into account to appropriately designate a mission risk tolerance class based on applicable mission criteria. The mission's risk tolerance class is designated by the appropriate Mission Directorate. Table 3 describes the mission risk classification designations and related factors.

Table 3: NASA Mission Risk Classifications and Factors to Determine the Classification

Mission Risk Classification	
Class A	The lowest risk tolerance that is driven more by technical objectives. This would normally represent a very high priority mission with very high complexity.
Class B	Low risk tolerance that is driven more by technical objectives. This would normally represent a high priority mission with high complexity.
Class C	Moderate risk tolerance that is driven more by technical objectives. This would normally represent a medium priority mission with medium complexity.
Class D	High risk tolerance that is driven more by programmatic constraints. This would normally represent a lower priority mission with a medium to low complexity.

Factors in Determining Mission Risk Classification	
Priority	
Relevance to NASA's strategic plan, national significance, and significance to NASA and its strategic partners.	
Very high priority	Class A
High priority	Class B
Medium priority	Class C
Low priority	Class D
Primary Mission Lifetime	
Greater than 5 years	Class A
Between 3 and 5 years	Class B
Between 1 and 3 years	Class C
Less than 1 year	Class D
Complexity and Challenges	
Interfaces, international partnerships, uniqueness of instruments, mission profile, technologies, ability to reservice, and sensitivity to process variations.	
Life-Cycle Cost[a]	
High cost	Class A
Medium to high cost	Class B
Medium cost	Class C
Medium to low cost	Class D

Source: NASA Procedural Requirements 8705.4A, *Risk Classification for NASA Payloads* (April 29, 2021).

[a] NASA does not provide specific dollar amounts to determine whether a mission is considered high cost, medium to high cost, medium cost, or medium to low cost. Therefore, each determination is essentially the subjective view of the decision-maker, and cost thresholds are subjectively determined relative to each Mission Directorate's portfolio of missions.

APPENDIX E: RELEVANT FUNDING HISTORY

Table 4 provides funding information for FYs 2021 to 2024 for the Agency overall, Science Mission Directorate, Planetary Science Division, and MSR Program.

Table 4: NASA, Science Mission Directorate, Planetary Science Division, and MSR Program Funding for FYs 2021 to 2024 (Dollars in Millions)

	FY 2021	FY 2022	FY 2023	FY 2024
Agency				
Agency Request	$25,246.0	$24,801.5	$25,973.8	$27,185.0
Agency Appropriation	23,271.3	24,041.3	25,383.7	TBD[a]
Science Mission Directorate				
Science Mission Directorate Request	$6,306.5	$7,931.4	$7,988.3	$8,260.8
Science Mission Directorate Allocation	7,297.3	7,610.9	7,795.0	TBD
Planetary Science Division				
Planetary Science Division Request	$2,659.6	$3,200.0	$3,160.2	$3,383.2
Planetary Science Division Allocation	2,699.8	3,120.4	3,200.0	TBD
Planetary Science Division Allocation as a Percentage of Agency Appropriation	11.6%	13.0%	12.6%	TBD
Mars Sample Return Program				
MSR Program Request	Combined under "Mars Future Missions"	$653.2	$822.3	$949.3
MSR Program Allocation	263.5[b]	653.2	822.3	TBD
MSR Allocation as a Percentage of Planetary Science Division Allocation[c]	9.8%	20.9%	25.7%	TBD[d]

Source: Various NASA annual budget requests, spending plans, and congressional appropriations documents.

[a] Initial Agency-level markups by appropriations subcommittees in the U.S. House and Senate were $25,366.5 million and $25,000.3 million, respectively.
[b] The amount shown for FY 2021 includes $21.9 million provided under "Mars Exploration" and $241.6 million under "Mars Sample Return."
[c] The 2023 Planetary Science Decadal Survey noted that from a financial perspective "[MSR's] cost should not be allowed to undermine the long-term programmatic balance of the planetary portfolio. If the cost of MSR increases substantially (≥20 percent) beyond the $5.3 billion level adopted in this report or goes above ~35 percent of the Planetary Science Division budget in any given year, NASA should work with the Administration and Congress to secure a budget augmentation to ensure the success of this strategic mission."
[d] Although actual amounts for FY 2024 are still to be determined as of February 2024, the requested amount of $949.3 million for the MSR Program is 28.1 percent of the $3,383.2 million requested for the Planetary Science Division.

Appendix F: Management's Comments

National Aeronautics and Space Administration

Mary W. Jackson NASA Headquarters
Washington, DC 20546-0001

Reply to Attn of: Science Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator of Science Mission Directorate and Chief Program Management Officer

SUBJECT: Agency Response to OIG Draft Report, "Audit of the Mars Sample Return Program" (A-23-01-00-SARD)

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on the Office of Inspector General (OIG) draft report entitled, "Audit of the Mars Sample Return Program" (A-23-01-00-SARD), dated January 24, 2024.

In this draft report, the OIG found that the Mars Sample Return (MSR) Program acknowledged that it likely cannot meet the life-cycle cost and schedule estimates set during formulation. Further, the OIG stated the Program has experienced significant cost growth and delays to its formulation timeline. The OIG opined that the potential magnitude of adjustments to the Program's design or cost and schedule commitments after formulation likely will have consequences to other NASA science missions.

The OIG makes three recommendations addressed to the Associate Administrator (AA) for Science Mission Directorate (SMD) to provide the Agency Program Management Council with the necessary information to make an informed decision at Key Decision Point C (KDP-C) in the best interest of stakeholders regarding development of the MSR Program. Additionally, the OIG makes one recommendation to the Chief Program Management Officer (CPMO).

Specifically, the OIG recommends the following to the AA for SMD:

Recommendation 1: Ensure the MSR Program establishes a stable Capture, Containment, and Return System (CCRS) design prior to establishing the life-cycle cost and schedule estimate at KDP-C, incorporating recommendations from the 2023 Independent Review Board (IRB) as appropriate.

> **Management's Response:** NASA concurs with this recommendation and considers the recommendation completed. The CCRS project held a successful Preliminary Design Review (PDR-2) in December 2023, chaired by the independent Goddard Standing Review Team, including MSR Standing Review Board members. The

PDR-2 demonstrated that CCRS: 1) had a technical design that closed and fully addressed the findings from the partial PDR (PDR-1) held in December 2022; 2) had sufficient technical reserves to complete development; 3) had a design that was compatible with both the Sample Retrieval Lander (SRL) Orbital Sample container and Earth Return Orbiter (ERO) spacecraft interfaces; and 4) had a cost and schedule profile that aligned with the baseline design.

To meet the fiscal year 2024 budget constraints, work on CCRS at Goddard and Jet Propulsion Laboratory has been paused following the PDR. The costs and schedule estimates developed for the PDR provided a credible cost estimate for the CCRS mission element for Agency Confirmation should CCRS remain part of the future architecture.

Estimated Completion Date: Response to this recommendation has been completed following the completion of the CCRS PDR in December 2023.

Recommendation 2: Ensure the life-cycle cost and schedule estimates properly incorporate MSR Program complexity and performance as factors and do not only focus on external cost growth impacts and ongoing design issues.

Management's Response: NASA concurs with this recommendation. NPR 7120.5F, NASA Space Flight Program and Project Management Requirements, and our risk management processes require NASA to incorporate complexity and performance as factors in life-cycle cost and schedule estimates. The MSR Program recognizes cost and schedule risks unique to large strategic missions and will follow the NASA response to the recommendations of the 2020 SMD Large Mission Study, the second MSR IRB in 2023, and Agency guidance (i.e., NASA Cost Estimating Handbook (CEH), Risk Management Procedural Requirements, and NASA Schedule Management Handbook) in development of the MSR cost and schedule baseline prior to Agency Confirmation. The CEH and the Schedule Management Handbook provide guidance for incorporating performance and risk factors into cost and schedule estimating. Furthermore, the MSR will address programmatic complexity through its continuous risk management process.

Estimated Completion Date: Life-cycle cost and schedule estimates for the MSR Program will be completed by Program PDR, in accordance with NPR 7120.5F. The Program PDR date and subsequent KDP-C will be dependent on the MSR IRB Response Team (MIRT) and Agency approval process. MIRT recommendations will be presented to the AA for SMD, and subsequently the AA for SMD will present recommendations to Agency leadership for an Agency decision by the end of March 2024. Once the Agency makes an architecture decision, the baseline will be refined by the MSR Program Office and a KDP-C will be set commensurate with NPR 7120.5.

Recommendation 3: Ensure the Agency Program Management Council is provided with a set of potential launch scenarios by KDP-C, including life-cycle cost and schedule estimates and an associated Joint Cost and Schedule Confidence Level for each.

Management's Response: NASA partially concurs with this recommendation. Due to the design maturity of the multiple variables associated with numerous re-architecture options and timeframe needed to conduct a Joint Cost and Schedule Confidence Level (JCL) for each alternative, performing a JCL for each scenario is not feasible and is inconsistent with Agency standard practices. However, parametric model-based estimates with acceptable reserves (commensurate with the 70-80 percent confidence levels) will be developed by the MIRT Business Team (BT) for all scenarios. The MIRT BT will provide a probabilistic estimate with associated confidence levels for the recommended scenario. NASA will follow Agency guidance for providing a JCL for the resulting MSR Program that enables the decision authority to make an informed decision at KDP-C.

Estimated Completion Date: MIRT recommendations will be presented to the AA for SMD, and subsequently the AA for SMD will present recommendations to Agency leadership for an Agency decision by the end of March 2024. Once the Agency makes an architecture decision, the baseline will be refined by the MSR Program Office and a KDP-C will be set commensurate with NPR 7120.5.

In addition, the OIG recommends NASA's Chief Program Management Officer:

Recommendation 4: Assess the efficacy of large mission pre-formulation guidance and develop a corrective action plan that addresses the concerns and recommendations of the October 2020 Large Mission Study.

Management's Response: NASA concurs with this recommendation and considers the recommended assessment completed. In July 2023, the Deputy Administrator and Chief Acquisition Officer chartered an Agency Portfolio and Project Risk Management Quick Look Tiger Team to investigate the steps NASA can take to strengthen the risk management framework to support Mission Directorates, Centers, and program and project managers in effectively managing and communicating their risk. The Risk Management Tiger Team (RMTT), chaired by the Chief Program Management Officer, identified initial implementation steps to update Agency policies and roles and responsibilities to improve the risk management process, including activities in the pre-formulation phase.

Specifically, the RMTT examined how NASA infuses risk management into acquisitions, the information needed to enable risk-informed decision making in pre-formulation, and the role of independent cost and schedule estimation in early formulation acquisition processes. The RMTT identified SMD's Large Mission Study (LMS) as a reference and explored many of the LMS concerns and recommendations in the context of improving Agency risk management beginning in pre-formulation, interviewing multiple individuals involved in the LMS team and LMS implementation plan team.

Estimated Completion Date: The RMTT provided its findings and recommendations to the AA and Chief Acquisition Officer in September 2023.

We have reviewed the draft report for information that should not be publicly released. As a result of this review, we have not identified any information that should not be publicly released.

Once again, thank you for the opportunity to review and comment on the subject draft report. If you have any questions or require additional information regarding this response, please contact Peter Meister at (202) 358-1557.

Sandra Connelly Digitally signed by Sandra Connelly Date: 2024.02.23 14:25:43 -05'00'

Nicola Fox
Associate Administrator for
Science Mission Directorate

David Mitchell Digitally signed by David Mitchell Date: 2024.02.23 12:52:50 -05'00'

David Mitchell
Chief Program Management Officer

Appendix G: Report Distribution

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(Assignment No. A-23-01-00-SARD)